NORTH CAROLINA OUTER BANKS BEACH NOURISHMENT SAND RESOURCE STUDY, FIRST INTERIM REPORT: SHALLOW, HIGH-RESOLUTION SEISMIC SURVEY, OFFSHORE NAGS HEAD AREA

by

Stephen W. Snyder

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Charles H. Gardner, State Geologist

1993

State of North Carolina

James B. Hunt, Jr., Governor

Department of Environment, Health and Natural Resources
Jonathan B. Howes, Secretary

North Carolina Outer Banks Beach Nourishment Sand Resource Study, First Interim Report: Shallow, High-Resolution Seismic Survey, Offshore Nags Head Area

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Stephen W. Snyder[1]

Department of Marine, Earth and Atmospheric Sciences

North Carolina State University

SUMMARY

This report presents the initial results of a reconnaissance survey focused on identification of potentially suitable sand resources for beach nourishment along the North Carolina Outer Banks. Approximately 300 kilometers of high-resolution seismic-reflection profile data were collected along 15 separate tracklines offshore of Nags Head, North Carolina. These data have been interpreted, scale-rectified, and reduced to seismic stratigraphic sections. The seismic sections present a window to the shallow, subbottom geology. They depict several large shoals overlying a stacked series of tabular stratigraphic units. Each stratigraphic unit is 6 to 20 meters thick and all are bound by unconformity surfaces cut by multiple, relict (buried) stream valleys. The shoal features exhibit 3 to 15 meters of topographic relief, are common at water depths greater than 20 meters, and appear to be erosional in origin.

An unusually thick bottom signal has masked the very shallow subbottom section (<5m), particularly in the shoal areas. This signal is either inherent to the surface geology (seafloor character), or a by-product of boat-noise from the vessel employed to collect the seismic data. Future surveys will utilize different research vessels and thereby provide a test regarding boat-noise artifacts.

Additional data are required to: (1) develop a detailed three-dimensional geological framework, (2) integrate the existing data set with onshore or barrier island stratigraphies and thereby develop an internally consistent geographically-referenced data base, (3) map the infilled channel thalwegs which crop out on the sea-floor, and (4) identify specific vibracore targets within the survey area.

[1] Department of Marine, Earth and Atmospheric Sciences
North Carolina State University
Box 8208, Raleigh, NC 27695-8208

INTRODUCTION

The Outer Banks of North Carolina present a major tourist attraction which, in turn, has provided accelerating annual tax revenues — as well as significant population growth — over the past 2 decades (Table 1). The lure for this flourishing economic development is a magnificent stretch of barrier island beachfront. Yet, the health of this very same beachfront property has been given a very poor prognosis. It is threatened by the natural hazards of slow and persistent sea-level rise which continues to force coastal erosion and shoreline retreat. More specifically, nor'easter storm damage over the past 5 years has become more frequent, and coastal destruction resulting from these *non-hurricane* storm events has become more severe (e.g., the HalloWind Storm of 1991). Coastal destruction from storm-surge flooding and beachfront erosion will likely increase in frequency and magnitude as sea-level continues to rise. The socioeconomic consequences of each storm-surge event, coupled with the forecast of higher-frequency in storm events, have collectively raised the status of shoreline preservation (and maintenance of emergency-evacuation routes) to higher levels of concern for the State of North Carolina, as well as the local governments and agencies of the Outer Banks' communities.

	Dare	Currituck	Total		Dare	Currituck	Total
Population (+161)				**Seasonal Housing Units (+291%)**			
1970	6,995	6,976	13,971	1970	1,783	136	1,919
1980	13,377	11,089	24,466	1980	4,643	706	5,349
1990	22,746	13,736	36,482	1990	6,416	1,096	7,512
Hotels/Lodging Earnings (000's) (+675%)				**Ad Valorum Tax Revenues (+280%)**			
1970	N/A	N/A	N/A	1970	$1,706	$133	$1,839
1980	$2,641,369	$1,822,753	$4,464,122	1980	$5,891	$125	$6,016
1990	$10,456,215	$6,503,846	$16,960,061	1990	$13,115	$1,143	$14,258

* Percent change is from earliest listed to most recent data

Table 1. Economic indicators for northern North Carolina Outer Banks (from LINC database, 1991).

A variety of erosion abatement practices have been attempted with minimal success along various segments of the coastline over the past 25 years (NRCD, 1984). After much debate, in 1984 the NC Outer Banks Beach Erosion Task Force produced recommendations regarding beach stabilization and erosion abatement practices. These recommendations were later incorporated into the North Carolina Administrative Code by the Coastal Resources Commission (Figure 1). The effect of these regulations is to establish beach nourishment as the preferred shoreline stabilization alternative. Still, the source(s) of beach-renourishment sand has not been identified for most of North Carolina's coastline, nor has any resource assessment program been established. The only previous sand-resource surveys have been completed under the Inner Continental Shelf Sediment and Structure (ICON) program administered through the U. S. Army Corps of Engineers Coastal Engineering Research Center. All ICON survey areas in North Carolina lie entirely south of Cape Lookout, and concentrate on shelf areas south of Topsail Island (Meisburger, 1979). North of Cape Lookout, the nearest area investigated during the ICON study is off the mouth of the Chesapeake Bay.

In order to facilitate rational cost/benefit evaluations for future beach-replenishment proposals along the Outer Banks, especially for those sectors forecasted as requiring remedial beach-erosion action within the next decade (Stone and others, 1991), detailed information delineating the location, texture, and volume of sand resources are required. This report represents the first step toward filling that information gap on offshore sand resources. Subbottom stratigraphic data from an area offshore of Nags Head are presented. These data are not dense enough to complete a detailed assessment of sand resources off Nags Head. Instead they provide an important data set which will initiate the process of constructing an internally consistent, three-dimensional geological framework. This framework will then serve as a blueprint for targeting core sites. Once the subbottom stratigraphy is coupled with core information, the identification and quantification of sand resources can be established.

DATA BASE

Approximately 300 km of high-resolution seismic-reflection data were collected along fifteen separate tracklines (Figure 2). The survey area lies between Oregon Inlet and Jockeys Ridge, and ex-

The 93 miles of shoreline from Cape Hatteras to the Virginia line average 4.7 feet of erosion per year (NRCD, 1984). Annual rates for selected segments of recently developed coastline commonly exceed 10 feet per year (McCullough, 1988). In July 1984, the Coastal Resources Commission's Outer Banks Erosion Task Force reported the results of a 6-month study which focused on erosion problems of Dare and Currituck Counties. They concluded with a series of policy recommendations for statewide applicability, many of which were accepted by the Coastal Resources Commission and incorporated into the North Carolina Administrative Code (*NCAC Ch15A, SC 7H, Sec. .0003*) under its rule making authority. The Task Force recommendations most pertinent to this proposal which were made part of the N.C. Administrative Code or adopted as official Commission policy are:

- Efforts to permanently stabilize the location of the shoreline by massive seawalls and similar protection devices which do not preserve public trust rights should not be allowed.
- Beach nourishment is the preferred response to erosion. Sand used for nourishment should be compatible with existing grain size and type and should be obtained from sources that minimize environmental damage.
- A systematic detailed survey of sources of suitable sand for beach nourishment should be done.
- All artificially accreted oceanfront lands, however financed, should be publicly owned.

Figure 1. A summary of North Carolina beach stabilization policy.

tends out from the base of the shoreface to about 16 nautical miles. The seismic lines were run parallel to proposed tracklines designed at a grid spacing of one nautical-mile. Weather and equipment failures prohibited completion of the entire grid of tracklines.

All data presented in this report were collected aboard a 36-foot charter boat captained by Mr. Charles Midgett of Wanchese, North Carolina. The seismic profiles are single-channel analog data. The seismic source (UNIBOOM™) emits a broadband, high-frequency wave-spectrum (400 Hz to 14 kHz). The theoretical vertical resolution of this instrument is 20 cm; working vertical resolution was found to be slightly less than 1 meter. Pulse-generation was powered at 300 joules and triggered by a mercury-vapor ignatron. Firing rates varied, but never exceeded 0.5 seconds/trigger in order to maintain extremely-high horizontal resolution. Sweep rate was fixed at 100 milliseconds (2-way travel time), and therefore penetration was limited to the first 90-100 meters (depending on the *in situ* subbottom seismic-velocity structure).

The incoming signal was collected on an eight-element hydrophone, amplified, filtered, and recorded on an analog graphical recorder. The data were also magnetically taped using a high-fidelity VCR. The taped data are used for post-cruise processing.

Navigation was determined using LORAN C time-differentials. Navigation positions were continuously logged at 1-minute intervals by employing a proprietary software program and a portable PC computer to capture and store this information. In addition, time-events were marked on the seismic profiles at 5 minute intervals (or less), and position information was simultaneously recorded for each time-event. This facilitated geo-referencing of the seismic data. Time differentials were converted to latitude/longitude coordinates using a NorthStar 800™ conversion program (Ver. 96).

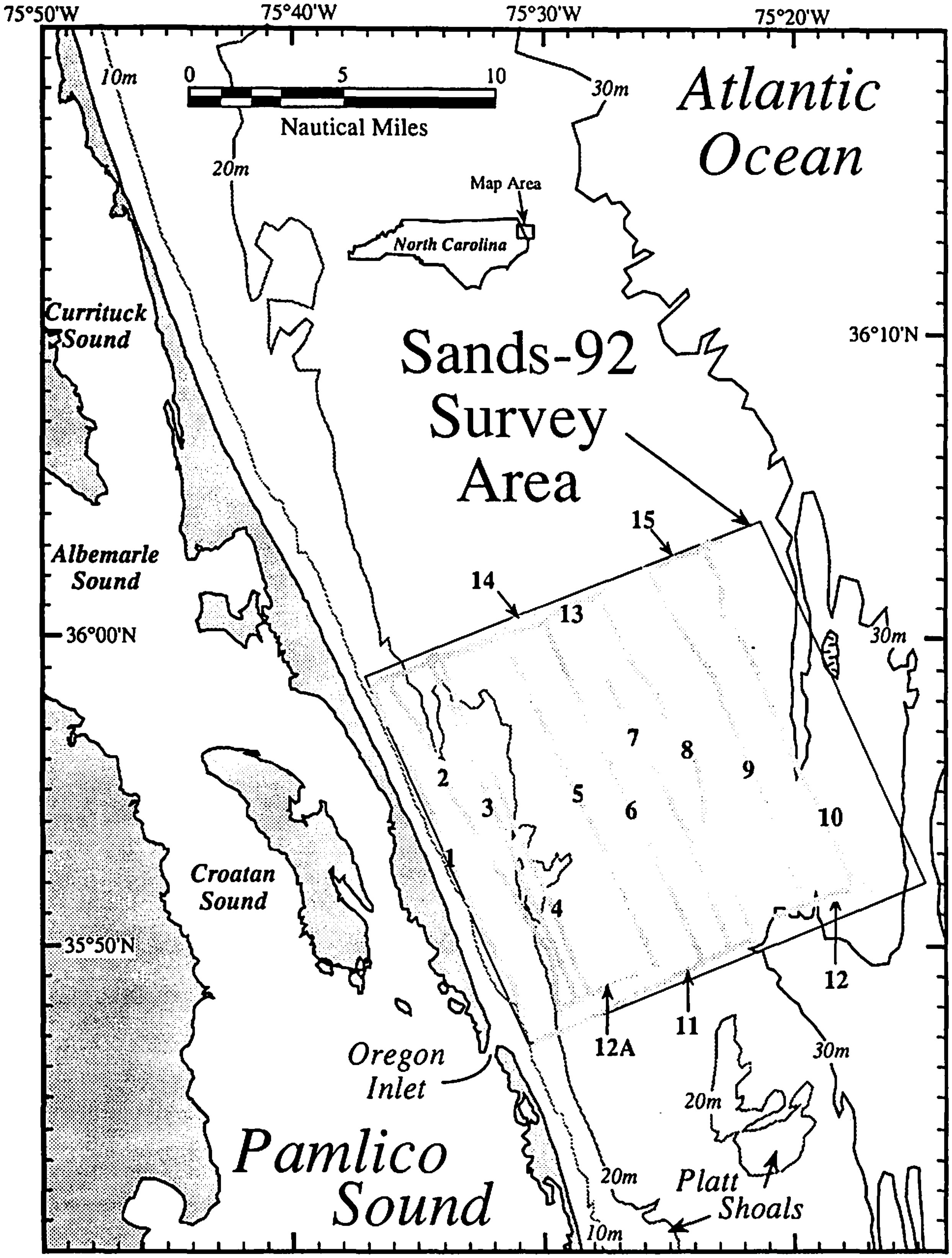

Figure 2. Base map delineating the 1992 Sands survey area and the location of seismic tracklines for profiles presented in this report. Numbers refer to individual seisections shown in Appendix A.

The latitude/longitude coordinate information was then plotted by hand on NOAA Coastal Chart # 12204, as well as entered and manipulated in computer mapping programs.

DATA REDUCTION

Only 271 km of the approximately 300 km seismic reflection data set were reduced to a series of seismic stratigraphic sections due to overlaps in tracklines or poor data quality. These seismic stratigraphic sections are presented in Appendix A, and are herein referred to as "seisections".

The method of translating the graphical seismic records to seisections is described in Snyder (1993). This method consists of 3 basic steps. First, the raw seismic data were photocopied, studied, and subbottom reflectors were interpreted to be either real reflecting horizons or a multiple of some type. Real reflectors were highlighted using a four-color scheme to subjectively portray the relative amplitude of the reflectors. Second, the interpreted photocopies were then systematically reduced to stratigraphic line-drawings by hand-digitizing each highlighted seismic reflector. The digitizing exercise utilizes a large-format (4 x 5 foot) digitizing tablet and microcomputer workstation. Proprietary software was used to rectify horizontal and vertical scaling. Digitized reflector information was stored in a 4-dimensional array (latitude, longitude, depth below sea-level in milliseconds, and reflector amplitude color code). Third, plots were then produced on a large-format drafting plotter at a pre-determined vertical exaggeration of 100:1. Color coding on these plots reflects relative amplitudes. In black and white illustrations, each color is assigned a different line weight.

Digitized seisection information was imported and manipulated through several Macintosh™ graphics programs, converted to stratigraphic line drawings, annotated, sized for publication, and then printed. Time-events corresponding to numbered navigation positions are shown at the bottom of each seisection and on the map view of the track line. The position of the time-events are plotted in both the map views and seisections presented in Appendix A.

The vertical meter scale shown in all seismic profile data and seisection drawings is an *approximate* scale. It was calculated using a water-column seismic velocity of 1500 meters/second, and a second velocity of 1700 meters/second for subsurface travel-times (an approximately 13 percent increase). Seismic velocities recorded in unconsolidated to semi-consolidated, siliciclastic or carbonate, stratigraphic sections range from 1600-2300 meters/second (Sheridan and others, 1966; Grow and Markle, 1977; Buffler and others, 1979; 1981; Grow and others, 1979; Ebeniro and others, 1986; Slowey and others, 1989). More typically, the velocity range for unconsolidated siliciclastics is in the 1650-1750 meters/second range (Snyder, 1993).

RESULTS

The seismic data depict a series of tabular subbottom sequences abruptly interrupted by multiple paleofluvial channel systems (Figure 3). Each seismic sequence is bound by erosional unconformities which appear parallel to subparallel with the seafloor. The seismic sequences range from 5 to 15 meters in thickness, and the physical anatomy (seismic facies) indicate these tabular units represent a stacked mosaic of shelf, estuarine and fluvial lithologies. However, no core data are presently available for correlations, nor have seismic lines been carried to existing borehole information.

The subbottom seismic sequences are overlain by several distinct shoal features (Figure 4). These shoals exhibit the following specific characteristics: (1) they are near-ubiquitous at water depths greater than 20 meters; (2) they range from a few meters to over 15 meters in thickness, and the thickness appears to increase with increasing water depth; (3) all shoals exhibit microtopographic relief ($\pm$2 meters) superimposed over the larger shoal-

Figure 3. Seisection S-92-06 illustrating the anatomy of the subbottom stratigraphy underlying the inner continental shelf area off Nags Head, North Carolina. Location of the seismic trackline is shown in Appendix A.

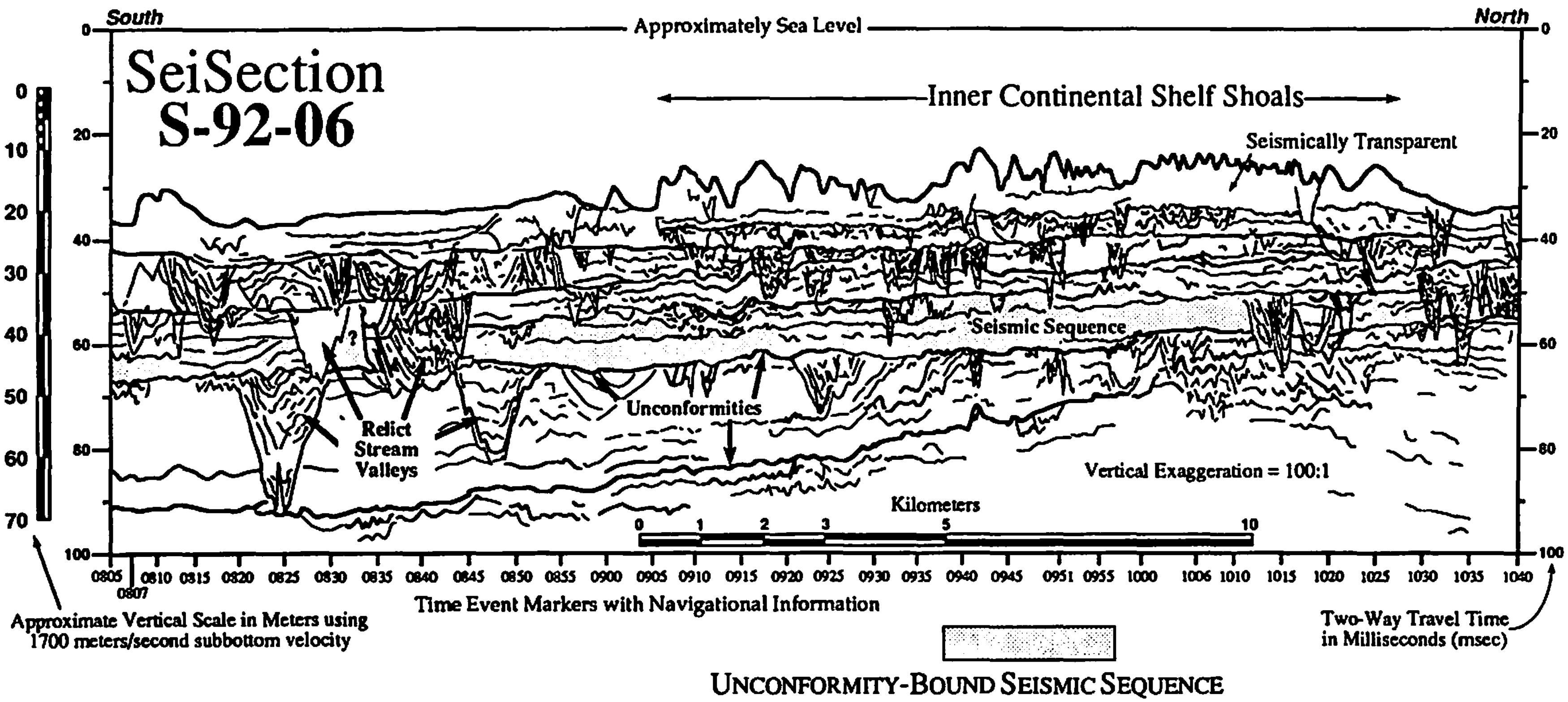

Figure 3. Seisection S-92-06 illustrating the anatomy of the subbottom stratigraphy underlying the inner continental shelf area off Nags Head, North Carolina. Location of the seismic trackline is shown in Appendix A.

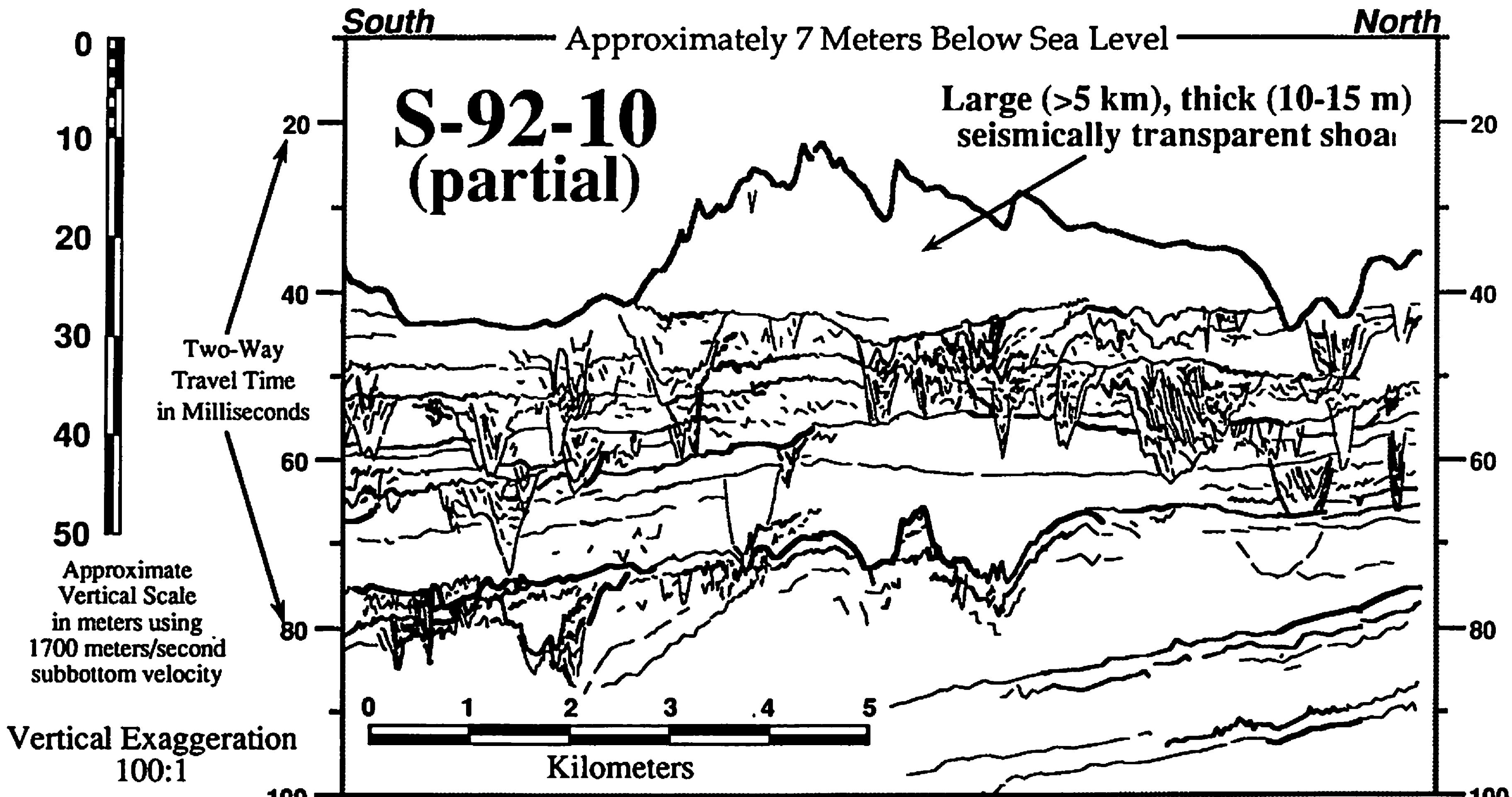

Figure 4. A segment of seisection S-92-10 which shows the size and shape of the larger shoal features identified at deeper water depths (>30 m) within the S-92 survey area. See seisection S-92-10 in Appendix A for reference to the location of this section.

feature (Figure 5); (4) most shoal features portray a transparent seismic facies (Figure 4); and (5) the seafloor seismic signature from all shoal areas is marked by an anomalously thick reflector (Figures 6 and 7).

The anomalous bottom reflector illustrated in Figure 6 severely handicapped resolution of subbottom information within the upper 3-8 meters of the seafloor. Seismic data collected in other shallow-marine habitats, both before and after the S-92 surveys, and employing the very same equipment and set-up, have not exhibited this same bottom signature. It is therefore concluded that the equipment is not the source of the problem. Two alternative explanations are possible. First, it may be an artifact of boat noise inherent to the survey vessel employed to collect the S-92 lines. Alternatively, it may be a characteristic of the surface geology. Thick, high-amplitude bottom-reflectors occur over very-hard shallow marine habitats such as the cemented carbonate-bank margins of the Bahama Banks (Hine and Neumann, 1977; Boss and Neumann, 1993). High-reflection coefficients in such habitats normally prohibit any subbottom reflectors below the bottom, because almost all the seismic energy is reflected. This produces a reflection-free seismic image below the seafloor. The transparent seismic facies commonly found immediately below the bottom reflector in the S-92 survey area implies the seafloor is indeed extremely hard; no reflected energy is returned from this zone. However, many reflection events are observed at depths below the transparent zone, and this indicates ample seismic energy is being transmitted past the seafloor.

Future seismic surveys will employ different research vessels. Each research vessel emits its own unique and characteristic noise. If the anomalous bottom signal persists in data collected from different vessels within the sand resources survey area(s), then the only reasonable explanation for the bottom signal is the inherent surface geology of the survey area.

Small, truncated channels and other internal reflectors are observed in some instances where shallow subbottom seismic information is imaged immediately beneath the shoals. The truncated nature of the internal reflectors, coupled with the possibility that these features are characterized by a very-hard seafloor, collectively indicate the shoal features are erosional in origin. That is, if the shoals were homogeneous sand bodies, then they would not exhibit many internal reflectors — and especially not truncated channel features. These structures therefore imply the topography of the shoal features is a product of erosional patterns, rather than large, unconsolidated, actively-migrating sand bodies. If this is true, it would deflate their value as potential sand resources.

Although many relict stream valleys have been identified in the S-92 data set, the density of data collected and interpreted to date is insufficient to permit projecting or mapping specific channels between seismic lines. Such features would likely make excellent targets for beach-renourishment resources due to the textural nature of the valley-fill fluvial sands.

SUMMARY AND RECOMMENDATIONS

The work completed under Year 1 funding has established a partial image of the subbottom and surface geology, as well as position and size of local shoal features within the study area. It provides a good fundamental start toward establishing a 3-dimensional stratigraphic framework for subsequent resource assessments. However, additional seismic data are required before an internally-consistent geologic framework is established, the subbottom geology evaluated, and a list of targets to be sampled by coring are tabulated and ranked in accord with the priorities of the NC/MMS Sand Resources Task Force.

The interpreted, scale-rectified, and reduced seisections depict several large shoals overlying a stacked series of tabular stratigraphic units. Each stratigraphic unit is 6 to 20 meters thick, and all

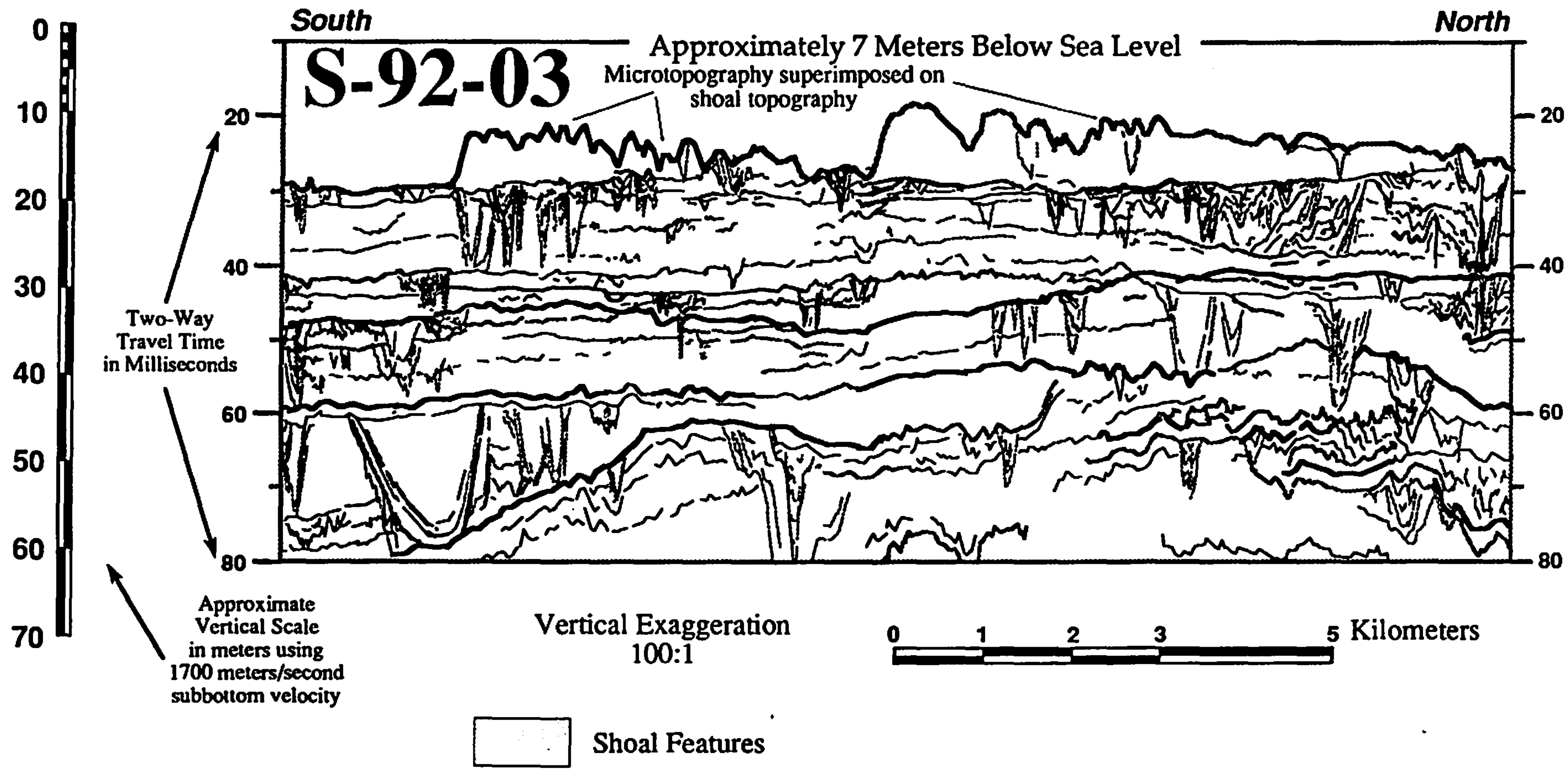

Figure 5. A segment of seisection S-92-03 showing the superposition of topographic features associated with the continental shelf shoals identified within the S-92 survey area. See seisection S-92-03 in Appendix A for reference to the location of this section.

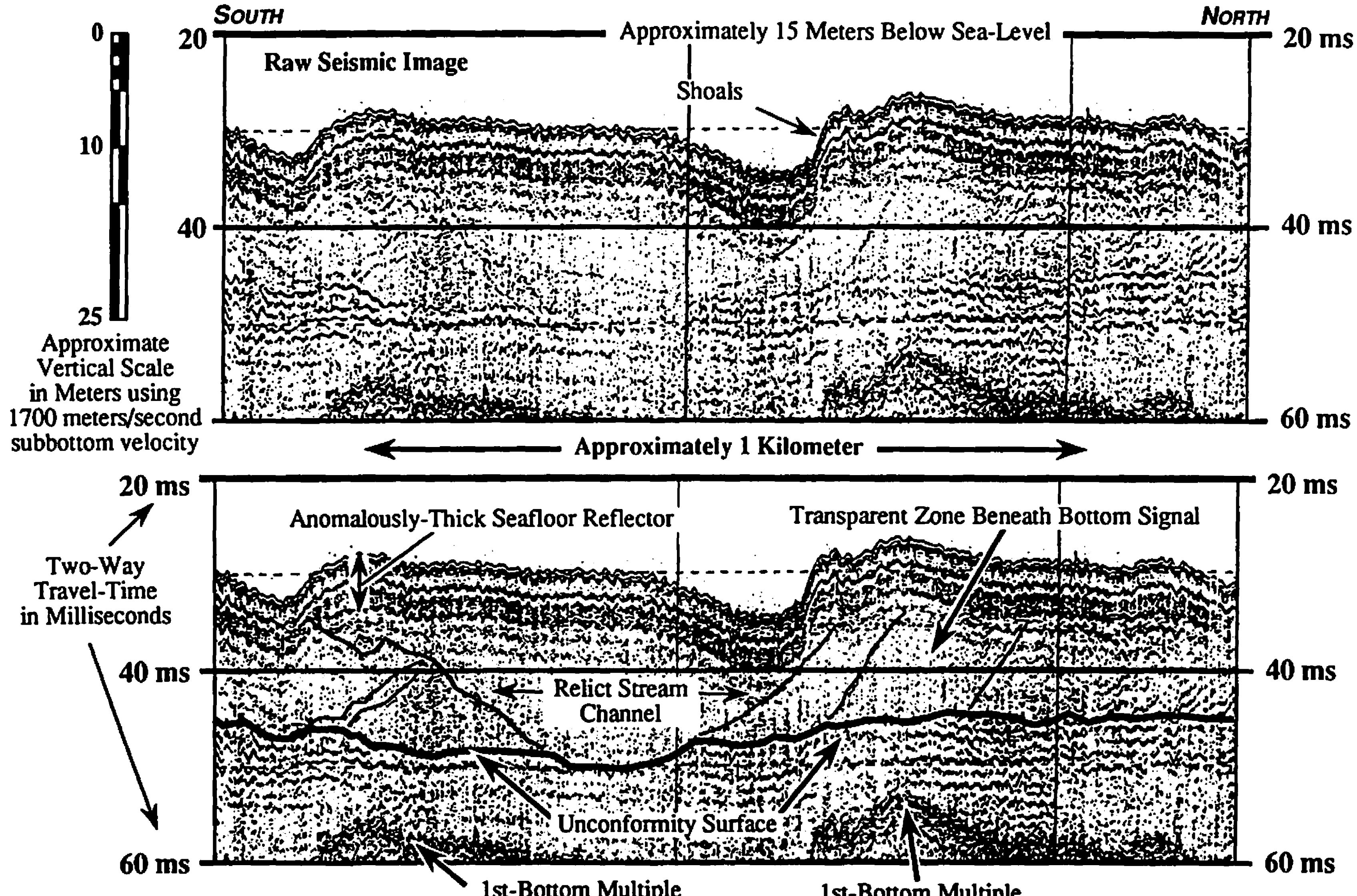

Figure 6. Seismic data exhibiting the anomalously-thick seafloor reflector and seismically-transparent zone(s) associated with the shelf-shoal features identified within the S-92 survey area. Upper panel presents the raw seismic image which is duplicated and annotated in the lower panel. The location of this profile is shown in Figure 7.

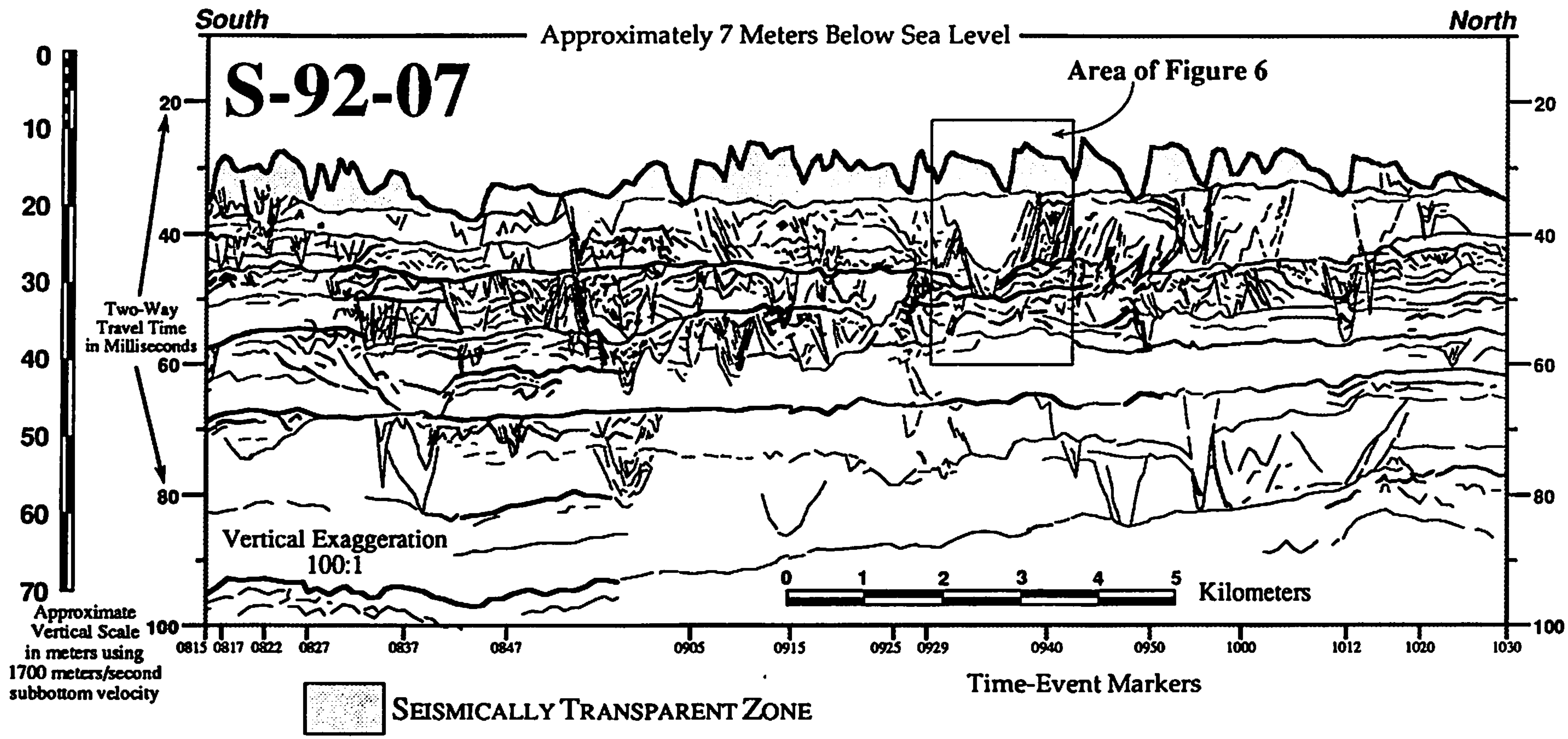

Figure 7. Seisection S-92-07 which illustrates the seismically-transparent zone underlying the shelf-shoal features identified within the S-92 survey area. The location of seisection S-92-07 is shown in Figure 2 and Appendix A.

are bounded by unconformity surfaces cut by multiple, relict (buried) stream valleys. The shoal features exhibit 3 to 15 meters of topographic relief, are common at water depths greater than 20 meters, and appear to be erosional in origin. The shoal bodies, in addition to anticipated near-surface paleofluvial channels, remain the primary features of interest. But, additional data are required to identify specific vibracore targets within the survey area.

Recommendations for future work, ranked in order of priority, are as follows.

(1) Complete the seismic-survey grid for the area off Nags Head and Kitty Hawk; interpret and reduce that data to seisections consistent in format with the existing data.

(2) Develop a detailed, three-dimensional, geological framework for the survey area. Map-out the subbottom seismic sequences, sites of all near-surface channels and their thalweg tracks, and the position and aerial extent of the large shoal features.

(3) Tie the stratigraphic information presented in the seisections to all existing cores, boreholes, or other geologic information, in order to forecast the lithologies of the seafloor outcrops prior to coring.

(4) Concurrent with tasks 1 through 3, integrate all existing data into a GIS data base for easy access by all interested parties, as well as annual updates via incorporation of new data.

ACKNOWLEDGEMENTS

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Charles W. Hoffman, Richard C. Dentman, and Mary E. Watson of the North carolina Geological Survey, Coastal Plain Office participated in various phases of collecting and preparing this data set for release.

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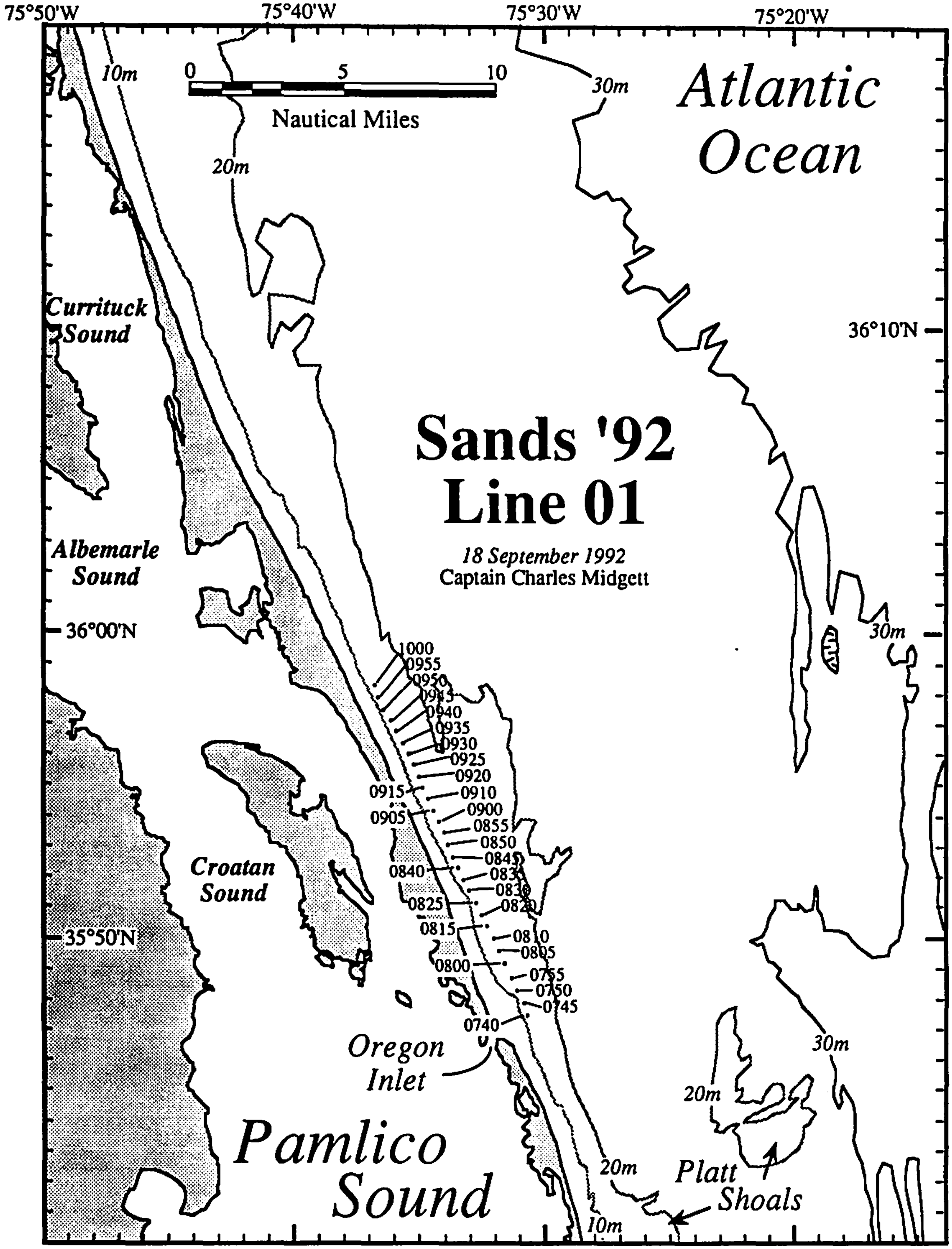
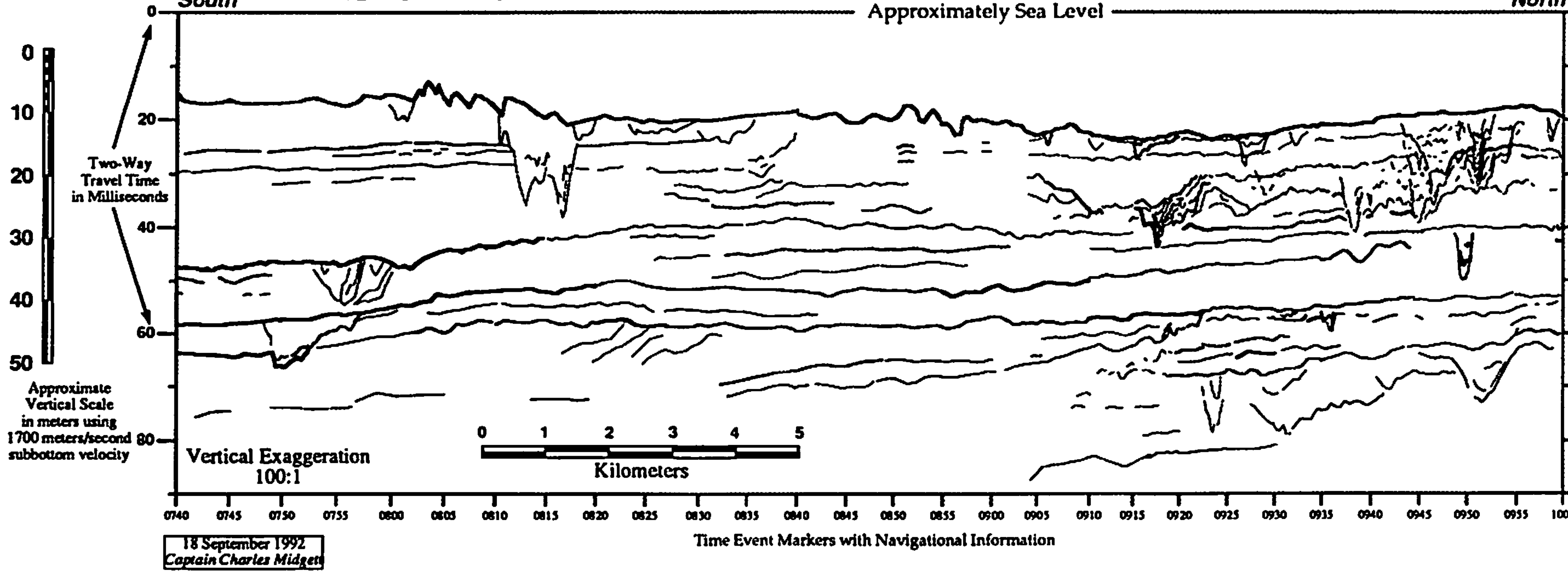
APPENDIX A

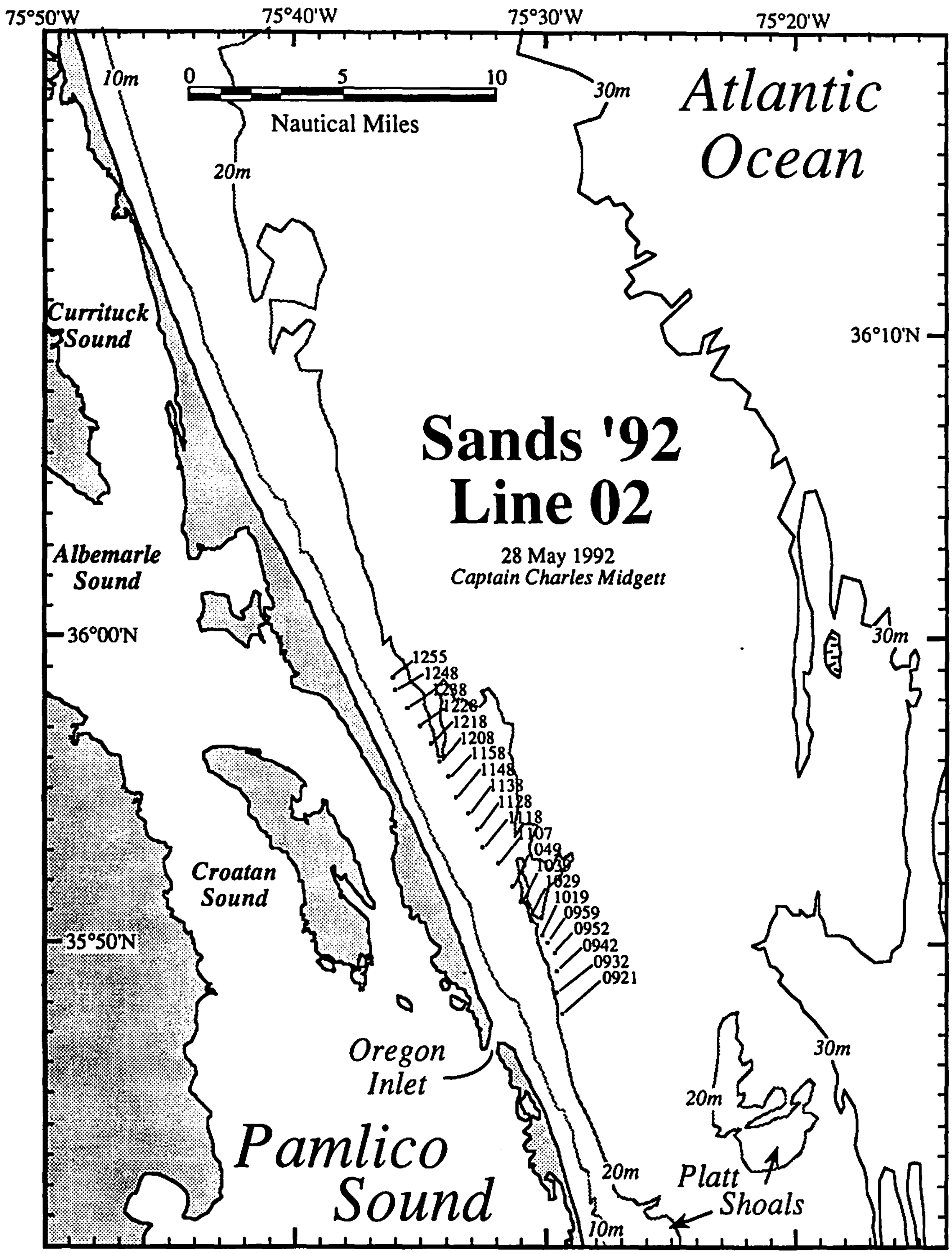
S-92 Seisections and Maps

Each seismic section that has been interpreted, digitized, scale-rectified, and plotted as stratigraphic line-drawings is presented in this appendix. The stratigraphic information is illustrated in 15 separate seisections plotted with a vertical exaggeration of 100:1. Refer to each section for its specific horizontal and vertical scales. Time-Event marks labeled along the base of each line refer to geographic positions labeled on the maps immediately preceding each seisection.


75°50'W
75°40'W
75°30'W
75°20'W
36°10'N
36°00'N
35°50'N
10m
20m
30m
0 5 10
Nautical Miles
Atlantic Ocean
Currituck Sound
Albemarle Sound
Croatan Sound
Sands '92
Line 01
18 September 1992
Captain Charles Midgett
1000
0955
0950
0945
0940
0935
0930
0925
0920
0915
0910
0905
0900
0855
0850
0845
0840
0835
0830
0825
0820
0815
0810
0805
0800
0755
0750
0745
0740
Oregon Inlet
Pamlico Sound
Platt Shoals

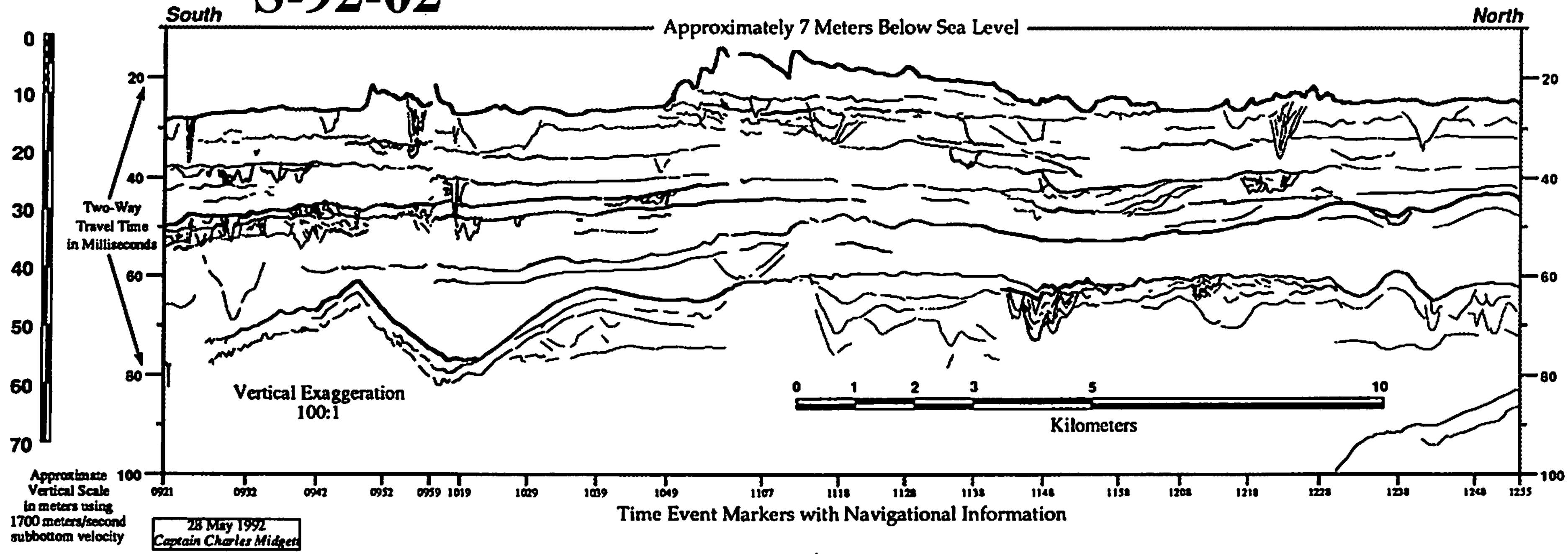
S-92-01

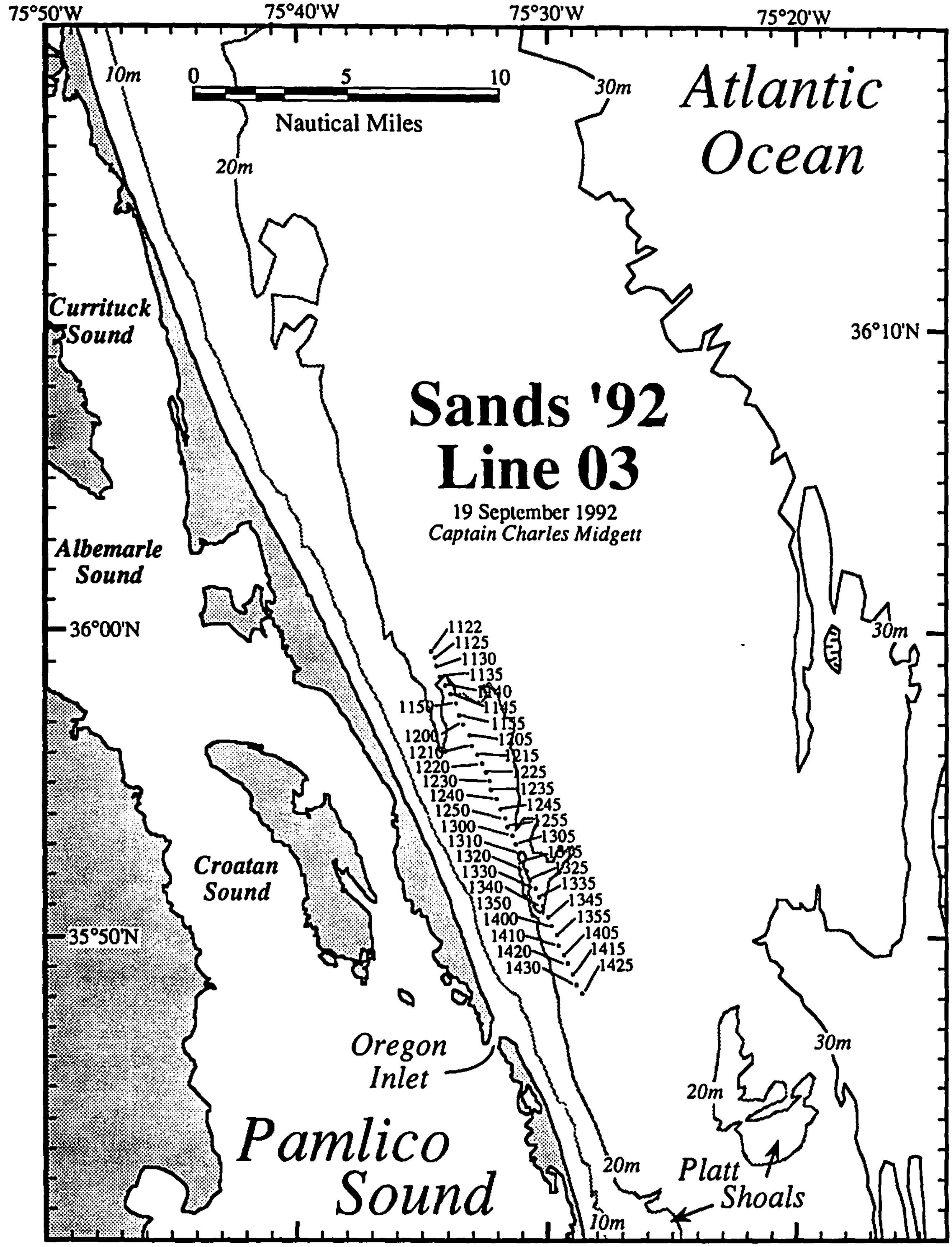

South
North
Approximately Sea Level
Two-Way Travel Time in Milliseconds
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Vertical Exaggeration 100:1
Kilometers
Time Event Markers with Navigational Information
18 September 1992
Captain Charles Midgett

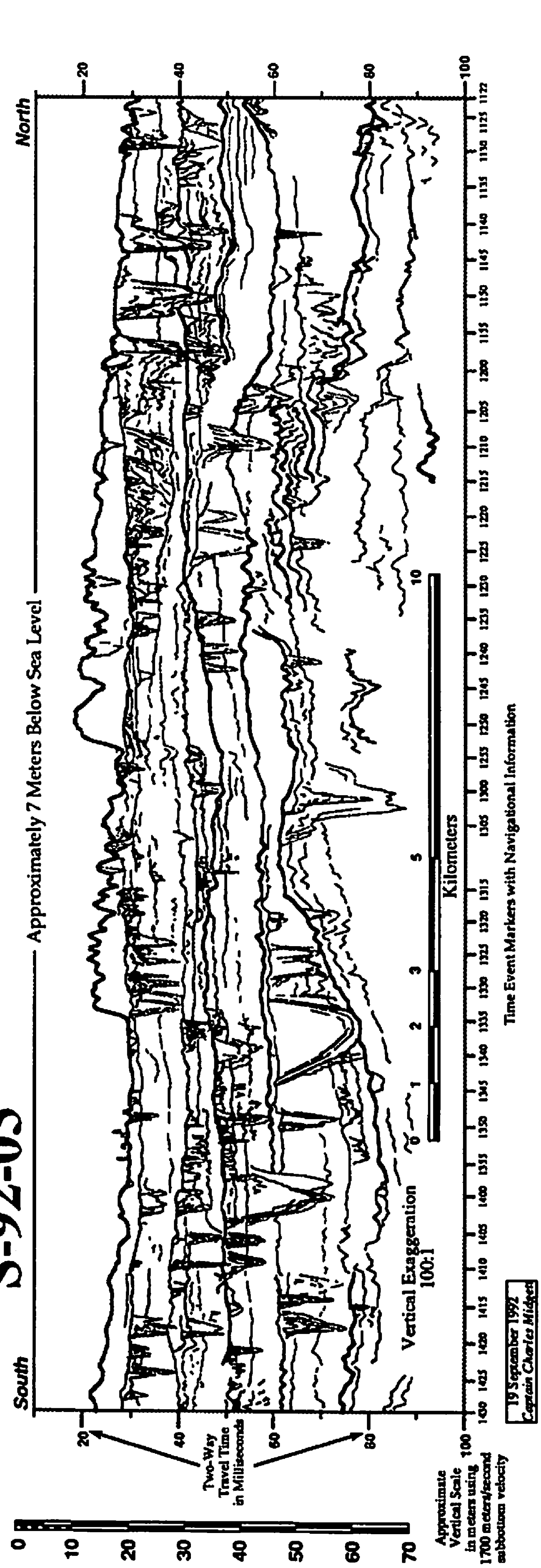


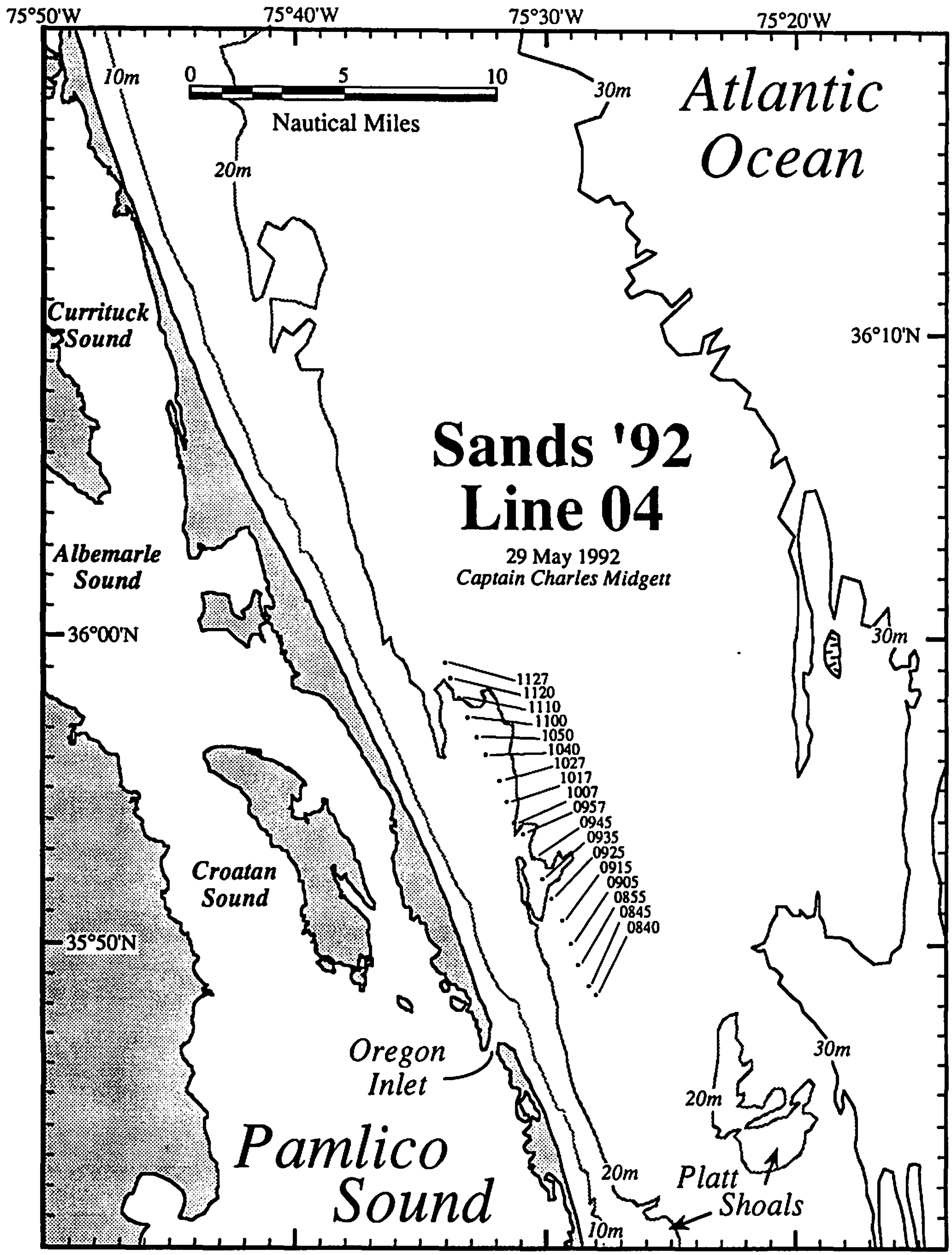
75°50'W
75°40'W
75°30'W
75°20'W
10m
0
5
10
Nautical Miles
30m
Atlantic Ocean
20m
Currituck Sound
36°10'N
Sands '92 Line 02
28 May 1992
Captain Charles Midgett
Albemarle Sound
36°00'N
30m
1255
1248
1238
1228
1218
1208
1158
1148
1138
1128
1118
1107
1049
1039
1029
1019
0959
0952
0942
0932
0921
Croatan Sound
35°50'N
Oregon Inlet
30m
20m
Pamlico Sound
20m
Platt Shoals
10m

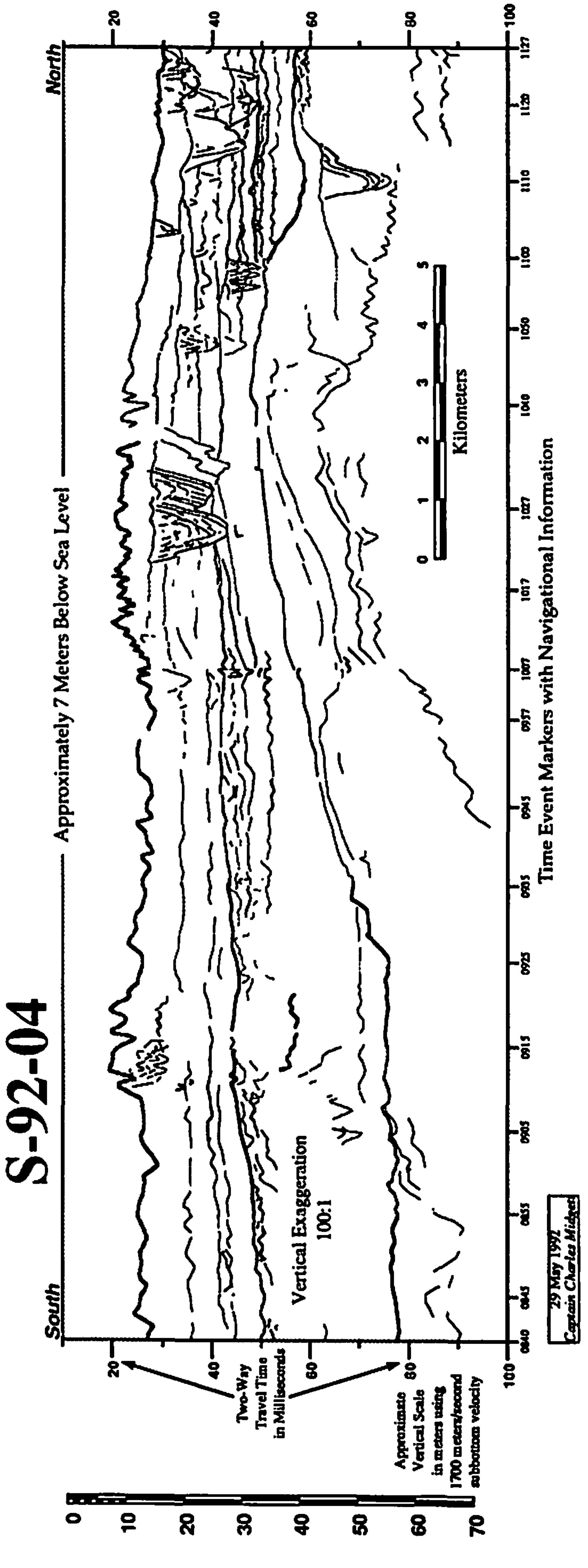
S-92-02


South
North
Approximately 7 Meters Below Sea Level
0
10
20
30
40
50
60
70
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Two-Way Travel Time in Milliseconds
20
40
60
80
100
Vertical Exaggeration 100:1
0 1 2 3 5 10
Kilometers
0921 0932 0942 0952 0959 1019 1029 1039 1049 1107 1118 1128 1138 1148 1158 1208 1218 1228 1238 1248 1255
Time Event Markers with Navigational Information
28 May 1992
Captain Charles Midgett

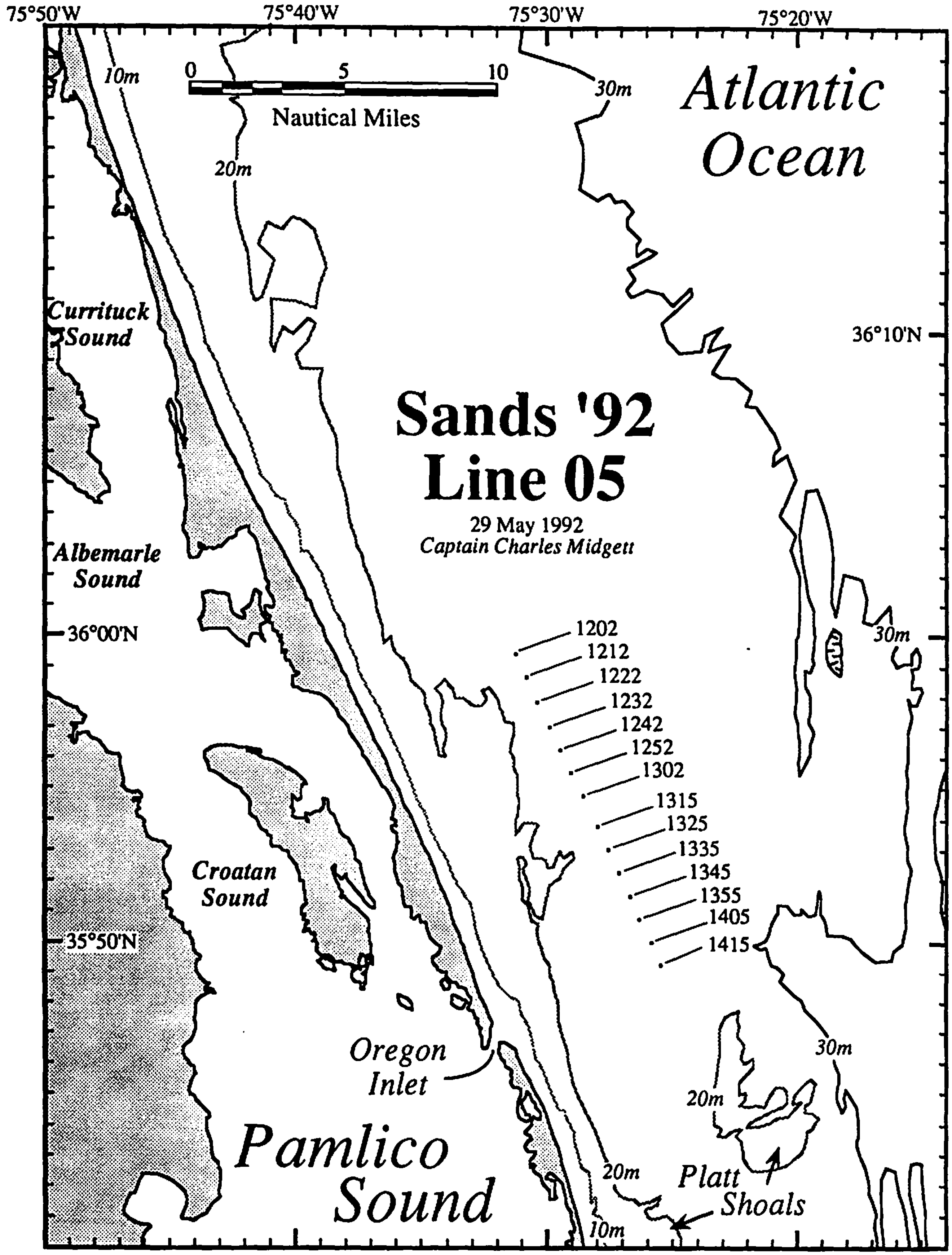

75°50'W
75°40'W
75°30'W
75°20'W
0 5 10
Nautical Miles
10m
20m
30m
Atlantic Ocean
Currituck Sound
Albemarle Sound
Croatan Sound
Pamlico Sound
Oregon Inlet
Platt Shoals
36°10'N
36°00'N
35°50'N
Sands '92
Line 03
19 September 1992
Captain Charles Midgett

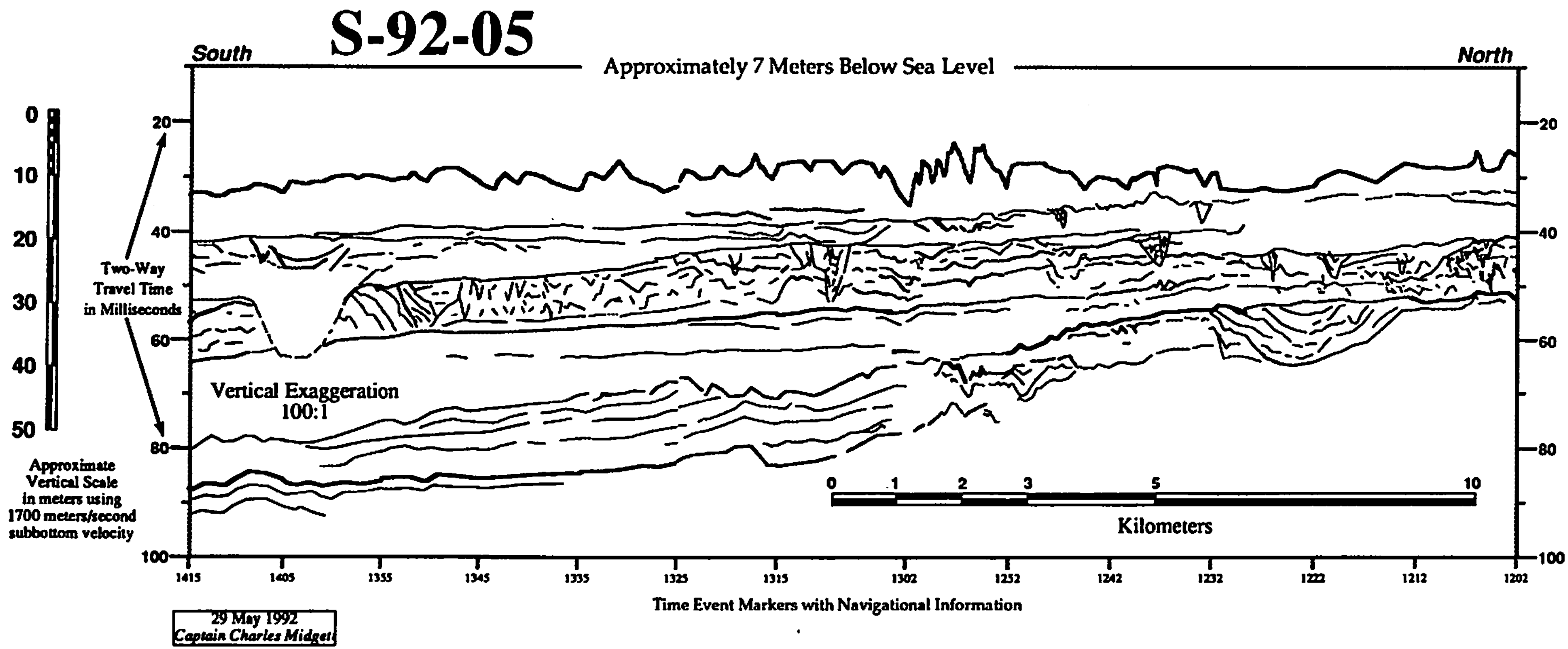

S-92-03
Approximately 7 Meters Below Sea Level
South
North
Two-Way Travel Time in Milliseconds
20
40
60
80
100
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
0
10
20
30
40
50
60
70
Vertical Exaggeration 100:1
Kilometers
0 1 2 3 5 10
Time Event Markers with Navigational Information
19 September 1992
Captain Charles Midgett

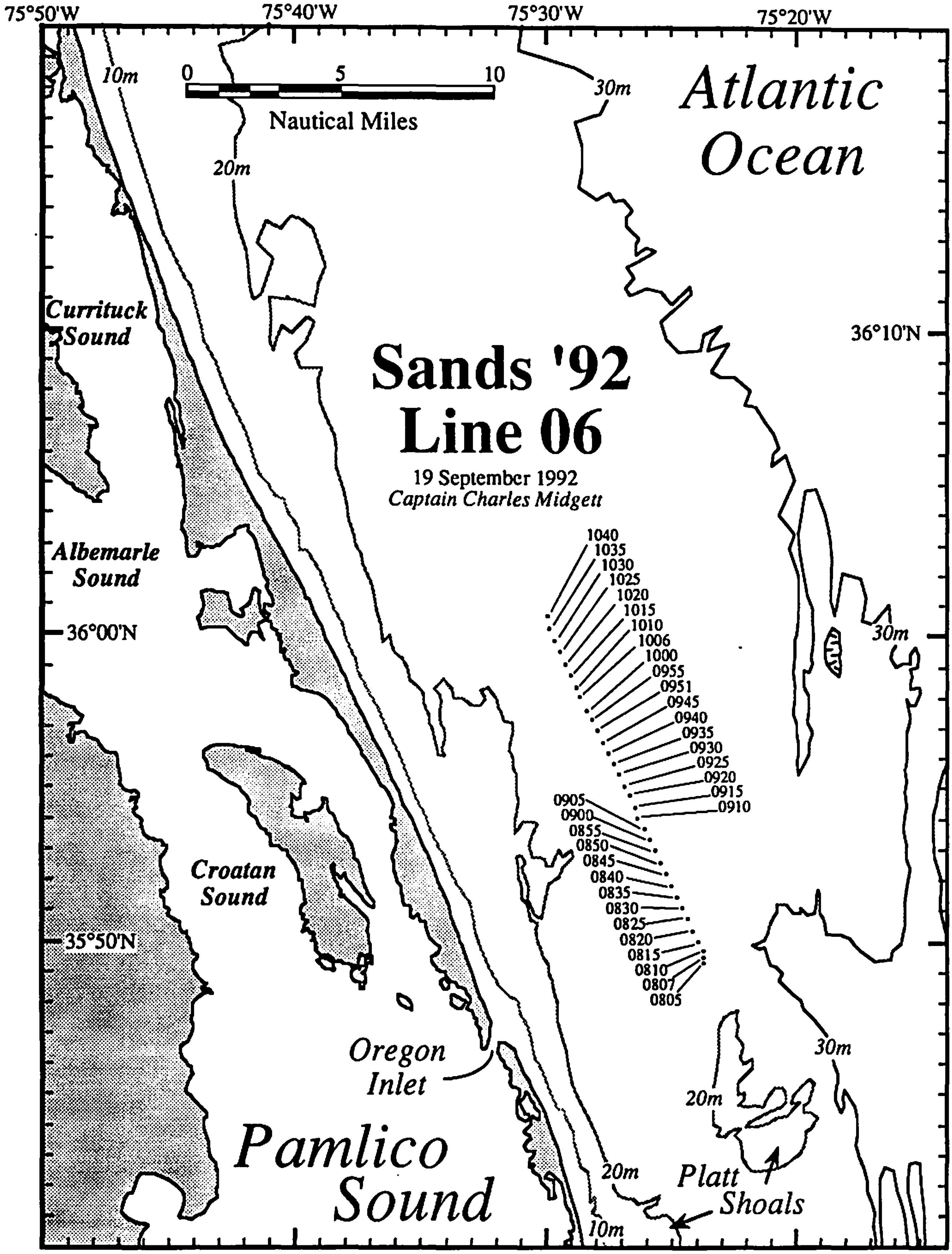

75°50'W
75°40'W
75°30'W
75°20'W
10m
0
5
10
Nautical Miles
30m
Atlantic
Ocean
20m
Currituck
Sound
36°10'N
Sands '92
Line 04
29 May 1992
Captain Charles Midgett
Albemarle
Sound
36°00'N
30m
1127
1120
1110
1100
1050
1040
1027
1017
1007
0957
0945
0935
0925
0915
0905
0855
0845
0840
Croatan
Sound
35°50'N
Oregon
Inlet
30m
20m
Pamlico
Sound
20m
Platt
Shoals
10m

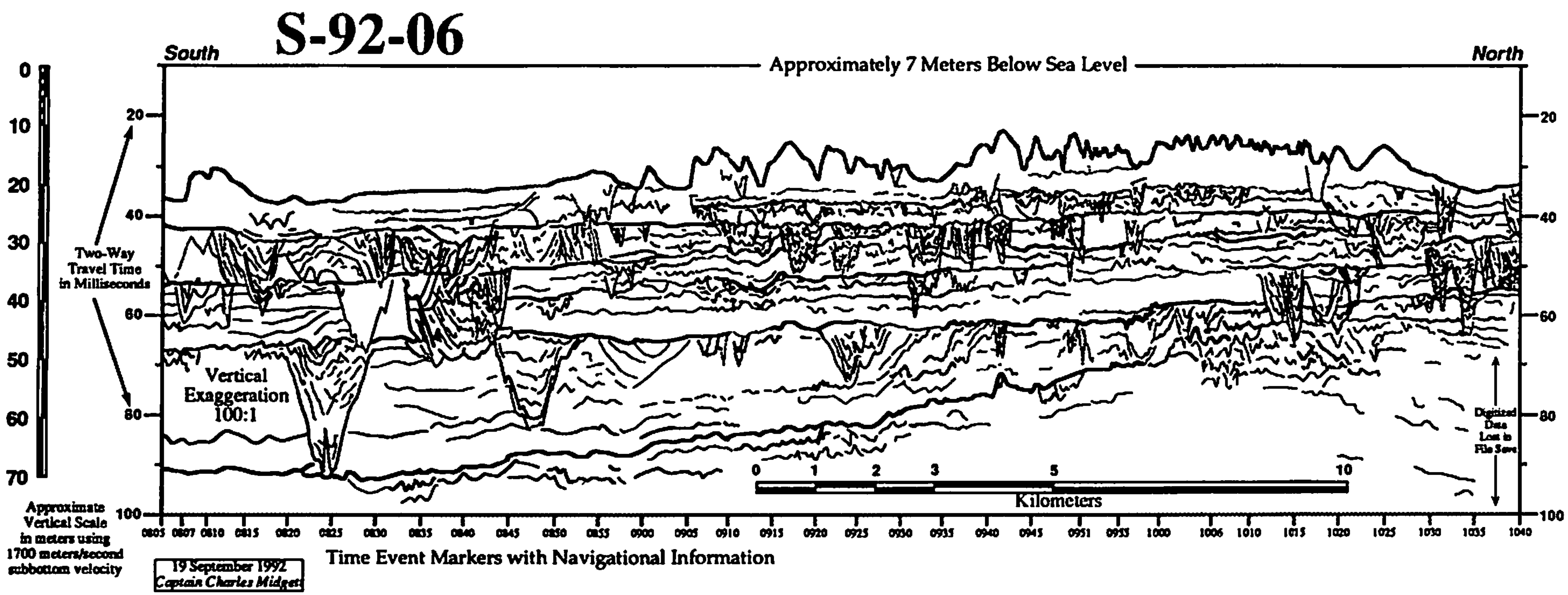


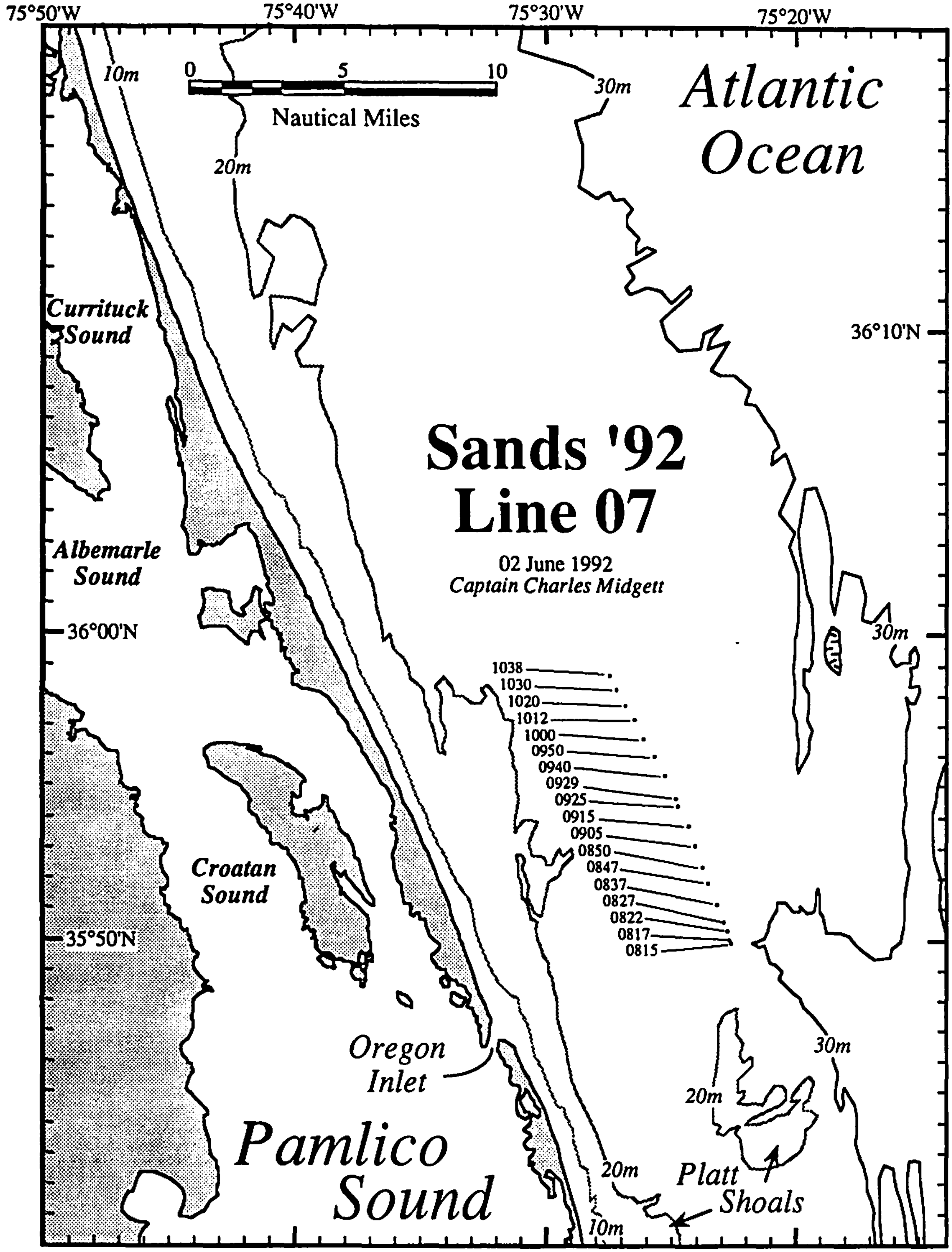
S-92-04
Approximately 7 Meters Below Sea Level
South
North
Vertical Exaggeration
100:1
Kilometers
0 1 2 3 4 5
Time Event Markers with Navigational Information
Two-Way Travel Time in Milliseconds
20 40 60 80 100
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
0 10 20 30 40 50 60 70
29 May 1992
Captain Charles Midget


75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic
Ocean
Currituck
Sound
36°10'N
Sands '92
Line 05
29 May 1992
Captain Charles Midgett
Albemarle
Sound
36°00'N
1202
1212
1222
1232
1242
1252
1302
1315
1325
1335
1345
1355
1405
1415
30m
Croatan
Sound
35°50'N
Oregon
Inlet
30m
20m
Pamlico
Sound
20m
Platt
Shoals
10m

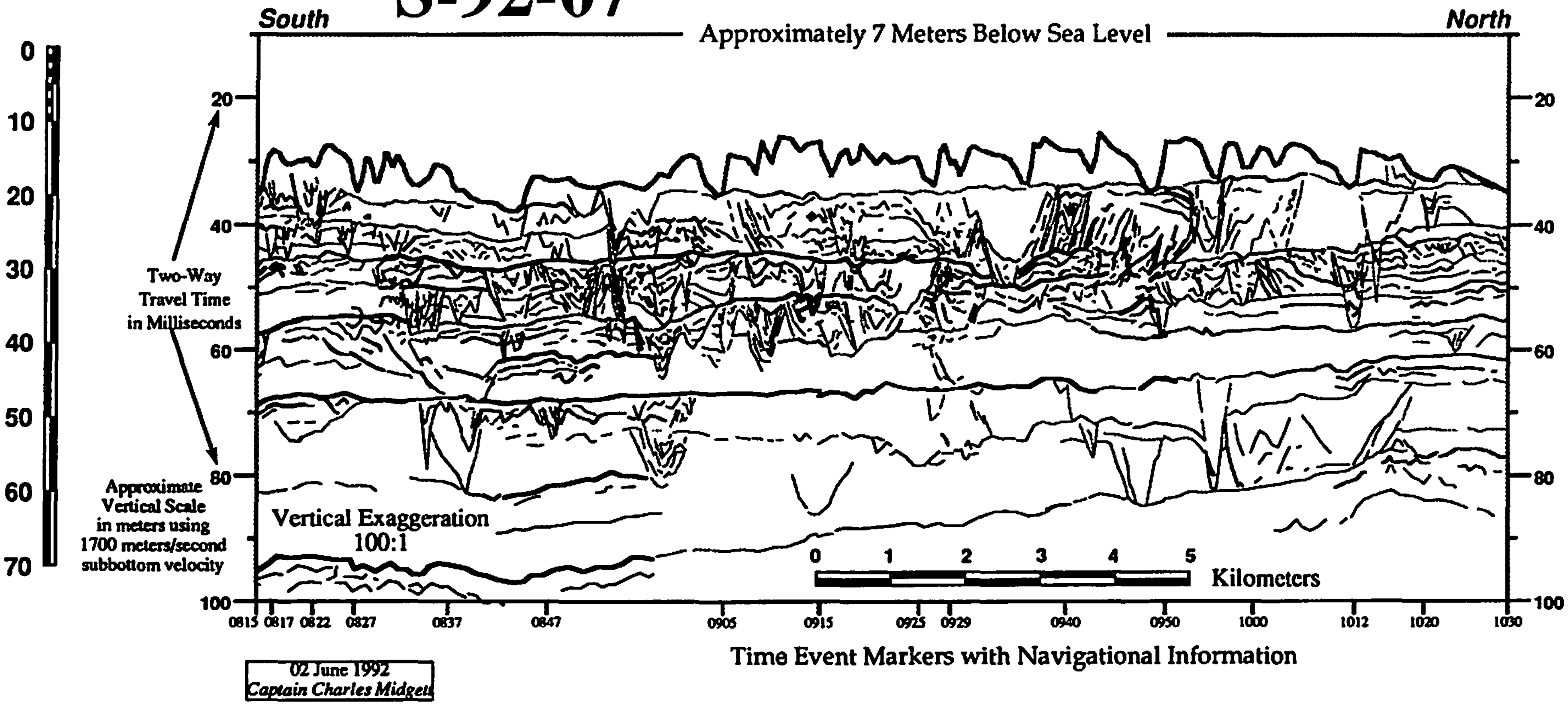

S-92-05
South
North
Approximately 7 Meters Below Sea Level
0
10
20
30
40
50
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Two-Way Travel Time in Milliseconds
20
40
60
80
100
Vertical Exaggeration 100:1
0
1
2
3
5
10
Kilometers
1415
1405
1355
1345
1335
1325
1315
1302
1252
1242
1232
1222
1212
1202
Time Event Markers with Navigational Information
29 May 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
Atlantic Ocean
Sands '92
Line 06
19 September 1992
Captain Charles Midgett
Currituck Sound
Albemarle Sound
Croatan Sound
Pamlico Sound
Oregon Inlet
Platt Shoals
36°10'N
36°00'N
35°50'N
10m
20m
30m
1040
1035
1030
1025
1020
1015
1010
1006
1000
0955
0951
0945
0940
0935
0930
0925
0920
0915
0910
0905
0900
0855
0850
0845
0840
0835
0830
0825
0820
0815
0810
0807
0805

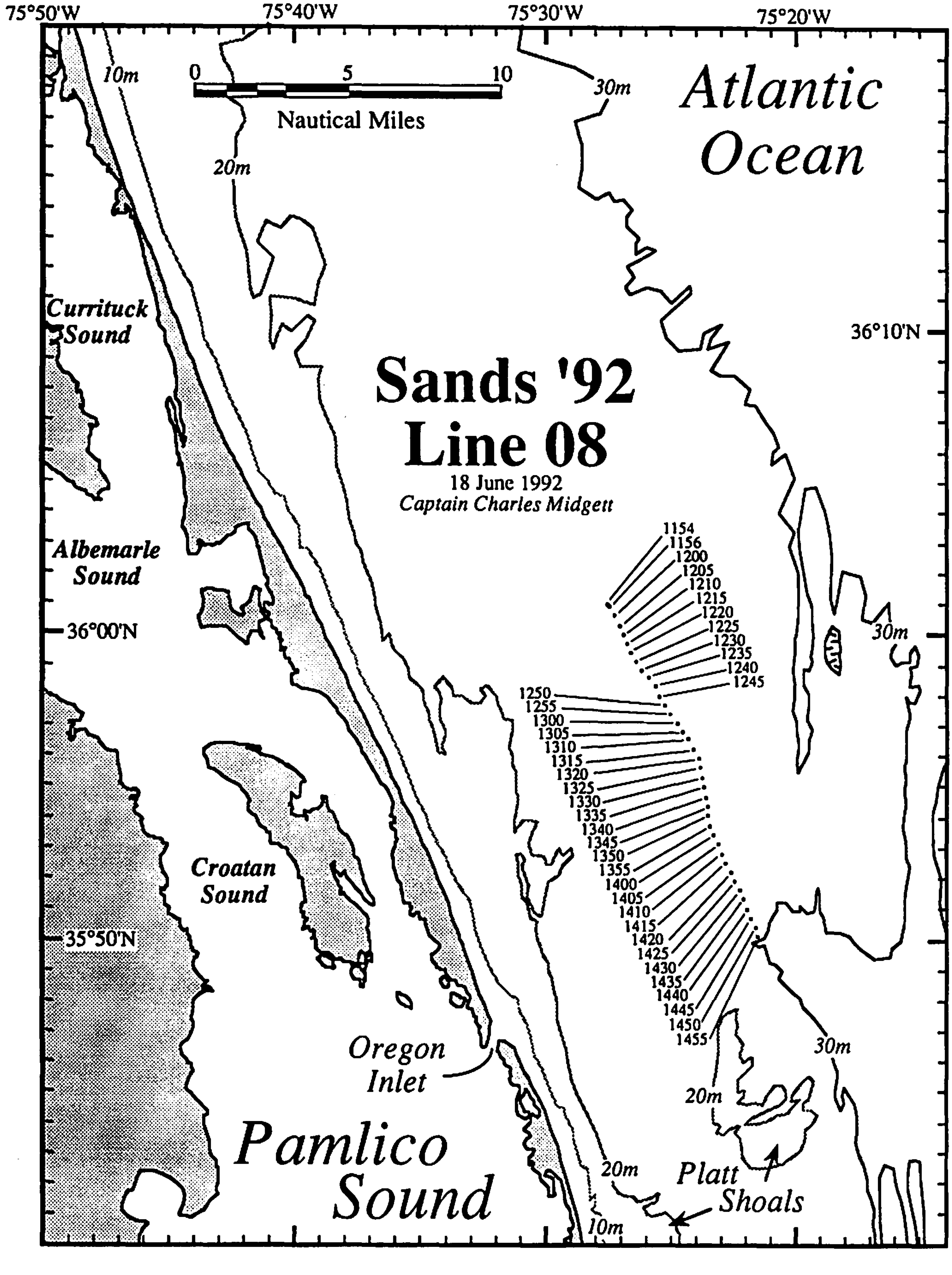

S-92-06
South
North
Approximately 7 Meters Below Sea Level
Two-Way Travel Time in Milliseconds
Vertical Exaggeration 100:1
Kilometers
Digitized Data Lost in File Save
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Time Event Markers with Navigational Information
19 September 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic
Ocean
Currituck
Sound
36°10'N
Sands '92
Line 07
02 June 1992
Captain Charles Midgett
Albemarle
Sound
36°00'N
30m
1038
1030
1020
1012
1000
0950
0940
0929
0925
0915
0905
0850
0847
0837
0827
0822
0817
0815
Croatan
Sound
35°50'N
Oregon
Inlet
30m
20m
Pamlico
Sound
20m
Platt
Shoals
10m

S-92-07

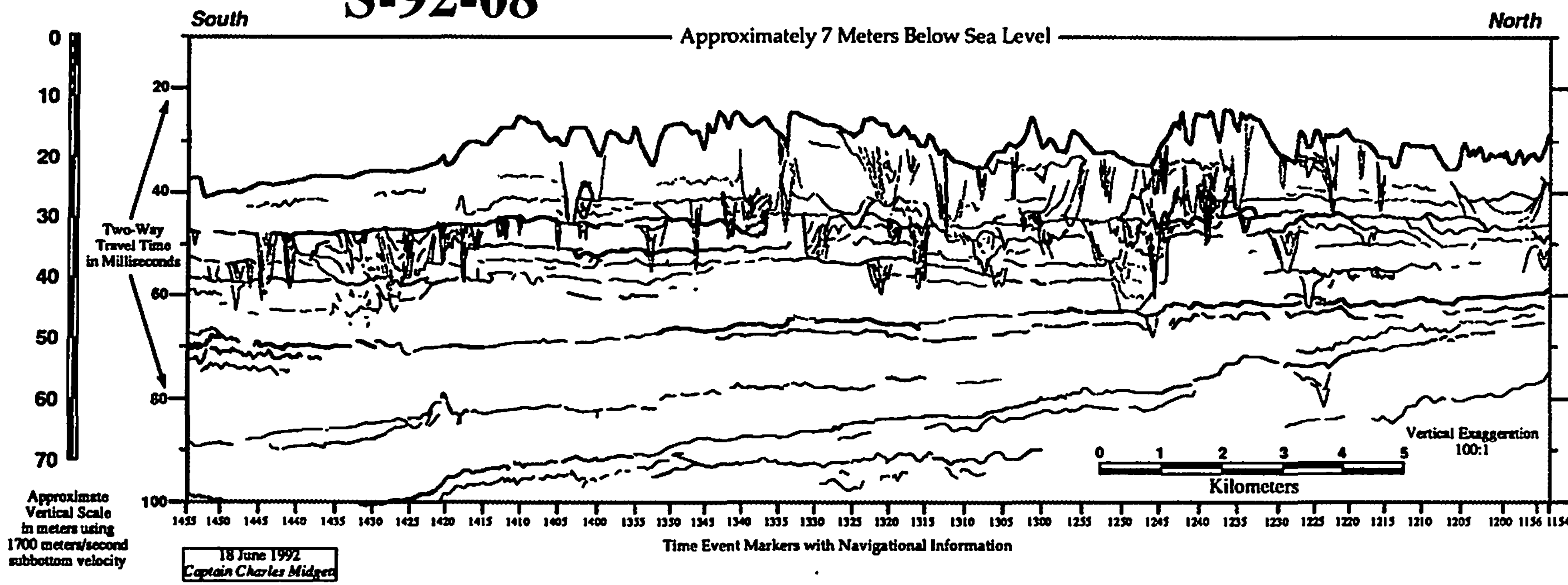


South
North
Approximately 7 Meters Below Sea Level
20
40
60
80
100
Two-Way
Travel Time
in Milliseconds
Approximate
Vertical Scale
in meters using
1700 meters/second
subbottom velocity
0
10
20
30
40
50
60
70
Vertical Exaggeration
100:1
0 1 2 3 4 5
Kilometers
0815 0817 0822 0827 0837 0847 0905 0915 0925 0929 0940 0950 1000 1012 1020 1030
Time Event Markers with Navigational Information
02 June 1992
Captain Charles Midgett

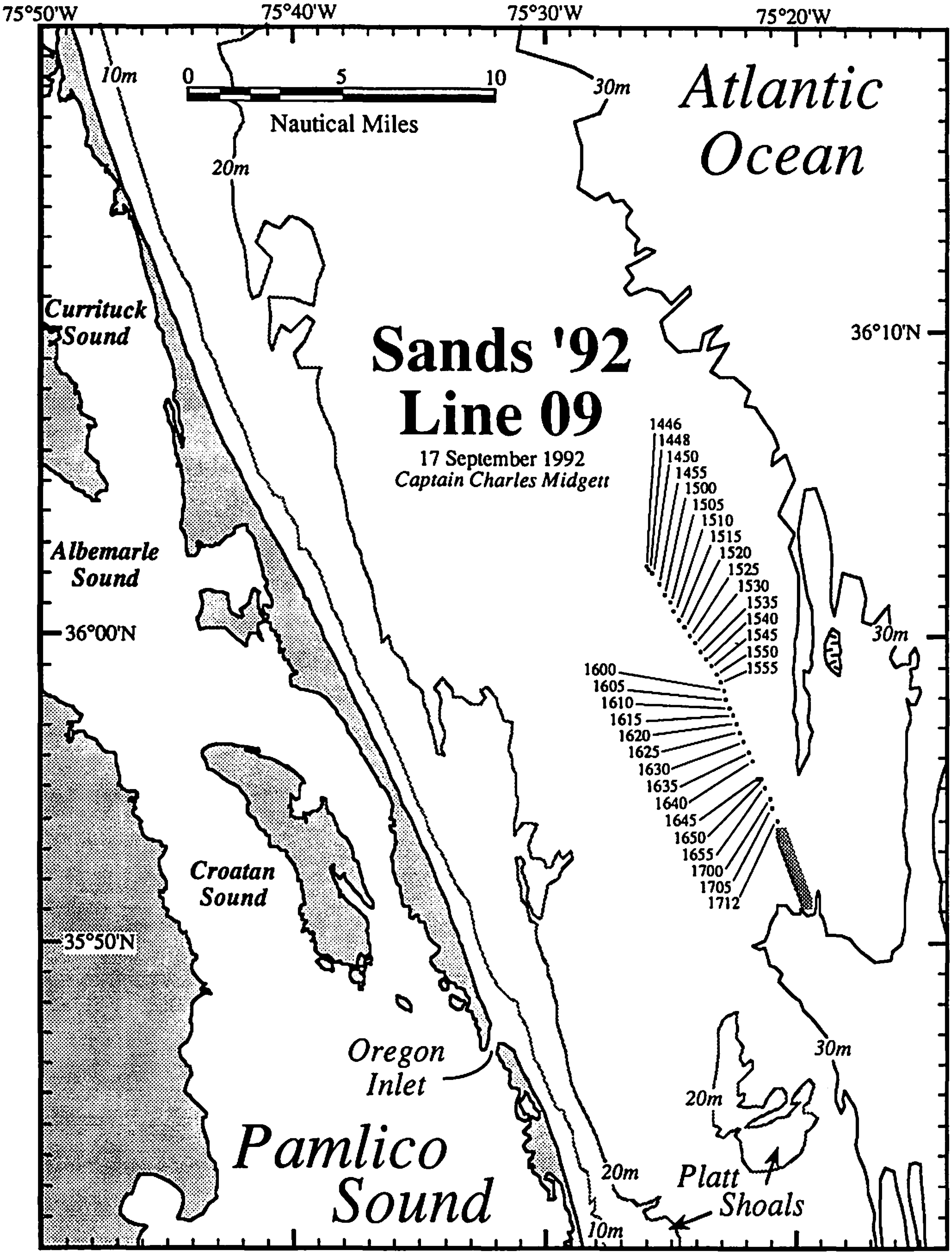


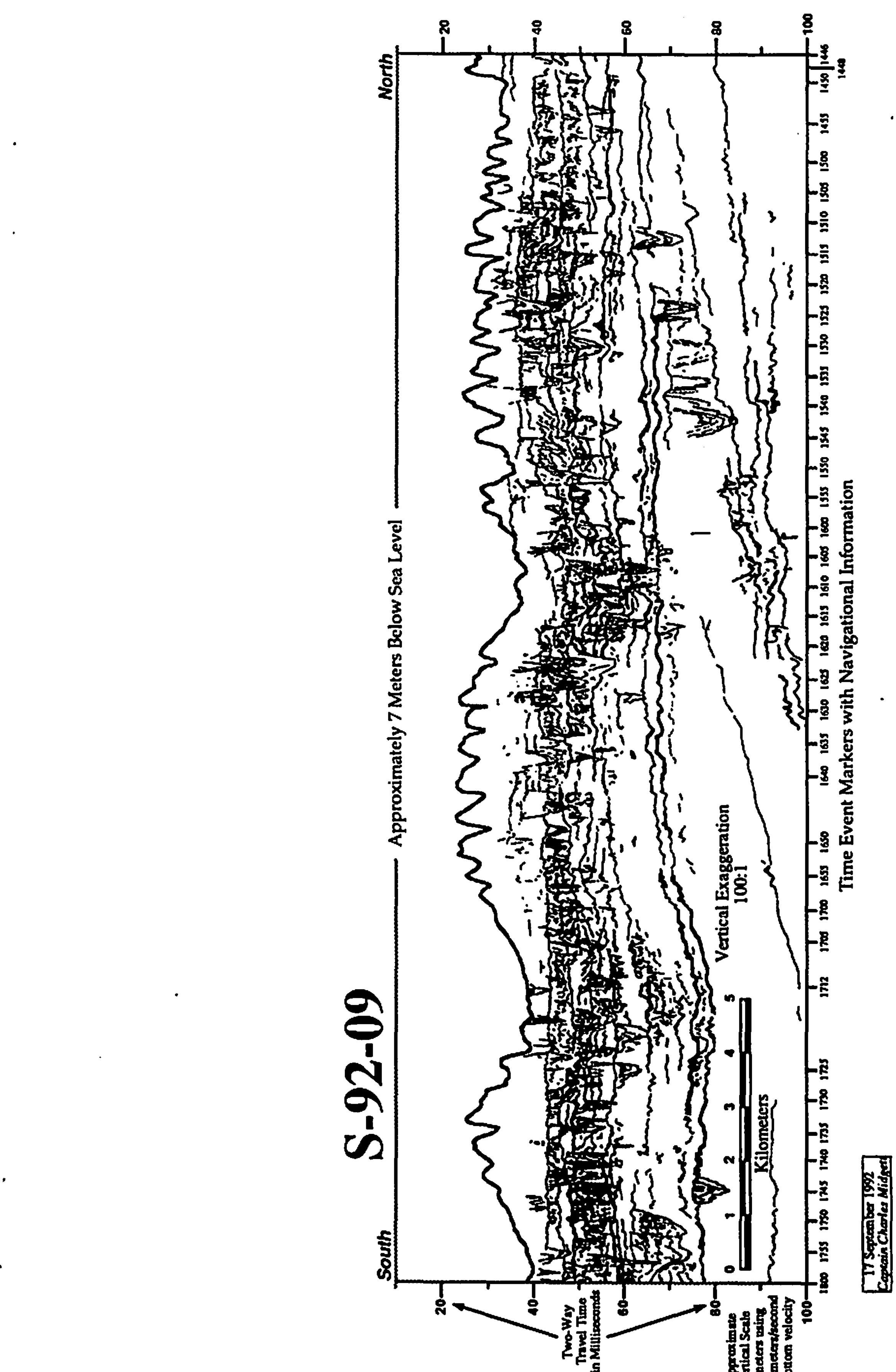
75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic Ocean
Currituck Sound
36°10'N
Sands '92
Line 08
18 June 1992
Captain Charles Midgett
1154
1156
1200
1205
1210
1215
1220
1225
1230
1235
1240
1245
1250
1255
1300
1305
1310
1315
1320
1325
1330
1335
1340
1345
1350
1355
1400
1405
1410
1415
1420
1425
1430
1435
1440
1445
1450
1455
Albemarle Sound
36°00'N
30m
Croatan Sound
35°50'N
Oregon Inlet
30m
20m
Pamlico Sound
20m
Platt Shoals
10m

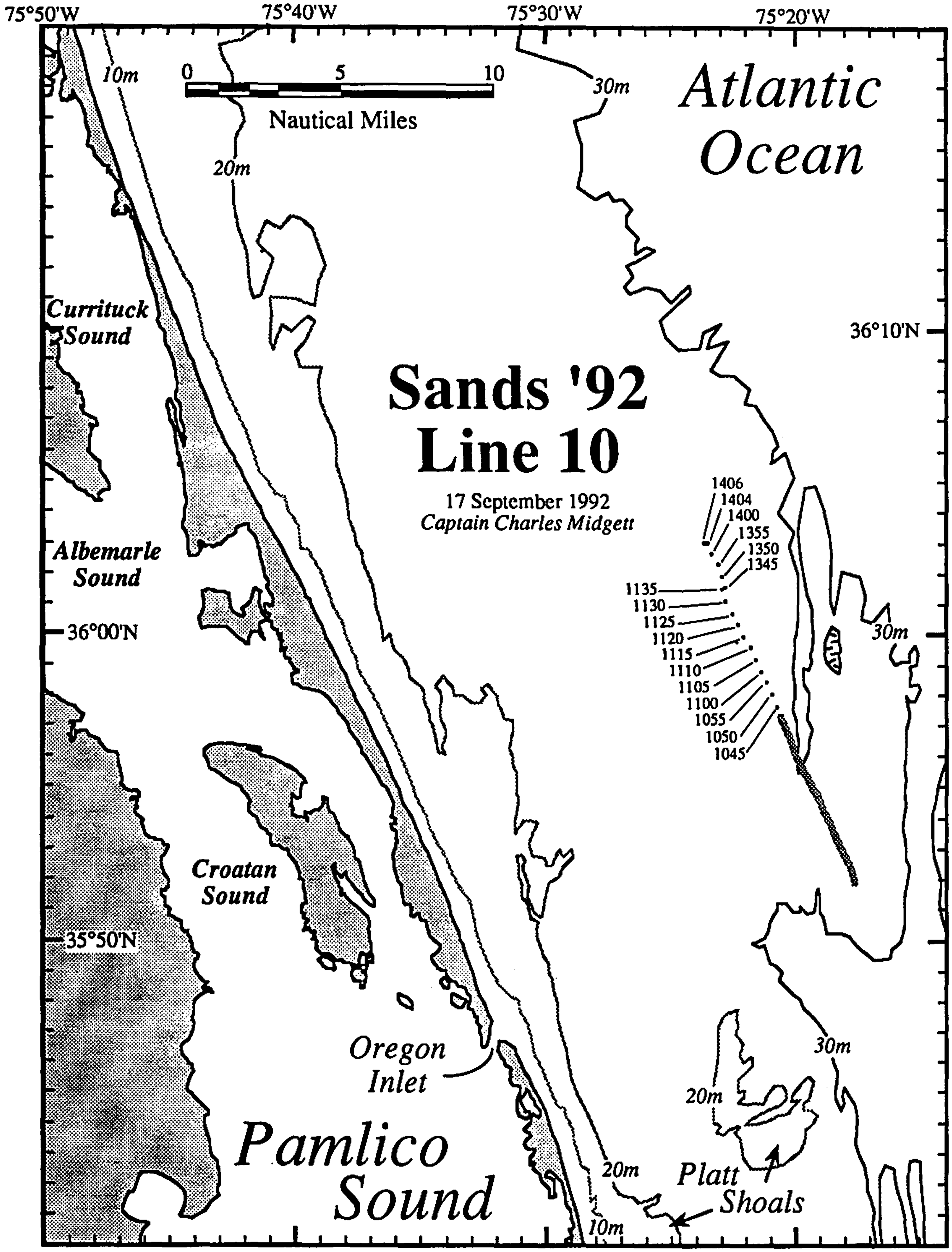
S-92-08



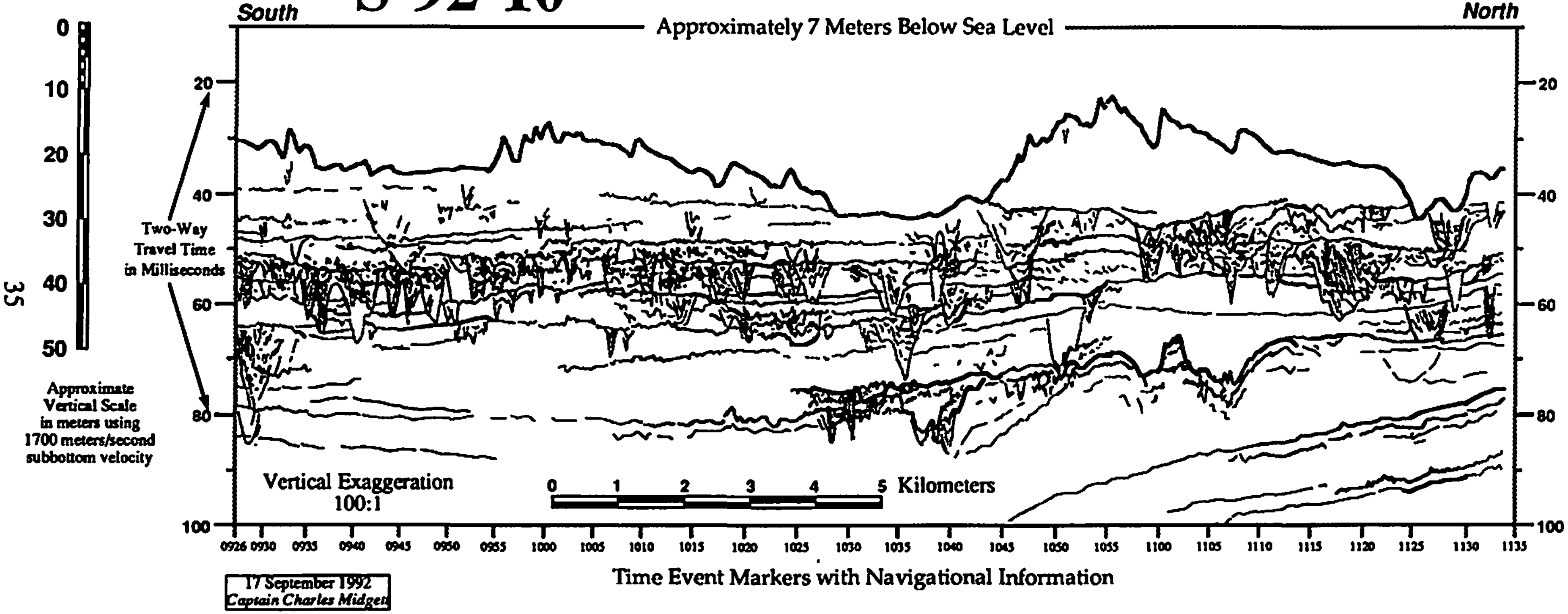
South
North
Approximately 7 Meters Below Sea Level
Two-Way Travel Time in Milliseconds
20
40
60
80
100
0
10
20
30
40
50
60
70
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Vertical Exaggeration 100:1
0 1 2 3 4 5
Kilometers
1455 1450 1445 1440 1435 1430 1425 1420 1415 1410 1405 1400 1355 1350 1345 1340 1335 1330 1325 1320 1315 1310 1305 1300 1255 1250 1245 1240 1235 1230 1225 1220 1215 1210 1205 1200 1156 1154
Time Event Markers with Navigational Information
18 June 1992
Captain Charles Midget


75°50'W
75°40'W
75°30'W
75°20'W
10m
0
5
10
Nautical Miles
30m
Atlantic
Ocean
20m
Currituck
Sound
Sands '92
Line 09
17 September 1992
Captain Charles Midgett
36°10'N
1446
1448
1450
1455
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
1650
1655
1700
1705
1712
Albemarle
Sound
36°00'N
30m
Croatan
Sound
35°50'N
Oregon
Inlet
30m
20m
Pamlico
Sound
20m
Platt
Shoals
10m

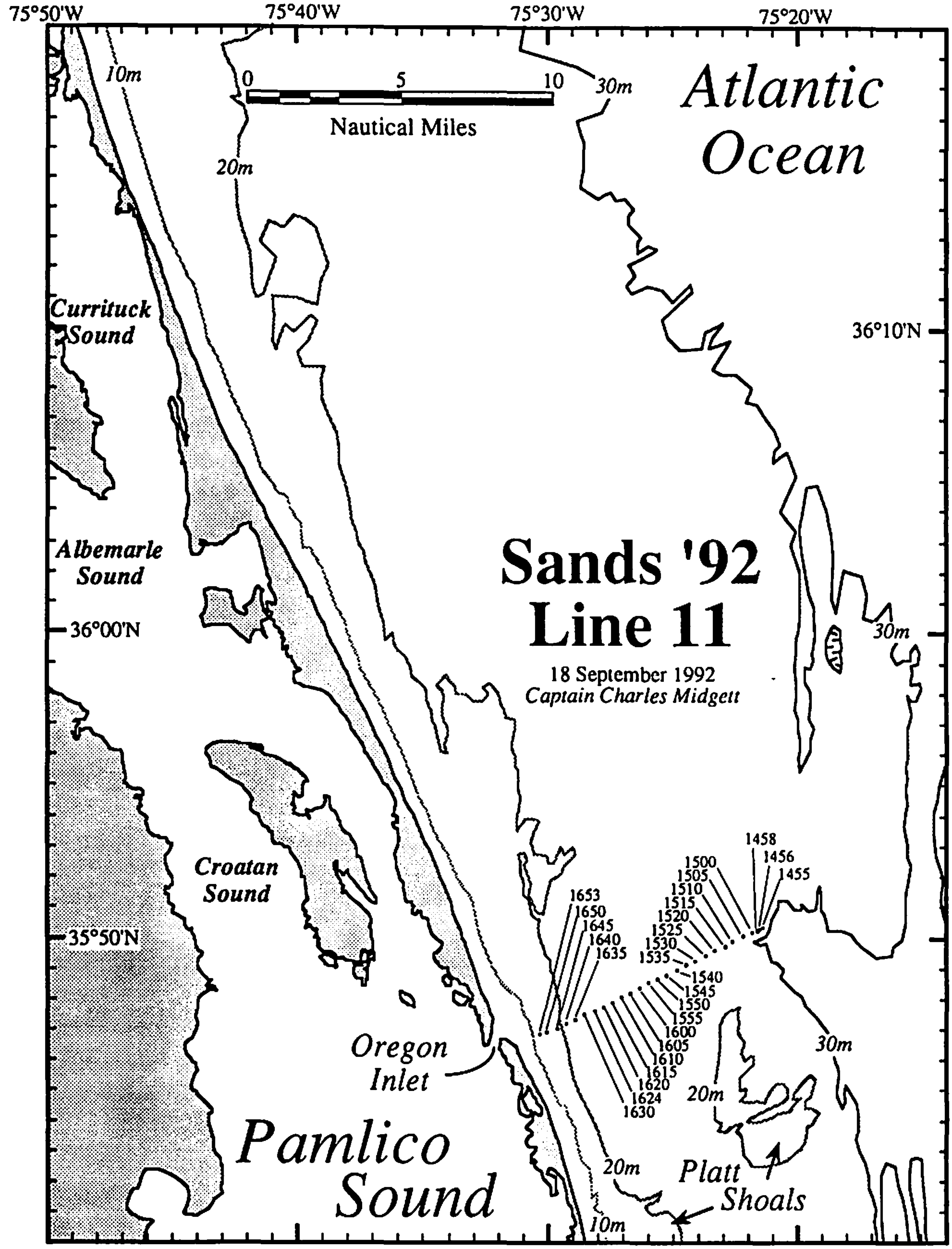

S-92-09
South
North
Approximately 7 Meters Below Sea Level
Two-Way Travel Time in Milliseconds
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Vertical Exaggeration 100:1
Kilometers
Time Event Markers with Navigational Information
17 September 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
10m
0
5
10
Nautical Miles
20m
30m
Atlantic
Ocean
Currituck
Sound
36°10'N
Sands '92
Line 10
17 September 1992
Captain Charles Midgett
1406
1404
1400
1355
1350
1345
1135
1130
1125
1120
1115
1110
1105
1100
1055
1050
1045
Albemarle
Sound
36°00'N
30m
Croatan
Sound
35°50'N
Oregon
Inlet
30m
20m
Pamlico
Sound
20m
Platt
Shoals
10m

S-92-10

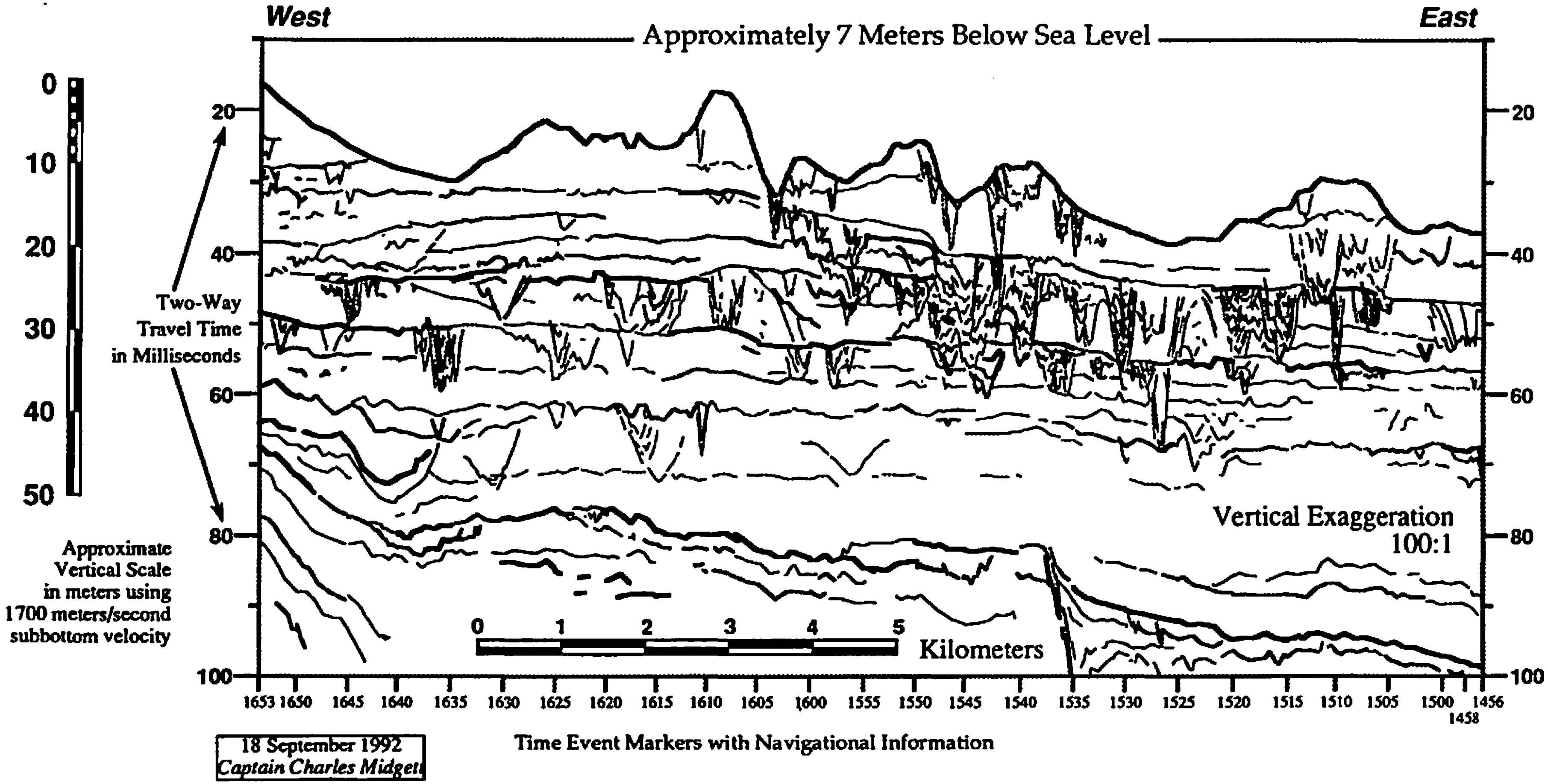


South
North
Approximately 7 Meters Below Sea Level
0
10
20
30
40
50
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Two-Way Travel Time in Milliseconds
20
40
60
80
100
Vertical Exaggeration 100:1
0 1 2 3 4 5 Kilometers
0926 0930 0935 0940 0945 0950 0955 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1100 1105 1110 1115 1120 1125 1130 1135
Time Event Markers with Navigational Information
17 September 1992
Captain Charles Midgett

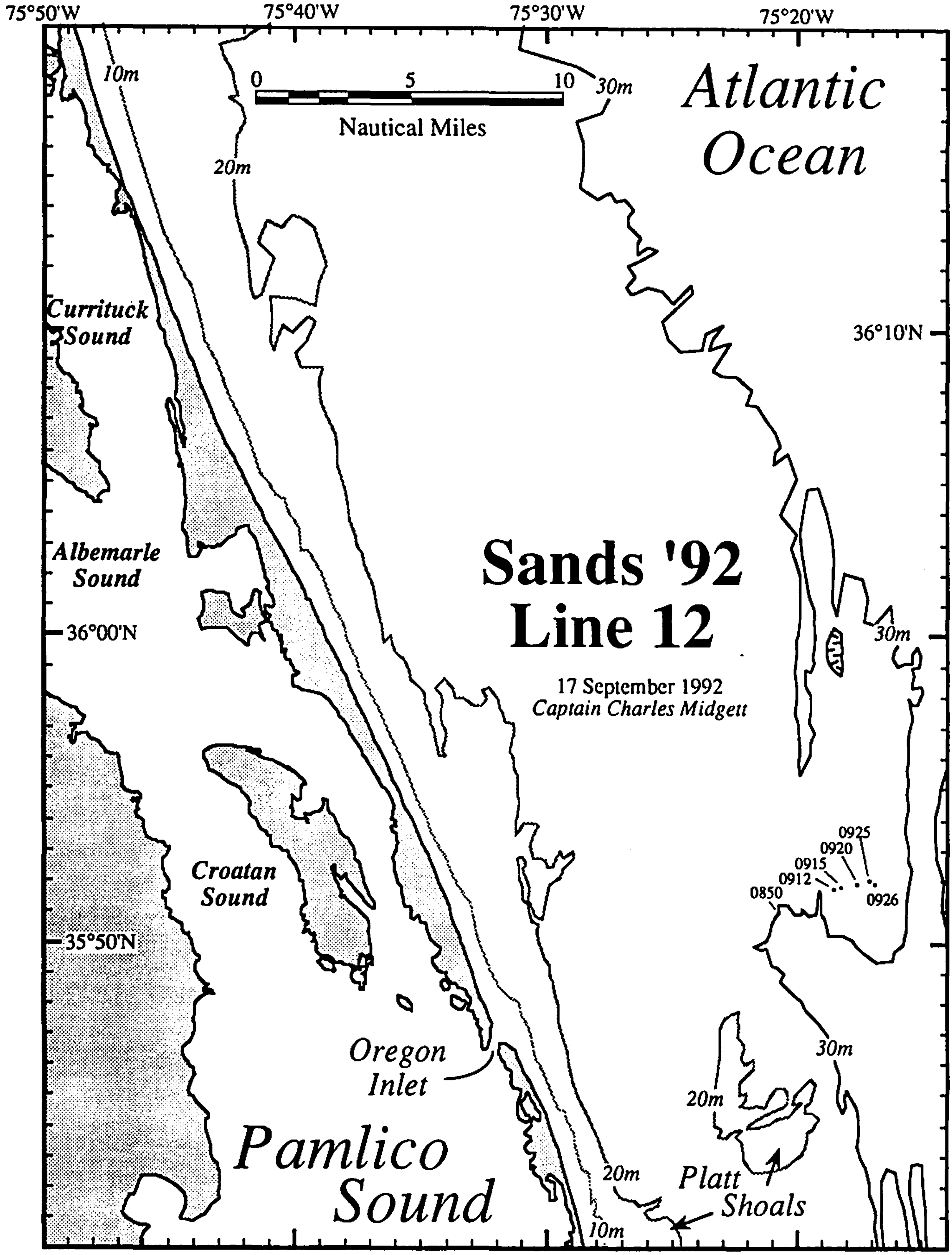


75°50'W
75°40'W
75°30'W
75°20'W
36°10'N
36°00'N
35°50'N
0
5
10
Nautical Miles
Atlantic Ocean
Sands '92
Line 11
18 September 1992
Captain Charles Midgett
Currituck Sound
Albemarle Sound
Croatan Sound
Pamlico Sound
Oregon Inlet
Platt Shoals
10m
20m
30m
1458
1456
1455
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555
1600
1605
1610
1615
1620
1624
1630
1635
1640
1645
1650
1653

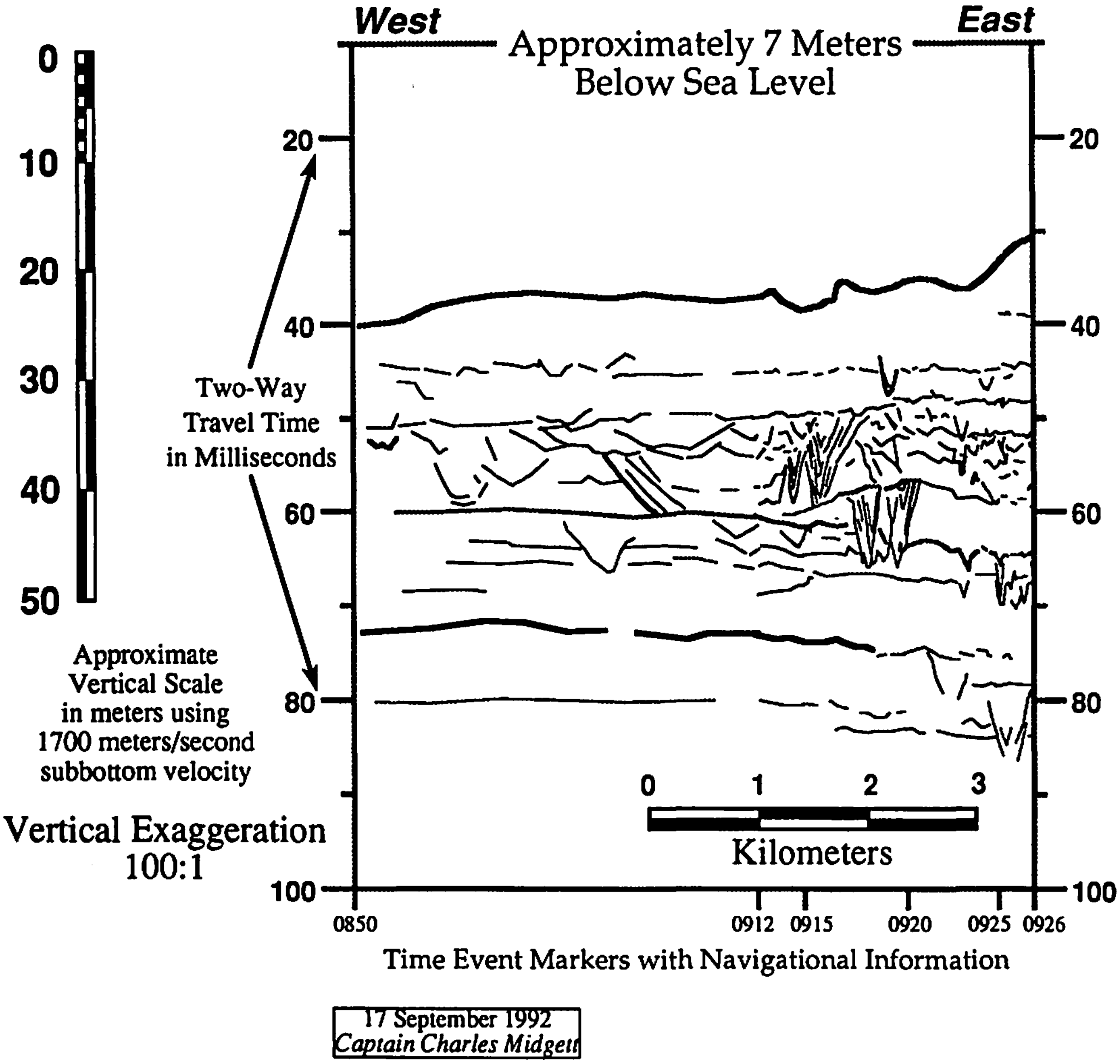
S-92-11

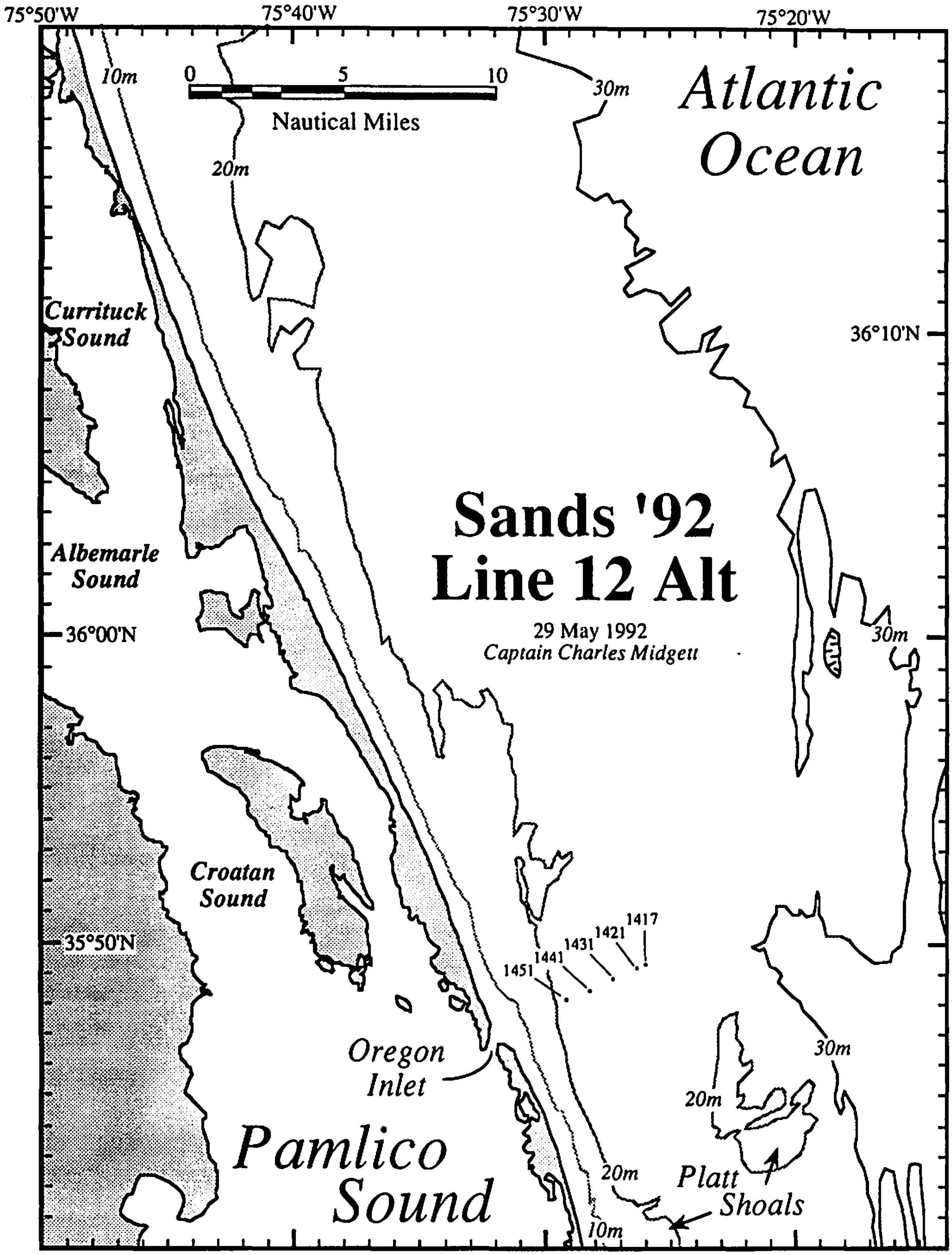


West
East
Approximately 7 Meters Below Sea Level
Two-Way Travel Time in Milliseconds
20
40
60
80
100
0
10
20
30
40
50
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Vertical Exaggeration 100:1
0 1 2 3 4 5 Kilometers
1653 1650 1645 1640 1635 1630 1625 1620 1615 1610 1605 1600 1555 1550 1545 1540 1535 1530 1525 1520 1515 1510 1505 1500 1458 1456
Time Event Markers with Navigational Information
18 September 1992
Captain Charles Midgett

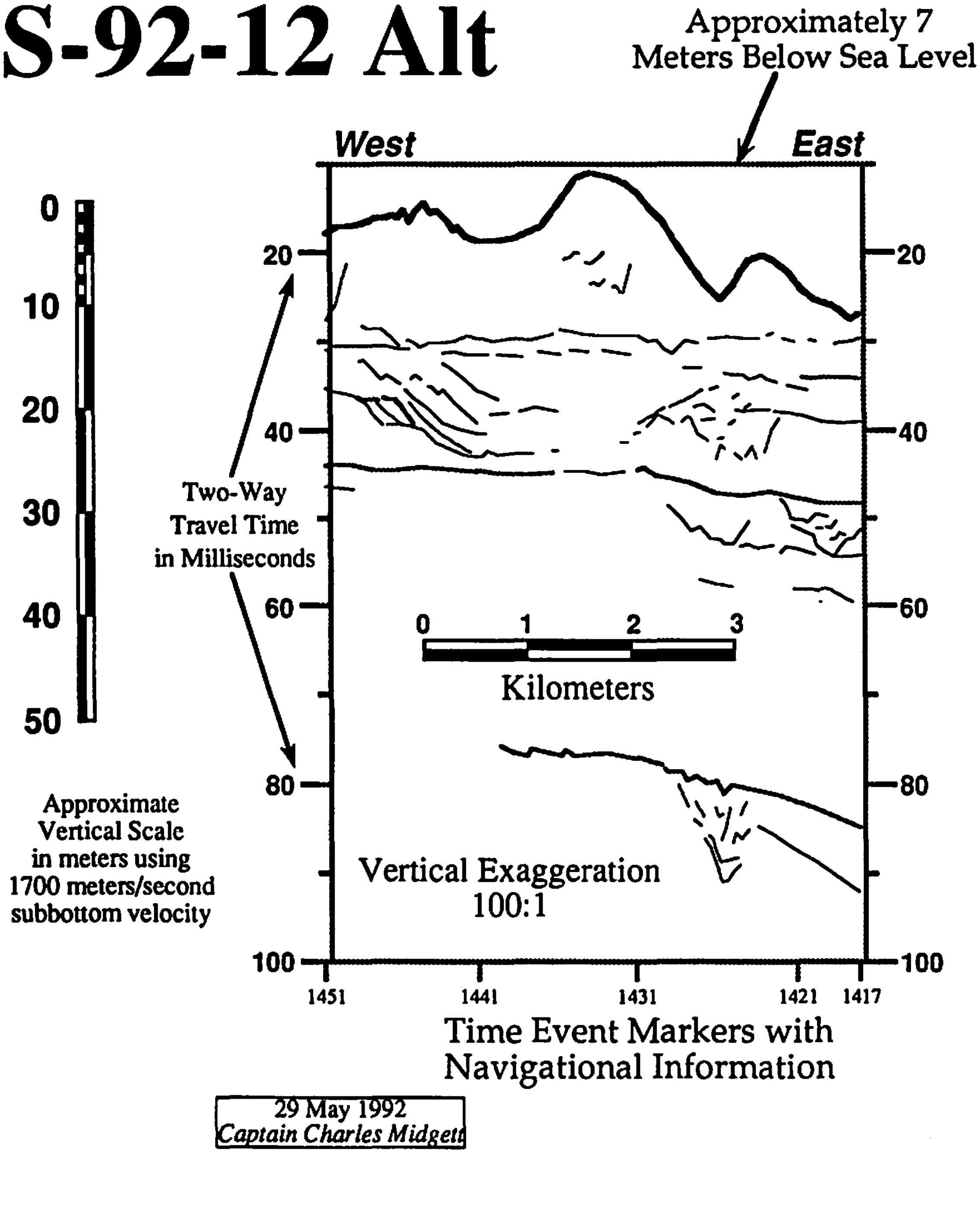

75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic Ocean
Currituck Sound
36°10'N
Albemarle Sound
Sands '92
Line 12
36°00'N
30m
17 September 1992
Captain Charles Midgett
Croatan Sound
0925
0920
0915
0912
0850
0926
35°50'N
Oregon Inlet
30m
20m
Pamlico Sound
20m
Platt Shoals
10m

S-92-12

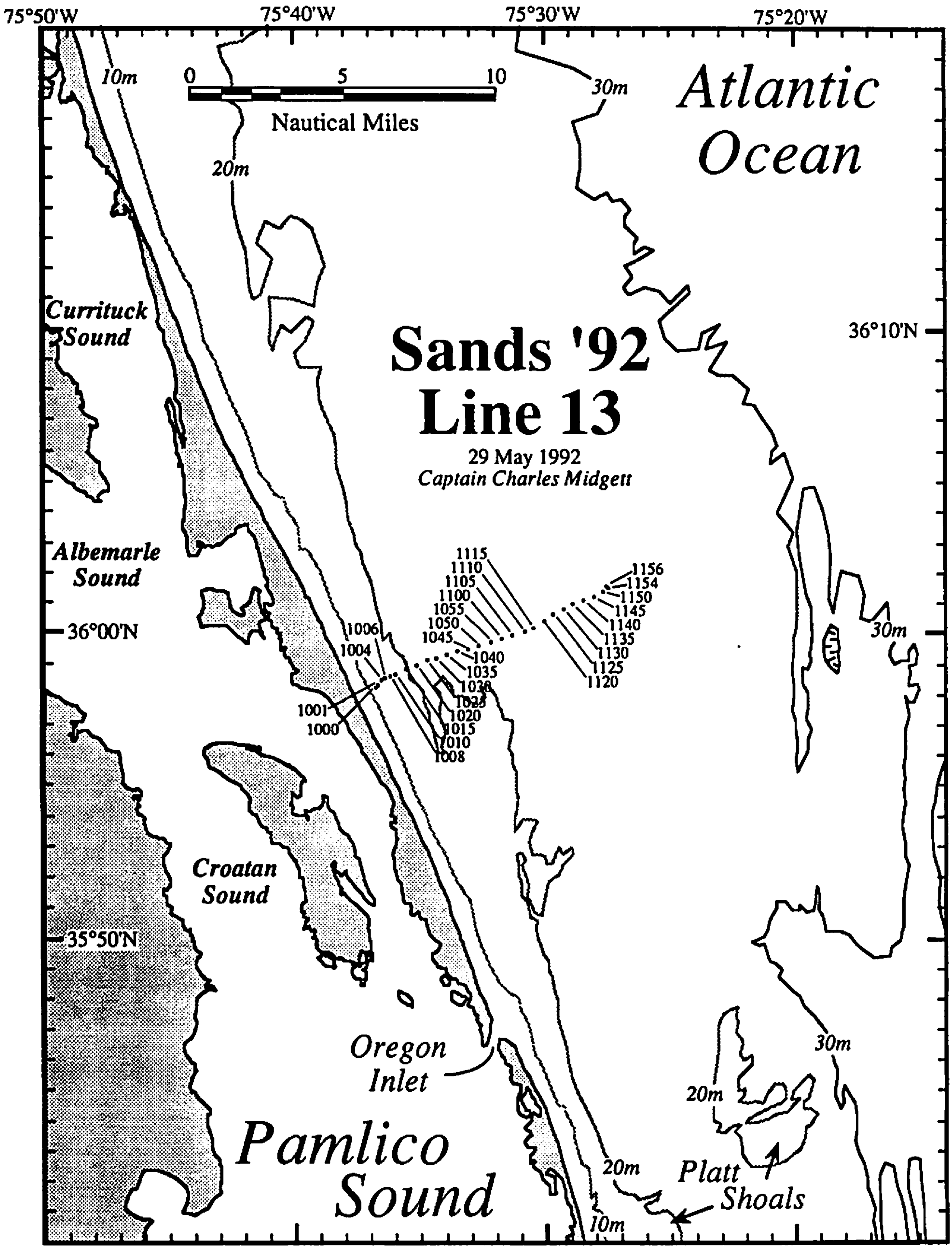

West
East
Approximately 7 Meters
Below Sea Level
0
10
20
30
40
50
Approximate
Vertical Scale
in meters using
1700 meters/second
subbottom velocity
Vertical Exaggeration
100:1
Two-Way
Travel Time
in Milliseconds
20
40
60
80
100
0 1 2 3
Kilometers
0850
0912 0915
0920
0925 0926
Time Event Markers with Navigational Information
17 September 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
36°10'N
36°00'N
35°50'N
0
5
10
Nautical Miles
10m
20m
30m
Atlantic Ocean
Sands '92
Line 12 Alt
29 May 1992
Captain Charles Midgett
Currituck Sound
Albemarle Sound
Croatan Sound
1417
1421
1431
1441
1451
Oregon Inlet
Pamlico Sound
Platt Shoals

S-92-12 Alt

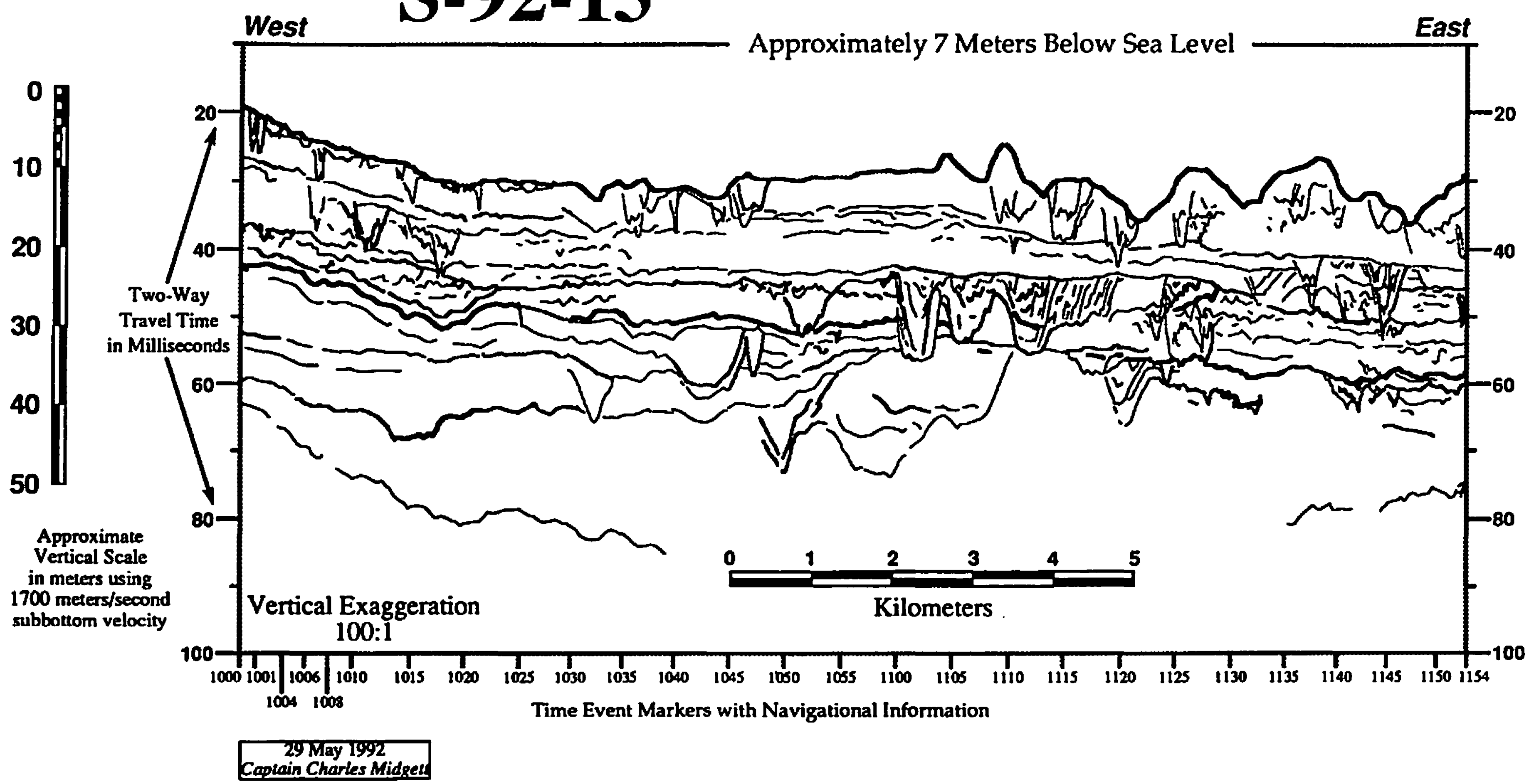


Approximately 7
Meters Below Sea Level
West
East
0
10
20
30
40
50
Approximate
Vertical Scale
in meters using
1700 meters/second
subbottom velocity
Two-Way
Travel Time
in Milliseconds
20
40
60
80
100
0
1
2
3
Kilometers
Vertical Exaggeration
100:1
1451
1441
1431
1421
1417
Time Event Markers with
Navigational Information
29 May 1992
Captain Charles Midgett

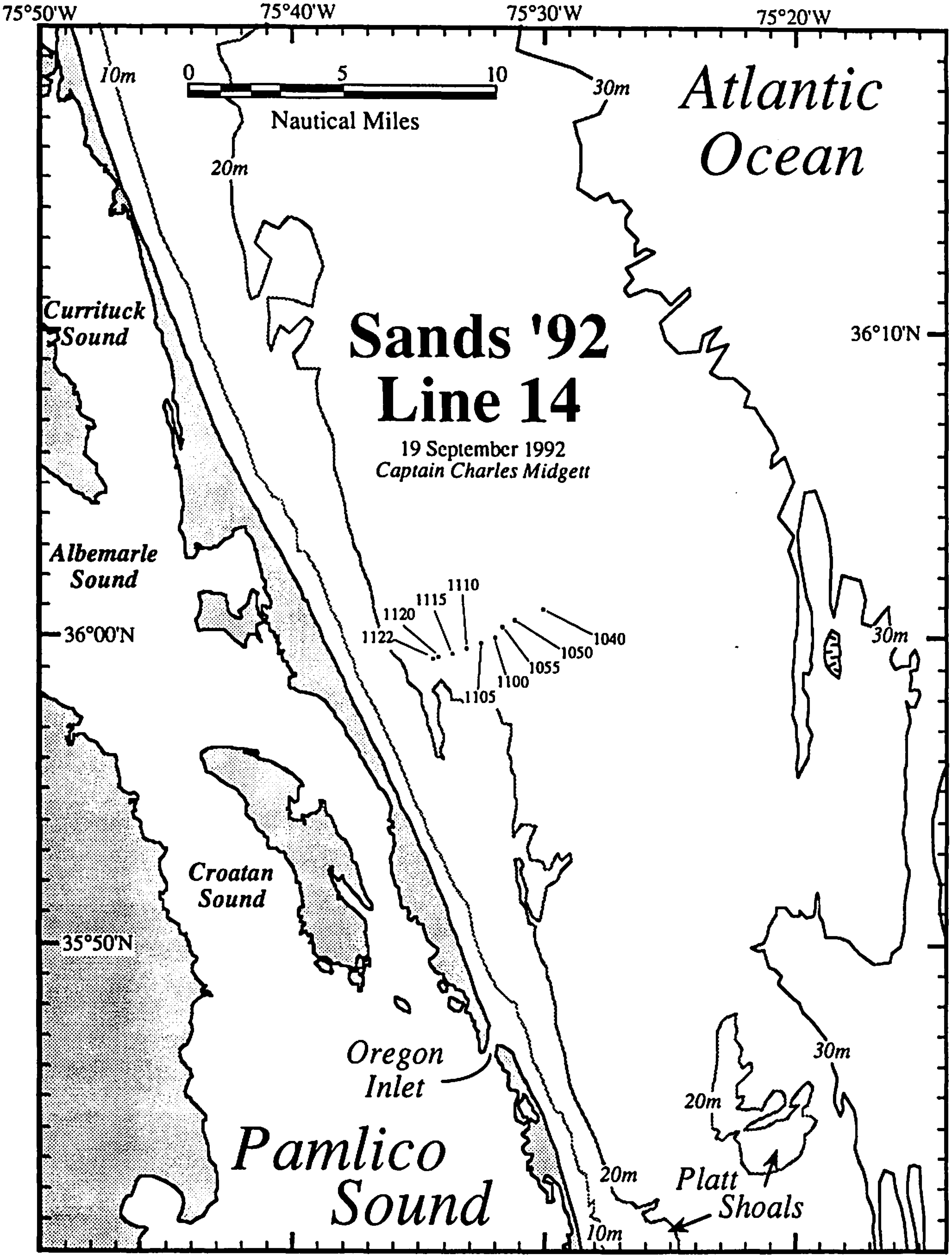


75°50'W
75°40'W
75°30'W
75°20'W
Atlantic Ocean
0
5
10
Nautical Miles
10m
20m
30m
Sands '92
Line 13
29 May 1992
Captain Charles Midgett
36°10'N
Currituck Sound
Albemarle Sound
36°00'N
1115
1110
1105
1100
1055
1050
1045
1040
1035
1030
1025
1020
1015
1010
1008
1006
1004
1001
1000
1156
1154
1150
1145
1140
1135
1130
1125
1120
30m
Croatan Sound
35°50'N
Oregon Inlet
Pamlico Sound
20m
10m
30m
20m
Platt Shoals

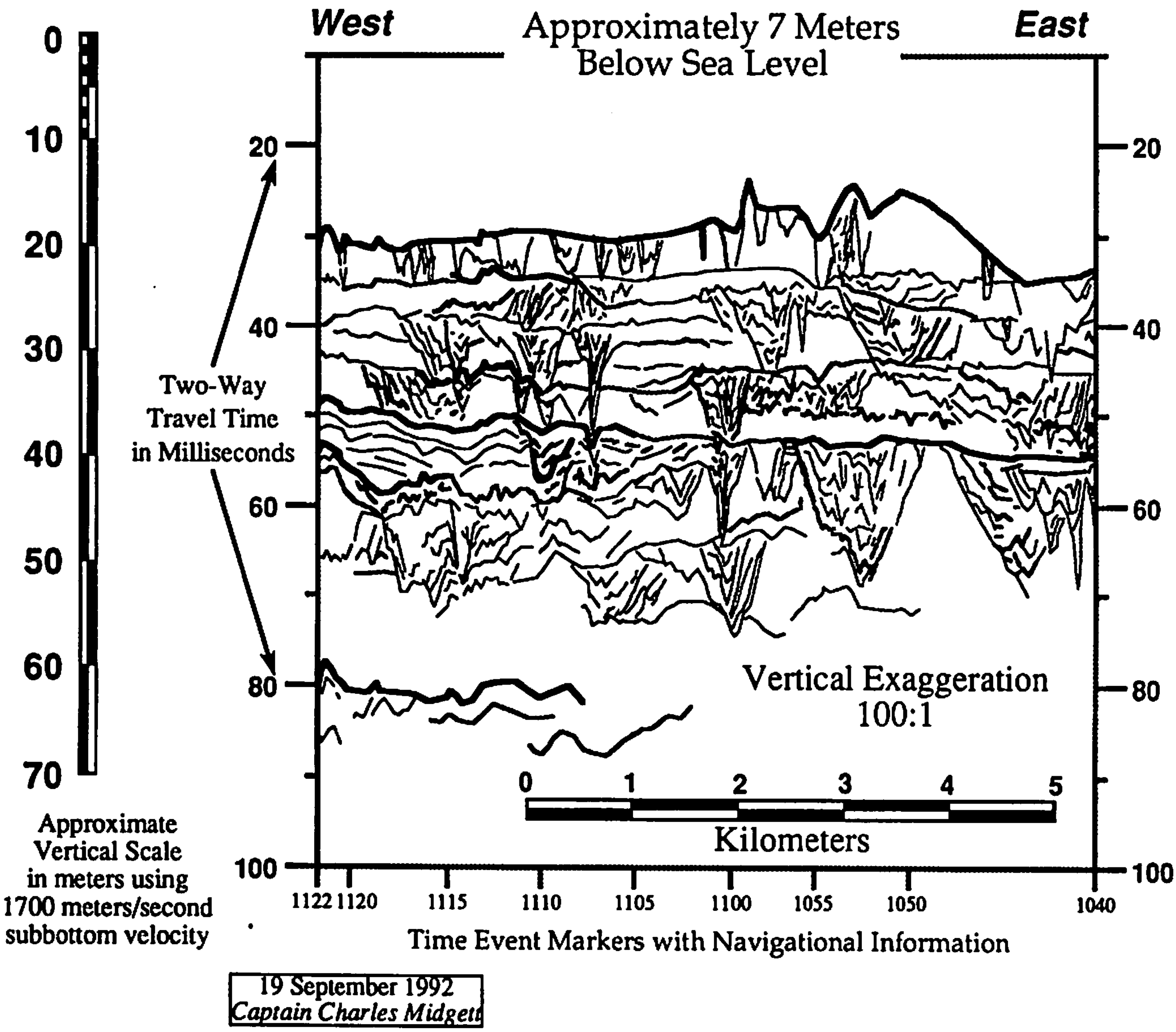
S-92-13



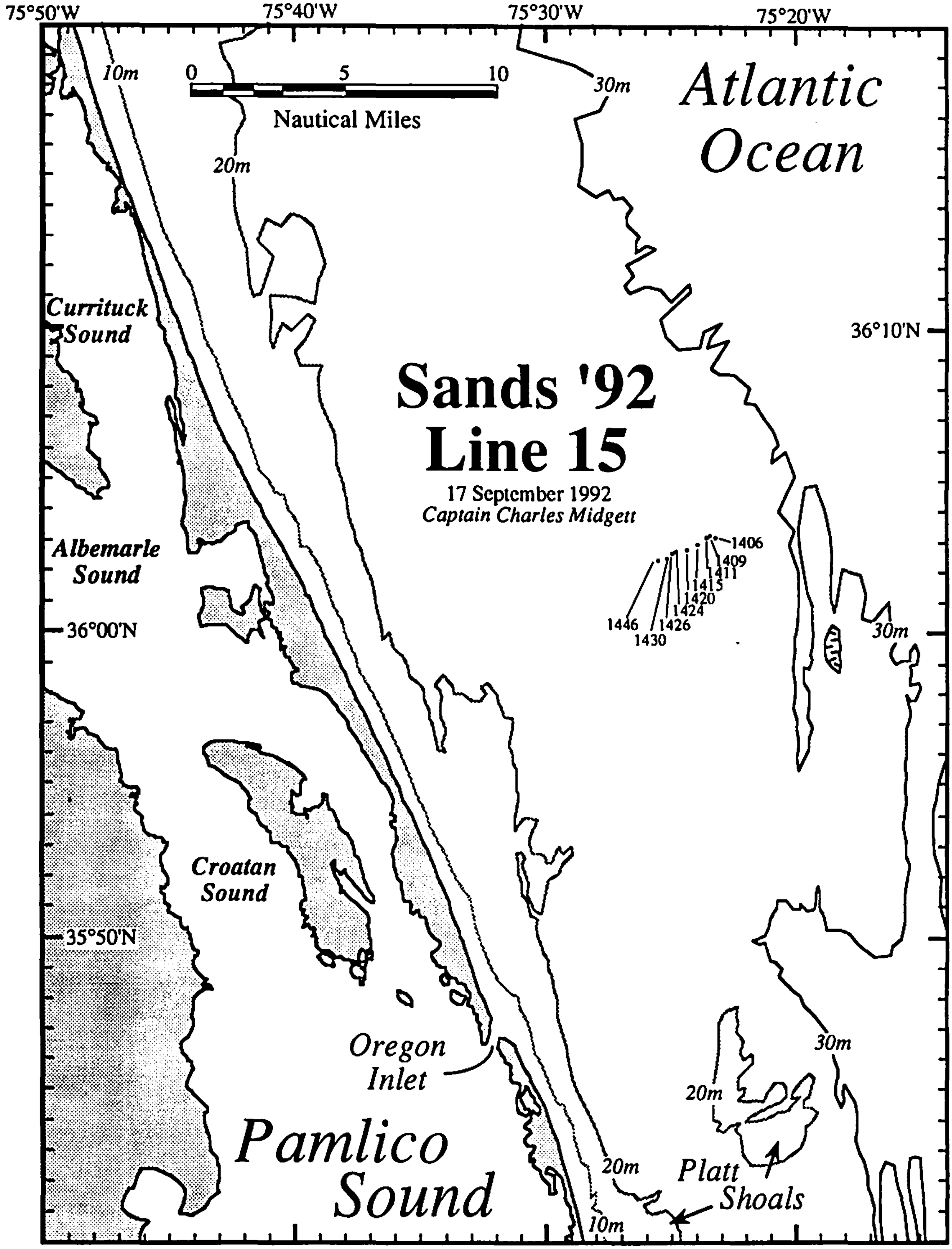
West
East
Approximately 7 Meters Below Sea Level
20
40
60
80
100
Two-Way Travel Time in Milliseconds
0
10
20
30
40
50
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Vertical Exaggeration 100:1
0 1 2 3 4 5
Kilometers
1000 1001 1004 1006 1008 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1154
Time Event Markers with Navigational Information
29 May 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic
Ocean
Sands '92
Line 14
19 September 1992
Captain Charles Midgett
36°10'N
Currituck
Sound
Albemarle
Sound
36°00'N
1110
1115
1120
1122
1105
1100
1055
1050
1040
Croatan
Sound
35°50'N
Oregon
Inlet
Pamlico
Sound
Platt
Shoals

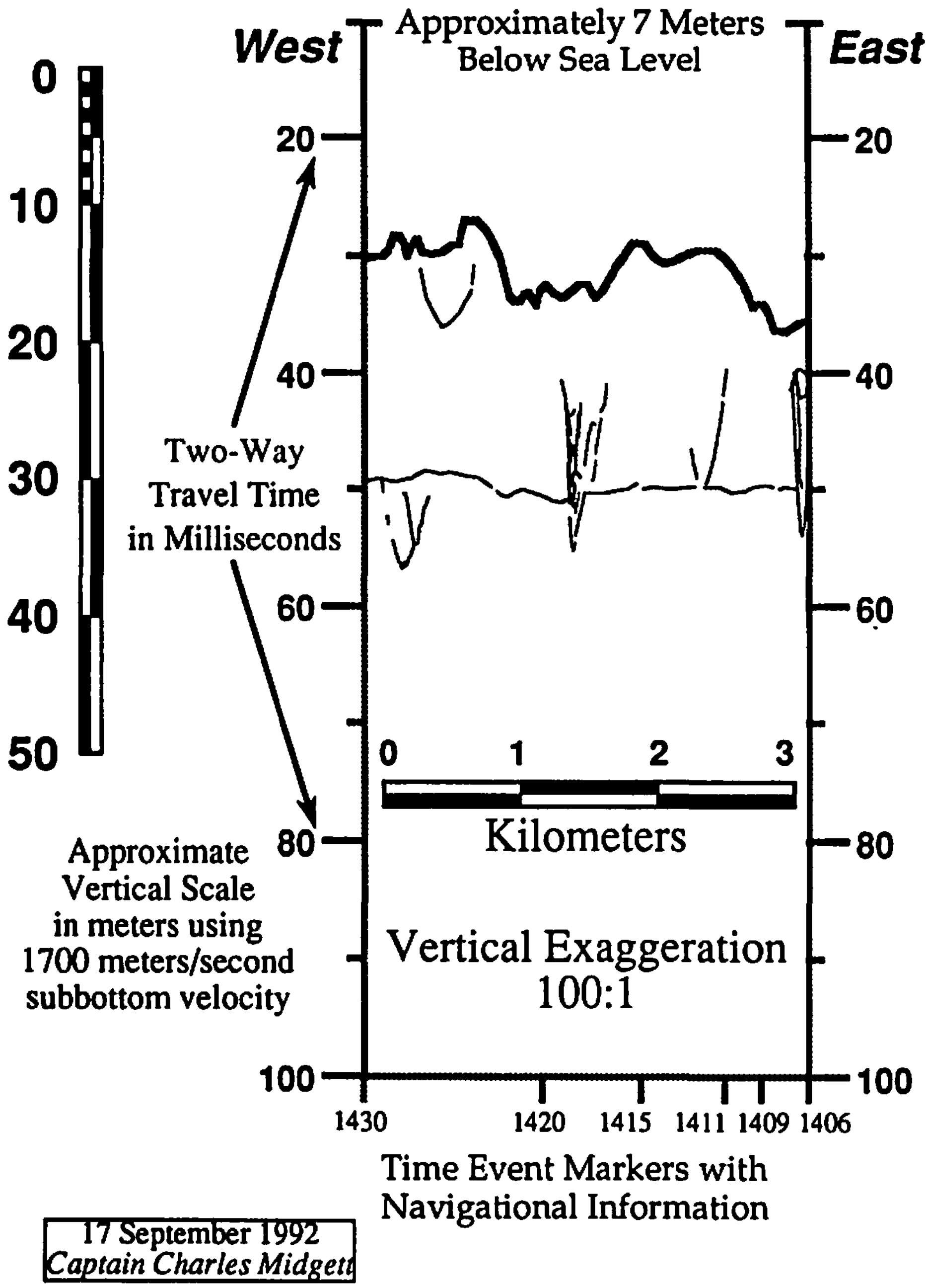
S-92-14



West
Approximately 7 Meters Below Sea Level
East
0
10
20
30
40
50
60
70
Approximate Vertical Scale in meters using 1700 meters/second subbottom velocity
Two-Way Travel Time in Milliseconds
20
40
60
80
100
Vertical Exaggeration 100:1
0 1 2 3 4 5
Kilometers
1122 1120 1115 1110 1105 1100 1055 1050 1040
Time Event Markers with Navigational Information
19 September 1992
Captain Charles Midgett


75°50'W
75°40'W
75°30'W
75°20'W
0
5
10
Nautical Miles
10m
20m
30m
Atlantic Ocean
Currituck Sound
Sands '92
Line 15
17 September 1992
Captain Charles Midgett
1406
1409
1411
1415
1420
1424
1426
1430
1446
36°10'N
Albemarle Sound
36°00'N
30m
Croatan Sound
35°50'N
Oregon Inlet
30m
20m
Pamlico Sound
20m
Platt Shoals
10m

S-92-15



0
10
20
30
40
50
West
Approximately 7 Meters
Below Sea Level
East
20
40
60
80
100
Two-Way
Travel Time
in Milliseconds
0 1 2 3
Kilometers
Vertical Exaggeration
100:1
Approximate
Vertical Scale
in meters using
1700 meters/second
subbottom velocity
1430 1420 1415 1411 1409 1406
Time Event Markers with
Navigational Information
17 September 1992
Captain Charles Midgett

The Geological Survey Section examines, surveys, and maps the geology, mineral resources, and topography of the state to encourage the wise conservation and use of these resources by industry, commerce, agriculture, and government agencies for the general welfare of the citizens of North Carolina.

The Section conducts basic and applied research projects in environmental geology, mineral resource exploration, and systematic geologic mapping. Services include identifying rock and mineral samples submitted by citizens and providing consulting services and specially prepared reports to agencies that need geological information.

The Geological Survey Section publishes Bulletins, Economic Papers, Information Circulars, Educational Series and Geologic maps. For a list of publications or more information about the Section, contact the Geological Survey Section, Division of Land Resources, at Post Office Box 27687, Raleigh, North Carolina 27611-7687 or call (919) 733-2423.

Jeffrey C. Reid
Chief Geologist