Shoreline Studies

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

Geotechnical Evaluation of Sand Resources on the Inner Shelf of Southern Virginia

Volume I: Report and Appendices A–B

Final Report
to the
City of Virginia Beach, Virginia

Prepared by

Suzette M. Kimball
James K. Dame

August 1989

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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. This report details the results of the exploration program to delineate reserves containing sufficient quantities of sand suitable for emplacement on public recreational beaches in the City of Virginia Beach. Volume I contains the Summary Report and Appendices A and B, which depict interpretations of seismic data. Volume II contains Appendices C through E, which detail the sediment analyses.

This study was funded by the City of Virginia Beach, Virginia. Correlative sediment data were provided through the Study of Economic Heavy Minerals of the Virginia Inner Continental Shelf, funded in part by the Virginia Subaqueous Minerals and Materials Study Commission and, in part, by 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.

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, M. Patricia Barthle, George R. Thomas, and Frank Farmer provided invaluable assistance in the field. Sediment analysis was completed by Cindy T. Fischler; assistance with the reduction of seismic data was provided by Angela Bryant. The authors thank each of these individuals for his/her dedicated efforts, without which this project could not have been completed. The authors especially thank C.H. Hobbs, III, for his hours of assistance with, and numerous discussions about, the interpretations of the seismic and sediment data.

The use of trade names within this document is for descriptive purposes only and does not imply endorsement of the products by the Commonwealth of Virginia or its agencies.

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GEOTECHNICAL EVALUATION OF SAND RESOURCES ON THE INNER SHELF OF SOUTHERN VIRGINIA

I. INTRODUCTION

Statement of the Problem.

The City of Virginia Beach, Virginia, is facing 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. In order to provide a means to implement long-term beach development strategies and develop backup measures in the event of a catastrophic storm, it is necessary to pursue aggressively the location of alternate sources of beach quality material.

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. 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 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.

Objectives.

The objectives of this study are to identify, locate and describe sources of beach quality material on the inner shelf that are within economical transport distances to the City of Virginia Beach. Specifically, the study includes (1) identification of potential offshore sources of beach quality sand; (2) mapping the aerial and vertical extent of suitable deposits; (3) determination of the characteristics of source and destination material.

II. GEOLOGIC SETTING

Limits of the Study Area.

The study area, shown in Figure 1, is a section of the inner shelf of Virginia generally bounded by Cape Henry to the north, the Virginia-North Carolina state line to the south, the ocean shoreline of the City of Virginia Beach on the west, and a line parallel to the shoreline and approximately three nautical miles offshore on the east.

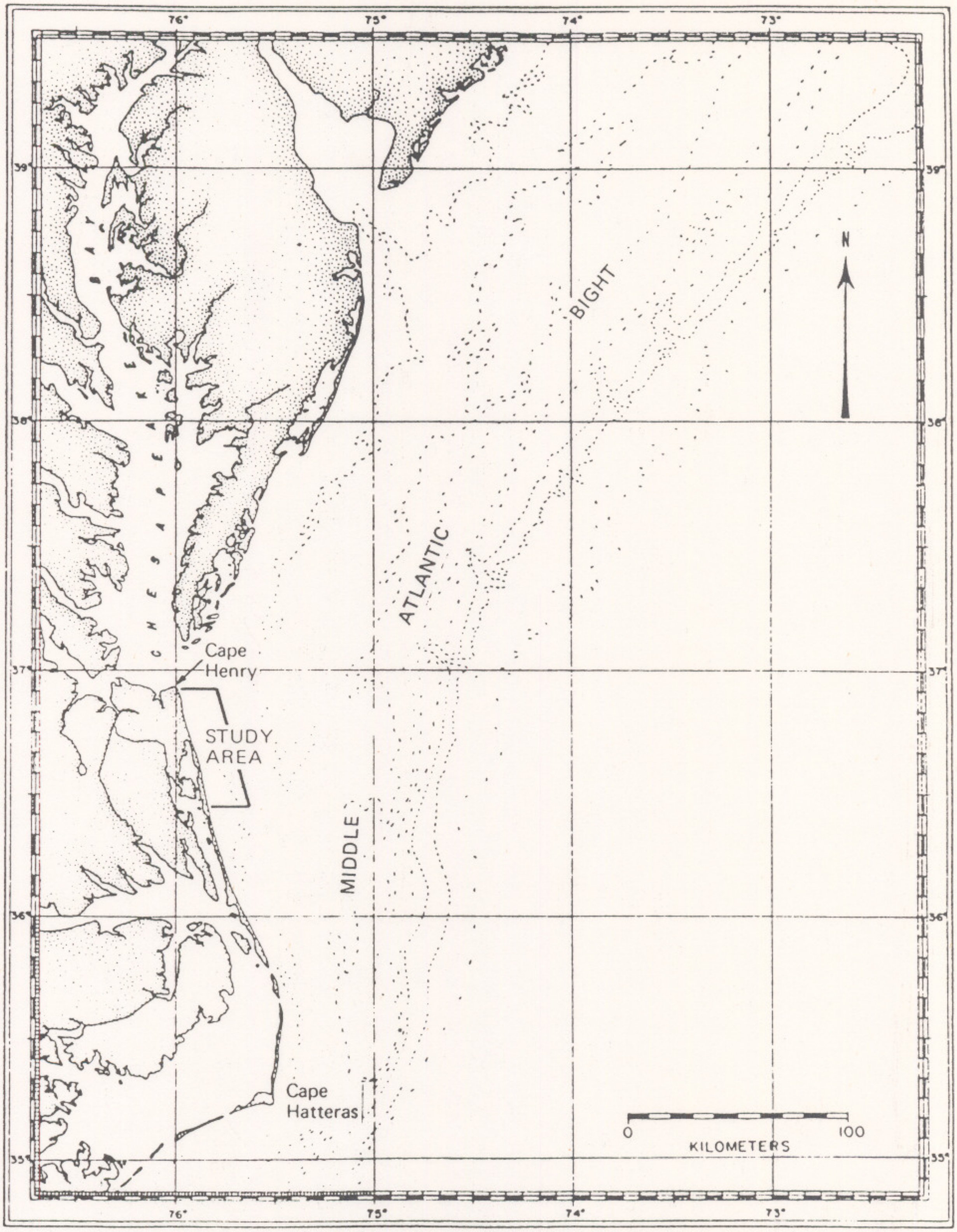

Figure 1. Site map showing location of the study area.

Regional Stratigraphy.

The study area delineated in Figure 1 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 (>15,000 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 15,000 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 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 (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 represents a discontinuous Holocene (recent to modern) transgressive sand sheet (Swift et al., 1977). 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.

Regional Bathymetry.

Figure 2 is a three-dimensional view of the bathymetry within the study area, from which several distinct morphological features can be described that are imposed on an otherwise gently seaward-dipping surface. A well-defined shelf valley extends southeastward from the mouth of the Chesapeake Bay. This valley is believed to be a modern topographic representation of a relict fluvial channel dating to the last major glacial advance (Meisburger, 1972). The Atlantic Ocean Navigation Channel, which is the major shipping approach to the Chesapeake Bay, lies within this topographic depression. To the west of the channel, extending landward to the shoreline, is the broad, shallow Cape Henry Shoal. This shoal is attached to the shoreface at the bay mouth and projects southward approximately 16 kilometers (10 miles), paralleling the present shoreline. Williams (1987) defines the Cape Henry Shoal as a modern depositional feature that is the product of ebb-tidal sedimentation processes occurring at the Chesapeake Bay Mouth.

Duane et al. (1972) defines shoal retreat "massifs" as large constructional sand features that are remnants of retreat paths of

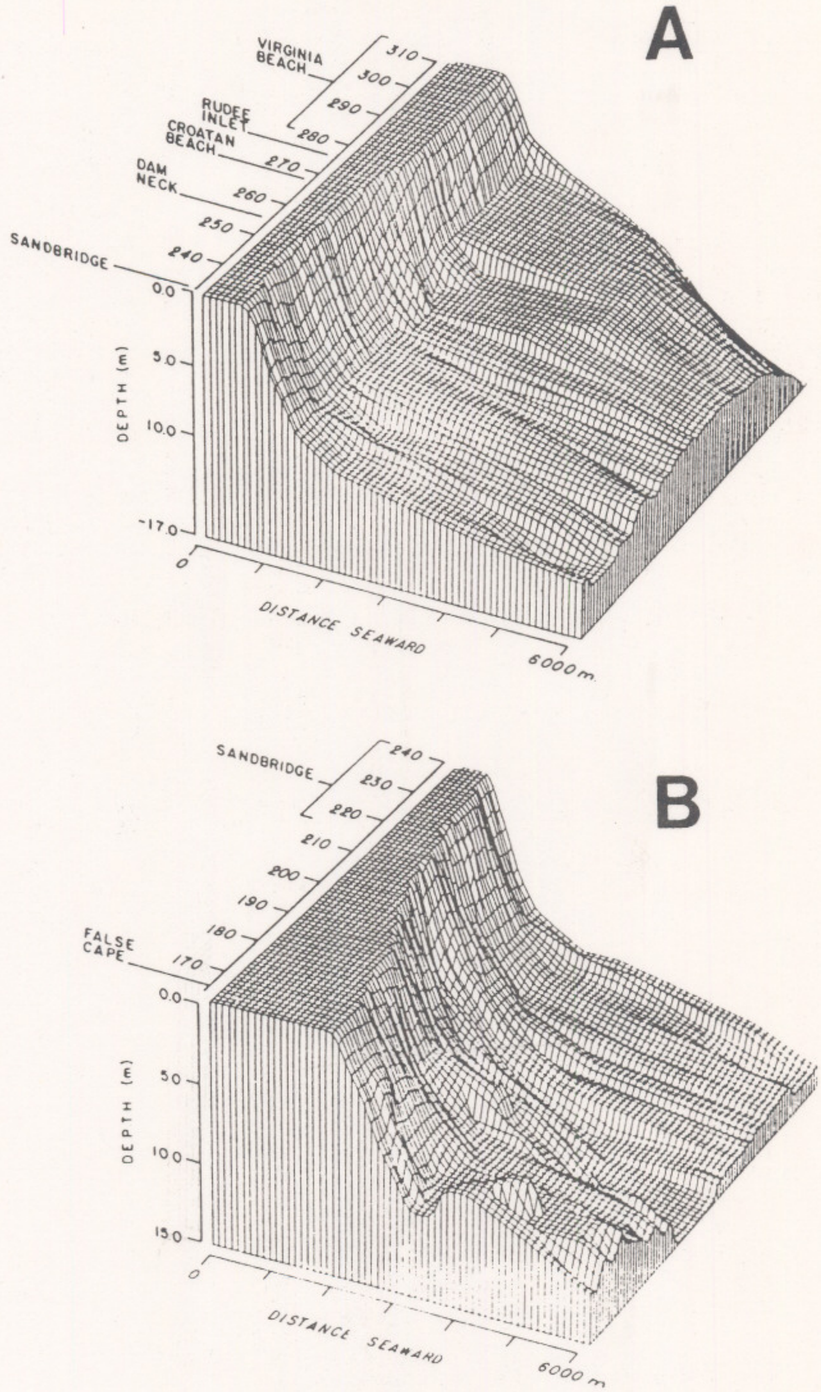

Figure 2. Bathymetry of the Virginia inner shelf between Cape Henry and North Carolina. The graphic representation uses a smoothed contour version of water depths digitized from recent navigation charts.

littoral drift convergences at estuary mouths or cuspate forelands during transgressive periods. Williams (1987) describes the broad Virginia Beach platform at the northern boundary of the study area and east of the Atlantic Ocean Navigation Channel as a portion of the Virginia Beach Massif. The presence of the two broad shoals offshore the Virginia Beach resort area results in a broad dissipative platform that provides a wave-damping mechanism.

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 kilometers to 60 kilometers, are spaced between one and six kilometers, 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 offshore shoal merges with the nearshore bar system and becomes shoreface connected. Such a case exists in the region offshore of False Cape, Virginia (see Figure 2), 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; sidescan data across the ridge field show small amplitude sand waves indicating an active sediment transport regime (VIMS, unpublished data).

If one assumes that the linear shoal fields are the result of ridges associated with a previous retreating estuary system, one would expect to see cross-cutting sequences of fluvial systems in the intershoal areas. Payne (1970) discusses one such case, the Virginia

Beach Valley, which trends northwest between the False Cape ridge field and a linear shoal field located approximately eight kilometers to the northeast in 20 meters of water. Recent high-resolution seismic profile data substantiate the existence of this system. Channel depths in excess of 30 meters and widths of several kilometers have been mapped (VIMS, unpublished data). Several episodes of channel infilling can be documented, with evidence of differential compaction of the channel sediments.

Seaward of the reach between Dam Neck and False Cape, the shelf surface is a gently sloping plain, broken by a moderately-sized, non-linear shoal situated approximately 5 kilometers offshore of Sandbridge Beach (Figure 2).

III. METHODS

Geophysical Methods.

Field data were acquired through three instrumentation systems: acoustic subbottom profiler; side-scan sonar; and a pneumatic coring rig. Seismic data were obtained using a Datasonics SBP-5000 subbottom profiler. This system consists of a two-channel, dual-frequency transceiver connected to a towfish carrying the transducers. The primary channel can operate at 3.5, 5.0, or 7.5 kilohertz (kHz). Most of the surveying in this area was conducted at 3.5 kHz; 5.0 kHz was used when greater depth of signal penetration was desired, or when a very strong surface reflector obscured deeper horizons. The second channel operates at 200 kHz 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 sweep rate of the recorders, which sets the scale of the hard copy, was set at 1/8 second and 1/16 second respectively. General interpretations of the data were made from the EPC 3200 hard copy, while the EPC 4800 record was used to resolve complicated records.

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 intensity of the recorded signal is a representation of the character of the seafloor. Dark areas on the record are the result of hard bottoms, coarse material, or areas of relief that reflect most of the acoustic signal. Light areas indicate soft or fine-grained sediments, or shadow zones behind areas of positive relief and are the result of absorption of acoustic energy. Side-scan records of the study area show little surface variation and contribute little new information to the interpretation of the regional conditions. Thus, these records are not discussed in detail in this report. Hard copies of all geophysical data are archived at the College of William and Mary, Virginia Institute of Marine Science and can be retrieved for more detailed analysis.

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, augmented by a Del Norte positioning system for accurate location of track lines. The lines were laid out relative to the 27/41 Loran net and fix marks recorded every five minutes on long lines and two minutes on short lines. A total of 534 kilometers (332 miles) of track line were surveyed, as depicted on Figure 3.

Sediment Sample Collection.

Vibracores were obtained during a 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 4.

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 C.

All 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 between 4.0 and -1.0 phi). Samples that contained more than 25% silt and clay

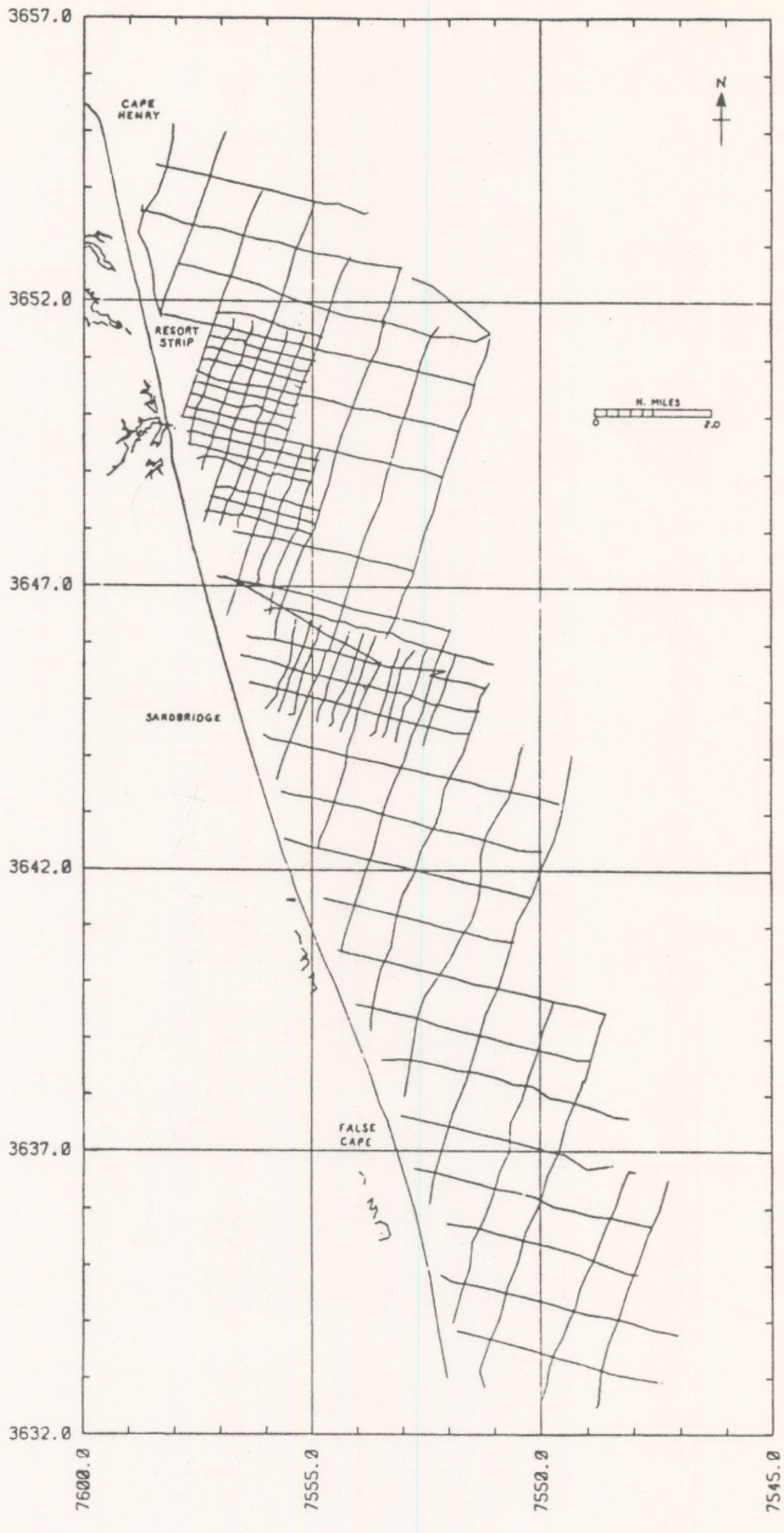

Figure 3. Locations of track lines along which geophysical data were collected.

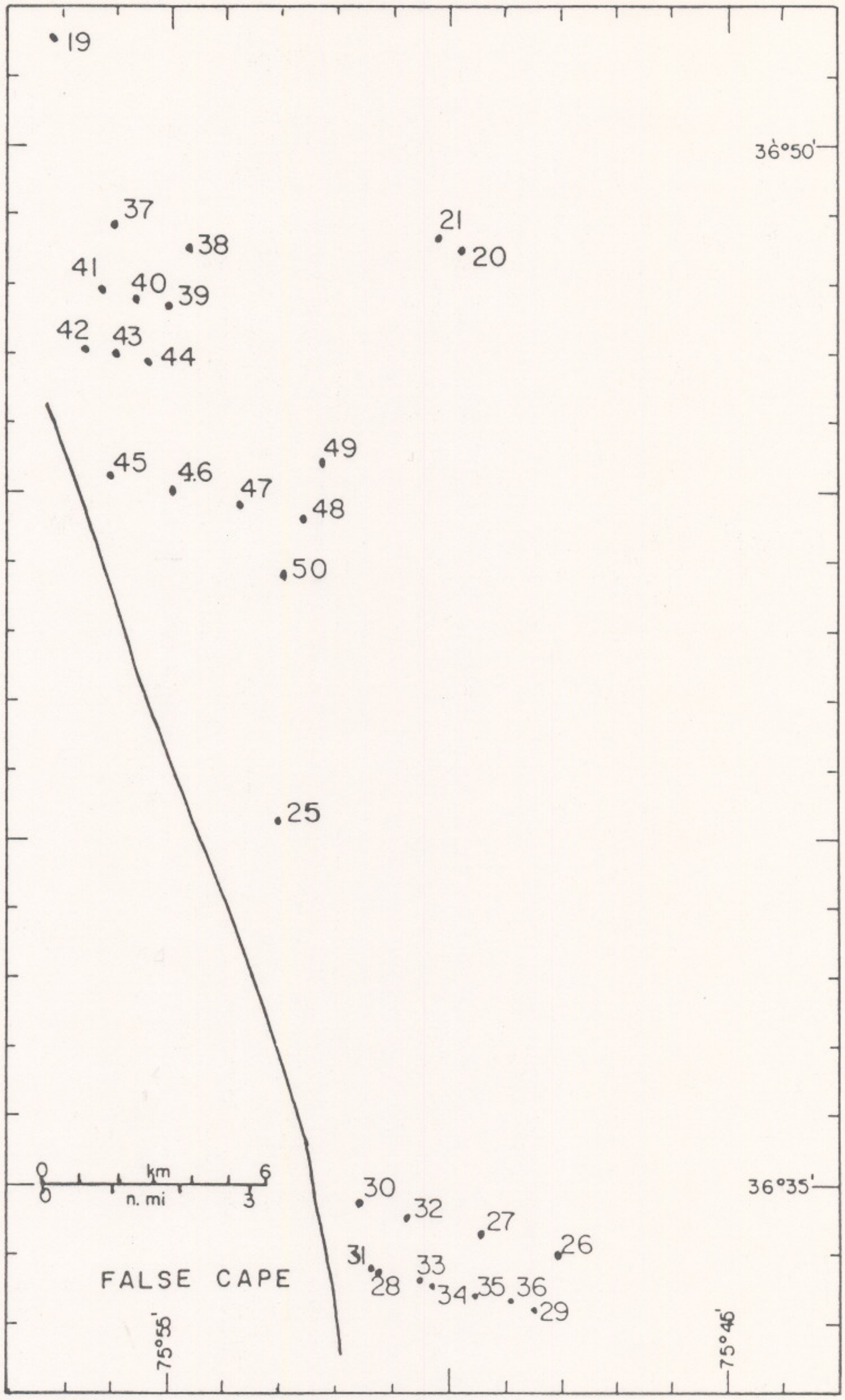

Figure 4. Location of vibracores taken within the study area (from Berquist and Hobbs, 1988).

were assumed to be unsuitable for beach nourishment and were not processed further. 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 D contains graphic representations of grain size statistics for each sample used in this study, including tables of graphic (Folk) statistics, methods of moments statistics, cumulative frequency curves, and probability curves. Appendix E contains tables of RSA velocities and calculations for each sample. Detailed mineralogic analyses of the samples can be found in Berquist and Hobbs (1988). All samples are archived at the College of William and Mary, Virginia Institute of Marine Science.

IV. RESULTS

General Characteristics.

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 typified by core sample #19. 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 muds 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 carries a high percentage of silts and clays (hereafter termed "fines"), ranging from 16% to greater than 20%, a mean grain size of 0.125 mm (3.0 phi), and has an unaesthetic appearance in terms of color and a characteristic odor from organic components. Because these characteristics are less desirable for recreational beach nourishment projects, these areas are not discussed in further detail. Should protective beach strategies be considered, these data should be re-evaluated.

The region offshore of False Cape is dominated by a twin-ridge linear shoal complex. The sediments in this complex are represented by cores #26 through #36. There is a clear distinction between sediments contained in the shoals and the surrounding intershoal and swale areas. Within the swales, typified by core #33, 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, represented by core #34, 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. The shoals contain large amounts of beach-quality sand. However, the distance between the source area and potential destinations within the limits of the City of Virginia Beach are such that mining the area would not be economical except in response to a catastrophic event. Consequently, discussion is limited to those areas that are potential sites for long-term sand mining.

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 5). Reproductions of the original acoustic subbottom records and their detailed interpretations are contained in Appendix A.

The characteristics of the sediments are represented by cores #19, and #37-#42. Table 1 lists the salient characteristics of these sediments; detailed statistical analyses are contained in Volume II, Appendices C-E, and in Berquist and Hobbs (1988).

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 (2.96-3.17 phi). The percentage of fines is high, reaching as much as 65% (core #42), but averaging 12% over the entire sand body. Three cores (#38, #41, and #42) 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).

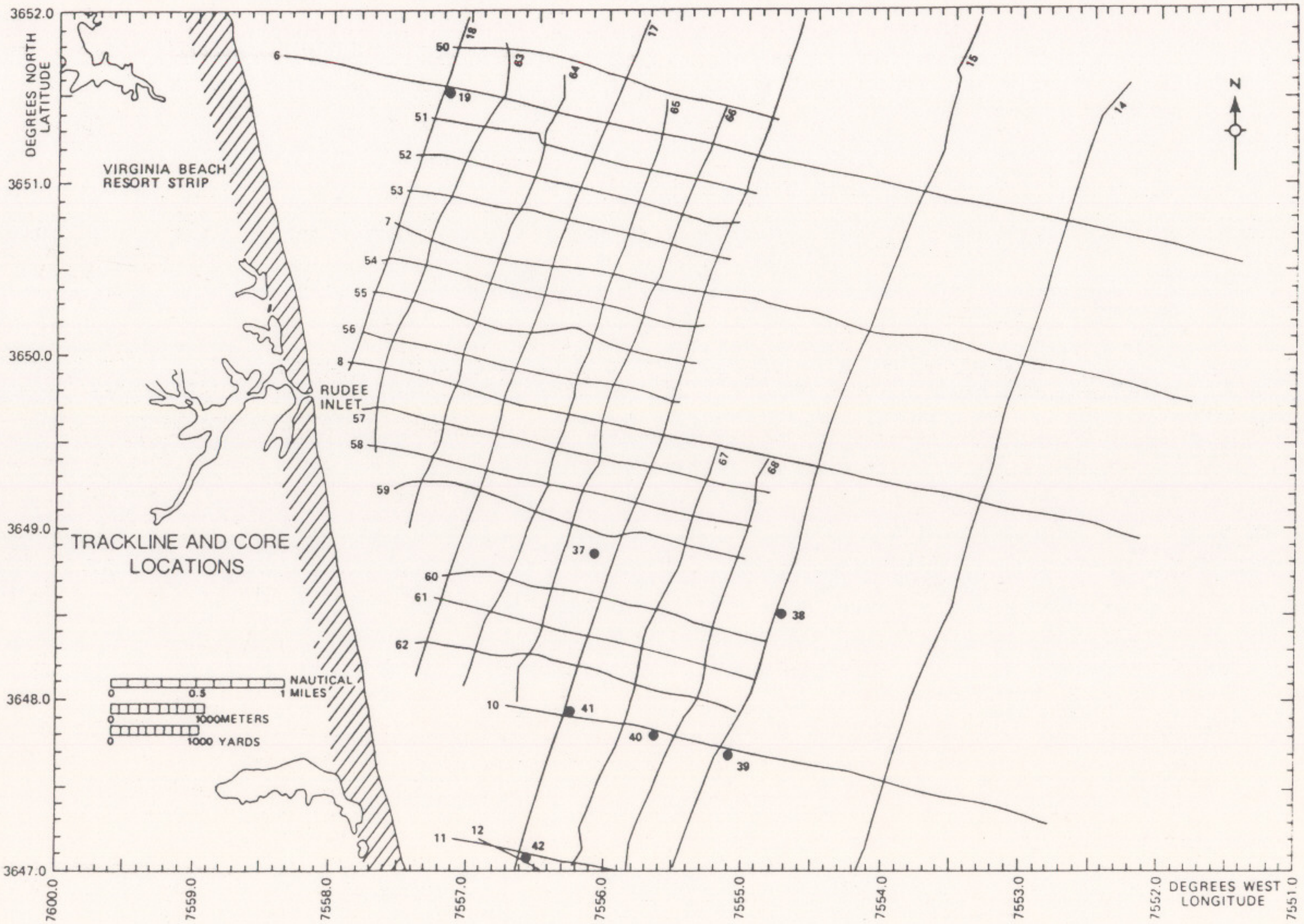

Figure 5. Locations of survey track lines and vibracores (solid circles) in the vicinity of Rudee Inlet. Track line and core numbers are referenced in the text. Transect B-B′ corresponds to Track Line #10.

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
42-1.7	92.1	0.1	7.8	2.08

Figure 6 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 7 is a cross-section across Transect B-B'. Subbottom records indicate a strong reflector that probably represents a Pleistocene/Pliocene(?) erosional 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 (see Appendix B), 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 8). The sedimentary characteristics of the shoal are defined

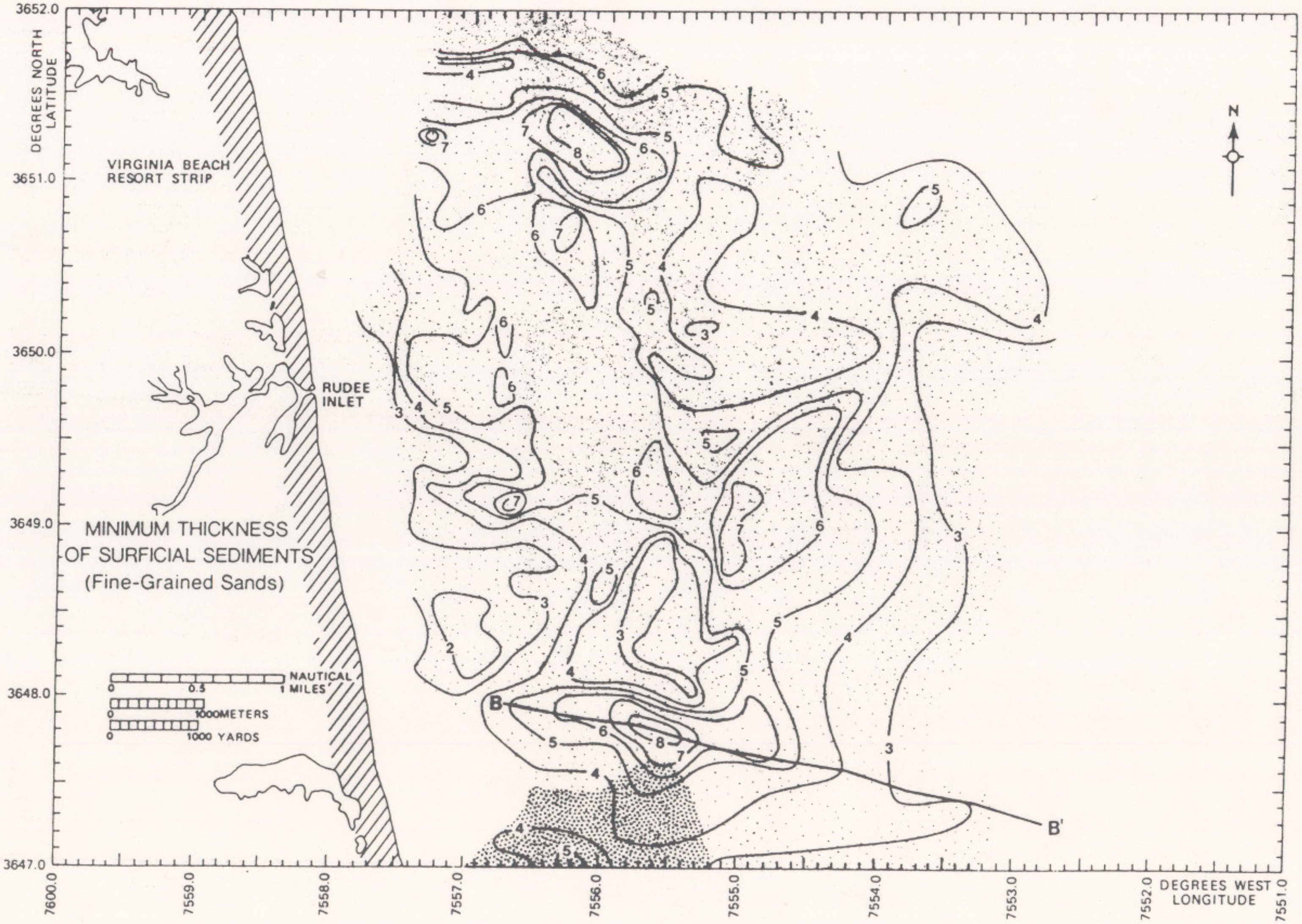

Figure 6. Isopach map showing the distribution and minimum thickness of the surface layer of very fine gray sand in the vicinity of Rudee Inlet. The contour interval is one meter.

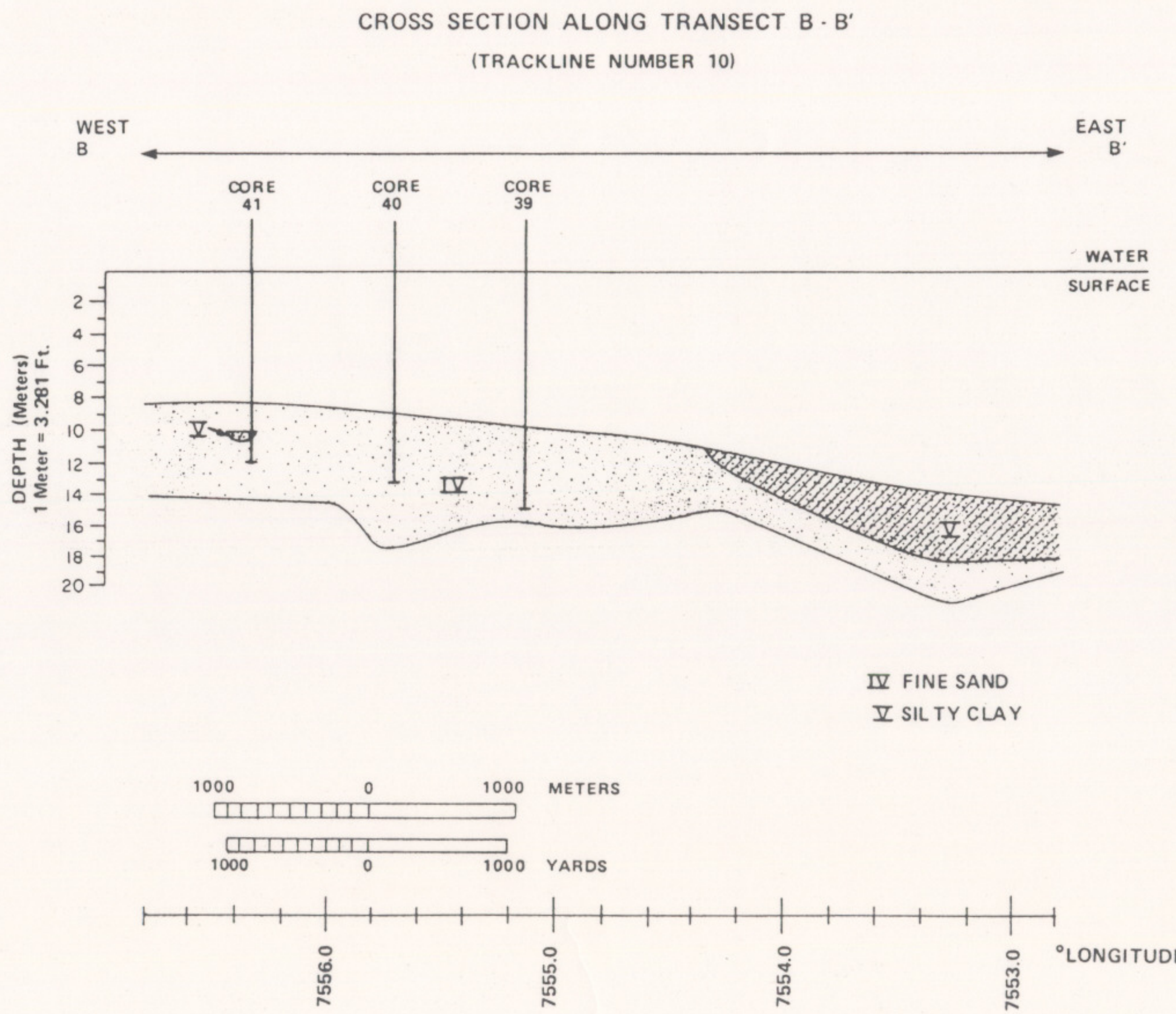

Figure 7. Cross-section along Transect B-B' (Track Line #10), showing the vertical and lateral distributions of very fine sand and sandy clay in the vicinity of Rudee Inlet.

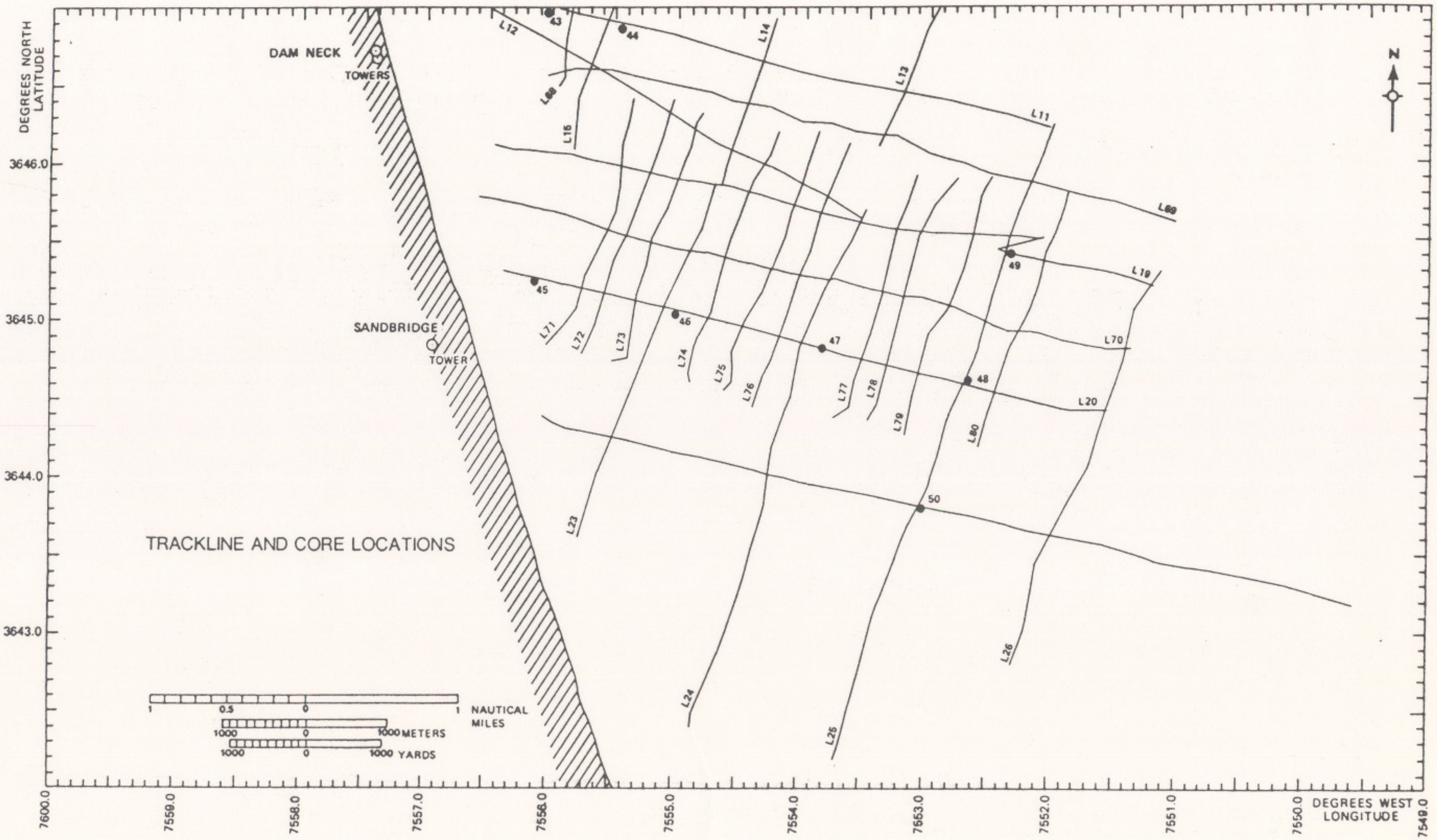

Figure 8. Locations of survey track lines and vibracores (solid circles) in the vicinity of Sandbridge. Track line and core numbers are referenced in the text. Transect A-A' corresponds to Track Line #20.

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 information is contained in Volume II, Appendices C-E, and in Berquist and Hobbs (1988).

Figure 9 shows a cross-section along Transect A-A', which corresponds to seismic track line 20 (Figure 8). Topographically, the shoal's western and southern flanks rise from a swale to a terrace located two to three meters (6.56-9.84 feet) above the surrounding shelf surface. Several terrace levels are evident on the southern perimeter (Lines 25 and 79, Appendix B), 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 (Figure 10). 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 (Table 2; Appendices D and E) show an overall coarsening upwards trend. Stratification within the shoal generally follows the surficial topography, becoming more horizontal towards the basal reflector.

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

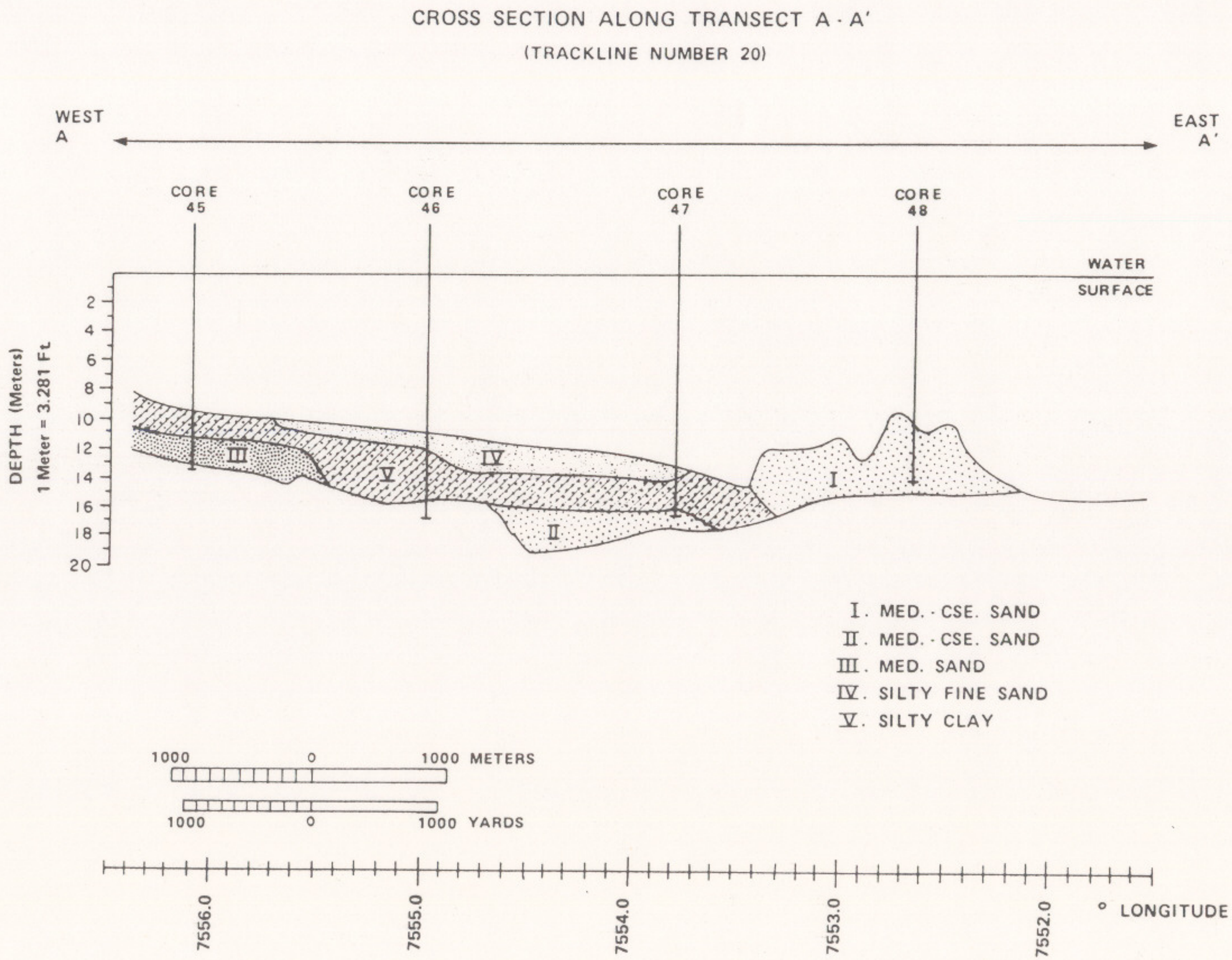

Figure 9. Cross-section along Transect A-A' (Track Line #20), showing the vertical and lateral distributions of an isolated shoal and attendant sand bodies in the vicinity of Sandbridge.

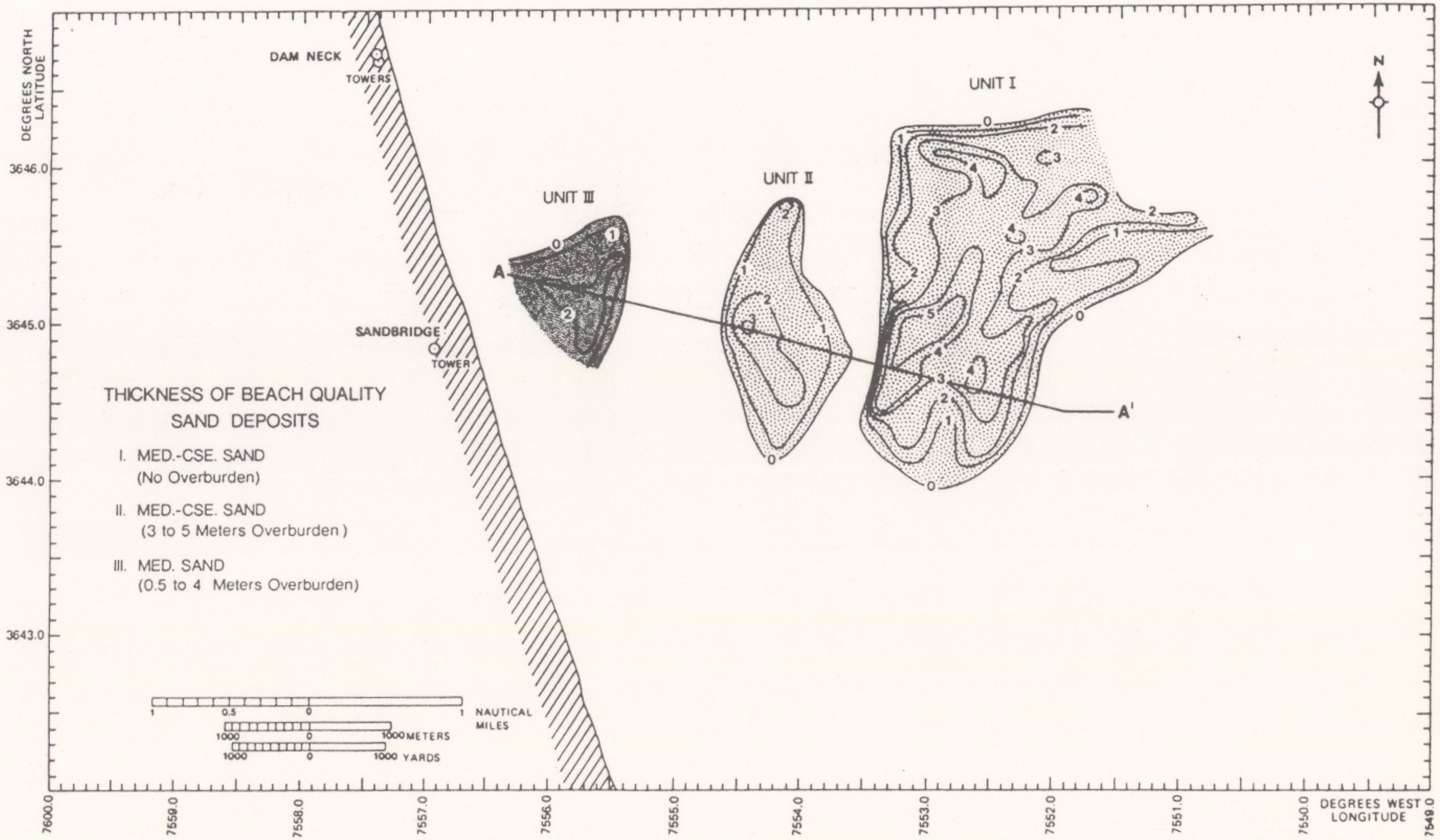

Figure 10. Isopach map showing the distribution and inferred thickness of medium to coarse sand deposits in the vicinity of Sandbridge. The contour interval is one meter.

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 11 illustrates the thickness and areal distribution of the clay. Where the clay outcrops at the surface, a heavy layer of suspended flocculates extends approximately one meter (3.28 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 (Line 25; Appendix B).

West of the shoal and covered by approximately three to five meters (9.84-16.4 feet) of overburden is a layer of medium to coarse sand (Unit II, Figure 9; Figure 10). 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 12. 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.

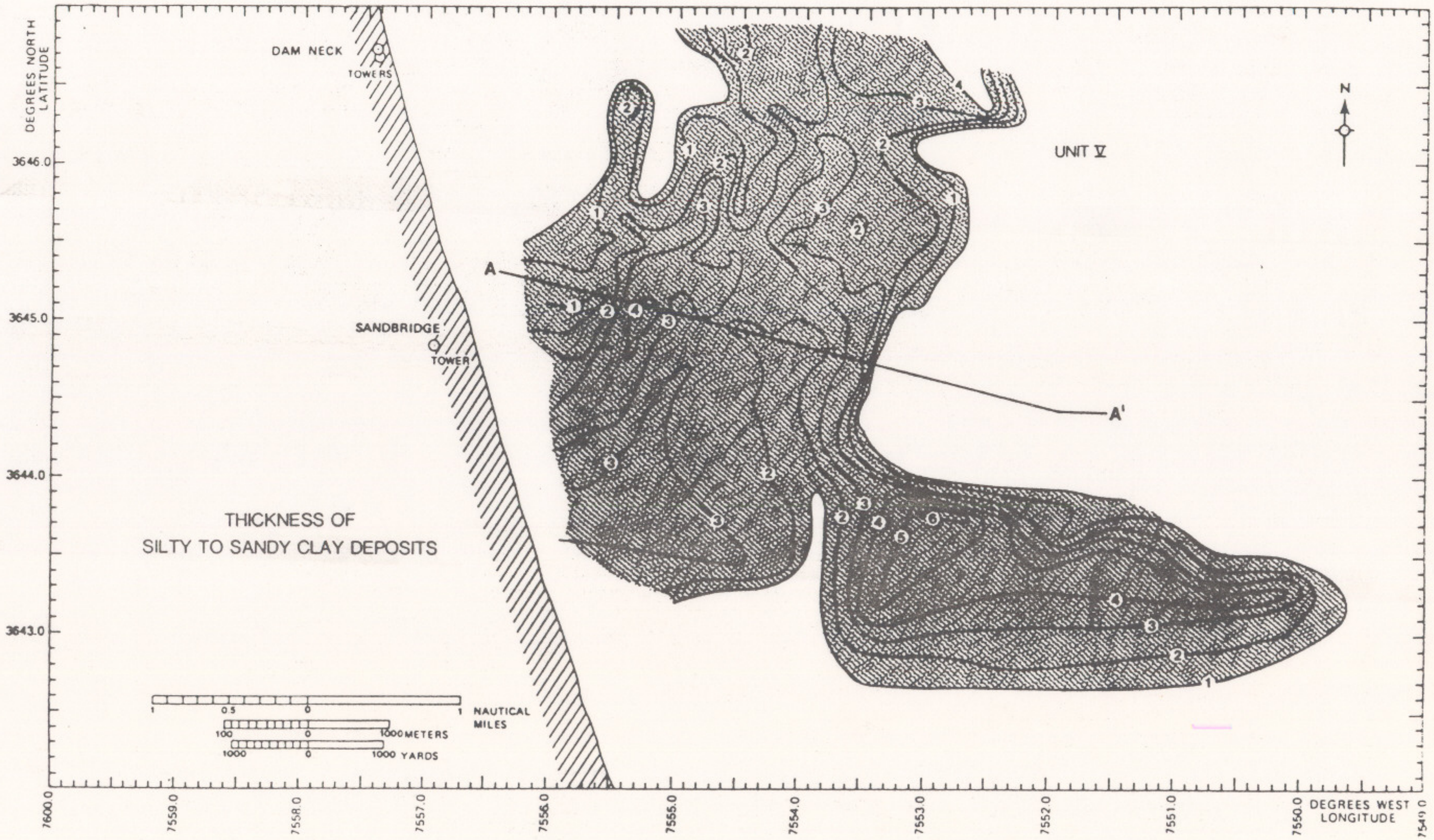

Figure 11. Isopach map showing the distribution and inferred thickness of clay units in the vicinity of Sandbridge. The contour interval is one meter.

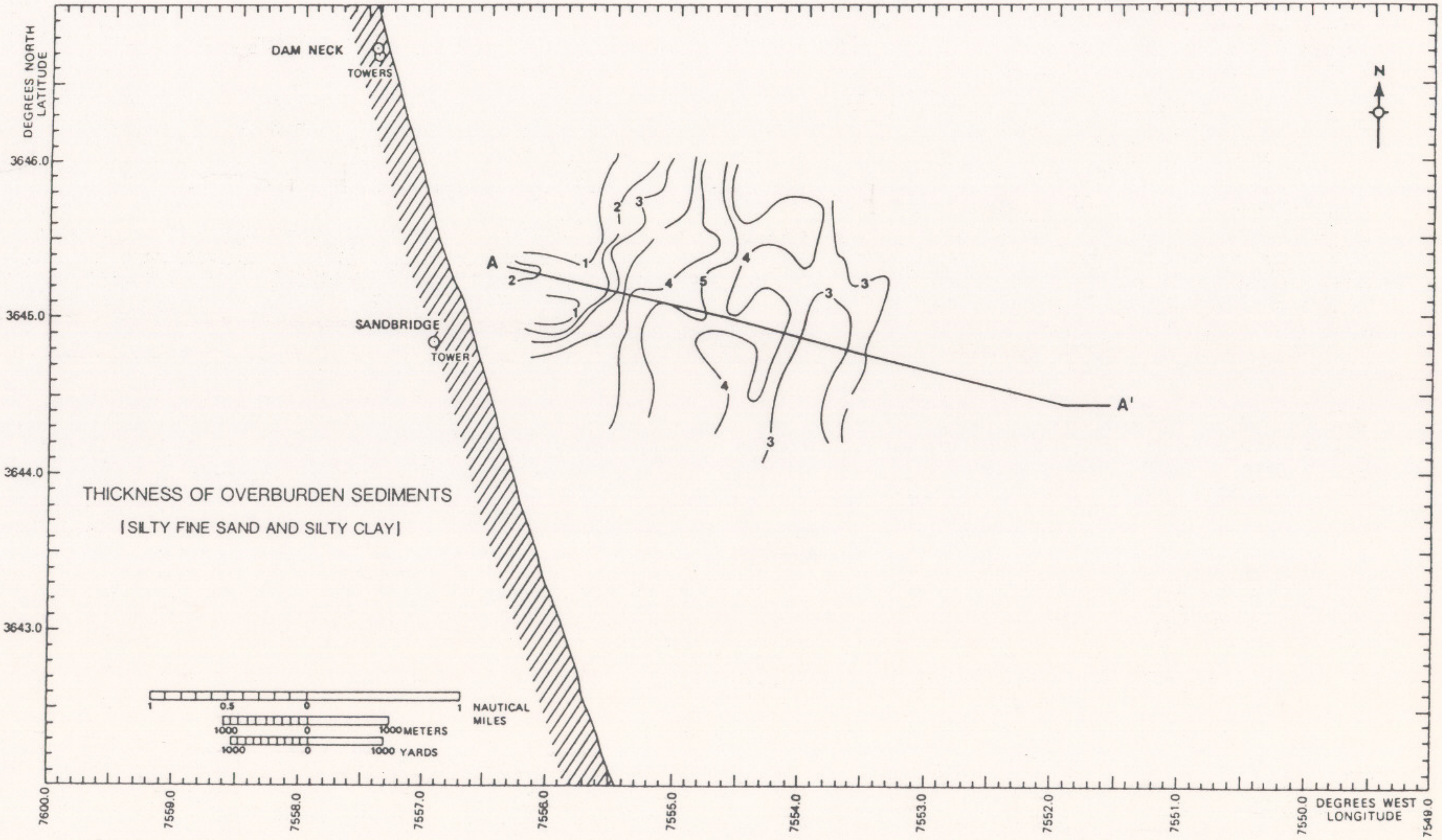

Figure 12. Isopach map showing the distribution and thickness of the overburden associated with beach quality sand deposits in the vicinity of Sandbridge. Total overburden includes both clay and very fine sand beds. The contour interval is one meter.

A third sand body, Unit III (Figures 9, 10), lies on the Sandbridge shoreface under two meters (6.56 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. DISCUSSION

In response to increasing pressures from economic development in the coastal zone, it has become incumbent upon local governments to provide maintenance and development of public recreational facilities, including beaches. The same development pressures affect the availability of upland sources of suitable beach nourishment materials, forcing localities to look for alternate sand reserves.

An intensive geophysical exploration program was instituted to determine if mineable reserves of beach-quality sand existed on the inner continental shelf adjacent to the Virginia Beach shoreline. Data collection included the acquisition of high resolution acoustic subbottom records, corroborated by a series of sediment cores.

The inner shelf and shoreface within five kilometers of the shoreline is covered by a veneer of fine to very fine gray micaceous sand with minor amounts of organic material. Typical concentrations of silts and clays exceed 20% by weight. This material lacks the texture and aesthetic values that are identified as important for nourishment of recreational beaches. However, the mean grain size, 0.125 mm (3.0 phi) is consistent with surface sediments in depths of water exceeding three meters (9.8 feet). Although the material is inconsistent with recreational beach use, its characteristics are similar to seafloor sedimentology in the nearshore zone. Consequently, these materials could be used to develop dissipative configurations on eroding shorefaces.

Three areas were identified with potential for providing beach-quality sands. The first, in the vicinity of False Cape, consists of a series of sub-parallel linear shoals trending northeast and connected to the shoreface through the nearshore bar system. The shoals extend as much as 2.5 km (1.6 miles) with a surface relief exceeding three meters (9.8 feet). The shoals contain medium to coarse sand with a mean grain size of 0.3 mm (1.75 phi). A conservative estimate of the volume of sand in the shoals is 2.5×10^6 m^3 (3.1×10^6 yd^3). The False Cape linear shoal field represents a significant reserve of beach quality sand. However, its distance from developed areas in Virginia Beach reduces its economic value to the City. This material should be considered as a possible emergency reserve in the event of a catastrophic storm.

The area east of the Rudee Inlet/Croatan shoreface appears to be undesirable in terms of reserves of beach quality sand. Surface sediments, to depths exceeding one meter (3.28 feet), are very fine sands and silts as described above. Although these deposits initially appear to be massive, homogeneous beds to depths exceeding maximum core retrieval, detailed sedimentary analysis reveals that a series of slightly coarser fine sand stratigraphic units exists with depth. These sands vary in texture between 0.25 mm (2.0 phi) and 0.125 mm (3.0 phi), with a regional average of 0.2 mm (2.25 phi) and an average of

10% fines by weight. The quality of these materials approximates that of sediment in the Cape Henry Navigation Channel which was placed on the Virginia Beach Resort Strip as part of the navigation channel enhancement project in 1989. Although these sediments are not optimal recreational beach quality, they can provide short-term relief to an eroding beach.

The third, and most promising, site is a large sand shoal located five kilometers (three miles) east of Sandbridge Beach in 12 meters (40 feet) of water. The shoal, as mapped, has an areal extent of 12.38 km^2 (4.76 mi^2). The northeastern limits of the shoal were not mapped as part of this project and remain undefined. The shoal is composed of clean, medium to coarse sand (0.3 mm; 1.5 phi) that tends to coarsen upwards in the section. Thickness of the shoal varies from one meter (3.28 feet) to five meters (16.4 feet). Using an average thickness of 2.5 meters (8.2 feet), a conservative estimate of the volume of beach-quality sand contained within the study area exceeds 17 million m^3 (39.8 million yd^3). Total reserves could double that amount.

Beach Sediments and Overfill Ratios.

Goldsmith et al. (1977) describes the importance of cyclic glacial activity and concomitant variability in sea level in creating the character of sediment sources in the area. The Traverse Group, Inc. (1980) attribute the textural variation of beach materials in the Virginia Beach area to inherited traits from heterogeneous Pleistocene sediments in the substrate. In addition, modern sediments distributed by tidal flow in and around the Chesapeake Bay entrance contribute an important component to the northern Virginia Beach sedimentology.

Beach sediment data from various sources have been collated and summarized in Wright et al. (1987). Although there is considerable variation in mean grain size both along the coast and across the profile, the following regional averages apply:

<u>Resort Strip</u>

Foreshore mean -- 2.0 phi
Foreshore standard deviation -- 0.8 phi

<u>Sandbridge</u>

Foreshore mean -- 1.75 phi
Foreshore standard deviation -- 0.4 phi

Similar average values can be calculated for each of the potential sand reserve sites:

<u>Rudee Inlet</u>

Surface mean -- 3.05 phi
Surface standard deviation -- 0.5 phi
Subsurface mean -- 2.25 phi
Subsurface standard deviation -- 0.6 phi

<u>Sandbridge Site</u>

Mean -- 1.48 phi
Standard deviation -- 0.5 phi

One measure of the suitability of a given borrow material for a beach nourishment project is the Overfill Factor (R_A). This measure was developed by James (1975) and is used widely by the U.S. Army Corps of Engineers. The assumption behind the overfill factor is that the distribution of grain sizes on a stable beach is representative of a dynamic equilibrium between the supply of material to the beach and the rate of transport that removes it (U.S. Army Corps of Engineers, 1984).

The most suitable renourishment sediments would have a grain size distribution similar to the native material. In areas that are receding, it is necessary to compensate for differences in the size distributions of native and borrow sediments by putting an initial amount of material on the beach that exceeds the desired design. This allows for readjustment of the sediment following placement.

R_A is calculated by comparing the phi-scale mean grain size of the borrow material with that of the native sand, and plotting those values against the ratio of the standard deviations of the borrow and native material. These values are plotted on a nomograph provided by the U.S. Army Corps of Engineers Shore Protection Manual (1984), from which R_A is read.

The Periodic Renourishment Factor (R_J) is a similar calculation that compares the rate at which the borrow material will erode with the rate at which the native material erodes. The phi mean difference and sorting ratios are calculated in the same manner as for R_A, and the resultant R_J factor read from a nomograph (U.S. Army Corps of Engineers, 1984).

R_A and R_J were calculated for each of the Resort Strip and Sandbridge beaches relative to potential sand reserves offshore of Rudee Inlet and Sandbridge. R_A for the Resort Strip, relative to the fine surface sand in the Rudee Inlet area is >10.0, which is in the unstable quadrant. It would not be advisable to use this material for renourishment of the Resort Strip. R_J is calculated at 6.0, indicating a potential for greater erosion rates than the native sediments. Relative to the subsurface sands offshore of Rudee Inlet, R_A for the

Resort Strip is 3.0, and R_J is 1.75. This material is comparable to the material dredged during the 1989 deepening of the Cape Henry Navigation Channel.

The Sandbridge beach sediments, relative to the offshore sand shoal, have an R_A of <1.02, which is stable; and a R_J of 0.14. These values indicate that the material in the sand shoal offshore Sandbridge is an excellent source of sand for renourishment of the Ocean-side beaches in Virginia Beach.

VI. SUMMARY

An geophysical exploration program was undertaken designed to identify reserves of beach quality sand on the inner shelf. Several areas containing potential reserves were identified, including the False Cape reach and the region in the vicinity of Rudee Inlet. The False Cape reserves are of good quality, but the distance separating the reserve from potential destinations lessens the economic viability of the deposit. The sand deposits on the inner shelf fronting Rudee Inlet are desirable in terms of location, but are less than optimal in terms of recreational beach material. Recent work by Berquist and Hobbs (1988) identify each of these areas as having high concentrations of economic heavy minerals, particularly the titanium suite. The possibility of dual commodity mining associated with the heavy mineral deposits may provide a favorable economic climate for extraction.

The most promising reserve is a moderately-sized sand shoal situated approximately five kilometers (three miles) east of Sandbridge

Beach. More than 17 million m^3 (39.8 million yd^3) of clean medium to coarse sand (0.3 mm; 1.5 phi) is concentrated in a discrete shoal feature with no overburden. No economic concentrations of heavy minerals have been identified in samples from this shoal (Berquist and Hobbs, 1988). However, overfill and renourishment factors relative to Sandbridge are <1.02 and <0.14, respectively, which indicates stability relative to the native sediments.

This shoal represents a very valuable sand reserve within economical transport distance for mining. Benthic resource evaluations have not been completed for this site. However, the proximity to the Dam Neck Disposal Site which has been studied extensively will allow preliminary evaluations of certain resources, including migratory species. Because of the thickness and areal extent of the shoal, mining activities should not extract the total volume of available sand. Sedimentary homogeneity within the shoal ensures that the nature of the substrate will not change appreciably as a result of sand extraction.

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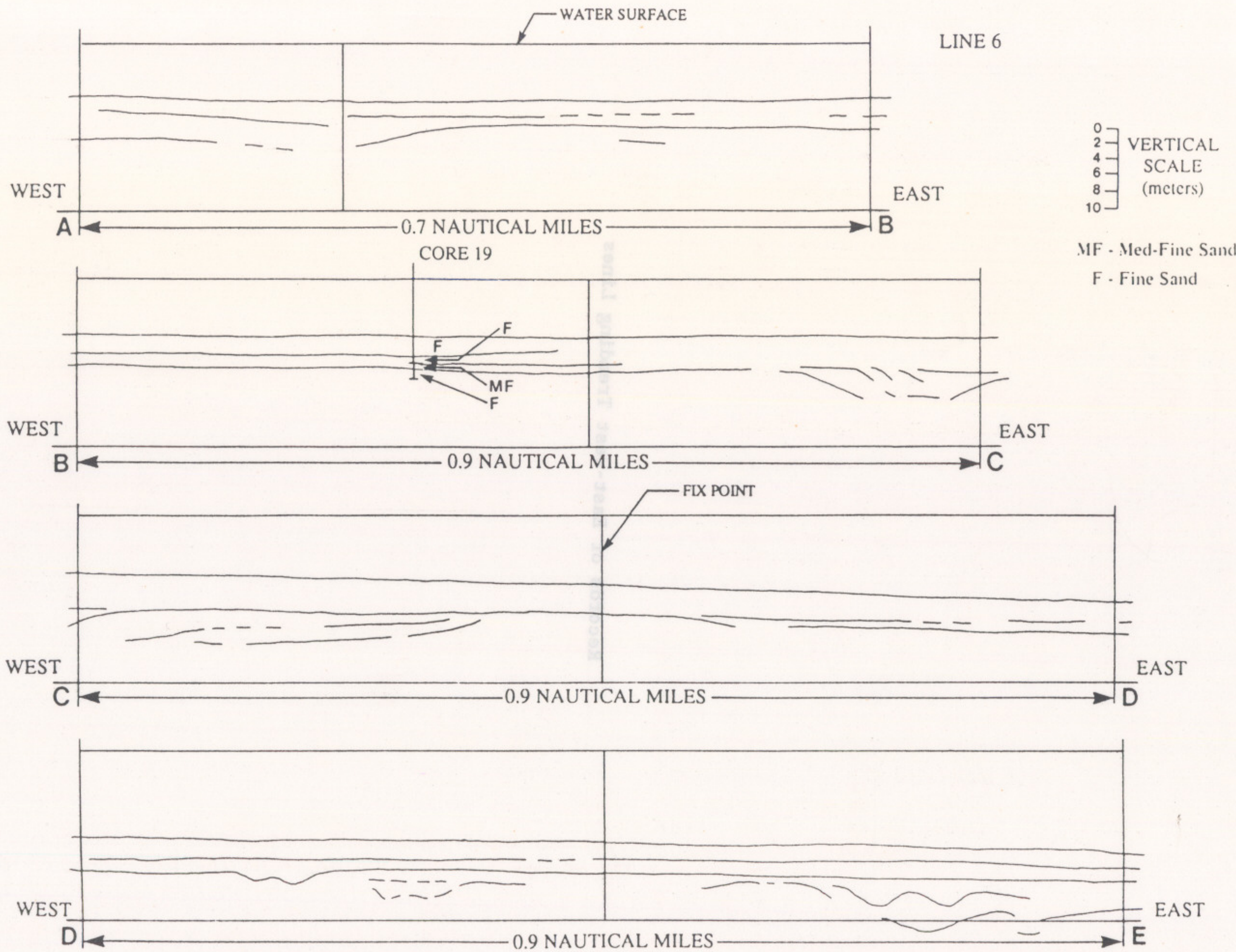
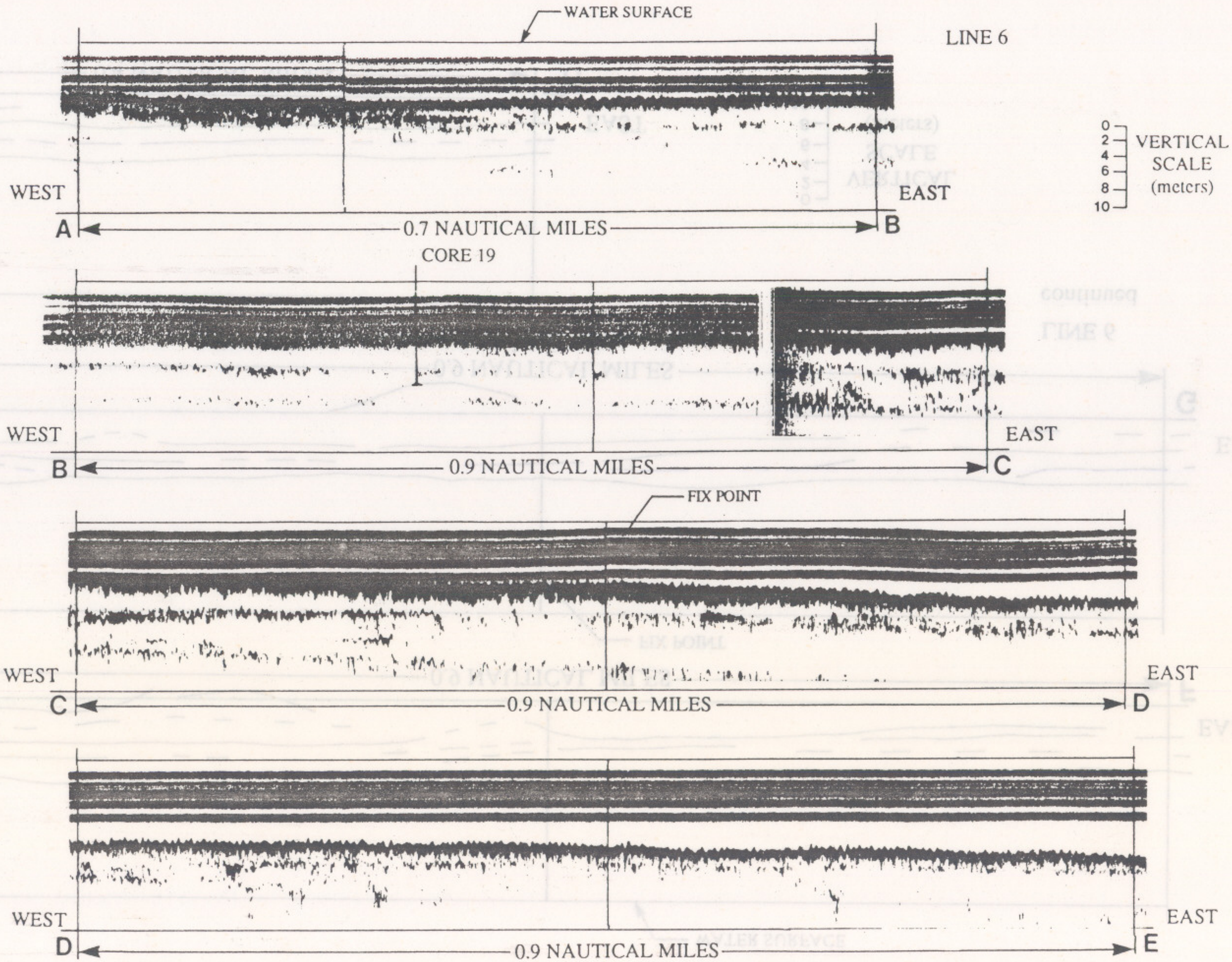
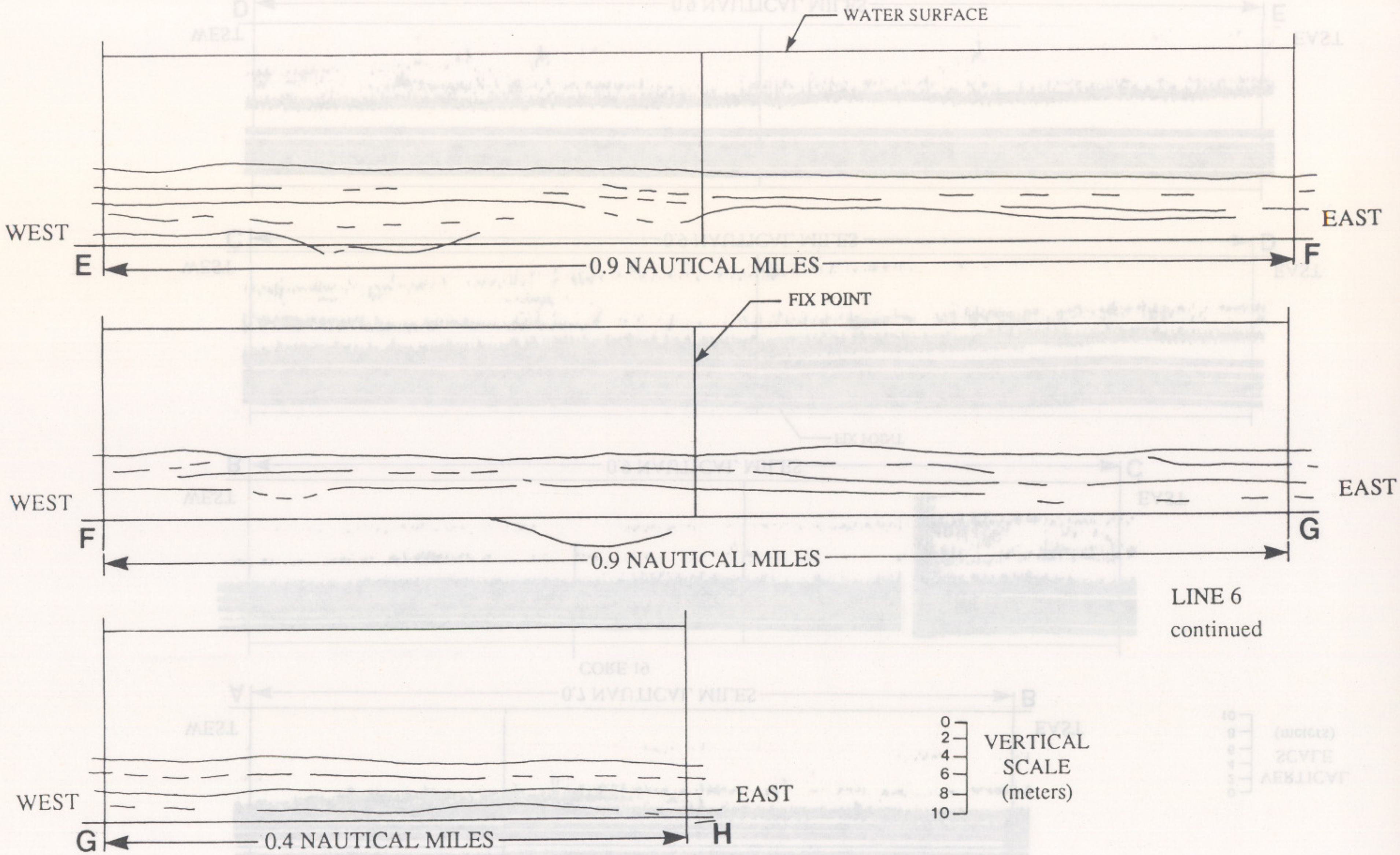
APPENDIX A

Reproductions of subbottom acoustic records retrieved from the Rudee Inlet section of the study area paired with interpretations of the seismic data. Track line locations are shown in Figure 5.

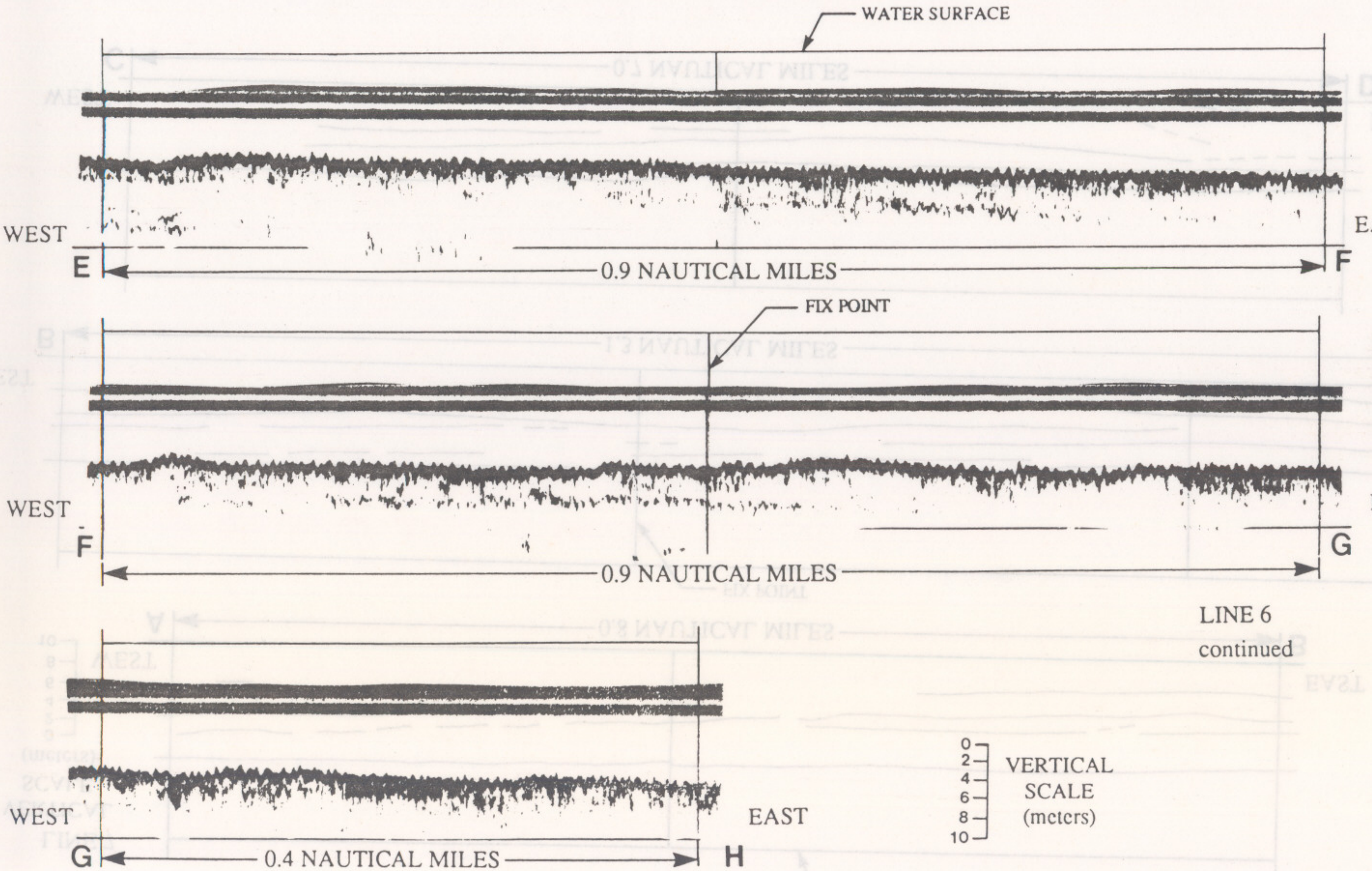
Records of East-West Trending Lines


WATER SURFACE
LINE 6
0
2
4
6
8
10
VERTICAL SCALE (meters)
MF - Med-Fine Sand
F - Fine Sand
WEST
EAST
A
B
0.7 NAUTICAL MILES
CORE 19
F
F
MF
F
WEST
EAST
B
C
0.9 NAUTICAL MILES
FIX POINT
WEST
EAST
C
D
0.9 NAUTICAL MILES
WEST
EAST
D
E
0.9 NAUTICAL MILES

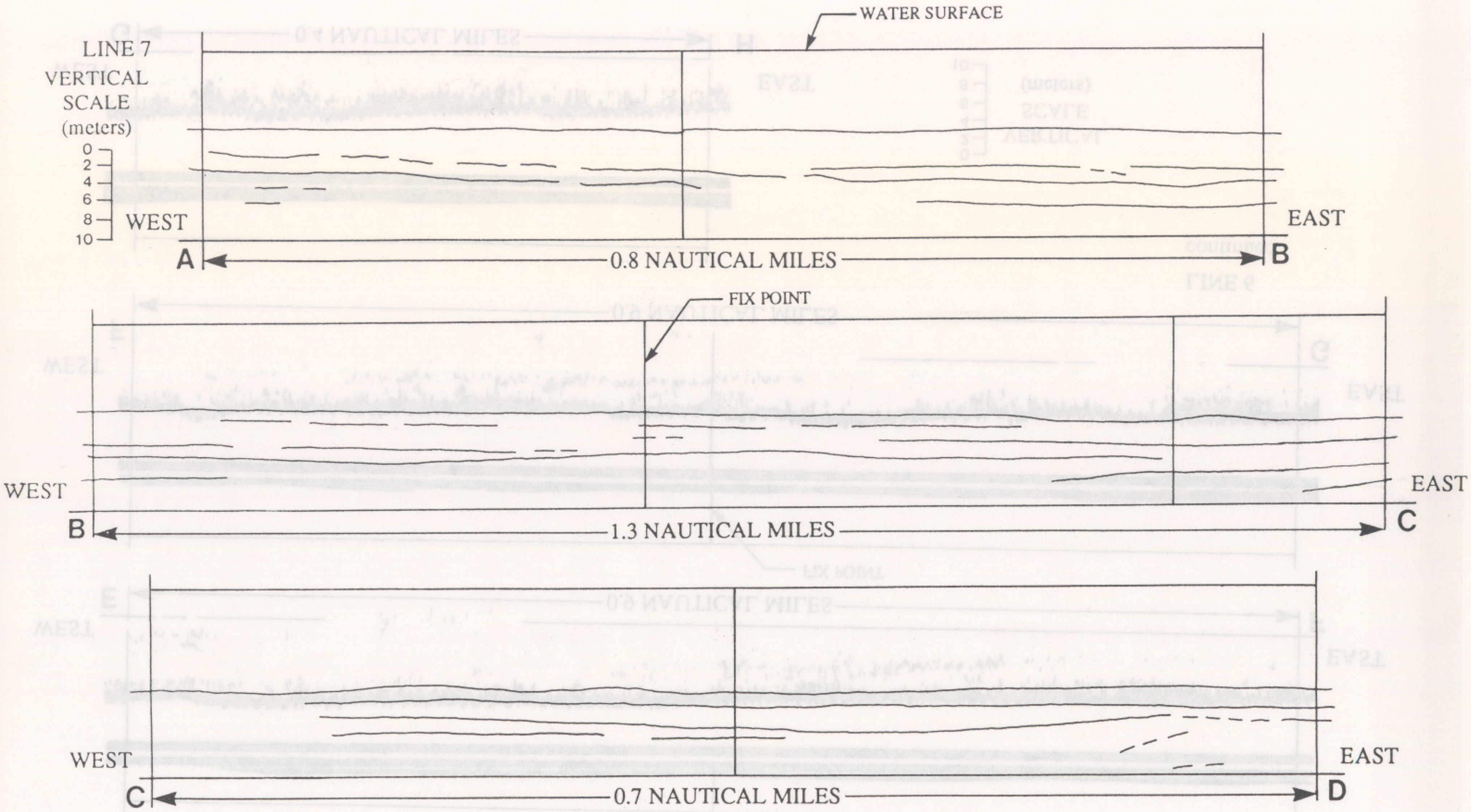

WATER SURFACE
LINE 6
0
2
4
6
8
10
VERTICAL
SCALE
(meters)
WEST
EAST
A
0.7 NAUTICAL MILES
B
CORE 19
WEST
EAST
B
0.9 NAUTICAL MILES
C
FIX POINT
WEST
EAST
C
0.9 NAUTICAL MILES
D
WEST
EAST
D
0.9 NAUTICAL MILES
E

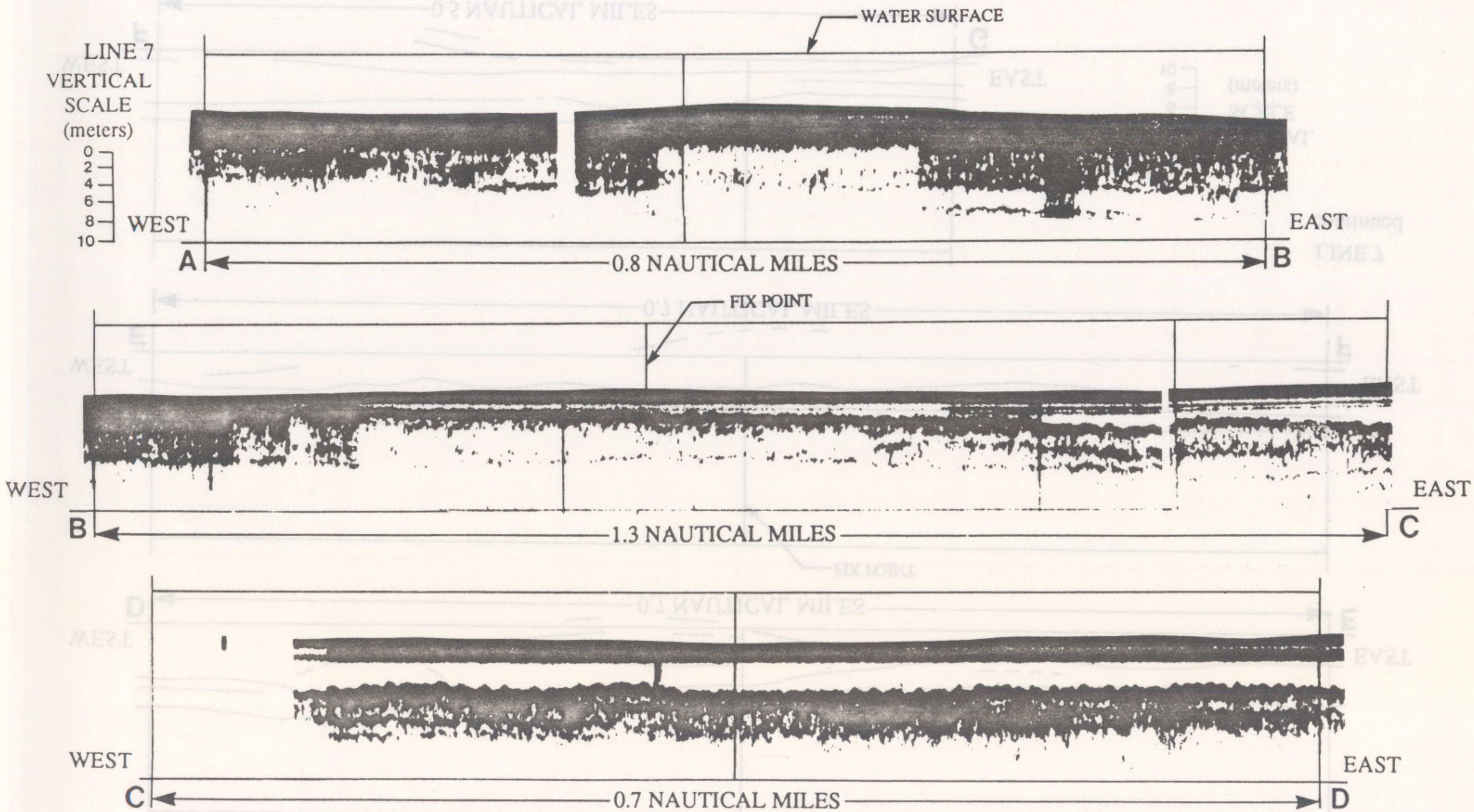


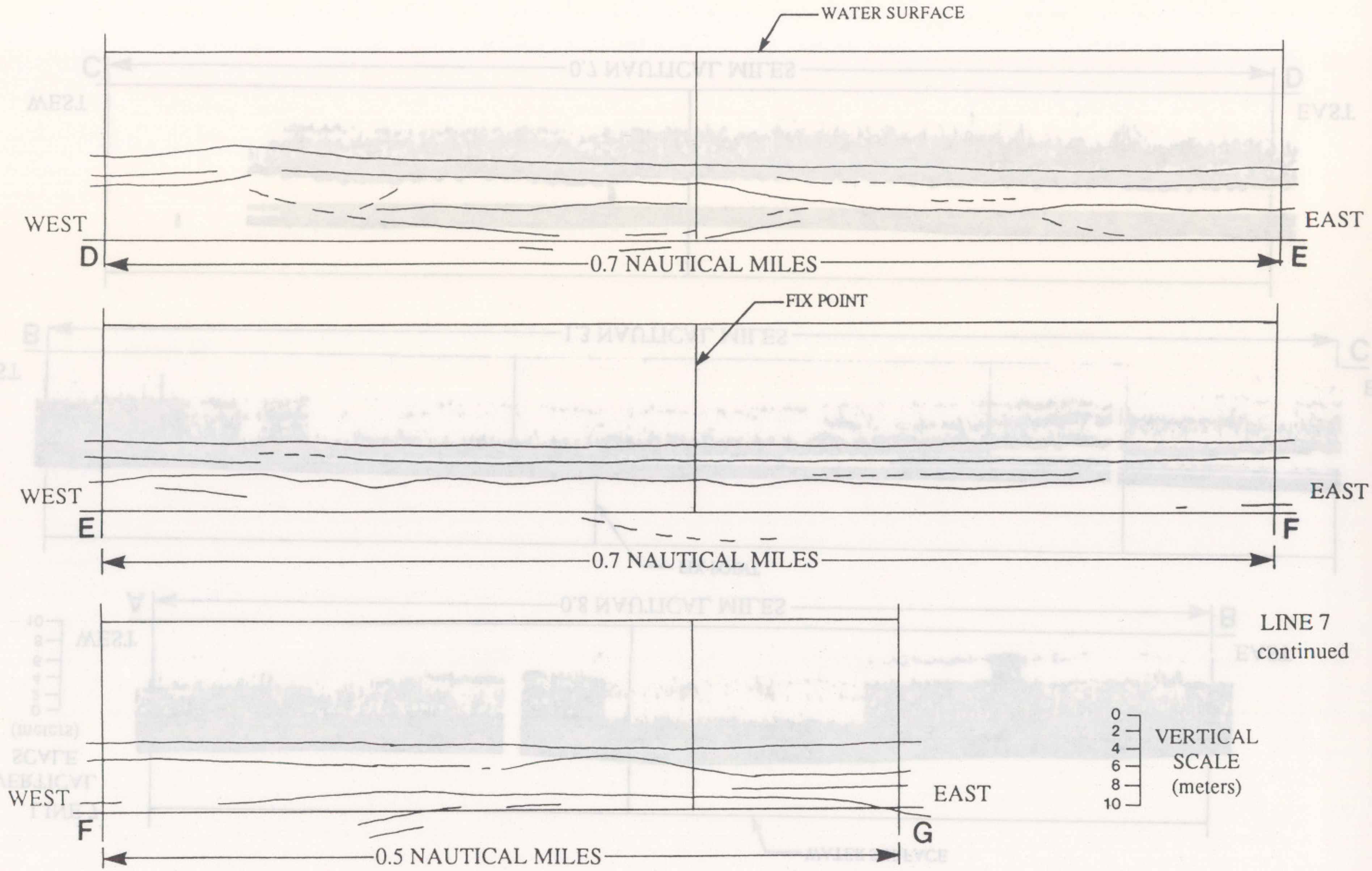
LINE 6
continued

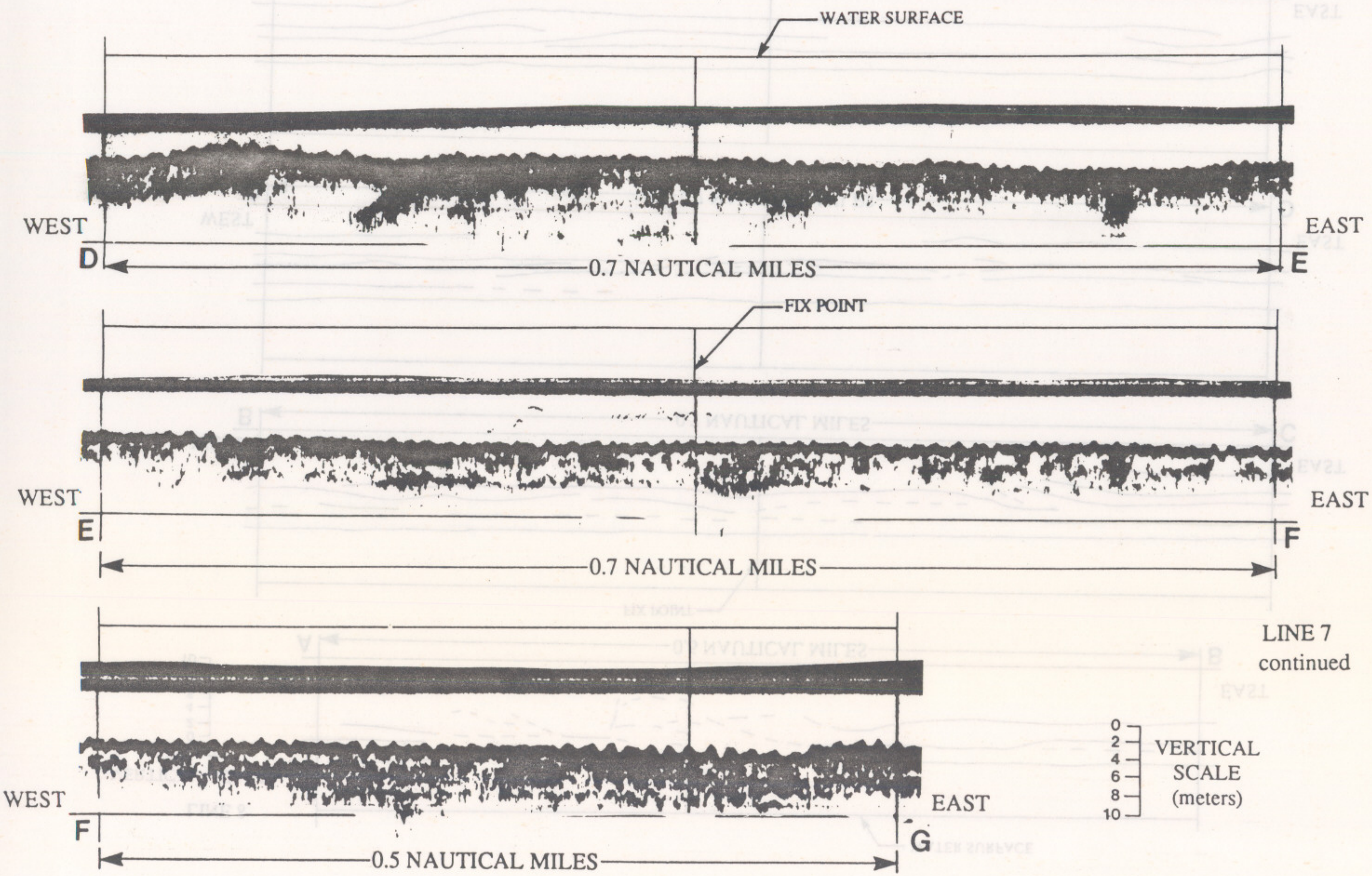


LINE 6
continued

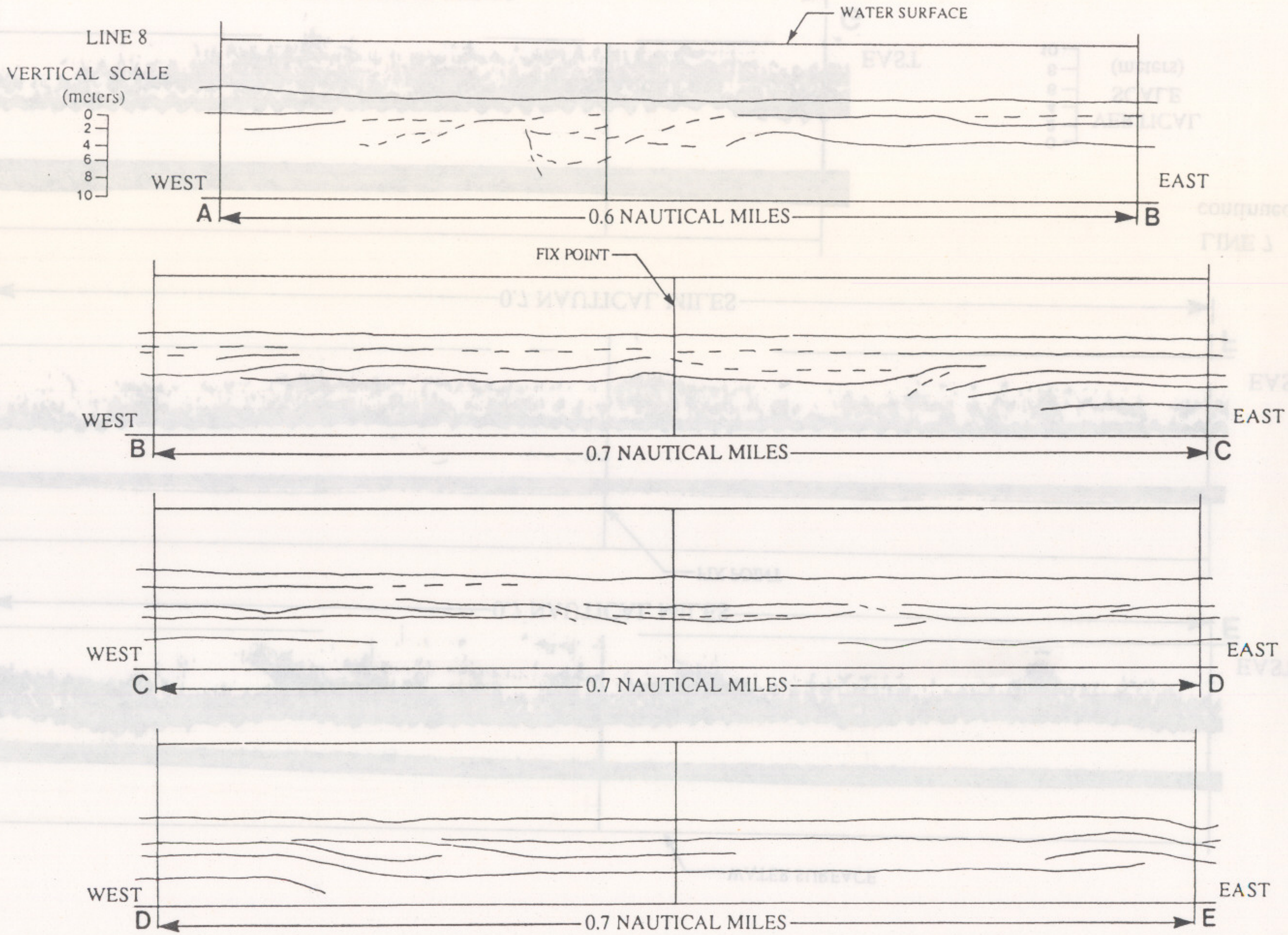

WATER SURFACE
LINE 7
VERTICAL
SCALE
(meters)
0
2
4
6
8
10
WEST
EAST
A
0.8 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
1.3 NAUTICAL MILES
C
WEST
EAST
C
0.7 NAUTICAL MILES
D

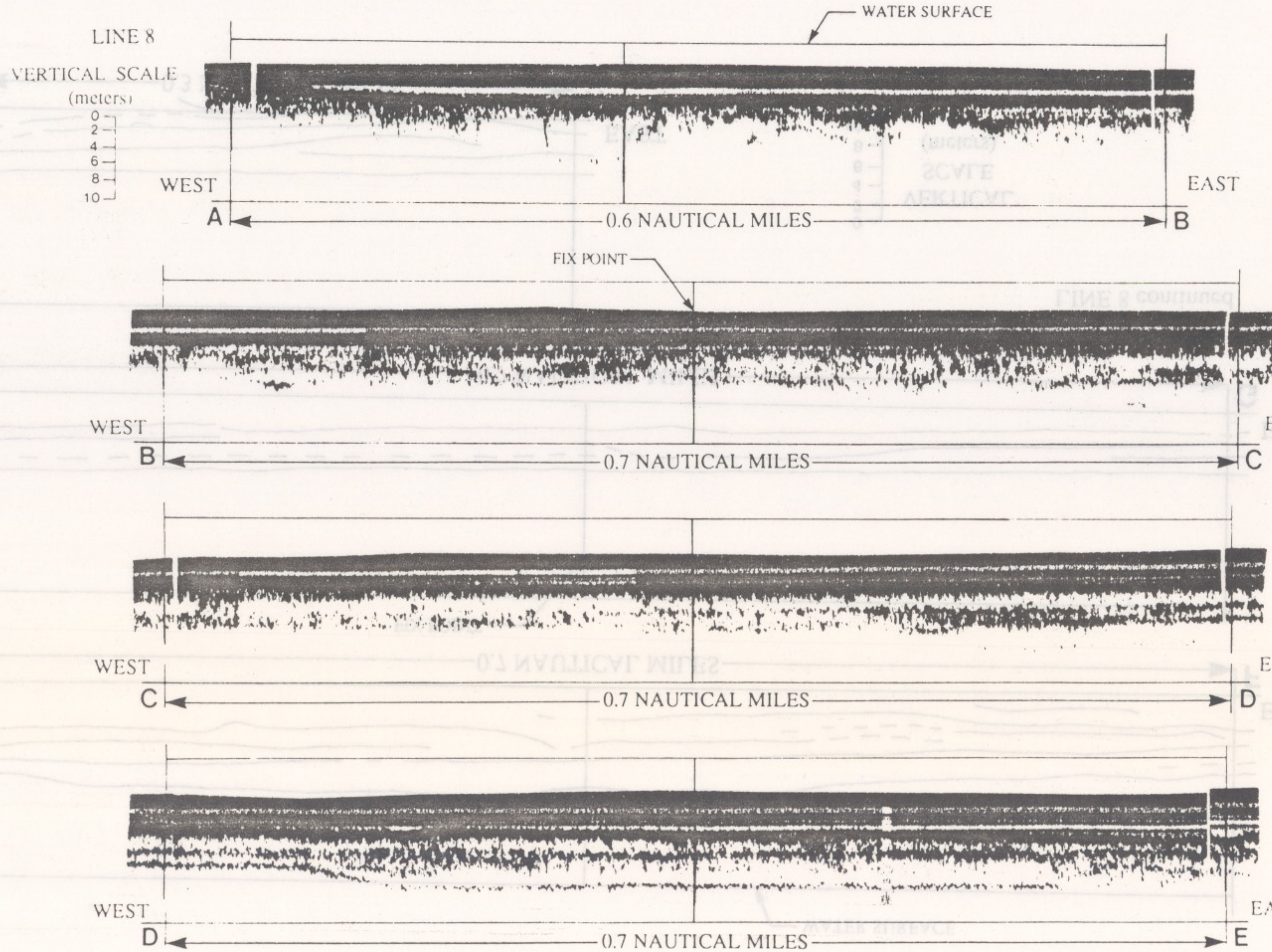

LINE 7
VERTICAL SCALE (meters)
0
2
4
6
8
10
WATER SURFACE
WEST
EAST
A
B
0.8 NAUTICAL MILES
FIX POINT
WEST
EAST
B
C
1.3 NAUTICAL MILES
WEST
EAST
C
D
0.7 NAUTICAL MILES

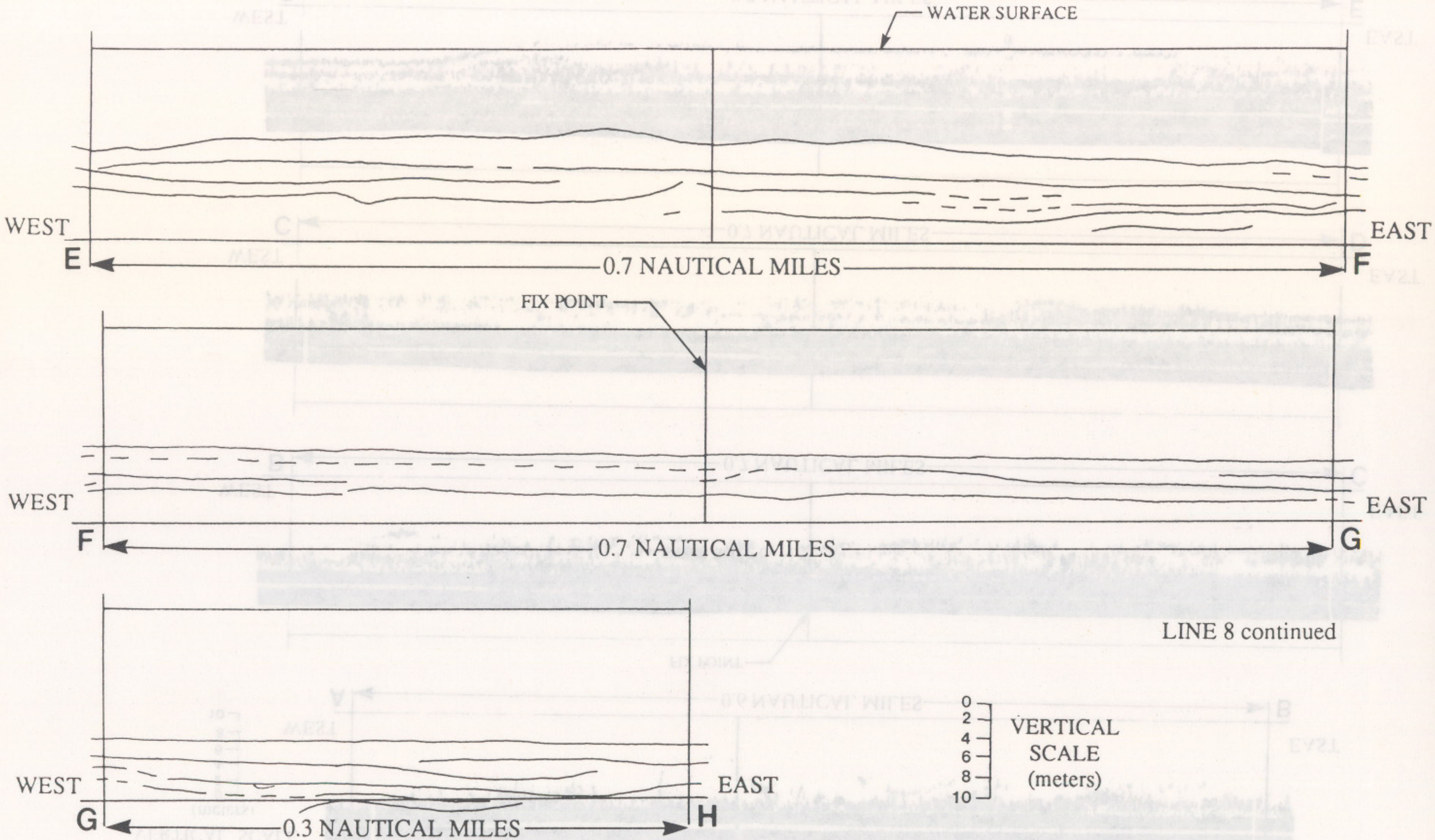

WATER SURFACE
WEST
EAST
D
E
0.7 NAUTICAL MILES
FIX POINT
WEST
EAST
E
F
0.7 NAUTICAL MILES
LINE 7
continued
WEST
EAST
F
G
0.5 NAUTICAL MILES
0
2
4
6
8
10
VERTICAL
SCALE
(meters)



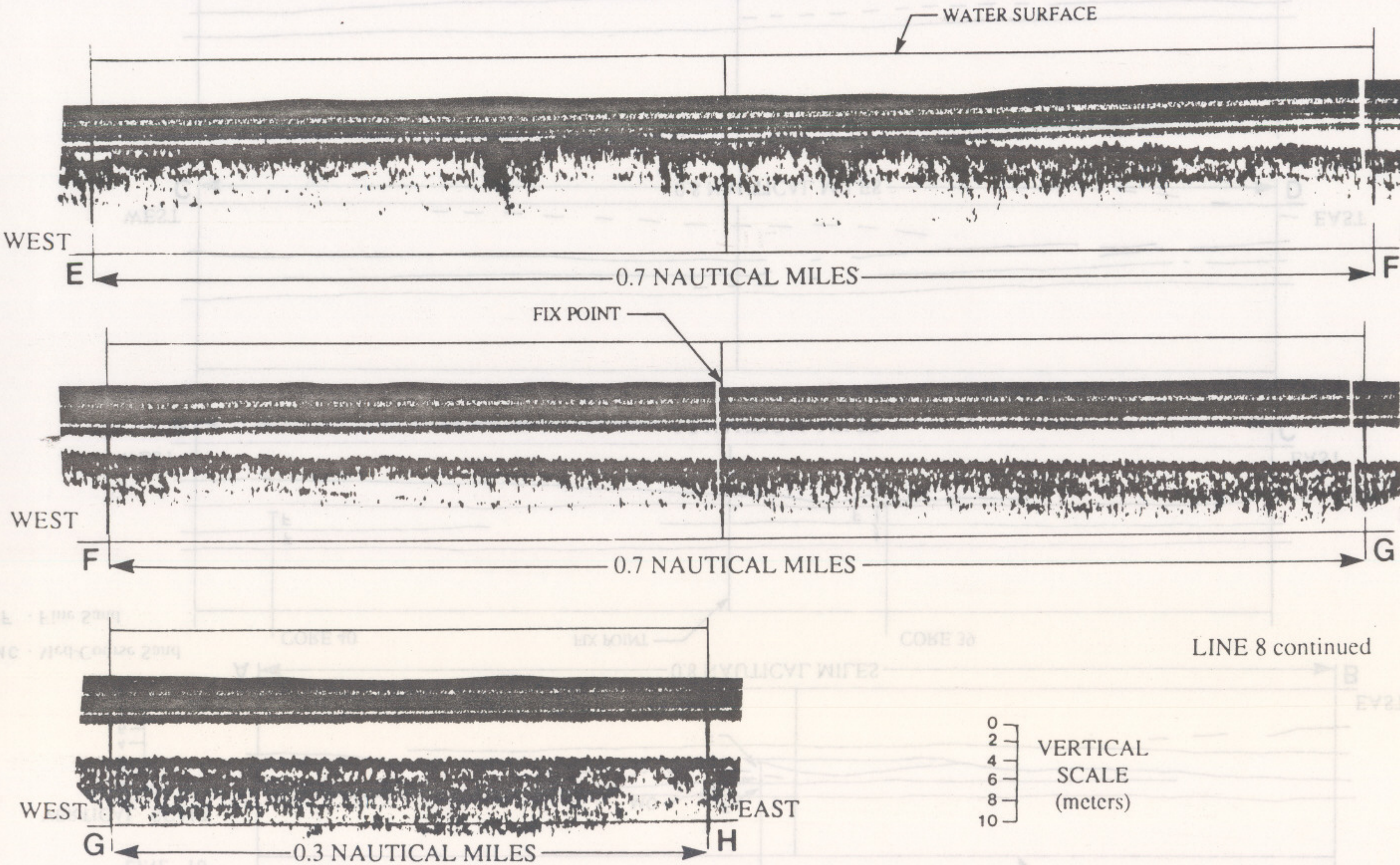
LINE 7
continued


WATER SURFACE
LINE 8
VERTICAL SCALE
(meters)
0
2
4
6
8
10
WEST
EAST
A
0.6 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
0.7 NAUTICAL MILES
C
WEST
EAST
C
0.7 NAUTICAL MILES
D
WEST
EAST
D
0.7 NAUTICAL MILES
E

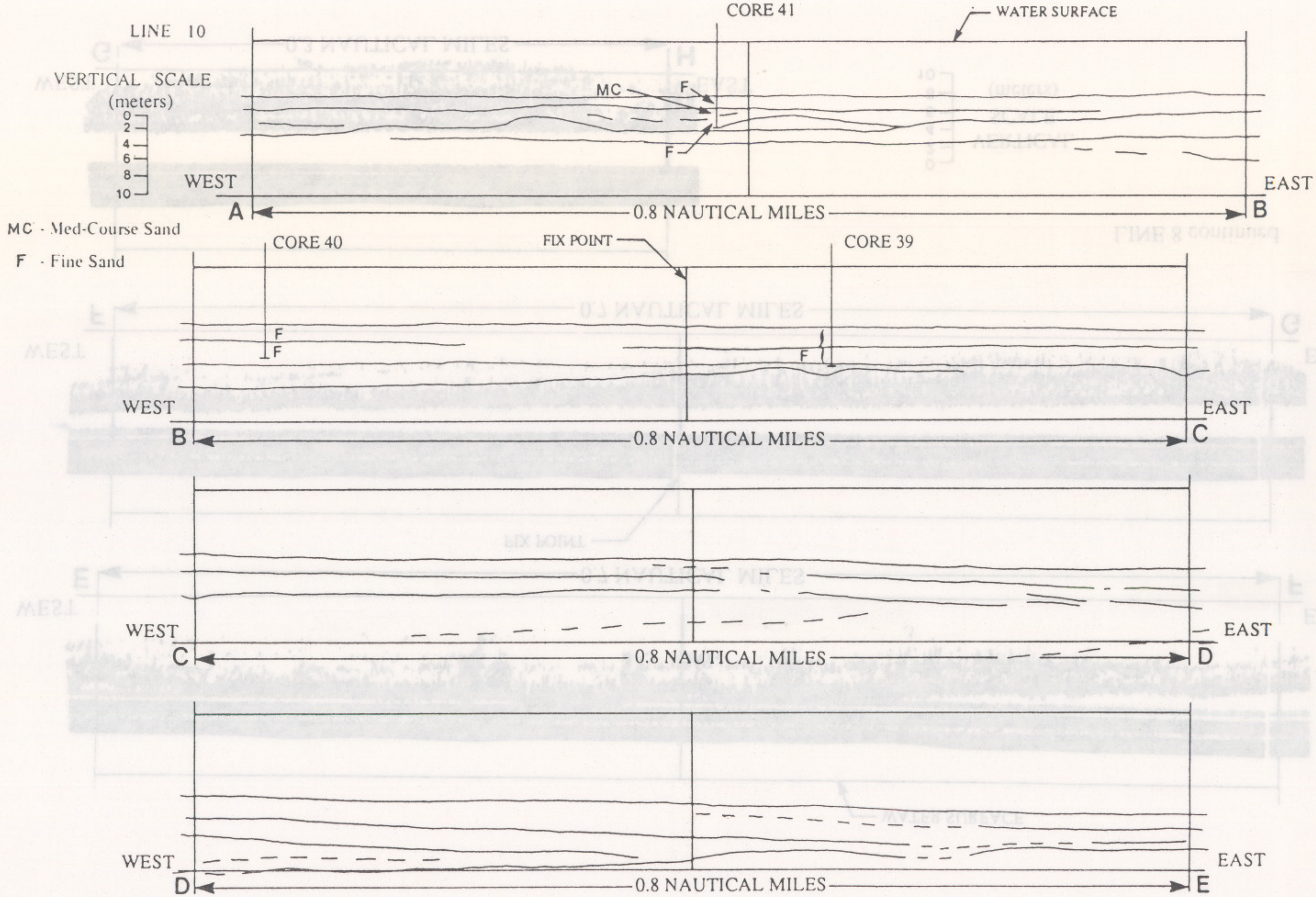

WATER SURFACE
LINE 8
VERTICAL SCALE
(meters)
0
2
4
6
8
10
WEST
EAST
A
0.6 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
0.7 NAUTICAL MILES
C
WEST
EAST
C
0.7 NAUTICAL MILES
D
WEST
EAST
D
0.7 NAUTICAL MILES
E

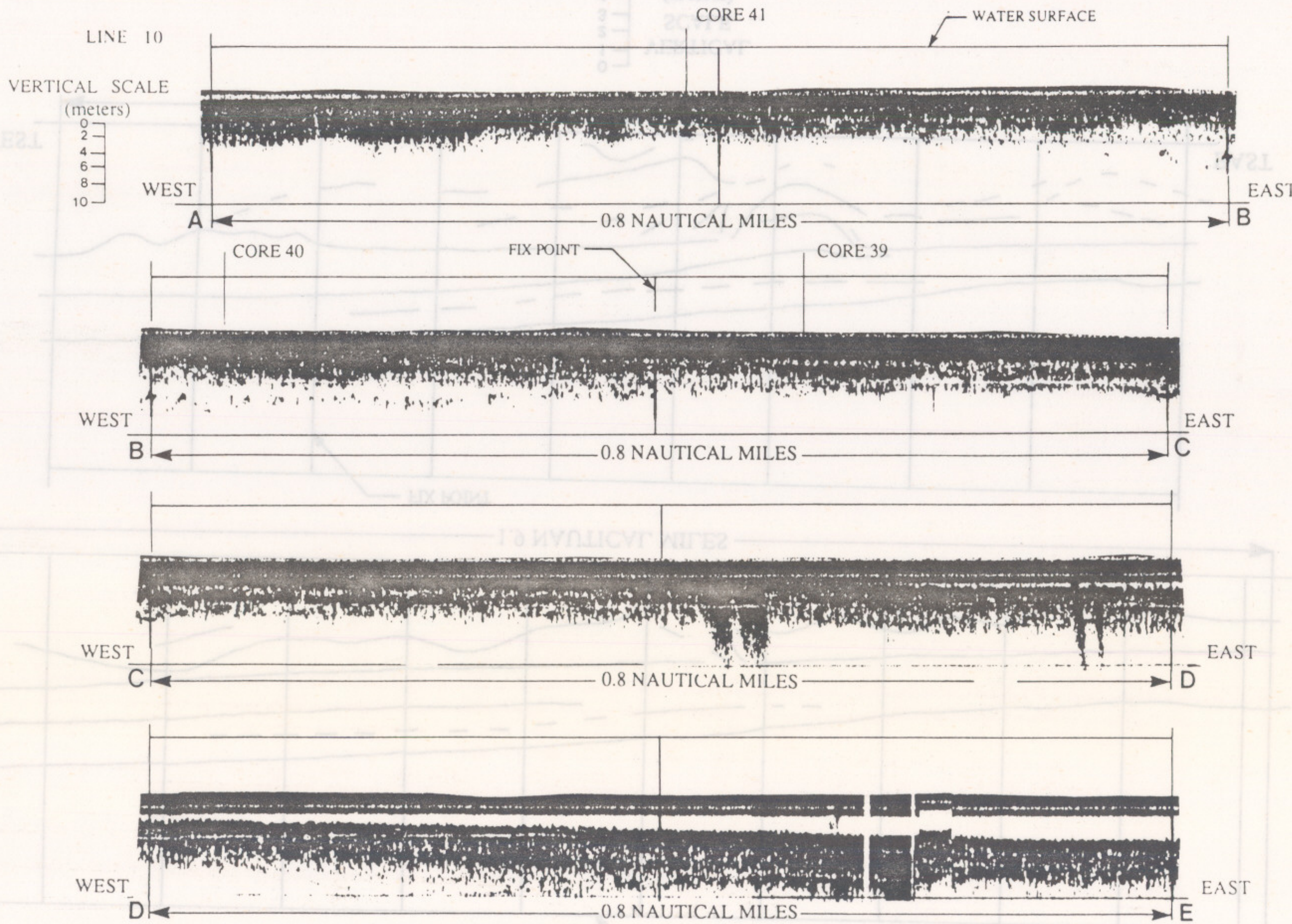


LINE 8 continued

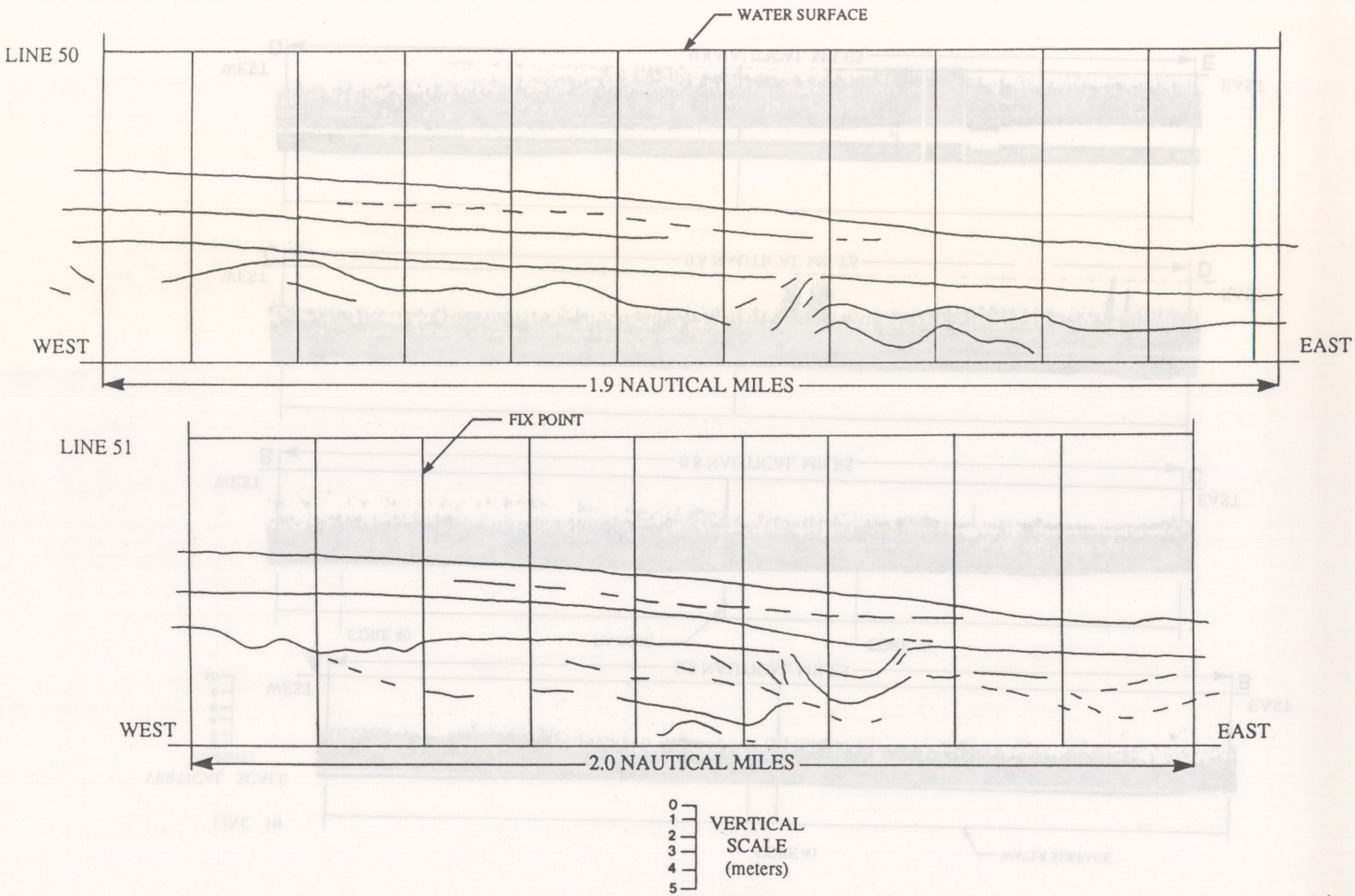


LINE 8 continued

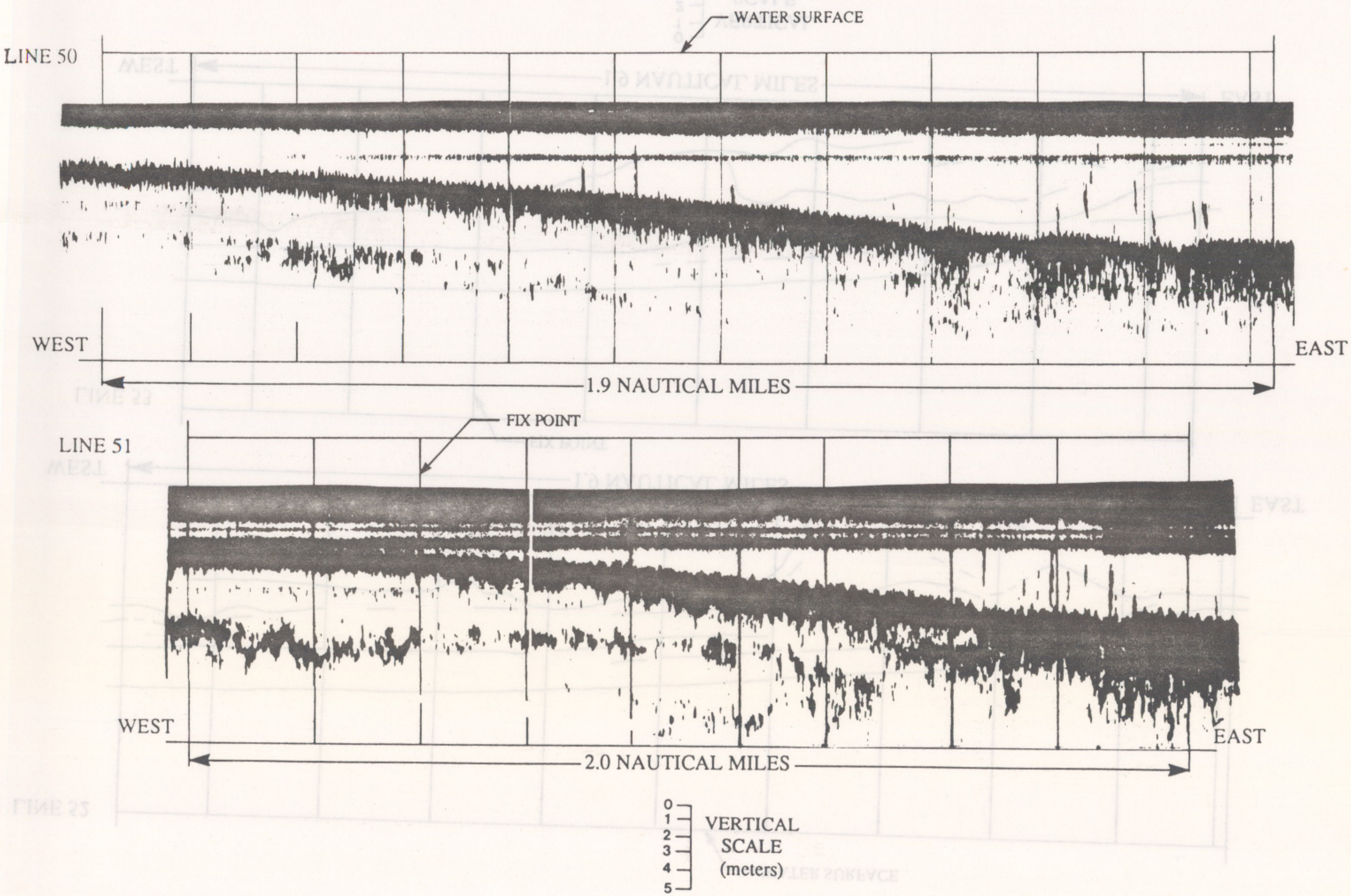

LINE 10
VERTICAL SCALE
(meters)
0
2
4
6
8
10
CORE 41
WATER SURFACE
MC
F
F
WEST
EAST
A
B
0.8 NAUTICAL MILES
MC - Med-Course Sand
F - Fine Sand
CORE 40
FIX POINT
CORE 39
F
F
F
WEST
EAST
B
C
0.8 NAUTICAL MILES
WEST
EAST
C
D
0.8 NAUTICAL MILES
WEST
EAST
D
E
0.8 NAUTICAL MILES



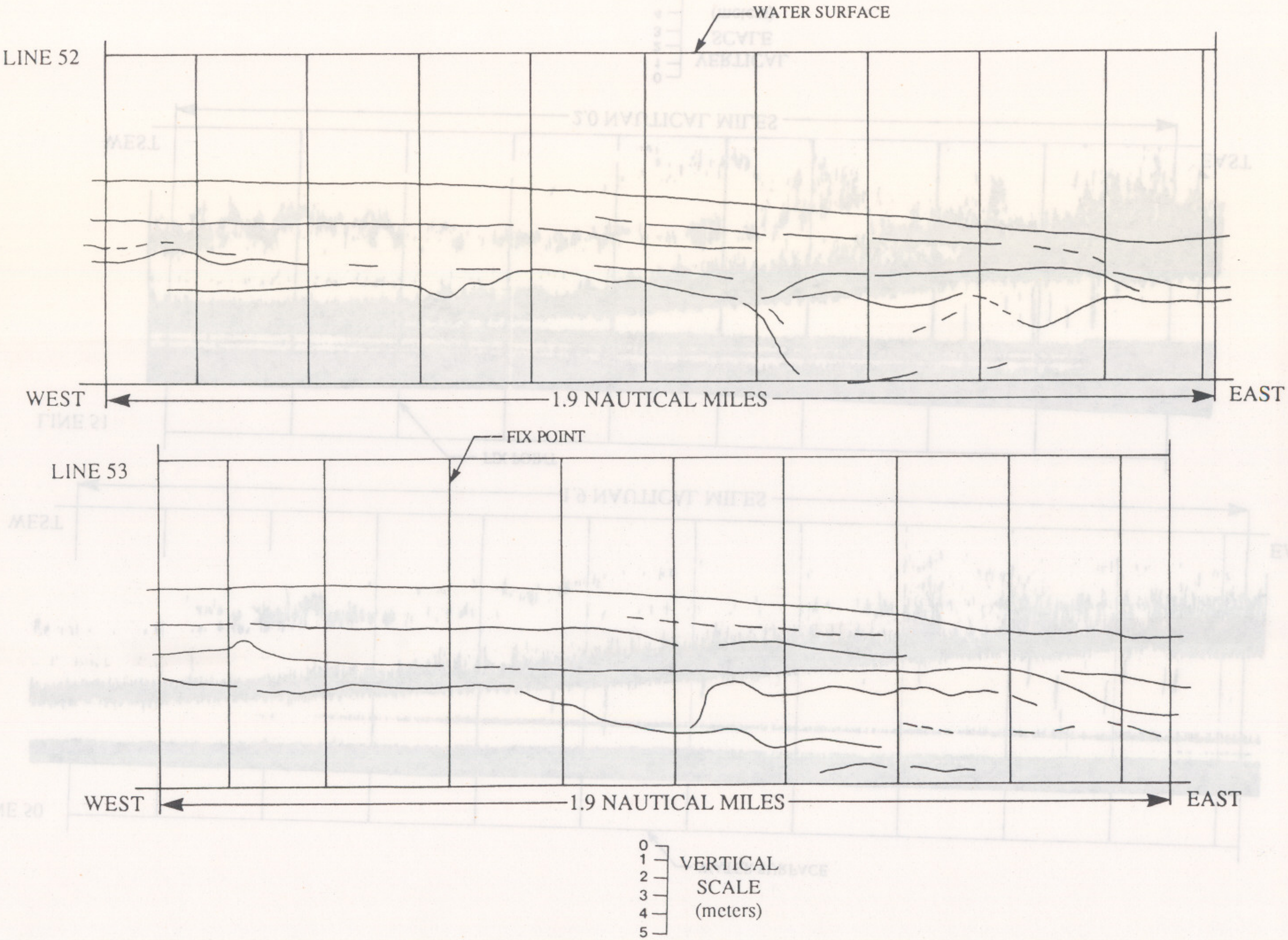
LINE 10
VERTICAL SCALE
(meters)
0
2
4
6
8
10
CORE 41
WATER SURFACE
WEST
EAST
A
B
0.8 NAUTICAL MILES
CORE 40
FIX POINT
CORE 39
WEST
EAST
B
C
0.8 NAUTICAL MILES
WEST
EAST
C
D
0.8 NAUTICAL MILES
WEST
EAST
D
E
0.8 NAUTICAL MILES



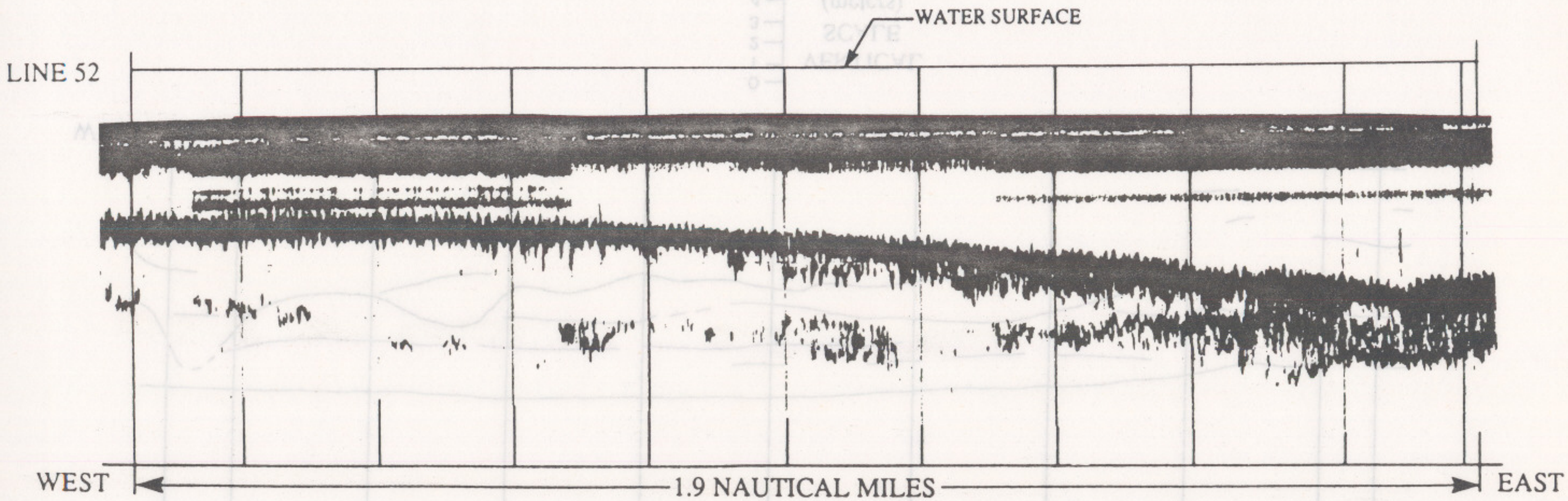
WATER SURFACE
LINE 50
WEST
EAST
1.9 NAUTICAL MILES
FIX POINT
LINE 51
WEST
EAST
2.0 NAUTICAL MILES
0
1
2
3
4
5
VERTICAL
SCALE
(meters)



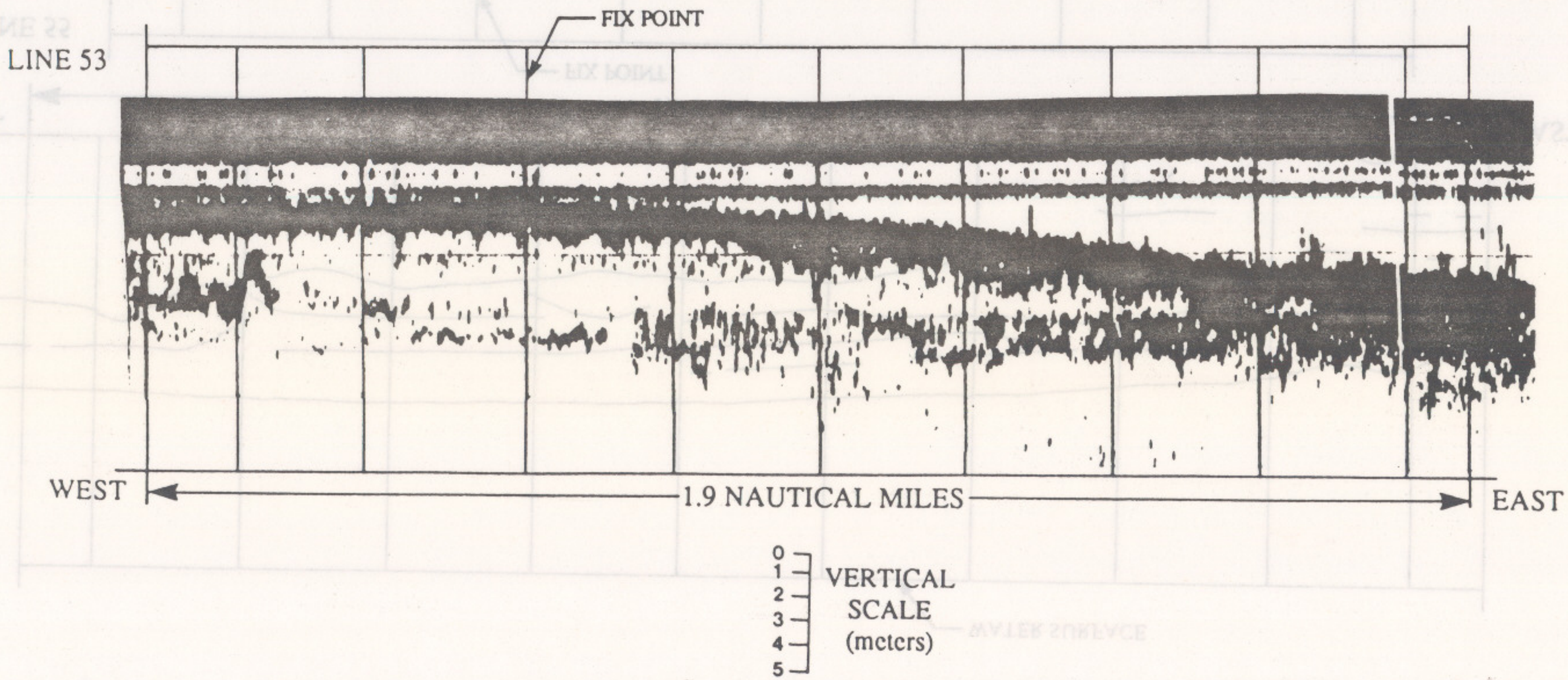
WATER SURFACE
LINE 50
WEST
EAST
1.9 NAUTICAL MILES
FIX POINT
LINE 51
WEST
EAST
2.0 NAUTICAL MILES
0
1
2
3
4
5
VERTICAL
SCALE
(meters)



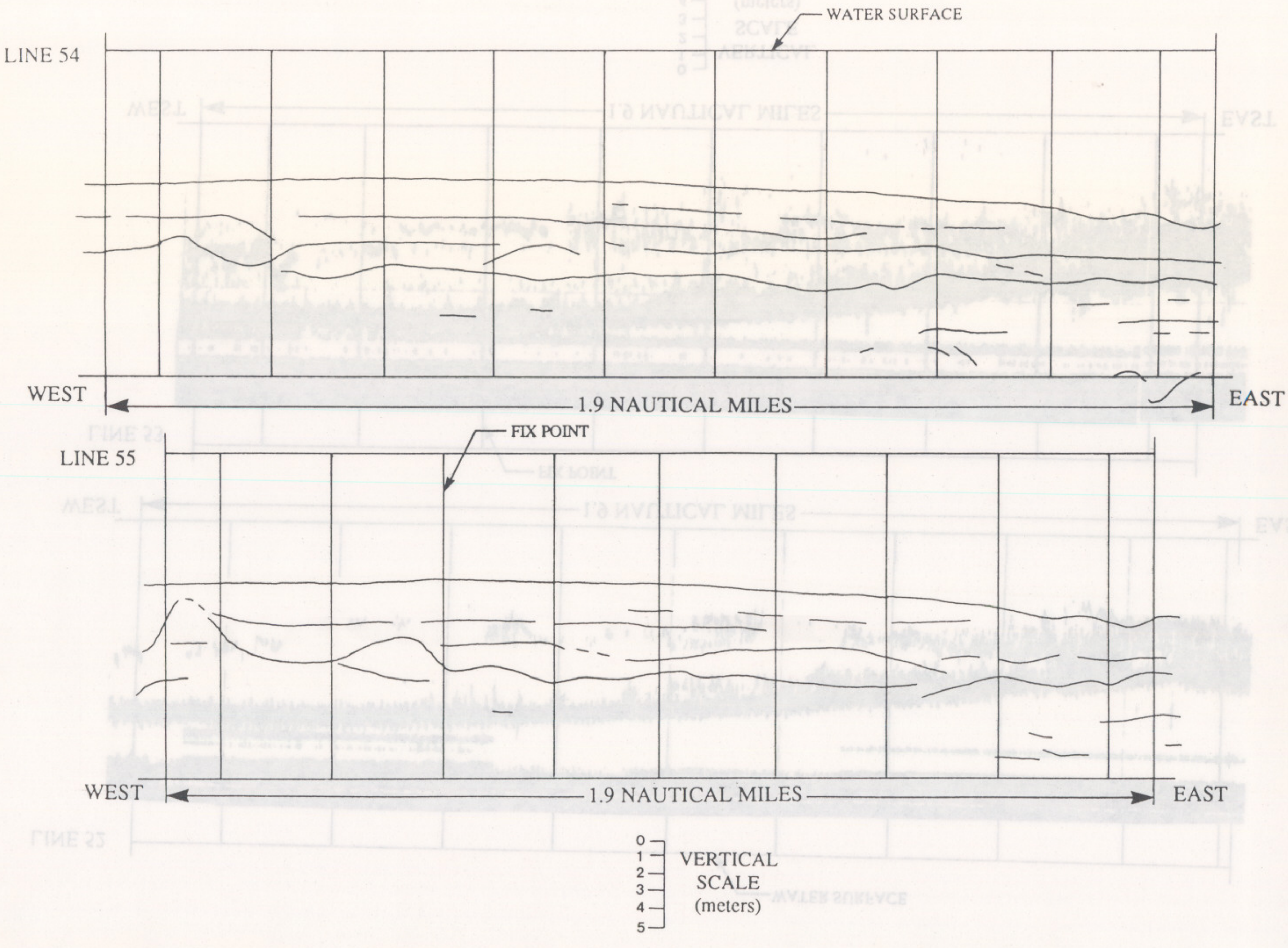
WATER SURFACE
LINE 52
WEST
1.9 NAUTICAL MILES
EAST
FIX POINT
LINE 53
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)



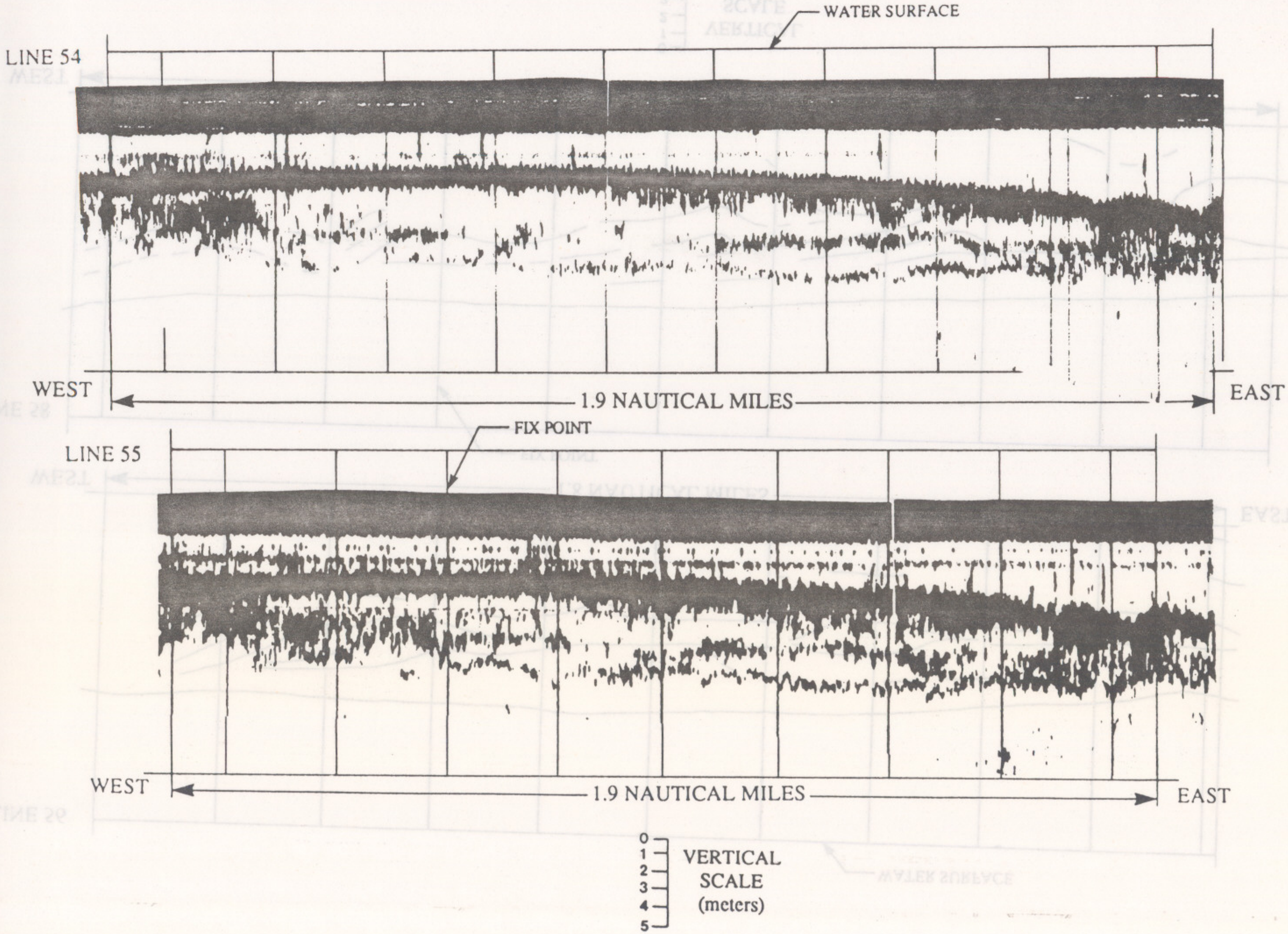
WATER SURFACE
LINE 52
WEST
1.9 NAUTICAL MILES
EAST

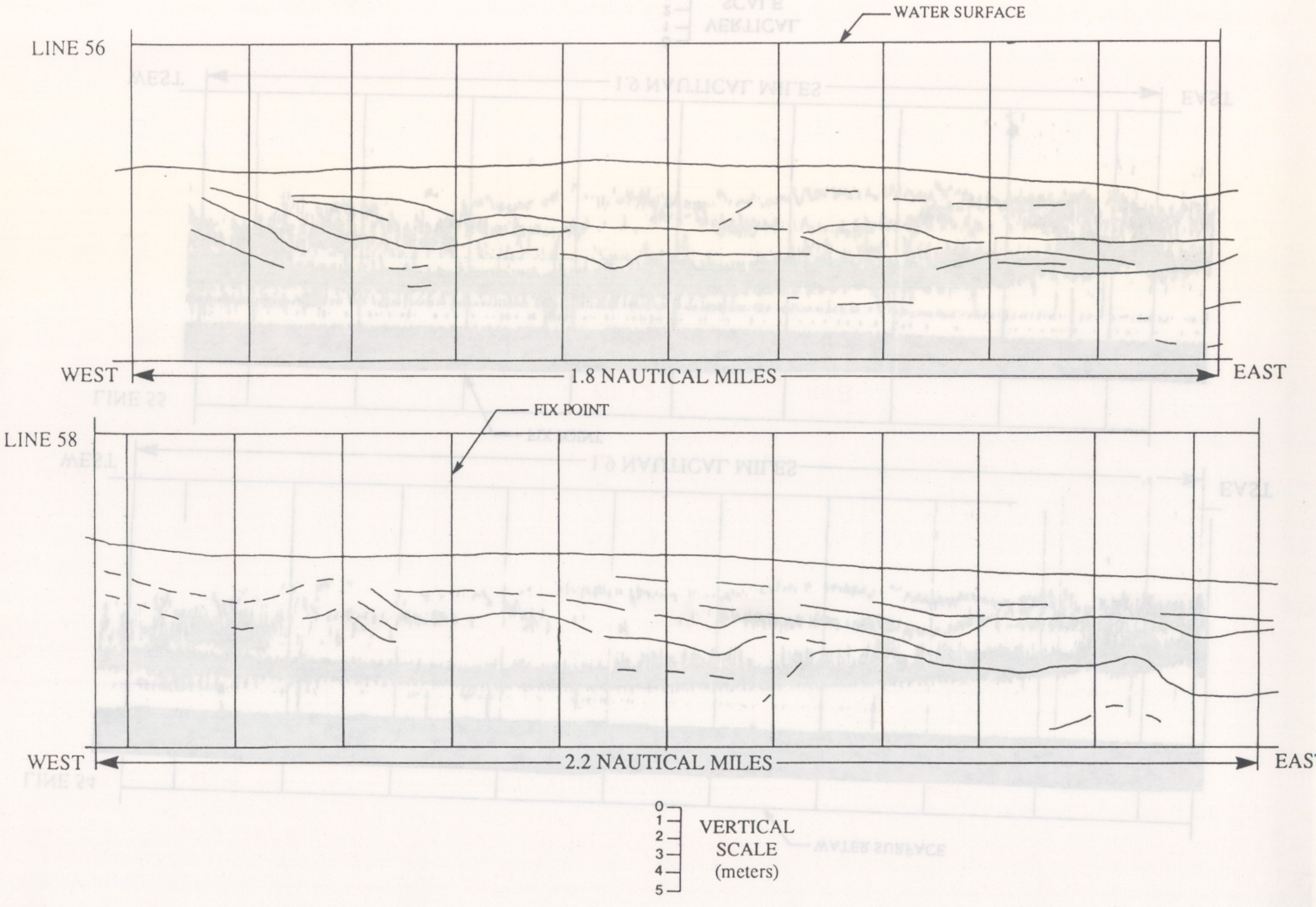


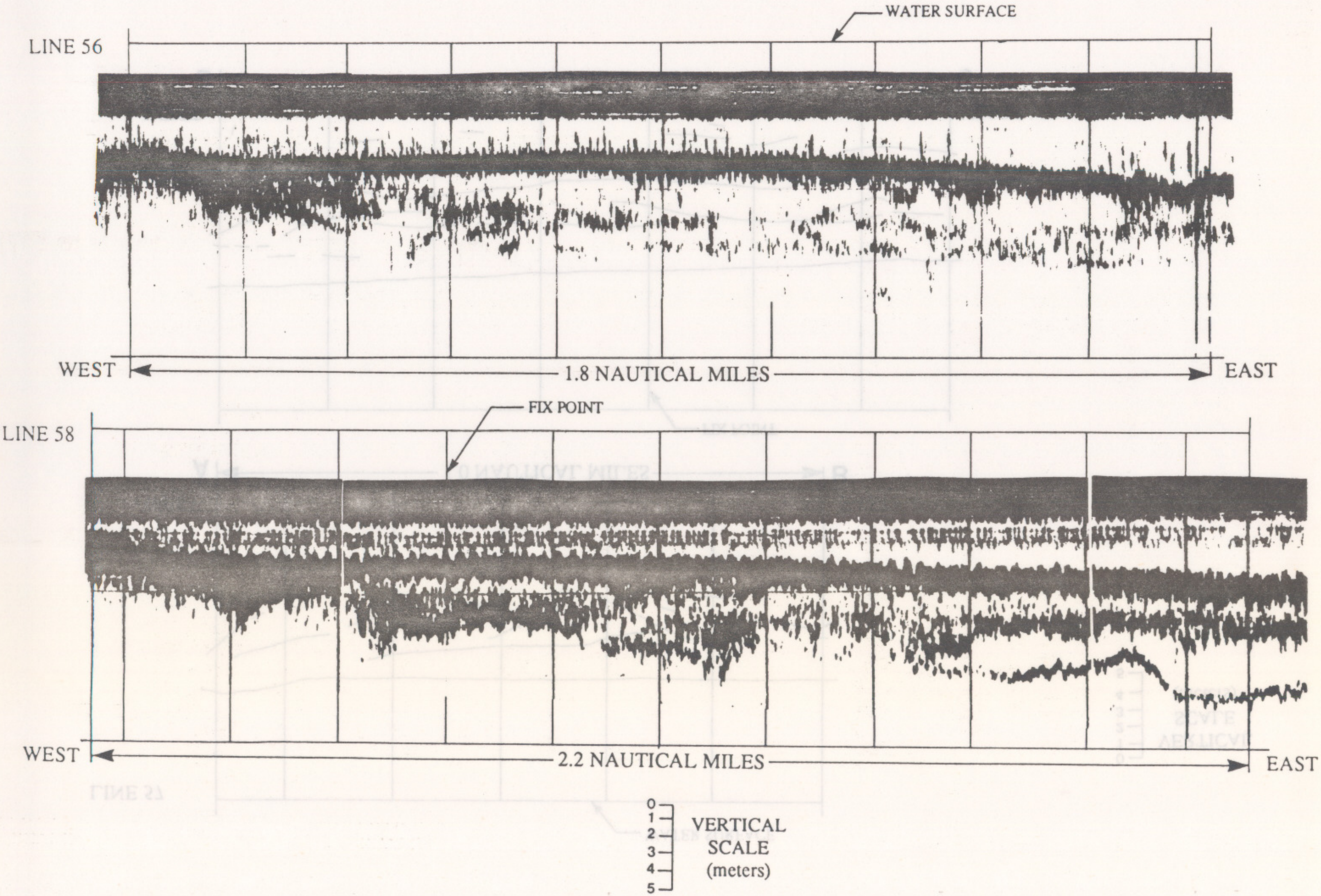
FIX POINT
LINE 53
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

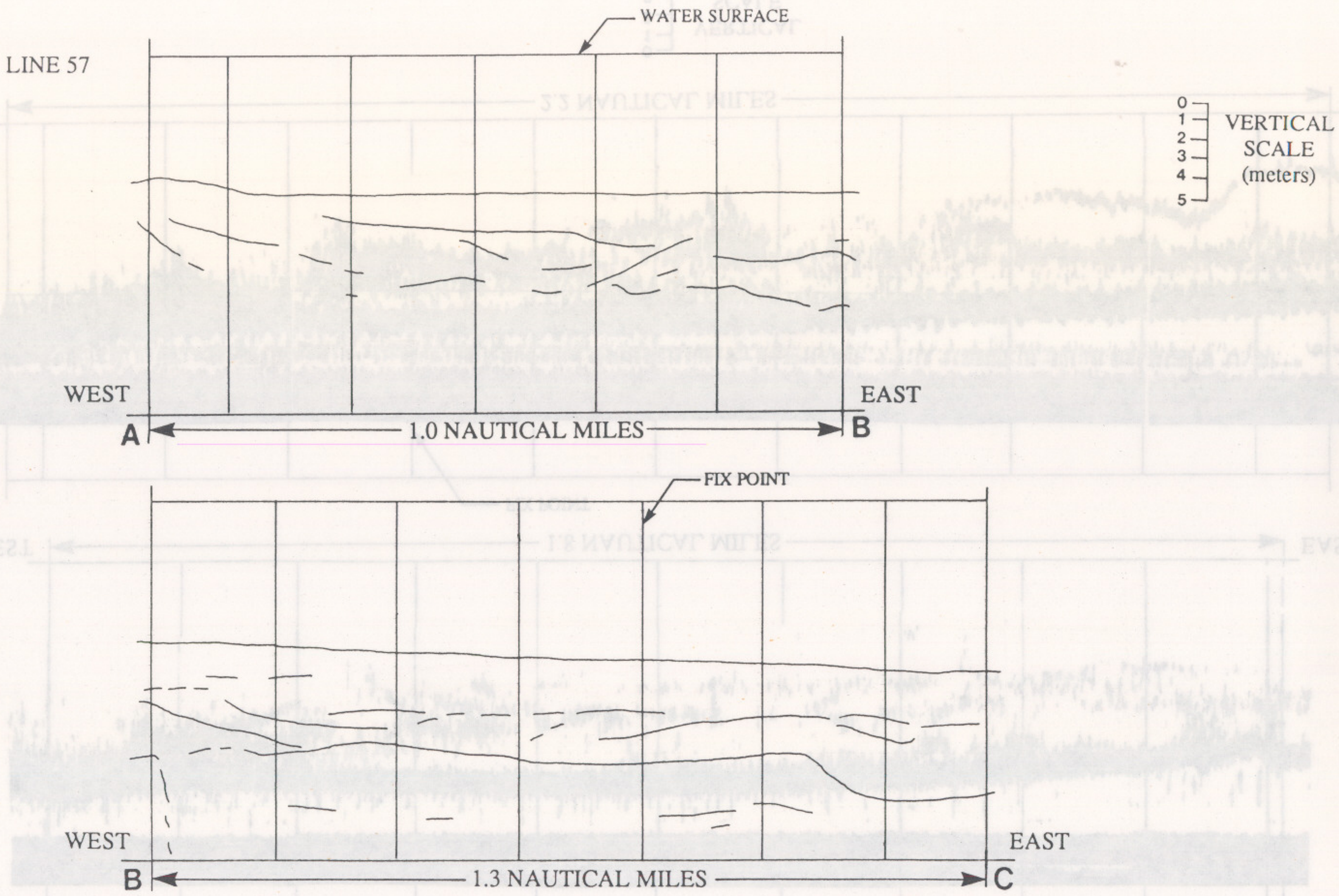


WATER SURFACE
LINE 54
WEST
1.9 NAUTICAL MILES
EAST
FIX POINT
LINE 55
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

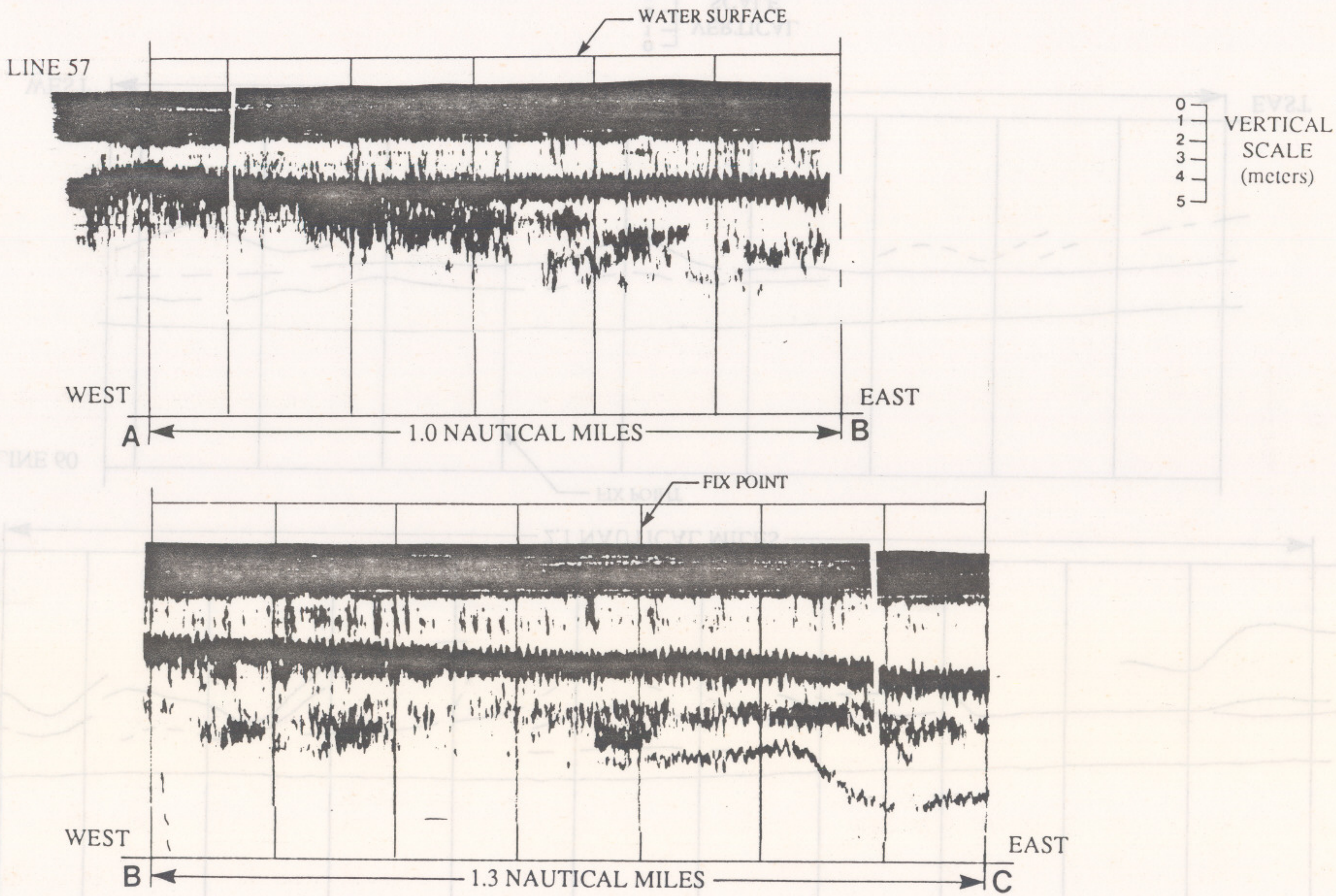

WATER SURFACE
LINE 54
WEST
1.9 NAUTICAL MILES
EAST
FIX POINT
LINE 55
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

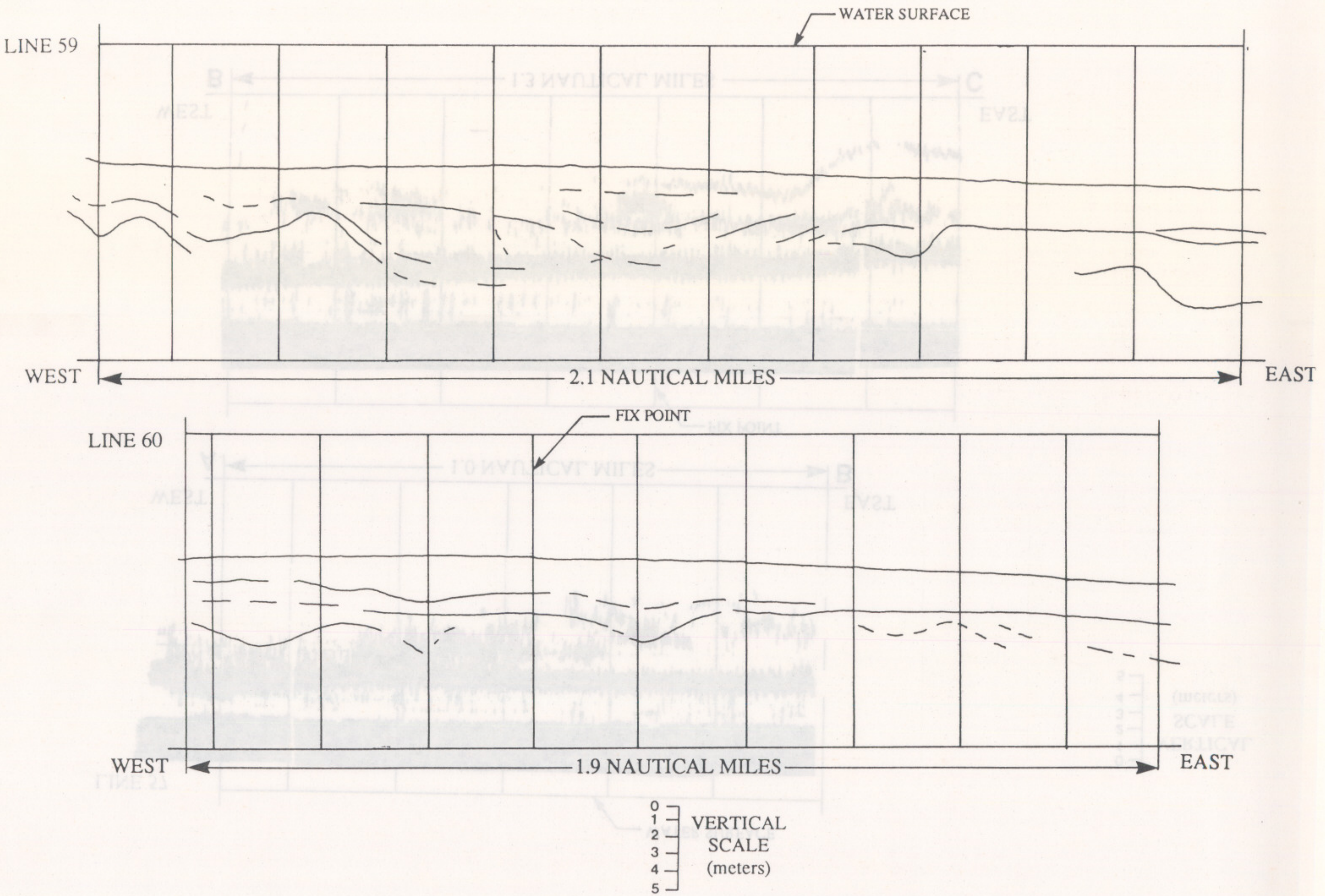

WATER SURFACE
LINE 56
WEST
1.8 NAUTICAL MILES
EAST
FIX POINT
LINE 58
WEST
2.2 NAUTICAL MILES
EAS'
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

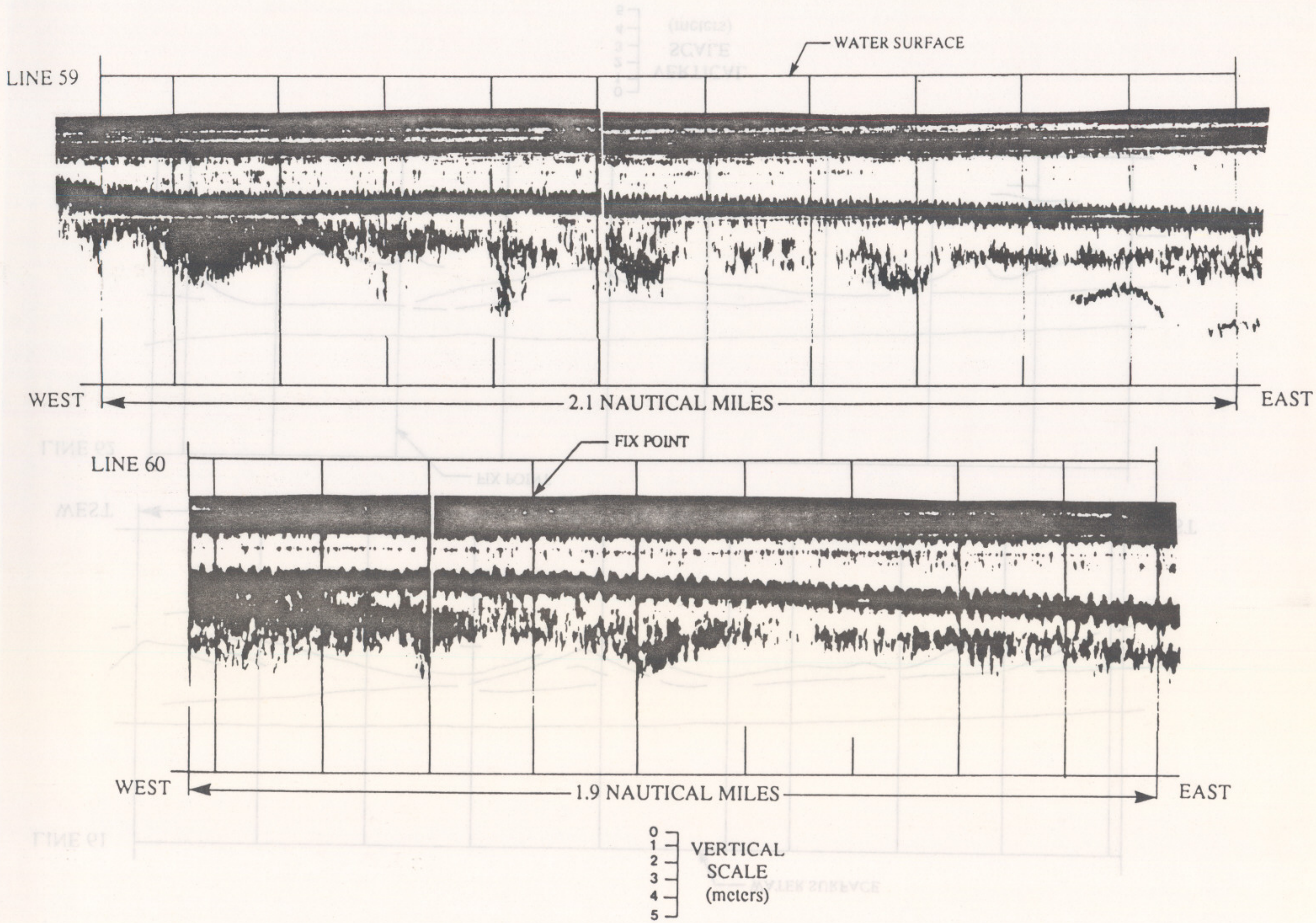

WATER SURFACE
LINE 56
WEST
1.8 NAUTICAL MILES
EAST
FIX POINT
LINE 58
WEST
2.2 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

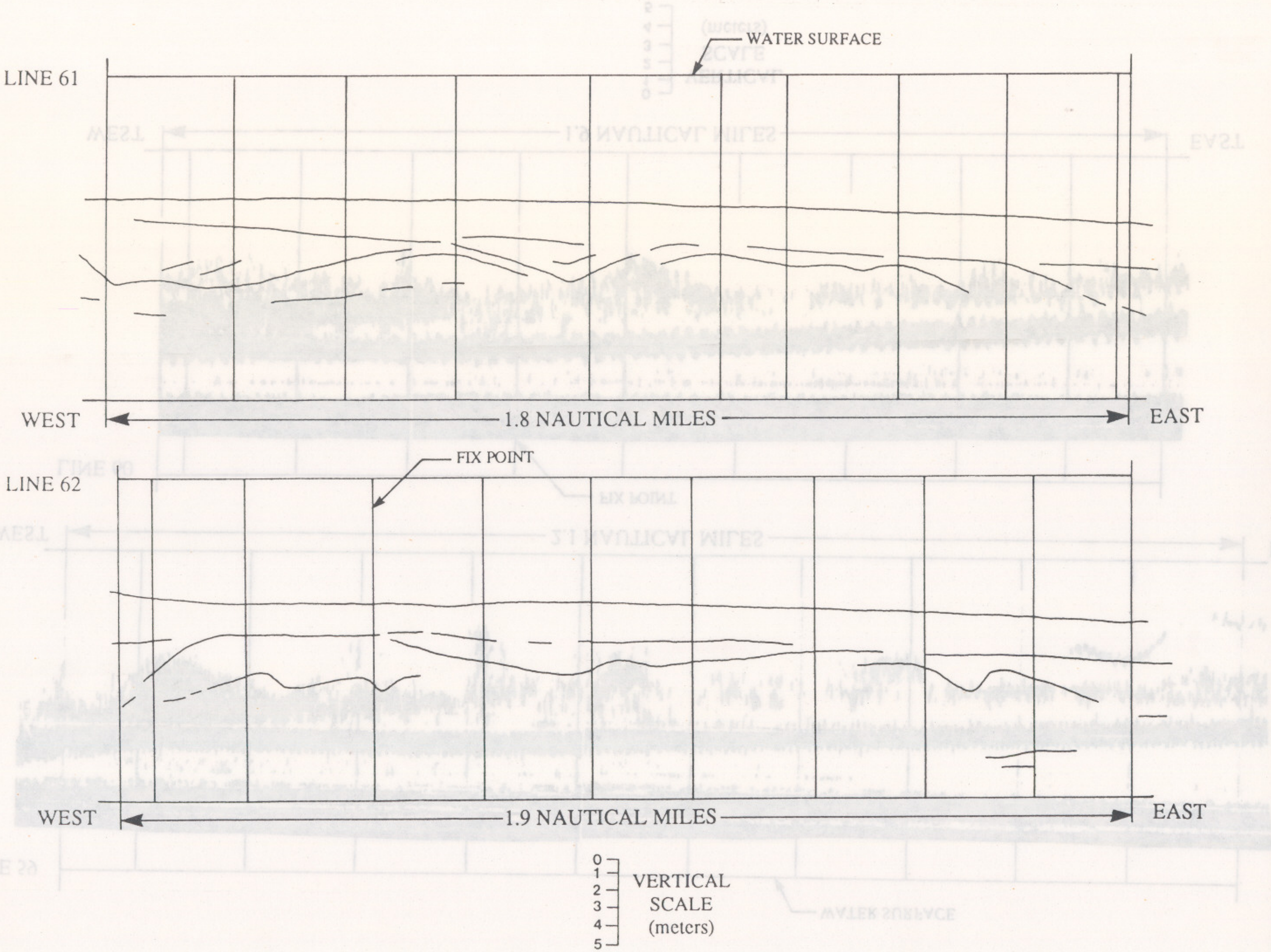


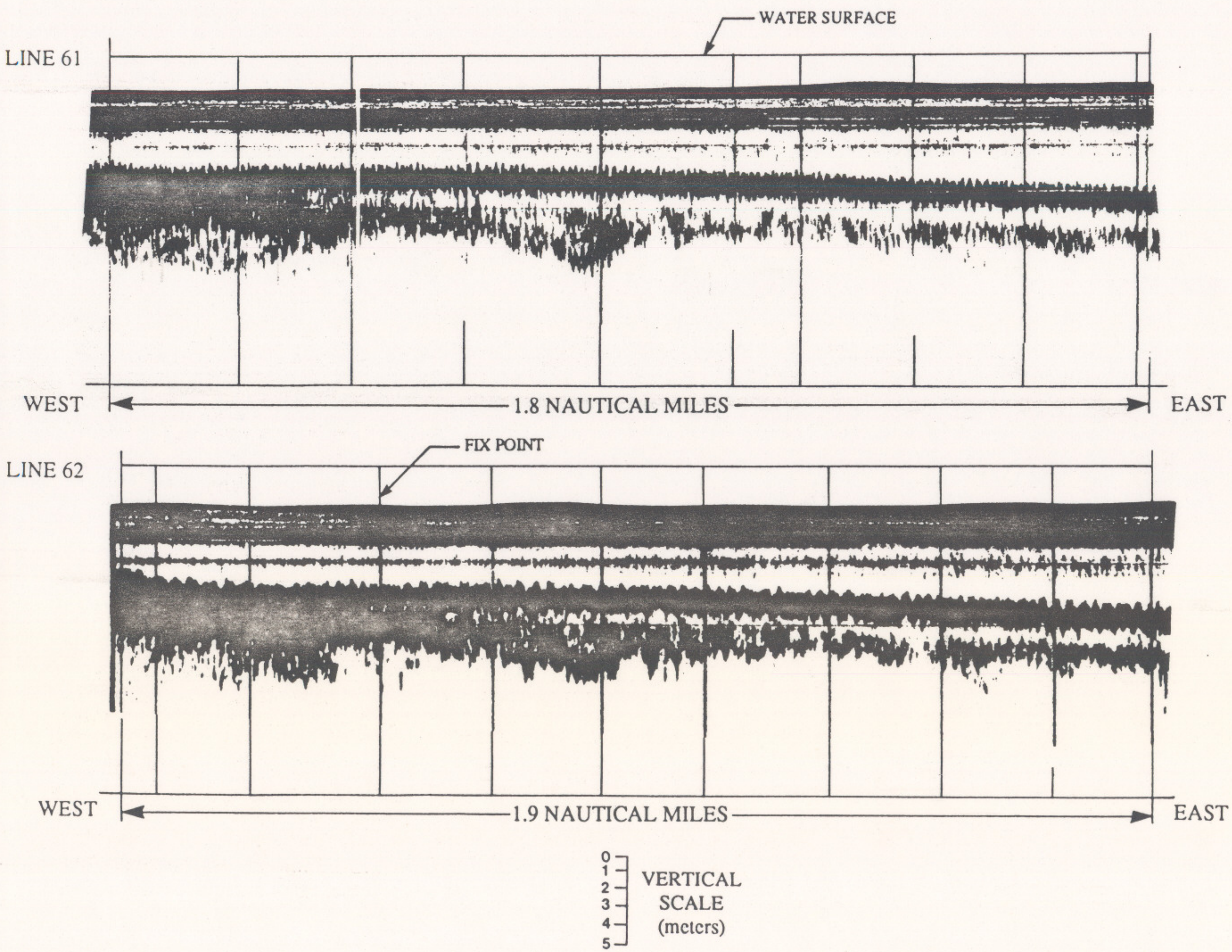
LINE 57
WATER SURFACE
0
1
2
3
4
5
VERTICAL SCALE (meters)
WEST
EAST
A
1.0 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
1.3 NAUTICAL MILES
C


WATER SURFACE
LINE 57
0
1
2
3
4
5
VERTICAL
SCALE
(meters)
WEST
EAST
A
1.0 NAUTICAL MILES
B
FIX POINT
WEST
EAST
B
1.3 NAUTICAL MILES
C


WATER SURFACE
LINE 59
WEST
2.1 NAUTICAL MILES
EAST
FIX POINT
LINE 60
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

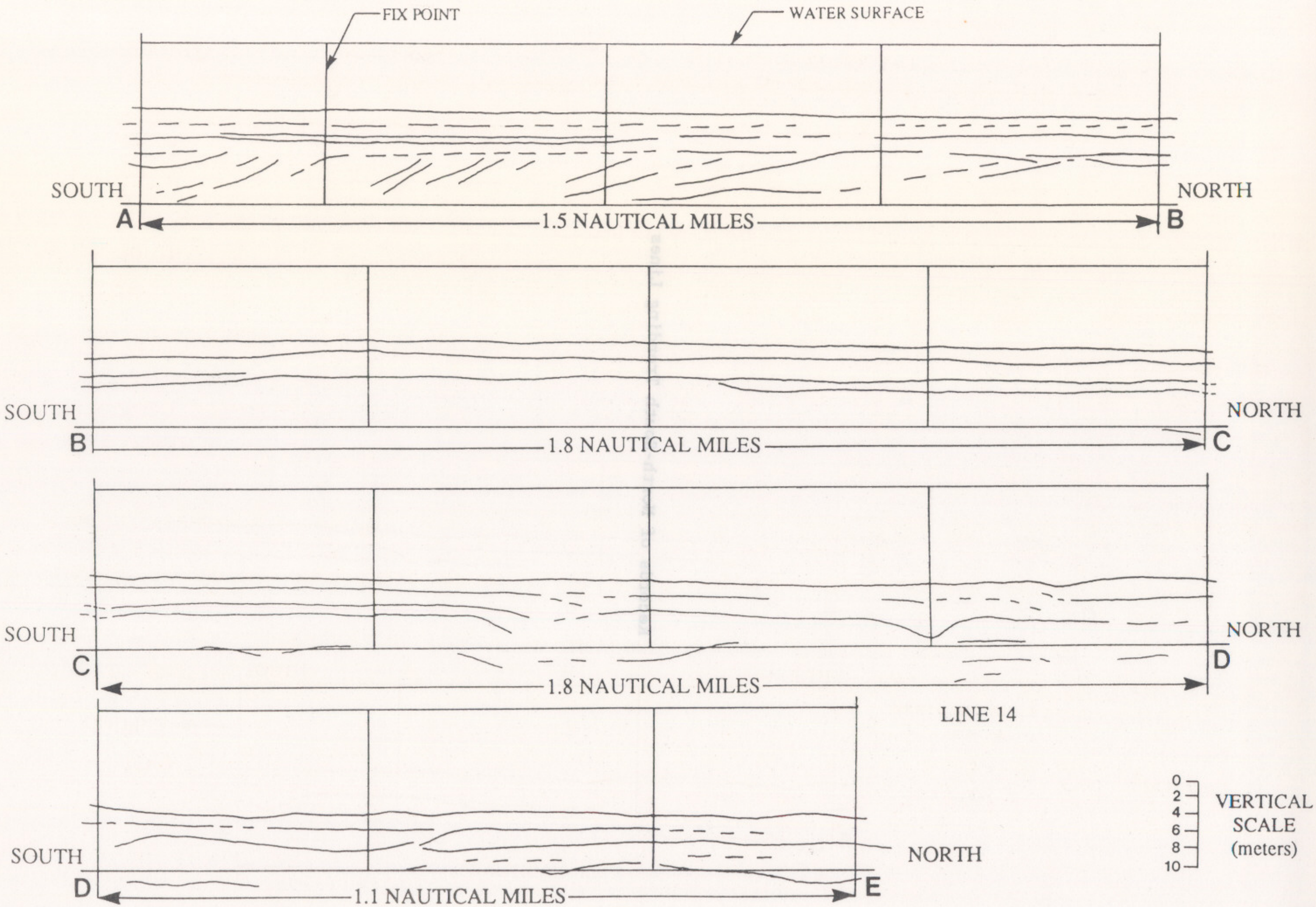

WATER SURFACE
LINE 59
WEST
2.1 NAUTICAL MILES
EAST
FIX POINT
LINE 60
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)


WATER SURFACE
LINE 61
WEST
1.8 NAUTICAL MILES
EAST
FIX POINT
LINE 62
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

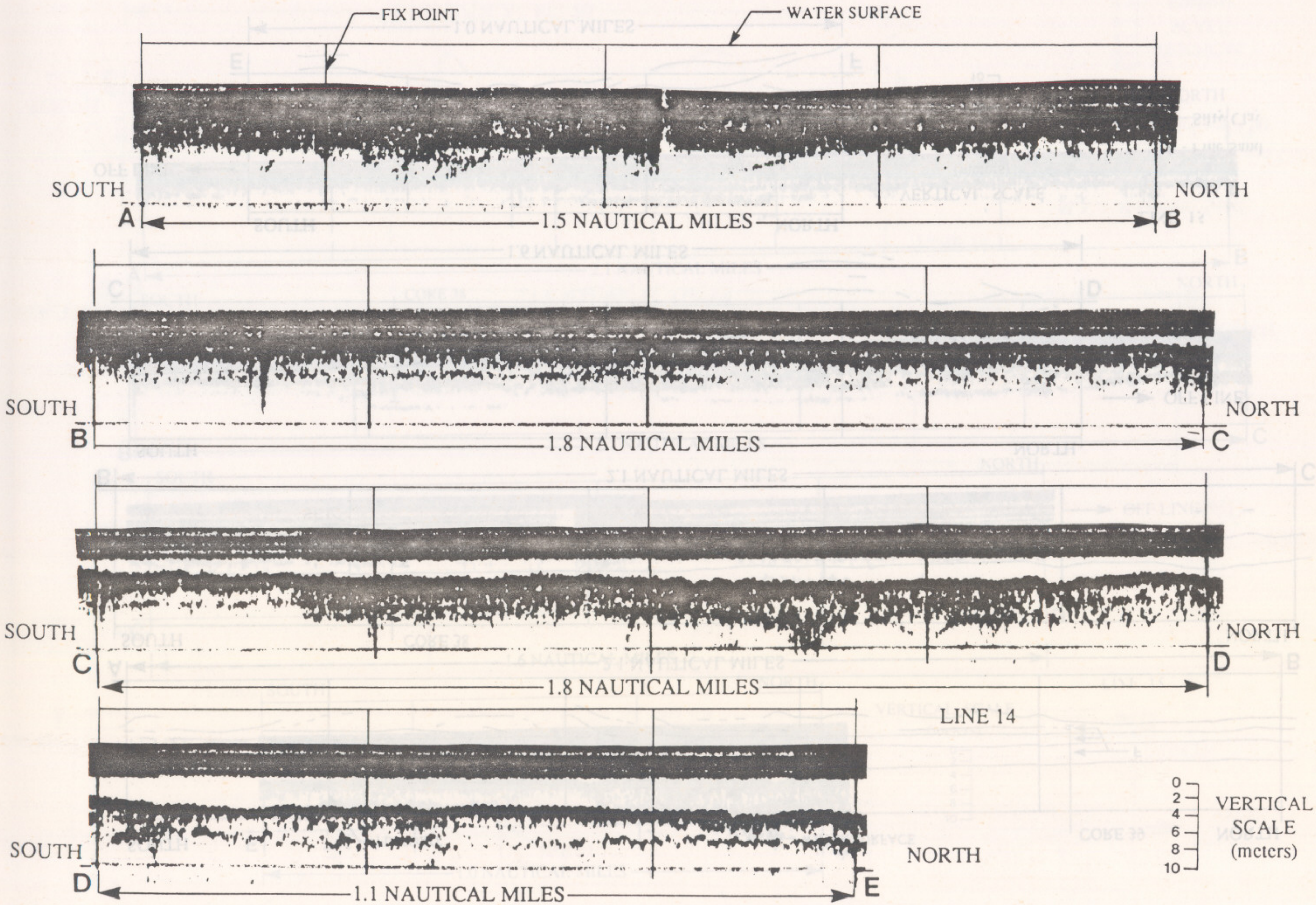


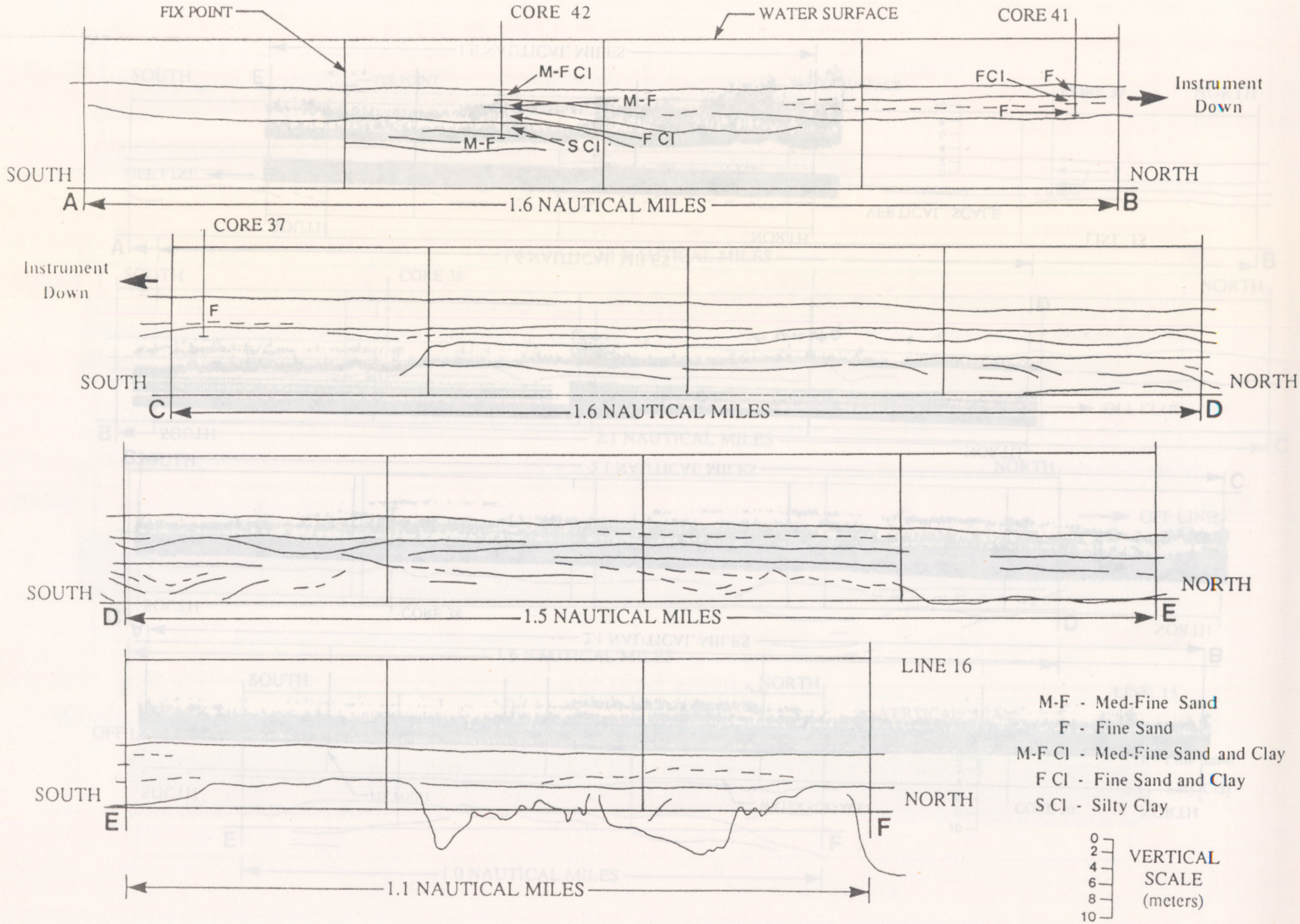
WATER SURFACE
LINE 61
WEST
1.8 NAUTICAL MILES
EAST
FIX POINT
LINE 62
WEST
1.9 NAUTICAL MILES
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

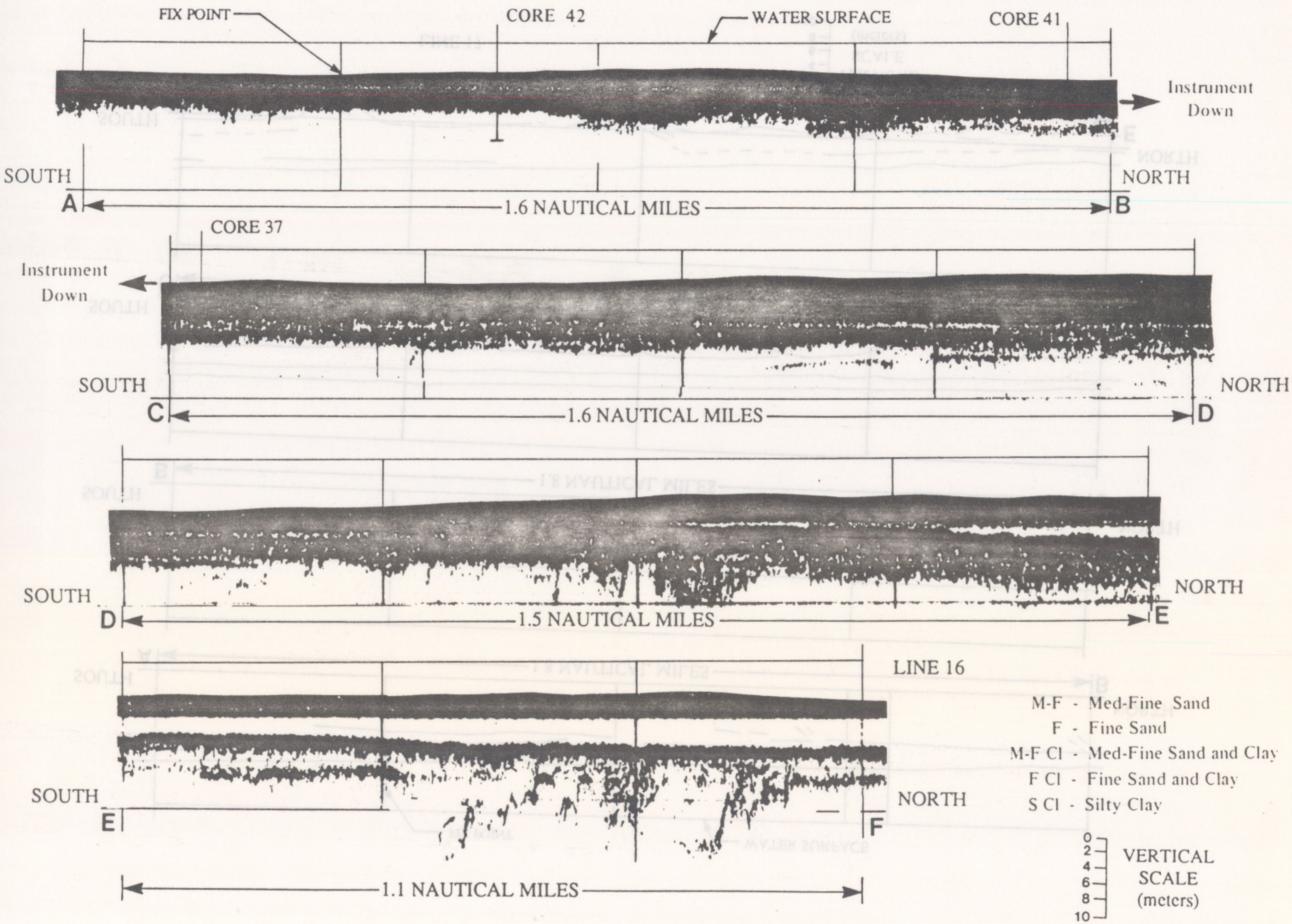
Records of North-South Trending Lines

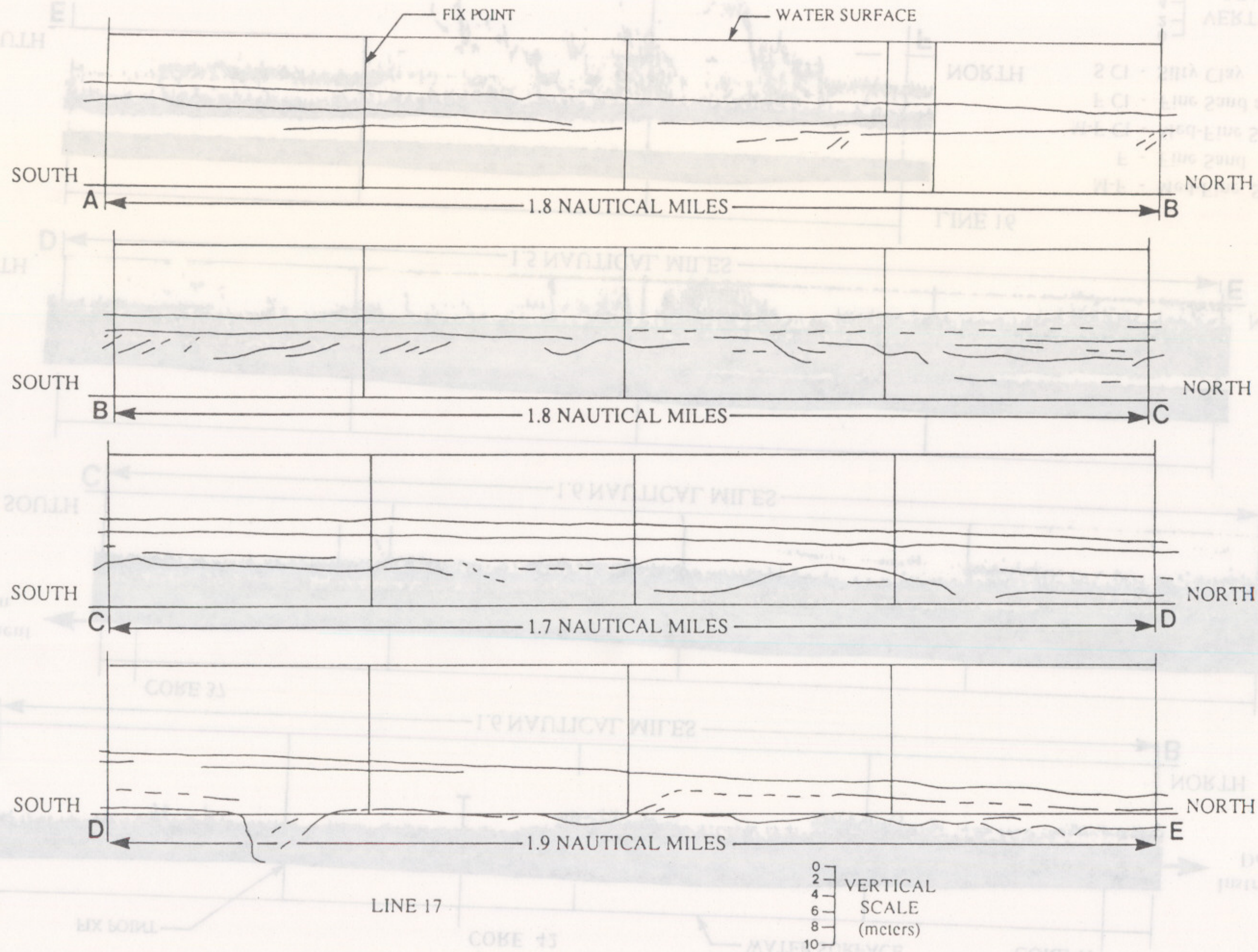


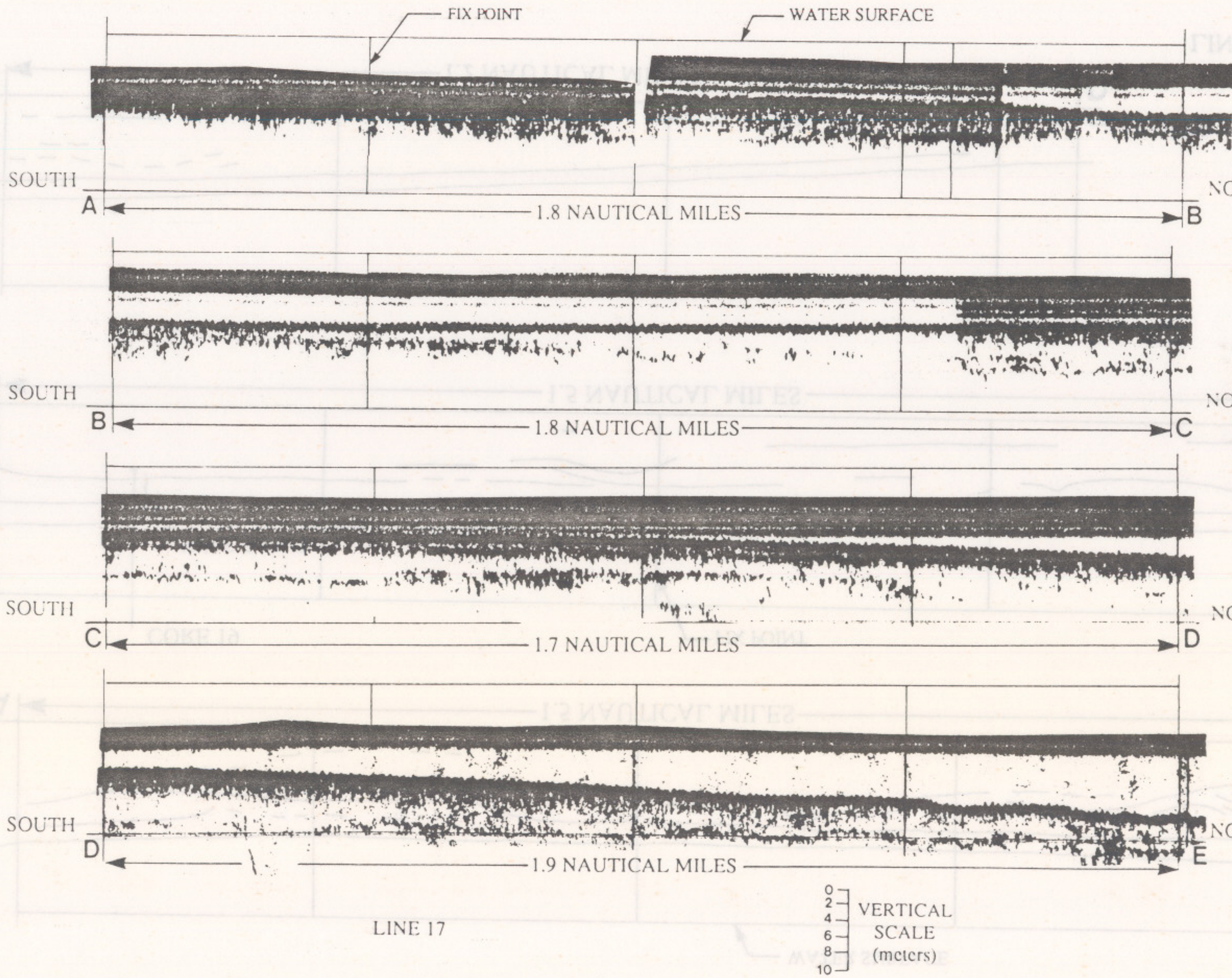
FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
SOUTH
NORTH
B
1.8 NAUTICAL MILES
C
SOUTH
NORTH
C
1.8 NAUTICAL MILES
D
LINE 14
SOUTH
NORTH
D
1.1 NAUTICAL MILES
E
0
2
4
6
8
10
VERTICAL
SCALE
(meters)


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)


FIX POINT
CORE 42
WATER SURFACE
CORE 41
M-F Cl
M-F
F Cl
S Cl
F Cl
F
F
Instrument Down
SOUTH
NORTH
A
1.6 NAUTICAL MILES
B
CORE 37
Instrument Down
F
SOUTH
NORTH
C
1.6 NAUTICAL MILES
D
SOUTH
NORTH
D
1.5 NAUTICAL MILES
E
LINE 16
SOUTH
NORTH
E
F
1.1 NAUTICAL MILES
M-F - Med-Fine Sand
F - Fine Sand
M-F Cl - Med-Fine Sand and Clay
F Cl - Fine Sand and Clay
S Cl - Silty Clay
0
2
4
6
8
10
VERTICAL SCALE (meters)

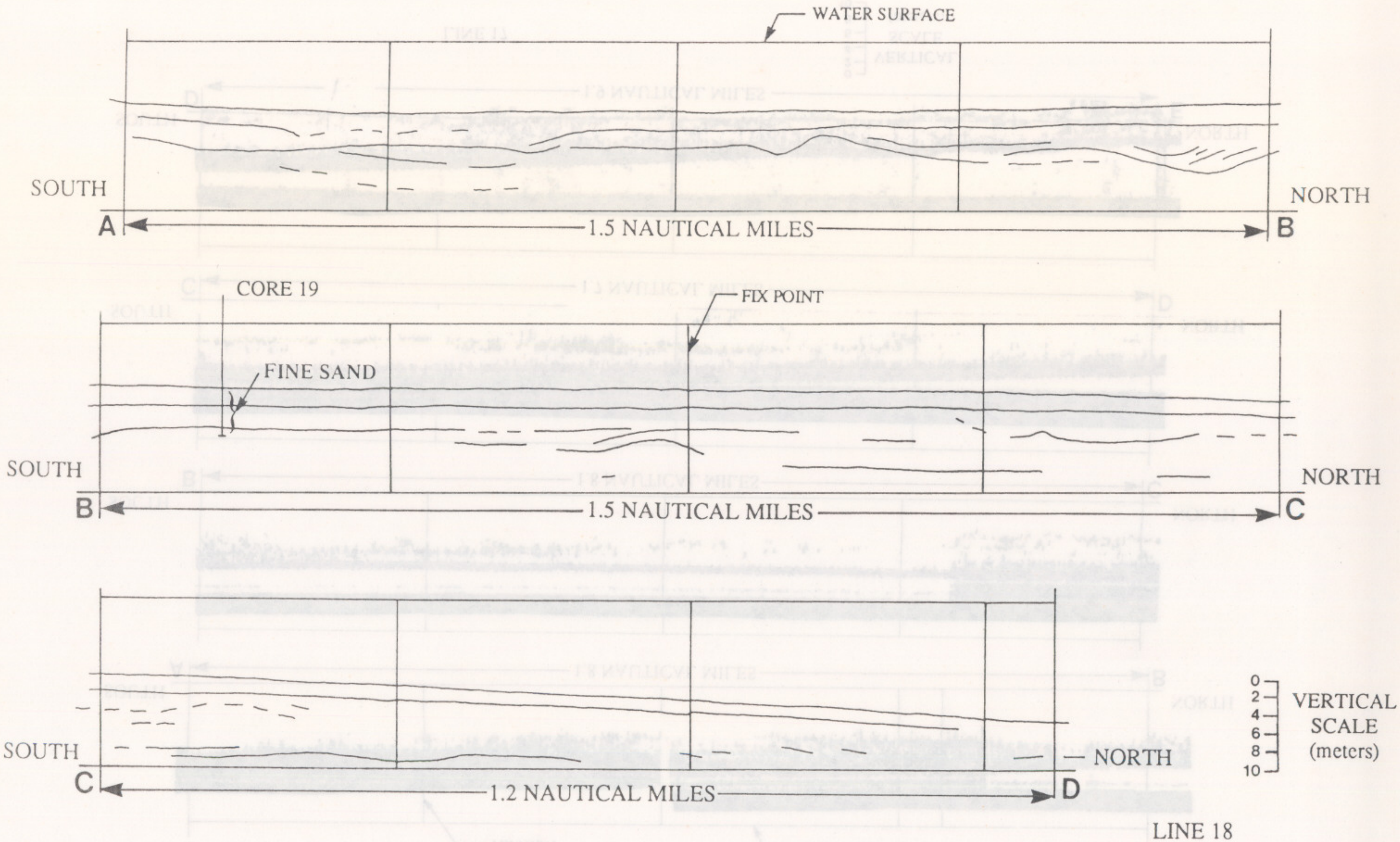

FIX POINT
CORE 42
WATER SURFACE
CORE 41
Instrument Down
SOUTH
NORTH
A
1.6 NAUTICAL MILES
B
CORE 37
Instrument Down
SOUTH
NORTH
C
1.6 NAUTICAL MILES
D
SOUTH
NORTH
D
1.5 NAUTICAL MILES
E
LINE 16
SOUTH
NORTH
E
F
1.1 NAUTICAL MILES
M-F - Med-Fine Sand
F - Fine Sand
M-F Cl - Med-Fine Sand and Clay
F Cl - Fine Sand and Clay
S Cl - Silty Clay
0
2
4
6
8
10
VERTICAL SCALE (meters)

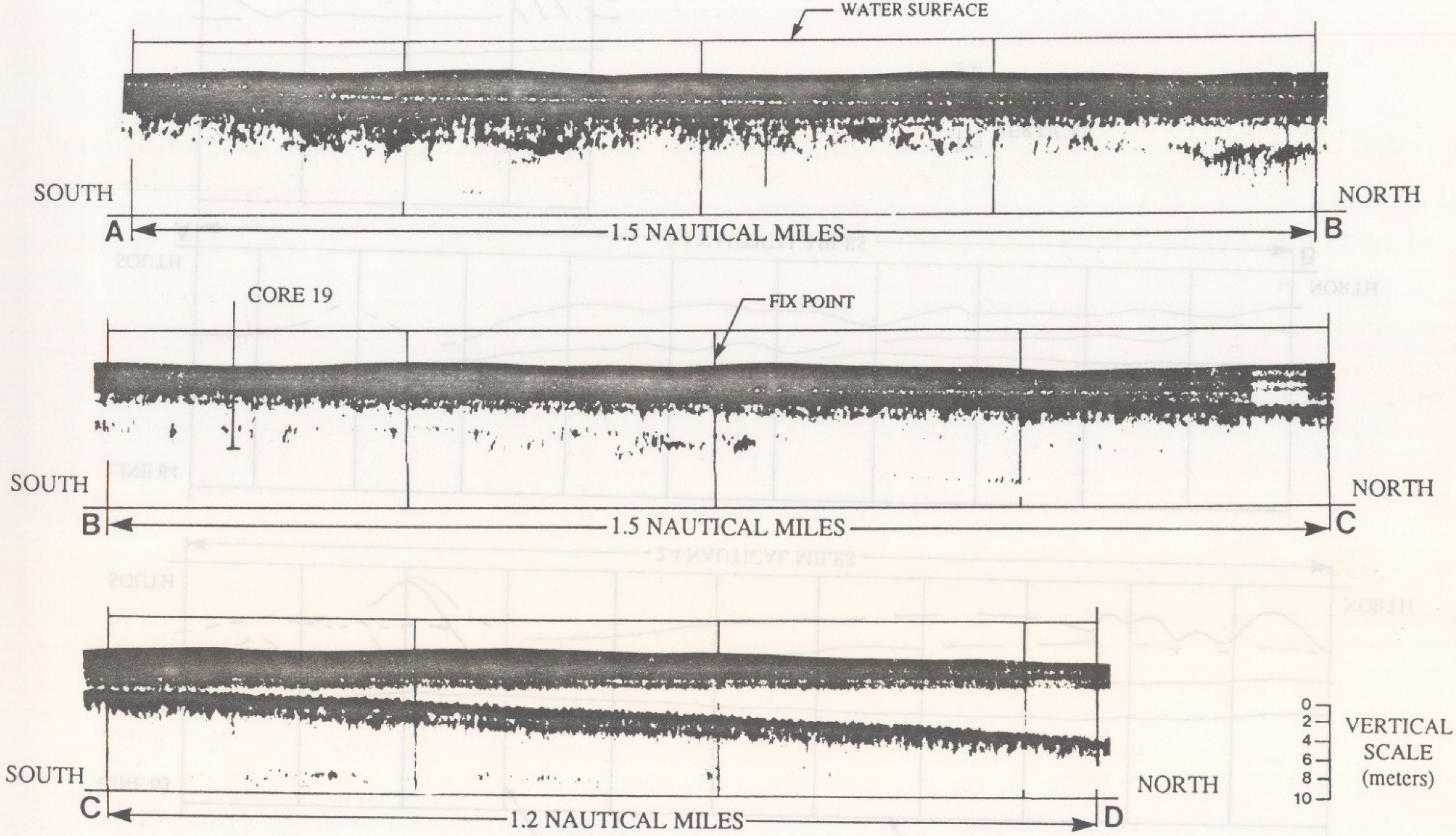

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
B
1.8 NAUTICAL MILES
SOUTH
NORTH
B
C
1.8 NAUTICAL MILES
SOUTH
NORTH
C
D
1.7 NAUTICAL MILES
SOUTH
NORTH
D
E
1.9 NAUTICAL MILES
0
2
4
6
8
10
VERTICAL
SCALE
(meters)
LINE 17



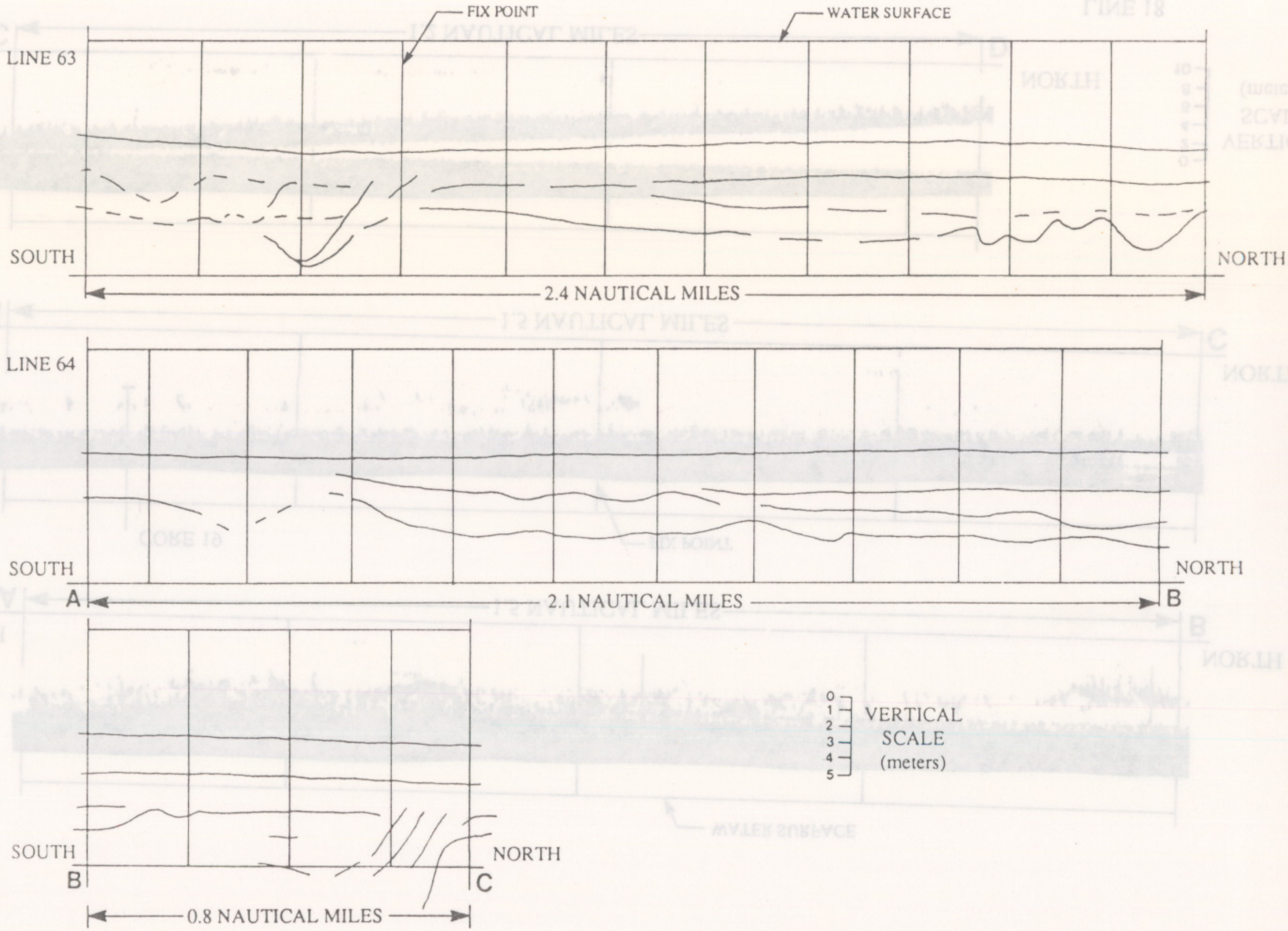
FIX POINT
WATER SURFACE
SOUTH
NORTH
A
B
1.8 NAUTICAL MILES
SOUTH
NORTH
B
C
1.8 NAUTICAL MILES
SOUTH
NORTH
C
D
1.7 NAUTICAL MILES
SOUTH
NORTH
D
E
1.9 NAUTICAL MILES
0
2
4
6
8
10
VERTICAL
SCALE
(meters)

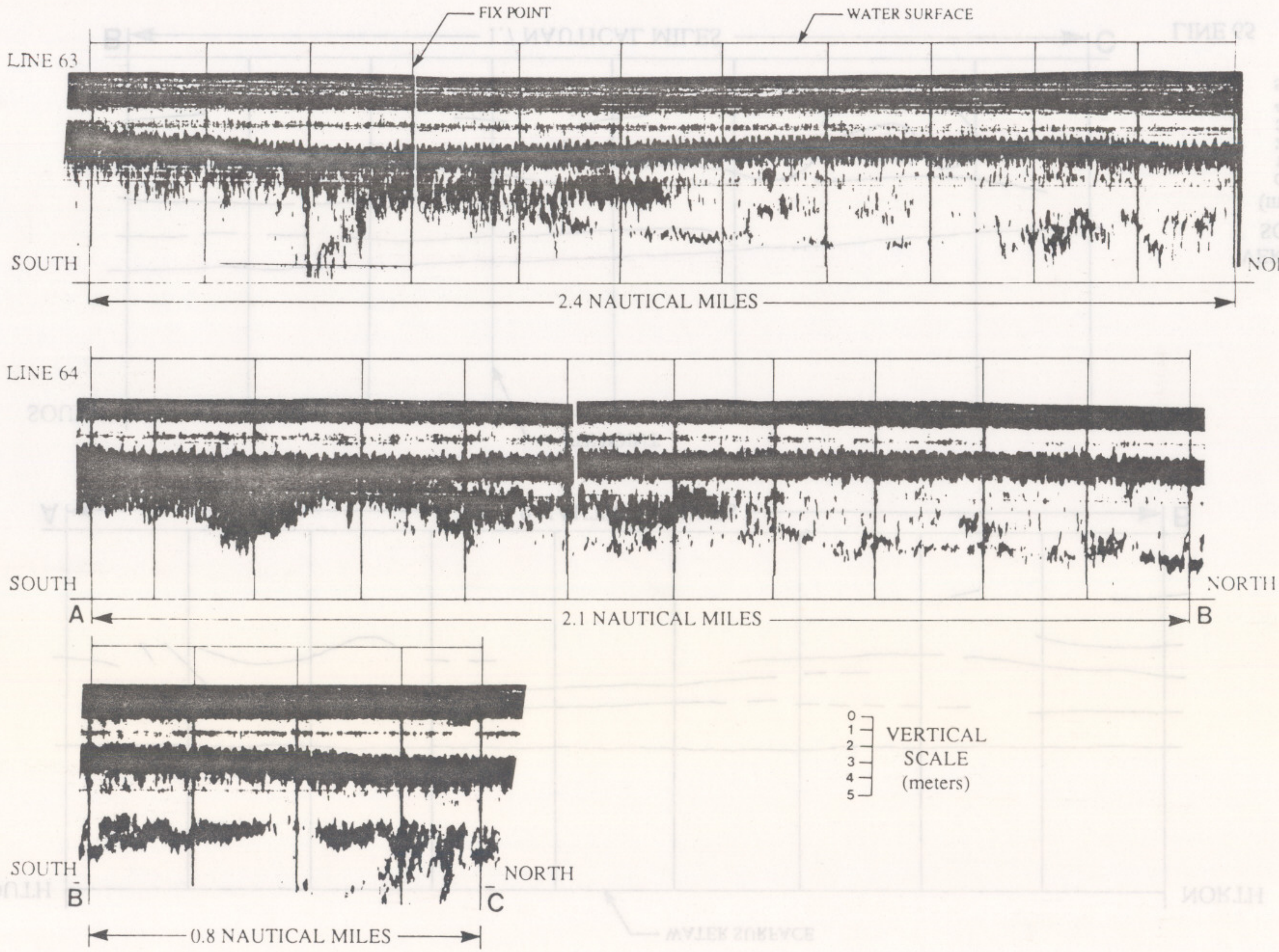
LINE 17

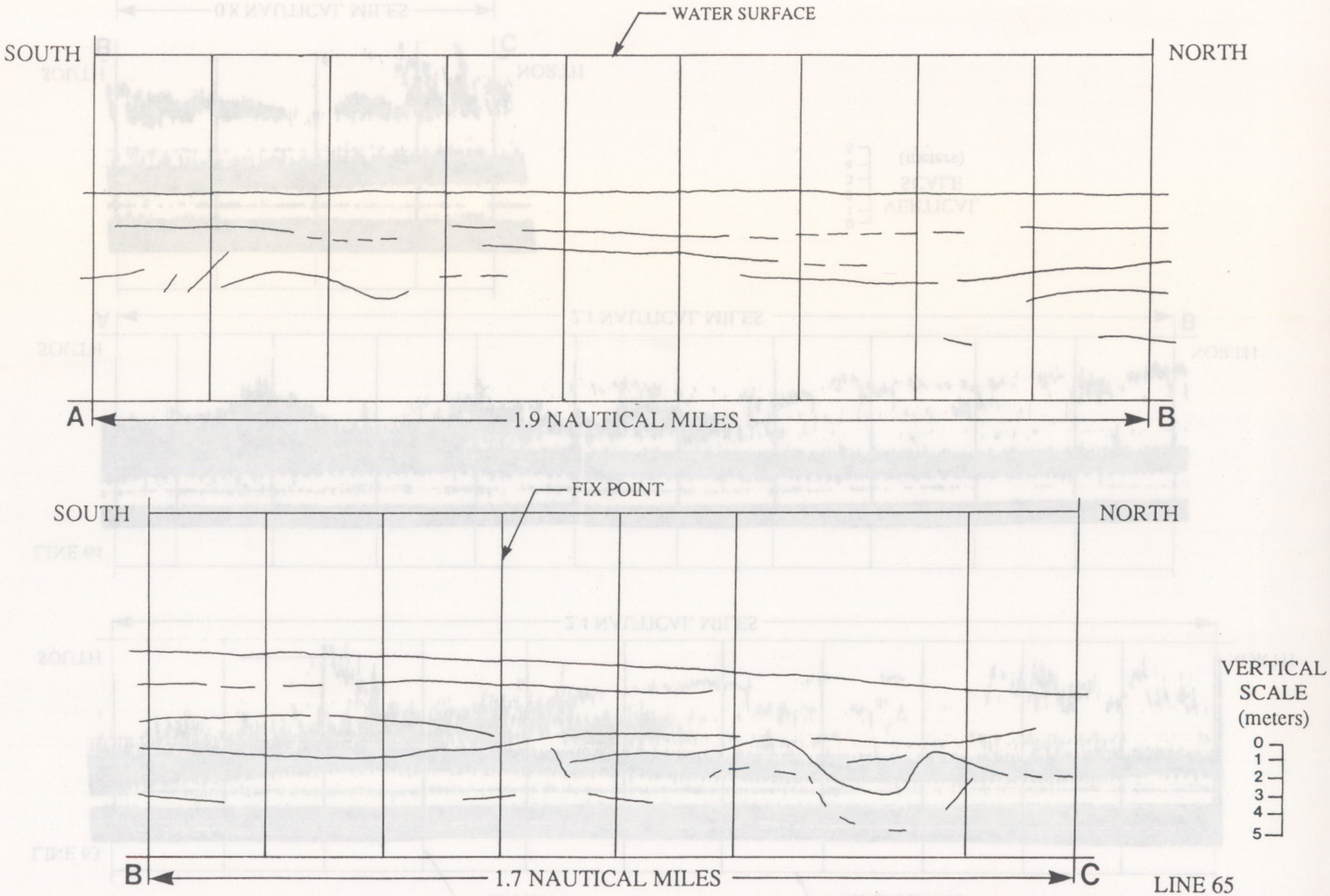

WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
CORE 19
FIX POINT
FINE SAND
SOUTH
NORTH
B
1.5 NAUTICAL MILES
C
SOUTH
NORTH
C
1.2 NAUTICAL MILES
D
0
2
4
6
8
10
VERTICAL
SCALE
(meters)
LINE 18

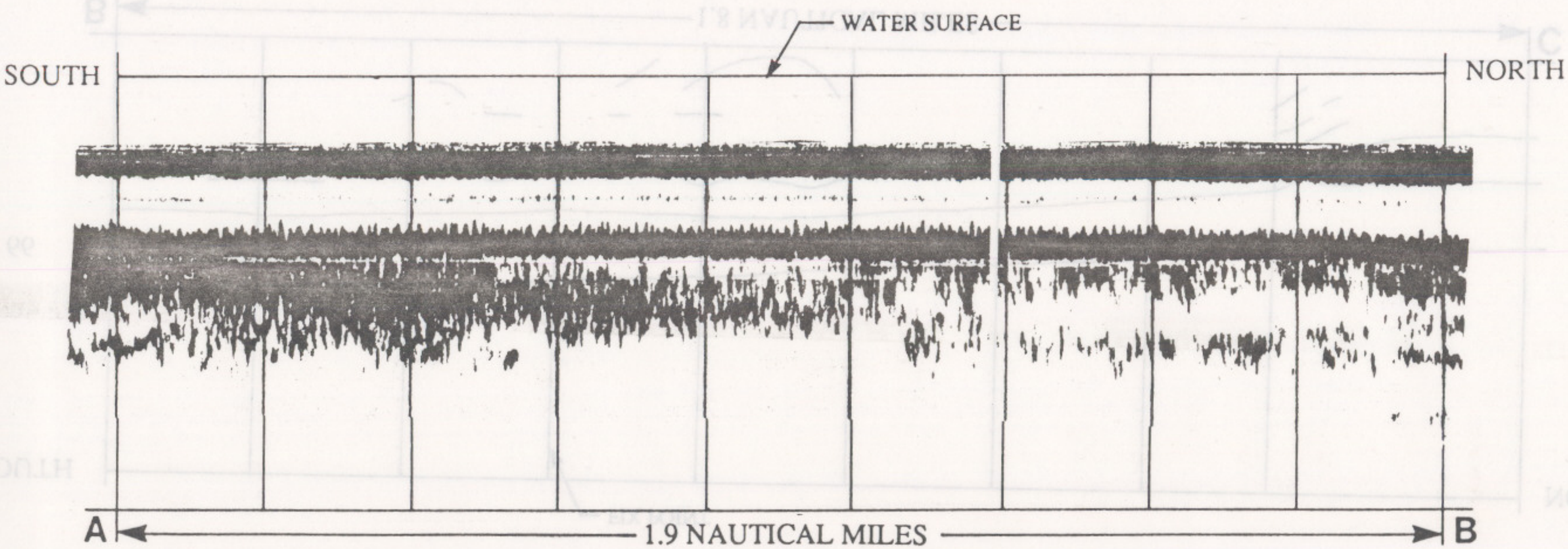

WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
CORE 19
FIX POINT
SOUTH
NORTH
B
1.5 NAUTICAL MILES
C
SOUTH
NORTH
C
1.2 NAUTICAL MILES
D
0
2
4
6
8
10
VERTICAL SCALE (meters)

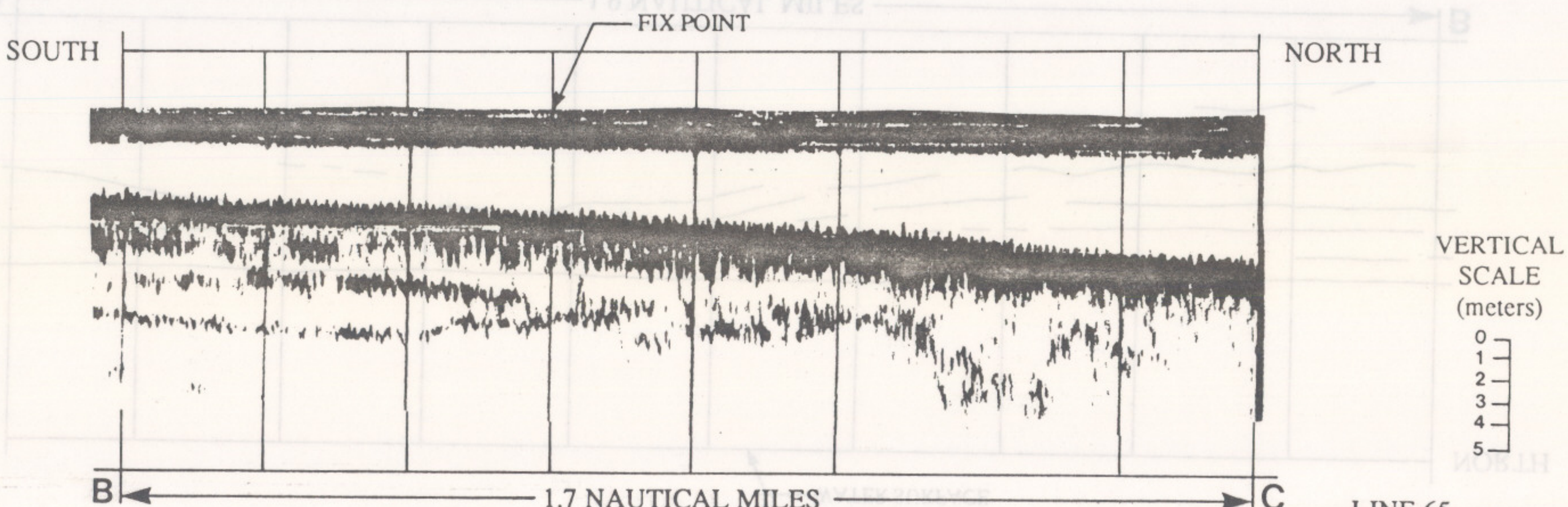
LINE 18


FIX POINT
WATER SURFACE
LINE 63
SOUTH
NORTH
2.4 NAUTICAL MILES
LINE 64
SOUTH
NORTH
A
2.1 NAUTICAL MILES
B
SOUTH
NORTH
B
C
0.8 NAUTICAL MILES
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

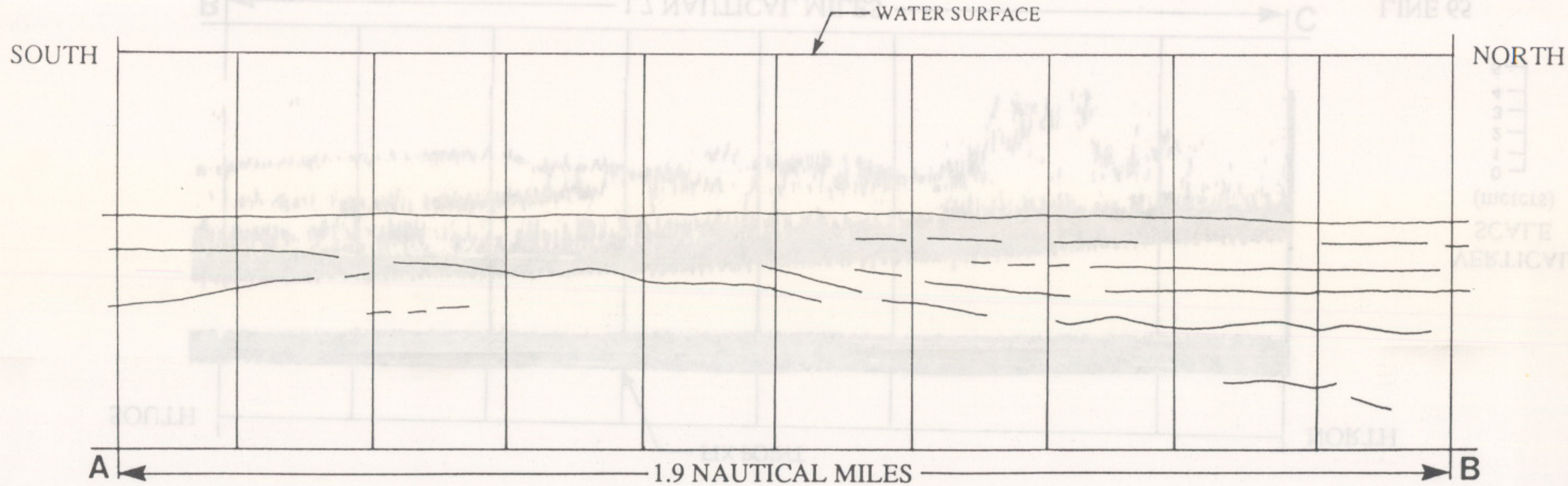

FIX POINT
WATER SURFACE
LINE 63
SOUTH
NORTH
2.4 NAUTICAL MILES
LINE 64
SOUTH
NORTH
A
2.1 NAUTICAL MILES
B
SOUTH
NORTH
B
C
0.8 NAUTICAL MILES
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

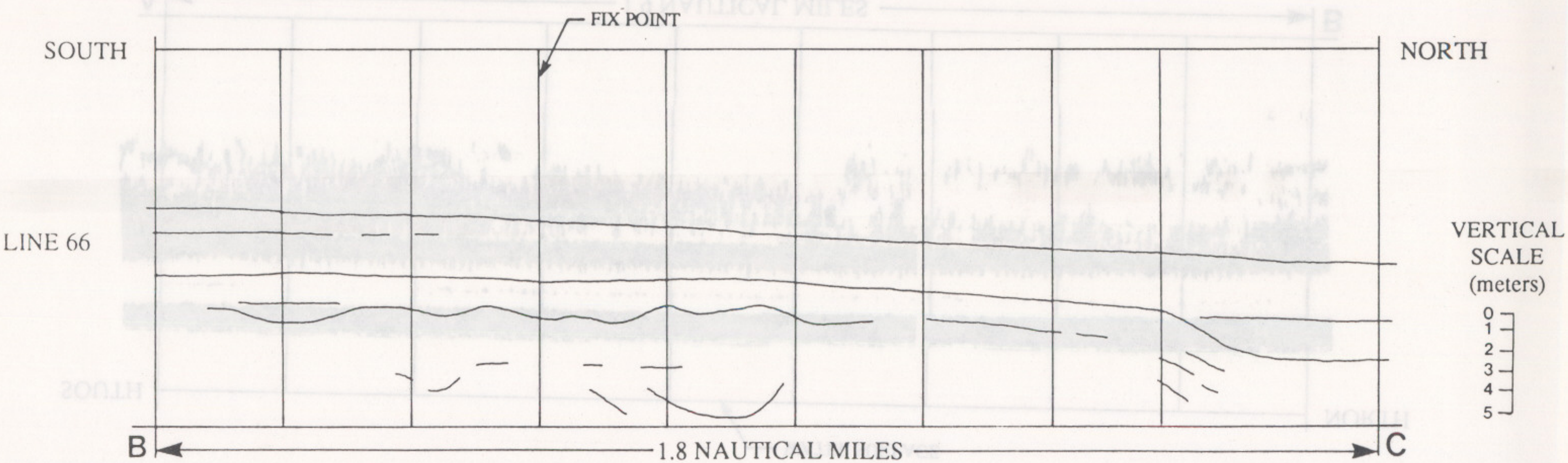

WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B
FIX POINT
SOUTH
NORTH
B
1.7 NAUTICAL MILES
C
VERTICAL
SCALE
(meters)
0
1
2
3
4
5
LINE 65

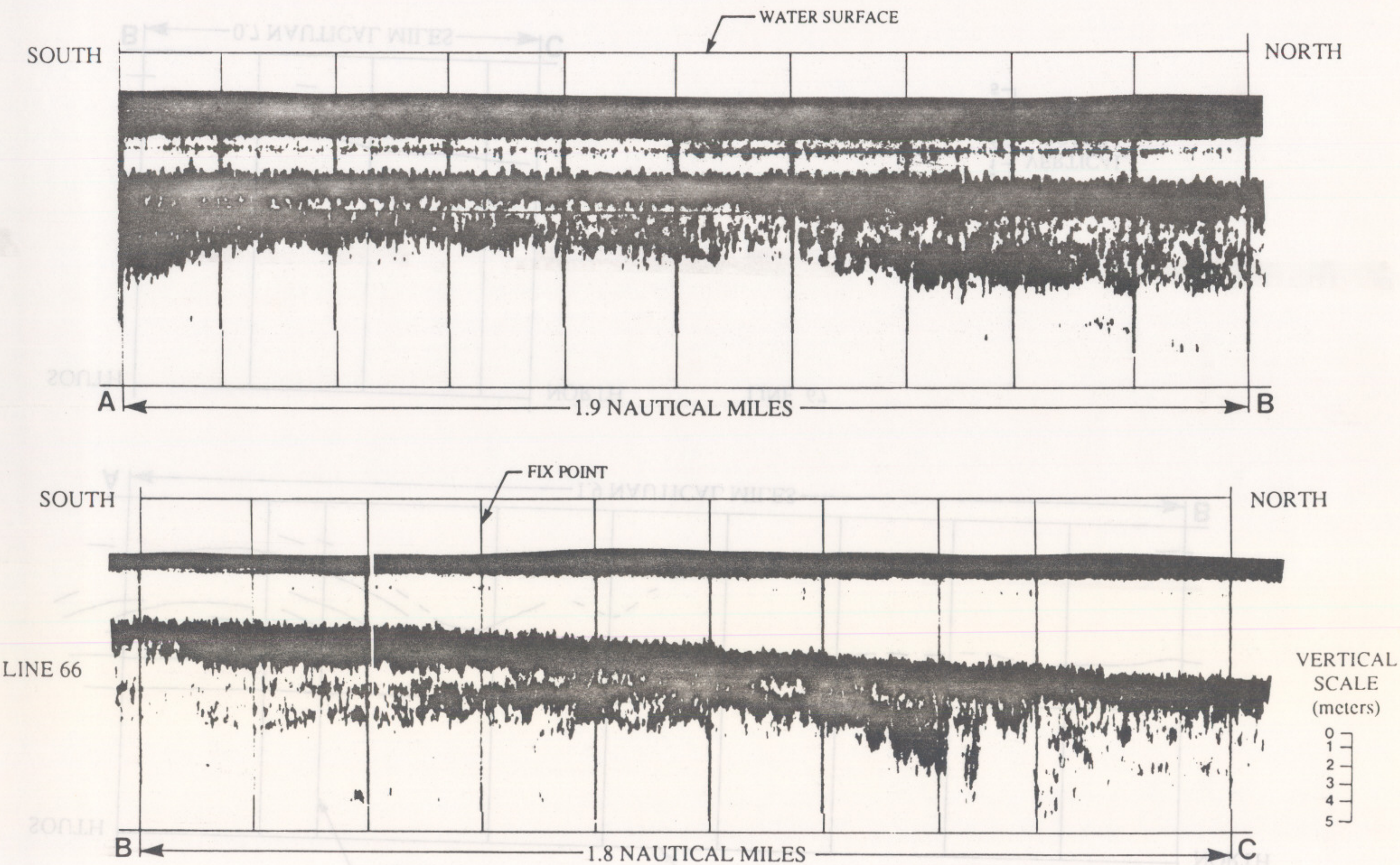

WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B

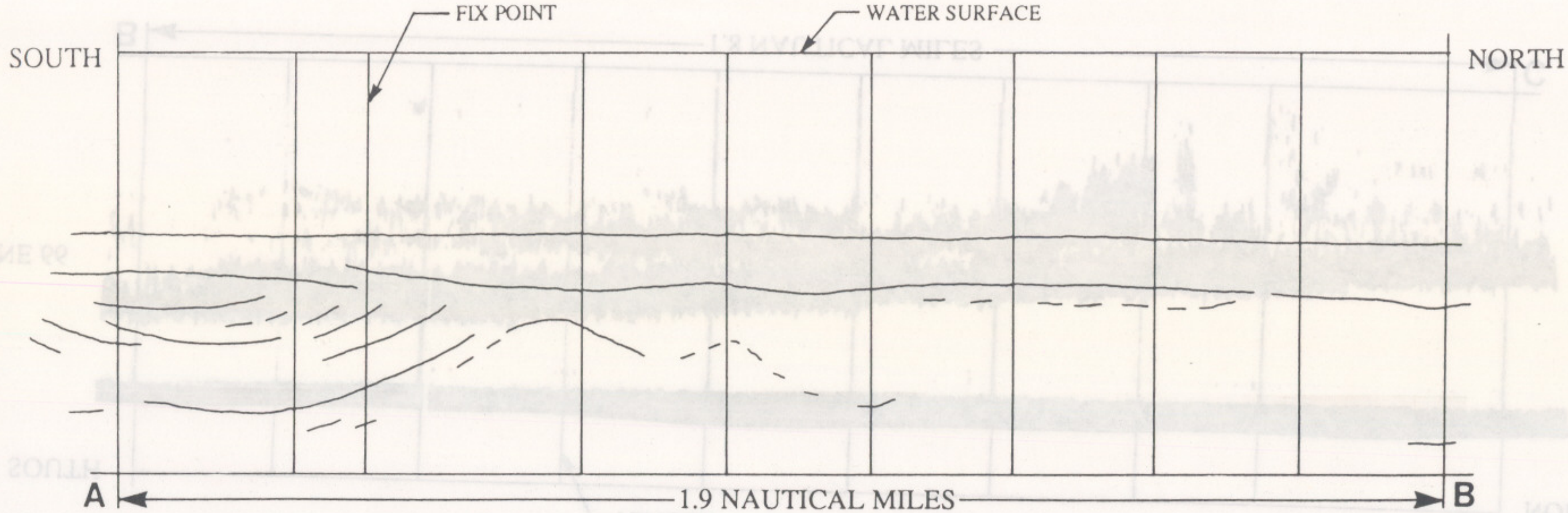

FIX POINT
SOUTH
NORTH
VERTICAL
SCALE
(meters)
0
1
2
3
4
5
B
1.7 NAUTICAL MILES
C

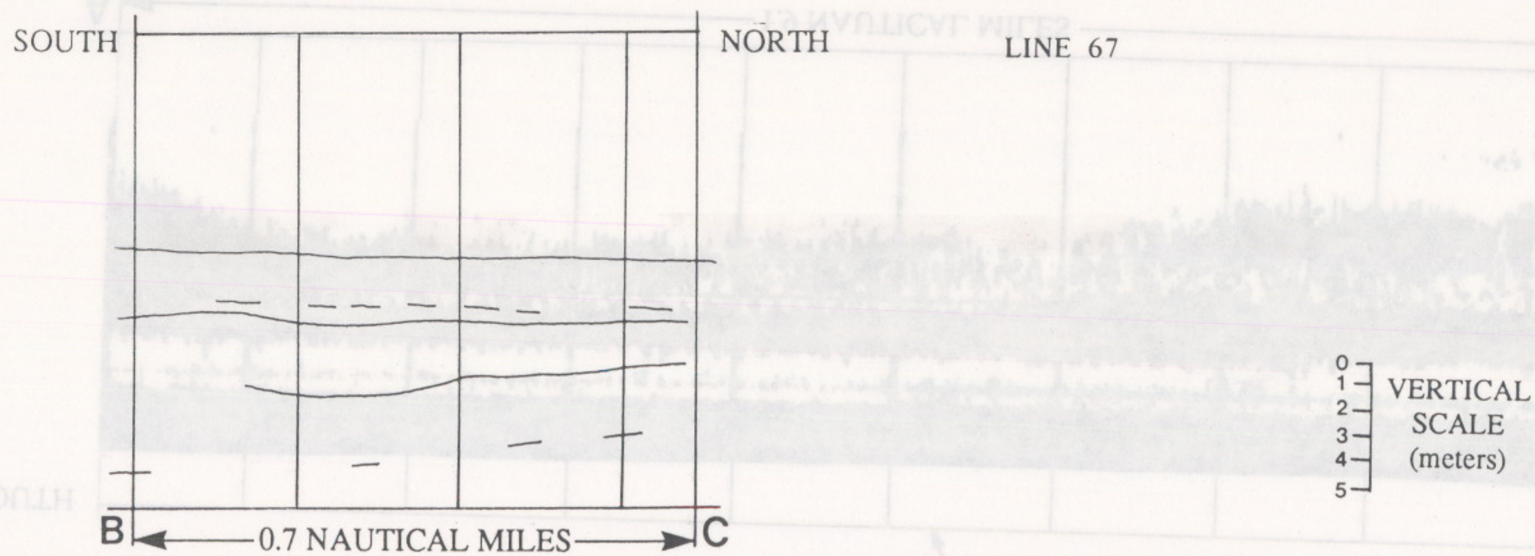
LINE 65

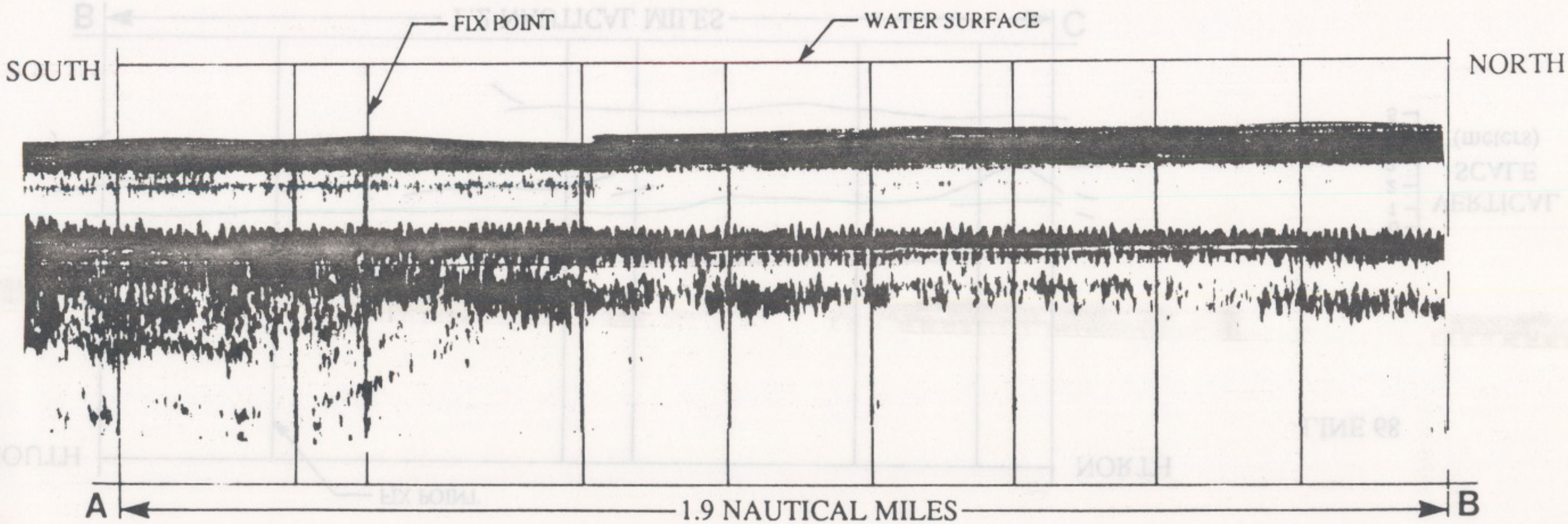

WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B


FIX POINT
SOUTH
NORTH
LINE 66
VERTICAL
SCALE
(meters)
0
1
2
3
4
5
B
1.8 NAUTICAL MILES
C


WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B
FIX POINT
SOUTH
NORTH
LINE 66
VERTICAL
SCALE
(meters)
0
1
2
3
4
5
B
1.8 NAUTICAL MILES
C

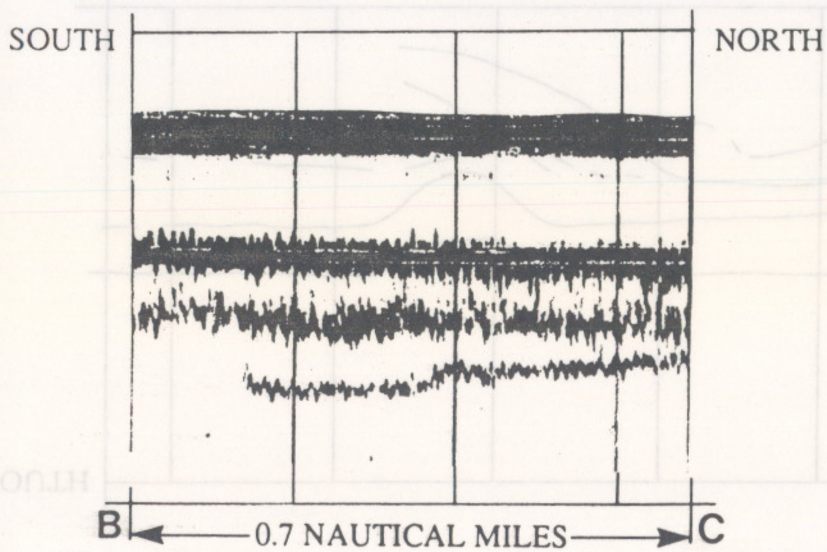

FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B


SOUTH
NORTH
LINE 67
B
0.7 NAUTICAL MILES
C
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

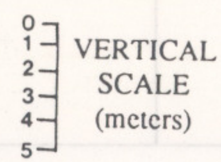


FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B

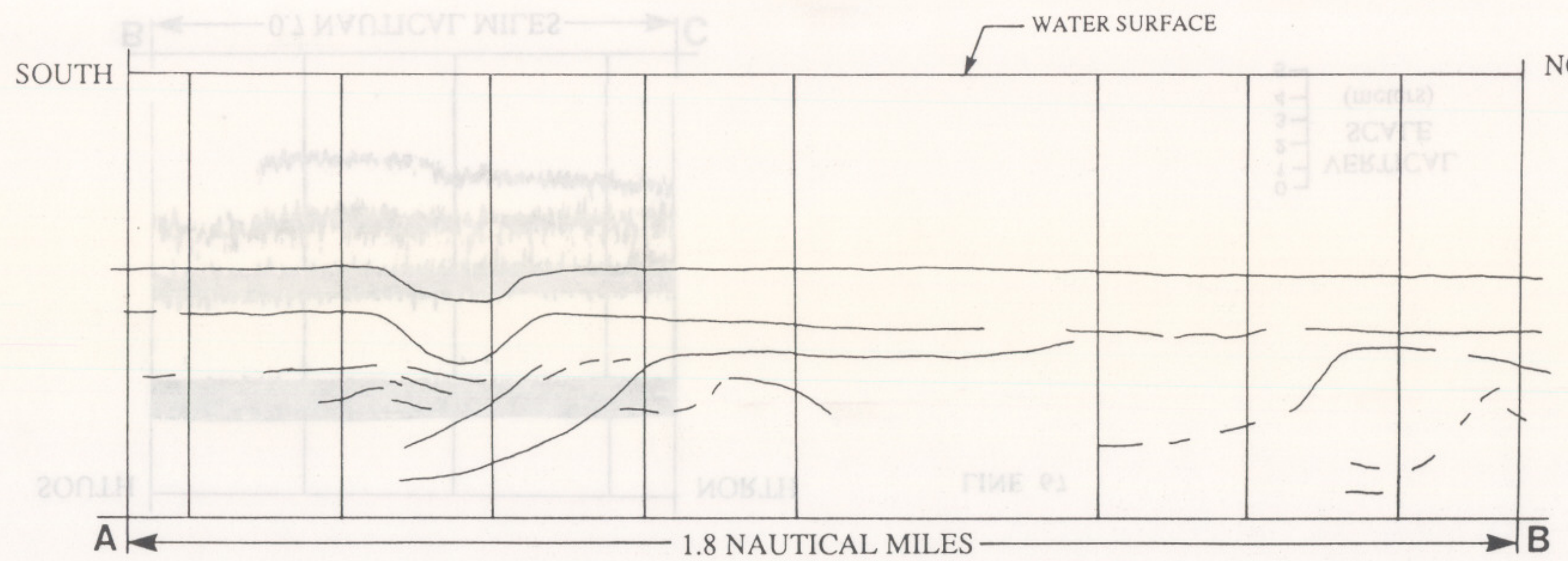
LINE 67



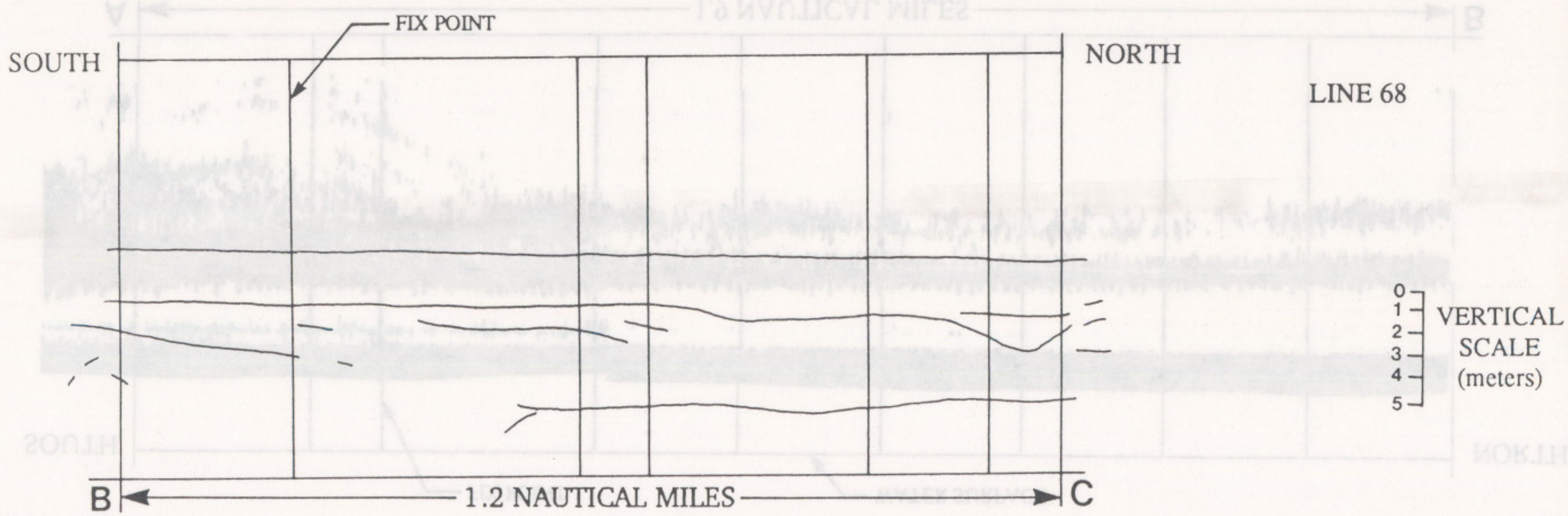
SOUTH
NORTH
B
0.7 NAUTICAL MILES
C



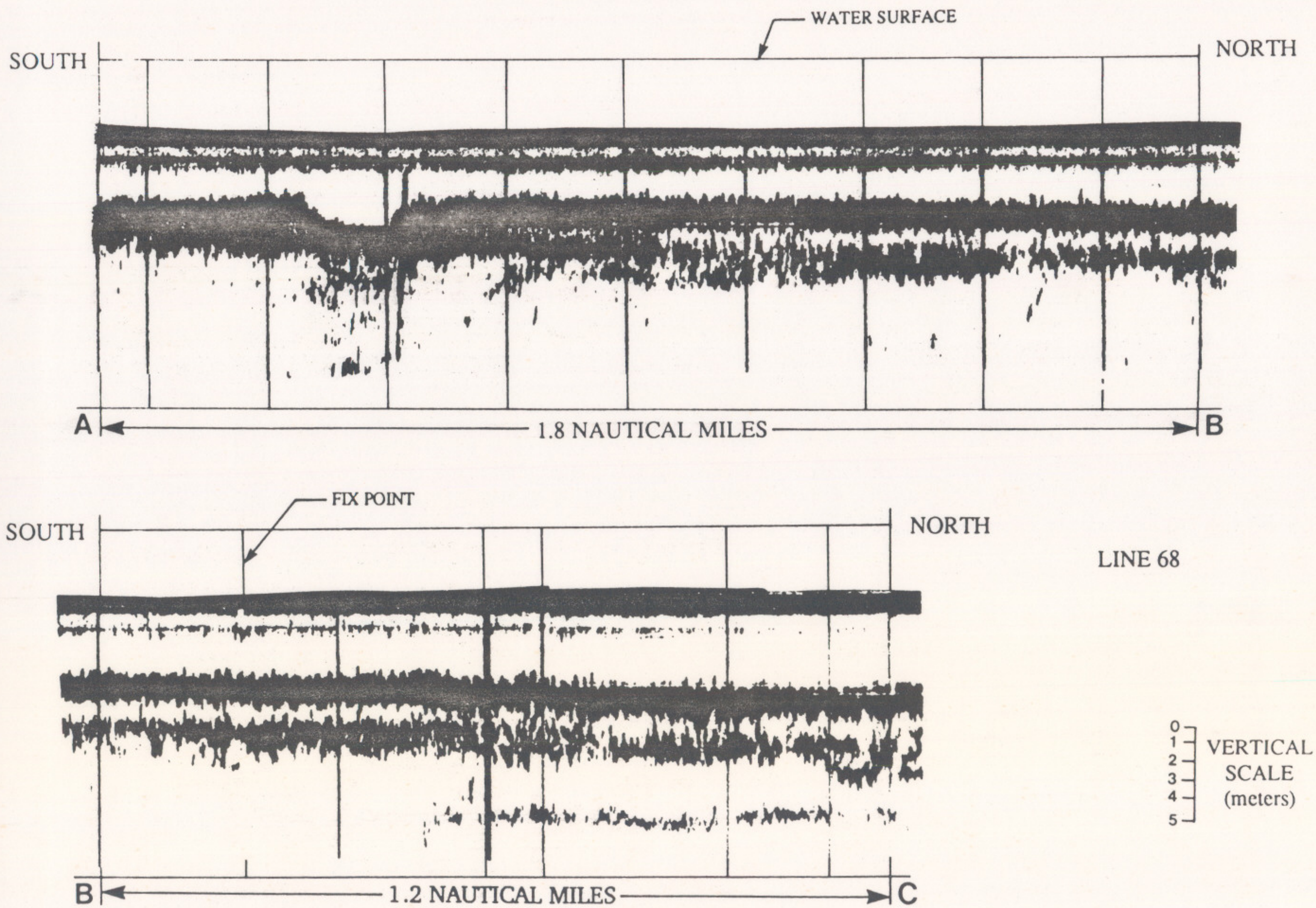
0
1
2
3
4
5
VERTICAL
SCALE
(meters)



WATER SURFACE
SOUTH
NORTH
A
1.8 NAUTICAL MILES
B



FIX POINT
SOUTH
NORTH
LINE 68
0
1
2
3
4
5
VERTICAL SCALE (meters)
B
1.2 NAUTICAL MILES
C

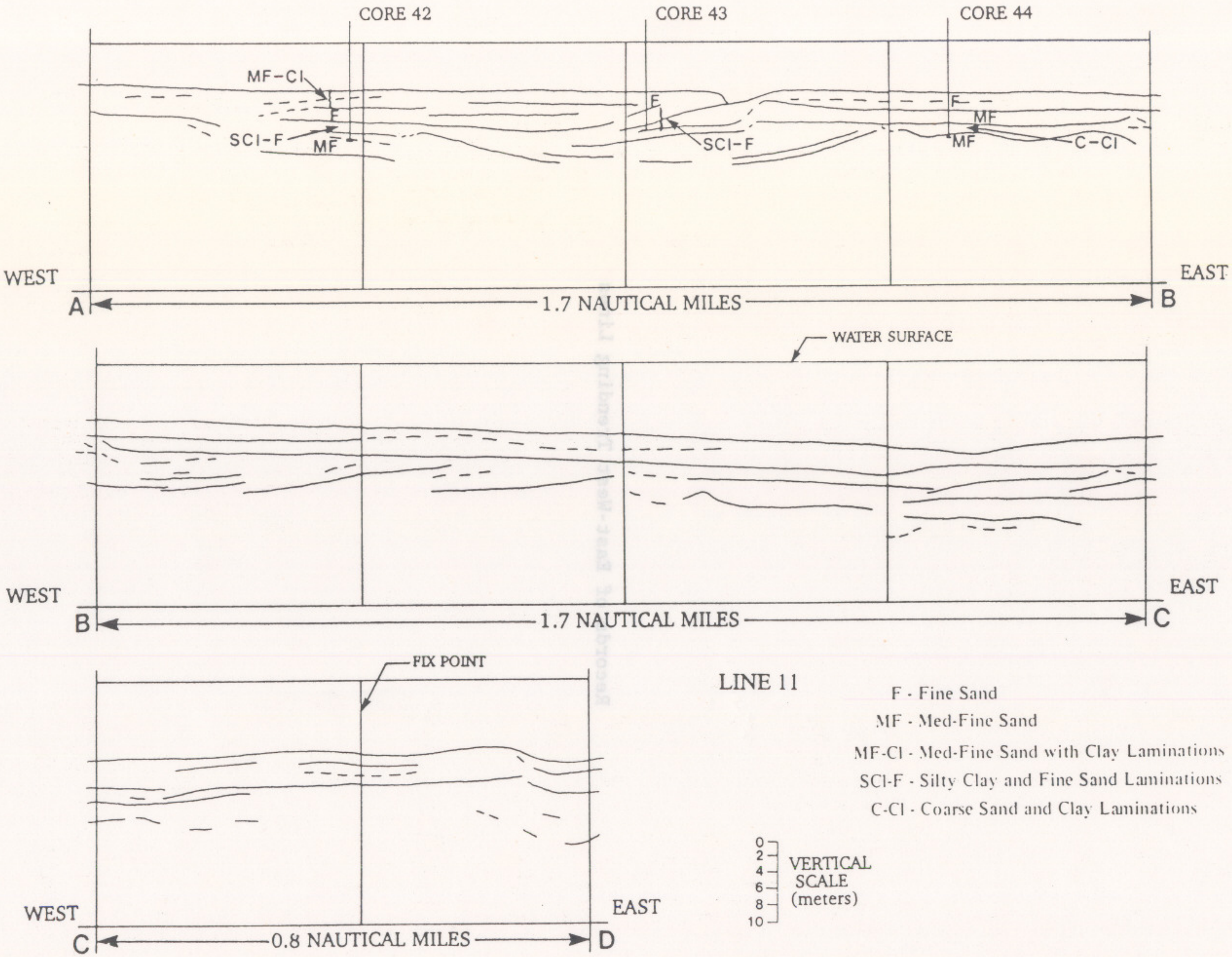

WATER SURFACE
SOUTH
NORTH
A
1.8 NAUTICAL MILES
B
FIX POINT
SOUTH
NORTH
B
1.2 NAUTICAL MILES
C
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

LINE 68

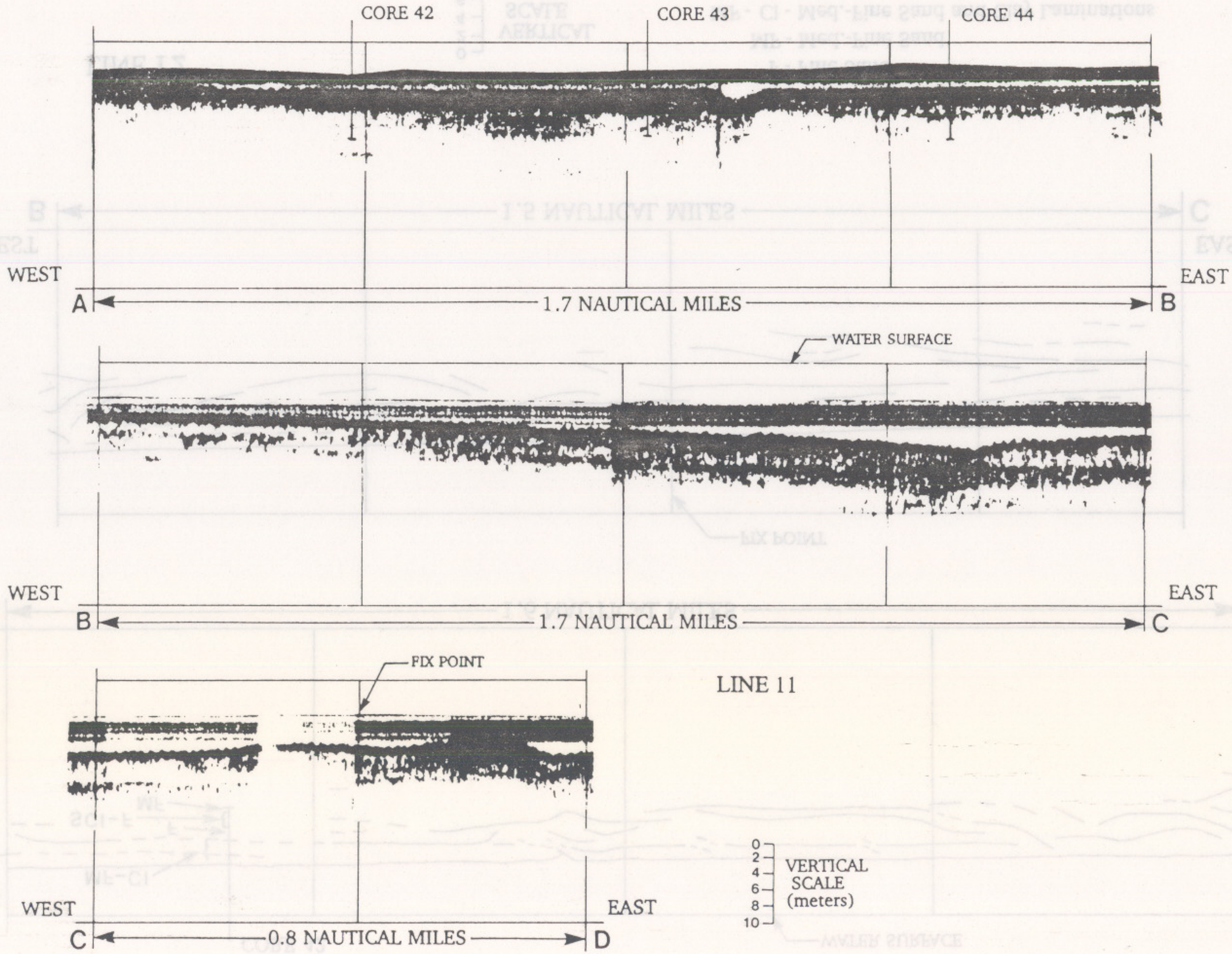
APPENDIX B

Reproductions of subbottom acoustic records retrieved from the Sandbridge Beach section of the study area paired with interpretations of the seismic data. Track line locations are shown in Figure 8.

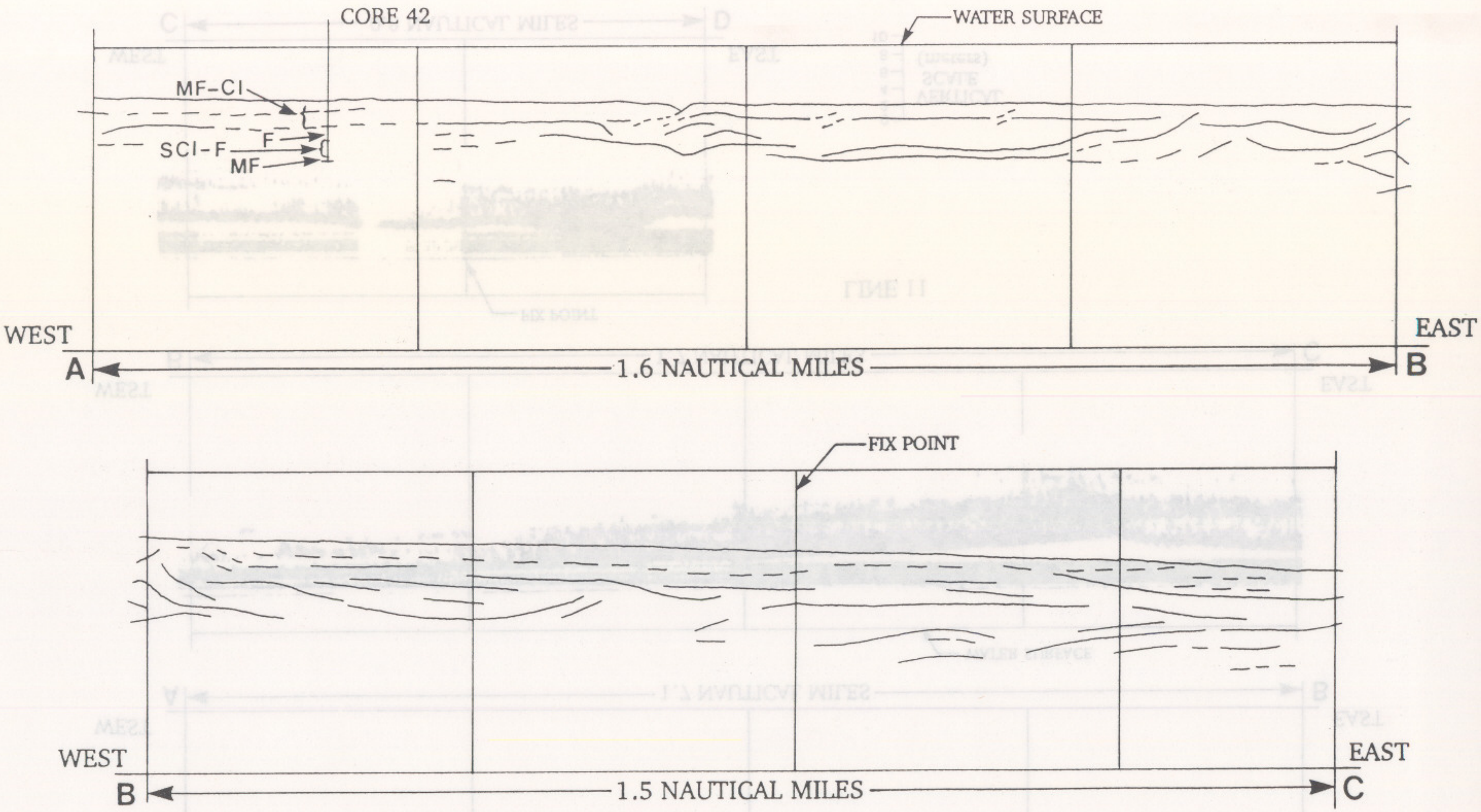
Records of East-West Trending Lines



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)



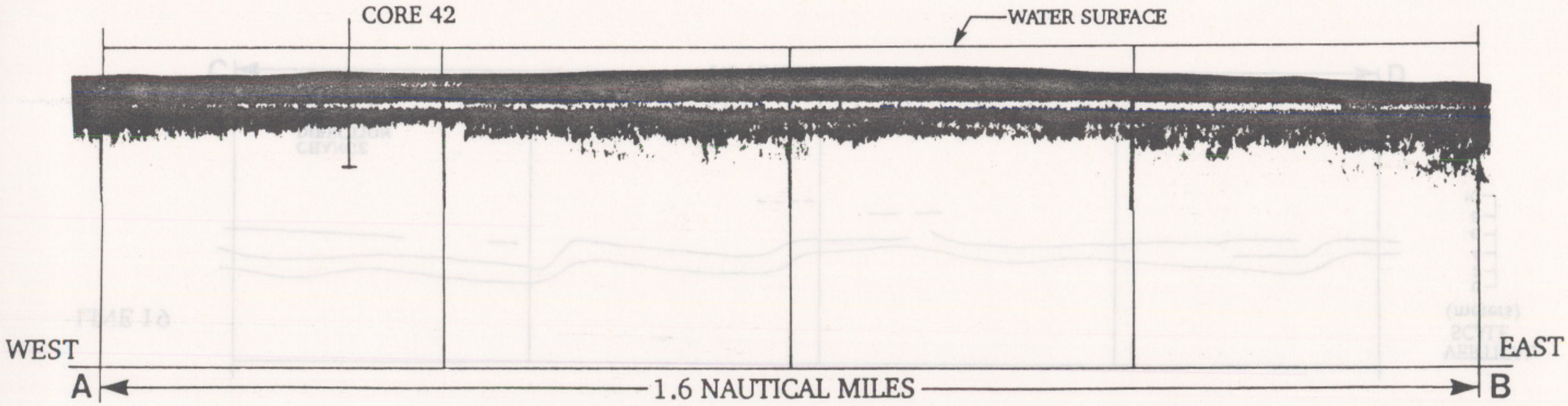
CORE 42
CORE 43
CORE 44
WEST
EAST
A
1.7 NAUTICAL MILES
B
WATER SURFACE
WEST
EAST
B
1.7 NAUTICAL MILES
C
FIX POINT
LINE 11
WEST
EAST
C
0.8 NAUTICAL MILES
D
0
2
4
6
8
10
VERTICAL
SCALE
(meters)

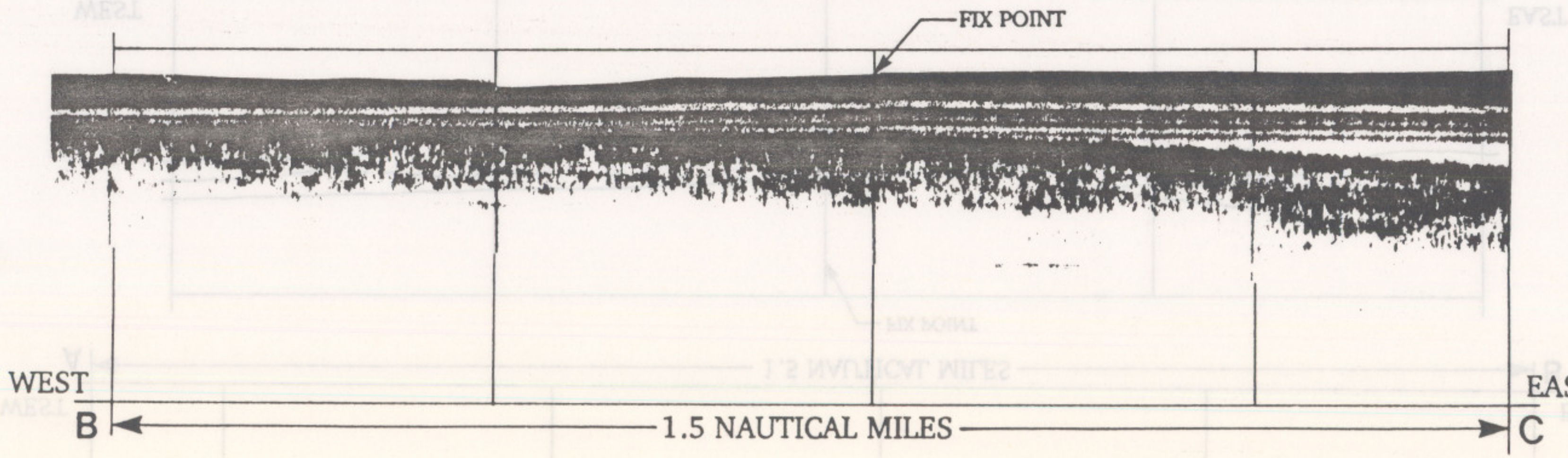


LINE 12

VERTICAL SCALE (meters): 0, 2, 4, 6, 8, 10

F - Fine Sand
MF - Med.-Fine Sand
MF - Cl - Med.-Fine Sand and Clay Laminations
SCl -F - Silty Clay and Fine Sand Laminations

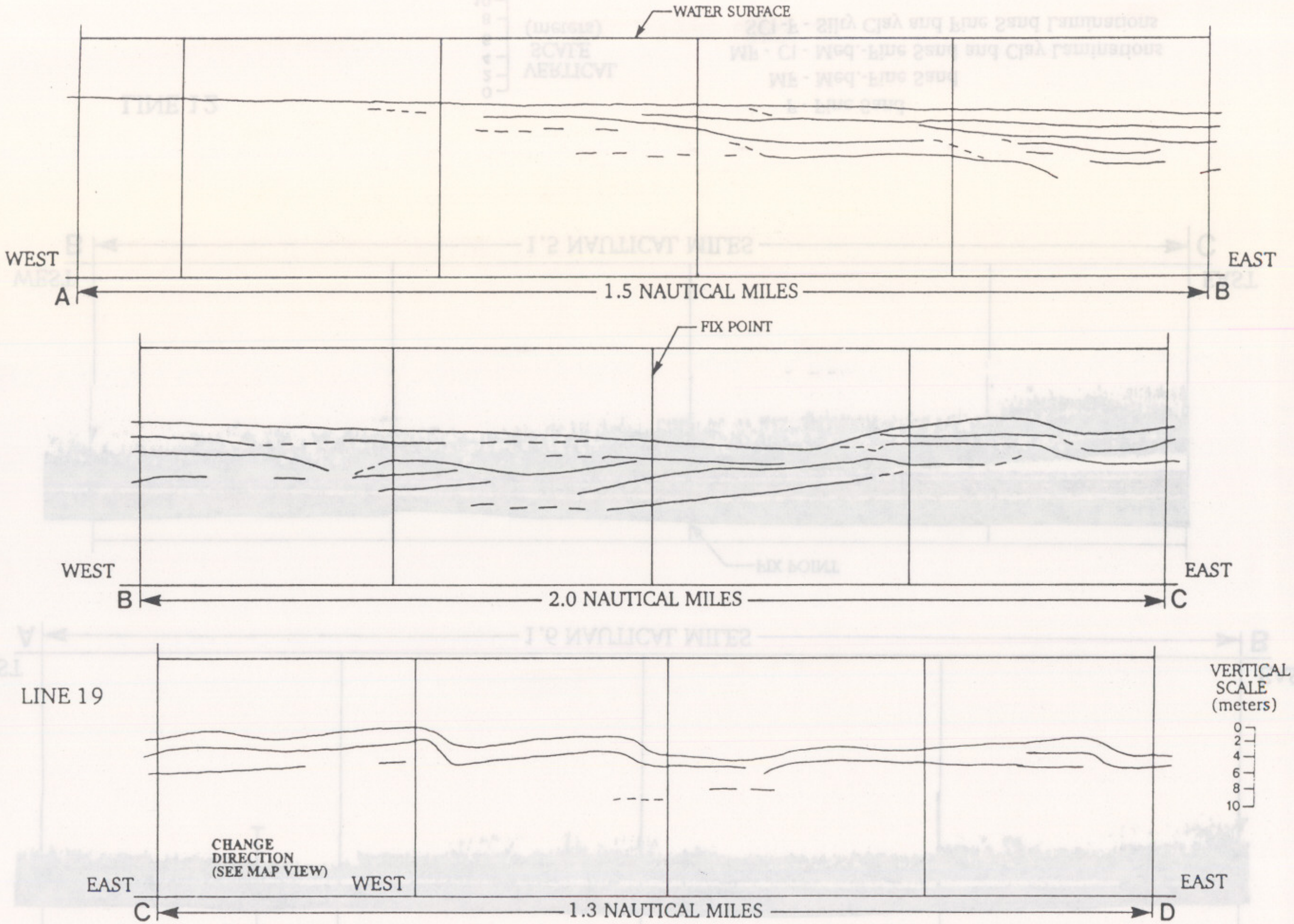




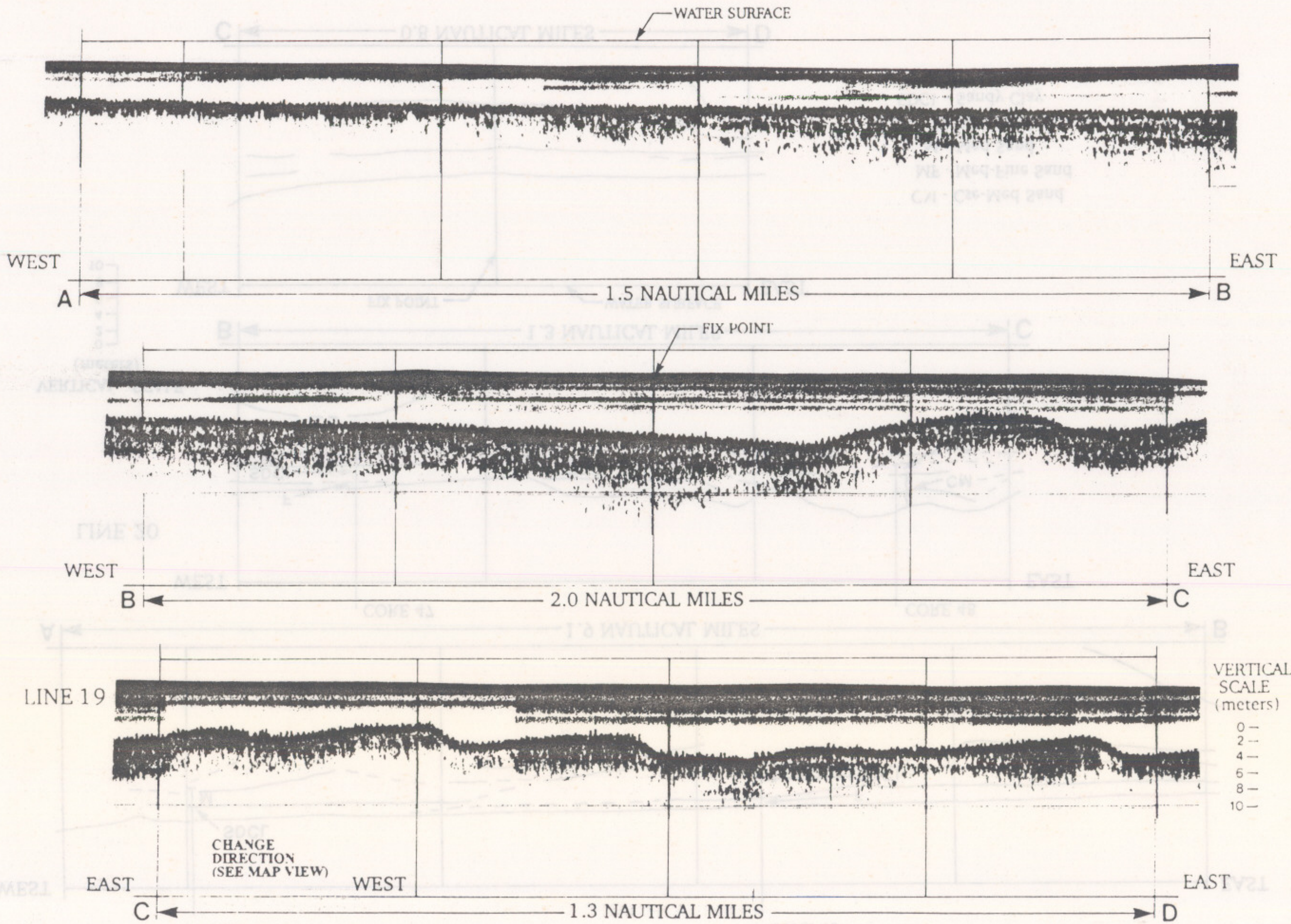
LINE 12

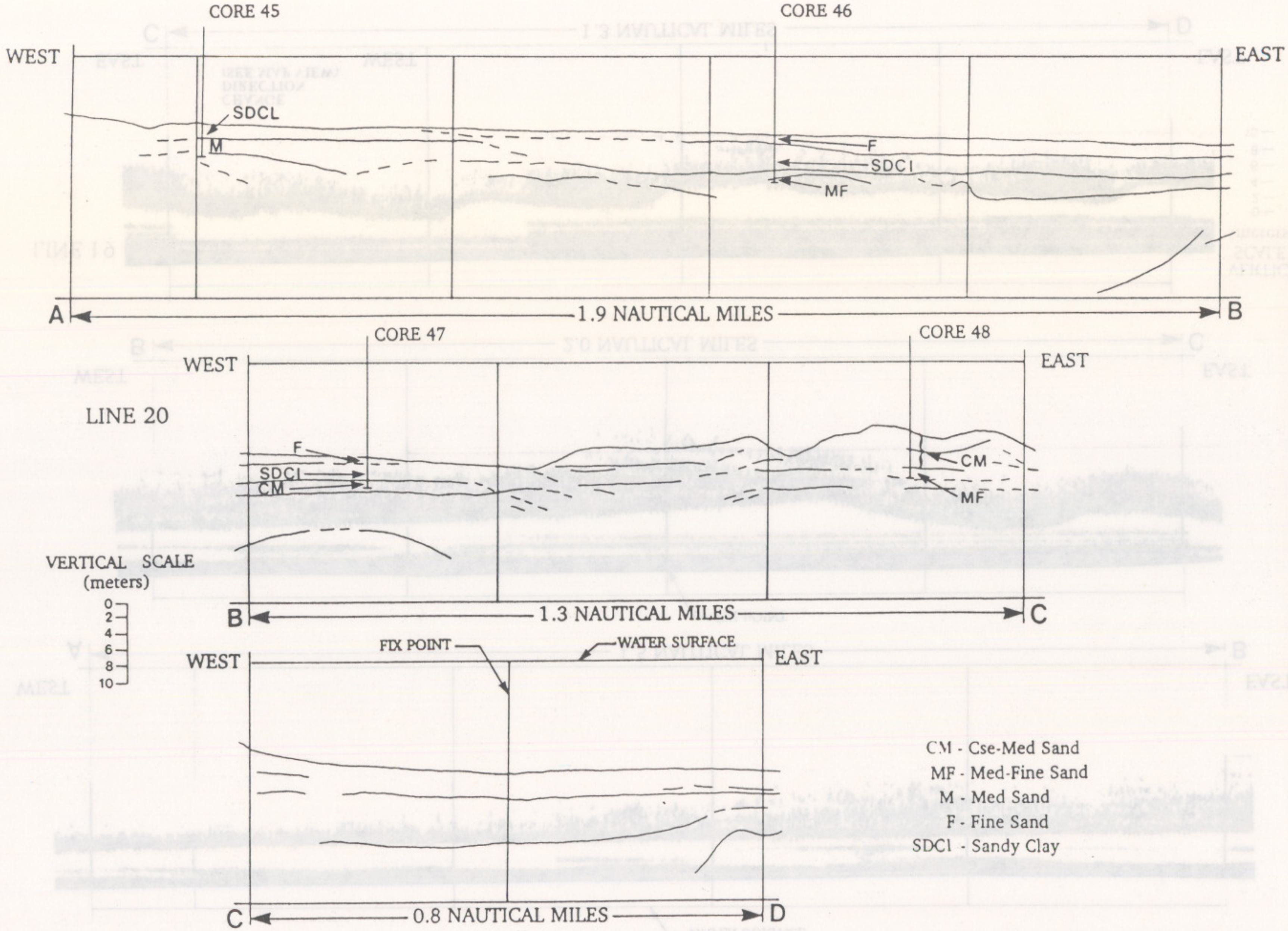
0
2
4
6
8
10
VERTICAL SCALE (meters)

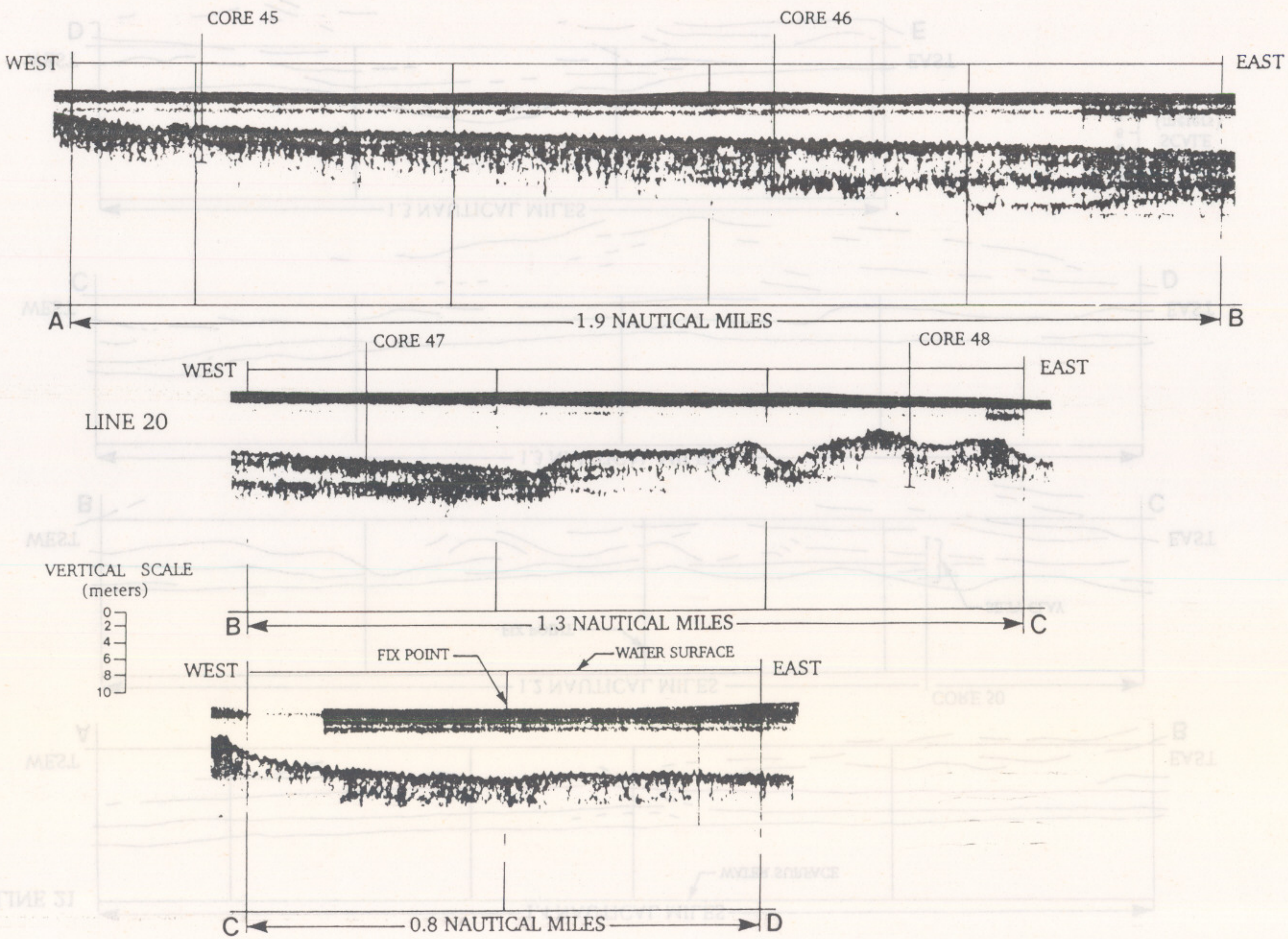
F - Fine Sand
MF - Med.-Fine Sand
MF - Cl - Med.-Fine Sand and Clay Laminations
SCl -F - Silty Clay and Fine Sand Laminations

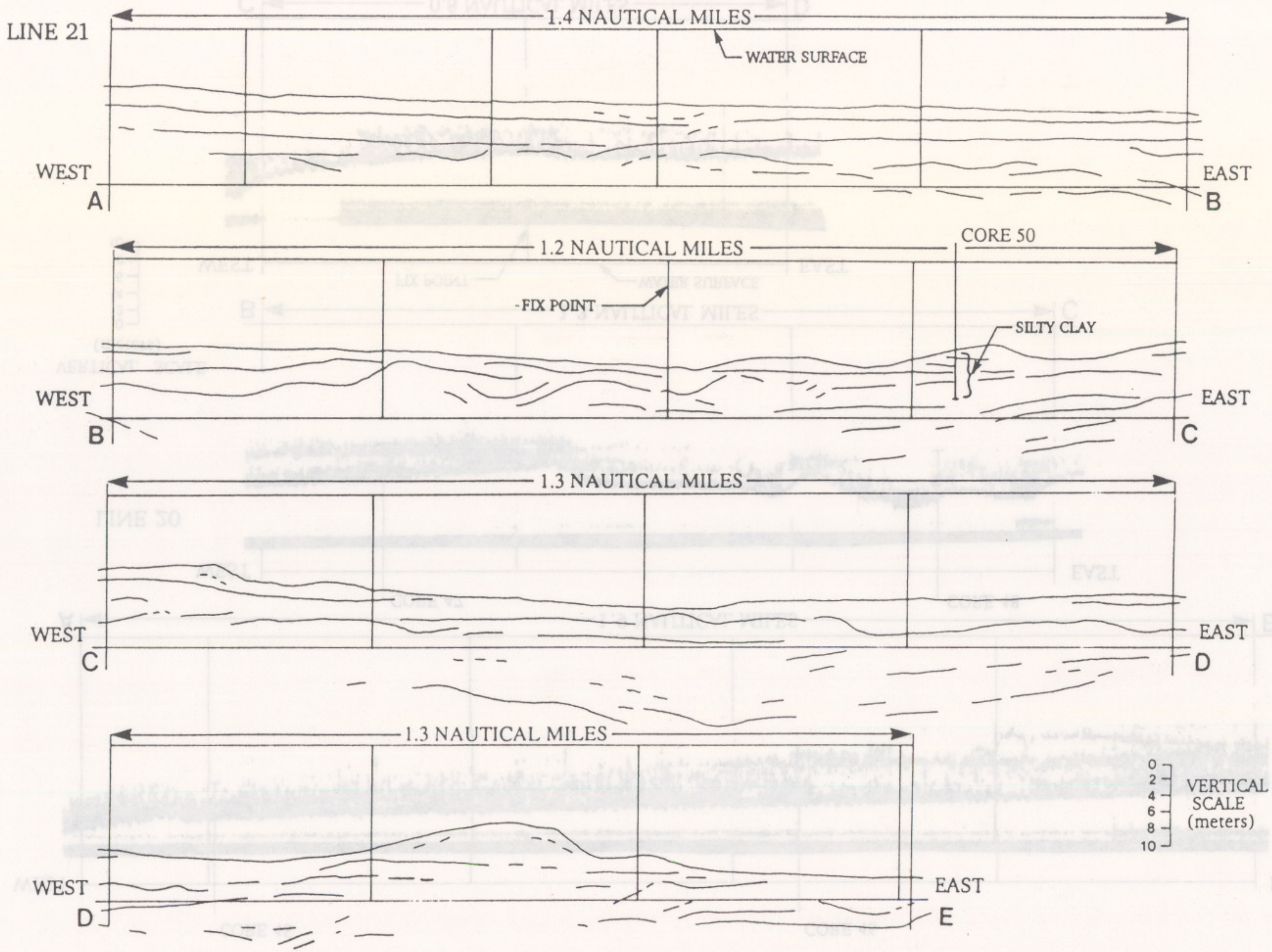


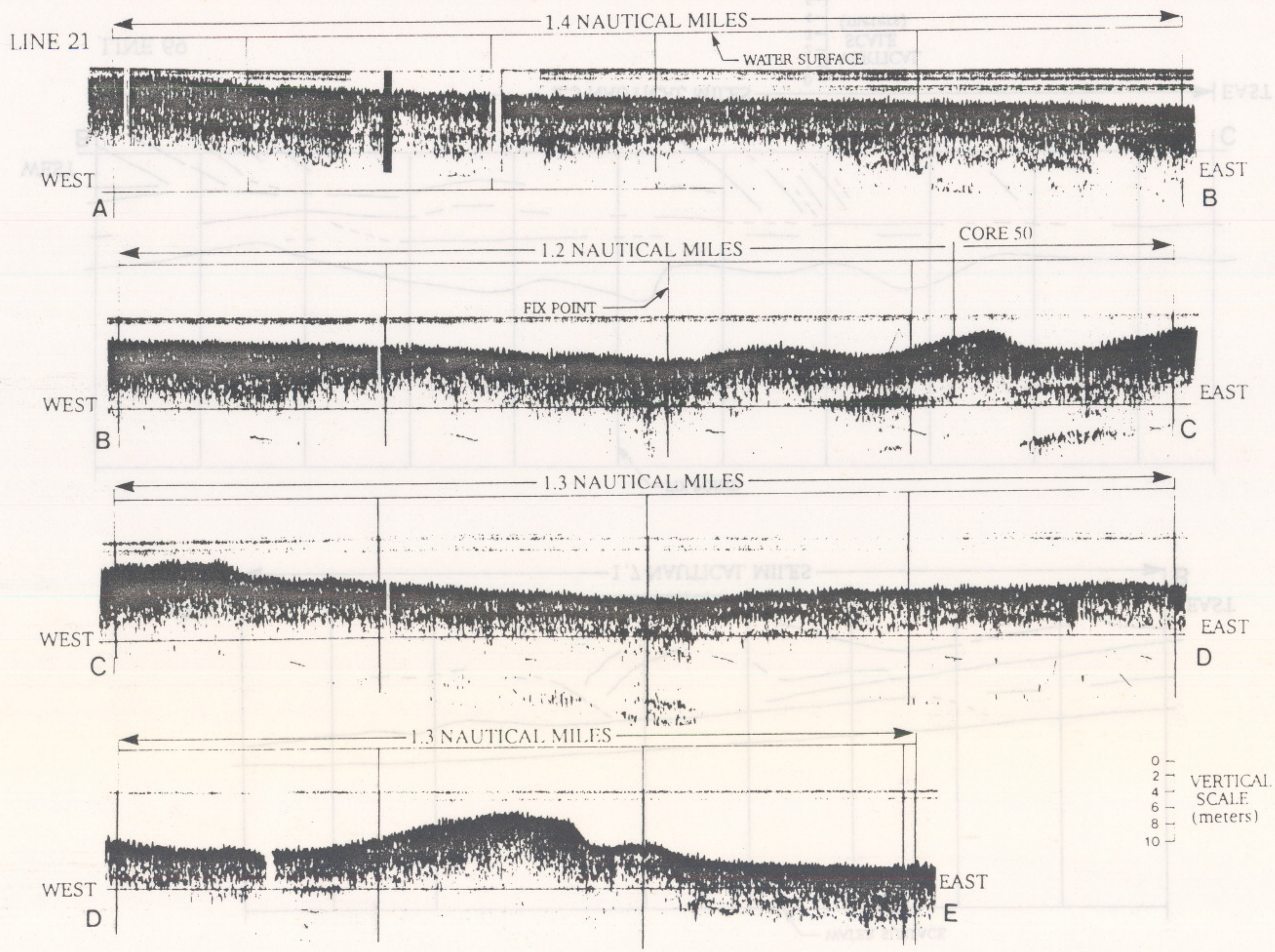
WATER SURFACE
WEST
EAST
A
B
1.5 NAUTICAL MILES
FIX POINT
WEST
EAST
B
C
2.0 NAUTICAL MILES
LINE 19
VERTICAL
SCALE
(meters)
0
2
4
6
8
10
CHANGE
DIRECTION
(SEE MAP VIEW)
EAST
WEST
EAST
C
D
1.3 NAUTICAL MILES


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

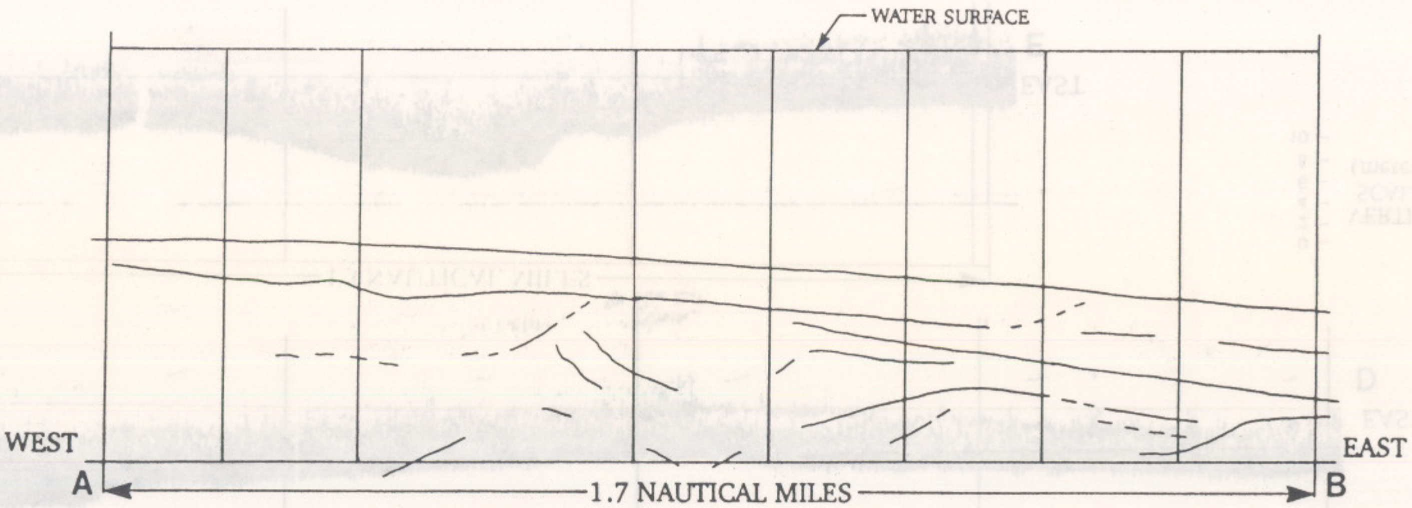

CORE 45
CORE 46
WEST
EAST
SDCL
M
F
SDCl
MF
A
1.9 NAUTICAL MILES
B
CORE 47
CORE 48
WEST
EAST
LINE 20
F
SDCl
CM
CM
MF
VERTICAL SCALE
(meters)
0
2
4
6
8
10
B
1.3 NAUTICAL MILES
C
FIX POINT
WATER SURFACE
WEST
EAST
C
0.8 NAUTICAL MILES
D
CM - Cse-Med Sand
MF - Med-Fine Sand
M - Med Sand
F - Fine Sand
SDCl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

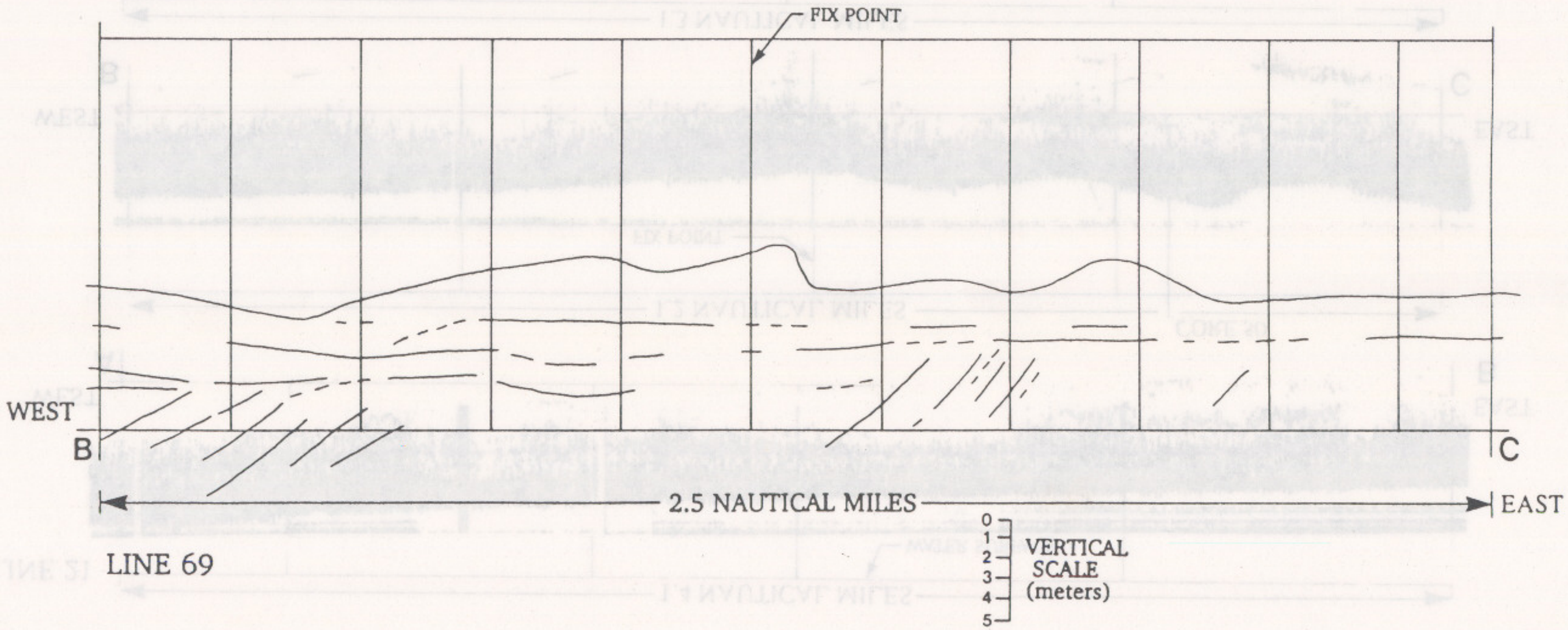

CORE 45
CORE 46
WEST
EAST
A
1.9 NAUTICAL MILES
B
CORE 47
CORE 48
WEST
EAST
LINE 20
VERTICAL SCALE
(meters)
0
2
4
6
8
10
B
1.3 NAUTICAL MILES
C
FIX POINT
WATER SURFACE
WEST
EAST
C
0.8 NAUTICAL MILES
D


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)

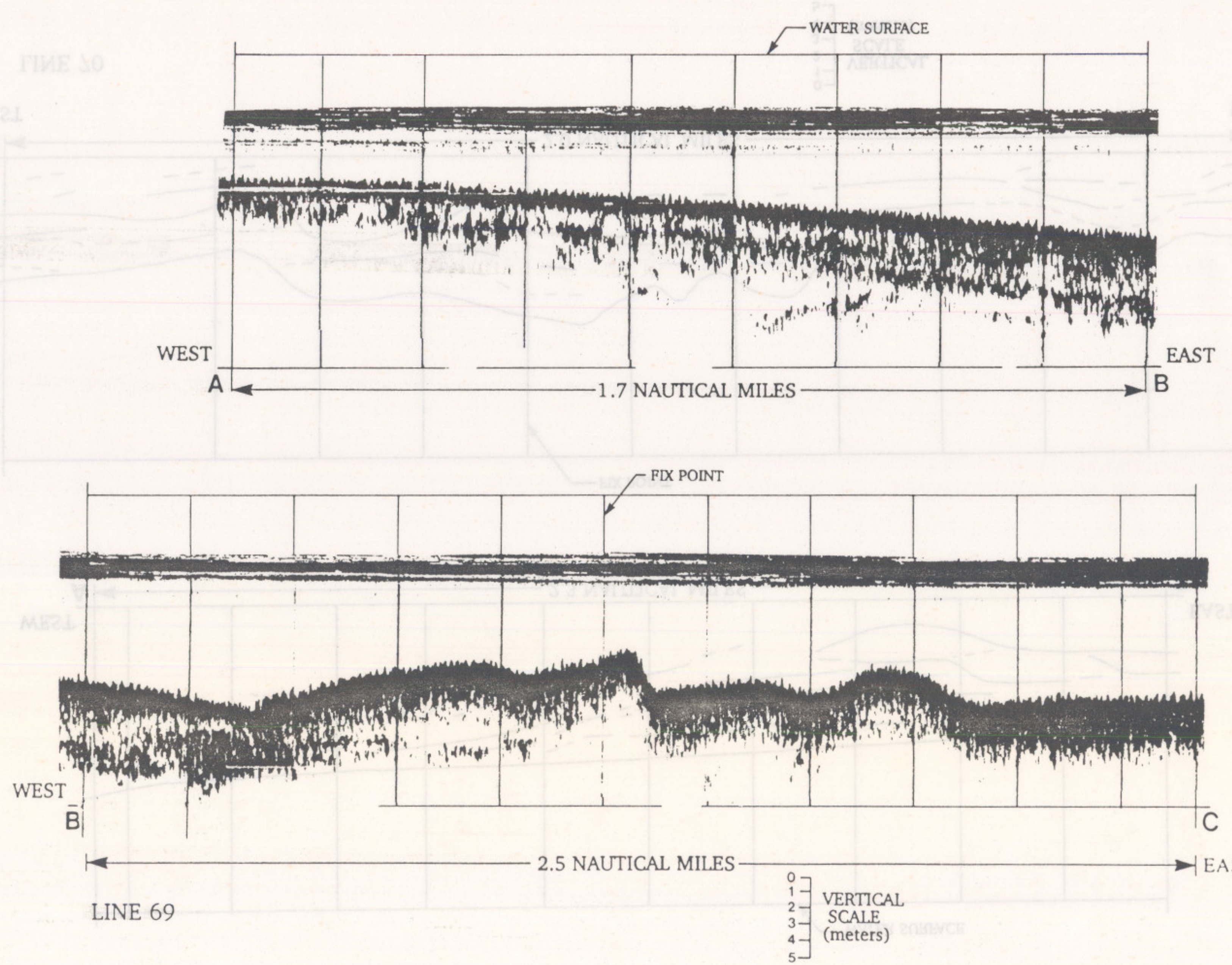


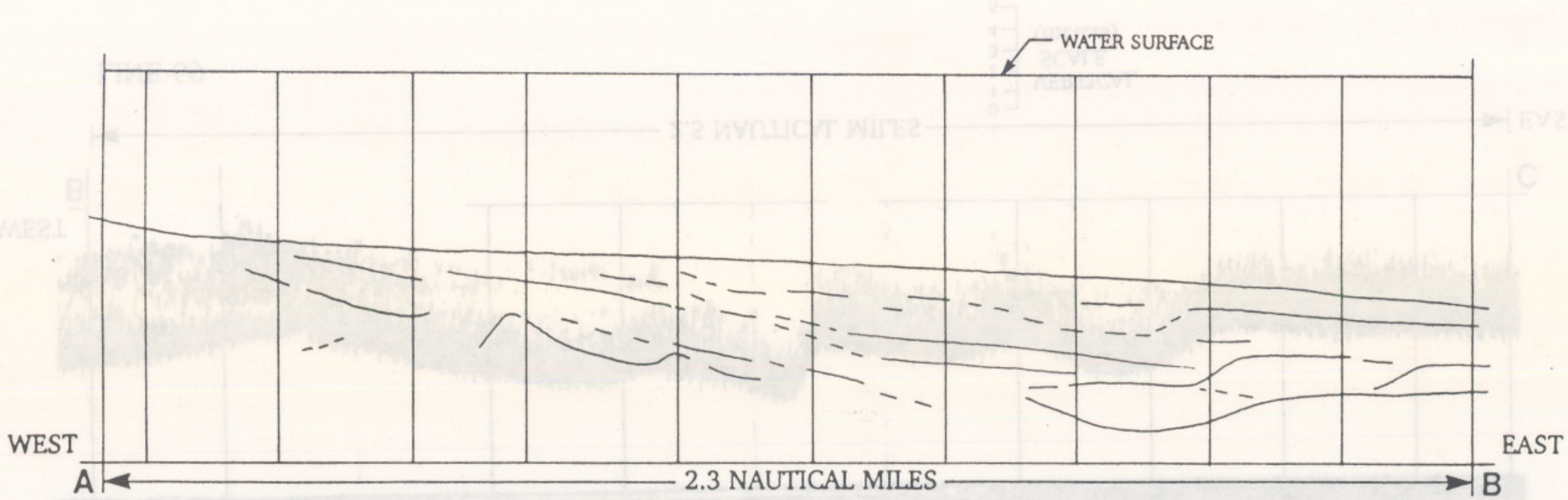
LINE 21
1.4 NAUTICAL MILES
WATER SURFACE
WEST
EAST
A
B
1.2 NAUTICAL MILES
CORE 50
FIX POINT
WEST
EAST
B
C
1.3 NAUTICAL MILES
WEST
EAST
C
D
1.3 NAUTICAL MILES
WEST
EAST
D
E
0
2
4
6
8
10
VERTICAL SCALE (meters)

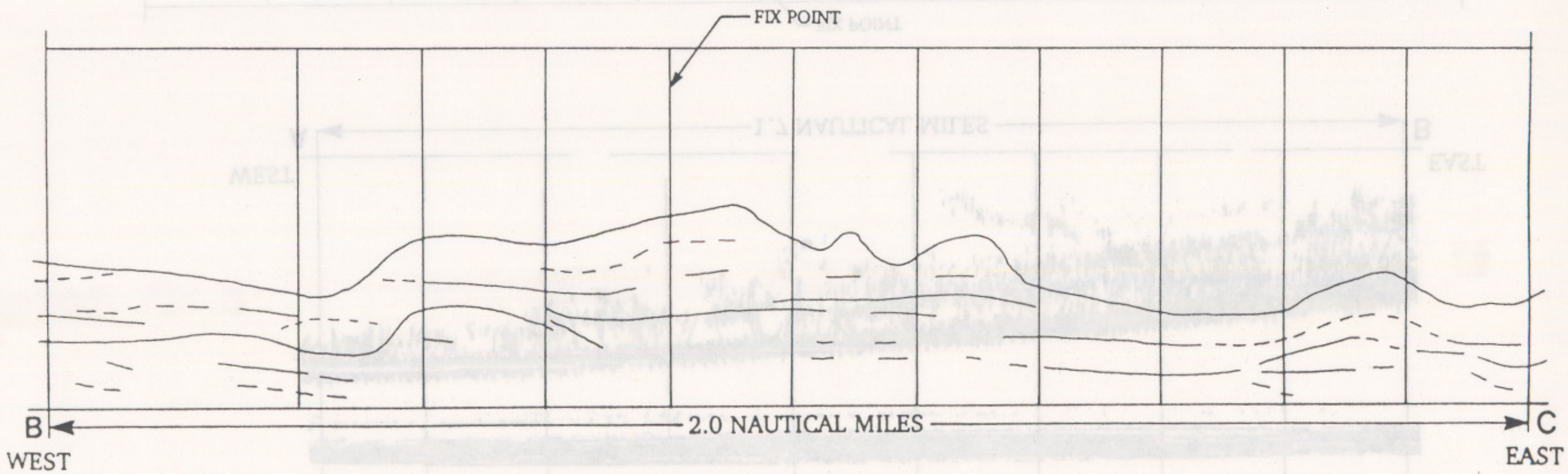

WATER SURFACE
WEST
EAST
A
B
1.7 NAUTICAL MILES


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

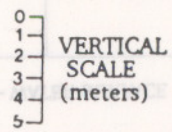
LINE 69

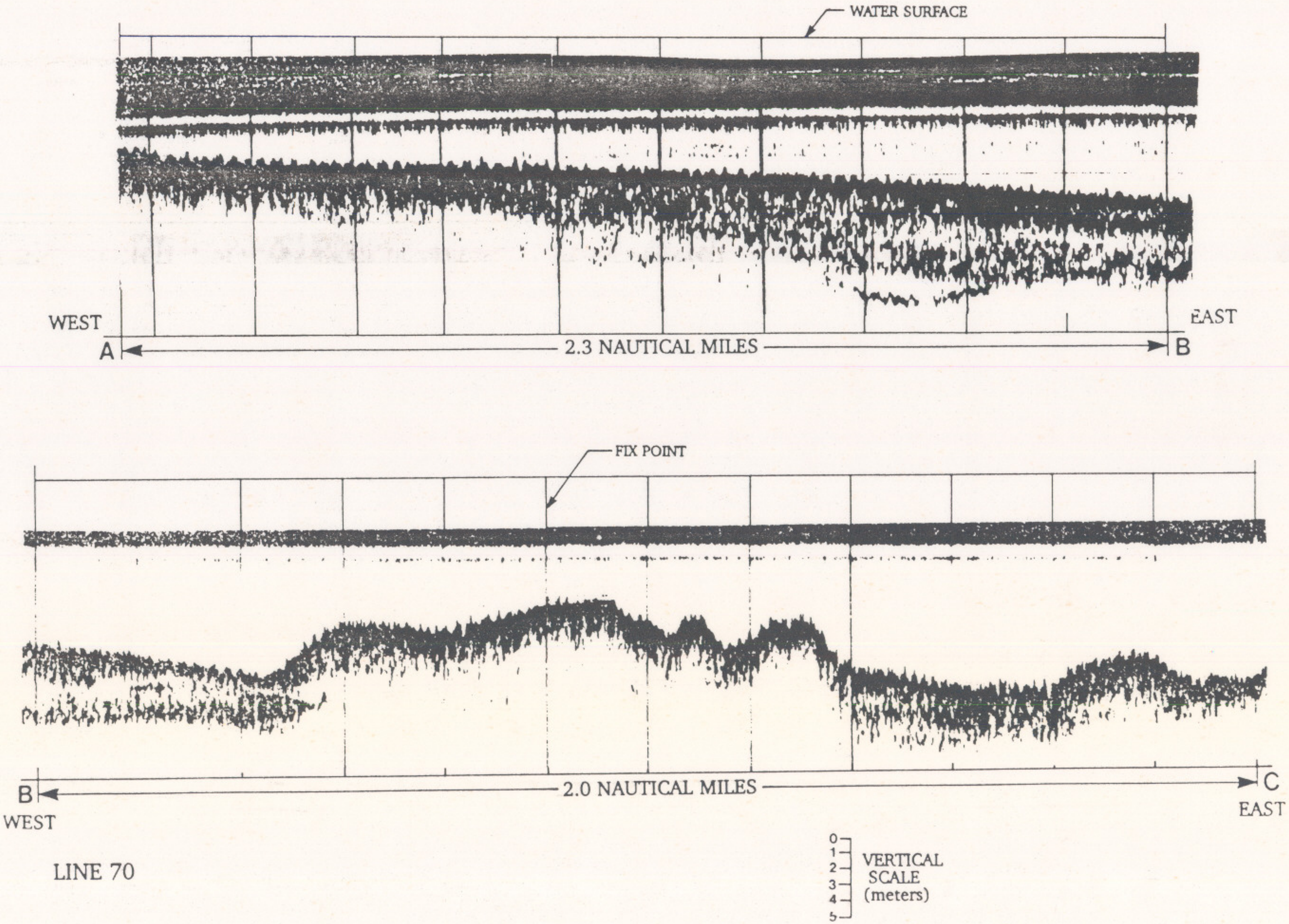

WATER SURFACE
WEST
EAST
A
B
1.7 NAUTICAL MILES
FIX POINT
WEST
B
C
2.5 NAUTICAL MILES
EAST
LINE 69
0
1
2
3
4
5
VERTICAL
SCALE
(meters)


WATER SURFACE
WEST
EAST
A
2.3 NAUTICAL MILES
B


FIX POINT
B
2.0 NAUTICAL MILES
C
WEST
EAST

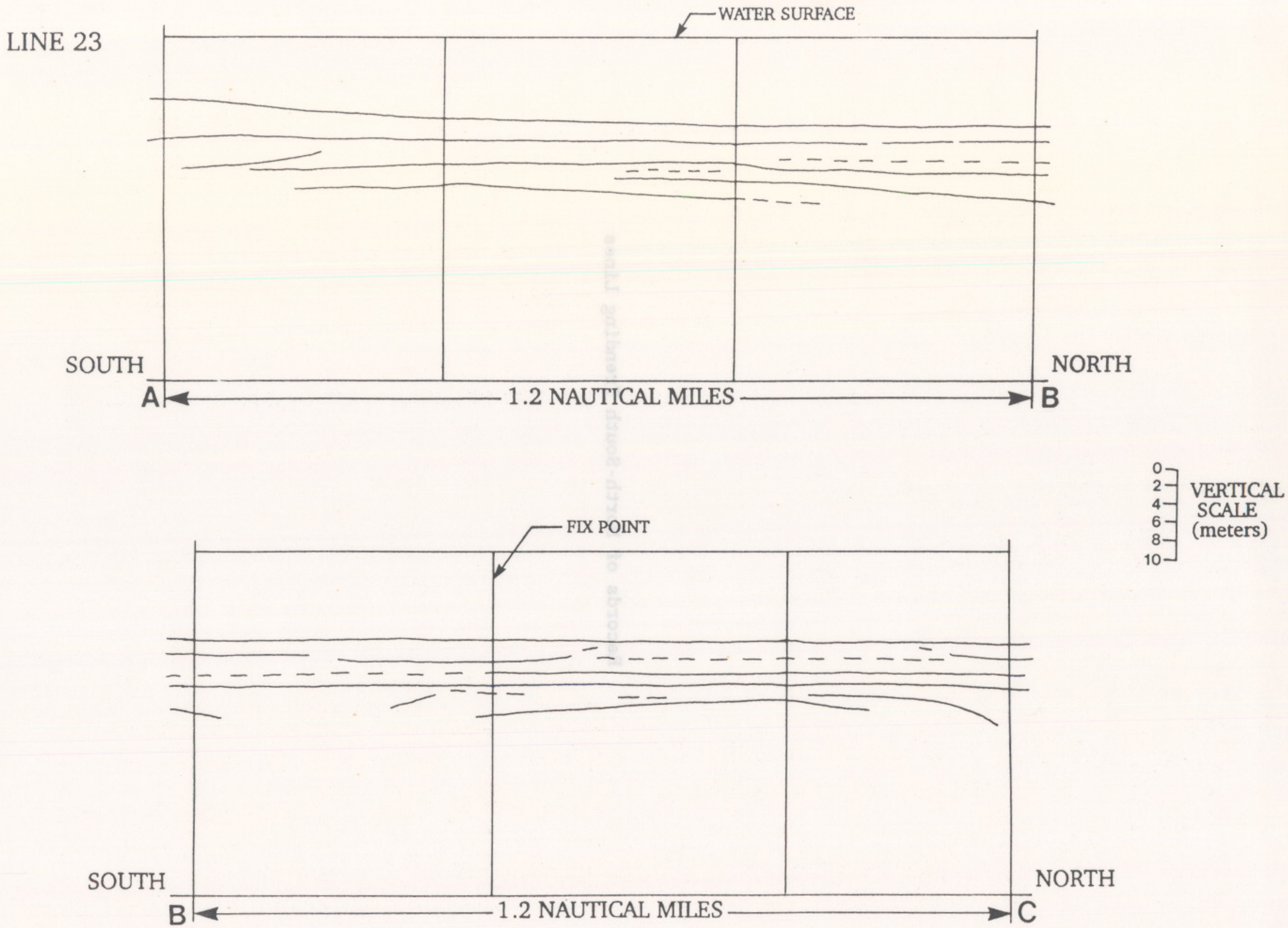
LINE 70


0
1
2
3
4
5
VERTICAL
SCALE
(meters)

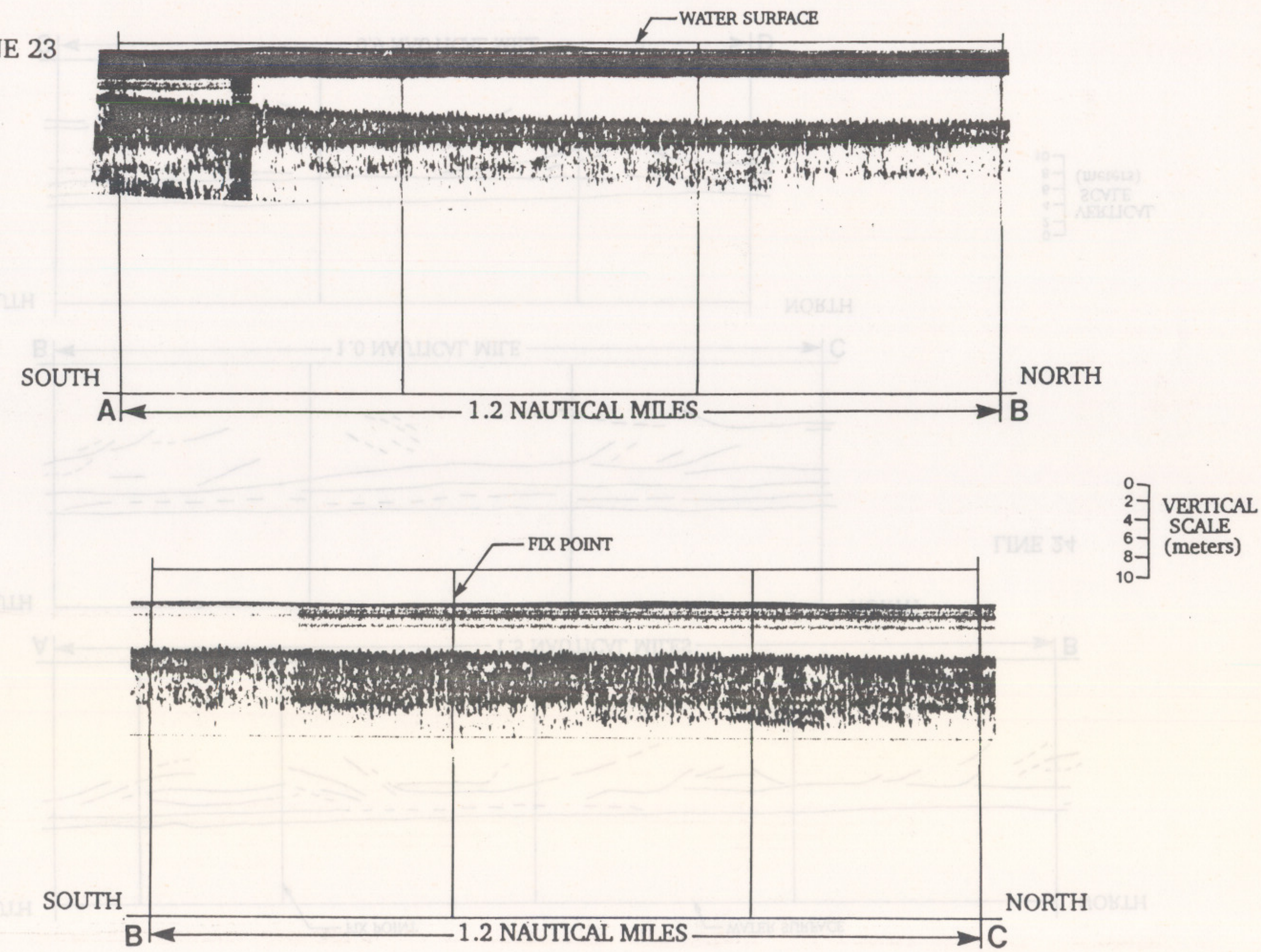

WATER SURFACE
WEST
EAST
A
2.3 NAUTICAL MILES
B
FIX POINT
B
2.0 NAUTICAL MILES
C
WEST
EAST
0
1
2
3
4
5
VERTICAL
SCALE
(meters)

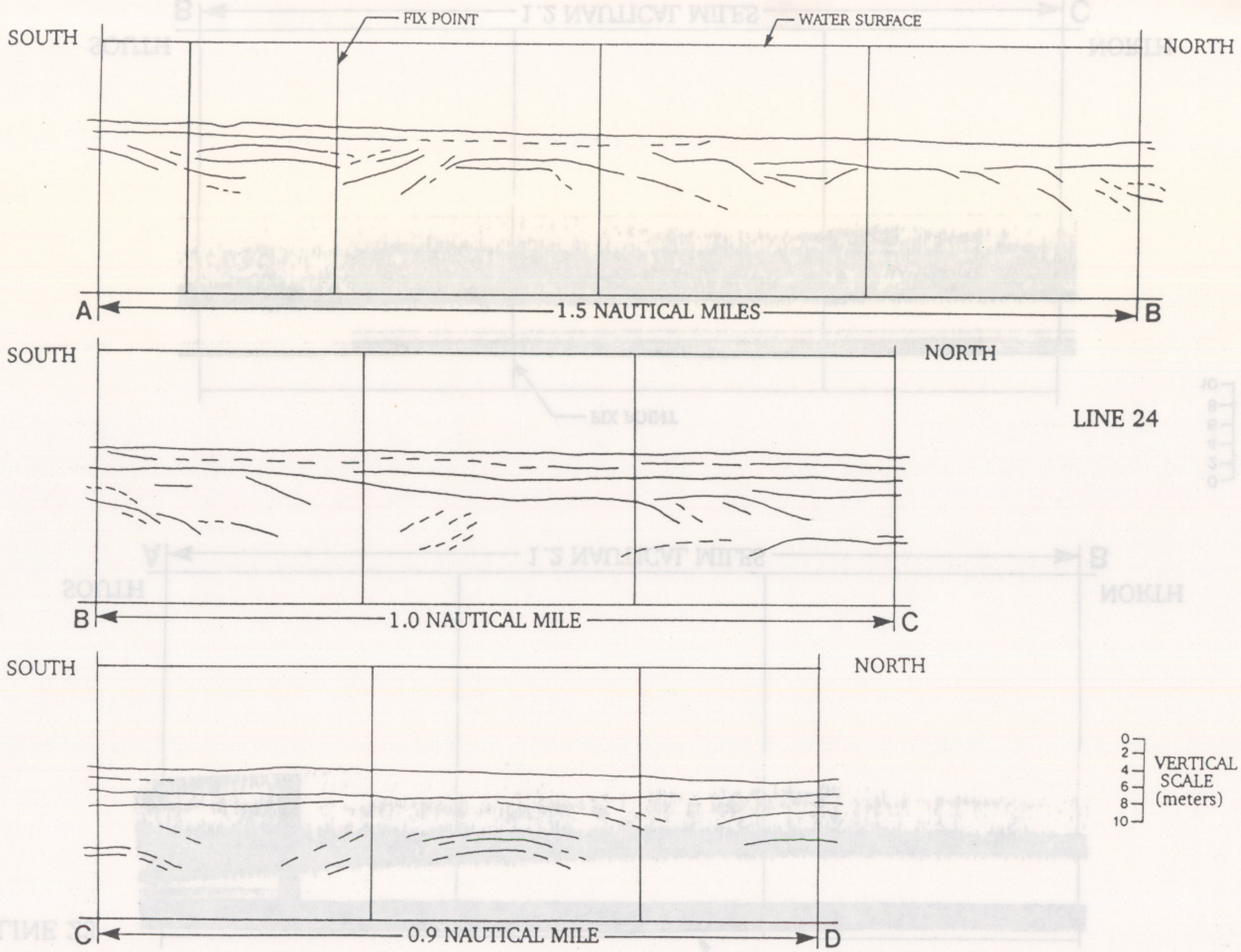
LINE 70

Records of North-South Trending Lines

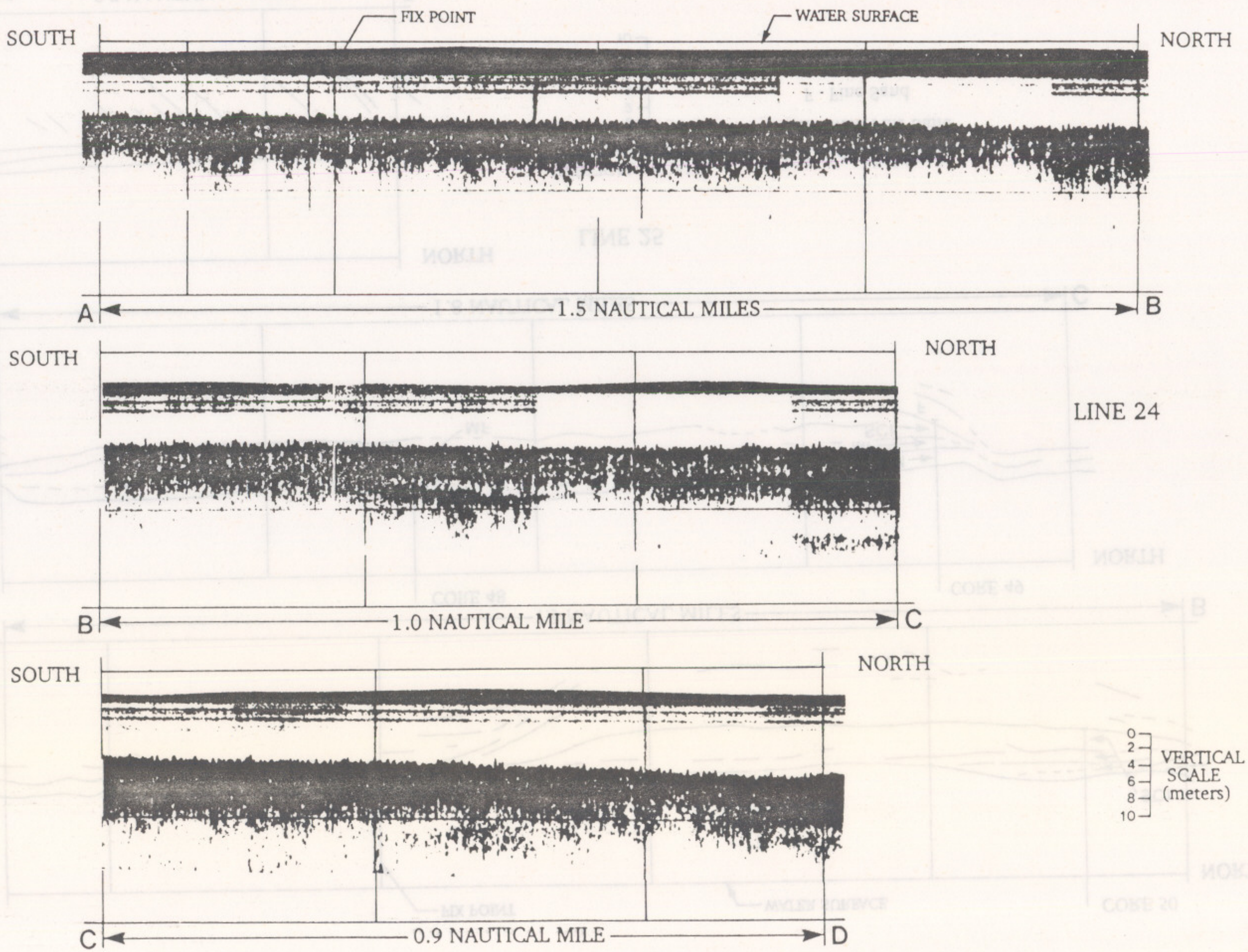

LINE 23
WATER SURFACE
SOUTH
NORTH
A
1.2 NAUTICAL MILES
B
0
2
4
6
8
10
VERTICAL
SCALE
(meters)
FIX POINT
SOUTH
NORTH
B
1.2 NAUTICAL MILES
C

LINE 23

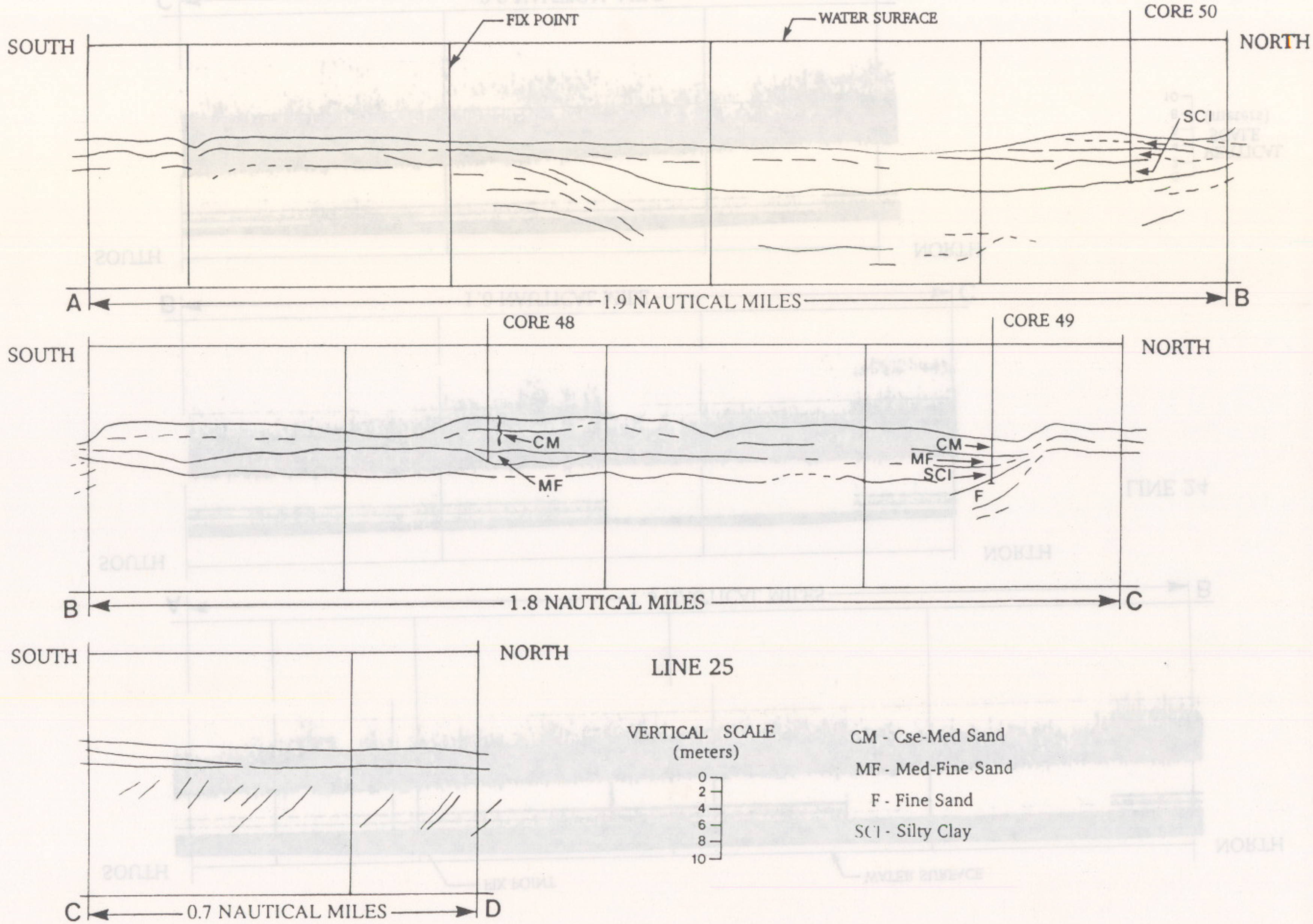

WATER SURFACE
SOUTH
NORTH
A
1.2 NAUTICAL MILES
B
FIX POINT
SOUTH
NORTH
B
1.2 NAUTICAL MILES
C
0
2
4
6
8
10
VERTICAL
SCALE
(meters)


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

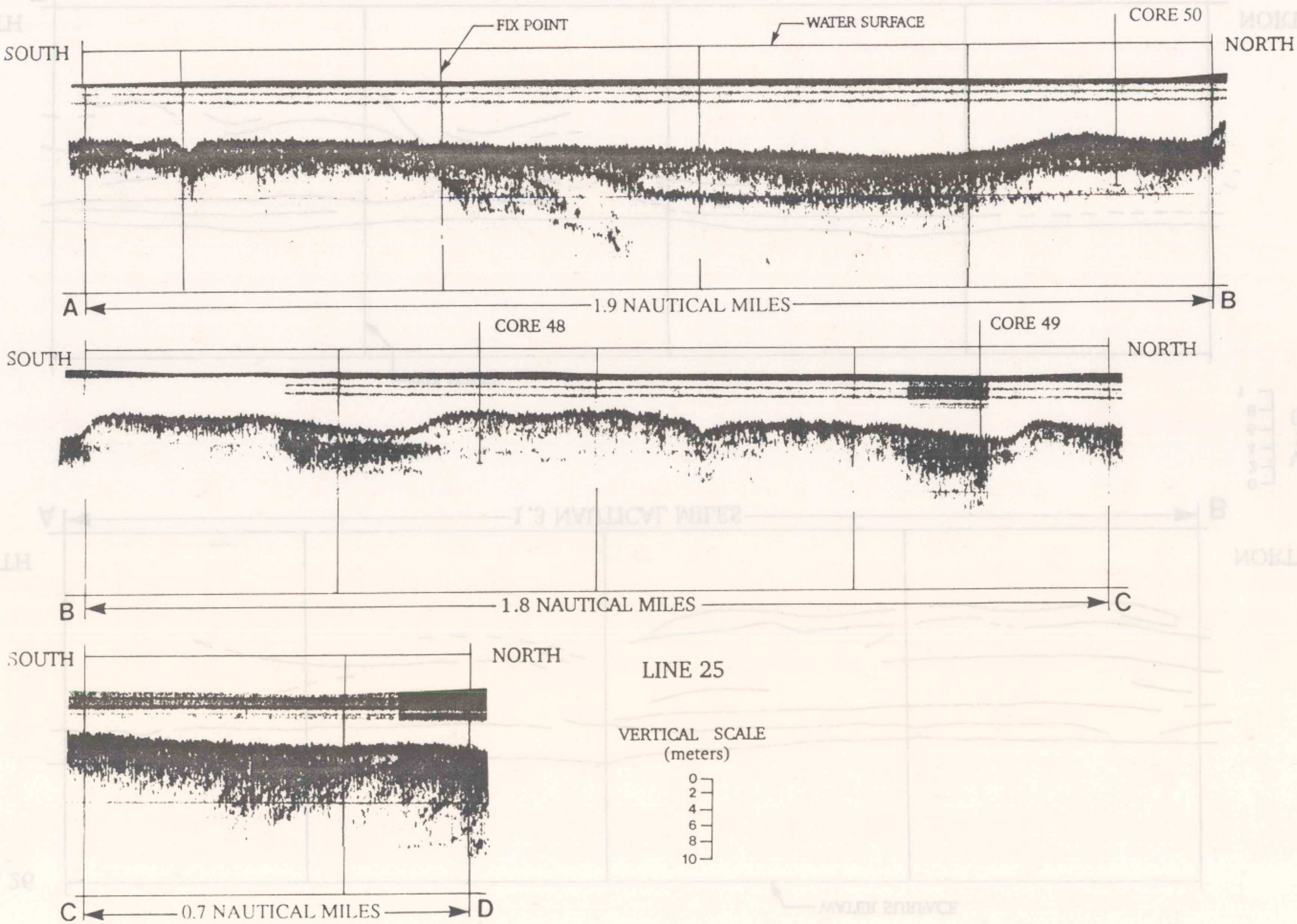
LINE 24



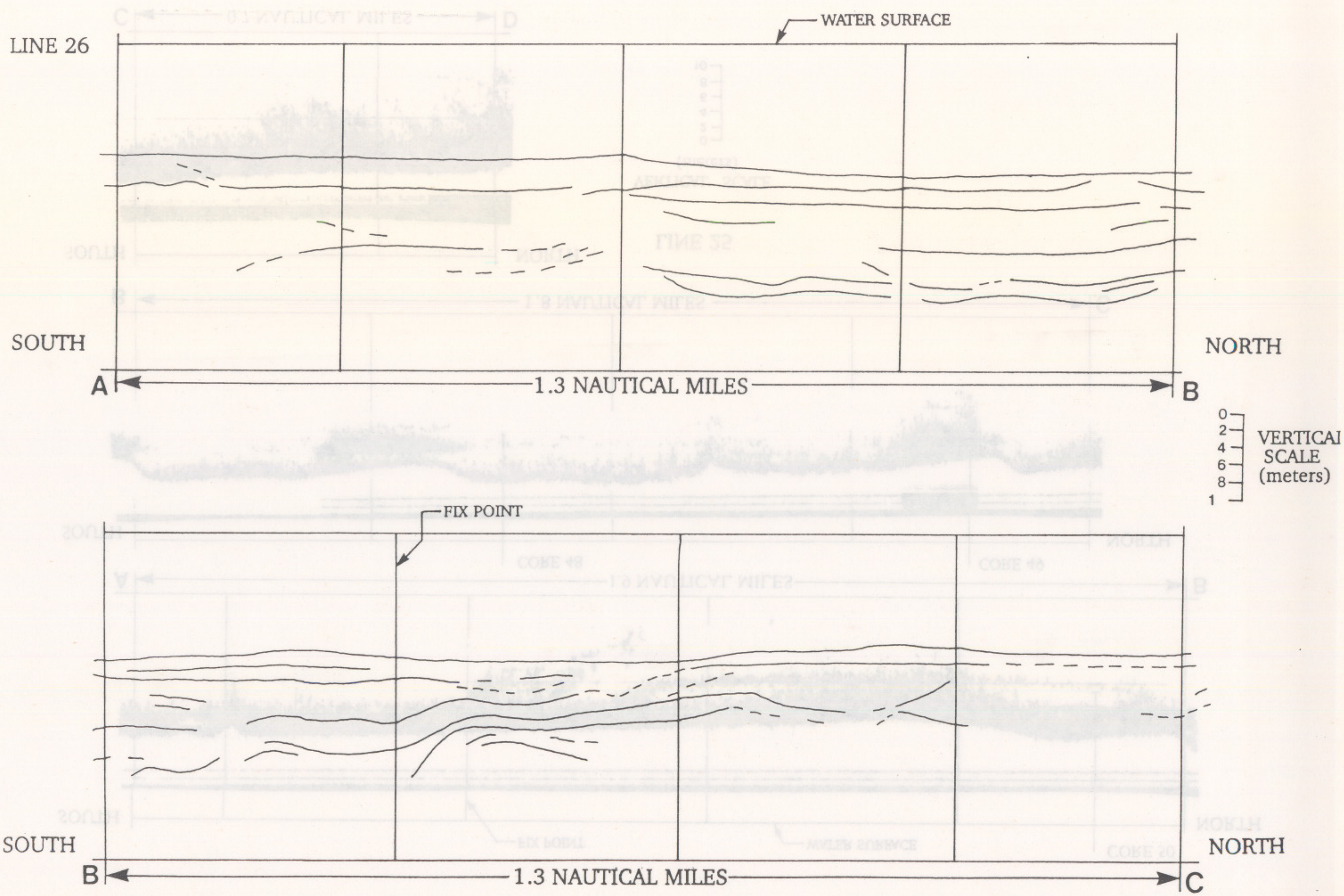
FIX POINT
WATER SURFACE
SOUTH
NORTH
A
1.5 NAUTICAL MILES
B
SOUTH
NORTH
LINE 24
B
1.0 NAUTICAL MILE
C
SOUTH
NORTH
C
0.9 NAUTICAL MILE
D
0
2
4
6
8
10
VERTICAL
SCALE
(meters)

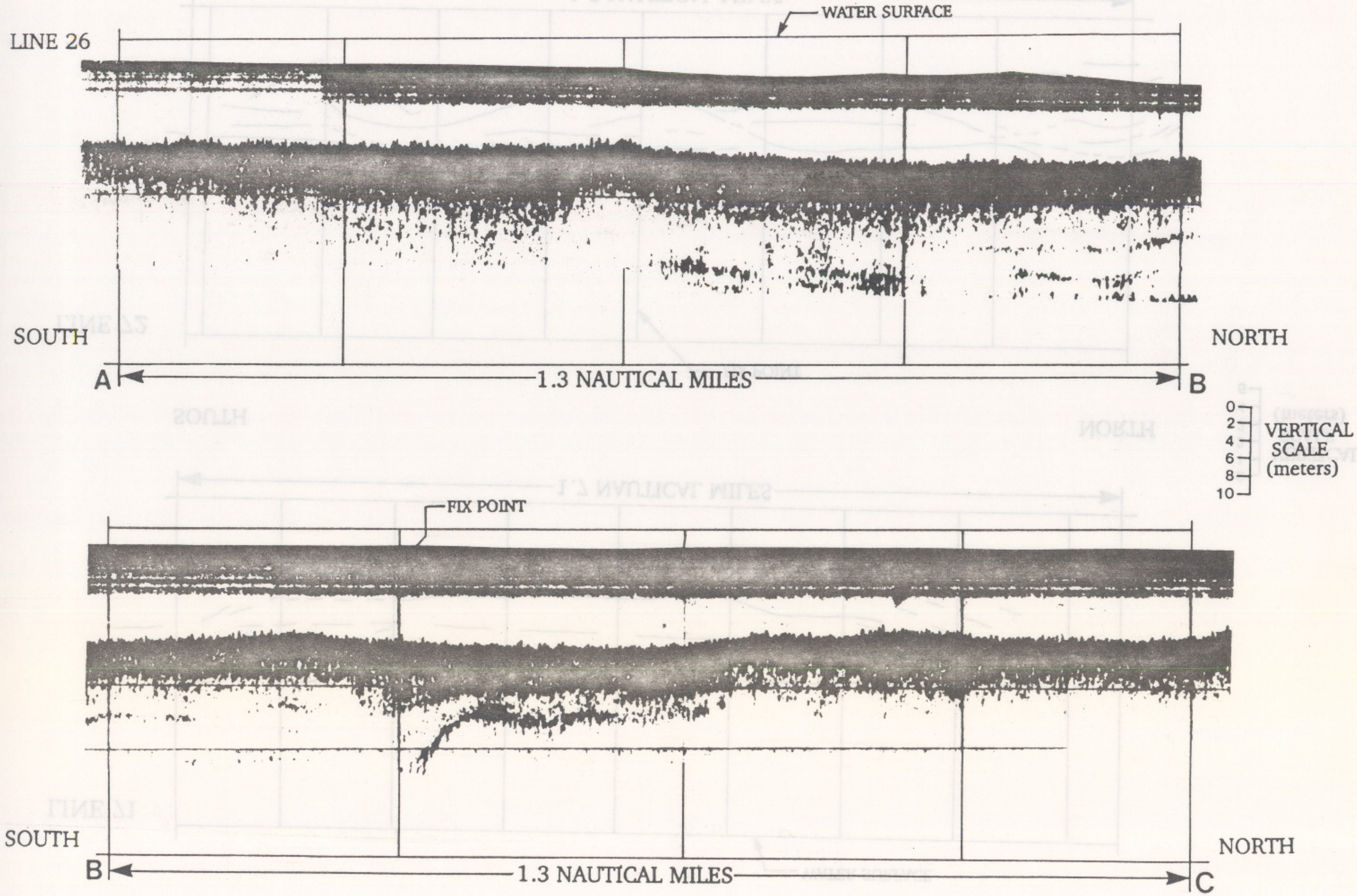


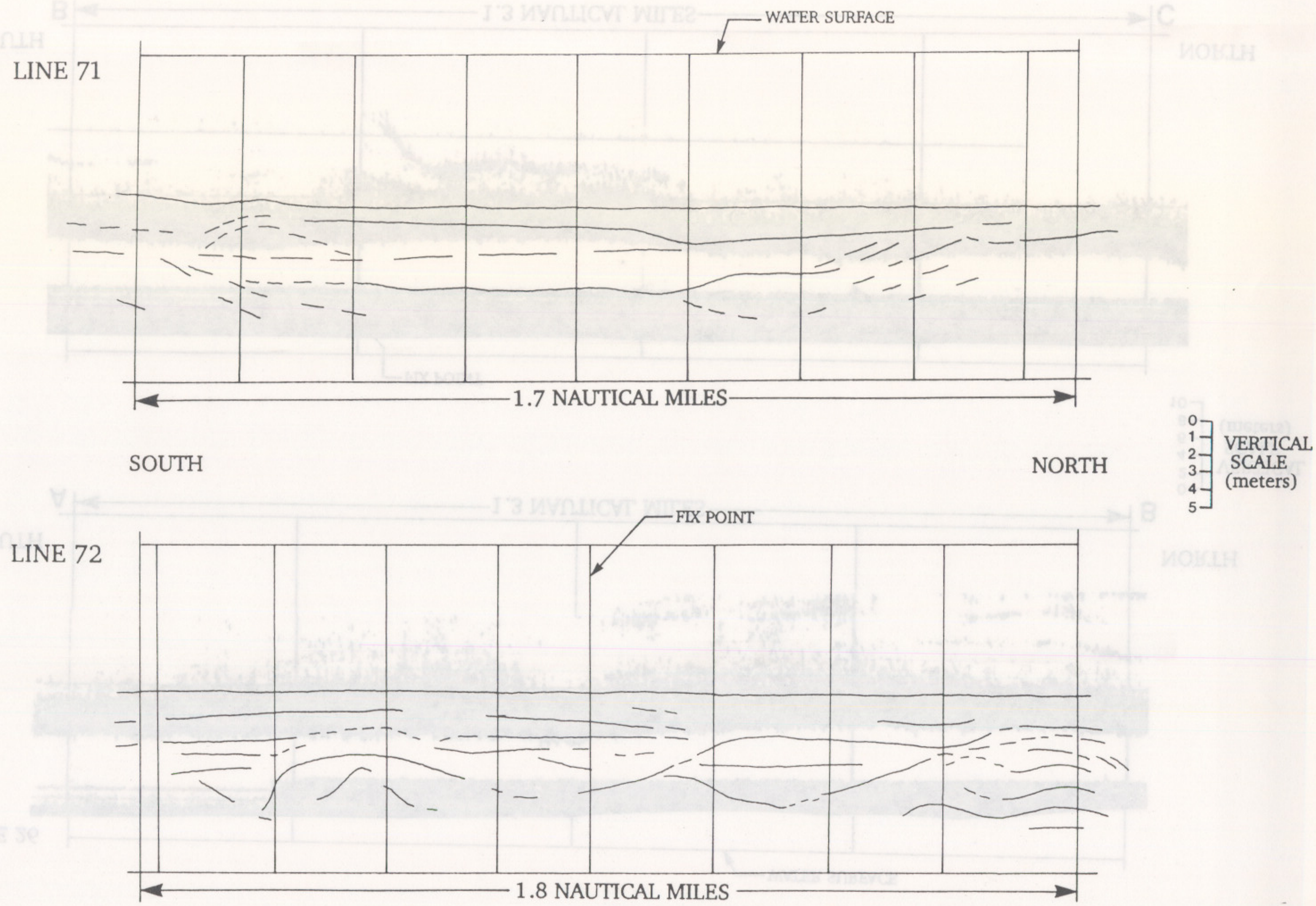
SOUTH
FIX POINT
WATER SURFACE
CORE 50
NORTH
SCI
A
1.9 NAUTICAL MILES
B
SOUTH
CORE 48
CORE 49
NORTH
CM
MF
CM
MF
SCI
F
B
1.8 NAUTICAL MILES
C
SOUTH
NORTH
C
0.7 NAUTICAL MILES
D
LINE 25
VERTICAL SCALE
(meters)
0
2
4
6
8
10
CM - Cse-Med Sand
MF - Med-Fine Sand
F - Fine Sand
SCI - Silty Clay

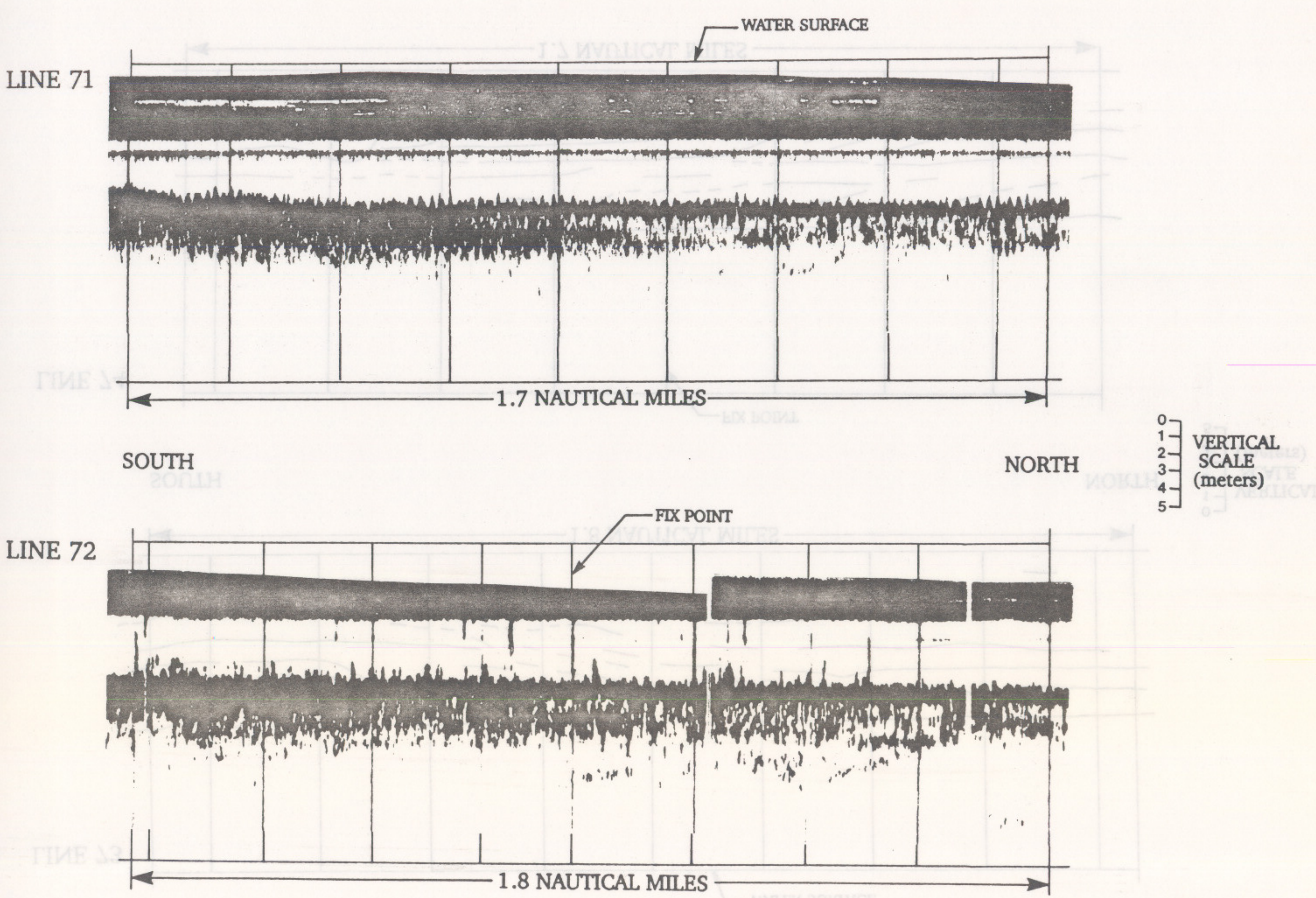


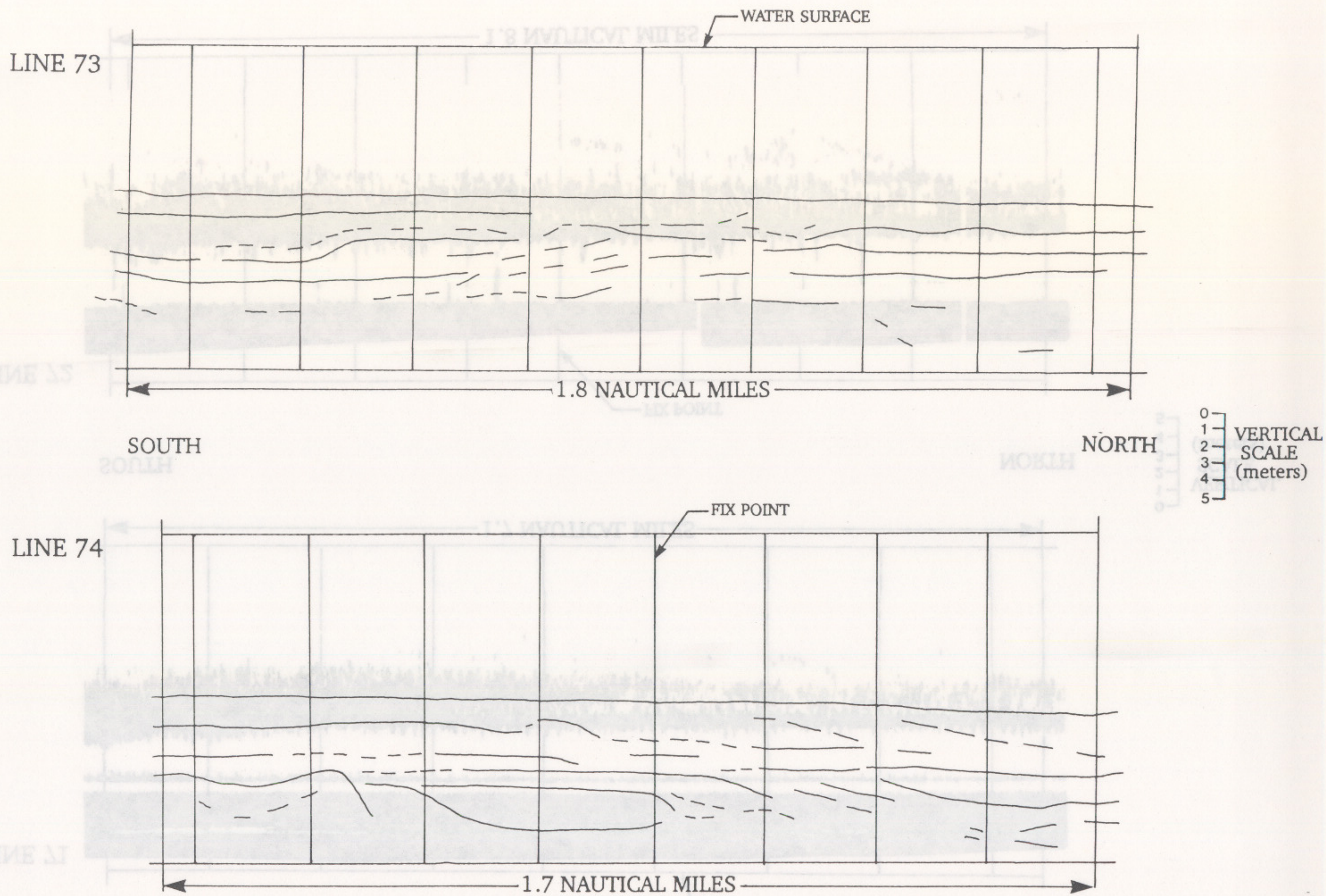
FIX POINT
WATER SURFACE
CORE 50
SOUTH
NORTH
A
1.9 NAUTICAL MILES
B
CORE 48
CORE 49
SOUTH
NORTH
B
1.8 NAUTICAL MILES
C
SOUTH
NORTH
C
0.7 NAUTICAL MILES
D
LINE 25
VERTICAL SCALE
(meters)
0
2
4
6
8
10

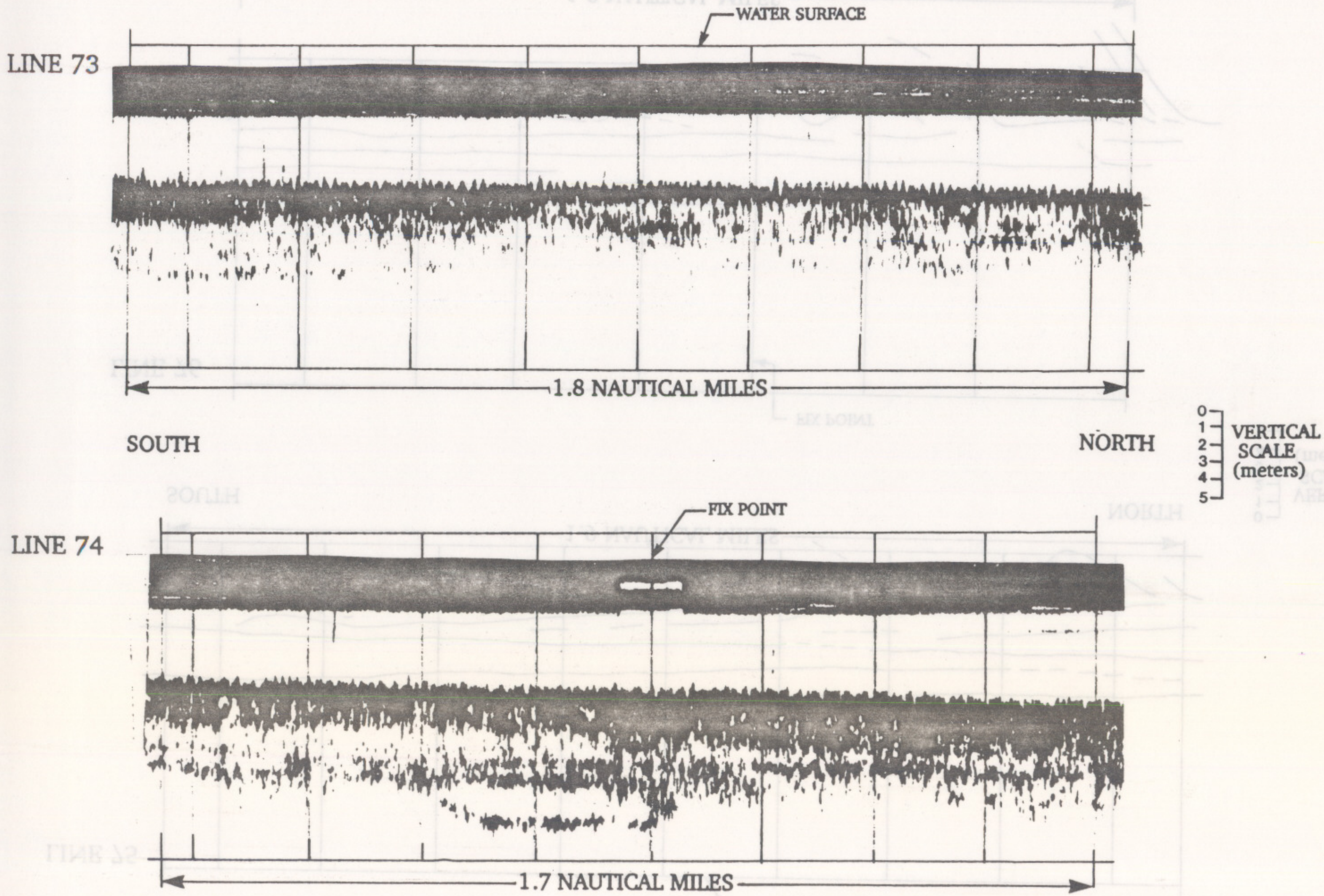

LINE 26
WATER SURFACE
SOUTH
NORTH
A
B
1.3 NAUTICAL MILES
0
2
4
6
8
1
VERTICAI
SCALE
(meters)
FIX POINT
SOUTH
NORTH
B
C
1.3 NAUTICAL MILES


LINE 26
WATER SURFACE
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
LINE 71
1.7 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL
SCALE
(meters)
FIX POINT
LINE 72
1.8 NAUTICAL MILES

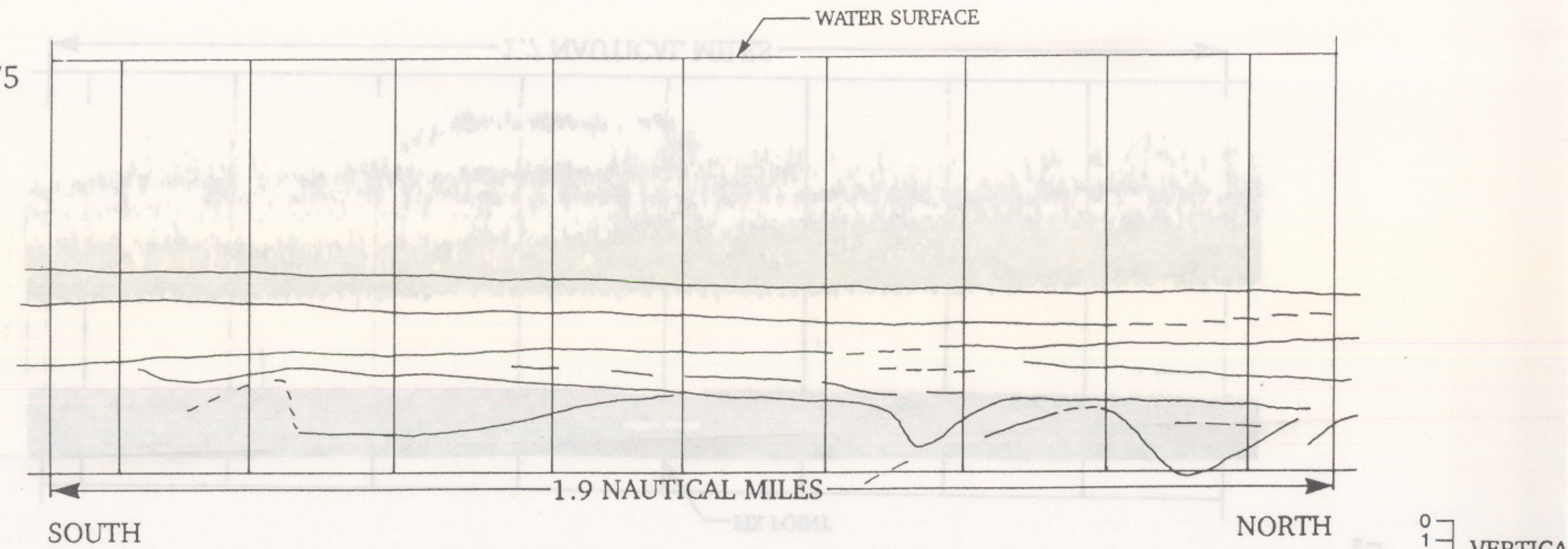

WATER SURFACE
LINE 71
1.7 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL
SCALE
(meters)
FIX POINT
LINE 72
1.8 NAUTICAL MILES


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

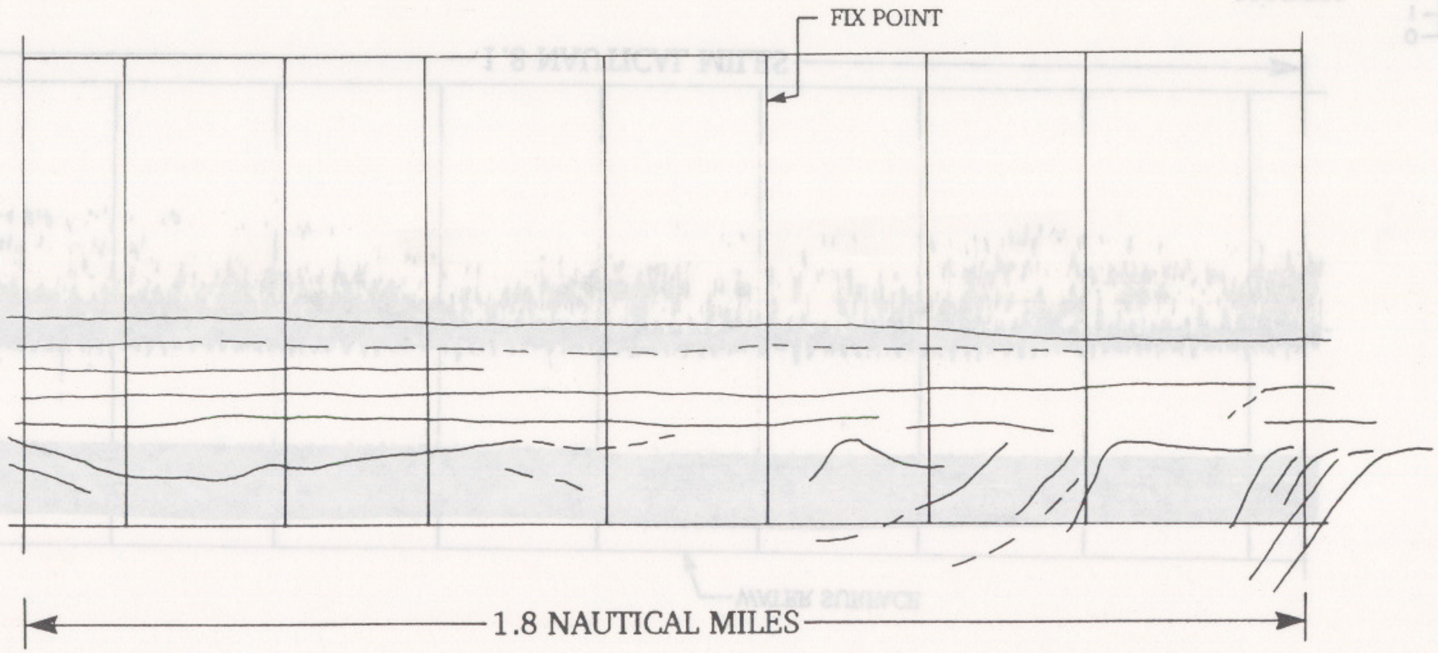


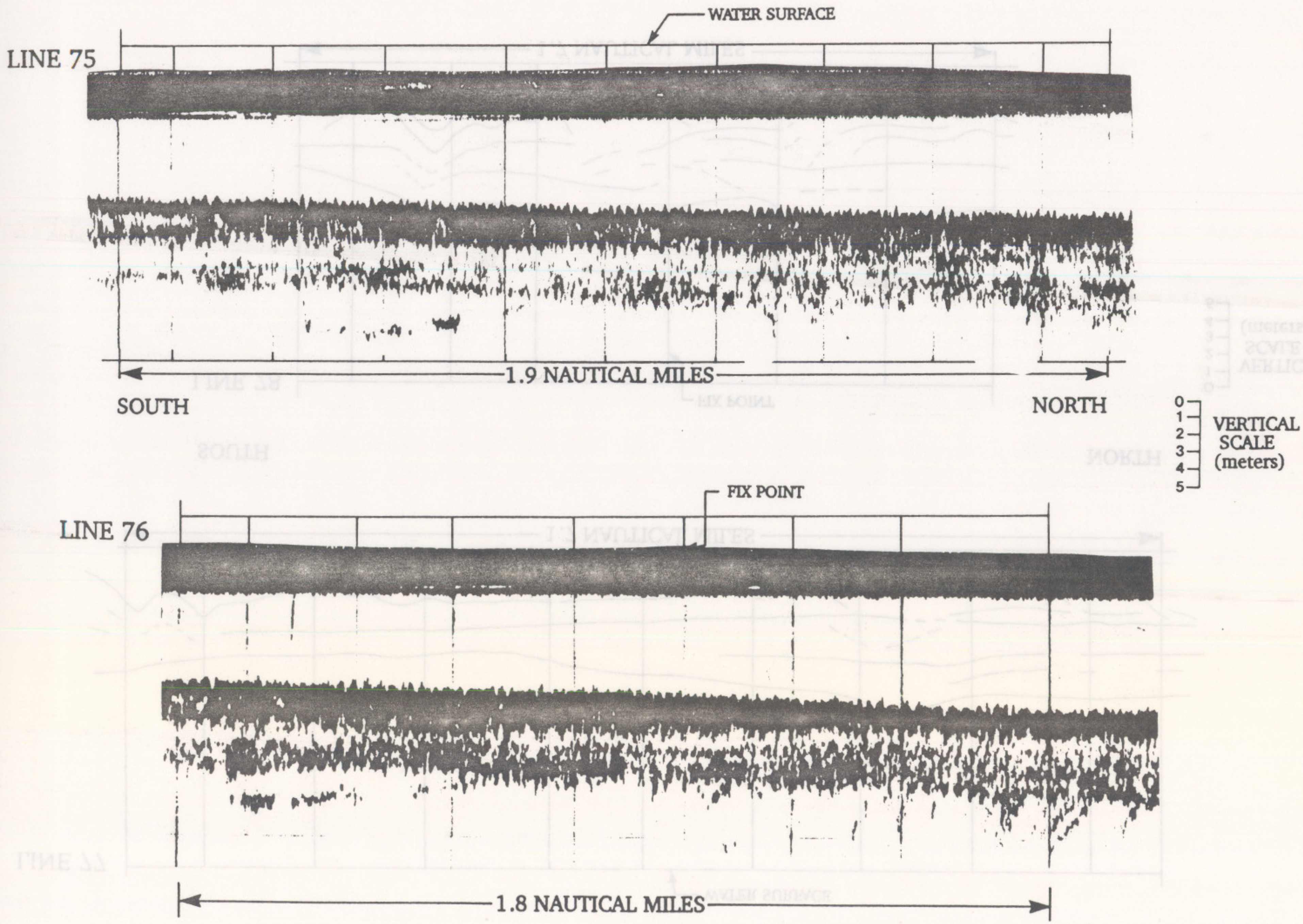
WATER SURFACE
LINE 73
1.8 NAUTICAL MILES
SOUTH
NORTH
0
1
2
3
4
5
VERTICAL SCALE (meters)
FIX POINT
LINE 74
1.7 NAUTICAL MILES

LINE 75

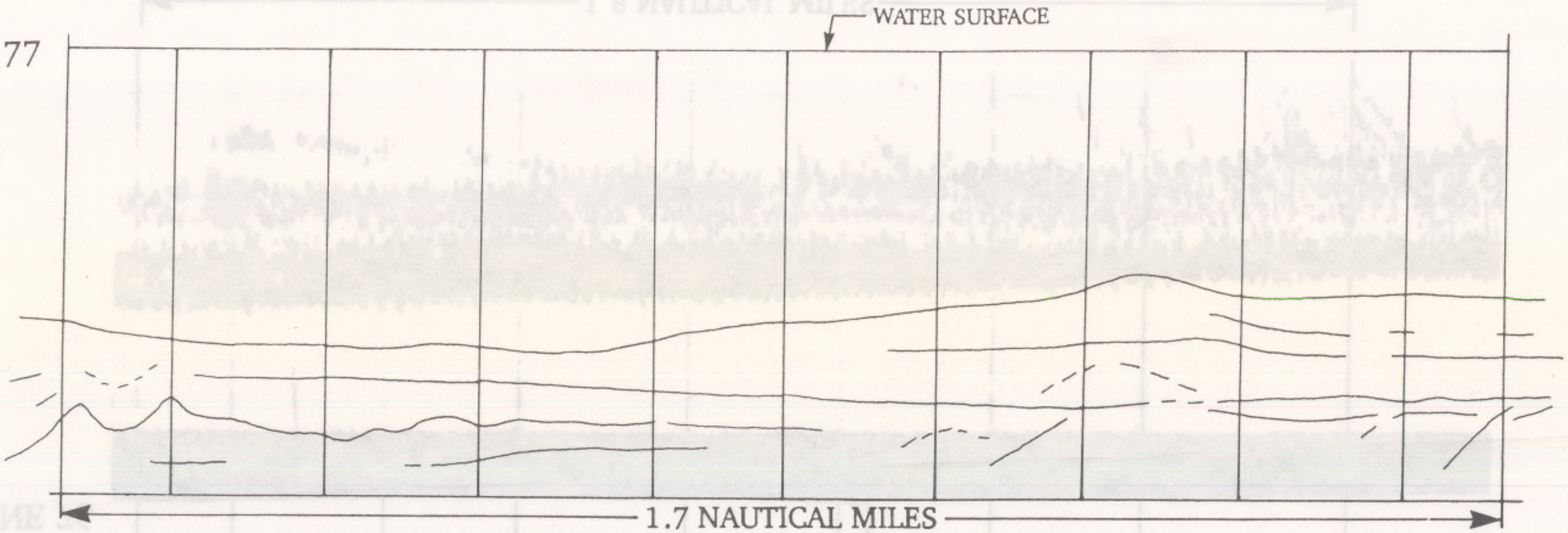


LINE 76




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

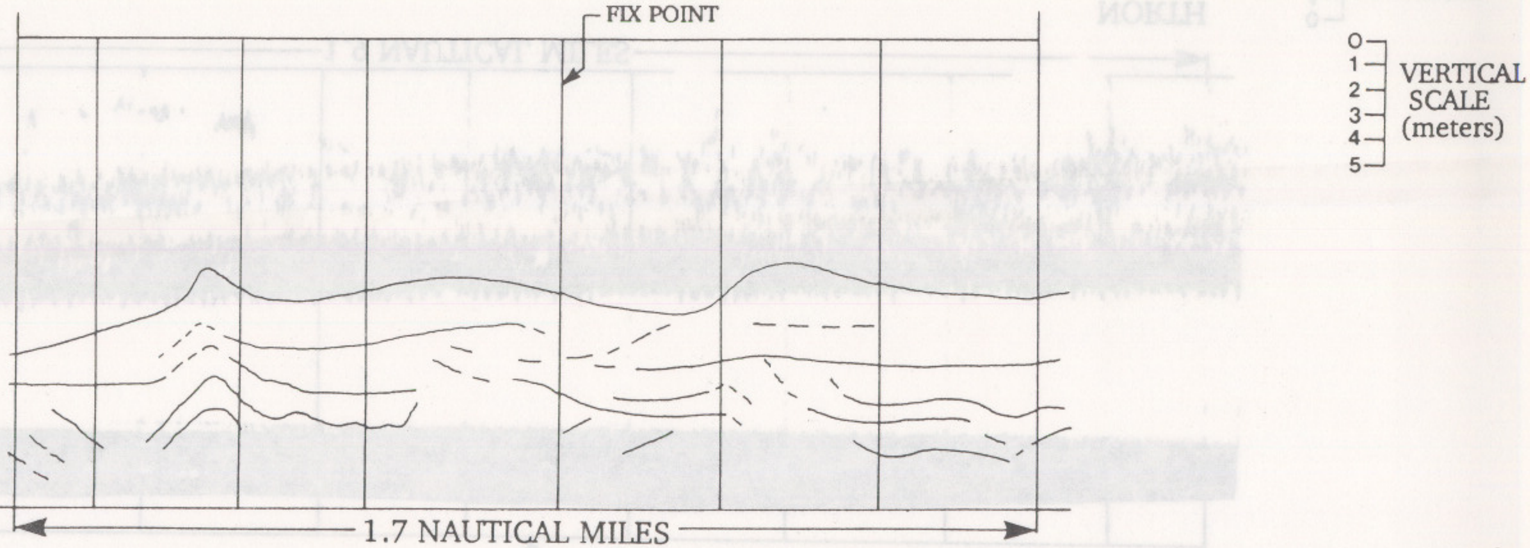
LINE 77

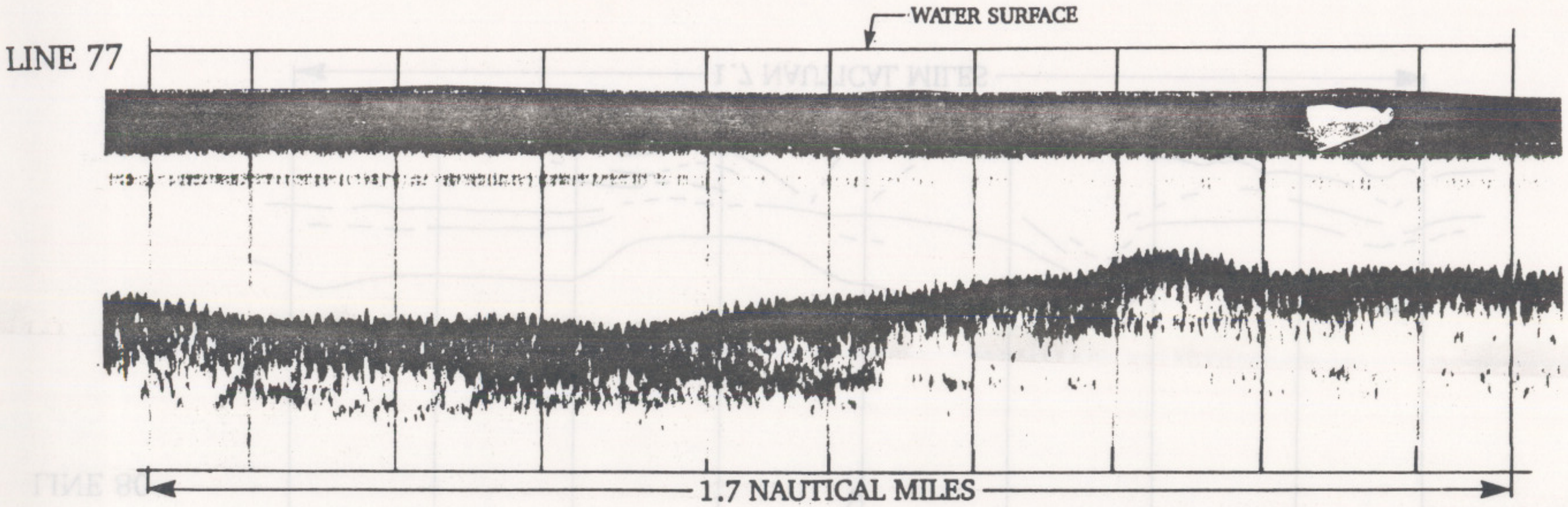


SOUTH

NORTH

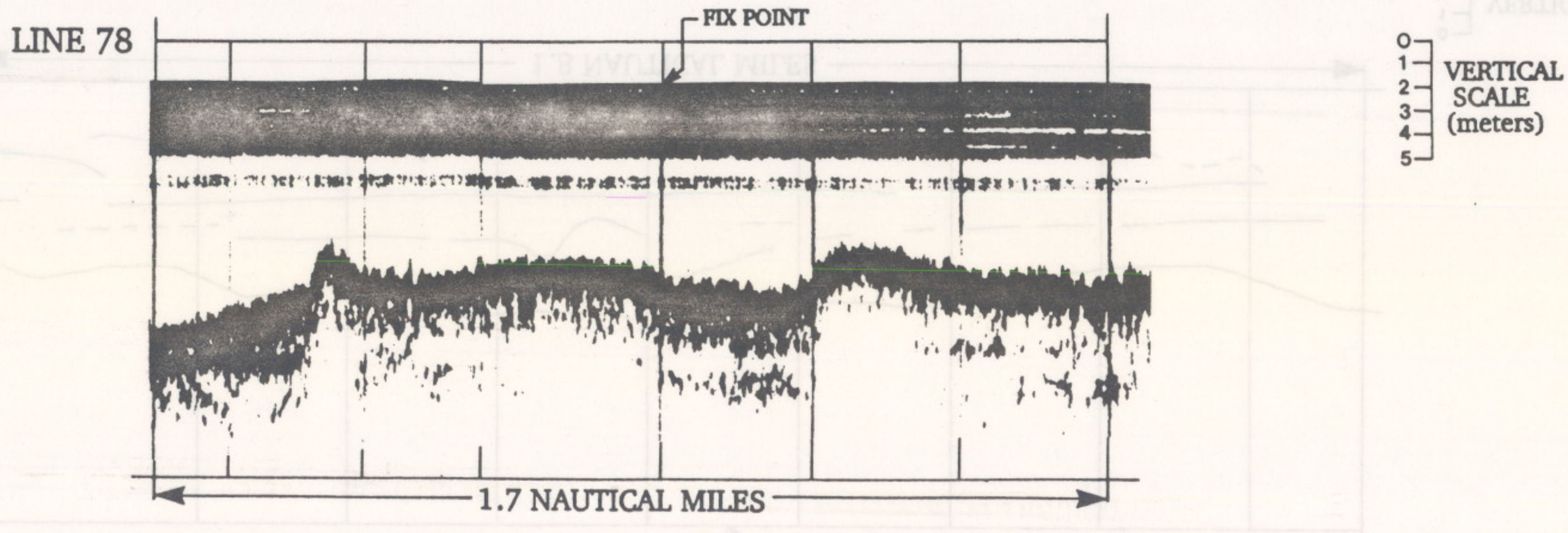
LINE 78





LINE 77
WATER SURFACE
1.7 NAUTICAL MILES

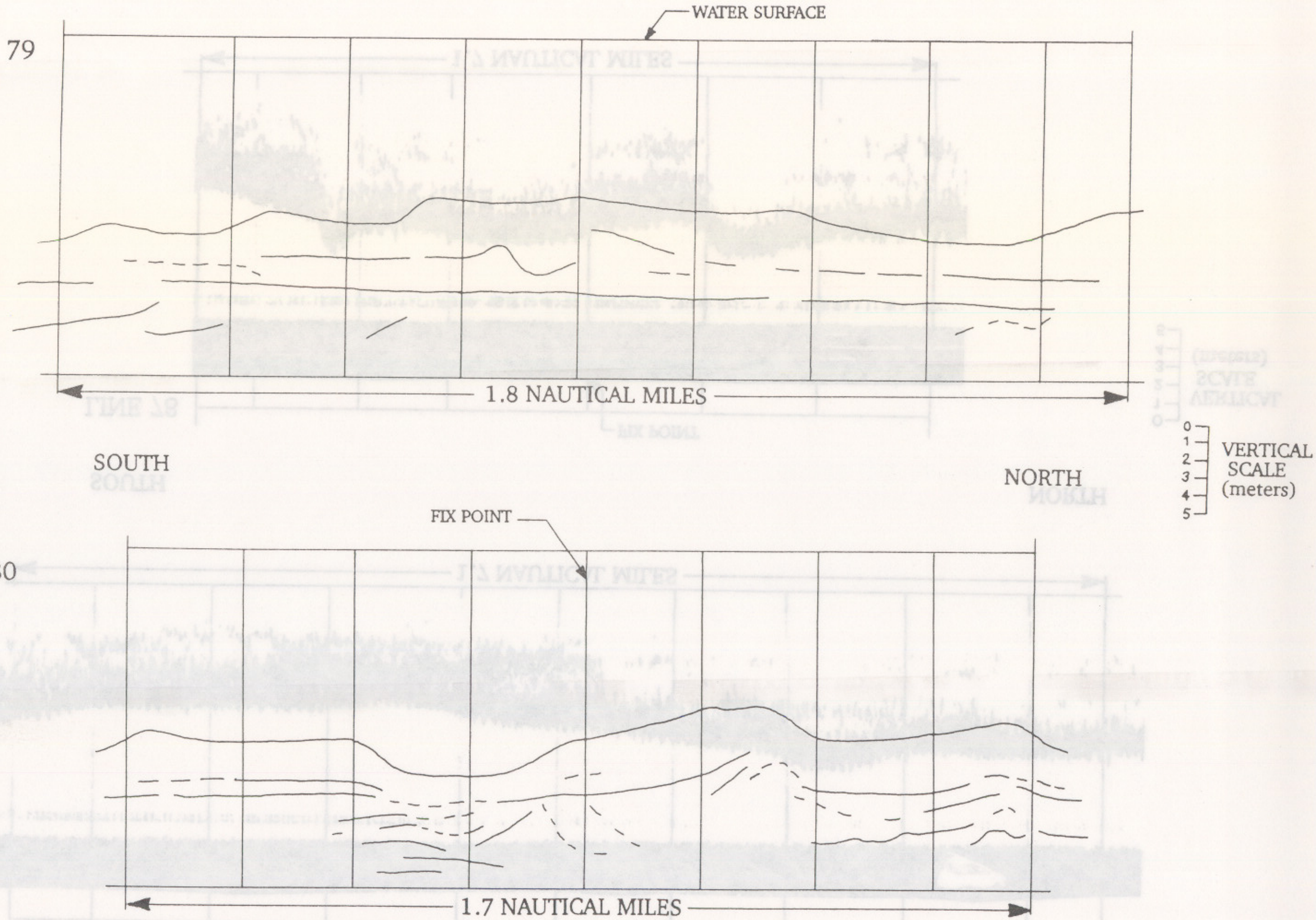
SOUTH NORTH

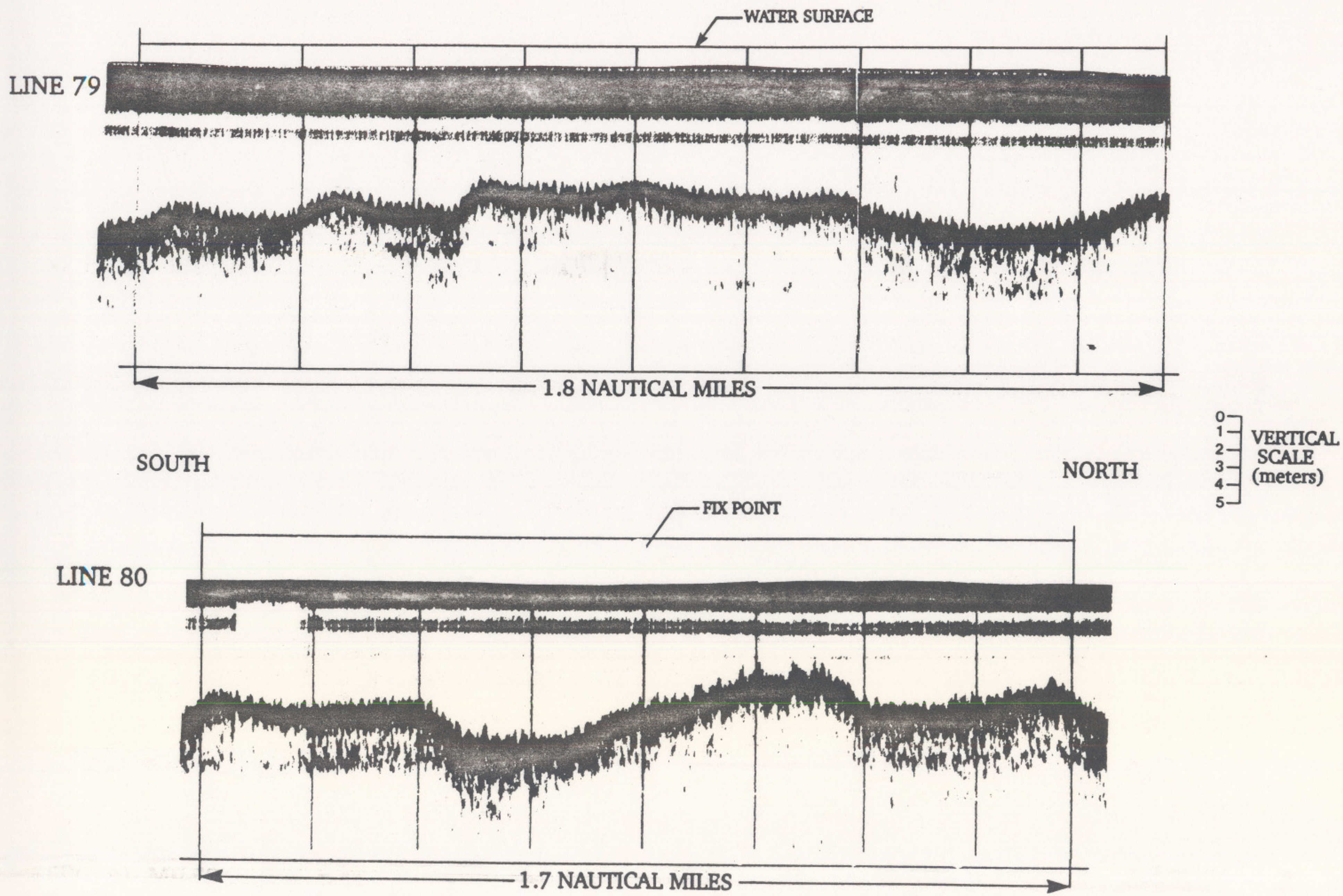


LINE 78
FIX POINT
1.7 NAUTICAL MILES
0
1
2
3
4
5
VERTICAL SCALE (meters)

LINE 79

LINE 80





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