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GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGIC STUDIES ON THE UNITED STATES MID- AND NORTH ATLANTIC OUTER CONTINENTAL SHELF AREA 1980-1982

VOLUME I. EXECUTIVE SUMMARY

By

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VOLUME I.

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INTRODUCTION

Our nation's increasing demands for natural resources have stimulated activity and interest in the potential of the Atlantic Outer Continental Shelf (OCS). An understanding of the geological processes and transport pathways of the continental margin is extremely relevant to assessing man's activity, safety, and impact on the marine environment. The Outer Continental Shelf (OCS) Lands Act of 1953 established U.S. jurisdiction over the submerged lands of the Continental Shelf seaward of the state boundaries. The Act made the Secretary of the Interior responsible for administration of the mineral exploration and development of the OCS and for formulating regulations so that provisions of the Act might be met. Subsequent to the passage of the OCS Lands Act, the Secretary of the Interior designated the Bureau of Land Management (BLM) as the administrative agency for leasing of submerged Federal Lands and the U.S. Geological Survey for supervising production.

The National Environmental Policy Act of 1969 required all Federal agencies to utilize a systematic, interdisciplinary approach in order to ensure the integration of natural and social sciences in any planning and decision making which may have impact on man's environment. The BLM responded to this Policy Act by instituting and funding Environmental Assessment Teams, marine environmental data-acquisition and analysis studies, literature surveys, socio-economic analysis studies, public conferences, and special studies, which result in comprehensive Environmental Impact Statements (EIS). The objective of the BLM environmental studies program is to provide resource managers with timely and usable information to support management decisions concerning OCS leasing and possible subsequent oil and gas development. The BLM entered into agreement with the U.S. Geological Survey (USGS) so that the USGS would provide data and information in the "Regional Studies Plan for the North and Mid-Atlantic Regions" (fig. 1). Since 1975, USGS and BLM have been conducting studies to assess the environmental conditions of the OCS. Data from these studies provided environmental information for several OCS Lease Sales, Mid-Atlantic 40, 49, and 59 and North Atlantic 42 and 52.

SCOPE

The general purpose of the BLM studies program is to provide information with which to (1) make rational decisions regarding the development of mineral resources of the federal OCS area; (2) evaluate the impact of oil and gas development on the marine environment; and (3) determine if modification of leasing regulations, operating regulations, or OCS operating orders is necessary to permit more efficient resource recovery with maximum environmental protection (Popenoe, 1981).

The USGS involvement in this program for BLM as defined in Memorandum of Understanding AA851-MU0-18 and Interagency Agreements AA851-IA1-17 and AA851-IA2-26 provides geologic and oceanographic information to address specific data needs of the BLM. The specific objectives of the USGS-BLM geologic research program for FY 80, 81, and 82 in the North and Mid-Atlantic OCS regions were: (1) to document shelf-canyon, shelf-slope, and slope-canyon bottom and current processes by obtaining field measurements of currents, temperature, density, and suspended sediments; (2) to characterize currents in Lydonia Canyon; (3) to establish a long-term monitoring program for currents

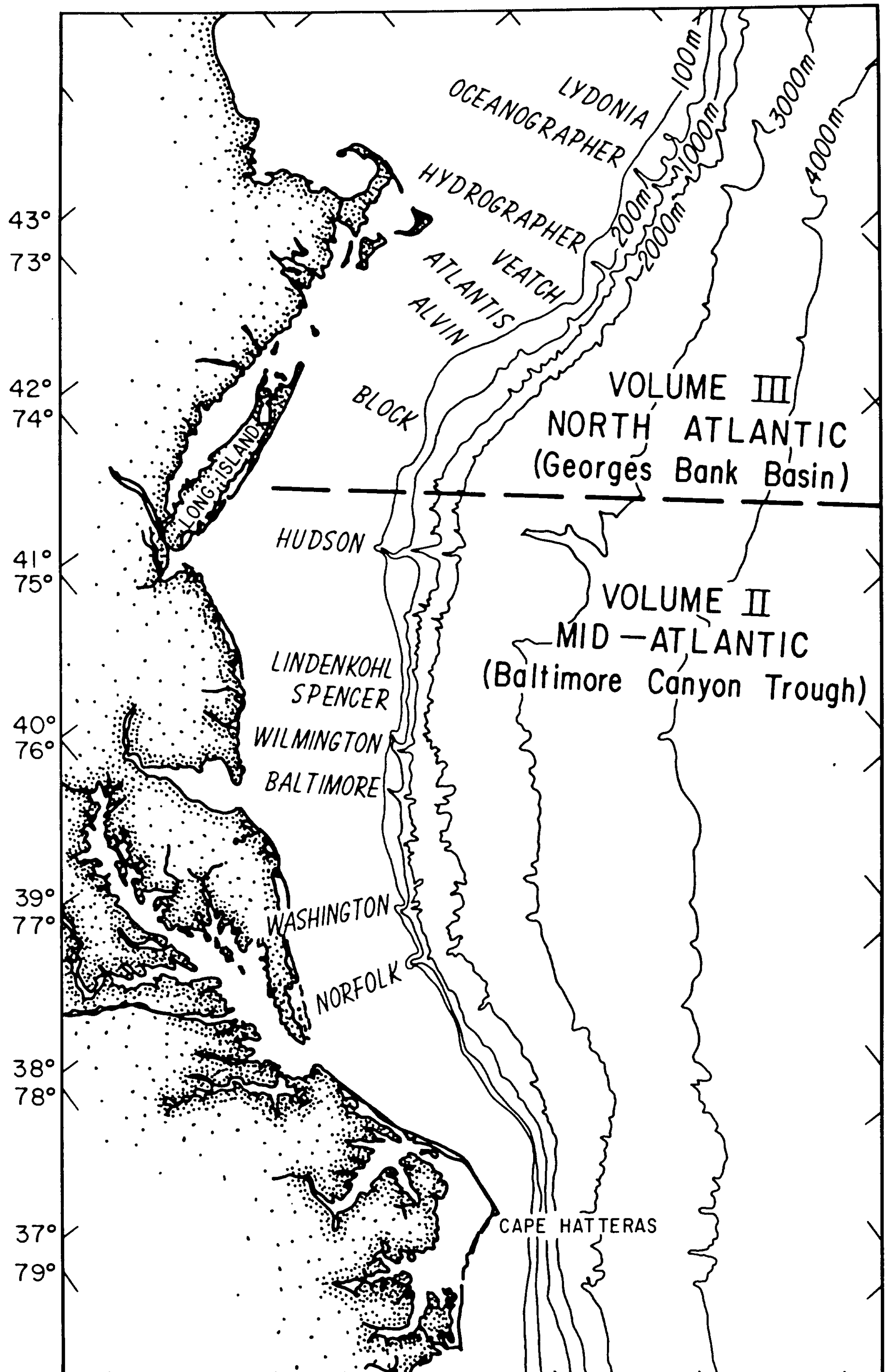

Figure 1. Index map showing the regional areas covered by Volumes II and III, (McGregor, 1983a, b).

in Lydonia and Oceanographer Canyons such that the seasonal variability and differences in canyon processes can be described; (4) to describe the transport mechanisms, currents, processes, and sediment properties on the Continental Slope and Rise that influence sediment and pollutant movement into and through submarine canyons; (5) to describe and map the morphology and shallow structure of the heads of Lydonia and Oceanographer Canyons and the adjacent shelf and slope in order to identify the processes responsible for shaping them so that pollutant transport into the canyons can be evaluated; (6) to determine the rate and direction of sand-wave movement and to define areas of sand erosion and accumulation for Georges Bank; (7) to texturally characterize sediments from the axis and walls of Lydonia Canyon and to determine the distribution of heavy metals and petroleum hydrocarbons; (8) to identify and map areas of mass sediment movement on the Continental Slope and in canyon areas and to relate movements to erosional processes within submarine canyon systems; (9) to assess the geotechnical properties of sediments in the areas of Lease Sale 49, 52, and 59; (10) to define the shallow subbottom stratigraphy and to identify potential geologic hazards for the nearshore environment in the Mid-Atlantic; and (11) to estimate the extent and rate of bottom sediment movement and to identify the major processes causing sediment movement with respect to seasonal variability and dynamics of currents.

This three volume final report presents (1) the methods, techniques, instruments, and procedures used to address the specific objectives listed above and (2) the results, interpretations, and conclusions originating from the research program. This volume of the report is a brief summary of Volumes II and III, but it in no way covers all of the results of the individual studies. Volume II addresses the objectives and the studies in the Mid-Atlantic OCS region, and Volume III covers those of the North Atlantic OCS region (fig. 1) (McGregor, 1983a, b).

ACKNOWLEDGMENTS

The investigations reported in this final report were carried out by the personnel of the USGS in Woods Hole, Massachusetts, and Reston, Virginia. In addition to the principal investigators, scientists, and technical staff who assisted in the data and sample analyses and preparation of this report, many other staff members participated in the cruises that collected the geological and oceanographic data.

The overall program was managed by Harley J. Knebel, USGS. Special appreciation is extended to Nancy Soderberg, USGS, who coordinated, typed, and supervised the preparation of this final report. Her assistance has been invaluable throughout the execution of the research program.

The BLM personnel who have supported the environmental geological oceanography program and aided in its direction have been Jeffrey Petrino, Contracting Officer, and Eiji Imamura, the Contracting Officer's Authorized Representative (COAR).

FIELD WORK

Twenty-six cruises were conducted over the three-year period by the U.S. Geological Survey to collect data and samples and to make observations and measurements in support of the cooperative USGS-BLM Environmental Program. Tables 1 and 2 summarize the field work completed during FY 80, 81, and 82. Additional data were collected aboard DSRV ALVIN in the Mid-Atlantic area. These dives were supported by funding from other sources.

The equipment used and the data collected on the numerous cruises were quite varied. The suite of geophysical data consisted of seismic-reflection airgun (40-in^3), 3.5 kHz, minisparker (800 joule), and Uniboom profiles, and sidescan sonographs (both shallow and deep water). Sediments were collected with a piston corer, gravity corer, grab sampler, bag sampler, and sediment traps. Temperature, salinity, transmissivity, current velocity, and current direction measurements were taken within the water column. Time-lapse photographs of the sea floor were used in conjunction with the current-meter and transmissivity data. Navigation for the geophysical surveys and positioning of the sample collection sites was based on LORAN-C. Two cruises, a geophysical survey in the Mid-Atlantic and a cruise in the North Atlantic regions, used an Integrated Navigation System (INS) which adjusted the LORAN-C positions with transit satellite information.

GEOLOGIC SETTING

In this final report, the Atlantic continental margin has been divided into two regional study areas, the Mid and the North Atlantic, based on the regional association with two of the deep structural basins of the margin, the Baltimore Canyon Trough and the Georges Bank Basin (Schlee and others, 1976; Grow and others, 1979; Klitgord and Behrendt, 1979). These two basins underlie the Continental Shelf and Slope, and are of interest because of their petroleum potential. The studies discussed in this report address the impact of the geologic hazards of the Continental Shelf, Slope, and Rise on petroleum-related activities and the possible impact of these activities on the environment of the continental margin.

Shelf

The Continental Shelf in the North and Mid-Atlantic is a broad shelf, over 120 km wide, which is mantled by a relict sand sheet (Emery and Uchupi, 1972; Milliman and others, 1972) except for a section on the southern New England shelf called the mud patch which has an accumulation of fine-grained sediment (Bothner and others, 1981; Twichell and others, 1981). The thickness of the sand sheet is variable from 0 to 20 m thick on the Mid-Atlantic shelf and up to 40 m thick on the North Atlantic shelf and is mappable using seismic-reflection profiling techniques (Knott and Hoskins, 1968; Knebel and Spiker, 1977). The morphology of the shelf consists of linear sand ridges (Veatch and Smith, 1939). Although extensively studied, the origin of this morphology is still debated. Swift and others (1972) believe the shelf surface was shaped by erosional shoreface retreat during the Holocene transgression, whereas McClennen and McMaster (1971) revived Shepard's (1948) hypothesis that the ridges were overstepped barriers and, therefore, early Holocene to pre-Holocene in age. Further studies on the New Jersey shelf indicate increasing complexity. The shelf ridges can be grouped into two populations with each population associated with one of the origins enumerated above (Stubblefield and others, 1983). Whatever the origin, relict or modern, ocean currents on the shelf especially during storms rework and redeposit the sand (Butman and others 1979; Vincent and others, 1981). Tidal currents are

Table 1. Summary of cruises conducted in the Mid-Atlantic area in support of the USGS-BLM Environmental Program, FY 80, 81, 82

Cruise ID	Dates	Purpose	No. of samples	Navigation	Chief Scientist
WHITEFOOT 80-1	June 11-19, 1980	Seismic-reflection 3.5-kHz, Uniboom, sidescan	888 km	LORAN-C	C. E. McClennen
R/V GYRE 80-G-7*	Aug. 6-23, 1980	Seismic-reflection 40-in^3 airgun, 3.5-kHz, minisparker	1,436 km	LORAN-C	J. M. Aaron
R/V GYRE 80-G-8*	Aug. 28-Sep. 14, 1980	Midrange sidescan, 3.5-kHz	665 km	LORAN-C	J. M. Robb
R/V ENDEAVOR EN-056*	Sep. 24-Oct. 16, 1980	Piston core, gravity core 3.5-kHz profiles	38 stations 1,082 km	LORAN-C	J. S. Booth
R/V GYRE 82-G-10	Aug. 26-Sep. 14, 1982	Seismic-reflection 40-in^3 airgun, 3.5-kHz, minisparker, Narrow-beam bathymetry	2,877 km 600 km 342 km	Int.Nav.Sys.	B. A. McGregor

*Cruises on which data were collected in both the Mid-Atlantic and North Atlantic

Table 2. Summary of cruises conducted in the North Atlantic area in support of the USGS-BLM Environmental Program, FY 80, 81, 82

Cruise ID	Dates	Purpose	No. of samples	Navigation	Chief Scientist
R/V OCEANUS 77	Dec. 13-20, 1980	Deploy tripod, current-meter moorings	9	LORAN-C	B. Butman
		Recover tripod, current-meter moorings	4		
		Surface-salinity samples	57		
		CTD casts	10		
		XBT´s	49		
WHITEFOOT I, II, III	Jan. 3-23, 1980	Deploy current meter, sediment trap	1	LORAN-C	B. Butman
		Recover tripod, current-meter moorings	2 1/2		
R/V OCEANUS 81	May 23-June 1, 1980	Deploy tripod, current-meter moorings	6	LORAN-C	B. Butman
		Recover tripod, current-meter moorings	9		
		CTD casts	43		
		XBT´s	49		
		Surface-salinity samples	93		
		Box cores	10		
		Grab samples	6		
WHITEFOOT WF 80-2	June 23-26, 1980	3.5-kHz profiles, sidescan	52 km	LORAN-C	D. C. Twichell
R/V GYRE 80-G-7*	Aug. 6-23, 1980	Seisimc-reflection 40-in^3 airgun, 3.5-kHz, minsparker	1,072 km	LORAN-C	J. M. Aaron
R/V LULU-DSRV ALVIN	Aug. 27-Sep. 5, 1980	Dives	9	LORAN-C	R. A. Slater
R/V GYRE 80-G-8*	Aug. 28-Sep. 14, 1980	Midrange sidescan, 3.5-kHz	330 km	LORAN-C	J. M. Robb
WHITEFOOT WF 80-3	Sep. 22-24, 1980	3.5-kHz profiles, sidescan	70 km	LORAN-C	D. C. Twichell
R/V ENDEAVOR EN-056	Sep. 24-Oct. 16, 1980	Piston core, gravity core	38 stations	LORAN-C	J. S. Booth
		3.5-kHz profiles	1,082 km		
R/V OCEANUS 88	Oct. 23-31, 1980	Deploy current-meter moorings	8	LORAN-C	B. Butman
		Recover current-meter moorings	5		
		Deploy surface buoys	6		
		Recover surface buoys	3		
		CTD casts	3		
		XBT´s	16		
		Surface-salinity samples	15		
		Grab samples	1		
R/V OCEANUS 90	Nov. 24-Dec. 3, 1980	Deploy current-meter moorings	12	LORAN-C	B. Butman
		Recover current-meter moorings	12		
		Deploy surface buoys	2		
		Recover surface buoy	1		
		XBT´s	37		
		Surface-salinity samples	35		

*Cruises on which data were collected in both the Mid-Atlantic and North Atlantic

Table 2. Summary of cruises conducted in the North Atlantic area, FY 80, 81, 82 (Cont.)

Cruise ID	Dates	Purpose	No. of samples	Navigation	Chief Scientist
R/V OCEANUS 91	Jan. 16-22, 1981	Deploy current-meter moorings	2	LORAN-C	B. Butman
		Recover current-meter mooring	1		
		CTD casts	18		
		XBT´s	13		
		Surface-salinity samples	28		
		Grab samples	104		
WHITEFOOT WF 81-1	Apr. 1-6, 1981	3.5-kHz profiles, sidescan	199 km	LORAN-C	D. C. Twichell
R/V OCEANUS 95	Apr. 23-May 6, 1981	Deploy current-meter moorings	6	LORAN-C	B. Butman
		Recover current-meter moorings	18		
		Surface buoys recovered	6		
		CTD casts	27		
		XBT´s	41		
		Grab samples	72		
WHITEFOOT and R/V LULU-DSRV ALVIN	June 30-July 1, 1981	Recover current-meter mooring	1	LORAN-C	B. Butman
WHITEFOOT WF 81-2	July 22-31, 1981	2.5-kHz profiles	89 km	LORAN-C	D. C. Twichell
		Uniboom profiles	888 km		
		Sidescan	401 km		
R/V GYRE 81-G-12	July 27-Aug. 17, 1981	Seismic-reflection 40-in^3, 3.5-kHz minisparker	1,230 km	LORAN-C	B. A. McGregor, D. W. O´Leary
		Midrange sidescan, 3.5-kHz	370 km		
R/V OCEANUS 104	Sep. 25-Oct. 2, 1981	Deploy current-meter moorings	10	LORAN-C	B. Butman
		Recover current-meter moorings	7		
		Deploy surface buoys	2		
		Recover surface buoys	2		
		CTD casts	35		
		XBT´s	25		
		Surface-salinity samples	56		
		Grab samples	58		
R/V OCEANUS 113	Jan. 26-Feb. 4, 1982	Deploy current-meter moorings	16	LORAN-C	B. Butman
		Recover current-meter moorings	9		
		Deploy surface buoys	7		
		Recover surface buoys	4		
		CTD casts	42		
		XBT´s	31		
		Surface-salinity samples	51		
		Grab samples	5		
WHITEFOOT	Apr. 21, 1982	Deploy current-meter mooring	1	LORAN-C	J. A. Moody
WHITEFOOT	May 26, 1982	Recover current-meter mooring	1	LORAN-C	B. Butman

Table 2. Summary of cruises conducted in the North Atlantic area, FY 80, 81, 82 (Cont.)

Cruise ID	Dates	Purpose	No. of samples	Navigation	Chief Scientist
WHITEFOOT	July 5, 1982	Deploy current-meter mooring	1	LORAN-C	B. Butman
R/V OCEANUS 122	July 6-15, 1982	Deploy current-meter moorings	6	LORAN-C	B. Butman
		Recover current-meter moorings	14		
		Deploy surface buoys	6		
		Recover surface buoys	6		
		CTD casts	67		
		XBT's	22		
		Surface-salinity samples	135		
		Oxygen samples	57		
		Grab samples	63		
		Gravity cores	9		
		Piston cores	4		
R/V GYRE 82-G-9	Aug. 8-21, 1982	Seismic-reflection 3.5-kHz	32 km	Int.Nav.Sys.	D. W. O'Leary
		minisparker	241 km		
		Angus photographic survey	271 km		
		Gravity cores	19		

important also in transporting the sand and shaping the morphology on Georges Bank (Jordan, 1962). Near the shelf edge, sand that is transported or suspended by ocean currents can be swept off the shelf and deposited on the upper slope or in canyon heads (Stanley and others, 1972; Nelsen, 1981).

Slope

The Continental Slope morphology in the North and Mid-Atlantic areas is highly dissected by downslope-trending canyons and valleys (Veatch and Smith, 1939). Some canyons have eroded back into the shelf edge tens of kilometers, whereas others only begin seaward of the shelf edge on the upper slope. The dendritic nature of this slope drainage was revealed on long-range sidescan sonographs collected with the GLORIA II system (Scanlon, 1982; Twichell and Roberts, 1982). The Continental Slope varies in width along the Atlantic continental margin. Where it is narrow the general sea-floor gradient of the slope is 7^{o} to 9^{o} and where the width of the slope is broader decreases to 4^{o} to 5^{o}. Locally on canyon walls the sea-floor gradients are often 20^{o} or more which no doubt facilitates the dissection of the Continental Slope. The morphology and associated sea-floor gradient are important when considering mass-wasting processes that can be geologic hazards. Sediment gravity flows and sediment slumps or slides can occur on steep slopes and when conditions are right on gentle slopes as well (Middleton and Hampton, 1976).

The sediments on the Atlantic Continental Slope are generally silts and clays except for sandy silt on the upper slope (Milliman and others 1972; Doyle and others 1979). The physical properties of the slope sediments (e.g., grain size, water content, shear strength, sensitivity, Atterberg limits, and organic content) are variable both along the slope and down the slope (Keller and others, 1979). This variability is not surprising given the variability of the slope morphology (McGregor, 1976). The unconsolidated sediments recovered in piston cores from the slope are Pleistocene to Holocene in age. The Pleistocene sediments can be as thick as 300 to 400 m (Poag, 1979, 1982). In many places the Pleistocene and possibly late Pliocene sediments lie unconformably on the older Tertiary strata that fill the Baltimore Canyon Trough and Georges Bank Basin and form the continental margin (McGregor and Bennett, 1981; Ryan and Miller, 1981). Tertiary and Late Cretaceous rocks of the margin are exposed in some of the Georges Bank canyons (Valentine and others, 1980) and early Tertiary rocks are exposed in canyons and on the lower slope on a portion of the Mid-Atlantic margin (Robb and others, 1981).

Transport processes and pathways on the slope are related to the morphology and the sea-floor gradient. On steep slopes, slumping can be an important process both on canyon walls and on the open slope (Knebel and Carson, 1979; MacIlvaine and Ross, 1979; McGregor and Bennett, 1981). The geometry of the subbottom strata may also contribute to the stability of the slope (McGregor, 1981). Debris flows, often associated with slumps, can redistribute slope sediments, depositing them further seaward on the rise (Embley and Jacobi, 1977). The submarine canyons are continuous morphologic features extending from the shelf, down the slope, and across the upper rise. The role of canyons as conduits to the deep sea is an important question. Turbidity currents within the canyons are a means of transporting and mixing shelf sands, swept into the canyon heads, with fine-grained slope sediments for deposition on the rise and abyssal plains. Graded sedimentary sequences cored on the rise show both a shelf and a slope source (Nelsen, 1981).

Besides sediment gravity flows, ocean currents within the canyon domain may also be important in transporting sediment, especially fine-grained sediment. Both tidal currents and internal wave forces (waves propagating along density interfaces within the water column) are important in erosion and transport of sediments on the floors and walls of the canyons (Keller and Shepard, 1978). The turbulence associated with internal waves as well as current velocities of 75 cm/s are capable of resuspending sediment as well as producing ripple marks observed on some canyon floors (Keller and Shepard, 1978). Because the currents are tidally driven, they have both an up-canyon and a down-canyon flow. Net transport however, generally is down canyon (Keller and Shepard, 1978). The siting of current meters is also important, because surrounding topography can greatly influence current velocities and direction (McGregor, 1979). In the dissected topography of the Continental Slope, attention must, therefore, be given to placement of the meters. A series of meters in an array on the shelf and slope is necessary to interpret the currents, their transport capability, and variability.

Rise

The Continental Rise generally is morphologically subdued with low topographic relief. The average sea-floor gradient is only 1^{o} to 2^{o}. Some submarine canyons which dissect the slope continue across the upper rise with leveed channels (Pratt, 1967). A few large topographic features with several hundred meters of relief are present on the Continental Rise in the North and Mid-Atlantic areas. Blocks of sediment with 300 to 400 m of relief and internal stratification that is discontinuous with the surrounding rise sediments have been interpreted as slump blocks (Emery and others, 1970; McGregor and Bennett, 1981). Seaward of Georges Bank, four seamounts at the western end of the New England Seamount chain are present on the rise. These volcanic peaks rise 2,000 m or more above the adjacent sea floor (Emery and others, 1970).

Sediments of the rise are generally silty clays although sandy turbidite sequences are present close to the canyon channels. Physical properties of the rise and slope sediments are similar; however, the rise sediments are much less variable (Lambert and others, 1981). Seismic-reflection profiles show that the rise sediments in places along the Atlantic margin are continuous with the slope sediments, and where erosion of the slope has removed much of the sediment, the rise sediments lap up onto the slope and are discontinuous with the subbottom reflectors of the slope (Emery and others, 1970). On seismic-reflection profiles, the rise sediments generally appear to be well statified; however, in cores which do not contain turbidite sequences, they display few primary sedimentary structures (Lambert and others, 1981).

The continuation of submarine canyons on the rise provides a pathway for sediments. The decrease in sea-floor gradient from the slope to the rise facilitates deposition in and adjacent to the canyon channels of sediments which originated from the shelf and slope and were transported in sediment gravity flows (e.g., turbidity currents). Debris flows that originate on the slope are also deposited on the rise often leaving a hummocky surface topography on the sea floor which can be mapped (Embley and Jacobi, 1977). Sediment slumps with sufficient energy to reach the base of the slope are also present on the rise. Erosional processes on the Continental Slope contribute to the construction and deposition of the wedge of Continental Rise sediments.

Depositional, erosional, and transport processes on the Continental Shelf, Slope, and Rise are all interrelated and should be viewed as a continuum.

Detailed studies

Building on this general background information, the detailed studies conducted by USGS were designed to address specific problems and questions. The morphology, geology, sediment stability, sediment mobility, and transport pathways of the U.S. Atlantic Continental Shelf, Slope, and Rise are the focus of these studies. Figure 2 shows the location of the detailed study areas described in the chapters of volumes II and III. The significant findings of each of these studies is summarized in the following sections of this report; however, the reader is referred to volumes II and III for a complete discussion of any area (McGregor, 1983a, b).

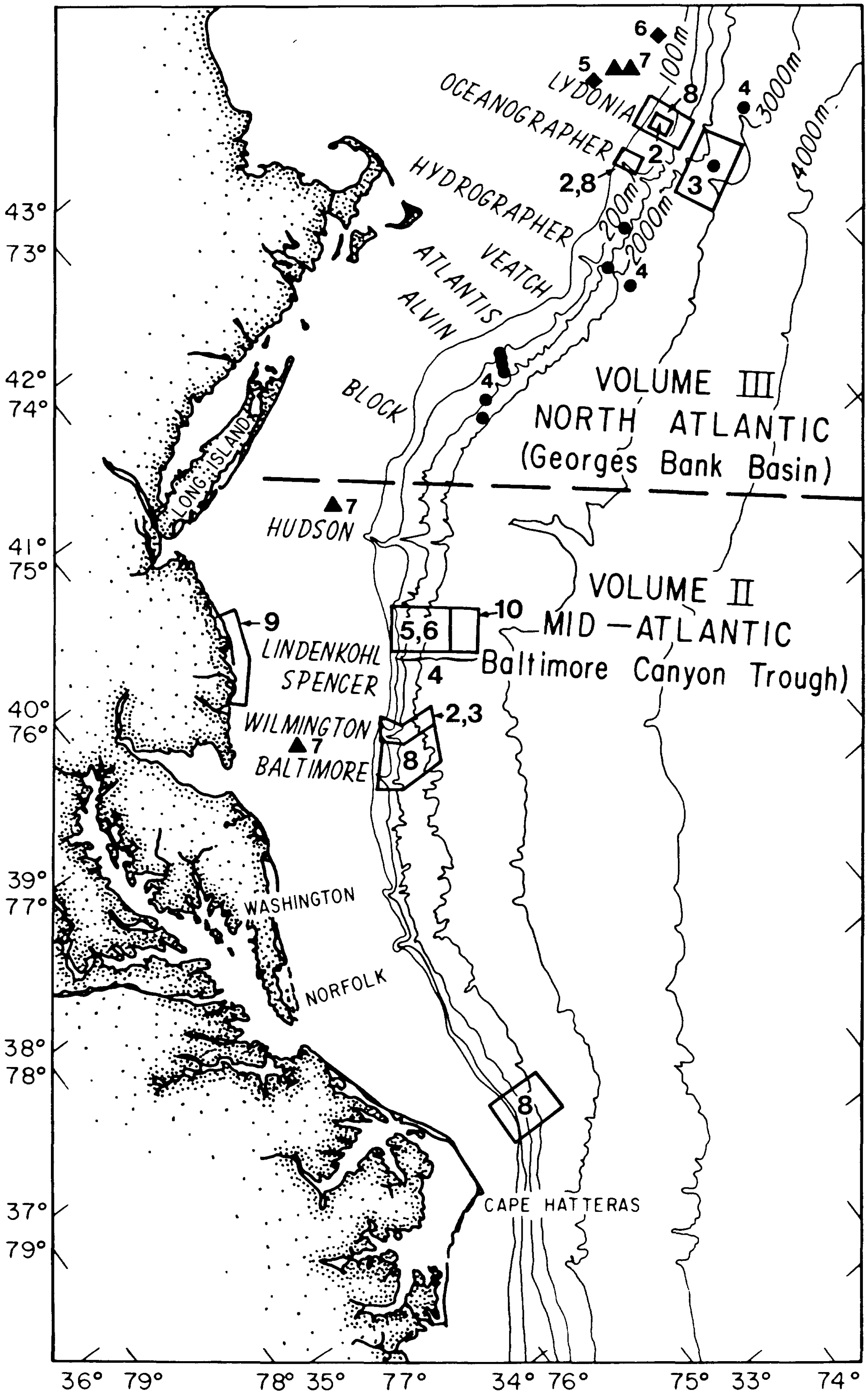

Figure 2. Index map showing the location of the study areas. Numbers refer to the chapters that are discussed in each volume.

SIGNIFICANT FINDINGS AND CONCLUSIONS

OF THE USGS-BLM

ENVIRONMENTAL GEOLOGIC STUDIES IN THE MID-ATLANTIC AREA

DURING FY 80, 81, 82

Wilmington Submarine Canyon area: a marine fluvial-like system

B. A. McGregor, W. L. Stubblefield, W. B. F. Ryan and D. C. Twichell

(Chapter 2)

In 1980, the newly developed midrange sidescan-sonar system (Sea-MARC I) was used to survey Wilmington, South Wilmington, and North Heyes Canyons on the U.S. Middle Atlantic Continental Slope. This survey was the first such survey on the U.S. Atlantic margin using this instrument. The water depths for the survey varied from 250 m to more than 2,500 m. A swath of sea floor 5 km wide was mapped with high resolution along each trackline. The images showed not only the shape of the canyons and tributary systems but also the microtopography within the valleys.

These new data indicate the Continental Slope is morphologically more complex and that the dendritic drainage pattern is more extensive and better developed than had been previously inferred (fig. 3). This pattern may prove most important to our understanding of submarine canyon processes. For example, some gullies are found in water depths greater than 1,000 m. At these depths the gullies must have formed in the submarine environment. The gullies on the slope generally trend parallel to the shelf edge, a trend compatible with a submarine origin. Finally, the gullies are associated with sea-floor gradients of 20° or more, suggesting that mass wasting may be important in their formation.

Marked differences are found between the canyons surveyed. Wilmington Canyon has eroded back into the shelf, whereas South Wilmington and North Heyes Canyons begin on the upper slope. Crescentic scarps surrounding the heads of these latter two canyons suggest that headward erosion may be taking place. Thus, these latter two canyons are probably younger in age than is Wilmington Canyon. In addition to differences in the position of the canyons' heads with respect to the shelf edge, there are also differences in channel morphology. Wilmington Canyon's channel meanders across the slope and upper rise, whereas the channels in the other two canyons trend straight down the slope onto the rise. These differences also are thought to be a function of canyon maturity.

The differences in sediment cover between the channels and the adjacent ridges suggest that these canyons may serve as conduits for sediment transport from the upper slope to the rise. If the thickness of sediment within the channels was comparable to that on the ridges, the shape of the channels would be masked; however, the channel features are well defined on the midrange sidescan-sonar records. Periodic transport events must occur to keep the channels clear of massive sediment accumulation.

The midrange sidescan sonar images provide a view of the U.S. Atlantic Continental Slope and Rise not previously known. From this view the canyon systems are found to be morphologically similar to subaerial fluvial systems. These similarities include: (1) dendritic pattern; (2) meander pattern; and (3) implied relationships of maturity and gradient to channel morphology. The processes responsible for the formation of the submarine canyons are not yet completely understood.

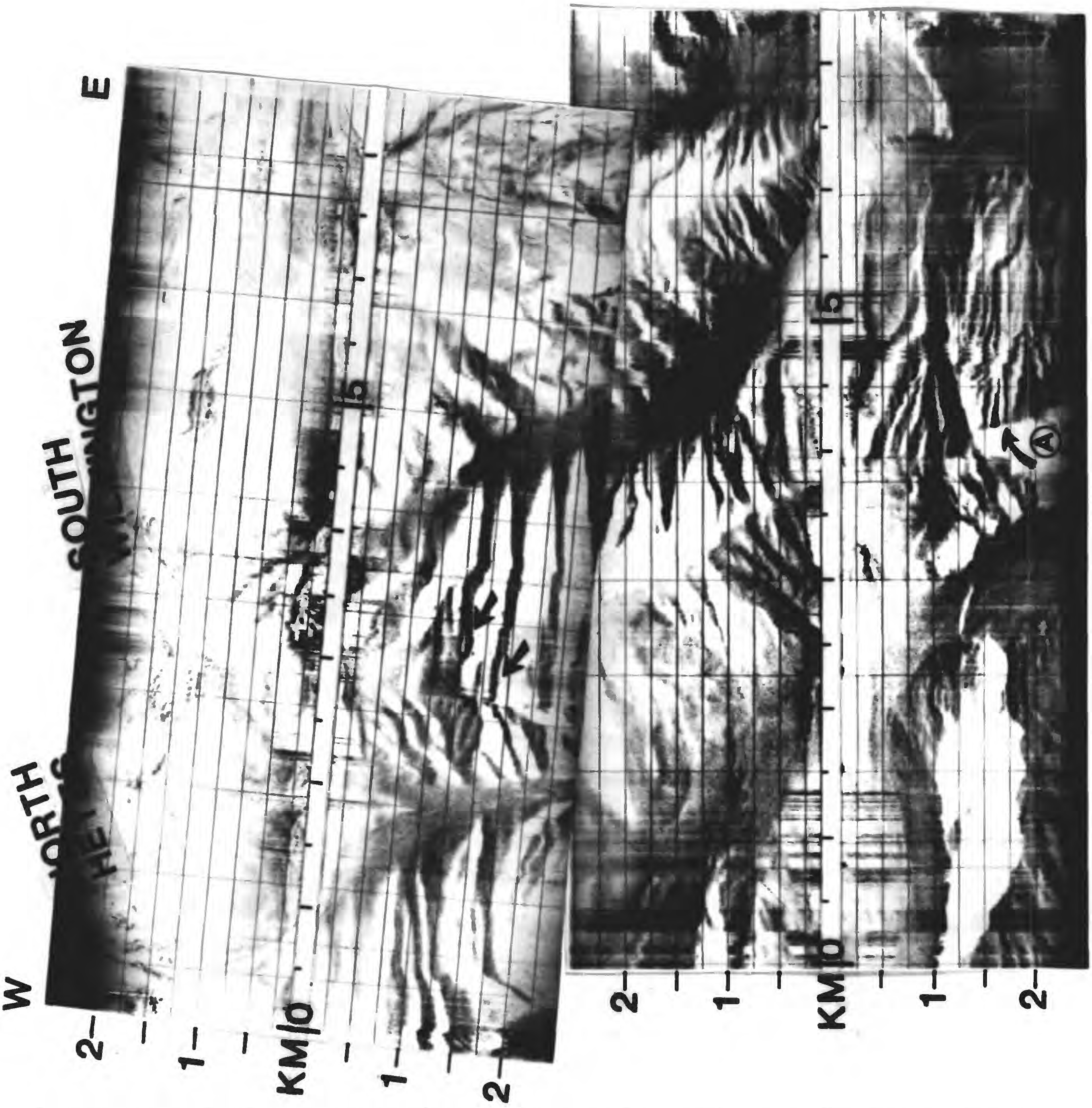

Figure 3. Photograph of sidescan data on the slope. Dark areas are the valleys of South Wilmington and North Heyes Canyons. Data have been corrected so that distance along the track is approximately equal to distance perpendicular to the track. Arrows indicate gullies. Area A has a dendritic pattern of gullies.

Reconnaissance in DSRV ALVIN of a "fluvial-like" meander system in Wilmington Canyon and slump features in South Wilmington Canyon

W. L. Stubblefield, B. A. McGregor, E. B. Forde,

D. N. Lambert, and G. F. Merrill

(Chapter 3)

Three dives in DSRV ALVIN on the United States' Atlantic Continental Rise in Wilmington and South Wilmington Canyons allowed examination and sampling of morphological features observed in the midrange sidescan-sonar data (figs. 4, 5). These features were in water depths of 2,300 to 2,400 m. The sampling included collecting _in situ_ sediment thickness, and monitoring bottom morphology with the submersible's sonar system. A continuous record of the sea floor along ALVIN's track was obtained with an array of hull-mounted and hand-held cameras.

Wilmington and South Wilmington Canyons were found to have markedly different morphologies and sediment characteristics. In Wilmington Canyon, the "fluvial-like" meandering system that had been observed in the midrange sidescan-sonar data was confirmed. At the dive site the meander wavelength was approximately 2 km and the width of the channel varied from 200 to 600 m. Within the meander channel the outer bank is undercut resulting in a near-vertical wall of over 20 m in relief. Outcropping clay is common on this wall. The inner meander wall is characterized by slope angles varying between 5^{o} and 15^{o} and is completely sediment covered. At the base of the steepened wall on the outer bank of the meander, the channel floor is 10 m deeper than it is at the base of the inner meander wall. Localized slumping of the over-steepened outer wall is inferred from the many step-like depressions. The absence of significant sediment cover on the floors of these step-like depressions suggests the small-scale slumping is a recent occurrence. In the channel of Wilmington Canyon, the sandy lutite sediment is in excess of 1.3 m thick, the limit of the sediment probe. The sediment surface is undulatory due to burrowing activity of benthic organisms. There was no evidence of current ripples in the sediment during the dive. The morphology and the sand component of the sediment within the channel suggest some form of episodic density flow. The frequency and nature of such a flow is unknown.

In contrast to Wilmington Canyon a meander system was not observed in South Wilmington Canyon. Instead, upturned beds at the base of the north wall, stratigraphically overlain by a gravel conglomerate and an oxidized thinly bedded sandstone suggest large-scale slumping. An interpretation of a shallow-water depositional environment for the gravel conglomerate and the oxidized sandstone is supported by the recovery of elongated tubular siltstone objects from within the sandstone. The shape of these objects and their finer grain size relative to the surrounding sandstone are suggestive of an infilled root cast. These data support the interpretation of a slump block identified from surface geophysical records by McGregor and Bennett (1981).

The combination of the deep-diving submersible and the midrange sidescan sonar provides a powerful tool for understanding the processes that shaped the morphology of the lower Continental Slope and upper Continental Rise. The

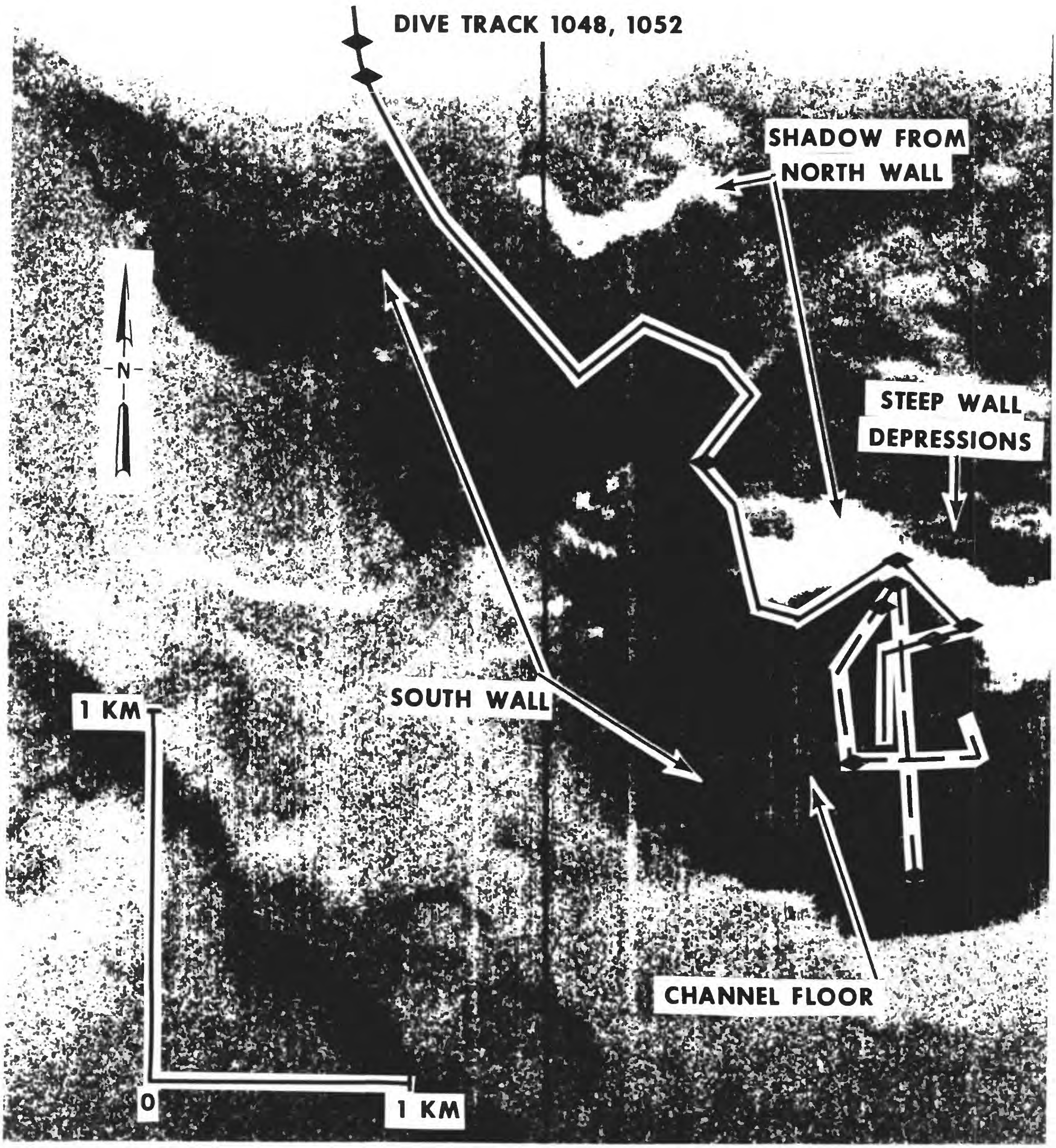

Figure 4. Dive tracks 1048 and 1052 superimposed on a sonograph of the meander channel in Wilmington Canyon. Dive 1048 is shown in dashed pattern; dive 1052 is shown as a solid line. Sample stations are marked with a diamond.

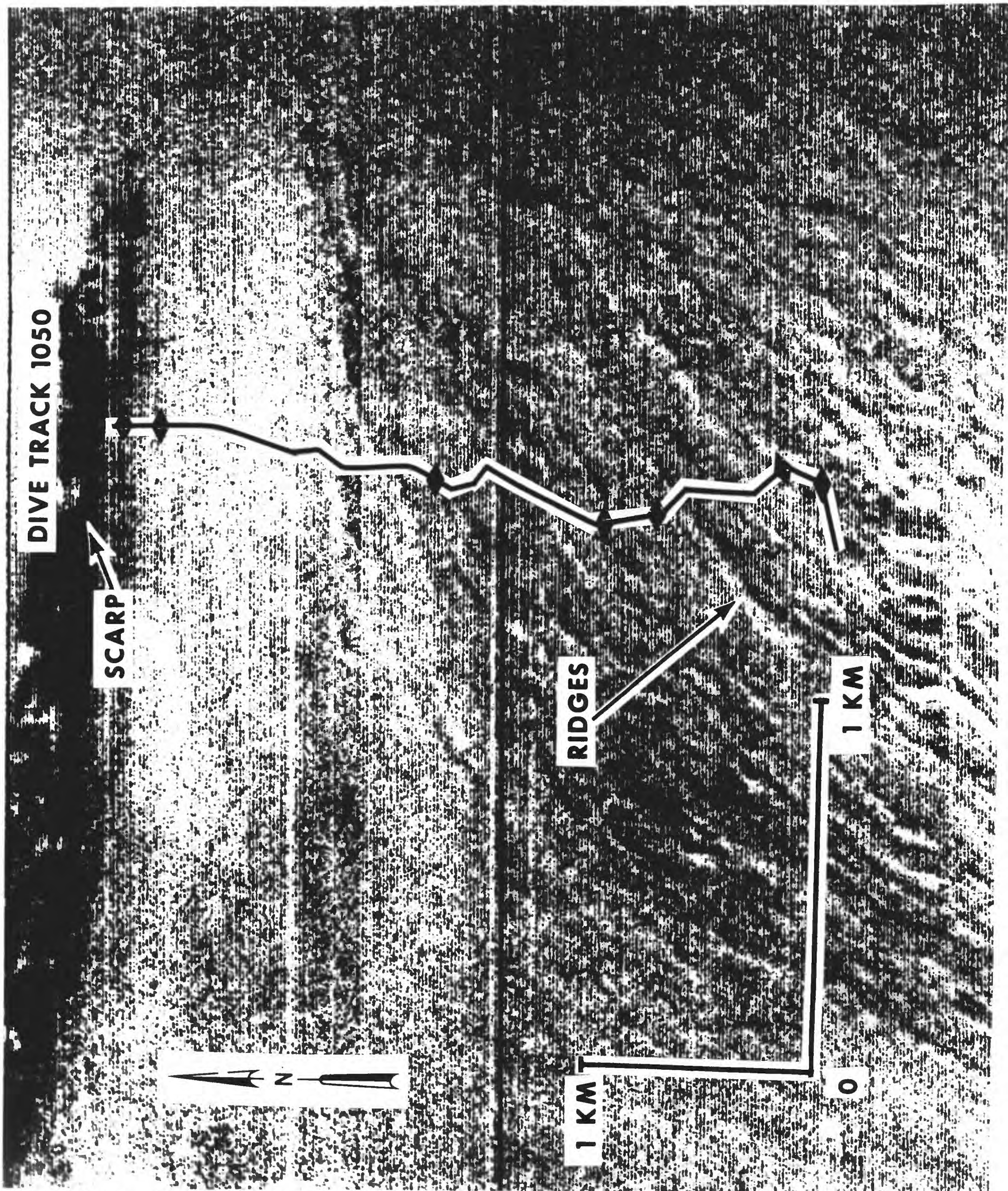

Figure 5. Dive track 1050 superimposed on sonograph of South Wilmington Canyon and the adjacent north wall. Sample stations are marked with a diamond.

midrange sidescan-sonar data provide an areal view of the morphology of the canyons, and *in situ* submersible observations provide more detailed information on the key morphologic features.

Geotechnical characterization and mass-movement potential of the U.S. Mid-Atlantic Continental Slope and Rise

J. S. Booth, R. C. Circé, and A. G. Dahl

(Chapter 4)

Mapping of the United States continental margin by geophysical means has revealed diverse and widespread evidence of mass movement. Because the spatial distribution of these slope failures, as well as their frequencies, types, and magnitudes, is not equitable, questions arise concerning future mass movements on different parts of the margin, particularly the slope and rise, and on the causes of these events. These questions can best be addressed by determining the properties of the sediments and the stresses which are acting on or within them. This report represents an initial attempt at such an investigation and it presents the results of geotechnical studies and slope-stability analysis of a portion of the Mid-Atlantic Continental Slope and Rise (fig. 6). These studies were undertaken to (1) determine the present-day stability of the slope and rise, and (2) determine the geologic conditions which may promote slope failures in this general setting.

The effect of superimposing both depositional and degradational processes on a complex topography has been to produce a surface marked by geotechnical variability. Consolidation states particularly serve to exemplify this, ranging from a state of underconsolidation to one of extreme overconsolidation (OCR~400). In addition, plasticity ranges from low to high, sensitivities range from insensitive to slightly quick, and shear strength ranges over two orders of magnitude.

Although extreme conditions are represented, the surficial sediments lend themselves to characterization. Typically, they fit into the category designated "CH" by the Unified Soil Classification System (inorganic clays of high plasticity). They have a soft consistency, are very sensitive, have very low permeabilities, and tend to be overconsolidated. Overall, the sediments have most of the geotechnical properties associated with a fine-grained sediment dominated by illite and less active minerals.

Results of slope stability analyses (which generally excluded areas of canyons and canyon systems) show that for static drained and undrained conditions, the slope and rise are generally stable: fewer than 15% of the sites investigated have factors of safety (against slope failure) of less than two. However, if abnormally high shear strengths associated with the surficial sediment are not representative of strengths down in the sediment column, up to one-third of the sites may have factors of safety in that range.

Several of the sites investigated would become metastable if subjected to relatively minor earthquake-induced ground accelerations. Further, excess pore pressures from gas or other sources, or slight increases in gradient from oversteepening or undercutting, would make some areas vulnerable to slope failure. Strength reduction related to strain-softening or elastic rebound (development of weak planes or joints) may also be occurring at some sites. Any of these processes or conditions may have contributed to past slope failures, particularly on a local scale. It appears that most processes or

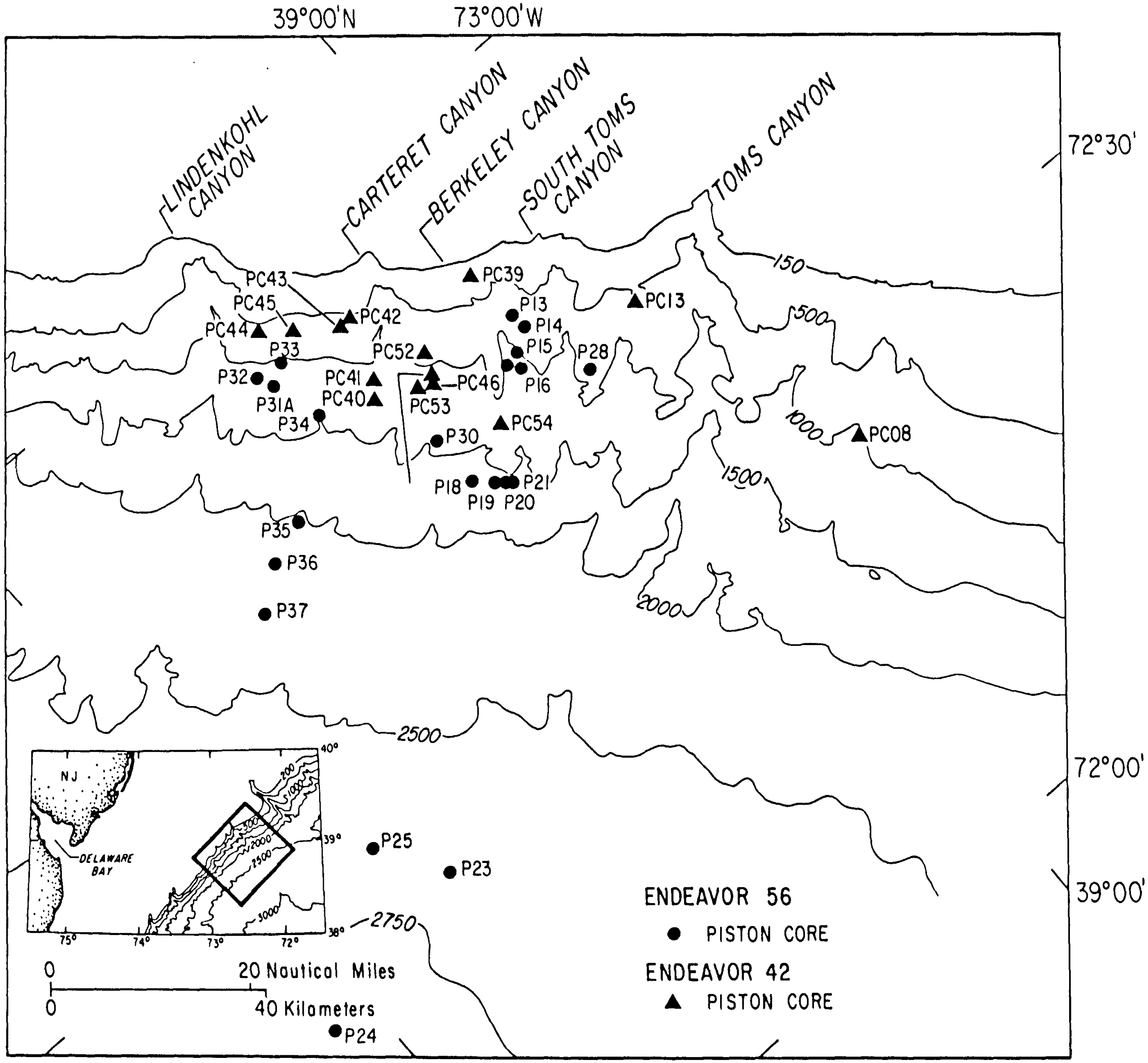

Figure 6. Piston core locations. Inset shows the location of the study area.

agents which may cause instability in this geologic setting have the potential to be more important locally than regionally. More focused and detailed research will be needed before the relative efficiency or future effects of the different possible causes can be evaluated because relative magnitudes, frequencies, and extents of these mechanisms have not yet been fully documented or quantified.

Surficial geologic studies of the Continental Slope in the Northern Baltimore Canyon Trough area--techniques and findings

J. M. Robb, J. C. Hampson, Jr., and J. R. Kirby

(Chapter 5)

Since 1978, the U.S. Geological Survey has been conducting a study of the Atlantic Continental Slope between Lindenkohl and South Toms Canyons, offshore New Jersey, to determine the nature of potential geologic hazards to hydrocarbon exploration and exploitation. The study has progressed from characterization of the near-surface stratigraphy, using single-channel seismic-reflection data and piston cores, to detailed geomorphological studies using midrange sidescan-sonar coverage, and finally, to targeted observations from deep-diving submersible. The seismic-reflection data and cores have shown that unconsolidated Pleistocene sediments as much as 400-m thick cover the upper and midslope, and that identifiable slump or slide features occupy only a small part of the slope area mapped (fig. 7). Much of the slope is mantled by a veneer of fine-grained Holocene sediment. We inferred that the slope topography is largely relict from late Pleistocene or early Holocene time and that present conditions of geomorphic change are probably quiescent. Subsequently acquired sonographs from a deep-towed sidescan-sonar system having a 5-km swath show such features as a debris field at the mouth of South Toms Canyon, oddly shaped features on the mid and lower slope suggestive of slump or slide origin, and areas of an enigmatic pattern of downslope-trending "stripes". Most recently, four dives in DSRV ALVIN during July 1981 on the area of Tertiary outcrops of the lower slope revealed 10-m-high talus blocks at the base of the slope, cliffs and steep-walled valleys having as much as 40 m relief, control of cliff surfaces and the shapes of valleys by sets of joints, occurrences of clastic dikes, and sets of parallel, 4-to-12-m-deep furrows (probably erosional) spaced 20-50 m apart in Eocene calcareous claystone at the mouth of Berkeley Canyon. In some places, the smaller scale topography of the lower slope appears fresh; some planar surfaces are unbored by organisms or scoured, and some of the talus fragments on the upper rise appear to be recent. However, a thin cover of fine-grained flocky sediment on horizontal surfaces implies that present-day activity is either not vigorous or is intermittent. Nevertheless, canyons and valley thalwegs should probably be viewed with caution if considered for structure sites.

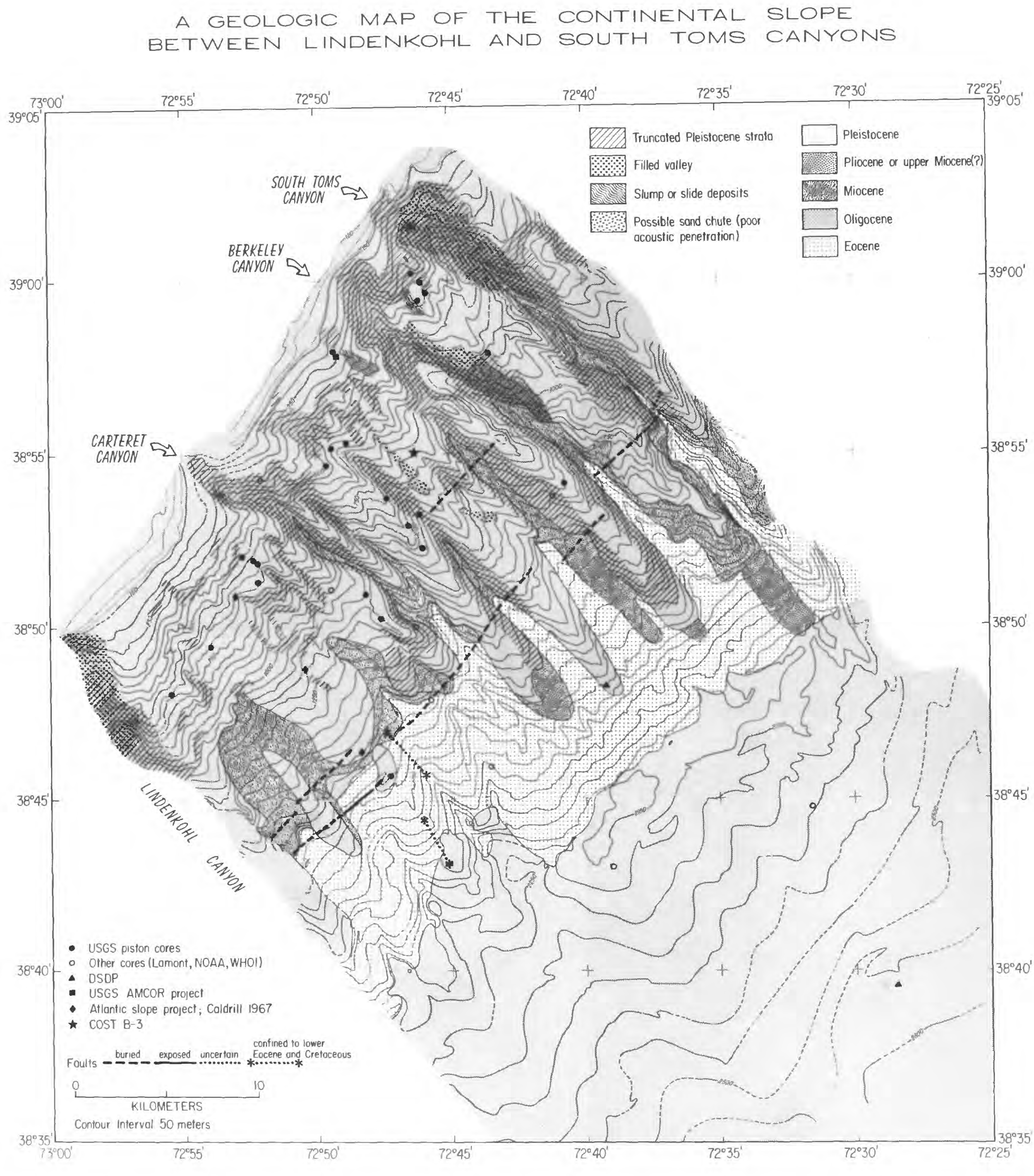

Figure 7. Geologic map of the Continental Slope and upper Rise between Lindenkohl and South Toms Canyons. Slump or slide deposits and faults are shown.

Furrowed outcrops of Eocene chalk on the lower Continental Slope offshore New Jersey

J. M. Robb, J. R. Kirby, J. C. Hampson, Jr., P. R. Gibson, Barbara Hecker

(Chapter 6)

Recent bathymetric and geologic mapping have shown that the Continental Slope offshore New Jersey is a region of complex topography, stratigraphy, and geologic history. Midrange sidescan-sonar (Sea-MARC I) images of the Continental Slope show a pattern of downslope-trending stripes at the mouth of Berkeley Canyon and on adjacent parts of the lower slope (fig. 8). A dive in DSRV ALVIN to investigate these features showed that the striped pattern represents a set of furrows cut into chalky sedimentary rocks of middle Eocene age. The furrows are 10 to 50 m apart, 4 to 13 m deep, and 3 to 5 m wide with flat floors of fine-grained, flocky, unconsolidated sediment. The slope of the furrow walls is commonly greater than 45^{o}, and in places, the walls are scoured. Although the furrows appear straight on the sidescan images, bends and kinks or jogs were observed by the submersible. These bends do not appear to be fault controlled, and the furrows are clearly erosional. Based on seismic-reflection profiles, the furrows are interpreted to be pre-late Pleistocene in age. In the area of the mouth of Berkeley Canyon, turbidity currents would probably have been particularly effective during the Pleistocene in eroding the furrows, however, the presence of furrows away from the canyon suggests that other processes may have formed them. The extensive cover of fine-grained, flocky, unconsolidated sediment implies that significant bottom-current erosion is not active now in the area.

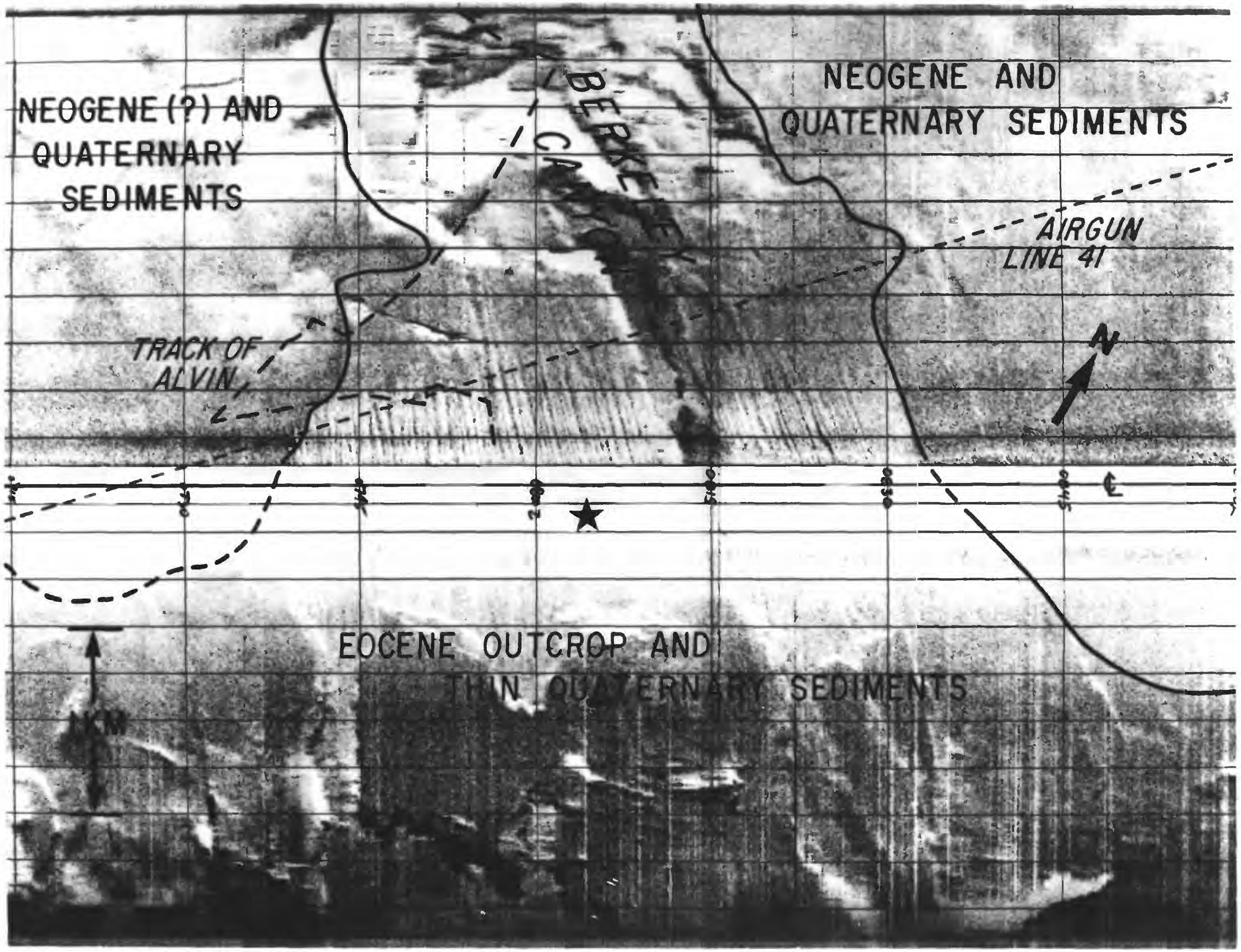

Figure 8. Sea MARC I sidescan sonograph of the lower Continental Slope at the mouth of Berkeley Canyon. Image shows scale-corrected 5-km-swath fish track at centerline, upslope direction is toward top of image. Water depth at center of image is about 2,000 m.

Observations of bottom currents and sediment movement along the U.S. East Coast Continental Shelf during winter

Bradford Butman and J. A. Moody

(Chapter 7)

This paper presents observations of near-bottom currents and sediment movement made at four locations along the U.S. East Coast Continental Shelf during the winter of 1978 (fig. 9). The major objective of the field measurements was to observe the frequency and direction of bottom sediment movement, the process causing movement, and the regional (essentially longshelf) variability of transport.

The winter near-bottom observations show: (1) rapid scour and resuspension of sediments, primarily by surface waves associated with storms on Georges Bank and in the Middle Atlantic Bight; (2) constant scour and reworking of the surface sediments by the semidiurnal tidal currents at station K and weaker reworking at station A on the southern flank of Georges Bank; (3) rapid return to tranquil bottom conditions in the Middle Atlantic Bight after storm-associated scour; (4) generally increased fluctuations in suspended-particulate matter on Georges Bank and near the shelf-water/slope-water front associated with advection by the tidal current; and (5) transport of fine material westward and southwestward, primarily along isobaths during the major storms.

It is clear from these observations that major resuspension of bottom sediment occurs during storms and that the resuspension is caused by near-bottom oscillatory currents associated with surface waves as suggested by Grant and Madsen (1979). Any calculations of near-bottom sediment transport must account for the effect of surface waves on bottom stress; near-bottom current observations alone are not adequate. The near-bottom effects of storms were only observed for a few days and thus long-term *in situ* observations are required to define sediment transport associated with infrequent intense storms; measurements from surface ships would be extremely difficult.

Although the stress estimates are crude, the statistics suggest a net westward movement of sediment from the southern flank of Georges Bank into the Middle Atlantic Bight. Fine quartz sand moves infrequently and only during storms, while very fine sand and fine sediment move quite often. Sand-sized barite (density 4.65 gm/cm^3), a major component of drilling muds, moves very infrequently. Any cross-shelf or off-shelf movement of sediment is not resolved by these measurements. The dynamics of the observed complex temporal changes in the extinction coefficient remain to be determined. In particular, the contribution of resuspension, advection, horizontal and vertical concentration gradients, and suspended-matter composition to the observed variability in extinction coefficient needs more detailed examination. In addition, the photographs suggest impact effects of the benthic biology on the resuspension of bottom sediments and potentially significant contributions to the suspended material in the water column at certain times.

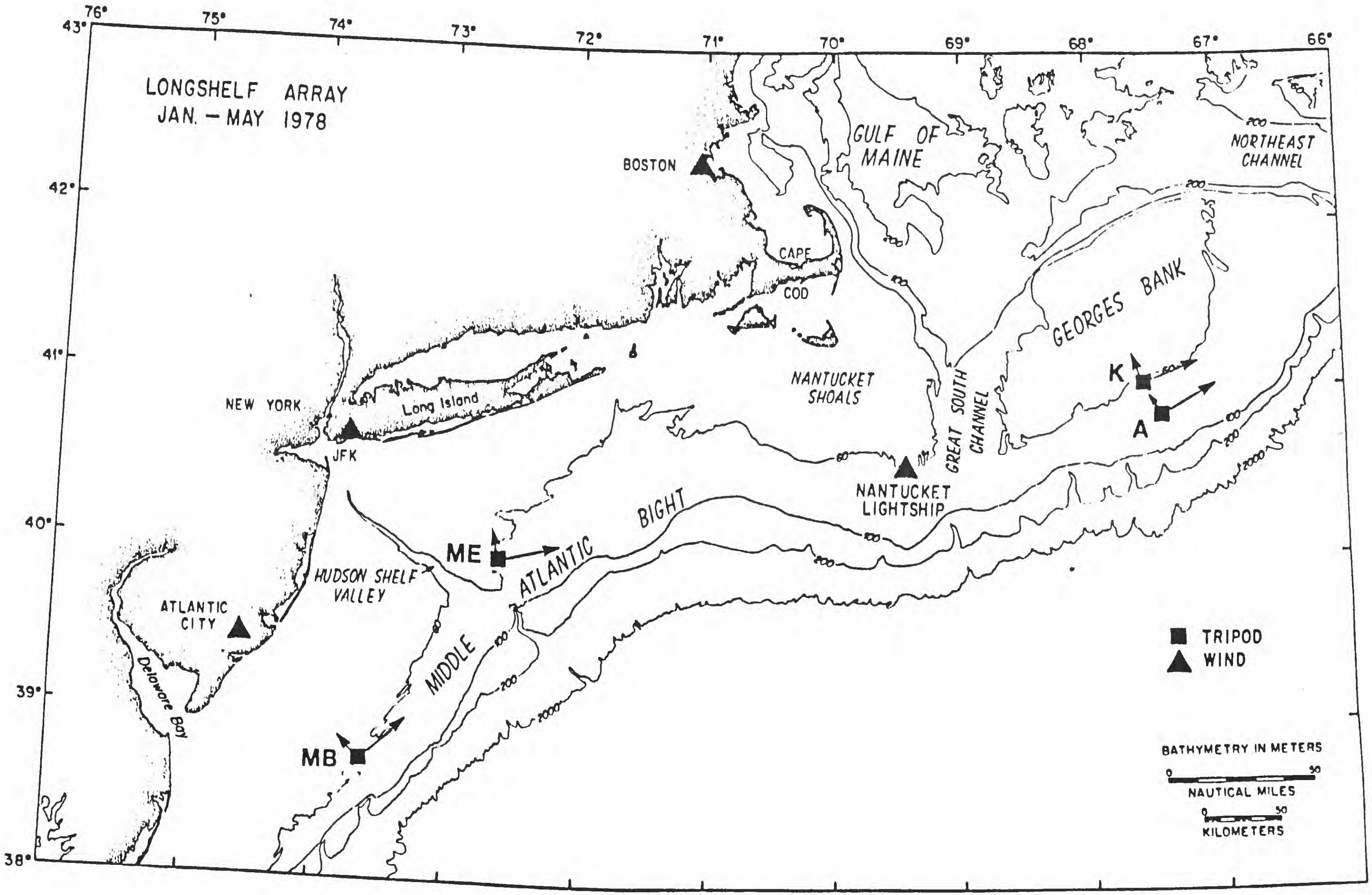

Figure 9. Location of tripod and wind stations on the shelf to determine near bottom currents and sediment movement.

Submarine canyon and slope processes on the U.S. Atlantic continental margin

B. A. McGregor

(Chapter 8)

Two regions on the U.S. Atlantic continental margin were surveyed using single-channel seismic-reflection profiling techniques. The general objective was to study and compare canyon and slope processes on the Continental Slope and Rise in each area. The Continental Slope and Rise in the Baltimore Canyon area and a portion of the slope and rise just north of Cape Hatteras are dissected by numerous submarine canyons. The dominant slope process appears to be different in the two regions, which may be correlated with the width and general sea-floor gradient of the Continental Slope. In the Baltimore Canyon area, the subbottom reflectors suggest that they formed by deposition associated with canyon processes. The broad width of the slope and gentle gradient are present in this region where the slope and rise have been prograded and built-up. Baltimore Canyon itself has had both a depositional and erosional origin. In the study area north of Cape Hatteras, the canyons are erosional features and mass wasting is the dominant erosional process. The Continental Slope in this area is narrow and the general sea-floor gradient is steeper. A difference in canyon ages also may exist. Baltimore Canyon is suggested to be as old as Late Tertiary, whereas a similar shelf-indenting canyon north of Cape Hatteras is suggested to be Pleistocene in age. Although the rise morphology characterized by a large ridge adjacent to Baltimore Canyon is similar to that adjacent to Wilmington Canyon, it appears to have had a different origin, which is related to canyon processes, rather than to slumping, as is the case for the ridge adjacent to Wilmington Canyon.

Middle Atlantic nearshore seismic survey and sidescan-sonar survey: potential geologic hazards off the New Jersey coastline

C. E. McClennen

(Chapter 9)

High-resolution seismic-reflection profiles (3.5 kHz and Uniboom) and sidescan data were collected along the New Jersey coast in water depths from 8 to 25 m between Corson and Manasquan Inlets. Seismic-reflection data suggest that the active surface sediments are 4 to 8 m thick south of Barneget Inlet and 2 to 4 m thick north of the inlet. The deeper subbottom reflectors can be classified in two groups: (1) essentially horizontal reflectors from Barnegat Inlet south; and (2) dipping reflectors inclined to the south-southeast north of the inlet (fig. 10). Buried channels are present seaward of Great Egg, Little Egg, and Barnegat Inlets. The sidescan sonographs indicate the presence of (1) megaripples (2-3 m crestal spacing) within strong reflective areas, (2) weakly reflective areas, and (3) mixed weak and strong reflective patches, some of which are elongate or linear in outline. From the sidescan data, it is clear that there is widespread, perhaps frequent, movement of the surface sands on the inner New Jersey shelf. However, the rates and depths of motion are not known, nor are seasonal variations identified.

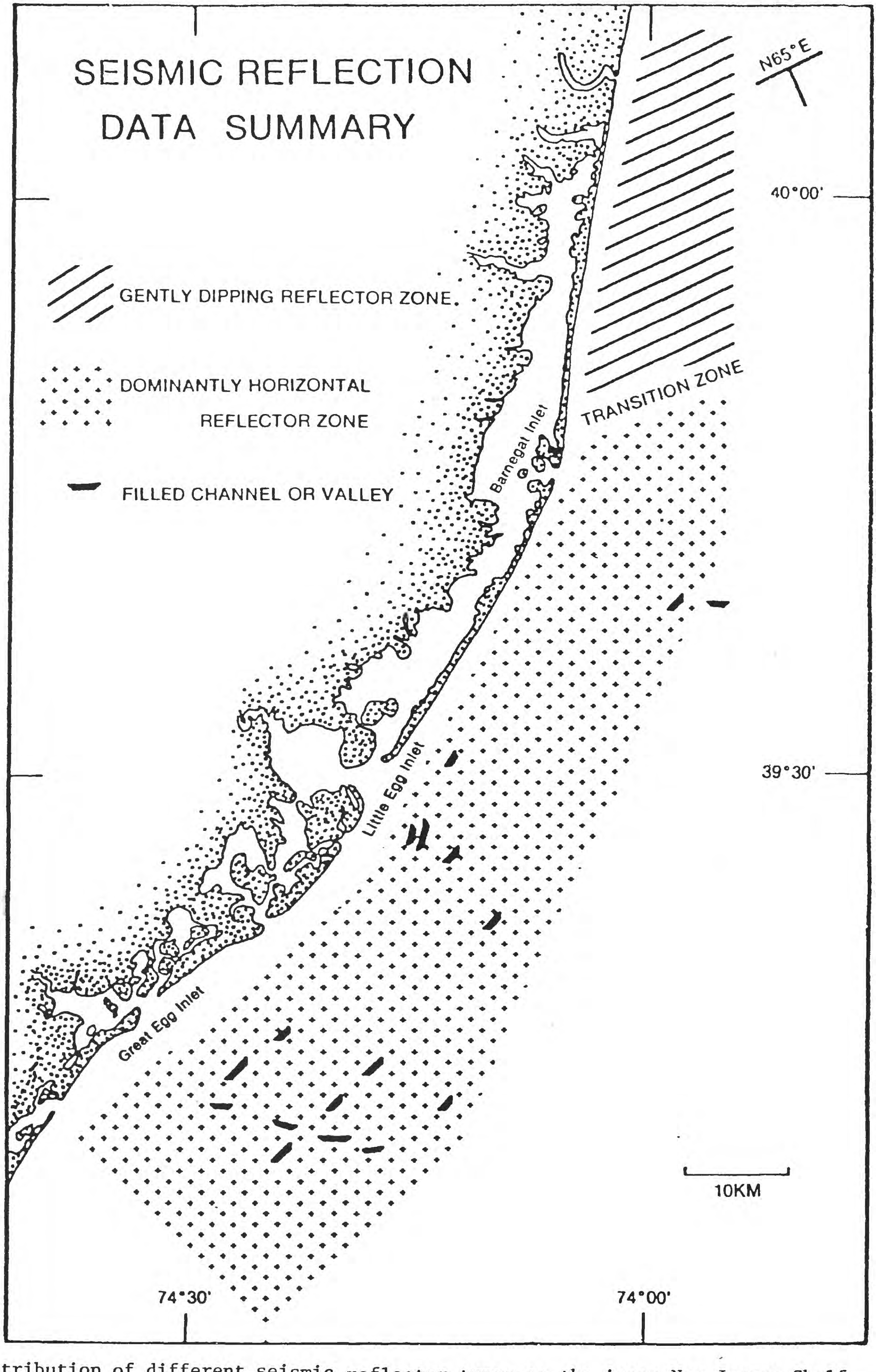

Figure 10. Distribution of different seismic reflector types on the inner New Jersey Shelf. Buried channels are present seaward of Great Egg, Little Egg, and Barnegat Inlets

Mid-Atlantic Upper Continental Rise:

Preliminary study of surficial geology and processes

James M. Robb and John C. Hampson, Jr.

(Chapter 10)

A 3,000 km^2 area of upper Continental Rise off New Jersey, lying between Lindenkohl and Toms Canyons, was investigated using about 800 km of seismic data acquired in 1982 as well as previously collected data. The seismic-reflection profiles extend as far as 90-m seaward of the slope-rise boundary, but the study focuses on the most shoreward 25 km. A bathymetric map, prepared using a 10-m contour interval, shows generally gentle topography except locally where steep slopes are found along channels from larger canyons (fig. 11). A mound about 300 m high and 2 to 3 km wide lies along the slope-rise boundary. The mound appears to be eroded where it is crossed by channelways of the canyons and slope valleys, and hence, is probably the result of early Pleistocene processes rather than presently continuing ones. Available data, however, do not have enough resolution to determine its origin. Seismic profiles show that similar mounds existed in places along the base of the slope during the Miocene and Pliocene. The present surface of the lower slope outcropping Eocene rocks is congruent with an unconformity that plunges below the upper rise and is onlapped by Miocene and younger sediments. That unconformity is correlated with the widespread A^u unconformity of the deep sea. Complex erosional unconformities separate Cenozoic strata of the upper Continental Rise. Growth faults related to rotational slumps within the Eocene section and erosional topography on top of the Eocene (the A^u unconformity) may have implications regarding the origin of the present-day topography of the lower slope, which may be of great age. Also fragments of Eocene rocks have been found in rise sediments of Miocene, Pleistocene, and perhaps recent age, implying that Eocene rocks have been exposed on the slope for a long time. Because of the deep water, conventional echo-soundings and seismic profiles have little resolution in this environment if intended for site-specific terrain analysis or geomorphic study. Deep-towed instruments will be necessary for definitive studies of the nature and activity of geologic processes.

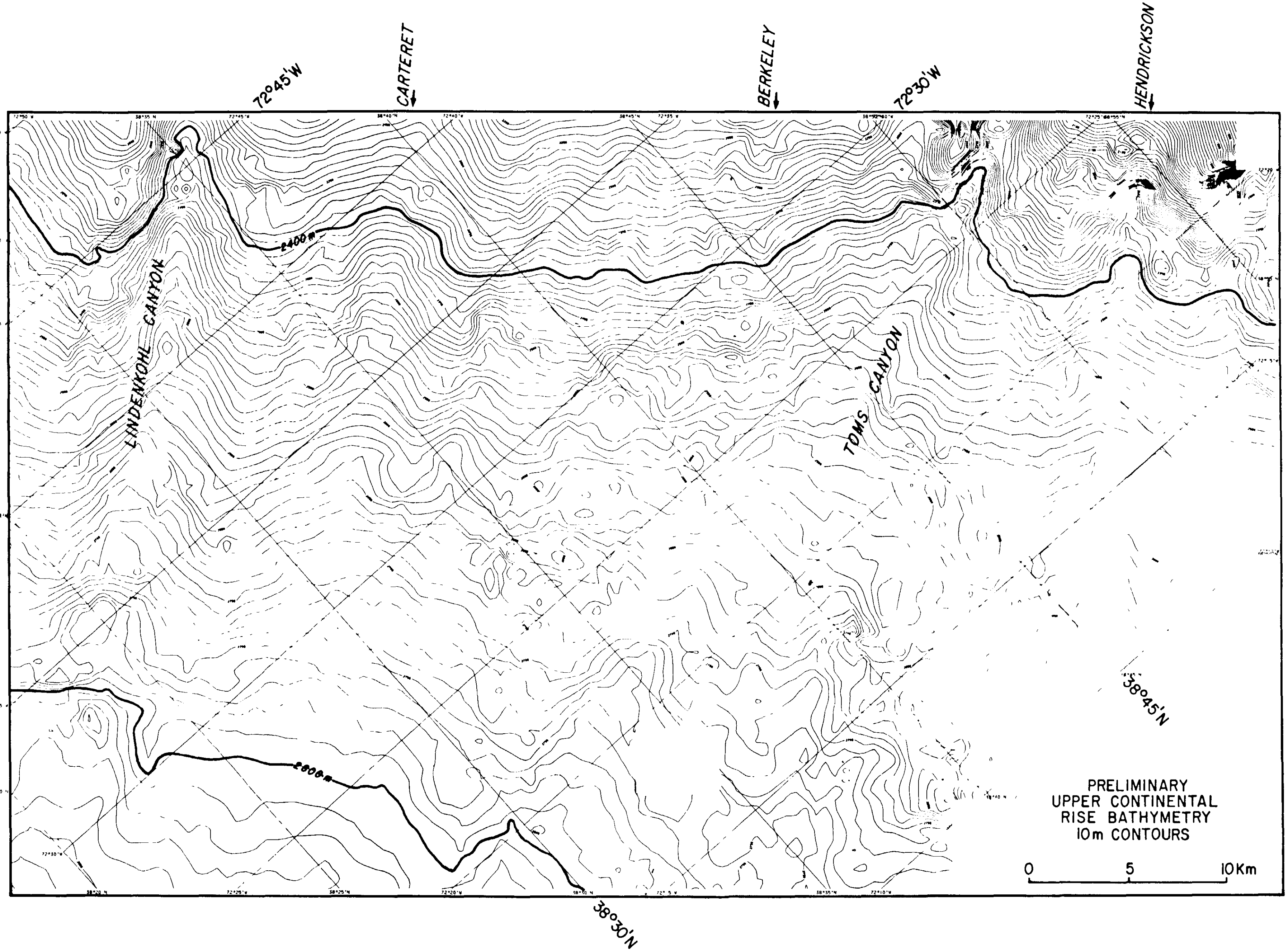

Figure 11. Bathymetric map with 10 m contour interval of the upper Continental Rise between Toms and Lindenkohl Canyons.

SIGNIFICANT FINDINGS AND CONCLUSIONS

OF THE USGS-BLM

ENVIRONMENTAL GEOLOGIC STUDIES IN THE NORTH ATLANTIC AREA

DURING FY 80, 81, 82

Geology of the Head of Lydonia Canyon,

Northeastern Atlantic Outer Continental Shelf

D. C. Twichell

(Chapter 2)

The geology of a part of Lydonia Canyon that lies shoreward of the edge of the Continental Shelf was mapped using high-resolution, seismic-reflection and sidescan-sonar techniques and surface-sediment grab samples. The head of the canyon incises Pleistocene deltaic deposits and Miocene shallow marine strata (Stetson, 1949; Knott and Hoskins, 1968) and was cut prior to the Holocene. During the Holocene, sedimentation in and around the canyon head has been complex. Medium sand containing some coarse sand and gravel covers the shelf except for a belt of very fine sand containing no gravel to either side of the canyon in 125-140 m water depth (fig. 12). Gravel and even boulders (Slater, 1981), presumably ice-rafted debris, cover the rim of the canyon. Within the canyon, the canyon floor and canyon-wall gullies are covered by Holocene-aged coarse silt that is as much as 25 m thick (fig. 12). Pleistocene and Miocene strata are exposed on the spurs between the gullies. The Holocene sediment is restricted to the part of the canyon shoreward of the shelf edge, and is thought to have been winnowed from the shelf principally during the initial part of the Holocene transgression. Furrows cut in the shelf sands and ripples on the shelf and in the canyon suggest that sediment continues to be moved in this area, however, sediment distribution is inconsistent with the pattern that would be expected from the inferred westward sediment transport on the shelf (Twichell and others, 1981). Either the fine-grained deposits are relict or there is a significant component of offshore transport around the canyon head.

A brief survey of the head of Oceanographer Canyon, which is only 40 km west of Lydonia Canyon, indicates that present processes are strikingly different in the two canyons. In contrast to the fine-grained deposit in Lydonia Canyon, the floor of Oceanographer Canyon is covered by sand waves. Their presence indicates active reworking of the bottom sediments by strong currents. The close proximity of these two canyons suggests that processes acting in canyons can be very localized.

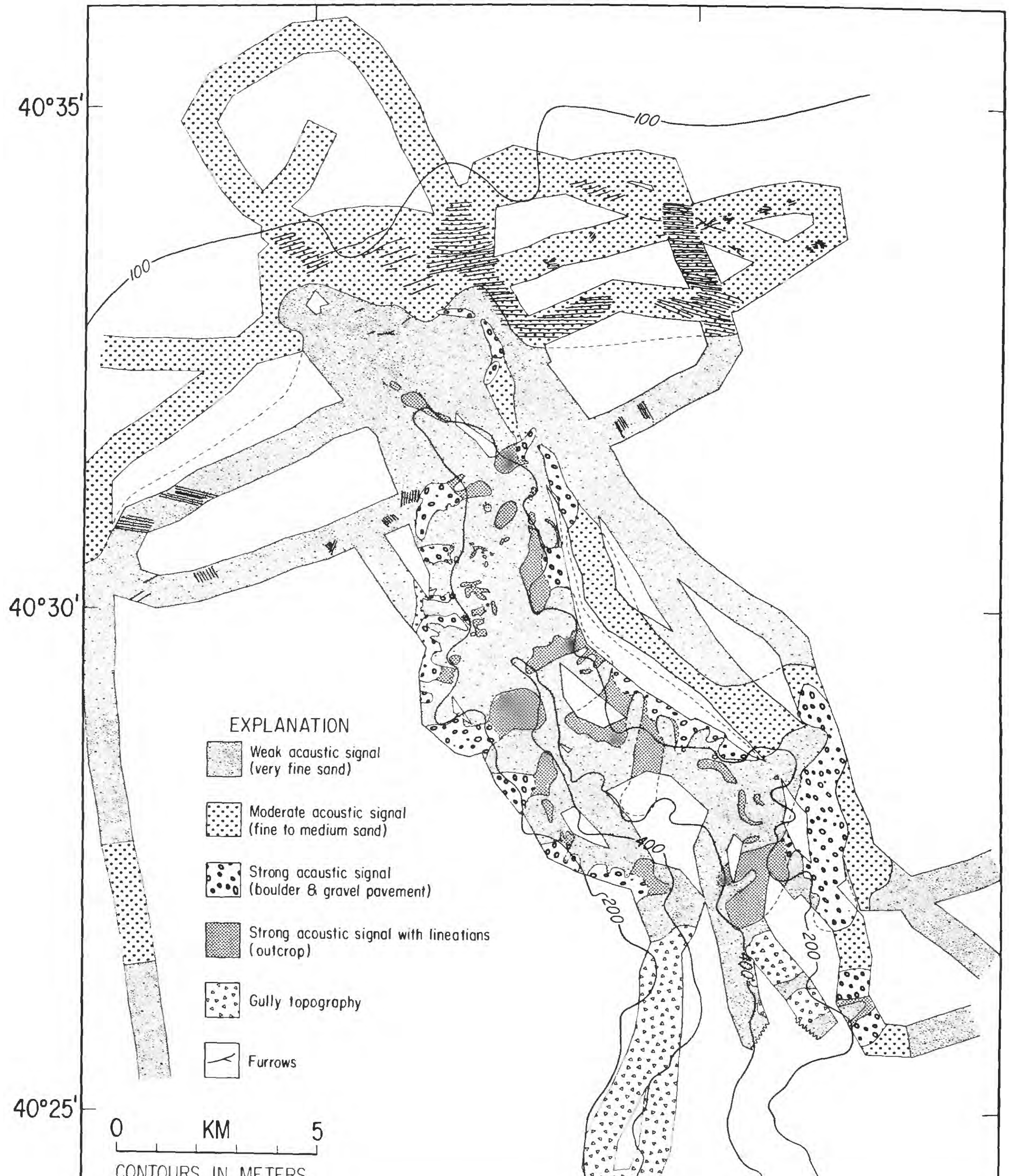

Figure 12. Map of Lydonia Canyon showing sea-floor character based on the sidescan sonographs.

Role of submarine canyons in shaping the rise between Lydonia and Oceanographer Canyons, Georges Bank

B. A. McGregor

(Chapter 3)

Three large submarine canyons, Oceanographer, Gilbert, and Lydonia Canyons indent the U.S. Atlantic Continental Shelf and, with four additional canyons, dissect the Continental Slope in the vicinity of Georges Bank. On the upper rise, these canyons merge at a water depth of approximately 3,100 m to form only two valleys (fig. 13). Differences in channel morphology of the canyons on the upper rise imply differences in relative activity, which is inconsistent with observations in the canyon heads. At present, Lydonia Canyon incises the upper rise more deeply than do the other canyons; however, seismic-reflection profiles show buried channels beneath the rise, which suggests that these other six canyons were periodically active during the Neogene. The rise morphology and the thickness of inferred Neogene and Quaternary-age sediments on the rise are attributed to the presence and activity of the canyons. The erosional and depositional processes and the morphology of these canyons are remarkably similar to those of fluvial systems. Bear Seamount, with approximately 2,000 m of relief, has acted as a barrier to downslope sediment transport since the Late Cretaceous (fig. 13). Sediment has piled up on the upslope side, whereas much less sediment has accumulated in the "lee shadow" on the downslope side. Seismic-reflection profile data show that Lydonia Canyon has not eroded down to the volcanic ediface of Bear Seamount. This implies the canyon is an erosionally young feature or more likely that both deposition and erosion occur periodically within the canyon.

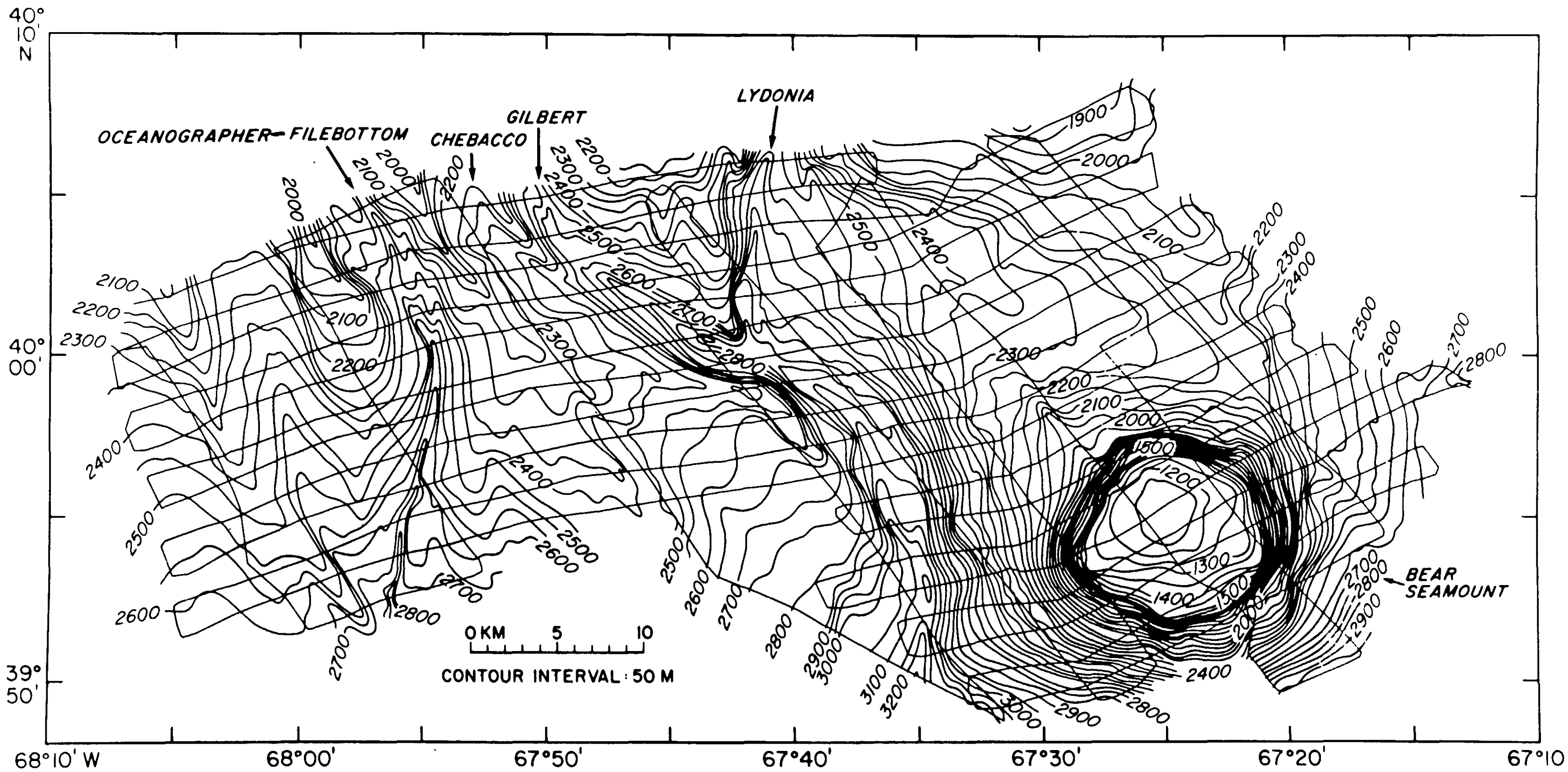

Figure 13. Bathymetry of the Continental Rise seaward of Georges Bank. Major morphologic features include the channels of five submarine canyons, which merge so that only two channels remain at a water depth of 3,100 m, and Bear Seamount, the westernmost seamount in the New England Seamount Chain. Track line locations of seimic-reflection profile data are superimposed on the bathymetry.

Geotechnical characterization and mass-movement potential of the United States North Atlantic Continental Slope and Rise

J. S. Booth, R. C. Circé, and A. G. Dahl

(Chapter 4)

The North Atlantic Continental Slope has experienced widespread mass movement. High-resolution seismic-reflection profiles and sidescan sonar images have shown evidence of rotational and translational slide scarps, rotated blocks, debris flows, rubble fields, displaced blocks, and other manifestations of slope failure. Despite this evidence, the cause or causes of these events have not been determined. Geologic mechanisms which could be responsible are present within the area, however, including external (e.g., earthquakes) and internal (e.g., excess pore pressures) processes and agents. The purpose of this study was to conduct a preliminary analysis of the causes of the past slope failures and to determine if these causes are likely to promote further slope failures. Because sediment geotechnical properties are a necessary part of such an analysis, they formed the data base for the study. In addition, because these data are useful for establishing a framework for stability analysis, a geotechnical characterization of the area was also a part of the investigation. This characterization is based on the cores shown in figure 14.

Reflecting the interplay between numerous geologic processes, the sediments of the North Atlantic Continental Slope and Rise displayed a marked geotechnical variability: 1) undrained shear strength ranges over two orders of magnitude; 2) plasticity ranges from low to high; 3) sensitivities range from insensitive to slightly quick; and 4) the sediments may be normally consolidated to heavily overconsolidated. Spatial and temporal changes in texture along with the presence of both depositional and erosional areas is the direct cause of the variability.

Despite the noted ranges in properties, the sediment can be characterized. Typically, they belong in the category designated "CH" by the Unified Soil Classification System and have a soft consistency. Further, they are very sensitive and have very low permeabilities. In general, they have most of the geotechnical properties associated with a fine-grained sediment dominated by illite and less active minerals.

Excluding areas of canyons and canyon systems, results of stability analyses show that the slope is generally stable for static drained and undrained conditions, despite declivities greater than 10^{o} in some locals. However, some sites would be vulnerable if subjected to relatively minor earthquake-induced ground accelerations, excess pore pressures from gas or other sources, or slight increases in gradient from oversteepening or undercutting. Each of these possibilities may have caused mass movements in the past at specific sites. Finally, it appears that, with the possible exception of earthquakes, most processes or agents which may cause instability in this geologic setting have the potential to be more important locally than regionally. More focused and detailed research will be needed before the relative efficiency or future effects of the different possible causes can be evaluated because relative magnitudes, frequencies, and extents have not yet been fully documented or quantified.

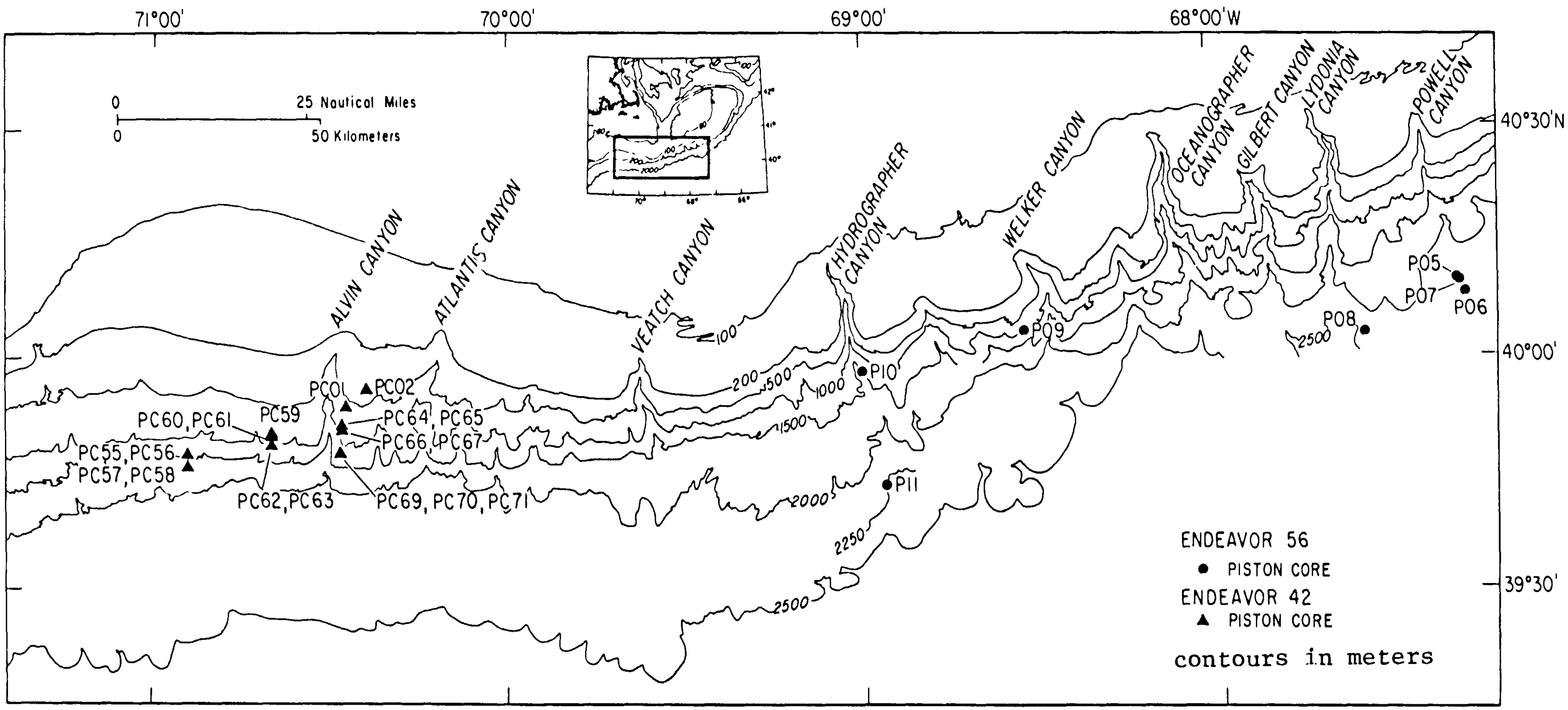

Figure 14. Piston Core locations. Inset map shows the location of the study area.

Sand-Wave Movement on Little Georges Bank

D. C. Twichell

(Chapter 5)

A 1-x-1.5-km area on Little Georges Bank (centered at 41°08´N., 68°04´W.) was mapped three times (June and September 1980 and April 1981) during a ten-month period by sidescan sonar and echo-sounding techniques to assess the morphology and mobility of sand waves on Georges Bank. Sand waves in the survey area, which ranged in water depth from 27 to 45 m, were from 1-11 m high although most were 5-7 m high. Their wavelengths were not constant because the crests were sinuous and, in places, bifurcated. The sand waves are asymmetrical, however, gradients of their steep sides mostly are 4°-10° which is well below the angle of repose for sand in water. Sand waves tended to have greater relief and a sharper asymmetry in September than in June or April (fig. 15).

The sand waves did move, but the motion was complex. Movement along an individual sand wave varied. Portions of some waves moved as much as 60 m between surveys while other parts remained stationary. Although the sand waves were asymmetrical, movement was not consistently in the direction that the steep sides faced. Along the same sand wave, some parts moved forward while other parts moved backwards. The mean displacement of the sand waves was 7 m to the southeast between the first two surveys and 3 m to the northwest between the second two surveys. Net movement of the sand waves for the ten-month survey period was 4 m to the southeast; a backwards movement based on the asymmetry of the sand waves.

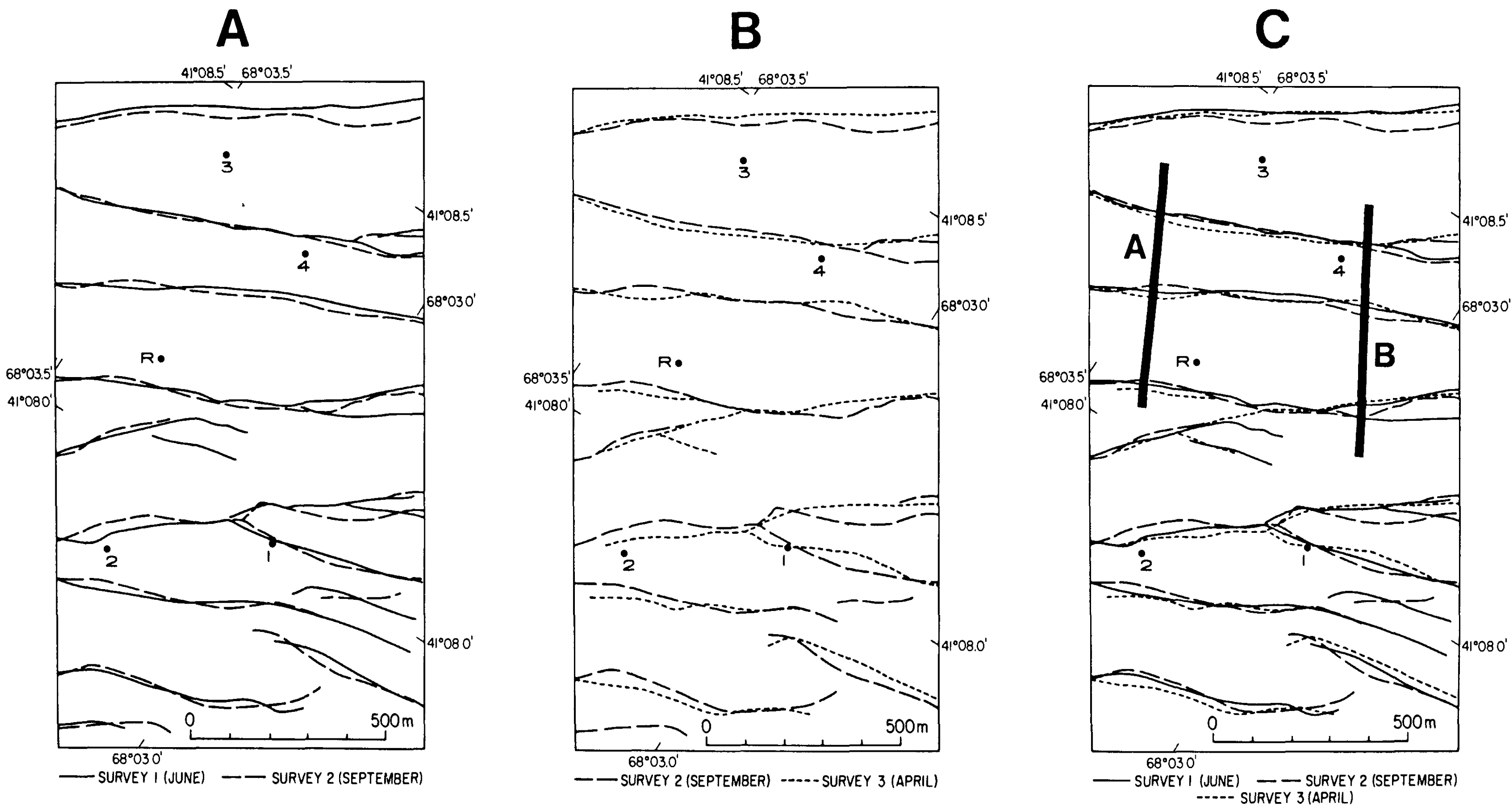

Figure 15. Summary of sand wave movement. (A) Locations of tops of steep slopes of sand wave in June and September, (B) locations of tops of steep slopes of sand waves in September and April, (C) locations of tops of steep slopes of sand waves during all 3 surveys. Dots refer to transponder locations (numbered) and sidescan reflector location (R).

The temporal and frequency structure of wind-current coupling on Georges Bank

M. A. Noble, B. Butman, and M. Wimbush

(Chapter 6)

Two and one-half years of current and wind-stress observation on the southern flank of Georges Bank show the wind-current coupling is mainly between alongshelf wind stress and alongshelf current. The currents on the southern flank of Georges Bank are polarized along isobaths; the alongshelf currents contain most of the current energy. In winter, when the water column is unstratified, the alongshelf currents are barotropic. Winter coherence amplitudes are greater than 0.90 and winter phase angles are less than 10^{o}. In summer, when the water column is highly stratified, the vertical coherence of the alongshelf currents is near 0.6, with slightly larger phase angles than are usually found in winter. The seasonal cycles of the alongshelf current and wind stress are in phase. High current and wind-stress energies occur in late fall and winter; summer energies are low. The mid-frequency band contains most of the alongshelf current energy, but the wind energy is spread over both the mid- and high-frequency bands.

The coupling between wind and current is a function of both frequency and season. The largest coherences (0.75) and transfer coefficients (4.5 cm^3/dyne-s and 3.5 cm^3/dyne-s for mid-depth and near-bottom currents, respectively) are found in the mid-frequency band. The coupling is much weaker at low and at high frequencies. At high frequencies, the decrease in transfer coefficient amplitudes and the increase in phase angle can be described by a simple model of a system, with a time lag of 20 hours, responding to a time varying force. The band-averaged coherence and transfer coefficients are largest in winter and smallest in late summer-early fall. The seasonal decrease in the wind-current coupling may be associated with the seasonal increase in the stratification.

Frictional effects are evident in the wind-current coupling on Georges Bank. Near-surface currents move to the right of the alongshelf wind. Near-bottom currents are rotated 20^{o} counterclockwise from mid-depth currents. These trends are consistent with Ekman dynamics. The spring-neap modulation of the bottom-drag coefficient for subtidal currents, caused by the modulation of the semidiurnal tidal amplitude, induces a spring-neap modulation in the wind-current coupling. The wind-current transfer coefficient is largest for neap tides, smallest for spring tides.

A sort of longshelf currents by longshelf wind stress indicates that the alongshelf current responds linearly to alongshelf wind-stress amplitudes. An asymmetry in the response may exist, for the slope of the current response to northeasterly winds is slightly larger than the slope for southwesterly winds. The difference in slopes is not significant at the 95% level, but is at the same sign as was previously found in coastal sea-level records in the Georges Bank-Gulf of Maine region.

Observations of bottom currents and sediment movement along the U.S. East Coast Continental Shelf during winter

Bradford Butman and J. A. Moody

(Chapter 7)

See pages 27 and 28 in this volume for summary of this chapter.

Lydonia Canyon Dynamics Experiment: Preliminary Report

Bradford Butman, M. A. Noble, J. A. Moody, and M. H. Bothner

(Chapter 8)

A field program was conducted to study the circulation and sediment dynamics in Lydonia Canyon, located on the southern flank of Georges Bank, and on the adjacent shelf and slope (fig. 16). The program included: (1) measurements by an array of moored current meters, bottom tripods, and sediment traps maintained between November 1980 and November 1982; (2) synoptic observations of the hydrography and suspended sediments; (3) sidescan and high-resolution profiles; (4) samples of the surficial sediments; and (5) direct observations of the sea floor from the submersible ALVIN.

The surficial distribution and the high-resolution profiles suggest that very fine sand and silts and clays accumulate in the head of the canyon and on an area of the adjacent shelf. However, the moored current measurements show that the surficial sediments are reworked and resuspended along the canyon axis to a depth of at least 600 m. Thus, although fine sediments may be accumulating, the axis is not tranquil. Maximum hour-averaged current speeds 5 meters above bottom (mab) were 50 cm/s at 282 and 600 m in the canyon axis. No evidence of sediment movement was observed at 1,380 m. Further analysis is required to determine the net transport of suspended sediment transport in the axis.

The mean Eulerian current on the shelf adjacent to Lydonia Canyon and above the level of the canyon rim was southwestward, consistent with previous studies of the mean circulation on Georges Bank. On the Continental Slope, the mean flow was strongly influenced by Gulf Stream eddies. Several eddies passed to the south of Lydonia Canyon during the observation period. The strong clockwise flow around the eddies caused eastward flow along the edge of the shelf as strong as 80 cm/s. On the slope, the influence of the eddies in the water column extended to at least 250 m, but not to 500 m. The influence of the Gulf Stream eddies did not extend onto the Continental Shelf to water depths of 125 m. There was a persistent off-shelf and downslope component of flow near the bottom of a few cm/s.

Within the canyon, the mean Eulerian current pattern was complex. At the head of the canyon at 282 m, net flow 5 mab was downcanyon at about 3 cm/s, and upcanyon at about 2 cm/s 50 mab. At 600 m in the canyon axis, net near-bottom flow was weak or upcanyon at a few cm/s, but down canyon at 100 mab. These observations suggest a convergence of the mean Eulerian flow between 300 and 600 m, and possibly several cells of recirculation along the canyon axis. However, because of the energetic non-linear high-frequency motion observed in the canyon and the small spatial scales, the mean Eulerian current may not indicate the central Lagrangian water particle motion. Further analysis is required to determine the Lagrangian circulation pattern. Measurements made on the eastern rim of the canyon show westward flow directly across the canyon axis. Measurements on the eastern wall of the canyon just a few kilometers away at comparable depths show northward inflow along the eastern wall. Measurements on the western wall show southward outflow. The mean Eulerian currents in the canyon thus suggest a complex vertical Eulerian circulation along the axis and horizontal exchange along the canyon walls.

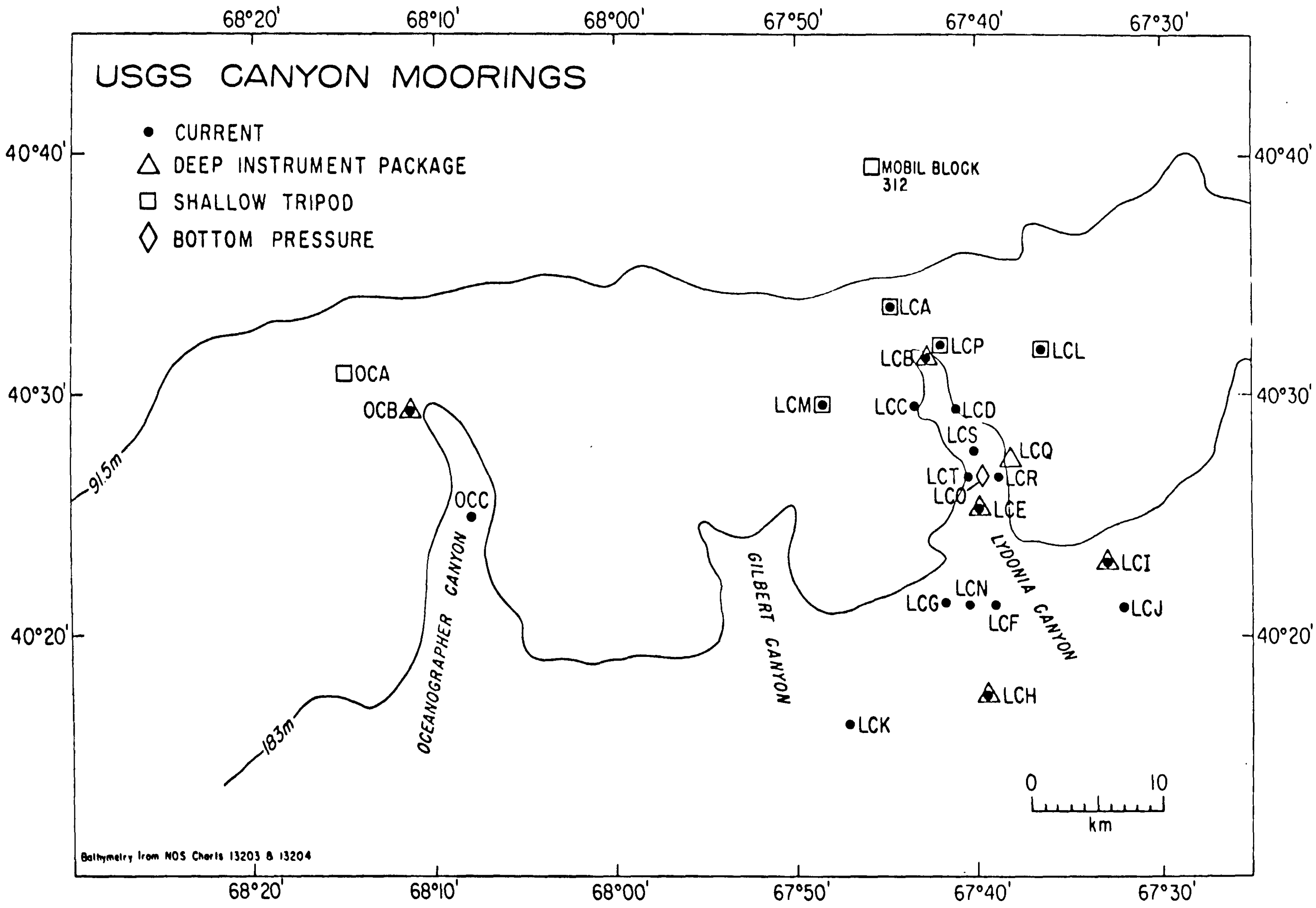

Figure 16. Location of moorings in Lydonia and Oceanographer Canyons.

The subtidal current (periods between 33 and 768 hours) can be separated into currents on the shelf, slope, and in the canyon. On both the shelf and slope, the subtidal currents were oriented primarily along isobaths, and were vertically and horizontally coherent over the separations measured. On the shelf, the subtidal current were 25-40 percent wind driven, except in the surface (10 km) Ekman layer. Although the currents on the slope were not wind driven, the currents on the shelf and slope were somewhat coupled. Within the canyon axis, the subtidal currents were much weaker than on the adjacent shelf or slope and were oriented along the canyon axis; analysis to date suggests that they were not very coherent vertically or horizontally over the spatial scales measured. The subtidal currents in the canyon were not strongly coupled to the currents on the shelf or slope and were not strongly driven by wind stress.

The currents on the shelf and slope and in the canyon were dominated by strong tidal currents. Within the canyon, the high-frequency currents (periods faster than 12 hours) increase in amplitude toward the canyon head and indicate highly non-linear processes within the canyon. High-frequency currents were not observed on the shelf or slope.

A small moored array experiment conducted in Oceanographer Canyon suggests that the current and sediment dynamics in Oceanographer are somewhat different than in Lydonia Canyon (fig. 16). Near-bottom currents at comparable depths in the canyon axis were larger in Oceanographer Canyon than in Lydonia Canyon. In addition, the mean Eulerian current was down canyon at both 300 and 600 m in Oceanographer Canyon, in contrast to Lydonia Canyon, where the net Eulerian current was down canyon at 300 m but up canyon at 600 m. Both the current observations, the surficial sediment texture, and large bed forms observed in the canyon axis suggest that Oceanographer Canyon is more energetic than Lydonia Canyon and, thus, that fine-grained sediments may not accumulate in the head of Oceanographer Canyon.

SUMMARY

Advances in technology have provided resolution of the sea floor at a scale sufficient to begin to interpret sea-floor processes. The morphology of the submarine canyons and the dendritic pattern of gullies which dissect the slope support the concept that canyons are important transport pathways on the continental margin. Canyons are also important features in building and shaping the Continental Rise. Differences in channel morphology and sediment distribution of nearby canyons suggest tha sea-floor processes can be variable over short distances.

Evidence of erosion on the Continental Slope and Rise is documented by seismic-reflection profile records, mid-range sidescan sonographs, and observations from DSRV ALVIN of outcrops on the sea floor. Stability analysis and geotechnical properties of 8-m-long piston cores indicate that in general the surficial sediments are stable, however, local conditions may vary and affect this state of stability. Small slumps were identified on the sidescan sonographs and seismic-reflection profiles. Talus blocks and deformed sediments observed on the rise from DSRV ALVIN also are evidence that mass wasting has occurred.

Ocean currents are important agents in eroding and transporting sediment in the shallow water of the Continental Shelf, resulting in the construction and migration of bed forms. In the deeper water of the Continental Slope, ocean currents facilitate transport of sediment into and through the submarine canyons. Bed forms and sediment grain size on the canyon floors also reflect the transport activity of currents in the canyons. Long-term measurements are important in monitoring these currents to determine their variability as well as to identify their forcing mechanisms.

REFERENCES

Bothner, M. H., Spiker, E. C., Johnson P. P., Rendings, R. R., and Aruscavage, P. J., 1981, Geochemical evidence for modern sediment accumulation on the Continental Shelf off southern New England: Journal of Sedimentary Petrology, v. 51, p. 281-292.

Butman, B., Noble, M., and Folger, D. W., 1979, Long-term observations of bottom current and bottom sediment movement on the mid-Atlantic continental shelf: Journal of Geophysical Research, v. 84, p. 1187-1205.

Doyle, L. J., Pilkey, O. H., and Woo, C. C., 1979, Sedimentation on the eastern United States continental slope, in Doyle, L. J., and Pilkey, O. H., eds., Geology of continental slopes: Society of Economic Paleontologists and Mineralogists Special Publication 27, p. 119-129.

Embley, R. W., and Jacobi, R. D., 1977, Distribution and morphology of large submarine sediment slides and slumps on Atlantic continental margins: Marine Geotechnology, v. 2, p. 205-228.

Emery, K. O., and Uchupi, E., 1972, Western North Atlantic Ocean: topography, rocks, structure, water, life, and sediments: American Association of Petroleum Geologists Memoir 17, 532 p.

Emery, K. O., Uchupi, E., Phillips, J. D., Bowin, C. O., Bunce, E. T., and Knott, S. T., 1970, Continental rise off eastern North America: American Association of Petroleum Geologists Bulletin, v. 54, p. 44-108.

Grant, W. D., and Madsen, O. S., 1979, Combined wave and current interaction with a rough bottom: Journal of Geophysical Research, v. 84, p. 1797-1808.

Grow, J. A., Mattick, R. E., and Schlee, J. S., 1979, Multichannel seismic depth sections and interval velocities over outer continental shelf and upper continental slope between Cape Hatteras and Cape Cod, in Watkins, J. S., Montadert, L., and Dickerson, P. W., eds., Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Memoir 29, p. 65-83.

Jordan, G. F., 1962, Large submarine sand waves: Science, v. 136, p. 839-848.

Keller, G. H., Lambert, D. N., and Bennett, R. H., 1979, Geotechnical properties of continental slope deposits-Cape Hatteras to Hydrographer Canyon, in Doyle, L. J., and Pilkey, O. H., eds., Geology of continental slopes: Society of Economic Paleontologists and Mineralogists Special Publication 27, p. 131-151.

Keller, G. H., and Shepard, F. P., 1978, Currents and sedimentary processes in submarine canyons off the northeast United States, in Stanley, D. J., and Kelling, G., eds., Sedimentation in submarine canyons, fans, and trenches: Strousburg, Penn., Dowden, Hutchinson and Ross, p. 15-32.

Klitgord, K. D., and Behrendt, J. C., 1979, Basin structure of the U.S. Atlantic Margin, in Watkins, J. S., Montadert, L., and Dickerson, P. W., eds., Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Memoir 29, p. 85-112.

Knebel, H. J., and Carson, B., 1979, Small-scale slump deposits, middle Atlantic continental slope, off eastern United States: Marine Geology, v. 29, p. 221-236.

Knebel, H. J., and Spiker, E., 1977, Thickness and age of surficial sand sheet, Baltimore Canyon Trough area: American Association Petroleum Geologists Bulletin, v. 61, p. 861-871.

Knott, S. T., and Hoskins, H., 1968, Evidence of Pleistocene events in the structure of the continental shelf off the northeastern United States: Marine Geology, v. 6, p. 5-43.

Lambert, D. N., Bennett, R. H., Sawyer, W. B., and Keller, G. H., 1981, Geotechnical properties of continental upper rise sediments-Veatch Canyon to Cape Hatteras: Marine Geotechnology, v. 4, p. 281-306.

MacIlvaine, J. C., and Ross, D. A., 1979, Sedimentary processes on the continental slope of New England: Journal of Sedimentary Petrology, v. 49, p.563-574.

McClennen, C. E., and McMaster, R. L., 1971, Probable Holocene transgressive effects on the geomorphic features of the continental shelf off New Jersey, United States: Maritime Sediments, v. 7, p. 69-72.

McGregor, B. A., 1976, Variations in bottom processes along the U.S. Atlantic continental margin, in Watkins, J. S., Mondtadert, L., and Dickerson, P. W., eds., Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Memoir 29, p. 139-149.

McGregor, B. A., 1979, Current meter observations on the U.S. Atlantic continental slope: variation in time and space: Marine Geology, v. 29, p. 209-219.

McGregor, B. A., 1981, Smooth seaward-dipping horizons-an important factor in sea-floor stability: Marine Geology, v. 39, p. M89-M98.

McGregor, B. A., ed., 1983a, Environmental geologic studies on the United States Mid- and North Atlantic Outer Continental Shelf area, 1980-1982, Volume II. Mid-Atlantic region: Final Report prepared by the U.S. Geological Survey for the U.S. Bureau of Land Management, OCS Office, New York.

McGregor, B. A., ed., 1983b, Environmental geologic studies on the United States Mid- and North Atlantic Outer Continental Shelf area, 1980-1982, Volume III. North Atlantic region: Final report prepared by the U.S. Geological Survey for the U.S. Bureau of Land Management, OCS Office, New York.

McGregor, B. A., and Bennett, R. H., 1981, Sediment failure and sedimentary framework of the Wilmington geotechnical corridor, U.S. Atlantic continental margin: Sedimentary Geology, v. 30, p. 213-234.

Middleton, G. V., and Hampton, M. A., 1976, Subaqueous sediment transport and deposition by sediment gravity flows, in Stanley, D. J., and Swift, D. J. P., eds., Marine sediment transport and environmental management: New York, John Wiley, p. 197-218.

Milliman, J. D., Pilkey, O. H., and Ross, D. A., 1972, Sediments of the continental margin off the eastern United States: Geological Society of America Bulletin, v. 83, p. 1315-1334.

Nelsen, T. A., 1981, The nature of general mass movement sedimentary processes on the outer shelf, slope, and upper rise northeast of Wilmington Canyon: Ph.D. Dissertation, University of Miami, Miami, Florida, 303 p.

Poag, C. W., 1979, Stratigraphy and depositional environments of Baltimore Canyon Trough: American Association of Petroleum Geologists Bulletin v. 63, p. 1452-1466.

Poag, C. W., 1982, Stratigraphic reference section for Georges Bank Basin depositional model for New England passive margin: American Association of Petroleum Geologists Bulletin, v. 66, p. 1021-1041.

Popenoe, P., 1981, A summary of environmental geologic studies on the southeastern United States Atlantic Outer Continental Shelf, 1977-1978: U.S. Geological Survey Open-File Report 81-583, 43 p.

Pratt, R. M., 1967, The seaward extension of submarine canyons off the northeast coast of the United States: Deep-Sea Research, v. 14, p. 409-420.

Robb, J. M., Hampson, J. C., Jr., Kirby, J. R., and Twichell, D. C. 1981, Geology and potential hazards of the continental slope between Lindenkohl and South Toms Canyons, offshore Mid-Atlantic United States: U.S. Geological Survey Open-File Report 81-600, 21 p.

Ryan, W. B. F., and Miller, E. L., 1981, Evidence of a carbonate platform beneath Georges Bank: Marine Geology, v. 44, p. 213-228.

Scanlon, K. M., 1982, Geomorphic features of the western North Atlantic Continental Slope between Northeast Channel and Alvin Canyon as interpreted from GLORIA II long-range sidescan-sonar data: U.S. Geological Survey Open-File Report 82-728, 8 p.

Schlee, J., Behrendt, J. C., Grow, J. A., Robb, J. M., Mattick, R. E., Taylor, P. T., and Lawson, B. J., 1976, Regional geologic framework off northeastern United States: American Association of Petroleum Geologists Bulletin, v. 60, p. 926-951.

Slater, R. A., 1981, Submersible observations of the sea floor near the proposed Georges Bank lease sites along the North Atlantic Outer Continental Shelf and upper slope: U.S. Geological Survey Open-File Report 81-742, 63 p.

Shepard, F. P., 1948, Submarine geology: New York, Harper and Row, 517 p.

Stanley, D. J., Swift, D. J. P., Silverberg, N., James, N. P., and Sutton, R. G., 1972, Late Quaternary progradation and sand spillover on the outer continental margin off Nova Scotia, Southeast Canada: Smithsonian Contribution Earth Sciences, v. 8, 88 p.

Stetson, H. C., 1949, The sediments and stratigraphy of the east coast continental margin-Georges Bank to Norfolk Canyon: Massachusetts Institute of Technology and Woods Hole Oceanographic Institution Papers in Physical Oceanography and Meteorology, v. 7, no. 2, 60 p.

Stubblefield, W. L., McGrail D. W., and Kersey, D. G., 1983, Recognition of transgressive and post-transgressive sand ridges on the New Jersey continental shelf, in Tillman, R. W., and Siemers, C. T., eds., Clastic sedimentary sequences: Society of Economic Paleontologists and Mineralogists Special Publication, in press.

Swift, D. J. P., Kofoed, J. W., Saulsbury, F. P., and Sears, P., 1972, Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America, in Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Stroudsburg, Penns., Dowden, Hutchinson and Ross, p. 499-574.

Twichell, D. C., McClennen, C. E., and Butman, B., 1981, Morphology and processes associated with the accumulation of the fine grained sediment deposit on the southern New England Shelf: Journal of Sedimentary Petrology, v. 51, p. 269-280.

Twichell, D. C., and Roberts, D. G., 1982, Morphology, distribution, and development of submarine canyons on the United States Atlantic Continental Slope between Hudson and Baltimore Canyons: Geology, v. 10, p. 408-412.

Valentine, P. C., Uzmann, J. R., and Cooper, R. A., 1980, Geology and biology of Oceanographer Submarine Canyon: Marine Geology, v. 38, p. 283-312.

Veatch, A. G., and Smith, P. A., 1939, Atlantic submarine valleys of the United States and the Congo submarine valley: Geological Society of America Special Paper 7, 101 p.

Vincent, C. E., Swift D. J. P., and Hillard, B., 1981, Sediment transport in the New York Bight, North Atlantic shelf: Marine Geology, v. 42, p. 369-398.