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The Geomorphology and Shallow Structure of the Northeastern New Jersey Continental Slope

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THE GEOMORPHOLOGY AND SHALLOW STRUCTURE OF THE NORTHEASTERN NEW JERSEY CONTINENTAL SLOPE

A Thesis
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The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

by
Nicole D. Scott
1995

APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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Master of Arts

Nicole D. Scott

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This thesis is dedicated to my mother, Rita V. Scott,
who is “the wind beneath my wings.”

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ABSTRACT

Forty-seven closely-spaced high-resolution seismic reflection profiles were integrated with core data to determine the subsurface nature of the present-day upper continental slope off northeastern New Jersey. The study area has three prominent subsurface reflectors whose mapped configurations are assumed to represent the surficial expressions of the slope during different phases of its development, from approximately 5 Ma to the Present. Structure maps of the age-constrained reflectors reveal the major morphologic feature identified within the study area (Mey Canyon) has existed on the slope since the late Miocene-Pliocene, approximately 5 Ma, and changed in configuration and position during the predominately Quaternary slope development. Isopach maps and seismic profiles indicate the shallow structure of the slope consists of a late Miocene-Pliocene to middle Pleistocene northeast-thickening sediment wedge overlain by a sediment blanket more or less uniform in thickness. Variations in sediment thickness are primarily attributed to episodic deposition and erosion that occurred during the Pleistocene sea-level fluctuations. Hummocky topography and discontinuous reflectors identified at the seafloor surface and a few meters below the seafloor are interpreted as both Holocene and Pleistocene mass-wasting features. The northeastern New Jersey continental slope therefore appears to be a relict feature that has been minimally influenced by Holocene mass-wasting events.

THE GEOMORPHOLOGY AND SHALLOW STRUCTURE OF THE NORTHEASTERN NEW JERSEY CONTINENTAL SLOPE

I. INTRODUCTION

Seismic studies reveal the eastern U.S. passive continental margin is comprised of cyclical patterns of deposition and erosion that coincide with global sea-level fluctuations (Poag and Mountain, 1987; Schlee, 1981). In general, depositional sequences and the surfaces of erosion or nondeposition separating them appear to be the products of fluvial and marine processes during trangressions and regressions of the sea, suggesting sediment flux on the margin is episodic. Although the concept of sequence stratigraphy provided the framework within which the development, or evolution, of portions of the continental margin have been interpreted, controversy remains concerning the origin and timing of sedimentary strata and unconformities on passive continental slopes. Thorne and Watts (1984) suggest sea-level fluctuations and subsequent periods of erosion and nondeposition explain the presence of shelf-wide unconformities, but do not solely explain the presence of slope-wide unconformities identified several hundreds to thousands of meters below sea-level. They suggest that alternative explanations involving oceanographic processes and sediment supply should be considered. In contrast, Poag and Schlee (1984) and Poag and Mountain (1987) identified several Cenozoic unconformities on the slope whose stratigraphic positions in boreholes matched those of Vail's major global sea-level-induced unconformities, strengthening the suggestion that perhaps unconformities and global sea-level lowerings coincide.

The definitive relationship between slope unconformities and eustatic sea-level changes remains as much an enigma as that between mass-wasting events, i.e., slumps and debris flows, and relative sea-level changes. It is unknown whether mass wasting events occur at times of maximum sea-level lowstand (and/or minimum sea-level lowstand) or sometime during rise (Pratson and others, 1993). The effect of such events on slope morphology during the late Quaternary has prompted debate. Prior and others (1983) suggest the continental slope is a relict landscape that evolves topographically within a geologic time frame in which cumulative effects of processes over the longterm have shaped the present morphology. Basically, downslope processes, such as mass wasting, have had no significant influence on slope morphology for the past 20,000 years. Stanley and others (1984) agree that the major morphologic features, such as canyons, result from processes operative over long-term geologic time-scales, but they also suggest that episodic mass wasting highly influences the present-day (< 10,000 yrs) slope morphology.

The primary objective of this investigation is to determine the relict nature of the present-day (Holocene) New Jersey continental slope morphology by integrating age-constrained structure maps of seafloor surfaces with seismic profiles. Some previous investigations suggest meso-scale features, such as canyons, primarily reflect events attributable to Quaternary fluctuations in sea-level (Pratson and others, 1993) while others have identified older processes (Uchupi and Ellis, 1982). In order to fully understand the nature of the present-day seafloor it will be necessary to determine the past seafloor morphologies of the slope and their relationships to the underlying shallow structure.

The morphology and the shallow structure of the New Jersey continental margin have been documented in previous seismic studies. Milliman and others (1990) and Davies and others (1992) delineated the shallow structure of the New Jersey outer shelf and deduced that late Quaternary shelf sedimentation resulted from glacially-induced sea-level fluctuations. Using deeper seismic data with less vertical and horizontal resolution, Pratson and others (1993) studied the morphology of the northeastern U.S. slope and concluded that subsea sediment flows generated submarine canyons located offshore New Jersey. The present study is unique because an extensive data base of closely-spaced seismic lines run at intervals of several hundred meters, compared to most lines which are run several to tens of km apart, will be utilized to define both the upper to middle slope morphology and the shallow structure of an area offshore New Jersey that had never been analyzed in great detail prior to the present investigation. In an attempt to further explain how modern processes affect the fine-scale surficial morphology of the continental slope and the relationship between sea-level fluctuations and slope unconformities, the following hypothesis will be tested:

> The morphology, shallow stratigraphy, and resulting acoustic characteristics of the New Jersey upper to middle continental slope predominately reflect sedimentologic events related to sea-level changes and to the episodic introduction or redistribution of sediment.

The secondary objective of this investigation is to define and explain the temporal and spatial variations in sediment accumulation by comparing and contrasting isopach maps of age-constrained reflectors. In this regard, the present study will define the developmental history of the study area.

REGIONAL SETTING

North Atlantic Margin

North America's Atlantic passive continental margin extends more than 2000 km from southern Florida to the maritime provinces of Canada. This structurally complex margin is comprised of a Mesozoic-Cenozoic sedimentary wedge that overlies a pre-rift igneous and metamorphic rock foundation (Schlee, 1981; Klitgord and others, 1988). Extreme subsidence of the North Atlantic Margin has resulted in thick accumulations of sediments within local basins, such as the Baltimore Canyon Trough.

Baltimore Canyon Trough

Extending more than 500 km along the North Atlantic Margin, the Baltimore Canyon Trough is a downfaulted sedimentary basin that underlies the continental shelf and the upper continental slope of New Jersey, Delaware, Maryland, and parts of Virginia (Poag, 1979; Poag and Watts, 1987). Flanked by both the Carolina Platform and the Long Island Platform, the trough widens from Virginia to its offshore New Jersey depocenter where as much as 18 km of sediment have accumulated since the Late Triassic, approximately 210 Ma (Sawyer and others, 1982; Farre and Ryan, 1987). Trough sedimentation results from the influx of land-derived sediment, margin subsidence, and sea-level oscillations (Schlee, 1981; Libby-French, 1984).

Sea-Level and Margin Stratigraphy

The siliciclastic sediment record of the eastern U.S. passive continental margin is a product of the complex interaction between tectonics, sediment supply, and sea-level change (both relative and global). Relative sea-level change results from variations in the amount of space available for sediment to accumulate. These variations, caused by eustacy and tectonics, prompt the back and forth migration of shorelines in both space and time (Miller and Mountain, 1994). A slow sea-level fall and rapid erosion or a rapid sea-level rise result in shoreline regression, whereas, a slow sea-level rise and rapid deposition or a rapid sea-level fall result in shoreline transgression (Curray, 1964). Relating the position of the shoreline to the rates of sea-level change, subsidence, and sedimentation, Pitman (1978) suggests the shoreline tends to stabilize at that point on the margin where the rate of rise (or fall) of sea-level is equal to the difference between the rate of subsidence of the shelf edge and the rate of sediment infill.

The geomorphology of the continental margin changes as sea-level rises and falls. During lowstands of relative sea-level, when the shelf is exposed to subaerial processes, major rivers, such as the Hudson, cut their channels across the continental shelf and deposit sediment at the shelf edge or upper slope. Periodic slumping of these deposits generates high-energy turbidity currents that can facilitate canyon formation along the slope (Pratson and others, 1993). During relative sea-level rise when the shelf is flooded, sediment deposition is focused landward. As a result, features further seaward such as the outer shelf and upper slope become sediment starved. Shoreline position and water depth may be independent of relative sea-level change due to time-dependent tectonics and sediment supply which also influence eustatic sea-level change via basin modification (Vail and others, 1977; Posamentier and others, 1988; Miller and Mountain, 1994).

STUDY AREA

The study site is the upper to middle northeastern New Jersey continental slope (water depth 150 m - 1350 m), between Hendrickson and Hudson Canyons (Figure 1). Mey Canyon, the area's most prominent submarine feature, primarily dissects the middle slope, whereas the upper slope, characterized by an 8° gradient (Pratson and Haxby, 1995), is smoother and less rugged (Figure 2). This section of the North Atlantic Margin contains a portion of the Hudson Apron, a Holocene plateau-like feature located on the outermost shelf that is blanketed by highly stratified glacial sands and clays (Milliman and others, 1990).

II. METHODS

SEISMIC DATA

The survey grid is comprised of 40 onshore-offshore (dip) lines and 7 along-slope (strike) lines that cover a 13.5 km by 12.5 km area of the northeastern New Jersey continental slope (Figure 3). This high-resolution seismic sparker data base is part of a series of Minerals Management Service/United States Geological Survey (MMS/USGS), pre-sale, lease block surveys run on the continental shelf and continental slope of New Jersey in April-May, 1978. An EG & G Model 402-7 twelve channel sparker subbottom profiler was fired once per second at a tow depth of 5 meters (15 feet) below sea-level. Analog copies of the seismic data were

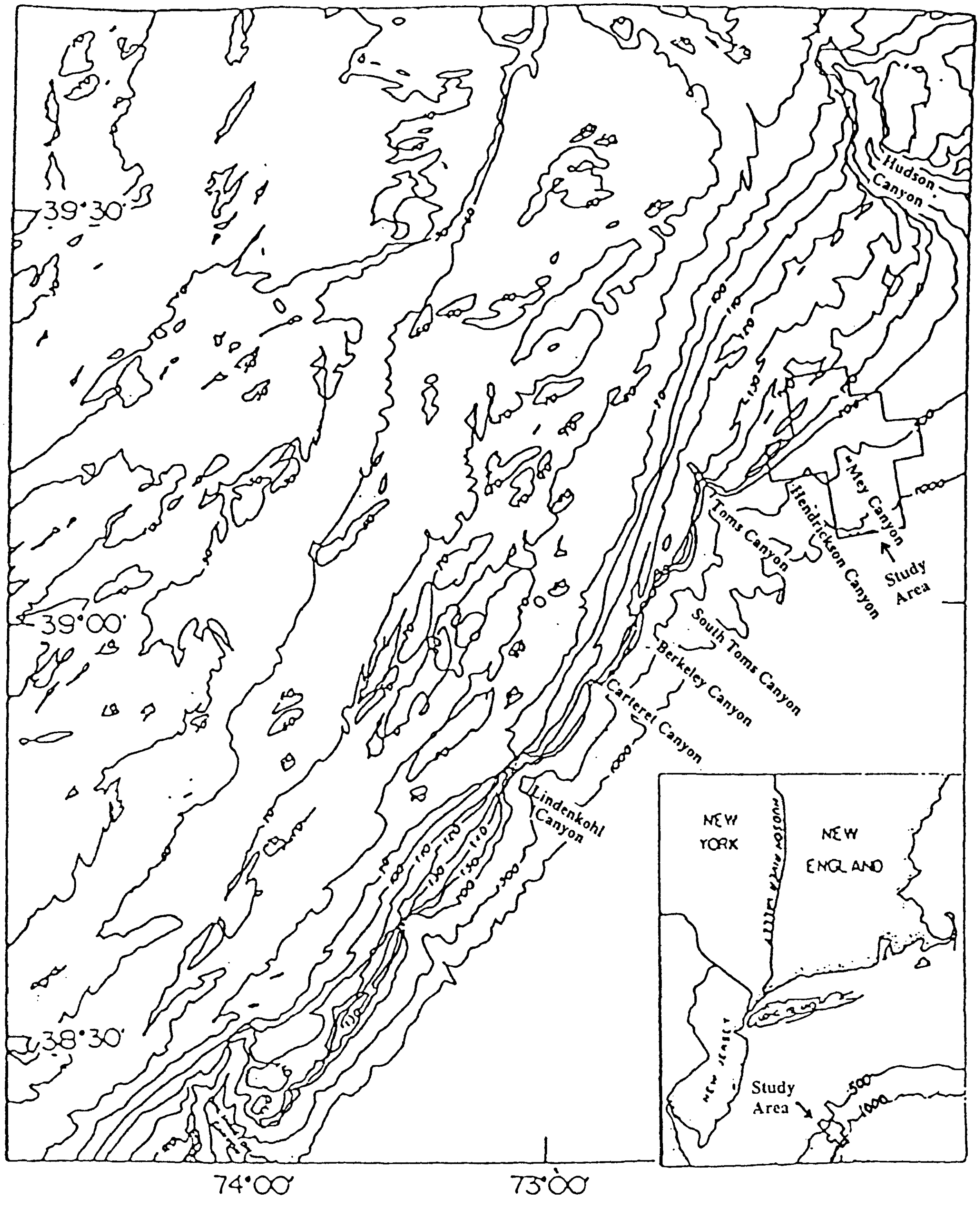


Figure 1. (after Milliman and others, 1990) Regional bathymetric map of the New Jersey outer shelf and upper slope (depths in meters). Study site (boxed-in) is located northeast of Toms Canyon. Inset map, in lower right corner, indicates the approximate location of the study area relative to the northeastern U.S..

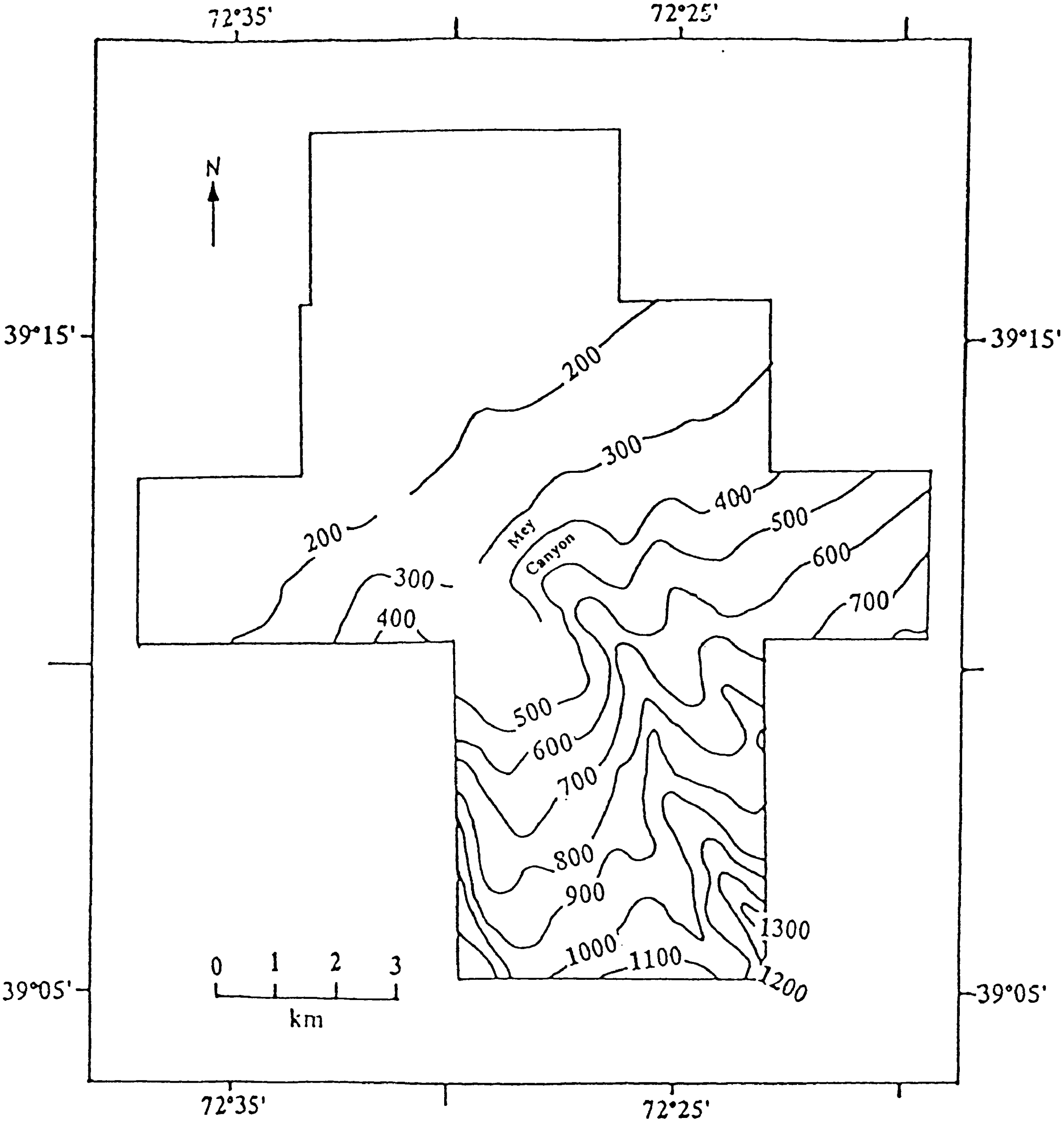


Figure 2. (based on MMS/USGS seismic profiles and NOAA/NOS chart NOS NJ 18-6) Bathymetric map of the study area. Contour interval is 100 m.

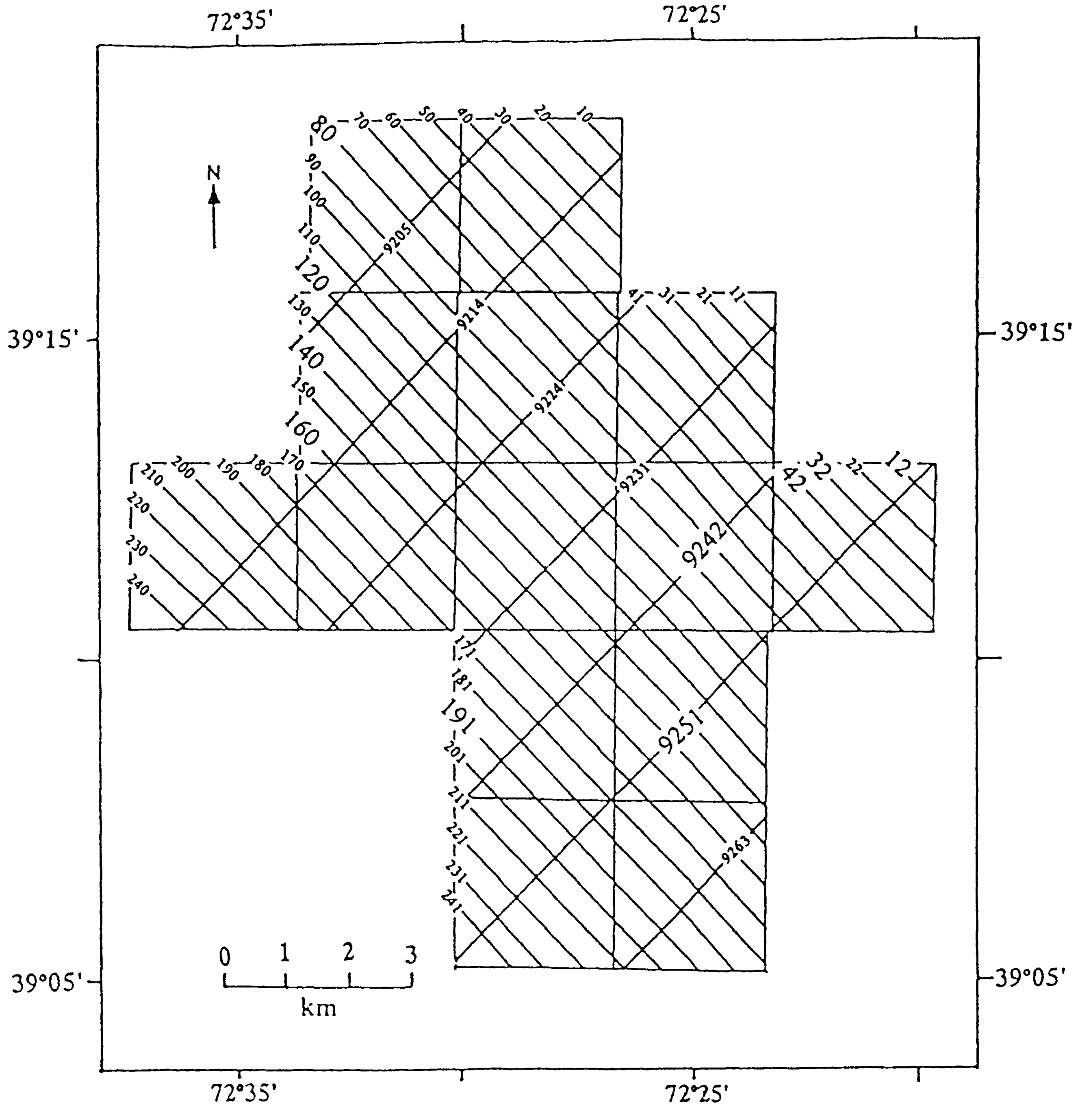


Figure 3. Survey grid of the study area showing MMS/USGS seismic lines. The survey area is approximately 13.5 km N-S. Line spacing along-slope is about 1.6 km and onshore-offshore line spacing is 500 km. Portions of the tracklines labelled with enlarged numbers are figures within the text.

retrieved and photocopied from 35 millimeter microfilm stored at the USGS warehouse in Woods Hole, Massachusetts; to this writer's knowledge, the original data no longer exist.

Subbottom Profiler

A sparker acoustic profiler produces medium to high resolution subbottom profiles of the uppermost few hundred meters of strata beneath the seabed (McQuillin and others, 1984). This system transmits acoustic signals by discharging stored electrical energy, a spark, through an electrode into the water. The released spark vaporizes the surrounding water and creates a steam bubble that expands until the outward pressure of the bubble is overcome by the hydrostatic pressure of the water, at which time the bubble collapses creating an acoustic pulse (Sieck and Self, 1977).

Each acoustic pulse is transmitted through the seabed and is reflected from acoustic interfaces, i.e., reflectors at which there is a strong change in acoustic impedance or a contrast in density and elastic properties. Acoustic interfaces may represent physical features (such as, unconformities, faults, or bedding planes) or changes in geotechnical character (i.e., bulk density or consolidation). Each acoustic interface is displayed graphically on a subbottom profile based on the time it takes the transmitted energy to travel from the acoustic source to the interface and back to the receiver. The distance can be described in milliseconds (ms) of travel-time. However, the round-trip time multiplied by the speed of sound in seawater and shallow subbottom sediment divided by two equals the calculated depth (in meters) to the interface (Sieck and Self, 1977).

SEISMIC PROFILE ANALYSIS

Analysis of the high-resolution seismic reflection data involved several steps. Photographs of the profiles were xeroxed to provide working copies for seismic reflector tracing and interpretation. The xeroxed portions of each profile were spliced together to create a continuous profile. Reflector configurations, depths, and shotpoint numbers were utilized to delineate specific reflectors that represent major sedimentary or non-depositional interfaces. Structure and isopach maps, which provide perspectives of subsurface morphology and overlying sediment thickness, respectively, were created for each major reflector (see below). Since cores were not collected within the study area, the reflectors were assigned tentative ages by correlating delineated seismic horizons to Ocean Drilling Program (ODP) Leg 150 drill hole data located just outside the study area (Figure 4). The subsurface maps and core data define the spatial and temporal relationships of the reflectors (Reynolds, 1990).

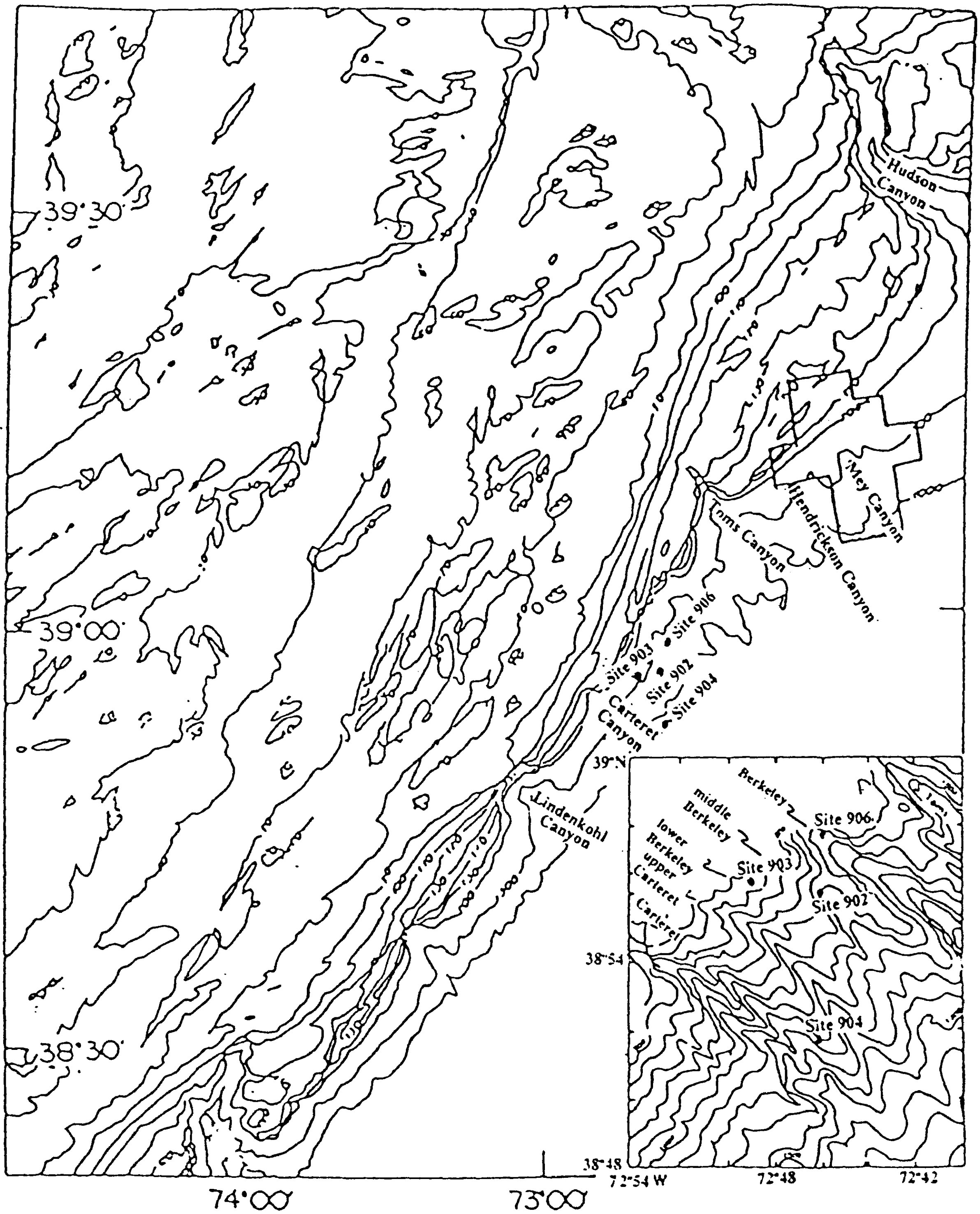


Figure 4. (after Milliman and others, 1990) Regional bathymetric map of the New Jersey continental terrace (shelf and slope) which shows the study area (boxed-in) relative to the approximate ODP 1994 drill area. Inset map (after Shipboard Scientific Party, 1994) in lower right, is the ODP Leg 150 bathymetric map of drill area indicating drill "Sites" relative to one another and the southwest portion of the New Jersey slope.

Structure Maps

Structure maps indicate surficial configurations, locations of buried features, i.e., canyons and gullies, and regional variations of reflectors. Structure depth (in seconds) was determined relative to the sea surface and converted to milliseconds (Figure 5).

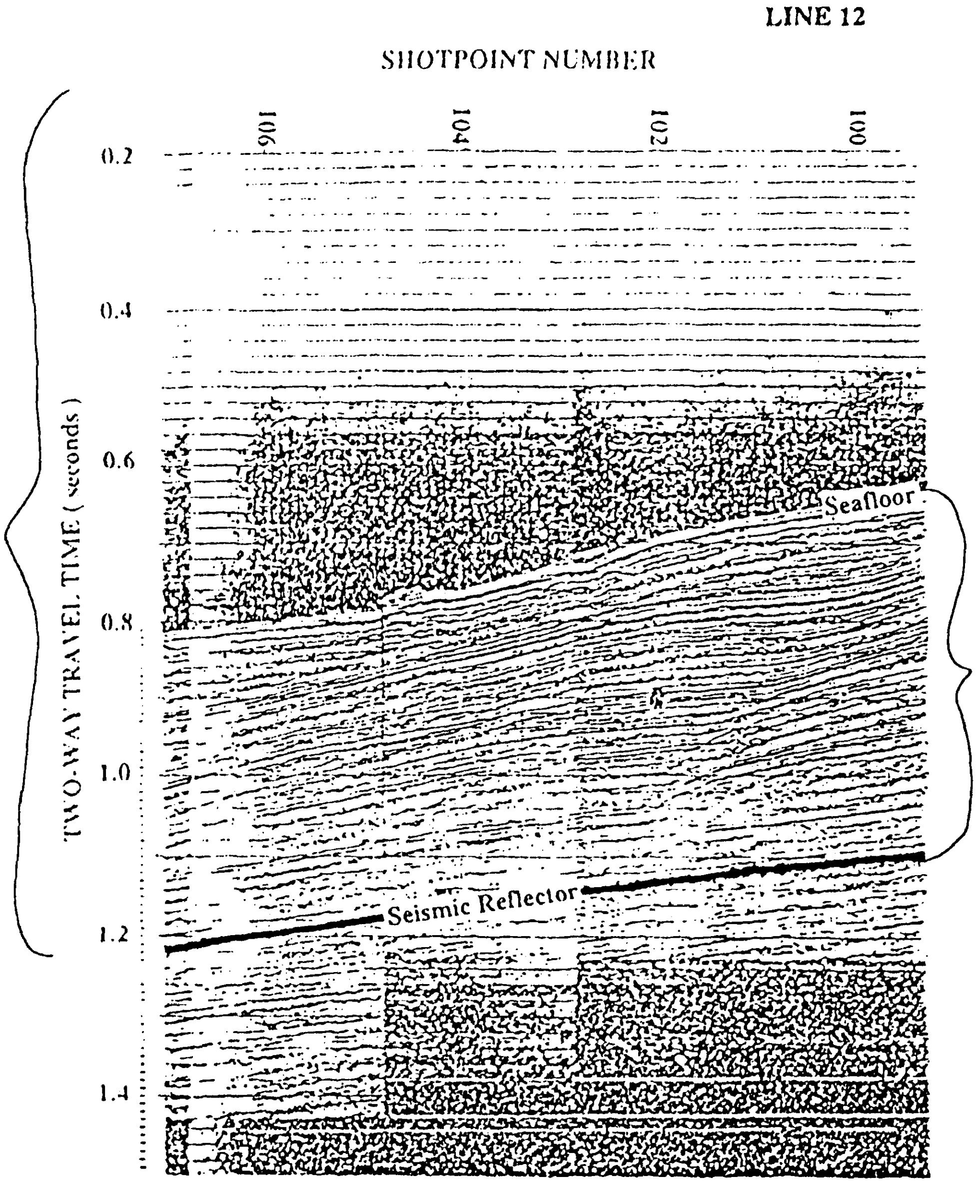
Isopach Maps

An isopach map displays the thickness of sediment overlying a particular reflector. As such, the contours can indicate existing erosional and depositional patterns that may reflect relative sea-level changes. Sediment thickness was determined by subtracting seafloor depth (in seconds) from its corresponding reflector depth (in seconds); this value was converted to milliseconds (Figure 5).

III. RESULTS

PRESENT-DAY SEAFLOOR BATHYMETRY

The bathymetric map of the study area reveals the middle portion of the New Jersey continental slope is heavily incised by two downward-trending submarine canyons whereas the upper slope (< 400 m) is morphologically subdued (Figure 2). Mey Canyon, the most pronounced submarine feature within the study area, initially incises the slope at 400 m below sea-level and is characterized by a relatively straight canyon axis. A smaller canyon, with a broader axis, occurs to the immediate east of Mey Canyon



Structure Depth
1.22-0 = 1.22 s
= 1220 ms
(Sea-level)

Isopach
Depth
1.10-0.64
=0.46 s
=460 ms

Figure 5. Calculation of isopach and structure depths (in seconds). The seafloor is the reference point for isopach depths. Sea-level is the reference point for structure depths.

where its canyon head also incises the slope at 400 m below sea-level (Figure 2).

MORPHOLOGY (STUDY SECTION)

Interpreted to represent the surficial expressions of the New Jersey continental slope during different stages of its development, prominent seismic reflectors are incised by submarine canyons (Figure 6). The lack of core data within the study area and the limited core record outside the area impede the dating of these major morphologic features. Thus, tentative ages are assigned to the features and will remain speculative until drilling occurs.

Blue Reflector

The bottommost delineated seismic interface, termed the Blue reflector, lies at the base of the predominately Quaternary study section (Figure 7). This reflector is relatively flat lying and dips from 375 ms below sea-level, near the shelf break, to more than 1500 ms below sea-level, midslope. The Blue reflector was traced throughout the study area and an additional 22 km southwest along the New Jersey continental slope to the site of ODP Core 903, where it correlates with reflector p6 (Figure 8), an erosional unconformity that corresponds to the late Miocene-Pliocene contact (Shipboard Scientific Party, 1994; Smith, 1995). Although Shipboard Scientific Party (1994) identified an average sound velocity of 1681 m/s at the Core 903 p6

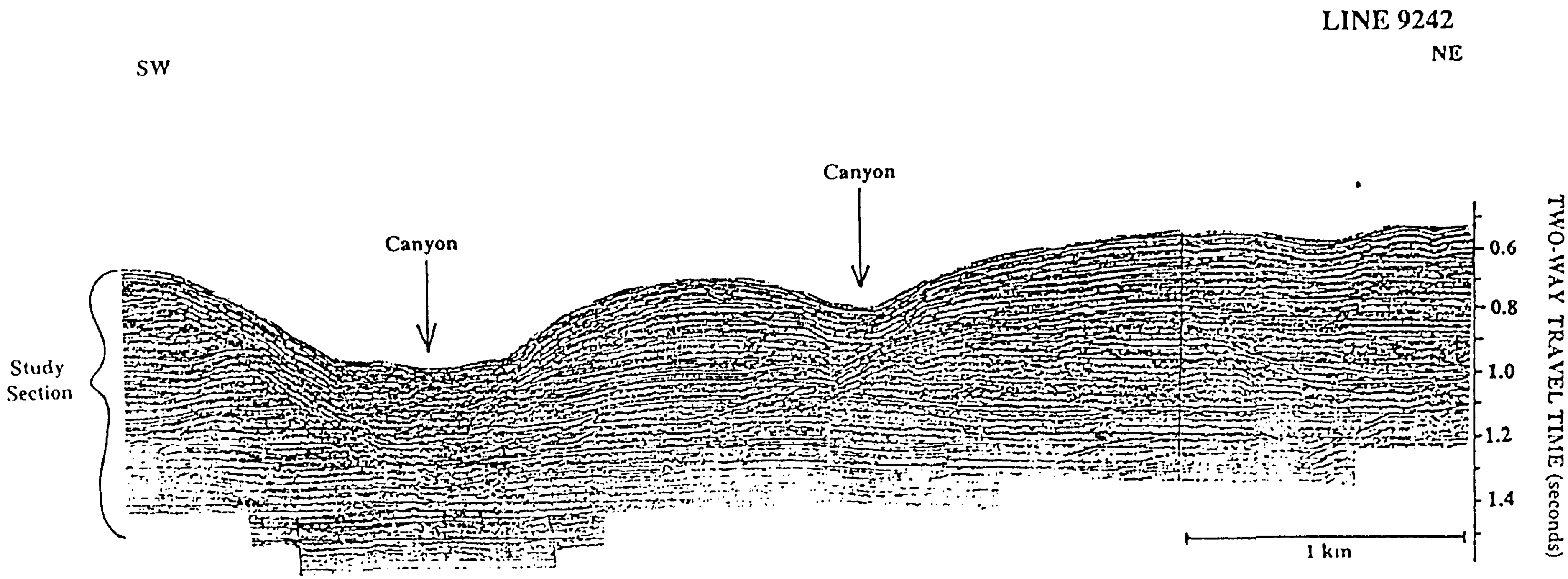


Figure 6. Profile contains submarine canyons that incise subsurface reflectors located within the study section.

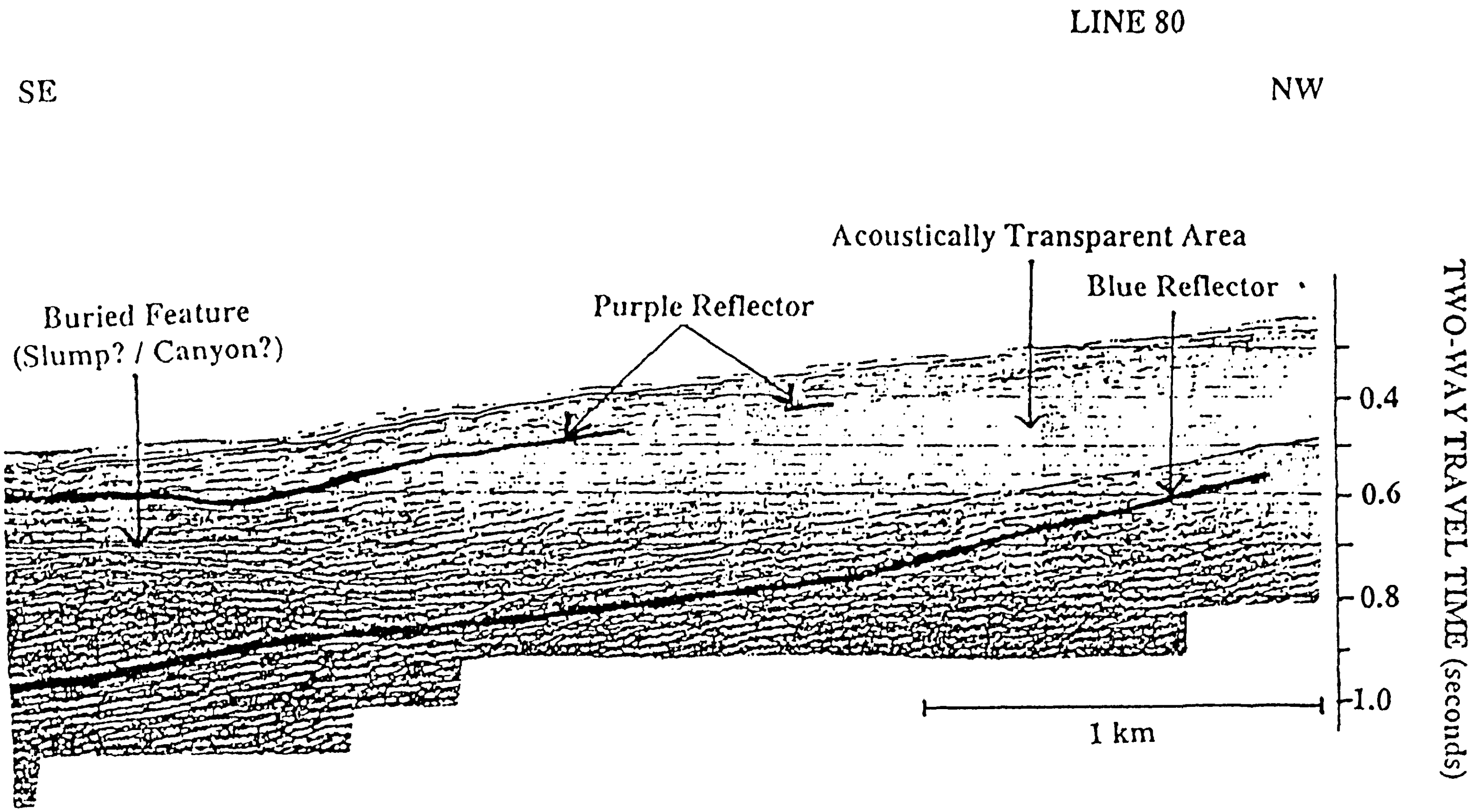


Figure 7. Seismic profile contains the two most prominent seismic reflectors identified within the study area. The Blue reflector is a non-undulating reflector that lies at the base of the study section. Untraceable through poorly defined portions of the seismic record, the Purple reflector has a configuration that is influenced by underlying features.

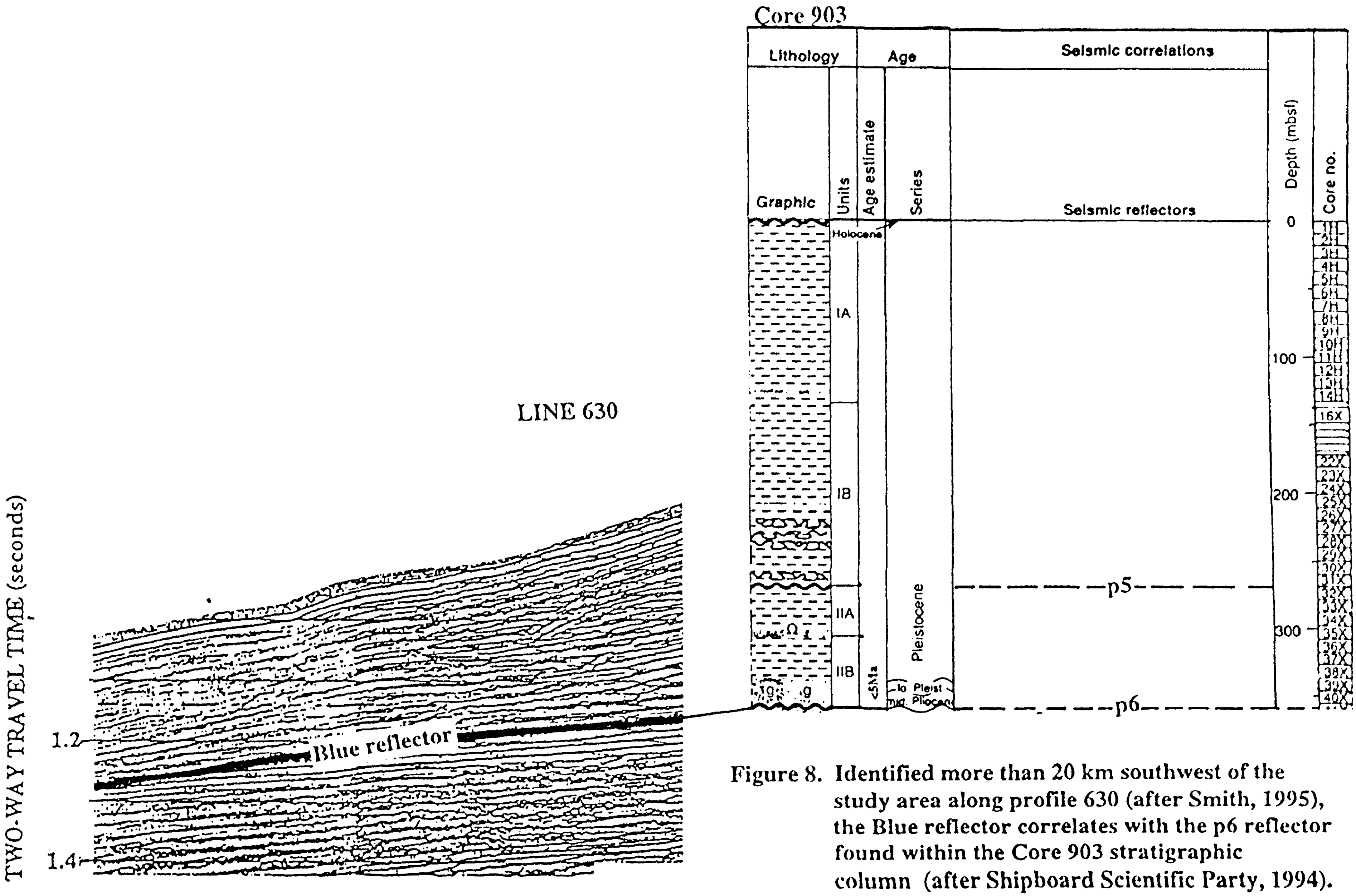


Figure 8. Identified more than 20 km southwest of the study area along profile 630 (after Smith, 1995), the Blue reflector correlates with the p6 reflector found within the Core 903 stratigraphic column (after Shipboard Scientific Party, 1994).

reflector depth, this present study assumed a velocity of 1600 m/s at the Blue reflector depth, or p6 depth, within Core 903. Subsurface mapped data were contoured within 125 ms intervals to account for the velocity difference.

Purple Reflector

The Purple reflector, which is the uppermost delineated seismic interface, dips from approximately 375 ms below sea-level, upslope, to more than 1375 ms below sea-level midslope. Untraceable within acoustically transparent portions of the seismic record (Figure 7), the Purple reflector cannot be followed throughout the entire study area.

Placement of an exact age constraint on the Purple reflector has been difficult. Smith (1995), utilizing seismic profiles from the same MMS/USGS sparker data base as the present investigation, identified a southwest-thickening sediment wedge basally bound by reflector Blue approximately 22 km southwest of the present study site (Figure 9). Smith's sediment wedge is divided by an erosional unconformity (reflector Orange) that separates a southwest-thickening lower sediment wedge from a southwest-thickening upper sediment wedge (Smith, 1995; Figure 9b). The Orange reflector, or erosional unconformity, was drilled during ODP Leg 150, and resulting analysis indicates it is reflector p5, the 475 Ka, middle Pleistocene unconformity (Shipboard

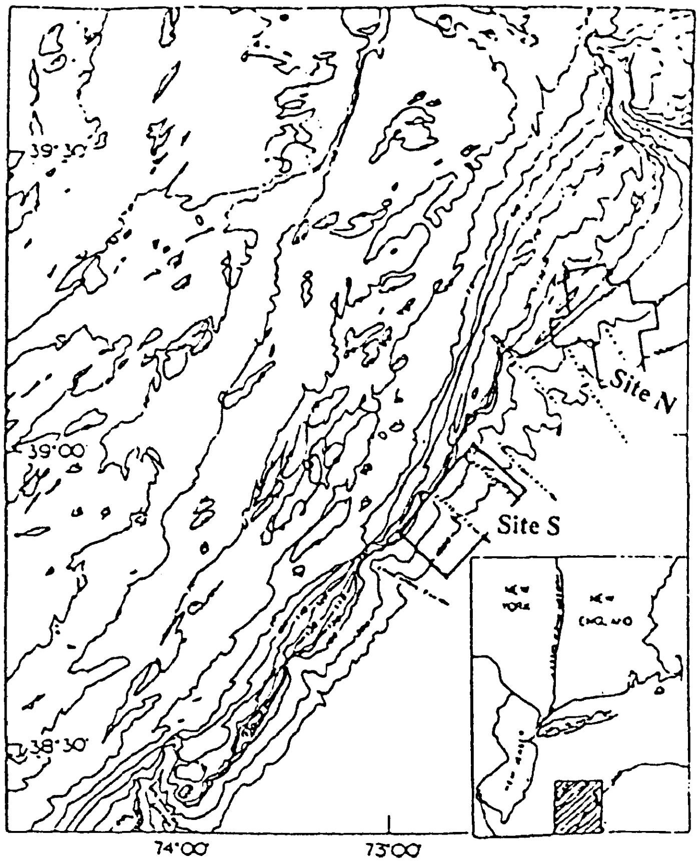


Figure 9a. Regional bathymetric map of the New Jersey continental shelf and slope. Sites N and S denote the present study area and the area studied by Smith (1995), respectively. Inset map, located in the lower right corner, indicates the position of the New Jersey continental terrace (shelf and slope) relative to other portions of the Atlantic continental margin.

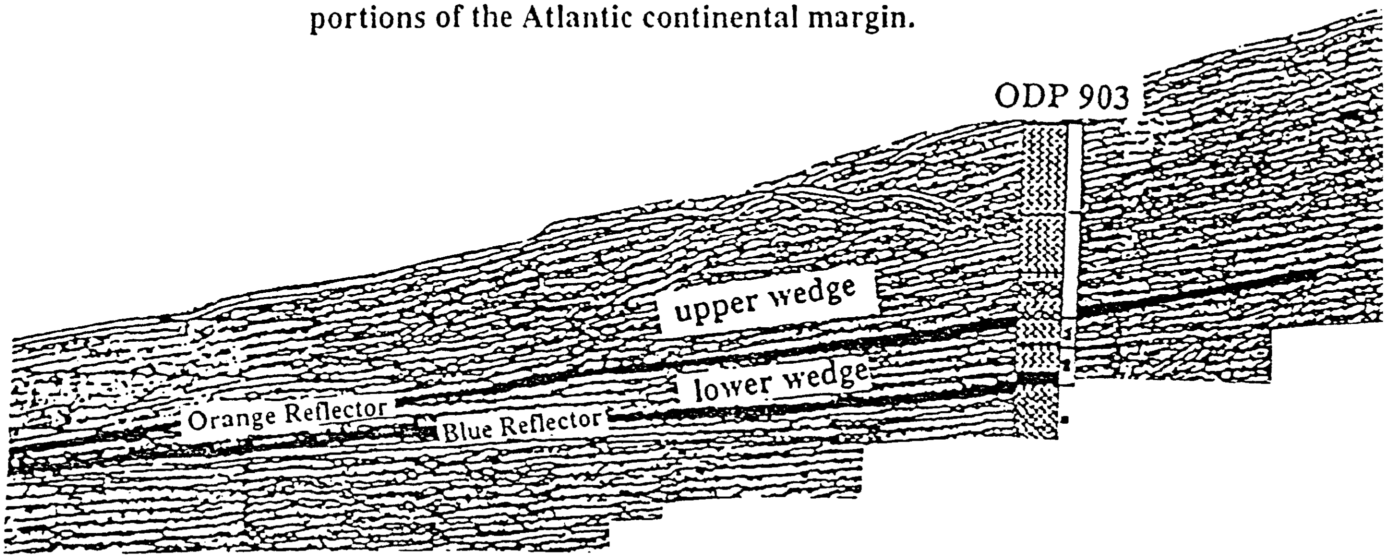


Figure 9b. Seismic profile of Smith (1995) sediment wedge identified throughout Site S (Figure 9a). This sediment wedge is basally bound by the same Blue reflector identified at the base of the Site N (Figure 9a) study section. The Site S wedge is separated into two smaller wedges, i.e., an upper and lower wedge, which were penetrated by ODP Core 903. The lower wedge is mostly middle Pleistocene clays and sands with a thin layer of graded Pliocene sands and glauconite at its base. The upper wedge is primarily composed of middle and upper Pleistocene fine sands and clays.

Scientific Party, 1994; Smith 1995; Figure 8). The close proximity (approximately 20 km) of the present study area to Smith's study area (Figure 9a) and the similarity of reflector configurations underlying the present study's Purple reflector and Smith's (1995) Orange reflector (Figures 10 and 9b) coupled with the observation that the same erosional Blue boundary exists at the base of both study sections, prompts speculation that the Orange erosional unconformity and the Purple reflector formed simultaneously. Consequently, the Purple reflector is assumed to correlate with ODP Leg 150's reflector p5, an erosional unconformity, approximately 475 Ka, found within middle Pleistocene sediment (Shipboard Scientific Party, 1994, Figure 8).

Infilled Submarine Canyons

Infilled submarine canyons are defined as partially buried canyons that have surficial expressions (Figure 11). V-shaped in seismic profile cross-section, infilled submarine canyons generally occur midslope within the southern section of the study area (Figure 2). Infilled canyon walls are outlined by truncated erosional surfaces that bound canyon fill characterized by episodic inter-phasing of erosion and deposition (Figure 11). Canyon-fill reflectors that continue onto the surrounding slope are assumed to represent broader episodes of deposition, whereas reflectors discontinuous with surrounding acoustic strata

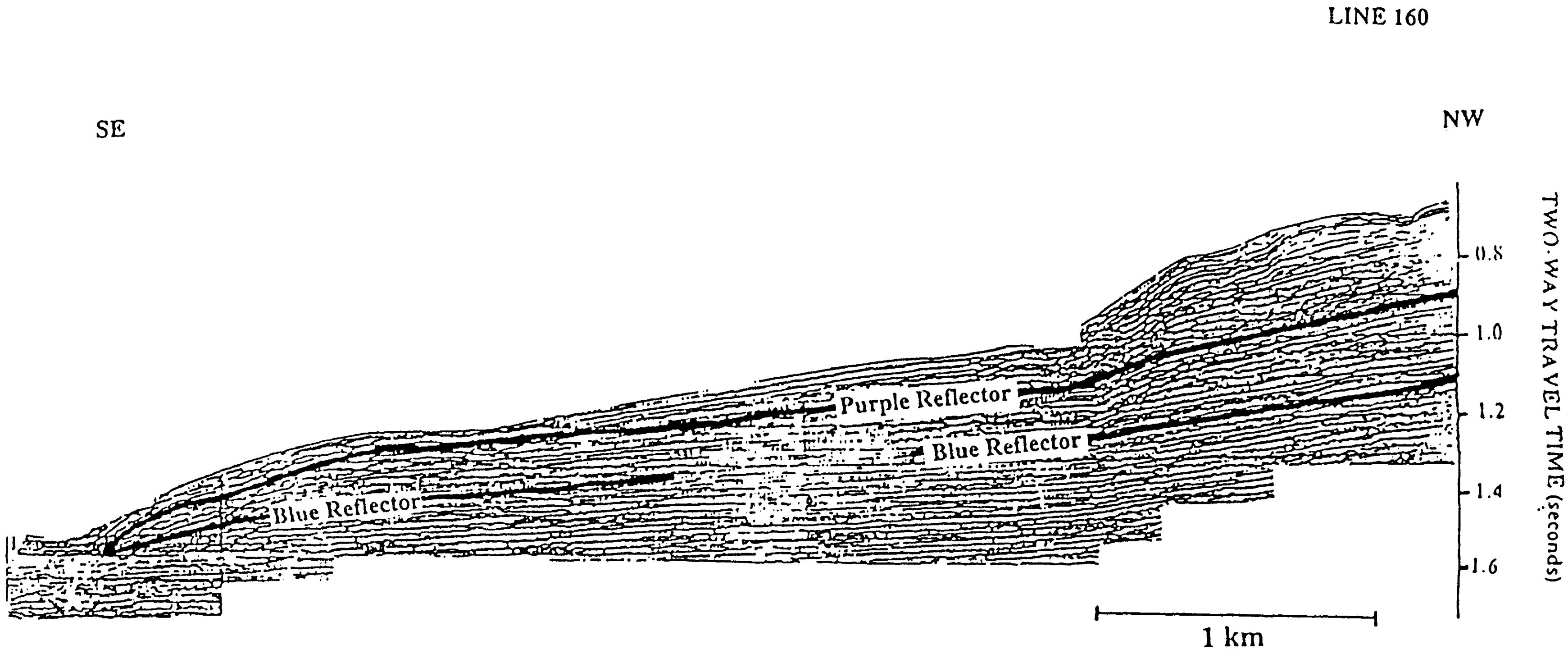


Figure 10. Purple reflector is underlain by reflectors resembling those below Smith's (1995) Orange reflector (See Figure 9b).

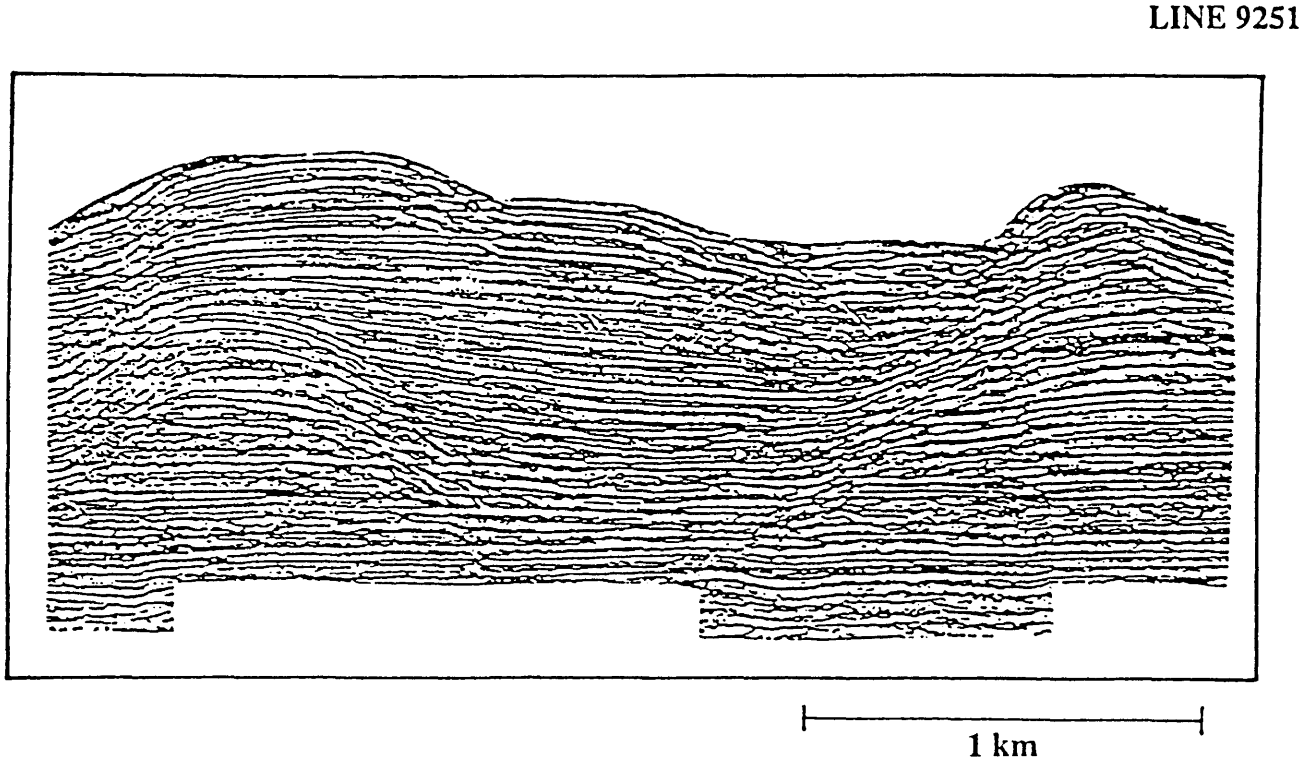
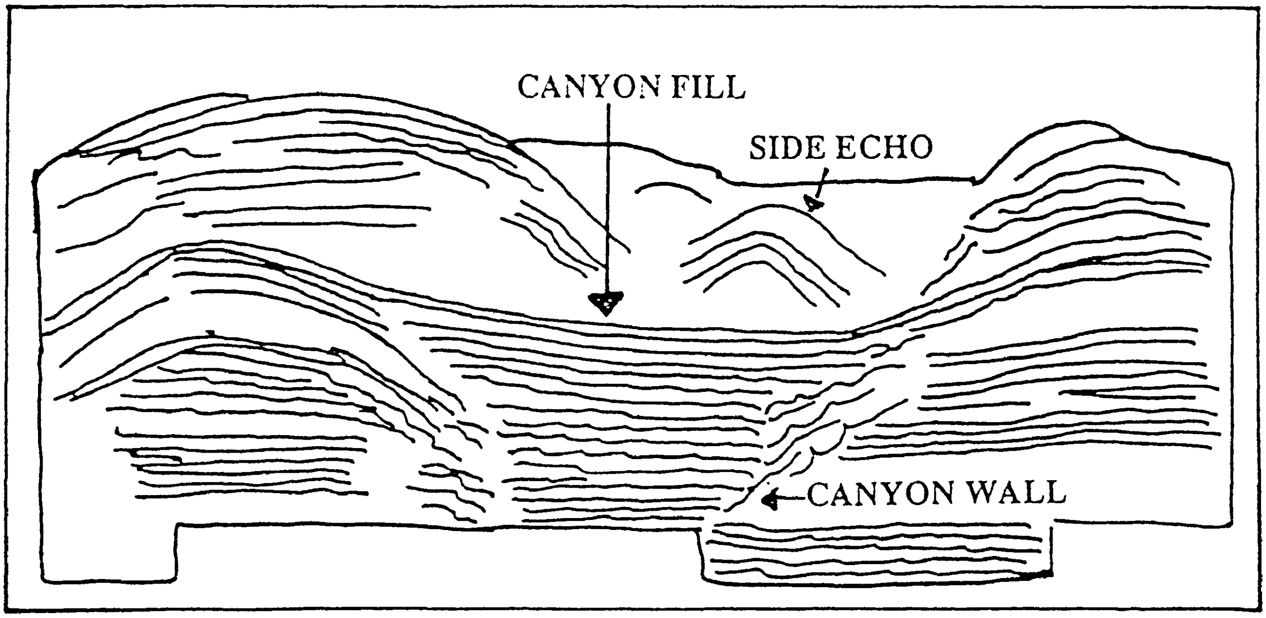


Figure 11. (Above) Seismic profile of an infilled canyon identified within the study area. (Below) Line drawing interpretation of the profile.



suggest episodic erosion confined to the canyon (Pratson, 1993; Figure 11).

Origin of submarine canyons and occurrence of sedimentary infilling along the New Jersey continental slope remain two of the most debated and least understood aspects of slope development. Relative ages of the infilled canyons can be inferred by canyon sinuousity and extent of headward erosion, with older canyons tending to be more sinuous and extending farther onto the shelf (McGregor and others, 1982; Twichell and Roberts, 1982; Sanford and others, 1990). Since Mey Canyon, the largest infilled submarine canyon within the study area, is more sinuous and its wide canyon head appears closer to the shelf than the smaller canyon to the east (Figure 2), Mey Canyon is inferred to be the oldest submarine canyon identified within the study area.

Buried Submarine Canyons

Well-defined buried canyons and gullies appear as chaotic mounds of reflectors discontinuous with surrounding strata (Alonso and others, 1990; Figure 12a). Offset strata and undulating seismic reflectors characterize buried features, possibly canyons (Figure 12b). Because most profiles are dip lines, these features cannot be easily defined. Much of the bottom roughness is an artifact of the oblique crossing of Mey Canyon and associated gullies. In fact, strike profiles show the seafloor within the study area to be relatively smooth, and there is no obvious

LINE 191

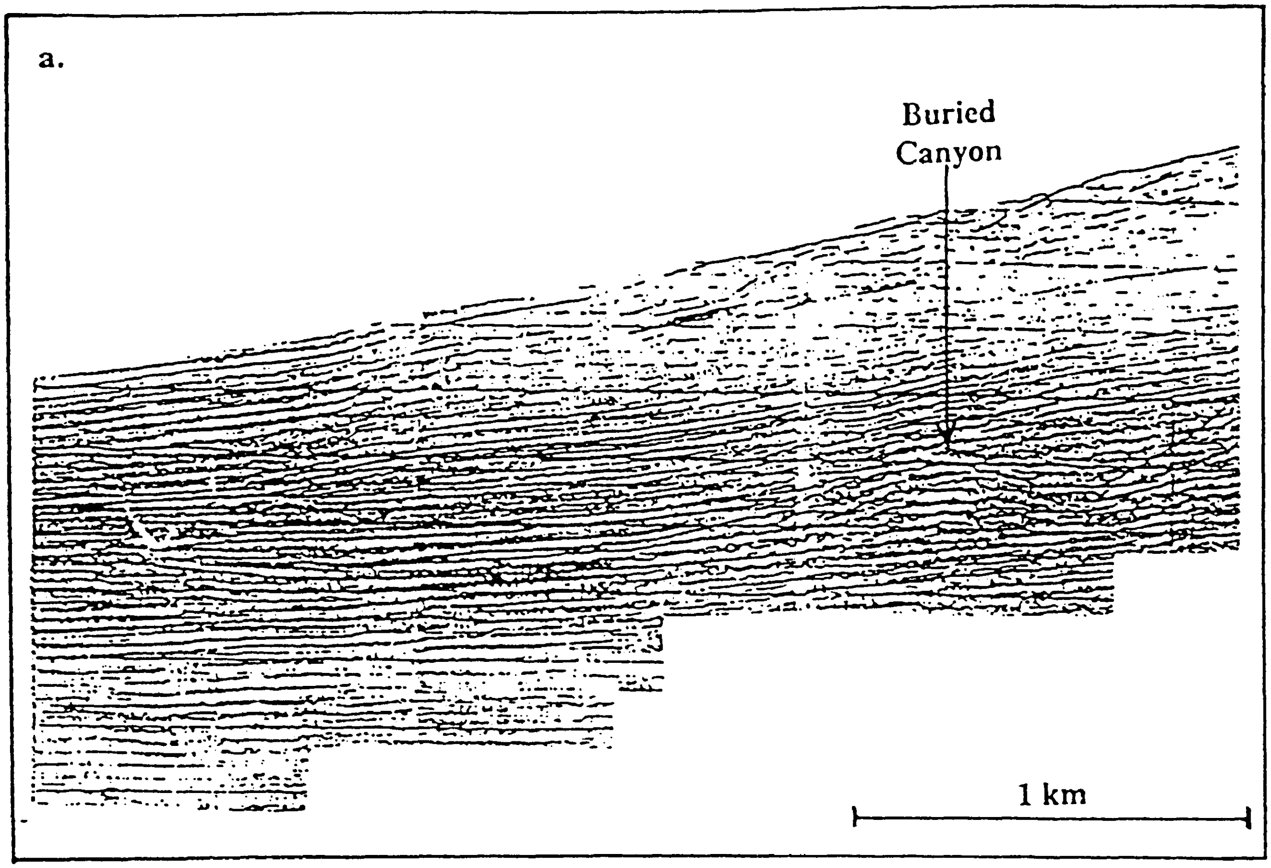
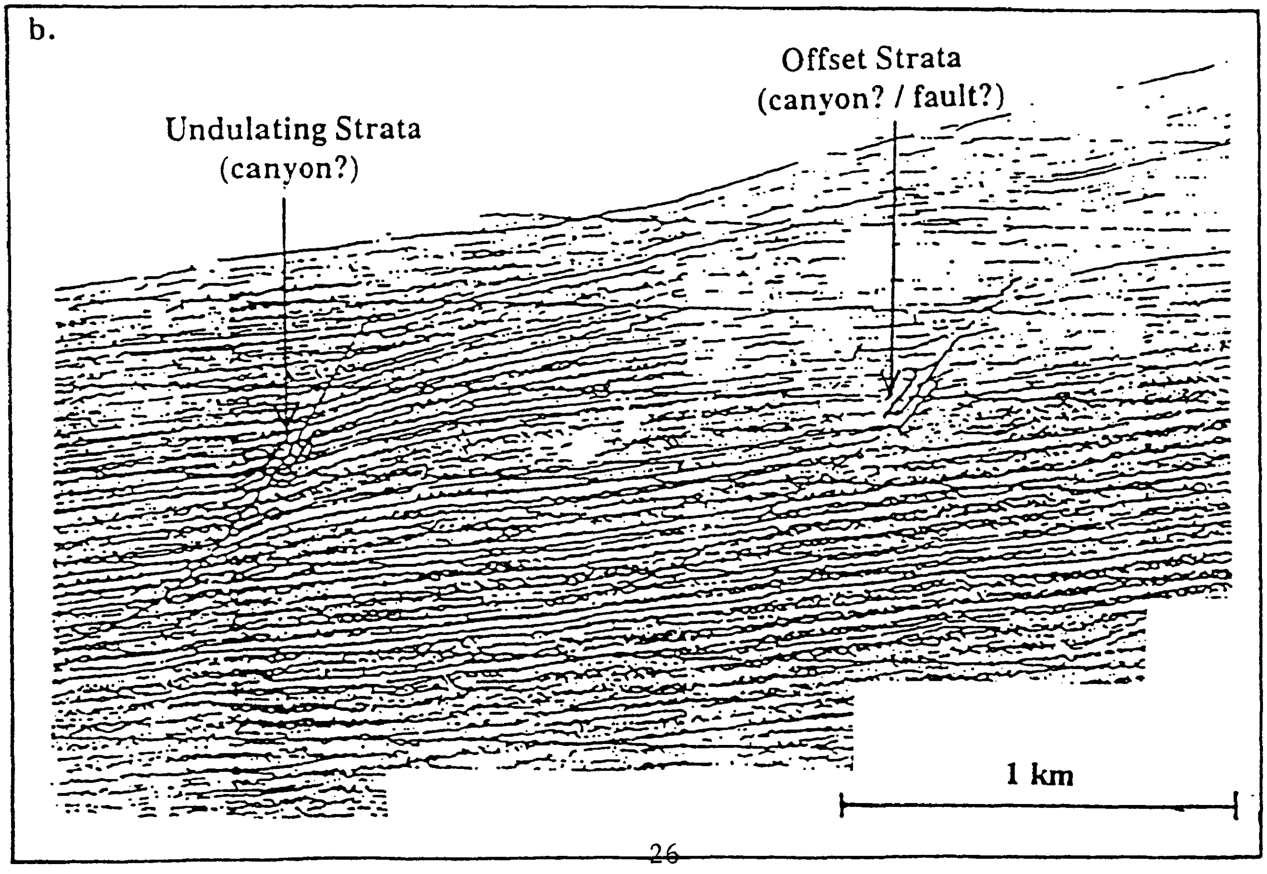


Figure 12. (Above) Buried canyon characterized by reflectors discontinuous with surrounding strata.
(Below) Undulating strata and offset strata, identified within the seismic record, may represent buried canyons or faults.

LINE 32



existence of slump features such as those noted by Smith (1995) approximately 20 km southwest of the study site.

One of the limitations of two-dimensional profiles, such as those utilized in the present study, is the inability to discriminate reflectivity variations caused by bottom roughness. During the preliminary analysis of the seismic profiles, MMS/USGS contractors, for example, labelled many of the offset and undulating strata as faults; whereas, this writer suggests they may actually represent buried canyons (Figure 12b). This problem is not unique to this study because post-Pleistocene faults identified on the adjacent New Jersey shelf by Sheridan and Knebel (1976) have been questioned by investigators (Milliman and others, 1990) who define the post-Pleistocene faults as horizontal facies changes.

Buried canyons, primarily confined between the Blue and Purple reflectors, are tentatively dated between the late Miocene-Pliocene and the middle Pleistocene. These canyons are speculated to be mostly composed of middle Pleistocene clays and sands, such as those recovered at sites 902, 903, and 904 by ODP Leg 150 (Figures 4 and 8).

SHALLOW STRUCTURE

Sediment Wedge

Bound at the bottom by the Blue reflector and bound at the top by the Purple reflector, a late Miocene-Pliocene to middle Pleistocene northeast-thickening Sediment Wedge is identified within the uppermost 424 m of the New Jersey continental slope (Figures 13 and 14). Wedge sediment thickness reaches a maximum of 404 m in the northeast and thins southeast until the Wedge ultimately disappears (Figure 13). Based on Smith (1995) and Shipboard Scientific Party (1994), this Wedge is presumably composed of a thin layer of middle Pliocene graded sands overlain by middle Pleistocene silty clays and sand with abundant glauconite at the base (Figure 15). This northeast-thickening Sediment Wedge contains many pronounced intra-wedge reflectors, such as the Green reflector, which frequently splits the Wedge into two smaller northeast thickening wedges, G_a and G_b (Figures 16 and 17). Reflector Green, which cannot be traced to previously collected cores, is assumed to be an erosional unconformity because underlying acoustic strata terminate against it and overlying strata parallel it (Figure 18). Since it lies between a late Miocene-Pliocene (Blue) reflector and a middle Pleistocene (Purple) reflector, the Green reflector is assumed to be Pliocene - middle Pleistocene in age (Figures 16 and 13).

Blanket

A sedimentary Blanket deposit, located between the Purple reflector and the seafloor surface, overlies the northeast-thickening Sediment Wedge (Figure 13). Incised by

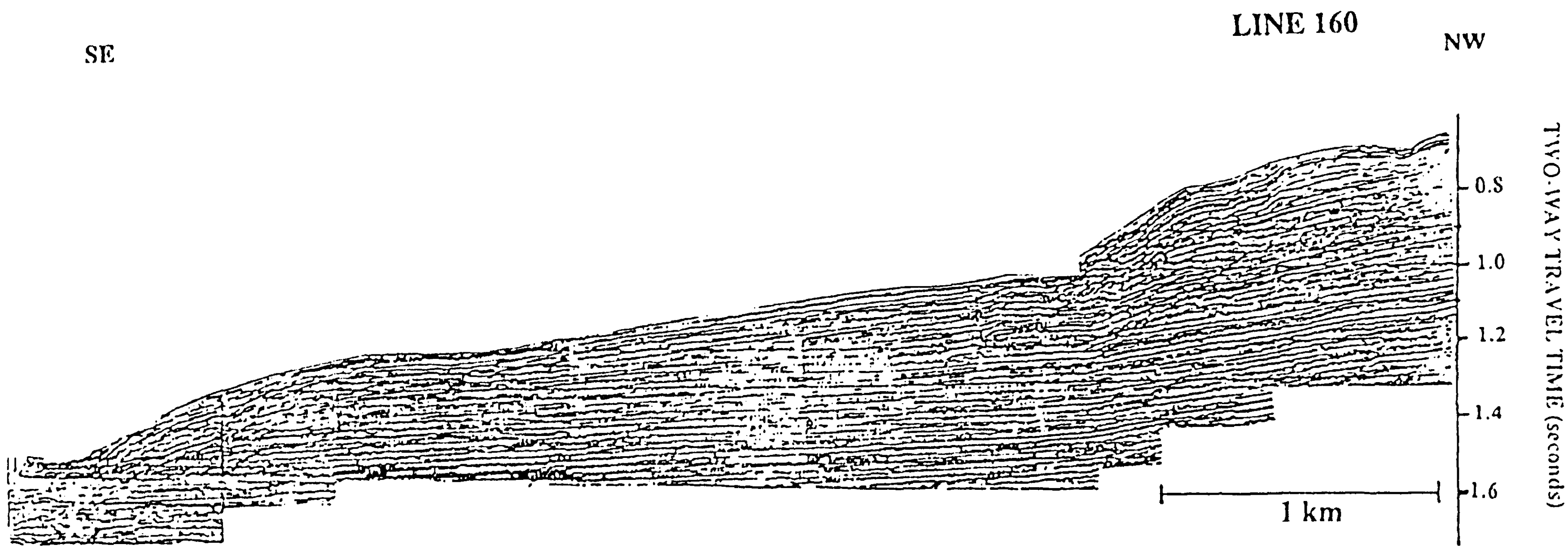
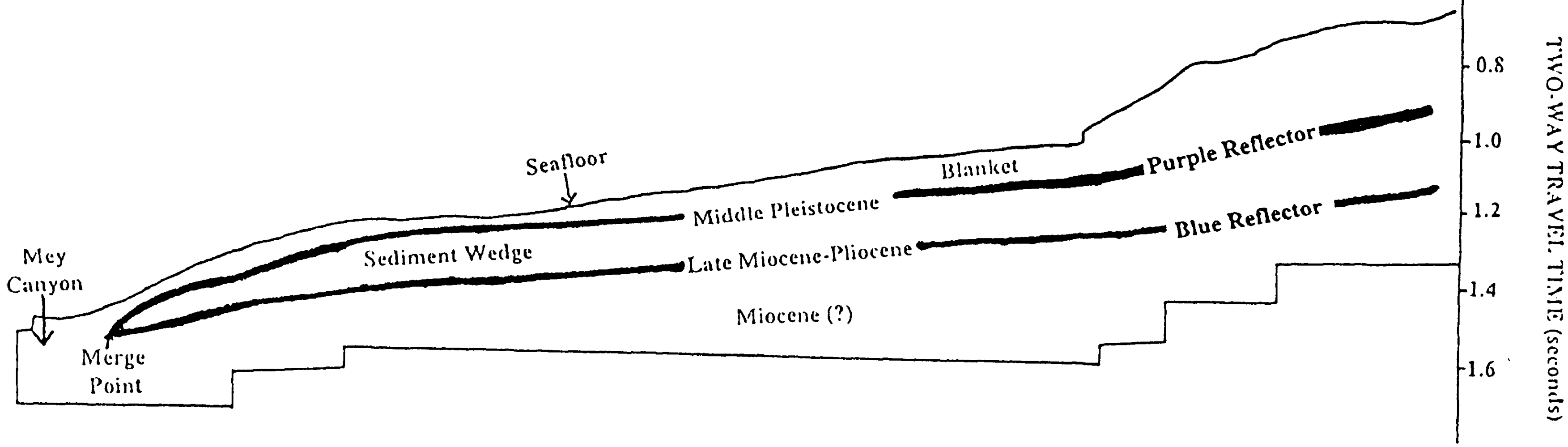


Figure 13. (Above) Seismic profile of the Sediment Wedge.
(Below) Line drawing interpretation of the profile.



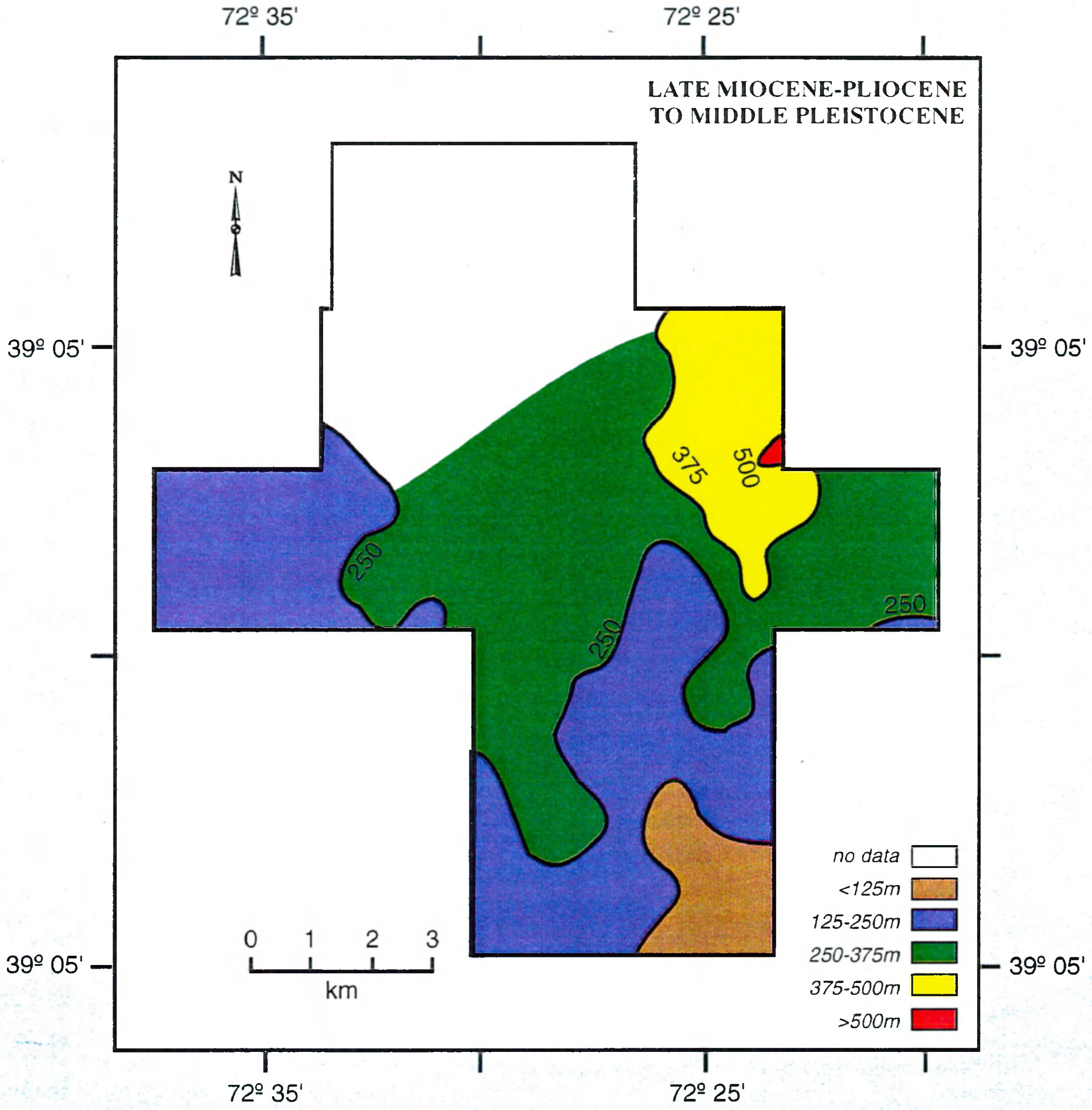


Figure 14. Isopach map of the Sediment Wedge, i.e., the sediment thickness between the Blue and Purple reflectors. Contour interval is 125ms.

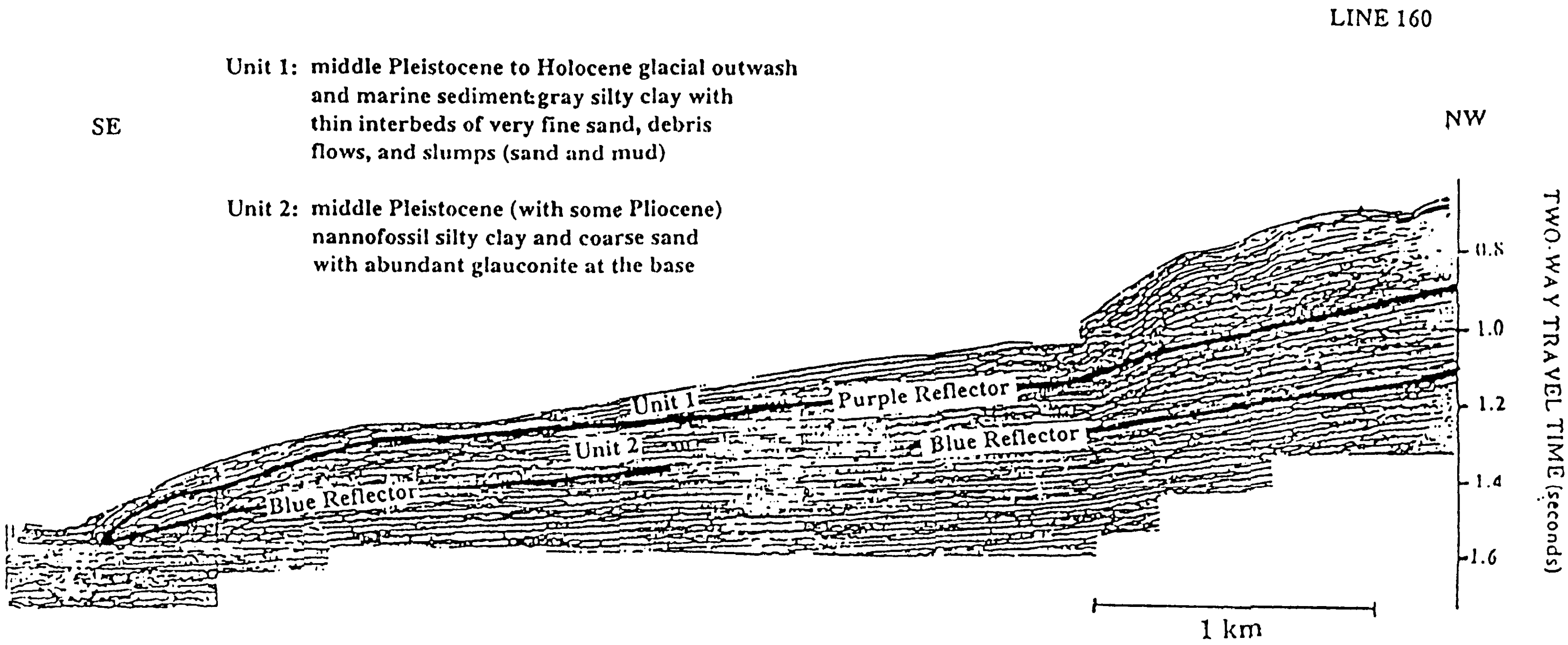


Figure 15. Lithologic interpretation of the Sediment Wedge (Unit 2) and the overlying Blanket (Unit 1) based on ODP Core 903 data (Shipboard Scientific Party, 1994).

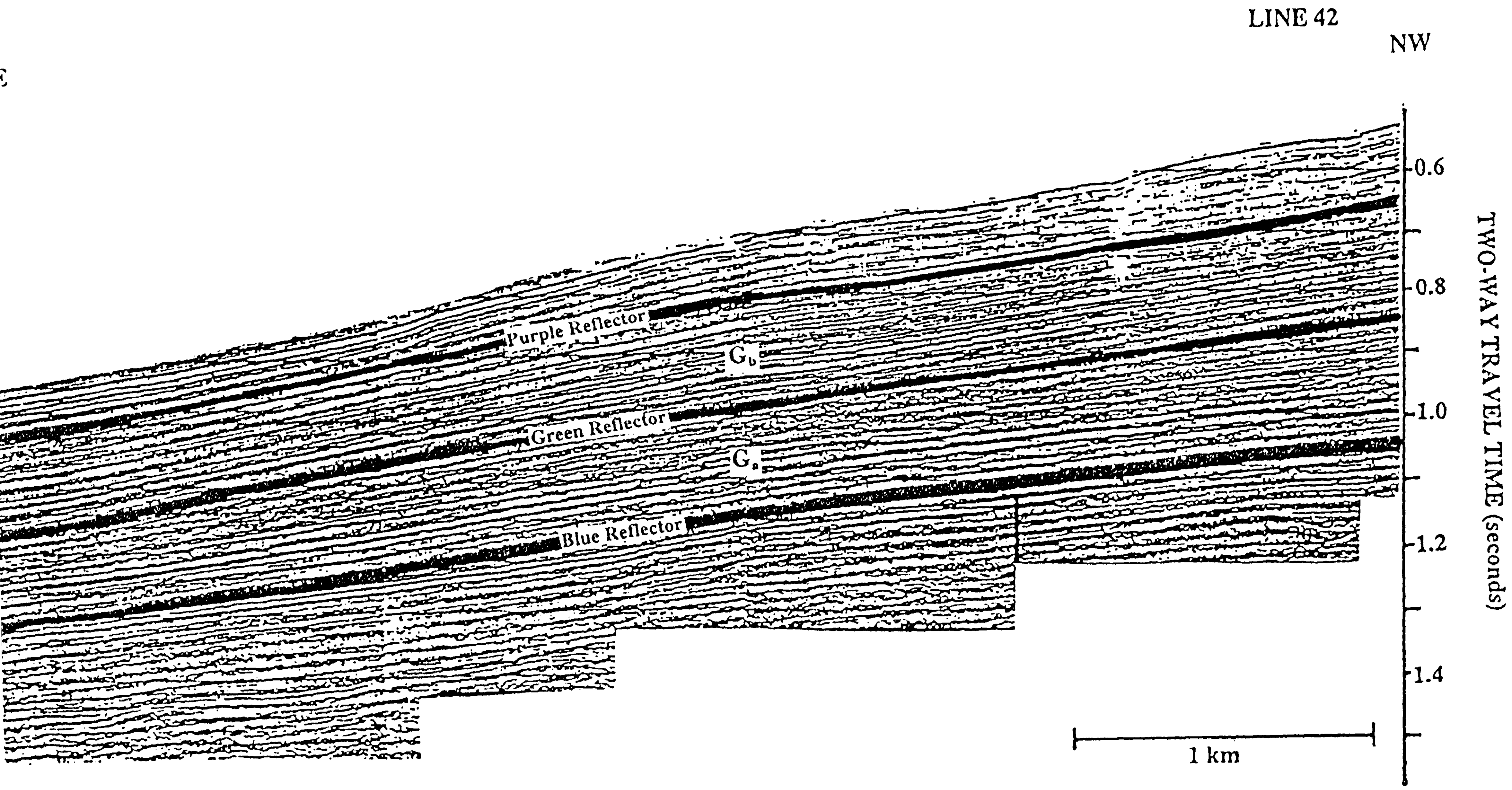


Figure 16. Profile indicates the Sediment Wedge, bound by reflectors Blue and Purple, is split by reflector Green into two smaller wedges, G_a and G_b.

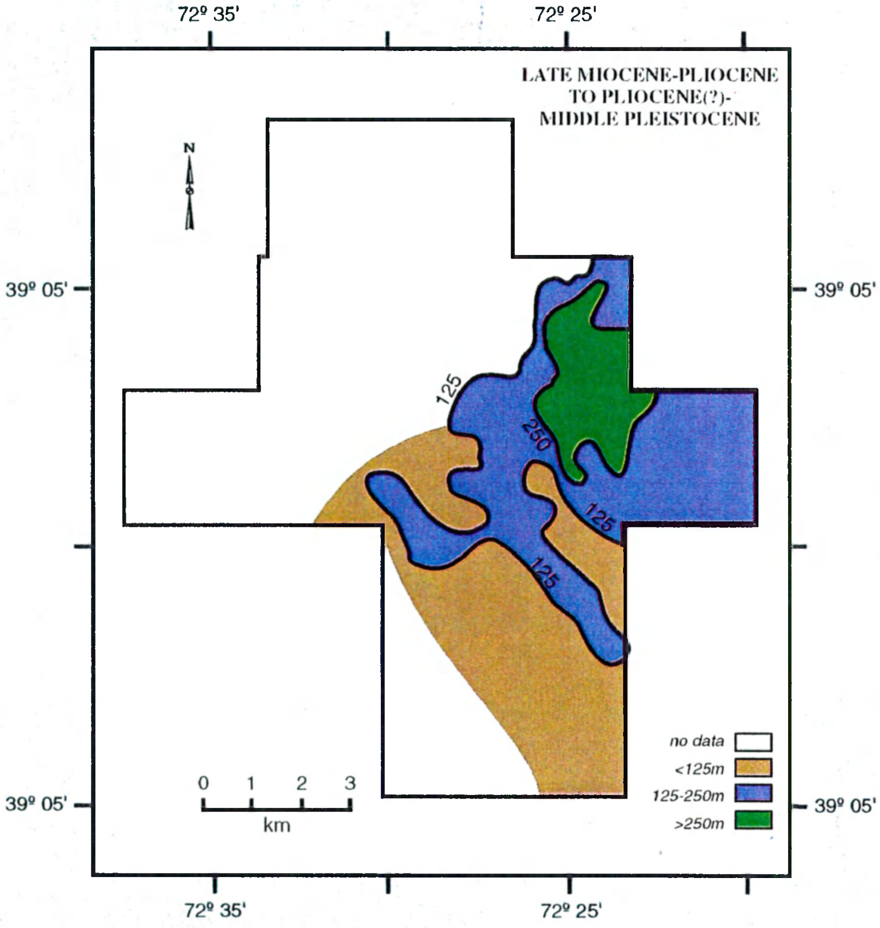


Figure 17a. Isopach map of sediment wedge G_a, i.e., sediment thickness between the Blue and Green reflectors.

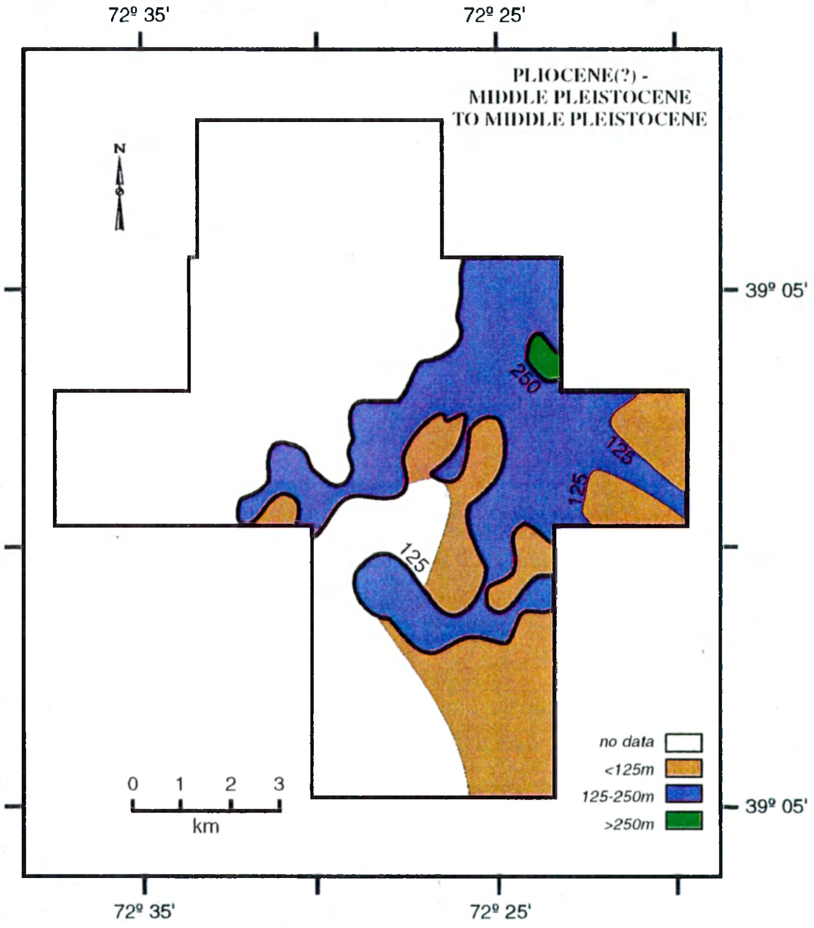


Figure 17b. Isopach map of sediment wedge G_b, i.e., sediment thickness between the Green and Purple reflectors.

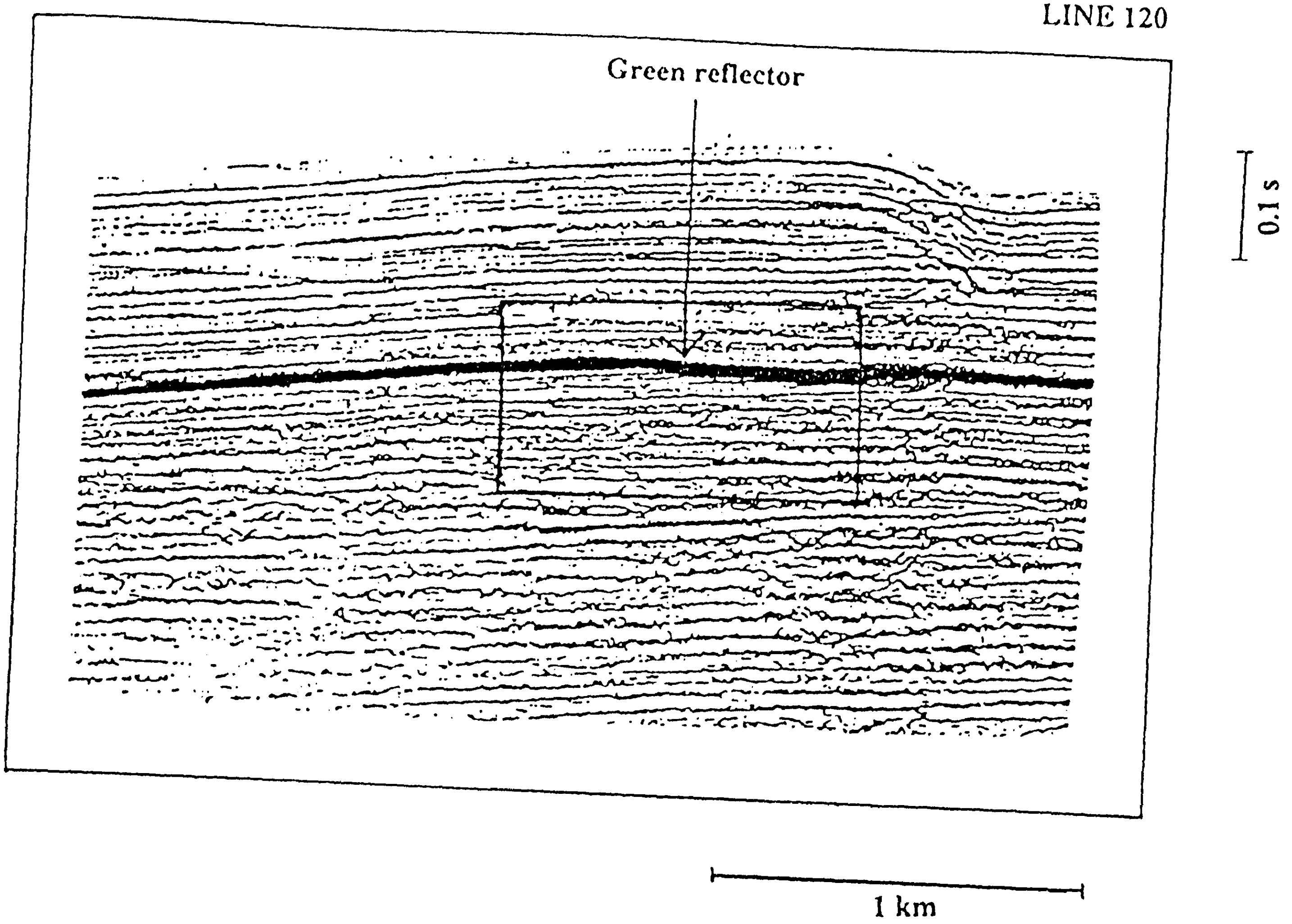


Figure 18. The boxed-in section of the profile contains a portion of the Green reflector which is underlain by reflectors that terminate against it and overlain by reflectors which moreso parallel it.

infilled submarine canyons, this sediment Blanket is generally less than 100 m thick (Figures 6 and 19). Characterized by both hyperbolic and discontinuous reflectors, hummocky topography occurs within the uppermost tens of meters of the Blanket (Figure 20). This irregular topography is inferred to represent reworked or redistributed sediment that may be related to mass-wasting events such as slumping and sliding (Knebel and Carson,1979).

The Blanket is assumed to be middle Pleistocene (the age of the Purple reflector) to Holocene (Figure 13). Within ODP Core 903, the section of Core 903 above p5 (or the Purple reflector) is composed of middle to upper Pleistocene glacial fine sands and silty clays (Shipboard Scientific Party, 1994; Figure 15); in addition, a thin layer of Holocene sediment may comprise the uppermost few centimeters of the Blanket (Scientific Shipboard Party, 1994).

IV. DISCUSSION

SHALLOW STRUCTURE DEVELOPMENT

Continental slopes may act either as sites of permanent deposition or as temporary storage areas for sediment in transit to the deep sea (Nardin and others, 1979). Analysis of the high-resolution seismic profiles and subsurface maps reveals the shallow structure of the New Jersey upper to middle continental slope consists of a Sediment Wedge bound

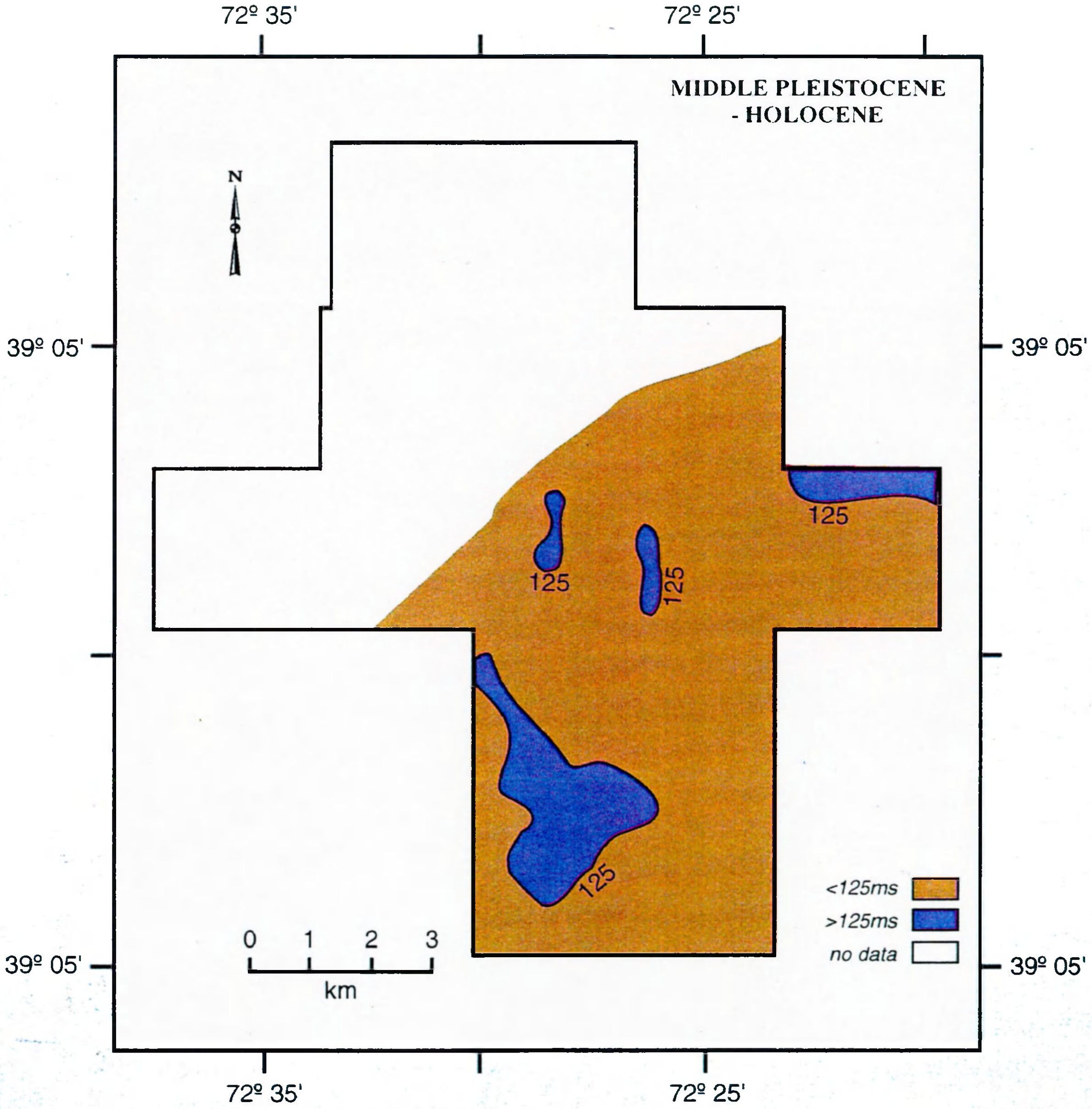


Figure 19. Isopach map of the Blanket, i.e., sediment thickness between the Purple reflector and the seafloor. Contour interval is 125ms.

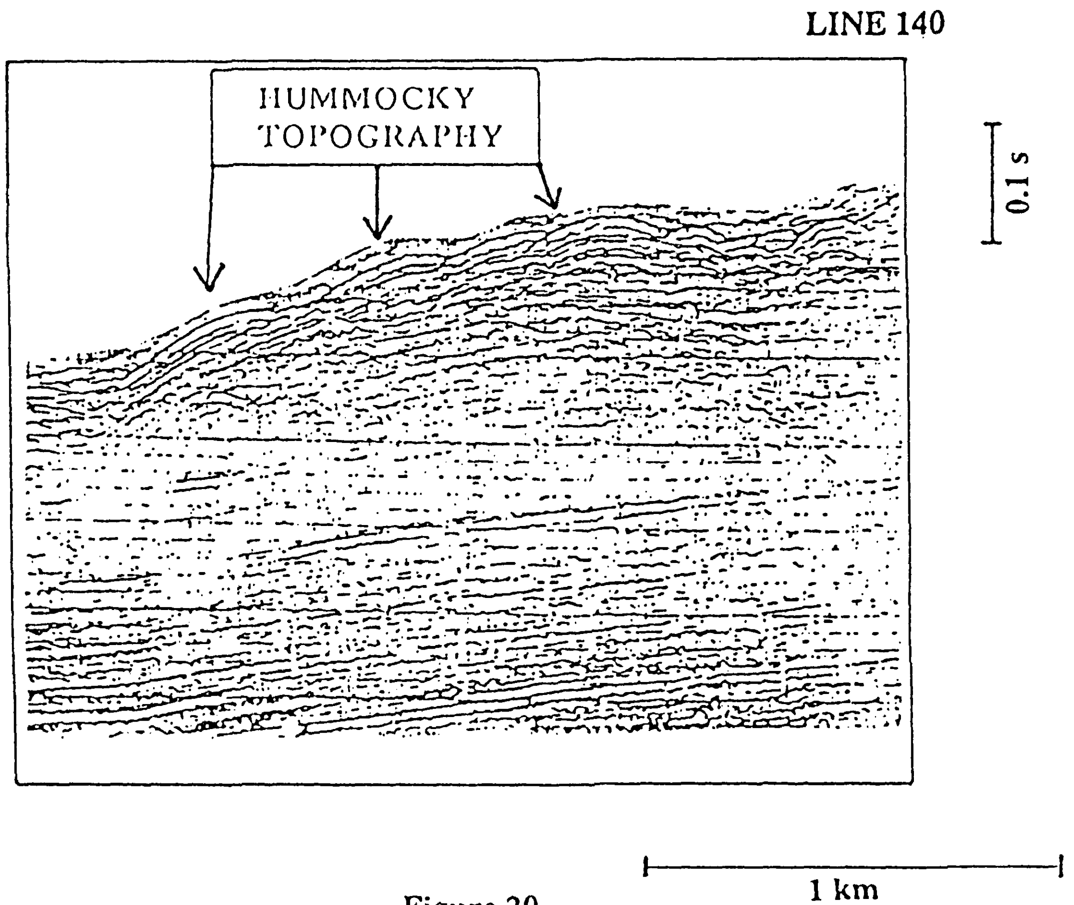


Figure 20.

at the bottom by a regional unconformity and bound at the top by a sediment Blanket (Figure 13). Thus, three major events occurred during the predominately Quaternary development of the continental slope: 1) the origin of the regional erosional unconformity (i.e., the Blue reflector); 2) deposition of the northeast-thickening Sediment Wedge; and 3) the transition from a Sediment Wedge to a Blanket deposit. The purpose of this section is to explain the nature of each event and their relation to one another as well as to those events which have been identified along other portions of the New Jersey margin.

1) Origin of the Blue Reflector (Table 1)

Correlation of the seismic reflection data with ODP Core 903 data suggests the Blue unconformity, which separates upper Miocene strata from Pliocene strata, may actually represent several episodes of erosion as opposed to one, i.e., the Messinian global sea-level lowering. The Blue reflector, identified 22 km southwest of the present study area at ODP drillsite 903 corresponds to the late Miocene (Messinian) drop in eustatic sea-level which occurred between 6.5 and 5 Ma (Smith, 1995). Sea-level was approximately 40-70 m below present sea-level at the end of the Messinian (Uchupi and others, 1982; Haq, 1991; Figure 21). Prior to the onset of the Messinian, however, sea-level was at a highstand of approximately 50 m above present-day mean sea-level (Haq, 1991). Thus, there was

Table 1. Events that influenced the development of the northeastern New Jersey continental slope.

EVENT	BRIEF POSTULATED EXPLANATIONS FOR THE OCCURRENCE OF EACH EVENT
1. Origin of the Blue Reflector	a.) Messinian sea-level lowering (6.5 - 5 Ma) b.) Pliocene glaciations
2. Sediment Wedge Deposition	a.) Migration of Hudson River (the sediment source) during Pleistocene sea-level lowerings
3. Transition from the Wedge to the Blanket	a.) Shift in sediment source or sediment distribution pattern b.) Redistribution of river influx by coastal currents

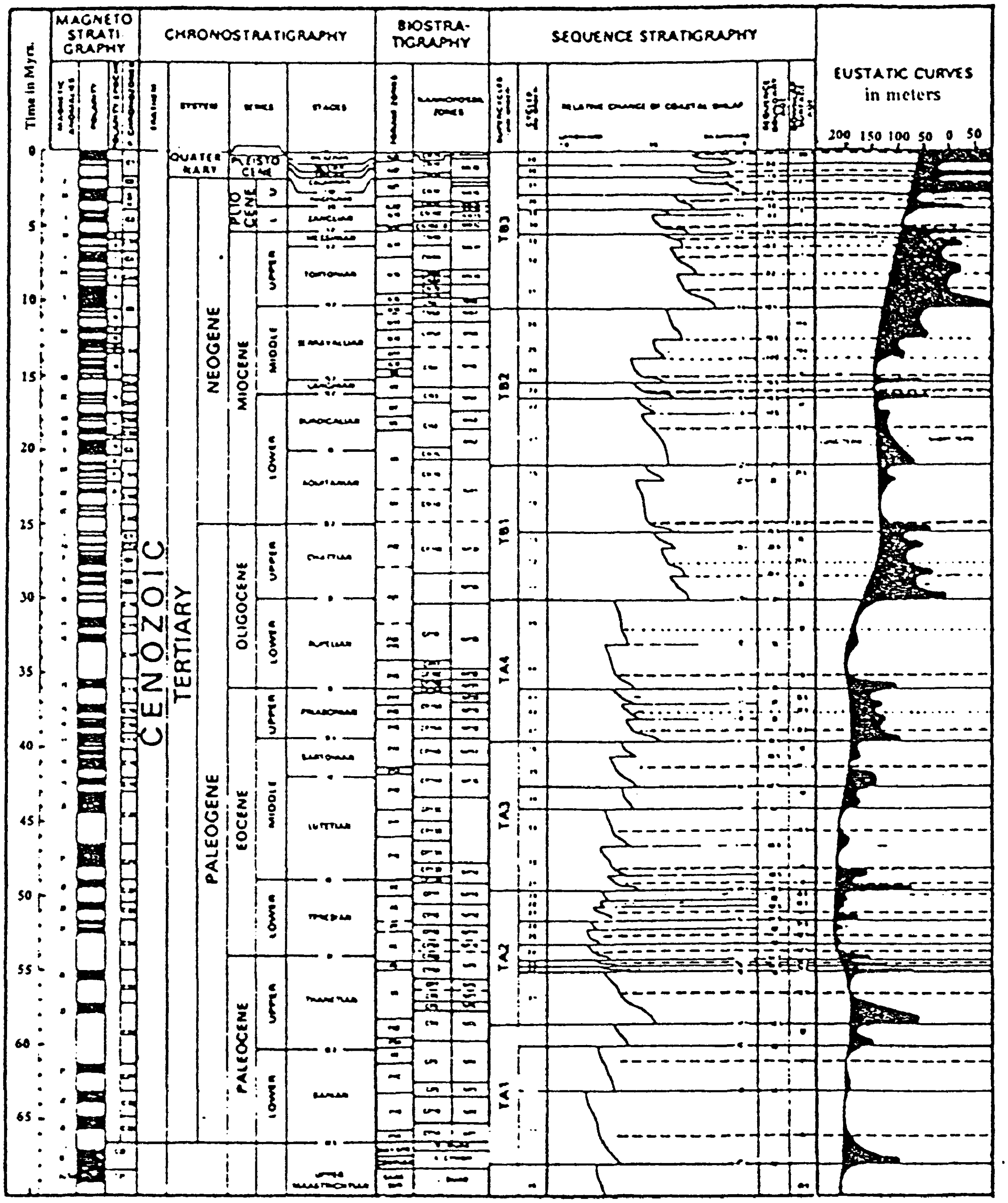


Figure 21. (from Haq, 1991) Cenozoic sea-level chart. Information relevant to the present investigation includes Time in Myrs (7Ma to the Present) and the corresponding Eustatic Curves.

perhaps an estimated 90-120 m drop in sea-level, which may have resulted in massive erosion such as is thought to have occurred during the Pleistocene sea-level lowstands. It is surmised that sediment, which had been deposited in great quantities along the coastal plain and inner shelf during the pre-Messinian highstand in sea-level, was transported towards the shelf break by rivers that incised the subaerially exposed shelf during the Messinian lowstand in sea-level. Downslope movement of shelf sediment may have led to upper and middle slope bypassing, resulting in the formation of the Blue erosional unconformity.

During the late Miocene, voluminous terrigenous sediment did not accumulate on the outer shelf and slope as in the middle Miocene. Instead, late Miocene sediment was channelled to the lower rise (Poag, 1987). Shipboard Scientific Party (1994) suggests the p6 reflector (or the Blue reflector) may be a slump/mass transport deposit. This deposit may correspond to the proposed catastrophic mass-wasting event surmised to be triggered by the Messinian sea-level lowstand.

The Blue reflector also may represent several mass-wasting events that occurred during glacially lowered sea-level in the Pliocene. The unconformities associated with the Pliocene glaciations may be represented by the Blue reflector, which is possibly composed of coalesced erosional surfaces whose interfaces are not detectable since the sparker's outgoing pulse is sufficiently "coarser" to prevent a 10 ms resolution of data on the MMS/USGS seismic profiles. This 10 ms (0-12 m) thickness, in fact, may represent millions to hundreds of thousands of years of the geologic record along this unconformity. According to Shipboard Scientific Party (1994) the p6 reflector contains a hiatus that presumably was formed prior to the onset of the Pliocene flooding, or sea-level highstand, approximately 3.7 Ma (Haq, 1991; Figure 21). By 3 Ma, sea-level was approximately 60 to 65 m above present-day mean sea-level (B. Haq, personal communication) and sediment was deposited on the coastal plain and inner shelf. This highstand in sea-level was followed by glaciation which began along the North Atlantic Margin in the Pliocene, around 3 Ma. Glacio-eustatic sea-level lowerings during the Pliocene resulted in large scale erosion and sediment bypassing along the continental slope. Most Pliocene sediment deposited on the New Jersey slope was subsequently eroded downslope and deposited on the continental rise (Poag, 1987). This explains why little if any Pliocene sediment is found in great quantities along the New Jersey slope. However, based on ODP Core 903 data (Shipboard Scientific Party, 1994), some Pliocene sediment lies at the base of the middle Pleistocene Sediment Wedge.

2) <u>Sediment Wedge Deposition</u> (Table 1)

Initial deposition of the Sediment Wedge began with the downslope displacement of coarse glauconitic sand and mud, perhaps sediment gravity flows, which must have eroded at least a portion of the missing Pliocene sediment (Poag and Low, 1987). Since the origin of glauconite is suggested to be shallow marine, it is inferred the glauconite was transported from the shelf and reworked along the slope (Scott, 1987). Transportation of large quantities of sediment from the shelf during lowered Pliocene-Pleistocene glacio-eustatic sea-level resulted in the formation of the Sediment Wedge. The succession of sediment layers within the Wedge, represented as reflector groupings on the profiles (Figure 13), correspond to intervals of melting and glacial retreat northeast of the study area (Davies and others, 1992). Erosional surfaces such as the Blue and Purple reflectors are assumed to represent times of lowered global sea-level because they coincide with lowstands in sea-level based on a eustatic curve proposed by Haq (1991). In addition, extensive interphasing of deposition and erosion, assumed to result from fluctuations in sea level, is most obvious within infilled submarine canyons (Figure 6). The isopach map of the Sediment Wedge indicates the Sediment Wedge thickens to the northeast and thins to the southeast (Figure 14). It is deduced that sediment accumulates in greater quantities closer to the northeast sediment source and thins farther away from the source which is presumably the Hudson River.

The close proximity to the study area (Figure 1), and the long-held assumption the ancestral Hudson River migrated southwards across the New Jersey shelf during various times of Pleistocene glacially lowered sea-level (Veatch and Smith, 1939; Kelling and Stanley, 1970) suggest the Hudson River was the main source of sediment to the predominately Pleistocene Sediment Wedge. Darby (1990) postulated the Hudson River during glacial melting events may have rivalled the sediment discharge of much larger rivers like the Mississippi River or Amazon River. Paleochannels of the ancestral Hudson River, which indicate migration to the south, have been identified along the New Jersey shelf (Knebel and others, 1979). In addition, an axinite heavy-mineral assemblage native to the Hudson River has been identified along the New Jersey shelf as far south as the Baltimore Canyon (Kelling and others, 1975).

3) Transition from a Wedge to a Blanket (Table 1)

It is unclear whether or not the Purple reflector which separates the Wedge and Blanket is nondepositional or erosional in nature. Profiles reveal seismic strata above and below Purple are conformable suggesting Purple is a nondepositional feature. If, however, Purple is analogous to Smith's (1995) Orange reflector (as assumed here), then Shipboard Scientific Party (1994) indicates p5 (i.e., the Orange and its assumed age-equivalent Purple reflector) is indeed an erosional surface which contains a hiatus.

The Purple reflector, approximately 475 Ka (Smith, 1995), not only marks the top boundary of the Sediment Wedge, but also the transition from a Sediment Wedge deposit to a mostly uniform sediment Blanket deposit (Figure 13). This transition may be attributed to the major shift in the magnitude of sea-level lowerings at the boundary between interglacial Stage 13 and glacial Stage 12 of the Pleistocene, approximately 450 ka to 500 ka (Shackleton and Opdyke, 1976; Figure 22). On the other hand, the transition may have resulted from a change in sediment source location. The more or less uniform sediment thickness of the Blanket suggests a possible shift in source or flux pattern. It is possible, for example, that a glacial melt which discharged across the New Jersey shelf may have resulted in more or less uniform deposition of sediment (Milliman and others, 1990; Darby, 1990). At the same time, the Hudson River may have become constrained within the Hudson Channel and Canyon. Another possibility is that sea-level regression never reached the shelf edge and coastal currents redistributed the river influx over a broad area.

SLOPE MORPHOLOGY DEVELOPMENT

Structure maps and isopach maps of age constrained reflectors are assumed to represent surficial expressions and overlying sediment patterns, respectively, of the New Jersey continental slope throughout its predominately

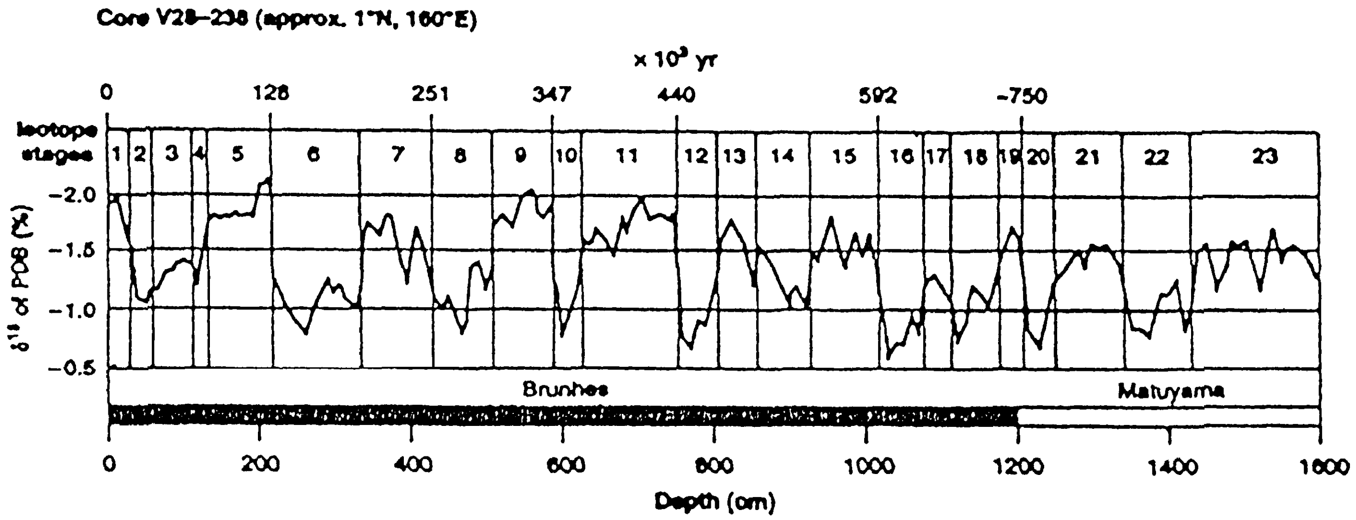
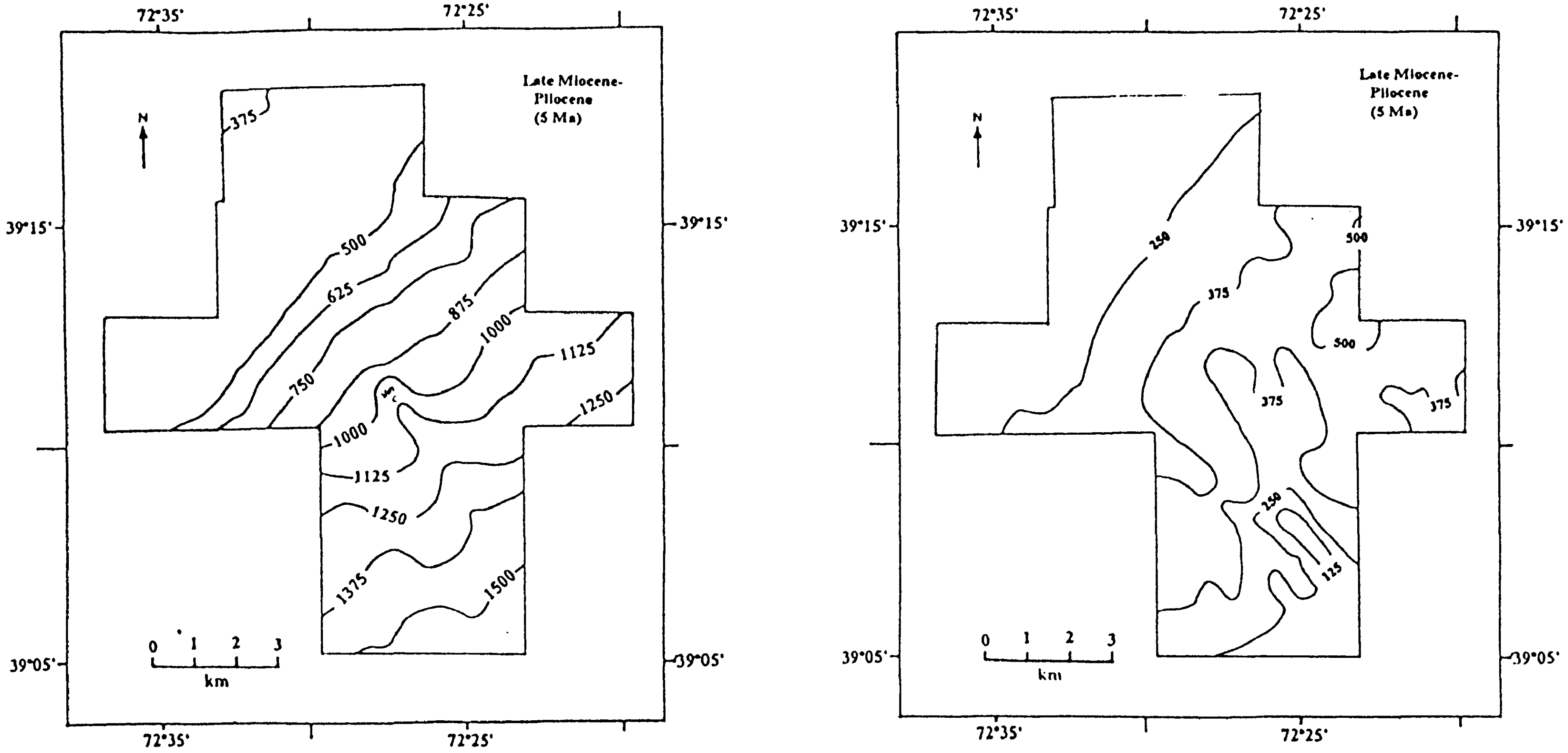


Figure 22. (from Shackleton and Opdyke, 1976) Oxygen isotope record of the past 1.6 million years.

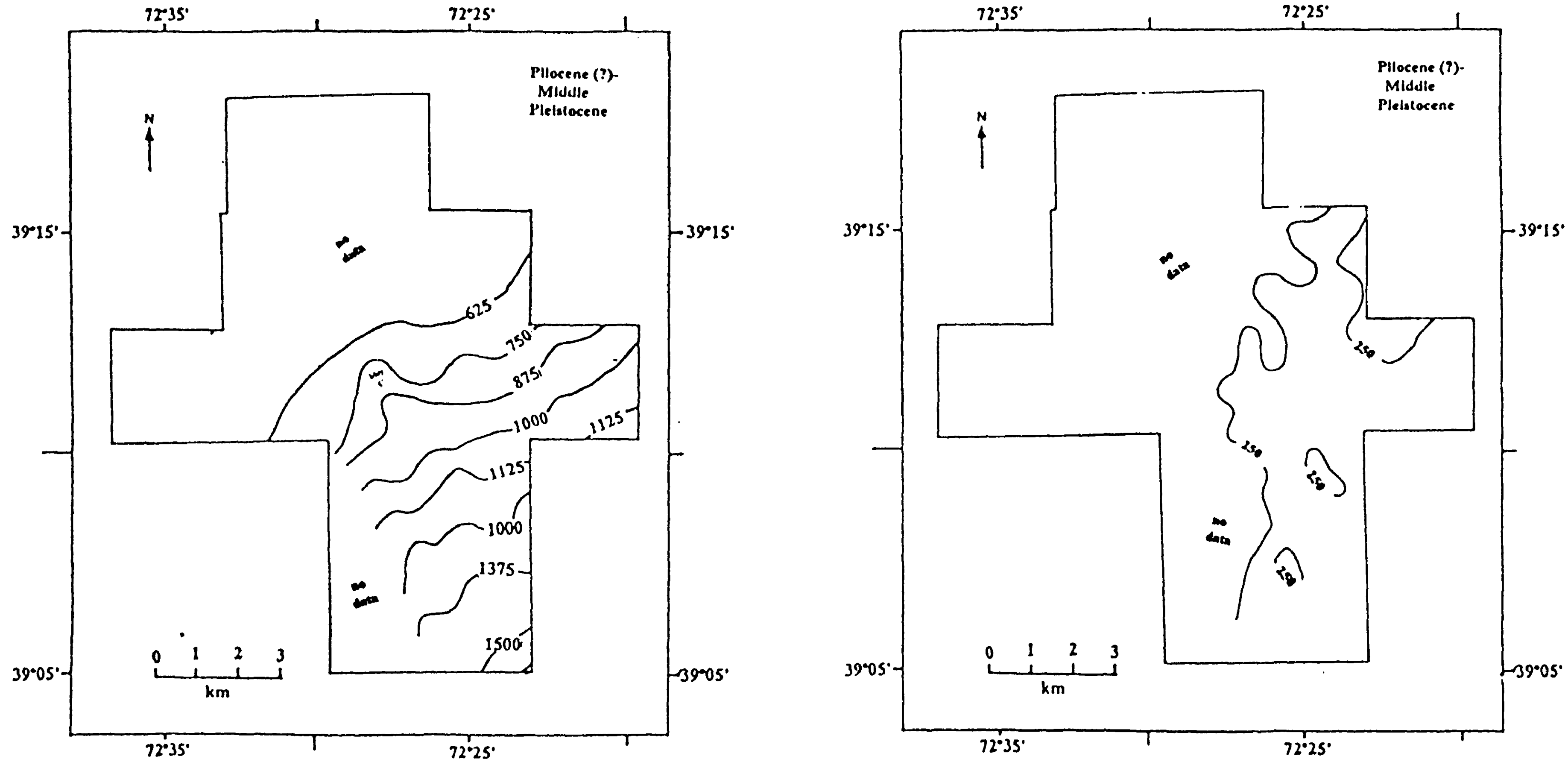
Quaternary development. Approximately 5 Ma, the ancestral Mey Canyon existed on the middle continental slope at about 1000 ms below present sea-level (Figure 23a.), whereas the upper slope was more subdued, appearing to have contained no canyons. An isopach map of sediment overlying reflector Blue indicates sediment thickens northeast of Mey Canyon and thins to the south of Mey Canyon's head (Figure 23b.), suggesting that about 5 Ma, the sediment source was in the northeast. The structure map of the Green reflector, constrained from the Pliocene to middle Pleistocene, shows a modified ancestral Mey Canyon characterized by broader contours and a canyon head which occurs 750 ms below present-day sea-level (Figure 24a.). There appears to be a smaller canyon forming to the immediate east of Mey Canyon. The corresponding isopach map, based on a limited number of data points, indicates sediment thickens northeast and west of the smaller developing canyon (Figure 24b.). This suggests a shift in erosional and depositional patterns between 5 Ma (Blue reflector) and the middle Pliocene to middle Pleistocene (Purple reflector). Mey Canyon and the smaller canyon to the east appear more complex and highly eroded by 475 Ka, as inferred from the closely spaced contours on the Purple reflector structure map (Figure 25a.). In addition, the head of the Mey Canyon appears to be 250 ms further upslope (from 750 ms in the Pliocene - middle Pleistocene) and incises the slope at 500 ms, while



a. Structure map of the Blue reflector. Contour interval is 125 ms.

b. Isopach map of the sediment thickness between the Blue reflector and the seafloor. Contour interval is 125 ms.

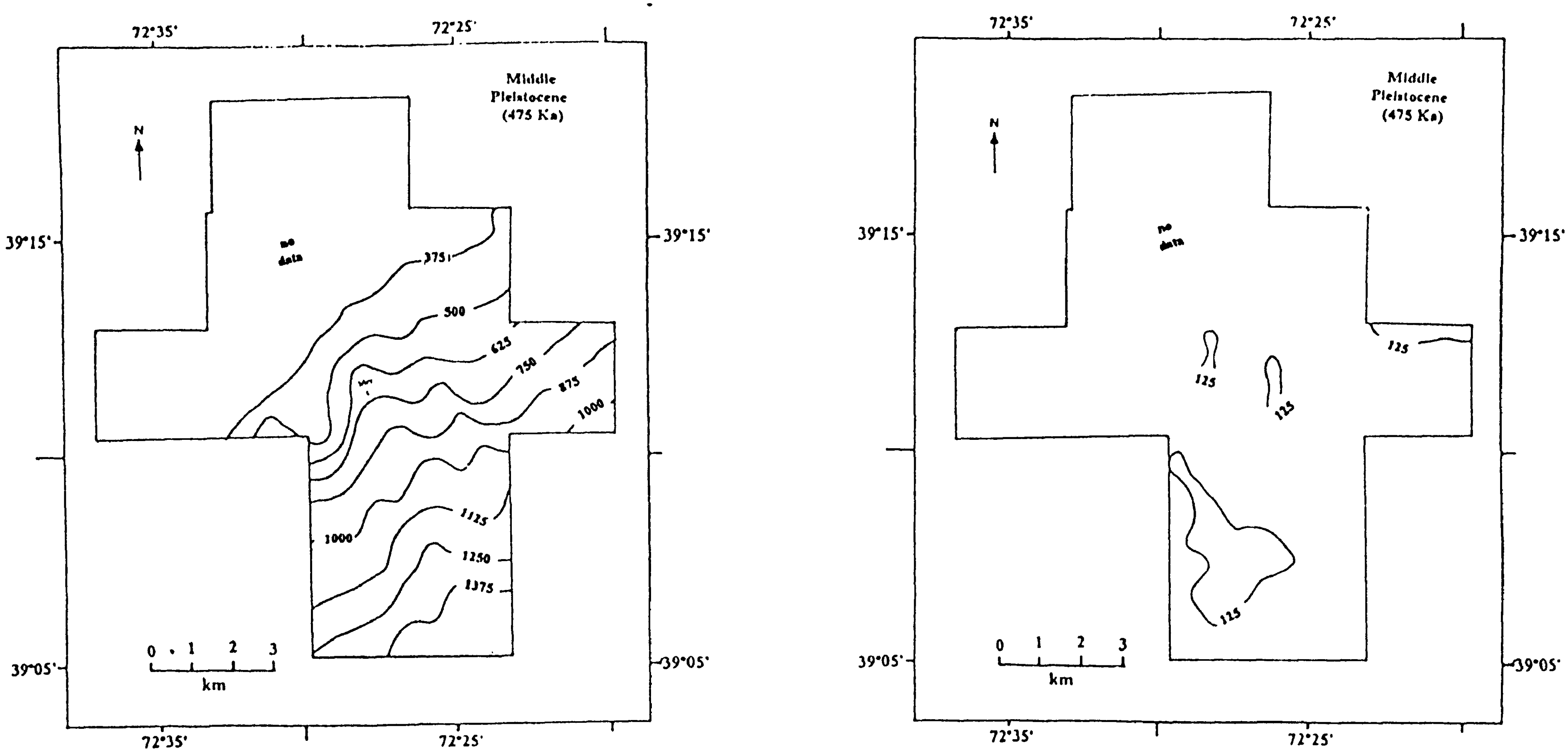
Figure 23.



a. Structure map of the Green reflector. Contour interval is 125 ms.

b. Isopach map of the sediment thickness between the Green reflector and the seafloor. Contour interval is 125 ms.

Figure 24.



a. Structure map of the Purple reflector. Contour interval is 125 ms.

b. Isopach map of the sediment thickness between the Purple reflector and the seafloor.

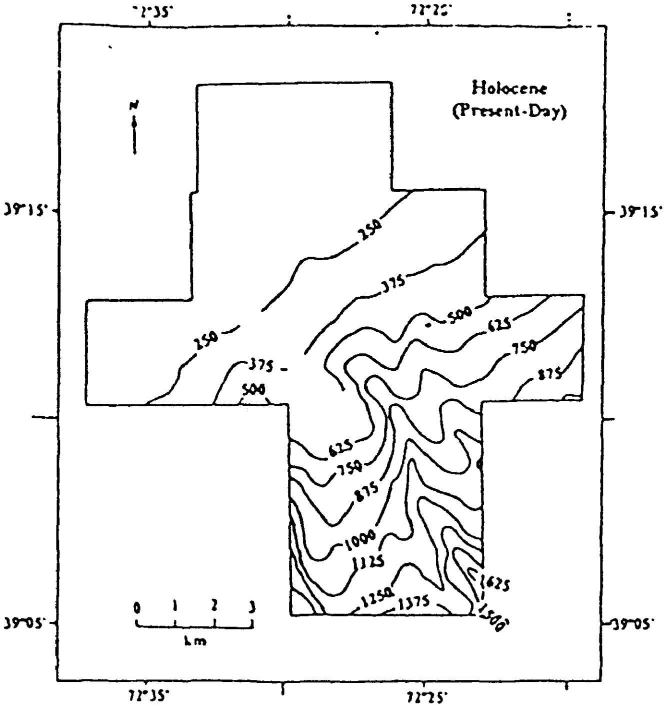
Figure 25.

the smaller canyon head is also visibly present at 500 ms. The isopach map representing sedimentation patterns 475 Ka indicates a more uniform sediment layer, with an average sediment thickness less than 125 ms (Figure 25b.).

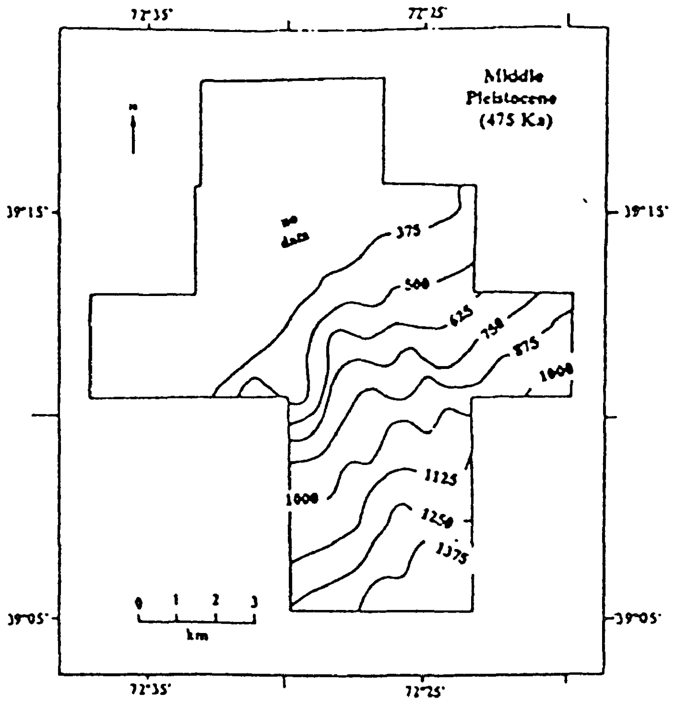
These findings suggest the shallow structure and sedimentation patterns along the slope changed a great deal between 5 Ma and 475 Ka from a Sediment Wedge to a Blanket, possibly due to the shifting of the sediment source and mass-wasting events (Figures 23b. and 25b.). Structure maps indicate the head of Mey Canyon eroded towards the shelf break upslope from a contoured depth of 1000 ms below present sea-level to 500 ms (Figure 26). Based on side-scan sonar, Twichell and Roberts (1982) and Farre and others (1983) have suggested that submarine canyons on the New Jersey slope are eroded by retrogressive mass wasting of the slope, i.e., submarine canyons erode upslope by mass wasting. Based on the present high-resolution sparker profiles, progressive upslope extension of Mey Canyon suggests retrogressive mass wasting may be occurring within the study area.

PRESENT SEAFLOOR

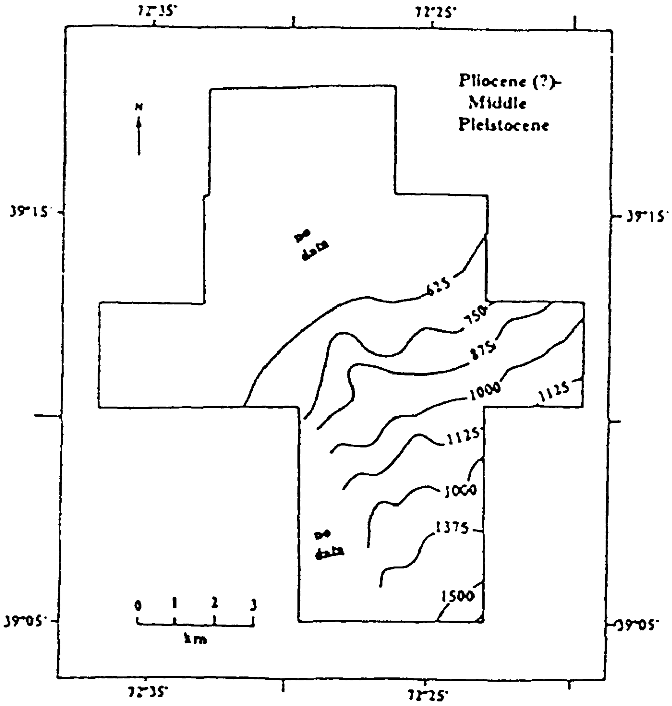
Variation in sediment thickness and slope structure throughout the past 5 Ma suggests the slope has been subjected to episodic deposition and erosion. Mey Canyon, the largest submarine canyon on the continental slope within



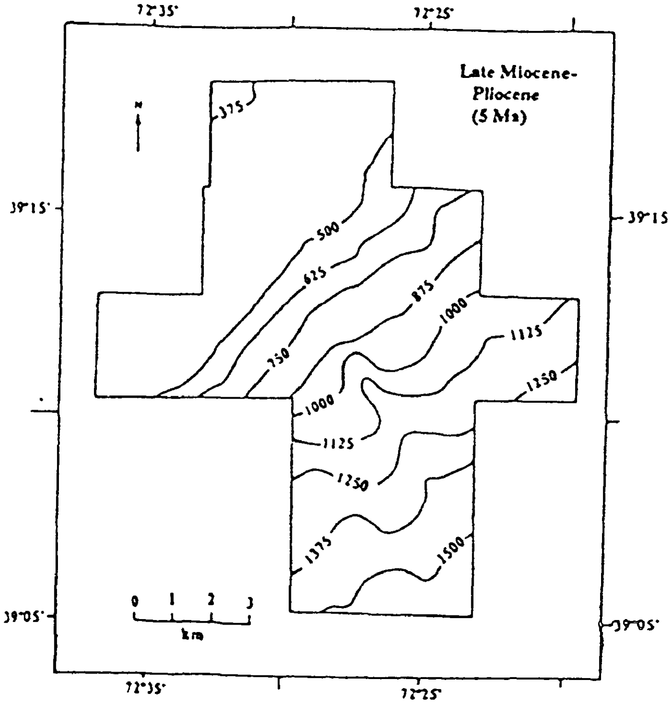
Bathymetric map of Study Area.



Structure map of the Purple Reflector.



Structure map of the Green Reflector.



Structure map of the Blue Reflector.

Figure 26. Structure maps of the age constrained reflectors (in milliseconds) and the bathymetric map of the study area (in milliseconds) demonstrate differences in the surficial expression of the seafloor throughout time. Contour interval is 125 ms.

the study area, predates the Blanket and the Sediment Wedge. Mey Canyon's migration upslope and sinuousity may conceivably be due to retrogressive mass wasting processes (Figure 26). Probable mass-wasting features, such as slumps and slides, have been identified within the uppermost portion of the Blanket based on the presence of hyperbolic and discontinuous reflectors (Figure 20). Since all the meso-relief features and sediments underneath the Blanket's base reflector Purple predate Blanket deposition, the presence of the Blanket suggests the proposed mass wasting features are contemporary because they occur closest to the seafloor.

V. CONCLUSIONS

1) The present-day New Jersey continental slope is primarily a relict landscape that has been modified minimally by Recent (Holocene) mass-wasting events.

Mey Canyon, the most prominent submarine feature within the study area, has existed on the slope since 5 Ma; and, the smaller canyon to the east has been present on the slope since the Pliocene - middle Pleistocene. Since these two canyons predate the Holocene and presently exist on the slope, they are considered relict features. Structure maps indicate that both canyons have undergone changes in configuration and position during the predominately Quaternary slope development. Hummocky topography, assumed to result from mass wasting, occurs at the seafloor surface and several meters within the uppermost subsurface. Because cores were not collected within the study area, it is difficult to discern if the mass wasting occurred during the Pleistocene and was overlain by a Holocene drape, or if it occurred as a result of Holocene events. This writer suggests the mass-wasting features identified within the study area may be a result of both Holocene and Pleistocene downslope movement of sediment since presently, the lower and middle slope offshore New Jersey continue to be sites of sediment failure (Poag, 1987) and a great deal of mass wasting occurred during the glacially-induced Pleistocene sea-level fluctuations.

2) **The morphology, shallow structure, and resulting acoustic characteristics of the New Jersey upper to middle continental slope predominately reflect local sedimentologic events related to sea-level fluctuations and to the episodic introduction or redistribution of sediment.**

Variations in sediment thickness and shallow structure since the late Miocene-Pliocene suggest episodic deposition and erosion have greatly influenced the predominately Quaternary slope development. The seismic record reveals that a northeast-thickening Sediment Wedge, bound by a regional unconformity at its base, is overlain by a Blanket, relatively uniform in sediment thickness. Differences in sediment thickness and shallow structure have been attributed to the distribution of sediment by the principle sediment source, the Hudson River, primarily during episodic Pleistocene sea-level fluctuations.

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VII. VITA

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