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et al

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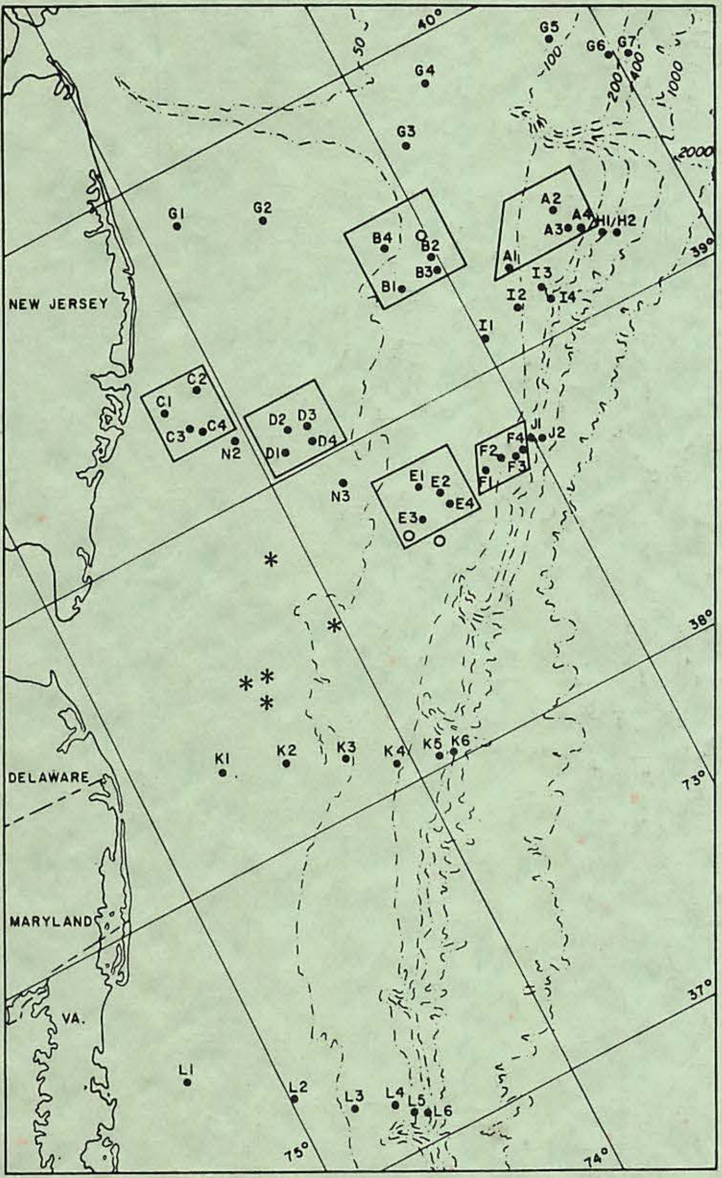
VOLUME III. GEOLOGIC STUDIES



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U.S. Geological Survey
Woods Hole, Massachusetts

Under Memorandum of Understanding
No. AA550-MU7-31

With the

Bureau of Land Management
United States Department of Interior

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VOLUME III. GEOLOGIC STUDIES

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[1] Appendices are provided on microfiche at the end of Volume IID.

[2] Appendices are provided on microfiche at the end of Volume III.

CHAPTER 1

INTRODUCTION

Harley J. Knebel[1]

This report summarizes the research effort by the U. S. Geological Survey (USGS) for the Middle Atlantic Outer Continental Shelf in accordance with the Memorandum of Understanding (AA550-MU7-31) between the USGS and the Bureau of Land Management (BLM). The general objectives of the research program in this area are to: (1) measure the rate of sediment mobility over the sea bed 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 nature and distribution of high molecular weight hydrocarbons in the near-surface sediment at selected locations; (4) evaluate the geotechnical properties of bottom and subbottom sediments and their potential hazard to oil and gas development; and (5) support the activities of the chemical and biological benchmark contractor by analyzing samples of suspended sediment and by helping to synthesize and interpret the geological data as it pertains to the physical, biological, or chemical shelf processes. The period of study covered by this report extends from 1 October 1976 to 30 September 1977.

Due to the varied nature of the investigations, this report is divided into individual chapters. Chapters 2 to 8 are syntheses of specific studies that can be grouped under the general headings of: (1) bottom sediment transport (Chapters 2, 8); (2) suspended sediments (Chapter 3); and (3) bottom sediment characteristics and seafloor topography (Chapters 4-7).

The basic data from this study have been grouped into four Appendices. These Appendices (listed here in proper order) are compilations of : (1) reports of the eight cruises which were run during the field operations; (2) the gravimetric and microscopic analyses of suspended-matter samples and the transmissometer results that were obtained during the year; (3) the C_{15} + hydrocarbon analyses that were made on bottom sediments collected during the VIMS seasonal cruises and on a variety of other samples for intercalibration, quality control, and contaminant detection; and (4) the analyses of the geotechnical properties of the sediments in vibracores that were taken during the R/V ANNANDALE cruise. These Appendices are provided in microfiche form with this report. In accordance with the Memorandum of Understanding, the basic data also are being submitted to the Environmental Data Service (EDS) for public distribution.

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[1] U. S. Geological Survey, Woods Hole, Massachusetts 02543

CHAPTER 2

BOTTOM CURRENTS AND BOTTOM SEDIMENT MOBILITY IN THE OFFSHORE MIDDLE ATLANTIC BIGHT, 1976-77

Brad Butman
Marlene Noble

CHAPTER 2

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List of Abbreviations

BNUV - Burst normalized unit vector (the ratio of vector current speed to average current speed computed over a burst measurement time period)

CTD - Conductivity-temperature-depth profiling system

PSDEV- Pressure standard deviation (standard deviation of bottom pressure in a burst of pressure measurements)

VACM - Vector averaging current meter

VNUV - Vane normalized unit vector (a substitute for BNUV when no speed measurements are available; direction measurements are weighted by a unit speed)

XBT - Expendable bathy-thermographs

CHAPTER 2

BOTTOM CURRENTS AND BOTTOM SEDIMENT MOBILITY IN THE OFFSHORE MIDDLE ATLANTIC BIGHT, 1976-1977

Brad Butman[1] and Marlene Noble[1]

INTRODUCTION

Knowledge of the extent of resuspension and transport of bottom sediments on the outer continental shelf is essential to assess environmental hazards to petroleum exploration and development. The major objective of this study was to determine the frequency and direction of bottom sediment movement and to identify the major processes causing movement and transport.

This report presents in situ observations made during 1976-1977 by means of an instrument system which measures bottom current speed and direction, light transmission, temperature and pressure, and photographs the bottom. Such long term observations are necessary to obtain adequate statistics on sediment movement, monitor catastrophic or infrequent events, and assess seasonal and spatial variability. A detailed description of the instrument system developed for these studies of sediment transport on the Continental Shelf is presented in Chapter 8 of this report. The measurement system was designed primarily to study processes of bottom sediment resuspension and the transport of fine suspended material.

The major conclusions of the sediment mobility studies conducted in the outer mid-Atlantic Bight in 1975-1976 (Butman, Noble, and Folger 1977) were:

1. Resuspension of bottom material occurred frequently in winter in the mid-shelf region (water depths of 60 m). Resuspension caused by surface waves and by storm-generated currents was observed. Small scale symmetrical and asymmetrical ripples formed in response to the currents; evidence of scour degraded 1-2 days after the generating flow ceased. Bottom observations made at comparable depths showed similar bedform response for stations separated by 100 km. In the absence of waves, typically a mean flow of approximately 30 cm sec^{-1} 1 m from the sea floor was required to resuspend bottom material. The mean flow required to move bottom material in the presence of large surface waves was substantially less.

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[1] U.S. Geological Survey, Woods Hole, Massachussetts 02543

2. Typical near-bottom water particle excursions associated with storms were 5-10 km cross-shelf and 10-30 km longshelf. Transport of resuspended material over these same distances can be expected and thus fine bottom sediment could be redistributed over much of the mid-shelf region in one eventful winter season.

3. In summer, bottom conditions were generally tranquil and light flocky material covered the bottom. Although the summer data records were short (15-30 days), no intense scour or bottom sediment resuspension was observed. However, there were changes in suspended matter concentration, possibly caused by advection or biological activity.

4. The bottom currents can be conveniently separated into cross-shelf and longshelf components. The major tidal flow was cross-shelf. The lower frequency currents, some associated with storms, were primarily longshelf. The bottom currents at the tidal frequencies were coherent along and across isobaths. The low frequency longshelf current was coherent over large areas of the outer mid-Atlantic Bight, while the cross-shelf flow was generally incoherent. The data suggests that in the winter winds were a major forcing mechanism of the mid-shelf currents.

5. In summer, packets of high frequency internal waves were observed. The waves within a packet had typical periods of 10-30 minutes and currents associated with the wave packets ranged from 5-15 cm sec^{-1}. An approximately 12 hour spacing between packets suggested tidal currents could be generating these internal waves at the shelf break. The waves were not sufficient to move the bottom sediments, but shoaling, dispersion effects and interaction with tidal or storm generated currents could amplify the waves sufficiently for resuspension to occur.

We will refer to the results of the first year sediment mobility study throughout this report.

FIELD PROGRAM

The 1976-1977 field program was designed to refine our understanding of sediment mobility and bottom currents in the outer mid-Atlantic Bight as defined by the 1975-1976 studies, and to study in more detail selected processes of sediment movement. In particular, the field study was designed to:

1. Begin to assess the seasonal variability in the bottom currents, sediment motion and sediment transport at one representative location on the mid-Atlantic Shelf.

2. Further investigate the importance of internal waves on bottom sediment movement in summer.

3. Investigate the sediment transport processes on the outer shelf where low frequency currents associated with the deeper ocean circulation may impinge on the shelf, and where cross-shelf movements of the shelf-slope water front may control the ambient levels of suspended matter in the bottom waters.

4. Investigate the relationship of the near-bottom tripod observations to the shelf circulation, particularly to the various coastal and oceanic water masses.

The location and dates of all U. S. Geological Survey tripod and current meter deployments made in the mid-Atlantic region of the continental shelf are listed in Table 2-1. Data throughout this report will be referenced by a three or four digit record identification number (Table 2-1). The station locations are shown in Figure 2-1 and the time sequence of the deployments by record number in Figure 2-2. The data obtained from the deployments is summarized in Table 2-2. In general, all instrument systems functioned well. Current meter reed switches failed on moorings 119, 122, and 129 and thus no current speed information was obtained. Current direction for these deployments was computed from the unweighted vane readings. To prevent loss of speed information in future deployments, we have added a backup rotor to all tripod systems and improved the reed switch design. We also anticipate replacement of many of the savonius rotor speed sensors with acoustic current sensors.

Station B was selected as a long term monitoring location; we expect to maintain a tripod at this station for at least 3 years. A meteorological buoy (EB41) is also maintained at this site by the NOAA Data Buoy Office (NDBO), which measures wind speed and direction, sea surface temperature, atmospheric pressure, and surface wave spectra. A cross-shelf transect of current meters and tripods (moorings 129 and 133 at station B, and mooring 131 at station C2) was deployed in the summer of 1977 to further investigate the summer circulation on the shelf and the packets of internal waves believed to be generated at the shelf break. Measurements of the cross-shelf temperature field were made on all deployment cruises by means of expendable bathythermographs (XBTs) to determine the position of the tripod with respect to the shelf-slope water front and the shelf water masses. The temperature sections also illustrate the seasonal variability in the shelf temperature field. We expect that the dynamics of the currents will be affected by the position of the front.

Table 2-1. Location and sequence of current meter and tripod deployments in Middle Atlantic Bight.

Station	Type[1]	Water Depth	Inst. Depth	Latitude	Longitude	Deployed	Recovered	Record ID[2]
A	T	60 m		39°23.5'N	72°59.5'W	10 Dec. 75	15 Jan. 76	104
	T	60 m		39°26.2'N	72°59.8'W	15 June 76	9 July 76	113
	T	58 m		39°26.8'N	72°59.8'W	28 Oct. 76	9 Dec. 76	1171
B	T	60 m		38°42.5'N	73°38.0'W	11 Dec. 75	26 Feb. 76	105
	T	60 m		38°43.5'N	73°37.5'W	2 Apr. 77	10 July 77	1221
	T	60 m				10 July 77	12 Sept. 77	1291
	CT	60 m	45 m			10 July 77	17 Sept. 77	1331
	CT		54 m					1332
	T	65 m				17 Sept. 77	22 Jan. 78	1351
	T	60 m				22 Jan. 78		1401
	CT	60 m	56 m			22 Jan. 78		1461
	C		59 m					1462
C1	T	80 m		38°32.5'N	73°30.5'W	11 Dec. 75	16 Jan. 76	106
	T	87 m		38°32.5'N	73°30.5'W	16 June 76	10 July 76	114
	T	75 m		38°33.5'N	73°31.4'W	8 Dec. 76	8 Apr. 77	1191
				(38°37.2'N	73°28.1'W)			
C2	T	79 m		38°35.7'N	73°26.2'W	12 July 77	12 Sept. 77	1311
E	T	59 m		39°57.1'N	72°35.6'W	22 Jan. 77		1411

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[1] C=Current Meter (AMF VACM), T=Tripod, CT=Current Meter (AMF VACM) with Transmissometer

[2] All USGS current and tripod moorings are assigned a sequential mooring number. Data from the moorings are referenced by this unique identification. For moorings with more than one instrument, the data records are numbered with a fourth digit to indicate vertical location in the mooring (for example, record AAA1 is the data record from the uppermost instrument in mooring AAA, AAA2 is the data record from the second shallowest instrument in mooring AAA, etc.).

[3] Mooring 119 was recovered approximately 5 miles NE of the deployment location, apparently dragged by a fisherman. Camera and current sensor were lost. Current speed sensor failed on launch.

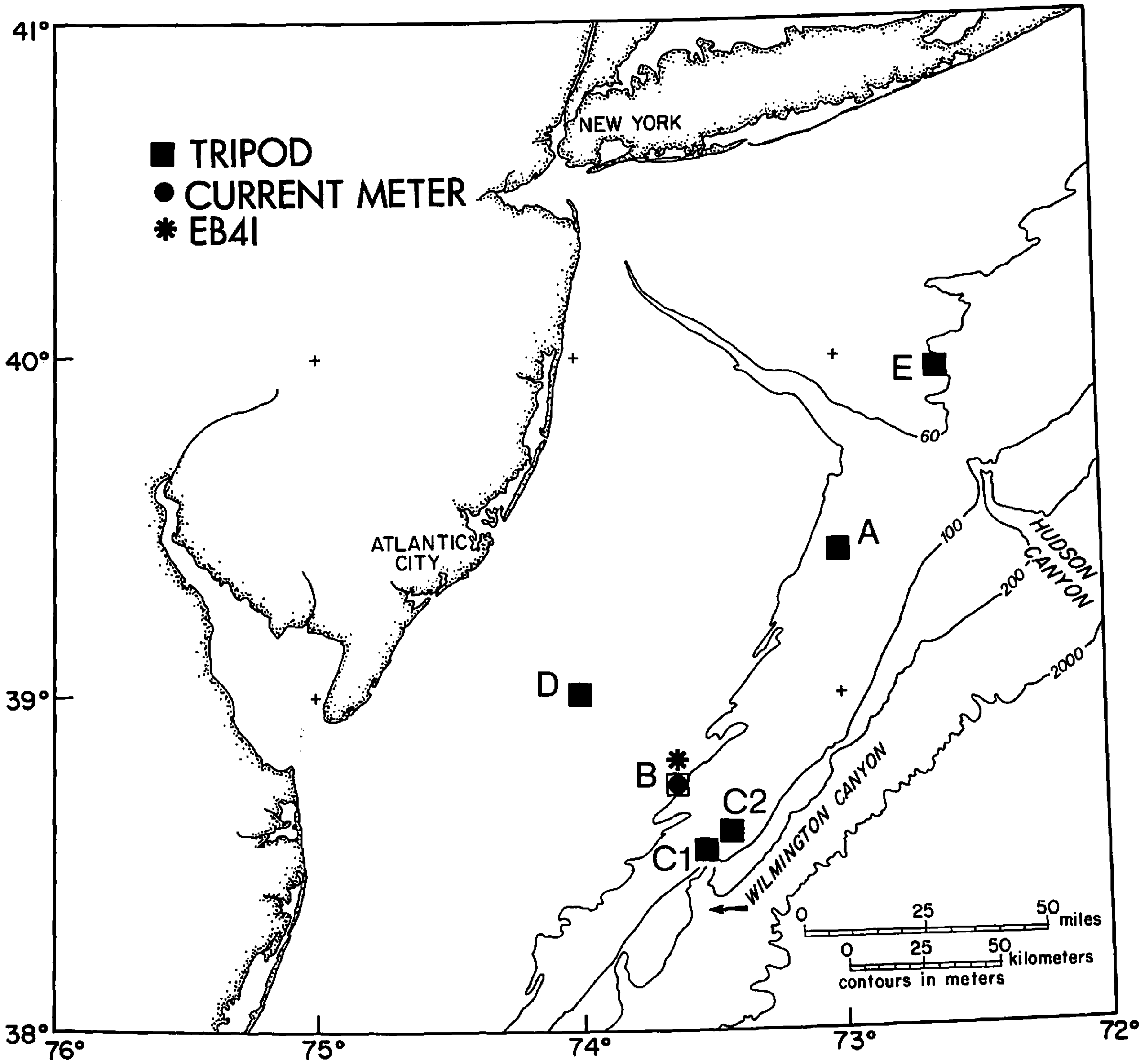


Figure 2-1. Location of U.S. Geological Survey moorings in mid-Atlantic Bight. Stations D and E are proposed locations to be occupied in 1978.

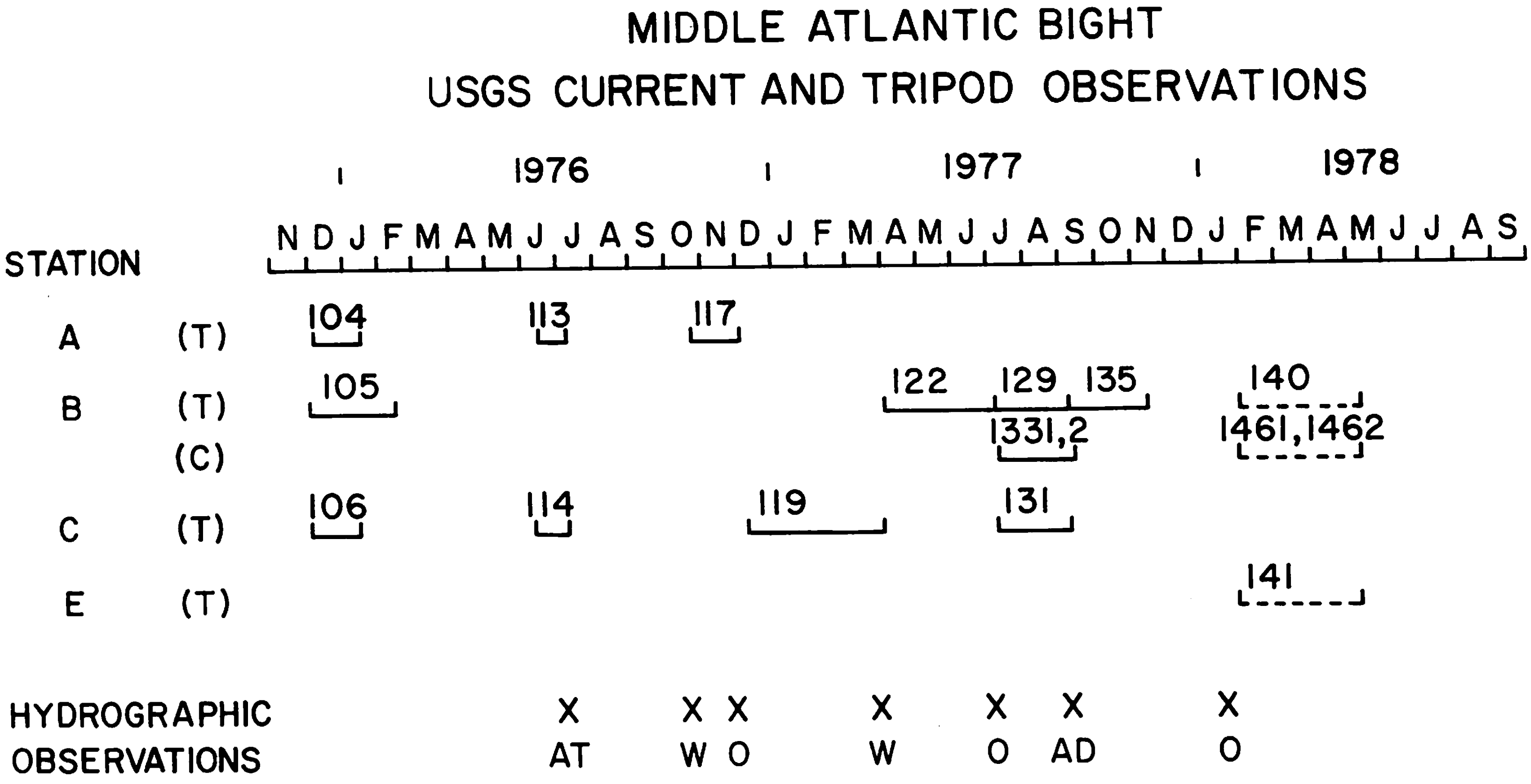


Figure 2-2. Time sequence of instrument deployments at each station. Number above each line is the data record identifier and will be referenced by this number. T indicates a tripod deployment, C a current meter. Letters below hydrographic observation are ship identifiers (AT, ATLANTIC TWIN; W, WHITEFOOT; O, OCEANUS; AD, ADVANCE II).

Table 2-2. Instrument performance.

Record	Current	Temperature	Transmission	Camera	Pressure	Wave
Tripods						
104	G	-	-	GP	-	-
105	G	-	-	G	-	-
106	G	-	-	N	-	-
113	G	G	G	G	G	G
114	GP	N	N	G	N	N
117	G	G	GP	G	G	G
119	D	G	G	L	G	G
122	D	G	G	GP	G	G
129	D	G	G	G	G	G
131	GP	G	G	N	G	G
Current Meters						
1331	G	G	G	-	-	-
1332	G	G	N	-	-	-

KEY:

G = Good
GP = Good, partial record
N = None, failed

\- = Not applicable (system did not measure these parameters)
D = Direction only, speed failed
L = None, lost

METHODS

The bottom instrument system used in this study measured bottom current speed and direction, temperature, light transmission and pressure, and photographs of the bottom. The instrument is described in detail in Chapter 8 of this report; it is recommended that the reader briefly review the instrument system prior to detailed study of Chapter 2. Additional current and transmission observations were made with AMF-Sea Link Vector Averaging Current Meters (VACM) deployed on a taut subsurface mooring. The VACM's were modified to record light transmission with a sensor identical to that used on the tripods. The VACM's were set to sample every 3.75 minutes. The basic sampling interval for the tripod deployments was set at 7.5 minutes for records 117, 119, and 122 and at 3.75 minutes for records 129 and 131. The faster 3.75 minute sampling rate in summer was necessary to resolve the internal wave field. The tripod systems burst sample current speed, direction and pressure. For all deployments presented in this report, the burst sample rate was 4 seconds. There were 16 samples in each burst for record 117, and 12 samples in a burst for records 119, 122, 129 and 131.

Hydrographic observations were made with expendable bathythermographs (XBT) and a Plessey 9040 conductivity-temperature-depth profiling system (CTD). Surface salinity determinations were made with a laboratory salinometer.

CURRENT OBSERVATIONS

The statistics of the near-bottom current observations are summarized in Table 2-3. For the mid-shelf region (depths of 60-80 m), current speeds 1 m from the sea floor were typically less than 15 cm sec^{-1} and the standard deviation of the speeds was less than 7 cm sec^{-1}. Maximum observed hour-averaged bottom current speeds were 45 cm sec^{-1} or less.

The magnitude of the vector mean current 1 m from the sea floor, was typically less than 3 cm sec^{-1}. The direction of the near-bottom flow was generally southwesterly and parallel to the New Jersey coastline, consistent with the observations of Bumpus (1973) and Beardsley, Boicourt and Hansen (1976). However, the mean current at station A in November-December 1976 was toward the north at 5 cm sec^{-1}. Measurements made as part of NOAA's MESA New York Bight field program also showed flow to the north and east at this time (Mayer 1978, personal communication). In addition, current observations made by the U. S. Geological Survey on the southern side of Georges Bank showed a retarded southwesterly flow in November and December 1976, and January 1977. Although no speed records are available, the direction of the net flow at station C was also to the north for much of February and March. The absence of a rotary signal in the current

Table 2-3. Current statistics[1].

		Depth	Length	Speed			Mean[2]		Tide[3]			LP[4]	
Sta.	Record	(meters)	(hrs)	Mean	SD	Max.	S	D	Maj.	Min.	Or	LS	CS
A	104		868	8	6	40	2.6	222°	7	3	318°	7	3
	113	66	546	7	3	20	1.2	251°	8	4	295°	4	1
	117	64	1001	11	6	35	5.1	13°	9	4	305°	8	4
B	105		1627	9	6	42	1.2	234°	7	3	312°	9	3
	1331	45	1609	17	7	45	6.8	215°	16	10	315°	6	2
	1332	54	1609	14	5	29	4.2	200°	14	7	316°	6	2
C	106		859	13	7	37	1.4	149°	7	3	307°	12	3
	114		328	6	4	19	2.1	129°	--	--	--	4	2
	131	80	880	8	4	20	2.7	208°	--	--	--	5	3

[1] All statistics are in cm sec^{-1} and were computed from hourly averages of the original data series. SD is standard deviation.

[2] Mean current speed and direction computed over the entire low passed data record. The low pass filter essentially removed energy with periods shorter than 33 hours. In filtering, the data series length was reduced by 66 hours (for a description of the low pass filter, see Flagg 1977).

[3] Major and minor axis of the semidiurnal tide, and tidal ellipse orientation. Ellipse parameters were calculated from fourier coefficients computed for 15 day piece lengths. Estimated errors are ± 1 cm sec^{-1} and ± 15°. All semidiurnal tidal currents rotated clockwise.

[4] Standard deviation of low passed longshore and cross-shore current components.

direction indicated the magnitude of the mean flow was greater than the longshelf (minor axis of the tidal ellipse) tidal current of 3 cm sec^{-1}. Thus, although the current is generally southwestward in this region of the mid-Atlantic Bight, reversals of the weak near-bottom flow do occur for significant periods of time. Mean flow at the two stations near the head of Wilmington Canyon indicated offshore flow.

The currents can conveniently be separated into cross-shore and longshore components. It is also convenient to conceptually separate the currents into 4 frequency bands: (1) the mean current (average over 30-60 days), (2) the low frequency currents (periods of 5-10 days, currents associated with storms or deep-ocean shelf-edge processes), (3) the tidal and inertial currents (periods of 12-24 hours), and (4) the high frequency currents (periods of 12 hours or less, currents associated with internal waves). In general, the tidal and high frequency currents are primarily cross-shelf, whereas the mean and low frequency currents are primarily longshelf. Due to the seasonal variability in the shelf density structure and the surface wind stress, the magnitude of the currents in all 4 frequency bands may be expected to vary seasonally. The present data set is not long enough to address the seasonal variability of the 30-60 day flow.

Typical water particle displacements associated with the bottom currents in these major frequency bands are shown in Figures 2-3a-c. Displacements in a 30 day period due to the near-bottom mean flow were typically 50-100 km. Thirty day displacements were 100-200 km for currents just slightly above the bottom (5-15 m). There was a wide scatter of the mean net flow between data records, especially at station A. Further measurements are required to determine the seasonal variability of the mean currents. Displacements by the low frequency currents (Figure 2-3b) were primarily longshelf. The longshelf excursion amplitude was comparable to the mean excursion amplitude, whereas the cross-shelf amplitude was typically less than 5 km. The low frequency excursion amplitudes were generally two to three times larger in winter than in summer at stations A and C (Table 2-3), probably due to the influence of winter storms. In contrast, displacements associated with the tidal currents (Figure 2-3c) were typically less than 2 km, and the tidal displacement ellipse was oriented cross-shelf. As expected, there was little seasonal variability in the tidal currents as determined from the available data set.

The current observations suggest that suspended sediments may be distributed over much of the outer shelf region in a relatively short time with most of the dispersal occurring along an isobath. In addition, the water particle displacements due to the mean flow imply that the near-bottom water has a residence time in the mid-Atlantic Bight of 2-4 months and that the suspended particulate distribution could be influenced by events upstream on the New England Shelf and on Georges Bank. Finally, the mean flow for water several meters above

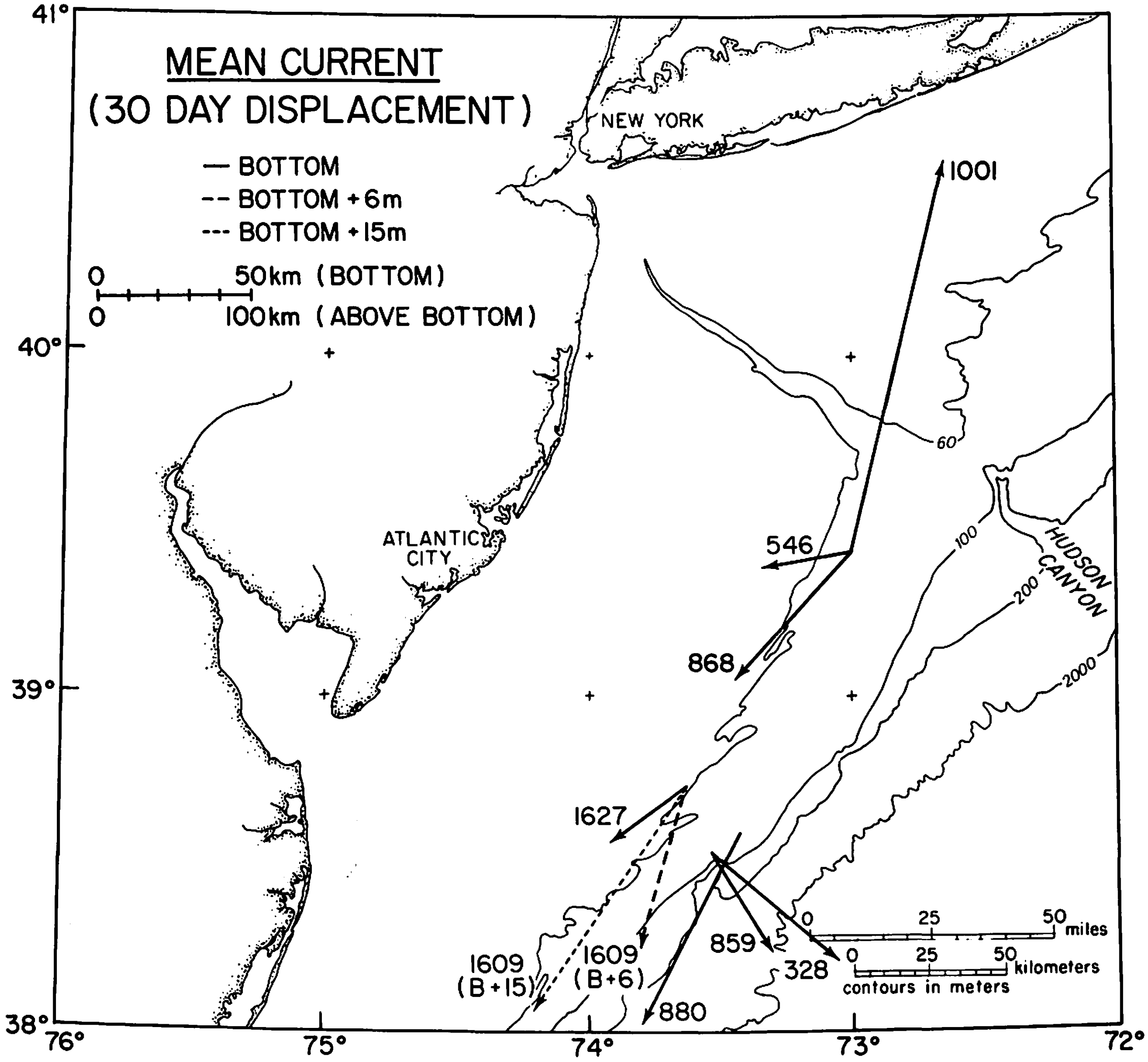


Figure 2-3. Near-bottom water particle displacements.

a. Water particle displacement in a 30 day period. The displacement vector was computed from each available current record at each station (Table 2-3) by multiplying the mean current computed for the entire record by 30 days. The digit at the tip of the vector is the record length in hours over which the mean was computed. The displacements at station B for the current record above the bottom are shown as dashed lines with a smaller scale. The scale for the bottom displacements is the same as the map scale.

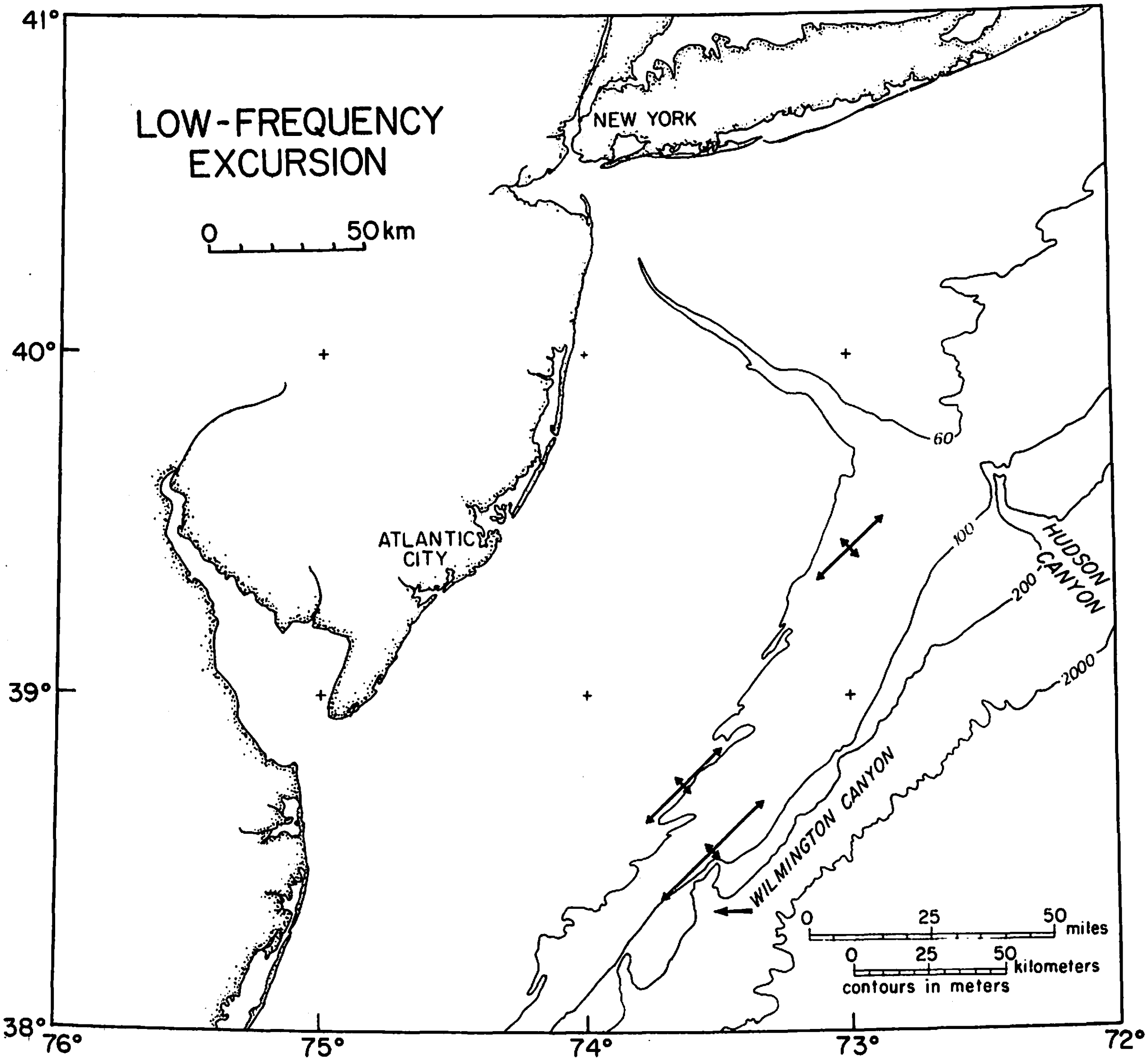


Figure 2-3. b. Water particle displacement by the low frequency near-bottom currents. The standard deviation (A) of the low passed cross-shelf and longshelf current records were multiplied by (1.41) TA/π for T = 3 and 5 days, respectively, to obtain a typical displacement associated with the low frequency current fluctuations. The maximum standard deviation for each station was used (Record 117, 105 and 106 for stations A, B, and C, respectively) (see Table 2-3). The scale for the displacement is the same as the map scale. The filter used to low pass the data records essentially passed all motions with periods larger than 33 hours.

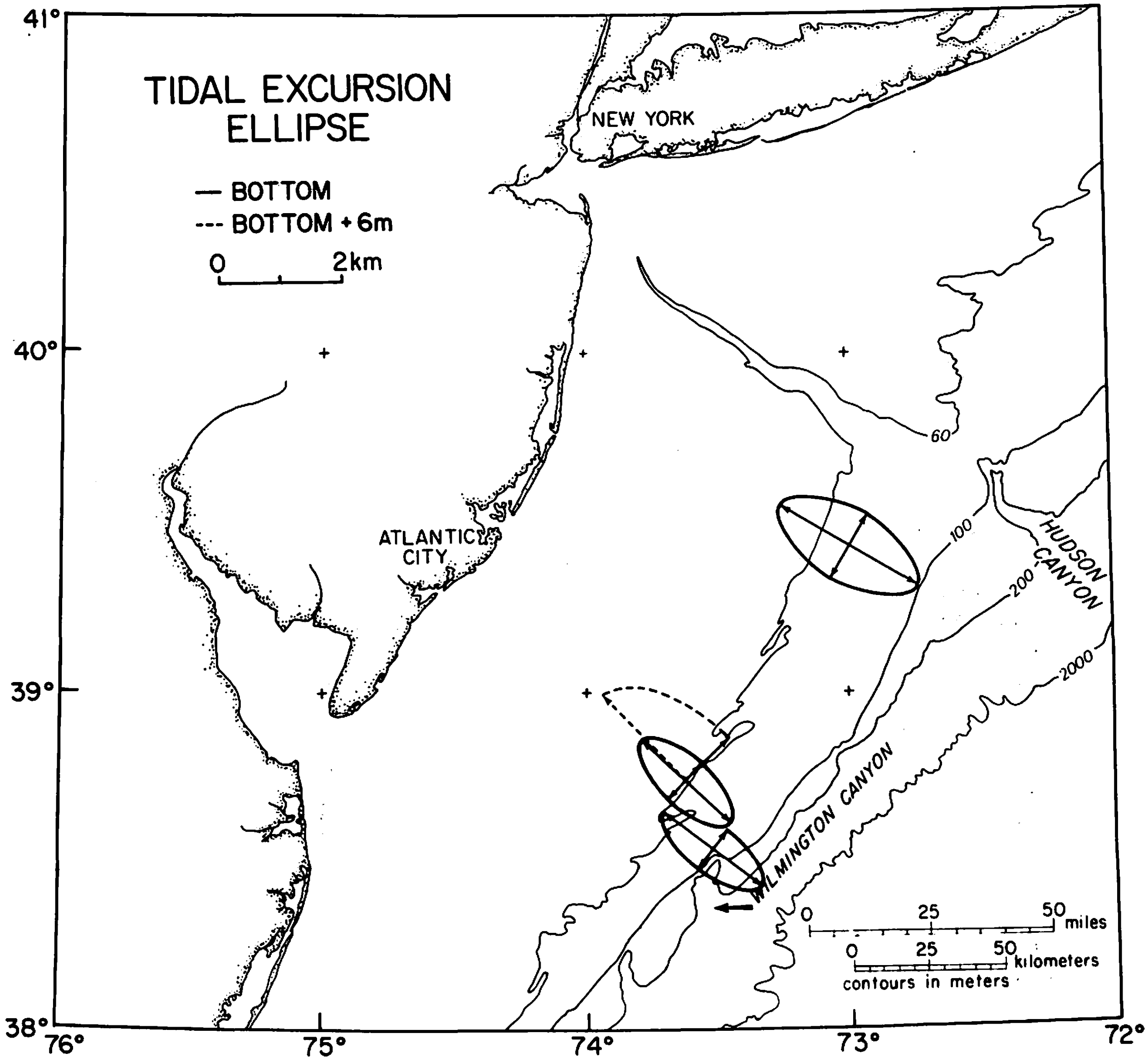


Figure 2-3. c. Water particle displacement for the semidiurnal tidal currents. The major and minor axes of the semidiurnal tidal displacement ellipse were obtained by multiplying the tidal ellipse axes by (T/π)A, (A = amplitude, T = tidal period). The displacement scale is 20 times map scale. The ellipse for the measurement 6 m above the bottom at station B is shown as a dashed line.

the bottom was substantially greater than 1 m above the bottom; thus the finer fraction of material resuspended into the water column could be transported further than indicated by the bottom observations.

SEDIMENT RESUSPENSION AND TRANSPORT

The bottom photograph sequences and transmissometer observations obtained during 1976-1977 showed occasional bottom sediment resuspension and movement during the period of observation at the stations sampled. The bottom changes were less violent than the winter observations of 1975-1976 which showed frequent resuspension and transport of bottom sediments. However, most of the 1976-1977 observations were made during the relatively calm spring and summer months and no observations were made at shallow depths where surface wave-induced bottom currents are expected (60 m or less) to resuspend material during the energetic winter season.

Bottom movement was observed at station A, occupied October-December 1976. Small asymmetric ripples formed during several periods where current speeds exceeded 30 cm sec^{-1} (7-8, 10-11, and 21-24 November, Figures 2-4, 2-5). During these periods net bottom flow was toward the northeast generally driven by strong winds blowing toward the northeast. Otherwise the bottom had a tranquil appearance. A cross-shelf temperature section made at deployment and recovery (Figures 2-6, 2-7a, and 2-7b) suggests that the tripod was located in slope water for much of the deployment period. Surface wave activity was low throughout the observation period, as indicated by PSDEV (Figure 2-4). Note that the ripples formed 23 November (Figure 2-5c) had degraded by 26 November (Figure 2-5d). Observations made by conventional techniques during quiet conditions would show little movement.

At station C1, occupied from December 1976-March 1977, the transmissometer and temperature records suggest that the ambient suspended concentration levels were controlled primarily by the position of the shelf-slop water front with respect to the mooring (Figure 2-8). Cross-shelf temperature sections at deployment and recovery show that station C1 was located near the front (Figure 2-9). Milliman, Bothner and Parmenter (Chapter 3, Figures 3-2, 3-4, 3-5, 3-6, for example) show that the warmer slope water had lower suspended concentrations than the colder shelf water. The higher transmission readings (Figure 2-8) associated with warmer temperatures suggest cross-shelf movement of the front past the mooring site. Laboratory tests of the temperature sensitivity of the transmissometer sensor used in this deployment were not performed; tests of similar sensors showed variations in signal output with temperature less than observed in situ, thus suggesting the suspended sediment variations were real and not instrumental.

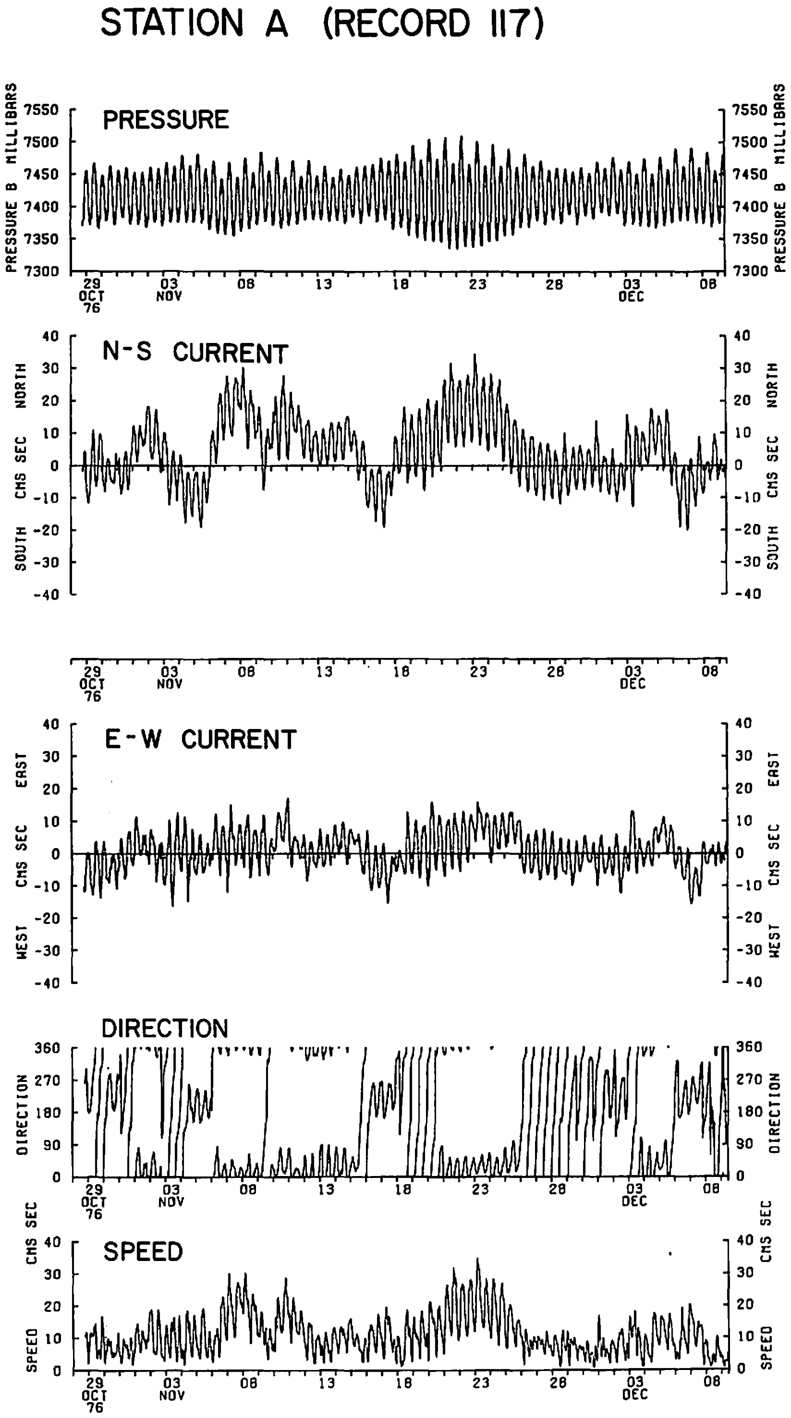


Figure 2-4. Tripod observations from station A (Record 117), October-December 1976. The plots are of hour-averaged data. The original sampling interval was 7.5 minutes. a. Pressure, north-south current, east-west current, current direction, current speed

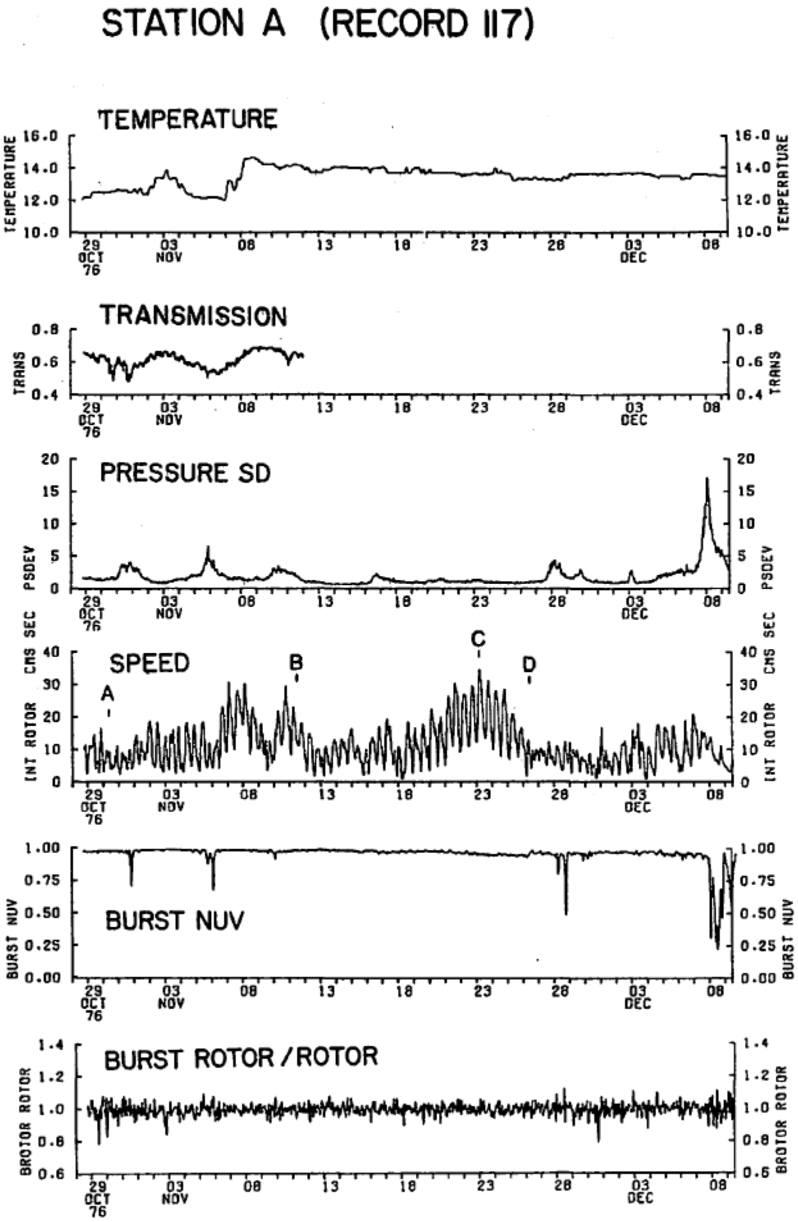


Figure 2-4. b. Temperature, transmission (normalized by output in clean water), pressure SD, rotor speed, burst NUV and burst rotor/rotor. A-D on speed trace indicate times of bottom photographs in Figure 2-5.

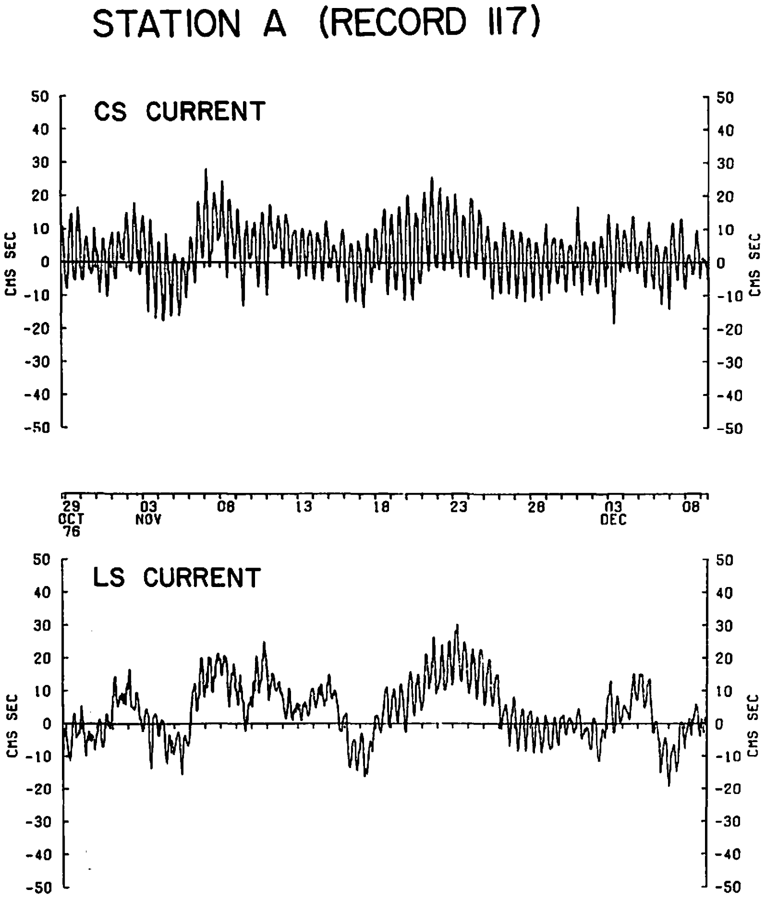


Figure 2-4. c. Longshelf (45°-225°) and cross-shelf (315°-135°) current.

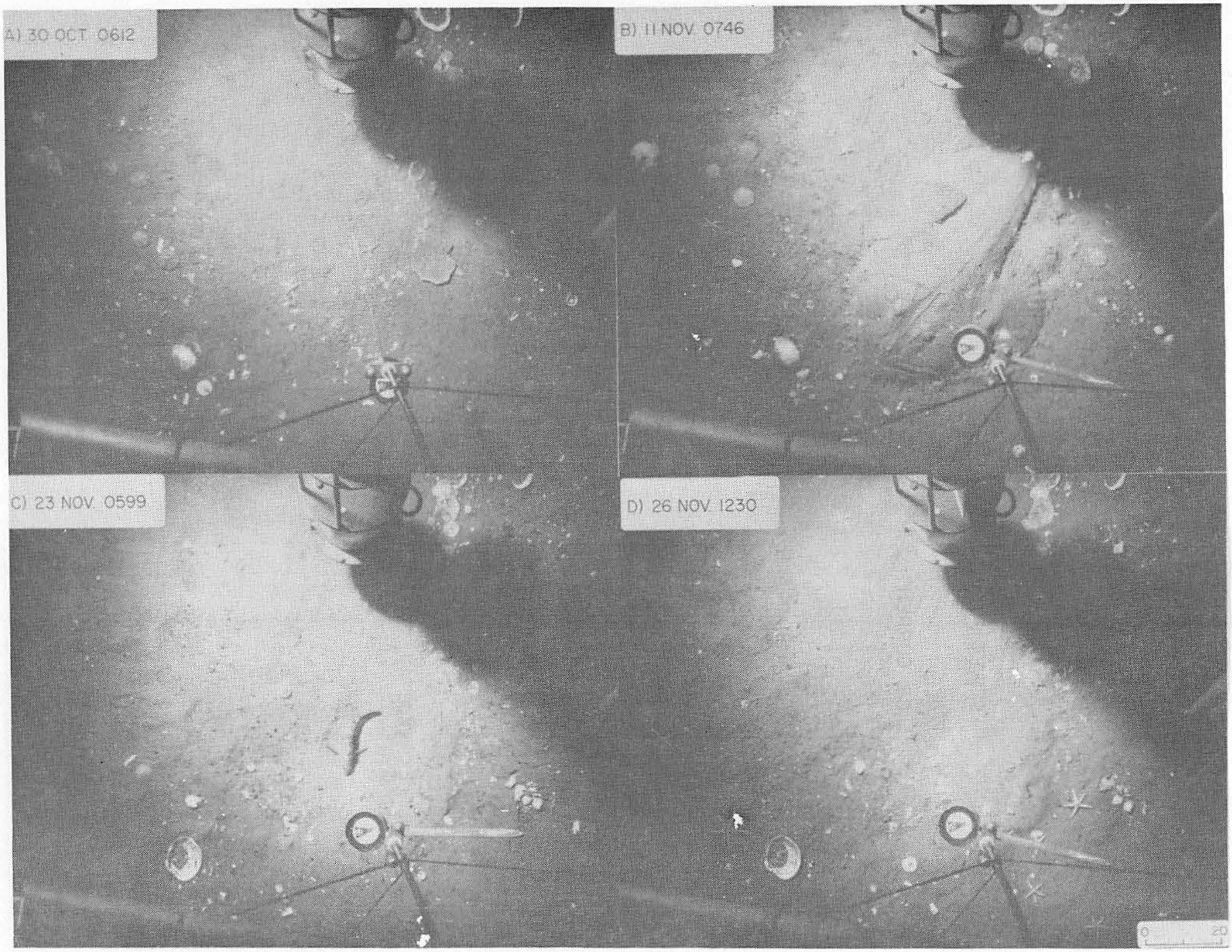


Figure 2-5. Bottom photographs from station A October-December 1976. a. 30 October, 9612; b. 11 November, 0746; c. 23 November, 0559; d. 26 November, 1230. The large fish in picture b is a goosefish (<u>Lophius americanus</u>) (Bigelow and Schroeder 1953).

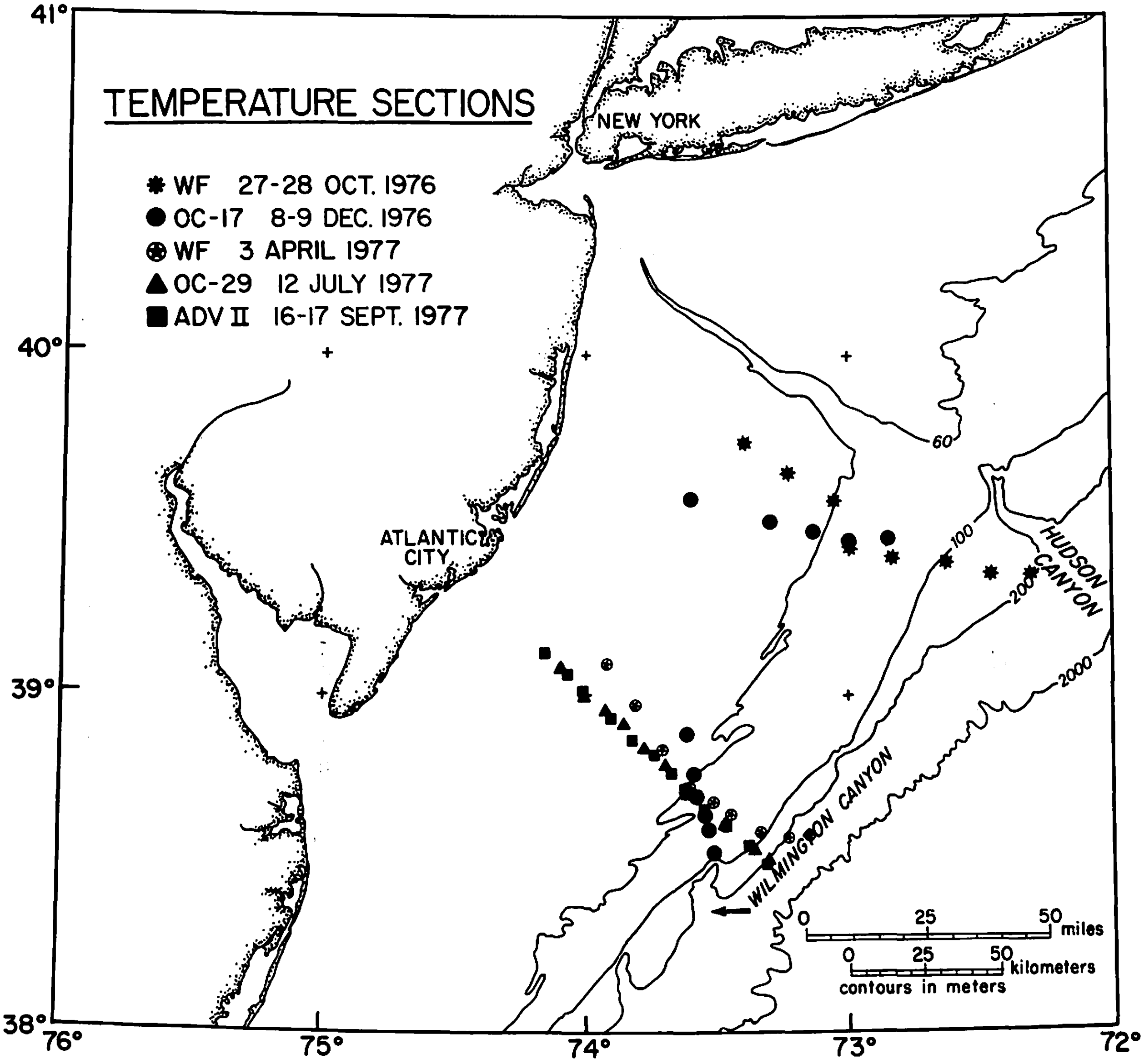


Figure 2-6. Location of temperature sections made 1976-1977.

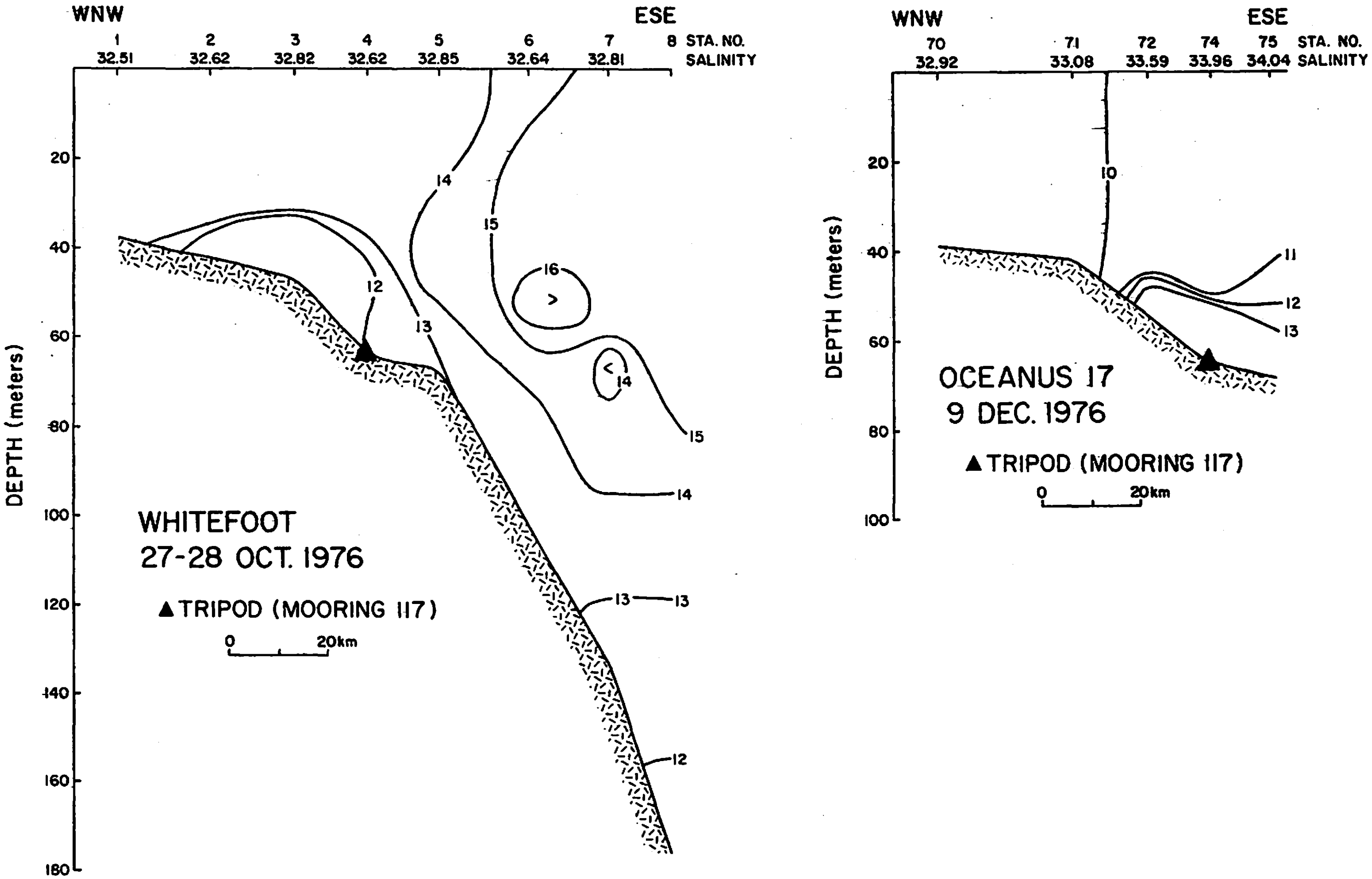


Figure 2-7. Cross-shelf temperature section at station A.
a. 27-28 October 1976 Beginning of tripod record 117.
b. 9 December 1976 End of tripod record 117.

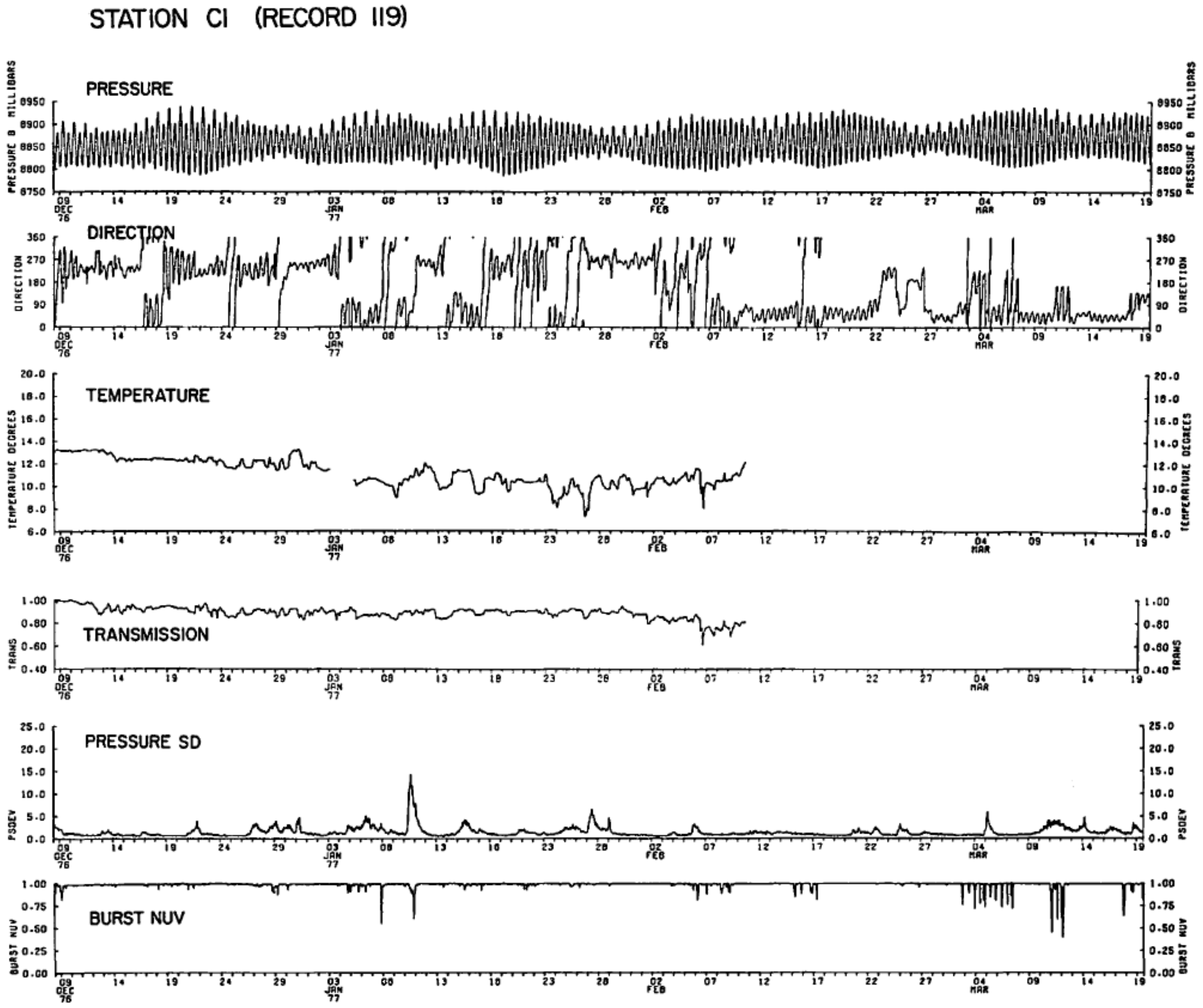


Figure 2-8. Tripod observations from station Cl (Record 119) December 1976-March 1977. The current speed sensor failed on this deployment; current direction is the unweighted vector average of the vane measurements. The transmission observations have been normalized by the maximum observed value. The plots are of hour-averaged data. The original sampling interval was 7.5 minutes.

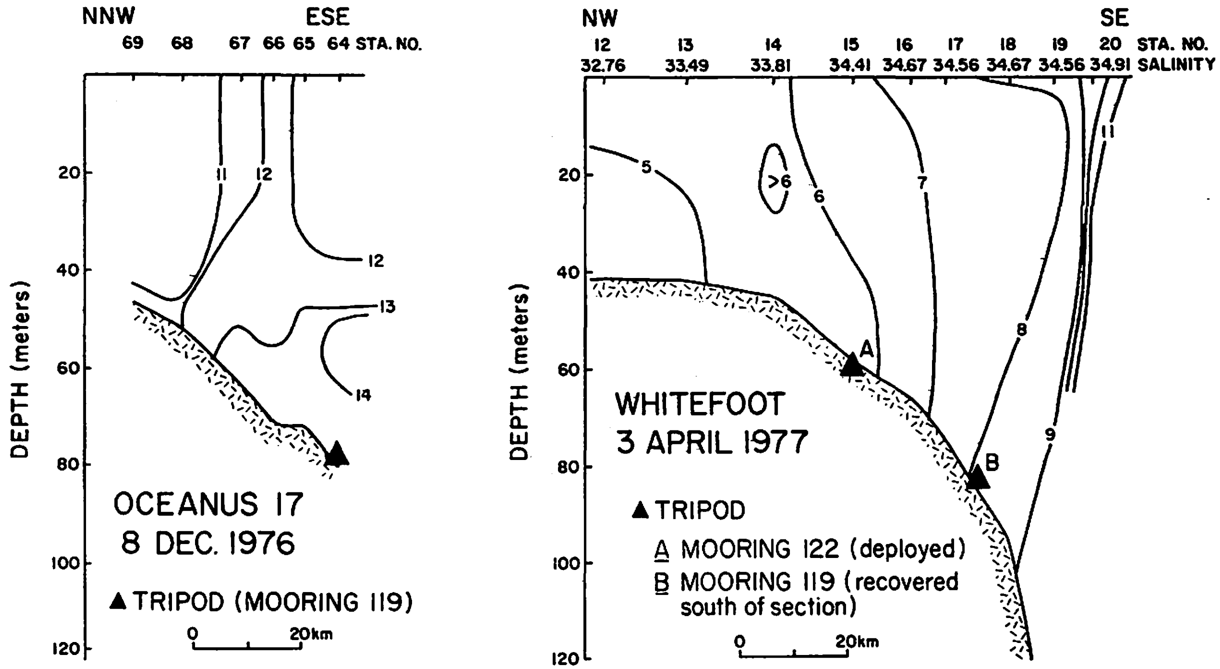


Figure 2-9. Cross-shelf temperature section at station B and C (See Figure 2-6 for locations). a. 8 December 1976, Beginning of record 119, Station C1; b. 3 April 1977, End of record 119, Station C1, beginning of record 122, Station B;

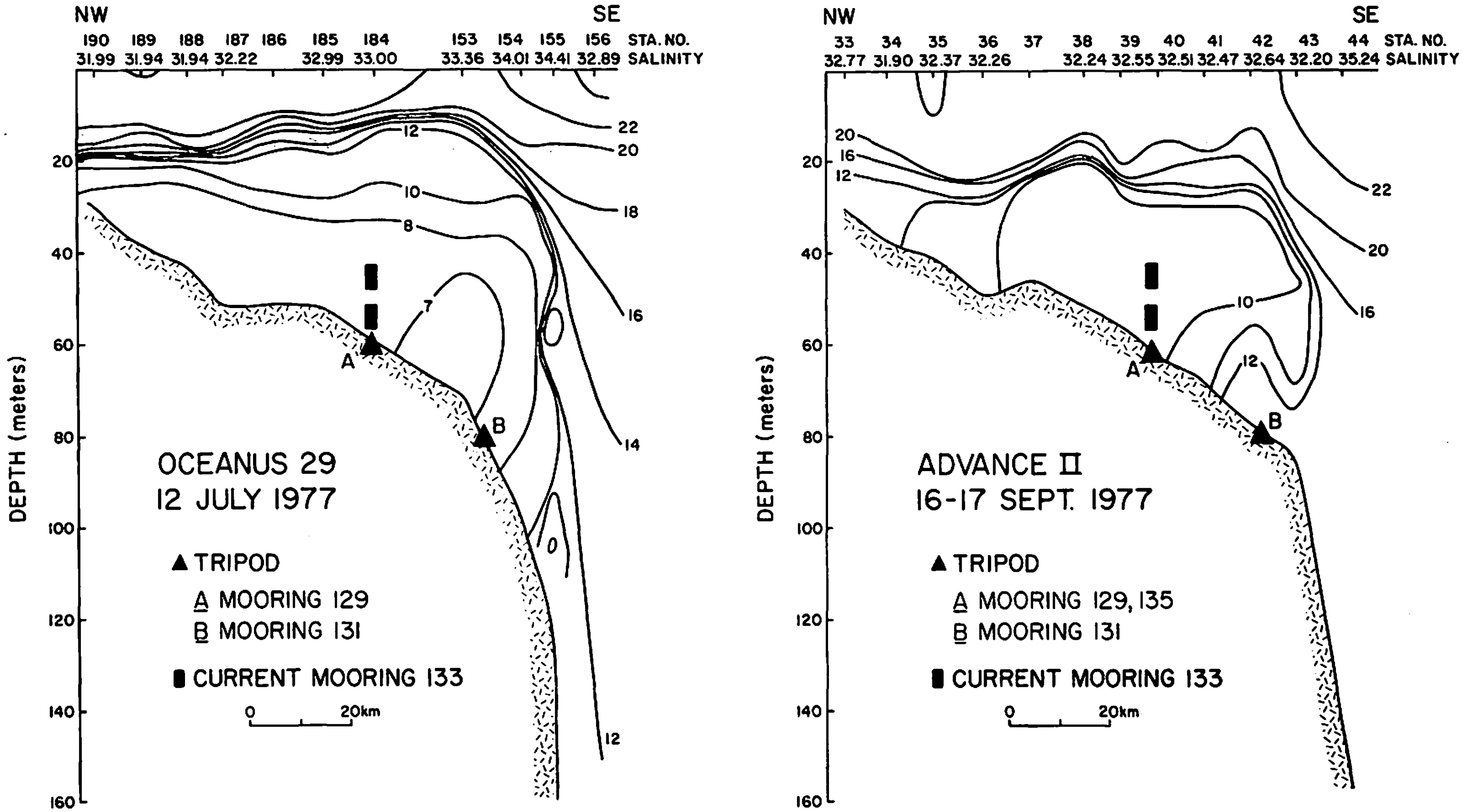


Figure 2-9. c. 12 July 1977, End of record 122 Station B, beginning of record 129, 1331, 1332 (Station B), and record 131 (Station C2); d. 16-17 September 1977, End of record 122, 1331, 1332 (Station B), and 131 (Station C2).

Milliman, Bothner and Parmenter (Chapter 3) also suggest resuspension of near-bottom sediments in the region of the front as indicated by an increase in suspended matter near-bottom (Figure 3-8, Chapter 3). The speed sensor failed on mooring 119 and thus speed information is lacking. In addition, the mooring was dragged by a fishing trawler and the camera was ripped from the mounting tabs and lost. As a result, no photographs are available to assess the extent of bottom movement or local resuspension. The unweighted direction measurements showed sustained periods of flow both to the northeast and southwest (Figure 2-8) suggesting low-frequency shelf edge currents. The relative decreases in transmission near the beginning of the record (12-13 and 16 December) occurred during periods of constant temperature, suggesting local resuspension. The direction sensor indicated a southwesterly flow, for the rotary tidal component of flow (approximately 3 cm sec^{-1} longshelf) was only weakly present in direction.

At station B (the long term monitoring station), bottom conditions were generally tranquil from April-September 1977 (Records 122 and 129, Figures 2-10 through 2-13). In April the temperature field was vertically isothermal with colder water nearshore and warmer water at the shelf-slope boundary (Figure 2-9b). By July a strong thermocline had developed and the cold band (Ketchum and Corwin 1964; Boicourt and Hacker 1975) core temperature was less than 7°C (Figure 2-9c). In September the cold pool core had warmed to 10°C (Figure 2-9d). The bottom temperature as measured by the tripod indicates that the instrument was located in the southward moving cold core, and that there were no major intrusions of nearshore or slope water at station B. Surface wave activity (as indicated by PSDEV and BORV) was generally low throughout the observation period. The current direction observations (unweighted by speed) show southerly flow and rotary tidal currents.

Bottom photographs at station B showed little change in local microtopography from April to early June 1977. On 10-11 June, small asymmetrical ripples with steepened faces toward the southwest developed (Figure 2-11), and the suspended sediment in the water column increased as indicated by the decrease in light transmission and the bottom photographs (Figures 2-10, 2-11c). The bottom scour was associated with an increase in surface wave activity (PSDEV) and net flow was toward the southwest. Several other decreases in relative light transmission occurred during June (June 17, 22, 24 for example) indicating local resuspension or advection of turbid water past the instrument location. The decreases in transmission were not associated with any increase in PSDEV or lower values of BNUV. The high frequency of several of the transmission decreases suggests resuspension by internal waves. Unfortunately, the camera functioned only for the first 2 months of deployment, and thus no photographs are available to assess bottom changes associated with these high frequency transmission decreases.

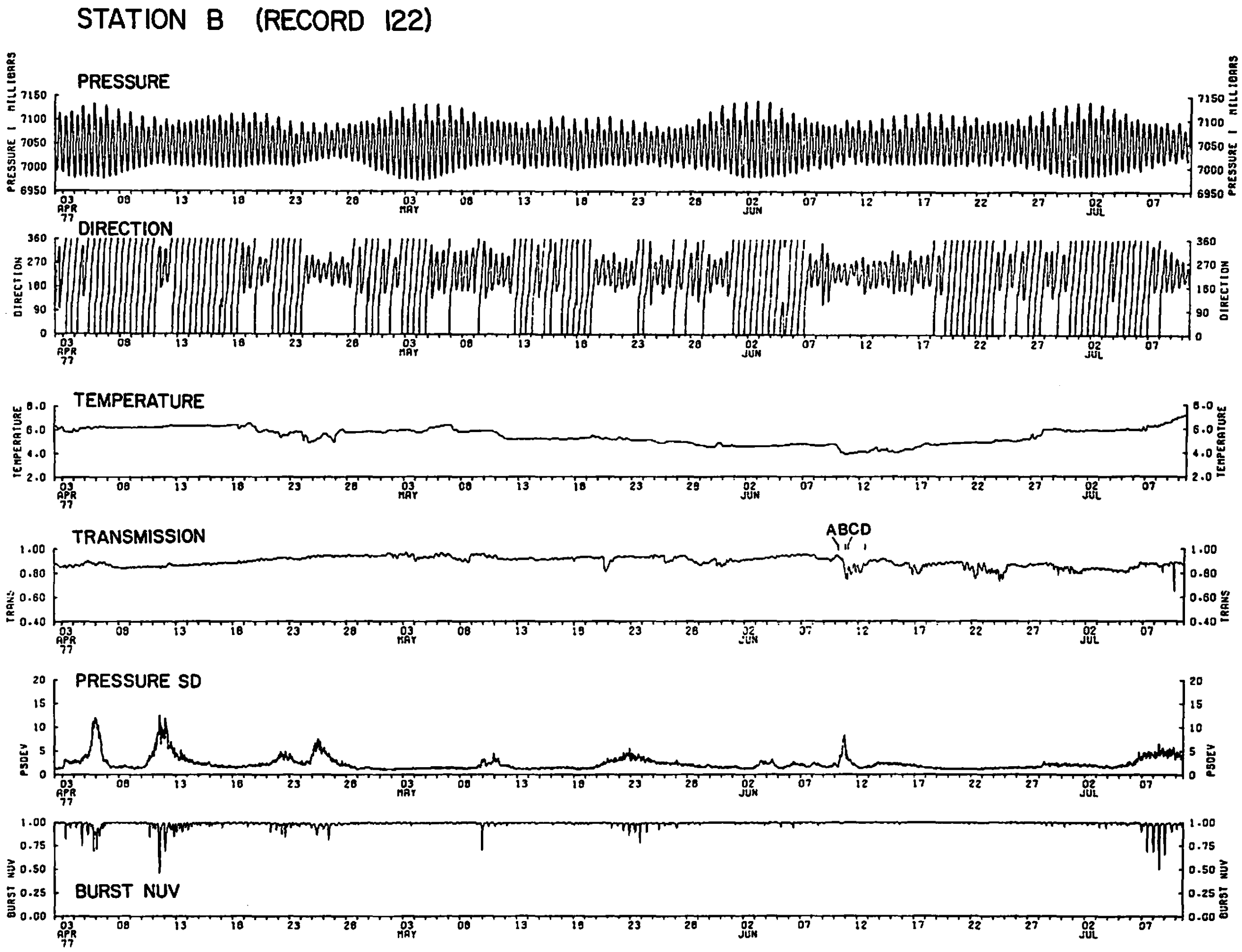


Figure 2-10. Tripod observations from station B, Record 122, April-July 1977. The current speed sensor failed on this deployment; current direction is the unweighted vector average of the vane measurement. The transmission observations have been normalized by the maximum observed value. A-D on transmission trace are times of bottom photographs shown in Figure 2-11. The plots are of hour-averaged data. The original sampling interval was 7.5 minutes.

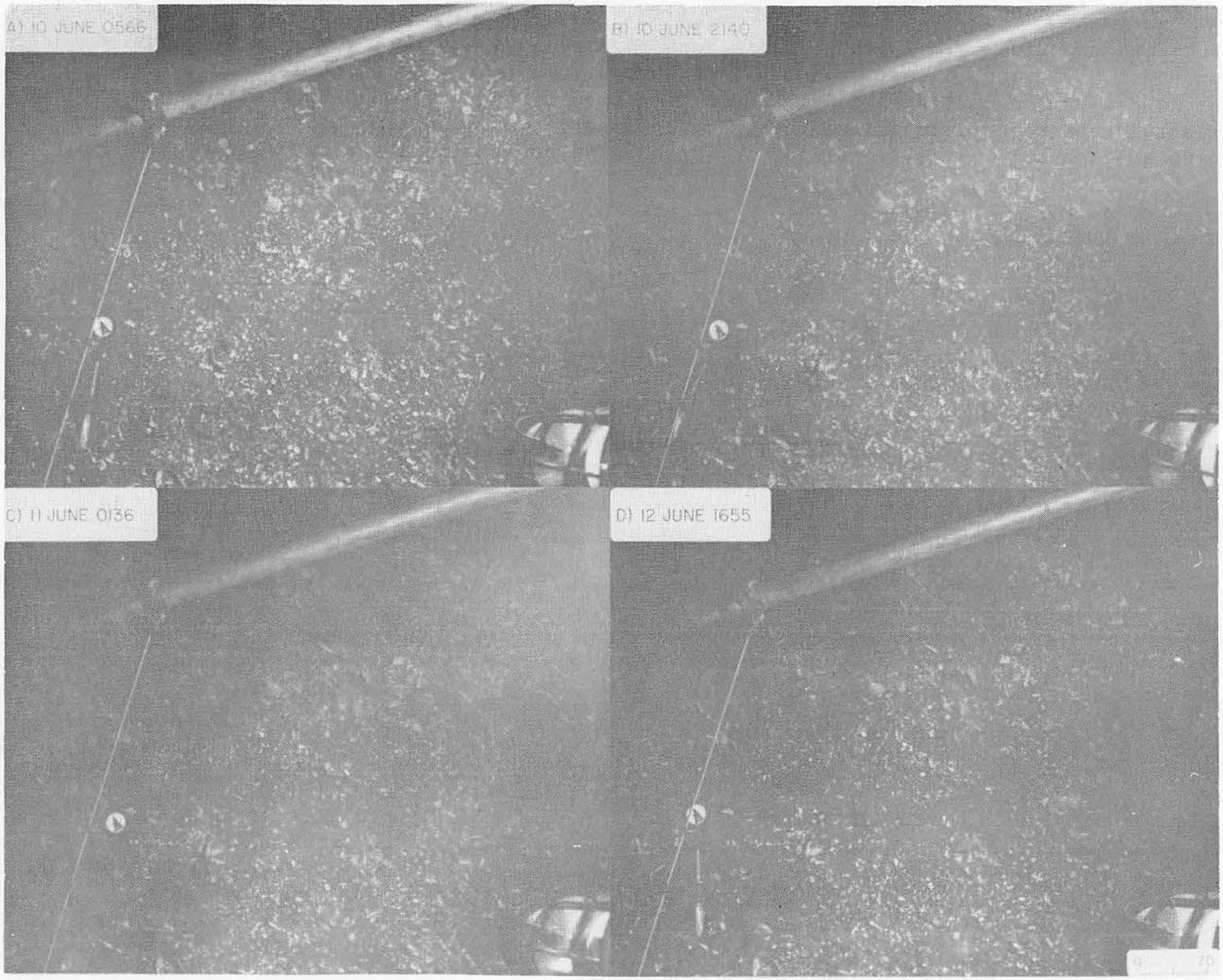


Figure 2-11. Bottom photographs from Station B. a. 10 June 556; b. 10 June 2140; c. 11 June 0136; d. 12 June 1655. The camera was slightly tilted at deployment and thus the angle of view of oblique to the bottom, and the picture illumination is not uniform. The reference scale is approximate.

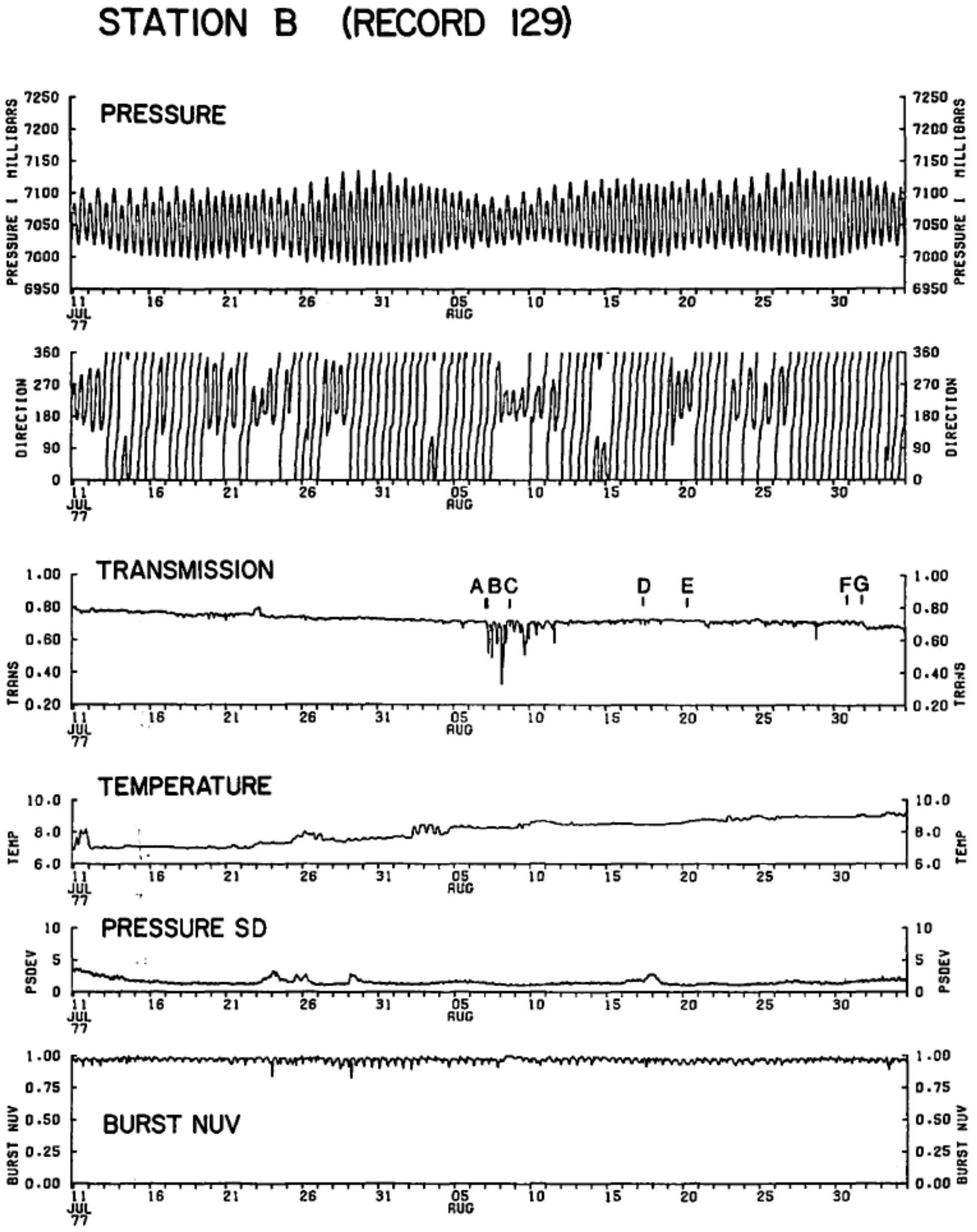


Figure 2-12. Tripod observations from station B (Record 129) July-September 1977. The current speed sensor failed on this deployment; current direction is the unweighted vector average of the vane measurements. The transmission observations have been normalized by sensor output in filtered distilled water. A-D on transmission trace are times of bottom photographs shown in Figure 2-13. The plots are of hour-averaged data. The original sampling interval was 3.75 minutes.

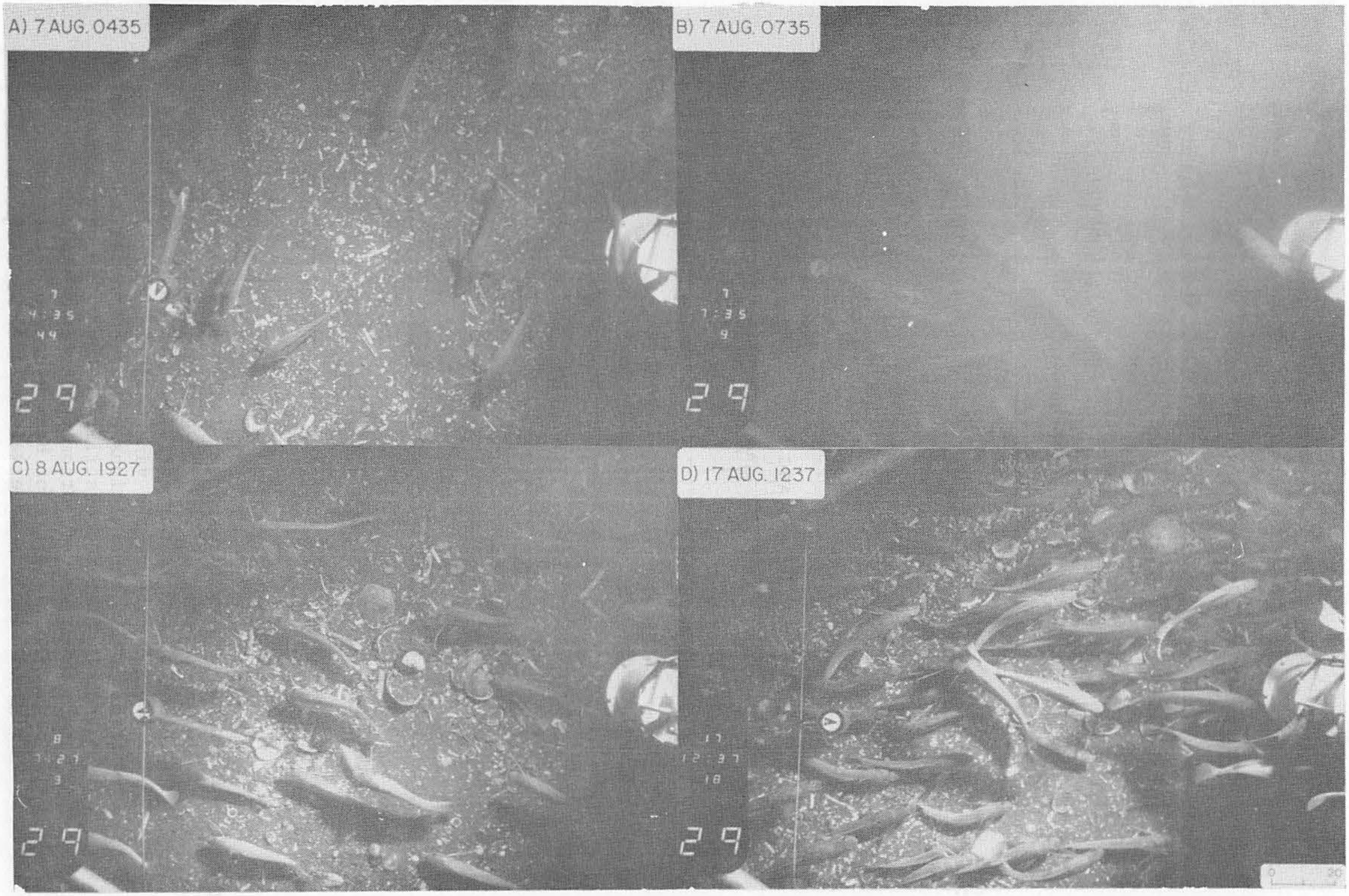


Figure 2-13. Bottom photographs from station B (Record 129). a. 7 August, 0435; b. 7 August, 0735; c. 8 August, 1927; d. 17 August, 1237 (Continued). The black arrow in the compass (left side of photograph) indicates magnetic north. The tripod orientation shifts twice during the picture sequence (between B and C and C and D). We suspect that the tripod was accidentally moved by trawlers fishing in the area and that the increase in suspended sediment in the water (B) was also caused by bottom trawling.

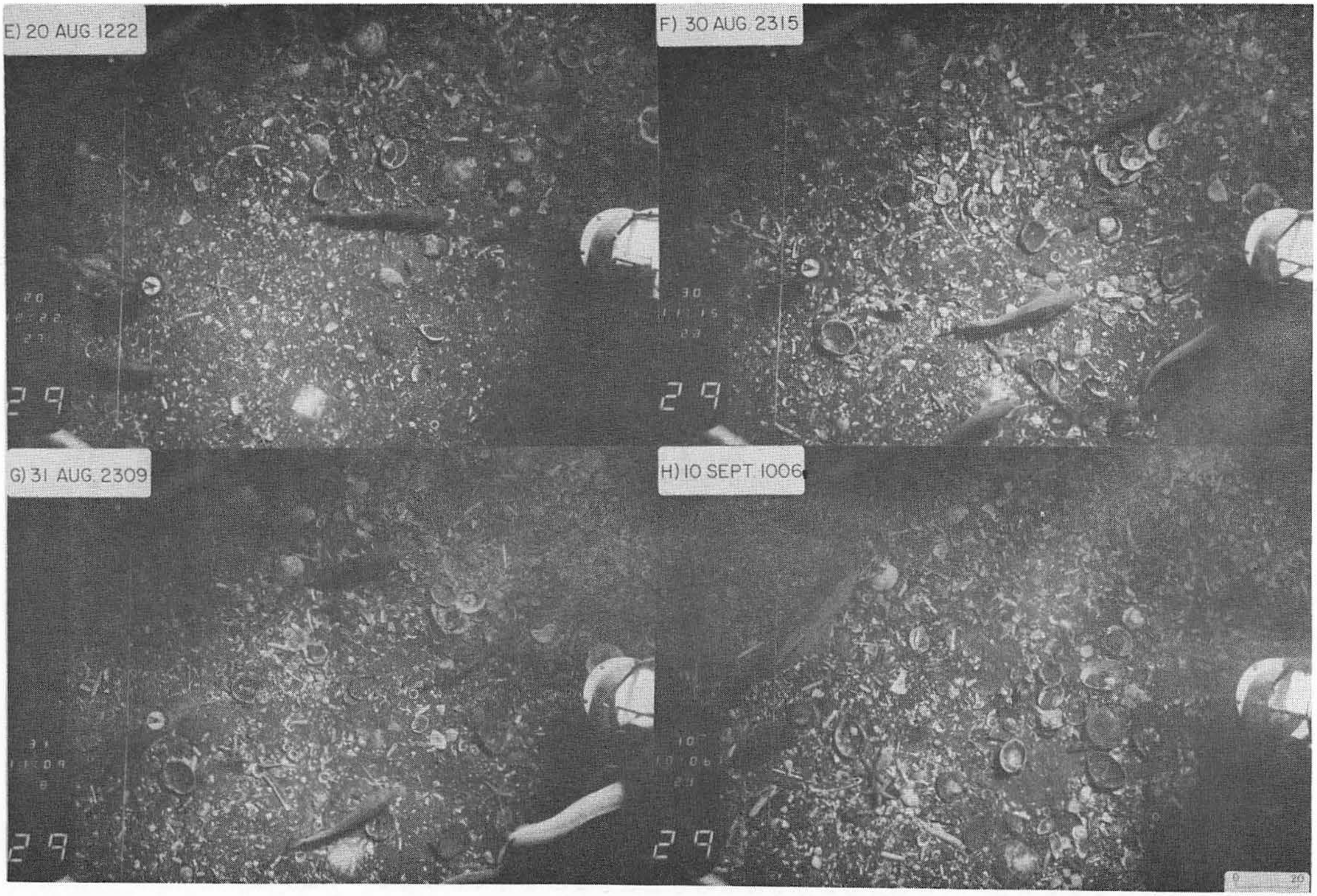


Figure 2-13. (Continued). e. 20 August, 1222; f. 30 August, 2315; g. 31 August, 2309; h. 10 September, 1006.

A period of low transmission was observed at station B from 7-11 August 1977 (Record 129, Figure 2-12). Intense resuspension of bottom sediments was confirmed by the bottom photographs (Figure 2-12). However, there was no increase in surface wave activity or near-bottom currents associated with the resuspension. During this period the tripod orientation with respect to north shifted twice. We suspect that bottom fishing by trawlers in the area was responsible for the increase in suspended matter and for the tripod movement. The area was open to foreign fishing and Coast Guard surveillance flight sightings near station B showed seven vessels fishing in an area 8-10 miles to the east on 7 August 1977. The data suggest that reworking of the surface sediments by trawlers is a mechanism for resuspending the finer material under tranquil current conditions.

Although the current records (Record 1332, Figure 2-15) and near-bottom transmission records (Record 129, Figure 2-12) indicate generally tranquil bottom conditions, the photographs show changes in bottom microtopography (Figure 2-12e-h), especially in the amount of exposed shell debris. For example, on 20 August there was little shell debris on the center of this bottom photograph. By 30 August, however, the bottom had a completely different appearance as additional shell material was exposed. Ten days later on 10 September, the arrangement of shell debris was again different and detail in the bottom photographs cannot easily be traced over the 10 day period. Some of the changes may have been caused by a large community of hake. Typically at least 5-10 fish were observed in most photographs from Record 129 and often as many as 50 bottom fish were present (Figure 2-13d for example). The transmission observations obtained every 3.75 minutes show decreases in transmission of relatively short duration from 13 August to the end of Record 129 (Figure 2-14). This was also a period of internal wave activity which may have caused some of the observed changes in the bottom microtopography. The relative transmission does not decrease for each increase in speed (Figure 2-14). However, the internal waves may not be of sufficient duration to resuspend material to the 2 m transmissometer level. In addition, mooring 129 and 133 were located approximately .5 nm apart. The internal waves will be addressed in more detail in the next section.

The two current records obtained in the summer of 1977 at station B at 6 and 15 m above bottom are similar (Records 1331 and 1332, Figure 2-15) and show a semidiurnal tidal current superimposed on a southwesterly mean flow. The transmission record obtained 15 m above the bottom (Figure 2-15b) is of particular interest and shows a relatively constant suspended sediment concentration from 12 July to 24 August 1977 when the transmissometer exhausted the available power supply. The near-bottom resuspension observed between 6-11 August at station B (tripod Record 129, Figure 2-12) was not observed 15 m above the bottom (this was the local resuspension we suspect was caused by bottom fishing in the area). The summer current, transmission, and hydrographic observations (Figure 2-9c, d) indicated there was little

STATION B

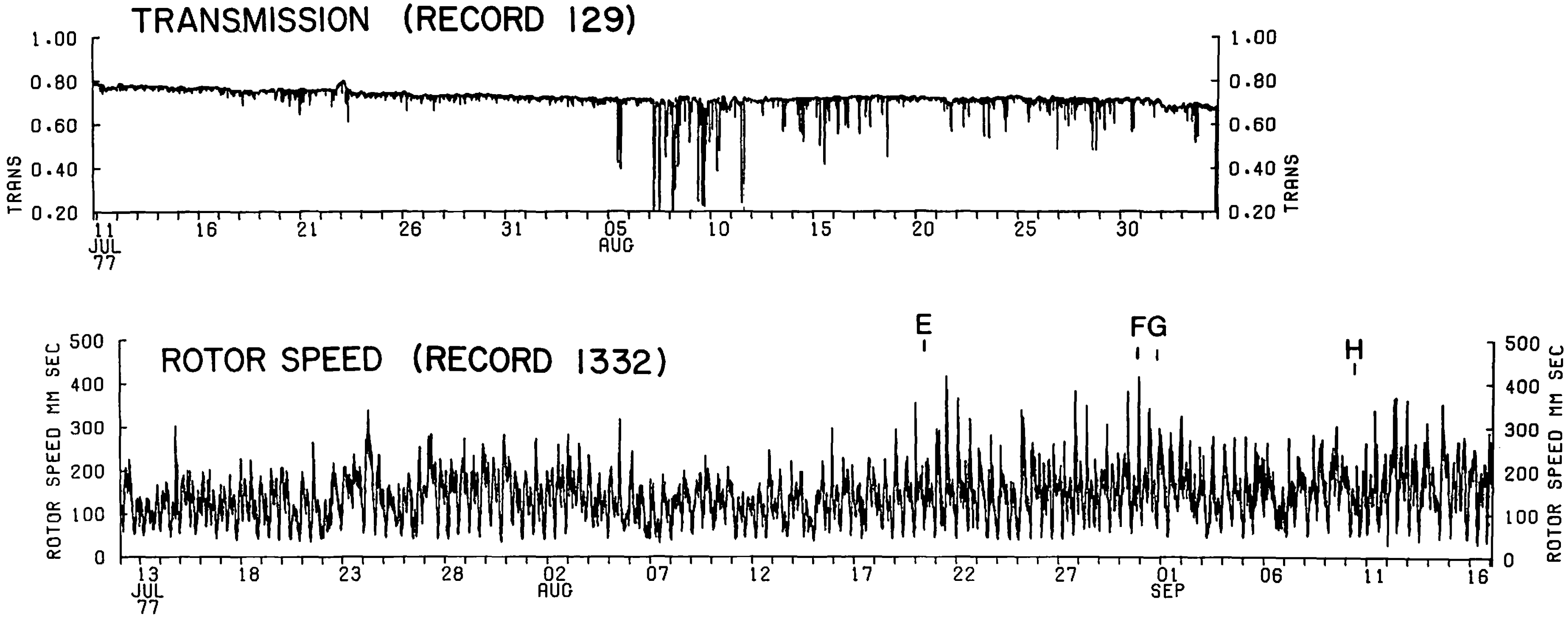


Figure 2-14. Transmission at station B 2 m from sea floor (Record 129) and rotor speed 6 m from sea floor (Record 1332). Data is at the basic sampling rate (every 3.75 minutes). Large spikes in rotor speed are internal waves (see Figure 2-17). E-H mark times of bottom photographs in Figure 2-13.

STATION B (RECORD 1331)

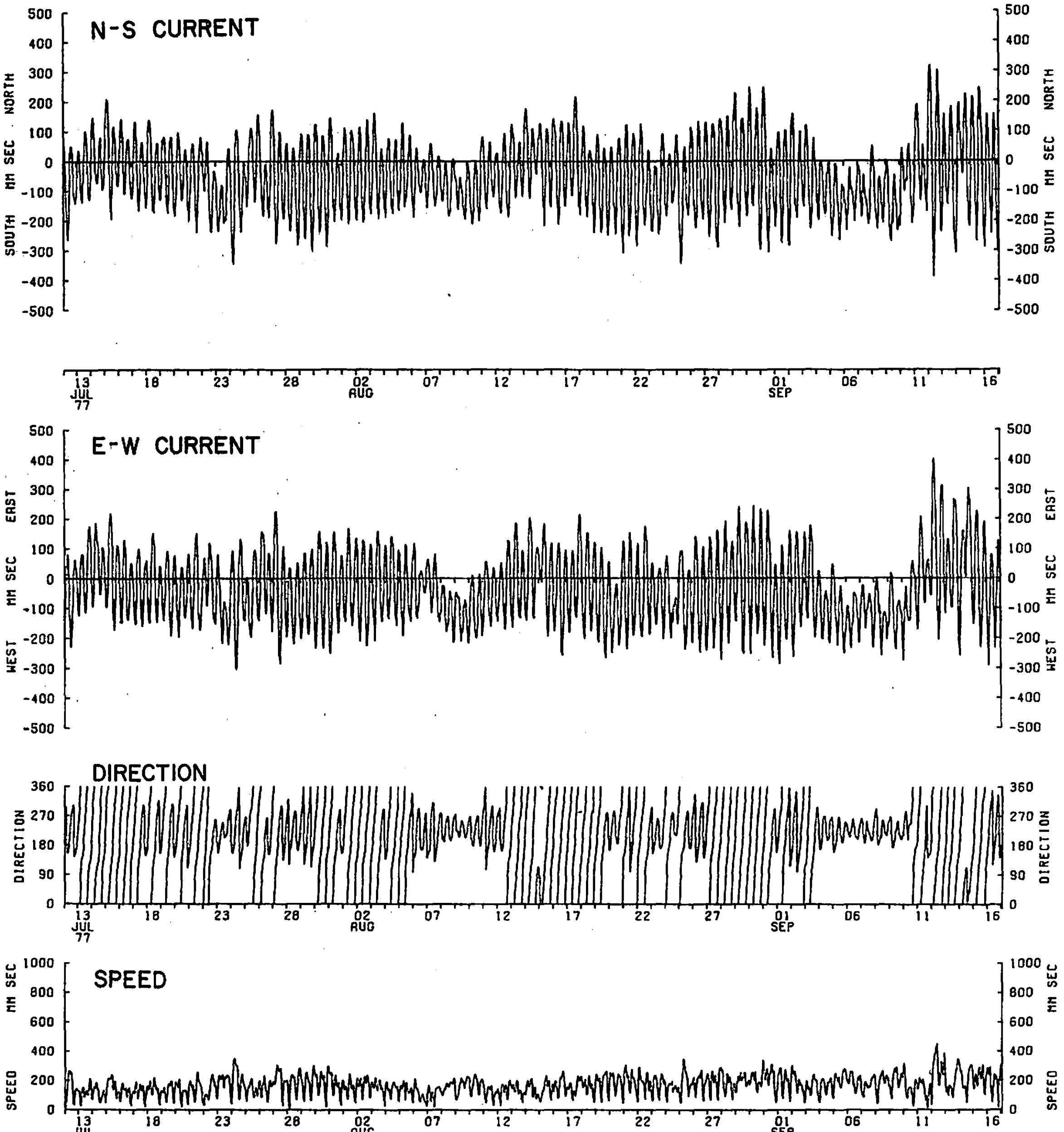


Figure 2-15. Current observations from station B, mooring 133, July-September 1977. Mooring 133 had two instruments; one 6 m above the bottom (Record 1332) and one 15 m (Record 1331) above the bottom. The VACM 15 m above bottom recorded transmission successfully; the transmission record has been normalized by sensor output in filtered distilled water. The plots are of hour-averaged data. The basic sampling interval was 3.75 minutes. a. Record 1331, north-south current, east-west current, current direction, current speed (continued)

STATION B (RECORD 1331)

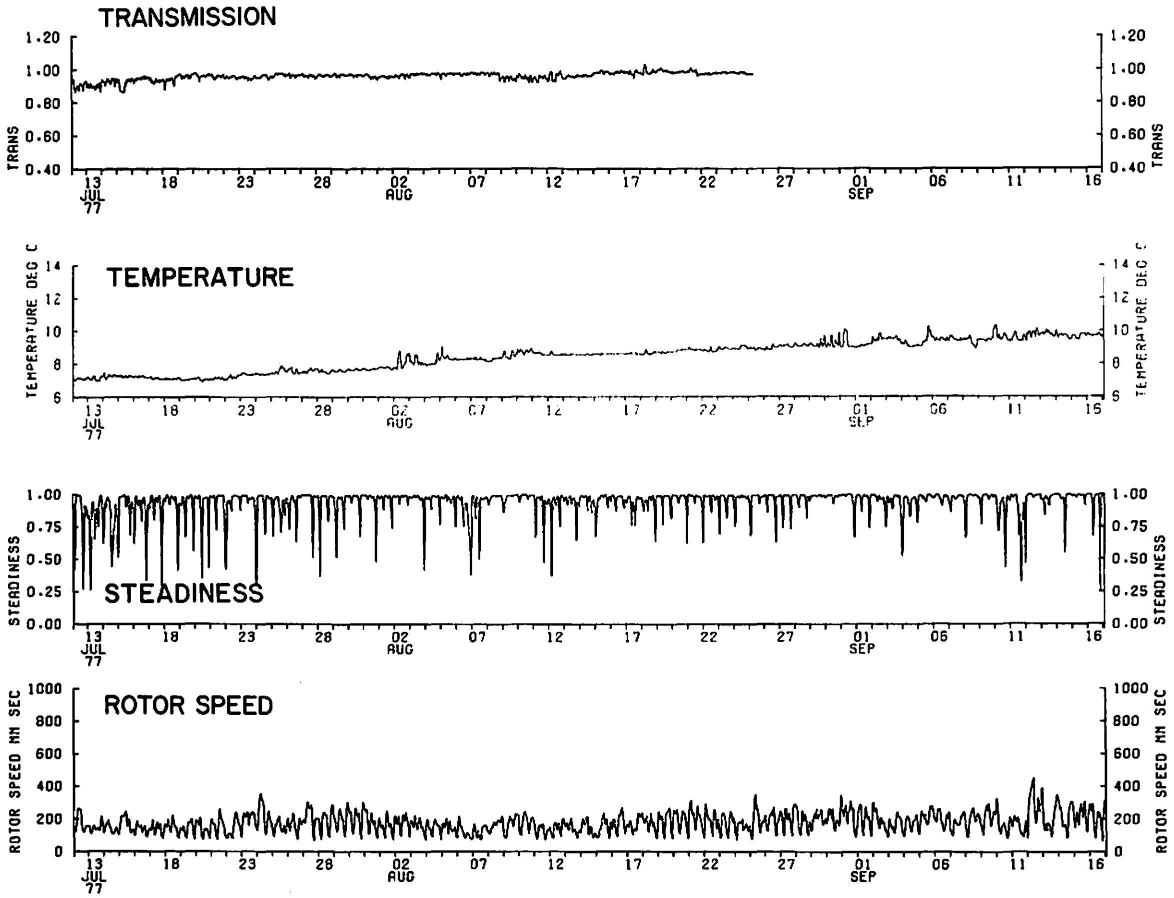


Figure 2-15 (cont'd) b. Record 1331, transmission (normalized by output in filtered distilled water), temperature, steadiness, rotor speed. Steadiness is (vector current speed)/(rotor current speed). (continued)

STATION B (RECORD 1331)

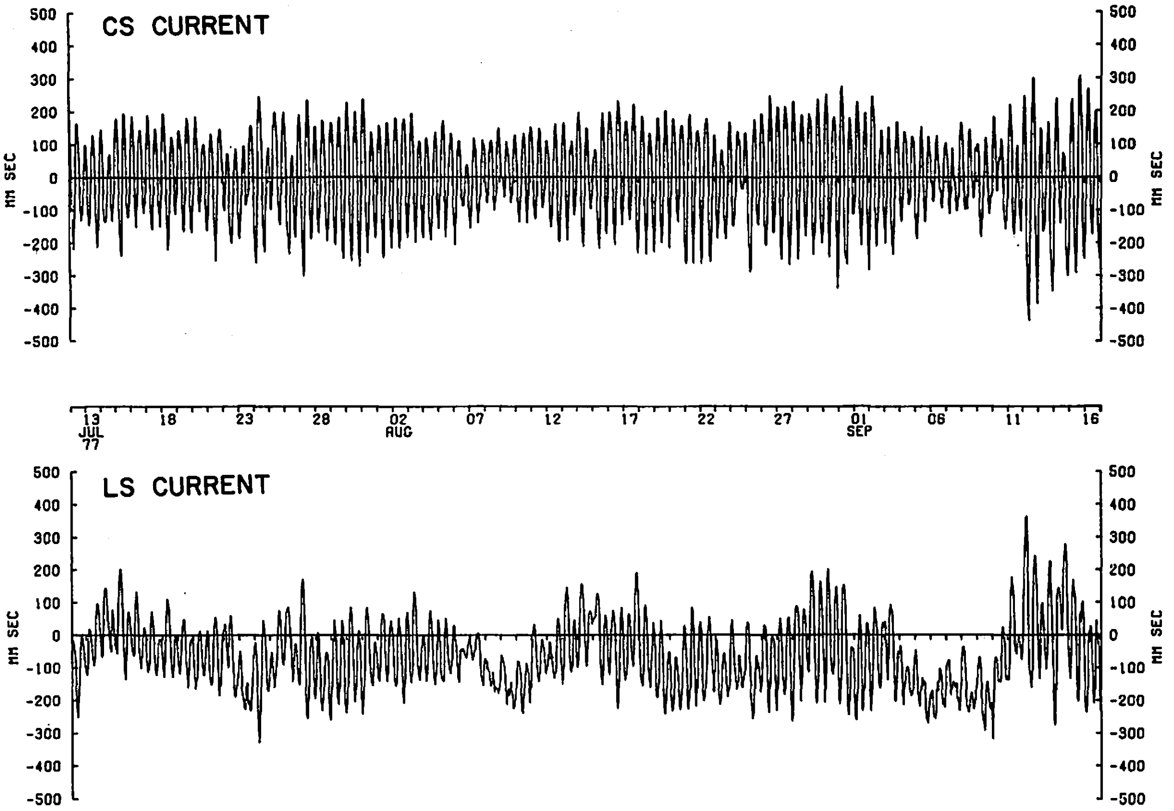


Figure 2-15 (cont'd) c. Record 1331, cross-shelf current (315°-135°) and longshelf current (45°-225°) (continued)

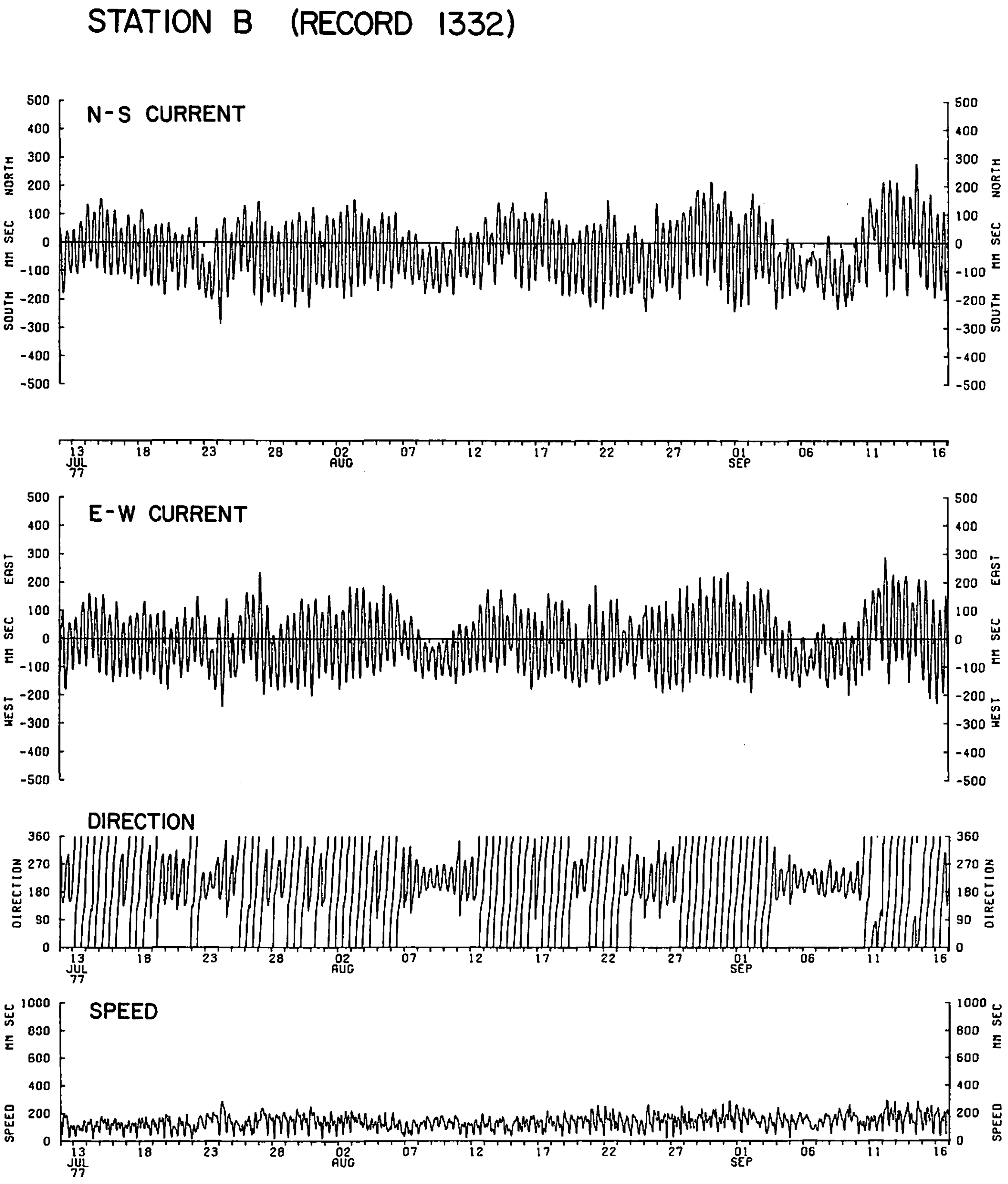


Figure 2-15 (cont'd) d. Record 1332, north-south current, east-west current, current direction, current speed (continued)

STATION B (RECORD 1332)

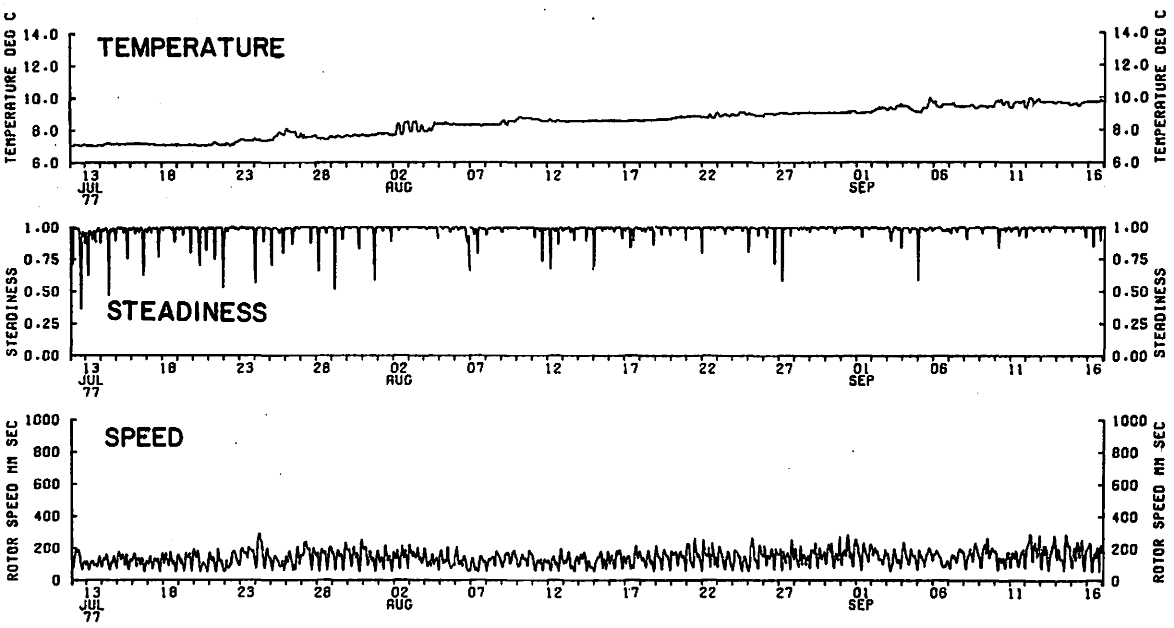


Figure 2-15 (cont'd) e. Record 1332, temperature, steadiness, rotor speed. Steadiness is (vector current speed)/(rotor current speed). (continued)

STATION B (RECORD 1332)

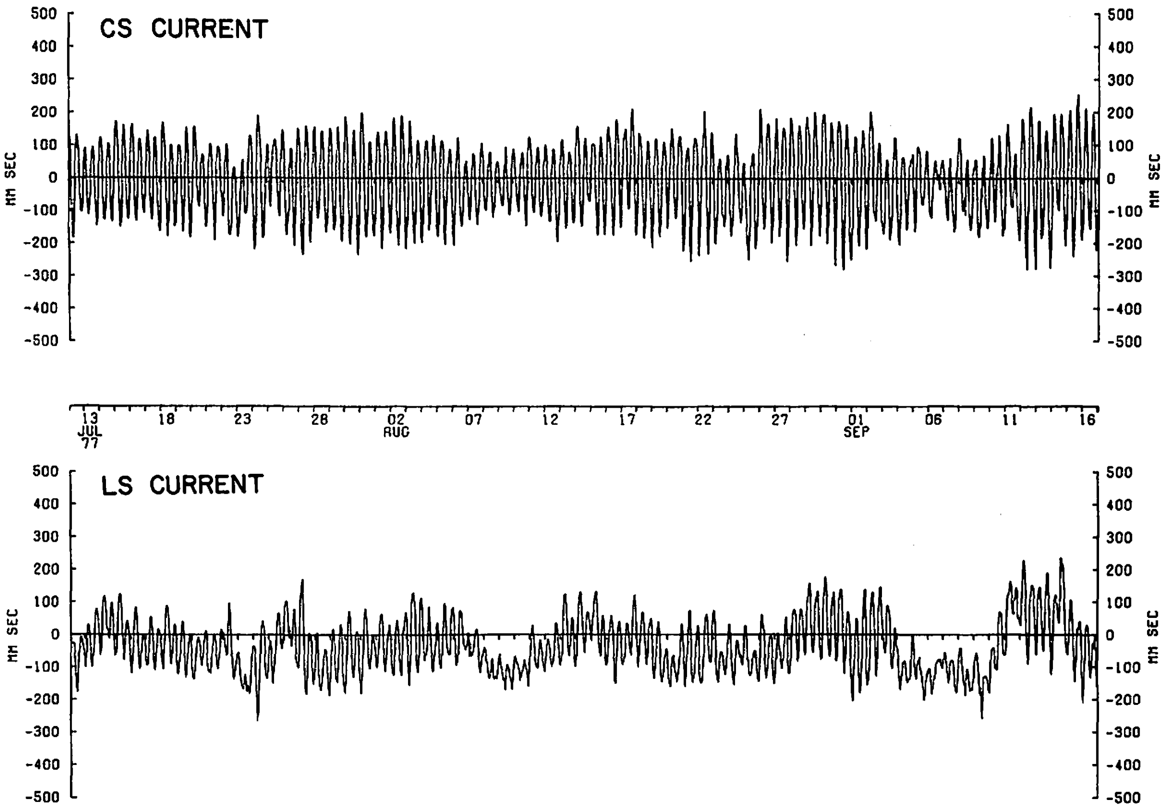


Figure 2-15 (cont'd) f. Record 1332, cross-shelf current (315° -135°) and longshelf current (45°-225°).

variation in suspended sediment concentration over a 6 week period in the southwesterly moving water of the cold pool.

At station C2, 25 km to the southeast of station B, tripod observations made in July and August show generally tranquil conditions (Record 131, Figure 2-16). The temperatures and transmission observations qualitatively resembled the measurements obtained at station C1, December 1976-March 1977 (Record 119, Figure 2-8). Variability in the ambient suspended matter concentration, as indicated by percent transmission, was larger at station C2 than at station B probably due to the proximity of the shelf-slope water front (Figure 2-9c, d). At deployment, the mooring was in the cold band (Figure 2-9c). In September the cold band had warmed and the mooring was located in a warm intrusion of slope water (Figure 2-9d). Bottom currents at station C2 were typically less than 15 cm sec^{-1} and the current direction was generally southwesterly throughout the observation period. A camera failure prevented direct observation of any surficial sediment resuspension.

In summary, the spring and summer observations at stations B and C2 showed generally tranquil conditions in the mid-shelf region of the cold band, with intermittent local resuspension. In contrast, near the shelf break, fluctuations of the ambient suspended sediment concentration was determined by the position of the shelf-slope water front. Due to a camera failure at the outer shelf station, the extent of movement of near-bottom material, if any, could not be assessed.

Slope water, as characterized by warmer water and low suspended concentration, was observed on the shelf for periods of time at stations A (60 m) in winter and C1 and C2 (85 m) in winter and summer. The distinction between shelf and slope water, as indicated by the temperature and transmissometer observations, suggests that mixing was inhibited across the shelf-slope interface. The less turbid slope water was advected past the mooring locations, but did not mix with the relatively more turbid shelf water. Material in the shelf water thus may remain trapped on the shelf, and be advected along isobaths with the mean flow. However, bottom material could become mixed into the slope water by resuspension while the slope water has intruded into the shelf. Material could be transported off the shelf if it remained in suspension for periods longer than the cross-shore excursion period of the slope water. Further study is needed to resolve both the frequency and extent of the cross-shelf excursions of slope water, and the degree of resuspension at the shelf-slope boundary in order to assess the on-off shelf transport of suspended material.

SUMMER HIGH FREQUENCY INTERNAL WAVES

Packets of internal waves were observed during the summer of 1976

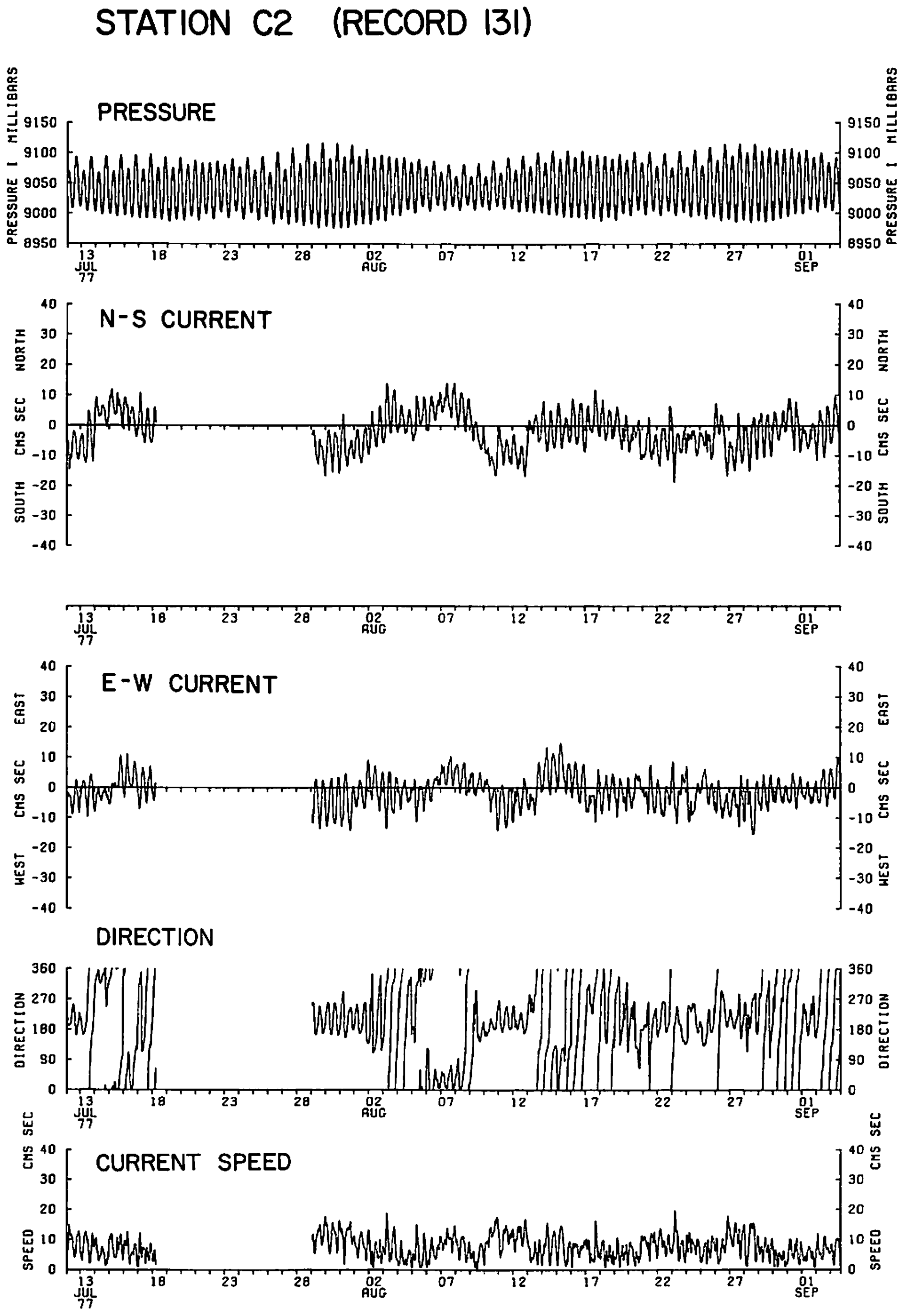


Figure 2-16. Tripod observations from station C2 (Record 131) July-September 1977. The plots are of hour-averaged data with the exception of d. which is data at the basic sampling interval of 3.75 minutes. a. pressure, north-south current, east-west current, current direction, current speed. (continued)

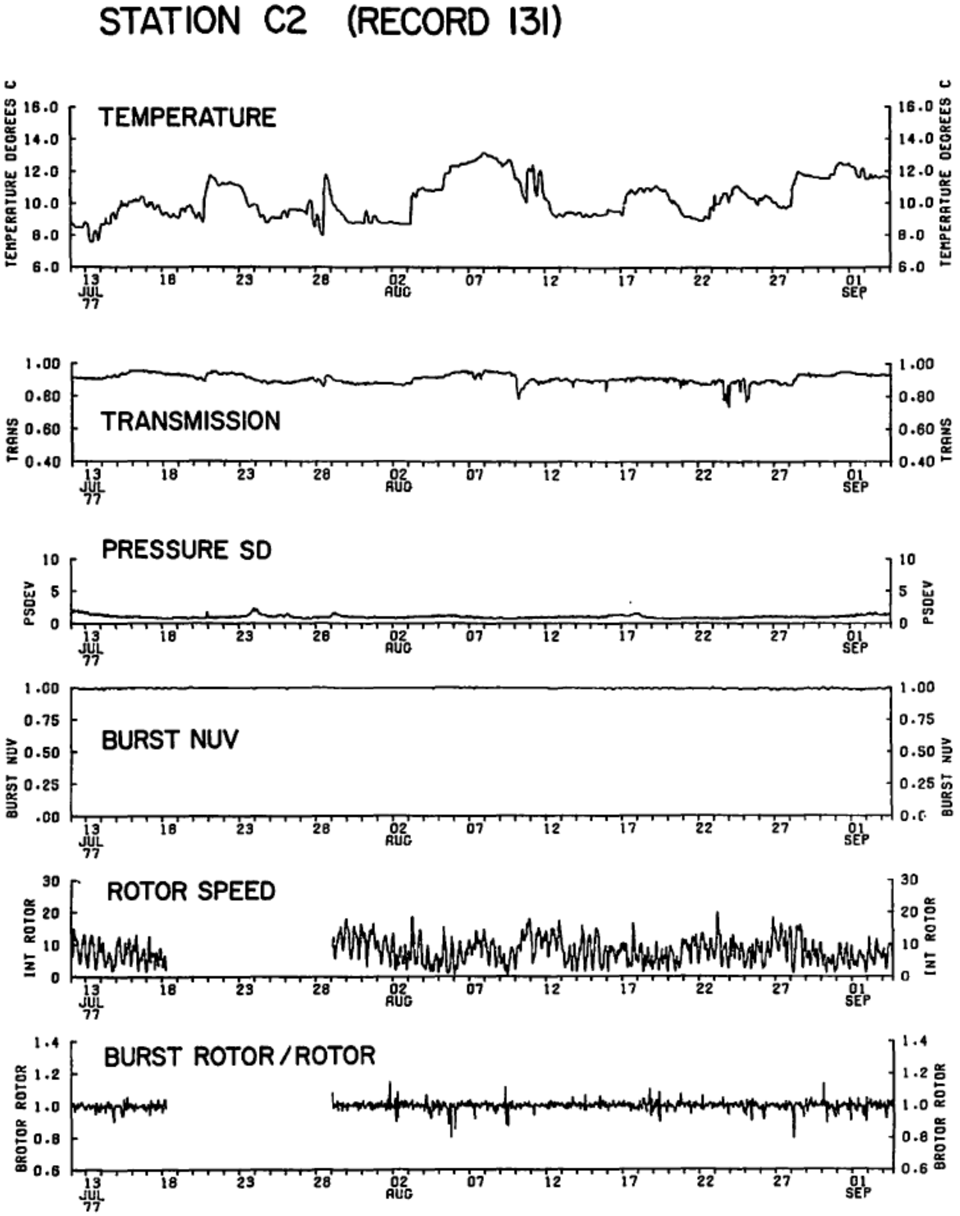

STATION C2 (RECORD 131)

Figure 2-16 (cont'd) b. temperature, transmission (normalized by sensor output in filtered distilled water), pressure SD, burst NUV, rotor speed, burst rotor/rotor. (continued)

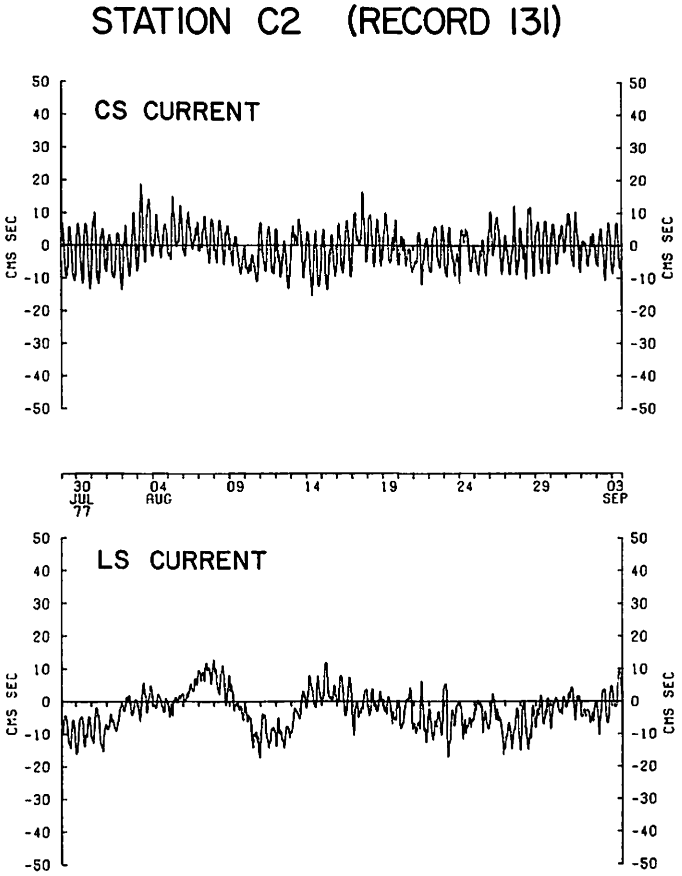


Figure 2-16 (cont'd) c. cross-shelf (315°-135°) and longshelf (45° -225°) current (hour-averaged data). (continued)

STATION C2 (RECORD 131)

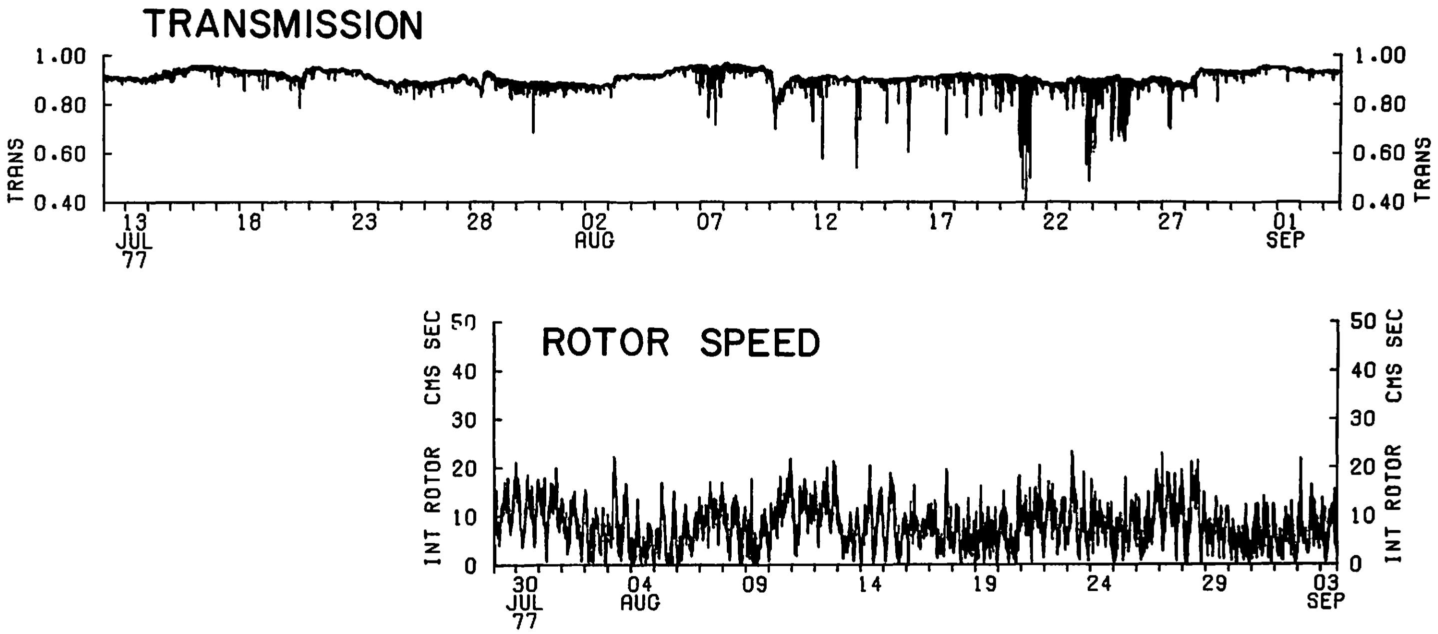
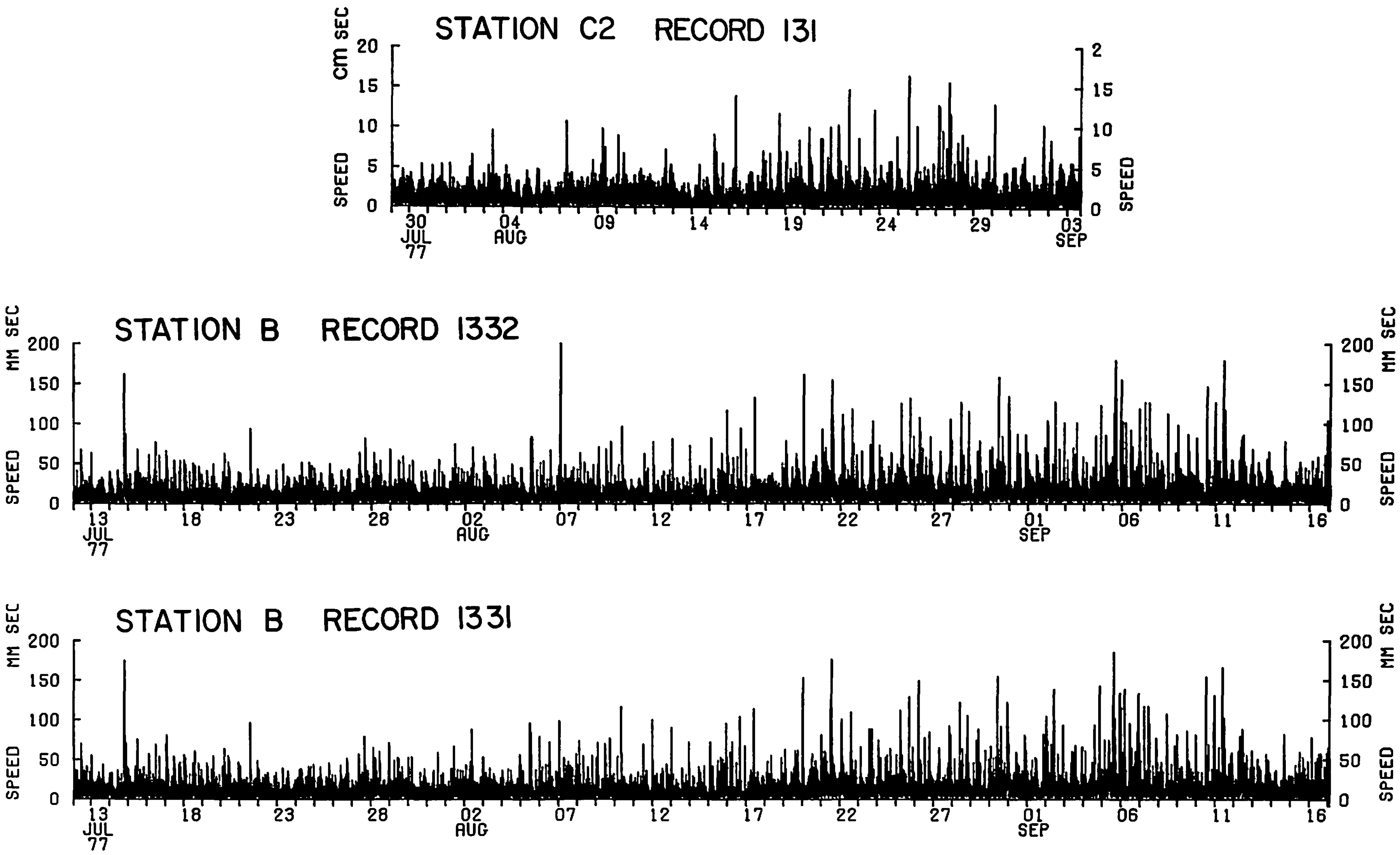


Figure 2-16 (cont'd) d. transmission and rotor speed; data is plotted at the basic sampling interval of 3.75 minutes. (continued) at stations A and C1 (Butman, Noble and Folger 1977). In the summer of 1977 a small scale cross-shelf array of two tripods, one at station B and one at station C2, and a current meter mooring at station B with AMF vector averaging current meters (VACM) at 6 and 15 m above the bottom was deployed to further investigate the internal wave motion and the importance of these waves for bottom sediment mobility. The current meters were modified to record light transmission with a sensor identical to that used in the tripods. The instruments sampled every 3.75 minutes. The data showed packets of internal waves throughout the observation period (Figure 2-17), with a spacing between packets of approximately 12 hours, suggesting these internal waves were generated at the shelf break by the semidiurnal tidal currents. The unequal spacing of the packet occurrence suggested sporadic generation at several sites along the shelf.

With a relatively calm sea, the surface expression of internal wave packets can often be observed visually as a long smooth band of water orientated perpendicular to the direction of packet propagation. On 16 September 1977 several internal wave slicks were observed near site A aboard the R/V ADVANCE II. Each slick was approximately 1/4 mile wide cross-shore and of a larger longshore extent than could be observed. The surface slicks were about one mile apart. A crude estimate of a $1 \pm .5$ m $\sec^{-1}$ average onshelf packet propagation speed for the area between station C2 and B was made by offsetting the time axes at stations C2 and B to align individual packets of waves. The estimated speed gives a 20-30 minute spacing between peaks in the observed slick, which is consistent with the 20-30 minute spacing between packet peaks found in the previous summer's deployment (Butman, Noble and Folger 1977).

The current amplitude associated with individual internal waves was typically 15 cm $\sec^{-1}$ or less, with a period of 5-20 minutes. This current amplitude is of the same order as the wind forced currents and of the tidal currents in the area during the summer season. Individually, none of the above currents are competent to resuspend sediments. However, the transmission and current measurements at the 3.75 minute sampling interval (Figures 2-14, 2-15d) do show some decrease in light transmission correlated with some of the large current speed peaks. However, resuspension, as indicated by transmission, does not occur for all speed peaks of a given amplitude. Possibly the duration of the waves is not sufficient to resuspend material to the 2 m above bottom level where the transmissometer is mounted to the tripod frame. In addition, the transmission measurement is a single short duration (1 sec) sample obtained every 3.75 minutes, while rotor speed is an average over the 3.75 minutes (see Chapter 8). The real peak in bottom current may not occur at the same time that light transmission is sampled. The data is thus inconclusive on the extent of movement of surficial sediments caused by internal waves. The bottom photographs at station B (Figures 2-13e-h) do show changes in bottom topography in summer, however, regardless of the movement process.

HIGH PASSED VECTOR SPEEDS


STATION C2 RECORD 131

STATION B RECORD 1332

STATION B RECORD 1331

Figure 2-17. High passed bottom speed at station B (Record 133, 1332) and C2 (Record 131) July-September 1977. Data was high-pass filtered with a gaussian filter which essentially passed all motions with periods shorter than two hours. Data points every 3.75 minutes.

SUMMARY AND CONCLUSIONS

The bottom tripod observations and hydrographic measurements made to date as part of the sediment mobility study clearly show intermittent but significant movement of the surficial sediments in the offshore mid-Atlantic Bight. The near-bottom currents are generally weak; the maximum observed current speeds in water depths of 60 m were less than 45 cm sec^{-1}. Resuspended bottom sediments could be transported several hundred km longshelf by the low frequency and mean bottom currents. The current observations are consistent with previous studies which show net bottom flow in the mid-Atlantic Bight is generally toward the southwest. Sediment sources to the northeast of the area may affect the ambient levels of suspended material. However, the near-bottom flow was weak and reversals of the mean flow toward the northweast, as in November 1976, did occur. Near the shelf-slope water front, the ambient level of sediment in the water column was partially determined by the position of the shelf in summer. However, the amplitude of these waves (15 cm sec^{-1} or less) was individually not large enough to resuspend bottom material at the stations mentioned, but there was some evidence for resuspension when the wave packets were superimposed on the maximum tidal current.

Continued in situ monitoring of the currents and bottom conditions at a single location (station B) is essential to define the seasonal and yearly variations in sediment transport processes and to monitor infrequent events. The importance of long term observations is clearly demonstrated by the anomalous northward mean currents which occurred during the winter of 1976. The observations made to date indicate that one station should be representative of much of the outer shelf region. In addition, measurements in shallower water (depths 20-40 m) on the inner shelf where surface wave activity is probably very important are required to define both the forcing mechanisms and the frequency of movement in these areas. Surface waves and shoaling internal waves may be important transport mechanisms in the shallower areas. Finally, additional measurements in the outer shelf region are needed to investigate the resuspension by currents associated with the shelf-slope front and to assess the importance of shelf-edge exchange mechanisms which may transport material off the shelf onto the slope and rise.

ACKNOWLEDGEMENTS

The skillful assistance of the Tug WHITEFOOT and R/V OCEANUS in deployment and recovery of the tripod systems is gratefully acknowledged. The assistance of the R/V ADVANCE II is also acknowledged. William Strahle, John West, Charles Deadmon, Gary Prisby, Stephanie Pfirman, and Sandra Conley (USGS) all assisted in various phases of the field work and data analysis. Val Wilson and Dave Hosom (Woods Hole Oceanographic Institution) also contributed substantially to the tripod program.

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CHAPTER 3

SESTON IN MIDDLE ATLANTIC SHELF AND SLOPE WATERS

J. Milliman
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CHAPTER 3

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CHAPTER 3

SESTON IN MIDDLE ATLANTIC SHELF AND SLOPE WATERS
1976-77

J. Milliman[1], M. Bothner[2], C. Parmenter[2]

INTRODUCTION

The prime purpose of this study has been to document and interpret the temporal and spatial distribution and composition of suspended particulates over the Middle Atlantic Outer Continental Shelf. Where are the concentrations highest? Lowest? What are the sources for the particulates? To what extent does resuspension of bottom sediments add to the particulate load in the water column? What evidence is there of the influx of anthropogenic particles? How do these various factors and distributions vary with season? To our knowledge, this is the first attempt in U. S. coastal waters to gain such a comprehensive picture of the particulate suspensates.

This report deals with distributions noted during five intervals within 1976-77, taken from four VIMS cruises and two separate USGS cruises. In addition, we compare the data obtained in August 1977 with that of August 1976 in an attempt to show that year-to-year variations in the seston distributions may be as significant as from season-to-season.

The combination of better coordination with VIMS, improved field and laboratory procedures, and additional USGS cruises which complimented the VIMS effort, have yielded a much more complete data set during this second year of the program.

METHODS

Generally, the cruises discussed here were completed within a week or ten days, thus giving us a quasi-synoptic view of the hydrographic and seston characteristics during that period of time. Exceptions to this are: (1) cruises in mid-November/early December (which combined data collected from the Fall 1976 VIMS cruise and those collected by OCEANUS 17 in December); (2) a VIMS cruise in August 1976, which lasted for nearly one month; and (3) a VIMS cruise

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in February 1977 which occurred in two legs separated by a 3-week period. As will be seen in a later section, preliminary observations show that, at least in some areas, resuspension of bottom sediments appears to occur periodically (perhaps on the order of a tidal cycle), which for these areas and conditions may invalidate the concept of quasi-synoptic observations.

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 mid-depth, and one approximately 1-2 m above the bottom. Attached to the rosette sampler was a transmissometer which continuously measured turbidity throughout the water column. On two cruises (OCEANUS 17 and SUB-SIG II), light transmission as a function of depth was displayed in real-time through a deck read-out, thus allowing us to choose the mid-depth sample where interesting maximums or minimums in light transmission occurred. Unfortunately, the CTD system used on VIMS cruises was not modified to provide real-time transmissometer data on deck until after the last FY 77 cruise. Thus, the mid-depth sample was collected on these cruises without knowledge of the turbidity structure. An additional unfortunate consequence of not having the means of monitoring the transmissometer output at sea was that instrumental problems were not immediately identifiable, resulting in occasional sequences of lost data. In spite of these occasional problems, the transmissometer data have provided valuable insights, particularly on the occurrence of active resuspension in near-bottom waters.

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 is so short, the problem of larger particles preferentially settling from suspension (Gardner 1977) does not appear to be a problem.[1] The 4-liter subsamples contained in graduated cylinders (with bottom withdrawals) were filtered by vacuum through inline filter holders containing paired pre-weighed Millipore® filters (nominal openings of 0.45 μ)[2]. The

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[1] Repeated samples from one station taken 5 minutes apart during the April 1977 (SUB-SIG) cruise show little change in total concentration, thus suggesting that settling within the first 15-20 minutes after collection is not significant.

[2] 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 3-1) and Millipore filters have the added advantage of clearing with optical oils for viewing with a petrographic microscope.

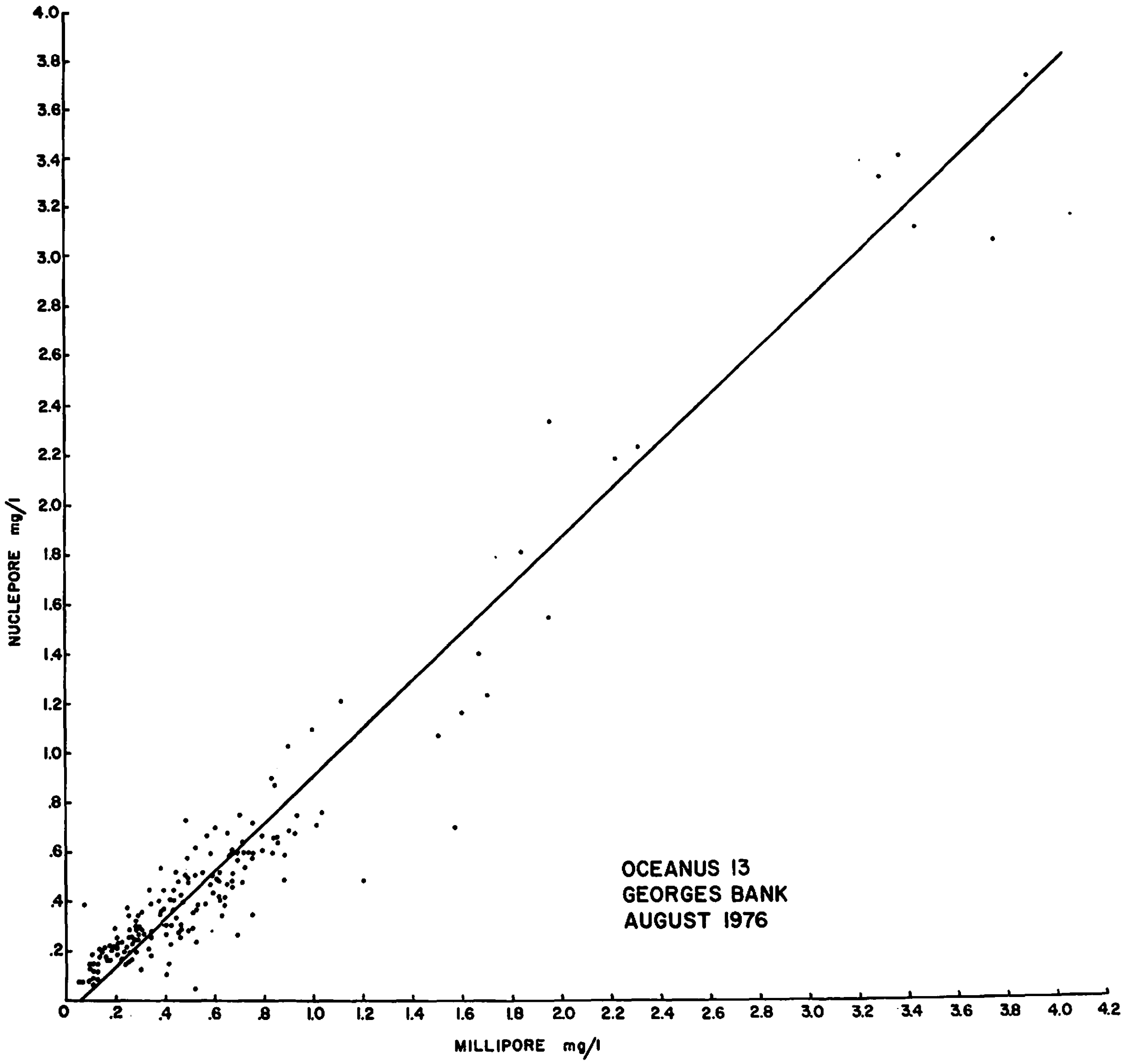

Figure 3-1. Comparison of suspended matter concentrations calculated from identical water samples filtered on Nuclepore and Millipore filters. Samples were collected and filtered during OCEANUS 13 on George's Bank and Nantucket Shoals, August 1976. Straight line is based on linear regression: $M = 1.04 N + .07$; $r^2 = 0.94$.

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 Millipore filters on both the OCEANUS and SUB-SIG cruises, samples were collected for analysis of particulate organic carbon, organic nitrogen, and chlorophyll on glass fiber filters. For organic carbon and nitrogen, 4 to 8 liters of water were passed through pre-ignited glass fiber 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 collections 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 sea water (buffered with $MgCO_3$) and then freezing in a desiccator until analysis.

Finally, water samples for laboratory analysis of dissolved nutrients were collected during the OCEANUS and SUB-SIG cruises. Analyses (performed by Mrs. Z. Mlodzinksa, 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 washed 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 analysed with a LECO® carbon and nitrogen analyser. The weight of the material upon the glass fiber filters was assumed to be equal to the product of the concentration of suspensate in the water sample (determined by total seston measure on Millipore filters) and the volume of water passed through the glass fiber 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 analyser.

RESULTS

Mid-November-December 1976

Samples collected during separate cruises by VIMS and the USGS during mid-November and early December were too few and scattered to be used individually in plotting areal distributions. Thus, although the two cruises were nearly one month apart, the data were combined in an attempt to delineate the particulate distributions during early winter. It must be remembered, however, that these data are not synoptic although they may indicate general trends.

Surface particulates were relatively high during this period (Figure 3-2a), ranging from greater than 2,000 µg/l in nearshore areas to just under 250 µg/l in outer-shelf water. The particularly high concentrations in coastal waters can be related to the absence of vertical stratification of the water column (Figure 3-3a) and the resulting redistribution of resuspended bottom sediments throughout the water column, as suggested by low levels of combustible material (Figure 3-2b). Generally, however, combustibles on the middle shelf average 80 to 90%, while on the outer-shelf values fall below 75%. The concentration of non-combustible particulates in surface waters (Figure 3-2c) is greater than at any other time of year.

Concentrations of bottom particulates also are much higher than the normal (Figure 3-2d) with much of the material containing less than 50% combustibles (Figure 3-2e). As a result, bottom non-combustible particulates are extremely high, generally more than 500 µg/l throughout the shelf; values on the outer shelf north of Hudson Channel appear to be much higher than those south of Hudson Channel.

The vertical distribution of seston also can be seen in the transect off New Jersey in which the increase in bottom particulates can be assumed to reflect resuspension (Figure 3-3b and c).

Most of the transmissometer profiles collected during these cruises support this assumption with increasing turbidity in the near-bottom water. A larger increase in turbidity is observed north of Hudson Channel in agreement with the higher concentration of suspended matter in bottom waters.

Mid-February 1977

A total of 22 suspended matter stations were occupied during the late winter cruises by VIMS, from which a total of 53 samples were collected. Unfortunately, sampling was divided between two cruises, with samples off southern New Jersey and northern Delaware being collected February 8-16 and samples to the north and south being taken

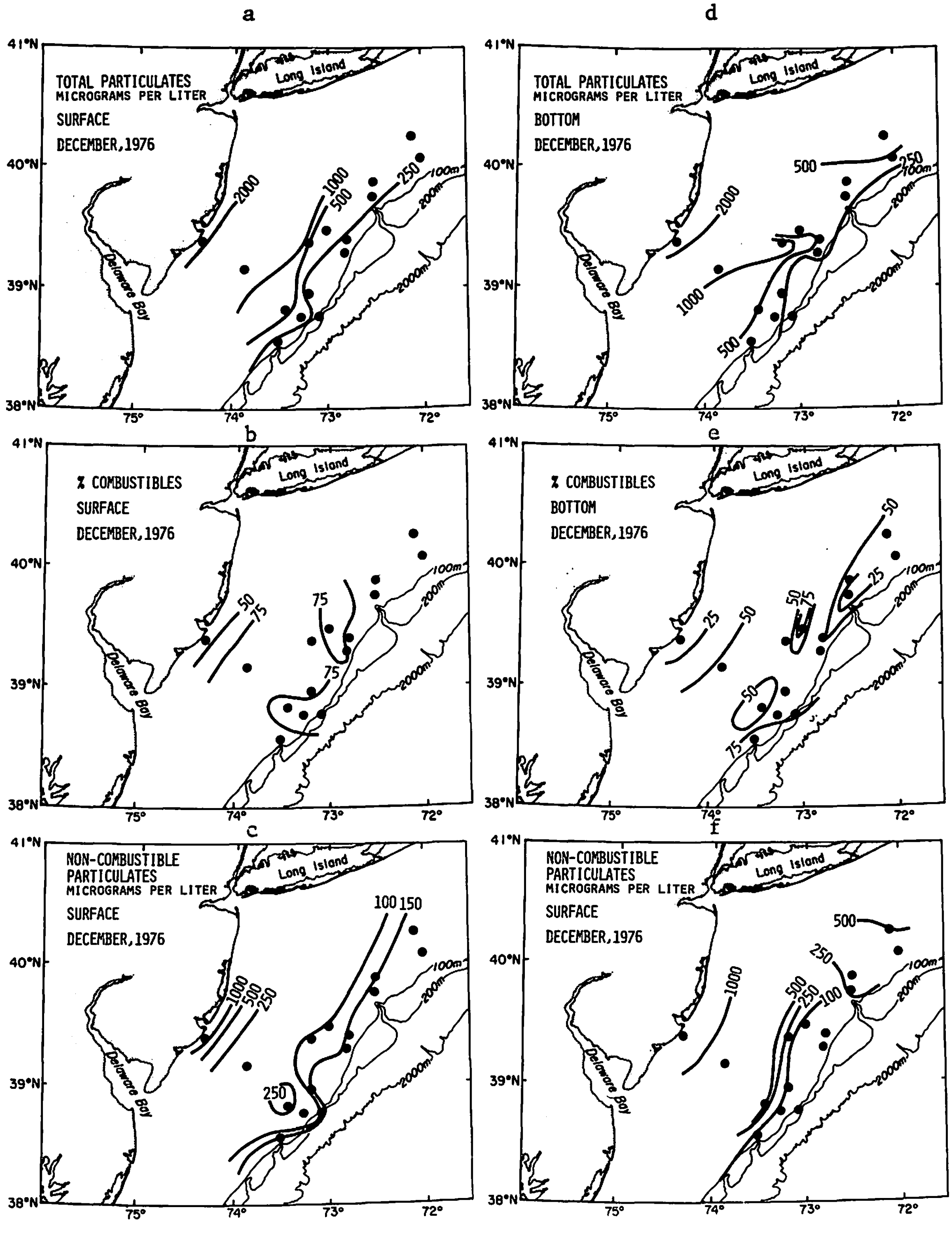

Figure 3-2. Areal distribution of suspended particulates in surface (left) and near-bottom waters (right) during mid-November-December 1976. Top illustrations (a and d) represent distributions of total particulate, middle plots (b and e) percent combustibles, and bottom plots (c and f) non-combustible concentrations.

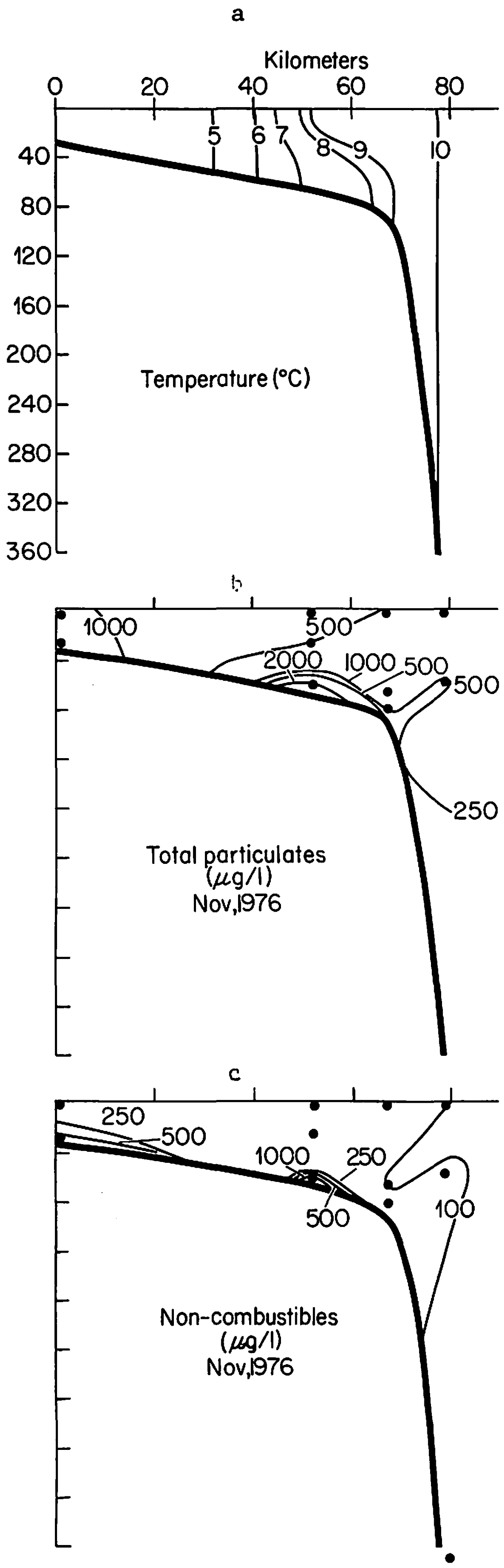

Figure 3-3. Vertical profile of temperature (a), total particulates (b), and non-combustible particulate (c) along a transect off Atlantic City, New Jersey during November 1976.

3 weeks later (March 8-13). Consequently, the results cannot be regarded as synoptic, although values from the two cruises appear roughly similar.

Mid-winter suspensates in the mid-Atlantic Bight looked somewhat similar to those seen in the early winter. Surface particulates tended to be high and contain relatively low percentages of combustibles, generally 50 to 65% on the middle shelf off New Jersey and 75 to 85% off the Delmarva Peninsula (Figures 3-4a, b). As a result, the concentrations of non-combustibles within the surface seston were relatively high; on the inner New Jersey shelf values surpassed 250 μg/l (Figure 3-4c).

Concentrations of total particulates in the bottom waters were lower (Figure 3-4d) than at the surface. While combustibles were more common in coastal bottom waters than at the surface (Figure 3-4e), outer-shelf percentages at the bottom generally were the same or lower than those at the surface. As a result, non-combustible concentrations in mid- and outer-shelf bottom waters are equal to or higher than those in the surface waters (Figure 3-4f).

An increase in turbidity near the bottom was seen in 10 of the 12 available transmissometer profiles. Although the magnitude of resuspension is small, as evidenced by the low concentrations measured, the effect is apparently widespread as locations on the inner, mid- and outer-shelf show this feature.

Late April 1977

A cruise in late April aboard the SUB-SIG II provided wide coverage of the mid-Atlantic outer continental shelf with close station spacings. Sixty-five full stations with 80 additional XBT casts were made in 11 transects across the shelf during an 8-day period resulting in observations that are relatively synoptic.

Waters had warmed considerably since February; a cross-shelf temperature profile from central New Jersey shows surface waters between 9° and 11°C, a strong thermocline, and the presence of cold (5°C) bottom waters on the middle and inner shelf (Figure 3-5a). The presence of the front between cold shelf and relatively warm slope waters was apparent at the shelf edge in all the transects during this cruise.

The concentration of total suspended matter in surface waters was somewhat higher than during previous months with values higher than 500 μg/l, except in mid-shelf areas (Figure 3-6a). Concentrations greater than 1,000 μg/l were observed at nearshore stations closest to the New York Bight and at the mouth of Delaware Bay. Values greater than 1000 μg/l were also measured on the upper slope off Delaware, the

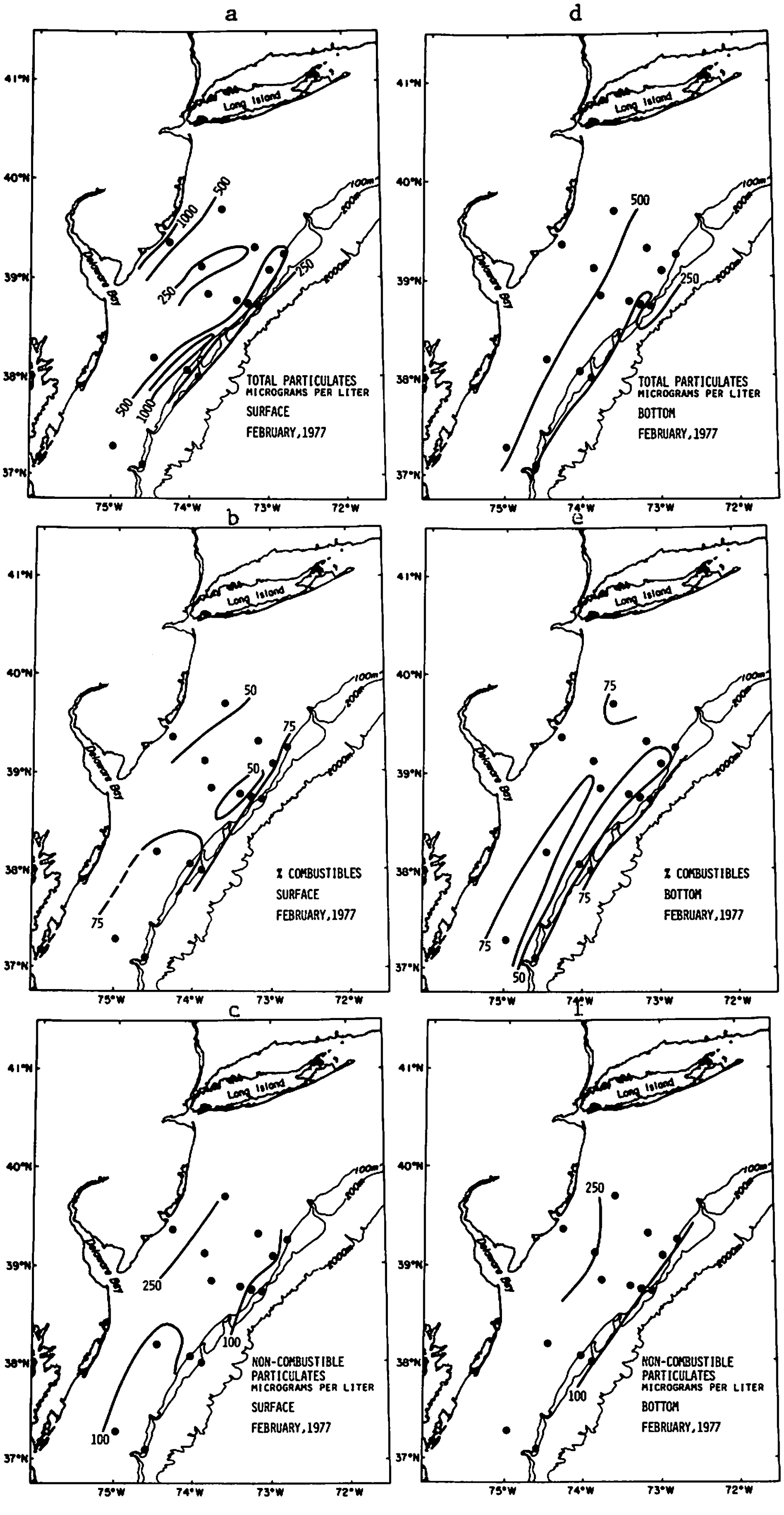

Figure 3-4. Areal distribution of suspended particulates in surface (left) and near-bottom waters (right) during mid-February and mid-March 1977. Top charts (a and d) represent distributions of total particulates, middle plots (b and e) percent combustibles, and bottom plots (c and f) non-combustible concentrations.

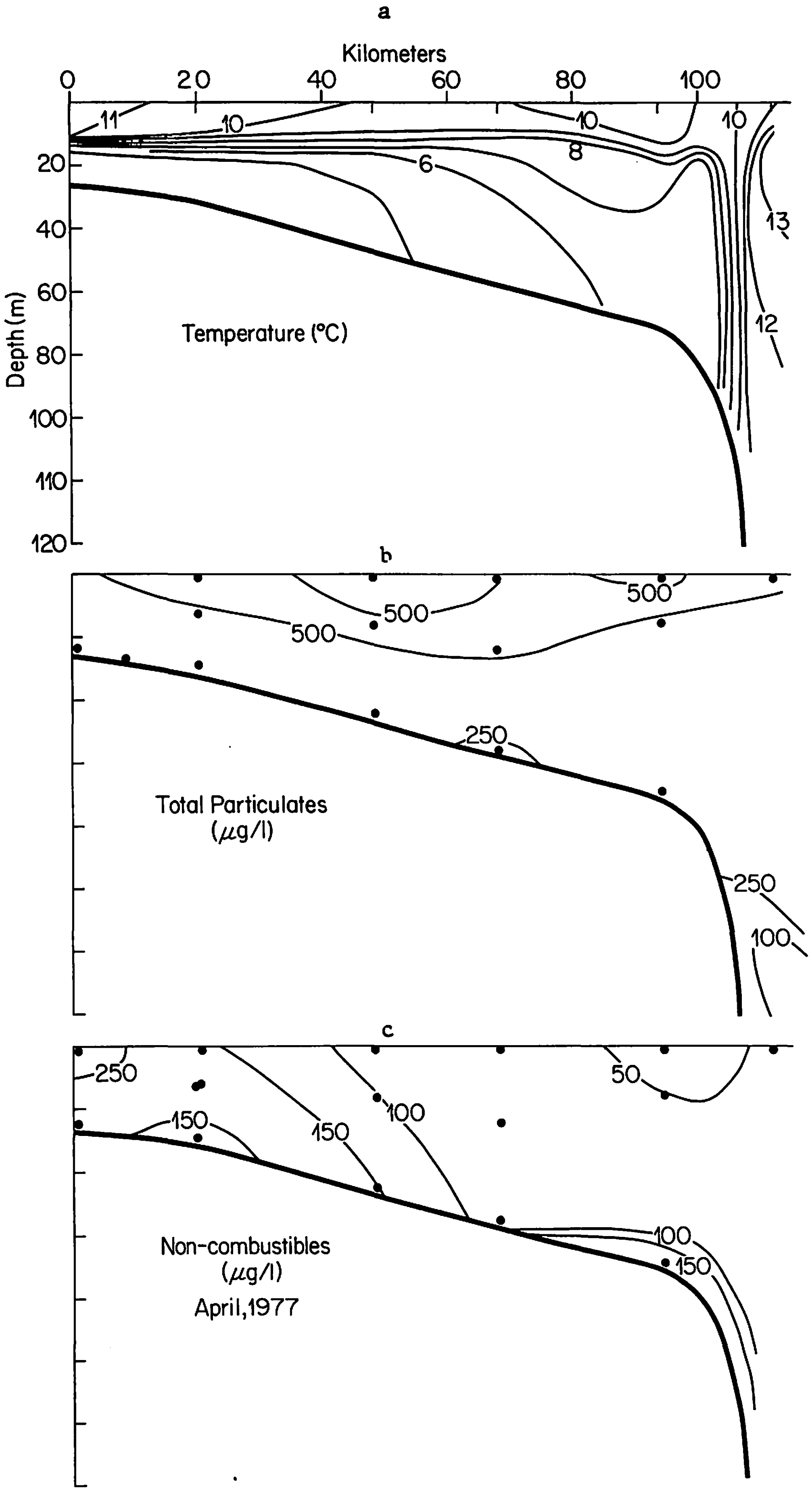

Figure 3-5. Vertical profile of (a) temperature, (b) total particulate, and (c) non-combusticle particulate along a transect north of Egg Inlet, New Jersey during late April 1977.

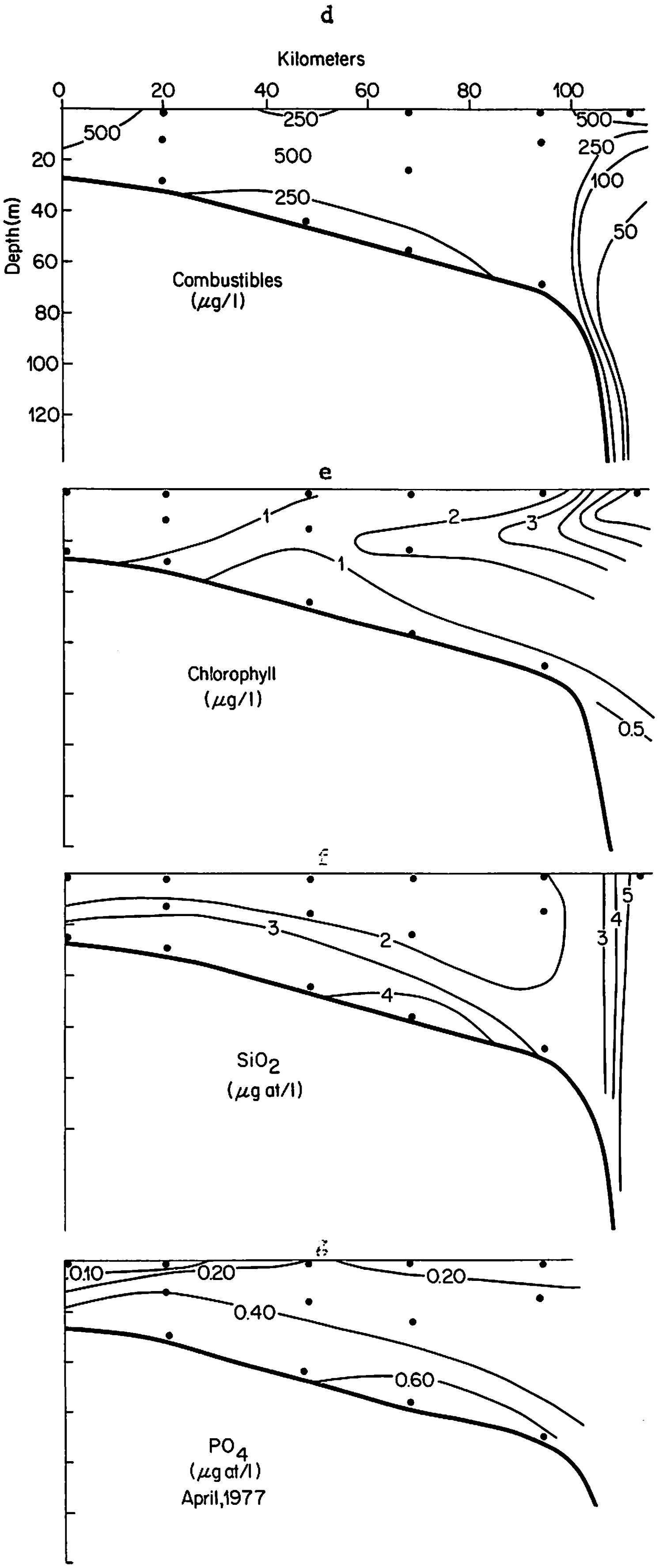

Figure 3-5. (Continued). Vertical profile of (d) combustibles, (e) chlorophyll, (f) silica, and (g) phosphate along a transect north of Egg Inlet, New Jersey during late April 1977.

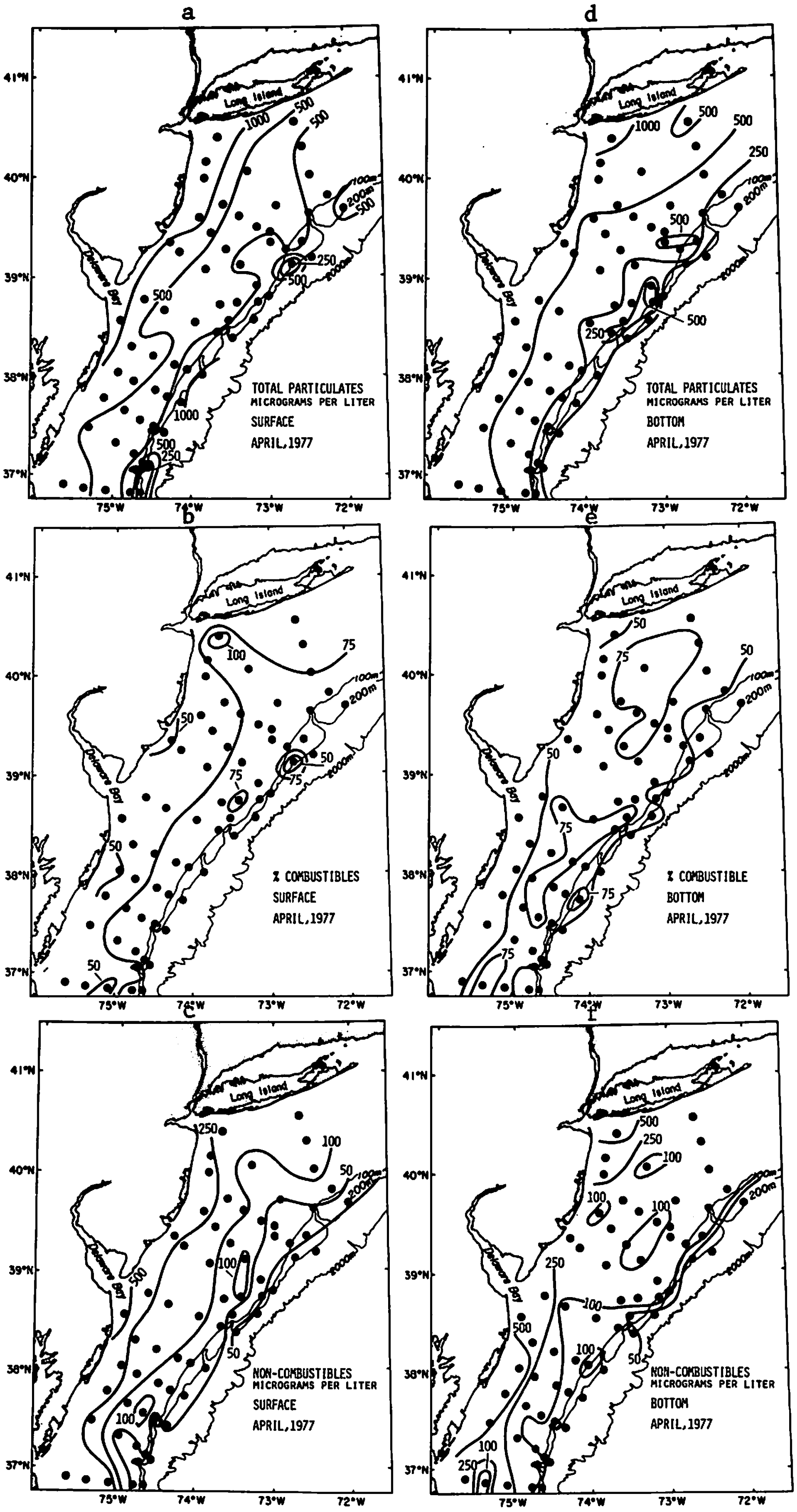

Figure 3-6. Areal distribution of suspended particulate in surface (left) and near-bottom waters (right) during late April 1977. Top illustration (a and d) represent distributions of total particulate, middle plots (b and e) percent combustibles, and bottom plots (c and f) non-combustible concentrations.

highest values observed for this area during any cruise.

Combustible percentages in surface waters generally increased from low values at or near 50% at most nearshore locations to near 90% at the shelf edge (Figure 3-6b). Values greater than 75% occurred at nearshore stations closest to New York City. The non-combustible particulate fraction decreased in concentration with distance from shore (Figure 3-6c). Highest values were observed in a plume south of New York City and at the mouth of Delaware and Chesapeake Bays, which suggests influx of sediment-laden water from these estuaries. The distribution of salinity (Figure 3-7) in surface waters confirms the influence of runoff from estuaries in surface waters. This runoff is probably carrying additional nutrients or is stimulating local upwelling which accounts for the higher concentrations of chlorophyll at the surface in the low salinity water.

Total particulates, combustibles and chlorophyll concentrations generally showed a maximum near the thermocline (Figure 3-5b). The depth of the mid-sample was selected on the basis of transmissometer data which for this period showed a turbidity maximum near the thermocline at more than 90% of the stations. Based on the distribution of chlorophyll and combustible particulate matter, the mid-depth turbidity maximum is related to primary production of phytoplankton, notably diatoms (Thallisosira, Coscinodiscus).

In bottom waters, the concentration of total suspended matter generally was less than surface values (Figure 3-6d). With distance from shore, concentrations decreased from a high of about 1,000 μg/l to about 100 μg/l at the shelf edge. Most mid- and outer-shelf concentrations were less than 500 μg/l. As seen in previous cruises, combustible percentages were lower in near-bottom waters, although values did exceed 75% in mid-shelf bottom waters. On the outer-shelf, however, values generally were less than 50%, and locally less than 40% (Figure 3-6e). Still, due to the generally low amounts of total suspensates, the non-combustible fraction on the middle and outer-shelf and upper slope was considerably lower than seen during winter months. Most of the shelf bottom waters contained values between 250 and 100 μg/l, and locally, less. Upper slope values generally ranged between 50 and 100 μg/l (Figure 3-6e).

Local increases in non-combustible concentrations (Figure 3-5c) were typically observed at or near the shelf-slope water front (Figure 3-5a). In addition, bottom waters showed increased concentrations of SiO_2 and PO_4 (Figures 3-5f and g) which are undoubtedly due to regeneration of nutrients in bottom sediments.

Three broad areas of active sediment resuspension (Figures 3-8b) were identified during this cruise, based on increases in turbidity in near-bottom waters and on the distribution of non-combustible particulates (Figure 3-6f). An area of resuspension was found south

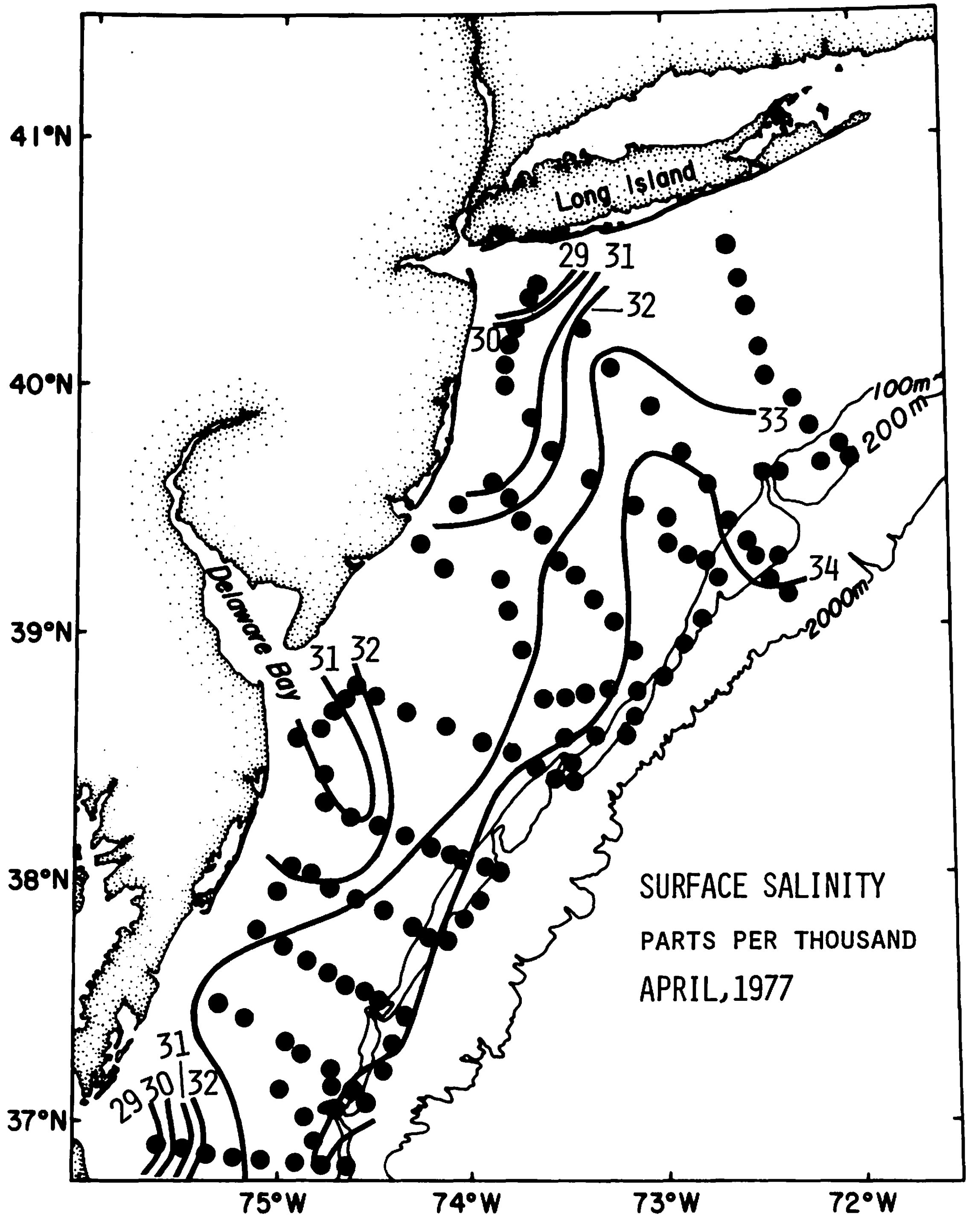

Figure 3-7. Surface salinities measured during SUB-SIG cruise in late April 1977.

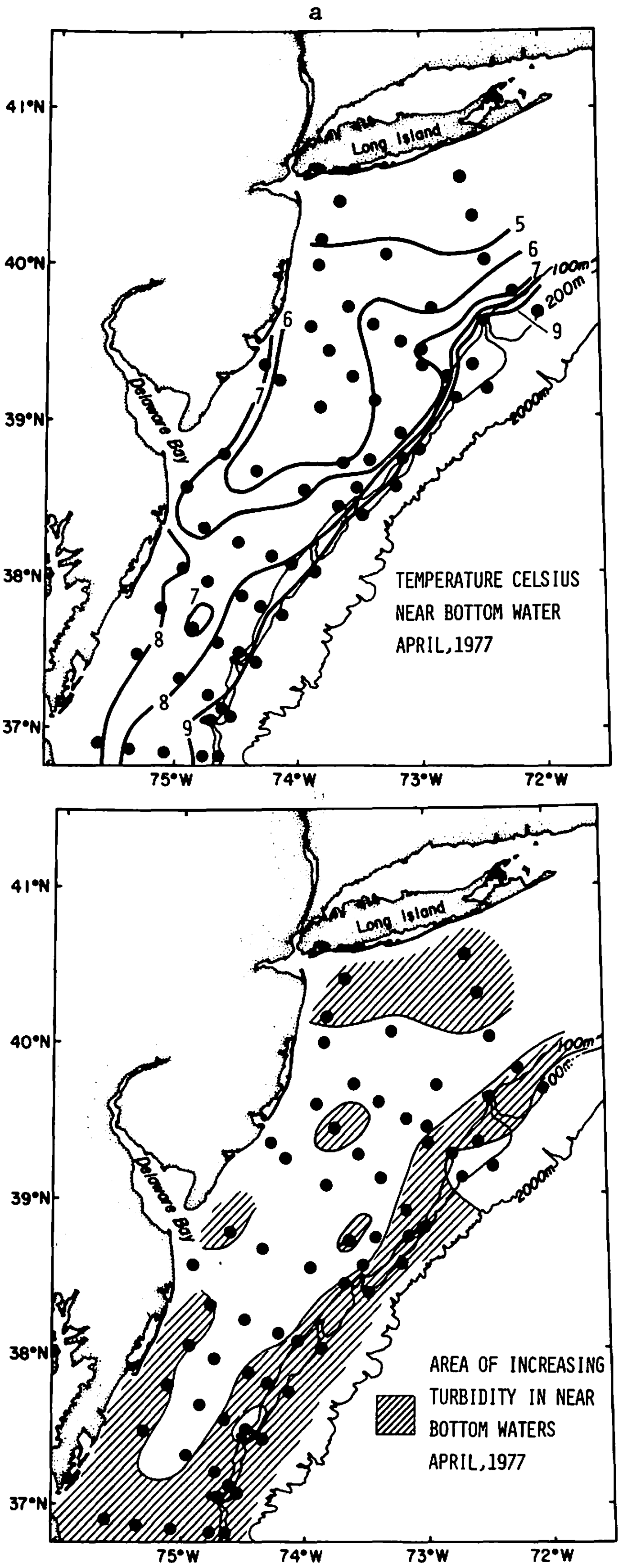

Figure 3-8. Areal distribution of (a) bottom water temperature during late April 1977, and (b) increasing turbidity near the bottom.

of Long Island where 4° bottom water was measured (Figure 3-8a), and where finer grained sediments had been reported previously (Schlee 1973). It is not known whether the increased resuspension is due to the proximity of a fine grained sediment source or to locally higher turbulence in the water mass characterized by 4° water.

Evidence of active resuspension also occurs along the shore, presumably due to higher wave-induced turbulence in shallow water. Active resuspension is noticeably absent in the central shelf region in areas occupied by water less than 8°C, perhaps due to greater stability of this water mass. The transect seaward of the Chesapeake Bay mouth shows resuspension across the shelf, possibly maintained by the shoreward flow of bottom water tied to estuarine circulation in the Bay.

The third extensive region of active resuspension includes the shelf edge and area of the shelf slope front. The presence of increased turbidity near the bottom was found consistently during the April cruise, and is commonly found on the outer-shelf during other seasons. Thus, the processes responsible for this feature may be effective in maintaining it almost continuously, although a time series study at one location suggests that the forces involved may be periodic.

The time series study was accomplished at location A (Figure 3-7) after an engine failed and the ship was forced to wait 20 hours for a tow into port. During that interval, 5 suspended matter (and 9 transmissometer) lowerings were made; the results of which are shown in Figure 3-9. Two episodes of relatively high concentrations were separated by a long period (12-14 hours) with low concentrations. Possibly, this interval suggests the importance of internal tides, although further data are needed. In any event, these data show that periodic processes can contribute markedly to sediment resuspension in bottom waters and that resuspension along the shelf edge may be related to a periodic oceanic event such as tides or internal waves.

The agreement in trend between the transmission data and the measured suspended matter concentration in Figure 3-9 is good. The correlation between the extinction coefficient (equal to $\ln(I_o/I)$, where I is the measured transmission and I_o is the calculated transmission in clear sea water) and the measured suspended matter concentration is 0.8 for the data in this figure. This high correlation coefficient indicates that the transmissometer data can be used to estimate the concentrations of suspended matter in bottom waters within a small area.

The accuracy of transmissometer data in predicting the suspended matter concentration over the entire study area is only within an approximate factor of 2. This is because the adsorption of light depends not only on the concentration of suspended matter but also on

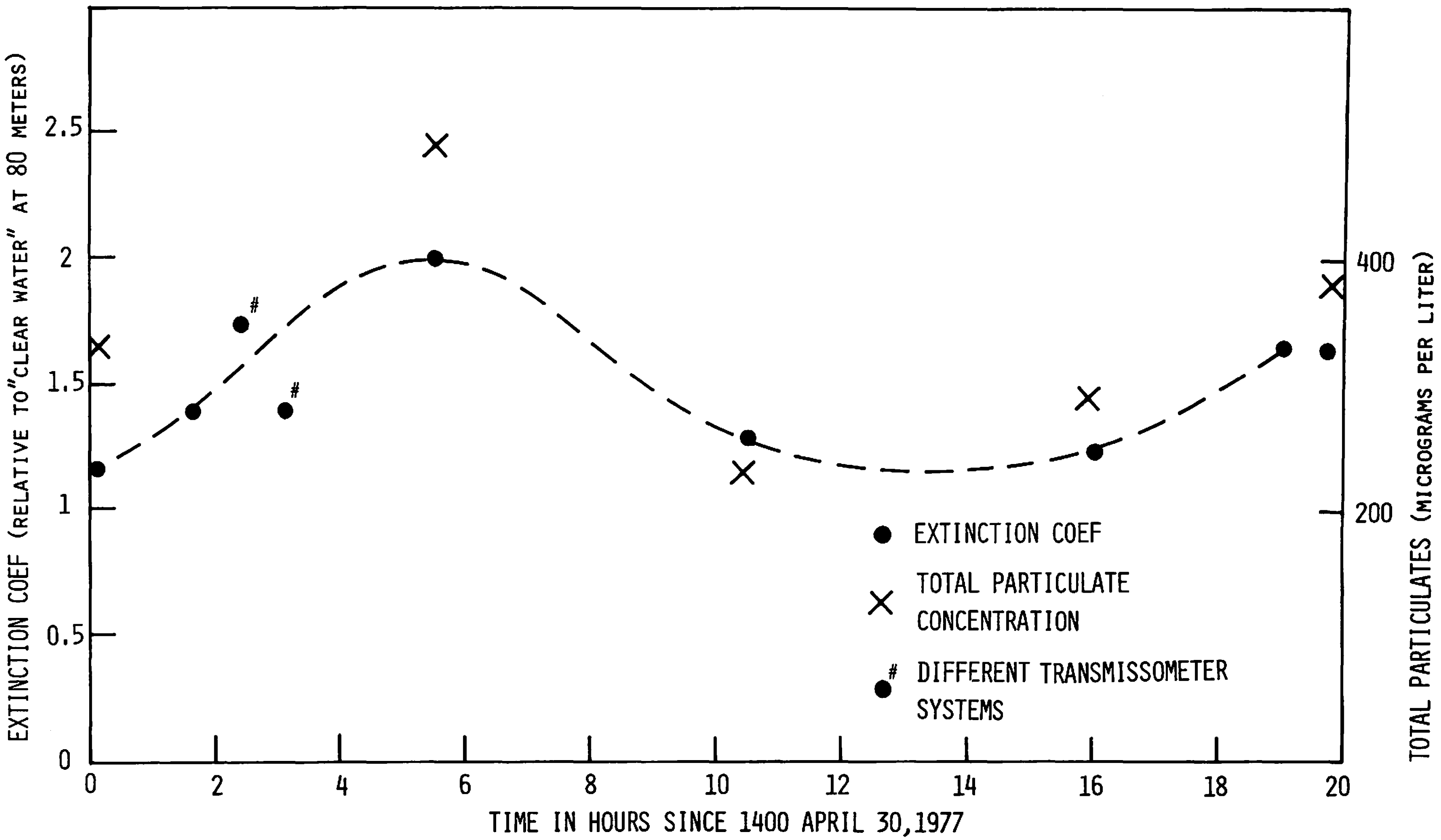

Figure 3-9. Variation in light transmission and total suspended particulate (μg/l) in near-bottom waters off Northern New Jersey during a 20 hour interval late April 1977.

the composition of particulate material and on the nature and concentration of dissolved organics. A correlation of only 0.5 was obtained between suspended matter concentration and extinction coefficient for all bottom water samples taken during the April cruise.

Transmissometer data at sea is important because it defines the general pattern of turbidity so that major features can be accurately sampled. Major features such as high turbidity in bottom waters due to resuspension can also be mapped with this data. The use of transmissometer data to predict the concentration of suspended matter appears to be restricted to small areas where the composition of particulate matter has little variability and where the background of dissolved organics is constant.

Early June 1977

Although surface water temperatures by early June had warmed to more than 14°C, the cold core was still evident along the middle and outer shelf. Slope water, although not apparent at the surface, was seen lapping onto the outermost shelf (Figure 3-10a).

Particulates in the surface waters during early June were as high as those seen during February (Figure 3-11a). Combustibles in all but coastal waters were greater than 80%, the result being that non-combustible concentrations were generally much lower than those seen during winter months (Figure 3-11c). In contrast, total particulates were higher, and the percentages of combustibles were lower in bottom waters (Figures 3-11 d, e); combustible percentages on the outer-shelf south of Hudson Channel/Canyon were less than 40%. Computed non-combustible concentrations were particularly low on the middle to outer-shelf, but increased substantially (as a result of low combustible percentages rather than total suspended load) on the outermost shelf and upper slope, apparently indicative of resuspension of bottom sediment.

A vertical profile of suspensates (Figure 3-10) shows the concentration of particulates in mid-depth waters along the outermost shelf. This material is mostly organic; the non-combustible fraction is considerably less than 50 μg/l.

A subsurface maximum in turbidity was observed in or near the thermocline at all stations except two nearshore locations north of Delaware Bay. Because mid-depth samples have a high percentage of combustible material, this widespread turbidity maximum is attributed to primary production. Increasing turbidity with depth near the sediment water interface is assumed to be indicative of active resuspension of bottom sediments (Figure 3-12).

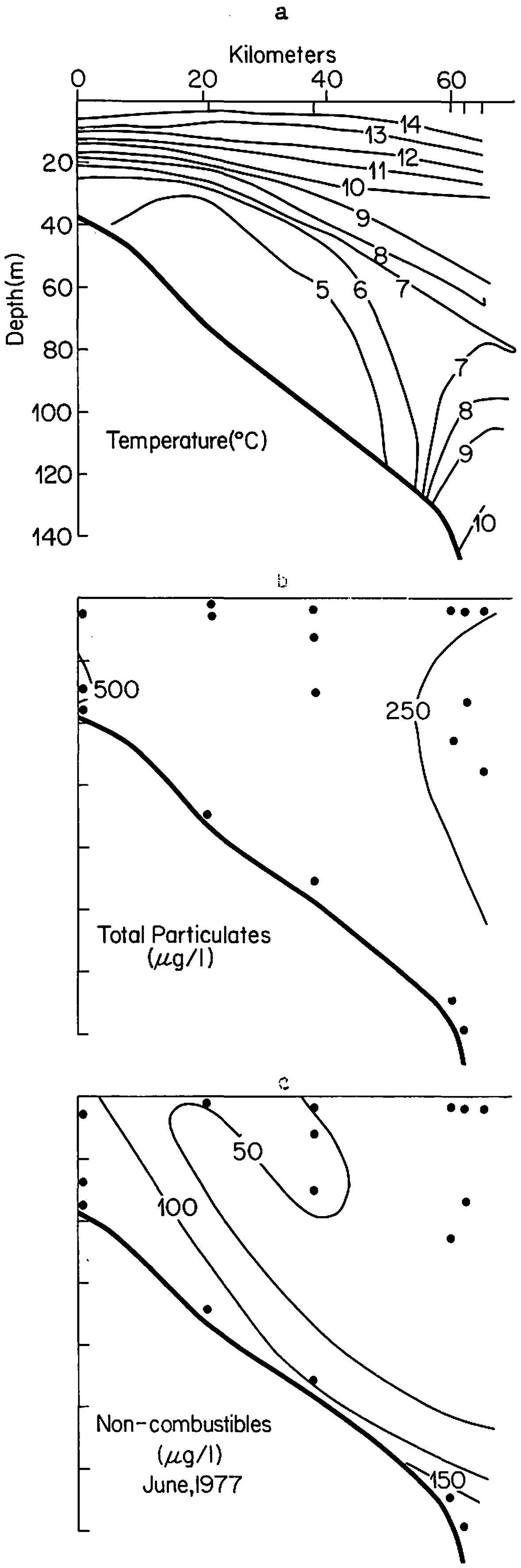

Figure 3-10. Vertical profile of (a) temperature, (b) total particulate, and (c) non-combustible particulates along a transect off Atlantic City, New Jersey early June 1977.

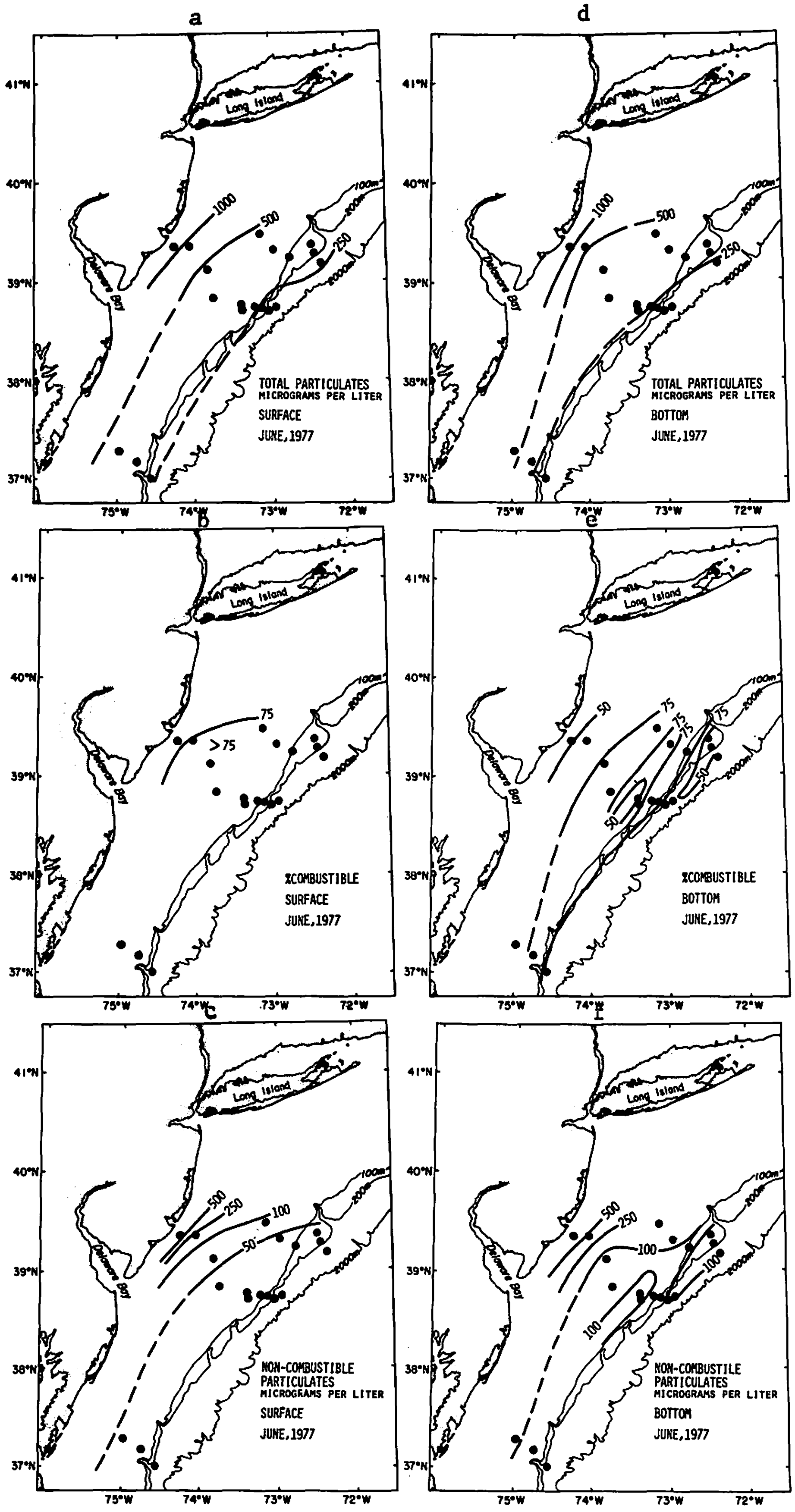

Figure 3-11. Areal distribution of suspended particulate in surface (a-c) and near-bottom waters (d-f) early June 1977.

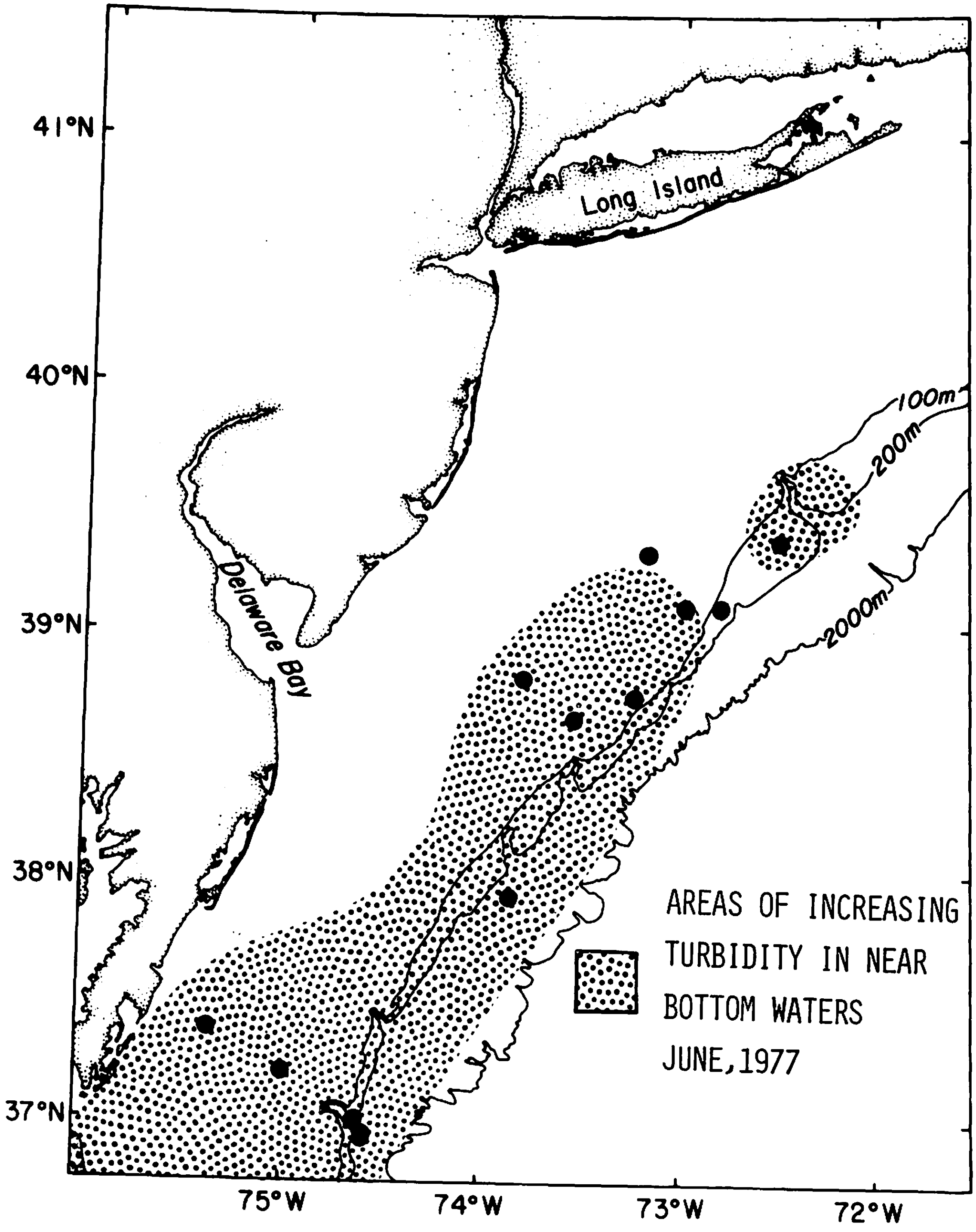

Figure 3-12. Areas of increasing turbidity near the bottom during early June 1977.

Early August 1977

By early August the shelf water had become fully stratified, with temperatures ranging from 23°C at the surface to 9°C at about 31 m on the middle shelf. Impinging slope water on the outer shelf was evidenced by a temperature inversion at approximately 60 m, and by the 11°C water covering the outer-shelf (Figure 3-13a). It is interesting to note that this warm slope water was nearly isothermal, suggesting that considerable turbulence was needed to maintain mixing.

Total particulates in both surface and bottom waters are very similar (Figures 3-14a, d); the nearshore concentrations reach 1,000 μg/l, while, on the outermost shelf and upper slope, values are less than 250 μg/l. The combustible and non-combustible fractions, however, show a marked difference within the water column. In the surface waters, particulates generally average more than 90% combustibles (Figure 3-14b). In contrast, near-bottom waters generally contain less than 75% combustibles, and on the outer shelf bottom particulates locally contain less than 25% (Figure 3-14e). As a result of this disparity, surface non-combustibles north of Delaware Bay are generally less than 100 μg/l (and the middle and outer-shelf waters less than 30 μg/l [Figure 3-14c]). In contrast, bottom waters on the inner shelf contain more than 250 μg/l, and much of the outer shelf and upper slope more than 100 μg/l (Figure 3-14f). The fact that the outer-shelf to upper slope near-bottom maxima appear to coincide with the isothermal slope water (Figure 3-13c), suggests that impingement of this water upon the outer shelf may cause resuspension of bottom material.

A typical feature observed in the suspended bottom distribution during this period is the concentration maximum along the thermocline (about 20-30 m water depth) on the middle shelf (Figure 3-13b). This feature is observed as a turbidity maximum in the transmissometer data and is found at all stations for which transmissometer data are available. The source of this material is primary production which results in the low concentrations of non-combustibles (Figure 3-13c).

August 1976

In addition to documenting the seasonal variations in the seston in middle Atlantic shelf waters, we are interested in variations from year-to-year. The paucity of data (or sampling errors) restricts this comparison to a single example: August (1976 versus 1977). However, the contrast between the two years is sufficiently strong to caution us from making too sweeping generalizations in discussing seasonal differences.

The summer of 1976 was unusual in that early stratification (during late May), combined with large blooms of dinoflagellates, led

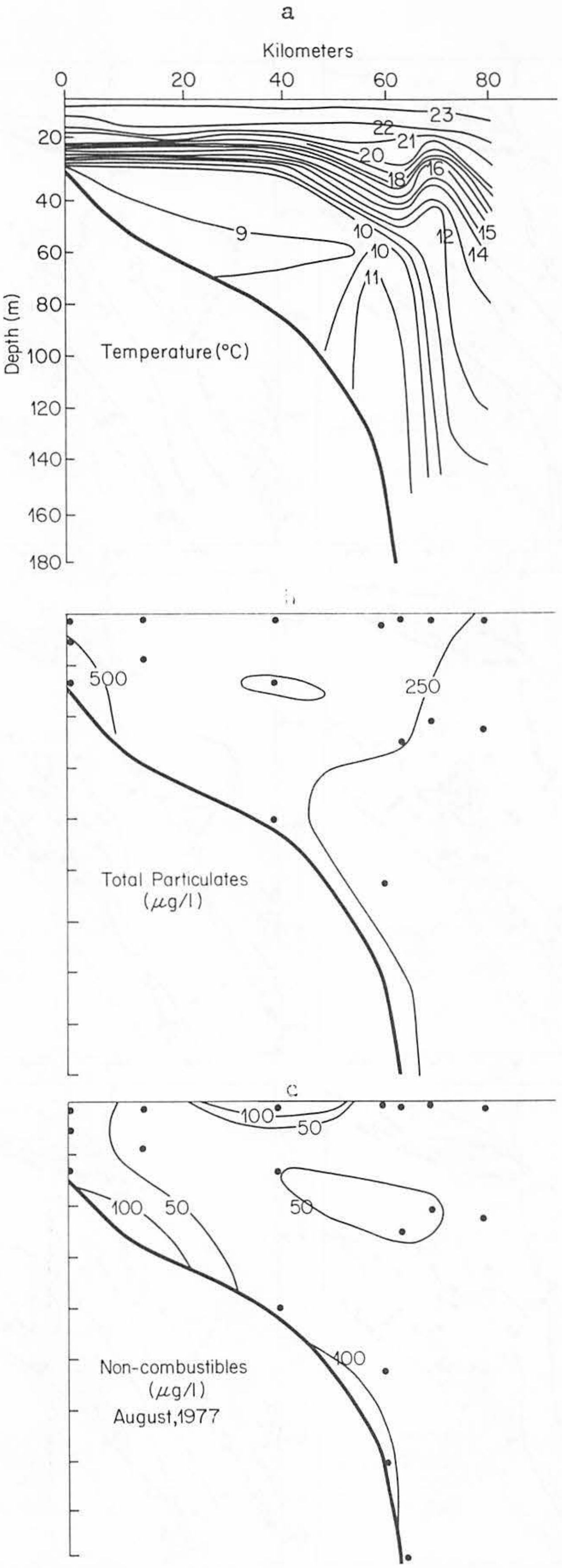

Figure 3-13. Vertical profile of (a) temperature, (b) total particulates, and (c) non-combustible particulates along a transect off Atlantic City, New Jersey early August 1977.

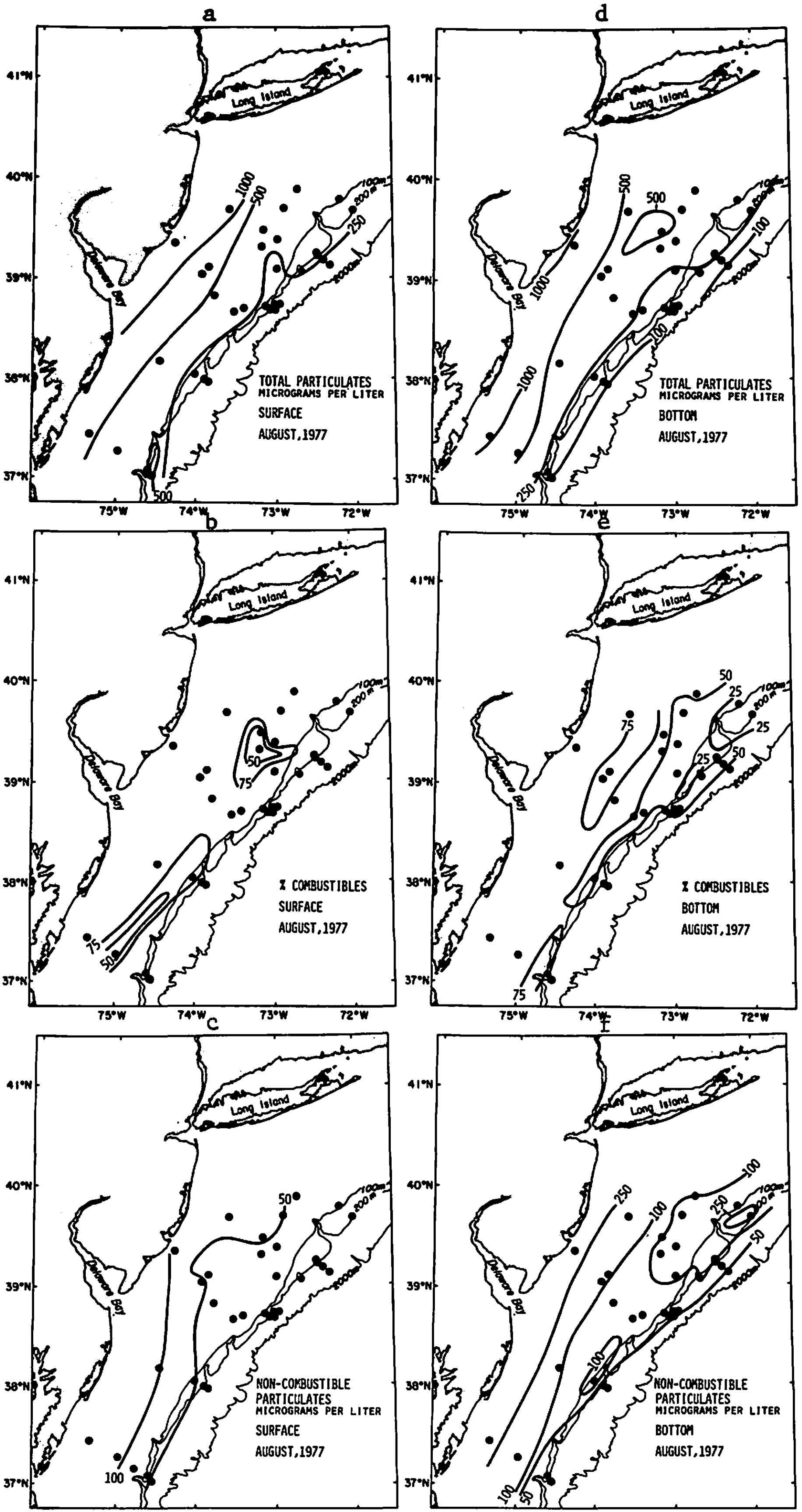

Figure 3-14. Areal distribution of suspended particulates in surface (a-c) and near-bottom waters (d-f) early August 1977.

to oxygen depletion of both bottom and mid-depth waters. The source of nutrients leading to local enhancement of the blooms is not clear, perhaps being the dump site in the New York Bight, or perhaps the outflow from New Jersey coastal sites. As will be seen in this discussion, some data suggest the latter possibility.

Most of the surface waters north of middle New Jersey contained total seston concentrations between 500 and 1,000 μg/l; nearshore concentrations to the south were greater, and middle and outer-shelf concentrations were somewhat lower (Figure 3-15a). The combustible fraction constituted about 80% of the total (somewhat less than that seen in 1977), with only the waters offshore of Delaware Bay containing less than 75% (Figure 3-15b). The resultant non-combustible fraction in surface waters was distinctly higher than that seen the following year, with most of the shelf containing more than 100 μg/l and the waters off Delaware Bay containing more than 500 μg/l (Figure 3-15c). Outer-shelf waters off Delaware Bay, however, contained concentrations less than 50 μg/l.

Differences between the two years were even more obvious in terms of bottom water seston. Total particulates in the inner shelf waters off central New Jersey exceeded 2,000 μg/l, and locally 4,000 μg/l (Figure 3-15d). Only on the outermost shelf did concentrations fall below 500 μg/l. Even more startling, however, was the very high concentration of combustibles in the inner shelf waters off central New Jersey, containing more than 90%, and much of the middle shelf containing more than 60%. Only the middle and outer-shelf waters south of Long Island contained less than 50% combustibles (Figure 3-15e). Even with these high combustible percentages, however, the non-combustible concentrations in August of 1976 were much higher than those seen the following year. Almost the entire shelf north of central New Jersey had bottom water suspensates containing more than 500 μg/l; only on the upper slope did values fall below 100 μg/l (Figure 3-15f). Given the well stratified nature of the shelf waters, it is perhaps surprising to find these very high concentrations of resuspended sediment.

DISCUSSION

The variation in seston regime in the Middle Atlantic Bight can be summarized as follows: in winter, the water column is relatively well mixed and biologic productivity is low. As a result, combustible percentages are low (locally less than 50%) and non-combustible concentrations high (particularly on the inner shelf, where vertical mixing presumably is greatest). The seasonal impact of winter is less apparent on the bottom; in fact, total and non-combustible suspended sediments were lower during the February cruise than during other months. Whether conditions during this cruise were anomalous, or

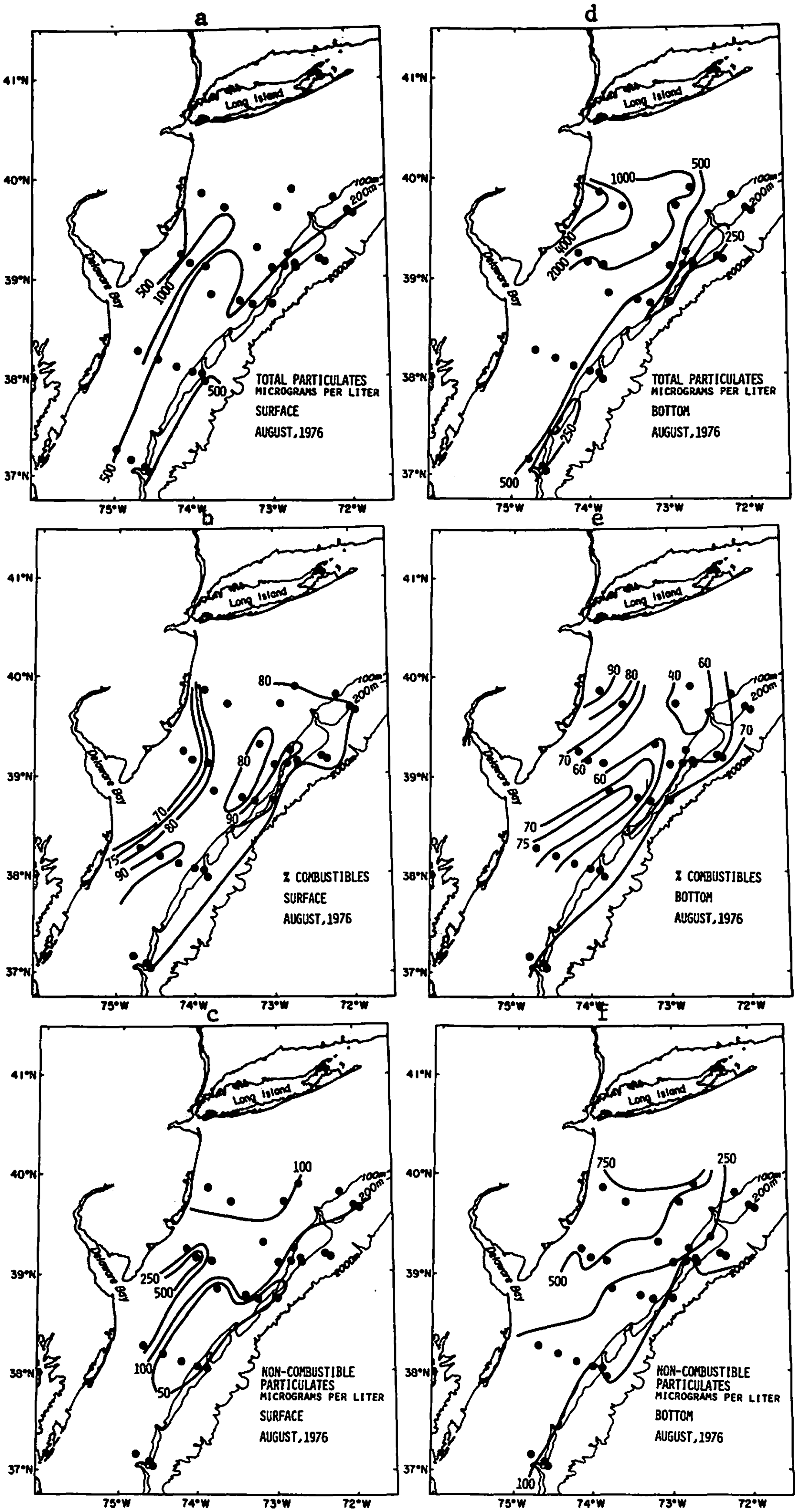

Figure 3-15. Areal distribution of suspended particulates in surface (a-c) and near-bottom waters (d-f) August 1976.

whether they represent normal winter conditions, cannot be ascertained at present.

April saw increased biological productivity, the result of spring plankton blooms. As a result, total suspended particulates increased in both surface and near-bottom waters, as did combustible percentages (generally greater than 85% in surface waters and 50 to 75% in the bottom). Thus, non-combustible particulates over most of the middle and outer shelf were less than 50 μg/l in surface waters, and in bottom waters they seldom were greater than 200 μg/l.

June again had high productivity, as noted in the high percentages of combustibles in the surface particulates. As with previous months, the non-combustible fraction of bottom waters was higher than at the surface, undoubtedly the result of resuspension of bottom sediment.

Full stratification of the shelf waters by August meant that the disparity between the contents of surface and near-bottom seston was at its greatest. Surface particulates were dominated by organic particles, the combustible fraction alone accounting for generally more than 90% of the total. In contrast, near-bottom waters were dominated by terrigenous particles; in fact most of the outer-shelf and upper slope bottom waters contained less than 50% combustible material.

Autumn and winter storms, and cold weather, perform two functions with respect to the seston in Middle Atlantic shelf water. First, biological productivity decreases markedly (as seen by the decrease in combustible percentages relative to August). Second, the breakdown of stratified waters means that resuspended sediment is able to be distributed more easily into overlying waters. Thus for instance, concentrations of resuspended non-combustibles in surface waters during early December are more than twice the values noted in August. The increased storm activity, of course, also means that more bottom sediment is stirred into the bottom waters, as seen from the fact that most of the shelf bottom water contains more than 500 μg/l suspended sediment, far greater than the 100 to 250 μg/l seen in August.

In addition to the annual cycle seen in the suspended particulate regime, several other trends are worthy of note. First, as noted by Meade et al. (1975), although highest bottom concentrations occur in nearshore waters (in the influence of wave activity), secondary highs occur throughout the outer shelf. This is most apparent when one looks at the percent combustibles; values often are less than 50% on the outermost shelf as opposed to 75% on the middle shelf. Thus, although total suspended concentrations tend to be lower on the outer-shelf, the non-combustible concentration may actually be higher (e.g., August 1977). How this sediment is resuspended is not known; however, observations made during the April cruise suggest that the resuspension may be episodic (Figure 3-9). Although observations during this 20-hour station were as many as 5 hours apart, two maxima were noted in concentration approximately 14 hours apart. Whether this may represent tidal resuspension or resuspension related to internal waves is not known. However, it does suggest that short-term (hourly) variations of bottom suspensates may be more significant than either seasonal or (to some degree) spatial changes. If this is so, then the problem of synoptic observations may be far more critical than previously thought; samples not collected during the same tidal or internal wave stage may display different concentrations and compositions.

Second, although data are sparse, we see some evidence of resuspended particulates that are greater in concentration on the outer-shelf/upper slope adjacent to Hudson Canyon than to the south (for example, see December, June, August). While this increase may be due to offshore transport of material from the New York Bight Dump Site, we see little evidence from elemental analysis of near-bottom seston to indicate that these particles contain any more anthropogenic influence than near-bottom particles to the south. More likely, these materials represent resuspension from nearby sediments; this is particularly obvious in the high concentrations (up to 600 μg/l of non-combustibles) seen during the December cruise, north of Hudson Channel where the ambient bottom sediment is mud. Whether or not this resuspended bottom sediment is transported significant distances is difficult to ascertain, although the localization of these resuspended concentrations suggest that transport is slight.

Third, during April, the surface waters off Delaware Bay contained relatively high concentrations of suspended particulates, with significantly smaller percentages of combustible particles than in nearshore waters to the north or south. It is doubtful that the influx of relatively high concentrations of non-combustibles from estuaries represents a significant sediment source, but its nature and influence upon both the seston and sediment regime need further investigation.

Fourth, while "offshore" dumping represents a major sediment influx to the New York Bight (Gross 1972), we see little evidence of resuspension or transport of this material in the suspended particulate regime (see above). Whether our sampling grid is too widely spaced (or too sporadic in time) to adequately examine this question, or whether resuspension actually is minimal, is not known; but certainly this factor deserves further and more detailed study.

SUMMARY

Seston concentrations in Middle Atlantic Bight waters are low, seldom exceeding 1,000 μg/l. With the exception of nearshore areas, bottom waters on the outer shelf show the highest concentrations, undoubtedly the result of resuspension of bottom sediment.

Although the causes of sediment resuspension are not well understood, there is some evidence from one 20 hour station on the shelf edge that the process may be periodic. During the sampling interval, two maxima in bottom-suspended matter concentration and in turbidity were observed approximately 14 hours apart. This period suggests that internal tides or groups of internal waves may be responsible, in part, for the occurrence of resuspension on the shelf edge.

During winter, suspended particulates in surface waters in the Middle Atlantic Bight are low in combustible percentages (due to relatively low productivity), and high in non-combustible material (the result of resuspension and upward transport of bottom sediment). In the well stratified summer waters, surface material is dominated by biogenic material but bottom particulates continue to contain large amounts of resuspended bottom sediments.

The diversity of diatoms appears greatest during late winter and spring; the diversity is most restricted in the nutrient depleted waters of late summer. Coccoliths are relatively sparse in the Mid-Atlantic area, and dinoflagellate and silicoflagellates are only locally significant.

In contrast to obvious signs of pollutants noted during 1976 (Ti, Sn, Fe, Mn), 1977 suspended particulates contained far fewer signs of anthropogenic activity. To what extent the 1977 data may represent the more normal condition is not known.

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CHAPTER 4

SUBMERSIBLE OBSERVATIONS OF THE BOTTOM IN LEASE AREAS IN THE BALTIMORE CANYON TROUGH

Sally A. Wood
David W. Folger

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CHAPTER 4

SUBMERSIBLE OBSERVATIONS OF THE BOTTOM IN LEASE AREAS IN THE BALTIMORE CANYON TROUGH

Sally A. Wood[1] and David W. Folger[1]

INTRODUCTION

In July 1976 the U. S. Geological Survey conducted seven dives in the petroleum lease areas as part of the on-going environmental assessment of the Baltimore Canyon Trough prior to and during petroleum exploration and development. The dives were conducted to assess, by direct observation, the geologic, biologic and hydrologic characteristics of the bottom, and to observe the in situ operation of two tripods.

SETTING AND PREVIOUS WORK

The dives in this survey were conducted in water depths of 68-80 m, 130 km east and 180 km northeast of Delaware Bay on the Mid-Atlantic Continental Shelf (Figure 4-1). These areas, as well as two dumpsite locations 80 km southeast of Delaware Bay, were observed in 1975 by the U. S. Geological Survey (Folger 1977). Long term observations of the bottom current and bottom sediment movement on the Mid-Atlantic Continental Shelf were also conducted in 1975 through 1977 by the U. S. Geological Survey with instrumented bottom tripods (Butman et al. 1977).

A few direct observations of the sea floor in the area have also been reported by McKinney et al. (1974), and Edwards and Emery (1968). Descriptions of morphology and sedimentology (Emery 1966; Schopf 1968; Emery and Uchupi 1972; Uchupi 1968, 1970; Schlee and Pratt 1972; Hollister 1972; Milliman 1972; Swift et al. 1972a, 1972b; Frank and Friedman 1973; Stanley and Swift 1976), shallow stratigraphy (Allen et al. 1969; Sheridan et al. 1974; Stubblefield et al. 1975; Swift and Sears 1973; Knebel and Spiker 1977), bottom water and bottom microtopography (Swift et al. 1973, McClennen 1973, Stubblefield et al. 1975; Swift 1976, Butman et al. 1977; Milliman and Bothner 1977), and sediment texture (Donahue et al. 1965; Hollister 1972; Swift et al. 1973; Milliman 1972; Stubblefield et al. 1975; Knebel 1975, 1977; Knebel and Spiker 1977; Johnson and Wood 1977) have been made previously.

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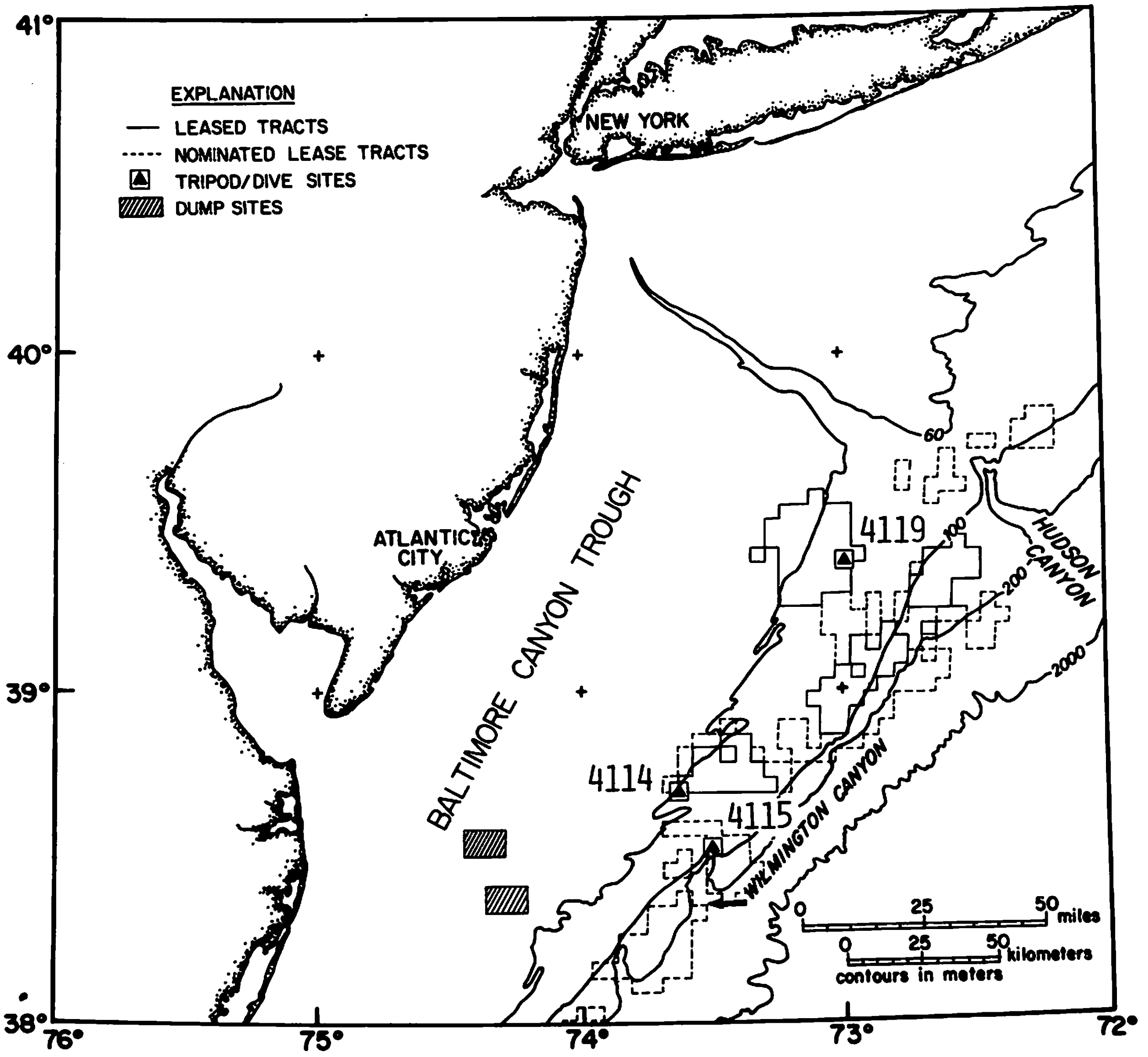

Figure 4-1. Map showing locations of sites where dives were conducted in 1975 and 1976 to assess geologic, biologic and hydrologic characteristics of the water column and bottom in areas that have been leased for petroleum exploration.

METHODS

Data were collected in July 1976 aboard DSRV NEKTON GAMMA and the R/V ATLANTIC TWIN. Stations were located using Loran A and C.

On board the submersible, photos were taken using 35 mm cameras. Temperatures were recorded during two dive descents and one ascent. Bottom current speeds and directions were estimated by observing movement of suspended particles. Concentrations of bottom organisms were estimated by biologists. All observations were recorded on tape.

OBSERVATIONS 1976

In August 1975, geological, biological and hydrologic characteristics were documented at three sites in the Baltimore Canyon Trough where vibracore pipes and railroad wheels had been emplaced in the bottom as reference markers. Instrumented bottom tripods also were deployed at these sites during the winter 1975-1976 and at two sites during the summer 1976.

In July 1976 a follow-up cruise was conducted to: 1) survey geologic and biologic conditions in the three sites observed in 1975 and the COST test well site, 2) observe the fully instrumented tripods in operation on the bottom, and 3) make a down slope traverse near the shelf edge where Conservation Division seismic data had revealed possible bottom instability. High winds and rain prevented diving at one of the reference sites, at the COST test well site, and along the down slope traverse near the shelf edge (Table 4-1). Two reference and tripod sites were surveyed and the tripods were observed in operation but reference markers were not located.

In 1975 at the three station locations 17 dives were conducted in four days. In 1976 only seven dives were conducted on two of the five days. Fifteen to 35 knot winds and rain precluded any diving on the other three days. Thus, continuity of bottom searches and surveys was poor and few objectives were attained.

Station 4115

The top of the thermocline occurred at 8 to 21 m water depth (Figure 4-2). Surface temperatures were as high as 23.5°C. Bottom flow was less than 10 cm/sec. Between 27 and 36 m water depth, visibility was reduced by high concentrations of suspended matter. At the bottom (79 m) visibility was approximately 10 m.

Microtopography at the bottom consisted of hummocks and depressions 4-5 cm across and 1-2 cm high. There was little evidence of ripple marks. A dark brown flocky layer overlay gray sand in 50%

Table 4-1. Operational Summary: R/V ATLANTIC TWIN - DSRV NEKTON GAMMA 7-14 July 1976.

			Location		Time					
Dive No.	Date	Sta.	Latitude	Longitude	Down	Up	Depth	Observer	Pilot	Notes
	7 July 76									Depart Woods Hole 2030
	8 July 76	4119								Arrive at Station 4119 at 2000
691	9 July 76	4119	39°25.5'N	73°00.5'W	0815	0955	66 m	Folger	Parsons	
692	9 July 76	4119	39°27.6'N	73°01.0'W	1350	1448	64 m	Serafy	Slater	
693	9 July 76	4119	"	"	1520	1602	64 m	Kraeuter	Czahara	
694	10 July 76	4115	38°33.3'N	73°30.8'W	0940		79 m	Butman	Parsons	Tripod and buoy mooring survey
695	10 July 76	4115	38°33.0'N	73°30.8'W	1225	1410	79 m	Folger	Slater	Tripod survey
696	10 July 76	4115	"	"	1440	1612	79 m	Serafy	Czahara	Biological survey
697	10 July 76	4115	"	"	1740	1815	79 m	Slater	Czahara	Attach line to tripod
	11 July 76	4114			No Dives					High winds and rain
	12 July 76	4114			No Dives					15-20 knot winds, moderate chop
	12 July 76	4119			No Dives					30-35 knot winds
	13 July 76				No Dives					Steaming for Woods Hole 0800 due to bad weather
	14 July 76									Arrive Woods Hole

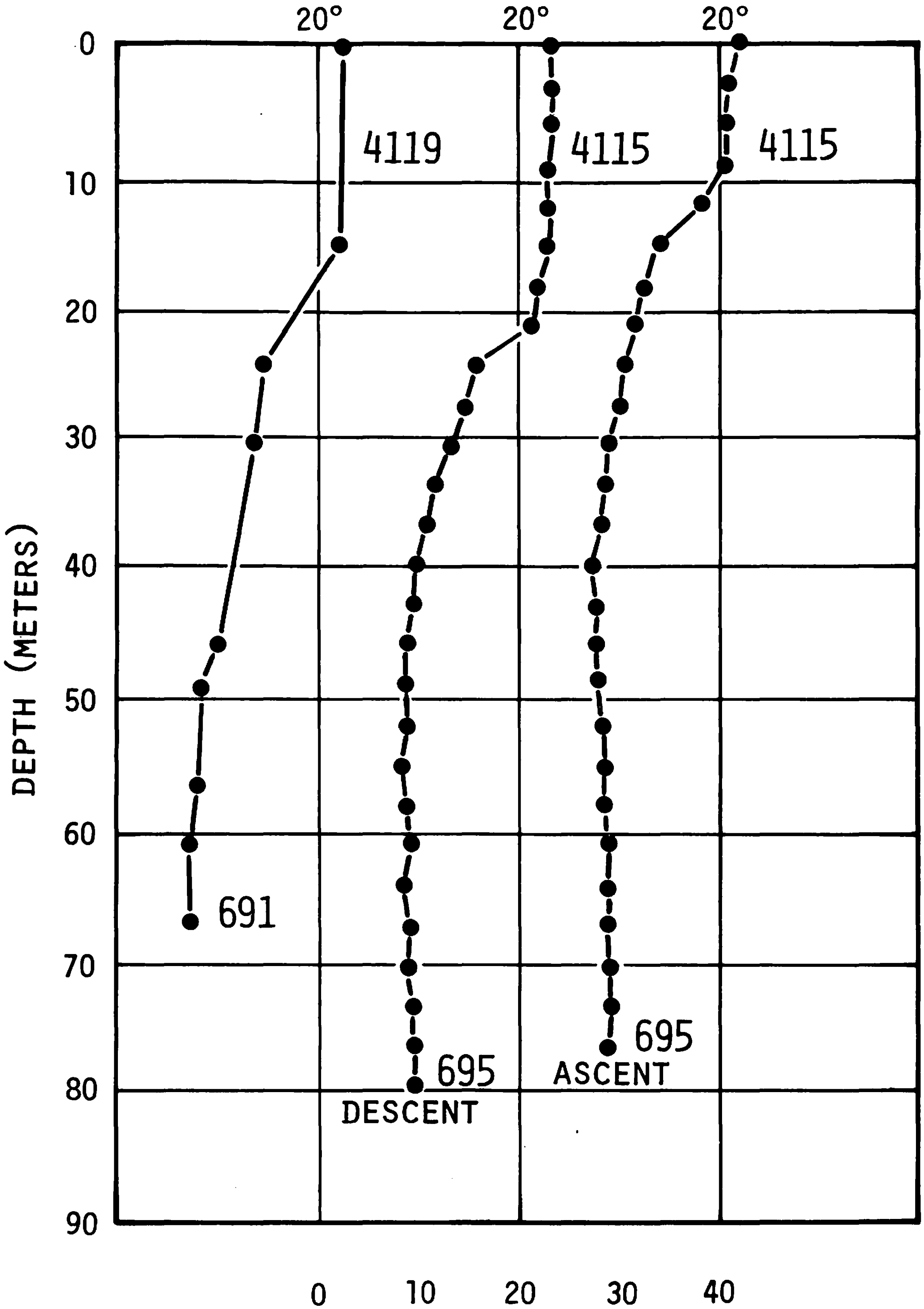

Figure 4-2. Temperature profiles were recorded by the observer in the submersible during descent at site 4119 and during descent and ascent at site 4115. Because temperature and depth gauges had to be watched simultaneously, the profiles should be viewed as approximate.

of the area. The sand appeared to be fine textured and contained many fine white shell particles. Shells were generally concave upward and consisted of large, quahog, clam and scallop shells. Common live organisms were starfish, crabs, hake, clams, scallops, and red worms.

The tripod at site 4115 was observed during one dive. It appeared to be intact and operating normally. Hake, however, periodically moved into the current meter vane and rotor (Figure 4-3). Each sediment trap was occupied by an eel pout, indicating that the design was useless.

These observations showed many similarities to observations made at this site in 1975. Observations again, as in 1975, suggest tranquil bottom conditions (Folger 1977).

Station 4119

At station 4119, the top of the thermocline was between 15 and 24 m (Figure 4-2) and the surface temperature was 22.5°C and declined to 7.2°C at the bottom (66 m). Bottom currents flowed at approximately 4 cm/sec from the southeast to the northwest. Visibility at the bottom was poor (5 m).

Microtopography consisted of hummocks and depressions and some remnants of ripple marks. Bottom sediments were composed of fine, light gray sand covered by a brown flocky layer in 60% to 80% of the area. The shell debris was scattered but not abundant. A mooring anchor on the buoy for the tripod, which had been deployed for almost one year, showed no appreciable deposition or scour. Live organisms on or near the bottom were abundant. These included scallops, crabs, starfish, sand dollars, hake, flounder, anemones, and arrow worms (Figure 4-4).

During one dive at site 4119, the bottom tripod was observed. The tripod appeared to be operating normally except for biologic interference. As at site 4115, hake were observed in the current meter, aligned with the current direction. Hake were also observed wrapped about one of the current meter rotors, preventing rotation. Eel pouts occupied the sediment traps (Figure 4-[illegible]) as at site 4115.

These observations at site 4119 vary little from observations made at this site in 1975. They indicate once again that the bottom water circulation is tranquil during summer (Folger 1977) as suggested by the lack of scour and deposition about the moored anchor.

CONCLUSIONS AND RECOMMENDATIONS

1. Bottom water circulation at the observed sites is slow (<10 cm/sec) when no storms are present.

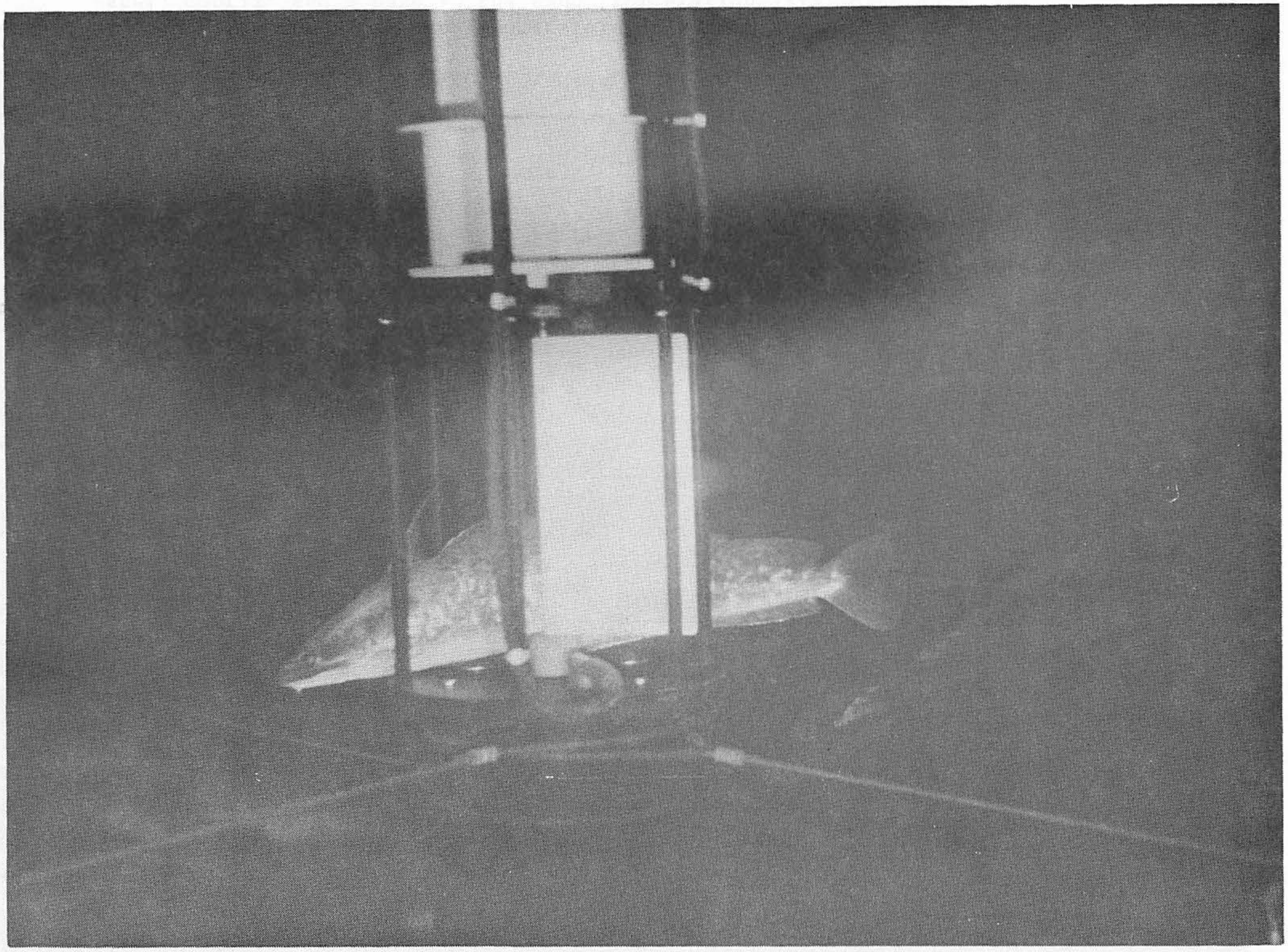

Figure 4-3. A photograph taken from the submersible showing a hake in the current vane of the tripod.

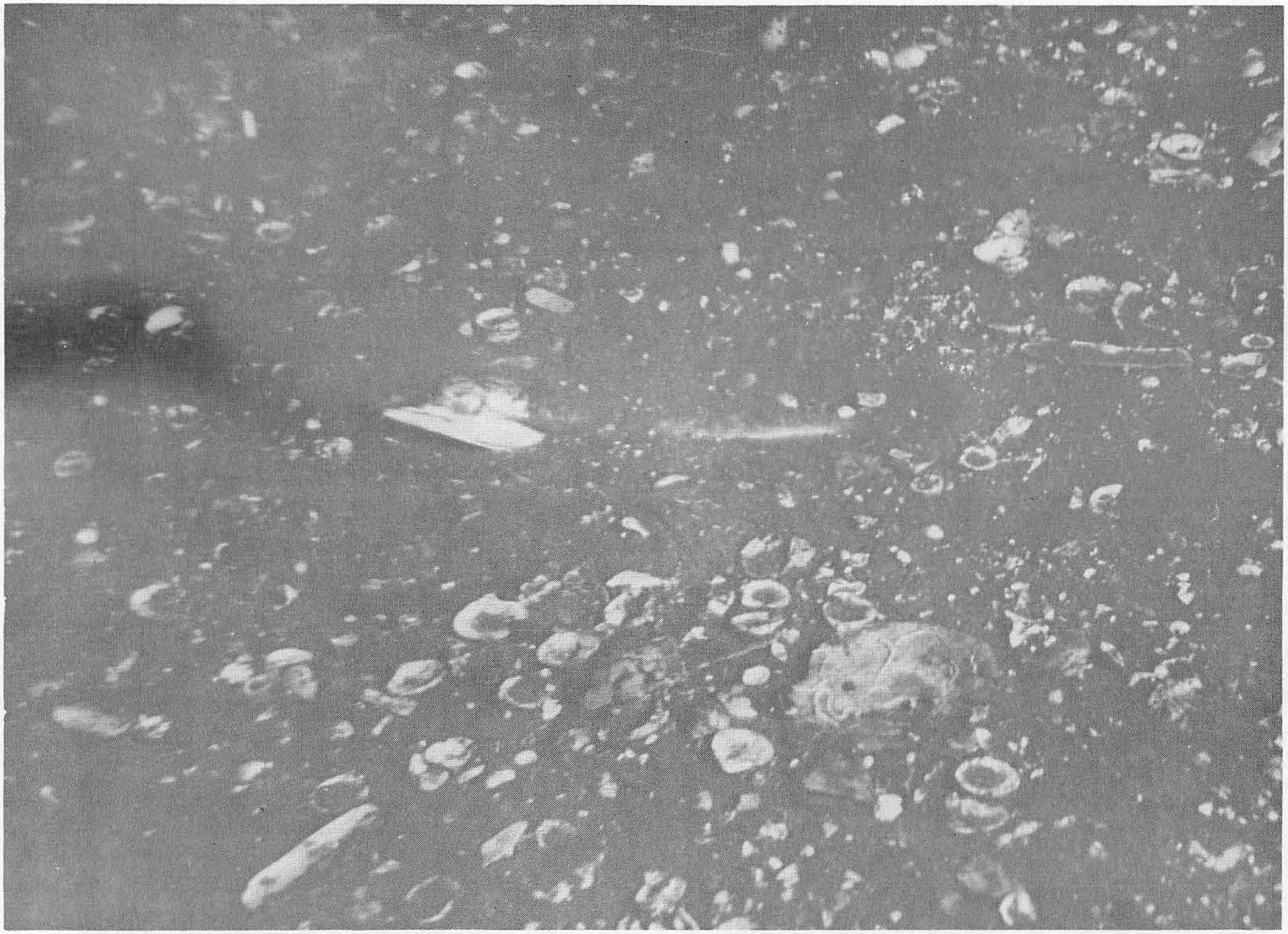

Figure 4-4. A photograph taken from the submersible of bottom sediments, shell debris, and a hake in the sand from station 4119, dive 695.

Figure 4-5. A photograph taken from the submersible of a sediment trap of the tripod occupied by an eel pout.

2. Bottom microtopography is characterized by hummocks and depressions.

3. A flocky brown layer covers 50% to 80% of the bottom.

4. Material collected in sediment traps does not show actual accumulations of suspended sediment. In the future, sediment traps should be protected with caging or eliminated.

5. Reference markers may not have been observed because they had been dragged or tipped over by fishing ships, but the poor weather prevented systematic searches.

6. Future observations should be carried out at drill sites to observe the fate and effects of drill cuttings along the shelf edge and upper slope to improve our understanding of slump causes, characteristics, and age.

ACKNOWLEDGEMENTS

Cruise participants included: B. Butman, P. Shea, and M. Mihalik of the USGS, A. Eliason (consultant), J. Kraueter and K. Serafy of VIMS, and submersible pilots, Slater, Parsons, and Czahara.

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CHAPTER 5

MEDIUM-SCALE POTENTIALLY MOBILE BED FORMS ON THE MID-ATLANTIC CONTINENTAL SHELF

David C. Twichell

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CHAPTER 5

MEDIUM-SCALE POTENTIALLY MOBILE BED FORMS ON THE MID-ATLANTIC CONTINENTAL SHELF

David C. Twichell[1]

ABSTRACT

Sand waves have been surveyed using combined high-resolution subbottom and side-scan sonar techniques in seven areas on the Middle Atlantic continental shelf to define their distribution, magnitude, and potential for sediment transport. Based on their internal character and their ordered distribution, orientation, amplitude, and asymmetry, only those adjacent to the head of Wilmington Canyon can be termed sand waves. However, their internal structure suggests that the origin and asymmetry of these sand waves are relict, yet the systematic sediment distribution across them implies that the surface skin is being reworked by the present hydraulic regime. These sand waves are not an indicator of present bottom response to the hydraulic regime, however, megaripples, fields of current lineations, and outcrops of subbottom horizons are interpreted to be a result of the present hydraulic regime.

INTRODUCTION

Seven areas on the Middle Atlantic continental shelf were surveyed for sand waves to define their distribution, magnitude, and potential for sediment transport. Sand waves, which usually are found in areas with strong tidal currents, typically are indicative of intense sediment movement (McCave 1971). For this reason they can be a hazard to pipeline and oil rig construction. However, on the Mid-Atlantic shelf the tidal component of the current regime is too weak to move sediment and the only observed sediment movement is sporadic, being associated with passing storm systems (Butman et al. 1977). A storm-dominated current regime such as that found on the Mid-Atlantic shelf (Swift et al. 1973) though, is destructive to sand waves (Ludwick 1972; Langhorne 1977). Because of the anomalous setting of these sand wave-like forms it is necessary to define (1) whether they are in fact sand waves, and (2) how they respond to the present hydraulic regime. Although the primary emphasis is directed at the origin and maintenance of these sand wave-like forms, some insight as to the presence and distribution of other bed forms on the

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Mid-Atlantic shelf is also achieved because of the broad reconnaisance coverage of this survey.

The survey areas are spread across the entire shelf (Figure 5-1). Five of these sites were selected based on sand wave-like forms crossed during a geophysical survey of the Middle Atlantic shelf on the R/V ATLANTIS II in 1975 (Knebel et al. 1976). Sand waves around Wilmington Canyon head have been reported by Kelling and Stanley (1970), McClennen (1973), Knebel et al. (1976) and Knebel and Folger (1976), but the side-scan sonar and high-resolution subbottom techniques employed by the present study provide further information on their distribution, orientation, surface sediment distribution, and internal structure. From these data a more complete picture of the origin and present activities of these sand waves was achieved. The shelf around Baltimore and Hudson Canyon heads was also surveyed to see if sand waves, like those around Wilmington Canyon, are also found around other canyon heads.

METHODS

A combined side-scan sonar and high-resolution subbottom survey of the seven areas of possible sand waves was completed aboard the R/V OCEANUS during July 8-14, 1977. Over 650 km of side-scan sonar records (sonographs) and 3.5 kHz and Uniboom profiles were collected. An Ocean Research Equipment, Inc. integrated seabed survey system which was comprised of a 97 kHz side-scan sonar (scanning 90 m to each side of the towed fish), and a variable frequency high-resolution subbottom profiler operating mostly at 3.5 kHz was used. A Uniboom (400-4000 Hz band pass, 300 joule) was also operated, except when ineffective due to rough seas. Ship's speed varied from 6-10 km/hr, and navigational fixes were taken at least every 10 minutes using Loran-C.

RESULTS

The sonographs reveal five distinct features suggestive of sediment movement on the Mid-Atlantic shelf (Figure 5-2). These forms are: (1) trawl marks, (2) subbottom outcrops, (3) fields of current lineations, (4) megaripples, and (5) possible sand waves.

Trawl Marks

Trawl marks, which of course are man-made, appeared as randomly oriented lineations on the sonographs. They were present in all seven surveys but were most abundant in the sureys around the three canyon heads.

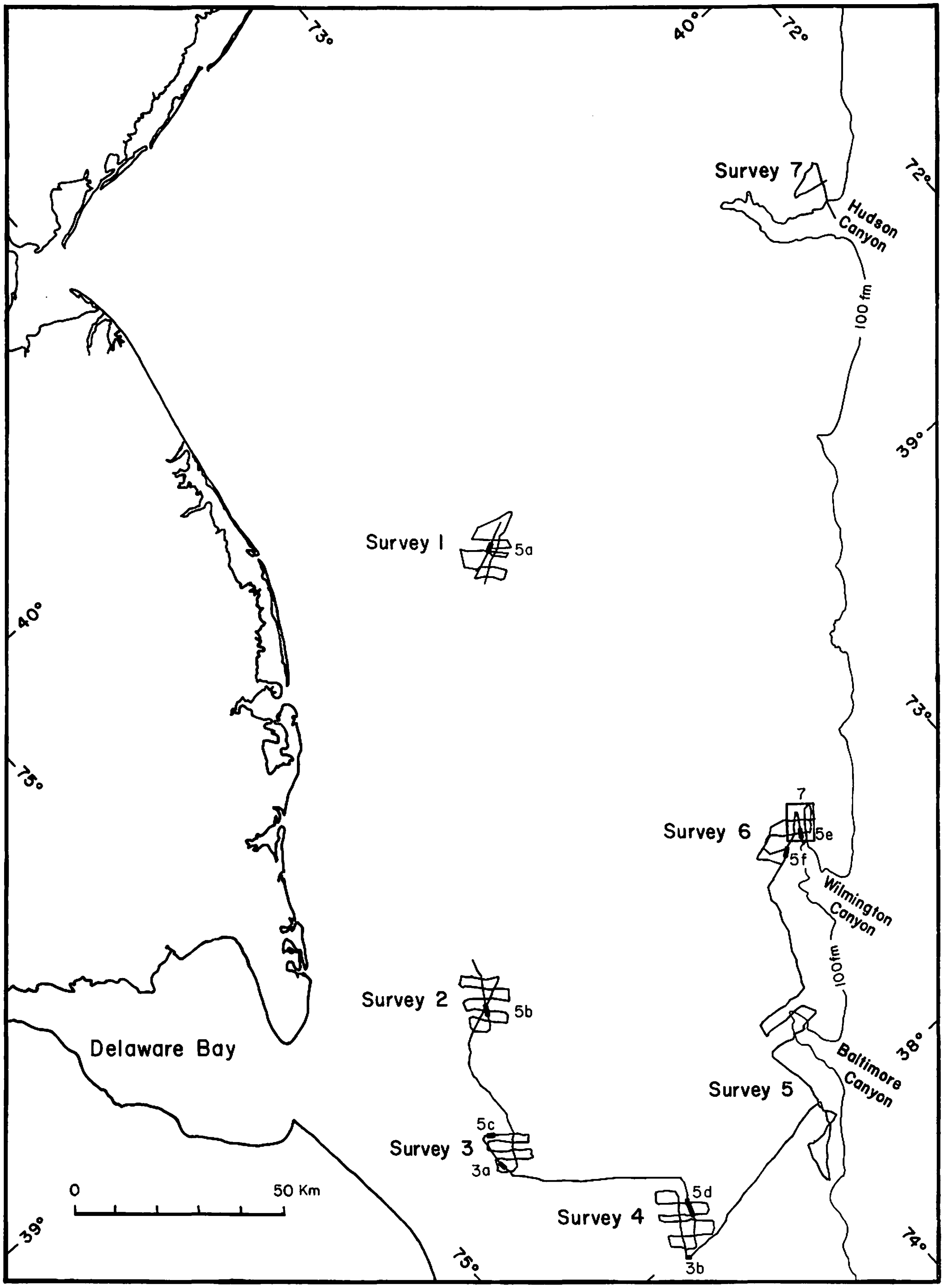

Figure 5-1. Location map of the ship's track and the seven survey areas as well as positions of example records shown in Figures 5-3 and 5-5 and of the block diagram of Figure 5-7.

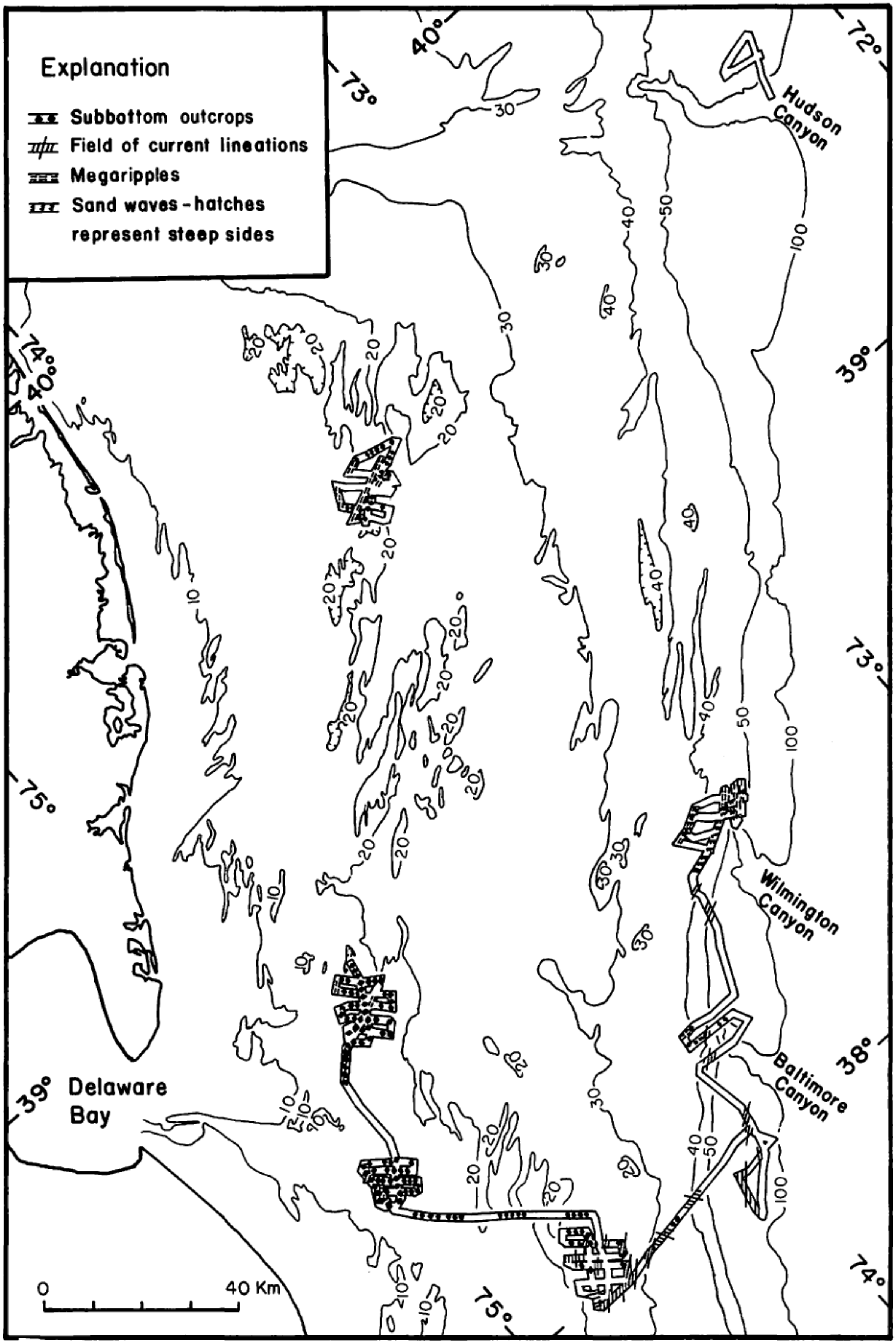

Figure 5-2. Distribution and orientations of features observed on the sonographs. Orientations are true; however, they are schematic in number. Bathymetry is in 10 fathom contours from navigational charts 12,200 and 12,300 published by the U. S. Department of Commerce (1976).

Subbottom Outcrops

Patches of strongly reflective sea floor, occurring mostly in depressions, were often associated with outcropping subbottom horizons seen on the seismic reflection profiles (Figure 5-3a). Submersible dives and cores suggested these outcrops were Pleistocene or Holocene aged clayey sediments (McKinney et al. 1974). The clay outcrops were not scoured clean; megaripples and wisps of less reflective sediment were present in some of these areas. The outcrops of subbottom horizons comprised at least 30% of the surveyed areas off the mouth of Delaware Bay in water depths less than 40 m. It covered 16% of the other inner shelf survey (Survey 1). In the middle and outer shelf surveys these outcrops were less extensive, covering only 0-12% of the sea floor (Figure 5-2).

Fields of Current Lineations

Current lineations, such as described by Newton et al. (1973) and McKinney et al. (1974) occurred in fields as lineations of strongly reflective sea floor 10-50 m wide, more than 50 m long, and separated by 5-50 m of less reflective sea floor (Figure 5-3b). They were found only on the middle and outer shelf in water depths exceeding 35-40 m (Figure 5-2). Within each field, the lineations closely paralleled each other, and except in three of the 23 fields crossed, the lineations were all striking northeast (parallel with the direction of flow). Lineations of the other three fields trended 323, 334 and 111 degrees. The fields of lineations occurred indiscriminantly on ridges and in depressions, and they showed no apparent association with subbottom horizons. However, on some sonographs a shadow was seen along the edge of the strongly reflective lineations nearest the ship indicating that these were slight depressions.

Megaripples

Megaripples were seen on the sonographs having slightly sinuous northeast-oriented crestlines and 1-3 wavelengths, but they did not have enough relief to be discerned by an echo sounder. Although only the most clearly defined megaripples are mapped (Figures 5-2 and 5-7), short segments of regularly spaced lineations with diverse orientations probably were remnants of older megaripples. Trawl marks often cut through the megaripple fields. Megaripples were most abundant in the three inner shelf surveys where they often occurred within the patches of strongly reflective sea floor, but they also were present around Baltimore and Wilmington Canyons (Figure 5-2).

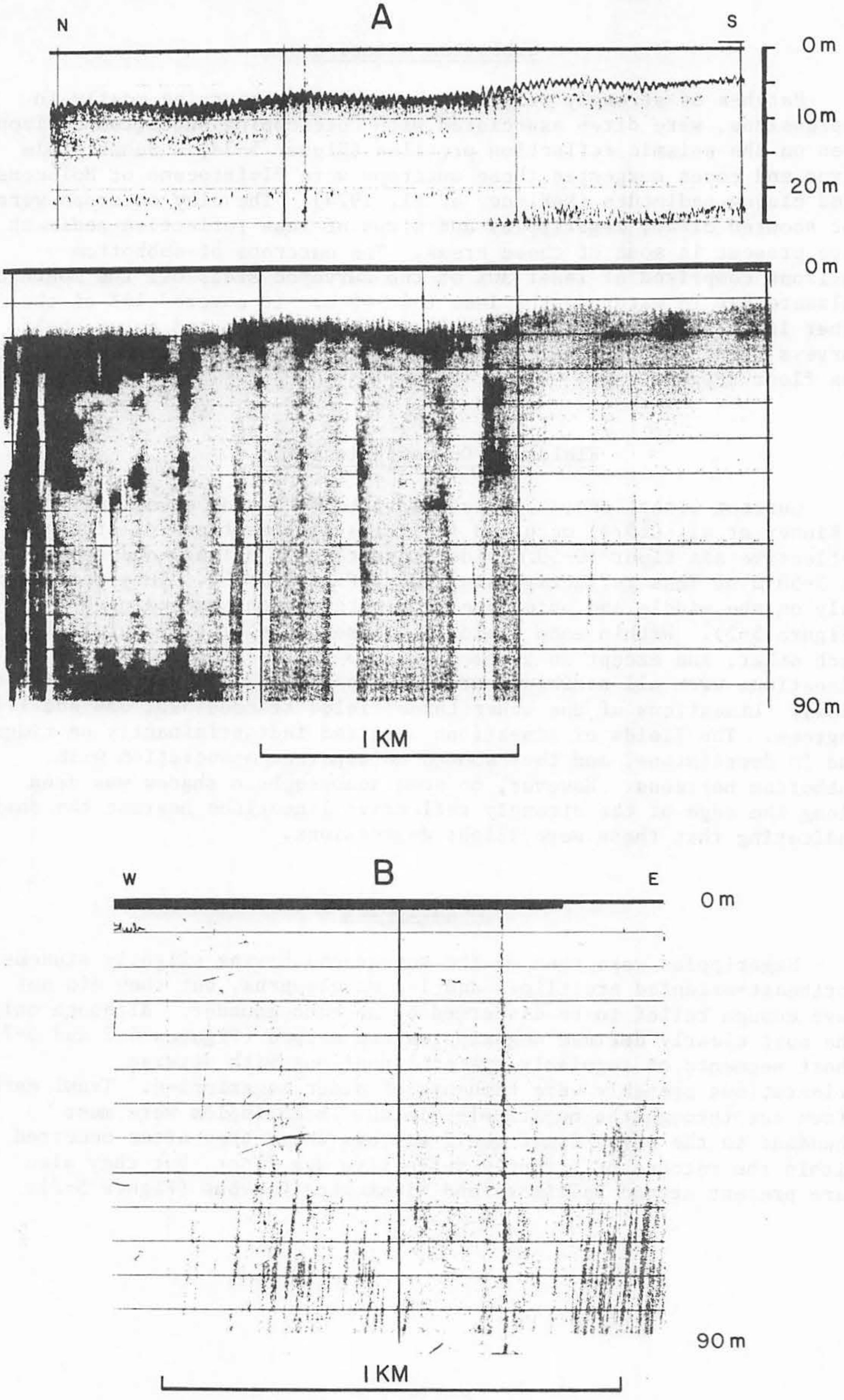

Figure 5-3. High-resolution subbottom and side-scan sonar profiles from locations shown in Figure 5-1. (A) Variations in surface texture related to outcrops of subbottom horizons, and (B) edge of a field of current lineations. Only the starboard channel of the side-scan records are shown.

Possible Sand Waves

The sand wave-like forms fell into two categories: (1) those bed forms found during the four surveys on the inner and middle shelf, and (2) those around Wilmington Canyon. The surveys near Baltimore and Hudson Canyons did not reveal any sand waves.

In each of the inner and middle shelf surveys, four to fourteen bed forms were crossed. These features had 1-7 m heights and, where in groups, were spaced 50-400 m apart. They were both symmetrical and asymmetrical with round crests (Figures 5-4 and 5-5), and crestline orientations varied by as much as 90-180 degrees. No other bed forms were present on them, and no internal structure was discerned (Figure 5-5).

By contrast, the Wilmington Canyon sand waves were more abundant and better ordered than those crossed on the inner shelf. Here, over 250 sand waves were crossed all having northwest-striking crestlines, 100-200 m wavelengths, 1-9 m heights, rounded crests, and mostly an asymmetrical shape with the steep sides facing southwest (Figures 5-5e,f, and 5-6a). Most of the sand waves fell into three fields that occurred within 15 km of the canyon head in 66-100 m water depths. Two of these fields were 0.3-1.5 km wide, were 11-15 km long, and were found on the seaward flanks of low ridges west of the canyon. The third one was 4 km wide, 6 km long, and northeast of the canyon head. Small patches of sand waves were interspersed between these fields, usually related to smaller topographic protuberances as well (Figure 5-6b).

Based on height, the Wilmington Canyon sand waves could be placed into two groups: (1) those near the canyon head and (2) those along the ridge flanks. The sand waves near the canyon head reached 8 m height with about half exceeding 4 m and almost all greater than 2 m. The ridge-associated sand waves were all less than 4 m and most of them reached only 2 m in height (Figure 5-6b).

Megaripples and sediment texture showed systematic distributions across the sand waves. Within the sand wave fields, the megaripples had crestlines oriented northeast (normal to the sand waves), and they occurred only on the crests and gentle sides of sand waves. The sediment characterizing the sand wave crests gave a weak acoustic signature whereas in the troughs, particularly northeast of the canyon head, bands of strongly reflective sediment 10-75 m wide were apparent (Figure 5-7).

Subbottom profiles revealed the internal character of the sand waves. Most of them rested on one to three discontinuous flat-lying reflectors, and, where these outcropped in the troughs, they coincided with the strong acoustic signal on the sonographs (Figures 5-5e, 5-7). A faint reflector parallel to the sand waves was observed in some sand

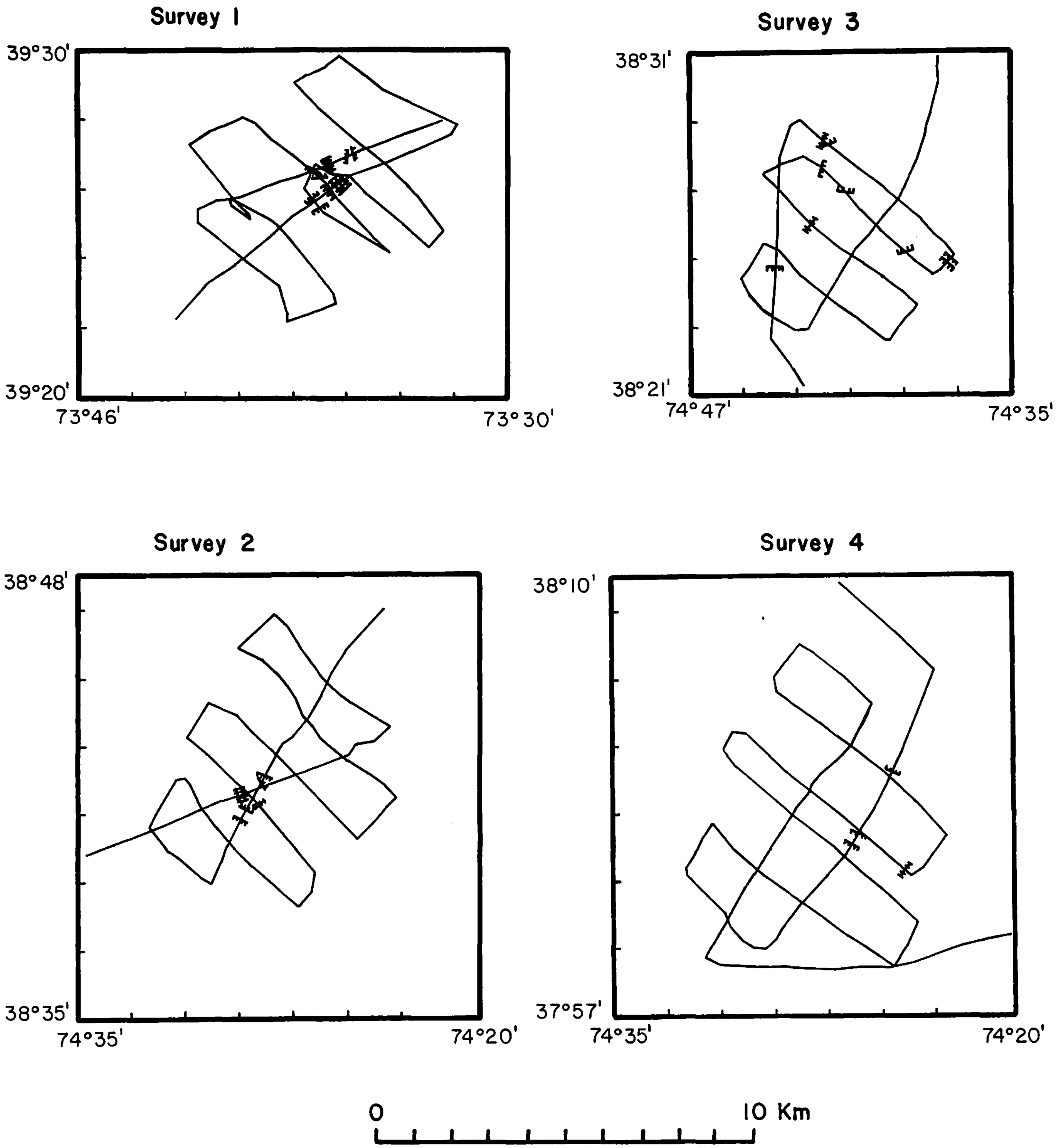

Figure 5-4. Distribution, orientation and asymmetry of wave-like forms found in the four inner shelf surveys. Symmetrical wave forms are indicated by hatch marks on both sides of the line showing the crestline location and orientation. Asymmetrical forms have hatch marks on the steep sides. Location of surveys is shown in Figure 5-1.

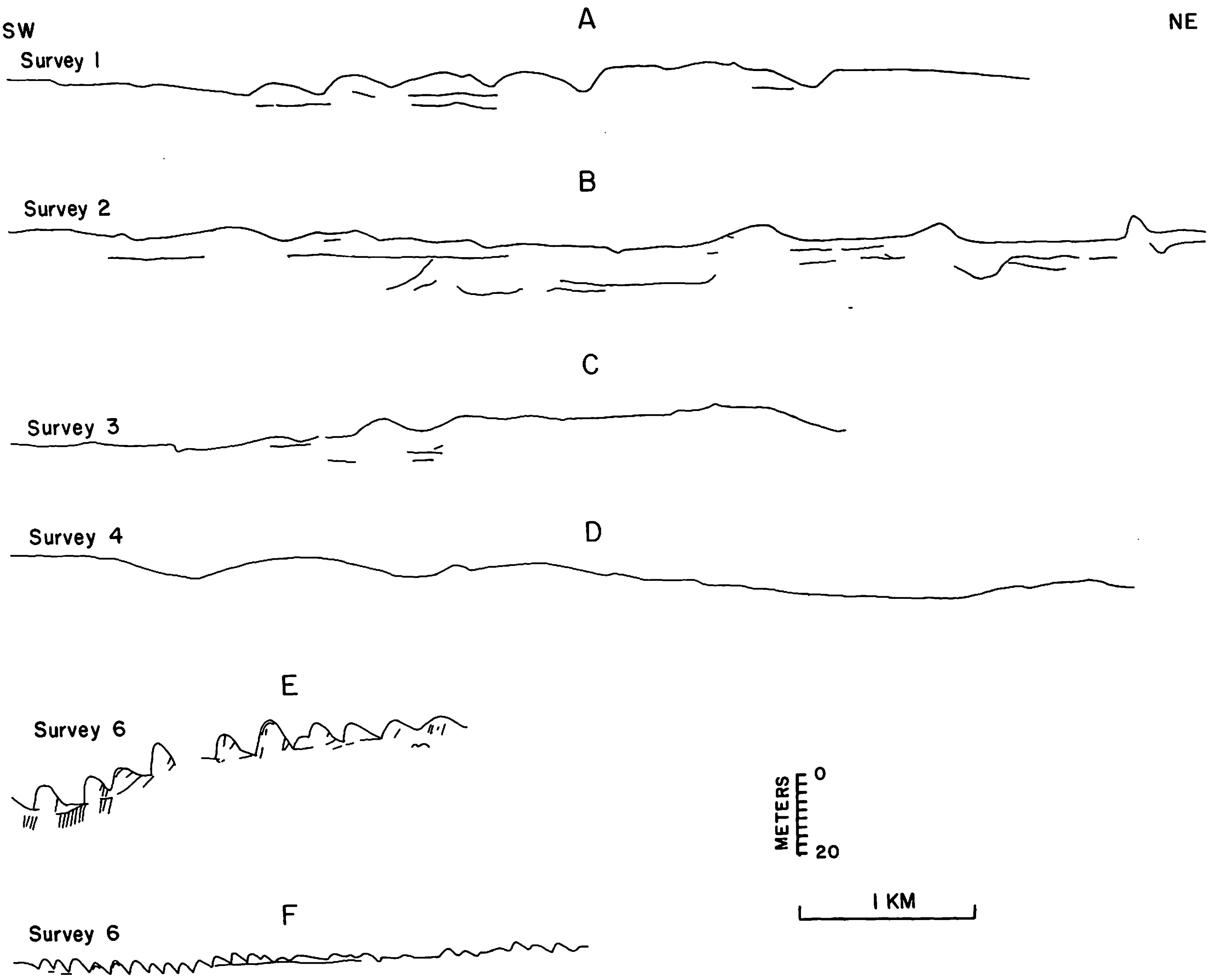

Figure 5-5. Line drawings representative of the wave-like forms from the four inner shelf surveys as well as two examples from the sand waves around Wilmington Canyon.

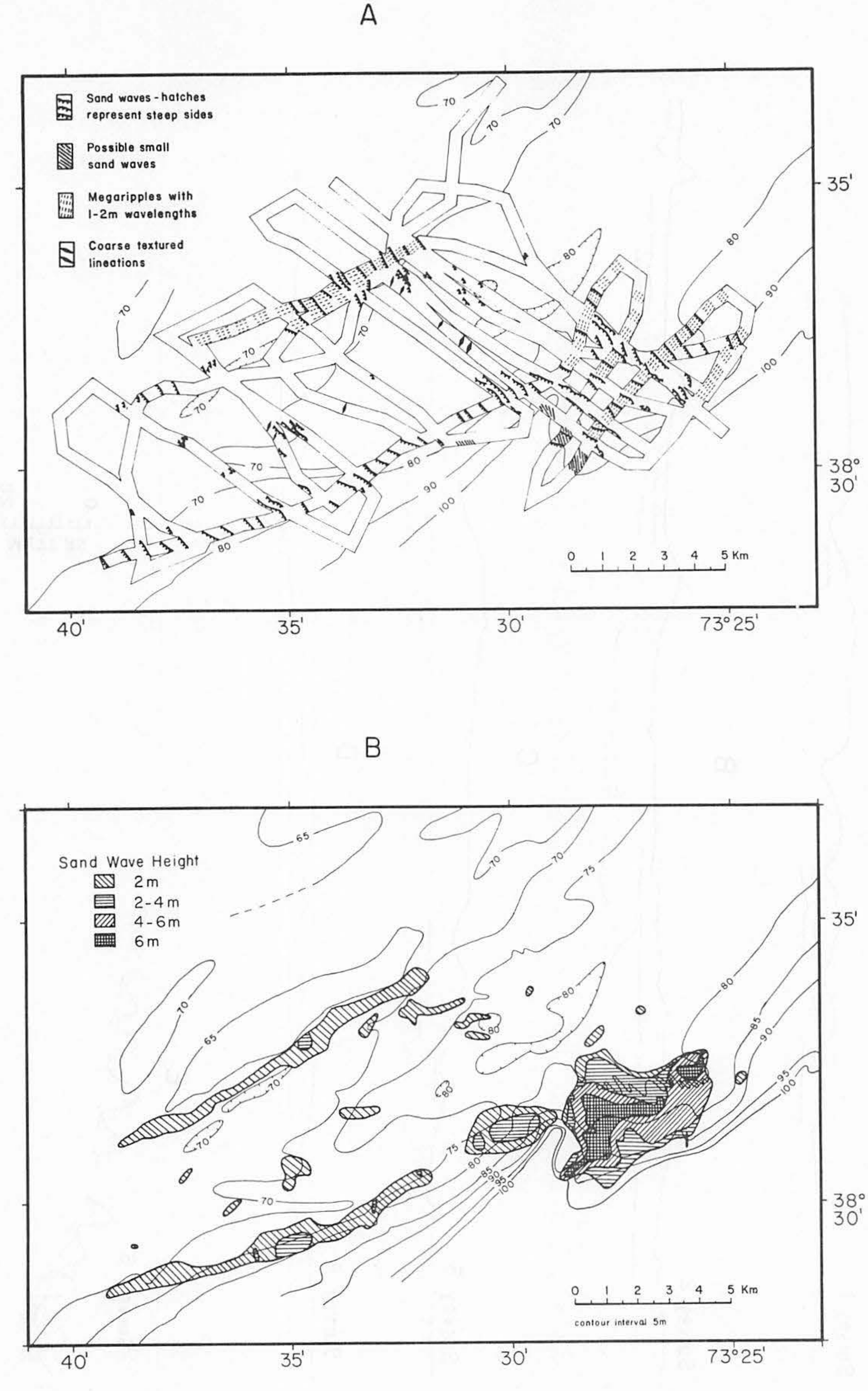

Figure 5-6. Sand wave distribution in Survey 6 around Wilmington Canyon. (A) Orientation of sand waves and megaripples, and (B) distribution and height of sand waves. Bathymetry is in meters, and was compiled from echo sounding profiles collected between 1973 and the present.

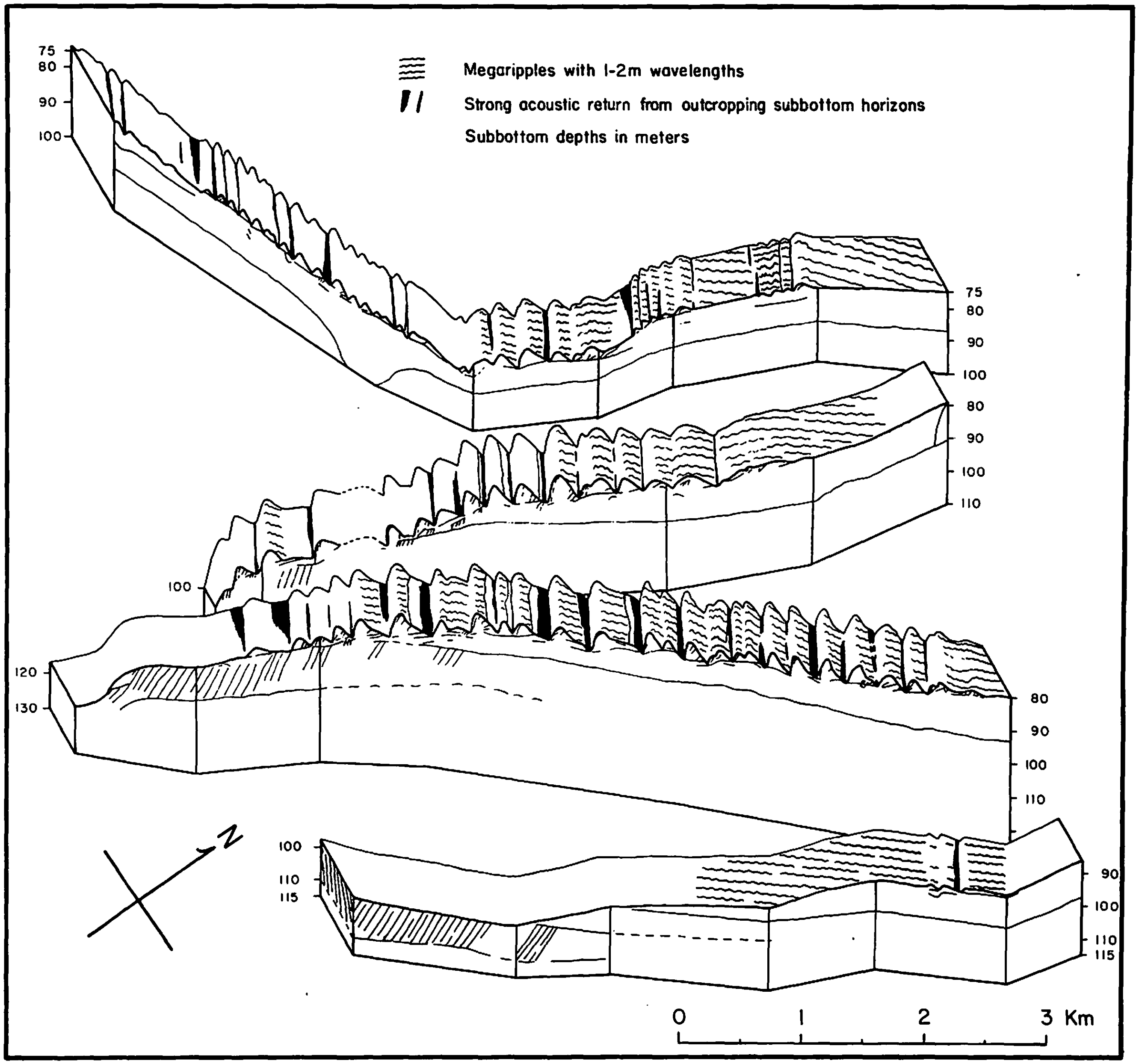

Figure 5-7. Block diagram of some of the profiles in Survey 6 northeast of Wilmington Canyon showing the relation of surface and subbottom features. Diagram was compiled using sonographs, 3.5 kHz and Uniboom profiles. Location is shown in Figure 5-1.

waves (Figure 5-5e). Underlying the base of the sand waves was a zone of 8-12 m thick foreset bedding that enveloped the canyon head. At the same depth, a southwest-trending valley opened into this same area of foreset bedding (Figure 5-7).

DISCUSSION

The morphology and structure of the wave-like forms indicate that only those bed forms at the head of Wilmington Canyon can be termed sand waves. Their large number, well-ordered distribution, and uniform orientation, wavelength, and asymmetry are in marked contrast to the small number and the random distribution, orientation, and symmetry of the wave-like forms present in the four inner and middle shelf survey areas (Figures 5-4, 5-5, and 5-6). Also, the internal character of the sand waves near Wilmington Canyon, which showed some foreset bedding, is contrary to those of the four other surveys which showed no foreset bedding (Figure 5-5). The morphology and structure of the Wilmington Canyon sand waves thus are different from those forms crossed in the other surveys, and are consistent with sand waves from other areas. The association of these sand waves with the bathymetric ridges (Figure 5-6b) is similar to that found in many areas of strong tidal currents, especially off estuary mouths (Off 1963). The foreset bedding, and the flat reflectors underlying them, also are consistent with high-resolution profiles across other sand waves (Moody and Van Reenan 1967).

Although the general morphology and structure of the Wilmington Canyon sand waves are consistent with active ones, the observed sediment movement is more sporadic and less intense. Continuous monitoring of the sea floor by bottom photographs has shown that bottom sediment movement, both by traction and by suspension, occurred less than 10% of the time during the winter (the time of greatest activity) (Butman et al. 1977). Megaripples, which are too large scale to be observed by the tripod system of Butman et al. (1977), had been inactive long enough prior to the survey to have been marked by the trawling of fishing boats. The origin of these megaripples is uncertain, but their uniform orientation and wide distribution supports the contention that they form during single events such as hurricanes or the heaviest winter storms (Swift et al. 1972; McKinney et al. 1974).

The observed sediment movement within the Wilmington Canyon area is not strong enough to have formed these sand waves, nor do the sand waves migrate under these conditions. The faint reflector paralleling the sea floor in some of the sand waves (Figures 5-5, 5-7) implies an unconformity in the sediment processes with only the upper meter being affected by present conditions. The uniform depth of the faint reflector across the sand waves suggests that although the surface skin presently is being reworked, no net migration of the sand wave bed forms is presently taking place. Within the sand waves, the southwest dip of the foreset beds (Figures 5-5 and 5-7) is consistent with the present asymmetry of the sand waves which suggests that although their asymmetry is perhaps maintained by present conditions, it is of relict origin.

Even though the sand wave form itself and its asymmetry are presently static, the systematic variations in sediment, and bed form distribution across them, are evidence that they are being preserved by the present processes of the outer shelf. The outcrops of subbottom horizons in some troughs (Figure 5-7), which probably are a silty clay substrate (Knebel and Folger 1976), indicate that sediment is not being deposited in the troughs. Megaripples are limited to the sand wave crests (Figure 5-7), probably because of the absence of mobile sand in most of the sand wave troughs, and because of the stronger bottom currents over the crests due to the greater restriction of water mass movement.

As the observed sediment activity on the Wilmington Canyon sand waves is inadequate to construct these bed forms which reach 8 m in height (Figure 5-6b) (Butman et al. 1977), it is necessary to outline the conditions under which they originated. The southwest trending channel, and the zone of foreset bedding enveloping the canyon head which were seen in the subbottom profiles underlying the sand wave fields (Figure 5-7), suggest that the sand waves lie on what originally was a deltaic environment. This delta may have developed in response to either the Delaware or Great Egg rivers, both of which drained into Wilmington Canyon during low stands of sea level (McClennen 1973; Twichell et al. 1977). During the Holocene transgression, the delta was submerged and reshaped by the nearshore processes characteristically found off an estuary or river mouth. Under such tidally-controlled environments, large fields of sand waves and sand wave covered linear ridges (Off 1963) are commonly found. One such setting is off the present Delaware Bay mouth whose sand wave distribution closely parallels the distribution and magnitude of the sand waves found at Wilmington Canyon (Jordan 1962; Sheridan et al. 1974).

After the formation of these sand waves at Wilmington Canyon, the transgressing sea removed them from the abundant sediment supply and the strong tidal currents off the estuary mouth. Under the storm dominated circulation of the middle and outer shelf, the sand waves ceased to move and took on their round crested appearance. They were not destroyed, possibly due to either the proposed intensification of currents at the shelf edge (Flemming and Revelle 1939) and around canyon heads (Shepard and Marshall 1973), or to a rapid sea level rise immediately after their development.

The sand waves at Wilmington Canyon then are remnants from a former environment and do not represent the bottom response to the present hydraulic regime. Basement outcrops, fields of current lineations, and megaripples, however, are a result of the present conditions as is evidenced by their extensive distribution, consistent orientations, and zonation by depth (Figure 5-2). Even though they are the result of present processes, they are only sporadically maintained as all three features were frequently cut by trawl marks.

The presence of megaripples and current lineations has been previously documented on the Middle Atlantic Shelf (McKinney et al. 1974), yet their zonation across the shelf was formerly unknown. The distribution of the magaripples and current lineations is strongly controlled by depth. Megaripples are most abundant in water shallower than 40 m, although some are present around Baltimore and Wilmington Canyons. Current lineations occur on the middle and outer shelf in water deeper than 40 m (Figure 5-2). The mutual exclusion of the two types of bed forms may be explained either by the greater wave activity or by more rapid burial of current lineations in the shallower water.

Outcrops of what may be Pleistocene aged horizons (Figure 5-3a) are most abundant off Delaware Bay (Figure 5-2). The strong tidal currents at the bay mouth, combined with wave activity, may have resulted in the sea floor being scoured cleaner here than on other parts of the shelf.

SUMMARY

In summary, the only sand waves found in the seven areas are those around Wilmington Canyon, yet their internal character and the observed sediment activity are inconsistent with modern sand waves found in other areas. These sand waves at Wilmington Canyon are interpreted to be of relict origin, probably having developed during the initial stages of the Holocene transgression. Under the present hydraulic regime of the Mid-Atlantic shelf, no net migration of these sand waves could be discerned, yet their surface sediments, which are systematically distributed across them, currently are being reworked. Because of their static nature, the sand waves are not a geologic hazard. Megaripples, current lineations, and subbottom outcrops are developed or maintained by present shelf processes; these features are only sporadically active, possibly in response to storms.

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CHAPTER 6

C_{15} + HYDROCARBON GEOCHEMISTRY OF MIDDLE ATLANTIC OUTER CONTINENTAL SHELF SEDIMENT

R. E. Miller
D. M. Schultz
H. Lerch
D. Ligon
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C. Gary

CHAPTER 6

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C_{15} + HYDROCARBON GEOCHEMISTRY OF MIDDLE ATLANTIC OUTER CONTINENTAL SHELF SEDIMENTS

R.E. Miller[1], D.M. Schultz[1], H. Lerch[1],
D. Ligon[1], D. Doyle[1], C. Gary[1]

INTRODUCTION

Objectives

The U.S. Geological Survey has completed the second year baseline hydrocarbon geochemistry analyses of surface sediments from selected stations in the Mid-Atlantic Continental Shelf. Most of the sampling stations from the first-year program were reoccupied during the second year study (41 of the original 51 stations). Four cluster stations (designated A, B, E, F), each composed of four substations and two cluster stations (designated C and D), composed of two substations, were sampled four times a year (fall, winter, spring, summer). The remaining transect and isolated stations (G_2 - G_6, K_2 - K_6, L_2 - L_6), and H_1, H_2, I_1 - I_4, J_1, J_2, respectively, were sampled twice a year, summer and winter (Figure 6-1).

To achieve as representative a sediment sample as possible for each station, a composite-blend sample was collected by taking approximately 150-200 g from each of six Smith-McIntyre grab samples taken at each station. This sample collection scheme was chosen with the following objectives: (1) to determine the hydrocarbon concentration and type of each sample station to allow comparisons to be made throughout the biological seasons; (2) to establish the statistical deviations that may occur in concentration and type at a given location; (3) to provide data points to continue the initial "natural variability" curve for the Mid-Atlantic; (4) to use this natural variability as a basis for the establishment of a natural baseline hydrocarbon concentration level and type for the areas studied in this program to assess the impact of petroleum exploration on the Middle Atlantic shelf.

Previous Work

The influence of man's exploitation of the outer Continental Shelves is difficult to assess without data and information regarding

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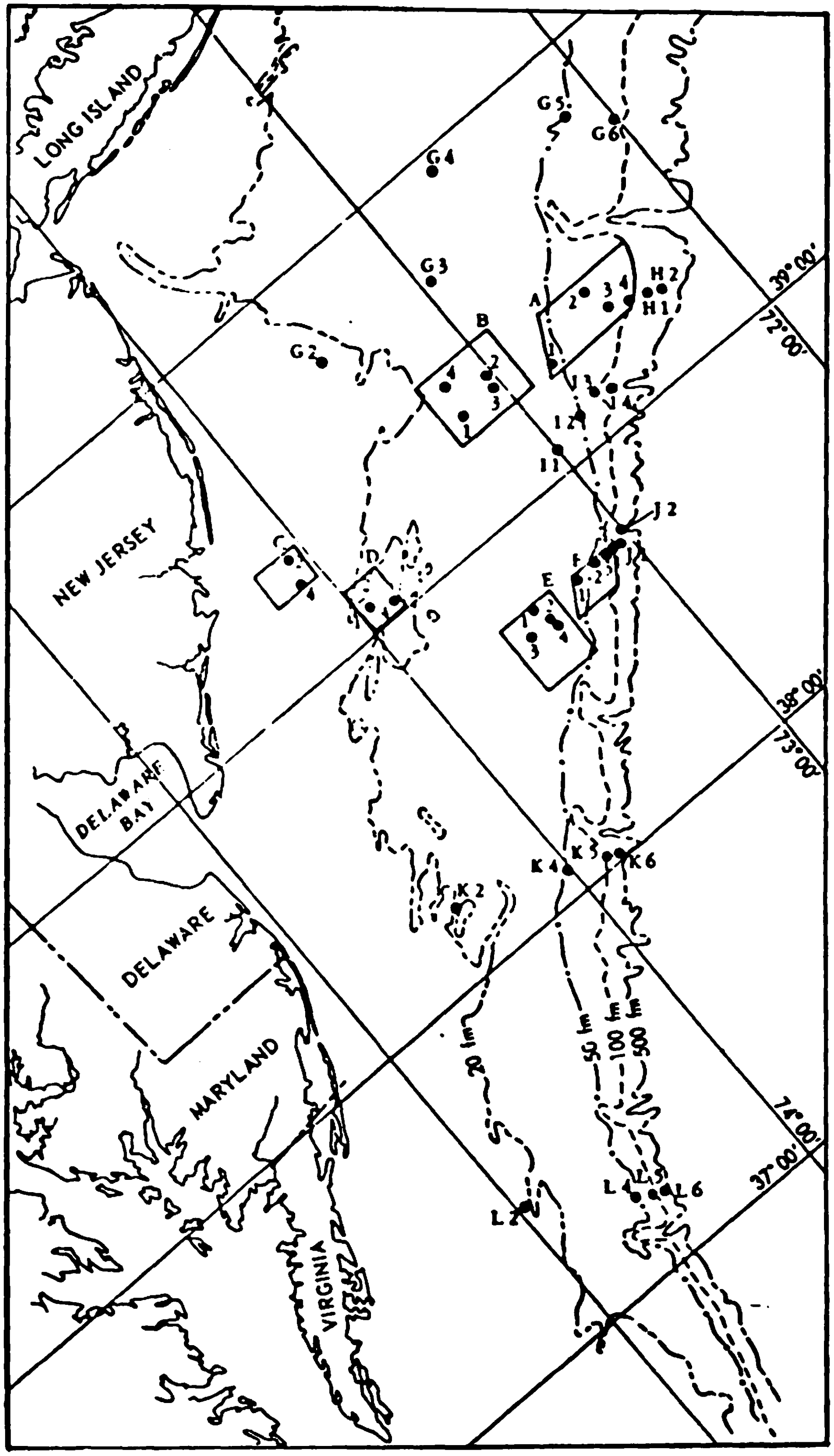

Figure 6-1. Station locations for Mid-Atlantic Continental Shelf and Slope hydrocarbon geochemical studies.

the natural variability of the concentration and composition of the shelf sediment organic material. Future environmental assessment of the outer Continental Shelf depends upon the accumulation of baseline data for a given area.

Data concerning the hydrocarbon concentration and distribution in the Mid-Atlantic Continental shelf sediments was reported for the first year of this present program (Miller and Schulz 1977). Farrington (personal communication) has also examined the hydrocarbons in New York Bight sediments. Farrington and Tripp (1977) have reported on the distribution and concentration of hydrocarbons in western North Atlantic surface sediments. Hydrocarbons from Recent sediments have been examined in the Narragansett Bay, Rhode Island, estuary (Farrington and Quinn 1973). Keizer et al. (1978) have studied the hydrocarbons in surface sediments from the Scotian shelf, but other data on the outer Continental Shelves of the northeastern United States are very sparse. A current baseline study is underway on the North Atlantic Continental shelf (Georges Bank), although the first year data have not yet been published. Previous studies have reported hydrocarbons from Gulf of Mexico shelf sediments (Stevens et al. 1956; Evans et al. 1957; Bray and Evans 1961; Parker et al. 1972; Aizenshtat et al. 1973; Gearing et al. 1976) and from Recent sediment in other areas (Clark and Blumer 1967; Tissier and Oudin 1973; Mackie et al. 1974). An attempt at determining the relationship of one investigator's data to that collected by another (intercalibration) has been reported (Farrington et al. 1973). Schultz and Quinn (1977), reported the concentration and distribution of hydrocarbons and fatty acids in particulate matter from Narragansett Bay.

Baseline monitoring of hydrocarbons in Gulf of Mexico sediments was carried out and reported (Parker et al. 1972; Gearing et al. 1976). Similar baseline studies are presently being carried out in the North Atlantic Continental Shelf and South Atlantic Shelf areas. Methods for examining the characteristics of naturally occurring and anthropogenic hydrocarbons, and establishing natural levels of hydrocarbons in sediments, were examined by Tissier and Oudin (1973), Clark (1974), and Smith et al. (1977).

ANALYTICAL METHODS AND PROCEDURES

The analytical procedures used in the analyses of these Mid-Atlantic shelf sediments were those recommended by BLM to the USGS in the Memorandum of Understanding AA550-MU7-31, pages 8-13 (11 July 1977).

The procedures used in analysing the sediments for C_{15}^{+} hydrocarbons are outlined in the following steps.

1. Extraction

Approximately 100-300 μg of sediment were freeze-dried, transferred to a pre-extracted paper Soxhlet thimble, then Soxhlet-extracted for 100 hr with a toluene:methanol azeotrope (3:7, V:V) (BP 63.7°C). The solvent was replaced by fresh solvent after the first 24 hr. Extracts were then combined and reduced in volume to approximately 500 ml using a roto-evaporator. The dry weight of the extracted sediment was determined after air-drying to a constant weight.

The Fall 1976 and Winter 1976-1977 sample extracts were placed in 500 ml volumetric flasks after reduction to about 500 ml volume. A 25 ml aliquot of the extraction volume was transferred to a tared vial from which the remaining solvent was removed by a stream of purified, filtered nitrogen, and the extract weight determined.

The Spring 1977 and Summer 1977 sample extracts were treated in a slightly different fashion to eliminate the severe emulsion problems (M.O.U.-9) that are encountered in the saponification step. The extraction mixture was diluted with a 100 ml volume of saturated NaCl solution to effect an efficient partitioning of the more polar non-hydrocarbon material which is more soluble in water than in organic solvents. If no emulsion formed, the toluene layer was decanted and the aqueous layer was extracted at least three times with n-hexane. When an emulsion did form, the entire mixture was extracted at least three times with n-hexane, the extracts were combined and back-extracted with an equal volume of saturated NaCl solution. The saturated NaCl solution was then re-extracted once with n-hexane. All organic solvent phases were combined and brought to 500 ml volume in a volumetric flask. A 25 ml aliquot of the extraction volume was transferred to a tared vial from which the remaining solvent was removed by a stream of purified, filtered nitrogen, and the extract weight determined.

The presence of elemental sulfur in each extract was determined by dipping activated copper wire into the gravimetric aliquot. If the wire became coated immediately, elemental sulfur was removed by passing the extract through a column of activated copper. The sample was saponified as described below.

2. Saponification

Saponification was carried out by heating the sample with a 1:1: mixture of 0.5N KOH in a methanol:toluene:water mixture at 100°C in a boiling water bath for 1/2 hr in a test tube sealed with a Teflon-lined screw cap.

After completion of the saponification, the mixture was diluted with an equal volume of saturated NaCl solution to effect an efficient partitioning of the nonsaponifiables. The toluene layer was removed and the aqueous layer was extracted at least three times with n-hexane.

3. Liquid Column Chromatography

Liquid chromatography (L.C.) was carried out using a solid support of silica gel, with a 1 mm plug of alumina on top to aid in retention of the more polar material. The column length to inner diameter ratio was approximately 20:1. Both the alumina (neutral) and silica gel were of activity 1 (heated for 16 hr at 240°C). The column was rinsed with at least two column volumes of n-hexane. The sample was applied to the column in a small volume of n-hexane, the aliphatic fraction was eluted with 18 ml volume of hexane, and the aromatic fraction was eluted with 32 ml volume of 6:4 benzene:hexane (V:V). The eluates from the two fractions were then taken to near dryness, at 35°C, transferred to screw cap vials with Teflon-lined caps, and reduced to near dryness under a stream of nitrogen.

4. Gas Chromatography - Mass Spectrometry

Gas Chromatography was carred out on a Perkin-Elmer model 3920 gas chromatograph equipped with a 20 m surface coated open tubular (SCOT) capillary column, using OV-1 as the liquid phase. The instrument conditions were: isothermal for 1 minute at 100°C after which the temperature was increased at 4°C/min to a maximum temperature of 240°C. The carrier gas was helium.

Quantitative values were determined by adding a known spike internal standard (n-C_{22} or n-C_{28}), and the concentration of each individual component calculated based upon the area of the internal standard peak and response factors. Response factors for each of the n-alkanes, pristane, and phytane as well as a series of aromatic hydrocarbons, were determined daily by running a standard calibration mixture of these hydrocarbon components and comparing the response to the known concentration. Each hexane and benzene fraction was run on the gas chromatograph both with and without an internal standard spike, and the concentration of the natural n-C_{22}, and n-C_{28} or methyl napthalene was determined. Correction was made for the amount of sample removed for gravimetric determination using the following expression:

$$\frac{500}{500-25} = \frac{500}{475} = \frac{20}{19}$$

5. Following preliminary gas chromatographic analyses, mass spectral studies were carried out on a Dupont Model 490B magnetic sector computerized gc-mass spectrometer system, equipped with an electron ionization source. Instrumental parameters were: source temperature, 200°C; source pressure, 6 x 10^{-8} torr; scan rate, 2 second/decade; OV-1, 20 m SCOT capillary columns were used. Compound identification was accomplished by generating a reconstructed gas

chromatogram, and then examining the mass spectra of the peaks provided clean, interpretable spectra could be obtained. Mass chromatograms of specific ions were generated and the peaks compared with the reconstructed gas chromatograms. Interpretable mass spectra were generated where the reconstructed gas chromatogram peaks coincided with peaks in the specific mass chromatogram. Compound identification was further supported by comparison of relative retention times of the unknown compound with known standards as well as with retention time values reported in the literature.

LABORATORY QUALITY CONTROL: SOLVENTS, EXTRACTION EFFICIENCY INTERCALIBRATION, STANDARDS, POSSIBLE CONTAMINANTS

Quality Control

Solvents were distilled through an all glass system and each batch was checked by gas chromatographic analysis of the residue. Control blanks were processed through the complete analytical procedure, including extraction, saturated NaCl wash, saponification, liquid chromatography and gas chromatography (Table 6-1). Hydrocarbon analysis of the ship's fuels, oils, greases, hydraulic fluids and bilge water from each cruise are shown in Appendix 3-7. Considerable effort was made to insure that the ship's captain, crew and scientific personnel were aware of guarding against contamination of sediment samples during shipboard handling. The Smith-McIntyre grab sampler was rinsed with either benzene, methanol, or ethanol prior to sediment sample collection. While not in use, the sampler was kept covered with a Teflon shroud. The results of the hydrocarbon analysis show that the sediment samples were generally free of contamination from the ship's environment. Immediately after their collection, the sediment samples were quick-frozen by using dry ice, and then stored in chest freezers until ready for processing.

Summary of Extraction Efficiency Recovery

The procedural blanks were spiked with n-docosane (n-C_{22}) and methyl phananthrene (both about 30 μg/g of hydrocarbon standard) during the initial solvent extraction step. These blanks, with spikes, were carried through the entire analytical procedure. Table 6-1 summarizes the results of the procedural blanks and spiking experiments. The data shows that the recovery of n-C_{22} through the entire procedure was good, while the recoveries of methyl napthalene were generally poor. Although losses may occur at other steps in the procedure, significant losses probably take place when the extract or L.C. fractions are evaporated to near dryness under a stream of nitrogen. The relatively high volatility of the aromatic hydrocarbons

Table 6-1. Results of procedural blanks, freeze dryer blanks, and material recovery for U.S.G.S. Mid-Atlantic Shelf, 1976-1977.

Procedural Blank	Total Resolved Hexane Fraction	Total Resolved Benzene Fraction	Material Recovery	
			% recovery $n\text{-}C_{22}$	% recovery Me Phenanthrene
#1(LC 7/1/77)	14.760 μg	0.564 μg	80.3	32.8
#2(LC 11/16/77)	5.704 μg	2.227 μg	89.6	57.1

	Total Resolved Components
Freeze Dryer	2.100 μg

will lead to considerable loss during their evaporation and drying steps. These experimental recovery results are consistent with the data from the initial year study, and are considered reasonable.

Intercalibration Samples

A total of 16 sediment samples were collected and aliquots of sediment sample blends prepared for hydrocarbon analysis. The USGS analysis of their portion of these intercalibration samples and the data are reported in Addendum 1. Aliquots of these intercalibration blends were delivered to VIMS immediately following each cruise for their own analysis and data reporting.

At the request of BLM, and in accordance with the M.O.U., the USGS and VIMS exchanged hydrocarbon intercalibration data from the Fall 1976, and Winter 1976-1977 sampling cruises. The results were discussed, and a commentary response to VIMS prepared by the USGS on the comparison of the two sets of data. The comparison of the intercalibration results from the Fall and Winter cruises demonstrates reasonably good agreement for the quantitative recovery of the total resolved aliphatics and aromatics and total resolved hydrocarbons. The differences are very reasonable in view of the extremely low concentrations, usually less than 1.0 μg/g or 1 ppm. The fact that these intercalibrations are the analyses of blended sediments without a known spike concentration, and that extractions were performed using two different procedures (soxhlet-USGS and reflux-VIMS) is significant in comparing the total extractables (H.C., salts and polar non-hydrocarbon classes). The soxhlet method recovered generally more of the non-hydrocarbon compounds which is normal and not unexpected. The lower recovery of the non-hydrocarbon classes by reflux apparently does not significantly influence the resolved aliphatic-aromatic hydrocarbon recovery.

The Pr/n-C_{17} and Phy/n-C_{18} ratios of the resolved aliphatics were comparable, although the USGS consistently found slightly higher concentrations of pristane. This could be due to the differences in resolving capabilities of the OV 101 (USGS) and SE 52 (VIMS) capillary columns and extremely low concentrations of pristane in these sediments. The USGS reported significantly higher pristane/phytane ratios than VIMS. This is consistent with the higher concentrations of pristane reported by the USGS than by VIMS.

A number of statistical treatments exist for the determination of the aliphatic Carbon Preference Index (C.P.I.). As a result of the intercalibration exercise it was mutually agreed upon by both the USGS and VIMS to use the Bray and Evans (1961) method to derive the C.P.I. values. The expression is as follows:

$$\text{C.P.I.} = \frac{C_{23} + C_{25} + C_{27} + C_{29}}{C_{24} + C_{26} + C_{28} + C_{30}}$$

The L.C. quantitative recovery (µg/gm) of the aromatic hydrocarbon fractions between VIMS and USGS showed good agreement, and was generally in the range of less than 0.1 µg/gm sediment. The major ring-type classification-identification was in general agreement, although several differences existed in specific reported compound types for several samples. The geochemical significance of such qualitative differences at these low concentration levels (i.e.) 1.0 ppb may be related to differences in column resolution, however, it also is possible that inhomogeneity of the aromatic fraction could also be a factor.

Standards

Alkane hydrocarbon standards ranging from C_{14} to C_{32}, including the isoprenoids pristane and phytane, were run each day to determine FID sensitivity response, and to establish consistent comparisons for hydrocarbon retention times and Kovat's indices. All alkane and isoprenoid standards used in the gas chromatographic work were obtained from Applied Science laboratories, and were of 99%, or greater, purity. Aromatic hydrocarbon standards, including alkyl benzenes, naphthalene, metyl napthalene, fluoranthene, acenapthene, fluorene, dibenzothiophene, phenanthrene, methyl phenanthrene, anthracene, chrysene, perylene, benzanthracene, and benzo(k) pyrene, to name a few, were run each day that aromatic fraction analyses were being performed. They were run to determine FID sensitivity response, and to establish consistent comparisons for aromatic retention times and derived aromatic Kovat's indices. The Kovat's indices determined for the aromatic fractions are experimentally derived Kovat's values, and are based on 21 aliphatic hydrocarbons, n-C_{10} to n-C_{32}, and 22 aromatic standards. The aromatic hydrocarbon standards were acquired from a number of sources, including ChemSamp Co., RFR Corp., K&K Lab, PFaltz & Bauer, Inc., and Eastman Kodak, Inc., and were usually of 97%, or greater, purity.

Summary of compounds suspected as contaminants and source

Mainly aromatic fractions

Kovat's Index	Identification
1930	GC column bleed
1984	GC column bleed
2020	GC column bleed

PRESENTATION AND DISCUSSION OF DATA

The hydrocarbon geochemical analyses for 122 sediment samples are located in Appendices 3-1, 3-2, 3-3, and 3-4. Representative chromatograms are included (Figures 6-2, 6-3, 6-4, 6-5, and 6-6) illustrating the following: little "triplet" but presence of plant wax hydrocarbons, winter G-2 hexane (Figure 6-2); large "triplet" and plant wax hydrocarbons present, Fall F-2 hexane and Summer I-3 hexane, respectively (Figure 6-3); presence of the "triplet" as the major component, Winter L-4 hexane (Figure 6-4); typical low concentration benzene fraction, Spring B-2 (Figure 6-5); typical high concentration benzene fraction, Summer D-4 (Figure 6-6). Mass spectral analyses, intercalibration analyses by the USGS, fuels, greases, hydraulic fluid and bilge water, are located in Appendices 3-5, 3-6, and 3-7 respectively. Tables 6-2, 6-3, 6-4, 6-5, and 6-6 summarize the hydrocarbon analyses for the Fall, Winter, Spring and Summer sampling seasons, as well as the USGS intercalibration analyses. Average values have been calculated and reported for each cluster station, as well as the transect stations across the shelf.

Gas Chromatographic - Mass Spectral Data

Appendix 3-5 contains a summary of the gas chromatographic-mass spectrometric data analysis for 12 selected samples (representing 10% of all samples). They were analysed on a Dupont 490-B Magnetic Sector-Mass Spectrometer-computer supported system. The mass spectrometer operating conditions were: source temperature 200°C; source pressure 6 x 10^{-8}; torr and scan rates of 2 sec/decade at 600 a.m.u. OV-101 capillary columns (20 m) were employed; G.C. conditions: isothermal for 3 minutes at 100°C, then 100°C-200°C at 12°C/minute, isothermal 240°C for 17 minutes.

Appendix 3-5 lists the mass scan number, retention time, diagnostic mass fragments, molecular weight and identification for each peak analysed in the hexane or benzene eluate. Appendix 3-5 also contains the total ion traces and normalized mass spectra for each peak scanned.

The mass spectral data analysis of the hexane eluates confirmed the presence of a series of normal aliphatic alkanes from n-C_{16} to n-C_{31}, as well as the isoprenoids, pristane and phytane. Traces of a branched aliphatic $\geq C_{22}$ with a Kovat's index of 2238 were observed. Branching was confirmed in the molecular species with carbon values of $\geq C_{26}$, and a Kovat's index of 2238.

The hexane eluates generally, but not always, contained a major component that in some cases comprised up to 10 - 12 percent of the total resolved n-alkanes. This is the same major component that was identified in the previous year's study. This component manifested

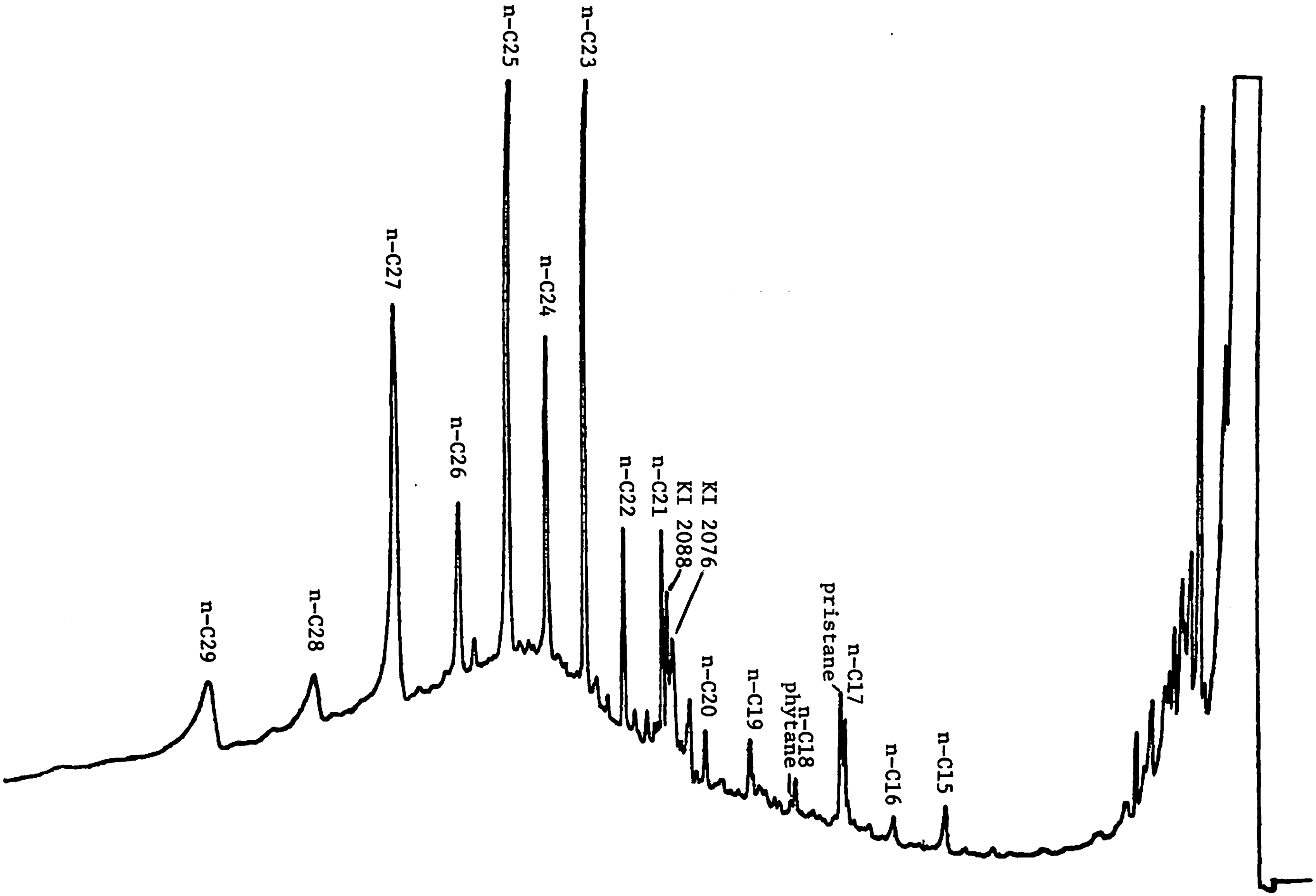

Figure 6-2. Chromatogram showing little "triplet" but presence of plant wax hydrocarbons in hexane fraction--station G-2, winter, 1976-77.

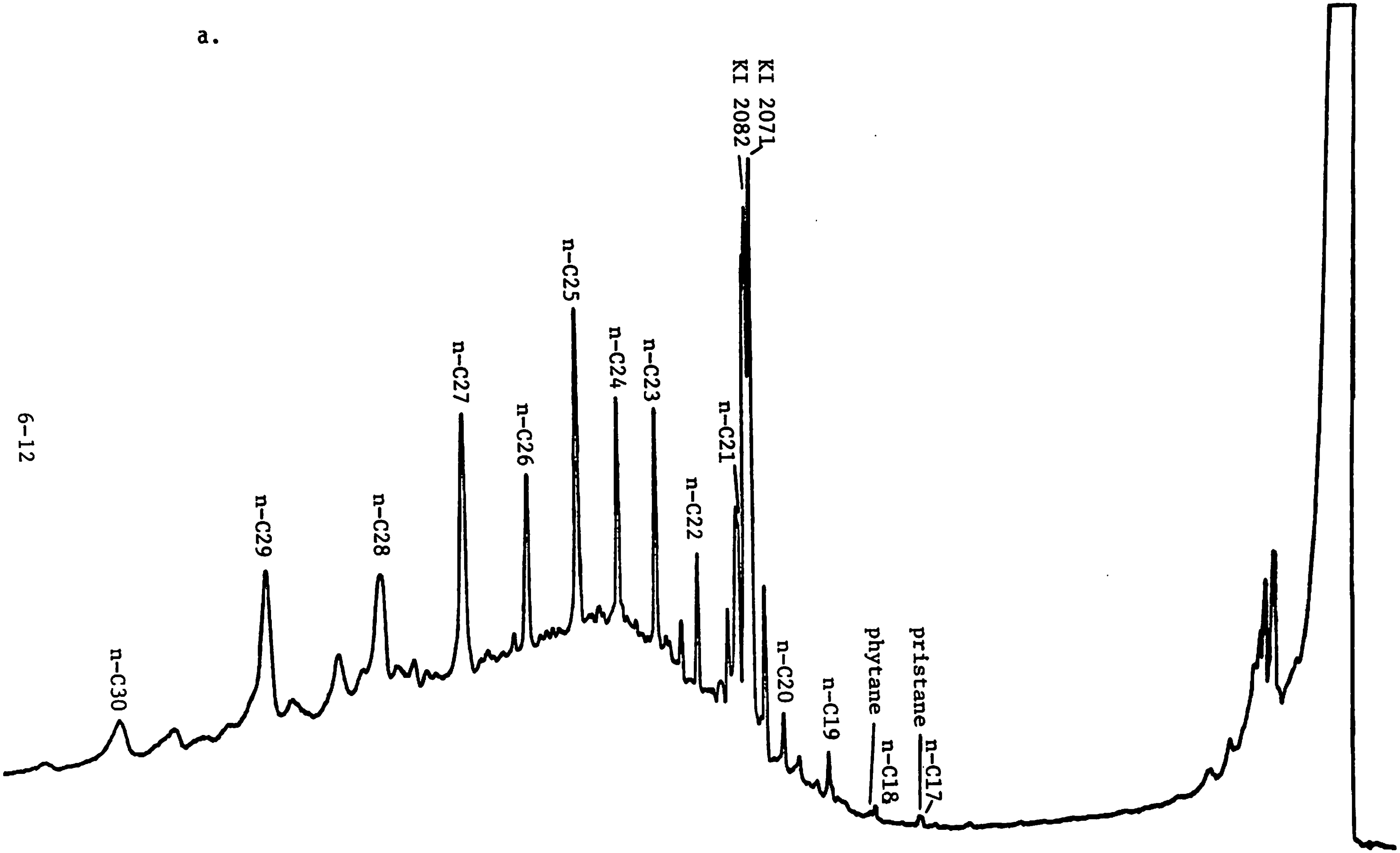

Figure 6-3. (a) Chromatogram showing presence of "triplet" and plant wax hydrocarbons in hexane fraction--station F-2, fall, 1976.

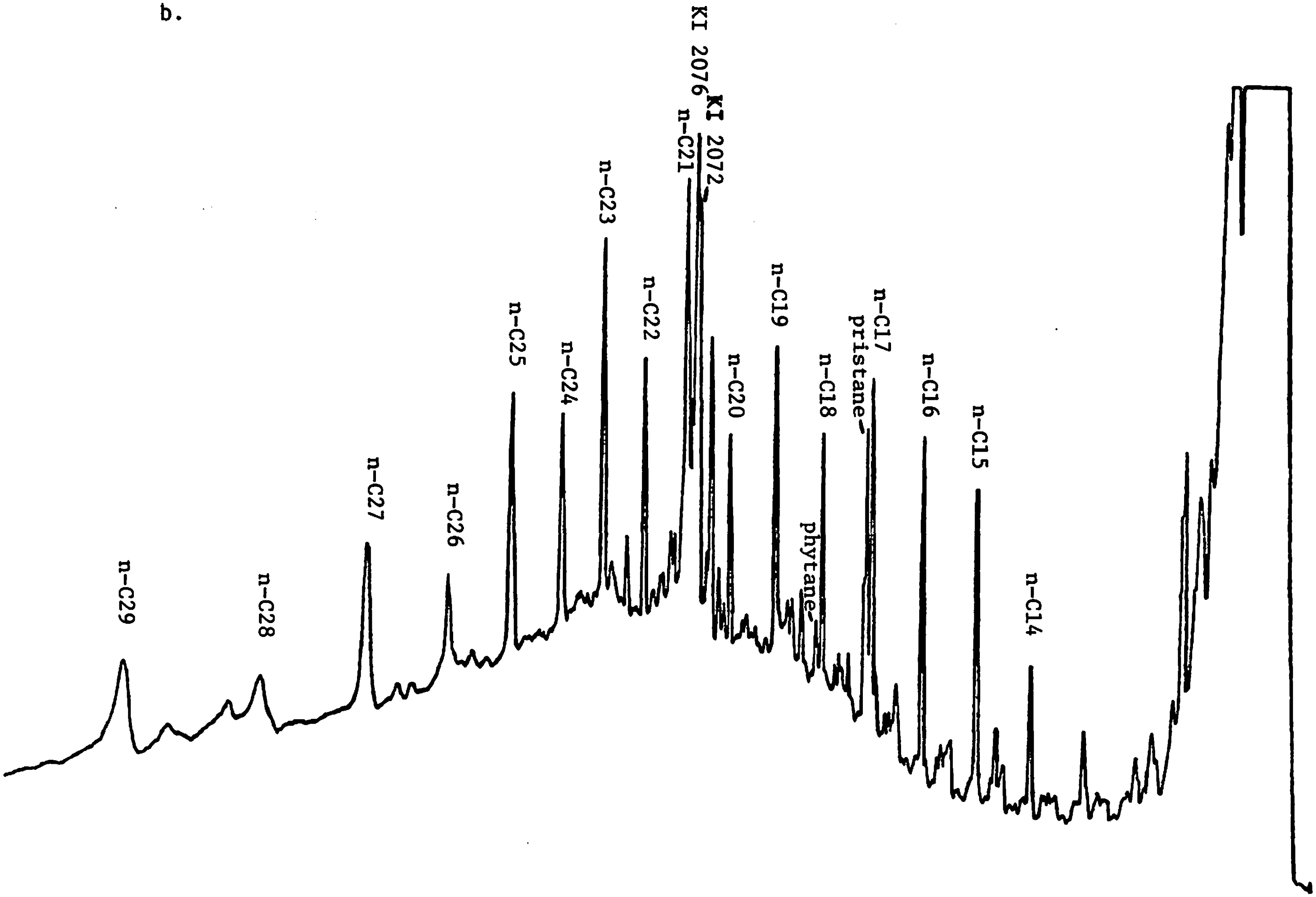

Figure 6-3. (b) Chromatogram showing presence of large "triplet" and plant wax hydrocarbons in hexane fraction--station I-3, summer, 1977.

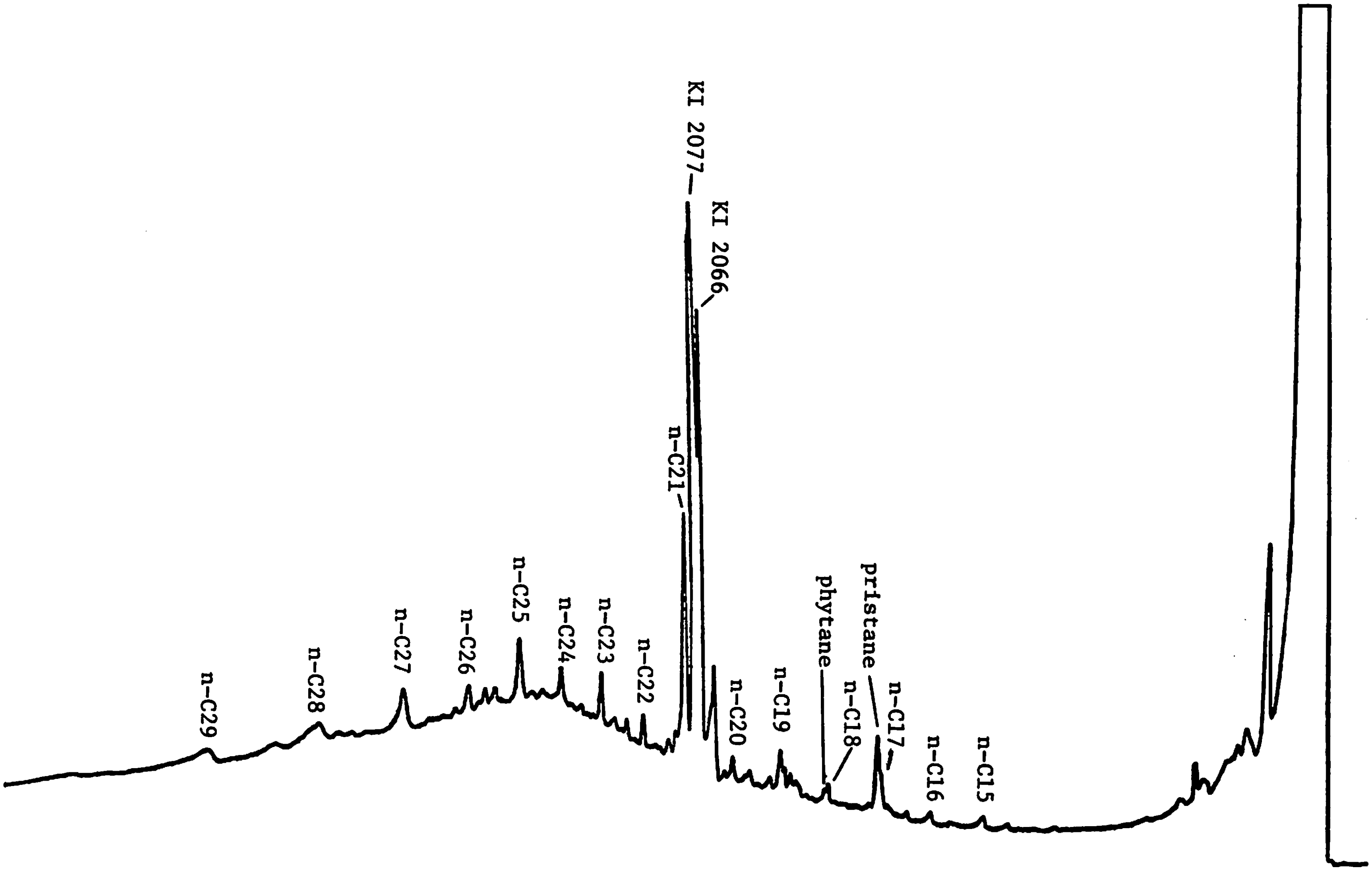

Figure 6-4. Chromatogram showing presence of "triplet" as the major component in the hexane fraction--station L-4, winter, 1976-77.

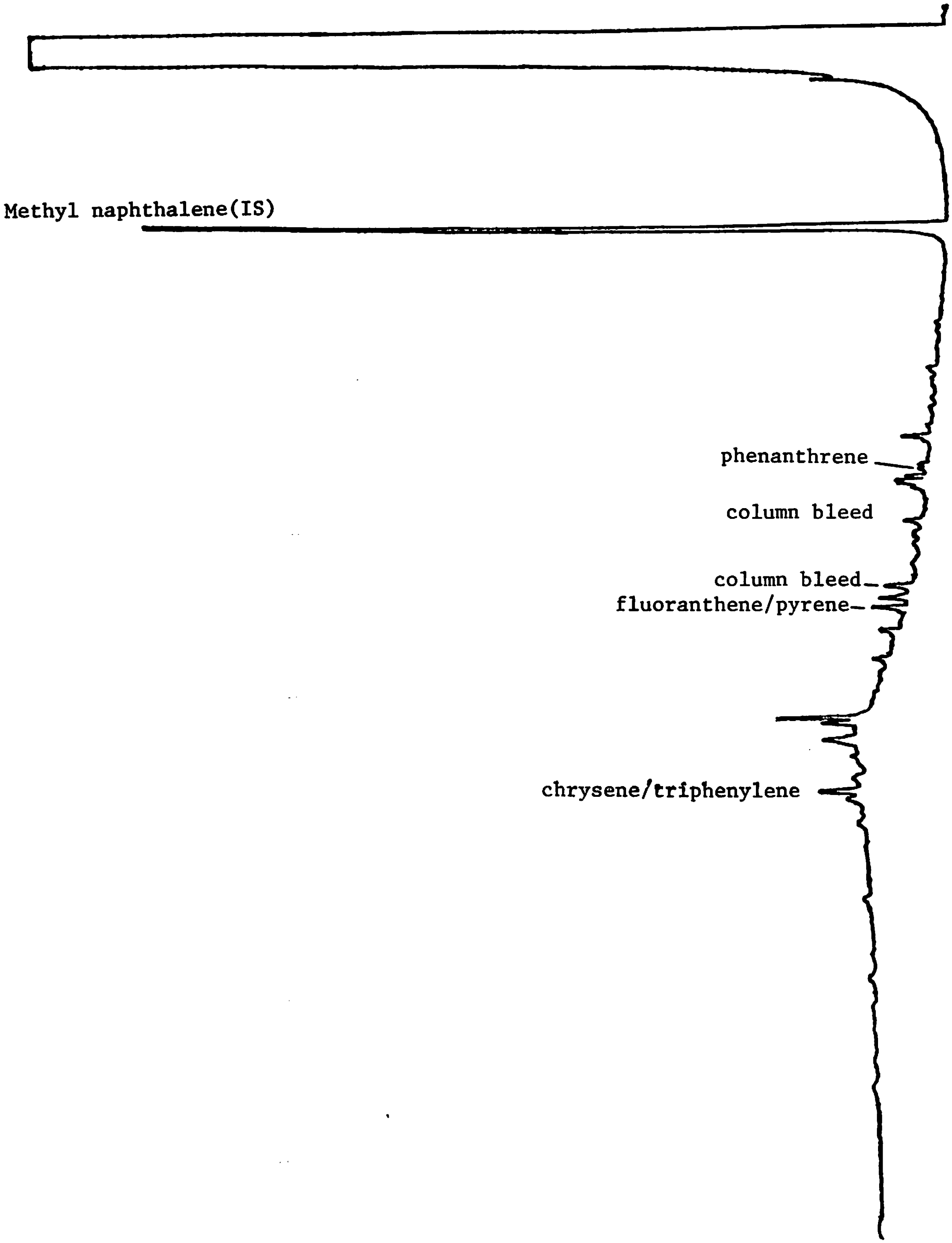

Figure 6-5. Chromatogram showing relatively low concentration benzene fraction--station B-2, spring, 1977.

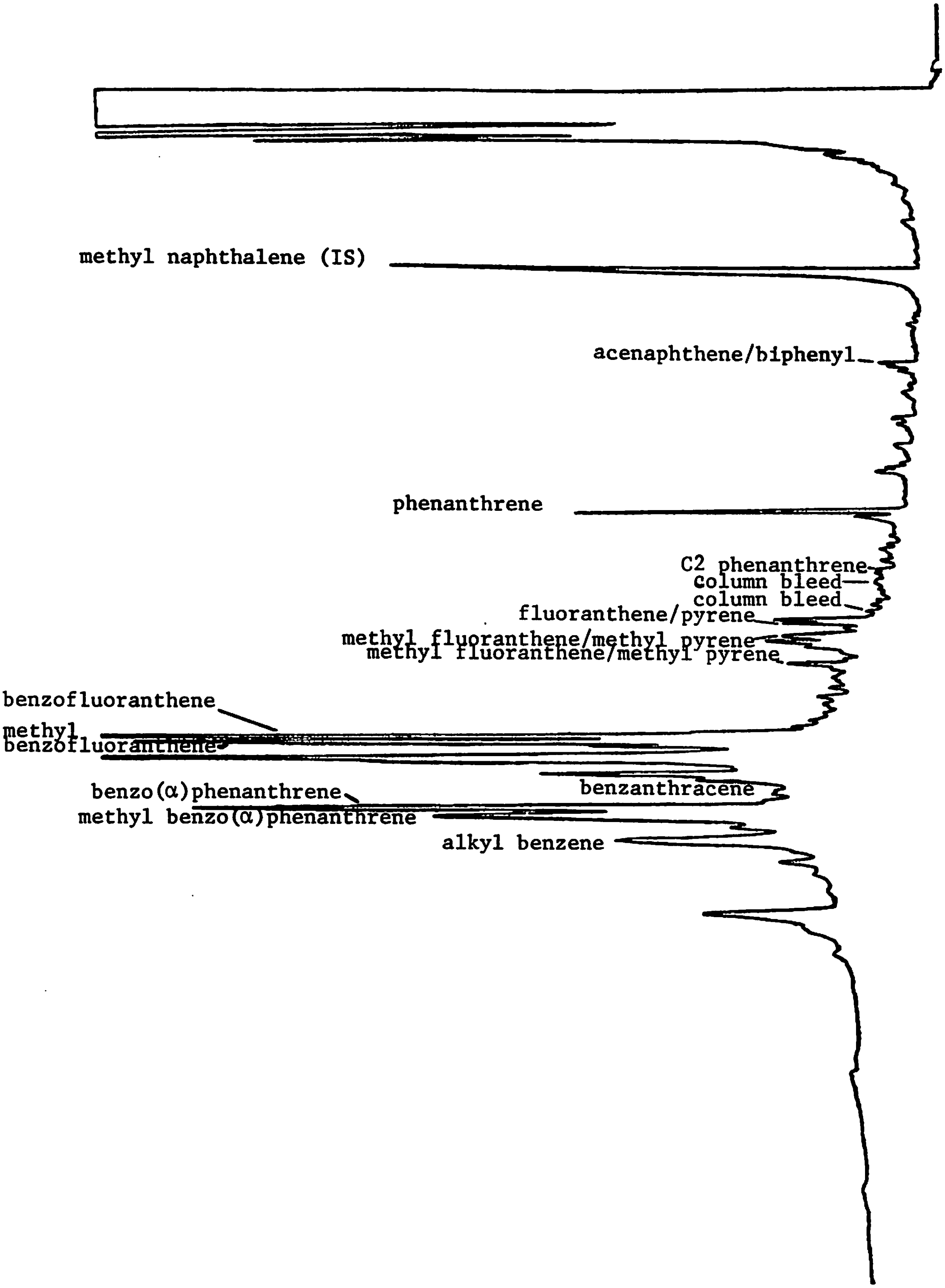

Figure 6-6. Chromatogram showing relatively high concentration benzene fraction—station D-4, summer, 1977.

Table 6-2. Summary of hydrocarbon analysis of composite sediment samples - USGS from Mid-Atlantic Shelf, 1976-1977. Fall, 1976.

Sample Stations	µg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid $\frac{\text{alkane}}{n\text{-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	µg/g sed Benzene resolved	Total extractables recovered (mg/g)
A-1	0.2435	3.691	0.005	0.887	0.953	1.089	0.0720	8.5577
A-2	0.3564	3.497	0.002	2.600	1.200	3.590	0.2536	8.5951
A-3	0.3822	3.541	0.009	10.140	2.340	0.053	0.0675	0.1420
A-4	0.3789	2.450	0.004	4.460	0.582	0.085	0.0533	13.5462
Average	0.3403 avg	3.295 avg	0.005 avg	4.522 avg	1.269 avg	1.204 avg	0.1116 avg	7.7103 avg
B-1	0.1944	2.636	0.002	3.670	0.446	0.258	0.1301	12.1809
B-2	0.0460	2.234	0.006	1.628	1.710	0.882	0.0131	11.3716
B-3	0.2549	3.455	0.004	0.926	0.798	0.604	0.0741	9.4078
B-4	0.0567	1.894	0.267	7.959	2.116	0.257	0.0119	0.3837
Average	0.1380 avg	2.555 avg	0.070 avg	3.546 avg	1.268 avg	0.500 avg	0.0573 avg	8.3360 avg
C-2	0.0583	2.408	0.006	0.950	0.660	0.942	0.0788	14.0118
C-4	1.1542	4.794	0.013	3.215	1.089	2.181	2.2080	9.9733
Average	0.6063 avg	3.601 avg	0.010 avg	2.083 avg	0.875 avg	1.562 avg	1.1434 avg	11.9926 avg
D-1	0.0382	1.736	0.004	1.060	0.240	1.200	0.0028	14.4791
D-4	0.3339	2.920	0.005	1.475	0.543	0.480	0.7430	13.7446
Average	0.1861 avg	2.328 avg	0.005 avg	1.268 avg	0.392 avg	0.840 avg	0.3729 avg	14.1119 avg
E-1	0.0704	1.632	0.001	0.315	0.142	0.793	0.0484	11.0868
E-2	0.0793	2.267	0.007	7.318	0.513	0.175	0.0077	9.8396
E-3	0.0459	3.060	0.048	12.300	7.479	0.526	0.0033	7.8888
E-4	0.0937	5.126	0.005	1.557	0.844	0.574	0.7332	6.7320
Average	0.0724 avg	3.021 avg	0.015 avg	5.373 avg	2.245 avg	0.517 avg	0.1982 avg	8.8868 avg
F-1	0.1228	1.825	0.007	1.079	0.388	0.600	0.0032	3.8197
F-2	0.2153	2.471	0.003	1.176	0.603	0.962	0.0087	12.3378
F-3	0.2013	2.731	0.004	0.836	0.707	1.032	0.0329	26.9488
F-4	0.2717	2.271	0.005	8.163	1.378	0.228	0.1475	14.0364
Average	0.2028 avg	2.325 avg	0.005 avg	2.814 avg	0.769 avg	0.706	0.0481 avg	14.2857 avg
Avg. for 20 cluster stations	Σ4.5983	Σ56.639	Σ0.407	Σ71.714	Σ24.731	Σ16.511	Σ4.6931	Σ209.0837
	0.2299 avg	2.832 avg	0.020 avg	3.586 avg	1.237 avg	0.826 avg	0.2347 avg	10.4542 avg

Table 6-3. Summary of hydrocarbon analysis of composite sediment samples - USGS from Mid-Atlantic Shelf, 1976-1977. Winter, 1976.

Sample Stations	µg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid $\frac{\text{alkane}}{\text{n-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	µg/g sed Benzene resolved	Total extractables recovered (mg/g)
A-1	0.7477	5.131	0.042	3.794	0.772	0.111	0.1326	5.3157
A-2	0.6990	5.787	0.027	6.270	0.491	0.107	0.0966	8.2976
A-3	0.4837	4.862	0.018	5.204	0.439	0.069	0.0585	7.0303
A-4	0.3469	4.777	0.022	6.330	0.437	0.057	0.0443	6.5177
Average	0.5693 avg	5.139 avg	0.027 avg	5.400 avg	0.535 avg	0.086 avg	0.0830 avg	6.7902 avg
B-1	0.2016	5.878	0.039	3.223	0.469	0.313	0.1329	6.9005
B-2	0.0902	3.905	0.061	3.623	0.947	0.505	0.0180	5.4813
B-3	0.4470	4.951	0.036	10.872	0.821	0.150	0.0997	6.3890
B-4	0.0328	2.175	0.047	1.850	0.403	2.168	0.0044	5.9802
Average	0.1929 avg	4.227 avg	0.046 avg	4.892 avg	0.660 avg	0.784 avg	0.0737 avg	6.1888 avg
C-2	0.0600	3.534	0.065	4.900	0.395	0.366	0.0155	5.2000
C-4	0.6141	4.151	0.022	4.954	0.824	0.524	0.8877	8.3184
Average	0.3371 avg	3.843 avg	0.044 avg	4.927 avg	0.610 avg	0.455 avg	0.4516 avg	6.7592 avg
D-1	0.0866	1.626	0.077	2.165	0.564	0.709	0.0110	4.6626
D-4	0.5196	6.611	0.041	8.299	0.739	0.317	0.7501	7.9122
Average	0.3031 avg	4.119 avg	0.059 avg	5.232 avg	0.652 avg	0.513 avg	0.3806 avg	6.2874 avg
E-1	0.0580	3.536	0.109	2.110	0.448	0.592	0.0066	6.3938
E-2	0.3158	6.446	0.034	4.351	1.077	0.327	0.1129	5.7530
E-3	0.0846	3.078	0.045	2.869	1.618	0.434	0.0177	6.8847
E-4	0.2563	6.199	0.035	5.219	0.596	0.676	0.0496	4.8656
Average	0.1787 avg	4.815 avg	0.056 avg	3.637 avg	0.935 avg	0.507 avg	0.0467 avg	5.9743 avg
F-1	3.9967	1.318	0.000	2.221	1.730	1.898	0.0022	5.8018
F-2	0.2863	3.075	0.035	4.838	1.615	0.733	0.0230	6.8433
F-3	3.6620	1.738	0.010	5.209	4.101	1.451	0.0174	8.0678
F-4	0.4629	3.319	0.023	3.316	1.042	0.520	0.1904	0.1432
Average	2.1020 avg	2.363 avg	0.017 avg	3.896 avg	2.122 avg	1.151 avg	0.0633 avg	5.2140 avg
Avg. for 20 cluster stations	Σ13.4518	Σ82.097	Σ0.788	Σ91.617	Σ19.528	Σ12.027	Σ2.7307	Σ 122.7580
	0.6726 avg	4.105 avg	0.039 avg	4.581 avg	0.976 avg	0.601 avg	0.1365 avg	6.1379 avg

(continued)

Table 6-3. (Concluded).

Sample Stations	µg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	$\frac{\text{Isoprenoid alkane}}{\text{n-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	µg/g sed Benzene resolved	Total extractables recovered (mg/g)
G-2	0.2626	5.636	0.005	8.582	0.864	0.448	0.0760	4.2552
G-3	0.8868	6.282	0.041	1.347	1.028	0.380	0.1455	4.2287
G-5	0.7039	6.056	0.014	2.841	1.433	0.491	0.0233	5.5963
G-6	0.4811	7.000	0.039	5.753	1.216	0.363	0.1940	7.1766
Average	0.4852 avg	5.943	0.022 avg	4.401 avg	1.154 avg	0.551 avg	0.0888 avg	5.1913 avg
H-1	1.2107	2.730	0.022	5.618	0.930	0.279	0.1000	0.1941
H-2	1.2306	4.816	0.013	7.776	0.319	0.097	0.1887	11.9356
Average	1.2207 avg	3.773 avg	0.018 avg	6.697 avg	0.625 avg	0.188 avg	0.1444 avg	6.0649
I-1	1.3661	12.416	0.019	0.794	0.523	0.422	0.0612	3.3915
I-2	0.1226	1.808	0.047	7.065	0.577	0.458	0.0073	4.8374
I-3	0.6571	3.553	0.046	6.125	0.795	0.216	0.0600	5.8921
I-4	1.2540	7.393	0.017	7.337	0.464	0.071	0.5102	16.5157
Average	0.8500 avg	6.293 avg	0.032 avg	5.330 avg	0.590 avg	0.292 avg	0.1597 avg	7.6592 avg
J-1	1.1189	7.955	0.014	2.794	0.247	0.316	0.5230	9.6559
J-2	2.4127	11.839	0.016	2.461	0.527	0.354	0.8000	17.6677
Average	1.7658 avg	9.897 avg	0.015 avg	2.628 avg	0.387 avg	0.335 avg	0.6615 avg	13.6618 avg
K-2	0.0620	3.481	0.030	0.582	0.123	0.665	0.0120	5.5835
K-4	0.5891	4.974	0.022	4.648	1.719	0.354	0.1203	11.1136
K-5	0.3127	3.472	0.045	8.381	2.072	0.266	0.0220	8.1150
K-6	0.6600	4.051	0.016	7.156	0.227	0.247	0.0899	8.7548
Average	1.6238 avg	3.995 avg	0.028 avg	5.192 avg	1.035 avg	0.383 avg	0.0611 avg	8.3917 avg
L-2	0.4187	3.102	0.053	4.323	0.975	0.906	0.1444	9.2853
L-4	0.2064	4.126	0.059	5.914	1.199	0.692	0.0311	5.6830
L-5	1.2267	3.769	0.036	2.167	0.458	0.437	0.6920	4.9956
L-6	0.9061	2.799	0.043	3.739	0.664	0.270	0.1320	4.9765
Average	2.7579 avg	3.449 avg	0.048 avg	4.036 avg	0.824 avg	0.576 avg	0.2499 avg	6.2351 avg
Avg. for 21 transect stations	Σ 16.1804 0.7705 avg	Σ 112.000 5.333 avg	Σ 0.610 0.029 avg	Σ98.885 4.709 avg	Σ17.590 0.838 avg	Σ8.807 0.419 avg	Σ3.9381 0.1875 avg	Σ154.5539 7.3597 avg
Average for 41 stations	0.7227	4.734	0.034	4.646	0.905	0.508	Σ6.6688 0.1627 avg	Σ277.312 6.7637 avg

Table 6-4. Summary of hydrocarbon analysis of composite sediment samples - USGS from Mid-Atlantic Shelf, 1976-1977. Spring, 1977.

Sample Stations	µg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid $\frac{\text{alkane}}{\text{n-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	µg/g sed Benzene resolved	Total extractables recovered (mg/g)
A-1	0.8057	3.775	0.049	6.886	1.719	0.447	0.0855	0.3564
A-2	2.8529	1.883	0.045	7.418	1.178	0.236	0.0342	0.1735
A-3	1.0300	2.807	0.048	7.921	1.572	0.276	0.0385	0.5192
A-4	0.4338	1.956	0.069	13.859	2.001	0.241	0.1010	0.3183
Average	1.2806 avg	2.605 avg	0.053 avg	9.021 avg	1.618 avg	0.300 avg	0.0656 avg	0.3419 avg
B-1	0.3601	6.440	0.038	4.358	1.492	0.556	0.0997	0.1693
B-2	0.0875	5.894	0.070	5.259	1.457	0.608	0.0112	0.1844
B-3	0.5976	6.504	0.022	5.384	1.694	0.481	0.0744	0.1716
B-4	0.0200	4.788	0.083	3.330	0.763	0.259	0.0660	0.0594
Average	0.2663 avg	5.907 avg	0.053 avg	4.583 avg	1.352 avg	0.476 avg	0.0628 avg	0.1462 avg
C-2	0.1175	1.982	0.050	3.244	0.715	0.686	0.0665	0.1824
C-4	2.3119	5.397	0.020	2.837	1.282	0.653	0.8409	0.6711
Average	1.2147 avg	3.690 avg	0.035 avg	3.041 avg	0.999 avg	0.670 avg	0.537 avg	0.4268 avg
D-1	0.1464	1.434	0.053	6.943	1.245	0.477	0.0321	0.2267
D-4	0.5084	5.876	0.023	6.365	0.847	0.175	0.3947	0.3128
Average	0.3274 avg	3.655 avg	0.038 avg	6.654 avg	1.046 avg	0.326 avg	0.2134 avg	0.2698 avg
E-1	0.1924	6.850	0.056	7.844	1.673	0.432	0.0298	0.0667
E-2	0.3517	6.241	0.064	3.273	1.749	0.983	0.0361	0.2208
E-3	0.1830	2.568	0.155	0.760	0.739	2.216	0.0253	0.3061
E-4	0.4842	6.550	0.062	2.861	1.364	0.966	0.0591	0.1827
Average	0.3053 avg	5.553 avg	0.084 avg	3.685 avg	1.381 avg	1.149 avg	0.0376 avg	0.1941 avg
F-1	0.1149	5.404	0.070	3.613	1.073	0.483	0.0107	0.0520
F-2	0.2548	6.028	0.077	6.858	2.597	0.556	0.0371	0.1219
F-3	0.4714	4.092	0.066	10.184	2.155	0.353	0.0275	0.0465
F-4	0.2964	6.146	0.110	12.104	2.892	0.463	0.0224	0.1658
Average	0.2844 avg	5.418 avg	0.081 avg	8.190 avg	2.179 avg	0.464 avg	0.0244 avg	0.0966 avg
Avg. for 20 cluster stations	Σ11.6206	Σ92.615	Σ1.230	Σ121.301	Σ30.207	Σ11.547	Σ2.0957	Σ4.5076
	0.5810 avg	4.631 avg	0.062 avg	6.065 avg	1.510 avg	0.577 avg	0.1048 avg	0.2254 avg

Table 6-5. Summary of hydrocarbon analysis of composite sediment samples - USGS from Mid-Atlantic Shelf, 1976-1977. Summer, 1977.

Sample Stations	µg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid $\frac{\text{alkane}}{\text{n-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	µg/g sed Benzene resolved	Total extractables recovered (mg/g)
A-1	0.5065	2.747	0.076	19.644	1.564	0.126	0.1873	0.2118
A-2	0.8595	3.017	0.073	1.884	1.257	0.692	0.1565	0.2833
A-3	0.2994	1.773	0.059	14.348	1.198	0.116	0.0981	0.1376
A-4	0.4156	3.758	0.047	8.869	1.031	0.180	0.1309	0.0788
Average	0.5203 avg	2.824 avg	0.064 avg	11.141 avg	1.263 avg	0.279 avg	0.1432 avg	0.1779 avg
B-1	0.1433	12.790	0.089	4.308	1.056	0.496	0.0887	0.0527
B-2	0.0616	2.484	0.130	19.976	1.758	0.193	0.0129	0.0413
B-3	0.4060	5.517	0.039	13.636	1.471	0.203	0.1337	0.1133
B-4	0.0784	3.878	0.073	9.739	1.073	0.280	0.0163	0.3926
Average	0.1723 avg	6.167 avg	0.083 avg	11.915 avg	1.340 avg	0.293 avg	0.0629 avg	0.1500 avg
C-2	0.1188	2.489	0.042	3.932	0.391	1.015	0.0500	0.3205
C-4	0.3118	5.367	0.043	3.509	1.328	0.767	1.0935	0.6194
Average	0.2153 avg	3.928 avg	0.043 avg	3.721 avg	0.860 avg	0.891 avg	0.5718 avg	0.4700 avg
D-1	0.0339	3.625	0.095	4.061	0.783	0.518	0.0369	0.1665
D-4	0.2080	3.660	0.058	13.951	0.960	0.140	0.2183	0.2471
Average	0.1210 avg	3.643 avg	0.077 avg	9.006 avg	0.872 avg	0.329 avg	0.1276 avg	0.2068 avg
E-1	0.0767	2.471	0.185	8.187	2.336	0.520	0.0116	0.3846
E-2	0.3401	3.457	0.042	4.759	1.247	0.366	0.1165	0.1403
E-3	0.0583	2.457	0.249	14.237	2.499	0.436	0.0209	0.3706
E-4	0.4845	6.722	0.081	10.705	2.642	0.414	0.0623	0.0729
Average	0.2399 avg	3.777 avg	0.139 avg	9.472 avg	2.181 avg	0.434 avg	0.0528 avg	0.2421 avg
F-1	0.0788	3.055	0.091	5.842	1.109	0.354	0.0175	0.3755
F-2	0.2825	2.857	0.148	18.585	4.387	0.418	0.0410	0.0260
F-3	0.2687	2.524	0.048	8.089	1.126	0.276	0.0460	0.0920
F-4	0.2542	1.593	0.019	10.520	1.324	0.222	0.0576	0.0720
Average	0.2211 avg	2.507 avg	0.077 avg	10.759 avg	1.987 avg	0.318 avg	0.0405 avg	0.1414 avg
Avg. for 20 cluster stations	Σ = 5.2866	Σ = 76.239	Σ = 1.687	Σ = 198.601	Σ = 30.540	Σ = 7.732	Σ = 2.5965	Σ = 4.1988
	AV=0.2643	AV=3.812	AV=0.084	AV=9.930	AV=1.527	AV=0.387	AV=0.1298	AV=0.2099

(continued)

Table 6-5. (Concluded)

Sample Stations	μg/g sed resolved n-alkane (Hexane)	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid $\frac{\text{alkane}}{\text{n-alkane}}$	$\frac{\text{Pristane}}{\text{Phytane}}$	$\frac{\text{Pristane}}{n\text{-}C_{17}}$	$\frac{\text{Phytane}}{n\text{-}C_{18}}$	μg/g sed Benzene resolved	Total extractables recovered (mg/g)
G-2	0.2048	6.418	0.020	13.017	0.843	0.234	0.0400	0.2578
G-3	0.5391	5.421	0.038	5.345	1.478	0.183	0.1987	0.1512
G-4	0.0795	2.402	0.158	25.809	2.114	0.198	0.0216	0.0273
G-5	0.1707	5.455	0.130	38.058	5.209	0.278	0.1241	0.1553
G-6	0.5497	2.183	0.084	27.814	2.240	0.173	0.1024	0.2530
Average	0.3088 avg	4.376 avg	0.086 avg	22.009 avg	2.377 avg	0.213 avg	0.974 avg	0.1689 avg
H-1	0.4130	2.834	0.072	1.203	0.748	10.587	0.0645	0.1178
Average	0.6241 avg	3.644 avg	0.050 avg	3.551 avg	0.649 avg	5.368 avg	0.1366 avg	0.1572 avg
I-1	0.2913	3.321	0.060	4.289	1.530	0.468	0.1110	0.0837
I-2	0.1859	3.880	0.120	19.554	2.739	0.273	0.0285	0.0797
I-3	0.2508	1.778	0.078	10.536	1.135	0.133	0.1037	0.3756
I-4	0.7108	4.496	0.075	7.977	0.924	0.201	0.2872	0.2464
Average	0.3597 avg	3.369 avg	0.083 avg	10.589 avg	1.582 avg	0.269 avg	0.1326 avg	0.1964 avg
J-1	0.3718	2.894	0.048	7.333	0.879	0.218	0.1651	0.1642
J-2	1.8569	2.927	0.025	8.316	0.699	0.143	0.3905	0.6663
Average	1.1144 avg	2.911 avg	0.037 avg	7.825 avg	0.789 avg	0.181 avg	0.2778 avg	0.4153 avg
K-2	0.1199	3.075	0.096	7.554	1.708	0.537	0.0213	0.0494
K-4	0.7300	6.198	0.206	41.752	5.627	0.287	0.1050	0.1772
K-5	0.3450	4.207	0.034	6.339	0.764	0.231	0.0455	0.4319
K-6	0.7558	6.543	0.031	6.621	0.572	0.206	0.1300	0.1030
Average	0.4877 avg	5.006 avg	0.092 avg	5.567 avg	2.168 avg	0.315 avg	0.0755 avg	0.1904 avg
L-2	0.1953	0.675	0.048	13.345	1.067	0.299	0.0829	0.0618
L-4	0.1626	2.499	0.107	20.934	2.178	0.313	0.0332	0.0608
L-5	1.0806	3.193	0.063	2.145	0.309	0.346	0.3040	0.1365
L-6	0.7372	4.448	0.047	7.200	0.775	0.148	0.2129	0.0957
Average	0.5439 avg	2.704 avg	0.066 avg	10.906 avg	1.082 avg	0.277 avg	0.1583 avg	0.0887 avg
Avg. for 21 transect stations	Σ= 10.5859 AV=0.5041	Σ= 82.005 AV=3.905	Σ= 1.568 AV=0.075	Σ= 280.740 AV=13.369	Σ= 34.087 AV=1.623	Σ= 15.304 AV=0.729	Σ= 2.7808 AV=0.1324	Σ= 3.8911 AV=0.1853
Average for 41 stations	Σ= 15.8725 AV=0.3871	Σ= 158.244 AV=3.859	Σ= 3.255 AV=0.079	Σ= 479.341 AV=11.691	Σ= 64 627 AV=1.576	Σ= 23.036 AV=0.562	Σ= 5.377 AV=0.131	Σ= 8.0899 AV=0.1973

Table 6-6. Summary of hydrocarbon analysis of composite sediment samples - USGS from Mid-Atlantic Shelf, 1976-1977

Intercal-bration Number	Resolved n-alkane (Hexane) µg/g sed	n-alkane odd/even ratio $\frac{n\text{-}C_{23} - C_{29}}{n\text{-}C_{24} - C_{30}}$	Isoprenoid alkane / n-alkane	Pristane / Phytane	Pristane / n-C_{17}	Phytane / n-C_{18}	Resolved Benzene µg/g sed	Total extractables recovered (mg/g)
				FALL				
1	0.6265	3.848	0.025	8.367	0.493	0.146	0.0825	7.8775
2	0.0885	2.205	0.030	7.160	0.503	0.189	0.0041	6.9877
3	0.0823	4.137	0.144	4.857	0.590	0.174	0.0082	6.0235
4	0.2081	4.673	0.032	5.127	0.626	0.292	0.0079	9.6045
Average	0.2514 avg	3.716 avg	0.058 avg	6.378 avg	0.553 avg	0.200 avg	0.0257 avg	7.6233 avg
				WINTER				
1	0.0682	3.242	0.066	7.123	0.697	0.070	0.0022	4.1278
2	0.3425	4.169	0.049	6.263	1.004	0.348	0.0566	0.3709
3	0.4245	3.905	0.017	4.751	0.867	0.149	0.1847	7.3174
4	0.2681	2.542	0.013	8.246	0.557	0.056	0.0530	5.3498
Average	0.2758 avg	3.465 avg	0.036 avg	6.596 avg	0.781	0.156 avg	0.0741 avg	4.2915 avg
				SPRING				
1	0.0435	3.147	0.078	4.040	0.658	0.364	0.0145	0.0850
2	0.5136	13.720	0.066	2.786	1.588	1.623	0.7904	0.7317
3	0.5919	6.760	0.022	6.404	0.947	0.216	0.0719	0.2742
4	0.3898	6.020	0.124	0.250	1.175	5.664	0.0369	0.3193
Average	0.3847 avg	7.412 avg	0.073 avg	3.370 avg	1.092 avg	1.967 avg	0.2284 avg	0.3526 avg
				SUMMER				
1	0.8831	2.863	0.073	2.510	0.320	0.307	0.2185	0.1413
2	0.8176	3.536	0.056	13.931	0.986	0.114	0.2567	0.0914
3	0.0575	4.655	0.111	121.655	2.854	0.068	0.0257	0.0618
4	0.3197	2.855	0.040	4.797	0.818	0.316	0.0428	0.1406
Average	0.5195	3.477 avg	0.070 avg	35.723 avg	1.245 avg	0.201 avg	0.1359 avg	0.1088 avg
Average of 16 samples	Σ= 5.7254 AV=0.3578	Σ= 72.277 AV=4.517	Σ= 0.946 AV=0.059	Σ= 208.267 AV=13.017	Σ= 14.683 AV=0.918	Σ= 10.096 AV=0.631	Σ= 1.8566 AV=0.1160	Σ= 49.5044 AV=3.0940

itself as a triplet with Kovat's indices ranging from 2074 to 2095. By using the diagnostic fragments (276, 348, 319, 320, 289) unsaturation was established for a C_{25} hydrocarbon with a molecular weight of 348 for the peak with Kovat's index of 2086. The peak at Kovat's index 2074 had fragments (55, 57, 237, 264, 348) also indicating an unsaturated C_{25}. At Kovat's index of 2095, the third peak of the triplet had diagnostic fragments of 93, 107, 121, 135, 149, 231, 247, 259, and 344. Interpretation and the biogeochemical significance of the C_{25} structure is still open to question, although it may be related to metabolic diagenesis.

A similar series of hydrocarbons with nearly identical Kovat's indices, similar molecular weight, and degree of unsaturation, have been reported in sediments from the northeast Gulf of Mexico (Gearing et al. 1976; J. Farrington, personal communication, 1977; and George Harvey, personal communication, 1977). Control blanks run during the sample processing, and comparison of hexane eluates from the ship's fuels, greases, hydraulic fluids and bilge waters have verified that these compounds are not contaminants from either the laboratory or ship.

The resolved aliphatic hydrocarbon concentrations, aliphatic odd/even ratio, pristane/phytane ratio, pristane n-C_{17}, and phytane/n-C_{18} ratios, for the fall through summer sampling periods at each of the cluster stations A-F, suggest a predominantly biogenic source for the aliphatic hydrocarbons (Tables 6-2 through 6-5). In this current year's study (1976-1977), the average resolved aliphatic concentrations varies from 0.23 µg/g (Fall) to 0.67 µg/g (Winter), and 0.58 µg/g (Spring) to 0.26 µg/g (Summer). The concentration levels for the total resolved aliphatic fractions are very low, less than 1.0 µg/g, but compare very well with the aliphatic concentrations reported from the same cluster stations of the first year studies. The average resolved aliphatic hydrocarbon concentrations from the 1975-1976 first year study of the A-F cluster stations were: 0.84 µg/g (Fall), 0.92 µg/g (Winter), 0.25 µg/g (Spring), and 0.28 µg/g (Summer) (Miller and Schultz 1977).

Figure 6-7 shows a plot of the total resolved aliphatic, and total resolved aromatic hydrocarbons (average values for all the cluster stations µg/g) as a function of each of the biological seasons (Fall, Winter, Spring and Summer) for the sampling years 1975-1976 and 1976-1977. In addition, the Standard Deviation for each sampling point is shown by the solid line. A reasonable interpretation of the natural variability curve for the resolved aliphatic and aromatic hydrocarbons requires that consideration must be given to: 1) the low concentration levels of aliphatic and aromatics, 2) the probability that the concentration level variation between the sampling years may be greater than the variation between sampling seasons, 3) that if seasonal changes occur, it occurs with relatively equal effect at each of the cluster station areas, 4) that geographic variability is small,

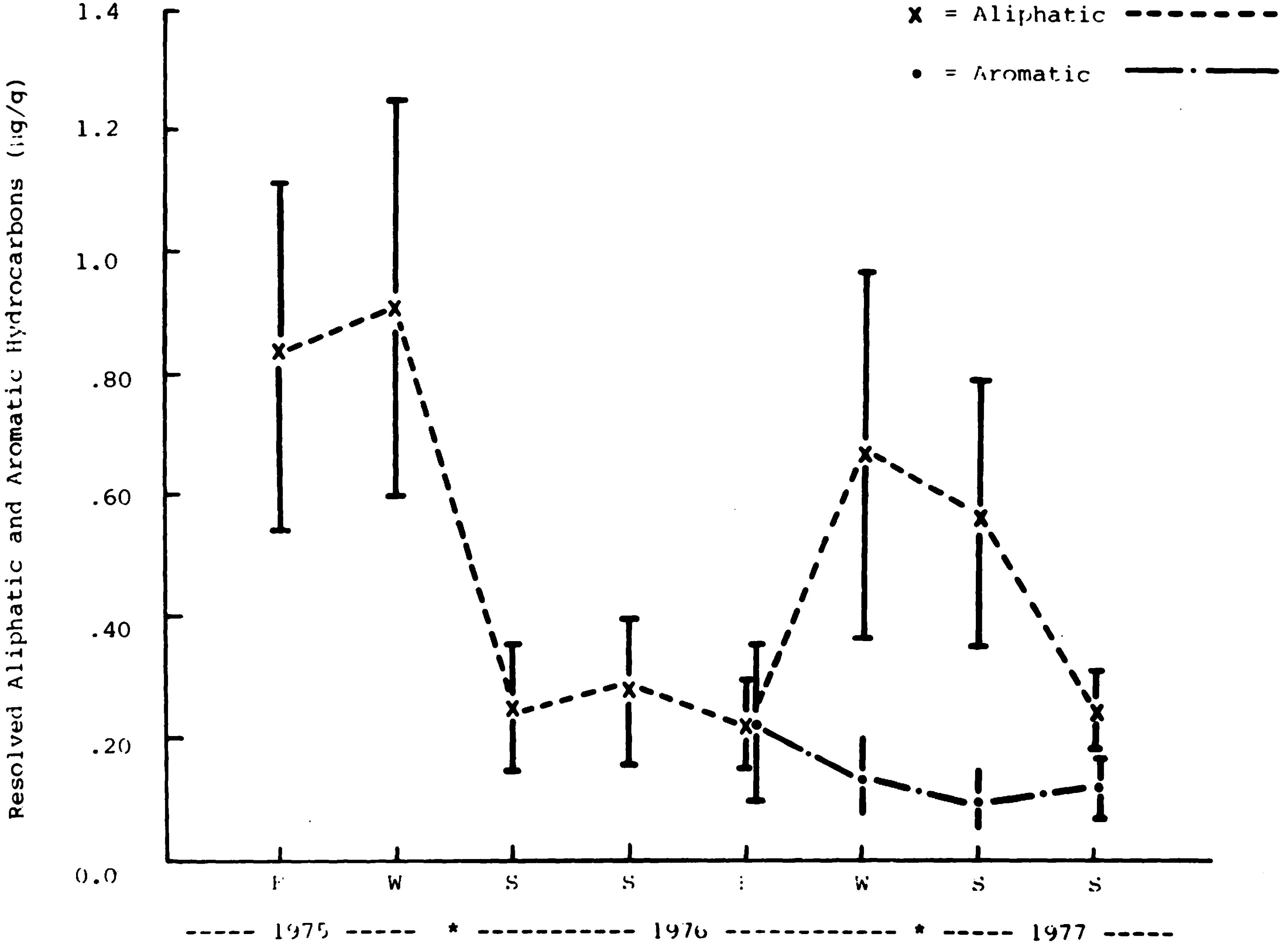

Figure 6-7. Sampling seasons Mid-Atlantic shelf.

and that the variability between individual stations in a cluster area is greater than variability between cluster areas (Smith et al. 1977), 5) caution must be exercised not to over-extend the statistical data treatment, and over interpretation for the natural variability with essentially two mean year data points representing the cluster stations, A, B, C, D, E, and F, for each biological sampling season. The cyclic nature of the resolved aliphatic data suggests that a trend exists in the concentrations of resolved aliphatic fractions that may be related to the biological sampling seasons, and may possibly be similar in principle to the phosphate:nitrate nutrient cycles where the maximum values occur during the winter and lowest values during the summer. A similar general trend is observed in the resolved aliphatic hydrocarbons, where the maximum concentrations occur in the Winter and minimum values in the late Summer-Fall. Many geochemical and geological factors can influence this cycle. The most important parameters are believed to be: a) bottom sediment transport processes acting to redistribute the sediment hydrocarbons; b) chemical and biological (including microbial) degradation of hydrocarbons in situ; c) residence time of the hydrocarbons in the water column as well as the influence of temperature, salinity and pressure gradients on settling rates of particulates carrying sorbed hydrocarbons; d) the interactions of humic and fulvic substances with hydrocarbons; e) anthropogenic sources as shipping traffic, sewage effluent, dumping, airborne particulates; f) phyto- and zooplankton seasonal blooms; g) changes in shelf-slope circulation patterns; h) sediment size and clay mineral composition; i) shelf-slope bottom topography. To indicate that one or two of these parameters are dominant would clearly be premature and an oversimplification of the mechanism controlling the natural hydrocarbon variability. It is entirely probable, however, that each of these factors is interactive-dependent and that it is the net result of this dynamic interaction that ultimately gives rise to the "natural variability" of the resolved aliphatic and aromatic hydrocarbons present in the mid-Atlantic surface sediments.

Previous environmental studies of polynuclear aromatics and their postulated natural and anthropogenic origin have been carried out by Geiger and Blumer (1974); Giger and Schaffner (1975); Youngblood et al. (1975) and Bieri (1977). It is known that biological organisms contain very few aromatic hydrocarbons, and where these compounds are present, they generally are simple alkyl benzenes of low concentrations. In this second year's study, Figure 6-6 shows the average total resolved aromatic hydrocarbons for the Fall, Winter, Spring and Summer, which ranged from (0.23 Fall), to (0.17 Winter), and from (0.10 Spring) to (0.13 Summer), respectively. The significance of such a small variation is, at best, difficult to assess. The aromatic concentration level appears to be essentially constant in the mid-Atlantic shelf sediments from all the cluster stations and seems to be independent of the aliphatic seasonal variation. In addition to the very low concentration, an important point is the very complex nature of the aromatic fraction composition.

The aromatic mixture was composed of phenanthrenes, methyl phenanthrenes, C^2 phenanthrenes, fluoranthene and pyrene, as well as benzo fluoranthene, methyl-benzo-fluoranthene, benzo (α) phenanthrene, benzanthracene and alkyl benzenes and in some samples traces of biphenyls. In this present study, the source and origin of the polynuclear aromatics is unknown. The polynuclear aromatics identified by gc/ms in these sediments are normally not associated with biological organism metabolism, therefore, other possible sources must be postulated. Small amounts of coal were observed in several of the sediment samples and could contribute to several of the fused ring aromatics, although this was normally not the case. Other possible sources of these polynuclear aromatic hydrocarbons at such low-levels may possibly be associated with either anthropogenic or natural air- or water-borne particulates deposited on the sediment- or air-water interface. Because of the very low levels of the polynuclear aromatics, the true environmental significance and the origin of these polynuclear aromatics, cannot be resolved without extended long term studies.

SUMMARY AND ENVIRONMENTAL IMPLICATIONS OF ANALYTICAL DATA

The second year hydrocarbon geochemistry study of the mid-Atlantic shelf has added to the first year's data base and confirmed the order of magnitude concentration levels of resolved hydrocarbons reported in the first year study. Only by establishing the "natural variability" curve for each hydrocarbon parameter determined, over a period of at least 5 sampling years, can the normal aliphatic and aromatic hydrocarbon concentration ranges for the mid-Atlantic shelf sedimentary environments be clearly established and, hence, provide a reasonable baseline or background level against which a departure due to anthropogenic inputs may be clearly defined. The following discussion section summarizes the results of the second year's hydrocarbon sampling and analyses program, and focuses on some general and specific environmental implications. Several general statements may be made concerning the hydrocarbon geochemistry of all of these mid-Atlantic shelf sediments: (1) The resolved n-alkane concentration levels are generally below 1.0 μg/g sediment for all of the stations sampled; (2) As was reported in the first year program, the resolved n-alkane fraction in many of the samples analysed contained a series of major peaks (three to four) in the n-C_{20} to n-C_{21} range that have tentatively been identified as an unsaturated, branched C_{25} with possible cyclic structure. Its significance is still unknown. It is noteworthy, however, that a similar series of peaks with nearly identical Kovat's indices (2074-2095) have been reported in the resolved n-alkane fraction of sediments from the northeast Gulf of Mexico; Gearing et al. (1976); J. Farrington, G. Harvey and P. Hatcher (personal communications, 1977) have also found these same peaks; (3) The resolved aromatic hydrocarbon concentration levels were below 1.0 μg/g sediment for almost all the stations sampled; (4) Seasonal variability was found to occur in the resolved n-alkane fractions between the Winter and Summer samples. Similar variability occurred in the pristane/n-C_{17} and pristane/phytane ratios. In contrast, the concentration level of the resolved aromatic hydrocarbons was fairly constant over the entire sampling period and showed no seasonal variation. The source of the aromatics is unknown, although an atmospheric source cannot be excluded; (5) Although present in trace levels, the signatures of petroleum or other fossil fuel n-alkane hydrocarbons, such as those found in coal, were tentatively identified in a few composite samples collected at the following stations: Winter, F-1 F-3; Summer, Intercalibration 1: (6) The most important geochemical and geological parameters that are believed to affect the natural variability of the concentration levels and distribution of hydrocarbons in these sediments are: (a) bottom sediment transport, redistributing sediment hydrocarbons, (b) chemical and biological (including microbial) degradation of hydrocarbons in situ, (c) residence time of the hydrocarbons in the water column as well as the influence of temperature, salinity, and pressure gradients on settling rates of particulates carrying sorbed hydrocarbons, (d) the interactions of humic and fulvic substances with hydrocarbons, (e) input from anthopogenic sources such as shipping traffic, sewage effluent, dumping and airborne particulates; (f) phyto- and zooplankton seasonal blooms, (g) changes in ocean circulation patterns, (h) sediment size and clay mineral composition, (i) shelf slope bottom topography. To select one or two of these parameters as being the most dominant factors would clearly be premature, and an over-simplification of the mechanism controlling the natural hydrocarbon variability. It is entirely probable, however, that each of these factors is interactive-dependent and that it is the net result of this dynamic interaction that ultimately give rise to the "natural variability" of the resolved aliphatic and aromatic hydrocarbons present in the mid-Atlantic surface sediments.

In summary, the mean concentration levels of the n-alkane in these sediments is very low, less than 1.0 µg/g sediment. Resolved aromatics were also present in very low concentration levels, also usually less than 1.0 µg/g sediment. Several stations did show a very low-level influence from possible anthropogenic hydrocarbon sources.

This second year program has established a series of data points that will lead towards the development of a natural "variability curve" for the hydrocarbon concentration levels and distribution in these selected mid-Atlantic shelf stations. Where this year's data points fall on this curve can only be assessed by comparison with data from repeated sampling over a period of 5 years.

LITERATURE CITED

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ADDENDUM 1

USGS Response to VIMS Intercalibration Report

December 14, 1977

The USGS agrees that the comparison of intercalibration results for cruises 05 and 06 demonstrates reasonably good agreement for the total resolved aliphatics, aromatics, and total extracts. The differences are reasonable in view of the extremely low concentrations and the fact that these are blended samples without a known spike concentration. Cruise 06 sample #2, total extract weight should read 0.5709, not 0.3709.

The signficance of the differences reported appear to focus more on the data reporting format for specific ratios, than on the recovered concentrations reported. Therefore, it seems reasonable that an agreement should be reached as to what specific ratios and parameters should be reported by both VIMS and the USGS.

1. The USGS agrees that the lower pristane values reported by VIMS probably are not significant because of the extremely low concentration levels encountered. A possible explanation may be in the resolution of the g.c. columns used.

2. The USGS does not consider the reporting of the normal/branched alkane ratio as absolutely essential, but rather included this ratio as part of the Survey's response to the USGS M.O.U. with BLM. The USGS did not assume all the peaks which were not n-alkanes, pristane, or phytane were branched, but rather defined them as such in the context of the BLM requirement. This particular ratio is not really significant in terms of petroleum pollution and could easily be deleted without loss of information significant to the program.

3. The USGS defined, not assumed, that the isoprenoids phytane and pristane would represent the isoprenoid part of the isoprenoid/normal alkane ratio. The USGS is very much aware of the possible occurrence of other isoprenoids. However, their concentration and absolute identification are extremely difficult, and many times misleading. This ratio, in the opinion of the Survey, should be reported provided an agreement on the definition of the use of isoprenoid in this ratio can be reached, because of its potential in earmarking petroleum.

4. The Cooper/Bray CPI for $(n\text{-}C_{23} - n\text{-}C_{29})/(n\text{-}C_{24} - n\text{-}C_{30})$ is agreeable to be used by the USGS for future comparisons.

5. The USGS and VIMS identified only the normal alkanes and the two isoprenoids pristane and phytane. The USGS convention defined all compounds eluting between the normal alkanes C_n and C_{n+1} (except pristane and phytane) as iso-C_n. Since alkanes and cycloalkanes may also elute between normal alkanes, this iso convention will be deleted. It should be pointed out, however, that the pristane and phytane isoprenoids elute after the normal (C_n) on both the USGS and VIMS columns, and are, of course, branched (iso) structures. VIMS aliphatic intercalibration data, for cruises 05 and 06, do not identify branching other than pristane and phytane. Where possible, both the USGS and VIMS may report other pieces of evidence that may allow partial identification of olefins, cycloalkanes and branched structures.

6. The USGS also uses retention times of available standards and molecular weights (when molecular ions are unquestionable) to supplement the mass spectra. In the sample 77-2-43 where the implied eight isomers of methyl phenanthrene occurred, should have been (4) possible isomers of methyl phenanthrene, and (3) possible isomers of anthracene.

7. It is well known that different liquid substrates will result in different separations, and of course, resolution is improved by increasing column length. Just how important is the need to distinguish fluoranthene from pyrene in the context of the BLM environmental assessment program has not been established, nor the real significance defined or stated. A second SCOT OV-1 column used by the USGS has separated benzo (α) anthracene and chrysene/triphenylene. The Survey does appreciate the chemical inertness of glass columns; however, the specific reaction with aliphatic and aromatic hydrocarbons remains unclear and undocumented. It would have been helpful and time conserving had the USGS been represented at the workshop attended by VIMS on glass capillaries held 28-30 July 1976. This would, of course, have allowed for adequate time in replumbing and fitting our gas chromatographs and gc/ms systems. This time is now not available within the USGS existing time schedule.

   In terms of the BLM program, the real question that should be addressed is what separation and column characteristics does the BLM program require? The question is not who can obtain a better separation of a given component at a given time, simply because as improvements are made in substrates and columns, what is best for today, may not be next month or next year. To this end we are including comments by L. S. Ettre (1973) concerning his comparison of (SCOT) and (WCOT) columns: (1) that peaks with very small partition ratio values cannot be separated on a given WCOT column while their separation is possible on a shorter SCOT column; (2) that a shorter SCOT column will give a better resolution in shorter time than a longer WCOT column for "early peaks"; (3) for the analysis of wide boiling sample mixtures the SCOT column most likely would permit a better resolution in a shorter time than the WCOT column; (4) SCOT columns can give a faster analysis and provide better detectability than WCOT columns. In other words, SCOT columns can be used in trace analysis. Since there is a difference in performance reported by Ettre and VIMS concerning SCOT and WCOT columns, the Survey will perform some comparative side studies involving both SCOT and WCOT using SE-52 as the liquid substrate. The Survey intends, for now, to continue with the stainless steel columns at this time, but, we will use the SE-52 liquid substrate, and possibly go to 100 ft SCOT columns, if the improved resolution is warranted. The conversion to all glass systems, at this time, does not fit within our present time schedule or projected budget as we will not be making our own columns and, therefore, will need to buy them on the open market.

Some of our colleagues have reported severe breakage problems, and in general, dissatisfaction because of handling problems, with glass capillaries although the recent results from Dupont indicate the thick-walled capillary columns seem to be an improvement. The preceeding discussion is not to be interpreted that the USGS is not interested in using glass capillary columns; we are, provided that the results, and time for conversion and check-out, as well as funds for such a conversion, can be unquestionably justified and made available.

8. The Survey concurs with the recommendation that at least one intercalibration sample should be obtained in sufficient quantity to permit three (3) laboratory replicate analyses.

CHAPTER 7

GEOTECHNICAL ENGINEERING STUDIES IN THE BALTIMORE CANYON TROUGH AREA

Dwight A. Sangrey
Harley J. Knebel

CHAPTER 7

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CHAPTER 7

GEOTECHNICAL ENGINEERING STUDIES IN THE BALTIMORE CANYON TROUGH AREA

Dwight A. Sangrey[1] and Harley J. Knebel[2]

INTRODUCTION

This study is concerned with evaluating the engineering characteristics of the sediments and any potential hazards within a representative transect across the Continental Shelf in the Baltimore Canyon Trough area (Figure 7-1). Specific information for the study was collected by the U. S. Geological Survey using the R/V ANNANDALE during 18-25 September 1977. During the cruise, 20 vibracores were collected at 17 stations across the shelf in water depths of 35 to 70m (Figure 7-1; Table 7-1). Immediately after the cruise, the cores were taken to the laboratories of Geotechnical Engineers, Inc. of Winchester, Massachusetts. There, an extensive series of geotechnical engineering tests was carried out on the cores (Appendix 4); these data are the basis of this report.

Geotechnical engineering properties have traditionally been a part of site-specific rather than regional surveys. However, knowledge of geotechnical engineering properties can be applied in several different ways to regional investigations. First, the engineering properties can be used to evaluate general geological hazards such as those associated with sediment liquefaction, sediment compressibility, and sediment shearing resistance. Second, the geologic processes, themselves, can be understood better if data on engineering properties are available. Finally, regional engineering studies provide a general data base for engineers who are contemplating projects in an area.

Existing information about the geotechnical engineering characteristics of the Baltimore Canyon Trough area is limited. Five coring stations from the U. S. Geological Survey AMCOR project in 1976 (Hathaway et al. 1976) were located in the general area (Figure 7-2). Geotechnical engineering studies of these sediments have been reported by Richards (1978), and by Swanson and Brown (1978). A detailed, site-specific study for an offshore nuclear power plant was done by Dames and Moore for Public Services Electric and Gas. The site was located nearshore off the Atlantic City, New Jersey area. Results of these studies are available (Public Service Electric and Gas 1975).

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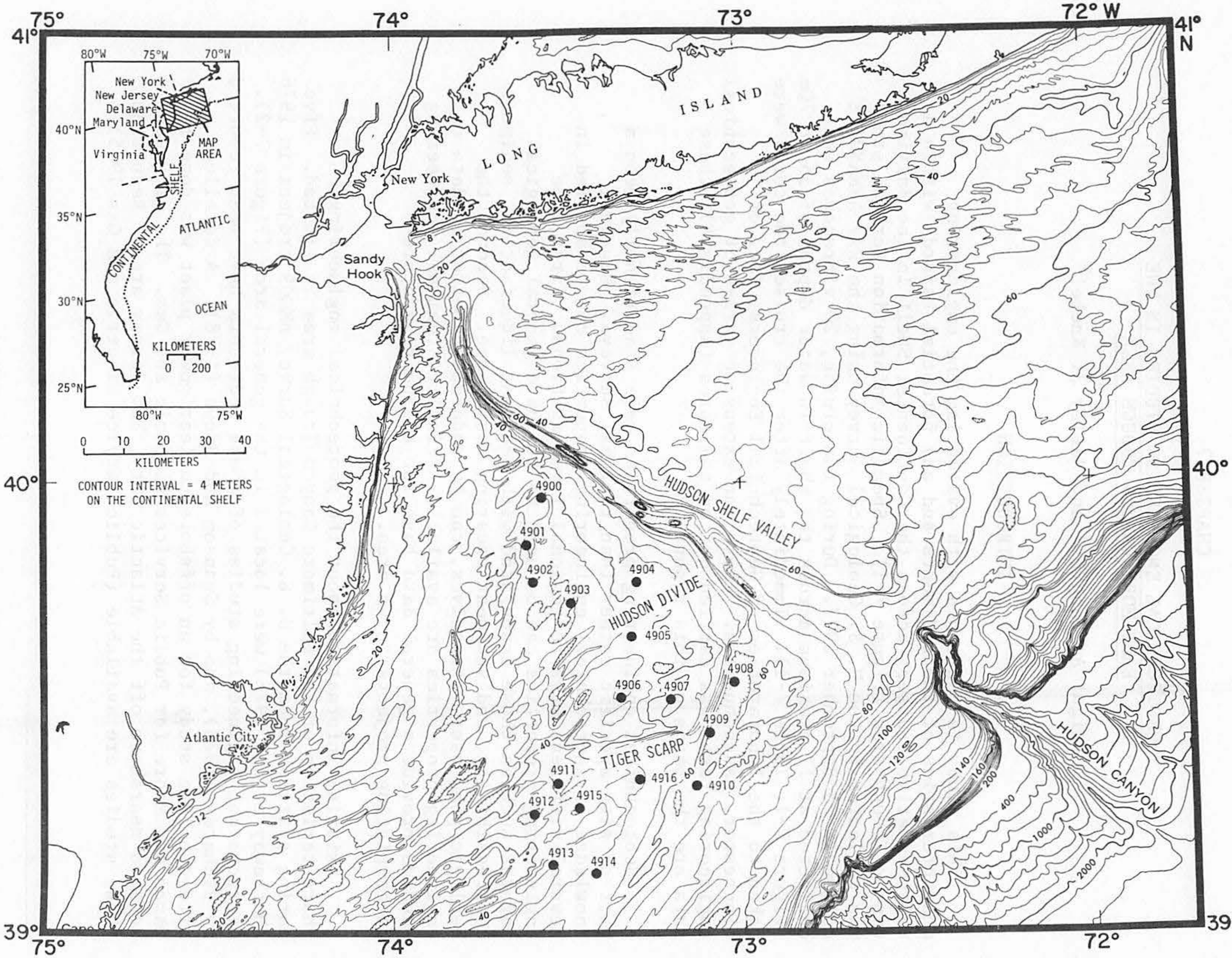

Figure 7-1. Location of the Baltimore Canyon Trough study, with bottom topography and coring stations.

Table 7-1. Vibracore data, Middle Atlantic Outer Shelf.

Station Number	Core Number	Date (1977)	Time (EDT)	Latitude		Longitude		Water Depth (m)	Core Length (m)
				Deg.	Min.	Deg.	Min.		
4900	VC-01	9-19	1447	39	57.93	73	34.74	39.3	0.6
4900	VC-02	9-19	1558	39	57.95	73	34.76	39.3	4.8
4901	VC-03	9-19	1737	39	51.94	73	37.31	35.4	2.2
4902	VC-04	9-20	0832	39	47.00	73	36.24	38.7	5.9
4903	VC-05	9-20	1040	39	44.51	73	29.31	43.0	6.1
4904	VC-06	9-20	1320	39	46.78	73	18.29	43.3	4.0
4905	VC-07	9-20	1517	39	39.59	73	18.88	42.4	3.6
4906	VC-08	9-20	1734	39	31.63	73	21.00	36.6	1.5
4907	VC-09	9-21	1527	39	31.06	73	12.64	44.8	2.0
4908	VC-10	9-22	1231	39	33.44	73	01.15	69.8	2.6
4908	VC-11	9-22	1306	39	33.46	73	01.17	69.8	2.6
4909	VC-12	9-22	1455	39	26.92	73	05.81	67.1	2.9
4909	VC-13	9-22	1533	39	26.92	73	05.79	67.1	1.8
4910	VC-14	9-22	1744	39	19.65	73	08.01	65.6	2.6
4911	VC-15	9-23	0721	39	20.03	73	32.31	48.8	1.8
4912	VC-16	9-23	0840	39	15.72	73	36.01	46.7	4.0
4913	VC-17	9-23	1015	39	08.71	73	33.25	50.6	2.2
4914	VC-18	9-23	1152	39	07.79	73	25.27	56.4	3.9
4915	VC-19	9-23	1355	39	16.62	73	28.44	50.6	2.9
4916	VC-20	9-23	1552	39	20.77	73	17.81	51.2	1.0

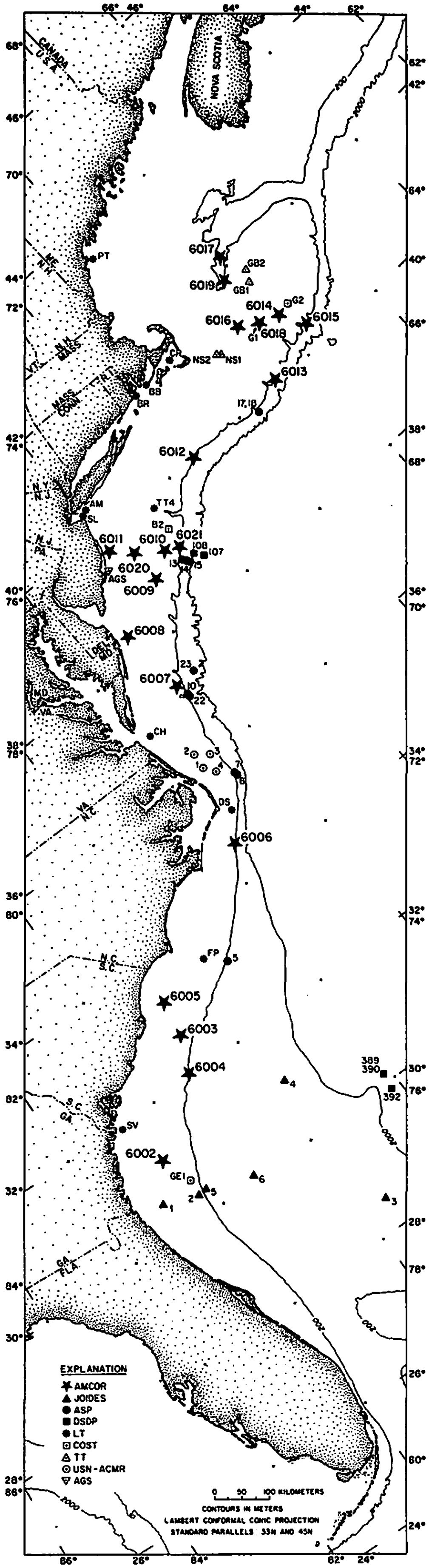

Figure 7-2. Location of other coring stations on the Atlantic Continental Margin with particular reference to AMCOR stations.

GEOLOGIC SETTING

The geologic setting for cores recovered in this study has been described by others (Schlee and Pratt 1970; Frank and Friedman 1973; Hollister 1973; McClennan 1973; Swift et al. 1973; Sheridan et al. 1974; Stahl et al. 1974; Knebel and Folger 1976; Knebel and Spiker 1977; and Twichell et al. 1977). A brief summary of the environmental characteristics that are applicable to a geotechnical engineering study is sufficient as a background review.

The sediments in the transect area can be divided into two units on the basis of the lithology, that is, a surficial sand unit and an underlying muddy unit (Knebel and Spiker 1977). The sand unit is dominantly a dark to olive gray, shelly, poorly sorted, medium to coarse sand. However, gravel dominates the sediments in some small patches (Schlee and Pratt 1970), and the muddy substrate may be exposed in small areas at the bottoms of bathymetric depressions (McKinney et al. 1974). The thickness of the sand unit ranges from zero to as much as 20 m, with the thicker deposits being associated with topographic ridges. The Hudson Divide, which occurs northwest of Tiger Scarp (Figure 7-1), may be a fluvial deposit created by the Pleistocene Hudson River, or it may have been built, in part, by nearshore deposition during the Holocene (Schlee and Pratt 1970; McClennen 1973; Knebel and Spiker 1977).

The mudder unit, beneath the sands, is texturally diverse, but it contains a preponderance of clays and silt-clays (Knebel and Spiker 1977). The top of the unit generally is flat, although subbottom depressions cause some local irregularities. The age of this unit is greater than 24,000 years B.P., and the sediments probably accumulated prior to the last regression of sea level.

Since the clays may have experienced terrestrial exposure with its potential for erosion (particularly incising by rivers and streams), it is reasonable to expect local deposits of soft, fine-grained silts and clays as infilling deposits during a subsequent marine transgression. Deposits of this type would have different geotechnical engineering properties than those that were subaerially exposed as a result of the different stress history.

METHODS

Vibracores collected during the R/V ANNANDALE cruise were contained within 8.9 cm ID plastic core liners. In the laboratories of Geotechnical Engineers, Inc., the cores were kept refrigerated at 2 to 4°C, and the following tests were performed:

	Number	ASTM
Bulk Unit Weight	131	--
Water Contents	160	D2216
Atterberg Limits-Liquid Limit	60	D423
Atterberg Limits-Plastic Limit	60	D424
Specific Gravity of Solids	70	D854
Textural Analysis	120	D422
One Dimensional Consolidation Test	32	D2435
Three Dimensional Consolidation Test	10	--
Consolidated Undrained Triaxial Compression	12	--
Visual Descriptions	199	--

The testing procedures are described in Appendix 4. During the tests, the recommendations of ASTM were followed whenever these were available. This was the case for all but the three-dimensional consolidation tests and the $\bar{R}$ triaxial compression tests.

The three-dimensional consolidation tests were done in conventional triaxal cells on specimens 7.1 cm in diameter and 8 cm high. The specimens were backpressure saturated under 392 kPa and then isotropically consolidated in eight loading increments.

The $\bar{R}$ tests were done on specimens 7.1 cm in diameter and 16 cm high. Backpressure saturation under at least 392 kPa was required to achieve a B value of 0.95 or greater. Undrained tests with pore pressure measurements were performed using a constant rate of strain of approximately 0.04 percent per minute. At this rate, the pore pressure equalization within the specimen was at least 90 percent at failure.

RESULTS

Index Tests

Index tests serve to provide an initial classification of marine sediments. The results of index tests also can be used in preliminary estimates of engineering properties and of behavior through empirical correlations and other experience. In some cases, the index test data are a meaningful engineering parameter in their own right, for example, as in defining the grain size of a sample.

Details of the index test data from cores taken in the Baltimore Canyon Trough area study are included in Appendix 4 and will not be repeated here. The index test data are summarized in Figures 7-3 and 7-4.

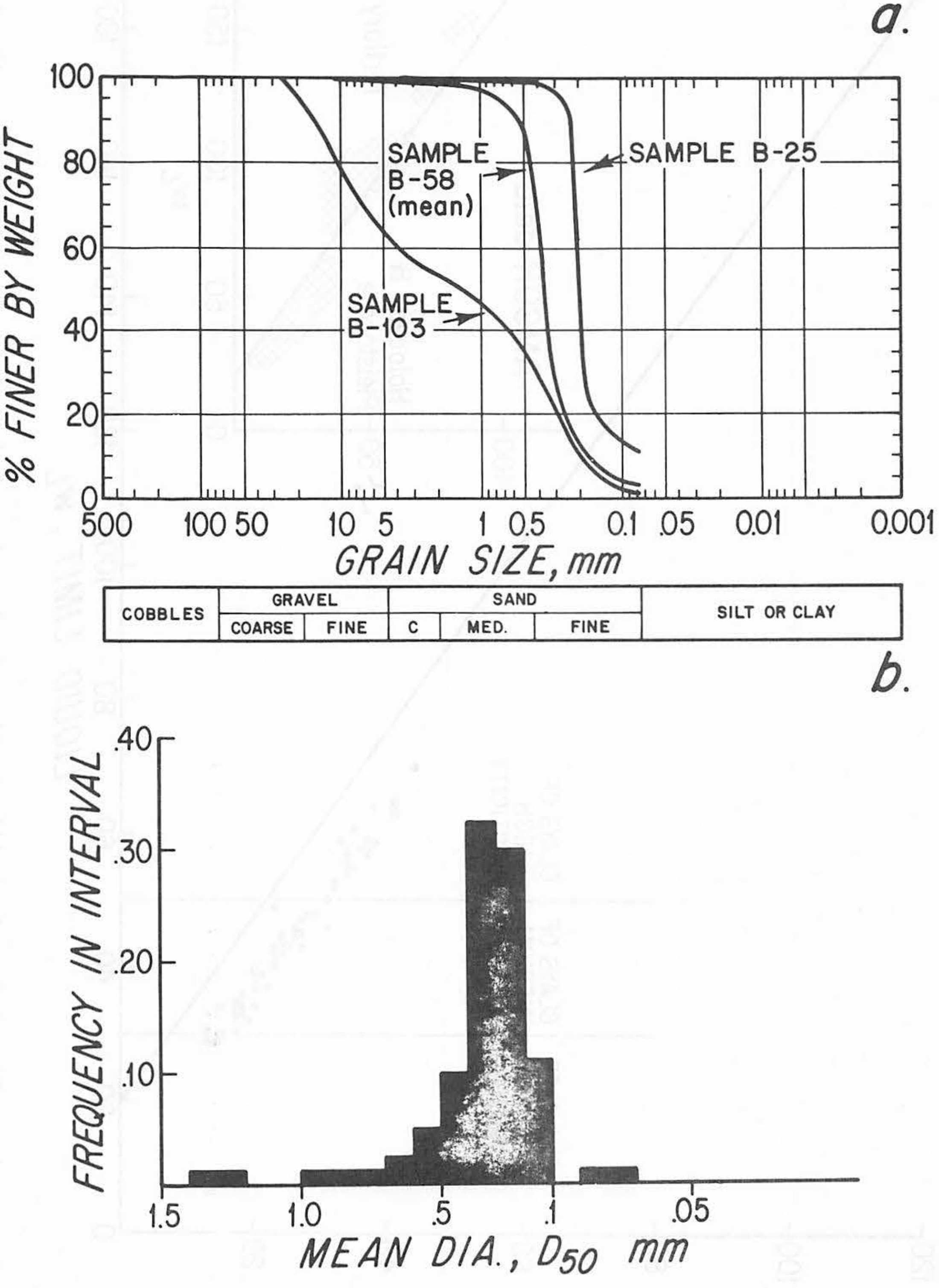

Figure 7-3. Summary of grain size distributions for sandy sediments. (a) Representative size distribution curves for extreme fine grained sandy sediments (B-25), extreme coarse grained sandy sediments (B-103) and the mean (B-58). (b) The distribution of mean diameters for the sandy sediments.

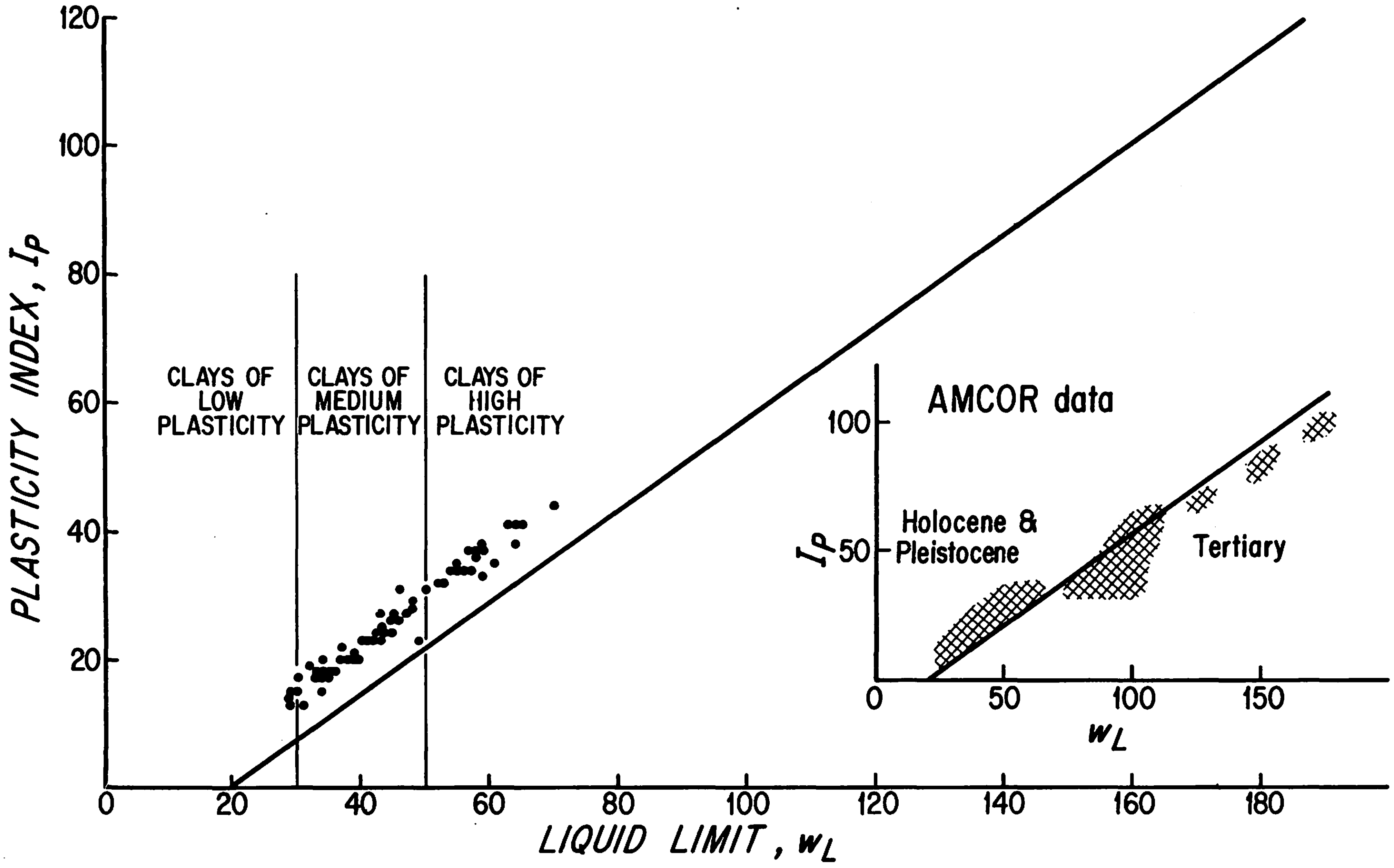

Figure 7-4. Plasticity chart illustrating the location of data from this study within the range of clays of low to high plasticity. Data from the AMCOR study (inset) indicate similar characteristics for Holocene and Pleistocene sediments.

Because of the vibracoring method, most index test data that are reported for sandy sediments are suspect. Vibracoring methods are known to disturb sands and to change their engineering properties. On the other hand, the finer-grained silty and clayey sediments probably have not been adversely affected by the vibracoring. Support for this contention is presented later in this chapter during a discussion of the triaxial compression tests. Therefore, most of the following remarks concern those measurements that were made on sediments that are primarily silts and clays. However, a brief discussion of the grain-size distributions of the sands are presented because these data are not affected by the sampling method.

The grain size distributions for 80 specimens of sandy sediments are presented in Appendix 4 and are summarized in Figure 7-3. As indicated in Figure 7-3, the sands range in mean size from coarse to fine, with the smaller sizes being most common. The range of grain size curves illustrates that a variety of size distributions and gradation curve shapes are represented in the total data set. The majority of sandy sediments were quite uniform with a mean coefficient of uniformity $C_u=D_{60}/D_{10} = 3.1$. No attempts have been made in this report to examine the trends in grain size distribution either spatially or with depth, although such an analaysis would have potential interest in sediment transport studies.

The index properties of greatest interest for the fine grained, clayey sediments taken during the study are the plasticity measurements (the Atterberg limits). A useful form for presenting these results is with a plasticity chart (Figure 7-4), on which the plasticity index and liquid limit are ordinates of a graph. A particular position or area on the plasticity chart corresponds to various classification units. Different engineering properties and problems are associated with these various units (Mitchell 1976). Other sediment properties such as clay mineralogy, size distribution, organic content, and geologic origin also are known to affect the classification characteristics.

The data presented in Figure 7-4 indicate that these clayey sediments have low to high plasticity. The results fall in a common part of the plasticity chart and are typical of terrestrial soils from the adjacent coastal areas of the northeastern and central United States. Other offshore data from the U. S. Atlantic Continental Margin were collected as part of the USGS AMCOR project (Hathaway et al. 1976). The AMCOR data were based on cores penetrating several hundred meters below the mud line, in contrast to the several meters of penetration in this study. Most of the AMCOR data fall in exactly the same part of the plasticity chart as do the results from this study (Figure 7-4). Some of the AMCOR data, however, did fall in an entirely separate part of the plasticity chart, and it was possible to attribute this difference to two entirely different geologic origins and ages (Hathaway et al. 1978). The sediments having lower liquid limits were all of Holocene or Pleistocene age, whereas the second group of data were all from Tertiary sediments.

In addition to the differences in plasticity and classification, the Tertiary sediments fro the AMCOR project had engineering properties that were distinctly different from the younger sediments. Because none of the classification data from the sediments collected in the present study fall in the region associated with the unusual Tertiary sediments, we have no reason to anticipate unusual engineering properties.

Natural water content can be used along with sediment plasticity characteristics to indicate a variety of general engineering behaviors. For example, soft, normally consolidated sediments typically will have a natural water content near to the liquid limit. In contrast, heavily overconsolidated sediments usually have water contents far below the liquid limit. For most of the specimens tested in this study, the natural water content falls well under the liquid limit with values of liquidity index[1] of approximately 0.5 being typical. This would indicate overconsolidation for these near-surface sediments, probably due to either erosion or desiccation.

In at least one coring location, station 4905 (Figure 7-1) and core VC-07, the values of liquidity index were distinctly higher (approximately 1.0). These results are more typical of normally consolidated sediments and may represent a local accumulation of soft sediment during or since the last transgression of sea level. Values of natural water content near the liquid limit, $I_L = 1.0$, would not be expected if there had been either significant erosion or subaerial exposure and desiccation of these marine sediments.

Consolidation-Compression Tests

The results from 42 consolidation-compression tests (32 one-dimensional and 10 three-deminstional) are given in Appendix 4. A typical illustration, Figure 7-5, confirms that the sediments from the Baltimore Canyon Trough area are overconsolidated. For typical clayey sediments, the results of a one-dimensional compression test (such as in Figure 7-5), will show a distinct break in slope and an increase in compressibility at higher stresses when presented on a logarithmic scale. The slope of this steeper, staight-line portion is called the compression index (C_c) and the stress corresponding to the break in

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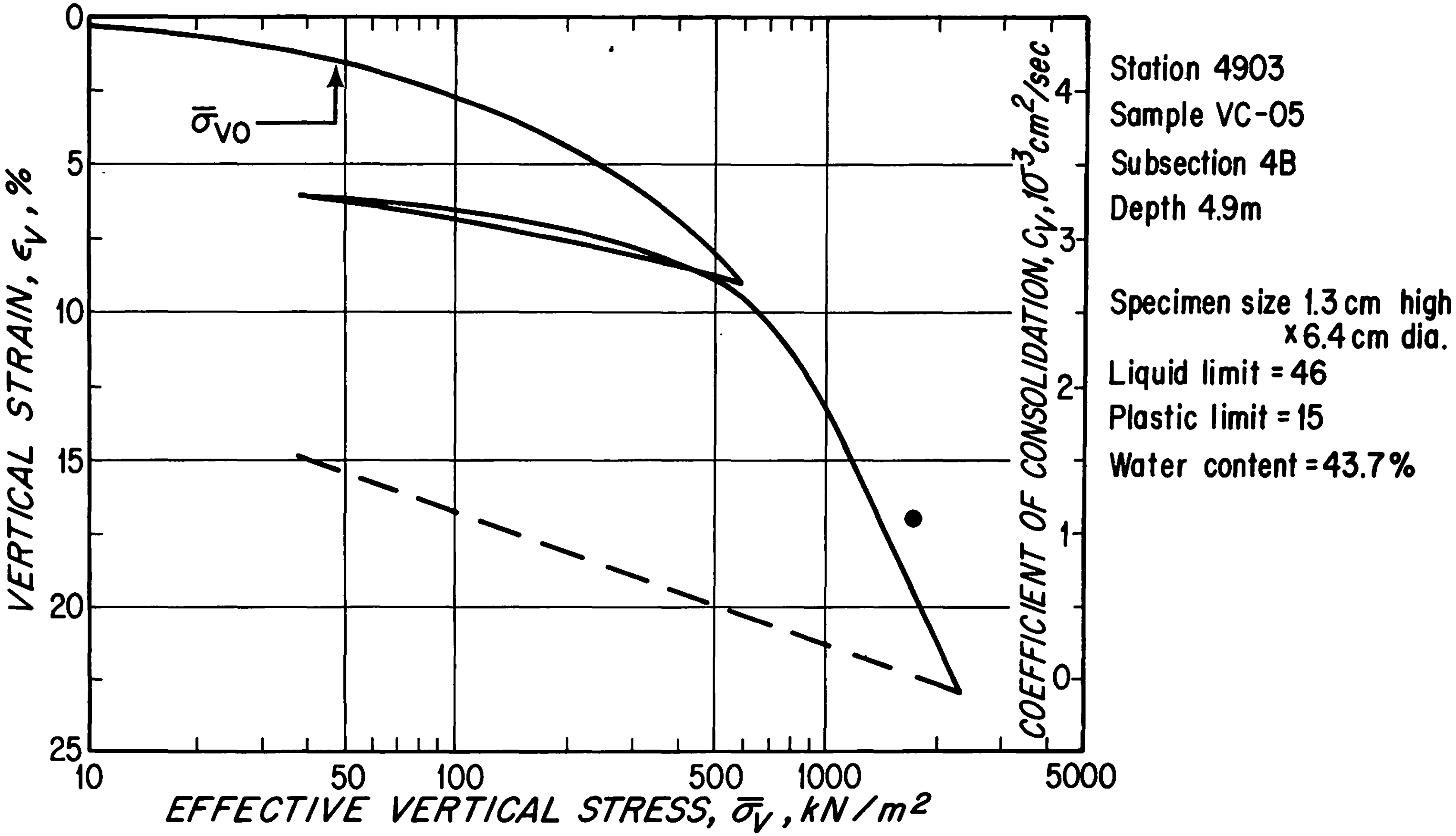
[1] Liquidity index is a quantitative measure of the relative position of natural water content between the plastic and liquid limits. Values of liquidity index greater than 1.0 are also used to express natural water contents above the liquid limit.

$$I_L = \frac{w - w_P}{w_L - w_P}$$



NOTE: SOLID POINT REFERS TO COEFFICIENT OF CONSOLIDATION

Figure 7-5. Typical results from the consolidation-compression testing program. See Figure 7-1 for station location.

slope is termed the precompression or preconsolidation stress ($\overline{\sigma}_{vc}$) (see Mitchell 1976). The precompression stress can be equated, approximately, to the largest past effective vertical stress acting on the sediment. Consequently, for a normally consolidated soil which has never had a larger effective stress acting than at present, the existing overburden effective stress ($\overline{\sigma}_{vc}$) should be approximately equal to $\overline{\sigma}_{vc}$. The existing stress ($\overline{\sigma}_{vc}$) will be much lower than $\overline{\sigma}_{vc}$ for an overconsolidated sediment as illustrated in Figure 7-5. The ratio of these two stresses is called the overconsolidation ratio (OCR) which ranges from values of 1.0 (normally consolidated) upward.

All of the fine grained sediments tested in this program were overconsolidated, as expected from the liquidity index results. The test results from the core at station 4905, however, did show a distinctly lower precompression stress for this area; this also is consistent with the index test results. Material from station 4905 was somewhat overconsolidated, but the range of OCR was very different, with OCR = 5 being typical as compared to OCR = 15+ for the other cores.

The compression index is a useful engineering parameter when predicting soil settlement problems. For the cores tested in this program, the values of C_c are summarized in a commonly used plot of compression index versus liquid limit (Figure 7-6). Empirical studies on natural soils have resulted in several relationships between these two soil characteristics. The most popular of these empirical relationships are illustrated in Figure 7-7. The general fit and scatter of our data are consistent with those of other soils, confirming that the offshore sediments recovered in this sampling program are not unusual or unique in their engineering properties.

The time process of settlement in soils is termed consolidation, and the coefficient of consolidation (C_v) is used in design or analysis. Values of C_v were determined from all of the one-dimensional tests done in this program. Values of C_v ranged from 0.5×10^{-3} to 3×10^{-3} cn^2/sec which is within the expected range for this type of sediment.

Triaxial Compression Tests

Only a limited triaxial compression testing program was done in this study, and the results should be considered representative rather than typical. Three series of four specimens each were tested, and the specimens being taken from adjacent sections in cores from stations 4900, 4904, and 4912 (Figure 7-1). In each series, three specimens were tested from an isotropic state of consolidation at three different levels of stress. The fourth specimen was consolidated anistropically to a state of stress that approximated in situ conditions (based on the measured unit weight and the subbottom

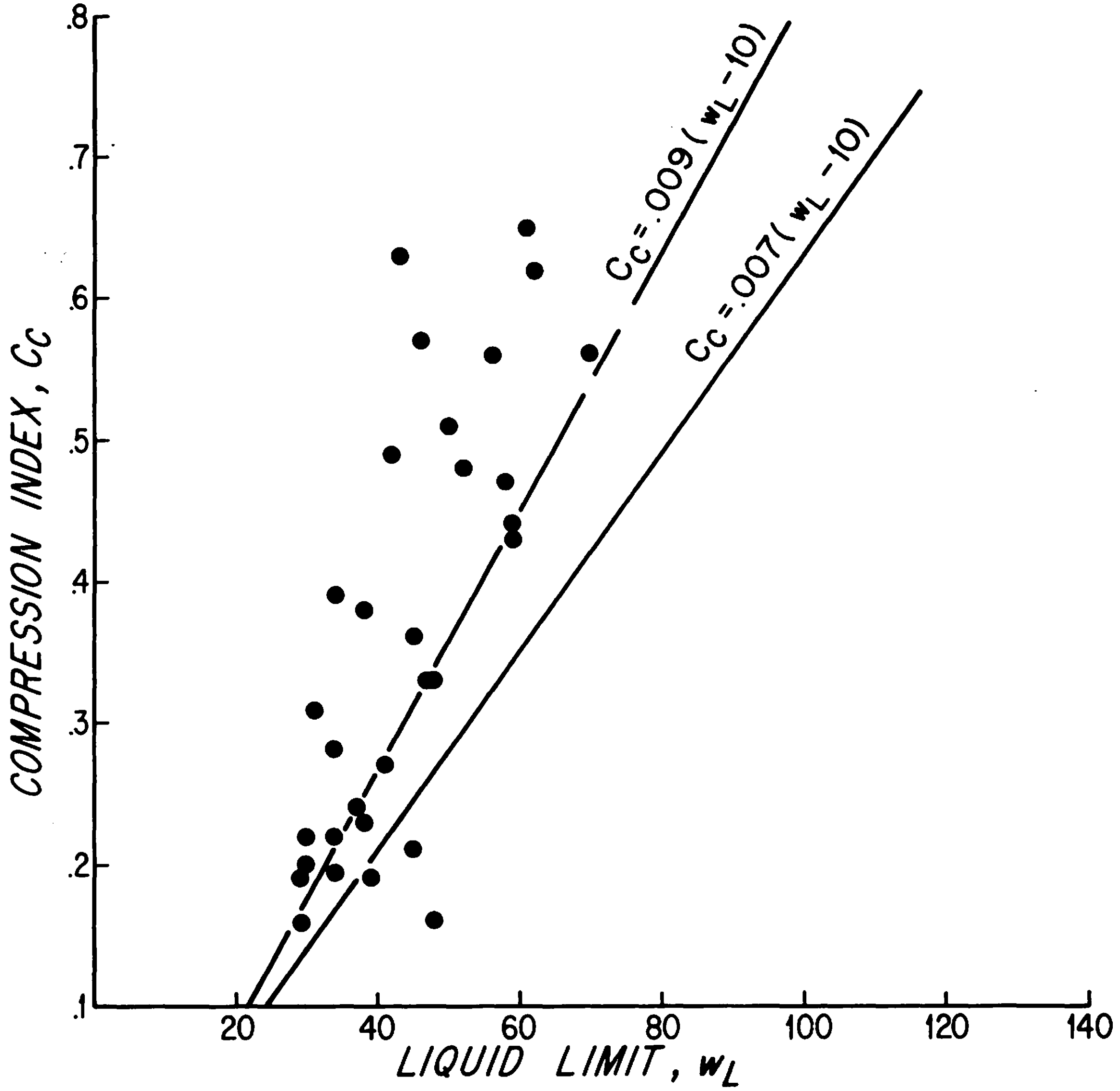


Figure 7-6. A summary of the compression characteristics of clayey sediments from the Baltimore Canyon Trough area with a comparison to accepted empirical relationships.

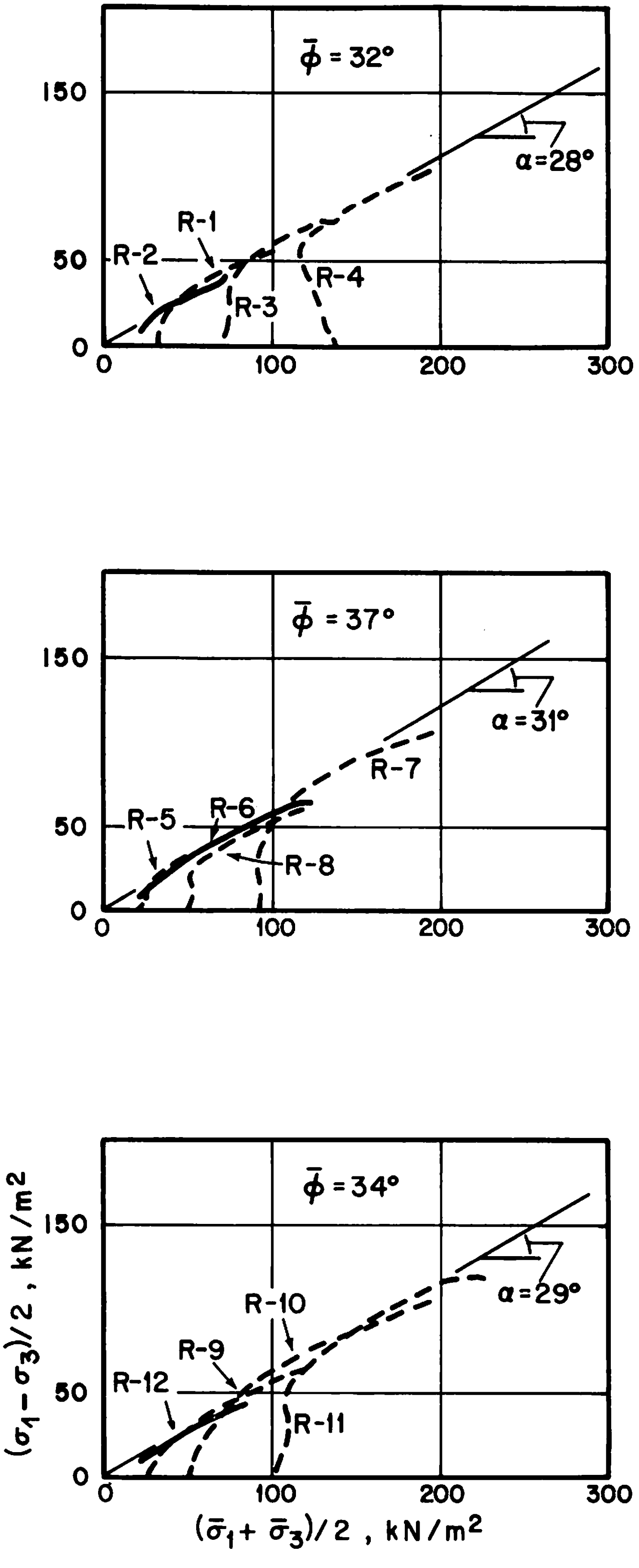


Figure 7-7. Triaxial compression test results on sediments from the Baltimore Canyon Trough area.

depth of the sample). All testing was done under undrained conditions with pore pressure measurements (Appendix 4).

Results of the triaxial compression testing program are summarized in Figure 7-7. In each case, a failure envelope can be drawn that defines a failure criterion with a friction angle but with no cohesion intercept. These results are typical and within the range of expectation for clayey marine sediments when effective stress methods are used in analysis of strength test data.

The clay specimens were all slightly to moderately dilative under the applied stresses as indicated by the stress path curves (to the right) in response to negative incremental excess pore pressures. This response is consistent with the previous interpretation of an overconsolidated stress history for these sediments. For these soils, the drained shearing resistance will be lower than the undrained shearing resistance.

Results of the triaxial testing program, particularly the anisotrocially consolidated tests, can be used to estimate the in situ undrained shearing resistance, S_u. Measurements of undrained shearing resistance, using a hand-held penetrometer and vane devices, on the recovered cores are reported in Appendix 4 and are plotted in Figure 7-8.

The broad scatter of points in Figure 7-8 is not surprising considering that 11 different cores are represented and that there is an unknown amount of disturbance affecting the data. Nevertheless, two conclusions are possible. First, the triaxial test results and the simple, total stress test measurements using the penetrometer and vane are consistent. A different conclusion was reached in the AMCOR studies (Hathaway et al. 1978), where disturbance effects reduced the total stress measurements to levels far below the apparent in situ undrained shearing resistance. Therefore, it would appear that there has been minimal disturbance of the silty and clayey sediments that were collected in this study. The second conclusion is that these sediments are all overconsolidated. For normally consolidated marine sediments, it is generally understood, from both theory and observation, that the undrained shearing resistance increases linearly with effective overburden stress or with depth below the sediment surface. This relationship is often expressed as the $S_u/\bar{\sigma}_v$ ratio (classically the C/P ratio), and several theoretical and empirical estimates of this ratio have been proposed (Sangrey 1972). A typical $S_u/\bar{\sigma}_v$ ratio for sediments of this type being studied in this program would be 0.20-0.30. The higher limit of this range is shown in Figure 7-8 and clearly illustrates that the undrained shearing resistance being measured is very much higher than would be expected for a normally consolidated soil.

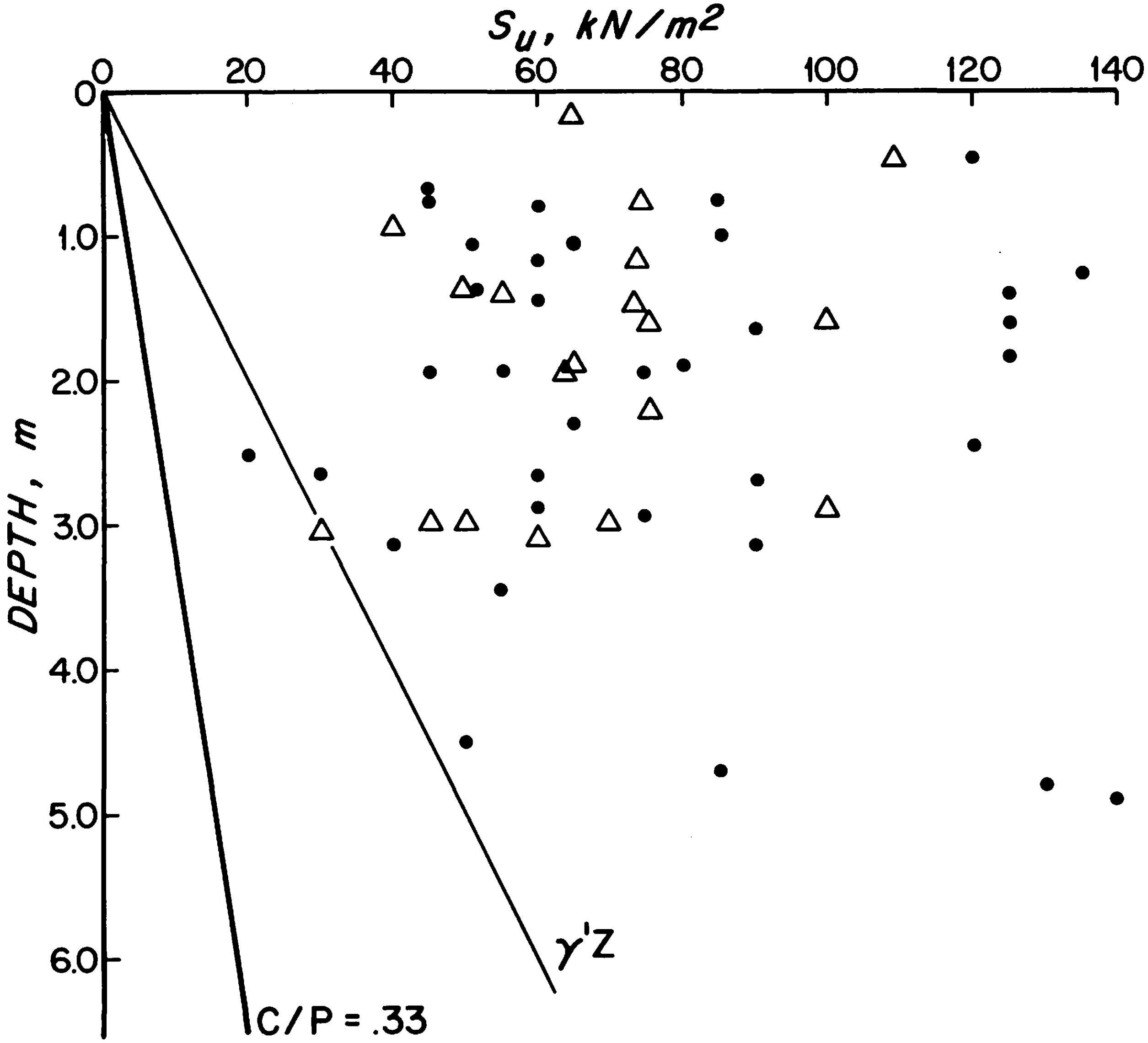


Figure 7-8. Measured undrained shearing resistance, S_u, for clayey sediments from the Baltimore Canyon Trough area illustrating higher shearing resistance than would be expected for normally consolidated sediments.

DISCUSSION

Most of the finer grained silt and clay sediments were heavily overconsolidated. Consequently, dilative behavior is to be expected. Because of their high position in the sediment profile and their relatively low effective vertical stresses, the sediments are classified as soft to stiff even though they are heavily overconsolidated.

Some of the clayey sediments, particularly from station 4905, appear to be more normally consolidated. This is indicated by both the liquidity index values and the soil compressibility. However, the majority of clays are overconsolidated as a consequence of desiccation and erosion during periods of lowered sea level. Softer clay may have accumulated in some local areas during the most recent trangression period.

Because of the vibracoring method, the engineering properties for undisturbed, sandy sediments cannot be determined. It can be stated only that the grain size distributions of these sediments are within the range of concern from the standpoint of liquefaction. However, without reliable estimates of in situ unit weights, no specific evaluation of liquefaction potential can be made.

Data collected in this study can be interpreted with respect to their general application to geotechnical engineering problems. Since the depth of sampling was limited, it may be inappropriate to extrapolate these results to greater depths, although other data (AMCOR) may be useful for that purpose. Consequently, application of these results to problems requiring knowledge of sediment properties at depth (such as a large offshore platform) will be limited in favor of lighter structures such as pipelines. Practical problems which can be addressed by using these shallow coring data include: all bottom-supported communication structures such as pipelines and cables; sea bottom trafficability; shallow excavation; lightweight structures; and several types of natural hazards.

In general, the clayey sediments that were sampled and tested in this study present only a moderate problem in terms of engineering applications. Settlement under light structures should be be excessive. The clays probably can be excavated or trenched for burial of pipelines and similar facilities by using conventional rather than expensive and exotic techniques. Because the clays are dilative, the drained shearing resistance will be lower than the undrained shearing resistance, and this should be considered for any long-term design. Another consequence of the dilative characteristics of these clays is their susceptibility to loss of shearing resistance under drained cyclic loading (Sangrey et al. 1978). Local deposits of soft clays may cause some settlement and strength problems, and it will be necessary to do site-specific investigations for any particular object. Engineering solutions to all of these problems are within the current capability of marine geotechnical engineering.

Few problems are likely to be associated with the sands, unless they are susceptible to liquefaction or are unstable under the action of bottom currents. Neither of these problems can be addressed definitively with the data collected in this study. However, data from epibenthic tripods (Chapter 2) clearly show that the surficial sands can be resuspended and transported throughout the year. In addition, bottom scour around objects on the sea floor has been observed during large winter storms (U. S. Geological Survey 1977).

SUMMARY OF HAZARD IMPLICATIONS

The geotechnical engineering properties data collected in this study of the Baltimore Canyon Trough area can be applied in consideration of the following.

Weak Sediments

The majority of clay sediments encountered were heavily overconsolidated, with adequate shearing resistance and low compressibility, so that they present no unusual hazard. There are local deposits of weak and more compressible sediments whose engineering properties may present a greater risk in some applications such as bearing capacity support for temporary or permanent structures. The frequency and distribution of weak sediments cannot be defined using the limited data available. Consequently, site-specific studies are appropriate for structures which would be vulnerable to this condition.

Slope Stability

The clayey sediments encountered in this study have adequate shearing resistance so that no unusual stability problems are anticipated on the gently-dipping (1.5 m/km) gradient of the Continental Shelf in this area. However, if larger, unnatural gradients are created (e.g. by dredging), the stability of the sediments should be evaluated on a site-specific basis.

Dynamic Loading

The majority of the clayey sediments from the top 5 meters in this area are dilative. Under undrained cyclic loading there should be no unusual hazard for these sediments, and only a modest strength reduction under cyclic loading with drainage should be anticipated.

No specific measurements of dynamic loading characteristics were done in this study.

The sandy sediments from this area are predominantly uniform fine-grained sands. This type of material is among the most vulnerable to liquefaction under drained cyclic and dynamic loading but only if it exists in situ in loose deposits of low relative density. No data are available at present to evaluate this characteristic. Determining the in situ unit weight, or bulk density, using sampled marine sediments, especially if sampled using vibracoring techniques, is extremely difficult and inaccurate because of sample disturbance. In situ measurements will be necessary to evaluate the unit weight. Because of the susceptibility of fine uniform sands to liquefaction, it is necessary for specific studies to be done to evaluate this hazard for a particular structure or facility. These studies should include cyclic loading tests and an evaluation of in situ unit weight.

Scour

The sandy sediments from this area are of size distribution which is vulnerable to scour. The water current regime determines the scour potential. Local currents associated with particular structural configurations could present scour problems and should be evaluated for each specific case.

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CHAPTER 8

AN INSTRUMENT SYSTEM FOR LONG-TERM SEDIMENT TRANSPORT STUDIES ON THE CONTINENTAL SHELF

Bradford Butman
David W. Folger

CHAPTER 8

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CHAPTER 8

AN INSTRUMENT SYSTEM FOR LONG-TERM SEDIMENT TRANSPORT STUDIES ON THE CONTINENTAL SHELF

Bradford Butman[1] and David W. Folger[1]

INTRODUCTION

We have designed and built an instrument system to investigate processes of bottom sediment movement on the Continental Shelf. The system is intended for use in regional studies of sediment transport to determine the physical processes responsible for bottom movement and to estimate the frequency, direction, and rate of sediment transport. The system measures bottom current speed and direction, pressure, temperature, and light transmission and photographs the bottom. It consists of three major components: (1) sensors for current, pressure, temperature, light transmission, and bottom photography; (2) a data recording unit; and (3) a tripod frame to which the sensors and data recording unit are mounted for deployment.

Direct observations, acquired in situ, are necessary to determine the character, extent, and causes of sediment dispersal over different regions of the Continental Shelf. Measurements must resolve motions with broad time scales ranging from a few seconds for wave frequency processes to weeks and months for processes associated with meteorological and oceanic forcing. Observations must be made to assess seasonal variability and to document catastrophic events. The tripod mounted instrument package, referred to hereafter as a bottom tripod system, was designed to measure the physical parameters necessary to understand sediment transport processes. Similar systems, previously developed and used on the continental shelf, influenced our design (Sternberg et al. 1973; Smith and McLean 1977). Photographs are taken periodically to document the bottom response to physical forcing. The photographs remove the need to rely exclusively on empirical competency curves to determine sediment movement (for instance, Miller et al. 1977). The photographs also document effects of biological organisms on sediment movement. The tripod system was designed for repeated deployments of 2 to 4 months duration.

The measurement of bottom stress is of prime interest in studies of sediment transport to determine movement threshold. However, the accurate measurement and parameterization of bottom stress requires the use of sophisticated instrumentation (Smith and McLean 1977),

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which is not yet routine in oceanography, especially for long time periods. Measurement of the stress profile in the bottom boundary layer is required to accurately determine the stress on a sediment particle. In designing the tripod system, we chose to measure current at a single fixed height from the bottom; a single velocity measurement is adequate to monitor and define processes of sediment movement and transport. Determination of bottom stress and sediment movement thresholds can probably best be made in short term detailed experiments using other specialized instrument systems.

THE BOTTOM TRIPOD INSTRUMENT SYSTEM

The tripod system (Figure 8-1) measures current speed and direction, pressure, temperature, and light transmission and photographs and bottom. A data recording package samples, formats, and records the data and distributes power to all sensors. The sensors are developed and recovered on a rigid tripod frame which causes minimal disturbance to the bottom flow while protecting the instruments from physical damage. All major tripod components and manufacturers of the components are listed in Table 8-1.

Sensors

Current Speed and Direction

Bottom current speed is measured by means of a savonius rotor sensor located approximately 1 m from the sea floor. Rotor motion is sensed by a reed switch which is activated by eight small magnets mounted on the rotor. A small vane directly below the rotor senses current direction; the vane is magnetically coupled with paired magnets to a magnetic compass inside an oil-filled pressure housing. Analog output from the direction sensor is 0-360°. Because the vane coupling magnets are not exactly paired the direction reading can have a systematic error of 0-5°. This error, although small and acceptable for each instantaneous direction measurement, may cause some error in the longer term mean of the current records, particularly in regions having strong tidal flows. In the future, more nearly linear current sensors having faster dynamic response, such as acoustic, propeller, or electromagnetic sensors, will be incorporated into the system for shallow water measurements to better define the large high frequency wave component of bottom flow.

Pressure

Pressure is measured by means of a quartz-crystal pressure sensor mounted approximately 1.5 m from the sea floor. The sensor is available with full scale ranges of 130, 270, or 600 m. Bottom

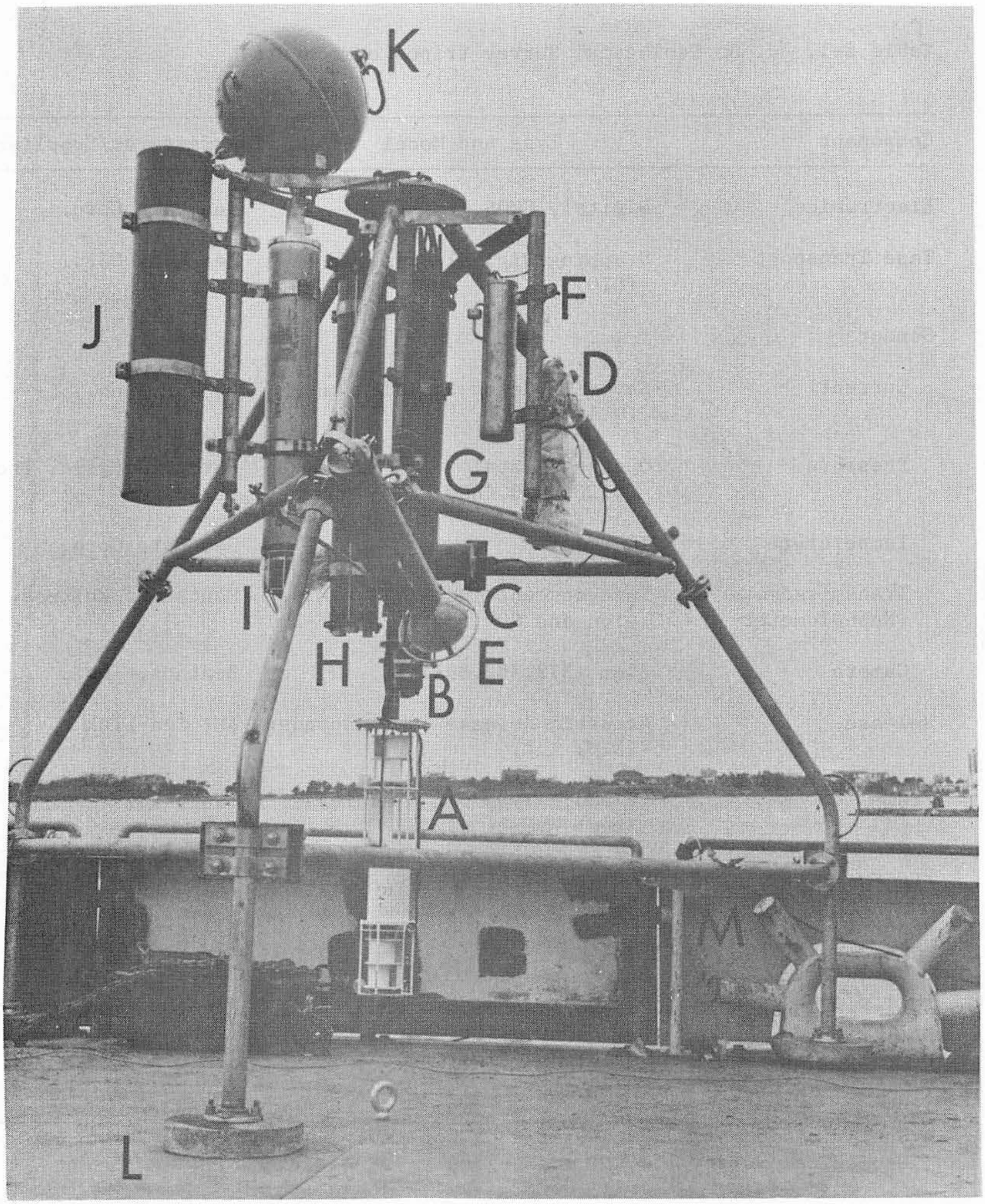

Figure 8-1. U. S. Geological Survey Tripod System: (A) current sensor, (B) pressure sensor; (C) transmissometer, (D) camera (wrapped in protective plastic bag to enclose anti-fouling ring); (E) strobe light; (F) camera battery pack; (G) Sea Data electronics; (H) battery pressure housing, (I) acoustic release transponder; (J) rope canister; (K) recovery float; and (L) lead anchor feet.

Table 8-1. U. S. Geological Survey tripod components.

Component	Type and Model	Manufacturer/Supplier*
Electronics	Digital, CMOS (651-4)	Sea Data Corp.
Tape Transport	Stepping Digital Cassette (610)	Sea Data Corp.
Sensors		
Current	Savonius Rotor & Small Vane (Q-9)	Bendix, Inc.
Pressure	Quartz Crystal (4130,4270,4600)	Paroscientific, Inc.
Temperature	Thermistor	Sea Data Corp.
Transmissometer-Nephelometer	Incandescent lamp. Transmission and 90° Scatter (TMU-1b)	Montedoro-Whitney
Camera	35mm (372,382,391)	Benthos, Inc.
Release	Acoustic Release - Transponder (325)	AMF Sea-Link
Frame	Tripod. Type 316 Stainless Steel	USGS/WHOI
Pressure Cases	Aluminium, hard anodized	Oceanic Industries
Penetrators, Connectors		Electro-Oceanics
Anti-Fouling	Porous bronze, impregnated with CeCAP (tri-butyl tin oxide and fluoride)	Miami Marine Research Inc.

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* Specification of manufacturer does not imply endorsement by U. S. Geological Survey.

pressure is sampled to measure both wave frequency variations and lower frequency changes in sea level due to tides and storms.

Turbidity

A transmissometer is used to monitor changes in the suspended matter concentration of bottom water. The sensor is mounted approximately 2 m from the sea floor. It uses a wide-spectrum incandescent light source regulated by a photocell. The light beam travels a folded path of 1 m length; a 180° prism is at one end of the path. To obtain a percent transmission measurement, the sensor output is normalized by the lamp output in clear water which is determined in the laboratory before and after deployments, using a calibration tank in which distilled water is continuously filtered to remove particulates. The sensor is also empirically calibrated in the field to determine the relationship between percent transmission and naturally occurring suspended matter. However, particle size and composition affect light transmission, and any absolute calibration of the transmissometer is qualitative. Also, many major near-bottom changes in transmission are due to resuspension of bottom material which may have different transmission characteristics than samples obtained in the field in calm weather. Biological growth on the transmissometer prism and windows also limits the long term stability of the sensor calibration. Growth is retarded by using porous bronze plates impregnated with tri-butyl tin oxide; the plates fit closely around the exposed surfaces and gradually release the tin oxide into the water during deployment, inhibiting growth. Despite calibration difficulties and problems with biological fouling, the transmissometer provides a good measure of the relative changes in bottom sediment concentration as a function of time.

The transmissometer sensor also incorporates a 90° scattering nephelometer, which shares the regulated incandescent light source. The nephelometer is extremely sensitive to scattered light, making laboratory calibration difficult. The sensor is not sensitive to the low concentrations of suspended sediment typical of the mid-Continental Shelf. The sensor may be more useful in areas where suspended sediment concentrations are high.

Temperature

Water temperature is measured by a thermistor mounted inside the aluminum electronics pressure housing on the lower end cap. The time constant of the end cap is several minutes.

Camera

Bottom photographs are obtained by means of a 35 mm deep-sea camera system; color or black and white film can be used. Quantitative estimates of changes in bottom microtopography (ripple size, ripple migration rates, etc.) associated with various forcing mechanisms such as storms and waves, and the effects of biological activity on the sediments can be determined from the photographs. Qualitative estimates of changes in the suspended matter concentration can also be made from the photographs to verify the transmissometer observations. In addition, the photographs provide information on benthic biological populations, variability in populations, and behavior patterns.

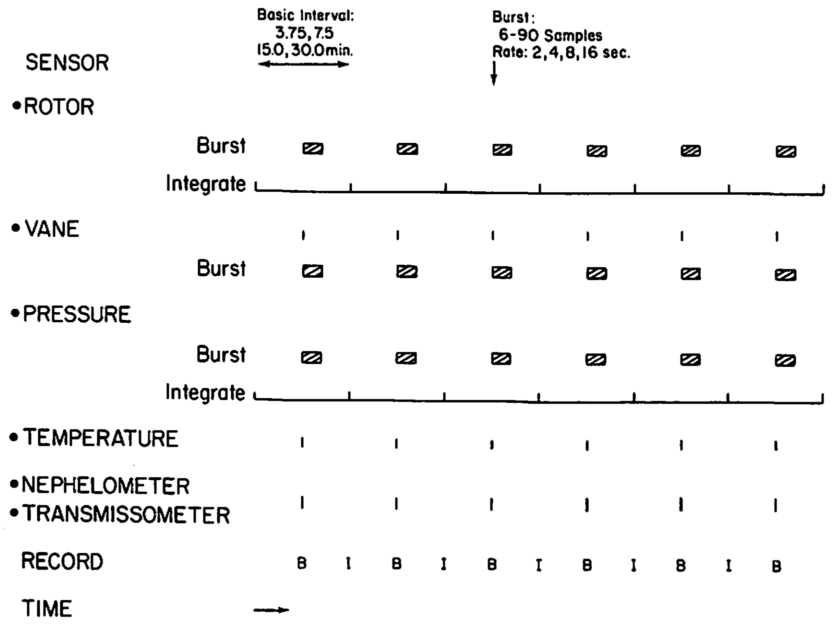
Data identification, date, and time are recorded directly on each 35 mm frame for reference in data analysis. A total of 750 frames are available for each deployment. The camera is mounted approximately 2 m from the sea floor; the 42° x 54° lens opening gives a 1.5 x 2 m viewing area on the bottom. The camera strobe is mounted at an angle to give some side lighting for good definition of the bottom microtopography. A magnetic compass and current vane is fixed in the camera field of view to provide frame orientation and a simple current direction measurement. Biological growth is inhibited by means of a porous bronze ring impregnated with tri-butyl tin oxide fitted around the camera window.

Data Sampling Scheme

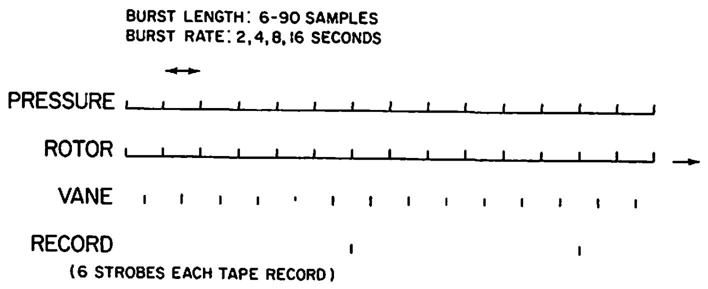
The tripod system samples the output from the sensors in two modes: interval mode and burst mode (Figures 8-2a-c). The sampling scheme allows resolution of high frequency processes without storing excessive data (Webster 1967). In the interval mode, pressure and rotor speed are averaged for a time period called the basic sampling interval, typically several minutes in length (in the present system 3.75, 7.5, 15.0, or 30.0 minutes can easily be selected). In the center of the basic sampling interval, a single sample of temperature, light transmission, and turbidity is made. The tranmissometer has a warmup period to allow the incandescent lamp to stabilize (Figure 8-2c). A sample of transmissometer and nephelometer sensor output with lamp on and off is made to measure the ambient light level. Housekeeping variables such as instrument identification, sampling scheme, and time are also recorded in the interval record.

In the burst sampling mode, a sequence of rotor speed, vane direction, and pressure measurements are taken at relatively short intervals (a "burst" of samples). The beginning of the burst sequence is centered in the basic sampling interval and is repeated at the basic interval (Figure 8-2b). The time between samples in the burst (burst rate) is typically several seconds (adjustable to 2, 4, 8, or

A) SEA DATA 651-4 SAMPLING SCHEME



B) SEA DATA 651-4 BURST SAMPLING SCHEME



C) SEA DATA 651-4 TRANSMISSOMETER SAMPLING SCHEME

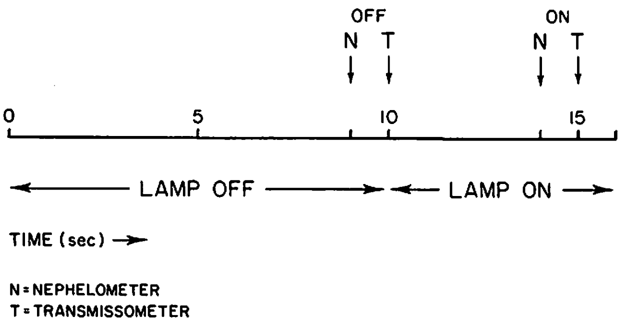


Figure 8-2. U. S. Geological Survey Tripod System Data Sampling Scheme: (see text for further discussion) (a) Interval and burst sampling scheme. The time at which data is written on the tape transport is indicated by I (record interval) or B (record burst); (b) Burst sampling scheme. Six measurement sets of rotor speed, pressure, and vane orientation are recorded in each burst record. The spacing between the burst samples is 2, 4, 8 or 16 sec. and 1-15 records (6-90 sample sets) comprise a burst; (c) Transmissometer-mephelometer sampling scheme.

16 seconds). The number of sample cycles within a burst (number of strobes in a burst) is adjustable from 6 to 90 strobes. Vector averaging electronics is not used for current measurements; the high frequency motions are of interest and are thus recorded.

For a typical four month deployment in 60-80 m of water, the basic sampling interval is 7.5 minutes, the burst rate is 4 seconds, and 12 samples (strobes) are made in a burst. The selection of the number of samples in a burst and of the burst rate for a deployment are primarily determined by water depth and experiment duration. Data record lengths for typical sampling selections are listed in Table 8-2. A larger number of data strobes and a faster burst rate are used in shallow water where the high frequency water waves reach the bottom. The basic sampling interval is selected to resolve the physical processes of interest; because the current meter is not vector averaging, the sampling interval must be rapid enough to prevent serious aliasing from motions that have time scales between wave periods and twice the basic sampling interval. Generally 7.5 minutes is adequate in winter when the water column is well mixed and the Brunt Vaisala period is long. In summer, when the Brunt frequency may be 10-15 minutes, a basic sampling interval of 3.75 minutes is selected.

The 35 mm camera is programmed to photograph the bottom at a fixed time interval, typically 2 or 4 hours for a 2 or 4 month deployment. In addition, logic circuitry has been developed to trigger the camera according to current speed, mainly to document bottom changes associated with high speed current event. In the present configuration, this conditional photographic sampling allows bursts of pictures. The photographic threshold (current speed above which a sequence of pictures is initiated), the number of pictures in a burst sequence, and the picture rate are adjustable within wide limits. The camera logic contains two provisions to avoid repetitious conditional picture taking and to insure that sufficient camera shots will be available for the evenly spaced time series; the total number of pictures triggered conditionally in a deployment may be specified, and the frequency at which the conditional logic is activated to examine current threshold may be fixed at a multiple of the basic instrument sampling interval.

Electronics

The data recording package utilizes low-power digital circuitry (Figure 8-3). The circular electronics rack fits inside a 15.5 cm (inner diameter) pressure housing; penetrators in the upper end-cap connect the data logger to the various sensors mounted on the tripod frame. Power is provided from stacks of alkaline batteries, arranged to give a 21 v 50 amp-hr supply. Two battery packs are used for a tripod deployment, one in the electronics pressure case and one in a

Table 8-2. Data capacity of Sea Data 651-4 data logger (with single tape transport) for a basic sampling interval of 3.75 min (A) and 7.5 min (B).

Strobes in Burst	Capacity (days)	
	A	B
6	104	208
12	69	138
18	52	104
24	41	82
30	34	68
36	29	58
etc.		

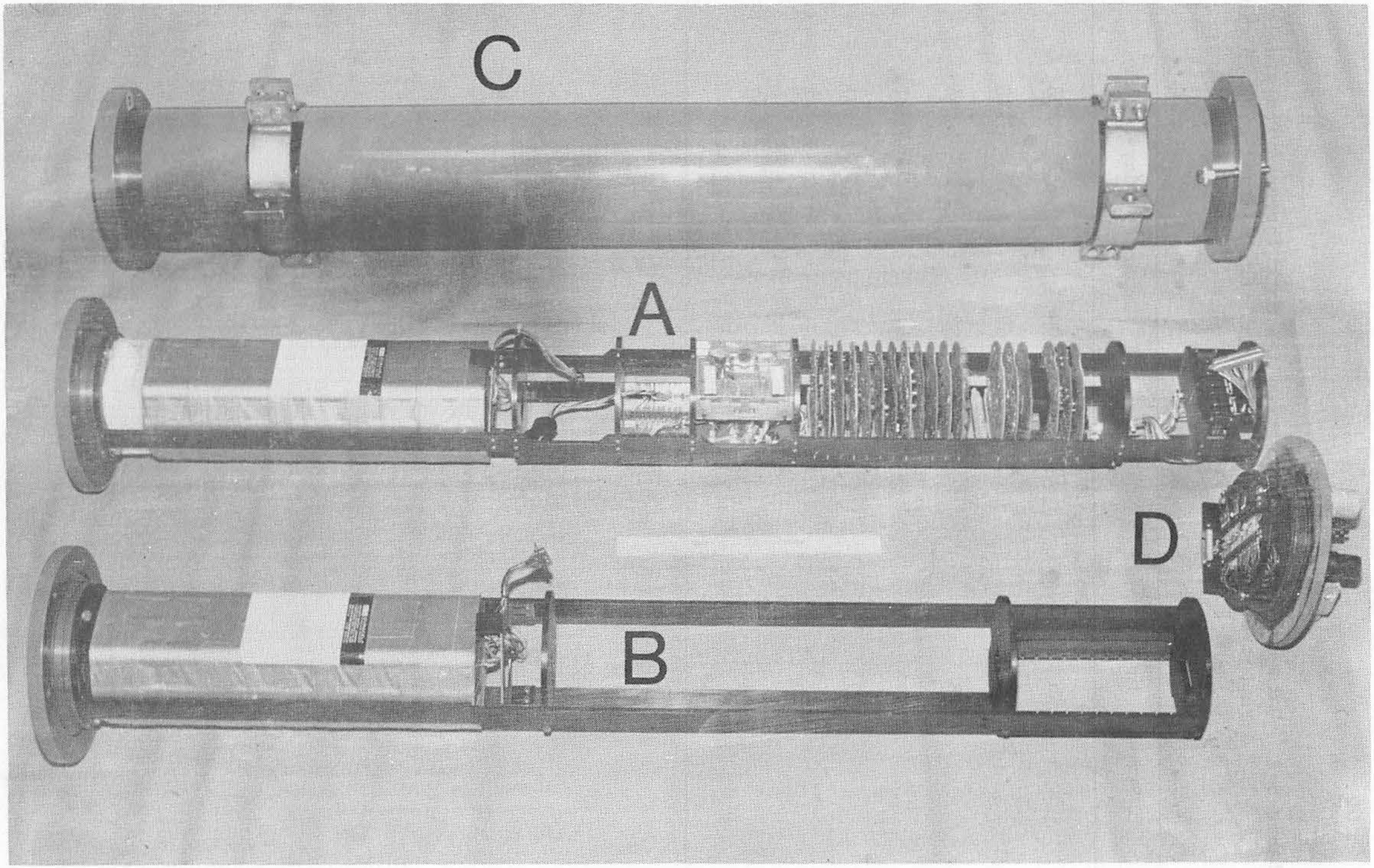


Figure 8-3. Sea Data Electronics (A), Battery Pack (B), Pressure Case (C), and End Cap (D).

separate battery pressure housing. The quiescent current drain of the data logger is approximately 5 ma; the 100 amp-hr supply is approximately twice as much as required for a typical deployment.

The incremental stepping digital cassette recorder writes four bits across the tape at a longitudinal density of 800 bits per inch. A longitudinal parity bit is written with each cassette record. Total cassette data capacity is 1.8×10^7 bits, or 10^5 data records of interval or burst type (interval and burst data records are of equal bit length). A burst record contains six samples of rotor speed, pressure, and vane direction. A second cassette recorder is planned to increase system data capacity.

Data Resolution and Accuracy

The resolution and estimated accuracy of the tripod measurements are summarized in Table 8-3. The accuracy has been determined from manufacturers' specifications and a limited in-house calibration program. The resolution for current speed and pressure depends on the time for which the measurements are averaged. In Table 8-3, the interval measurement resolution is for an averaging period of 225 seconds, and the burst measurement resolution is for an averaging period of 225 seconds, and the burst measurement resolution is for a burst rate of 4 seconds. For current direction, temperature, and light transmission, the resolution is determined by the number of bits used to represent the parameter digitally.

Tripod Frame: Deployment and Recovery

The tripod components are deployed and recovered attached to a rigid tripod frame (Figure 8-1) designed to cause minimum disturbance to the current flow and still be durable enough to withstand repeated deployments and harsh treatment at sea. The frame is 3.4 m high, 3.4 m on a base, and is constructed entirely of type 316 stainless steel; the major structural members of 6.03 cm (outer diameter) schedule 40 or 80 pipe. All components are bolted together; thus the frame can be dismantled and shipped easily. Instruments are mounted by means of clamshell-like brackets so that placement can be easily changed and adjusted, and so that additional instruments for specific studies can be attached and removed as required. All dissimilar metals are completely insulated from the frame by neoprene rubber or PVC blocks, and sacrificial zinc anodes are mounted at several places on the frame as well as on the instruments to minimize corrosion. A tripod with anchor pads and all instruments weigh approximately 950 kg (2100 lbs.) in air, and 600 kg (1300 lbs.) in water. Each lead anchor pad weighs 91 kg (200 lbs.) in air. On the basis of static calculations, the tripod is probably stable in steady currents as fast as 150 cm sec^{-1} (3 knots).

Table 8-3. Resolution and estimated accuracy of tripod measurements.

Variable	Resolution	Accuracy*
Current speed (cm sec^{-1})[1]		± 2.5
Burst (single sample)	1.2	
Burst (12 samples)	.1	
Interval	.02	
Current direction (degrees)	1.41	± 5
Pressure (millibars)		± 3
Burst (single sample)	∿ 1	
Interval	∿ .04	
Temperature (degrees centrigade)	.02	.1
Transmission (% full scale)	.05	∿ 5
Time (seconds)	56.25	1 in 10^5
Bottom photographs (cm)	.1 to 150	

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* Accuracy from manufacturer's specifications. Accuracy of transmissometer estimated from laboratory experiments. Current sensor accuracy is for steady conditions. Accuracy will be less under dynamic conditions (for instance, waves) (McCullough, 1975).

[1] Assumes burst rate of 4 seconds, interval period of 225 seconds.

For deployment, the tripod is lowered to the bottom on a braided polypropylene slip line; once the system is on the bottom, the deployment line is retrieved. The acoustic-release transponder is the system is fitted with a tilt switch which, when interrogated from the surface, modifies a reply code if the unit is tipped at an angle greater than 30° from the vertical. The release is interrogated immediately after deployment and before recovery to determine that the tripod is upright.

For recovery, a coded acoustic command from the surface actuates the release; a float pulls one end of a 100 m long, 1.6 cm (5/8") diameter nylon line from a rope cannister on the tripod to the surface. A radio transmitter and strobe light are mounted on the float to enable it to be located on the surface. The entire tripod frame is recovered with the nylon line.

We deploy one to four large lighted buoys (Figure 8-4) around the tripod site so that fishermen can identify the instrument location and avoid fouling their nets.

DATA PROCESSING AND QUALITY CONTROL

Once a tripod is recovered, the data are decoded, reviewed, and edited prior to scientific analysis and display. They are first transcribed from the digital cassette to a nine track tape. The clock values are examined for erroneous sequencing, and the sequence of interval and burst records is checked. Sections of the data are dumped in binary, in decimal, or in engineering units and are reviewed to assess sensor performance and general data quality. The entire data record is then decoded, applying appropriate sensor calibrations, and is placed on nine track tape in a convenient format (Maltais 1969).

The decoding program computes and stores 16 data variables derived from the burst and interval measurements (Table 8-4). East current, north current, current direction, and current speed are computed from the burst measurements of current speed and direction. The ratio of burst vector current speed to average burst rotor speed (called burst normalized unit vector, BNUV) is computed as a measure of the current variability within a burst. The ratio of average burst rotor speed to interval rotor speed (called BROTOR/IROTOR) is also computed as a measure of the variability of current flow between burst and interval measurement periods. The standard deviation of the burst pressure measurements is computed as a first order indicator of wave induced pressure fluctuations. Spectra of the burst pressure measurements can be calculated to resolve frequency and amplitude of the high frequency pressure field. Finally, the difference between average burst pressure and interval pressure is computed as a crude measure of the pressure variability between burst and interval time

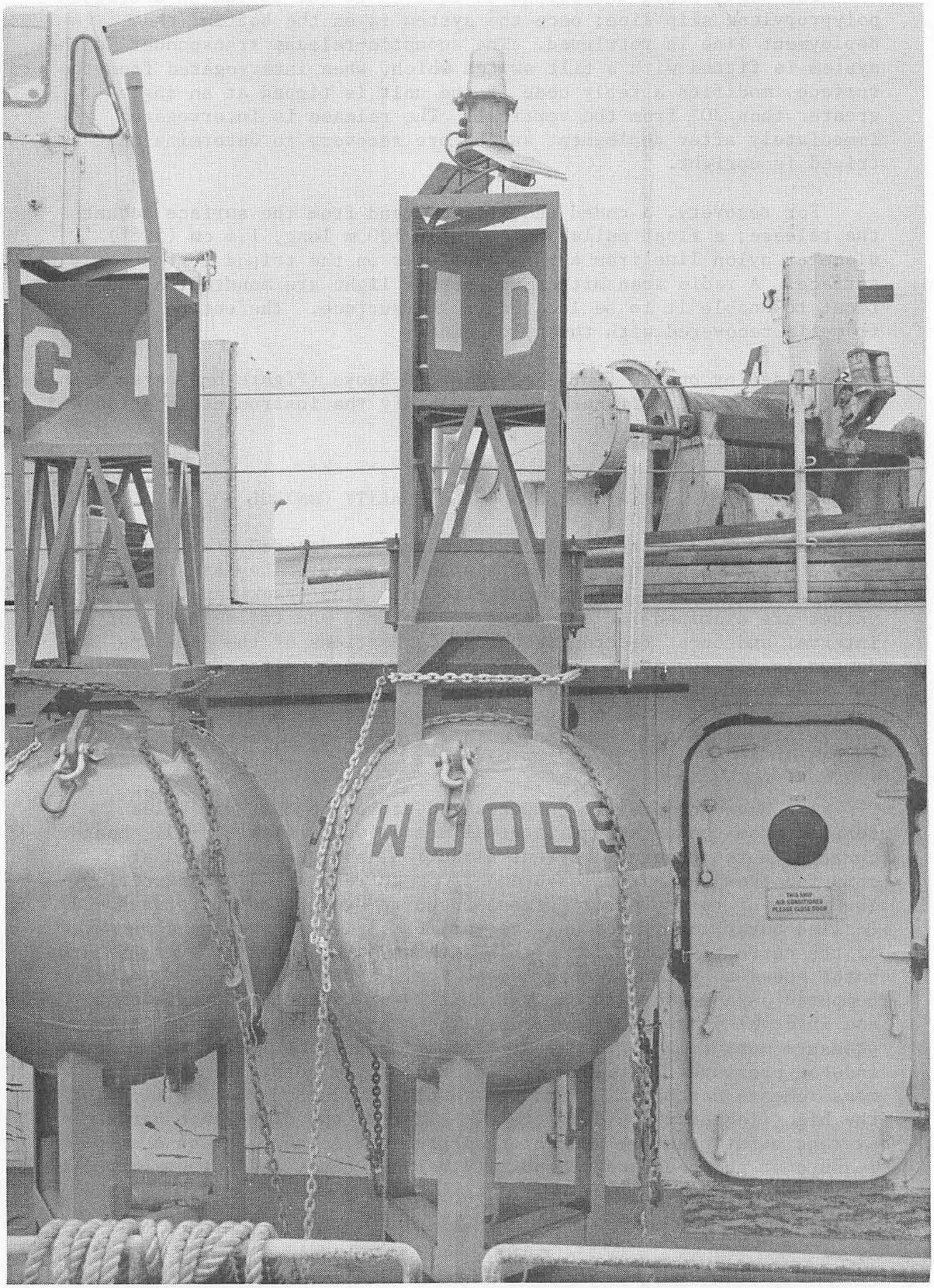

Figure 8-4. Surface buoy used to mark tripod locations.

Table 8-4. U. S. Geological Survey tripod system - measured and derived parameters.

Variable	Units	Definition
1. East current	cm sec^{-1}	computed from burst speed & direction pairs
2. North current	cm sec^{-1}	same as variable 1
3. Current speed	cm sec^{-1}	computed from variables 1 and 2
4. Current direction	degrees	computed from variables 1 and 2
5. Interval rotor	cm sec^{-1}	average rotor speed over basic interval
6. Interval pressure	mb	average bottom pressure during basic interval
7. Temperature	^{o}C	temperature inside instrument pressure case endcap
8. Average burst-interval pressure	mb	average burst pressure - variable 6
9. Burst pressure standard deviation	$(mb)^2$	standard deviation of burst pressure
10. Burst rotor speed/ interval rotor speed	non-dimensional (ratio)	average rotor speed in burst ÷ variable 5
11. Burst normalized unit vector	non-dimensional (ratio)	vector current speed ÷ scalor current speed
12. Transmissometer (trans.) off	relative units	trans. output with lamp off
13. Transmissometer on	relative units	trans. output with lamp on
14. Nephelometer (neph.) off	relative units	neph. output with lamp off
15. Nephelometer on	relative units	neph. output with lamp on
16. Time	sec.	internal digital quartz clock

scales and as an instrumental check.

After decoding, the data are displayed in a time histogram format which is convenient for rapid review of data quality and for identification of erroneous data points. Bad values are replaced by linearly interpolated data points. After editing, the data are again displayed to verify that the improper points have been replaced. This extensive editing procedure is necessary to insure that the data set used for scientific analysis is free of erroneous data points. Typically fewer than 50 points in 2×10^5 (0.02%) require editing.

Once the data are edited and stored at the basic sampling interval, many programs are available to time-average, manipulate, and display the data. The programs are part of the extensive Woods Hole Oceanographic Institution Buoy Group library used to process time series data.

U.S. GEOLOGICAL SURVEY SEDIMENT TRANSPORT STUDIES

We have constructed nine bottom tripod systems for a cooperative program with the U.S. Bureau of Land Management (BLM); this program is designed to investigate processes of sediment mobility in the three major petroleum lease areas on the Continental Shelf of the United States East Coast. Observations have been made on Georges Bank, in the Middle Atlantic Bight, and in the South Atlantic Bight (Figure 8-5). These areas differ widely in factors that affect sediment movement, for example, meteorological and oceanic forcing, depth, topography, tidal range, river input, and biological populations.

In each area, one tripod is maintained continuously at a selected location to provide long-term observations of sediment movement. If possible, the long-term station is located where meteorological observations are also made so that correlations between atmospheric forcing and sediment movement can be made. The BLM environmental studies have supported U.S. Department of Commerce National Data Buoy Office (NDBO) meteorological buoys in all the lease areas; the buoys provide wind, atmospheric pressure, sea surface temperature and, in several locations, surface wave observations. Shorter term measurements of the cross-shelf and alongshelf variability of the processes of sediment resuspension and transport are made by means of a second tripod system. At present, measurements have been made primarily in mid-shelf regions where tracts have been leased or nominated for leasing. Nearshore measurements to study sediment movement in shallow water and to address specific pipeline corridor problems as well as measurements on the Continental Slope are planned.

In areas where the regional circulation pattern is not well understood, tripod measurements are coordinated with ongoing physical oceanographic programs. Limited studies of the near bottom currents

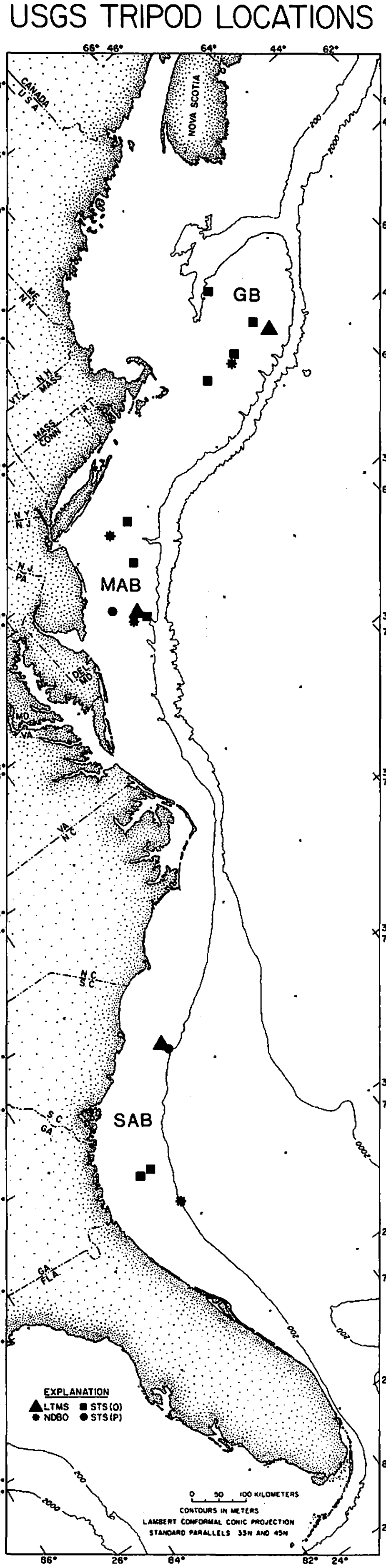

Figure 8-5. Locations of U. S. Geological Survey tripod deployments on U. S. East Coast Continental Shelf. [LTMS (▲) = Long term monitoring station; STS (0) (■) = occupied short-term monitoring station; STS (P) (•) = proposed short-term monitoring station; NDBO (*) = environmental buoys]. The three major petroleum lease areas on the East Coast shelf are located on Georges Bank (GB), in the Middle Atlantic Bight (MAB), and in South Atlantic Bight (SAB).

and the regional circulation are also conducted by means of conventional instruments where additional observations are needed. Hydrographic observations are made on each instrument deployment and recovery cruise to determine the position of the tripod with respect to the various coastal and oceanic water masses.

EXAMPLES OF OBSERVATIONS

Observations made during the winter of 1976-1977 by means of a tripod system on the southern side of Georges Bank near the mean position of the shelf-slope water front showed frequent resuspension of the surficial bottom material (Figures 8-5, 8-6, and 8-7) and are typical of measurements made to date. The current and pressure signals were dominated by the semidiurnal tide. The semidiurnal tidal current rotated clockwise; the major axis of the tidal ellipse was oriented approximately 20° west of north. The magnitude of the major and minor axes was 21 cm sec^{-1} and 13 cm sec^{-1} respectively. During the first month of the deployment, the bottom temperature gradually decreased from 16° to 6°C, as the shelf-slope water front apparently moved offshore. The temperature signal was also modulated by the semidiurnal tide. Short periods of steady flow having magnitude greater than the tidal current to the west and east were observed (30-31 December 1976, and 8 January 1977, for example).

The transmissometer indicated changes in suspended sediment concentrations caused by several processes (Figure 8-6). The cold shelf water is generally less turbid than slope water (Milliman and Bothner 1977). Gradual movement of slope water offshore at the tripod location and a corresponding decrease in transmission took place during the first month of the deployment. A rapid temperature decrease on 25 December 1976, indicating offshore movement of the front, was associated with a drop in relative transmission; conversely, a temperature increase on 1-2 January was associated with an increase in relative transmission, suggesting onshore movement of the front.

The peaks in PSDEV (pressure standard deviation) and slight drops in BNUV (burst normalized unit vector) in December and January indicate periods when surface waves were large (Figure 8-6). The storm on 21-22 December in which the ARGO MERCHANT broke apart is clearly shown. Increases in PSDEV on 8, 13, 22, 27 December, 8, 11, 28, 29 January, and 7 February are correlated with a marked decrease in transmission. For scale, the amplitude of bottom pressure fluctuations associated with an 11-sec wave having a 2 m peak-to-trough amplitude in 85 m of water is 14 mb, and maximum bottom current speed is 8 cm sec^{-1}. Superimposed on the wave resuspension events and low frequency variations in transmission (attributed to movements of the shelf-slope water front) were variations in suspended concentration at the tidal period and at harmonics of the tidal

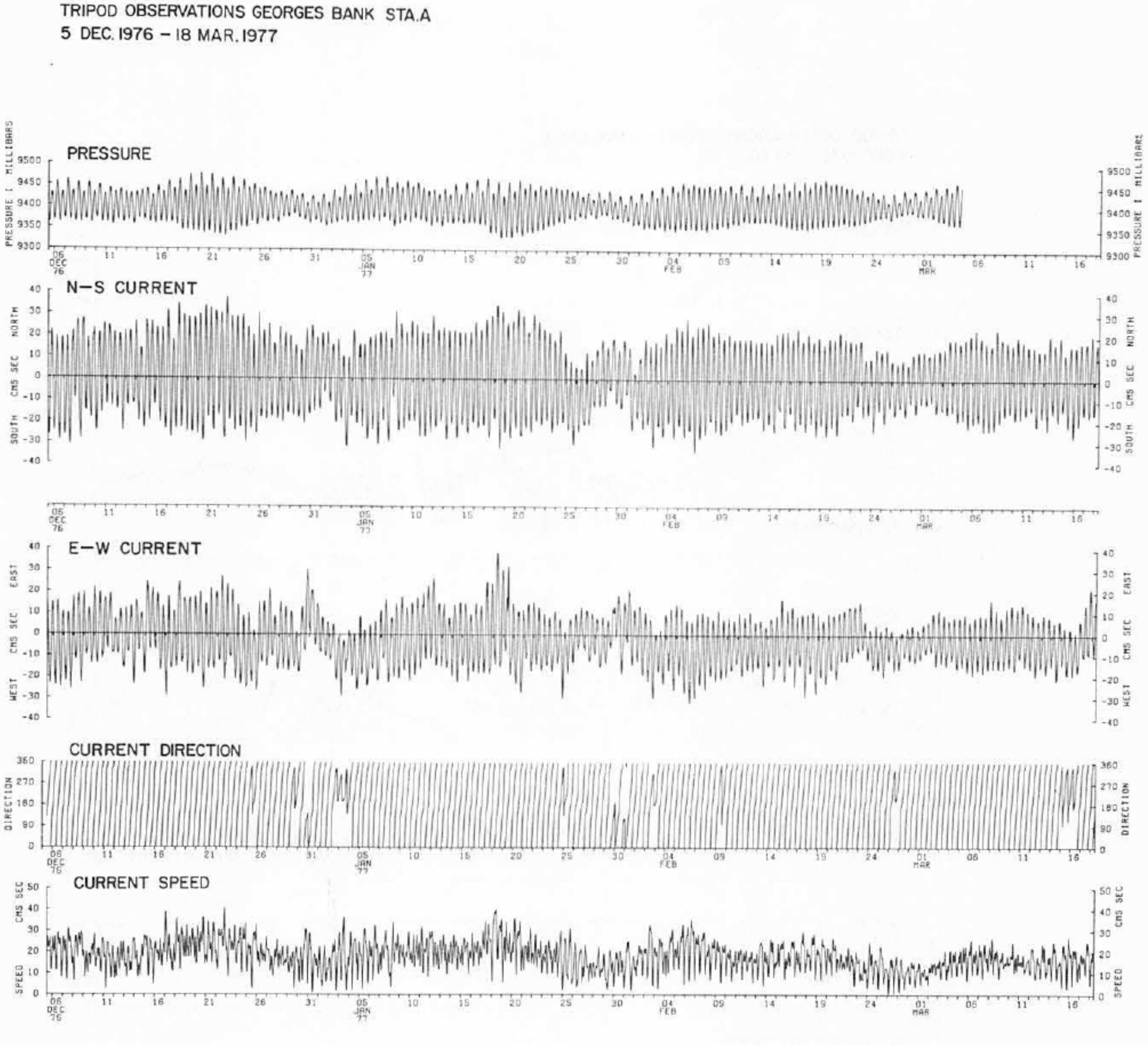

Figure 8-6. Tripod observations from southern flank of Georges Bank, winter 1967-1977. (a) Bottom pressure, north-south current, east-west current, current direction and current speed (continued)

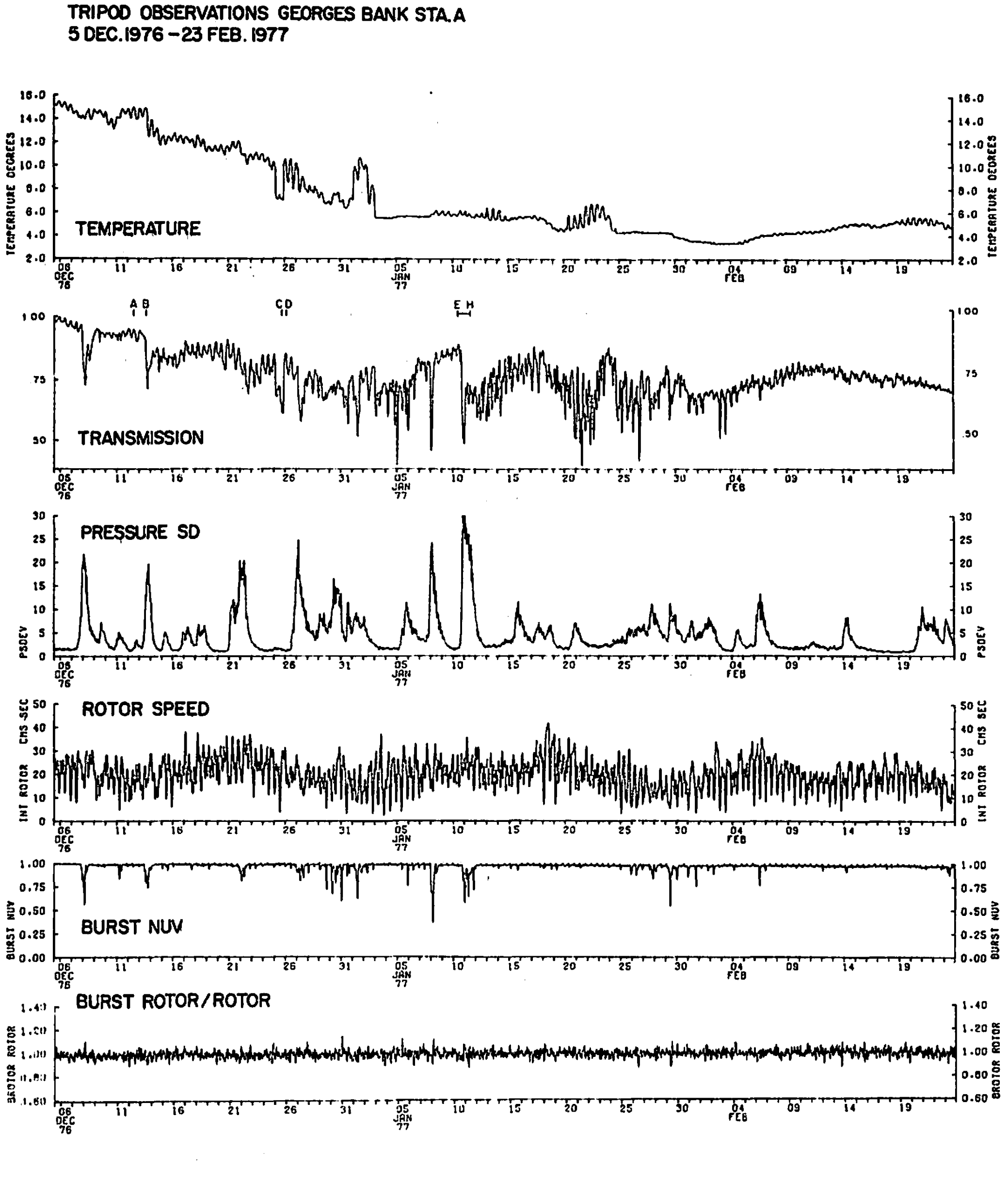

Figure 8-6. (b) Temperature, relative light transmission (normalized by maximum observed value), pressure standard deviation, internal rotor speed, burst normalized unit vector, and burst rotor/interval rotor. Calibration from field observations made in calm weather suggests that a relative transmission of 1.0 = .5 mg l^{-1}, and .5 = 1.0 mg l^{-1}.

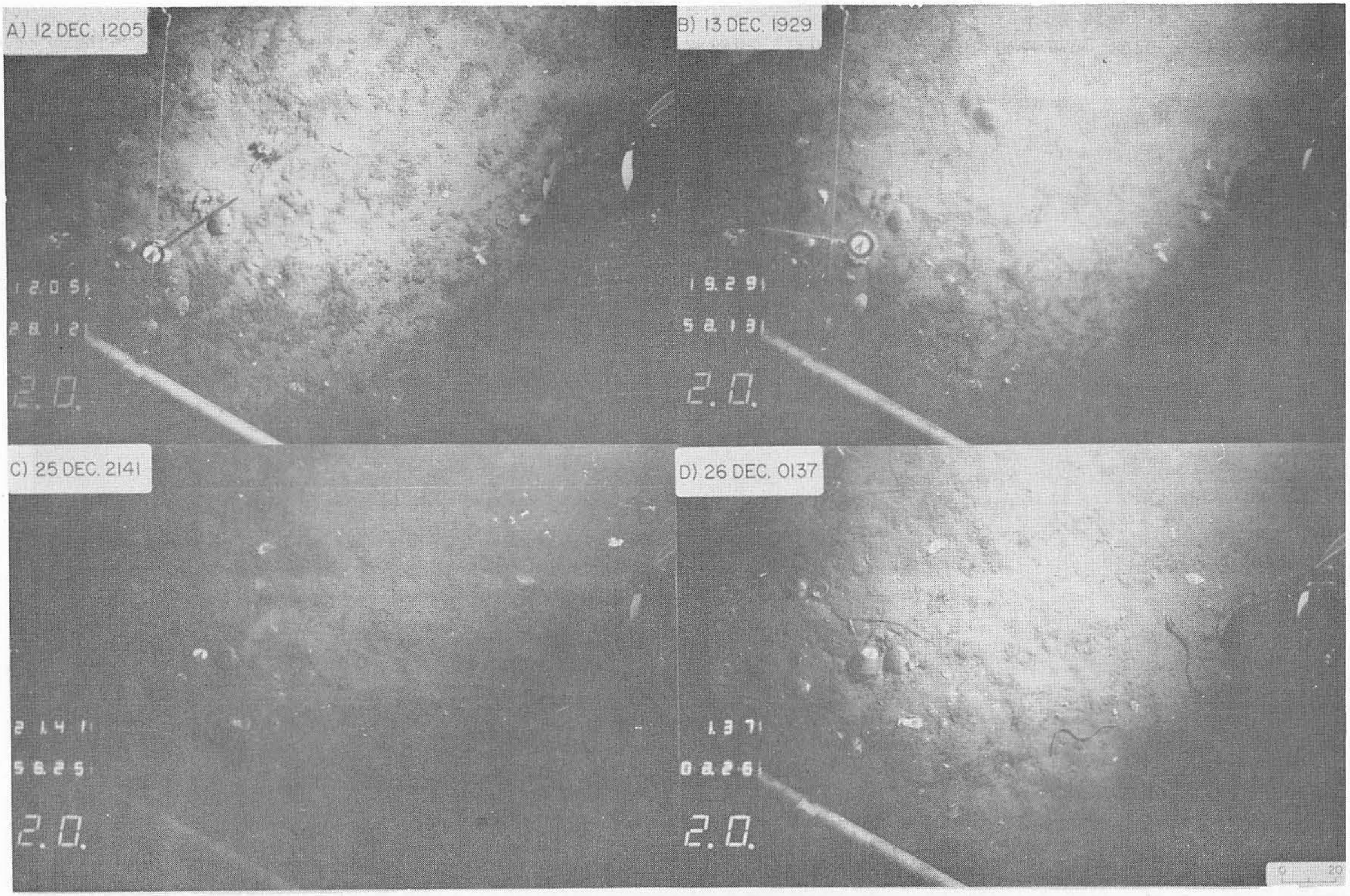

Figure 8-7 (concluded). (e) 1336 Jan. 10, 1977; (f) 1731 Jan. 10, 1977; (g) 0120 Jan. 11, 1977; (h) 1303 Jan. 11, 1977. Date and time when bottom photographs were taken are indicated in upper left hand corner of photograph. Scale in lower right corner is 0-20 cm.

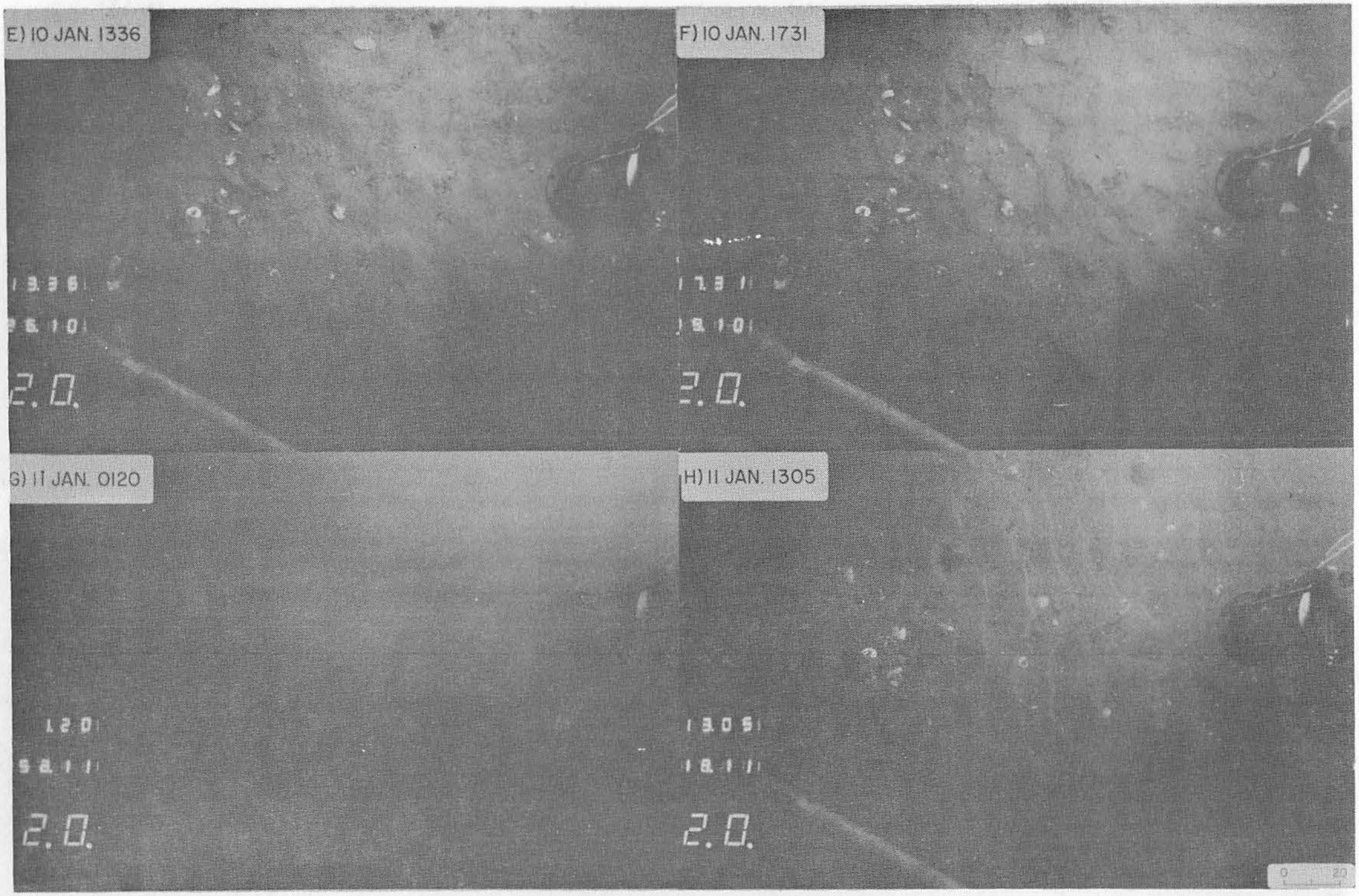

Figure 8-7. Typical bottom photographs from Georges Bank tripod deployment December 1976-February 1977 (water depth = 85 m). North is at 1 o'clock. The total viewing area is approximately 2.3 x 1.6 m. (a) 1205 Dec. 12, 1976; (b) 1929 Dec. 13, 1976; (c) 2141 Dec. 25, 1976; (d) 0137 Dec. 26, 1976; (continued)

period.

Bottom photographs taken on Georges Bank illustrate scour and other changes in bottom microtopography. They also show, qualitatively, changes in suspended sediment concentrations caused by tidal currents, surface waves, and water mass variability (Figure 8-7). The clarity of photographs taken in the warm slope water at mooring site A early in December 1976 indicates a low level of suspended sediment (see photograph taken on 12 December, Figure 8-7a). On 13 December (Figure 8-7b), apparently in response to an increase in surface waves (Figure 8-6, see pressure standard deviation), small ripples formed, and suspended matter in the water increased. An intrusion of cool turbid shelf water occurred at the mooring site on 25 December (Figure 8-7c); the photographs appear underexposed because of the increase in suspended material. A return to clearer water took place on 26 December (Figure 8-7d). Bottom sediments were resuspended sufficiently on 11 January to entirely obscure the bottom from view; this resuspension was associated with large surface waves (Figures 8-7e-h).

Observations off the New Jersey coast during winter were similar to those acquired on Georges Bank, but tidal currents were weaker. However, during summer, turbidity was observed when no storms or large waves were present. Bottom photographs (Figures 8-8a-d) made in July and August 1977 on the Outer Continental Shelf off New Jersey showed resuspension of the surficial sediments, probably due to bottom trawling. The sea floor on 7 August 1977 was tranquil and was covered by a thin layer of fluffy material (Figure 8-8a). Resuspension of bottom sediments or advection of turbid water past the tripod site obscured the bottom from view (Figure 8-8b). The tripod orientation with respect to north shifted between 7 and 8 August, and again on 9 August. Bottom current records show no large bottom flow; we suspect that the tripod movement and the observed sediment resuspension were due to bottom trawling. Many hake were at the tripod site.

DISCUSSION

Knowledge of the frequency, direction, and extent of bottom sediment movement on the sea floor of the Continental Shelf is important to assess the environmental consequences of many potential uses of the shelf area. For example, decisions on disposal of drilling muds, drill cuttings, dredge spoil, or industrial wastes on the sea floor require information on the expected patterns and extent of dispersal of dumped material. Information on sediment stability and anticipated scour around structures is necessary for offshore petroleum exploration and development, particularly for planning and constructing offshore pipelines. Dispersal and distribution of sediments, particularly the finer material which may accumulate the most toxic pollutants from offshore activity, is important to

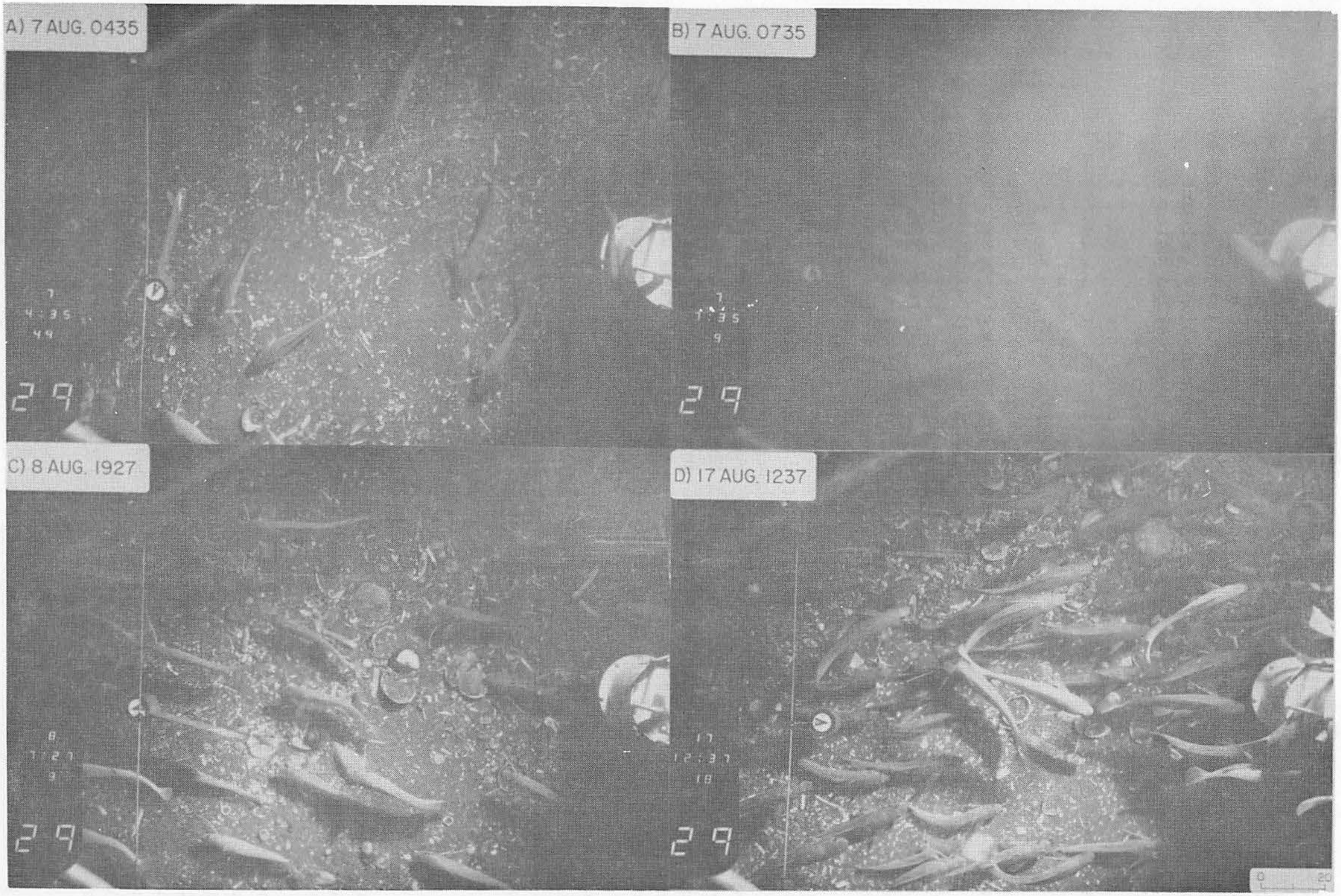

Figure 8-8. Typical bottom photographs from summer tripod deployment off New Jersey July-September 1977 (water depth = 65 m). The tripod moved twice during this picture sequence with respect to north. Total picture viewing area is approximately 2 x 1.4 m. (a) 0435 Aug. 7, 1977; (b) 0735 Aug. 7, 1977; (c) 1927 Aug. 8, 1977; (d) 1237 Aug. 17, 1977. Date and time when bottom photographs were taken are indicated in upper left corner of photographs. Scale is 0-20 cm. The tripod movement was probably caused by bottom trawlers (see text).

determine the effects of these materials on the unusually productive biological communities of the shelf region. Spatial and temporal variability of bottom stress on the Continental Shelf may also significantly affect shelf circulation.

Deployments of the bottom tripod systems on Georges Bank and on the New Jersey Continental Shelf have shown bottom sediment resuspension and transport caused by surface waves, tidal currents, and storms. The fine sediments can be transported 10-20 km alongshore in the mid-shelf region during one winter storm; thus fine material could be distributed over significant areas of the shelf in several years.

The intermittent and seasonal nature of sediment movement on the shelf indicates the absolute necessity of continuous long-term monitoring of bottom conditions to adequately define the frequency and processes of bottom sediment transport. Short-term measurements have been misleading. Several months of observation appear adequate to determine the typical influence of surface waves, internal waves, tides and storms on the bottom at one location during a particular season. Several years of observation are probably required to assess seasonal variability, whereas many years of continuous observation (or different measurement techniques) may be necessary to determine the influence of catastrophic events. Simultaneous observations from tripod arrays and in the water column are required to determine the large scale regional sediment transport patterns and the variability of processes on the shelf. The diversity of transport mechanisms also indicates the need for multisensor instrument packages that measure the appropriate physical parameters. For example, interpretation of the transmission record presented in this paper would be extremely difficult without simultaneous current, wave, temperature, and visual observations. The sensor sampling scheme must resolve both low frequency and high frequency processes.

Future deployments of the instrument systems should continue to increase and refine our rather crude understanding of local bottom processes and of regional sediment transport on the Continental Shelf.

ACKNOWLEDGEMENTS

Winfield Hill (Sea Data Corporation) designed and constructed the data recording package used on the tripod to U. S. Geological Survey specifications and provided invaluable assistance throughout the program. Marlene Noble and William Strahle (USGS), and Dave Hosom, Woods Hole Oceanographic Institution (WHOI), have made substantial contributions to the engineering design and construction of the systems. John West, Charles Deadmon, Stephanie Pfirman, and Gary Prisby (all of USGS) assisted in tripod deployment, maintenance, contruction, and data processing. The Woods Hole Oceanographic

Institution assisted in design, construction and maintenance of the tripod systems. The use of the WHOI Buoy Group data processing program library is gratefully acknowledged. A similar tripod system has been constructed by USGS, Office of Marine Geology, Pacific Arctic Branch, which utilizes four electromagnetic current sensors to obtain a current profile in the bottom 2 m.

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