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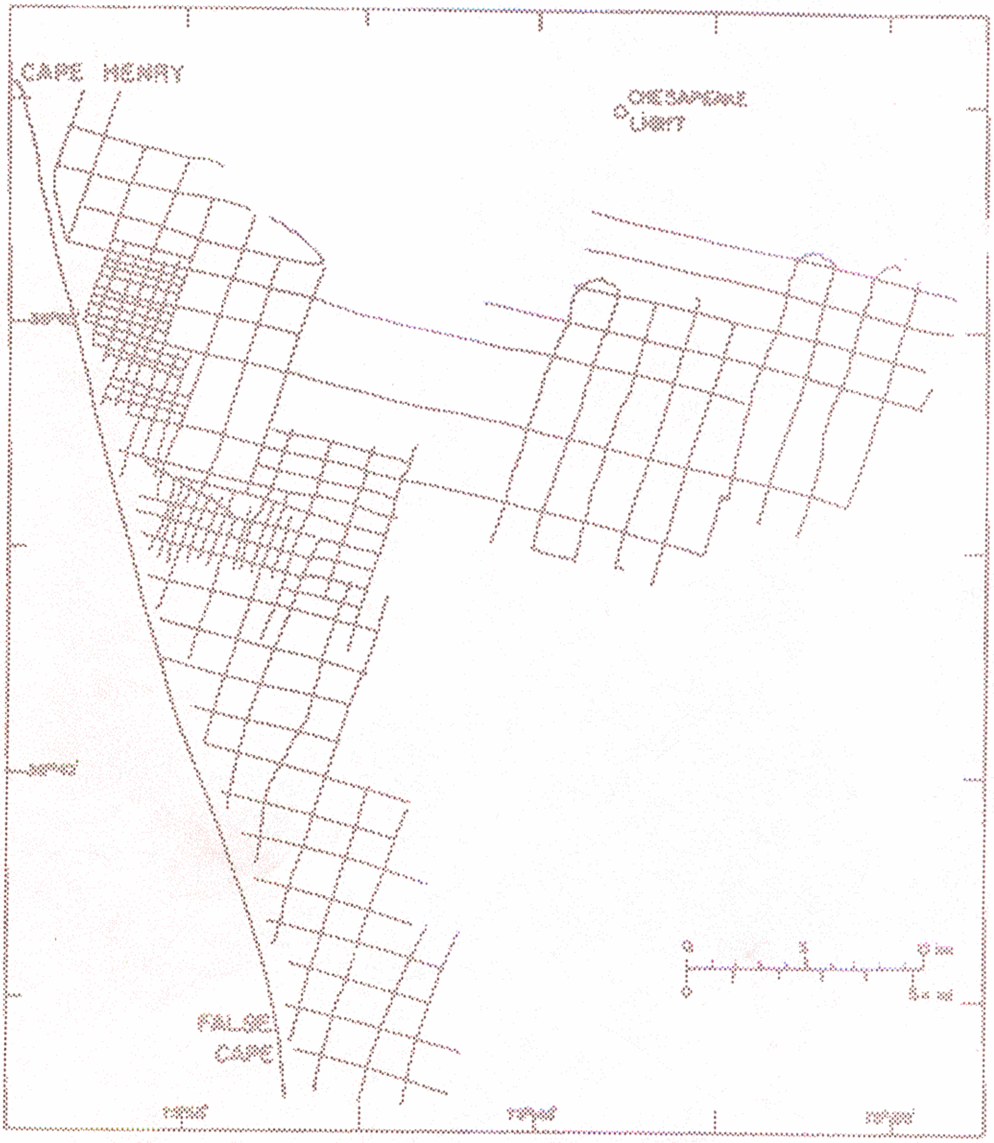
College of William and Mary
School of Marine Science
Virginia Institute of Marine Science

INVESTIGATION OF ISOLATED SAND SHOALS ON THE INNER SHELF OF SOUTHERN VIRGINIA



Final Report

Prepared By

Suzette M. Kimball
James K. Dame, II
Carl H. Hobbs, III

APRIL, 1991

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FORWARD

The Coastal Erosion Abatement Commission, in its report to the General Assembly (1979), recommended that "there is a need to locate sources of sand supplies for rebuilding public beaches." The Sand Resources Inventory, completed in 1982 by the College of William and Mary, Virginia Institute of Marine Science, was initiated in response to this directive. The Sand Resources Inventory, however, focused on the Chesapeake Bay. The City of Virginia Beach, facing a chronic need to renourish beaches facing the Atlantic Ocean, elected to develop an inventory of beach-quality sand reserves existing on the inner shelf of the Atlantic coast (Kimball and Dame, 1989). A correlative study examined the distribution of heavy minerals in the same area (Berquist and Hobbs, 1988). This report details the results of a secondary exploration program to delineate potential sand and aggregate reserves contained in isolated shoals on the inner shelf of southern Virginia.

This study was funded by the Minerals Management Service, United States Department of the Interior, Cooperative Agreement No. 14-12-0001-30432 to the University of Texas at Austin, Texas through a subagreement with the Virginia Division of Mineral Resources (No. 30432-VA) and the College of William and Mary, Virginia Institute of Marine Science. Earlier studies that provide data for this analysis were funded by the City of Virginia Beach, Virginia, the Virginia Subaqueous Minerals and Materials Study Commission and the Minerals Management Service, United States Department of the Interior, through a subagreement between the Texas Bureau of Economic Geology and the Virginia Division of Mineral Resources. Many aspects of the project are incorporated into a thesis presented by one of the authors, J.K. Dame, in partial fulfillment of the requirements for the degree of Master of Arts at the Graduate School of Marine Science, College of William and Mary.

The work described herein could not have been accomplished without the dedication and expertise of the captain and crew of the R/V Bay Eagle, L. Durand Ward and Steven H. George. Robert A. Gammisch and Margaret Calvert were indispensable in the field and provided invaluable assistance reducing and analyzing the geophysical data. Dr. Daniel Belknap of the University of Maine provided the amino acid racemization analysis that was used by J.K. Dame in the completion of his thesis and which provides corroborative information for this study. The Geotechnical Division, Norfolk District, U.S. Army Corps of Engineers (USAE) graciously allowed access and subsampling of sediment cores collected for various USAE navigation and exploration projects. The authors thank each of these individuals for his/her dedicated efforts, without which this project could not have been completed.

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ABSTRACT

Offshore of Sandbridge Beach, Virginia, the surface of the inner continental shelf is a generally featureless, gently sloping plain, broken by several isolated sand shoals. The westernmost shoal, commonly called the Sandbridge Shoal, is located approximately 5.5 km from the shoreline in 10 - 12 m of water. An analogous feature is located approximately 15 km northeast of the Sandbridge Shoal at depths greater than 15 m. During a preliminary study conducted in 1987, 534 km of trackline were surveyed with acoustic subbottom and side-scan sonar systems. Geophysical data were recorded for an additional 318 km of trackline between 1988 and 1990. Genetic similarities between the two shoal features were analyzed and conceptual models of development were proposed. In addition to the geophysical data, 11 vibracores with a maximum length of six meters and 18 surface grab samples were acquired. Shell materials in the cores were dated using amino acid racemization and radiocarbon methods.

Correlation of seismic data with vibracores and surface grab samples indicate the Sandbridge Shoal is approximately 6 x 8 km in areal extent and has a horseshoe shape in plan view. The shoal contains at least 8 x 10^7 m^3 of clean, well-sorted, medium to coarse sand, and tapers to the north and east. The offshore shoal has a larger areal extent, but its relief above the surrounding seabed is less than half that of the Sandbridge Shoal. Both shoals are associated with large paleochannel systems, and inferred lagoonal or estuarine sediments are located below and landward of the sand bodies. Sediments within the shoals fine downwards, have little evidence of an aeolian overprint, lack high concentrations of heavy minerals, and contain remains of only high-salinity organisms.

Geophysical and geochronological data show that Sandbridge Shoal is comprised of two separate sedimentological units of different ages. Geophysical data from the offshore shoal are similar in terms of the geometries of the reflectors. A model of two-stage formation is presented for these features. The lower shoal units represent reworked remnants of a barrier or submerged bar that was present on the shelf during a late Pleistocene high-stand of sea level (Isotopic Stage 5, 60,000-80,000 ybp). The upper shoal units formed during the Holocene transgression at which time sediment was deposited as an offshore bar or sand sheet over the earlier sediments.

INVESTIGATION OF ISOLATED SAND SHOALS ON THE INNER SHELF OF SOUTHERN VIRGINIA

I. INTRODUCTION

Statement of the Problem.

The Commonwealth of Virginia faces an increasing threat from erosion of its ocean-side beaches. It is becoming more difficult to locate sufficient material to restore beaches economically as upland sand pits are closed due to development. Similarly, upland sources of construction aggregate are shrinking as urban development moves into more rural areas. In order to provide a means to implement long-term beach development strategies, develop backup measures in the event of a catastrophic storm, and to maintain adequate reserves of aggregate material for economic development, it is necessary to pursue aggressively the location of alternate sand and gravel reserves.

Shoreline erosion is a result of natural long-term processes, including (1) wave action and tidal flooding due to storms; (2) reduction in the amount of sand being supplied to the nearshore system by upland and/or updrift sources; and (3) elevation of relative sea-level due to global warming and subsidence of coastal areas (Williams, 1987). Demographic shifts toward the coastline increase the hazard potential of the natural processes. Increased economic pressures require that the maintenance of beach width be a management priority in coastal communities. Resort areas use sand as fill material on their eroding beaches for both preventive and remedial purposes. Moreover, these localities can augment their appeal to tourists by maintaining a sizable beach.

Several engineering alternatives are available to mitigate the effects of shoreline recession. Beach renourishment is gaining attention because it is perceived to be less disruptive to the natural ecological system than are hard-structure alternatives. Williams (1986) reports that more than 40 beach restoration projects had been completed in the United States between 1950 and the publication date through joint funding among federal, state, and local governments. The federal projects alone used over 59 million cubic meters of sand for the initial work, and approximately half these projects have required additional, periodic maintenance (U.S. Army Corps of Engineers, 1984).

Recent activities by the City of Ocean City, Maryland, associated with the restoration of its resort beach, indicate that there is the potential to locate large volumes of beach quality sand stored in the linear shoal fields that dominate the seabed surface in the mid-Atlantic Bight. These shoals, many of them shoreface-connected, are located in 6.01 meters (20 feet) to 18.28 meters (60 feet) of water with local elevations of 3.05 meters (10 feet) to 9.14 meters (30 feet).

In the particular case of the Atlantic Coast of Virginia, linear shoals are shoreface-connected at False Cape and trend offshore to the northeast. In addition, there is a large shoal feature associated with the mouth of the Chesapeake Bay and located along the northern half of the Virginia Beach Atlantic Coast (Figure 1). Surface samples collected in these areas document widespread deposits of coarse sand, with median grain sizes as large or larger than the beach sand on Virginia Beach (>0.2 mm). The vertical extent of these deposits has not been documented

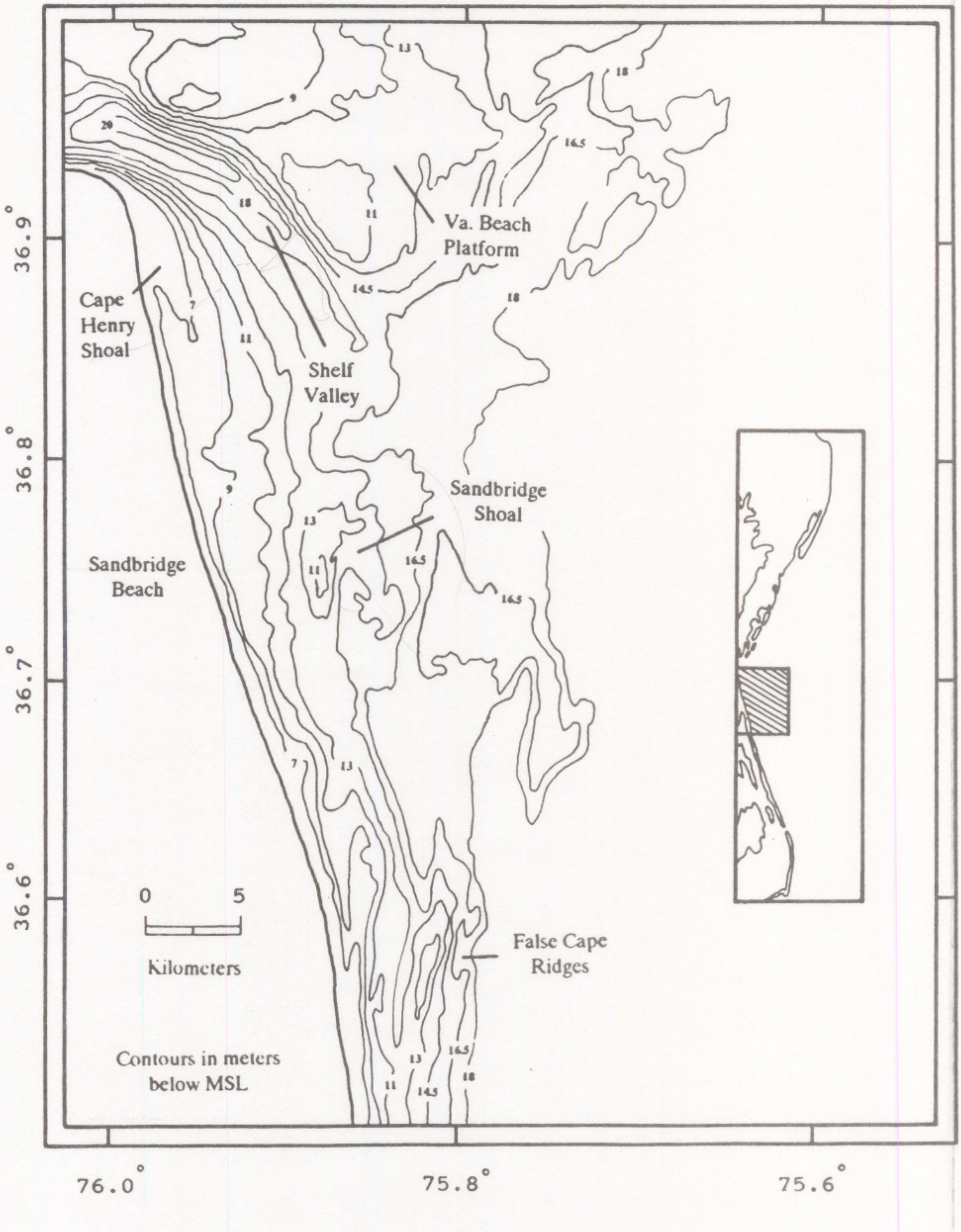


Figure 1. Virginia's inner shelf morphology between Cape Henry and False Cape. (adapted from Goldsmith, 1973)

in the literature and there is no detailed map of their distribution. However, the body of existing data suggests that sufficient sand of beach or near beach-quality is stored offshore of the Virginia Beach area at distances short enough to render sand mining for beach renourishment an economically viable alternative.

A study performed at the College of William and Mary, Virginia Institute of Marine Science (VIMS) documented the existence of a large, isolated, horse-shoe shaped sand shoal located five kilometers east of Sandbridge, Virginia (Kimball and Dame, 1989) (Figure 2). Further work identified possible modes of origin for this sand body (Dame, 1990). Navigational charts show several other isolated shoals in varying depths of water on the inner shelf of Virginia that are geometrically similar to the Sandbridge Shoal. A better understanding of the morphology and sedimentology of the Sandbridge Shoal will generate the information necessary to make informed predictions about the sand and gravel reserve capacity of other isolated shoal features. The study described herein was developed to provide detailed information about certain sedimentological aspects of the Sandbridge Shoal and related aggregate deposits and apply that information to the analysis of a morphologically similar shoal feature located approximately 20 km offshore of Virginia Beach.

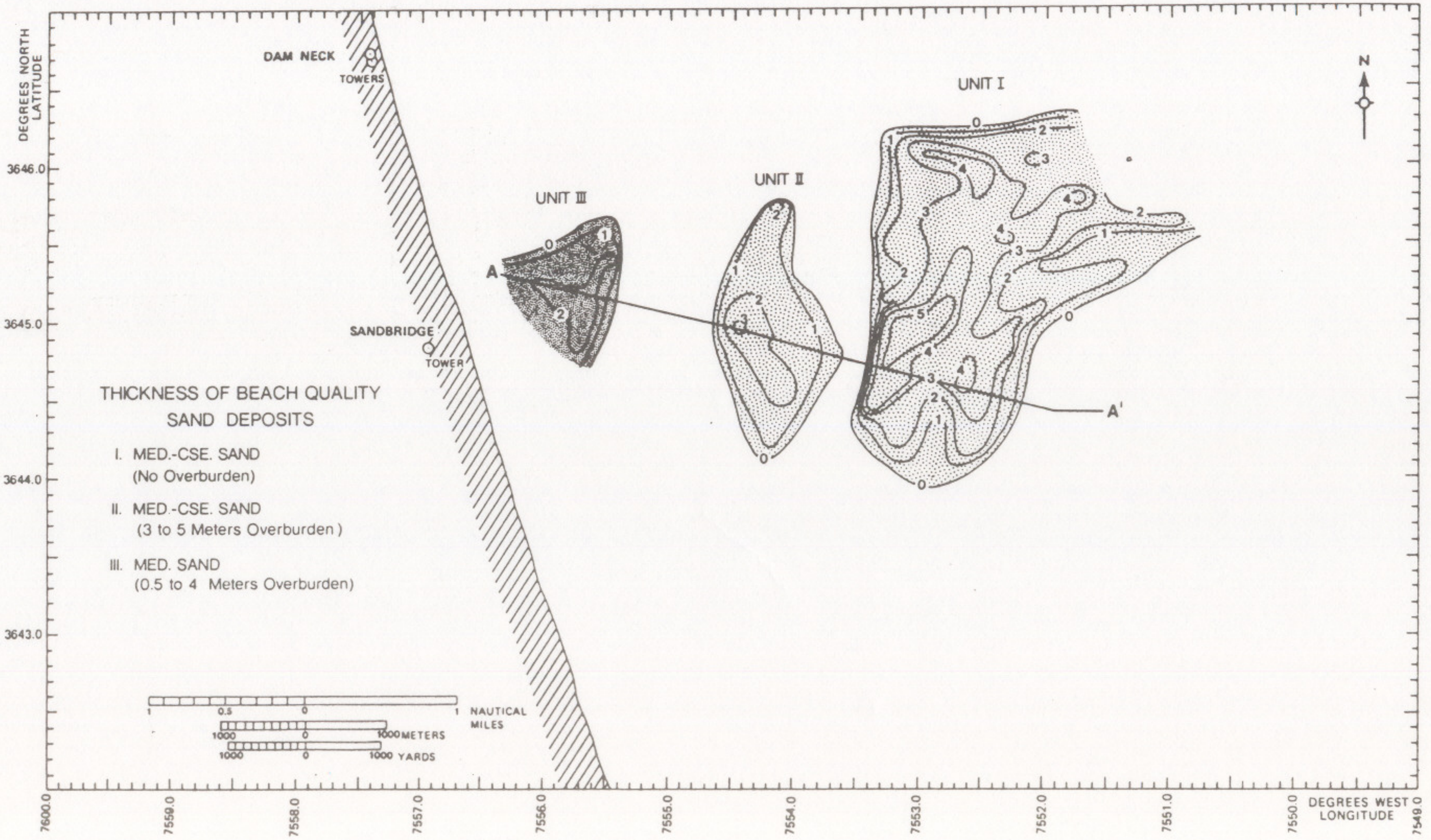


Figure 2. Isopach map showing the distribution and inferred thickness of medium to coarse sand deposits in the vicinity of Sandbridge. The contour interval is one meter.

Objectives.

The objective of this study is to perform detailed geophysical and sedimentological analyses of the isolated sand shoal commonly known as the Sandbridge Shoal and associated gravel lag deposits in order to develop criteria to evaluate the potential sand and gravel reserve capacity of morphologically similar shoals on the inner shelf of southern Virginia.

Specifically, this study includes the following tasks: (1) delineate the eastern margins of the Sandbridge Shoal; (2) map the aerial and vertical extent of suitable deposits the shoal and associated aggregate deposits; (3) determine the age and sedimentology of the shoal material; (4) identify other sand shoal features on the inner shelf with similar characteristics; (5) de-scribe the geophysical character and sedimentology of other shoal features; (6) assess the ability to identify potential sand and gravel reserves through the analysis of similarities to known reserves.

II. GEOLOGIC SETTING

Limits of the Study Area.

The study areas, shown in Figure 3, include a section of the inner shelf of Virginia generally bounded by Cape Henry to the north, Rudee Inlet to the south, the ocean shoreline of the City of Virginia Beach on the west, and a line parallel to the shoreline and approximately 20 km offshore on the east; and the area commonly known as the Sandbridge Shoal.

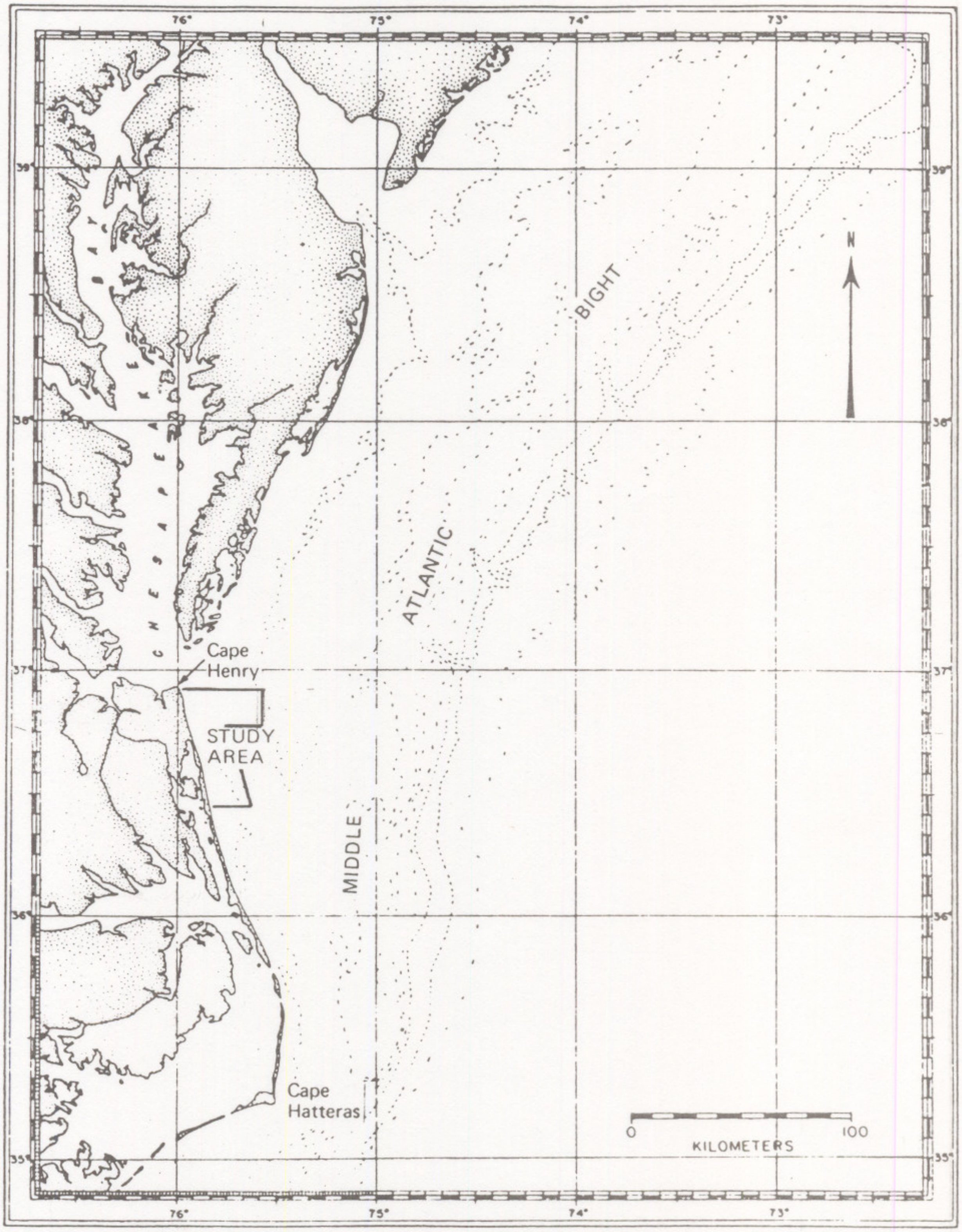


Figure 3. Site map showing location of the study area.

Regional Stratigraphy.

The study area delineated in Figure 3 is part of the inner continental shelf which is a submerged extension of the Virginia Coastal Plain Province. No fewer than six stratigraphic units have been identified that form the substrate in this region (Williams, 1987). These units, ranging from late Miocene (11.2 - 5.3 million years before present (ybp)) to late Pleistocene (10,000 ybp) in age, are overlain by a veneer of modern Holocene sediments transported into the area from the Chesapeake Bay and from shoreface sources.

The continental shelf is believed to have experienced multiple episodes of marine transgression and regression driven by Pleistocene glacial and interglacial variability in global sea level (Shideler and Swift, 1972). The resulting shelf morphology is a complex palimpsest surface where features have been modified by subsequent shelf processes (Swift et al., 1972). In addition to morphologic features formed by long-term and large-scale processes, there exists a secondary set of features created by modern flow and transport regimes through and around the mouth of the Chesapeake Bay.

During the last major marine lowstand (>18,000 ybp), sea-level was as much as 120 meters below the present level and the continental shelf was subaerially exposed with a shoreline near the modern slope break (Belknap and Kraft, 1977). Fluvial processes were the predominant factors in morphologic development. The ancestral Susquehanna River, located along the axis of the present-day Chesapeake Bay, and its tributaries, including the James River system, were responsible for creating channels and resultant sedimentary deposits many miles east of the modern shoreline. These deposits reflect the upland areas that the rivers drained.

Between 18,000 ybp and 7,000 ybp, a period of intricate, short-term climatic fluctuations resulted in a rapid net rise in eustatic sea-level (Curray, 1964). Finkelstein and Ferland (1987) demonstrated that rates of sea level rise in the mid-Atlantic Bight during that period were as much as six millimeters per year (mm/yr). Other research suggests that rates of as much as 10-12 mm/yr may have occurred (Nummedal, 1987). During the past 6,000 years the rate of global rise has slowed and is now estimated at 1.2 mm/yr, with local rates of relative rise estimated between 2.7 mm/yr and 4.4 mm/yr (Froomer, 1980).

The rapid fluctuations of sea level are evident in the stratigraphy and subbottom structure of the inner shelf, which are as complex as the climatic history. Downcutting by ancestral fluvial systems during regressive periods resulted in widespread erosional surfaces and fluvial channel deposits (Shideler and Swift, 1972). During subsequent periods of rapid transgression, many of the subaerial topographic features were modified by marine processes, creating the present configuration of filled channels, shoals, remnant barriers and relict shorelines (Stubblefield and Duane, 1988).

The broad scale stratigraphy of the Virginia inner continental shelf has been well documented through the analysis of seismic records and sediment core logs (Shideler and Swift, 1972; Shideler et al., 1972; Meisburger, 1972; and Swift et al., 1977). These studies indicate four distinct sedimentary sequences that can be dated to the late Pliocene (1.6 million ybp). The sequences are named Unit A (oldest) through Unit D (youngest), by convention (Shideler and Swift, 1972). The oldest, Unit A, correlates with the Pliocene age Yorktown Formation (Fm), a widespread, shelly, marine sequence whose erosional surface underlies much of the southeastern coastal plain in Virginia. The altered surface of the Yorktown Fm generally is seen as a clear reflector in seismic records. Williams (1987), however, was able to locate only a faint and discontinuous seismic trace that could be ascribed to the Yorktown Fm in the area between Cape Henry and Virginia Beach.

Radiocarbon dating and stratigraphic position are indicators that the next younger sequence, Unit B, represents a regressive assemblage formed during early Pleistocene low stands of sea level. It consists of fluvial and nearshore deposits characterized by lenticular to planar stratification within well-developed local channels that trend southeast and exhibit considerable local relief (Shideler and Swift, 1972). This unit is correlated with the Great Bridge Fm/Sandbridge Fm sequence of the adjacent coastal plain, as defined by Shideler et al. (1972).

Unit C, which overlies Unit B, is composed of homogeneous, horizontal layers of silt and clay that thicken slightly in an eastward direction. The deposit was formed in a low-energy environment, such as an estuary or back-barrier lagoon during a late Pleistocene highstand of sea level (Williams, 1987). No onshore correlative sequence has been identified.

The youngest and, hence, shallowest sequence, Unit D, composes the majority of modern surficial inner shelf deposits. This sequence is a discontinuous Holocene (recent to modern) transgressive sand sheet (Swift et al., 1977; Hobbs, 1990).

It is composed of fine to medium sand or muddy sand with shell remains of modern fauna. Little internal stratification is visible (Williams, 1987). This deposit is forming as the result of rising sea level over an eroding shoreface, with substantial redistribution of material by shelf currents.

Occurrence and Description of Linear Shoals.

The Middle Atlantic Bight is characterized by numerous linear sand shoals that are present from the shoreface to the shelf break. Along the inner portions of the shelf, these sand bodies normally occur within shoal fields that may exist as secondary features on arcuate inlet or cape associated shoals, or may exist as independent fields along the open coast. Those shoals on the open coast may described further as either shoreface-connected or isolated.

Duane et al. (1972) noted the presence of linear shoals along the inner continental shelf offshore of New York, New Jersey, Delaware, Maryland and Virginia. Their analysis of several hundred shoals demonstrated that these features exist at three discrete depths: 10 m, 15 m, and 24 m. In addition, these shoals, with the exception of those occurring offshore of Long Island, New York, have axes whose azimuths are oriented to the northeast regardless of the net direction of littoral drift.

Seismic reflection profiles and vibracore data have been used in studies of shoals offshore of Beach Haven Inlet, New Jersey (Stahl et al., 1974), the central Delmarva Peninsula (Field, 1979), and False Cape, Virginia (Swift et al., 1972). These studies describe linear inner shelf shoals as planoconvex in cross-section with some internal stratification and crest elevations commonly three meters above the surrounding seabed. The shoals are composed of clean, medium to coarse sand separated from underlying strata by strong horizontal acoustic reflectors.

Field (1979) described a series of sub-parallel sand ridges in the mid-Atlantic Bight along the Virginia and Maryland coasts. The shoals vary in length from six to 60 kilometers, are spaced between one and six kilometers apart, and have amplitudes ranging as high as ten meters (Duane et al., 1972; Field, 1979). All sources note that the nearshore shoal fields are aligned on a northeast strike at a reasonably constant 20° to 30° from the present trend of the coastline. In some cases the shoal system extends into the nearshore bar system and becomes shoreface connected. Such is the case at False Cape, Virginia, and accounts for the relatively wide shoreface platform in that area. The amplitudes of the ridges in the False Cape area exceed seven meters less than one kilometer from the shoreline; side-scan data across the ridge field show small amplitude sand waves indicating an active sediment transport regime (VIMS, unpublished data).

Genetic Interpretations of Linear Shoals.

The genesis of these linear features has been a matter of discussion and a consensus has not yet been reached. One explanation is that the sand shoals are remnants of Pleistocene beach ridges or barrier islands that became stranded and then drowned during the Holocene marine transgression. Curray (1960) interpreted elongate sand ridges on the Texas shelf as drowned barrier islands. Penland et al.

(1986) described Ship Shoal offshore Louisiana as a relict barrier feature. Sanders (1962) suggested that the False Cape, Virginia, ridges represent a coastal dune and beach complex formed during Pleistocene still-stands. Kraft (1971) explained the shoreface connected linear shoals of Delaware and New Jersey as relict coastal barriers. He demonstrated the parallelism between the offshore shoals and oneshore pre-Holocene barrier ridges near Bethany Beach, Delaware.

A second interpretation, first suggested by Moody (1964), describes linear shoals as modern features. Studies of the sand ridges on the Delaware shoreface suggested significant movement and redistribution during the Ash Wednesday storm in 1962, prompting the conclusion that the linear shoals form as a result of modern shoreface hydraulic processes. Swift et al. (1972) propose that a significant process responsible for the growth and development of a shoreface shoal is storm-generated coastal currents. The dominant storm waves on the middle Atlantic shelf are from the northeast and cause headward erosion of the troughs and accretion on the crests and seaward flanks of the shoreface connected shoals. The resulting elongation of the shoal coupled with shoreline retreat during a marine transgressive episode results in a transition from a shoreface connected to an isolated shoal. Duane (1972) noted that the strong similarities between the geometries of the Atlantic shelf shoals suggests a single mode of formation.

Sea-Level Fluctuations and Linear Shoals.

Sea-level oscillations accompanying Pleistocene glacial activity have been well documented. Shackleton and Opdyke (1973) used oxygen isotope analyses of deep sea cores to define isotopic stages that represent fluctuations in sea level. These stages are defined by variations in $^{18}O/^{16}O$ ratios found in foraminifera tests. Odd numbered stages represent inter-glacial episodes and are characterized by higher amounts of the ^{16}O isotope.

Other studies have used radiocarbon and uranium series dating to estimate the age of sea-level variations. Chappell (1974) and Chappell and Shackleton (1986) used both radiocarbon and uranium series dates from terrace reefs in New Guinea to define sea-level maxima for the past 240 ka. Cronin et al. (1981) used uranium series dates from corals along the U.S. Atlantic coastal plain and paleoclimate data to document five high-stands of sea level during the last 200 ka. The depth sensitive coral Acropora palmata was used by Fairbanks (1989) to determine radiocarbon dates from which to define a sea level record for the past 17 ka, and by Bard et al. (1990), who applied mass spectrometry to obtain uranium series dates. These and other studies show regional trends in sea levels. Variability among the data sets may be attributed to regional tectonism, sediment loading, and isostatic and hydrostatic crustal adjustments.

Comparing the described references, the following general sea-level trends have been established:

1. A high-stand approximately 120,000 ybp at or above present levels followed by two cycles of fluctuations with sea-level maxima increasingly less than the 120,000 ybp high-stand. This period is identified as isotopic Stage 5, and ended approximately 75,000 ybp.

2. A low-stand identified as isotopic Stage 4, that ended approximately 65,000 ybp.

3. A series of decreasing sea-level highs, labelled isotopic Stage 3, that ended 25,000 ybp.

4. Isotopic Stage 2, which represents a low stand that marks the end of the Pleistocene. Sea level is believed to have been as much as 120 m below present levels (Bard et al., 1990). This event reached its maximum about 18,000 ybp.

5. The Holocene marine transgression which has supported a sea level rise of as much as 100 m during the past 18,000 yr.

At 18,000 ybp, sea level was approximately 120 m below its present level and what is now the continental shelf was subaerially exposed with a shoreline near the modern slope break (Bard et al., 1990). Fluvial processes dominated the regime. Large fluvial channels and related sedimentary deposits were located over much of the shelf. Widespread erosion of the coastal plain provided abundant sediments to the coastline. These sediments have been, and continue to be, reworked into a series of barrier complexes and shoreface shoals during the Holocene marine transgression.

Large arcuate shoals can be formed by the progressive landward migration of shoreline depositional centers during a marine transgression (Swift et al., 1977). Sedimentary records of the mid-Atlantic shelf indicate precursors to present barrier systems existed throughout the Holocene transgression (Field and Duane, 1976).

The evolution of these features is a function of sediment supply and the rate of sea level rise.

Theoretically, barrier beaches can respond to rising sea level by building upward and seaward, being overstepped or drowned, or migrating shoreward (Dillon, 1970). If the rate of sea level rise outstrips the supply of sediment, either barrier drowning or migration will occur. Remnants of an overstepped barrier may remain on the shoreface as one or more shoal.

Kraft (1971), Swift (1975), and Leatherman (1983) have been proponents of the concept of continuous landward migration of barrier systems throughout the Holocene transgression. This theory does not imply that all barrier islands formed at the same time and place, nor that the same barriers have existed throughout the Holocene epoch, but that their formation and migration on the shelf has been intermittent in both space and time (Field and Duane, 1976). The surf zone transgresses across the shelf, and back barrier sediments are exposed to continuous reworking on the shoreface. Belknap and Kraft (1981) predicted that the rate of sea-level rise is the main factor governing sequence preservation because it controls the amount of time that an area is exposed to shoreface erosion. Transgressive facies deposited in stream valleys and topographic lows are more likely to be preserved because they are more likely to below the depth of shoreface erosion.

III. METHODS

Geophysical Methods.

Field data were acquired through two instrumentation systems: acoustic subbottom profiler and side-scan sonar. Seismic data were obtained using a Datasonics SBP-5000 subbottom profiler. This system consists of a SBP-220 two-channel, dual-frequency transceiver connected to a towfish carrying the transducers. The primary channel can operate at variable frequencies and up to 12 kw. Most of the surveying in this area was conducted at 3.5 kHz; 5.0 kHz was used when greater resolution of reflectors was desired, or when a very strong surface reflector obscured subsurface horizons. Bottom penetration varies from less than five meters in areas of hard packed sand to over 25 m. The second channel operates at 200 kHz and one kilowatt and was used to provide an accurate record of the bottom surface and water depth beneath the towfish.

Hard copies of the seismic data were recorded on electrostatic paper by both an EPC Model 3200 dual-channel graphics recorder and an EPC Model 4800 three-channel graphics recorder. The recorders were operated with a 63 ms (8^{-1} s) sweep yielding a full graphic scale covering approximately 47 m. In determining the depth of reflectors, an arbitrary standard of 1,500 m s^{-1} was used for the speed of sound in both sea water and unconsolidated, shallow sediments.

Side-scan sonar records were acquired with an EG&G Model 960 Seafloor Mapping System. A 105 kHz acoustic signal is transmitted in an arc variably set to scan a fixed distance on each side of the track line (100 meters, in this study). This system produces a planimetric image of the seafloor corrected with respect to the vessel speed.

The recorded image on the side-scan printer depicts variations in the roughness of the sea-bed on the basis of variations in acoustic backscatter. Very small scale changes in roughness, such as those caused by variations in sediment grain size appear as broad changes in darkness or tone. The intensity of the recorded signal is a representation of the character of the seafloor. A lighter or brighter image is indicative of coarser, sandier material, or areas of relief that reflect most of the acoustic signal. Dark images indicate soft or fine-grained sediments, or shadow zones behind areas of positive relief and are the result of absorption of acoustic energy. Larger scale features, bedforms and anthropogenic elements appear with a relatively high degree of clarity because of the strong relief associated with such features.

The geophysical surveys were carried out aboard the Virginia Institute of Marine Science R/V Bay Eagle. Navigation was controlled by a shipboard microprocessor loran-C system along lines of constant time-delay. Fix marks were recorded at the start and finish of each line and automatically every five minutes on long lines and two minutes on short lines. The loran was interfaced with a laptop computer to facilitate recording. The loran, sub-bottom profiler, and side-scan systems were interconnected for simultaneous annotation of fixes. A total of 852 km (506 mi) of track line were surveyed in 1987, 1988, and 1990, as depicted on Figure 4. Of these tracks, 534 km (332 mi) were surveyed for the original Virginia Beach Sand and Gravel Resources

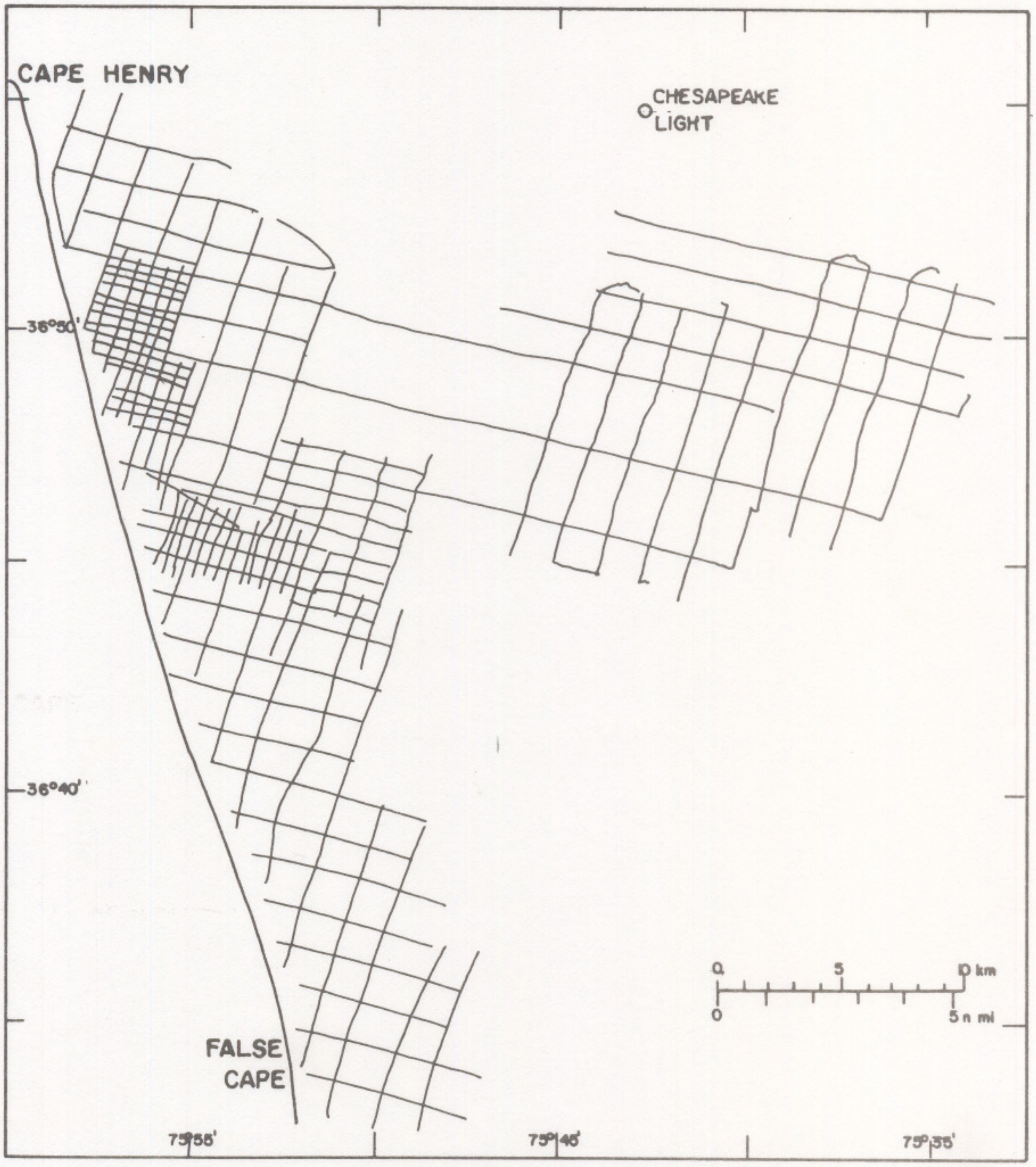


Figure 4. Locations of all the survey track lines within the overall study area.

Study and 318 km (174 mi) were surveyed under the scope of work reported herein. Raw data and interpreted seismic sections those tracklines in the immediate study area are reproduced in Appendix A.

Sediment Sample Collection.

Vibracores were obtained during a 1987 correlative study that assessed economic heavy mineral distributions on the inner shelf (Berquist and Hobbs, 1988). Cores were retrieved by Alpine Ocean Seismic Survey Inc., using a pneumatic rig aboard the R/V Atlantic Twin. The inside diameter of the cores is a standard 8.9 centimeters (3.5 inches). Recoverable lengths reached a maximum of 6.1 meters (20 feet); however, jetting was required to reach this limit in coarse sand. Sample locations pertaining to this study are shown on Figure 5. For the purposes of this study, access was provided to a second set of cores obtained in 1988 by Exmar Inc., through the Geotechnical Division of the Norfolk District of the U.S. Army Corps of Engineers. Sedimentological characteristics were identified in each of the cores and correlated with reflectors identified in the subbottom cross-sections to provide an interpretation of the stratigraphy.

Surface grab samples were obtained for this study with a Smyth-McIntyre sampler, which gives a disturbed sample of the top 15-20 cm of sediment. These samples were correlated with geophysical data in order to delineate the eastern boundary of Sandbridge Shoal and to characterize the gravel lag deposits. Locations of the cores and grab samples pertaining to the Sandbridge Shoal are shown in Figure 5.

Cores were labeled, capped, sealed, and returned to the laboratory where they were split, described and logged. Channel samples were taken from each stratigraphic interval. Logs of each of the cores used in this study are included as Appendix B.

All channel and grab samples were processed in the laboratory to remove and weigh the silt and clay fraction (<0.063 mm or >4.0 phi) and calculate the size distribution of the sand fraction (0.063 mm to 2.0 mm or 4.0 to -1.0 phi). The sand fractions were processed using a Rapid Sediment Analyzer (RSA) which detects the sediment size distributions based on the hydraulic equivalent radius of the particles. The RSA is a computerized settling tube filled with de-ionized water and containing an electrobalance connected to a personal computer. This technique is preferable to mechanical sieving when the transport characteristics of a material are important, because grain shape and density are considered when particles are grouped in a size classification.

Appendix C contains tabular summaries of grain size statistics for each sample used in this study. Detailed mineralogic analyses of the samples can be found in Berquist et al. (1990). All samples are archived at the College of William and Mary, Virginia Institute of Marine Science.

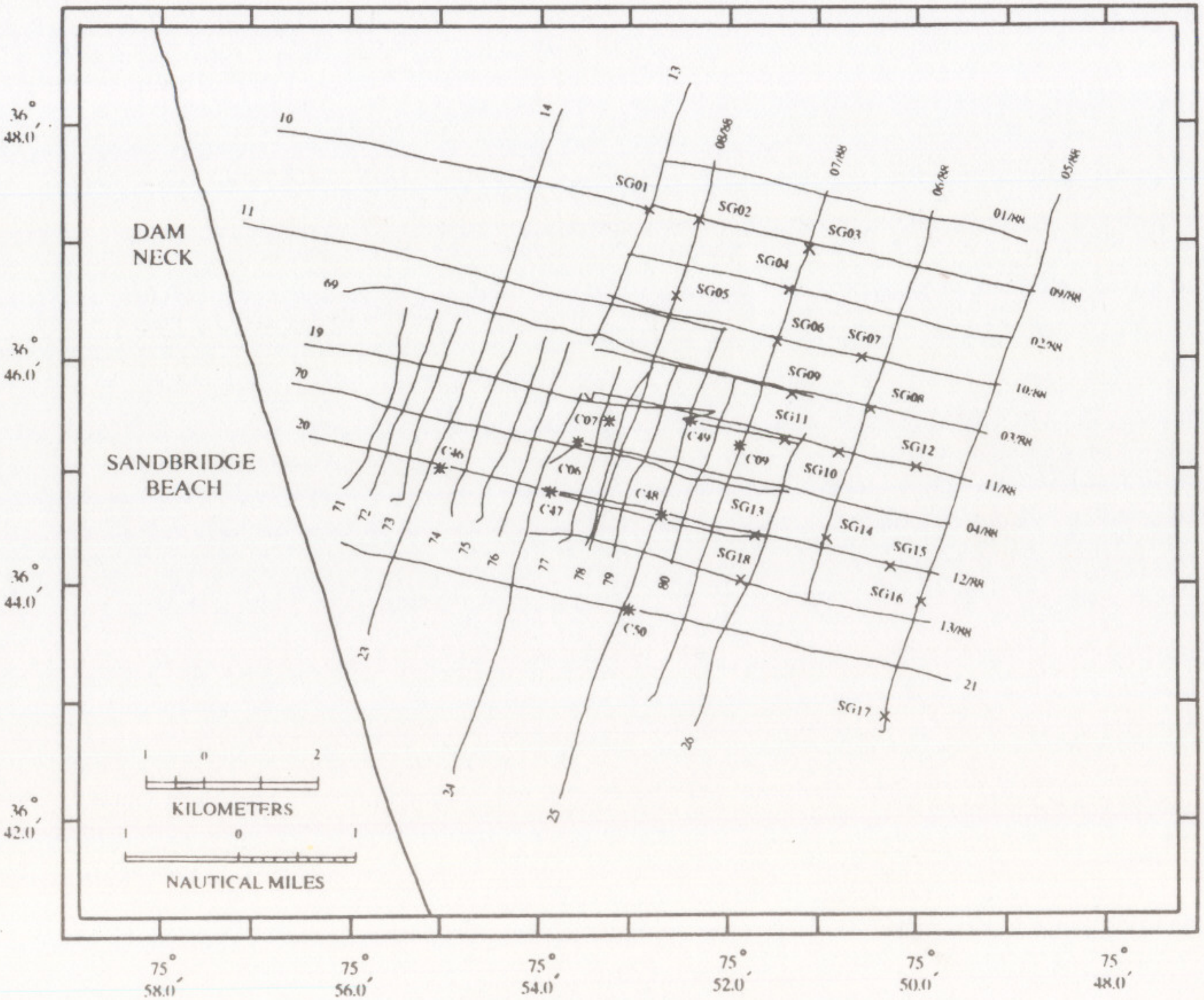


Figure 5. Locations of survey track lines and surface grab samples adjacent to Sandbridge Beach. Track line and core numbers are referenced in the text and appendices. Track Line #20 corresponds to Transect A–A′ (Figure 2) and Track Line #10 corresponds to Transect B–B′ (Figure 7).

Geochronology.

Two dating techniques, amino acid racemization and ^{14}C isotope analysis, were used to evaluate the formation of the Sandbridge Shoal. Amino acid dating is based on the diagenesis of proteins in an organism (Miller and Hare, 1980). In the living state, an organism integrates proteins into its shell material as growth continues. After death, the breakdown of peptide bonds, which hold amino acids together in the form of proteins, results in the freeing of amino acids. In addition, some amino acids undergo racemization after the organism dies, through which L-isomers of the amino acid are converted to D-isomers. The racemization ratios (D/L) and the ratios of free to bound amino acids increase with time. They are, however, temperature dependent. It is assumed that shell material within a particular region would be subjected to similar temperature variations through time. The technique proves reliable when shells from the same genera within the same geographic region are compared (Wehmiller et al., 1988).

Different genera racemize at different rates; therefore, relative dating of specific material within geographical regions can be performed by comparing the D/L ratios of each sample (the greater the ratio, the older the sample). D/L data can also be used as a stratigraphic tool by assigning samples to aminozones (Wehmiller et al., 1988; Groot et al., 1990). Aminozones are defined by a range or cluster of D/L values. When the D/L ratio of a sample lies within one of these ranges, the sample is assigned the same relative age as that of the aminozone. This approach minimizes small variations in D/L values at specific sites, as well as small age differences among sites within a given region. When correlating D/L rations from different regions, temperature gradients from any given time in the Pleistocene would be assumed to follow similar latitudinal trends of modern temperature gradients. The assumption of similar paleoclimatic histories across a region effectively eliminates the temperature dependence and allows the method to be independent of the kinetics and mechanisms of racemization (Miller and Hare, 1980).

Absolute ages of material can be obtained through amino acid diagenesis only by calibrating D/L values to independent chronologic data. Radiocarbon dating was performed in order to provide chronologic data for quality control and to allow correlations to the amino acid data for absolute age determinations. Radiocarbon methods were chosen over other techniques because the ages of the material were expected to be relatively young.

Twelve samples of shell material from the Sandbridge Shoal were analyzed by amino acid racemization and those results compared with radiocarbon dates extracted from portions of two of those samples. All samples were from the phylum Mollusca and ranged from solitary valves to material from discrete shell layers. Weighed samples ranging between 0.5 g (amino acid) to 10.0 g (^{14}C) were selected that had not been visibly reworked nor chemically altered. Broken and fragmented shells and those showing visible signs of secondary mineralization and leaching were discarded. Whenever possible, articulated valves and shells in growth position were used. An effort was made to retrieve material from stratigraphic contacts. After sampling, the matrix was cleaned from the shell material by brush and dental tools.

The amino acid analysis was carried out by Dr. D.L. Belknap at the University of Maine. Scraped, unaltered shells were cleaned in dilute HCl and NH_4OH, then dried and weighed. After cleaning, the samples were dissolved and hydrolyzed in 6N HCl and hydrolyzates were desalted on cation exchange resin. This procedure results in a total amino acid mixture. Ester derivatives of this mixture were prepared and analyzed by capillary column gas chromatography. Peak height ratios were determined directly from the chromatograms to give D/L values.

Radiocarbon age determination was performed by Geochron Laboratories. Sample preparation consisted of cleaning the shell material in an ultrasonic cleaner and removing surficial material with dilute HCl. The cleaned shells were hydrolyzed with HCl under vacuum. This produces CO_2 which was recovered and analyzed by proportional gas counting. By international convention, the dating is based on a radiocarbon half life of 5570 years, and ages are referenced to 1950 A.D. No significant radiocarbon activity was detected from these samples, which indicates the age limits of this method were being approached. Thus, reported dates are given as minimum ages based on a 95% probability. To correct for man's influence on the environment, the samples were compared to a modern standard that has 95% of the activity of the National Bureau of Standard's oxalic acid. The reported ages also are ^{13}C corrected.

IV. SUMMARY OF VIRGINIA BEACH SAND AND GRAVEL STUDY (KIMBALL AND DAME, 1989)

General Sedimentary Characteristics of the Virginian Inner Shelf.

With the exception of several discrete isolated shoals, the inner shelf of Virginia is uniformly covered by a layer of fine to very fine, angular, gray micaceous sand. This layer varies from less than one meter to five meters thick throughout the region. The thickest deposits are concentrated on the inner shelf north of Rudee Inlet and result from the Chesapeake Bay plume. Locally, patches of coarse shelly sand or mud may occur at the surface. Areas dominated by mud may carry a suspended load of flocculates ranging a few centimeters to approximately one meter above the seafloor. These areas are typical on the shoreface adjacent to Sandbridge Beach and Back Bay.

The fine sand cover, which has a mean grain size of 0.125 mm (3.0 phi) carries a high percentage of silts and clays (hereafter termed "fines"), ranging from 16% to greater than 20%, has an unaesthetic appearance in terms of color and a characteristic odor from organic components.

The region offshore of False Cape is dominated by a twin-ridge linear shoal complex. There is a clear distinction between sediments contained in the shoals and the surrounding intershoal and swale areas. Within the swales, a fine to silty fine sand overlies interbedded layers of clay, silty clay, and silty sand with lenses of coarse shell fragments and gravel. The shoals are medium to coarse sand with a mean grain size of 0.3 mm (1.75 phi) containing occasional laminae of silt, clay, and/or shell hash.

Rudee Inlet Deposits.

It has been suggested that a deep channel consisting of sand runs east-southeast from Rudee Inlet (Holton, 1987). A detailed geophysical sampling grid was developed to investigate the possibility of large sand reserves in the vicinity of the Resort Strip and Rudee Inlet (Figure 6).

The surface sediments overlying this region are uniform gray to olive gray, fine to very fine sand with a consistent mean grain size of 0.125 mm (3.0 phi). The percentage of fines is high, reaching as much as 65%, but averaging 12% over the entire sand body (Table 1). Three locations show thin (0.1 meter, 0.3 feet) layers of quartz gravels and gravel-sized shell. Sand layers underlying the surface deposit have mean grain diameters between 0.25 mm (2.0 phi) and 0.125 mm (3.0 phi). Average grain size for the entire sand fraction underlying the very fine to fine sand at the surface is 0.2 mm (2.25 phi).

Figure 7 shows the minimum thickness, based on recoverable core length and correlated to seismic data, of the surficial fine sands.

Thickness varies from two meters to as much as six meters (maximum recoverable core length). Surface sediments become slightly more coarse in the southwest corner of the area. Figure 8 is a cross-section across Transect B-B'. Subbottom records indicate a strong reflector that probably represents a Pleistocene/Pliocene(?) erosional

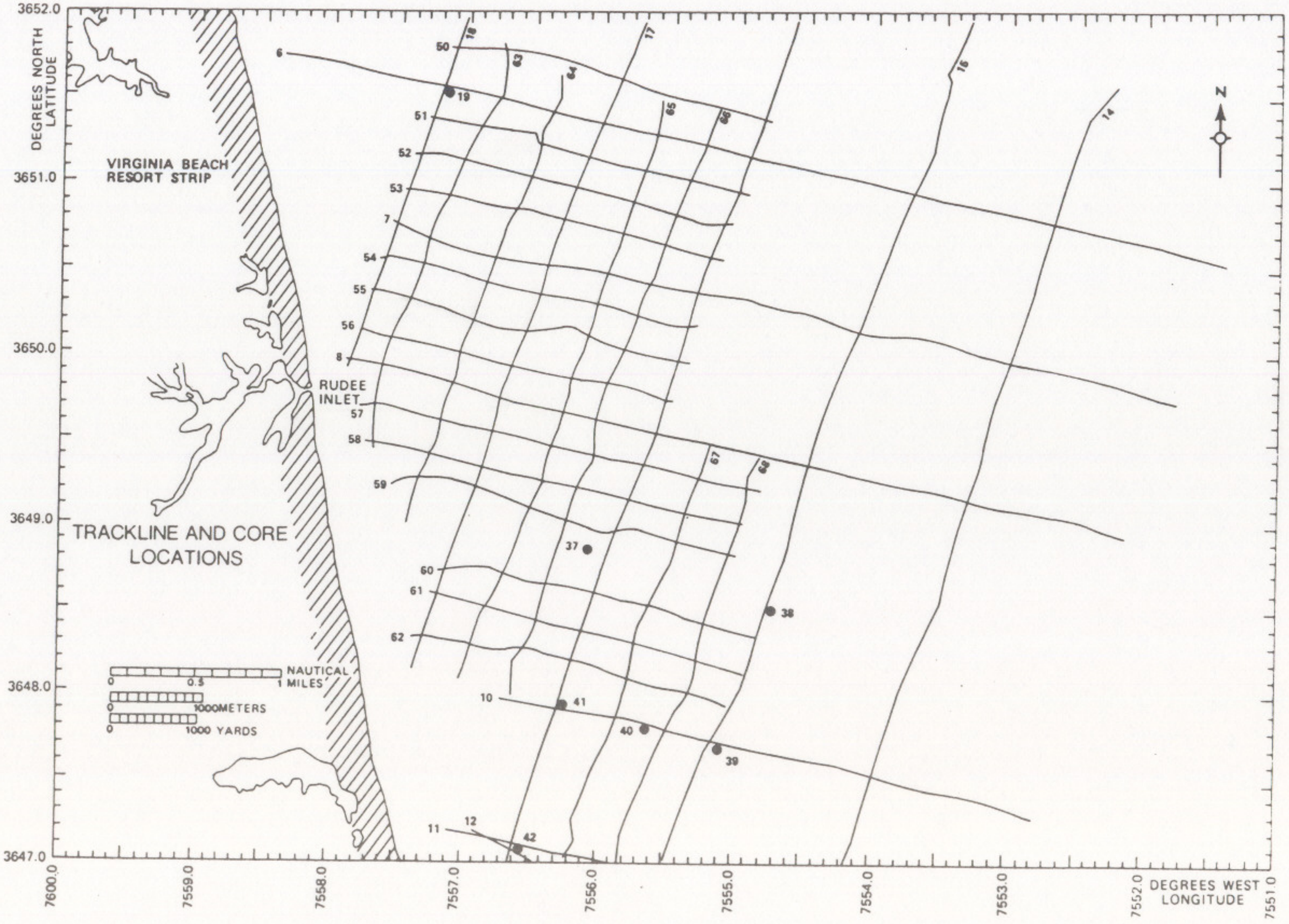


Figure 6. Locations of survey track lines and vibracores (solid circles) in the vicinity of Rudee Inlet. Track line and core numbers are referenced in the text and appendices. Track Line #20 corresponds to Transect A–A' (Figure 2) and Track Line #10 corresponds to Transect B–B' (Figure 7).

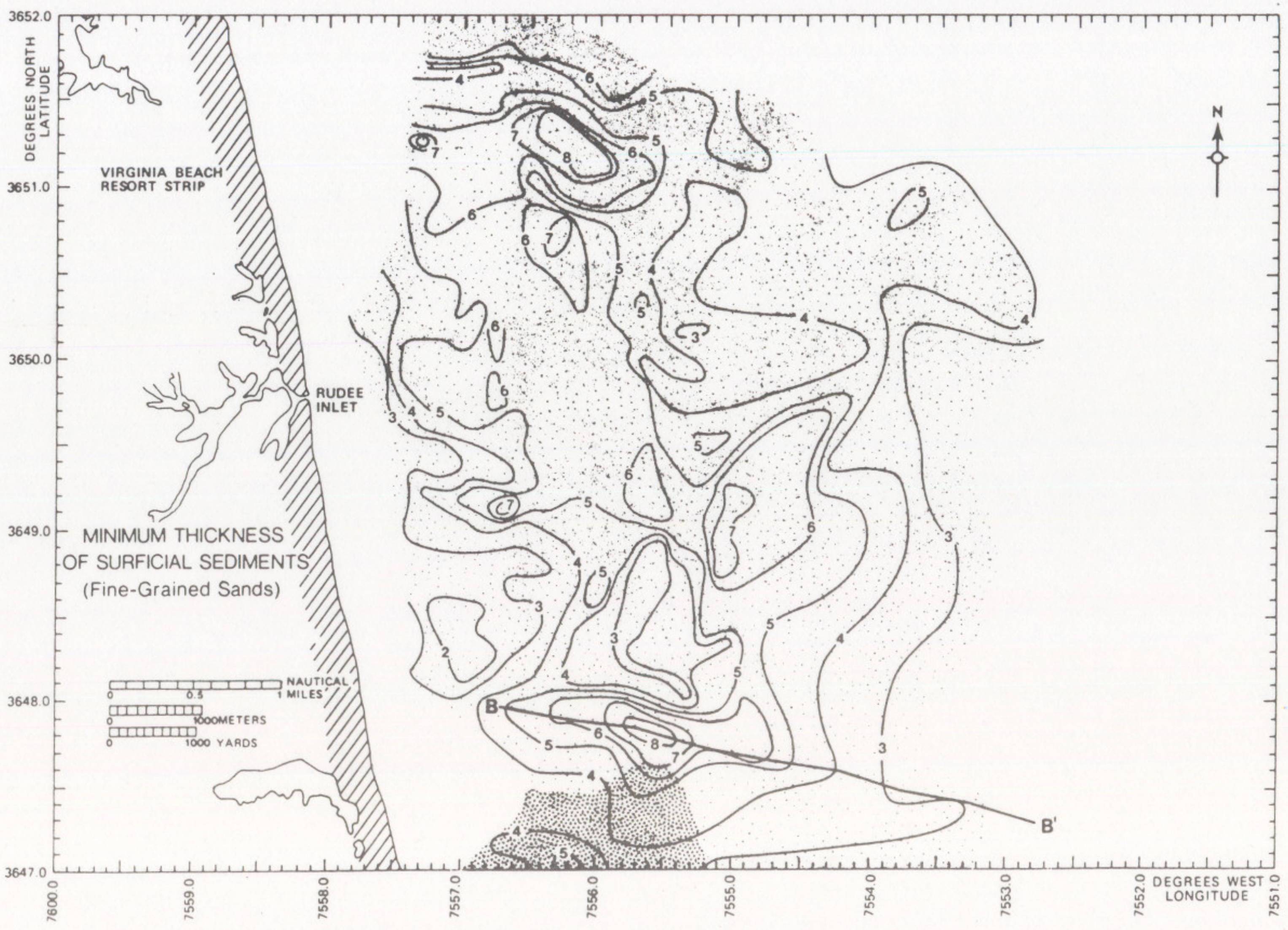


Figure 7. Isopach map showing the distribution and minimum thickness of the surface layer of very fine gray sand in the vicinity of Rudee Inlet. The contour interval is one meter.

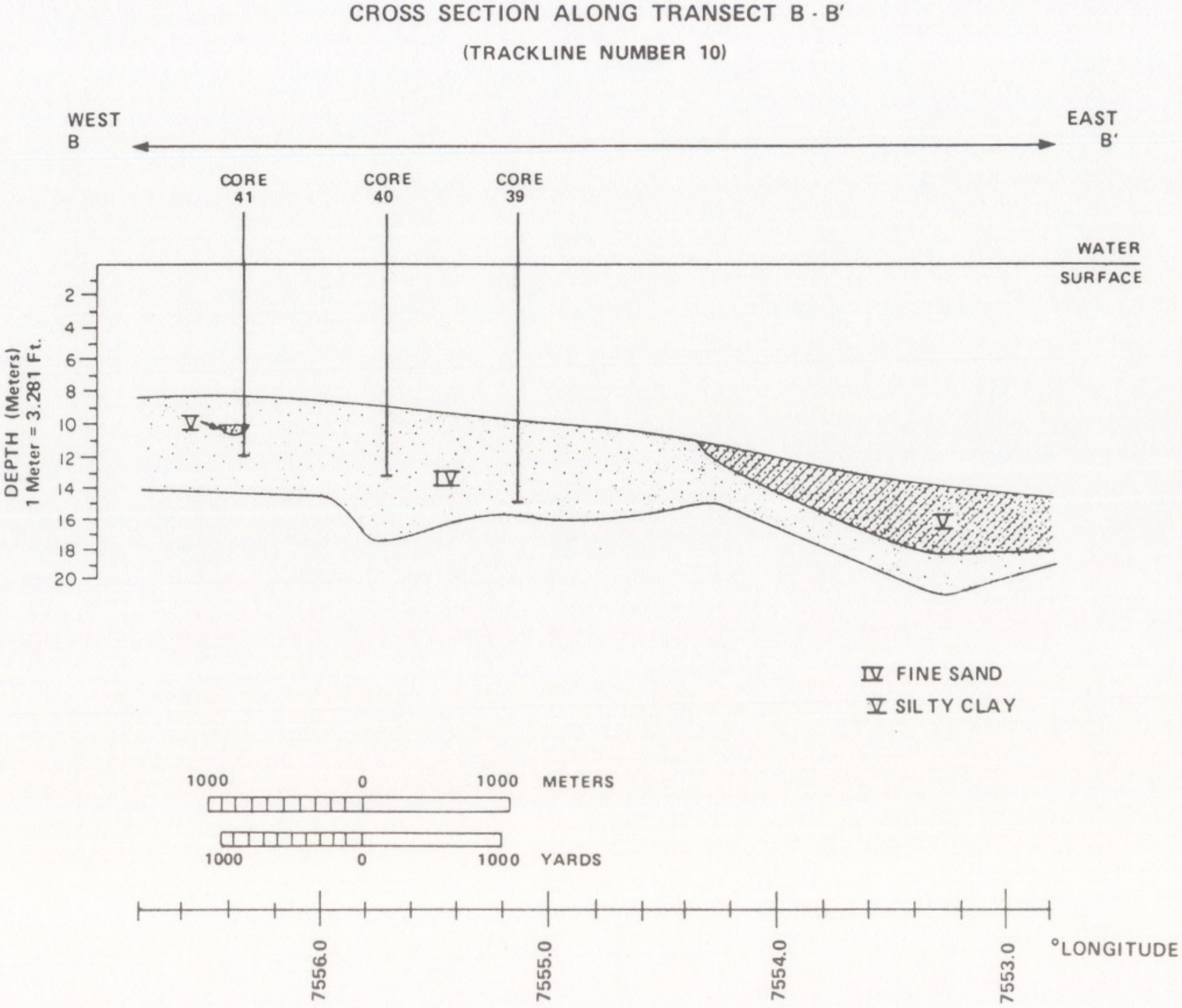


Figure 8. Cross-section along Transect B-B' (Track Line #10) showing the vertical and lateral distributions of very fine sand and sandy clay in the vicinity of Rudee Inlet.

surface. Incised channels are evident on this surface. Above the contact are massive fine sands (Unit IV), representing recent deposition. Moving eastward, surficial sediments become finer, grading to a silty clay (Unit V) approximately five kilometers (three miles) offshore. Although there are lenses of gravel and coarse shell hash locally throughout the region, there is no indication of large-scale, sand-filled channel features.

Sandbridge Deposits.

Initial geophysical surveys showed the presence of a large, amorphous shoal located approximately five kilometers (three miles) offshore of Sandbridge Beach. Although a shoal feature does appear in this location on nautical charts, neither its extent nor its composition has been documented in the literature. Because of its topography as seen on the seismic records, which resembled remnant beach ridge or barrier morphologies, it was anticipated that the shoal may be largely composed of shallow marine sands. A high-density geophysical sampling program was initiated (Figure 5). The sedimentary characteristics of the shoal are defined by cores #48 and 49. Cores #45, #46, and #47 show the presence of other discrete sand bodies at depth, whereas core #50 effectively limits the extent of sand reserves. Table 2 lists summary sediment characteristics for each of these cores. Detailed mineralogical information is contained in Berquist et al. (1990).

Figure 9 shows a cross-section along Transect A-A', which corresponds to seismic track line 20 (Figure 5). Topographically, the shoal's western and southern

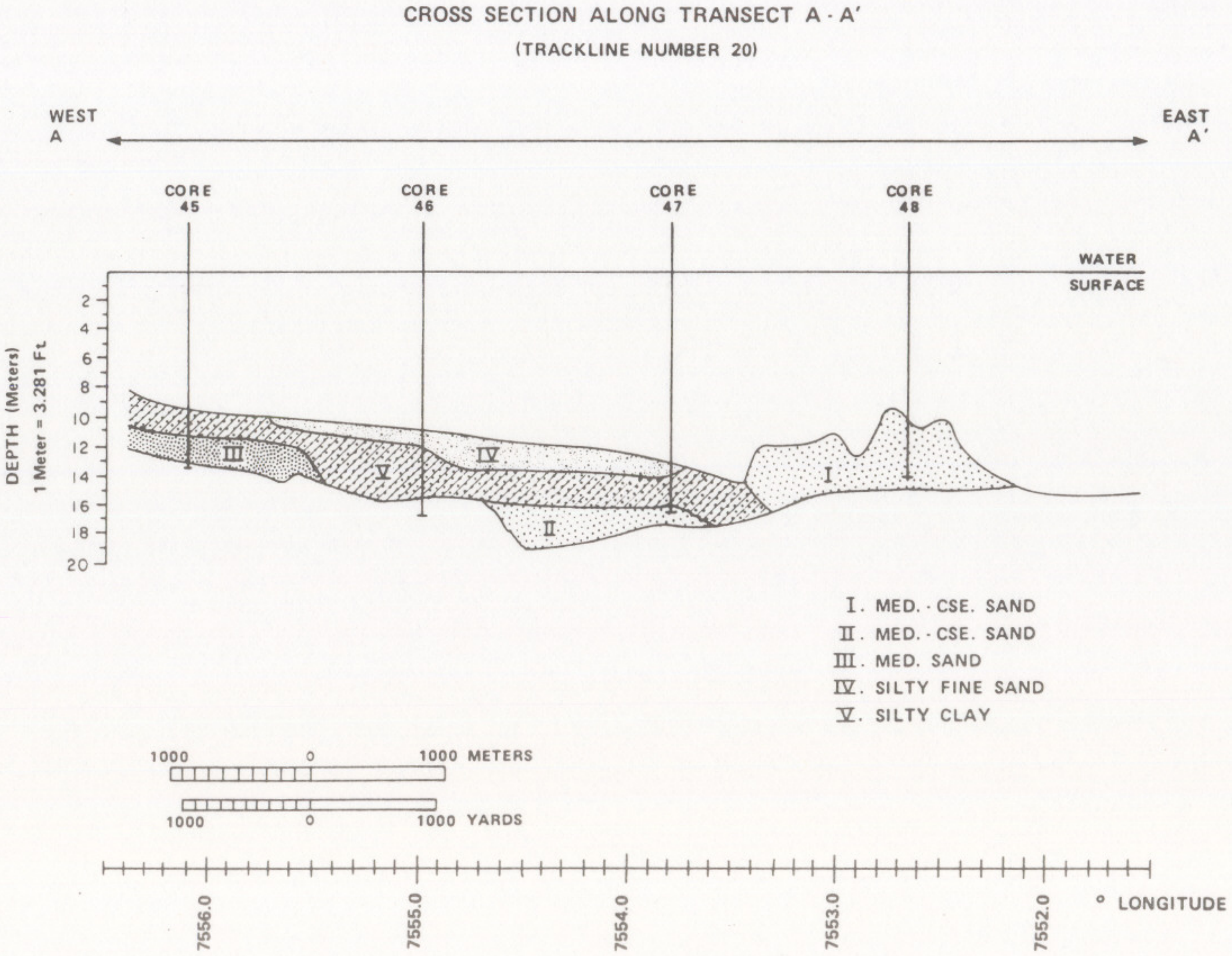


Figure 9. Cross-section along Transect A-A' (Track Line #20), showing the vertical and lateral distributions of an isolated shoal and attendant sand bodies in the vicinity of Sandbridge.

flanks rise from a swale to a terrace located two to three meters (six to ten feet) above the surrounding shelf surface. Several terrace levels are evident on the southern perimeter (Lines 25 and 79, Appendix A), while the eastern and northern flanks slope gently offshore. The mid-section contains the highest relief (>3.0 meters; 9.84 feet), which is characterized by a series of ridges and troughs oriented N35°E. Planimetric dimensions of the shoal are approximately 2.75 kilometers by 4.5 kilometers (1.7 miles by 2.8 miles) within the study area. However, the shoal continues in a northeasterly direction for an unknown distance beyond the limits imposed for this study.

The shoal is composed of clean medium to coarse sand (0.3 mm; 1.5 phi mean grain size) separated from the underlying material by a pervasive, sharp horizontal reflector. Analyses of cores #48 and #49 (Appendix A) show an overall coarsening upwards trend. Stratification within the shoal generally follows the surficial topography, becoming more horizontal towards the basal reflector.

With the exception of the extreme northeast section, the underlying material is silty to sandy clay. The silty clay found in cores #49 and #50 is correlative to the sandy clay found in cores #45, #46, and #47. The clay horizon also outcrops and borders the western and southern margins of the shoal. The extent of the underlying clay beds (defined as Unit V) and their relationship to the sand shoal (Unit I) is depicted in Figure 9, which shows a very sharp contact zone between the two deposits. Figure 10 illustrates the thickness and areal distribution of the clay. Where the clay outcrops at the surface, a heavy layer of suspended flocculates extends

TABLE 1

Sediment Characteristics -- Rudee Inlet

Sample Number	% Sand	% Gravel	% Fines	Sand Mean (phi)
19-1.1	91.5	0.0	8.5	3.02
19-1.2	72.3	8.6	19.1	2.66
19-1.3	59.1	35.3	5.6	0.73
19-2.1	90.4	0.1	9.5	3.05
19-2.2	94.9	0.3	4.8	1.81
19-3.1	95.8	0.5	3.7	1.89
19-3.2	92.2	0.1	7.7	2.41
37-1.1	88.6	0.4	11.0	3.05
37-1.2	91.4	0.2	8.4	2.55
37-1.3	88.3	0.6	11.1	1.90
37-1.4	82.8	0.1	17.1	2.29
37-1.5	84.6	0.1	15.3	2.42
38-1.1	86.1	0.0	13.9	3.17
38-1.2	71.6	24.8	3.6	0.72
38-1.3	80.3	0.6	19.1	1.74
38-1.4	90.4	1.0	8.6	1.14
38-1.5	88.8	0.3	10.9	2.12
38-1.6	73.3	1.0	25.7	2.68
38-1.8	57.2	26.8	16.0	0.99
39-1.1	91.7	0.1	8.2	3.09
39-1.2	92.6	4.1	3.3	1.63
39-1.3	88.6	2.0	9.4	2.58
39-1.4	88.3	1.9	9.8	2.51
40-1.1	91.5	0.1	8.4	3.14
40-1.2	84.0	0.8	15.2	2.82
40-1.3	89.0	0.1	10.9	2.67
41-1.1	90.9	0.6	8.5	3.07
41-1.2	80.7	1.6	17.7	2.94
41-1.3	70.7	27.2	2.1	0.61
41-1.4	96.6	0.0	3.4	2.07
42-1.1	88.2	1.8	10.0	2.96
42-1.2	64.0	26.9	9.1	0.96
42-1.3	87.7	3.7	8.6	2.22
42-1.4	34.7	0.3	65.0	2.56
42-1.5	63.8	22.3	13.9	1.81
42-1.6	90.0	0.0	10.0	2.33

TABLE 2
Sediment Characteristics -- Sandbridge

Sample Number	% Sand	% Gravel	% Fines	Sand Mean (phi)
45-1.1	85.3	1.4	13.3	2.31
45-1.4	84.7	7.4	7.9	2.00
45-1.5	76.1	17.8	6.1	1.11
45-1.6	97.1	0.0	2.9	2.44
45-1.7	94.1	0.6	5.3	2.48
45-1.8	68.1	26.1	5.8	0.99
45-1.9	94.5	0.0	5.5	2.05
46-1.1	80.7	1.5	17.8	3.02
46-1.2	73.1	6.3	20.6	1.93
46-1.4	80.2	0.4	19.4	1.85
46-1.5	76.6	2.1	21.3	1.87
46-1.7	47.1	0.4	52.5	2.01
46-1.9	84.2	0.2	15.6	2.11
46-1.10	78.7	1.3	20.0	1.36
46-1.11	95.6	0.1	4.3	2.18
47-1.1	85.2	1.0	13.8	3.16
47-1.4	59.7	14.9	25.4	0.72
47-1.5	96.6	1.5	1.9	1.36
48-1.1	97.4	1.3	1.3	1.48
48-1.2	97.4	0.4	2.2	1.59
48-2.1	97.8	0.3	1.9	1.64
48-2.2	96.1	1.4	2.5	1.48
48-3.1	95.3	2.5	2.2	1.71
48-3.2	95.7	1.0	3.3	2.13
49-1.1	98.8	0.0	1.2	1.46
49-1.2	92.3	3.2	4.5	1.57
49-1.3	95.1	0.2	4.7	1.94
49-1.6	87.3	0.1	12.6	2.72
42-1.7	92.1	0.1	7.8	2.08

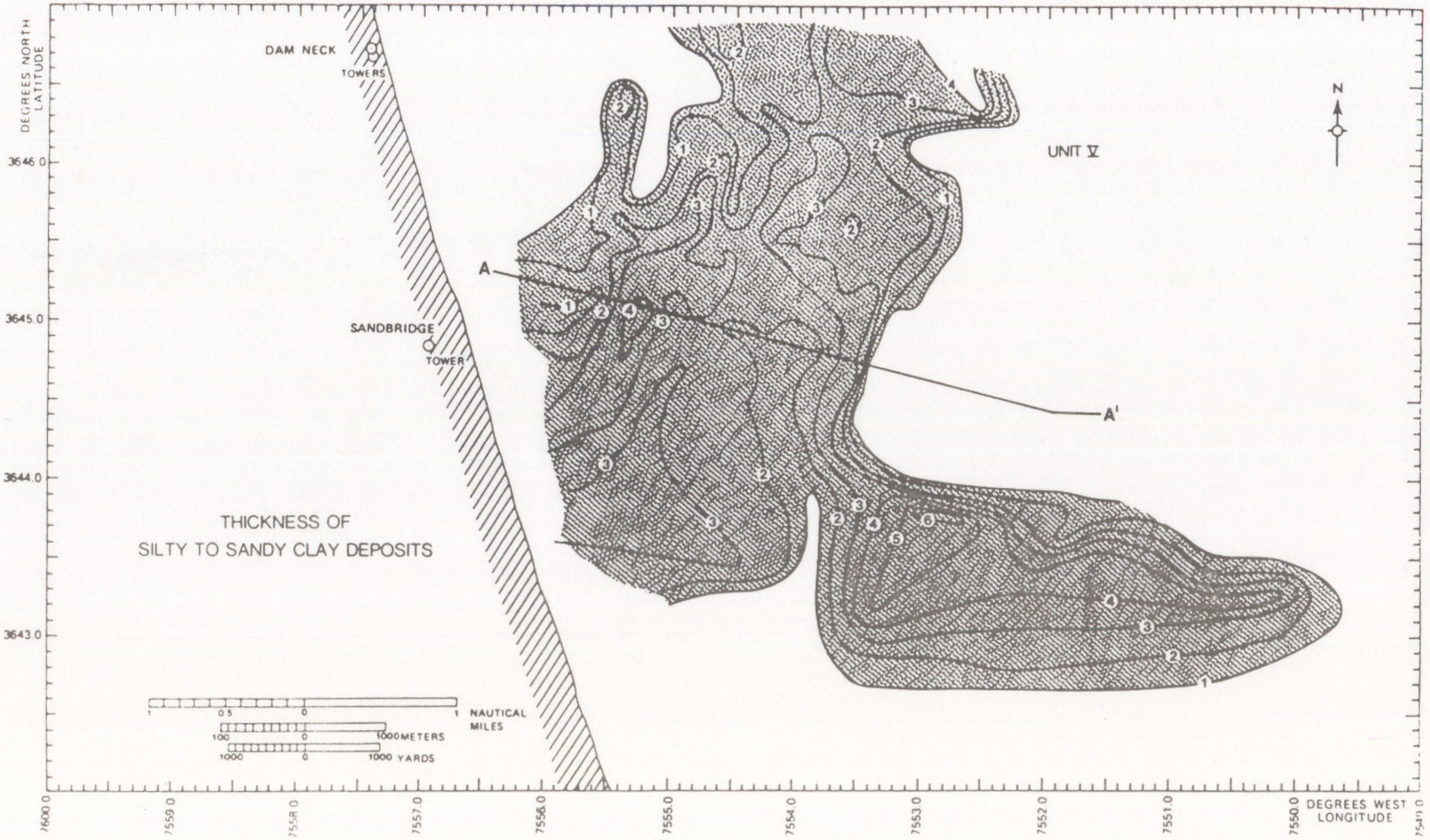


Figure 10. Isopach map showing the distribution and inferred thickness of clay units in the vicinity of Sandbridge. The contour interval is one meter.

approximately one meter (3.3 feet) above the sea floor. In the northeast, the presence of steeply dipping beds beneath the shoal prevent a clear definition of the underlying material.

West of the shoal and covered by approximately three to five meters (10-16 feet) of overburden is a layer of medium to coarse sand (Unit II, Figure 9). The overburden is composed of fine sand with similar characteristics to the Rudee Inlet deposits discussed above, overlying silty clay (Unit V, above). Total thickness and distribution of the overburden is depicted in Figure 11. Unit II has sedimentary characteristics, including composition and grain size distribution, similar to Unit I. Thickness varies between 1.5 meters (4.9 feet) and 3.5 meters (11.5 feet). The similarity between Units I and II strongly suggests a single feature that has been subsequently bisected.

A third sand body, Unit III (Figure 9), lies on the Sandbridge shoreface under two meters (6.5 feet) of silty clay (Unit V). This unit is composed of medium sand with a mean grain size of 0.19 mm (2.4 phi).

V. RESULTS - AMPLIFICATION OF VIRGINIA BEACH STUDY

The Virginia Beach Sand and Gravel Resource Study (Kimball and Dame, 1989) demonstrated the existence of a large, isolated sand shoal containing minable reserves of sand and, possibly, of aggregate materials. However, additional work was required to characterize the age, stratigraphy and origins of the Sandbridge Shoal in

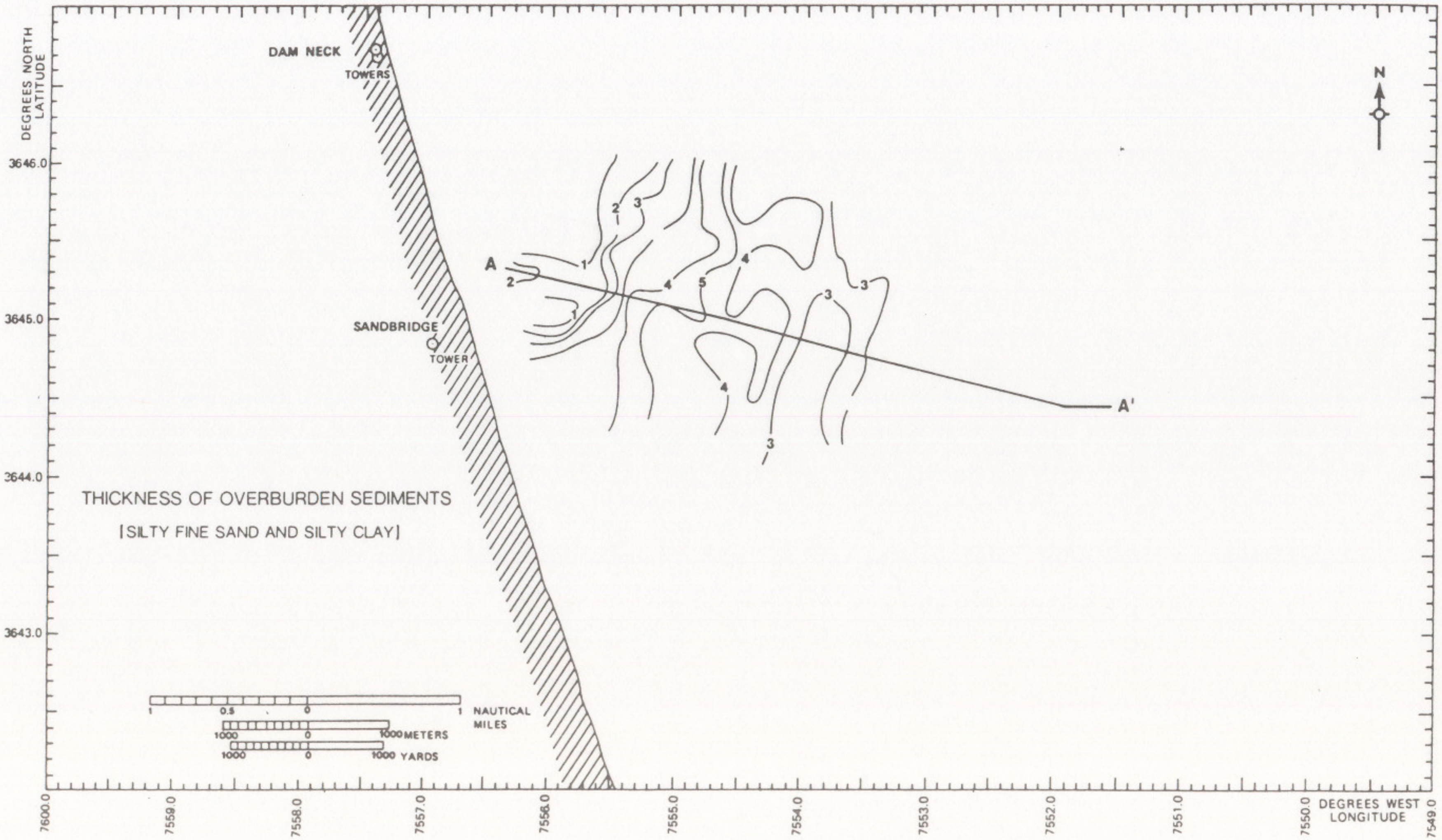


Figure 11. Isopach map showing the distribution and thickness of the overburden associated with beach quality sand deposits in the vicinity of Sandbridge. Total overburden includes both clay and very fine sand beds. The contour interval is one meter.

order to understand its position on the shelf and relate other isolated shoal features to Pleistocene/Holocene marine events. Further research was undertaken under this scope of work in 1989 and 1990 to address these issues.

An additional 235 km (126 mi) of trackline were surveyed using the subbottom acoustic profile system to better delineate the eastern margins of the shoal and provide more detailed stratigraphic information (Figure 5). In addition, three cores acquired by the Norfolk District of the U.S. Army Corps of Engineers and 18 grab samples were used to augment the sedimentological data acquired in the original study. Interpretations and analyses of these data are presented below and are contained in a thesis presented to the Graduate School of Marine Science, College of William and Mary by one of the authors (Dame, 1990).

Morphological and Sedimentological Characteristics of Sandbridge Shoal.

Remapping of the Sandbridge Shoal with newly acquired subbottom and grab sample data demonstrates that the surface area of the shoal is approximately 48 km^2, and is horseshoe shaped in plan view (Figures 12 and 13). In cross-section, the shoal is a wedge of sand that thins to the north and east. The western limb of the shoal is characterized by a series of ridges and troughs oriented N35°E. Relief along these ridges is as much as four meters (13 ft) above the adjacent seabed. The southern and western margins grade into a terrace with two to three meters (six to ten feet) relief above a shallow depression in the shelf surface (Plates 1B and 2B). The terrace becomes progressively less well developed to the north. The eastern limb of the

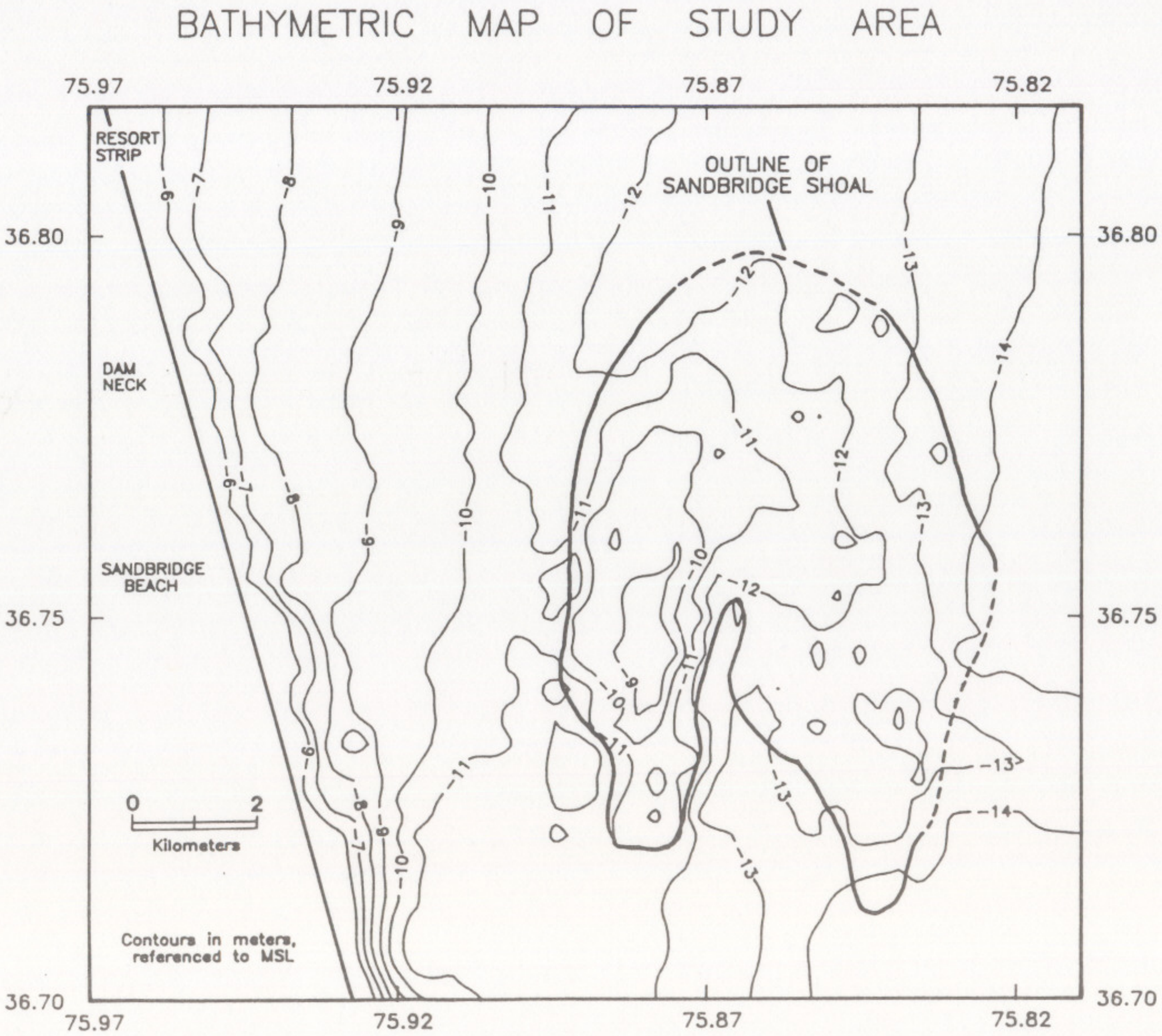


Figure 12. Detailed bathymetry of study area showing outline of Sandbridge Shoal.

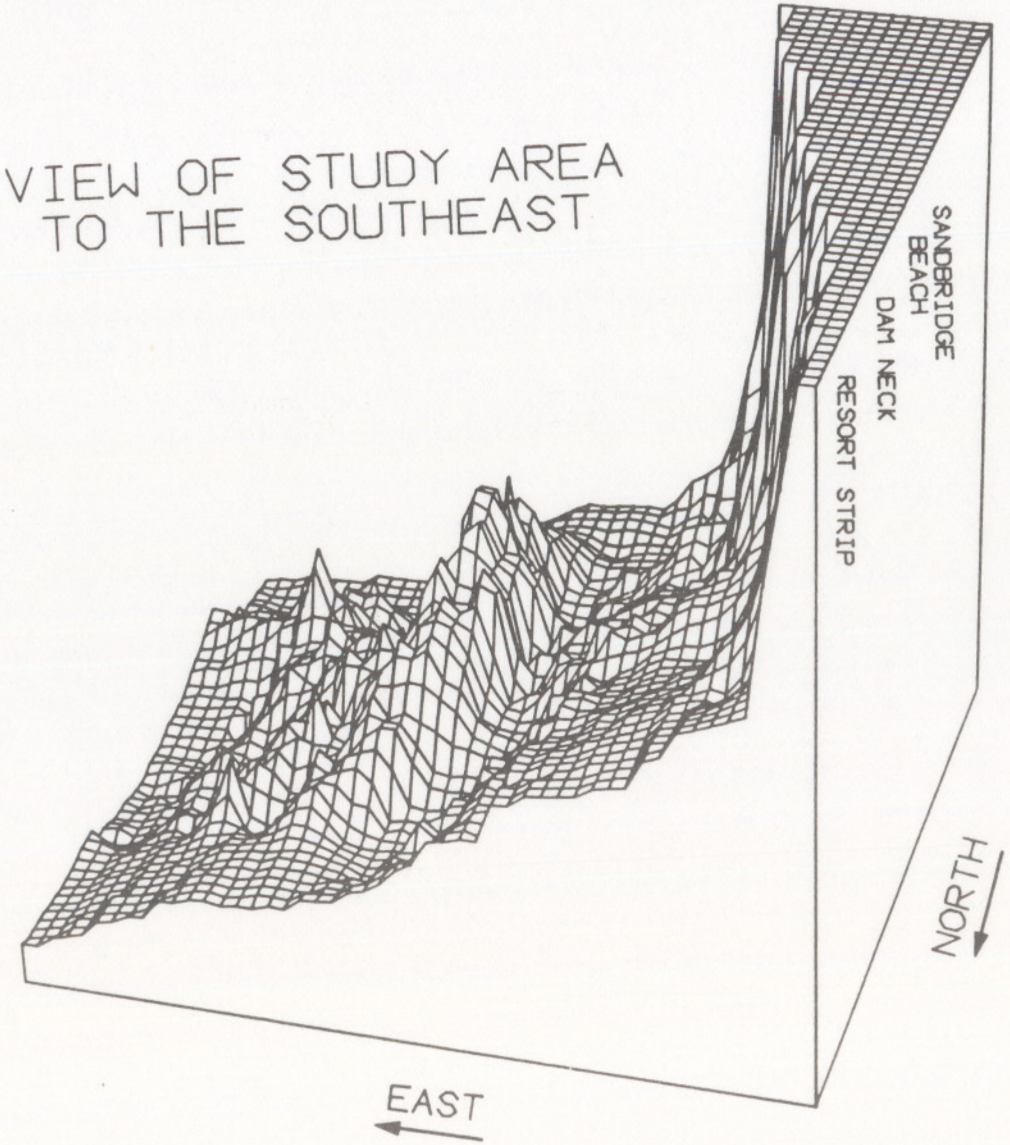


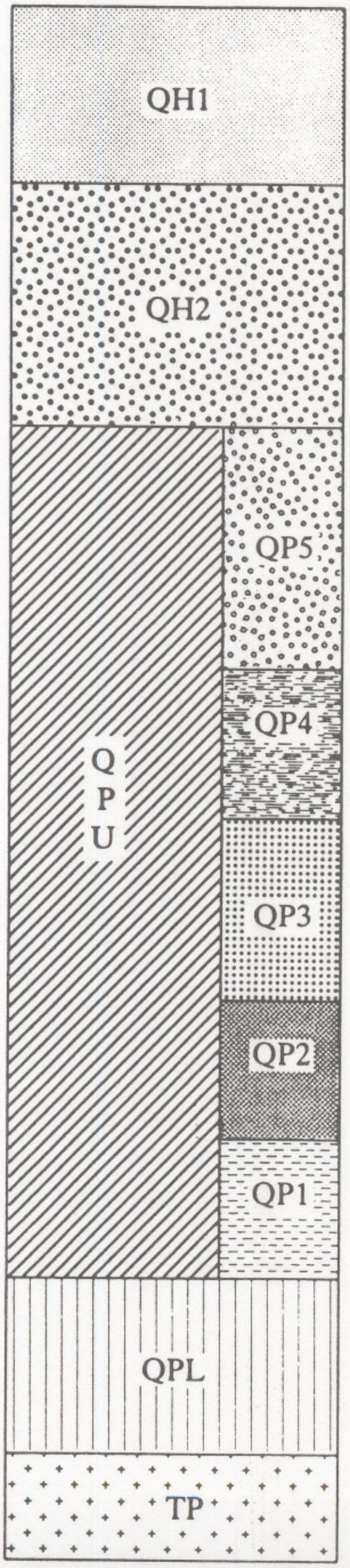
Figure 13. Three dimensional view of shelf surface in the study area. View is towards the southeast.

horseshoe is characterized by low, undulating topography one to three meters (three to ten feet) in elevation (Plate 1B). The two limbs are separated by a narrow swale, identified by inward-dipping strata on both limbs.

Table 3 presents a generalized stratigraphic column derived from a composite of sediment core data. Unit names are assigned on the basis of stratigraphic relationships and geochronology data. Stratigraphically, the shoal can be divided into two units. The upper unit, QH2, is composed of clean, well-sorted medium to coarse sand. The sand typically is olive gray in color and becomes darker with depth. It has a mean grain size of 0.35 mm (1.5 phi) and generally contains less than 3% fines (Appendix B). The sediments fine with depth; coarse layers distributed throughout the cores are indicative of storm deposits. The unit averages 2.5 to three meters (7.5-10 ft) in thickness but increases to six meters (20 ft) thick in some areas. Grab sample data show that the surface sediments of the shoal coarsen toward the north and east. Gravel percentages are highest in the northeast section of the shoal (Figure 14). Several subbottom reflectors and the character of the surficial features are suggestive of active southwesterly sediment transport.

The lower unit, QP5, is present through the western half of the shoal, thinning beneath the upper unit before outcropping at the surface. QP5 is characterized by medium to fine sand (0.28 mm; 1.8 phi). The unit fines downward, grading into silty fine sand (Appendices B and C). There is some evidence of poorly developed crossbedding. QP5 generally is thinner than QH2, varying between one and two

TABLE 3: GENERALIZED STRATIGRAPHIC SECTION OF THE STUDY AREA



QH1 - Holocene sand sheet. Dark gray fine to very fine micaceous sand. Some coarser layers indicating storm sequences. Characterized by s-1 in core 47. Also appears in core 46.

QH2 - Upper unit of Sandbridge Shoal. Olive gray, clean, well sorted, medium to coarse sand. In general coarsens upward. Found in upper portions of cores 7, 9, 48, & 49. Separated from lower unit by by weak reflector, R4, which is seen as a thin silt layer in cores 48 & 49, and gravelly shell layer in core 7.

QPU - Upper Pleistocene valley-fill sequence.

QP5 - Lower unit of Sandbridge Shoal. Slightly darker and finer than QH2. Exhibits some crossbedding in core 7. Bottom boundary is strong reflector, R3, which is documented in cores 7 and 48 as a shell layer.

QP4 - Clay and silt interpreted as estuarine. Found in cores 6, 7, 46, 47, and 50.

QP3 - Gray, clean, well sorted, medium to coarse sand. Silty layers and gravelly towards upper contact. Found in s-4 & s-5 of core 47. N-S seismic lines suggest it is a tidal channel.

QP2 - Dark gray fine sand. Found in bottom of core 48. Interpreted as bay-mouth or tidal shoal due to its relationship with QP3.

Qp1 - Clay and silty clay. Interpreted as estuarine from seismic line 25/87. Found in core 49.

QPL - Lower Pleistocene valley-fill sequence. Separated from QPU by strong reflector, R2. Cutting relationships of QPU & QPL seen in seismic lines 7/88 & 8/88.

TP - Interpreted as Pliocene. Defined by deep channel boundaries. Separated from upper units by intermittent reflector, R1. See seismic line 12/88.

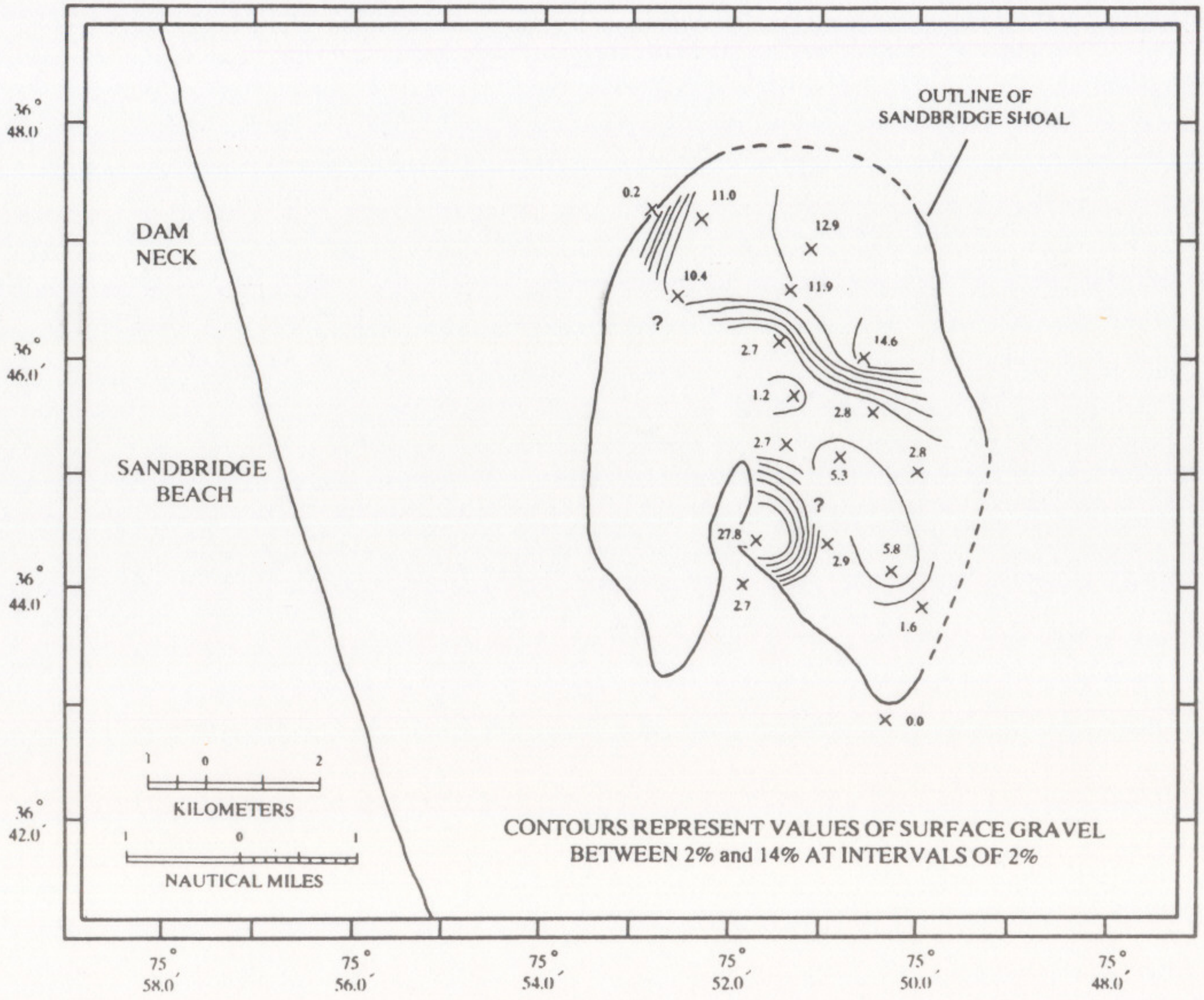


Figure 14. Contour map of percent gravel found in surface grab samples.

meters (three to six feet) in thickness. A conservative estimate of the combined volume of both units is 8 x 10^7 m^3.

The two primary units are separated by a relatively weak and intermittent reflector, labelled R4 on Plates 1-5. R4 is indicative of a five centimeter thick layer of sandy silt and clayey silt at a depth of -13 m MSL over much of the area, with local deposits of gravelly, shelly sand at -14.4 m MSL. It is possible that the local absence of silt is an erosion phenomenon. The R4 reflector generally slopes downward to the east and north (Plates 1B-5B).

Throughout most of the area, the two units comprising Sandbridge Shoal have a sharp, continuous, horizontal contact with the underlying material (R3 on Plates 1-5). This reflector is represented in the cores by a 10-25 cm layer of shell fragments and shell hash.

In the southwest quadrant, three separate units underlie the R3 reflector. QP3 underlies a small portion of the shoal's western boundary (Plate 1B) and is characterized by 1.5 m of gray, medium to coarse sand with higher concentrations of silt and gravel towards the upper surface. Channel-shaped reflectors in north-south trending seismic lines (Plate 3B) and the sedimentology suggest this unit represents a relict tidal channel. East of, and adjacent to, QP3 lies another sand body, QP2, which is interpreted as a relict bay-mouth or tidal shoal (Plate 1B). QP2 consists of fine to medium dark gray sand with a mean grain size of 0.23 mm (2.1 phi).

Beneath QP2 is a layer of dark gray silty clay (QP1) with an average thickness of 1.5 to two meters. The clay contains pods and stringers of sand. Reflectors on seismic lines 25/87 (Appendix A) and 11/88 (Plate 3B) are indicative of a period of channel infilling, most probably an estuarine clay.

QP1 thins to the north and the underlying material cannot be correlated to known core sediments because of the steep apparent dip of the beds to the southwest. Seismic records reveal the shoal partially overlies a large paleochannel system (Plates 1B-5B). The steeply dipping beds are most likely representative of channel migration (Plate 3B; line 25/87 in Appendix A). The relict fluvial system consists of two major southeast trending channels (Figure 15). Cross-cutting relationships of these channels (Plate 3B) indicate that the southernmost channel is younger. Sediments associated with channel filling in the younger paleochannel are labelled QPU and those of the older channel are labelled QPL; the two units are separated by a strong reflector labelled R2 (Plates 3B and 5B). Beneath the southeast quadrant of the shoal, a broad interfluve separates the two paleochannels.

The thalweg depths of both these paleochannels are below the limit of acoustic penetration. However, based on the angle of dipping strata and the geometry of the tracklines, it is estimated that thalweg depths are approximately -40 m MSL. Inferred channel widths are two kilometers for the older channel and 4.5 km for the younger. The deepest channel boundaries are believed to be Tertiary in age and are labelled TP (Plates 1B - 5B). Sediments of QPL outcrop at the surface (Plate 4B). QPU sediments outcrop at two locations in the study area. One location is in a swale abutting the western boundary of the shoal and the second is in the depression between the two limbs of the shoal (Plates 1B and 3B). A cross-section taken along

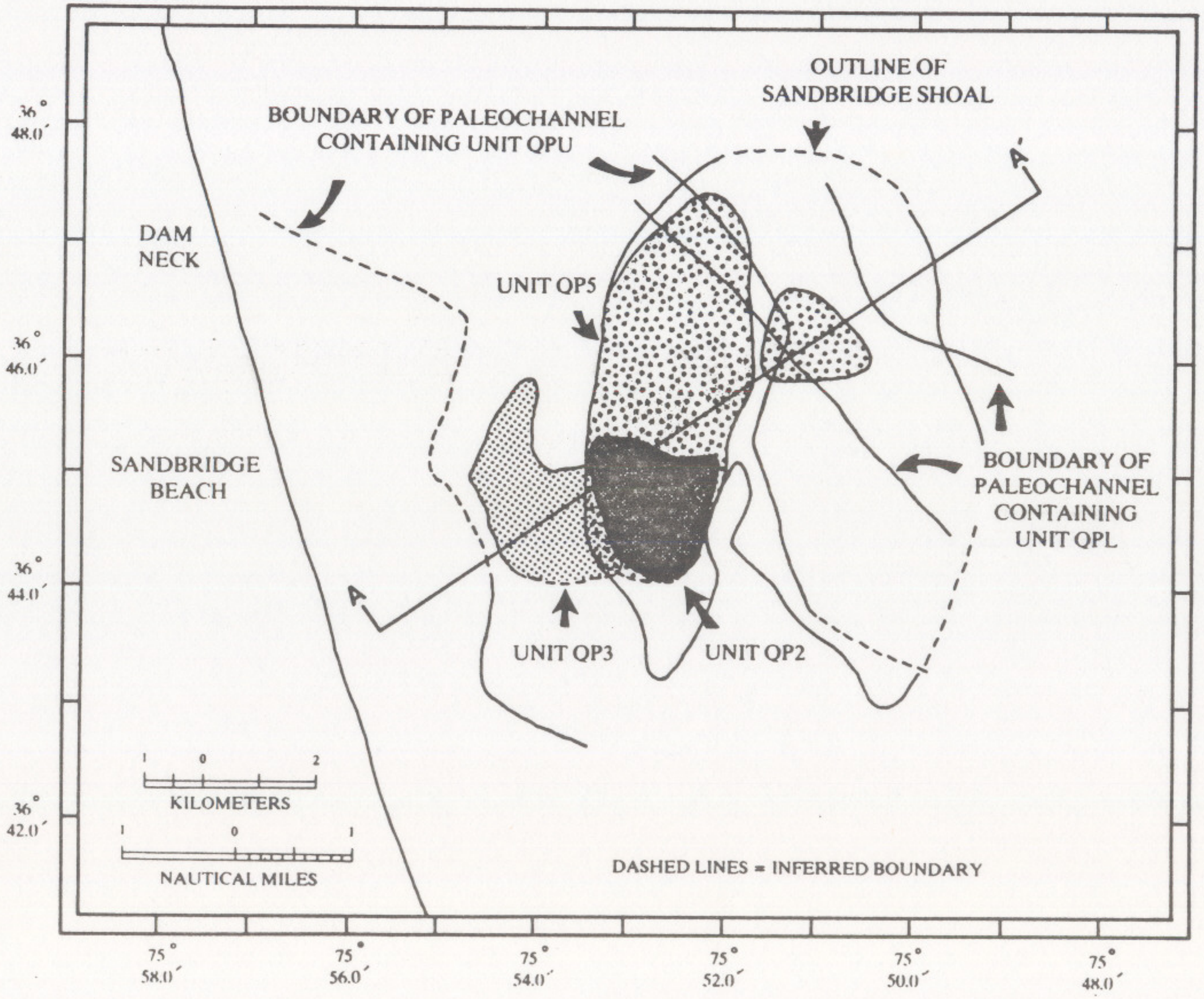


Figure 15. Areal relationships of major stratigraphic units. Note that not all stratigraphic units are portrayed here. See Figure 16 and Table 3.

line A-A' (Figure 15) is shown in Figure 16 and demonstrates the relationships among the various units.

Geochronology.

Summary results from the amino acid racemization analysis are depicted in Table 4. Detailed sample data are presented in Dame (1990). All samples except #6 and #11 are estimated to be between early and late isotopic Stage 5. Sample 6 is estimated to be >1.2 x 10^6 yrs and Sample 11 is considered to be modern, <2 ka.

Portions of the same shells used in the amino acid dating of Samples 2 and 12 were also subjected to radiocarbon analysis. Each sample is at the limits of the range for ^{14}C dates: Sample 2 is >42,700 yrs and Sample 12 is >38,500 yrs. The consistency of the data is such that all samples with the exception of #11, which is Holocene in age, may be considered either upper Pleistocene (QPU) or lower Pleistocene (QPL). The amino acid analysis points to an Isotopic Stage 5 (75,000-130,000 ybp).

Most sample shells were single valves with a lustrous appearance and shell fragments were angular. None of the shells showed significant signs of abrasion or other indications of reworking. Consequently, most sample shells are considered to be representative of the sedimentary units in which they were found. Two samples are exceptions: Sample 6 is believed to be reworked because the age estimate is much greater than other samples within the same horizon. Sample 8 is dated as Pleistocene, but is placed in a Holocene stratigraphic unit (Table 4) because the

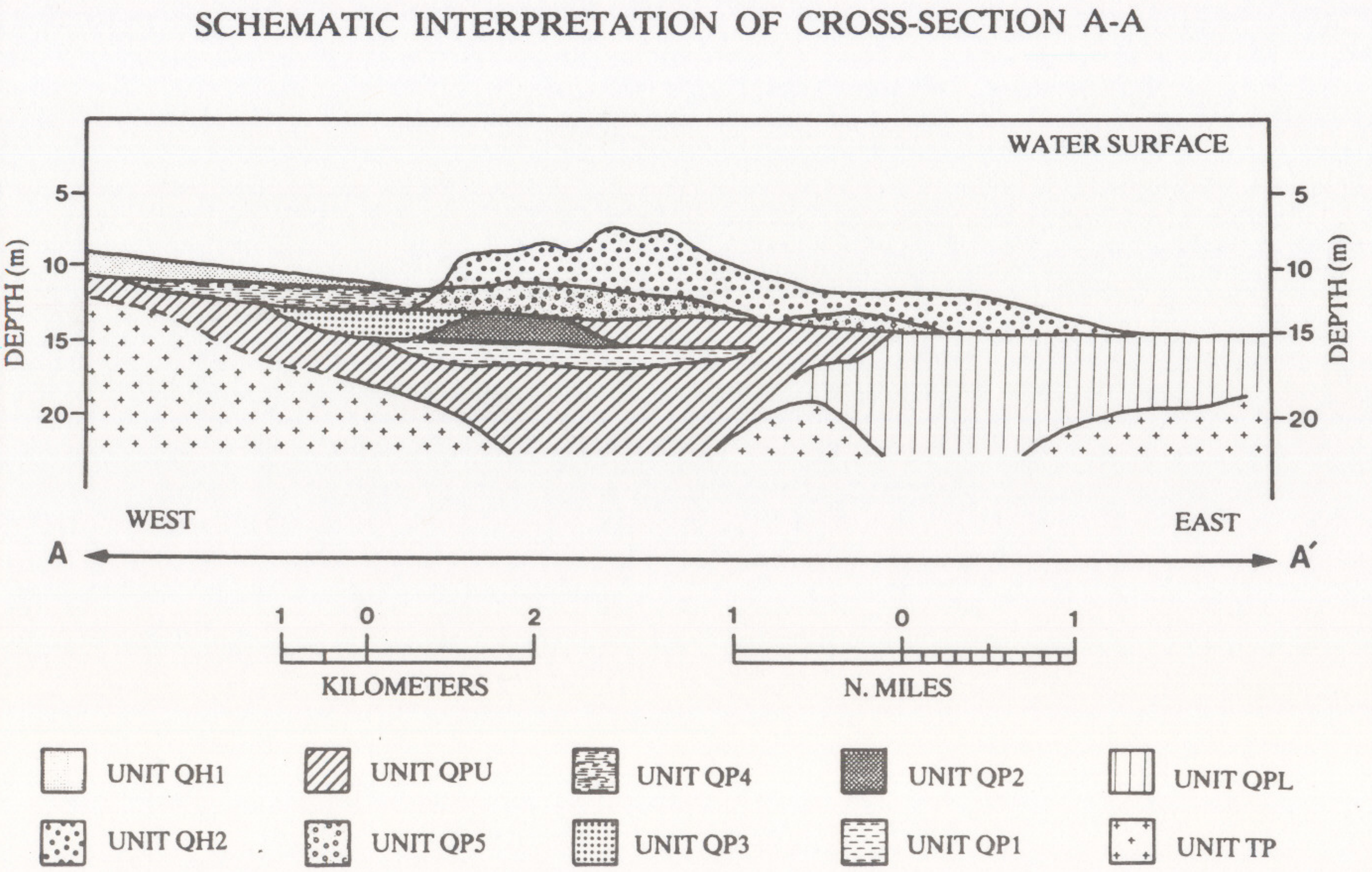


Figure 16. Schematic interpretation of a cross-section along segment A-A′ on Figure 15. See Table 3 for description of stratigraphic units.

TABLE 4
KINETIC MODEL AGE ASSIGNMENTS

SAMPLE	LOCATION	STRATIGRAPHIC UNIT	KINETIC MODEL AGE	ISOTOPIC STAGE
11	Core 09 -1.9 m	QH2 - Upper unit of Sandbridge Shoal	< 2 ka	Stage 1 (modern)
4	Core 48 -5.0 m	QP5 - Lower unit of Sandbridge Shoal	60 - 80 ka	
5	Core 49 -4.2 m	QP1 - estuarine clay and silt	60 - 80 ka	EQT 6.5 C
8	Core 07 -1.6 m	QH2 - Upper unit of Sandbridge Shoal	60 - 80 ka	
9	Core 07 -1.9 m	QP5 - Lower unit of Sandbridge Shoal	60 - 80 ka	middle to late Stage 5
1	Core 46 -4.7 m	QP4 - estuarine clay and silt	64 ka +13 -11	
3	Core 47 -2.8 m	QP3 tidal channel	70 ka +14 -11	
2	Core 47 -1.6 m	QP4 - estuarine clay and silt	81 ka +16 -11	EQT 8.5 C
10	Core 07 -3.6 m	QP4 - estuarine clay and silt	88 ka +17 -14	
12	Core 09 -2.1 m	QPU - Upper Pleistocene undivided	91 ka +18 -15	early Stage 5
7	Core 06 -2.9 m	QPU - Upper Pleistocene undivided	112 ka +22 -18	EQT 10 C
6	Core 50 -5.3 m	QPU - Upper Pleistocene undivided	> 1.2 ma	

sample was located slightly above reflector R4 which separates the Holocene QH2 from the Pleistocene QP5. Sample 8 may represent mixing or reworking of older material at the base of unit QH2.

With the exception of Sample 11 (<2,000 ybp), all samples in this study represent aminozones IIa-IIb and possibly IIc and IIe (Sample 6) as defined by Wehmiller et al. (1988). Wehmiller et al. (1988) documented the occurrence of aminozone IIa and IIc in several outcrops of the Sedgefield member of the Tabb formation in reference sections of the New Light and Gomez pits (southeastern Virginia). Peebles (1984) defined the Sedgefield member as valley-fill deposits resulting from a late Pleistocene marine transgression, which is consistent with the character of QPU defined in this study. Sample 6 is probably reworked material from the older Yorktown or Chowan Formation.

VI. RESULTS - STUDY OF ISOLATED OFFSHORE SHOAL

During June, 1991, we operated a side-scan sonar system and a sub-bottom profiling system aboard the VIMS R/V Bay Eagle. Data were collected along sixteen lines totalling approximately 235 km (126.4 n mi) (Figures 4 and 17). The lines were run in grid oriented roughly ESE-WNW by NNE-SSW across the series of shoals southeast of Chesapeake Light. Three lines (numbers 6, 7, 12) extend further to the west connecting with survey lines from earlier projects described in this report. Line 6

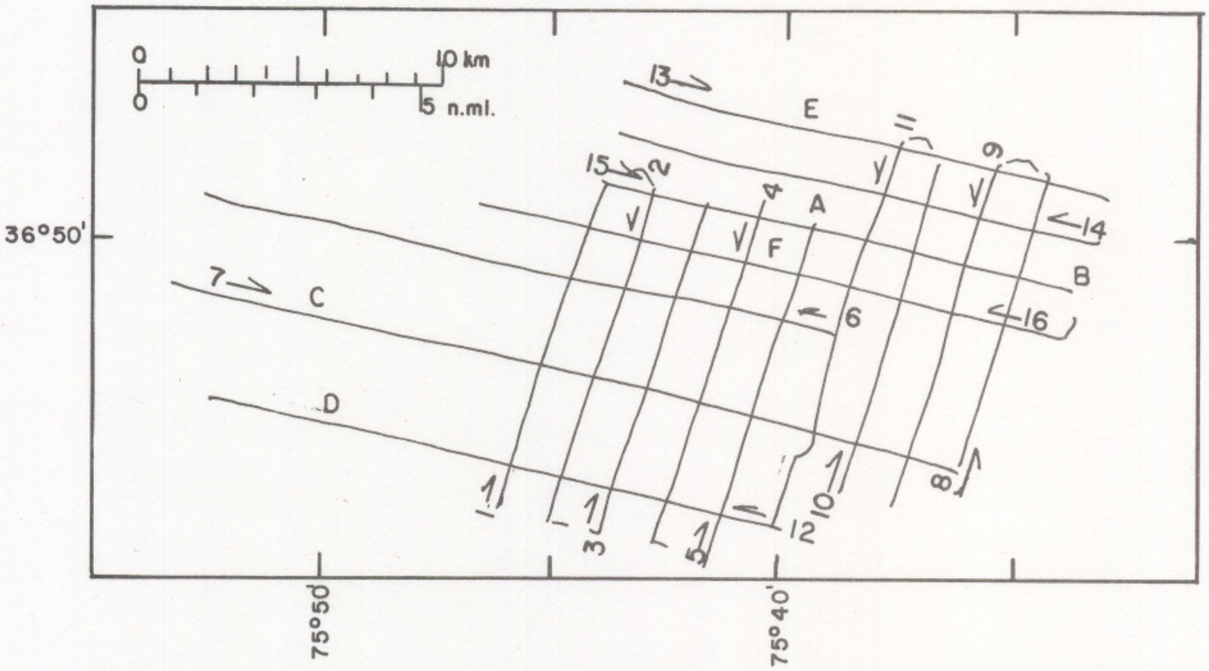


Figure 17. Locations of track lines surveyed in June, 1990. The locations of the line segments shown in Figures 18 through 23 are indicated by the letters A thorugh F respectively.

also includes the sites of two vibracores that were collected in 1987. Water depths varied from approximately 12 to 23 m (40 to 75 feet).

The shoal feature surveyed in this effort had been identified on navigation charts because its gross morphology was similar to the charted Sandbridge Shoal (broad horseshoe shape). The purpose of this survey was to determine if the two shoal features are genetically and, hence, sedimentologically similar. If so, the particular morphologic features associated with certain isolated sand shoals can be identified from charts and maps and thus targeted for exploration relative to sand and gravel reserves. A targeting mechanism can eliminate expensive "shotgun" exploration methods.

Side-scan Sonar Data.

The side-scan sonograms generally are similar to those from adjacent areas as described in Kimball and Dame (1989). The most noticeable feature of the collected data is a change in trend of major features. Throughout most of the area studied, the fabric of larger scale features trends roughly northwest - southeast, except in the eastern section where the trend is northeast - southwest. This change is relatively abrupt, occurring within a few hundred meters. The eastern area coincides with the eastern shoal that is separated from the other shoals by a linear depression approximately 1.5 km (0.8 n mi) wide and approximately 23 m (75 ft) deep. These linear features probably are the crests of long wave length, low amplitude bedforms.

Another noticeable set of features on the sonograms is a "patchiness" suggestive of variations in grain size. The "dark" patches or regions probably result from the occurrence of finer grained sediments that do not return as much acoustic energy to the transducers. There are no indications of anthropogenic influence on the bottom.

Subbottom Acoustic Surveys.

The focus of this study is the sedimentological and stratigraphic character of the offshore shoal feature relative to the Sandbridge Shoal. Here, as in adjacent areas studied in earlier works (Kimball et al., this volume; Dame, 1990; Kimball and Dame, 1989) the shoals appear to rest upon a reflector that is a continuation of the contiguous seafloor (Figure 16). This agrees with earlier works on the Virginia shelf (Shideler et al., 1972; Swift et al., 1972, 1977; Hobbs, 1990) in which the youngest sedimentary units are described as discontinuous and lying atop a regionally widespread reflector.

This set of subbottom surveys show an internal reflector within the offshore shoal body that is also clearly consistent with the stratigraphy of the Sandbridge Shoal (Figures 18 and 19). This reflector is an indicator that the offshore shoal may also be separated into upper/lower or younger/older components. The scope of the present study did not support the acquisition of cores that fully penetrate the offshore shoal. Thus, there is insufficient material to determine absolute dates on the interfaces manifested by the reflectors.

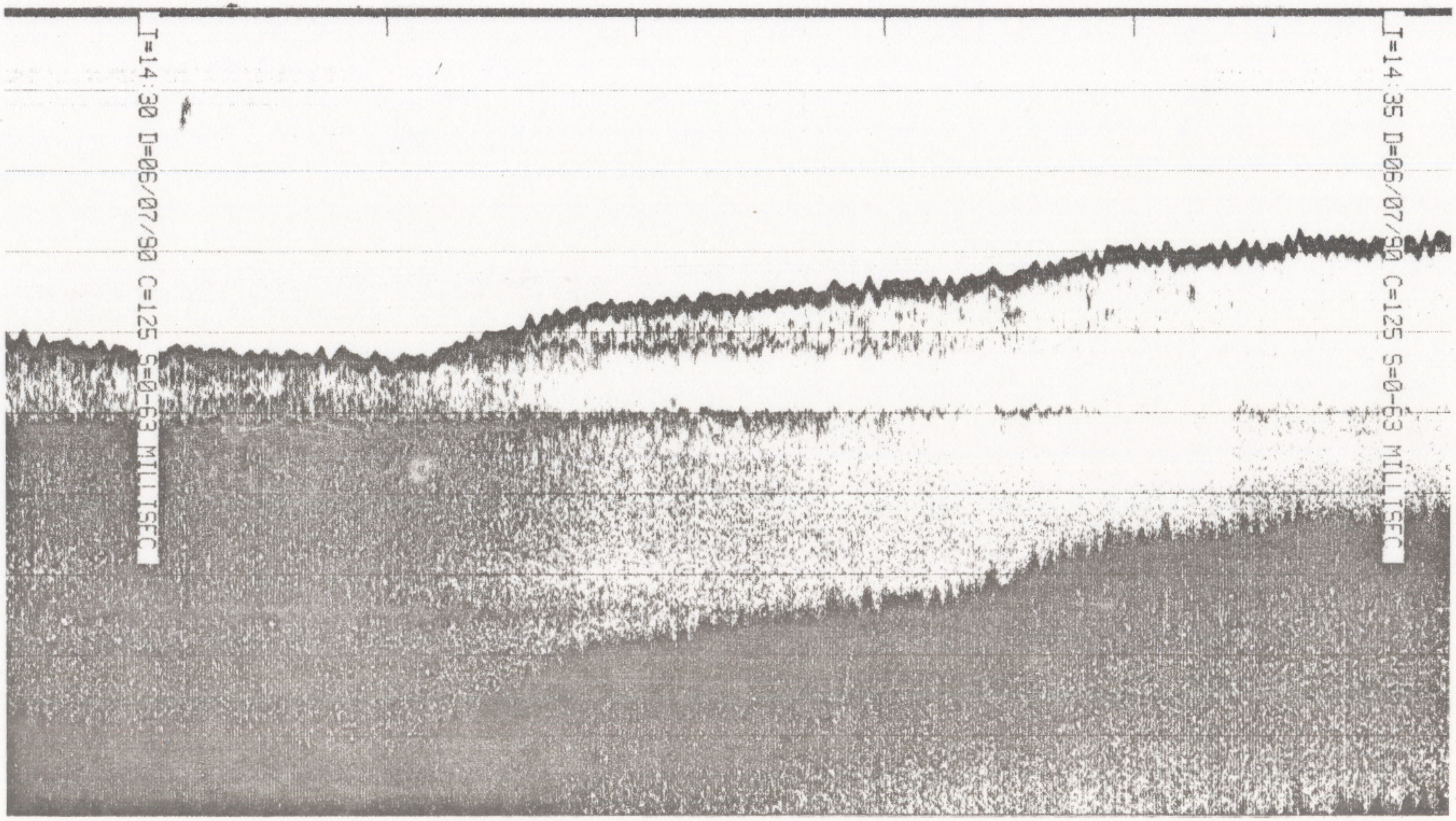


Figure 18. A portion of Line 15, June, 1990, illustrating the continuation of the seafloor as an acoustic reflector beneath the shoal. The full vertical scale is approximately 47 m.

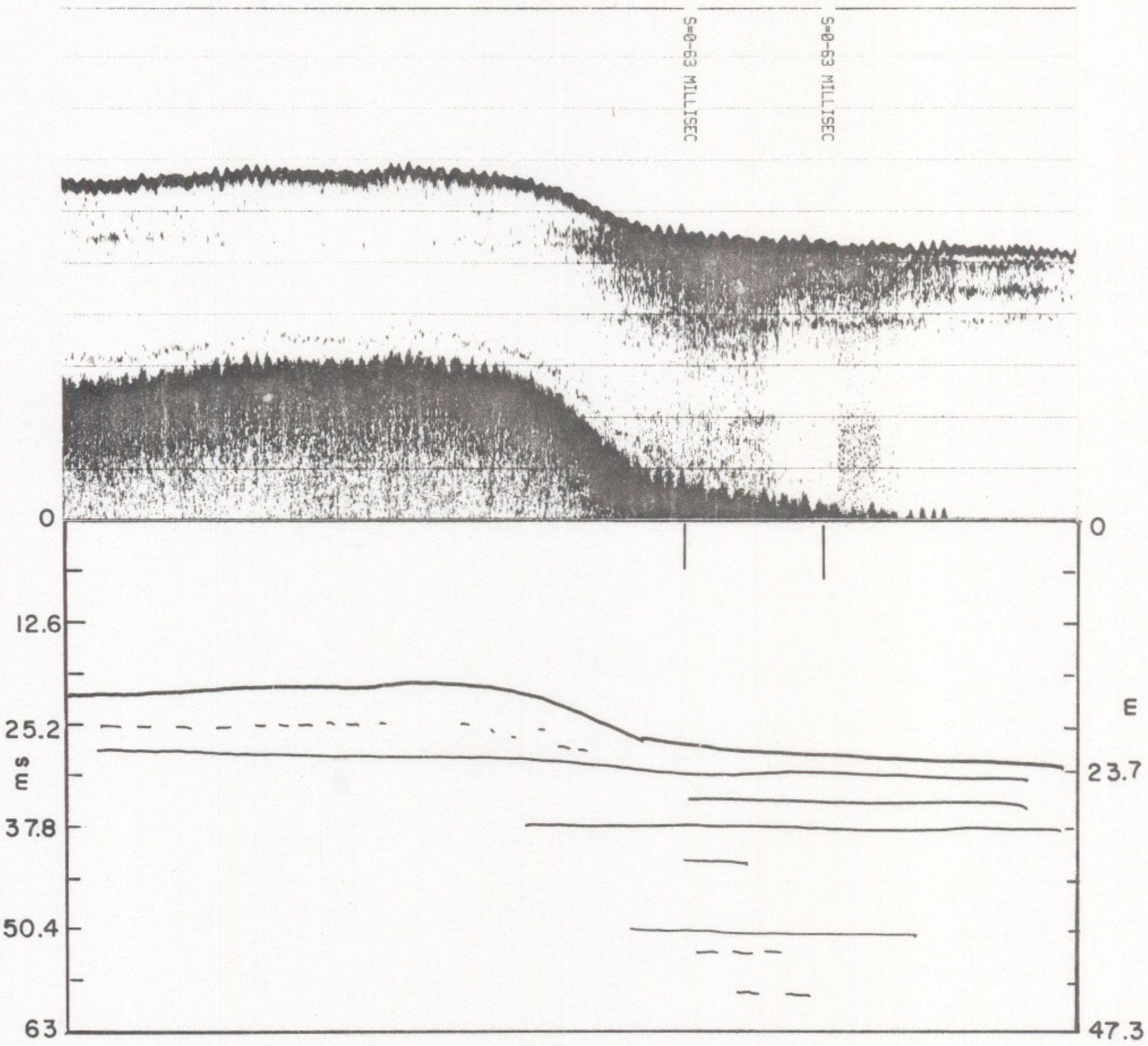


Figure 19. A portion of Line 15, June, 1990, and an interpretation depicting both the continuation of the adjacent seafloor beneath the shoal as an acoustic reflector and an internal reflector within the shoal.

Two cores that penetrated the shoal feature were obtained in 1987. The core logs (Cores #22 and 24) are contained in Appendix B. Like those cores obtained in the Sandbridge Shoal, each core in the offshore shoal exhibits a fining downward sequence of olive gray medium to coarse sand that darkens with depth. Large shell fragments are present, but there is no evidence of strong internal structure. A weak internal reflector is represented by a six centimeter layer of silty clay in Core #24 and a 10 cm layer of coarse gravel in Core #22. Although no dates are available for these units, the morphology and sedimentology are consistent with those of the Sandbridge Shoal.

The most striking features of the sub-bottom profiles are the complex channel structures on lines 7 (Figure 20) and 12 (Figure 21). This channel system forms the western boundary of the offshore shoal feature. The channels are indicative of multiple episodes of channel incisement and infilling within the confines of a large (4 km wide) and deep (15 m) paleochannel. The large channel is similar in acoustic morphology to the large channel underlying the Sandbridge Shoal. The lack of sediment cores and datable samples from the channel system makes it impossible to place in the context of the Sandbridge channels. However, their sizes, complexity, orientations and relationships to the shoals are suggestive of genetic similarities among the paleochannel complexes.

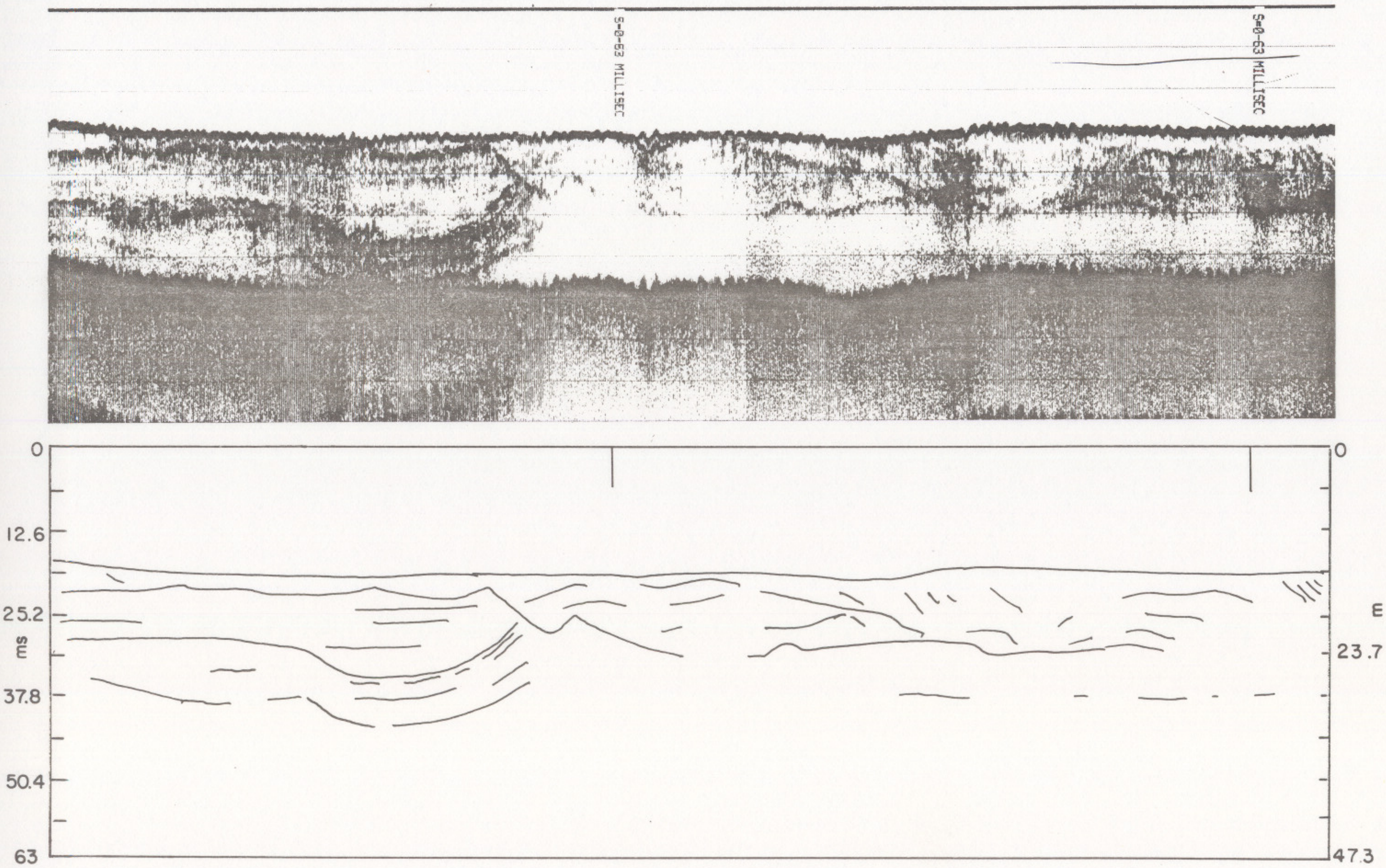


Figure 20. A portion of Line 7, June, 1990, depicting a complex channel and fill sequence.

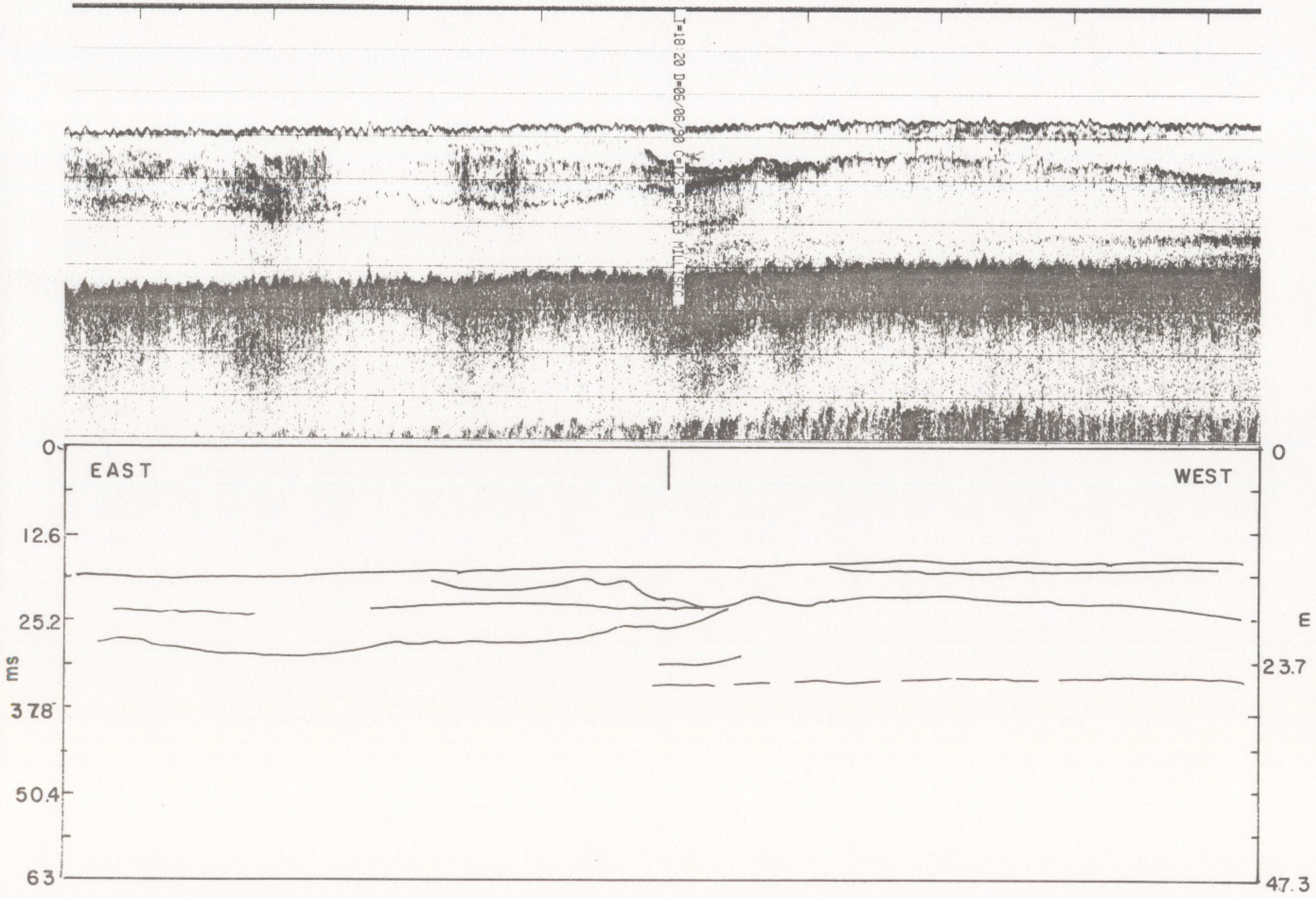


Figure 21. A portion of Line 12, June, 1990, and a drawn interpretation depicting a complex channel and fill sequence.

VII. DISCUSSION

The two shoals under consideration in this study exhibit several morphological characteristics in common. A distinctive feature is the presence of a weak, internal, acoustic reflector. In the Sandbridge Shoal this reflector is represented as a thin silt layer through the eastern sections and a coarse shelly layer to the west. Geochronology data based on samples from both the top and bottom boundaries indicate that the lower unit may be much older than the upper. Further evidence of a separate unit is given by a slightly finer grain size and weak crossbedding in the lower unit. Similarly, the offshore shoal is characterized by a fining downward sequence with a distinct but discontinuous thin layer of silty clay at depths between three and four meters.

Peebles (1984) presented a model of the types of stratigraphy that can be expected to result from a marine transgression. This model consists of (but is not limited to) a valley-fill sequence made up of coarse fluvial basal sediments grading upward into paludal and estuarine deposits. The sedimentary package is bounded by unconformities and may be capped by barrier and/or subaqueous bar deposits.

The data collected in the Sandbridge Shoal are indicative of this type of sedimentary sequence. The channel fill sequence is inferred from the geophysical data, with only the upper estuarine sediments penetrated by the cores. Silts and clays in units QP1 and QP4 are likely estuarine in origin (Table 3) and the fine sands in unit QP2 are interpreted as bay-mouth or tidal shoal deposits. The medium to coarse sands in unit QP3 are interpreted as tidal channel sediments. QP5, the uppermost unit of the Pleistocene valley-fill sequence may be interpreted as the discontinuous remnant of a barrier or bar that survived shoreface erosion during the transgression. The medium sand, fining downwards trend, shell content and weak cross-bedding support this interpretation.

The morphology of the Sandbridge Shoal and the spatial distribution of sedimentological characteristics are suggestive of a period of landward transport of material from the upper units. However, the horseshoe shape of the shoal feature is not consistent with massive and steady landward sediment transport. Two lines of reasoning may explain the shoal shape and internal structure. First, sediments in Sandbridge Shoal may have accumulated in two separate events. The first event deposited material along the western margin with subsequent event-driven sedimentation focused in the northern and central sections of the shoal. However, there is no real evidence of a discontinuity in the shoal sediments.

A second consideration is that the plan shape may be the result of modern hydraulics. Evidence for modern transport includes the presence of large scale bedforms on the side-scan sonar records and indications of northerly movement of material in the swale between the shoal arms.

It is most likely that Sandbridge Shoal formed in two stages. The characteristics of the lower unit as well as its relationship with surrounding stratigraphy indicates that it likely represents the remnants of a barrier or submerged bar that was present on the shelf during a late Pleistocene transgression. Correlation of amino acid dates to aminozones (Wehmiller et al., 1988), indicates that the two shoal units were deposited during isotopic Stage 5. The boundary between the lower shoal unit (QP5) and underlying strata lies approximately -15 m MSL. Considering the sea level curves promulgated by Cronin et al. (1981), Chappell and Shackleton (1986), and Bard et al. (1990), three possible marine transgressions have been documented during which QP5 may have been deposited. These climaxed at 75,000-80,000 ybp (-18 to +10 m MSL), 95,000-105,000 ybp (-18 to +10 m MSL), and 115,000-125,000 ybp (0 to +18 m MSL). Differences in the timing and elevation of these high-stands as referenced to present sea level are due to regional tectonics and crustal adjustments due to glacial activity and sediment loading.

The second stage in the formation of the Sandbridge Shoal has occurred during the Holocene transgression. It is inferred from the data that the upper unit (QH2) was deposited as an offshore bar. The source for this material is not immediately apparent.

A similar suite of data is lacking for the offshore shoal. However, similarities to the Sandbridge Shoal in the plan-view shape (broad horseshoe) as well as similar stratigraphic and sedimentological characteristics as inferred from a limited data base (two cores) are suggestive of genetically similar features. The offshore shoal is generally lower relief and the lower shoal unit (which may be analogous to QP5) is thinner. This would be expected from a feature that has been subjected to longer periods of shoreface erosion and sediment reworking under a transgressive sea.

It is probable that the surface upon which the shoals have formed (the underlying reflector - R4 - or contiguous seafloor) represents the late Pleistocene (Wisconsin) low stand of sea level. If this is the case, then the younger reflector might represent a mid-Wisconsin sea-level high.

Locally, acoustic basement generally is assumed to be the pre-Pleistocene unconformity atop the Pliocene Yorktown Fm. The widespread, regional reflectors usually exhibit a gentle eastward (seaward) dip which can result in the exposure of different stratigraphic units at the seafloor.

Evidence that the reflectors mark unconformities also is given by the occurrence of a series of filled channels cut into a prominent reflector (Figure 22). Further, there is evidence that individual reflectors have been reoccupied at different times (Figure 23) suggesting that the sediments marking the top of the unconformity (a basal lag?) might have been sufficiently erosion-resistant to serve as a base through which later erosive processes could not cut. These strong internal reflectors might correlate with the channel cutting episodes described within Chesapeake Bay by Colman and Hobbs, (1987, 1988), Colman et al., (1990), and Halka et al. (1990).

VIII. CONCLUSIONS

Located approximately 5.5 km offshore, the Sandbridge Shoal is a deposit of clean, well sorted, medium to coarse sand that tapers and thins to the northeast. A similar feature is located approximately 20 km offshore Virginia Beach, although the

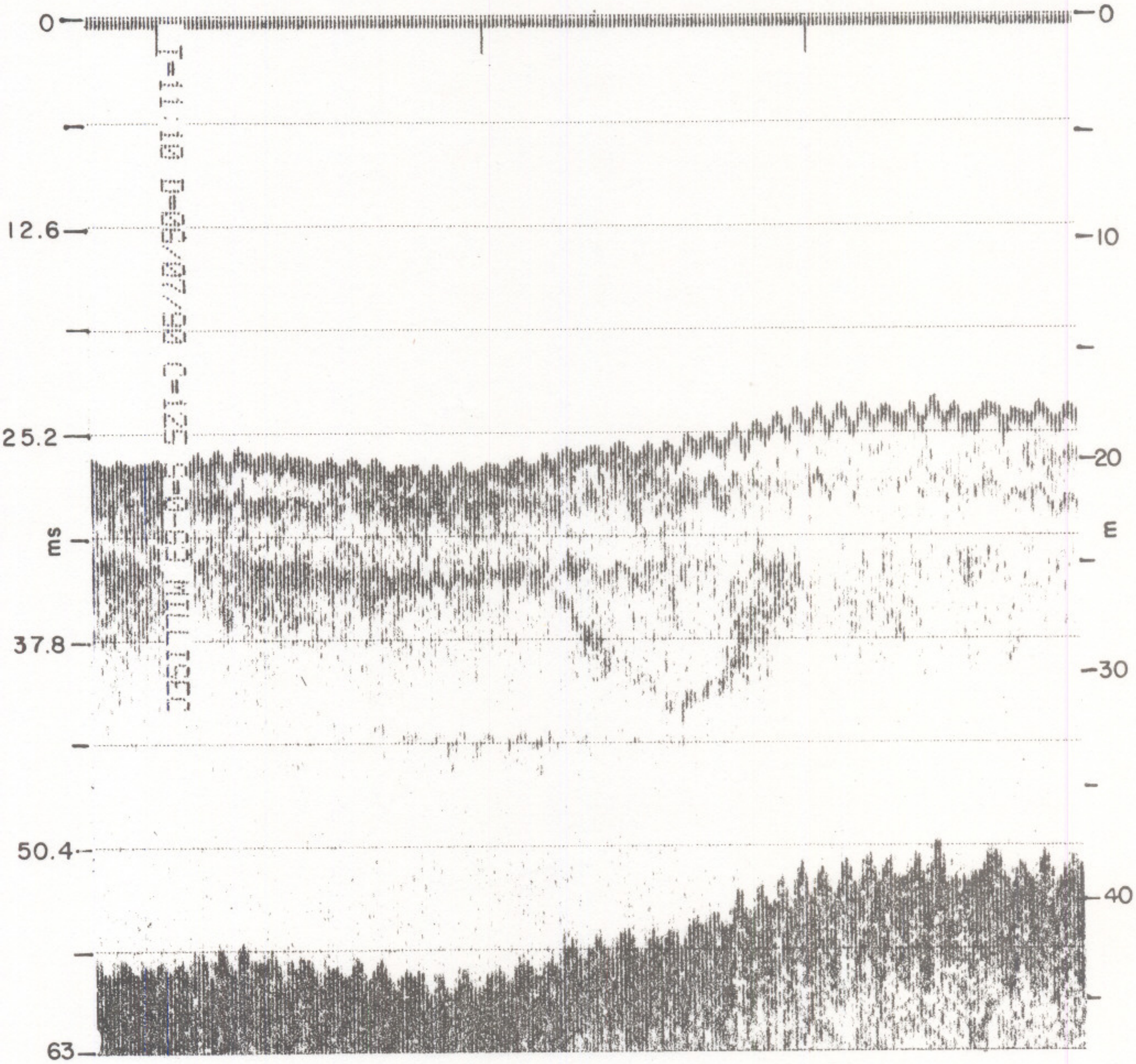


Figure 22. A portion of Line 13, June, 1990, depicting a smaller channel cut into a subsurface reflector.

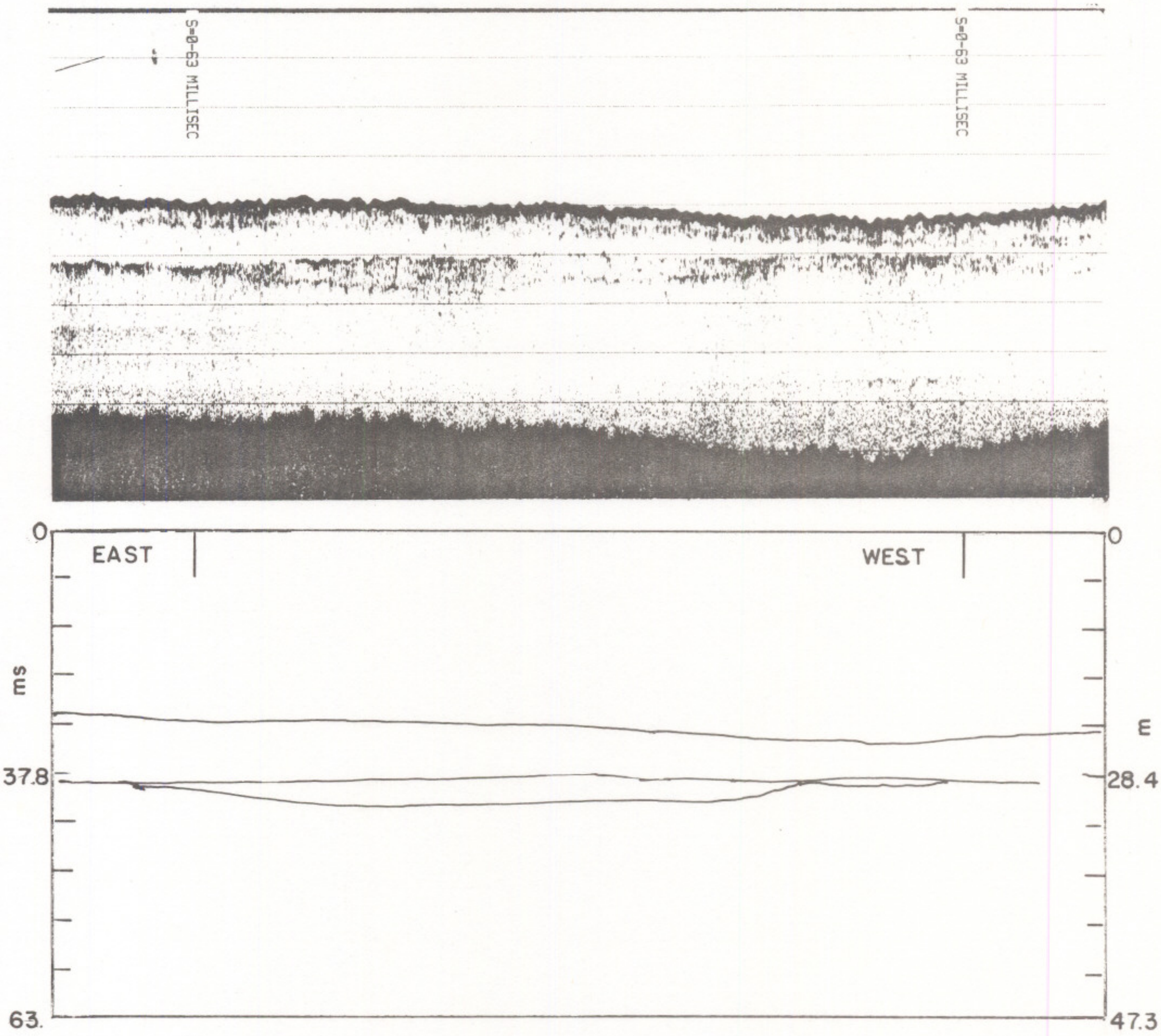


Figure 23. A portion of Line 16, June, 1990, and a drawn interpretation illustrating the reoccupation of a subsurface reflector suggesting that the unconformity represented by the reflector was exposed on more than one occasion.

offshore feature exhibits less relief than the Sandbridge Shoal. Both shoals are associated with large paleochannel systems, and inferred lagoonal or estuarine sediments are located below and landward of the sand bodies. Sediments within both shoals fine downward. Sandbridge Shoal has its coarsest sediments concentrated in the northeast quadrant. The sediments show little evidence of aeolian processes, lack high concentrations of heavy minerals, and contain remains of only high salinity organisms. No surface samples are available on the offshore shoal; therefore, spatial distribution of sediment characteristics cannot be described.

Geophysical and geochronological data are interpreted to show that Sandbridge Shoal is comprised of two separate sedimentological units of different ages. Geophysical data from the offshore shoal are similar in terms of the geometries of the reflectors and in terms of limited correlations with sediment core analyses. None of these data support the traditional theories of linear shoal origin (i.e., the shoal is either entirely relict or entirely modern).

Therefore, a model of two-stage formation is presented for these isolated features. The lower unit of Sandbridge Shoal represents reworked remnants of a barrier or submerged bar that was present on the shelf during a late Pleistocene transgression. The limited data set available for the offshore shoal is similar. The second stage of formation occurred during the Holocene transgression during which time the upper unit was deposited as an offshore bar over the earlier sediments. Again, similarities between the geophysical data sets are suggestive of a similar genesis for the offshore bar. Limited sedimentological and the lack of geochronological data preclude an absolute genetic link.

Several questions remain unanswered. The source material for these large, clean sand bodies has not been established. Relict fluvial deposits to the northeast may be a source of material. Paleochannels and lag gravel deposits that outcrop at the surface have been identified. These represent potential sources. However, these sources are heterogeneous sediments and sediment transport pathways on the shelf have not been determined. It is unclear how the sorting process during transport would result in the accumulation of massive deposits of homogeneous material.

The processes responsible for the locations of these features on the shelf have not been addressed. Their existence may be explained by an equilibrium response of the shoreface to a decreasing rate of sea level rise. During a rapid rise in sea level, erosion on the upper shoreface is relatively more severe than at other locations. A slowing of sea level rise would produce an approach of the shoreface profile to equilibrium. This would result in a shift to relatively more erosion on the middle and lower portions of the shoreface and foster onshore transport (Van Straaten, 1973).

Fairbanks (1989) and Bard et al. (1990) documented three periods during the Holocene when the rate of sea level rise decreased: 14,000 ybp, 11,000-11,500 ybp, and 4,000-6,000 ybp. The position of the shoreline relative to present MSL was approximately -70 m MSL, -70 to -40 m MSL, and -8 to -12 m MSL, respectively. Given relative rates of sea level rise between 2.7 and 4.4 mm/yr (Froomer, 1980) and considering a lag period may exist between the slowing of sea level rise and the approach to equilibrium, the position of the upper unit could be related to a decrease in the rate of sea level rise 4,000-6,000 ybp. It has been determined from the seismic data that the lower unit of Sandbridge Shoal had as much as 1.5 m relief when it was exposed on the shelf surface. This relief may have directed shelf transport such that sediments of the upper unit were deposited on the emerging shoal face as they were transported across the shelf.

Qualitative evidence is suggestive of a genetic link between the offshore shoal and Sandbridge Shoal. It will be necessary to acquire sedimentological (i.e., long cores) and geochronological data before this link can be demonstrated. In addition, further work is necessary to document the influence exerted by the paleochannel systems. A better understanding of these systems will result in more effective assessments of sand and gravel reserves on the inner shelf and a better capability to predict shelf evolution under transgressing seas.

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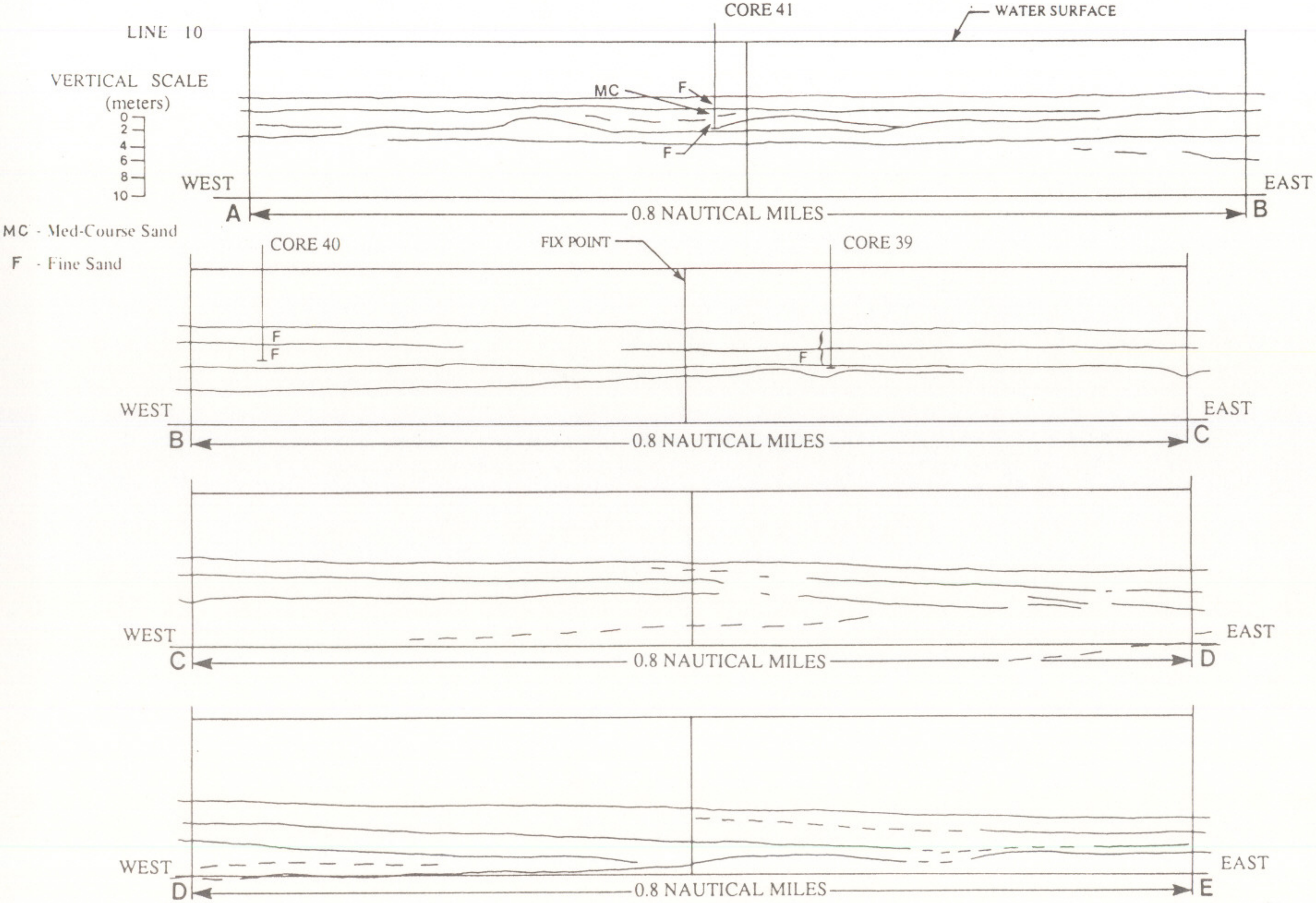
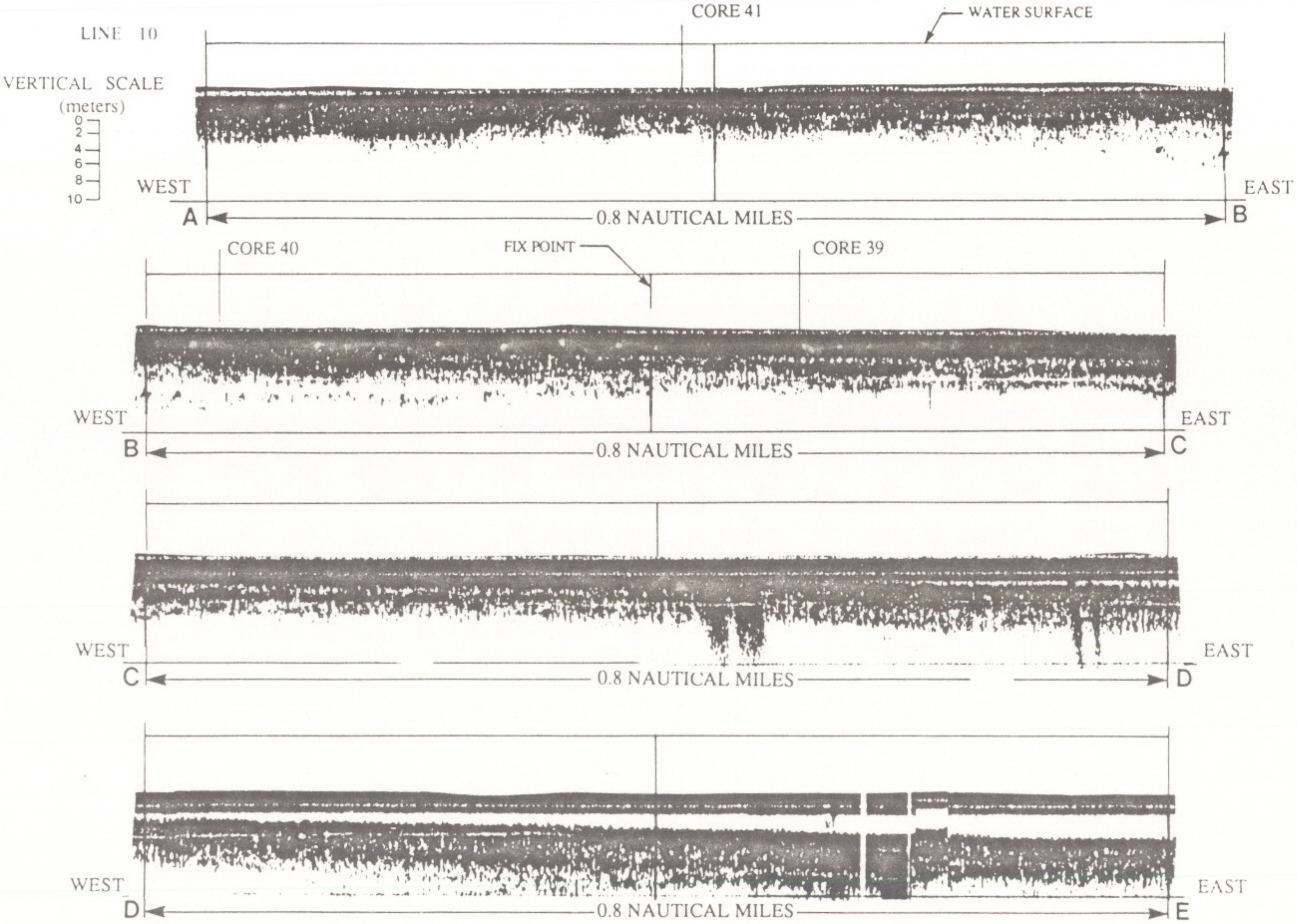
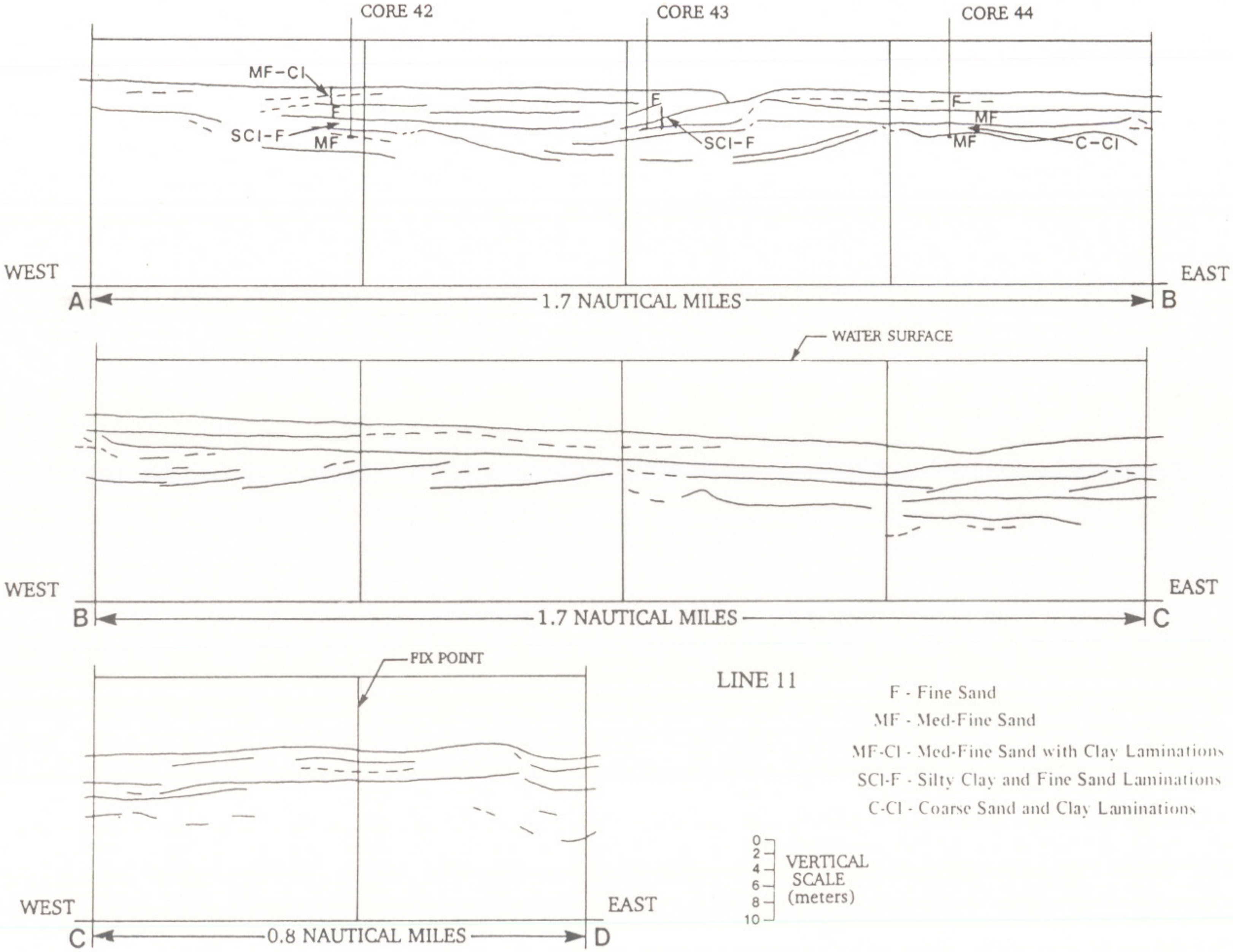
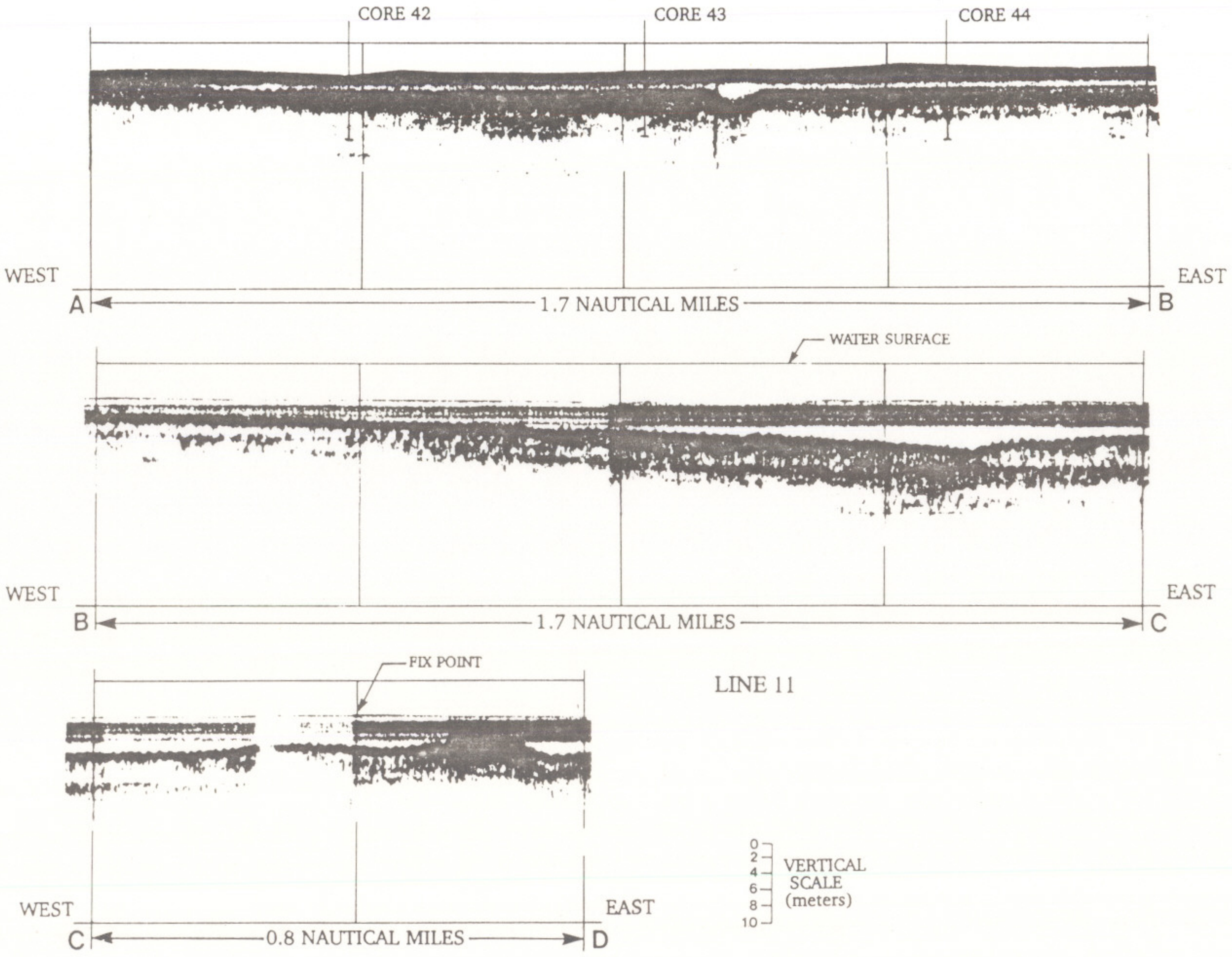
APPENDIX A

Reproductions of subbottom acoustic records obtained during the Virginia Beach Sand and Gravel Resource Study (Kimball and Dame, 1989) in the vicinity of Sandbridge Shoal and corresponding interpretations. Trackline locations are shown in Figure 5. Descriptions of stratigraphic units are given in Table 3.

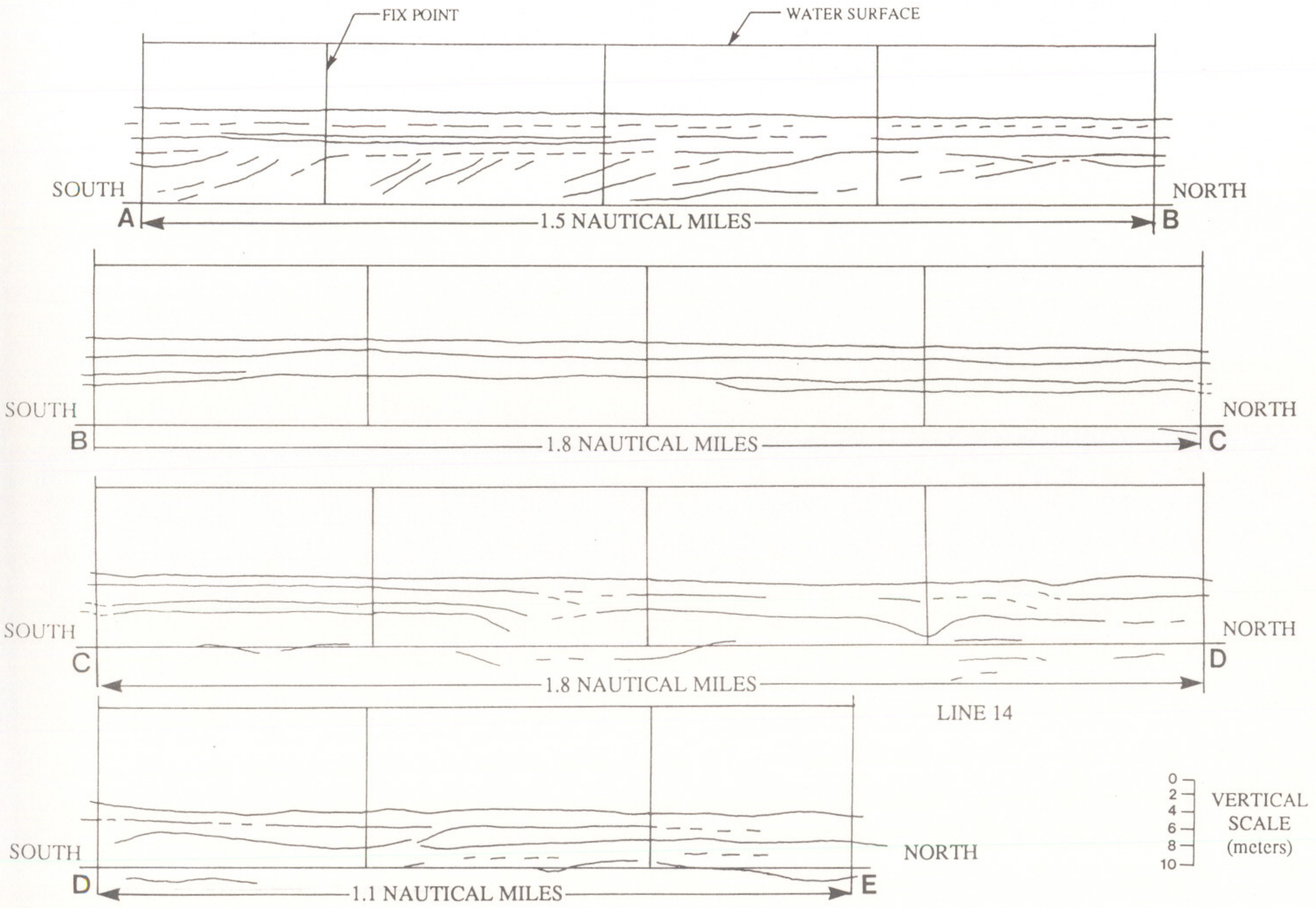

LINE 10
VERTICAL SCALE
(meters)
0
2
4
6
8
10
MC - Med-Course Sand
F - Fine Sand
CORE 41
WATER SURFACE
MC
F
F
WEST
EAST
A
0.8 NAUTICAL MILES
B
CORE 40
FIX POINT
CORE 39
F
F
F
WEST
EAST
B
0.8 NAUTICAL MILES
C
WEST
EAST
C
0.8 NAUTICAL MILES
D
WEST
EAST
D
0.8 NAUTICAL MILES
E

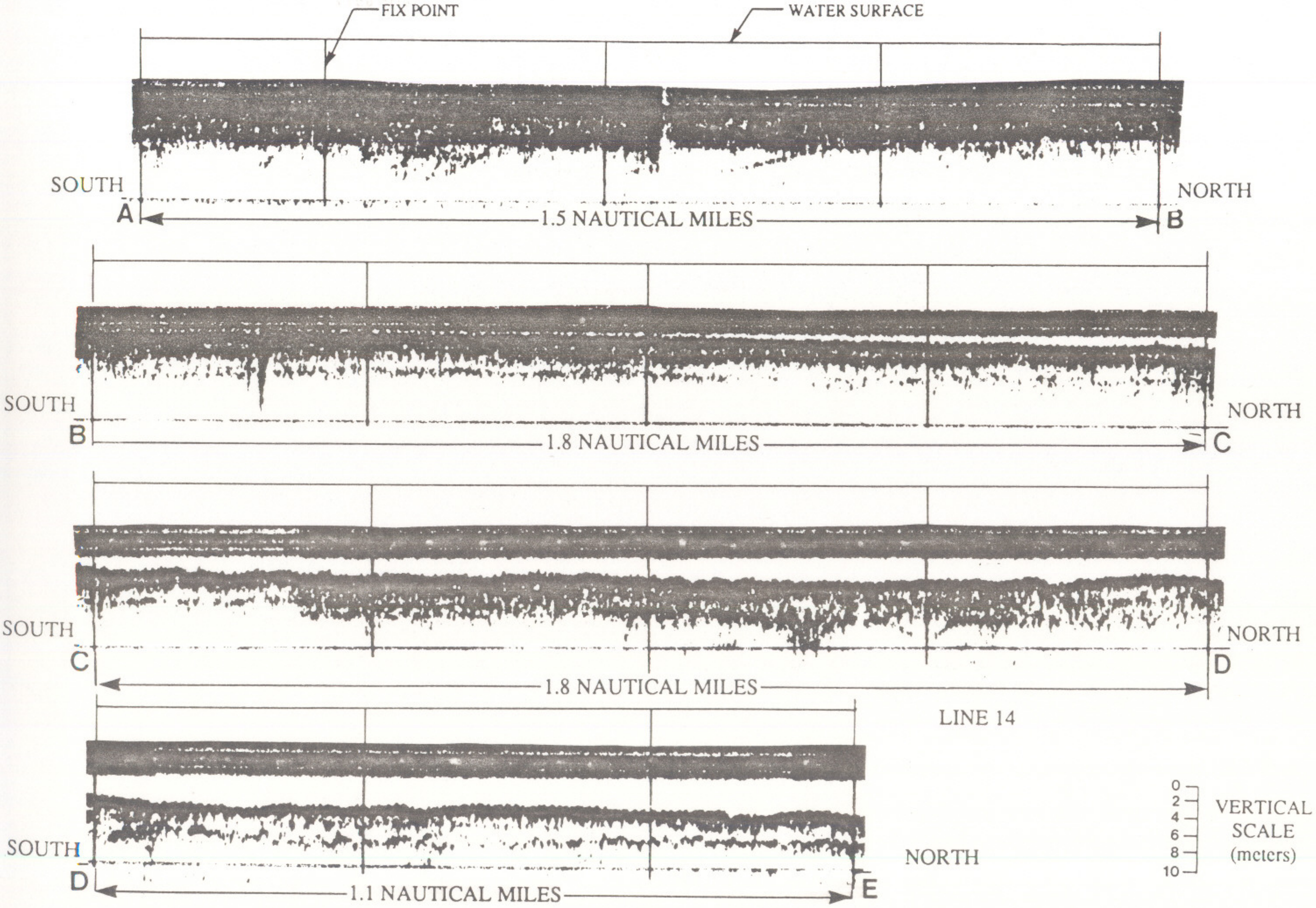

LINE 10
VERTICAL SCALE
(meters)
0
2
4
6
8
10
CORE 41
WATER SURFACE
WEST
EAST
A
B
0.8 NAUTICAL MILES
CORE 40
FIX POINT
CORE 39
WEST
EAST
B
C
0.8 NAUTICAL MILES
WEST
EAST
C
D
0.8 NAUTICAL MILES
WEST
EAST
D
E
0.8 NAUTICAL MILES

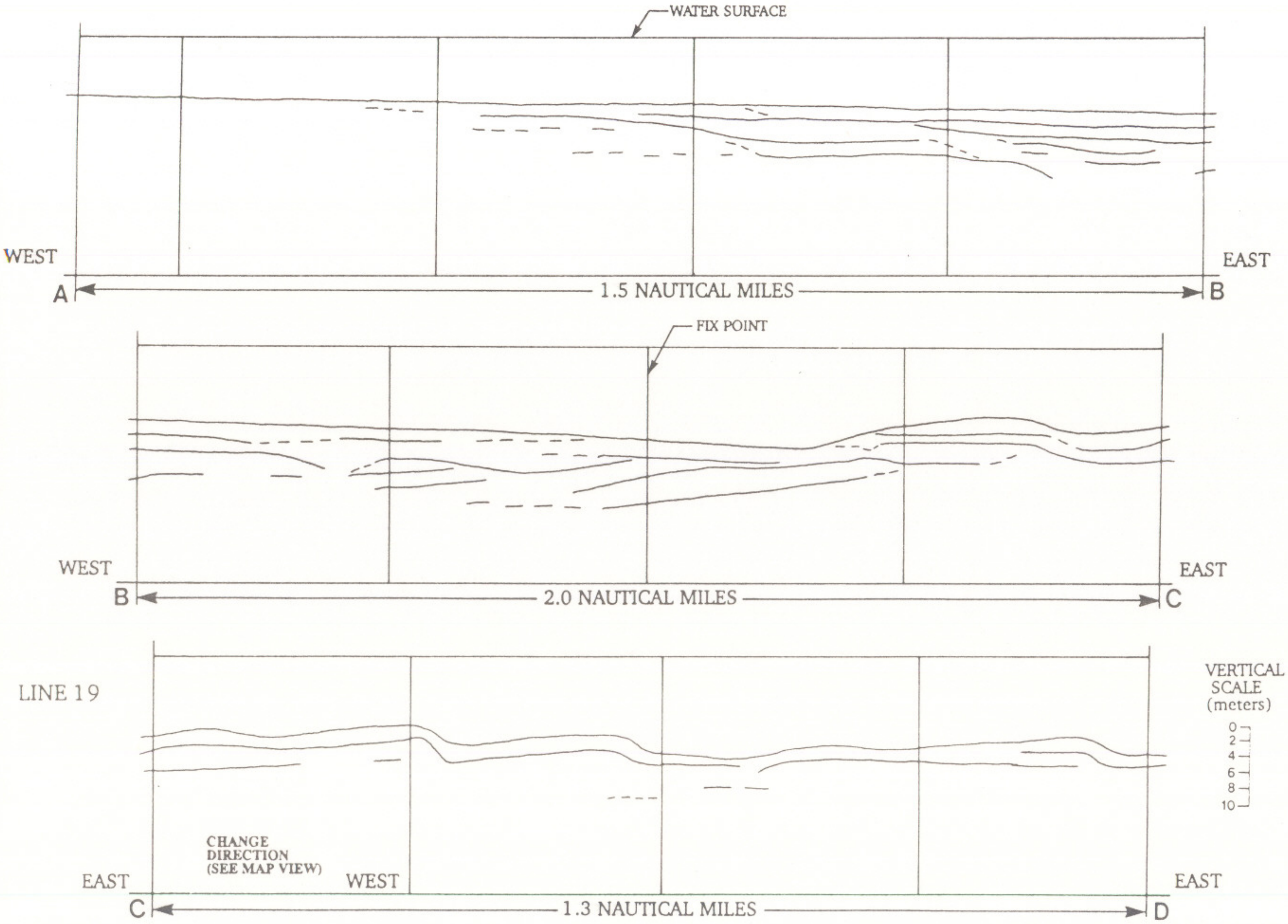

CORE 42
CORE 43
CORE 44
MF-Cl
F
SCl-F
MF
F
SCl-F
F
MF
MF
C-Cl
WEST
EAST
A
1.7 NAUTICAL MILES
B
WATER SURFACE
WEST
EAST
B
1.7 NAUTICAL MILES
C
FIX POINT
WEST
EAST
C
0.8 NAUTICAL MILES
D
LINE 11
F - Fine Sand
MF - Med-Fine Sand
MF-Cl - Med-Fine Sand with Clay Laminations
SCl-F - Silty Clay and Fine Sand Laminations
C-Cl - Coarse Sand and Clay Laminations
0
2
4
6
8
10
VERTICAL SCALE (meters)

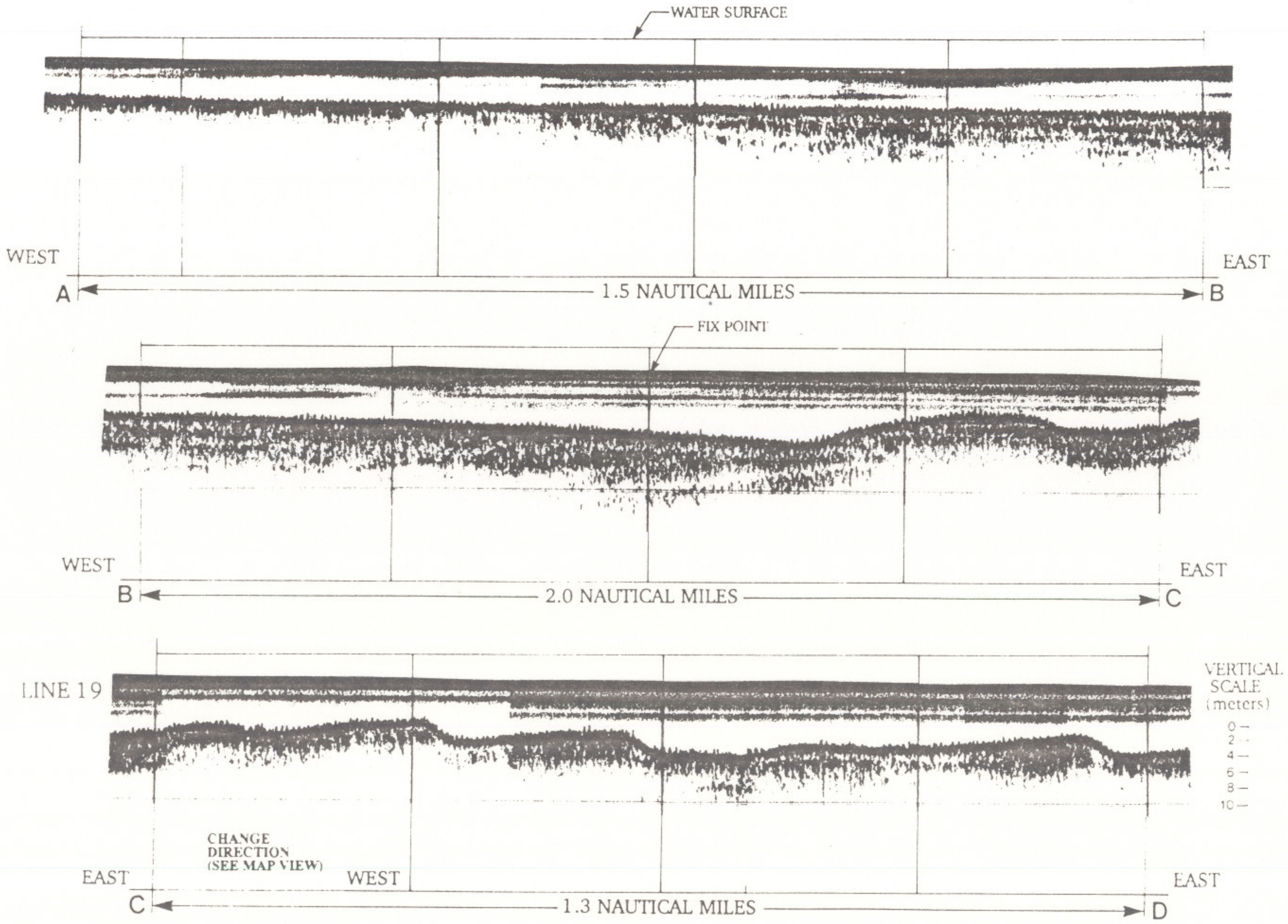

CORE 42
CORE 43
CORE 44
WEST
EAST
A
1.7 NAUTICAL MILES
B
WATER SURFACE
WEST
EAST
B
1.7 NAUTICAL MILES
C
FIX POINT
WEST
EAST
C
0.8 NAUTICAL MILES
D
0
2
4
6
8
10
VERTICAL SCALE (meters)

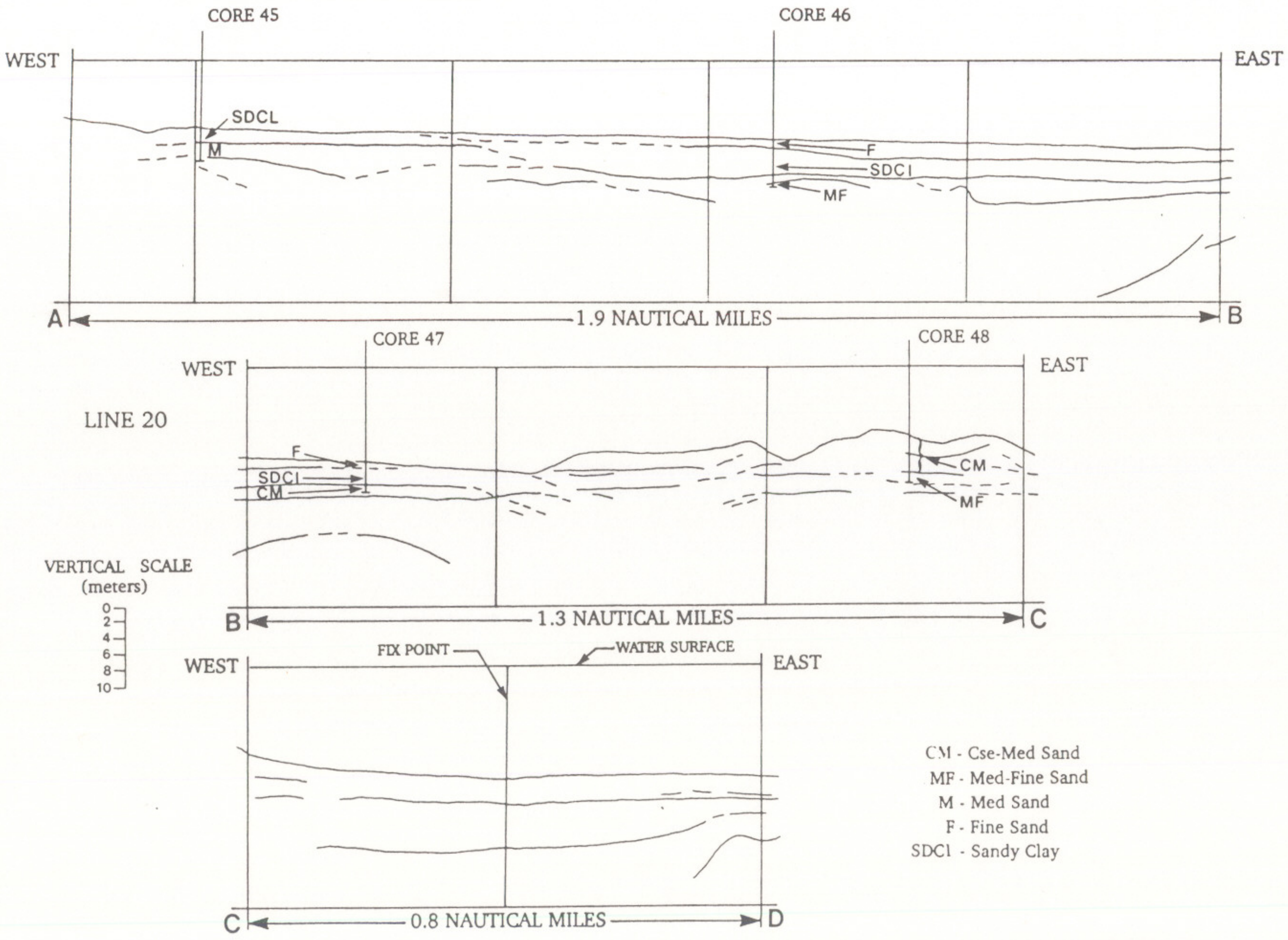
LINE 11

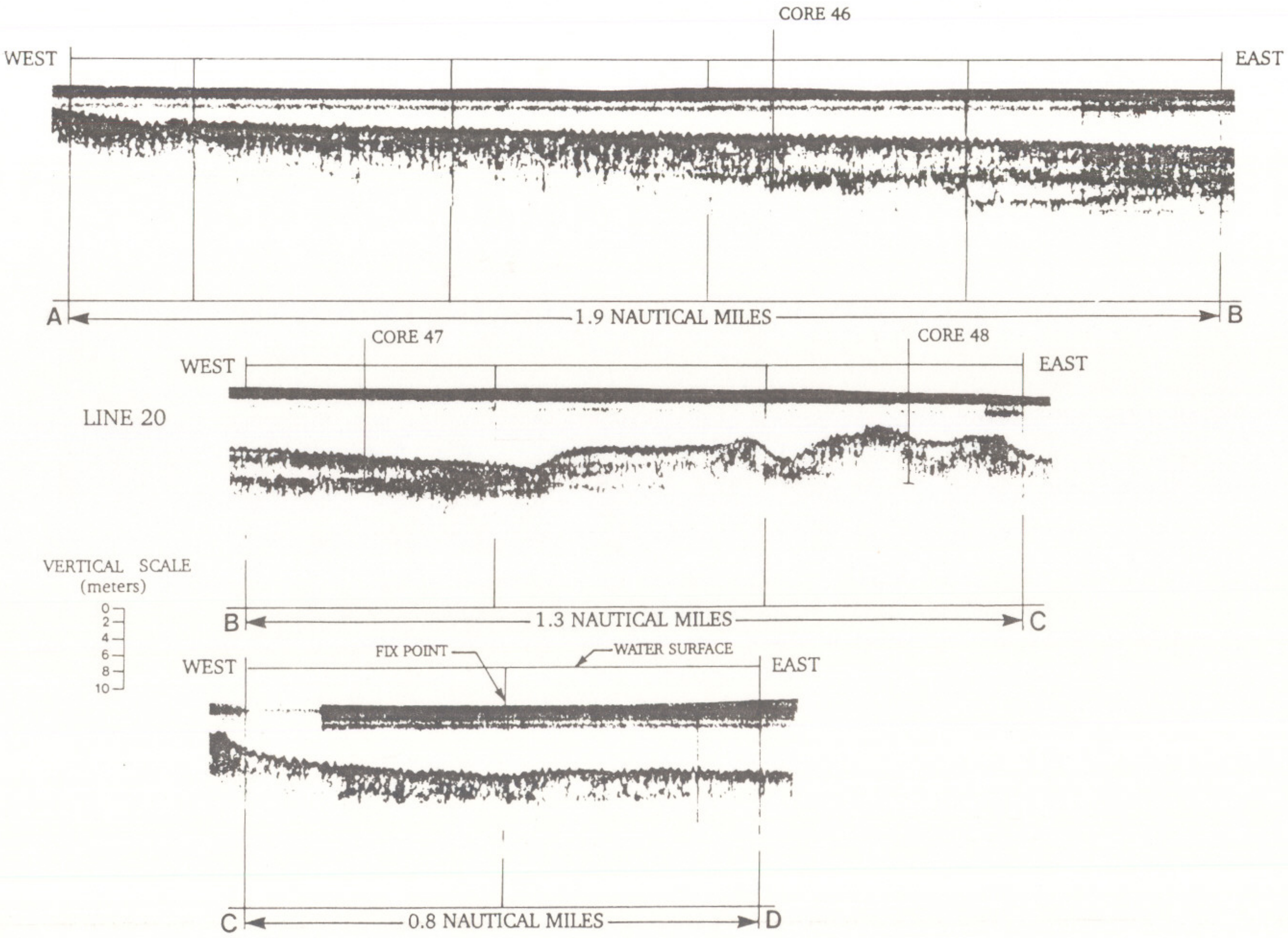

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
B
1.5 NAUTICAL MILES
SOUTH
NORTH
B
C
1.8 NAUTICAL MILES
SOUTH
NORTH
C
D
1.8 NAUTICAL MILES
LINE 14
SOUTH
NORTH
D
E
1.1 NAUTICAL MILES
0
2
4
6
8
10
VERTICAL SCALE (meters)

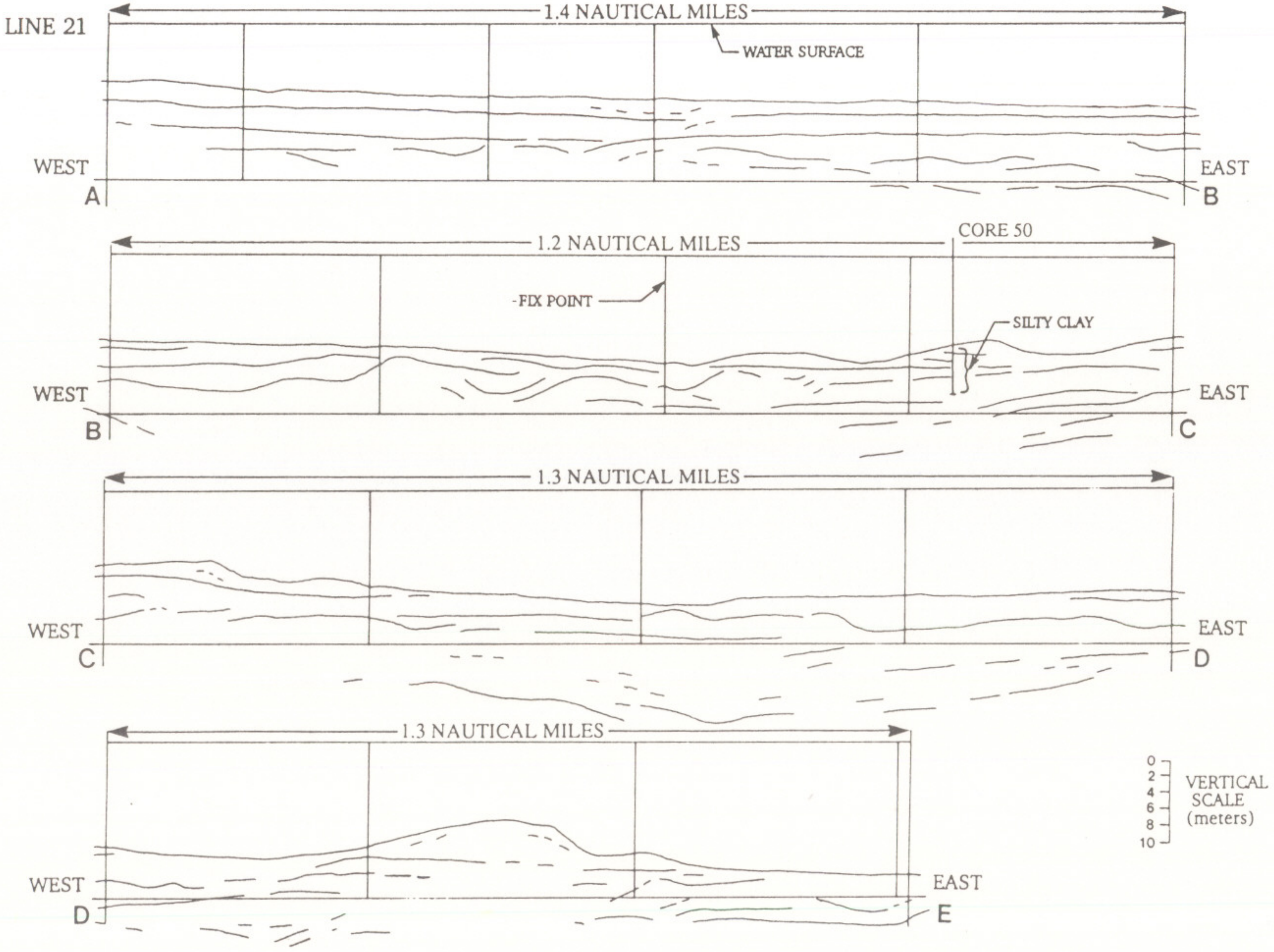

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
B
1.5 NAUTICAL MILES
SOUTH
NORTH
B
C
1.8 NAUTICAL MILES
SOUTH
NORTH
C
D
1.8 NAUTICAL MILES
LINE 14
SOUTH
NORTH
D
E
1.1 NAUTICAL MILES
0
2
4
6
8
10
VERTICAL SCALE (meters)

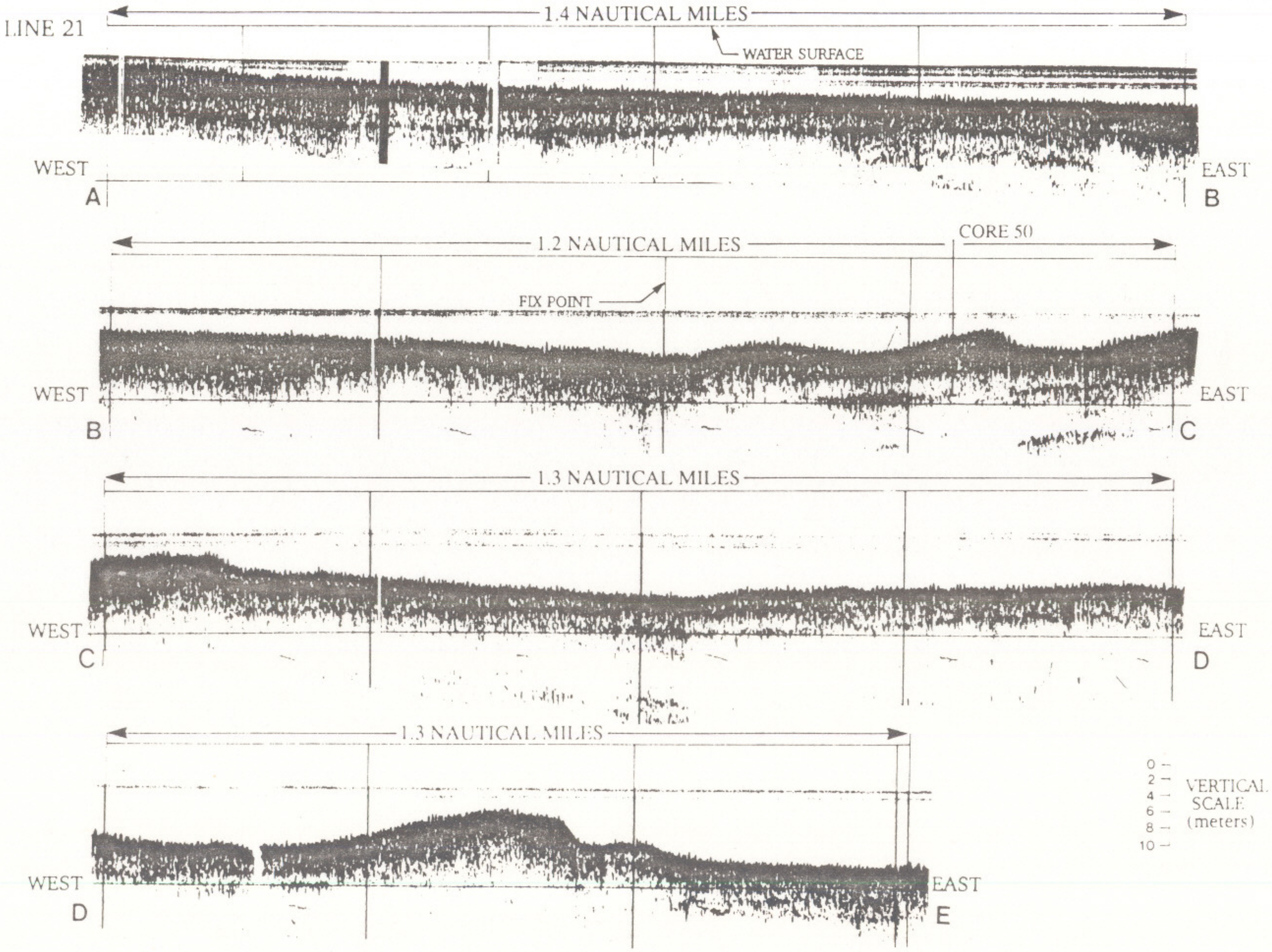

WATER SURFACE
WEST
EAST
A
1.5 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
2.0 NAUTICAL MILES
C
LINE 19
VERTICAL SCALE (meters)
0
2
4
6
8
10
CHANGE DIRECTION (SEE MAP VIEW)
EAST
WEST
EAST
C
1.3 NAUTICAL MILES
D

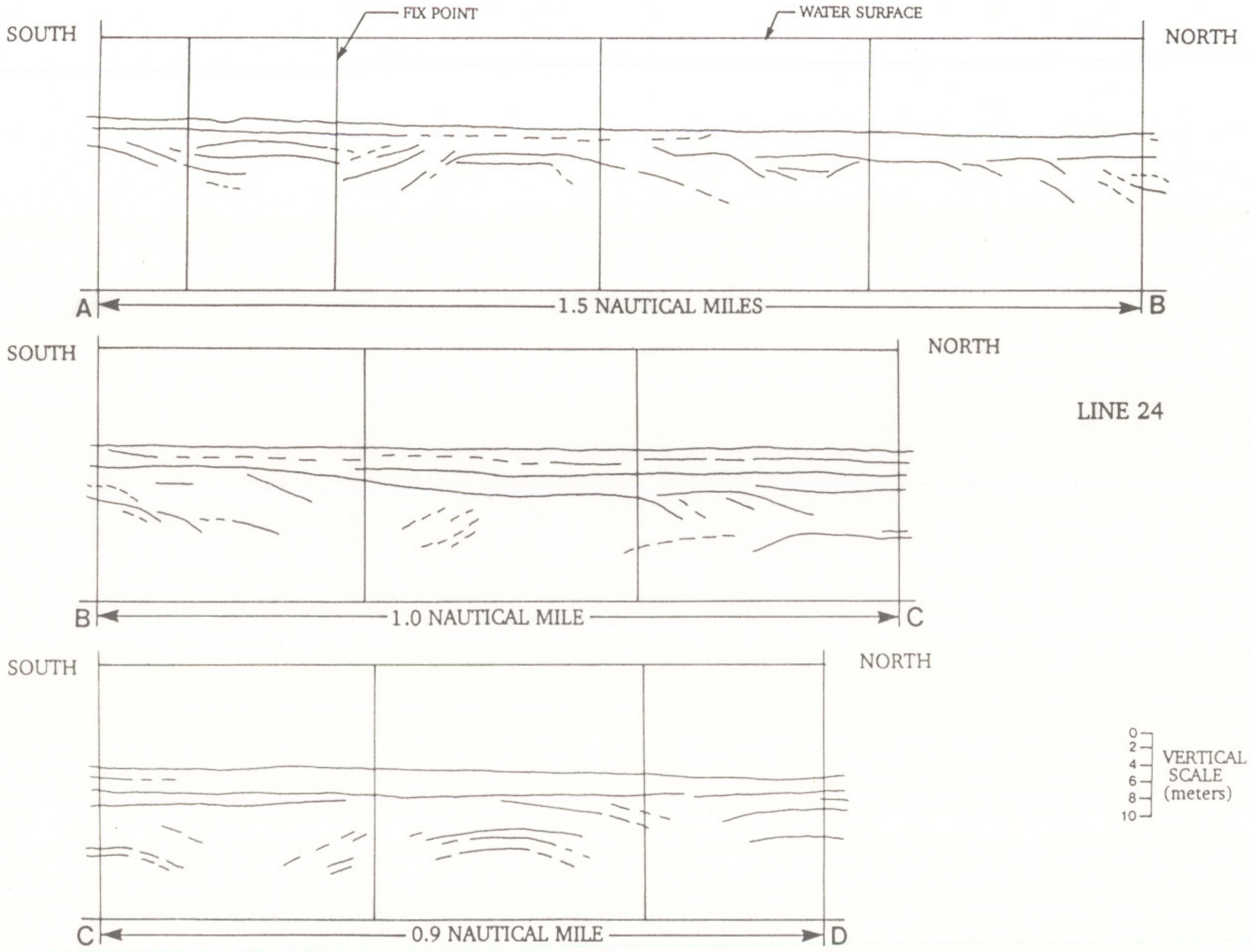

WATER SURFACE
WEST
EAST
A
1.5 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
2.0 NAUTICAL MILES
C
LINE 19
VERTICAL SCALE (meters)
0
2
4
6
8
10
CHANGE DIRECTION (SEE MAP VIEW)
EAST
WEST
EAST
C
1.3 NAUTICAL MILES
D

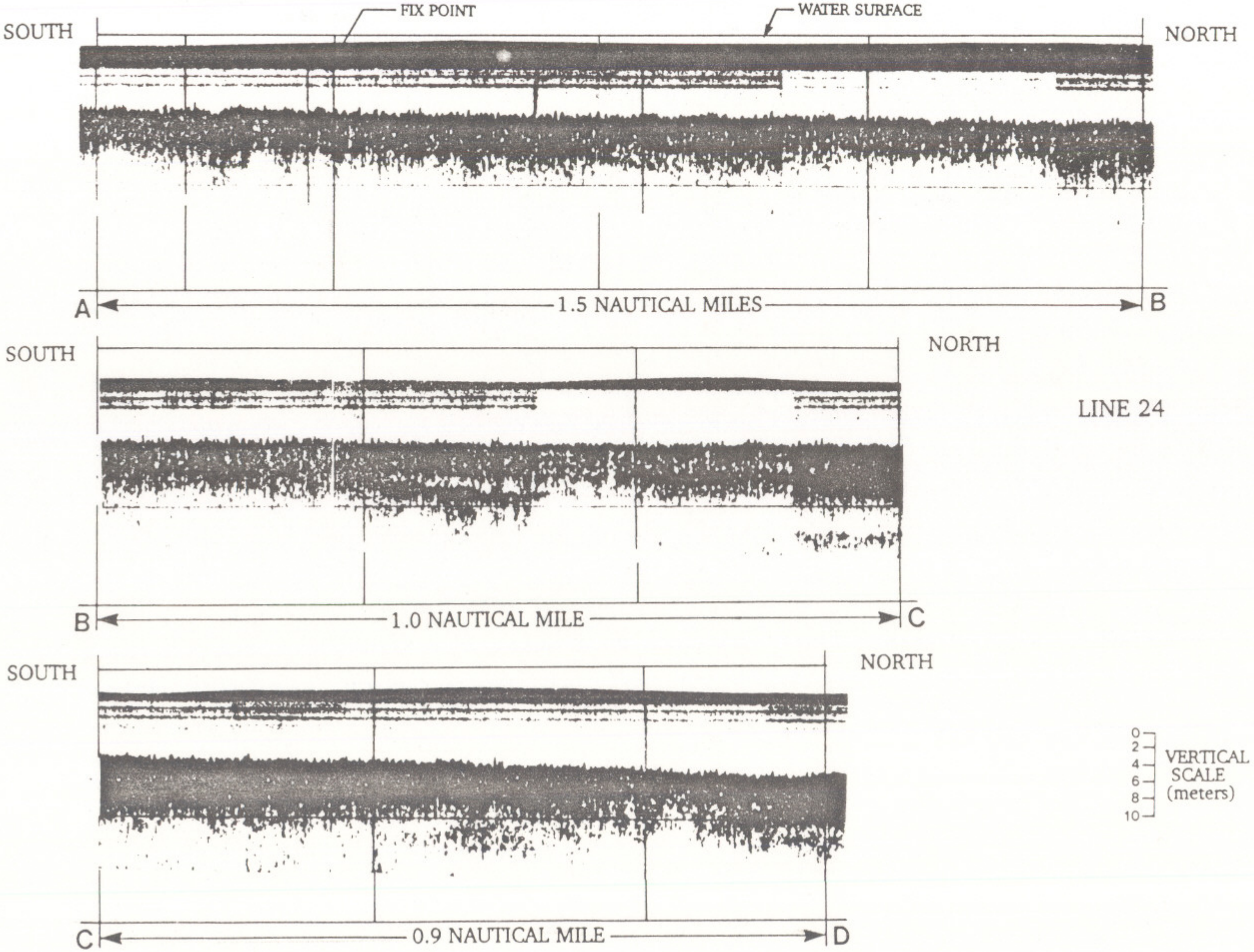

CORE 45
CORE 46
WEST
EAST
SDCL
M
F
SDCI
MF
A
1.9 NAUTICAL MILES
B
CORE 47
CORE 48
WEST
EAST
LINE 20
F
SDCI
CM
CM
MF
VERTICAL SCALE (meters)
0
2
4
6
8
10
B
1.3 NAUTICAL MILES
C
FIX POINT
WATER SURFACE
WEST
EAST
C
0.8 NAUTICAL MILES
D
CM - Cse-Med Sand
MF - Med-Fine Sand
M - Med Sand
F - Fine Sand
SDCl - Sandy Clay

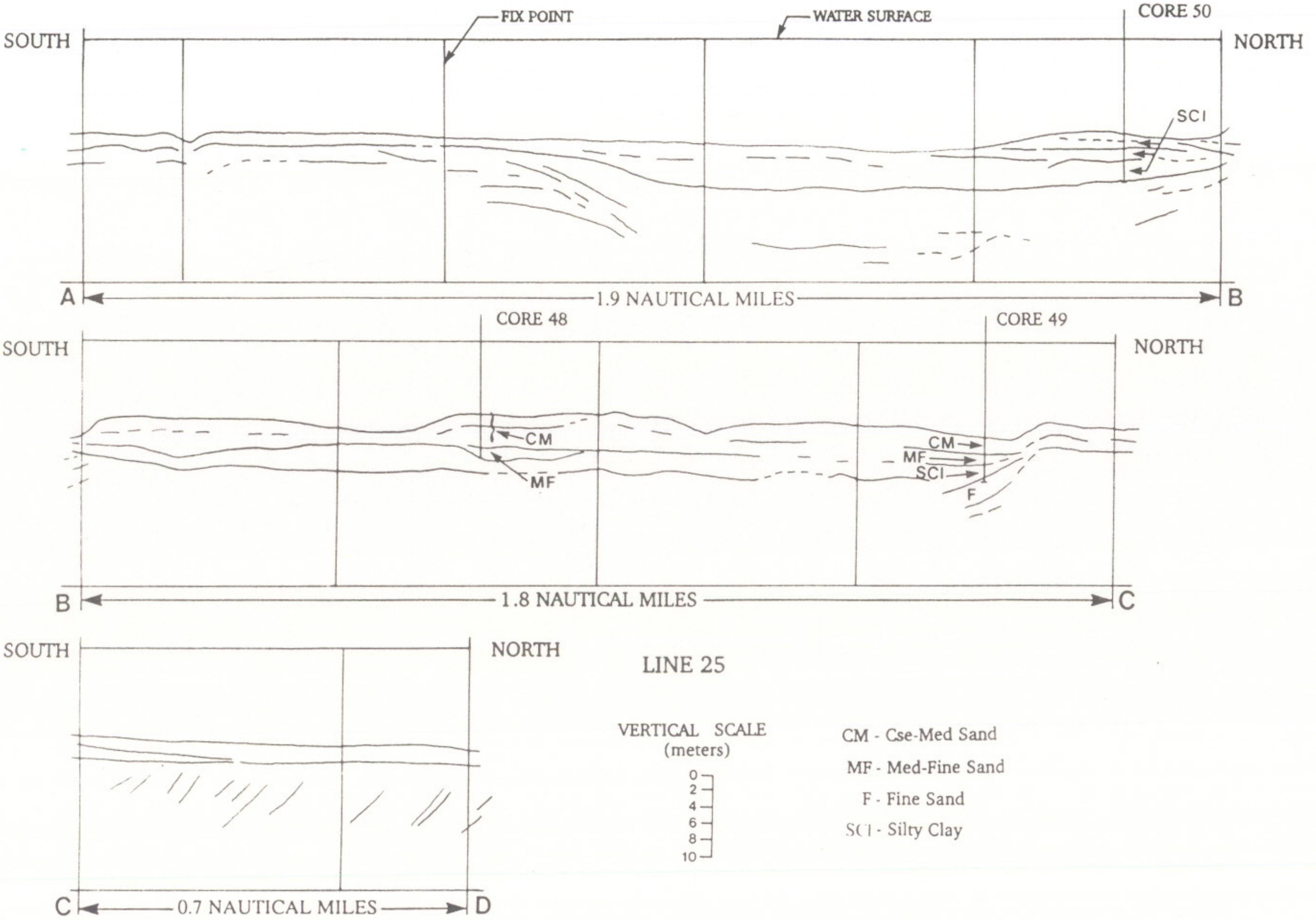

CORE 46
WEST
EAST
A
1.9 NAUTICAL MILES
B
CORE 47
CORE 48
WEST
EAST
LINE 20
VERTICAL SCALE
(meters)
0
2
4
6
8
10
B
1.3 NAUTICAL MILES
C
FIX POINT
WATER SURFACE
WEST
EAST
C
0.8 NAUTICAL MILES
D


LINE 21
1.4 NAUTICAL MILES
WATER SURFACE
WEST
EAST
A
B
1.2 NAUTICAL MILES
CORE 50
FIX POINT
SILTY CLAY
WEST
EAST
B
C
1.3 NAUTICAL MILES
WEST
EAST
C
D
1.3 NAUTICAL MILES
WEST
EAST
D
E
0
2
4
6
8
10
VERTICAL SCALE (meters)


LINE 21
1.4 NAUTICAL MILES
WATER SURFACE
WEST
EAST
A
B
1.2 NAUTICAL MILES
CORE 50
FIX POINT
WEST
EAST
B
C
1.3 NAUTICAL MILES
WEST
EAST
C
D
1.3 NAUTICAL MILES
WEST
EAST
D
E
0
2
4
6
8
10
VERTICAL SCALE (meters)

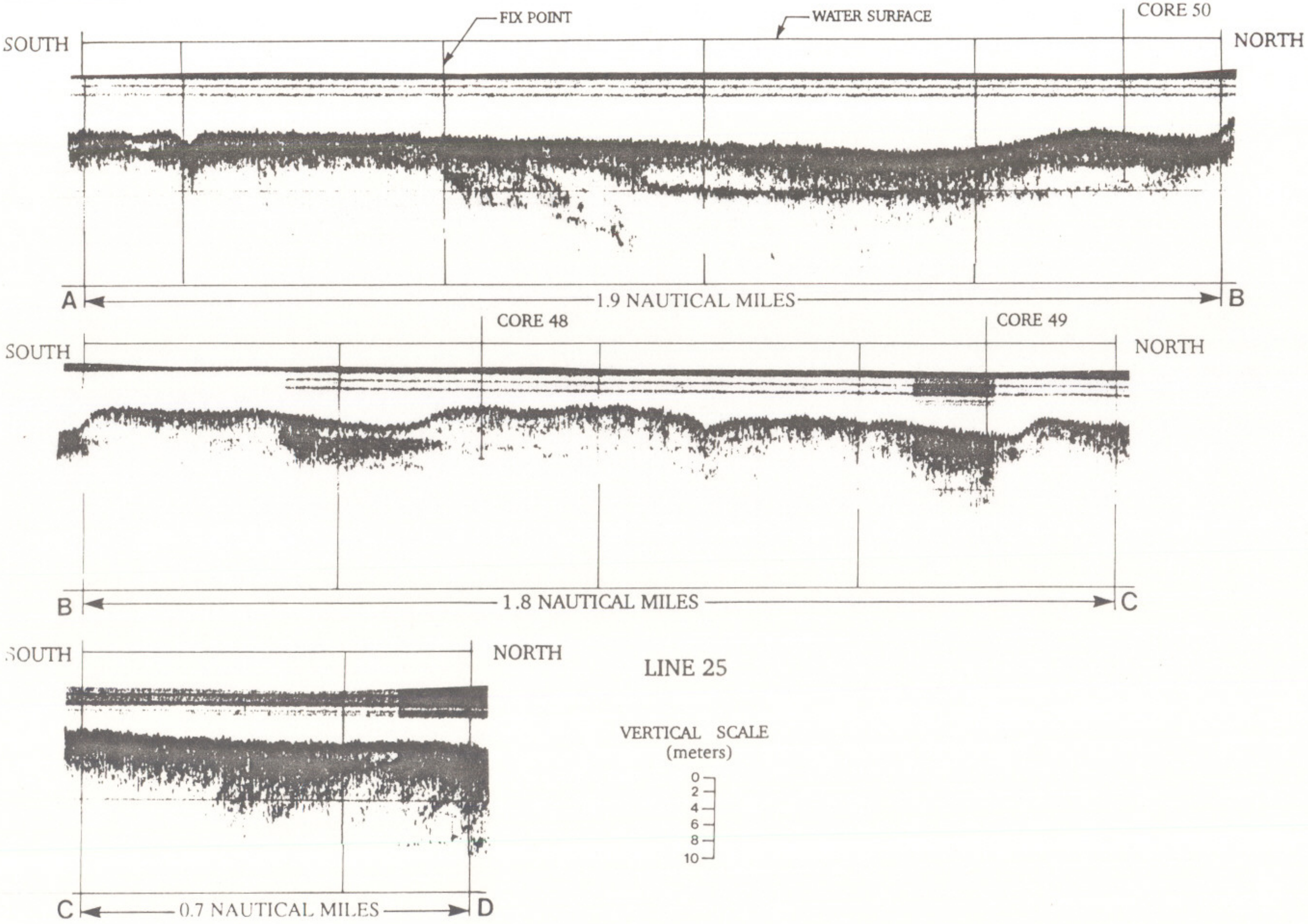

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
SOUTH
NORTH
LINE 24
B
1.0 NAUTICAL MILE
C
SOUTH
NORTH
C
0.9 NAUTICAL MILE
D
0
2
4
6
8
10
VERTICAL SCALE (meters)

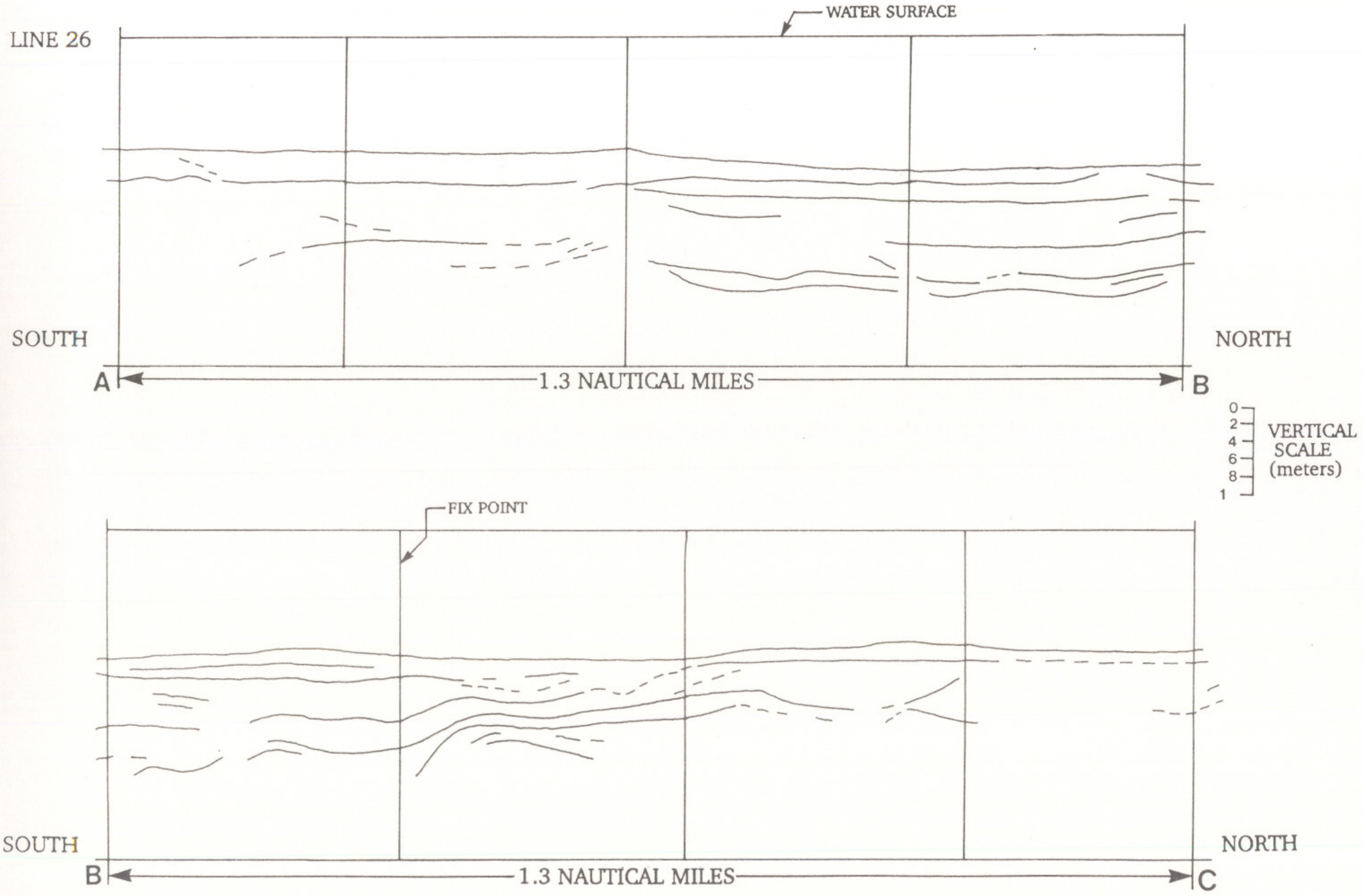

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
SOUTH
NORTH
LINE 24
B
1.0 NAUTICAL MILE
C
SOUTH
NORTH
0
2
4
6
8
10
VERTICAL SCALE (meters)
C
0.9 NAUTICAL MILE
D

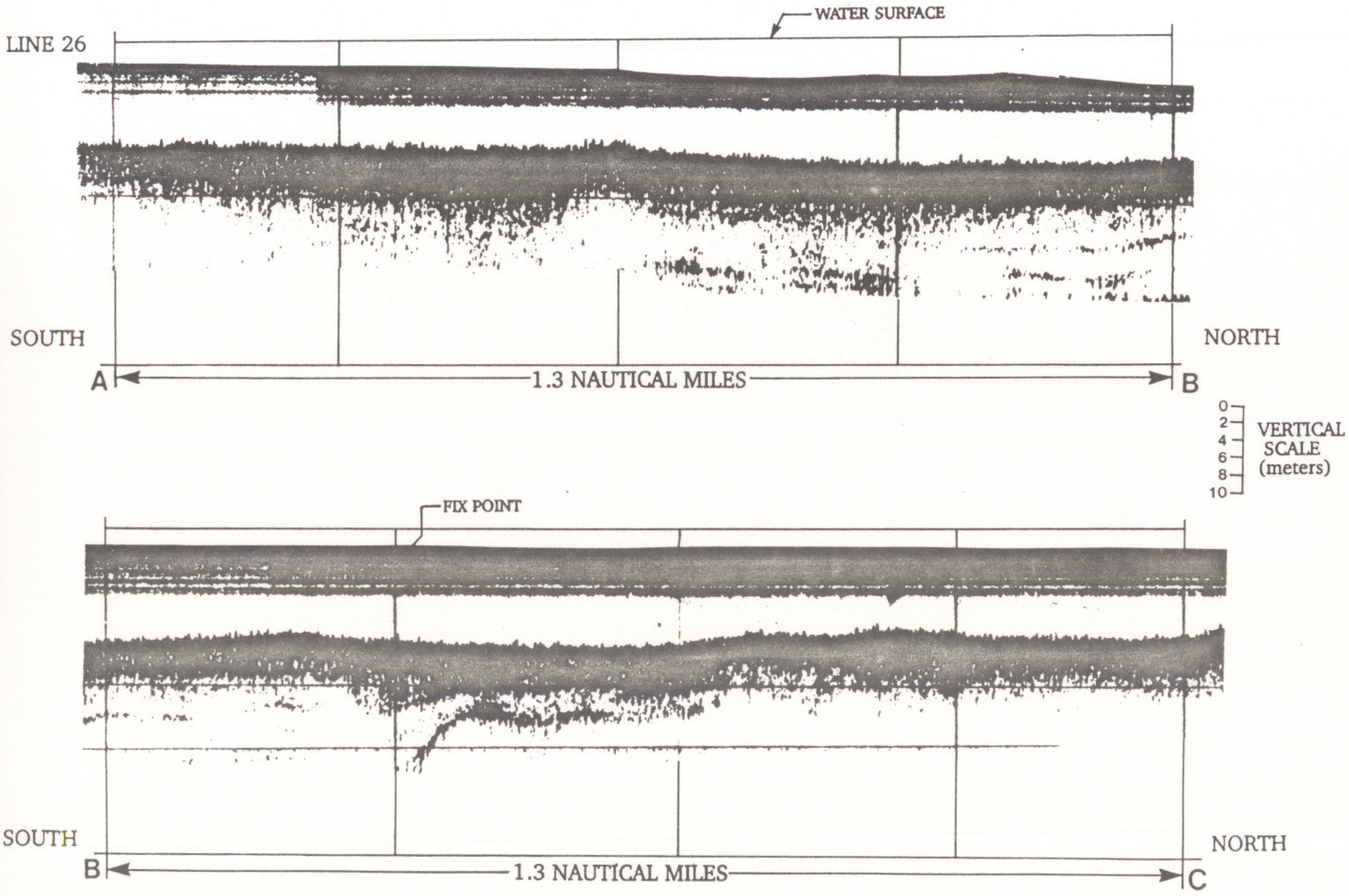


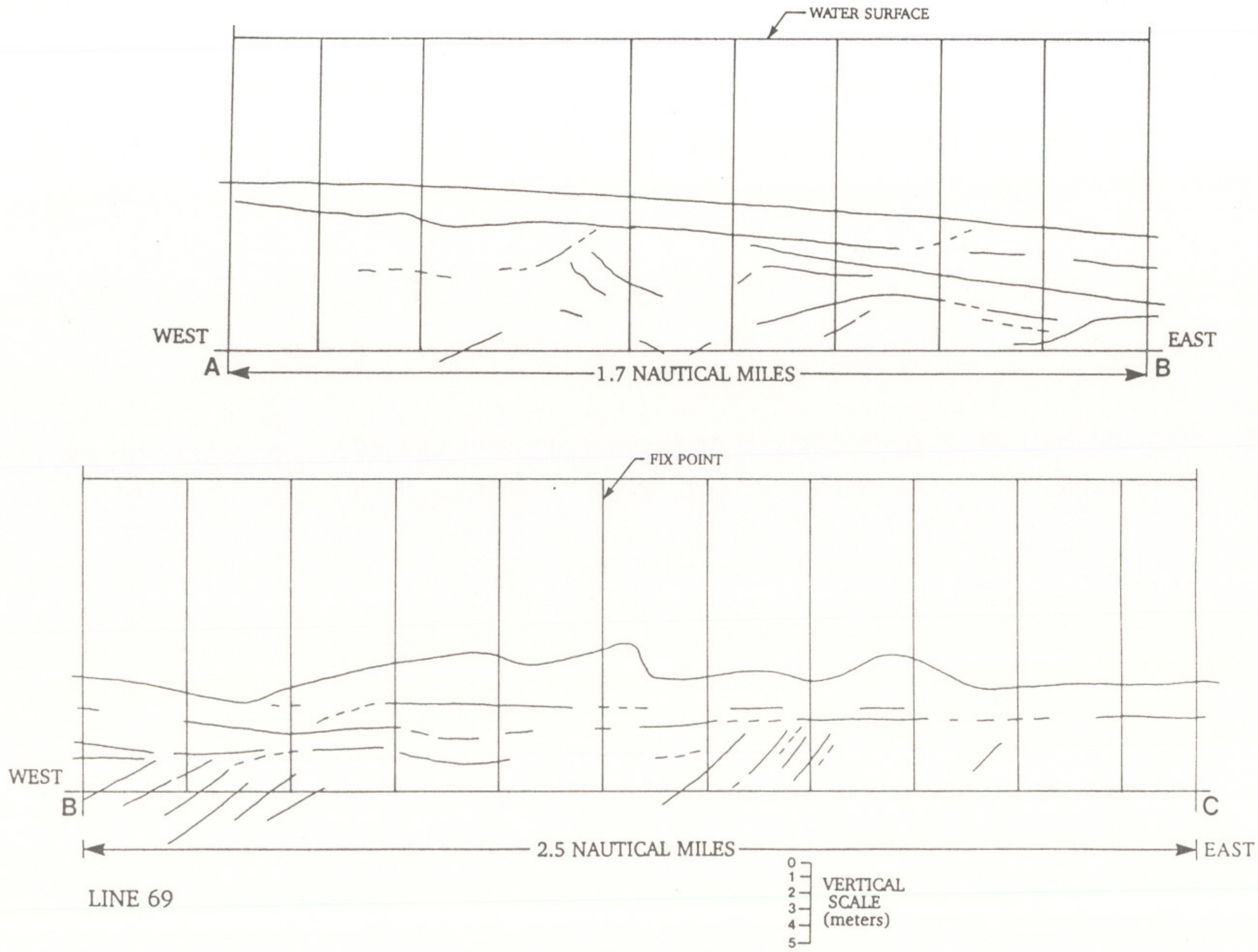
LINE 25

FIX POINT
WATER SURFACE
CORE 50
SOUTH
NORTH
SCl
A
1.9 NAUTICAL MILES
B
CORE 48
CORE 49
SOUTH
NORTH
CM
MF
CM
MF
SCl
F
B
1.8 NAUTICAL MILES
C
SOUTH
NORTH
C
0.7 NAUTICAL MILES
D
VERTICAL SCALE
(meters)
0
2
4
6
8
10
CM - Cse-Med Sand
MF - Med-Fine Sand
F - Fine Sand
SCl - Silty Clay

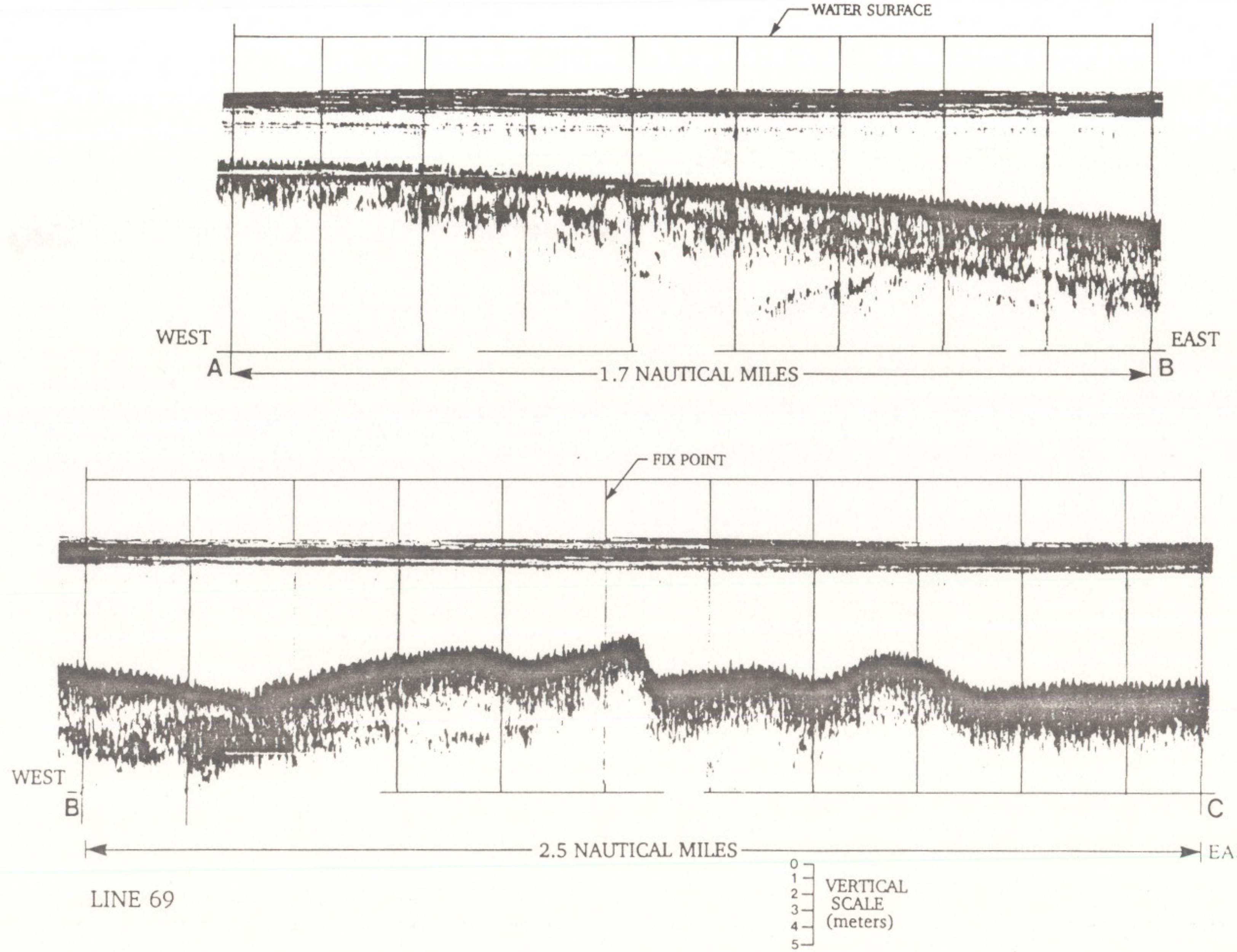

FIX POINT
WATER SURFACE
CORE 50
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B
CORE 48
CORE 49
SOUTH
NORTH
B
1.8 NAUTICAL MILES
C
SOUTH
NORTH
C
0.7 NAUTICAL MILES
D
LINE 25
VERTICAL SCALE
(meters)
0
2
4
6
8
10


LINE 26
WATER SURFACE
SOUTH
NORTH
A
1.3 NAUTICAL MILES
B
0
2
4
6
8
1
VERTICAL SCALE (meters)
FIX POINT
SOUTH
NORTH
B
1.3 NAUTICAL MILES
C

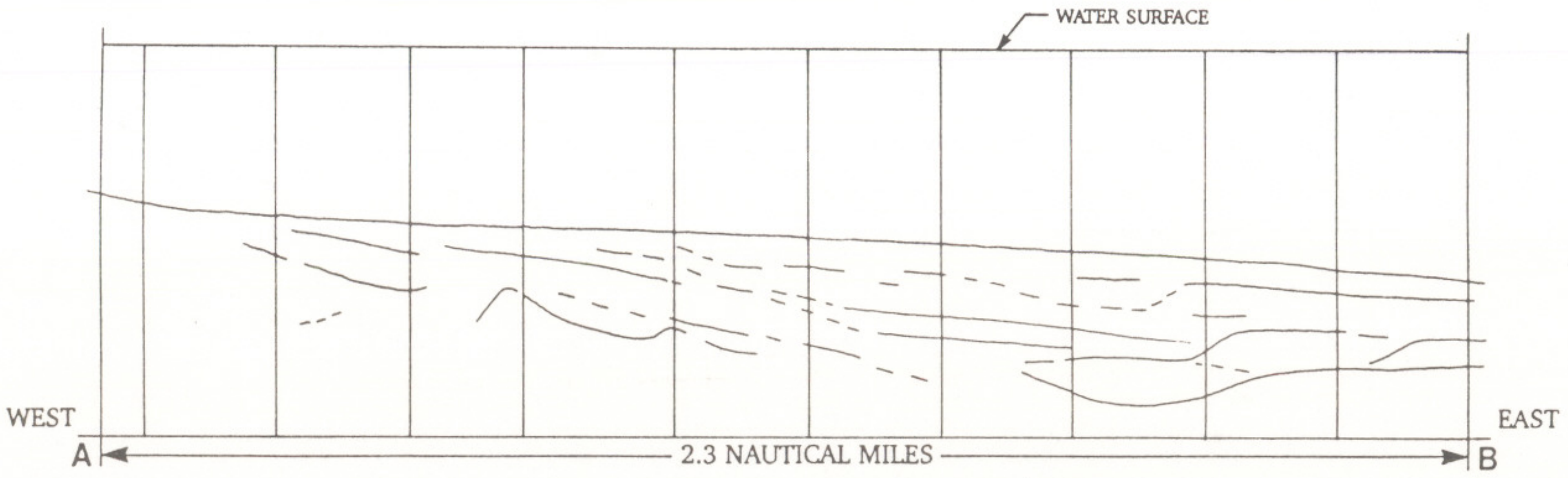

WATER SURFACE
LINE 26
SOUTH
NORTH
A
1.3 NAUTICAL MILES
B
0
2
4
6
8
10
VERTICAL SCALE (meters)
FIX POINT
SOUTH
NORTH
B
1.3 NAUTICAL MILES
C

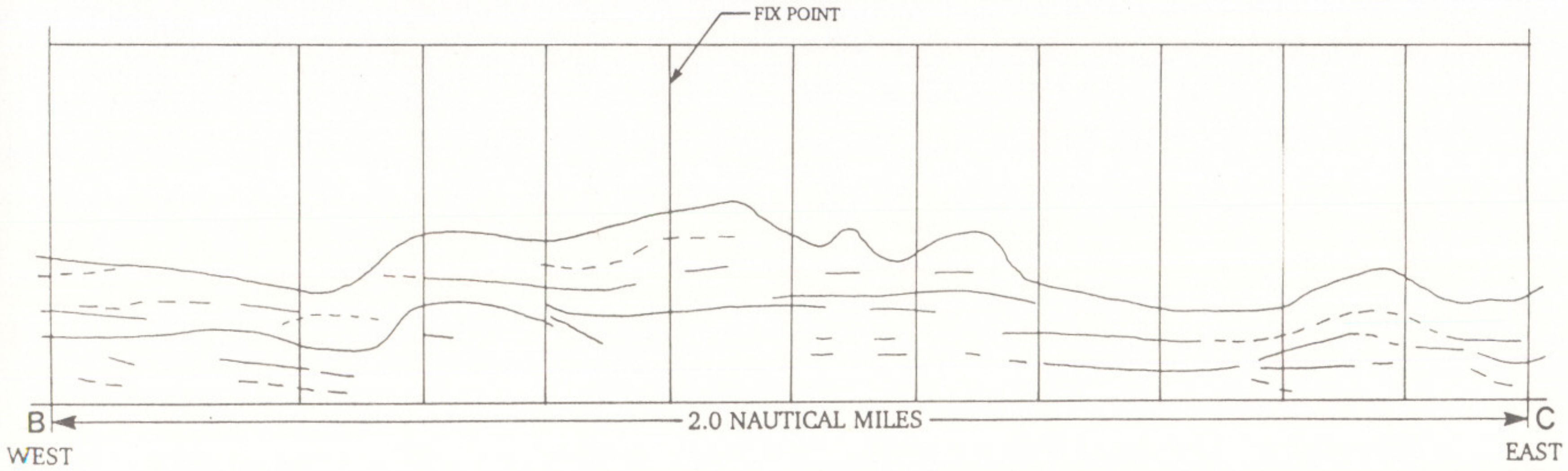

WATER SURFACE
WEST
EAST
A
B
1.7 NAUTICAL MILES
FIX POINT
WEST
B
C
2.5 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL SCALE (meters)

LINE 69


WATER SURFACE
WEST
EAST
A
B
1.7 NAUTICAL MILES
FIX POINT
WEST
B
C
2.5 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL SCALE (meters)

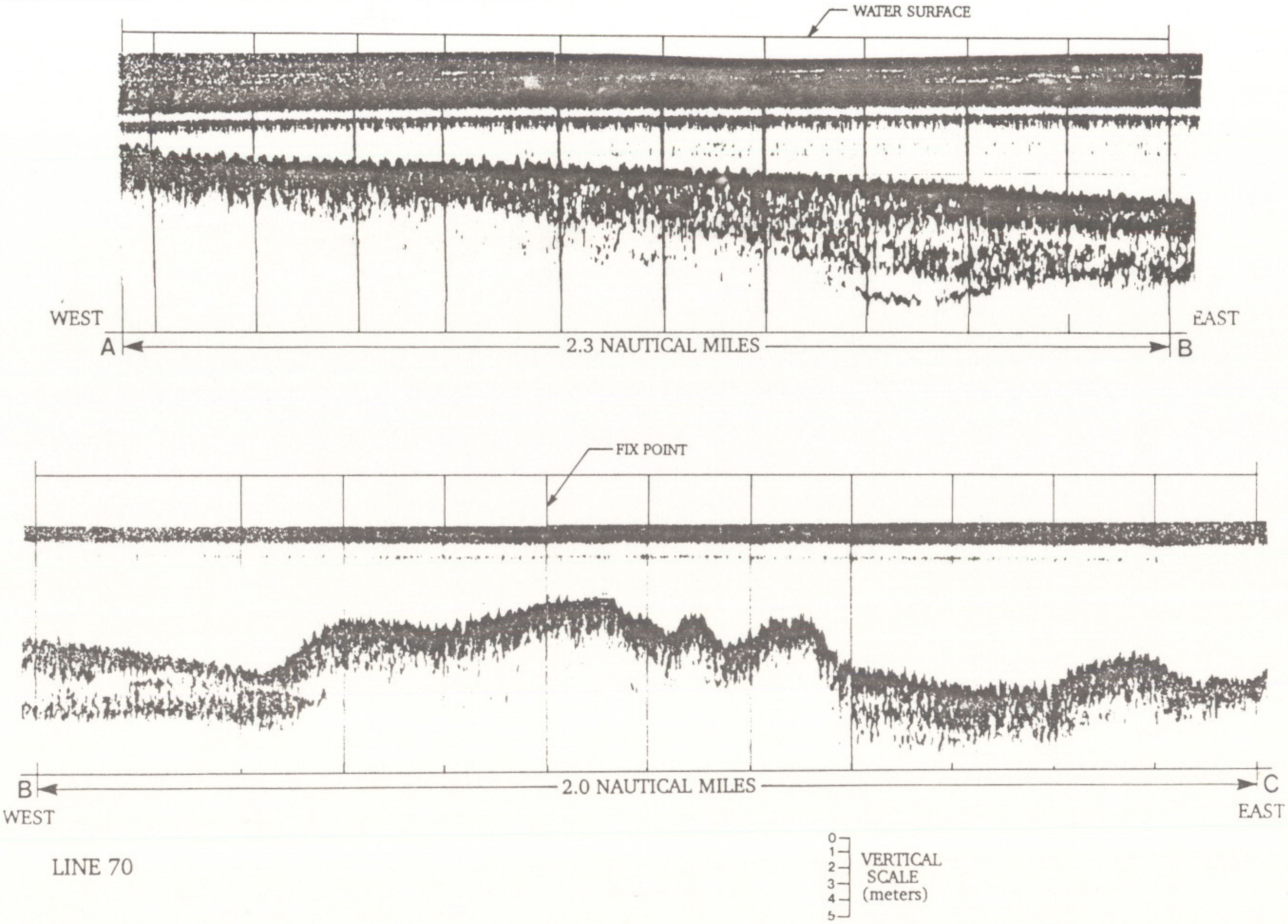
LINE 69


WATER SURFACE
WEST
EAST
A
2.3 NAUTICAL MILES
B

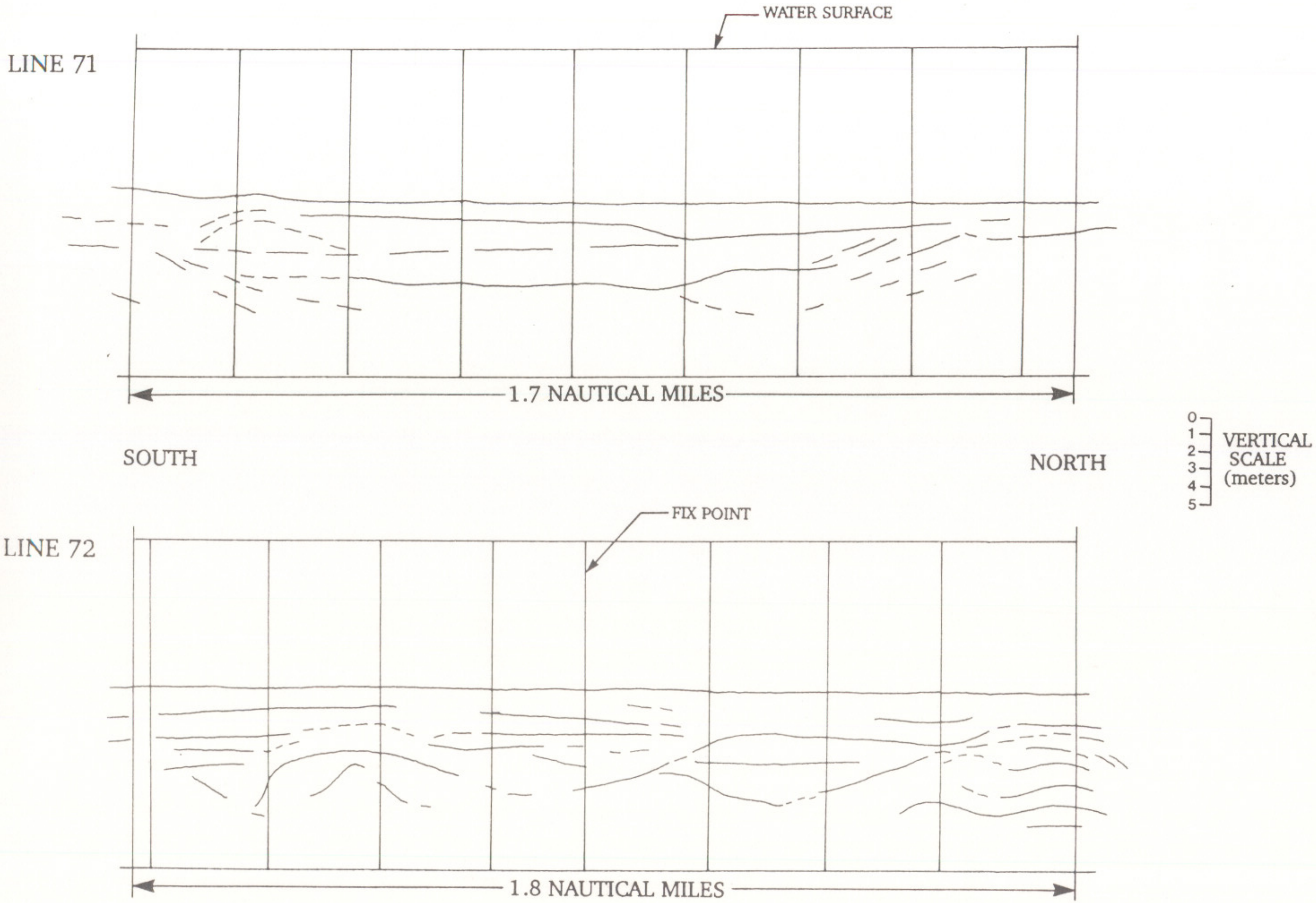

FIX POINT
B
2.0 NAUTICAL MILES
C
WEST
EAST

LINE 70

0
1
2
3
4
5
VERTICAL SCALE (meters)

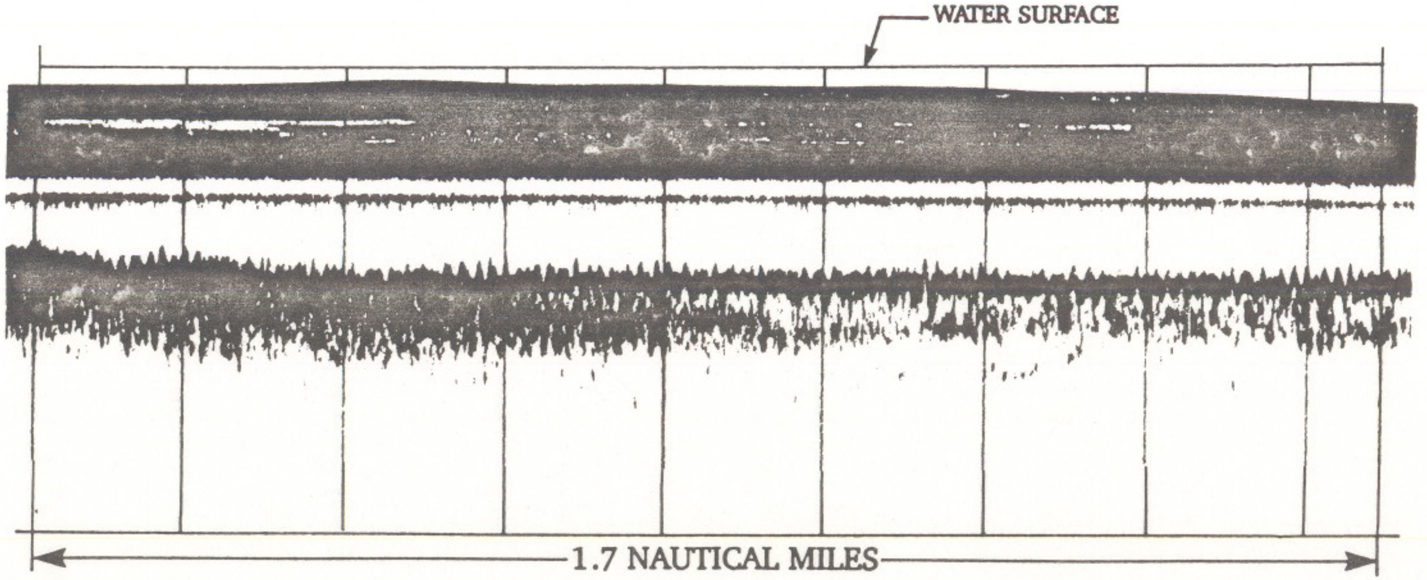

WATER SURFACE
WEST
EAST
A
B
2.3 NAUTICAL MILES
FIX POINT
B
C
2.0 NAUTICAL MILES
WEST
EAST
0
1
2
3
4
5
VERTICAL SCALE (meters)

LINE 70

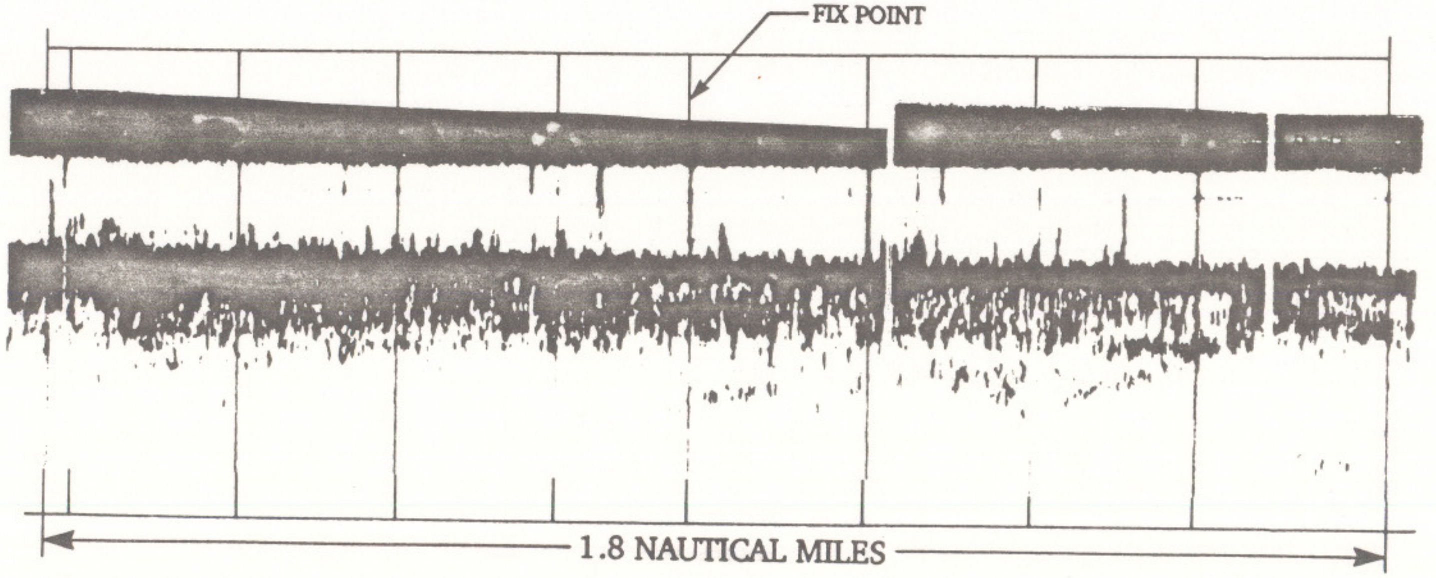


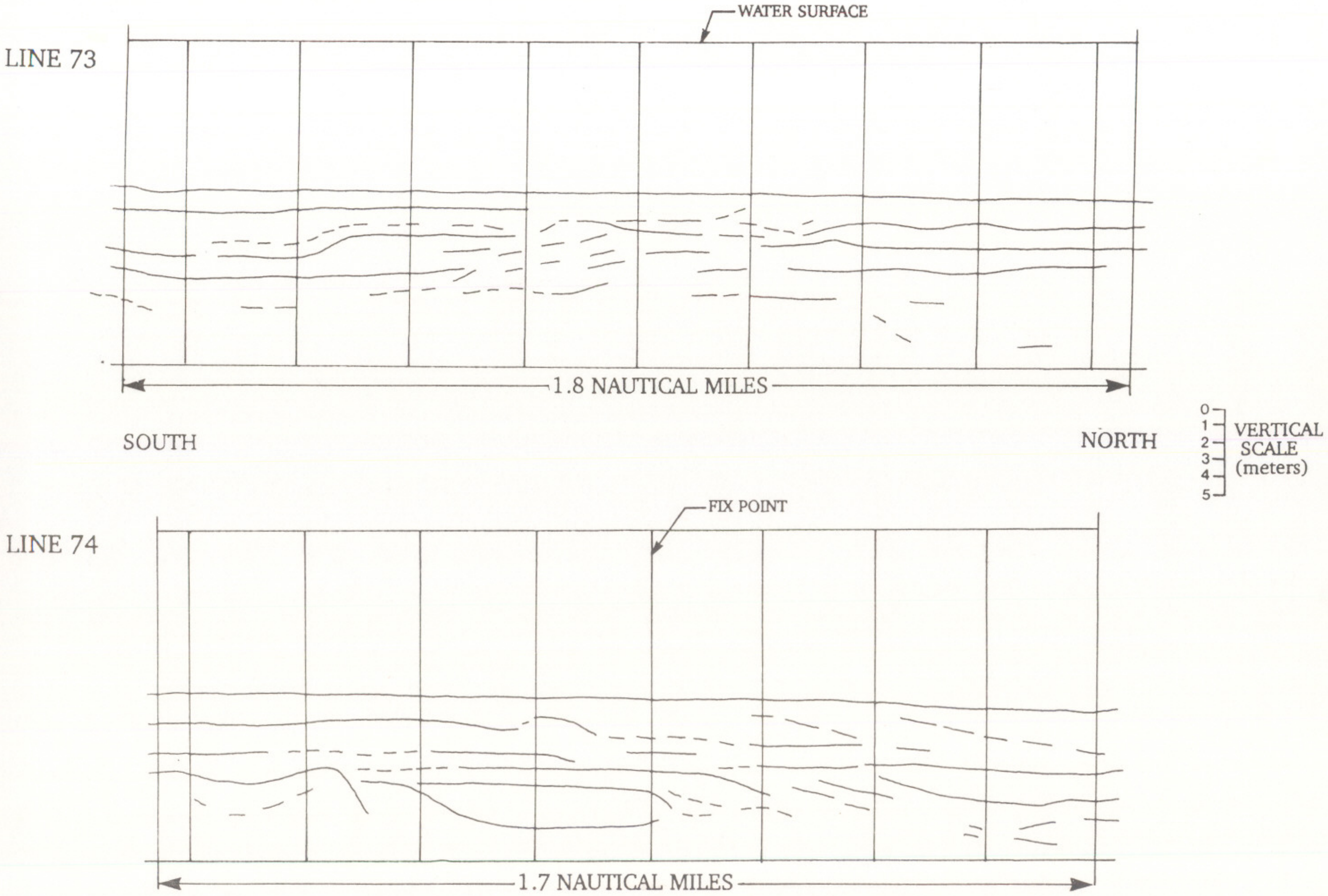
LINE 71
WATER SURFACE
1.7 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
LINE 72
FIX POINT
1.8 NAUTICAL MILES

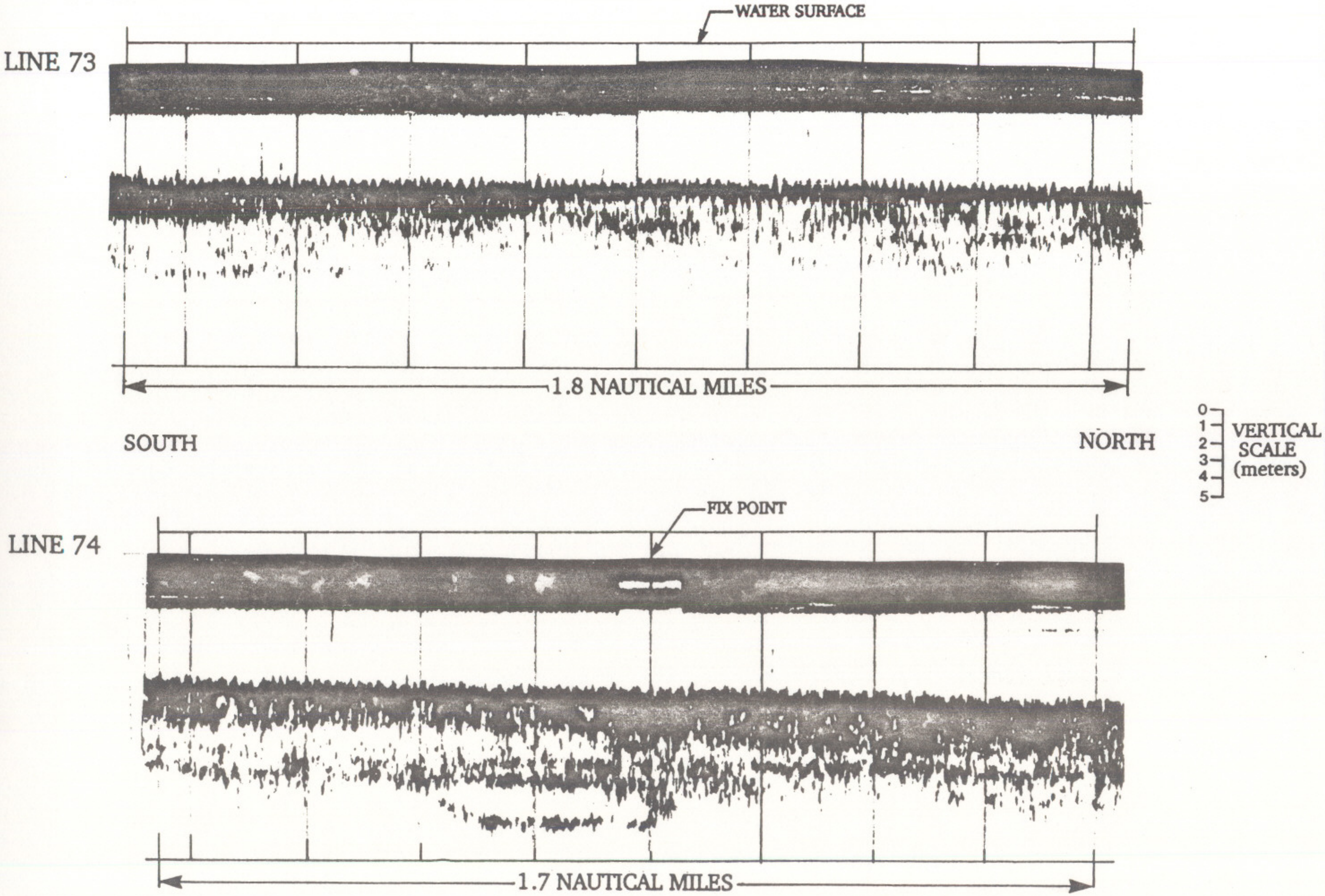
LINE 71



LINE 72

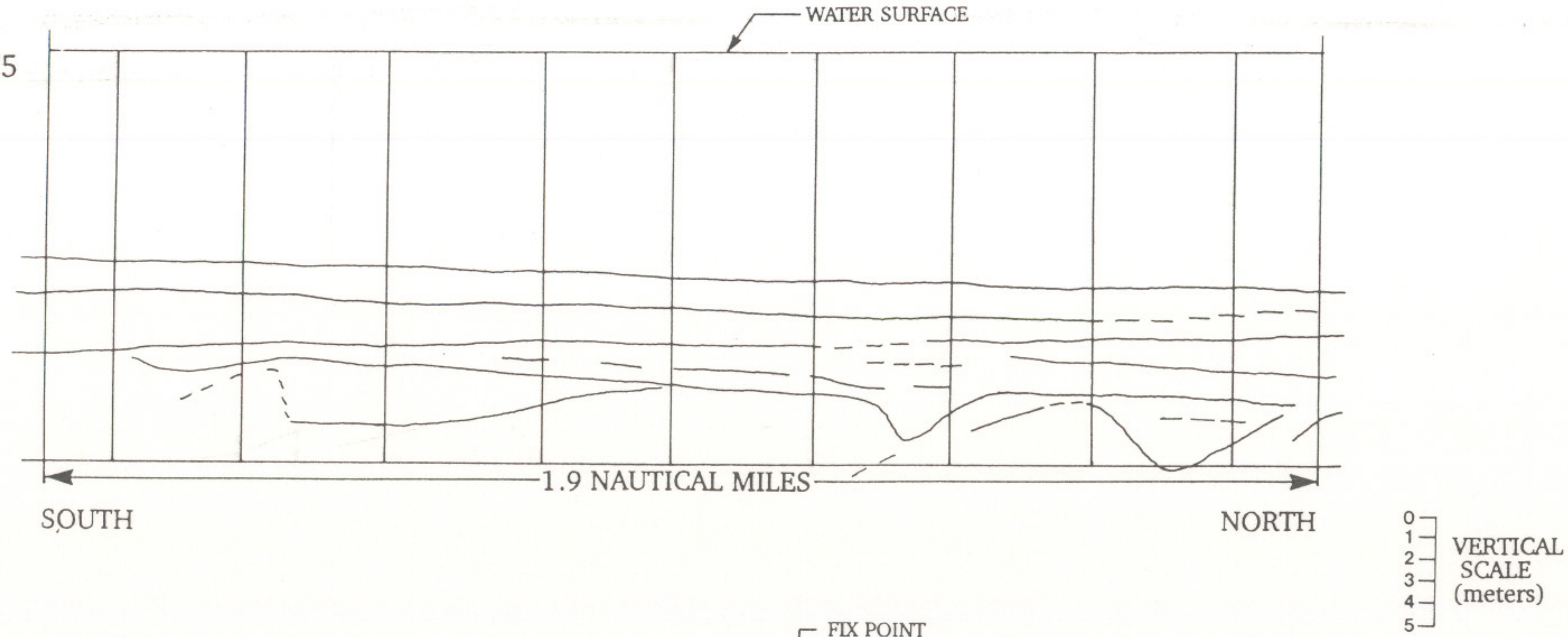



WATER SURFACE
LINE 73
1.8 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
FIX POINT
LINE 74
1.7 NAUTICAL MILES

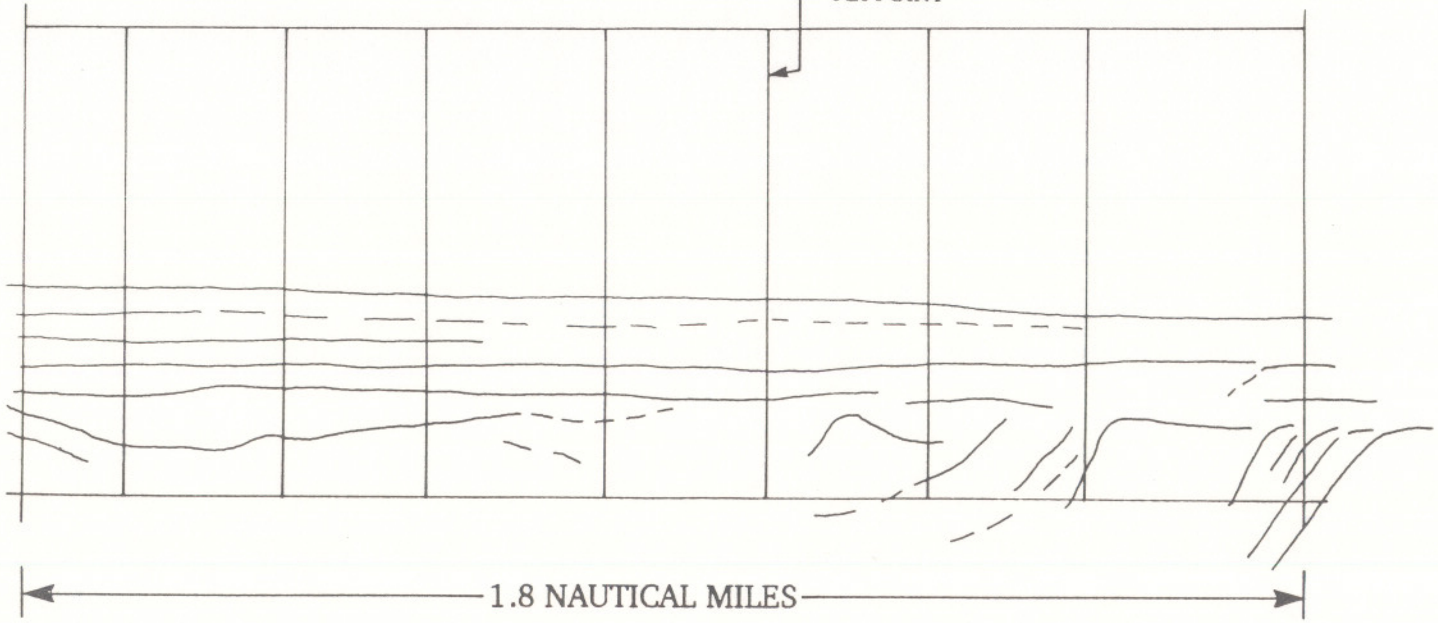


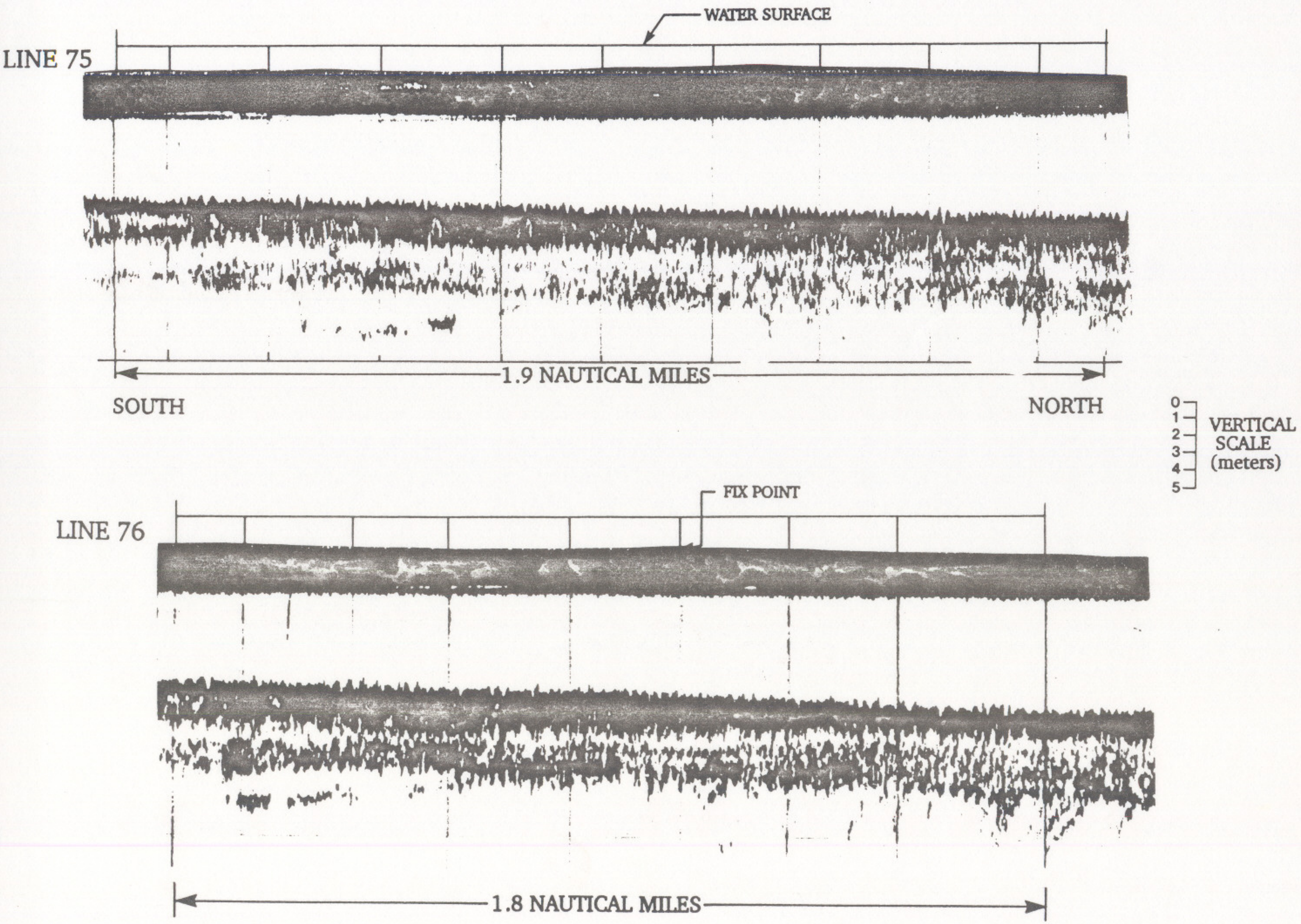
WATER SURFACE
LINE 73
1.8 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
FIX POINT
LINE 74
1.7 NAUTICAL MILES

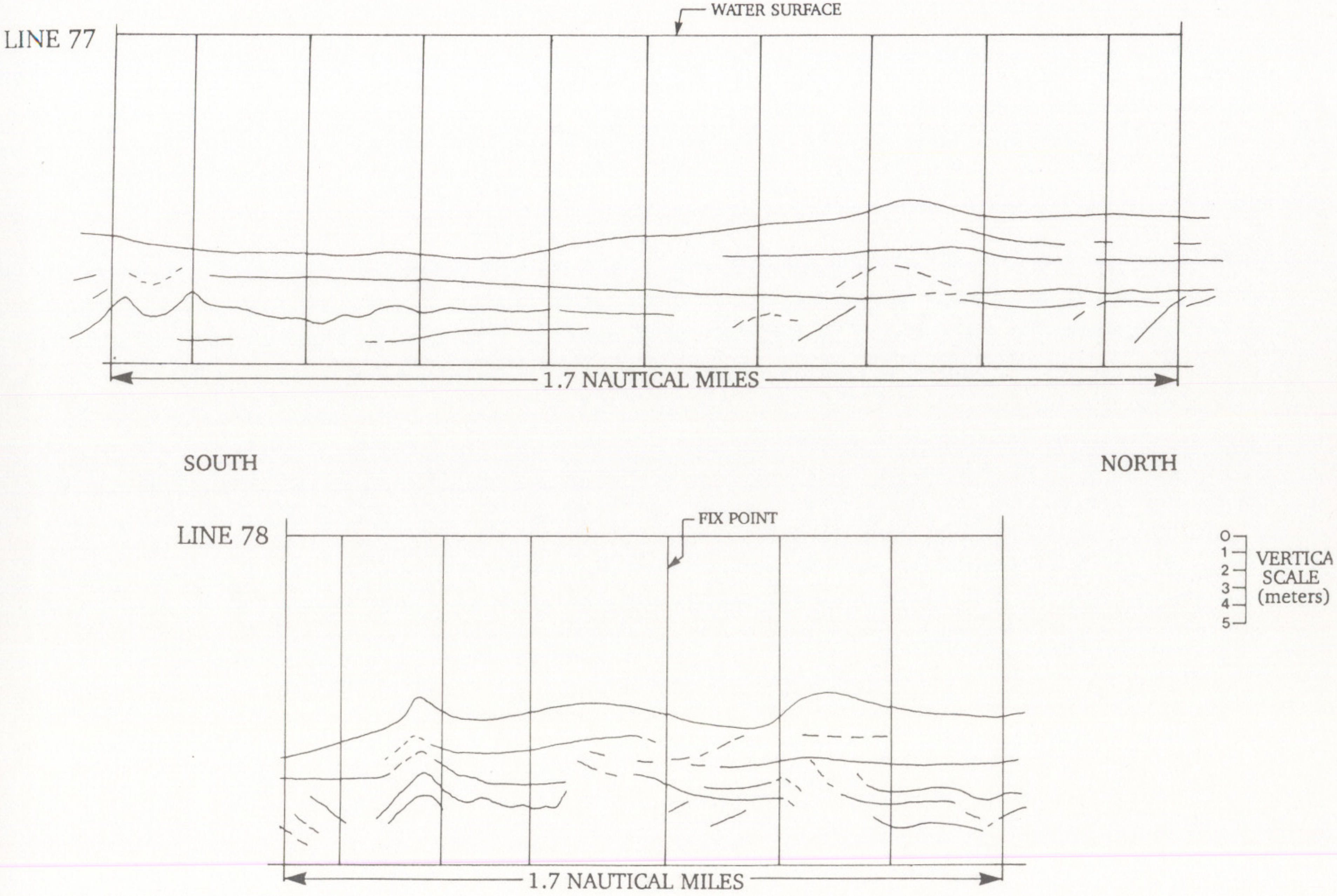
LINE 75

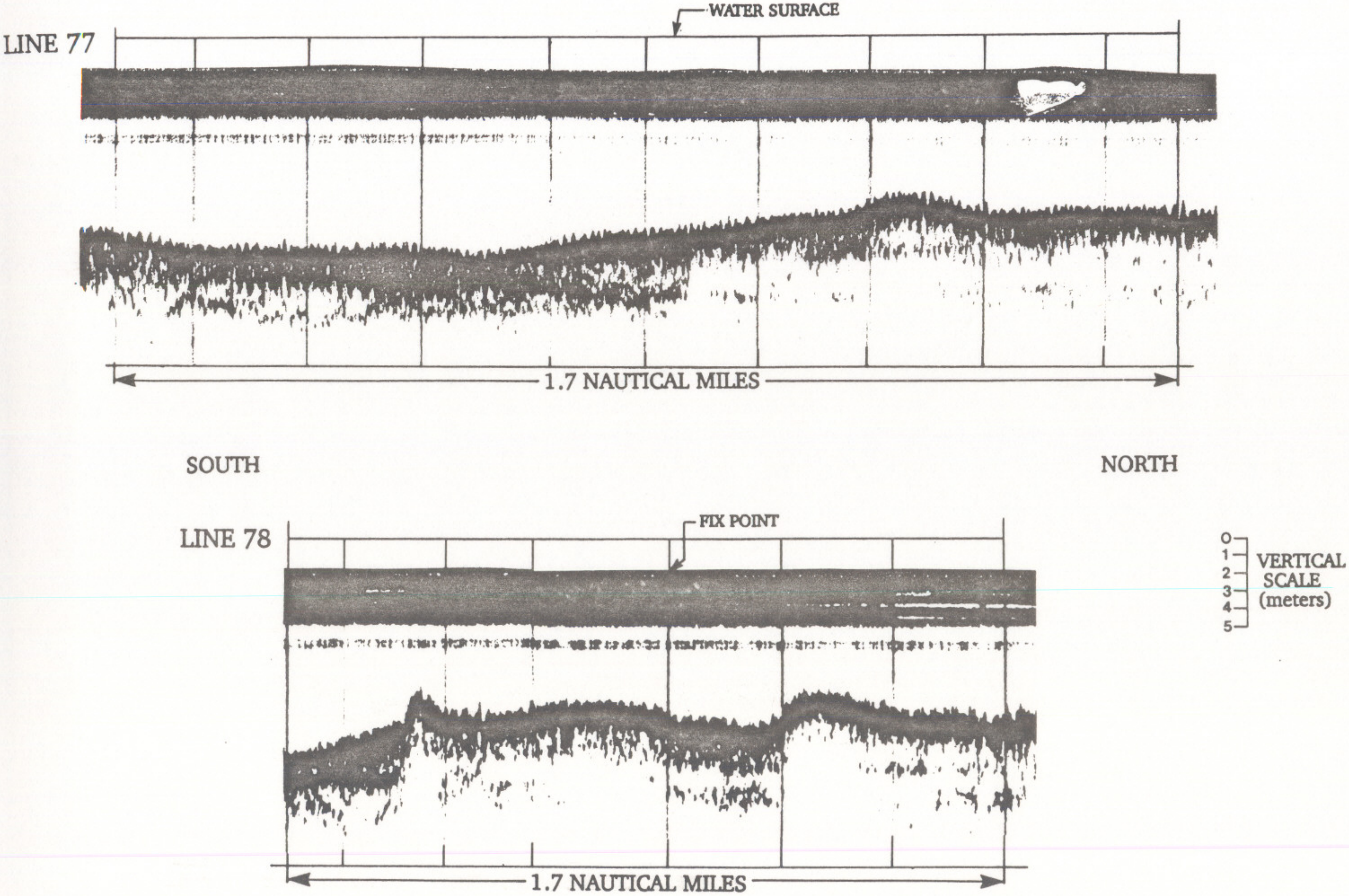


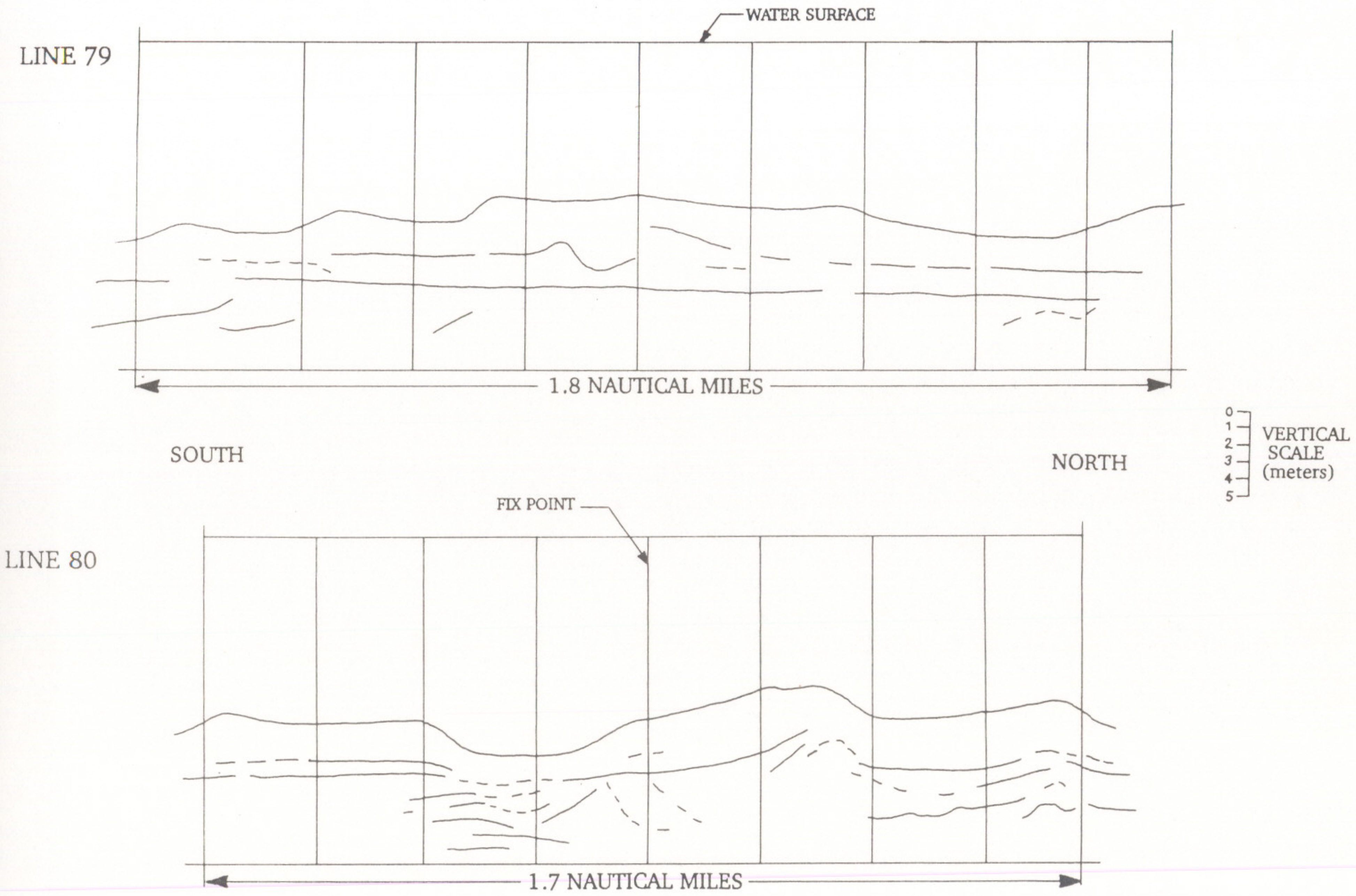
LINE 76

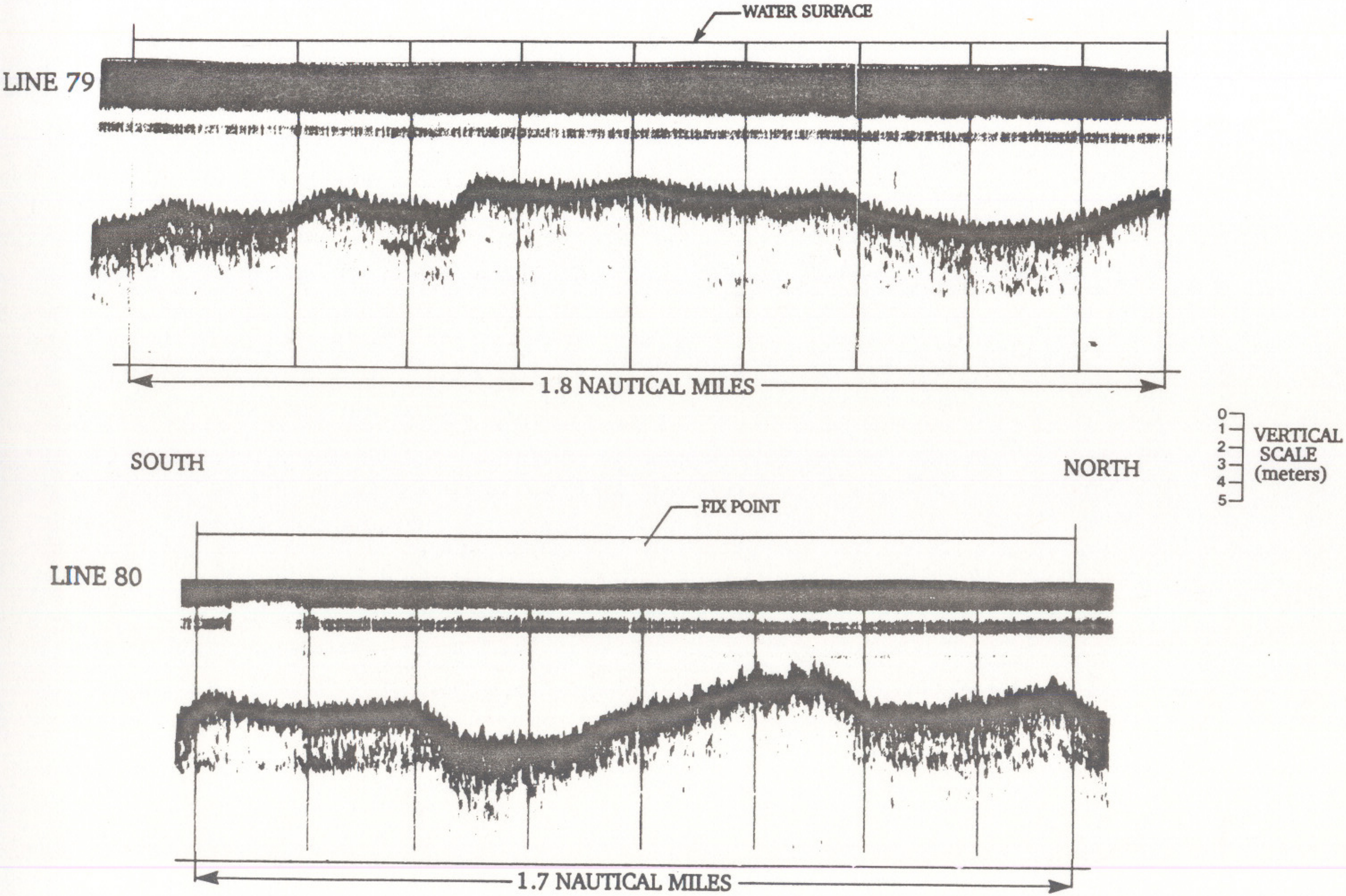



LINE 75
WATER SURFACE
1.9 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
LINE 76
FIX POINT
1.8 NAUTICAL MILES


LINE 77
WATER SURFACE
1.7 NAUTICAL MILES
SOUTH
NORTH
LINE 78
FIX POINT
1.7 NAUTICAL MILES
0
1
2
3
4
5
VERTICA
SCALE
(meters)


LINE 77
WATER SURFACE
1.7 NAUTICAL MILES
SOUTH
NORTH
LINE 78
FIX POINT
0
1
2
3
4
5
VERTICAL SCALE (meters)
1.7 NAUTICAL MILES


WATER SURFACE
LINE 79
1.8 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
FIX POINT
LINE 80
1.7 NAUTICAL MILES


WATER SURFACE
LINE 79
1.8 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
FIX POINT
LINE 80
1.7 NAUTICAL MILES

APPENDIX B

Sediment core logs describing those vibracores taken in the vicinity of Sandbridge Shoal and on the offshore shoal. Core locations are shown in Figure 5. Stratigraphic unit names (Remarks columns) and amino acid age determinations are described in Tables 3 and 4, respectively.

LOG OF VIBRACORE

CORE 06 SEPT. 29, 1989 **DEPTH: 13.1 m**

LORAN: 27130.0, 41165.0 LAT/LON: 36 45.25 N, 75 53.54 W

Composite of two runs (R1,R2) with total PENETRATION = 6.10 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00			Micaceous, very fine, sandy silt with widely scattered shell fragments. Top 15 cm is fluid.	UNIT QP4 Upper Pleistocene estuarine clay and silt
0.50				
			Becomes clayey silt with some fine sand.	
1.00			high concentration of clam shells, up to 4 cm	
			Becomes silty clay with scattered shell fragments.	
1.50				
			Muddy fine to medium sand with fragments up to 4 cm.	
			Silty clay with pods and stringers of fine to very fine, silty sand.	R1: pen. 3.35 m rec. 3.88 m
2.00				
2.50				
			sandy silt lense with several subangular, white, quartzitic, coarse gravel	
		#7 AA	Silty coarse sand with some subrounded gravel and pods of fine sandy silt.	UNIT QPU Upper Pleistocene undivided
3.00				
			becomes medium to fine sand	
		s-1	becomes coarser, mostly medium sand	#7 MSL -16.0 m
3.50				*Mercenaria:* AA = 112 ka +22 -11
			begin to have scattered shell fragments with some fibrous "woody" material	
			Silty clay with occasional stringers and pods of silty medium to fine sand. Stringers up to 1 cm thick. Infrequent layers (5 - 10 cm thick) of widely scattered, very fine, shell fragments. Dark Greenish Gray 5GY 4/1	
4.00				
4.50				
5.00				R2: jet to 3.35 m vib. to 6.10 m rec. 3.70 m
			stringers more infrequent and contain mostly silt	
5.50				
6.00				BOTTOM @ 6.10 m

LOG OF VIBRACORE

CORE 07
SEPT. 29, 1989
DEPTH: 12.8 m
LORAN: 27128.5, 41167.5
LAT/LON: 36 45.44 N, 75 53.21 W
Composite of two runs (R1,R2) with total PENETRATION = 6.10 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00	░	s-2	Coarse sand with some medium sand and gravel. Loosely packed with abundant shell fragments. Yellowish Gray 5Y 7/2	UNIT QH2 Upper unit of Sandbridge Shoal
0.50 1.00	░	s-3	Medium sand with some coarse sand and very widely scattered shell fragments. More tightly packed. Alternating layers of Light Olive Gray, 5Y 6/2, and Olive Gray 5Y 5/2. layer of coarse sand and shell fragments, 5 cm thick layering of color diminishes, becomes Light Olive Gray	R1: pen. 4.88 m rec. 3.78 m #8 MSL -14.4 m
1.50	░	s-4 #8 AA	becomes coarser shelly, gravelly layer	*Mulinia:* AA = 60 - 80 ka
	⁘	s-5	Medium to fine sand, siltier with depth. Dark Gray 5Y 4/1 Some cross-bedding, but not well developed.	UNIT QP5 Lower unit
	⁘	s-6 #9 AA	Silty fine to very fine sand. Olive Black 5Y 2/1 Shell layer & shell hash at base in clayey, sandy, silt matrix.	Sandbridge Shoal
2.00	≡		Silty clay with pods and lenses of silty sand. Clay is Dark Gray, 5Y 4/1, and sand is Light Gray, N7. clay becomes Grayish Olive 10Y 4/2	UNIT QP4 Upper Pleistocene estuarine clay and silt #9 MSL -14.7 m
2.50	≡	S-7	Med-cse sand, yellow gray to orange brown, inclined 50 .	*Mulinia:*
	≡		Silty clay layer, inclined approximately 30 .	AA = 60 - 80 ka
	≡	S-8	Medium sand, yellow gray to orange brown, inclined 20 .	
3.00	≡		Silty clay with pods and lenses of silty sand. Above 3.0 m lenses are inclined. Clay is Dark Gray, sand is Light Gray	#10 MSL -16.4 m *Pitar:*
3.50	≡	#10 AA	Abundant clam shells in very silty, medium to coarse sand matrix.	AA = 88 ka +17 -14
4.00 4.50 5.00 5.50	▨		Muddy, medium to coarse sand interbedded with silty clay. Sandy layers contain shell material (mostly clam shells), and the clay layers have lenses and pods of silty fine sand. Dark Gray 5Y 4/1	UNIT QPU Upper Pleistocene undivided R2: jet to 3.68 m vib. 6.10 m rec. 3.0 m
6.00	▨		Silty fine to very fine sand with silt lenses, very compact. Upper contact, 10 cm layer of medium to fine sand, inclined approximately 30 . Dark Gray 5Y 4/1	BOTTOM @ 6.10 m

LOG OF VIBRACORE

CORE 09
SEPT. 29, 1989
DEPTH: 13.3 m
LORAN: 27122.5, 41167.5
LAT/LON: 36 45.22 N, 75 51.83 W
Composite of two runs (R1,R2) with total PENETRATION = 5.33 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00	░	s-1	Medium to fine sand. Pale Yellowish Brown 10YR 6/2 coarser layer 5cm thick	UNIT QH2 Upper unit of Sandbridge Shoal
0.50	░			
	░			R1: pen. 5.33 m rec. 4.25 m
1.00	░			
	░		becomes Olive Black 5Y 2/1 in pods and layers	
1.50	░			
	░	s-2 #11 AA	becomes finer and more homogeneous in color, Dark Gray 5Y 4/1	#11 MSL -15.2 m *Spisula:* AA < 2 ka
2.00	▨	#12 AA/RC	Silty to sandy clay with gravel and shells at base.	
	▨	s-3	Medium to fine sand with pods and laminations of very silty fine sand and silty clay. Coarser sand is Light Gray, N7, and fine sand and clay is Olive Black, 5Y 2/1.	UNIT QPU Upper Pleistocene undivided
2.50	▨			#12 MSL -15.4 m *Mercenaria:* AA = 91 ka +18 -15 RC > 38.5 ka
3.00	▨	s-4		
3.50	▨			R2: jet to 3.68 m vib. to 4.59 m rec. 0.91 m
4.00	▨	s-5	concentration of clam shell fragments with occasional gravel	
4.50	▨		very fine sandy silt layer	BOTTOM @ 4.59 m
5.00				
5.50				
6.00				

LOG OF VIBRACORE

CORE 46
LORAN: 27135.1, 41159.9
PENETRATION: 5.82 m

AUGUST 02, 1987
LAT/LON: 36 45.02 N, 75 55.00 W
RECOVERY: 6.10 m

DEPTH: 11.0 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00 0.50	░	s-1	Fine micaceous sand with scattered shell fragments. Dark Gray 5Y 4/1	UNIT QH1 Holocene sand sheet
	░	s-2	Coarse shelly sand with silty clay.	
1.00	░	s-3	Silty clay and silty sand laminations.	
1.50	░	s-4	Medium sand with scattered shell fragments. Dark Gray 5Y 4/1	
	░	s-5	shell hash 6 cm thick, becomes Gray 5Y 5/1	
2.00 2.50 3.00	▤	s-6	Silty clay with 2 to 10 cm thick laminations of fine sand. Gray 5Y 5/1 shell hash with fine sand 5 cm thick	UNIT QP4 Upper Pleistocene estuarine clay & silt
3.50 4.00 4.50	▤	s-7	coarse sand 5 cm thick	
	▤	s-8 #1 AA		#1 MSL -15.7 m *Mercenaria:* AA = 64 ka +13 -11
5.00	▨	s-9	Coarse sand layer (5 cm thick) over medium sand with scattered shell fragments. Dark Gray 5Y 4/1 Medium to fine sand with silty clay laminations up to 2 cm thick.	UNIT QPU Upper Pleisotcene undivided
5.50	▨	s-10	Coarse sand with abundant shell fragments. silty clay layer 2 cm thick	
6.00	▨	s-11	Medium to fine sand with scattered shell fragments.	BOTTOM @ 6.10 m

LOG OF VIBRACORE

CORE 47
LORAN: 27130.0, 41159.9
PENETRATION: 4.15 m

AUGUST 02, 1987
LAT/LON: 36 44.81 N, 75 53.82 W
RECOVERY: 3.55 m

DEPTH: 12.0 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00	░	s-1	Fine to very fine micaceous sand. Very Dark Gray 5Y 3/1	UNIT QH1 Holocene sand sheet
0.50	▤		Slightly silty clay with coarse to fine sand laminations 1 to 5 cm thick. Dark Gray 5Y 4/1	UNIT QP4 Upper Pleistocene estuarine clay and silt
1.00	▤	s-2		
1.50	▤	#2 AA/RC		#2 MSL -13.6 m *Mercenaria:* AA = 81 ka +16 -11 RC > 42.7 ka
2.00	▤	s-3		
2.50	▒	s-4 #3 AA	Coarse shelly sand with shell fragments up to 5 cm. silty clay layer 5 cm thick	UNIT QP3 Upper Pleistocene tidal channel sands
3.00	▒	s-5	Medium to coarse sand with scattered shell and trace of subangular gravel. Gray 5Y 5/1	#3 MSL -14.8 m *Astarte:* AA = 70 ka +14 -11
3.50				BOTTOM @ 3.55 m
4.00				
4.50				
5.00				
5.50				
6.00				

LOG OF VIBRACORE

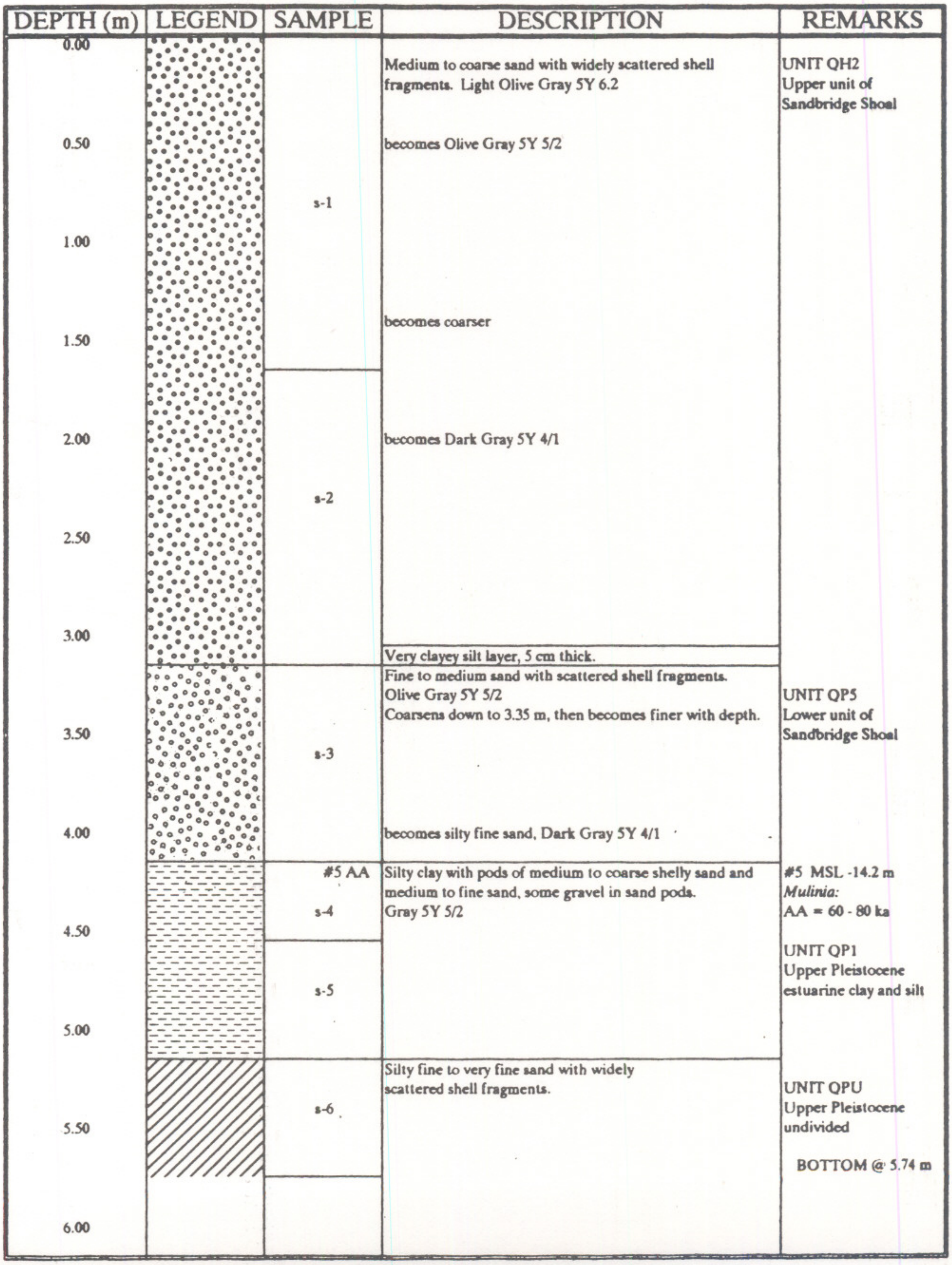
CORE 48
AUGUST 02, 1987
DEPTH: 8.8 m
LORAN: 27135.1, 41160.0
LAT/LON: 36 44.61 N, 75 52.66 W
Composite of three runs (R1,R2,R3) with total PENETRATION = 5.79 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00	⁘	R1 s-1	Medium to coarse sand with scattered shell fragments. Light Olive Brown 2.5Y 4/4	UNIT QH2 Upper unit of Sandbridge Shoal
0.50				R1: pen. 2.22 m rec. 2.10 m
1.00		R1 s-2	becomes fine to coarse sand with fewer shell fragments Olive Gray 5Y 4/2	
1.50				
2.00				R2: jet to 1.92 m vib. to 4.39 m rec. 3.99 m
2.50		R2 s-1 (?)	becomes coarse to medium sand, Dark Gray 5Y 4/1	
3.00			begin medium to fine sand layers	
3.50		R2 s-2 (?)	becomes finer	
			Very fine sandy silt layer 5 cm thick.	
4.00	○		Medium to fine sand with widely scattered shell fragments. Coarsens downward and lightens in color. Olive Gray 5Y 4/2	UNIT QP5 Lower unit of Sandbridge Shoal
4.50		R3 s-1		R3: jet to 4.21 m vib. to 5.79 m rec. 1.22 m
		#4 AA	becomes coarse to medium very shelly sand Grayish Brown 2.5Y 5/2	#4 MSL -13.8 m *Mulinia:* AA = 60 - 80 ka
5.00	▩	R3 s-2	Medium to fine sand. Dark Gray 5Y 4/1	UNIT QP2 Upper Pleistocene bay-mouth or tidal shoal
5.50				BOTTOM @ 5.79 m
6.00				

CORE 49
LORAN: 27125.1, 41170.0
PENETRATION: 6.03 m

LOG OF VIBRACORE
AUGUST 02, 1987
LAT/LON: 36 45.43 N, 75 52.34 W
RECOVERY: 5.74 m

DEPTH: 10.0 m



DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00			Medium to coarse sand with widely scattered shell fragments. Light Olive Gray 5Y 6.2	UNIT QH2 Upper unit of Sandbridge Shoal
0.50			becomes Olive Gray 5Y 5/2	
		s-1		
1.00				
1.50			becomes coarser	
2.00			becomes Dark Gray 5Y 4/1	
		s-2		
2.50				
3.00			Very clayey silt layer, 5 cm thick.	
			Fine to medium sand with scattered shell fragments. Olive Gray 5Y 5/2 Coarsens down to 3.35 m, then becomes finer with depth.	UNIT QP5 Lower unit of Sandbridge Shoal
3.50		s-3		
4.00			becomes silty fine sand, Dark Gray 5Y 4/1	
		#5 AA s-4	Silty clay with pods of medium to coarse shelly sand and medium to fine sand, some gravel in sand pods. Gray 5Y 5/2	#5 MSL -14.2 m *Mulinia:* AA = 60 - 80 ka
4.50				UNIT QP1 Upper Pleistocene estuarine clay and silt
		s-5		
5.00				
			Silty fine to very fine sand with widely scattered shell fragments.	UNIT QPU Upper Pleistocene undivided
		s-6		
5.50				
				BOTTOM @ 5.74 m
6.00				

LOG OF VIBRACORE

CORE 50
LORAN: 27125.0, 41150.0
PENETRATION: 5.82 m

AUGUST 02, 1987
LAT/LON: 36 43.79 N, 75 53.01 W
RECOVERY: 6.10 m

DEPTH: 11.9 m

DEPTH (m)	LEGEND	SAMPLE	DESCRIPTION	REMARKS
0.00	▒	s-1	Micaceous silt with very fine sand and clay. Dark Gray 5Y 4/1	UNIT QP4 Upper Pleistocene estuarine clay and silt
0.50			becomes micaceous silty clay	
		s-2	Mottled micaceous fine sand and clay. Sand increases downward. Very Dark Gray 5Y 3/1	
1.00				
	▨	s-3	Clay. Gray 5Y 5/1	UNIT QPU Upper Pleistocene undivided
1.50			becomes well compacted silty clay Dark Gray 2.5 Y 4/1	
2.00		s-4		
2.50				
3.00				
3.50		s-5		
4.00				
4.50				
5.00			concentration of shell fragments	
		#6 AA	concentration of shell fragments	#6 MSL -17.2 m *Rangia:* AA > 1.2 mya
5.50		s-6	layer of fine sand and silty clay, 5 cm thick Very Dark Gray 5Y 3/1	
6.00			becomes Dark Gray 5Y 4/1 shell hash in clay matrix	Bottom @ 6.10 m

CORE LOG

CORE I.D.:__22__________________ PROJECT:ST MINS, VA BEACH SD_
DATE:__JULY 30, 87___ DRILLER:__ALPINE, ATLANTIC TWIN________
LOC: LAT. 36 48.61_LONG._75 41.26_LORAN_27088.0___,_41229.9__
FIELD LOCATION DETERMINED BY:_____LORAN-C___________________
DESCRIPTIVE LOCATION:_VIRGINIA BEACH_________________________
TYPE OF CORE:__3.5 INCH VIBRACORE, 20 FEET__________________
LOGGED BY:__L._CALLIARI, H._EVANS_______ DATE:_AUG 24, 87____
WATER DEPTH:_60 FEET__PENETRATION:_17.6_____RECOVERY:_17.8___

DEPTH		SAMP #	DESCRIPTION		
ft	m		cs sand w/a lot of shell frags	ft	m
1			up to 6cm 5Y 4/2 olive gray	1	
2	-0.5	22-1	cs to m sand w/ scat shl frgs	2	-0.5
			5Y 4/2 olive gray		
3				3	
	-1				-1
4			m sand w/scat shl frgs	4	
			5Y 4/2 olive gray		
5	_1.5		m sand	5	_1.5
			---cs sand w/6cm shell frgs		
6			m sand / cs sand w/shl / m sand	6	
	-2		m sand w/lots of shell frgs		-2
7			m sand 5Y 4/1 gray	7	
		22-2			
8	_2.5		-----m sand w/lots of shell frgs--	8	_2.5
9			m sand	9	
			--big oyster		
10	-3		m to f sand w/scat shell frags	10	-3
11			f sand w/scat shell frags	11	
	_3.5		5Y 3/1 v dk gray		_3.5
12		22-3		12	
13			___small slty clay pod	13	
	-4				-4
14			----cs sand----------------------	14	
			-f-m sand w/silt, scat shell 5Y3/1		
15	-4.5		m-cs sand, some 2cm grv, 5Y 4/2	15	-4.5
16			m to cs sand 5Y 4/2 olive gray	16	
	-5	22.4	----------------------------------		-5
17			m to f sand w/scat shell &	17	
			scat grvl <2cm 5Y 4/2		
18				18	
	-5.5				-5.5
19				19	
			.		
20	-6			20	-6

CORE LOG

CORE I.D.:____24________________ PROJECT:_ST MINS, VA BEACH SD
DATE:_JULY 30, 87____ DRILLER:__ALPINE, ATLANTIC TWIN_________
LOC: LAT._36 49.07_LONG._75 42.85_LORAN__27092.5__,_41230.6__
FIELD LOCATION DETERMINED BY:____LORAN-C______________________
DESCRIPTIVE LOCATION:_VIRGINIA BEACH__________________________
TYPE OF CORE:_____3.5 INCH VIBRACORE, 20 FEET_________________
LOGGED BY:L._CALLIARI, B._DAME___________ DATE:_SEPT 8, 87____
WATER DEPTH:_57 FEET__PENETRATION:_16.8 FT__RECOVERY:_9.7____

DEPTH		SAMP #	DESCRIPTION		
ft	m			ft	m
1				1	
			cs-m sand 5Y 4/1 dk gray		
2	-0.5	24-1		2	-0.5
3				3	
	-1		cs sand + grvl w/scat shell frags		-1
4			to 8 cm 5Y 4/1 dk gray	4	
			m-f sand w/fines at bottom, some		
5	_1.5		3-4cm bivalves at 1.55m 5Y 4/1	5	_1.5
		---------	------------------------------------		
6			cs-m sand w/scat shell frags	6	
	-2				-2
7			m-f sand w/scat shell frags	7	
		24-2	2.5Y 4/1 dk gray		
8	_2.5			8	_2.5
			2-8-2.95 m interlams of slty clay		
9			and m-f sand, 1 cm thick	9	

10	-3		f sand w/7cm shell frags	10	-3
11				11	
	_3.5				_3.5
12				12	
13				13	
	-4				-4
14				14	
15	-4.5			15	-4.5
16				16	
	-5				-5
17				17	
18				18	
	-5.5				-5.5
19				19	
20	-6			20	-6

APPENDIX C

Results of textural analyses of sediment samples from Sandbridge Shoal. Core locations are shown in Figure 5. Sub-samples are described fully in the sediment core logs (Appendix B). Stratigraphic unit names are described in Table 3.

SAMPLE	DEPTH (m)	UNIT	% GRAVEL < -1 PHI (> 2mm)	% SAND > -1 PHI & < 4 PHI (>1/16 & <2mm)	% OF DOMINANT SAND SIZES PER SAMPLE	% SILT & CLAY > 4 PHI (< 1/16mm)	MEAN/ ST.DEV. (PHI)
CORE 7							
s-2	0 - 0.5	QH2	15.9	83.6	42.7 M 28.3 C 11.2 VC	0.5	0.9/0.7
s-3	0.5 - 1.25	QH2	0.7	98.1	69.2 M 19.8 C 5.2 VC	1.1	1.3/0.6
s-4	1.25 - 1.60	QH2	2.4	96.7	61.5 M 23.4 C 6.3 VC	0.9	1.2/0.6
s-5	1.60 - 1.80	QP5	0.5	96.3	68.0 M 19.9 F 6.0 C	3.2	1.7/0.4
s-6	1.80 - 1.90	QP5	0	77.1	31.3 F 26.3 M 17.2 VF	22.9	2.4/0.7
s-7	2.52 - 2.66	QPU	1.4	88.9	42.6 C 37.9 M 5.8 VC	9.6	0.9/0.5
s-8	2.68 - 2.74	QPU	3.6	89.9	82.6 M 4.6 C 1.2 F	6.5	1.3/0.2
CORE 9							
s-1	0 - 1.55	QH2	0.3	98.6	66.3 M 16.1 C 12.0 F	1.1	1.5/0.5
s-2	1.55 - 2.05	QH2	0.7	90.1	50.7 M 22.6 F 11.7 C	9.2	1.7/0.7
s-3	2.20 - 3.05	QPU	0.3	91.9	45.8 M 40.8 F 3.7 VF	7.8	2.0/0.4
s-4	3.05 - 4.25	QPU	0	97.2	48.5 M 45.2 F 2.2 VF	2.8	2.0/0.3
s-5	3.65 - 4.59	QPU	0	95.8	51.4 F 40.5 M 3.0 VF	4.2	2.1/0.4

SAMPLE	DEPTH (m)	UNIT	% GRAVEL < -1 PHI (> 2mm)	% SAND > -1 PHI & < 4 PHI (>1/16 & <2mm)	% OF DOMINANT SAND SIZES PER SAMPLE	% SILT & CLAY > 4 PHI (< 1/16mm)	MEAN/ ST.DEV. (PHI)
CORE 47							
s-1	0 - 0.6	QH1	1.0	85.2	63.3 VF 15.5 F 3.6 C	13.8	3.2/0.6
s-4	2.40 - 2.85	QP3	14.9	59.7	25.1 C 17.6 M 12.3 VC	25.4	0.7/0.8
s-5	2.85 - 3.55	QP3	1.5	96.6	49.5 VC 21.1 C 14.9 F	1.9	1.4/0.8
CORE 48							
R1 s-1	0 - 0.82	QH2	1.3	97.4	74.2 M 13.1 C 7.8 F	1.3	1.5/0.5
R1 s-2	0.82 - 2.10	QH2	0.4	97.4	70.5 M 14.4 F 11.1 C	2.2	1.6/0.5
R2 s-1	2 - ?	QH2	0.3	97.8	69.1 M 17.4 F 9.6 C	1.9	1.6/0.5
R2 s-2	? - 4.39	QH2	1.4	96.1	61.5 M 15.5 F 14.8 C	2.5	1.5/0.6
R3 s-1	4.21 - 5.10	QP5	2.5	95.3	52.2 M 26.1 F 11.4 C	2.2	1.7/0.6
R3 s-2	5.10 - 5.79	QP2	1.0	95.7	60.4 F 24.0 M 5.7 VF	3.3	2.1/0.5

SAMPLE	DEPTH (m)	UNIT	% GRAVEL < -1 PHI (> 2mm)	% SAND > -1 PHI & < 4 PHI (>1/16 & <2mm)	% OF DOMINANT SAND SIZES PER SAMPLE	% SILT & CLAY > 4 PHI (< 1/16mm)	MEAN/ ST.DEV. (PHI)
CORE 49							
s-1	0 - 1.61	QH2	0	98.8	71.0 M 15.3 C 10.1 F	1.2	1.5/0.5
s-2	1.61 - 3.14	QH2	3.2	92.3	65.2 M 14.4 F 10.9 C	4.5	1.6/0.5
s-3	3.15 - 4.14	QP5	0.2	95.1	46.7 F 38.9 M 5.0 C	4.7	1.9/0.5
s-6	5.13 - 5.74	QPU	0.1	87.3	60.4 F 22.1 VF 3.5 M	12.6	2.7/0.5

NOTE:	VC - Very Coarse	0.0 to -1.0 PHI	1.00 to 2.00 mm
	C - Coarse	1.0 to 0.0 PHI	0.50 to 1.00 mm
	M - Medium	2.0 to 1.0 PHI	0.25 to 0.50 mm
	F - Fine	3.0 to 2.0 PHI	0.125 to 0.25 mm
	VF - Very Fine	4.0 to 3.0 PHI	0.0625 to 0.125 mm

PHI = -log base 2 of grain diam. in mm

PLATES 1 - 5

Plates 1 through 5 are reproductions of the subbottom acoustic records (labelled "A") and corresponding interpretations (labelled "B") for tracklines surveyed to complete this study. Trackline locations are shown in Figure 5 and are identified by the notation "*/88", where "*" represents the line number printed on each plate. Stratigraphic units are described in Table 3.

LEGEND FOR PLATES

STRATIGRAPHIC UNITS

(see Table 1 for description)

QH1 - Holocene sand sheet

QH2 - Upper unit of Sandbridge Shoal

QPU - Upper Pleistocene undivided

QP5 - Lower unit of Sandbridge Shoal

QP4 - Upper Pleistocene estuarine

QP3 - Upper Pleistocene tidal channel

QP2 - Upper Pleistocene baymouth or tidal shoal

QP1 - Upper Pleistocene estuarine

QPL - Lower Pleistocene undivided

TP - Pliocene

REFLECTORS

R1 - Reflector at top of TP

R2 - Reflector separating QPU & QPL

R3 - Reflector at base of Sandbridge Shoal

R4 - Reflector separating QH2 & QP5

GRAB SAMPLE SEDIMENT DESCRIPTIONS

(see Appendix A for vibracore descriptions)

VGC - Very gravelly coarse sand

GMC - Gravelly medium to coarse sand

MC - Medium to coarse sand

MF - Medium to fine sand

VSM - Very silty medium to coarse sand

F - Fine sand

SNS - Sandy silt

SC - Silty clay

5 AA - Indicates sample number of dated material and method used

PLATE 1A

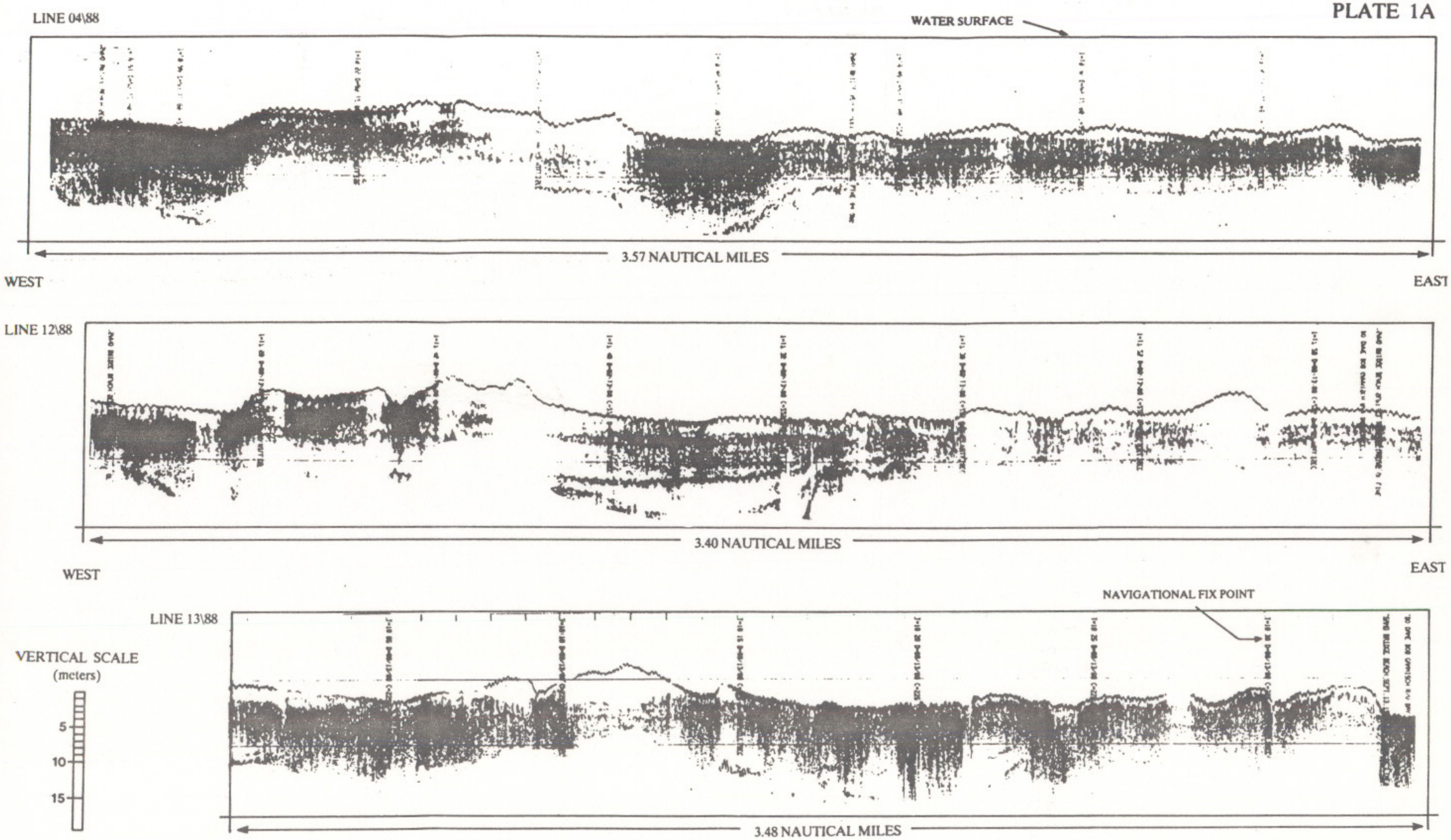

LINE 04\88
WATER SURFACE
3.57 NAUTICAL MILES
WEST
EAST
LINE 12\88
3.40 NAUTICAL MILES
WEST
EAST
NAVIGATIONAL FIX POINT
LINE 13\88
VERTICAL SCALE
(meters)
5
10
15
3.48 NAUTICAL MILES

PLATE 1B

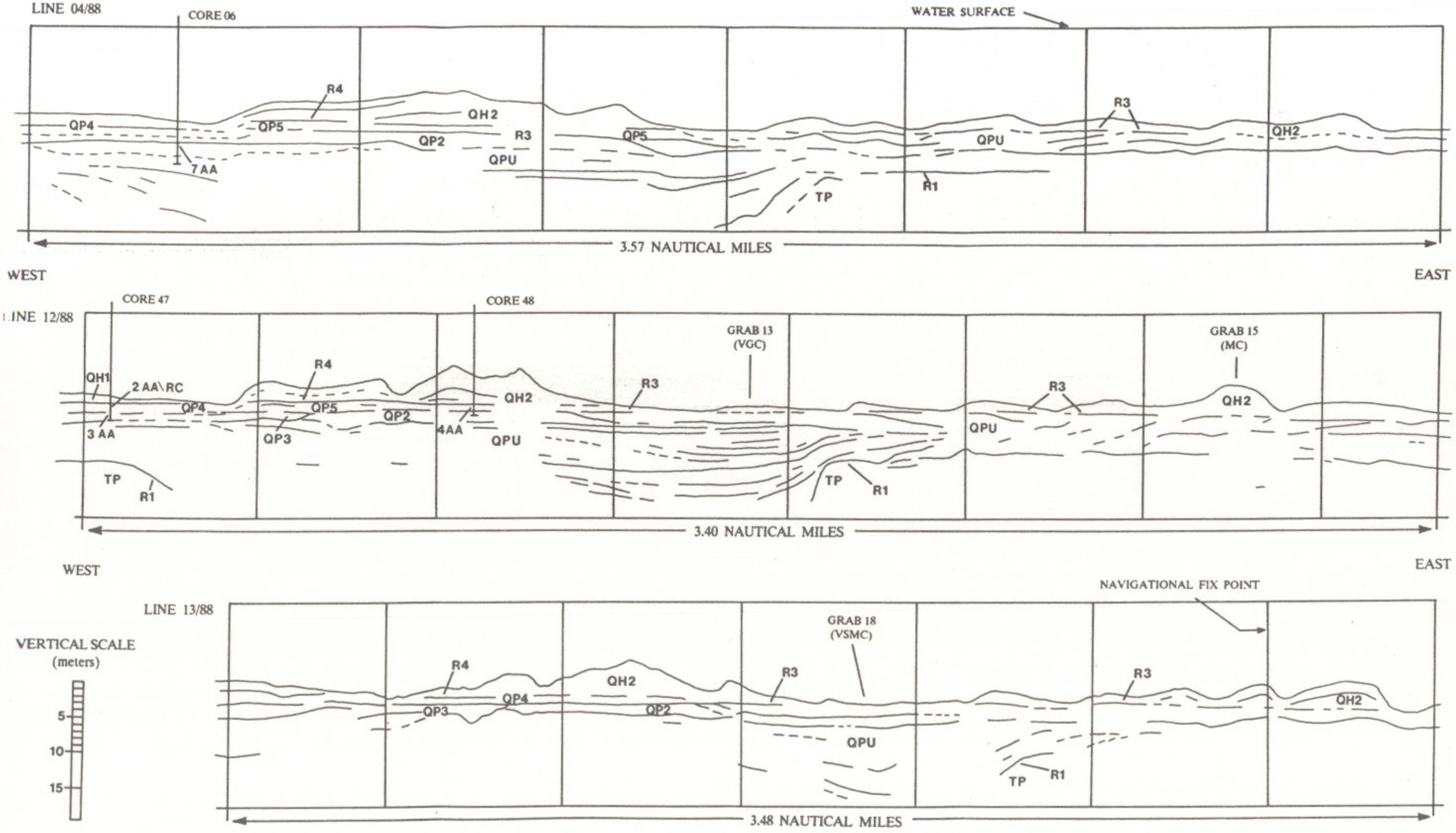

LINE 04/88
CORE 06
WATER SURFACE
R4
QH 2
QP4
QP5
QP2
R3
QPU
QP5
7 AA
TP
R1
QPU
R3
QH2
3.57 NAUTICAL MILES
WEST
EAST
LINE 12/88
CORE 47
CORE 48
GRAB 13
(VGC)
GRAB 15
(MC)
QH1
2 AA\RC
QP4
R4
QP5
QP3
QP2
4AA
QH2
QPU
R3
3 AA
TP
R1
TP
R1
QPU
R3
QH2
3.40 NAUTICAL MILES
WEST
EAST
NAVIGATIONAL FIX POINT
LINE 13/88
GRAB 18
(VSMC)
VERTICAL SCALE
(meters)
5
10
15
R4
QP4
QP3
QH2
QP2
R3
QPU
TP
R1
R3
QH2
3.48 NAUTICAL MILES

PLATE 2A

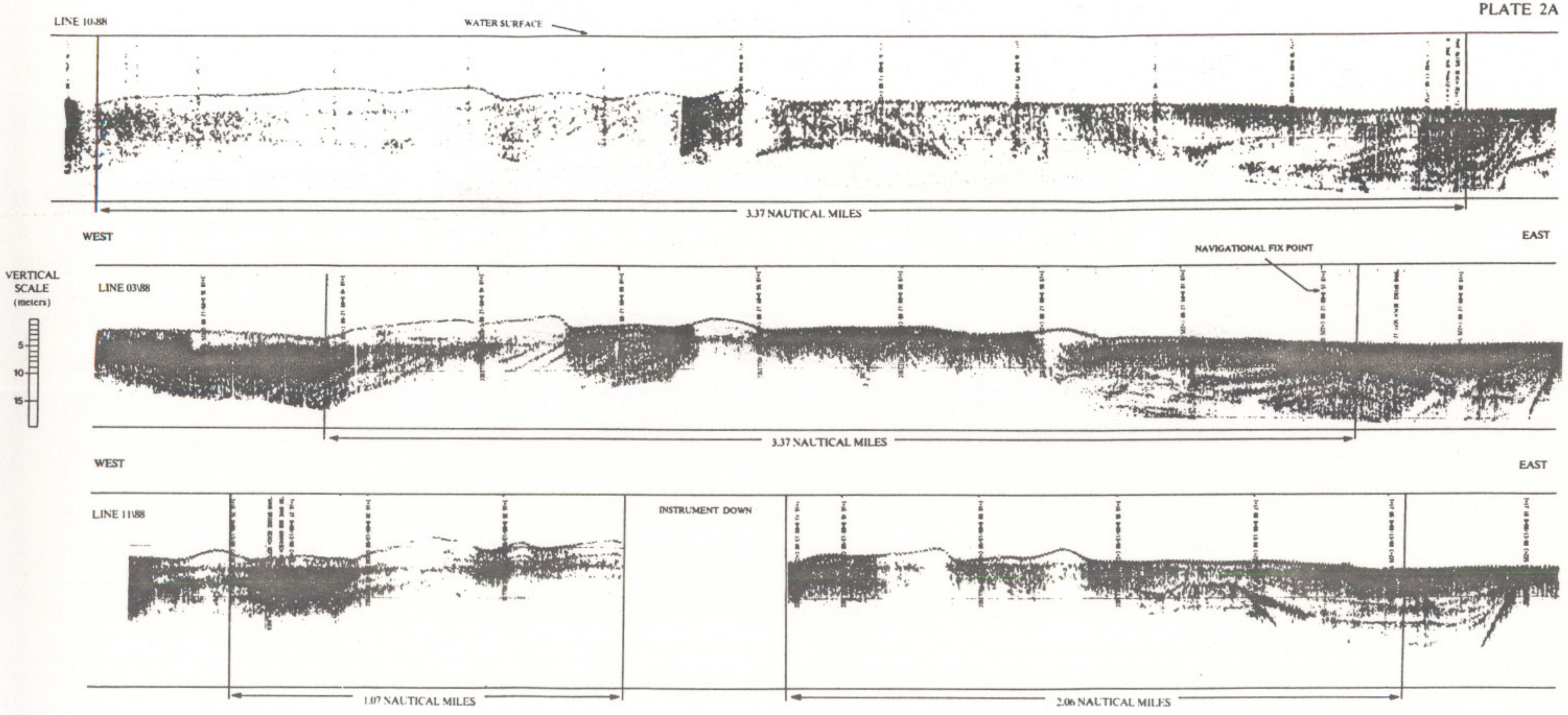

LINE 10\88
WATER SURFACE
3.37 NAUTICAL MILES
WEST
EAST
VERTICAL SCALE (meters)
5
10
15
LINE 03\88
NAVIGATIONAL FIX POINT
3.37 NAUTICAL MILES
WEST
EAST
LINE 11\88
INSTRUMENT DOWN
1.07 NAUTICAL MILES
2.06 NAUTICAL MILES

PLATE 2B

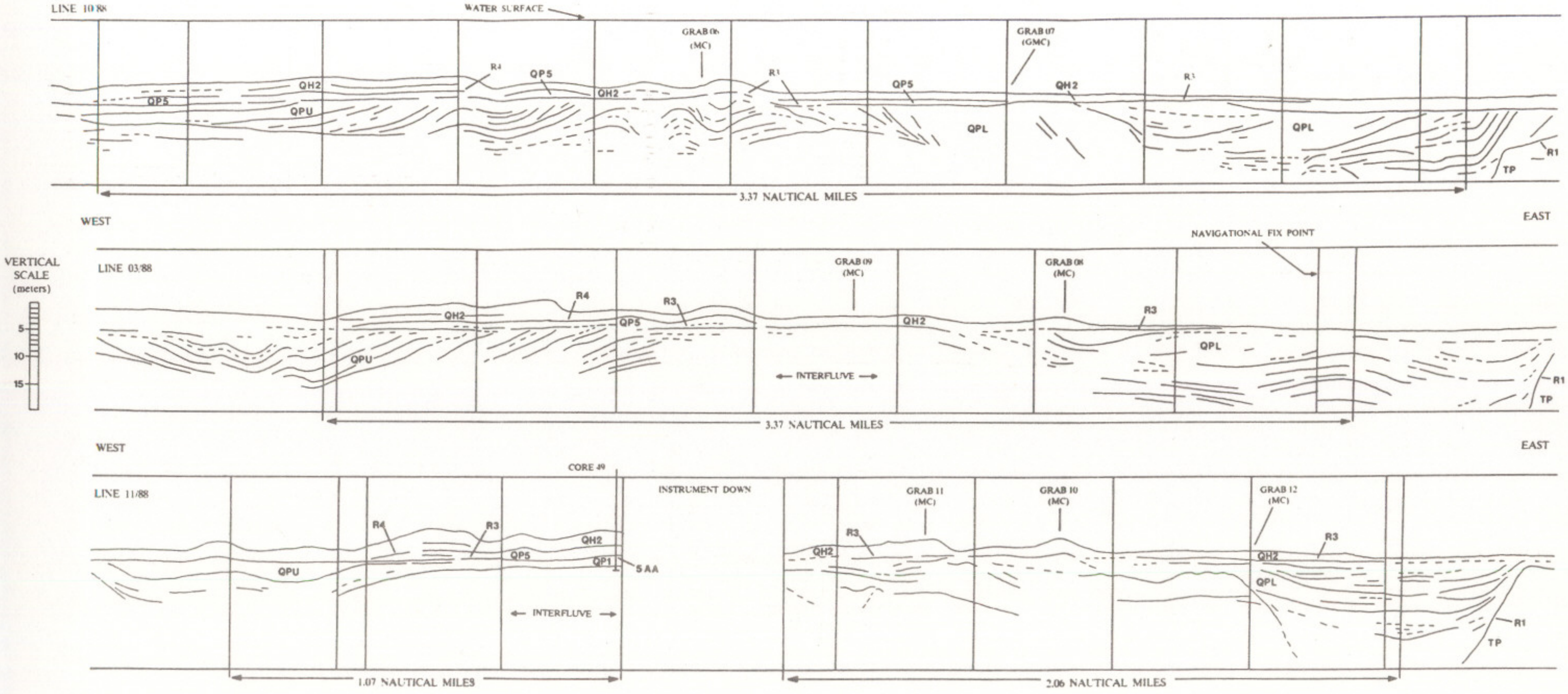
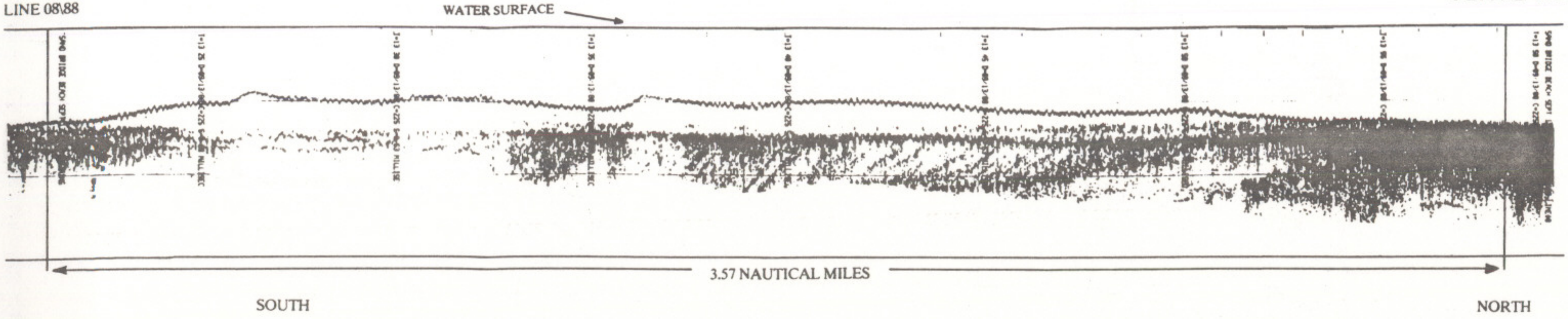
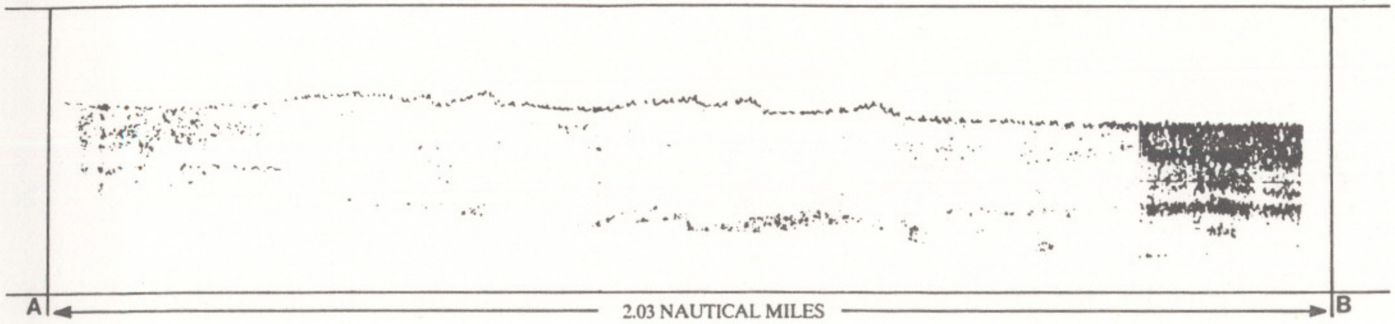

LINE 10/88
WATER SURFACE
GRAB 06 (MC)
GRAB 07 (GMC)
R4
QP5
QH2
QPU
R3
QPL
R1
TP
3.37 NAUTICAL MILES
WEST
EAST
VERTICAL SCALE (meters)
5
10
15
LINE 03/88
NAVIGATIONAL FIX POINT
GRAB 09 (MC)
GRAB 08 (MC)
INTERFLUVE
3.37 NAUTICAL MILES
WEST
EAST
LINE 11/88
CORE 49
INSTRUMENT DOWN
GRAB 11 (MC)
GRAB 10 (MC)
GRAB 12 (MC)
QP1
5 AA
INTERFLUVE
1.07 NAUTICAL MILES
2.06 NAUTICAL MILES

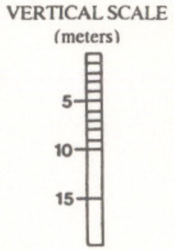
PLATE 3A

LINE 08\88



LINE 07\88





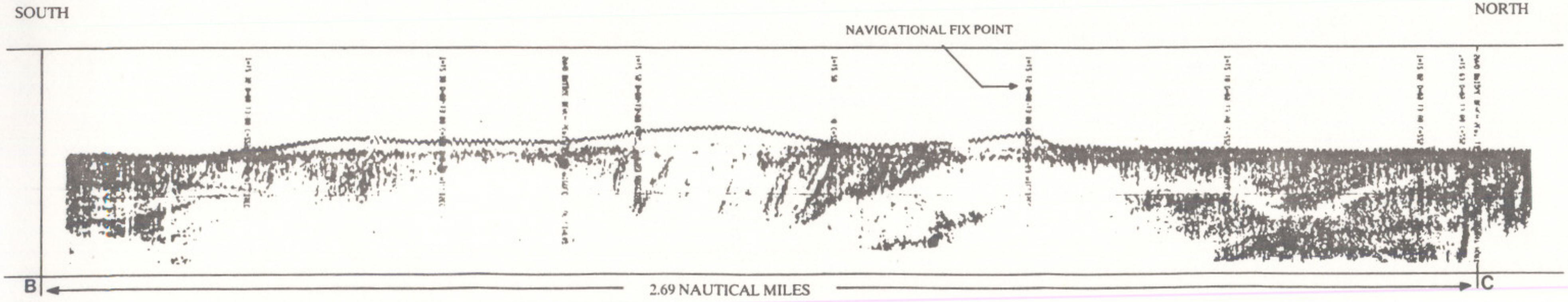


PLATE 3B

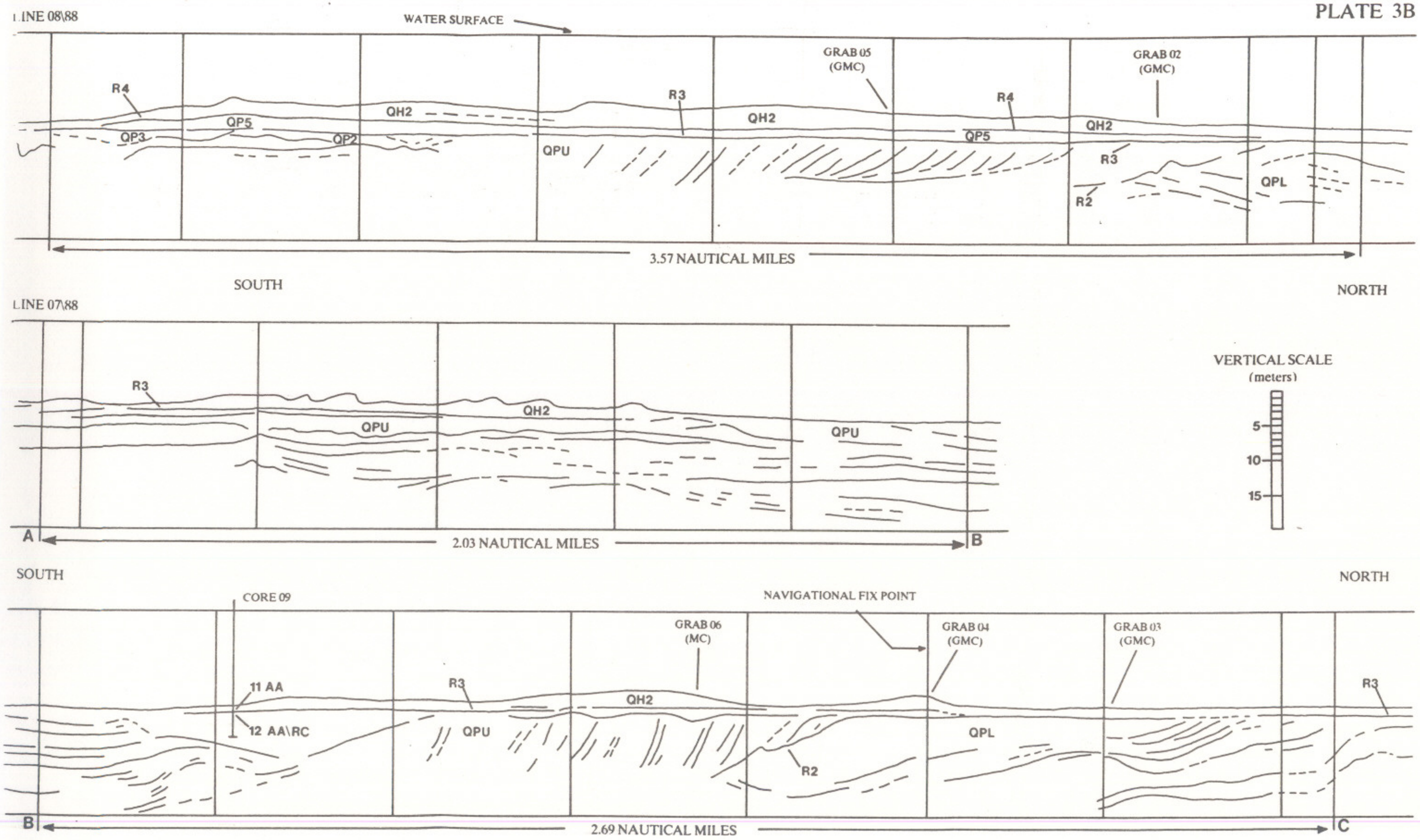

LINE 08\88
WATER SURFACE
R4
QP5
QP3
QP2
QH2
R3
QPU
GRAB 05 (GMC)
QH2
R4
QP5
GRAB 02 (GMC)
QH2
R3
R2
QPL
3.57 NAUTICAL MILES
SOUTH
NORTH
LINE 07\88
R3
QPU
QH2
QPU
A
2.03 NAUTICAL MILES
B
VERTICAL SCALE (meters)
5
10
15
SOUTH
NORTH
CORE 09
11 AA
12 AA\RC
R3
QPU
GRAB 06 (MC)
QH2
R2
NAVIGATIONAL FIX POINT
GRAB 04 (GMC)
QPL
GRAB 03 (GMC)
R3
B
2.69 NAUTICAL MILES
C

PLATE 4A

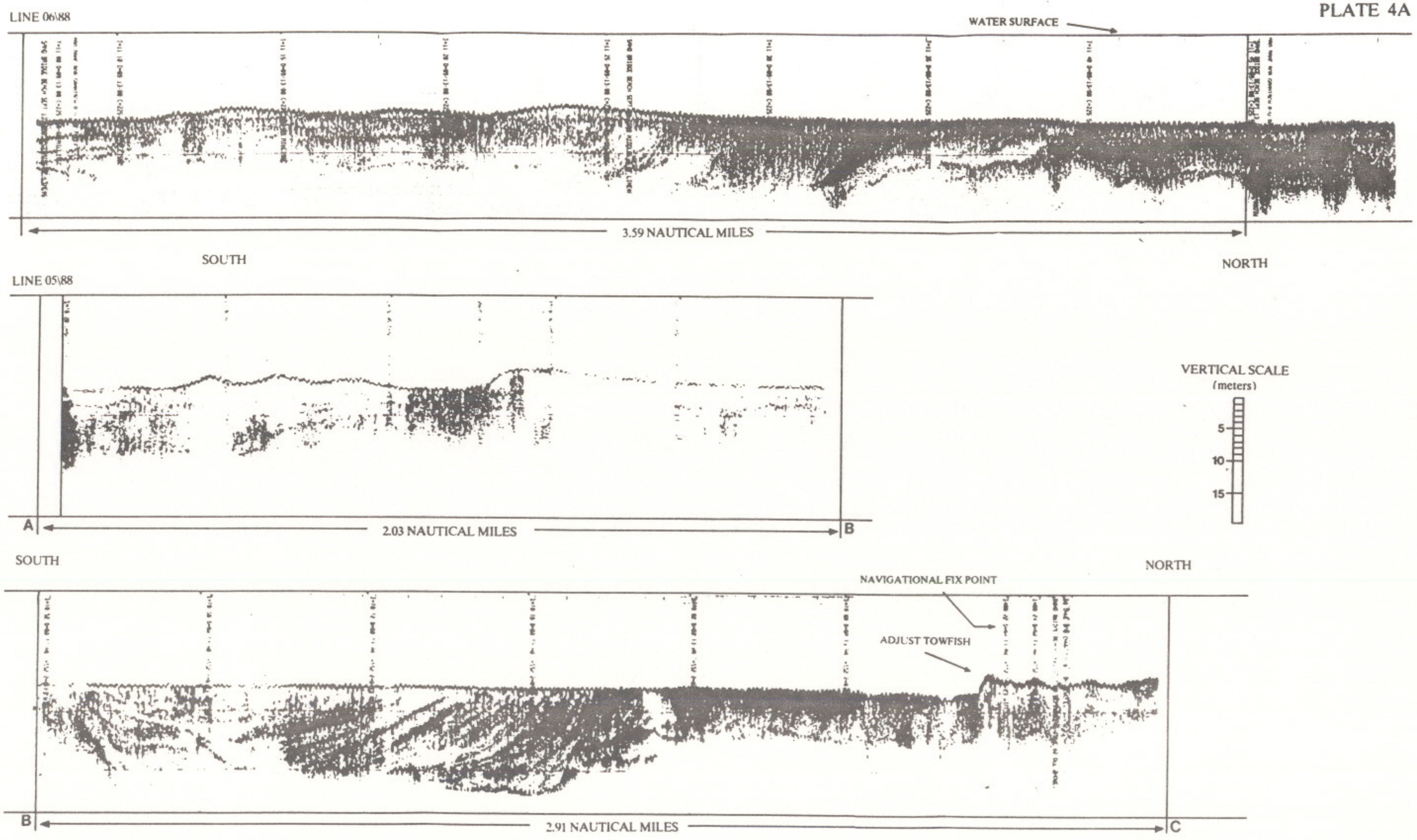

LINE 06\88
WATER SURFACE
3.59 NAUTICAL MILES
SOUTH
NORTH
LINE 05\88
A
2.03 NAUTICAL MILES
B
VERTICAL SCALE
(meters)
5
10
15
SOUTH
NORTH
NAVIGATIONAL FIX POINT
ADJUST TOWFISH
B
2.91 NAUTICAL MILES
C

PLATE 4B

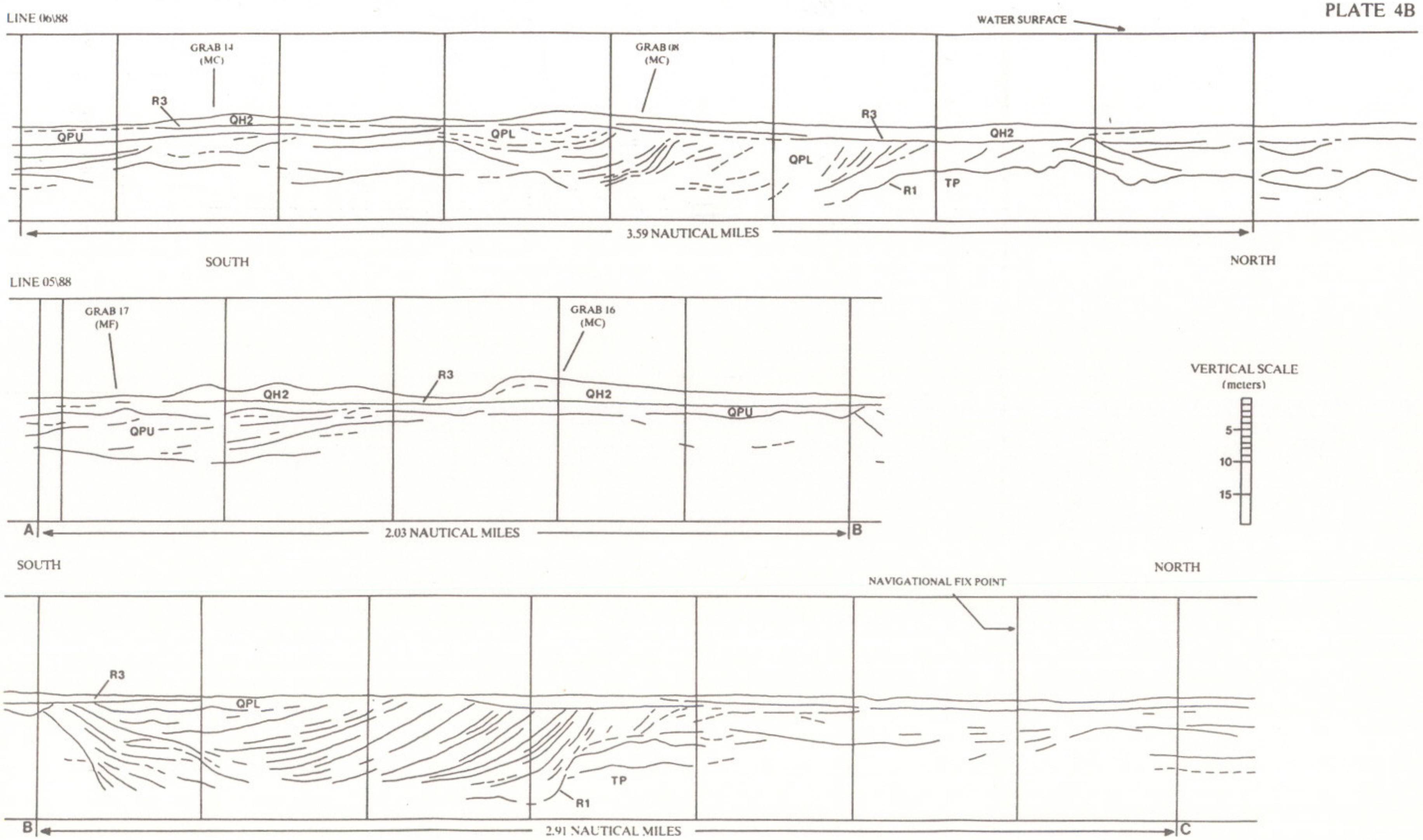

LINE 06\88
WATER SURFACE
GRAB 14 (MC)
GRAB 08 (MC)
R3
QH2
QPU
QPL
R3
QPL
QH2
R1
TP
3.59 NAUTICAL MILES
SOUTH
NORTH
LINE 05\88
GRAB 17 (MF)
GRAB 16 (MC)
R3
QH2
QH2
QPU
QPU
A
2.03 NAUTICAL MILES
B
VERTICAL SCALE (meters)
5
10
15
SOUTH
NORTH
NAVIGATIONAL FIX POINT
R3
QPL
TP
R1
B
2.91 NAUTICAL MILES
C

PLATE 5A

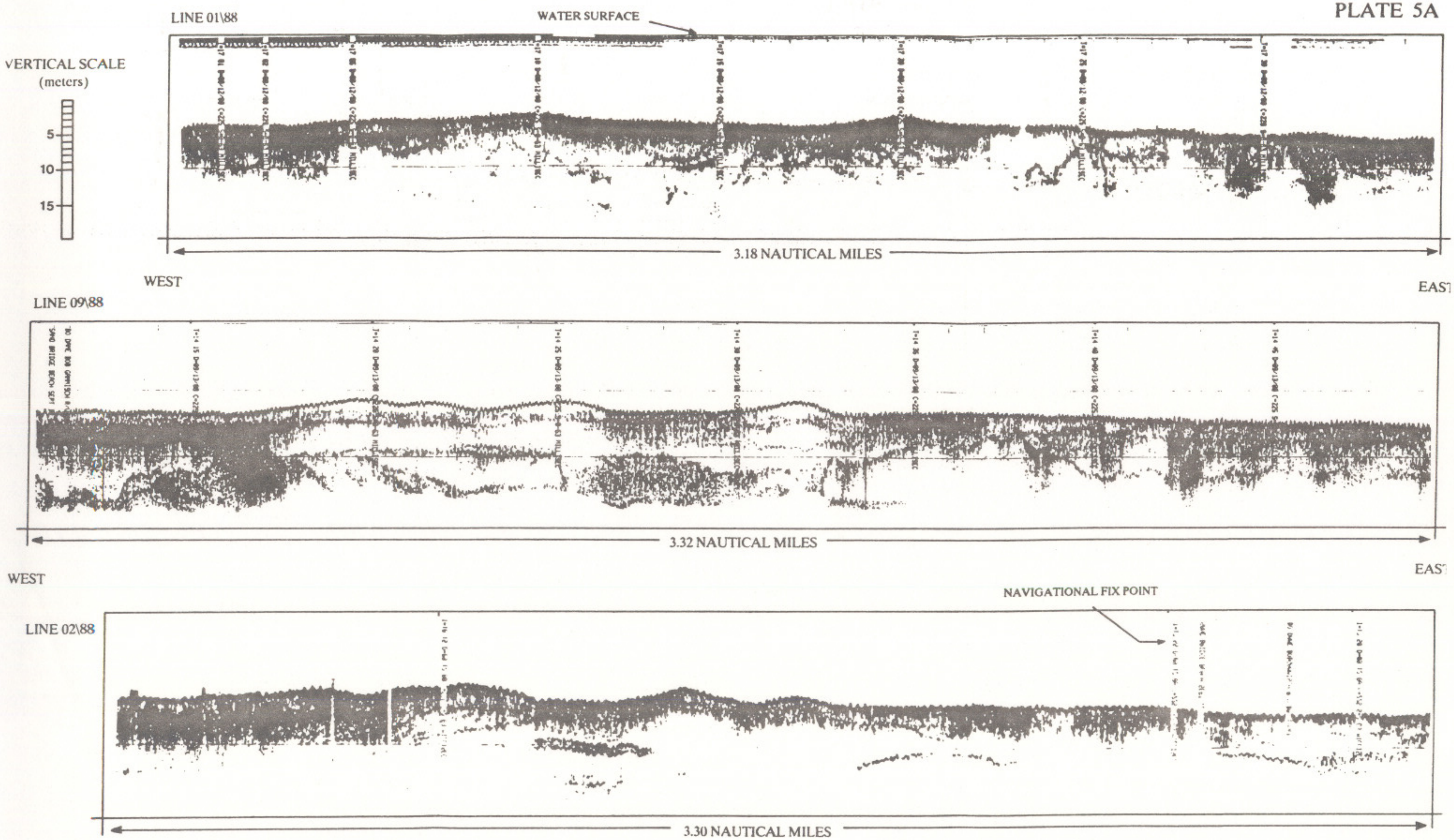
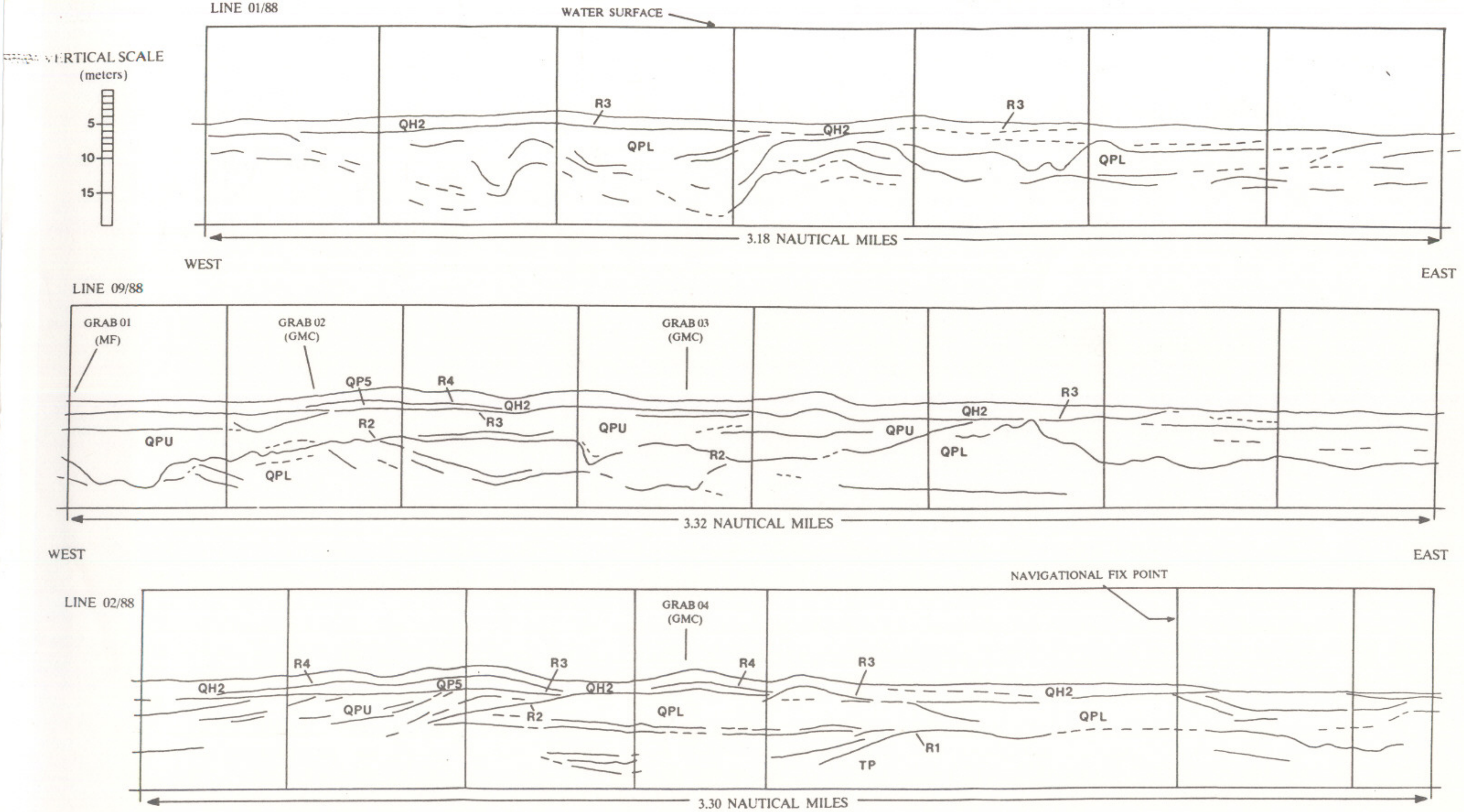

LINE 01\88
WATER SURFACE
VERTICAL SCALE
(meters)
5
10
15
3.18 NAUTICAL MILES
WEST
EAST
LINE 09\88
3.32 NAUTICAL MILES
WEST
EAST
NAVIGATIONAL FIX POINT
LINE 02\88
3.30 NAUTICAL MILES

PLATE 5B


VERTICAL SCALE
(meters)
5
10
15
LINE 01/88
WATER SURFACE
R3
QH2
QPL
QH2
R3
QPL
3.18 NAUTICAL MILES
WEST
EAST
LINE 09/88
GRAB 01
(MF)
GRAB 02
(GMC)
GRAB 03
(GMC)
QP5
R4
QH2
R3
R2
QPU
QPU
QPL
R2
QPU
QH2
R3
QPL
3.32 NAUTICAL MILES
WEST
EAST
LINE 02/88
NAVIGATIONAL FIX POINT
GRAB 04
(GMC)
R4
QH2
QPU
QP5
R3
QH2
R2
R4
QPL
R3
QH2
QPL
R1
TP
3.30 NAUTICAL MILES