

# Regional Geophysical Survey and Interpretive Report: Virginia Wind Energy Area Offshore Southeastern Virginia



US Department of the Interior  
Bureau of Ocean Energy Management  
Office of Renewable Energy Programs



# **Regional Geophysical Survey and Interpretive Report: Virginia Wind Energy Area Offshore Southeastern Virginia**

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Prepared under BOEM Cooperative Agreement  
M12AC00023  
and Virginia Department of Mining, Minerals, and Energy  
C13-6030

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**US Department of the Interior  
Bureau of Ocean Energy Management  
Office of Renewable Energy Programs  
November, 2013**



## DISCLAIMER

Funding was provided by the US Department of the Interior, Bureau of Ocean Energy Management, Washington, DC, under Cooperative Agreement M12AC00023. This project was part of a cooperative agreement with the Commonwealth of Virginia, Department of Mines, Minerals, and Energy and was jointly funded with contributions from Fugro Atlantic. This report has been technically reviewed by BOEM and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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## CITATION

McNeilan, T.W., K.R. Smith, and J.E. Fisher. 2013. Regional Geophysical Survey and Interpretive Report: Virginia Wind Energy Area Offshore Southeastern Virginia. US Dept. of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Herndon. OCS Study BOEM 2013-220. 240 pp.



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## EXECUTIVE SUMMARY

### PROJECT DESCRIPTION

Fugro Consultants, Inc. (Fugro) has prepared this Regional Geophysical Survey and Interpretive Report to provide information to aid development of the Virginia offshore Wind Energy Area (WEA) located offshore southeastern Virginia. The WEA is a rectangular-shaped area that is approximately five blocks wide (east-west direction) by four blocks long (north-south direction). It is approximately 28 kilometers (km) by 17km [15 nautical miles (Nm) by 9 Nm] in dimension and encompasses approximately 476 km<sup>2</sup> (135 Nm<sup>2</sup>). The western boundary of the WEA is located about 45 km (24.5 Nm) from Cape Henry, Virginia Beach.

The WEA is located on the Outer Continental Shelf (OCS), where the development will be regulated by the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM). BOEM considers the Atlantic OCS a *Frontier Area*, since there has been no historical energy development on the Atlantic OCS. Thus, there is no historical record of how structures have performed and the subsurface conditions and engineering properties of the subsurface sediments are poorly defined.

Because there has never been historical (energy) development on the Atlantic OCS, this regional geophysical survey has been conducted to advance the state of knowledge relative to the geologic and subsurface conditions in the WEA. Therefore, the regional geophysical survey will provide critical information towards the objectives of: a) optimizing potential demonstration wind turbine generators (WTGs) and met tower locations, b) accelerating such installations, c) providing insight to seafloor and subsurface variability in the WEA, d) defining how the conditions and variability will affect substructure and foundation optimization and standardization, e) serializing fabrication and production economics, and f) ultimately to accelerate leasing and development of the Virginia WEA.

The regional geophysical survey includes 1) a grid of widely-spaced, regional survey lines across the WEA (20 primary lines oriented northeast-southwest, and 9 tie lines oriented northwest-southeast), 2) a tighter-spaced grid of survey lines across the southern pair of potential Research Lease No. 1 met tower aliquots, and 3) tie lines from the WEA to the Chesapeake Light Tower (CLT) and entrance to Chesapeake Bay Bridge Tunnel (CBBT) alignment. The regional geophysical survey lines are important to interpret the regional subsurface conditions with the aid of existing data (i.e., geotechnical borings conducted for the CLT and CBBT).

Along with the regional geophysical survey, Fugro has previously completed a geosciences-focused literature review (subsequently referred to as the Desktop Study) as part of this regional study. The Desktop Study (provided under separate cover) accumulated, synthesized, and presented information as gleaned and extracted from existing data sources. The results of the study help to define and understand the seafloor and subsurface conditions and to plan the proposed regional geophysical survey. The data sources include both public data sources and proprietary data from Fugro and our client's files. From that information, the



desktop study helped the preliminary determination 1) if site and subsurface conditions pose hazards to future project development, and 2) of how the site and subsurface conditions could affect structure foundation-type selection, design, and installation.

Additional hydrographic data within the WEA were made available by the National Oceanic and Atmospheric Administration (NOAA). These data were acquired in 2011 and 2012 using high-resolution multibeam bathymetry systems and covered the entire WEA. Therefore, these data allowed for direct comparison with Fugro's multibeam data to assess seafloor morphology (and potential sediment transport/scour geohazards) within the WEA. The ability to analyze both of these datasets not only represents an invaluable component for this project, but also an unique opportunity to discuss and illustrate potential seafloor morphology issues within the Atlantic OCS in general with a higher degree of certainty.

The regional geophysical survey and DTS are funded by: a) the Virginia Department of Mines, Minerals and Energy (DMME), b) the U.S. Department of Interior Bureau of Ocean Energy Management (BOEM), and c) Fugro Consultants, Inc. (Fugro). Fugro's authorization for the regional geologic survey of the WEA is provided by DMME Agreement Number: C13-6030, dated March 2013.

## **SEAFLOOR AND SUBSURFACE CONDITIONS**

The foundations of an offshore wind farm are typically 20 to 30 percent of the total cost of the project. An early appreciation of the seafloor and subsurface conditions and their affect on foundation design, installation, and cost is an important component of the development of offshore wind energy. European project experience has documented the importance of subsurface conditions and geotechnical engineering for offshore wind development.

### **Water Depth, Bathymetry, and Seafloor Morphology**

The bathymetry in the WEA regionally slopes from west to east. The area includes local topography that produces water depth variation in an OCS block often greater than the regional variation across multiple OCS blocks. The local topographic variations, or seafloor morphology, are due to: 1) relict geologic features associated with sea level low stands and subsequent sea level transgression, and 2) active sediment transport processes driven by waves and storm currents.

The water depth within the WEA area ranges from about 18 to 41 meters (59 to 135 feet) Mean Lower Low Water (MLLW). The shallowest water depths exist on 1) the sand ridges along the northwestern and western regions of the WEA (OCS blocks 6012, 6013, 6062, 6063), and 2) the shoal retreat massif (ridge complexes) in the southern region of the WEA (OCS blocks 6064, 6065, 6113, 6114, 6115, 6116, 6162, 6163, 6164, 6165, and 6166). Water depths in those areas are locally between 60 and 100 feet (18 to 30 meters) deep MLLW.

The deepest water depth areas generally occur in the adjacent troughs of the ridges. Within the northern/northwestern area, the troughs have water depths of ranging from approximately 32 to 36 meters (105 to 118 feet) MLLW, while troughs within the shoal complex

vary from 30 to 34 meters (98 to 112 feet) MLLW. The deepest water depths in the WEA are in the northeastern/eastern section (OCS blocks 6016, 6066 and 6116) within a trough where the water depths range from approximately 30 to 41 meters (98 to 135 feet) MLLW. Within the troughs, linear features are often found with steep slopes (typically between 5 and 7 degrees). These features could be relict geologic features influenced by modern hydrodynamic (bottom current) conditions.

The seafloor features in the WEA includes ridge and swale topography common to the Mid-Atlantic shelf, as well as a shoal retreat massif. Sand ridges within the WEA generally extend up 10s to 100s of meters in length with widths ranging from 10s to 100s of meters (potentially up to several kilometers in width and length if associated with the shoal retreat massif). Sand ridge relief ranges from 4 to 10 meters.

Crest lines and trough axes climb obliquely southwest across the shelf. Most of the ridges form a small acute angle with the coastline open to the north. Seaward flanks of the sand ridges are generally steeper than the landward flanks, especially for ridges in the central and southern WEA. In these areas, the steeper seaward flanks have a slope ranging between 1 and 4 degrees while the landslide flanks are generally less 1.5 degrees (and most often less than 0.5 degrees).

In general, these ridges are postulated to be relic shoreface deposits (geologic features) abandoned as the shoreline transgressed during the last rise in sea level. However, present-day hydrodynamic conditions driving sediment transport also influence the morphology of the ridges. For example, the steeper seaward flanks for ridges in deeper waters suggest net sediment transport in the seaward direction. This morphology supports the hypothesis that infrequent and strong storm events drive sediment transport by eroding sediment from the landward flanks and depositing sediment on the seaward flanks.

A shoal retreat massif is also present within the WEA. These features are broad areas with topographic relief related to former positions of estuary mouths. Near the estuary mouth, littoral drift converges on one or both sides of the estuary to create levee-like highs. This process occurs as the estuary retreats during transgression and creates the massifs. Shoal retreat massifs typically have broader, flatter crests than the sand ridges and their axes exhibit more curvature than the sand ridges. Within the WEA, the dimensions of these features vary, with amplitudes ranging from several meters to greater than 10 meters, and lengths on the order of 100s of meters to several kilometers.

The seafloor morphology consists of the migration of bedforms (dunes) and the construction/destruction of dunes and smaller sand ridges. For example, in the western and northern sections of the WEA, the seafloor is irregular (rough bottom topography) consisting of sand ridges and superimposed bedforms (dunes). The smaller-scale bedforms (which are found throughout the WEA) show evidence of active sediment transport (e.g., dune migration). There is also evidence of features eroding (change in areal extent and/or volume). Therefore, in these areas the seafloor is more frequently modified by bottom currents and waves of various speed, direction, and duration. These conditions were confirmed based on the comparison of NOAA multibeam data sets (2011 and 2012) and Fugro's multibeam data (2013).

## Subsurface Conditions

This regional geophysical survey provides the initial step for developing a geologic framework within the WEA. Information acquired and interpreted during this study reveal much information regarding the seafloor and subsurface conditions. Our subsurface characterization is based on a conceptual understanding of the geologic history of the continental shelf, detailed seafloor mapping data, and high-resolution subsurface seismic data.

The upper portion of the subsurface stratigraphy is interpreted to be composed of late Pleistocene and Holocene sediments. Variability of the subsurface conditions are most influenced by the presence, or absence, of buried, relict drainage systems and clay-filled paleochannels or “back-barrier” estuary (typically fine-grained) deposits. The back-barrier features are broad, elongated to semi-circular, and extend up to about 18 meters below the seafloor in areas. Their seismic stratigraphic character suggests they may be comprised of fine-grained and interbedded deposits.

Several subsurface ancestral river systems, and their associated tributaries, have been mapped in the vicinity of the WEA. This is typical of the conditions off the Mid-Atlantic shelf. The youngest generation (Cape Charles Channel) of the paleo-Susquehanna River drainage has been mapped to the northwest of the WEA. The geophysical data collected during this study indicate that the main stem of the Cape Charles Channel does not pass through the WEA and is likely located an unknown distance to the north. The geophysical data revealed numerous channel features throughout the WEA. One large channel complex was mapped from the center of the WEA to the northeast corner. That channel complex appears to be about 12 to 16 meters deep and likely connected to the Cape Charles Channel during the last sea level lowstand.

Within paleochannel systems, considerable lateral and vertical variations in soil stratigraphy should be expected. Alternating layers of clay and silty sand, or interbedded clay and sand, will have variable thicknesses and lateral extents. In some instances, fine-grained layer thickness could be significant over considerable distances, while other layers may be laterally discontinuous and vary in thickness.

We identified back-barrier deposits that represent sequences of Transgressive deposits that are thicker than the laterally adjacent, equivalent deposits. Geologic models presented in the desktop study agree well with data collected during this study and from recent NOAA surveys. Together, the seismic, multibeam, and side scan sonar data area used to delineate back barrier deposits that are 20 to 50 percent thicker than the laterally adjacent, time-equivalent deposits in the WEA and likely contained fine-grained deposits.

Tertiary-aged deposits are inferred to underlie the Quaternary deposits beneath the WEA. The Tertiary deposits mapped to be within about 4 to 20 meters of the seafloor in the WEA. Horizon 40, a prominent reflector throughout the survey area is tied into the upper section of the borehole at the Chesapeake Light Tower. Horizon 140, a distinct reflector beneath the WEA, deepens from about El. -90 meters in the northwest to about El. -125 meters

in the southeast corner. Horizon 140 is mappable on the regional survey lines and projects to the Chesapeake Bridge Tunnel area at about El. -40 to -50 meters.

The upper Tertiary units, which underlie the Quaternary deposits in the onshore and nearshore areas of Virginia, include (in descending order) the Yorktown, Eastover, and St. Marys formations. Those formations are primarily comprised of marine sands and clay deposits.

Data to define the expected engineering properties of the sediments beneath the WEA is non-existent. The only deep (100-ft below the seafloor) geotechnical data are two borings near the Chesapeake Light Tower roughly 10 Nm (19 km) west of the WEA. Seismic data from this survey are used to map from the boring into the WEA. Based on regional data sources and past project experience, the engineering character of the soils may vary considerably, with engineering properties varying significantly in both vertical and lateral directions for a given soil stratum.

## **ENGINEERING IMPLICATIONS**

### **Water Depth Variations**

Due to the irregular seafloor and ridge and swale topography:

- Wind turbines will be sited in water depths that will vary between adjacent structures and
- Cables will be routed over complex seafloor topography.

### **Sediment Mobility and Scour**

The Mid-Atlantic continental shelf in the WEA is considered to be a storm- and wave-dominated hydrodynamic environment with secondary influence from tidal and circulation currents. It is the interrelationship between the bottom currents (produced by the various oceanographic conditions) and the seabed and seafloor sediments that: 1) produces the seafloor geomorphology and 2) creates the potential for erosion, transport, and re-deposition of the seafloor sediments. That interrelationship varies both spatially and temporally. Subtle changes in the seafloor have been documented during minor storms, while large storms can produce significant changes in the seafloor due to erosion, transport, and re-deposition of the seafloor sediments.

Based on information reviewed in the Desktop Study, regional mapping indicates that the continental shelf sediments are generally fine and medium grained sand with lesser amounts of gravel and minor occurrences of fine-grained sediments. Regional bottom shear stress studies indicate that bottom currents are capable of frequently mobilizing sediments within the WEA and vicinity. Evidence of dune migration within the WEA supports the information provided in the Desktop Study, and indicates that erosion and scour should be considered during wind farm planning.

The installation of a structure can unbalance the dynamic equilibrium at the ocean – seafloor interface. This can increase the potential for sediment mobility and cause scour around the structure. The changes in the ocean – seafloor dynamics are created by: 1) introducing obstructions (wind turbine substructures) that create localized areas of increased bottom currents and 2) disturbing the sediment (and increasing its scour susceptibility) around the structure. This is anticipated to be one of the more significant physical hazards that could affect the performance of offshore wind structures and cables.

## Foundation Type Selection

Conventional opinion among many in the OW industry has been that monopiles are the most cost effective foundation for wind turbines in water depths that are less than about 80 to 100 feet (25 to 30 meters), and possibly up to a water depth of as great as 115 feet (35 meters). Most of the WEA is in a water depth of 65 to 100 feet (22 to 30 meters) and, therefore, near the maximum water depth where monopiles are assumed to be the most cost-effective foundation.

Selection of monopile versus jacket or tri-pod foundation systems will need to consider a number of criteria including not only water depth but subsurface conditions, performance during storm events (e.g. hurricane or nor'easters), constructability, and experience or level of comfort from design and construction teams. We note that in areas underlain by thick (~50 to 100 feet deep) soft, clay infilled paleochannels, jacket structures may have advantages over monopile foundations. However, each location is unique and the choice of foundation type will depend on subsurface conditions, anticipated loads, scour environment, and the prices of steel and equipment at the time of construction.

## Foundation Design

Where buried paleochannels are filled with clays, their presence will reduce axial and lateral pile capacity and soften the load-deformation response of the pile-soil system (as compared to areas outside of the paleochannels). The potential variation of axial compressive capacity of a pile (of given size and tip elevation) might be as follows:

- Potential variation due to stratigraphy: +/- 30 percent, and
- Potential variation due to soil properties: +/- 15 percent.

Similarly, the pile deflection at the waterline may vary as follows:

- Potential variation due to stratigraphy: +/- 50 percent.
- Potential variation due to local seafloor topography: +/- 30 percent.
- Potential variation due to scour: 25 to 50 percent increase.

## 1.0 INTRODUCTION

### 1.1 PROJECT DESCRIPTION

Fugro Consultants, Inc. (Fugro) has conducted a regional marine geophysical survey for the Virginia Department of Mines, Minerals and Energy (DMME) and the U.S. Department of Interior, Bureau of Ocean Energy Management (BOEM) in the designated Wind Energy Area (WEA) on the Outer Continental Shelf (OCS) offshore southeastern Virginia.

Figure 1-1 shows the location of the approximately 20 OCS Blocks that comprise the Virginia WEA, as well as: a) the proposed Research Lease No. 1 that includes two pairs of potential meteorological tower aliquots on the southern and northern perimeters of the WEA, b) the proposed Research Lease No. 2 along and adjacent to the western boundary of the WEA, c) the existing Chesapeake Light Tower (CLT), and d) the entrance area to the Chesapeake Bay. The designated WEA is offshore of the southern portion of the Chesapeake Bay and the northern shoreline of Virginia Beach. The WEA is 5 OCS Blocks wide (east-west direction) by 4 OCS Block tall (north-south direction) and is located about 40 to 70 kilometers offshore from the entrance to Chesapeake Bay (Figure 1-2). The WEA includes the following OCS blocks within the Chincoteague Protraction Area (NJ18-08):

- 19 complete blocks (6013 through 6016, 6062 through 6066, 6112 through 6116, and 6162 through 6166) and 1 partial block (6012),
- Meteorological towers aliquots, Research Lease 1 in OCS blocks 6014 and 6164, and
- Demonstration aliquots, Research Lease 2, that are adjacent to the western boundary of the WEA (OCS Blocks 6061 and 6111).

The geophysical survey was comprised of regional survey lines within the WEA (20 primary lines oriented northeast-southwest, and 9 tie lines oriented northwest-southeast), plus regional tie-lines to the Chesapeake Light Tower (CLT) and the Chesapeake Bay Bridge Tunnel (CBBT) alignment. The regional geophysical survey lines allow the regional geologic structure and subsurface stratigraphy underlying the WEA to be correlated to the existing subsurface (i.e., geotechnical boring) data at those structures.

The regional geophysical survey's primary purpose is to advance the state of knowledge relative to the geologic and subsurface conditions in the WEA. In addition, the collected data are used to evaluate the physical seafloor conditions (along the survey track-lines). Interpretation of the geophysical data relative to archaeological or cultural resources, and benthic habitat is not part of the scope of work. Seafloor targets and/or magnetometer anomalies that could be of archaeological significance are noted and that information has been forwarded to BOEM for their consideration and interpretation.

In advance of the regional geophysical survey, Fugro completed and submitted a geosciences-focused literature review (subsequently referred to as the Desktop Study) as part of this regional study. That report (Fugro, 2013), which was submitted under separate cover, accumulated, synthesized, and presented information as gleaned and extracted from existing data sources. The results of the Desktop Study helped to define and appreciate the seafloor and subsurface conditions and to plan the proposed regional geophysical survey. The data

sources include both public data sources and proprietary data from Fugro and our client's files. The data collected during this study have been incorporated into a project GIS.

Both the marine geophysical survey data and the Desktop Study will ultimately help to promote, plan, and further the goals of the future commercial development of the WEA, and also provide additional information to advance the objectives of the two potential Research Leases.

## **1.2 PURPOSE AND OPPORTUNITY FOR REGIONAL STUDY**

Because there has never been historical (energy) development on the Atlantic OCS, the Bureau of Ocean Energy Management (BOEM) considers the Atlantic Outer Continental Shelf (OCS) a *Frontier Area*. That designation recognizes the lack of: a) available data defining the physical conditions (e.g., the atmospheric, ocean, seafloor and subsurface conditions) on the OCS and b) historical knowledge relative to structure performance. The advocates of the initial offshore wind industry, however, often have not begun the process required to define those atmospheric-ocean-seafloor-subsurface conditions. This has created a conundrum that has been an obstacle to creating an offshore wind industry.

That conundrum has been discussed among the Virginia Department of Mines, Minerals and Energy (DMME), BOEM, and Fugro and its colleagues at the Marine Energy Group (MEG). The conundrum, however, provides opportunity for the Commonwealth of Virginia to initiate such data collection and, by doing so, to advance the pathway to industry creation offshore the Virginia shoreline. This regional survey serves as an important step that initiates the collection of tangible data to characterize the physical and environmental conditions, which is a critical pre-requisite to appropriate siting of wind energy structures and economic development of the offshore wind energy resources in the Atlantic OCS.

The regional geological study and geophysical survey specifically provides critical information towards the objectives of: a) optimizing potential demonstration wind turbine generators (WTGs) and met tower locations, b) accelerating such installations, c) providing insight to seafloor and subsurface variability in the WEA, d) defining how the conditions and their variabilities will affect substructure and foundation optimization and standardization, e) serializing fabrication and production economics, and f) ultimately to accelerate leasing and development of the Virginia WEA.

## **1.3 IMPORTANCE OF GEOSCIENCES CONSIDERATIONS FOR OFFSHORE WIND DEVELOPMENT**

The foundations of an offshore wind facility are typically 20 to 30 percent of the total cost of the project. Thus, an early and advanced understanding of the seafloor and subsurface conditions, and their influence on foundation design, installation and cost, is an important component of the development of offshore wind energy. European project experience has documented the importance of subsurface conditions and their variability, and geotechnical engineering for offshore wind development.

However, there has been no historical energy development on the Atlantic OCS, and thus the subsurface conditions and engineering properties of the subsurface sediments are poorly defined. In addition, there is limited historical record of how structures have performed on the Atlantic OCS.

The implications of those prior two considerations (i.e. significance of foundation costs and lack of development experience on the Atlantic OCS) is that an early-on appreciation of the conditions - including what insight can be drawn from existing data and what understanding can be gained only by conducting project-specific studies - is an important early activity for planning the development of offshore wind energy projects.

Therefore, the decision by the Virginia DMME, in cooperation with the BOEM, to perform a planning-phase, geosciences-focused Desktop Study and regional geophysical survey is an important recognition of the critical importance of the geological and geotechnical conditions and their future importance relative to project development.

#### **1.4 STUDY OBJECTIVES AND INTENT**

The regional geophysical survey's primary purpose is to advance the state of knowledge relative to the geologic and subsurface conditions in the WEA. Survey data were collected and interpreted to evaluate the physical seafloor and subsurface conditions.

The regional-scale survey includes: a) a grid of widely-spaced, regional survey lines across the WEA, b) a tighter-spaced grid of survey lines across the southern pair of potential Research Lease No. 1 met tower aliquots, and c) tie lines from the WEA to the Chesapeake Light Tower and entrance to Chesapeake Bay.

#### **1.5 SCOPE OF WORK**

Fugro acquired high resolution geophysical data aboard the *Tiki XIV* vessel (Figure 2-1) from May 28<sup>th</sup> through July 3<sup>rd</sup>, 2013. Multibeam hydrographic, side scan sonar, magnetometer, and two seismic reflection systems were utilized to map the seafloor and sub-bottom within the WEA. Figure 1-3 depicts the survey vessel tracklines. The area survey included:

- 20 primary survey lines oriented northeast-southwest (100 series tracklines) within the WEA,
- 9 tie survey lines oriented northwest-southeast (200 series tracklines) within the WEA
- 17 primary and 3 tie survey lines (300 and 400 series tracklines, respectively) within the Research Lease No. 1 southern meteorological tower aliquots, and
- 6 regional survey lines (500 series tracklines), including:
  - 3 lines passing through the CLT area
  - 3 lines passing through the CBBT area.

#### **1.6 AUTHORIZATION**

The regional geophysical survey (and Desktop Study) is funded by: a) the Virginia Department of Mines, Minerals and Energy, b) the U.S. Department of Interior Bureau of Ocean Energy Management, and c) Fugro Consultants, Inc. Fugro's authorization for this study is provided by DMME Agreement Number: C13-6030, dated March 2013.

## 1.7 FUGRO PROJECT TEAM

Project authorization permitted Fugro to provide hydrographic and geophysical surveying, interpretation, mapping, and report preparation services. The equipment choices and survey plan were prepared by: Mr. Tom McNeilan, Vice President; Mr. Kevin Morris, Survey Manager; Mr. Kevin Smith, Associate Geologist; and Mr. Mike Barth, Senior Geophysicist.

The principal personnel involved in the field survey of the project were:

- Kevin Morris - Survey Manager
- Trey Emmons - Survey Technician
- Brendyn Meisinger – Survey Technician
- Sam Bedinger– Survey Technician
- Allison Bowman – Field Data Processor
- Mike Barth - Senior Geophysicist

The 2-dimensional (2D) seismic reflection data were processed by Legg Geophysical. The interpretation, mapping, and reporting team included: James Fisher (Staff Engineering Geologist), Kevin Smith (Associate Geologist), and Kevin Morris (Survey Manager). Report graphics and charts were prepared by Fugro staff under the supervision of Kevin Smith. The report text was authored by James Fisher and Kevin Smith, and reviewed by Tom McNeilan.

## 1.8 SUMMARY OF AVAILABLE DATA

Fugro has searched available public and internal, non-proprietary sources for data that describe the general physical setting, geologic conditions, seafloor conditions, and subsurface conditions within the study area. Non-proprietary data and reports from Fugro's files and database also were retrieved. The pertinent data from the various sources have been compiled in a geographic information system (GIS) database for the project area.

Wherever possible, the information entered into the GIS database has been input electronically or extracted electronically from the source files. Only when necessary has other map information been digitized into the GIS. Other data (such as historical sample and boring data) have been entered into the GIS so that the information can be electronically synthesized and subsequently extracted and analyzed using Fugro's proprietary geotechnical GIS routines.

The available regional data from public sources included:

- Published academic and research agency (e.g., USGS) studies related to:
  - Seafloor geomorphology, seafloor conditions, and sediment mobility,
  - The geology (and geological history) of the OCS,
  - Regional geophysical surveys (NOAA),
  - Geologic hazards, and
  - Subsurface conditions.
- Project reports available in the public record, such as:
  - Geophysical survey reports (such as various Virginia Beach sand resource studies) in the nearshore and offshore area between the WEA and the coast, and
  - Geotechnical study reports (such as the 1963 Chesapeake Light Tower report).

Available data and reports from Fugro files that have been accessed for the study include:

- Documents and data developed for a recent BOEM TA&R seabed scour study (Fugro, 2011),
- Geotechnical borings for the Chesapeake Light Tower (Fugro, 1963):

Although the historical Chesapeake Light Tower (CLT) borings are located west of the WEA, they are the only known geotechnical borings on the OCS within the vicinity of the WEA. Those borings were advanced to depths of engineering interest (for foundation design) and include engineering testing data. The historical CLT boring logs are shown in Figure 1-4.

We also were able to obtain recent multibeam bathymetry and side scan sonar data from NOAA (2011 and 2012). These bathymetric data from multiple surveys were conducted in 2011 and 2012, and cover the entire WEA area. This high-resolution data set was very useful in allowing a direct data comparison of similar data sets to illustrate the complexity of seafloor morphology and potential sediment transport and/scour hazards within the WEA (and the Atlantic OCS in general as well). The data coverage for each survey is depicted on Figure 1-5. We note that the regional bathymetric data (within the WEA) shown in the Desktop Study were from 1981 and 1935 (Figure 1-5).

## 1.9 REPORT FORMAT

The report includes into the following sections.

1. Introduction
2. Marine Geophysical Field Survey Methods and Data Processing
3. Regional Geologic Setting
4. Site Conditions
5. Subsurface Conditions
6. Limitations and Capabilities
7. Summary
8. References

The report text is followed by various figures that support the descriptions provided in the report text. Figures associated with the 1st section of text are numbered: 1-1, 1-2, etc, while figures associated with the 2nd section of text are numbered 2-1, 2-2, etc. The report also includes multiple charts, which depict the marine survey data and interpretation. Report tables, figures, and charts are listed under the table of contents.

The report also includes four appendices, including:

- Appendix A – Seismic Data Processing
- Appendix B – Survey Line Logs
- Appendix C – Magnetic Anomaly Table
- Appendix D – Side Scan Sonar Target Table and Individual Images

## 1.10 COORDINATE SYSTEM, DATUMS AND UNITS OF MEASUREMENT

The horizontal coordinate system used during the survey is Universal Transverse Mercator (UTM) Zone 18 North, North American Datum 1983 (NAD83), meters. Elevations in this report are referenced to Mean Lower Low Water (MLLW) and are in meters. The tidal corrections are based upon the observed water levels reported from NOAA's tidal monitoring station No. 8651370 located at Duck, North Carolina. That tidal reference proved to provide a better reference, based on our evaluation of consistency of water depths at primary-tie line intersections than did data corrections based on the NOAA's tidal station No. 8638863 located at the Chesapeake Bay Bridge Tunnel, Virginia. During prior NOAA multibeam surveys in the WEA, NOAA also used the measured tide data for tidal corrections of their water depth measurements from station No. 8651370 located at Duck, North Carolina.

## 2.0 MARINE GEOPHYSICAL FIELD SURVEY METHODS AND DATA PROCESSING

### 2.1 SURVEY OVERVIEW

Fugro acquired high-resolution, geophysical data aboard the *Tiki XIV* vessel (Figure 2-1) from May 28<sup>th</sup> through July 3<sup>rd</sup>, 2013. Multibeam bathymetry, side scan sonar, magnetometer, and two sub-bottom mapping systems were utilized to map the seafloor and sub-bottom within the WEA. Sub-bottom stratigraphic mapping was accomplished using: a high frequency Chirp system to image the upper 10 meters and a seismic reflection system, composed of a double-plate boomer seismic source and a multi-channel GeoEel hydrophone array, provided stratigraphic data down to in excess of 550 meters below seafloor.

Figure 2-2 shows the tow configuration of the systems used during the survey. All systems were deployed and run simultaneously along each survey trackline. Vessel speed during surveying was maintained at approximately 4 knots. Much care was taken to maintain the vessel speed at 4 knots to ensure constant shot point distances. However, if vessel speeds deviated from the target firing rate due to currents, waves, and/or wind conditions, then the firing rate on the boomer system was adjusted in order to maintain a constant shot point distance.

Operations for this survey were conducted in accordance with the parameters, requirements, and mitigation procedures defined by the Final EA (BOEM, 2012b) for the mid Atlantic OCS. Survey operations were limited to daylight hours and personnel provided by REMSA, Inc. conducted the marine mammal observations during the survey.

The survey track-lines are shown on Figure 1-3 and Chart 1. The survey track-lines included:

- A grid of widely-spaced, regional survey lines across the WEA (100 and 200 series survey lines. Figure 1-3a),
- A tighter-spaced grid of survey lines across the southern pair of potential Research Lease No. 1 meteorological tower aliquots (300 and 400 series survey lines. Figure 1-3c), and
- Ties-lines from the WEA to the Chesapeake Light Tower (CLT) and entrance to Chesapeake Bay (500 series survey lines, Figure 1-3b).

A total of approximately 8880 line-kilometers of survey data were acquired during the survey. This included about: 635 line-kilometers of data collected across the WEA (line number series 100 and 200), 35 line-kilometers of additional, more closely-spaced data within the southern meteorological tower aliquots (line number series 300 and 400), and 210 line-kilometers of regional lines outside the WEA (line number series 500 and 600).

The orientation of the survey grid across the WEA is based on Fugro's experience offshore the Mid-Atlantic and the results of the Desktop Study. The primary lines (line number series 100) within the WEA are oriented northeast-southwest and sub-parallel with the regional bathymetry (Figure 1-3a). This grid orientation is preferred so as to be perpendicular to the regional trend of the buried offshore paleochannel system that underlies the Mid-Atlantic OCS. The tie- lines (line number series 200) are oriented northwest-southeast and perpendicular to the primary lines. The primary lines are spaced at 1.5 kilometers and the tie-lines are spacing at 3.5 kilometers.

The primary and tie-lines across the southern Research Lease No. 1 aliquots (line number series 300 and 400, respectively) are oriented at the same headings as are the longer 100 and 200 series lines across the WEA lines. The 300 and 400 series lines are spaced to provide coverage at 150-meter-spacing in the primary direction and 600-meter spacing in the tie-line direction. The closer spacing was intended to illustrate the additional detail of geologic interpretation that ultimately will be derived from project level geophysical surveys in the WEA (Figure 1-3c). Regional survey lines extended from the WEA to the Chesapeake Light Tower (CLT) and from the CLT to the entrance to Chesapeake Bay. These survey data were collected to aid regional subsurface mapping (line number series 500 and 600) and to relate the stratigraphy in the WEA to the subsurface conditions encountered in borings for the Chesapeake Bay Bridge Tunnel and CLT. Locations of these survey lines (Figure 1-3a) are optimally situated to help better understand the geological conditions and structure beneath the WEA in context to those conditions farther inland where geotechnical borings were available.

## **2.2 POSITIONING AND NAVIGATION**

A wide-area Differential Global Positioning System (DGPS) was used to position the survey vessel. DGPS is a satellite-based positioning system operated by the U.S. Department of Defense. A "wide-area" application operates with correction values applied to a stand-alone DGPS receiver from base stations located over large distances. DGPS corrections were supplied to the system using the STARFIX II network, a nationwide differential network operated by Fugro. STARFIX II broadcasts differential corrections via a communications satellite downlink to field receivers. DGPS signals provided the field navigation information to sub-meter accuracy. Post-processing of the positioning data utilized data recorded from six United States Army Corps of Engineers (USACE) base stations. This post-processing improved the horizontal positioning of the common reference point (CRP) on the vessel to be resolved to within about one inch.

Equipment offsets and laybacks (Figure 2-2) from the CRP were measured during mobilization using a steel tape and level. Measurements were recorded to the tenth of an inch. Layback distances during deployment were measured and noted if adjusted. Coordinate locations of targets reported herein have been corrected for instrument layback and offset.

Vessels attitude, heading and position were recorded using an Applanix POSMV 320. The POSMV 320 delivers full six-degree-of-freedom position and orientation solutions for marine survey vessels and outputs all motion variables at high rate: position, velocity, heave, roll, pitch, true heading, acceleration vectors, and angular rate vectors. The system combines GPS/GNSS with supplemental Starfix HP corrections with rugged high-quality inertial sensors. The system measures true heading together with roll and pitch to 0.02 degree accuracy under dynamic conditions including hard turns and rapid acceleration and deceleration with heave accuracy of five centimeters in real time. The POSMV system included two GPS antennas mounted atop the Tiki XIV with a separation of 1.969 meters. The Inertial Measurement Unit (IMU) was mounted above water close to the multibeam transducer to minimize any offset issues. Data were fed from the processor to Hypack via Ethernet at 200 hertz. Delayed heave and position data, used for the post-processing of data, were logged at 50 hertz.

## **2.3 HYDROGRAPHIC (MULTIBEAM BATHYMETRY) SURVEY**

A hydrographic survey was conducted by Fugro using an R2Sonic 2024 multibeam echosounder. The bathymetric survey was used to document the seafloor bathymetry at the time of the survey and locate possible exposed obstructions. The R2 Sonic 2024 has a beam steerable functionality which allows the beam orientation and beam separation to be modified electronically without requiring to stop and conduct a patch test. This allows for the beam orientation (e.g. beam separation angle or swath footprint location) to be adjusted electronically during in order to optimize swath footprint location or data density. We elected to use this system to (1) facilitate our ability to focus beams on objects of interest and improve our ability to locate and identify them, and (2) provide optimal data density across the variable water depths. The processed multibeam data were used to develop an elevation model of the seafloor to depict the elevation variation throughout the WEA. We note the bathymetric elevations may change over time in response to environment conditions (i.e., storm and/or current flow events that result in changes in sediment supply, migrating bedforms, and/or scour development around existing structures).

### **2.3.1 Data Acquisition**

Swath bathymetry coverage of the seafloor was acquired using an R2Sonic 2024 multibeam system. The multibeam data were acquired using 256 beams at approximately 0.5 degree beam separation; the system achieved swath coverage to about 60 degrees each side of nadir. The total swath width is a function of water depth and ranged from about 60 to 125 meters along the WEA survey lines. Multibeam data coverage within the WEA is shown in Figure 2-3.

Prior to surveying, a patch test was conducted to confirm that equipment offsets, calibrations, and navigation settings were correct. Multibeam surveying commenced after successfully completing the patch and calibration tests.

The R2Sonic 2024 transmits a shaped continuous wave pulse at the user-selected frequency (200 to 400 kilohertz [kHz]). We collected the data at 300 kHz in order to optimize data resolution, swath coverage width, and reduce cross talk (interference) with other systems that were running simultaneously. The transmitted pulse is narrow in the along-track direction, but wider in the across-track direction. The reflected acoustic energy is received via the

R2Sonic 2024 receivers, within the receive module the beams are formed and the bottom detection process takes place. The resultant bottom detections (range and bearing) are sent via Ethernet deck lead to the Sonar Interface Module (SIM). The SIM then sends the data out to the R2Sonic control software and the data acquisition software.

### **2.3.2 Data Processing**

The CARIS 8.1 software package was used to process the multibeam data. The CARIS Processing Software was used on a Windows 7 64-bit workstation to edit and bin the raw data sets. Multibeam bathymetric data processing involves two steps:

- The application of acquisition or field specific variables and
- Data editing to remove spurious soundings.

Sound velocity casts, used to measure the acoustic velocity vertical profile in the water column, were performed at 2 hour intervals during survey operations (or as needed). Sound velocity data were used during processing to determine water depth from the acoustic multibeam sounding data.

All sounding data were adjusted for tides using the verified NOAA tidal station 8651370 Duck, North Carolina (the same tide stations used for the NOAA 2011 and 2012 surveys). All data were reduced to Mean Lower Low Water (MLLW).

## **2.4 MAGNETOMETER SURVEY**

A magnetometer survey conducted to locate ferrous or magnetically susceptible objects on the seafloor or within the shallow subsurface. Magnetometer survey lines were conducted throughout the survey area as shown in Figure 1-3 and Chart 1.

### **2.4.1 Data Acquisition**

A Marine Magnetic Corporation SeaSpy model marine magnetometer was used for the survey to measure the ambient magnetic field. The Marine Magnetics' SeaSpy magnetometer measures the ambient magnetic field using a specialized branch of nuclear magnetic resonance technology applied specifically to hydrogen nuclei producing very high sensitivity and accuracy. The sensor is reported to have an absolute accuracy of  $0.2\eta\text{T}$  and a counter sensitivity of  $0.001\eta\text{T}$ . The tow sensor was further equipped with a pressure/depth sensor and an altimeter to maintain optimum towing altitude. Total field readings were logged together with the sensor altitude and depth data to the navigation computer through the SeaSPY's communications transceiver.

The magnetometer was towed from the stern of the vessel generally within 6 meters of the seafloor. Layback measurements were collected utilizing a PI5600 Cable Counter, recorded and time stamped in real time to calculate sensor position behind the vessel. Raw cable changes were also noted in the geophysical line log. Ambient magnetic field measurements were recorded at a rate of 4 hertz. Data were recorded using Starfix.Seis where measurements were attributed with position coordinates

## 2.4.2 Data Processing

Interpreting the magnetometer data for magnetic anomalies for probable man-made artifacts and/or some geologic trends was performed by individual analysis on a line-by-line basis using Chesapeake Technology's SonarWiz software program. Individual anomalies were then examined to determine whether there is reasonable gradient change before and after the anomaly. A certain degree of judgment is involved with this method of interpretation.

The anomalies were 'picked' and summarized in Excel tables. The locations of the anomalies were loading into a project GIS and cross checked against obstructions observed in the multibeam and side scan sonar data. The magnetic anomaly information summarized includes the following:

- ID Anomaly Identifier
- Easting UTM Zone 18 North, WGS84, Meters
- Northing UTM Zone 18 North, WGS84, Meters
- Gamma Anomaly Intensity
- Duration Duration of the magnetic anomaly in meters
- Type Shape of anomaly
- Description Possible source of anomaly

A table with the interpreted magnetic anomalies is included in Appendix C.

## 2.5 SIDE SCAN SONAR

### 2.5.1 Data Acquisition

The side scan sonar data were collected using an EdgeTech Model 4125 tow fish controlled by the EdgeTech Discovery Side Scan Sonar Acquisition interface to record side scan sonar intensity data of the seafloor. The system operated on a simultaneous dual frequency of 400 kHz/900 kHz at a slant range of 50 meters for a total swath of 100 meters.

The tow fish was deployed from the stern of the *Tiki XIV*. Cable changes were made with a hydraulically controlled winch. All cable changes were calculated using a PI5600 Cable Counter. These data were then recorded in real time to calculate the sensor's position using the industry layback calculations and applying the georeferenced position data. All cable changes were recorded and time stamped in Starfix.Seis navigation system and used to record the position information of the "towed" sensor.

### 2.5.2 Data Processing

Chesapeake Technology's SonarWiz software program was used for processing all side scan sonar data. During data processing, the individual sonar data files, were reviewed and corrected for tow fish altitude using standard bottom tracking methods. Once bottom tracking and navigation QA/QC was confirmed the data were then slant range corrected to remove effects of the water column from the sonar records. The individual files were then merged and geospatially referenced to construct a side scan mosaic of each individual survey line. With the regional survey line spacing being so large it would have made it impractical to create all data as one mosaic so each survey line was made into individual geo-referenced images to increase

maximum resolution and reduce the size of the mosaic file. The mosaic file provides a view of the seafloor using the collected intensity data that looks much like a black and white image similar to an aerial photograph. Final contrast adjustments, filtering, and line editing was performed before the final mosaic image was produced.

The positions of seafloor contacts were interpreted and digitized in the SonarWiz software program. These features were cataloged and input in tabular format. A table with the interpreted side scan sonar contacts is included in Appendix C.

## **2.6 SUB-BOTTOM (CHIRP) PROFILER**

A sub-bottom profiler (Chirp) system was used to collect shallow sub-bottom seismic reflection data. The Chirp data were used to interpret the shallow stratigraphic conditions. Figure 1-3 and Chart 1 present the locations of the sub-bottom profiler survey track-lines.

### **2.6.1 Data Acquisition**

An EdgeTech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) system was utilized to obtain shallow seismic reflection data of the sediment layers immediately beneath the seafloor. These shallow data provide information on the spatial distribution and thickness of shallow sediments. The EdgeTech 3200 system included a SB-216S Towfish, a Model 3200 topside processor, and an EdgeTech's Discover acquisition software. The system was triggered at a 8-Hertz pulse rate with a swept frequency range between 2 to 15 kiloHertz over 20 milliseconds. All navigation information and sub-bottom data were time tagged and logged to a hard drive.

### **2.6.2 Data Processing**

Chirp sub-bottom data processing included checking and de-spiking all navigation points using Starfix.Proc, an application for automated (batch) processing of navigation data. After the data were cleaned, verification was made that the corrected navigation files were referenced from the towed position (where the sub-bottom was towed from the vessel). The corrected navigation data were then inserted into a raw JSF file (Edgetech's Proprietary format) using Starfix.Gplot (Addxyz). The JSF files were replayed through the Discover software for TVG, swell filtering, and direct arrival removal. Following the data filtering, the JSF files were then converted to SEG-Y format and loaded into IHS Kingdom Suite version 8.8 for interpretation.

## **2.7 MULTI-CHANNEL (BOOMER) SEISMIC REFLECTION SURVEY**

High resolution, two-dimensional seismic reflection survey data were collected to interpret the geologic structure and deeper stratigraphic layers. The seismic reflection system consisted of a double plate "boomer" seismic source, power and tow cable, power supply, deck cable, multi-channel hydrophone streamer, and acquisition hardware and software. Figure 1-3 and Chart 1 present the locations of the seismic reflection survey track-lines.

### **2.7.1 Data Acquisition**

An Applied Acoustics Engineering's CSP seismic energy source was used to power the Subsea Systems d-plate "boomer" system. The boomer plate(s) is an electro-mechanical transducer made of an insulated aluminum plate and a rubber diaphragm adjacent to a flat wound electrical coil. A short duration high-energy pulse is discharged from the energy source into the coil and the resulting magnetic field repels the plate in the transducer. The plate motion

is transferred to the water by the rubber diaphragm, generating a broadband acoustic pulse that does not have strong cavitation or ringing. The source was fired at 0.75 second intervals to provide an average shot point interval of 1.5 meters.

The reflected acoustic signal was received using a Subsea Systems' ethernet-based GeoEel digital hydrophone array. The hydrophone array was a 32-channel hydrophone streamer that included two separate sections. The front section was comprised of 16 channels spaced at an interval of 1.562 meter group interval (mgi), while the aft section consisted of 16 channels at 3.125 mgi. This allows the recorded data to be processed as either 16 channels at 1.562 mgi or 32 channels at 3.125 mgi data.

The streamer was towed approximately 0.5 meter below the water surface. Data were recorded at a 0.25-millescond sampling rate and 500-millisecond record length. Data were stored on hard disk in SEG Y format for later post-processing. Data were also backed up on DVD and an external hard drive.

## 2.7.2 Data Processing

Basic seismic data processing consists of filtering in time and space, deconvolution to provide a sharper and more consistent seismic wavelet for interpretation, correction of normal move-out due to varying subsurface velocity structure, stacking of data traces to increase the signal-to-noise ratio, and migration to put the reflecting horizons back into their proper lateral positions. To provide the best image resolution for these acquisition parameters, a final binning interval of 0.39 meters (1.3 feet), equal to one-half the nominal binning interval for the streamer group interval was used. To increase fold and signal-to-noise ratio for this short CMP spacing, a three-element source mix was used with weights of 1-2-1 to form an acoustic beam focused downward with minimal side-lobes in the radiation pattern. Further random noise attenuation was accomplished after stacking, but before migration, by applying an F-X predictive filter with a high-cut frequency set to 900 Hertz. The remainder of the processing steps and the specific parameters used are typical for multichannel high-resolution seismic data listed below.

- Trace Editing, Scaling and Filtering,
- Spiking Deconvolution,
- Spatial Filter Design and Velocity Analysis,
- Normal Move-out Correction and Stack,
- Post-Stack Migration,
- Surface-Related Multiple Suppression, and
- Post-Migration Predictive Deconvolution.

At the onset of the data processing phase of this study, we evaluated several processing methods in order to select the method that provided the highest quality data. We also assessed whether to proceed with processing the 16 channels at 1.56 mgi dataset or 32 channels at 3.125 mgi. During the evaluation we compared processed data from the 1.56 mgi and 3.125 mgi streamers from selected lines. Figure 2-4 presents data examples from a portion of line 500. Based on our assessment, the 1.56 mgi streamer data provided slightly higher resolution and more detail particularly within 20 to 30 ms (approximately 15 to 25 meters) of the seafloor. However, the 3.125 mgi streamer provided more coherent signal in the interval between about 30 to 100 ms (approximately 25 to 75 meters) below the seafloor. Thus, for the purpose of



providing a geologic framework of the study, we deemed that the 3.125 mgi would be the preferred dataset for interpretation. Figure 2-4 provides a comparison of data from the two different streamers collected on line 500 near the Chesapeake Light Tower structure. Appendix A further describes these processing procedures.

### **2.7.3 Compressional Wave (P-Wave) Velocity**

During signal processing, velocity analyses were conducted across the site. Based on the velocity analyses, we deemed that a compressional (P-wave) velocity of 5,000 feet per second was reasonable for the water column and upper 100 meters of deposits.

### 3.0 REGIONAL GEOLOGIC SETTING

Discussion on the regional geologic setting provided in this report section summarizes information, as it pertains to the geophysical survey interpretation, that was included in Fugro's "Geoscience-focused Desktop Study, Virginia Offshore Wind Energy Area, Virginia Outer Continental Shelf" report (May 2013). Refer to the Desktop Study for an expanded discussion regarding the geologic development of the study area.

#### 3.1 PHYSIOGRAPHIC SETTING

The WEA is located on the western half of the continental shelf, which is the submerged extension of the Coastal Plain Province. In general, the continental shelf has a gentle, regional slope of about 0.001 degree and extends from the Virginia coastline eastward for about 120 kilometers. The edge of the continental shelf is demarcated by the shelf break at about the 100-meter isobath, where the slope of the seafloor gradient steepens as the shelf drops along the continental slope. Predominant features on the continental shelf include ridge and swale topography, filled channels (shelf valleys), and shoal retreat massifs (Figure 3-1).

The inner and mid continental shelf off the Mid-Atlantic coastline is comprised of ridges and swales that have a northeasterly trend. The sand ridges typically exhibit relief of 4 to 15 meters, are between 1 to 3 kilometers wide, and may extend for distances of tens of kilometers. The ridges are postulated to be shoreface deposits abandoned as the shoreline transgressed during the last rise in sea level (Swift et al., 1973). As discussed by Snedden et al. (1999), ridge shape and morphology are inferred to be a function of the hydrodynamic environment with ridges evolving over time until dynamic equilibrium is reached with the hydrodynamic environment.

Several filled channels cross the Mid-Atlantic shelf. These features can have seafloor expressions that appear as surface channels or valleys (Swift et al., 1980; Duane and Stubblefield, 1988). These shelf valley complexes are considered to represent a retreat path of an estuary-mouth scour channel or a river valley modified by estuarine processes during transgression (Swift et al., 1980). At the estuarine mouth, tidal scour processes incise a channel (shelf valley) as it retreats up the estuary axis during transgression. However, the surface expression of the current shelf valleys does not always coincide with the buried river valley locations.

As discussed in the Desktop Study report, two shelf valleys are within the vicinity of the WEA (referred to as the northern and southern shelf valleys). The northern shelf valley extends from the mouth of the Chesapeake in an easterly direction and curves around the WEA across the continental shelf, and is inferred to connect to the head of the Norfolk Canyon. The southern shelf valley, which is located to the south of the WEA, extends from the Atlantic Ocean Channel (AOC) and runs shore parallel until changing direction to the east-normal offshore the False Cape area. Within both shelf valley areas, the seafloor generally appears to be relatively flat and featureless, but may have isolated sand ridges within the regions.

Shoal-retreat massifs are broad areas with topographic relief related to former positions of estuary mouths. Near the estuary mouth, littoral drift converges on one or both sides of the estuary to create levee-like highs. This process occurs as the estuary retreats during transgression and creates the massifs (Swift 1973; Swift et al., 1980). The WEA has a shoal-

retreated massif region in the southern area that was possibly created as the mouth of the Cape Charles paleo-drainage system retreated during the last sea level rise.

### **3.2 GEOLOGIC HISTORY AND SIGNIFICANT FEATURES**

The study area is within the Baltimore Canyon Trough, a northeast-southwest-trending rift basin structure that formed as a result of extensional tectonics during the Jurassic and Triassic periods (Grow et al, 1988). Following the basin formation, from Late Cretaceous through the Cenozoic, sedimentation and erosional processes related to fluctuating sea levels primarily controlled the geologic development. The Baltimore Canyon Trough consists of a wedge of sediments that thickens to the east and overlies the crystalline basement.

The shallow geologic units underlying the site are comprised of Cenozoic-age sediments (Figure 3-2). The sediments consist of sand, gravel, silt, and clay that have deposited during cycles of sea level fluctuations. The degree of induration of the sediments generally increases with depth. Today, the continental shelf in the study area is covered by a layer of Quaternary sediments. The seafloor in the study area is comprised predominantly of sand, with varying amounts of gravel and patches of fined-grained sediments. A schematic geologic profile depicting the shallow strata is shown in Figure 3-3.

The subsurface geologic conditions have been extensively influenced by the glacial-interglacial cycles (even though glaciers did not advance across the region), as depicted in Figures 3-4 and 3-5. This is because sea-level fluctuations that occurred as a result of the glacial-interglacial cycles caused the shoreline to regress and transgress across the shelf several times throughout geologic time. Those geologic processes during the Quaternary are primarily responsible for shaping the geology that will influence the siting, type selection, engineering design, and installation of wind facility structures.

During periods of inundation, marine sediments were deposited on the shelf, whereas during sea level low-stands, paleodrainages crossed the shelf, deltas formed at river mouths, and estuary-lagoon-barrier complexes formed near inlets (Figures 3-4 and 3-5). During the Last Glacial Maximum (Wisconsin glacial period, approximately 25 to 15.7 thousand years ago [kya]), the sea level was approximately at the 120-meter isobath. During this time, drainages flowed across and carved channels into what is now the shelf (Figure 3-5 inset A). As the sea level rose and the shoreline transgressed and retreated westward (Figure 3-5 - inset B), the channels began to flood, transition into estuaries, and infill with sediments. The channels typically are infilled with a fining-upward sequence of sediments. That sequence often includes coarse basal lag deposits overlain by sands and then silts or clays. The infill sediments may be dissimilar to the sediments outside the incised channel or they may be composed of similar, but younger, materials. This has created a significant degree of stratigraphic layering and variation.

Additionally, as sea levels rose, an estuary-lagoon-barrier depositional system transitioned westerly across the shelf (see inset C on Figure 3-4). Estuary and lagoon deposits are generally fine-grained, may contain organics, and can be channelized to varying degrees. Barrier deposits (islands, spits, or bars) are generally sandy sediments. After the shoreline transgressed to near its current position, the shelf was inundated and marine sediments deposited over the shelf. These marine deposits have buried and masked the underlying

geology, and former barrier deposits were modified (and sometimes evolved) to become sand ridges that now cover the inner continental shelf.

The combined effects of these processes have created subsurface stratigraphy that often is composed of sequences of layered deposits. In some locations, individual layers may be many tens of feet thick and extend over significant distances. Elsewhere, the layers may be much thinner and laterally discontinuous.

### 3.2.1 Ancestral Drainage Systems

Buried paleochannel deposits are one of the primary sources of variability both horizontally and vertically within the subsurface. River incisions, formed during sea level low-stands that were subsequently infilled as sea level rose, result in deposits that may be dissimilar or similar but younger, and likely have different engineering properties than surrounding deposits in which the paleochannels incised. Locations of these paleochannel deposits are typically masked by overlying nearshore marine or bay-floor deposits. The paleochannel deposits are thickest near former thalweg locations except where channels are nested (or stacked) and thin toward the channel edges.

Figures 3-4 and 3-5 depict how buried paleochannels systems were formed. The paleochannels that underlie the Eastern Shore were incised by the paleo-Susquehanna River in response to sea level low-stands during successive glacial periods in the Late Pliocene and Pleistocene. As sea level rose during the interglacial periods, the channels would infill with sediment from longshore currents and become capped by the southern extension of the Eastern Shore. During each lowstand, the main stem channel of the paleo-Susquehanna River was diverted south as the Delmarva Peninsula lengthened causing the progression of paleochannels to become younger toward the south. Several generations of filled channels from the paleo-Susquehanna River system have been mapped within the region. The successive paleochannels, which become younger to the south, are named the Exmore, Belle Haven, Eastville, and Cape Charles paleochannels. Each paleochannel generation developed during a specific sea level low-stand event.

Figure 3-6 shows paleochannel systems mapped in the nearshore region for offshore Virginia. Channel locations were mapped primarily using seismic reflection data. The location of the Cape Charles paleochannel is projected just south of Fisherman's Island. In some areas, the Cape Charles paleochannel is as deep as 45 to 60 meters (Harrison et al., 1965; Meisburger, 1972; Colman and Mixon, 1988) below sea level. Note the secondary and tertiary tributaries that feed into the main stem and form a complex buried drainage network (Foyle, 1995). This paleodrainage network likely extends offshore to the Norfolk Canyon.

Few examples of paleochannels have been mapped near the WEA. Sub-bottom, shallow penetrating seismic reflection data collected offshore Virginia Beach show potential secondary and tertiary tributaries that are inferred to feed a main stem, and thus are part of a larger drainage system. The main stem for these ancestral drainage networks could be the Cape Charles systems (inferred to be part of the northern shelf valley), or part of the southern shelf valley system that extends beneath the present day Atlantic Ocean Channel (AOC).

This survey represents the first comprehensive seismic dataset that can be used to map buried paleodrainage networks located beneath the WEA. The seismic indicate that the main

stem of the Cape Charles system is not located beneath the WEA. However, mapped a large buried drainage that projects to the northeast and may have connected to the main stem of the Cape Charles system (Figure 3-6). We also identified other buried paleodrainage features throughout the WEA that likely represent secondary or tertiary stems of the paleodrainage network that existing on the continental shelf during seal level lowstand(s). These features are discussed in the subsurface section of this report.

## 4.0 SITE CONDITIONS

Water depth is a critical parameter for siting, designing, installing, and operating OWF structures. Wind facility costs and the complexity of design and installation challenges generally increase as water becomes deeper and the relationship may not be linear. Moreover, reducing wind turbine visibility, often considered due to public concerns, pushes projects into deeper water farther from land. Identifying suitable sites that balance visual impact and water depth constraints is often a key component of the planning and siting an OWF. Current operating OWFs in Europe are generally located in water depths of up to 150 feet (45 meters), which also coincides with the approximate water depth limit of proven OWF foundation systems.

Bathymetric data not only provides the needed water depth information but also insightful information regarding the seafloor morphology and the geologic/oceanographic processes that create and modify seafloor features. Those same processes may have adverse or positive impacts on offshore wind-facility structures. Understanding those processes and how they may affect wind facility structures will help: 1) manage and reduce risks, and 2) reduce construction and operating costs.

Fugro acquired high-resolution multibeam bathymetry data within the Virginia WEA from May 28 to July 3, 2013. The multibeam data were acquired along regional track-lines within the WEA, as well as closer spaced lines within the southern meteorological tower aliquots (refer to Figure 1-3b). Fugro also processed and evaluated multibeam bathymetric data from three NOAA hydrographic surveys (2011 and 2012). The NOAA bathymetric data sets allow for; 1) evaluation of water depths within the entire WEA (NOAA data coverage shown in Figure 1-5), and 2) comparison of the Fugro 2013 data with historical data of similar resolution.

### 4.1 BATHYMETRY

The WEA bathymetry is shown on Figure 4-1a and 4-1b and Charts 2a and 2b. Figures 4-1c through 4-1d present the cumulative frequency distribution of the water depths based on a 1-meter bin size analysis of the NOAA dataset. In general, the water depth within the WEA increases from west to east with minimum and maximum water depths of approximately 18 to 41 meters (59 to 135 feet) MLLW (OCS blocks 6012 and 6066, respectively). The shallowest water depths exist on the crests of the low frequency sand ridges (the dominant seafloor features) along the northwestern and western regions of the WEA. These areas are separated by a low lying and low relief swale area (from OCS block 6112 diagonally through block 6015).

The northwest area of the WEA (OCS blocks 6012, 6013, 6062, and 6063) has an irregular seafloor with bedforms superimposed along broad shoals. The water depth varies from approximately 18 meters (60 feet) on the shoals to 28 meters (85 feet) in the adjacent. Bedforms (e.g., dunes) in this area are generally of lower relief and extent, with localized bathymetric relief (e.g. height between ridge crest and adjacent swale) varying from approximately 1 to 3 meters (3 to 10 feet).

In the central and southern areas of the WEA, the seafloor consists of a shoal complex (shoal retreat massif) with sand ridges superimposed on a broader, shallow water area. This complex is generally present in OCS blocks 6064, 6065, 6113, 6114, 6115, 6116, 6162, 6163, 6164, 6165, and 6166. Water depth again varies from approximately 18 to 26 meters (60 to 85 feet). Sand ridges as part of this complex are generally of much higher relief and extent when



compared to other sand ridges within the WEA. The localized bathymetric relief for these sand ridges is up to 10 meters (33 feet) in the southwest area (OCS block 6113) and 7 meters (23 feet) in the southeast area (e.g. OCS block 6166).

The sun-illuminated hillshaded relief rendering of the seafloor shown in Figure 4-2 illustrates quite clearly the difference between the smaller-scale and shorter wavelength sand ridges in the northwest area and broader, longer wavelength, sand ridges in the central and southern portion of the WEA.

For both the ridge areas, the deepest water depths occur in the adjacent swales (or troughs). Within the northern/northwestern area, the troughs have water depths ranging from approximately 32 to 36 meters (105 to 118 feet) (OCS blocks 6013, 6014, 6015, 6064, and 6065), while troughs within the shoal complex vary from 30 to 34 meters (98 to 112 feet). However, the deepest water depths are in the northeastern/eastern area off of the shoal complex and range from approximately 30 to 41 meters (98 to 135 feet) (OCS blocks 6016, 6066 and 6116).

A statistical evaluation of water depths within the WEA using the NOAA bathymetry datasets collected in 2011 and 2012 and processed into 1 by 1 meter (3 by 3 foot) bins is shown in Table 4-1. This table includes the average water depth, standard deviation and range of water depth according to the NOAA 2011 and 2012 data within each block. The standard deviation was included to provide a useful parameter for comparing variability between blocks. The NOAA dataset covers nearly all of the WEA.

**Table 4-1. Water Depth Statistical Summary**

<b>OCS block number shown at top (* indicates partial block)</b> <b>Mean Water Depth (Meters, MLLW) listed in middle</b> <b>with Standard Deviation in Parentheses.</b> <b>Range of Water Depth (Minimum and Maximum) in meters listed at bottom.</b> <i>Table layout has OCS blocks progressing from north to south and west to east</i>				
<b>6012*</b> 25 (2) 18 to 32	<b>6013</b> 29 (2) 20 to 37	<b>6014</b> 31 (2) 20 to 36	<b>6015</b> 31 (1) 27 to 39	<b>6016</b> 33 (2) 28 to 41
<b>6062</b> 27 (1) 23 to 31	<b>6063</b> 28 (1) 24 to 32	<b>6064</b> 30 (2) 23 to 36	<b>6065</b> 30 (3) 25 to 37	<b>6066</b> 35 (2) 26 to 41
<b>6112</b> 28 (2) 21 to 31	<b>6113</b> 27 (3) 21 to 33	<b>6114</b> 29 (3) 22 to 34	<b>6115</b> 30 (2) 24 to 35	<b>6116</b> 31 (2) 26 to 39
<b>6162</b> 24 (2) 19 to 29	<b>6163</b> 26 (2) 21 to 32	<b>6164</b> 26 (1) 22 to 31	<b>6165</b> 29 (2) 24 to 33	<b>6166</b> 28 (1) 23 to 34

Note: OCS blocks are located within the WEA and categorized by mean water depth (meters, MLLW). The six shallowest blocks are highlighted green and the six deepest blocks are highlighted blue. Water depth statistics are for the entire OCS block.

## 4.2 SEAFLOOR GRADIENT

Seafloor slope gradient data provide valuable insight relative to several important siting, design, and performance considerations. Steep slopes or irregular seafloor conditions may be indicative of potential geohazards or challenges for anchoring construction vessels, installing structures, and laying cables.

In general, an irregular seafloor may be indicative of:

- Slope instability features (e.g. landslide scarps, debris flow lobes, etc.),
- Mobile sediments (e.g. actively moving dune complexes or sand waves),
- Escarpments or fault scarps,
- Boulder, cobble, and/or gravelly deposits (e.g. glacial moraines), or
- Gas escape features.

We calculated the slope gradient of the seafloor from the 2013 hydrographic survey data, as well as the 2011 and 2012 NOAA bathymetric data. The slope gradient maps of the WEA are presented in Figures 4-3a and 4-3b.

Most of the seafloor relief within the study area is attributed to the ridge-and-swale topography. In general, the seaward flanks of the ridges are steeper than the landside flanks, as observed by the sand ridges in the central and southern portions of the WEA (OCS Blocks, 6064, 6065, 6113, 6114, 6162, 6163, and 6164). In these blocks, the steeper seaward flanks have a slope ranging between 1 and 4 degrees while the landslide flanks are generally less than 1.5 degrees. Figure 4-3b (Inset 1 and 2) provides detailed views of sand ridges in OCS blocks 6114 and 6166 showing steeper slopes along the seaward flanks.

Higher slope gradients associated with smaller scale features also are observed in the slope gradient map. In the northwest area of the WEA (OCS blocks 6012, 6013, 6014, 6062, and 6063), sand ridges and superimposed bedforms (dunes) create an irregular seafloor topography where the landward flanks appear to be steeper than the seaward flanks. Slopes typically range between 2 and 7 degrees on the steeper landward flanks and less than 2 degrees along the seaward flanks (for example, Figure 4-3b, Inset 3) in the vicinity of these features. Steeper slopes also occur in the vicinity of linear features (postulated to be relic geologic features and/or modern hydrodynamic features). Slopes in the trough of these features are up to 5 to 7 degrees.

### 4.2.1 Bathymetric Profiles

Bathymetric profiles based on the lower-resolution regional data were included in Fugro's Desktop Study report (May 2013). As shown in Figure 1-5, the sounding data within the WEA as presented on these profiles were from 1981 and 1935. These profiles were updated based on the higher-resolution multibeam bathymetry data. Six additional bathymetric profiles were created along the Fugro survey track-line alignments. These bathymetric profiles are useful for: 1) evaluating seafloor variability within the WEA, and 2) evaluating the larger-scale (regional) features (e.g., shoal retreat massif complex) within the WEA.

Locations of bathymetric profiles are shown in Figure 4-4a. The Desktop Study profiles are oriented as follows: a) east-west oriented profiles (A through D) through the center of the four east-west rows of OCS blocks in the WEA (Figures 4-4b and 4-4c) and b) north-south

oriented profiles (1 through 5) the center of the north-south columns of OCS blocks in the WEA (Figures 4-4d and 4-4e). The six additional profiles created along Fugro survey track-lines consist of three primary line profiles (lines 103, 109, and 115) (Figure 4-4f), and three tie-line profiles (202, 204, and 206) (Figure 4-4g). All bathymetric profiles have a vertical exaggeration of 250x.

As discussed in the Desktop Study report, the east-west profiles show that the water depth within the WEA generally increases from west to east (nearshore to offshore). The northern east-west profiles (A and B) generally show the irregular seafloor area to the west, with sand ridges becoming smoother in the eastern area. The southern east-west profiles (C and D) show predominantly large shoal complexes (especially profile C-C'). The north-south profiles (1 through 6) show another water depth trend within the WEA: the southern blocks are generally shallower than the northern blocks, due to the sand ridge/shoal complexes within the southern region of the WEA. These sand ridges and complexes appear as a larger-scale undulation (almost sinusoidal) with smaller-scale features superimposed (especially to the northern end of these features).

The updated profiles show the value of the higher-resolution multibeam data. Several of the larger-scale features are now shown in greater detail than shown in the 1981 and 1935 regional data sets. For example, the sand ridges in OCS block 6013 (depicted in Profile A, Figure 4-4b) are more defined and show smaller-scale bedforms superimposed on the ridges. Thus the data spacing in the regional data sets smoothed features and did not detail the ridges and the superimposed bedforms. Also, the higher-resolution data better defines the characteristics of the sand ridge troughs (for example, refer to Profile 3 in Figure 4-4d).

The Fugro profiles are generally aligned parallel and perpendicular (primary lines and tie- lines, respectively) to major bathymetric features. The primary lines are aligned along troughs (bathymetric lows) and the axis of sand ridges/shoal complexes, whereas the tie lines transverse these features.

- The series of profiles shown in Figures 4-4a through 4-4g illustrate four main water depth areas comprised of :
  - a shallower water depth (typically less than 28 meters) area in the northwestern and western section of the WEA (OCS blocks 6012, 6013, 6062, 6063, and 6112),
  - an intermediate water depth (typically 28 to 34 meters) area in the northern section (mainly OCS blocks 6014, 6015, but localize in troughs in OCS blocks 6103, 6112, 6063, and 6064),
  - a deeper water depth (greater than 34 meters) area in the eastern section (OCS blocks 6016, 6066, and 6116), and
  - a shallower water depth (typically less than 28 meters) area associated with the shoal retreat massif (and multiple ridge complexes) in the central and southern sections (OCS blocks 6162 through 6166, 6113 through 6116, and partially in 6064, 6065, and 6015).
- Water depth variation in the northwestern section of the WEA is depicted in Profiles 103, 204, A, B, and 1. These profiles show the area has a shallower water depth

and irregular seafloor consisting of sand ridges and bedforms with amplitudes of 1 to 3 meters. The sand ridges and dunes typically have steeper northward facing slopes (refer to inset 3 in Figure 4-3b).

- Water depth variation in the intermediate water depth area is depicted in Profiles 109, 206, A, 3, and 4. These profiles show the area has a sinusoidal trend over the shallower features and a slightly irregular seafloor (when compared to the northwest area). Dune features are also smaller in dimension (amplitudes of 0.5 to 2 meters).
- Water depth variation in the deeper water depth area is depicted in Profiles 115, 206, B, and 5. As typically with other bathymetric lows within the WEA, the deeper water area (e.g., OCS block 6066) is associated with trough(s) adjacent to ridges or shoal massif retreat ridge complexes. As shown in the profile for line 206 (Figure 4-4g), even the deeper water area is comprised of sand ridges, although other bedforms are infrequent.
- Within the shoal retreat massif (and related ridge complexes), water depth variation is more dependent on position related to crests and troughs (shallower and deeper water depth areas, respectively). As shown in the profiles for lines 202 and 204, the shoal retreat massif is made up of complexes which are kilometers in width and several meters thick. In Profiles C and D the regional scale shoal complexes show relief greater than 9 meters (30 feet). The flanks for these features are generally steeper in the seaward direction (Inset 2, Figure 4-3b). The dimensions of these features decrease with increasing water depth (as evident through the comparison of the 200 series profiles in Figure 4-4g).

### 4.3 SEAFLOOR FEATURES

#### 4.3.1 Shoals (Sand Ridges) and Bedforms

Generally the Virginia shelf is characterized by ridge-and-swale topography, broad cross shelf valleys, and shoal retreat massifs. These regional (relic) seafloor features were created by geologic processes in the past but continue to be modified by oceanographic processes today. Within the WEA, sand ridges are present within: 1) areas of irregular seafloor in the northwestern area, and 2) within the shoal retreat massif (ridge complexes). These features are evident in the bathymetric profiles shown in Figure 4-4. Also, bedforms at various scales are observed in the WEA.

Shoal retreat massifs (consisting of multiple shoal complexes) represent the largest-scale features in the project area. Dimensions of these features vary, with amplitudes of several meters to 10s of meters, and lengths on the order of 100s of meters to several kilometers. Figure 4-5 illustrates two ridge crests above 23 meters with a swale feature separating the ridges at approximately 28 meters. These ridges have lengths ranging from 1 to 4 kilometers, widths up to 2 kilometers, and bathymetric relief of 4 to 10 meters. Both ridges contain steep seaward flanks which indicate a net migration direction to the southeast (refer to bathymetric profile D in Figure 4-4c).

The seafloor in the north and northwest region of the WEA is highly irregular and consists of frequent bedforms (dunes) superimposed on broad sand ridges (Figure 4-6a). This

irregular bathymetry of bedforms superimposed on sand ridges is generally found in shallower water depths (18 to 26 meters). The sand ridges in the northwest are typically of shorter length and width, occur at a higher frequency, and display a lower bathymetric relief than the larger ridges that make up the shoal complexes to the south. Figure 4-6a presents an example of an irregular seafloor area in OCS block 6012 where dune and ridge features are superimposed on a shoal in 24 to 28 meters water depth. Profile A shown in Figure 4-4b crosses from west to east across this area. The asymmetrical shape of the high frequency sand ridges are clearly depicted with steeper flanks toward the west, which likely indicates a net north-northwest migration direction. The smaller-scale dune features have amplitudes less than 2 meters and wavelengths on the order of 10s of meters, which is typical of these types of features (Bridge and Demicco, 2008).

#### 4.3.2 Linear Features

Several linear features are present in the WEA. An example of those features is shown in Figure 4-6b (black arrows). Typically these features occur within the trough of sand ridges or at the edge of the shoal complexes. Where adjacent to sand ridges in the irregular seafloor area (OCS blocks in the northwest section of the WEA), the linear features occur in shorter, discontinuous sections with lengths of up to several hundred meters. Where adjacent to the shoal complexes, the features are longer and continuously extend up to several kilometers to 10s of kilometers.

The regional distribution of these features is shown in Figure 4-7. In profile view, the linear features appear as abrupt troughs with acute angles at the deepest section - for example, refer bathymetric profile C in Figure 4-4c (near the intersection with profile 3) and profile 202 in Figure 4-4g (approximately 6 kilometers southeast from the northwest end of the profile). It is inferred that these features are either: 1) related to adjacent geologic features (i.e., relic features), 2) could be a result of the modern hydrodynamic environment, or 3) perhaps are due to a combination of those reasons.

A possible geologic model for the linear features would be their relation to former back barrier (tidally-influenced estuary) environments. Linear features may represent the break between back barrier environment and shoreface (sand ridge). These areas could have formed during the retreat of an estuary-mouth scour channel or a river valley modified by estuarine processes during transgression (Swift et al., 1980). As shown in Figure 3-1, Holocene back barrier deposits can be exposed at the seafloor on the landward side of sand ridges (or shoal retreat massifs).

Supporting evidence demonstrating these linear features are related to the adjacent geologic features (ridges) is their occurrence in the troughs of the sand ridges (and deeper water areas adjacent to the shoal complexes). Within these areas, linear features also coincide with a change in the side scan sonar reflectivity. As shown in Figure 4-7, these bathymetric lows typically consist of contrasting side scan sonar reflectivity when compared to the crests of sand ridges, which likely indicates a change in sediment type. This contrasting reflectivity correlates with differences in sediment types from grab samples collected by Fugro during the geophysical survey, as well as regional sediment samples (Figure 4-7).

However, these features could also be a result of hydrodynamic conditions (bottom current flow). For example, in Figure 4-6b the linear features in the top of the image relate to the shape of the adjacent ridges (ridges are elongated to the southern direction along these troughs). This could indicate a bottom current flow condition that is modifying the ridges. It is likely, given the relation of the linear features to adjacent, high-relief ridges, that the linear features are sustained and modified by modern flow conditions (whether or not they represent relict geologic features).

### 4.3.3 Interpretation of Magnetometer and Side Scan Sonar Data

Magnetometer and side scan sonar data were interpreted to identify magnetic anomalies and sonar contacts (targets). Chart 4 presents locations of the magnetic anomalies and side scan sonar targets within the WEA. A total of 120 magnetic anomalies and 98 side scan sonar targets were found within the WEA and the surrounding 1 kilometer buffer zone. Tabulations and descriptions of magnetic anomalies and side scan sonar targets are presented in Appendix C and D, respectively. Appendix D also includes detailed side scan sonar data images of the individual targets.

The 120 magnetic anomalies within the WEA and vicinity can be summarized as follows:

- Measured magnetic intensity (in gammas) of anomalies ranged from 50049 to 51545, with a mean of 50252 and standard deviation of 142.
- Anomaly durations ranged from 11 to 19731 meters, with a mean of 1207 meters, and standard deviation of 3405 meters.
- A total of 7 magnetic anomalies occur within the southern meteorological tower aliquots. The measured magnetic intensity ranged from 50049 to 50241, with durations ranging from 37 to 174 meters.

The 98 side scan sonar targets within the WEA and vicinity can be summarized as follows:

- Measured heights of targets ranged up to 6.6 meters, and lengths up to 16.1 meters.
- A total of 3 targets are within the southern meteorological tower aliquots.

## 4.4 SEAFLOOR MORPHOLOGY

The Virginia continental shelf has the characteristic ridge-and-swale topography of the Mid-Atlantic shelf. It is postulated that these larger-scale seafloor features are relict shoreface deposits (geologic features) abandoned during sea level transgression (Swift et al., 1973). However, these features, and the bedforms (dunes) superimposed on them, are continually modified by the present-day hydrodynamic processes (i.e., bottom current flow and wave-action).

It is the interrelationship between the hydrodynamic conditions (wave action and bottom current flow produced by various oceanographic conditions), seafloor topography and sediments that: 1) creates the potential for erosion, transport, and redeposition of the seafloor sediments, and thus 2) produces seafloor morphology. These interrelationships vary both spatially and temporally and often correlate with regional water depth trends. Because the ocean - seafloor boundary exists in a condition of dynamic equilibrium, the bottom shear

stresses caused by various magnitudes of storms and currents can suspend, transport, and redeposit the seafloor sediments.

The Virginia continental shelf is considered a storm-dominated environment. Observations (Swift, 2010) suggest that most of the movement of the seafloor sediments occur during larger events. According to Swift (2010), sand waves and sand ridges are modified due to large storms that occur on a frequency of one to three times each year. These large storm events often produce forerunner waves with long wave periods (e.g., 15 seconds) that produce strong oscillatory bottom flow and induce sediment suspension and/or transport. Obviously, the amount of movement of the seafloor sediments and changes in the seafloor morphology increase as the severity of the storm increases, implying that larger storms with longer return periods can cause larger changes than comparatively smaller, more frequent storms with shorter return periods. However, subtle changes in the seafloor have been documented on the Mid-Atlantic shelf during minor storms. Table 4-2 below summarizes major storms (tropical storms and nor'easters) between the NOAA 2011 survey and Fugro 2013 survey. It is inferred that some or all of these storms may have influenced the seafloor morphology within the WEA.

**Table 4-2. Recent Large Storms Within Vicinity of Virginia WEA Area**

Date	Storm	Max Wind Speed (mph)	Description
July 17 - 22, 2011	Bret	70	Tropical Storm near WEA (July 21, 2011)
August 21 – 28, 2011	Irene	120	Hurricane near WEA (August 27, 2011)
August 29 – Sept 10, 2011	Katia	140	Hurricane near WEA (September 9, 2011)
May 19 – 22, 2012	Alberto	60	Disturbance near WEA (May 22, 2012)
May 26 – 30, 2012	Beryl	70	Disturbance near WEA (May 30, 2012)
October 22 – 29, 2012	Sandy	115	Hurricane near WEA (October 29, 2012)
October 28 – November 1, 2011	Nor'easter		Formed near Virginia Coast
November 7- 9, 2012	Nor'easter		Formed near Delmarva Penninsula
February 7 – 10, 2013	Nor'easter Nemo		Formed near Delmarva Penninsula

As shown in the bathymetric profiles, the predominant bedforms within the WEA include sand ridges, shoal retreat massif (sand ridge complexes), and smaller-scale bedforms (e.g., dunes). Based on the distribution and dimensions of features, the WEA was divided into areas inferred to consist of similar morphology (Figure 4-8). These areas are: 1) features in the shallower water depths (yellow areas in the northwestern and western WEA), 2) features in intermediate water depths (light blue areas in northern and central WEA), 3) features in deeper water depths (dark blue areas in the eastern WEA), and 4) features part of the shoal retreat massif (brown areas in the central and southern WEA). These areas consist of seafloor features (e.g., bedforms) at various scales that are related to the larger-scale geologic features, surficial sediments, and hydrodynamic environment.

The seafloor in the north and northwest region of the WEA is highly irregular and consists of frequent dunes superimposed on broad shoal complexes. Profiles 204 and A (Figure 4-4) are within this area and show the prominent features. The ridges are in shallower water depths (18 to 30 meters), and when compared to ridges on the shoal retreat massif are: 1) shorter in length and width, 2) occur at a higher frequency, and 3) display a lower bathymetric relief. Also, the ridges are asymmetrical with steeper flanks toward the west (inferred to indicate a net north-northwest sediment transportation direction). Figure 4-6a presents a detailed example of an irregular seafloor area in OCS block 6012 with dune and ridge features superimposed on a shoal in 24 to 28 meters water depth.

As with the sand ridges, dunes within the northwestern area have asymmetry which indicates net bottom current flow directions. These bedforms can be used to evaluate sediment transport conditions and/or bottom current magnitudes (Ashley, 1990). Several localized bathymetric profiles (referred to as geomorphic profiles) were created across features in this area to evaluate changes from 2011 to 2013 based on the NOAA and Fugro bathymetry data sets. Profile locations (Figure 4-9a) were chosen along lines 102 (Figure 4-9b), as well as 101 and 104 (Figure 4-9c), as being representative of the conditions within the shallow water depth region. These profiles show that: 1) dune bedforms show migration over the short time-frame between the multibeam surveys (line 102 and 101), and 2) sediments are being also redistributed (erosion) over a localized area (line 104). The latter is important because, unlike with bedform migration, localized sediment redistribution may not show a pattern based on hydrodynamic flow conditions. Therefore, general seafloor erosion and sediment redistribution (if occurring) would be more difficult to evaluate and mitigate for OWF components (e.g., cable layout).

Larger-scale features associated with the shoal retreat massif are inferred to be more stable than the smaller-scale bedforms. Figure 4-9d depicts a geomorphic profile along survey line 202 (between line 103 and 111) showing a shoal complex, ridges, and several linear features in the adjacent troughs. Comparison of the NOAA and Fugro multibeam data sets (2011 and 2013, respectively) indicate that the ridges remain mostly unchanged during the two years between the surveys. Therefore, it is inferred these features are in dynamic equilibrium with the modern hydrodynamic environment, which means active sediment transport processes are occurring, but that the gross morphology of these features ultimately remains stable during engineering time scales (e.g. 30 years). However, the linear features may be more susceptible to erosion due to bottom flow forcing along the troughs.

Evaluation of erosion, accretion, and migration of bedforms can be performed by comparing two bathymetric datasets collected at different times of the same area. Figure 4-10 compares the Fugro 2013 and NOAA 2011/2012 multibeam (MBES) data by mathematically subtracting one elevation model from the other. The difference between the two elevation models reveals areas that have undergone accretion and erosion and can be used to interpret the migration or shifting of bedforms and assess mobile sediment areas. Four examples of sediment mobility within the WEA are shown (each within a different inferred morphologic region). These examples are summarized as follows:

- Inset 1 shows inferred dune migration within the shallower water depth region (sediment mobility shown here is similar to what is shown in the geomorphic profiles in Figures 4-9b and 4-9c).
- Seafloor feature examples within the intermediate water depth area are shown in Inset 2 (elevation [El.] between El. -30 and -32 meters MLLW). This image shows that seafloor features in this region are also subject to erosion. However, it is uncertain if these features migrate (e.g., dune migration) or if this is an example of sediment erosion and redistribution (localized construction and destruction of features).
- Inset 3 shows erosion features (scars) in the margin between the shoal retreat massif and deeper water depth areas (between El. -29 and -34 meters MLLW). The erosional features (scars) shown in the difference grid do not extend into NOAA data set (gray background) but are present to the east.
- Examples of features within the shoal retreat massif area are shown in Inset 4 (between El. -29 and -31 meters). Within this area, erosion is occurring along a linear feature in a trough (lower right corner), as well as erosion of features associated with irregular seafloor (center).

In summary, seafloor features observed within the WEA indicate a complex and dynamic seafloor. The Mid-Atlantic continental shelf is considered to be a storm and wave dominated hydrodynamic environment with influence from tidal and circulation currents. The nature of these geologic features relate to conditions that will influence design of OWF components, the installation of piled foundations and cables, and erosion, deposition, and scour around structures founded on and beneath the seafloor.

## 5.0 SUBSURFACE CONDITIONS

### 5.1 SUBSURFACE STRATIGRAPHY

This regional geophysical survey provides the initial step for developing a geologic framework within the WEA. Information acquired and interpreted during this study reveal much information regarding the seafloor and subsurface conditions. Our subsurface characterization is based on a conceptual understanding of the geologic history of the continental shelf, detailed seafloor mapping data, and high-resolution subsurface seismic data. Together, the data are interpreted to map the thickness and distribution of surficial Quaternary deposits and the elevation of the underlying pre-Quaternary deposits. The following provides a description of the seismic stratigraphy and notable subsurface features.

The seismic reflection (Chirp and multichannel boomer) data have been used to interpret seismic horizons. Seismic horizons selected for mapping appear as distinct seismic reflections (or events) in the data and are deemed to represent a notable seismic stratigraphic boundary. Seismic reflections occur when the seismic energy generated by a source (e.g. boomer) travels into the subsurface and encounters a seismic impedance contrast and some of the seismic energy reflected at the impedance contrast is recorded by a receiver (e.g. hydrophone). The amount of energy reflected at an interface is proportional to the impedance contrast. Impedance ( $I$ ) is the product of the medium's density ( $\rho$ ) and P-wave velocity ( $V_p$ ). Thus, interfaces with strong impedance contrasts (e.g. soft clay overlying dense sand or unconsolidated sediments overlying rock) will generate "strong" or "high amplitude" reflections.

The depth limit of interpretation for such events was within the inferred depth of interest with respect to offshore wind turbine foundations [i.e., the upper 45 to 90 meters (150 to 300 feet)]. We infer that sediments within this depth of influence for wind turbine foundations are likely to be comprised of Quaternary (Holocene and Pleistocene) and Tertiary (Pliocene and Miocene) age deposits (Figure 3-2). Those depositional periods are generally summarized as follows:

- **Holocene (last 11,000 years)** – These modern deposits typically consist of a sequence of shelf sands, barrier sand deposits, and back-barrier deposits (lagoonal, estuarine, and fluvial deposits as illustrated on Figure 3-3 and Inset C on Figure 3-4). As the sea level rose following the last glacial sea level low-stand, channel-fill sequences infilled the incised fluvial channels that formed drainages on the shelf. The infill deposits are referred to as transgressive deposits. The drainages represent paleo-river systems that flowed across the shelf and connected to the sea where submarine canyons (e.g. Norfolk Canyon) now exist at the shelf break and upper slope. Fine-grained, lagoonal-estuarine and marsh deposits infilled the channels and deposited behind barrier features (Figures 3-4 and 3-5). This was followed by the deposition of sandy barrier sediments creating the sand ridge topography that dominates the Mid-Atlantic shelf. Lastly, as the area transitioned to an open-shelf marine environment, a sheet of marine sand was deposited on the seafloor (note: this layer may be locally absent in swales).
- **Pleistocene (11,000 to 2.6 million years ago)** – During glacial stages in the Pleistocene epoch, the continental shelf was subjected to subaerial erosion and

fluvial deposition during and subsequent to the periods of rising sea level, resulting in: 1) the working and reworking of the pre-Quaternary sediments, and 2) the working and reworking in turn of the glacial and interglacial sequences that were subsequently deposited. Due to these complex processes, the thickness on the continental shelf of the Pleistocene sequence is likely variable. The surface between the Holocene sediments and Pleistocene sediments represents an erosional or ravinement surface that has deeply incised the subaqueous surface of the Pleistocene sediments through fluvial processes.

- **Tertiary (Pliocene and Miocene, 2.6 to 23 million years ago)** – Tertiary age strata are inferred to underlie the Quaternary deposits. Within the depth of interest for a wind turbine foundation, these sediments may include deposits equivalent to the onshore units referred to as the Yorktown, Eastover, and St. Marys Formations. The Yorktown formation is an extensive nearshore marine deposit of sandy shelly clay that grades upward to quartzose silty sand. The bedding is massive and compact with discontinuous layers of shell (less than 1 meter thick), and thin lenses of clayey silt. The clay content decreases upward in the deposit, while the shelly beds become more abundant. In general, these deposits are inferred to have a gentle seaward dip (as depicted in Figure 3-3). The Eastover Formation is separated from the overlying Yorktown Formation by an unconformity and is a marine deposit comprised of silty to clayey fine sand with interbeds of coarser materials. The St. Marys Formation underlies the Eastover Formation is comprised of sandy clay to silty/clayey fine sand marine deposits.

Interpretations in the seismic reflection data included events pertaining to each of these depositional environments. Seismic data examples included in this report illustrate these subsurface conditions as encountered within the WEA. Locations of seismic profiles are shown in Figures 5-1a and 5-1b. Shallow stratigraphic conditions interpreted in Chirp sub-bottom records are shown in Figure 5-2, whereas deeper stratigraphic conditions interpreted in the boomer seismic reflection records are shown in Figures 5-3a through 5-3h. Figures 5-3a and 5-3b show deep seismic sections that illustrate regional trends. Figure 5-3g presents the correlation between the WEA and borehole located near the Chesapeake Light Tower Structure. Figures 5-3i and 5-3j present seismic data examples from the Research Lease 2 area.

### 5.1.1 Marine Deposits (Holocene Age Sequence)

Modern marine sediments present within the WEA and are inferred to be composed mainly of granular (e.g. sand) sediments of varying grain size (and grain size distribution) and density. These granular sediments occur on, or adjacent to, shoals/sand ridges based on: 1) the presence of bedforms (which indicate mobile granular sediments, and 2) the seismic character underlying the sand ridges. The upper several meters of the surficial deposits are likely loose and mobile. As discussed in the geomorphology section, the sand ridges are likely being continually modified (e.g. built up and then deconstructed) and sand waves (dune and ripple scale) are subject to migration. Figure 5-2a shows a profile from Chirp sub-bottom record line 201 of a sand ridge where the highlighted reflector likely represents the base of loose sands.

The marine deposits are thickest beneath the sand ridges where they may be up to 10 meters thick. The sand ridges have a distinct, flat bottom that is inclined gently (Figures 5-3a through 5-3e). The reflector at the base of the sand ridges is distinct and commonly exhibits a negative amplitude reflection that is to be expected for sandy deposits overlying fine-grained Transgressive deposits. Horizon 10 (denoted as "H10" on the seismic records) is inferred to represent the base of the Holocene marine deposits.

We observed shallow channeling in the marine deposits. The shallow channeling is likely related to tidal processes near the barrier shore zones. Based on the seismic stratigraphy, fine-grained to interbedded sand with silt/clay deposits also are interpreted to be present within the Holocene deposits. These sediments typically occur in: 1) shallow channels and 2) former back-barrier/estuarine environments now exposed in the trough of sand ridges (swales). Figure 5-2b shows a profile from Chirp sub-bottom record line 113 with inferred surficial fine-grained/interbedded deposits as interpreted from the stacked reflectors. This seismic character is consistent with infilled channel deposits (as shown in Figures 5-2c and 5-2b).

### 5.1.2 Pleistocene Deposits

Pleistocene-age deposits within the WEA are inferred to be derived from three depositional environments: 1) fluvial systems, 2) fluvial-estuarine systems, and 3) potentially barrier complex (shoreface) environments. Transgressive deposits associated with the fluvial systems (higher energy environment) likely consist of sandy deposits with varying amounts of gravel as a result of the erosion, reworking, and deposition of underlying strata (Pliocene or previously deposited Pleistocene deposits). Intermediate channels interpreted in the seismic records are likely an example of this depositional environment. Deposits associated with the fluvial-estuarine systems (mixed energy environment) often have fine-grained deposits of varying thickness, but may also be interbedded fines (clay and/or silt) and sand depending on the proximity to the barrier complex system. Pleistocene transgressive shoreface deposits, if encountered, likely consist of thicker sequences of sand within dune and shoreface area, as well as interbedded deposits in the tidal/delta environment.

The base of the Pleistocene has been interpreted by a prominent positive amplitude reflector that exhibits high relief (10s of meters) and represents an erosional surface. The underlying reflectors dip gently (deepen) from west to east (offshore), are relatively parallel bedded, and are truncated by the erosional surface (Figure 5-3a). The gently dipping reflectors that are truncated by the erosional surface are inferred to represent the underlying Tertiary strata. The elevation of this reflector (base of Pleistocene) varies from El. -38 to -50 meters in the WEA (Figure 5-4 and Chart 5). The variation in elevation is inferred to be related to fluvial incision.

We have grouped the Holocene and Pleistocene deposits together (which represent the Quaternary deposits) and mapped their inferred combined thickness as shown on Figure 5-6 and Chart 7. The thickness of the Quaternary deposits in the WEA is interpreted to range from about 4 to 20 meters. The Quaternary deposits are thickest beneath the sand ridges and in channel infill areas (e.g. northeast corner of WEA and back-barrier environments highlighted on Chart 8).

### 5.1.3 Tertiary Age Deposits

Tertiary age deposits beneath the WEA are likely comprised of Pliocene and Miocene strata. The units appear in seismic data as relatively parallel bedded units that dip gently to the southeast (Figure 5-3a). The interface between the Tertiary and overlying Quaternary deposits is inferred to be Horizon 30. Horizon 30 exhibits relief inferred to be related to fluvial incision and truncates the Tertiary beds where they intersect (Figure 5-4 and Chart 5). Tertiary age deposits are inferred to lie approximately 4 to 20 meters below the seafloor in the WEA (Figure 5-6a and Chart 7).

Horizon 40 appeared as a prominent reflector throughout the study area and ties into the upper section of the Chesapeake Light Tower borehole (Figure 5-3g). Figure 5-5 and Chart 6 present the interpreted elevation contours of Horizon 40. The horizon is absent in the northwest corner of the WEA where it was likely eroded during a sea level low-stand. Horizon 40 deepens from El. -40 meters in the northwest to El. -80 meters in the southwest corner of the WEA.

Horizon 140 appears as a distinct, high-amplitude event throughout the survey area (Figures 5-3a, 5-3b, and 5-3g). Beneath the WEA, it deepens from about El. -90 meters in the northwest to about El. -125 meters in the southeast corner. Horizon 140 is mappable on the regional survey lines and projects to the Chesapeake Bridge Tunnel area at about El. -40 to -50 meters.

## 5.2 SUBSURFACE FEATURES

Paleochannels were interpreted in both the Chirp sub-bottom and Boomer seismic reflection data. Within the Chirp data, surficial and shallow fine-grained/interbedded deposits were also interpreted. Locations of these features are shown Chart 8.

Paleochannels interpreted in the Chirp data were generally within the upper 6 meters of the subsurface. Prominent channel features were interpreted in the vicinity of the northwestern section of the WEA (near or within OCS Block 6016). Shallow fine-grained/interbedded deposits were also mapped within the WEA. These deposits are inferred to be Holocene (mainly) fine-grained or interbedded sediments associated with low energy environments. These deposits frequently correlate with bathymetric lows in the multibeam data and/or areas of contrasting lower side scan sonar backscatter energy (when compared to return energy for the sand ridges).

Paleochannels interpreted in the boomer data appear as distinct fluvial drainages or as former back-barrier environments. A large, prominent fluvial system was mapped from the interior of the WEA and formerly flowed to the northeastern corner. Chart 8 presents the mapped extent and shows the inferred bottom (thalweg) elevation and depth below seafloor. Thalwegs of the upper reaches of the drainage extend 7 to 9 meters below the seafloor and up to 12 to 16 meters in the northeastern corner of the WEA. The drainage system is about 2 kilometers wide where it exits the WEA in the northeast. This drainage likely connected to the major Cape Charles channel of the paleo-Susquehanna River where it connected to the Norfolk Canyon at the last glacial maximum sea level low-stand. Figures 5-3f and 5-3g present detailed seismic images of this drainage area. Seismic data in Figure 5-3f reveal gassy sediments that suggest the channel infill in this area likely contains fine-grained and organic deposits. Gas in these environments is generally related to decaying organics in these channel infill deposits.

We also note channelized deposits related to former back-barrier depositional environments. As discussed in the geomorphology section, the multibeam and side scan sonar data reveal distinct sand ridges that appear to have finer-grained deposits on the western sides. Seismic data reveal thicker Transgressive deposits within the broad embayments and nested channeling on the western flanks of some of the sand ridges. Figures 5-3c and 5-3d show detailed examples of this relationship as interpreted from seismic data. The back-barrier embayments are locations where the Transgressive deposits are thicker than surrounding areas. The back-barrier feature shown in Figures 5-3c and 5-3d exhibit Transgressive deposits (unit Qe between horizons H20 and H30) that are interpreted to be 8 meters thick compared to 3 to 5 meters thick in the adjacent Transgressive unit. We delineated several of these thicker sequences of back-barrier deposits with blue shading on Chart 8. Modern examples of those back-barrier environments include the Isle of Wight Bay, Maryland near the Ocean City inlet or Rehoboth and Indian River Bays in Delaware.

## 6.0 SUMMARY

### 6.1 WATER DEPTH VARIATIONS, SEAFLOOR FEATURES, GEOMORPHOLOGY CONSIDERATIONS

As described within this report, the available information suggests the seafloor in the WEA offshore Virginia includes significant complexity. This complexity is due to both geologic processes that occurred as the sea level rose following the last ice-age and the dynamic nature of the currents on the ocean bottom.

The water depth within the WEA generally increases from west to east with minimum and maximum water depths of approximately 18 to 41 meters (59 to 135 feet) MLLW (OCS blocks 6012 and 6066, respectively). The shallowest water depths exist on the low frequency sand ridges (the dominant seafloor features) along the northwestern and western regions of the WEA. These ridges are separated by a low lying and low relief swales (from OCS block 6112 diagonally through block 6015).

The northwest area of the WEA (OCS blocks 6012, 6013, 6062, and 6063) has an irregular seafloor with bedforms superimposed along broad shoals. The water depth varies from approximately 18 meters (60 feet) on the shoals to 28 meters (85 feet) in the adjacent swales. Bedforms (e.g., dunes) superimposed on the large ridges and swales in this area are generally of lower relief and extent, with localized bathymetric relief (e.g. height between ridge crest and adjacent swale) varying from approximately 1 to 3 meters (3 to 10 feet).

The central and southern areas of the WEA consist of a shoal complex (shoal retreat massif) with sand ridges superimposed on a broader, shallow water area. Water depth varies from approximately 18 to 26 meters (60 to 85 feet). Sand ridges, which are part of this complex, are generally of much higher relief and extent when compared to other sand ridges elsewhere within the WEA. Water depths in the swales and troughs within the shoal complex vary from 30 to 34 meters (98 to 112 feet).

In the northern area, the swales and troughs have water depths ranging from approximately 32 to 36 meters (105 to 118 feet), and the deepest water depths are in the northeastern/eastern area off of the shoal complex and range from approximately 30 to 41 meters (98 to 135 feet) (OCS blocks 6016, 6066 and 6116).

Most of the seafloor relief within the study area is attributed to the ridge-and-swale topography. In general, the seaward flanks of the ridges are steeper than the landside flanks. In the southern area, ridges part of the shoal retreat massif have steeper seaward flanks with slope ranging between 1 and 4 degrees while the landside flanks are generally less than 1.5 degrees. In the northwest area of the WEA, sand ridges and superimposed bedforms (dunes) creates an irregular seafloor topography where the landward flanks of these smaller-scale features appear to be steeper than the seaward flanks. Slopes typically range between 2 and 7 degrees on the steeper landward flanks and less than 2 degrees along the seaward flanks in the vicinity of these features. Steeper slopes also occur in the vicinity of linear features (postulated to be relic geologic features and/or modern hydrodynamic features). Slopes in the trough of these features are up to 5 to 7 degrees.

The WEA can be divided into four regions, based on water depth and seafloor features that include: 1) a shallower water depth (typically less than 28 meters) area in the northwestern

and western section of the WEA (OCS blocks 6012, 6013, 6062, 6063, and 6112), with a highly irregular seafloor consisting of sand ridges and superimposed bedforms; 2) an intermediate water depth (typically 28 to 34 meters) area in the northern section, which consists of lower-relief seafloor features; 3) a deeper water depth (greater than 34 meters) area in the eastern section; and 4) shallower water depth (typically less than 28 meters) area associated with the shoal retreat massif (and multiple ridge complexes) in the central and southern sections. These areas consist of seafloor features (e.g., bedforms) at various scales which are related to the larger-scale geologic features, surficial sediments, and hydrodynamic environment.

Within the WEA, sediment mobility was evaluated based on the available multibeam bathymetry data. The data show that 1) bedforms migration occurs over the short time-frame between the multibeam surveys, and 2) sediments are being also redistributed (erosion) over a localized area, and 3) larger-scale geologic features (e.g., ridges part of the shoal retreat massif complex) are in dynamic equilibrium with the modern hydrodynamic environment and remain mostly unchanged (i.e., the gross morphology remains relatively stable).

Based on the morphological evaluation, sediment mobility and scour are anticipated to be a potential geohazards relative to the development and performance of an offshore wind development. The installation of a structure and burial of cables can unbalance the dynamic equilibrium at the ocean - seafloor interface, which may increase the potential for sediment mobility leading to scour around the structures. The changes in the ocean - seafloor dynamics are created by: 1) introducing obstructions that create localized areas of increased bottom currents and 2) disturbing the sediment (and increasing its scour susceptibility) around the structure and along the cable routes. The variation of scour will depend on the following factors and the interrelationship among these factors: 1) seabed current velocities, 2) seabed conditions (e.g. seafloor roughness/bedforms), 3) seabed sediment type and conditions, and 4) degree of seabed disturbance caused by: a) inner-array cable installation, b) turbine substructure and foundation, and/or c) construction vessel anchors and barge legs.

Since, scour potential is related to oceanographic and seabed conditions and how the installation of OWF structures and cables will alter the natural environment, the design of an OWF with respect to scour consideration and mitigation requires the input from and use of information from several disciplines. Therefore, an integrated approach to that effort and detailed evaluation is encouraged as part of the OWF siting, design, and installation planning.

## **6.2 SUBSURFACE CONDITIONS FOR FOUNDATION DESIGN**

Within the WEA, it is inferred the upper portion of the subsurface stratigraphy is typically composed on late Pleistocene and Holocene sediments. Subsurface conditions at any specific location in the WEA can be influenced by the presence or absence of buried relict drainage systems and clay-filled paleochannels and/or "back-bay" estuary deposits. These conditions are typical of the subsurface conditions (within the depth of engineering interest for pile foundations) within the inner and mid shelf of the Mid-Atlantic.

Prior scientific studies have mapped the general alignments of ancestral river drainages that were incised into what is now the continental shelf during glacial periods when the sea level was as much as 100 meters below present sea level. This study represents the first mapping of such paleodrainages and develops the initial geologic framework for the WEA. The data

collected during this study indicate that the main stem of the major paleodrainages do not appear to be present within the WEA. However, the data illuminate numerous smaller drainages that extend 5 to 12 meters below the seafloor throughout the area. One of the large drainages appears to have drained to the northeast and likely fed into the Cape Charles channel of the paleo-Susquehanna River during the last sea level lowstand. This study also interpreted and mapped the locations of back-barrier features that likely contain fine grained or interbedded deposits. Those features are interpreted to extend up to 19 meters below the seafloor.

The presence or absence and location of buried, clay-filled paleochannel systems will define the capacity, load-deformation characteristics, and resonance frequency of wind turbine foundations. Where such paleochannels are filled with thick deposits of silt and clays, their presence will reduce axial and lateral pile capacity (as compared to areas outside of the paleochannels). For example, the axial compressive capacity of a pile (of given size and tip elevation) driven through a clay-filled paleochannel and tipped in dense sand below the paleochannel, could be 20 to 40 percent (or more) less than the axial compressive capacity outside of the paleochannel. If such paleochannel fill includes gravel or other lag deposits, those conditions will have implications on the pile drivability and pile installation considerations.

An integrated program of geophysical surveys and geotechnical exploration will be appropriate for defining the locations, characteristics of the subsurface stratigraphy, engineering properties of the subsurface sediments, and their influence of foundation design (capacity, load-deformation, frequency of vibration), installation, and performance.

### **6.3 NEW INSIGHTS FROM THE REGIONAL GEOPHYSICAL SURVEY**

The regional geophysical survey provided high-resolution data sets (multibeam bathymetry, side scan sonar, magnetometer, Chirp, and multichannel seismic reflection) within the WEA. The interpretation of these data has given important insight into the geologic and surface conditions of the WEA. The key knowledge aspects gained are summarized as follows:

- The multibeam bathymetry data better defined seafloor features and water depth trends within the WEA when compared to the lower-resolution data used in the DTS (refer to Figures 4-4a through 4-4e).
- Smaller-scale features (e.g., dune bedforms) were resolved in the higher-resolution bathymetry data (refer to Figure 4-6a) than were illustrated on the older data.
- More detailed analysis using the Fugro and NOAA multibeam bathymetry data further revealed the seafloor morphology and was useful in defining regions of similar morphological features, and evaluating sediment mobility (e.g., dune migration) (refer to Figures 4-9 and 4-10).
- The side scan sonar data, when integrated with the other data sets, was useful in evaluating surficial sediment changes within the WEA, as well as evaluating seafloor morphology (refer to Chart 4 and Figure 4-7).
- Interpretation of the Chirp data revealed the presence of shallow channels, as well as areas of shallow fine-grained/interbedded deposits. The latter correlated with contrasting side scan sonar reflectivity and are inferred to represent possible back barrier (tidally-influenced estuary) environments.
- Lastly, the multichannel (boomer) data was useful in:

- Defining stratigraphic contacts between the Holocene, Pleistocene, and Tertiary,
- Identifying buried channels and mapping their distribution, and
- Identifying subsurface features relevant to the design and construction of OWF components.

## 7.0 REFERENCES

- Ashley G.M. (1990), "Classification of Large-scale Subaqueous Bedforms: A New Look at an Old Problem," *Journal of Sedimentary Petrology*, Vol. 60, pp. 363-396.
- Bridge, J.S., and Demicco, R.V. (2008), *Earth Surface Processes, Landforms, and Sediment Deposits*. Cambridge University Press.
- Bureau of Ocean Energy Management (2012a), *Guidelines for Geological and Geophysical, Hazards, and Archaeological Information Pursuant to 30 CFR Part 585*, November 9, 2012.
- Bureau of Ocean Energy Management (2012b), *Commercial Wind Lease Issuance and Site Assessment Activities on the Atlantic Outer Continental Shelf Offshore New Jersey, Delaware, Maryland, and Virginia, Final Environmental Assessment*. Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Document Number OCS EIS/EA BOEM 2012-003.
- Chen, Z.-Q. and Hobbs, C.H. (1995), "Late Quaternary paleochannel systems on the continental shelf south of the Chesapeake Bay entrance," *Journal of Coastal Research*, vol. 11, no. 3, p. 605-614. Fort Lauderdale, FL, ISSN 0749-0208.
- Colman, S.M., Berquist, C.R., Jr., and Hobbs, C.H., III (1988), "Structure, age, and origin of the bay-mouth shoal deposits, Chesapeake Bay, Virginia," *Marine Geology*, vol. 83, p. 95-113.
- Colman, S.M., and Mixon, R.B. (1988), "The record of major Quaternary sea-level changes in a large coastal plain estuary, Chesapeake Cay, Eastern United States," *Palaeogeography, Palaeoclimatology, and Palaeoecology*, vol. 68, p. 99-116.
- Duane, D.B. and Stubblefield, W.L. (1988) Sand and gravel resources: U.S. Atlantic continental shelf. In Sheridan, R.E. and Grow, J.A. editors, *The Atlantic continental margin: U.S. Volume I-2: The geology of North America*. Boulder, Colorado: Geological Society of America.
- Duncan, C.S., Goff, J.A., Austin, Jr., J.A., Fulthorpe, C.S. (2000), Tracking the last sea-level cycle: seafloor morphology and shallow stratigraphy of the latest Quaternary New Jersey middle continental shelf. *Marine Geology*, V. 170, pg. 395-421.
- Foyle, A.M. (1995), "Quaternary Seismic Stratigraphy of the Inner Shelf and Coastal Zone, Southern Delmarva Peninsula, Virginia," Ph.D., Dissertation, Old Dominion University, Norfolk, Virginia, p 468.
- Fugro Consultants, Inc. (2013), "Geoscience-focused Desktop Study, Virginia Offshore Wind Energy Area, Virginia Outer Continental Shelf," Prepared for the Commonwealth of Virginia Department of Mines, Minerals and Energy, Fugro Project Number 04.81130003, dated May 2013.
- Fugro (1963), "Fathometer Survey & Foundation Investigation, Chesapeake Bay Entrance Offshore Structure, Cape Henry, Virginia," Report to Commandant, U.S. Coast Guard,

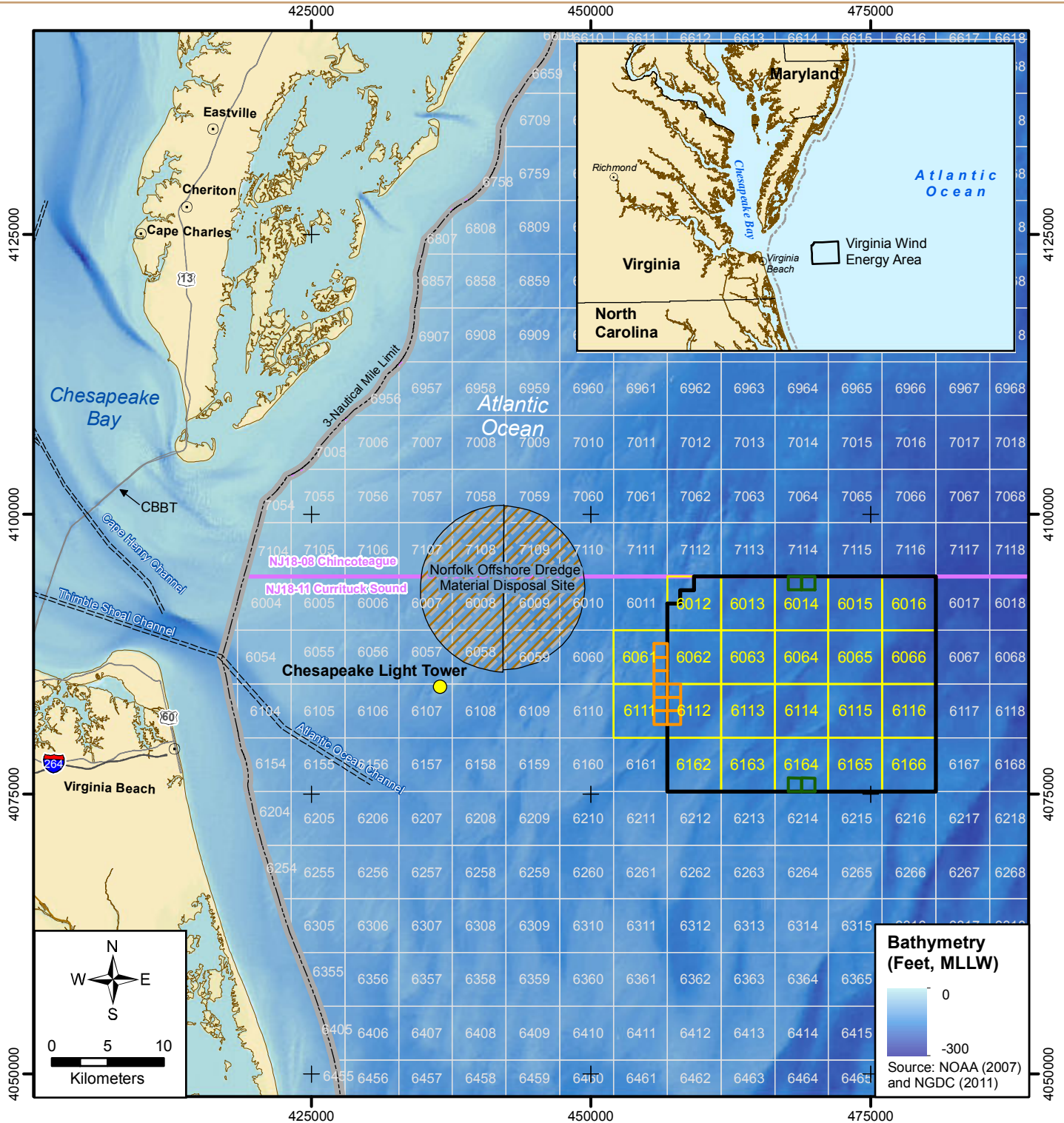
- Washington, D.C., Report No. 6383-2, August 1963, Published by McClelland Engineering (subsequently merged with Fugro).
- Grow, J.A., Klitgord, K.D., and Schlee, J.S. (1988), "Structure and evolution of the Baltimore Canyon Trough," in R.E. Sheridan and J.A. Grow, editors, *The Atlantic Continental Margin: U.S. Geological Society of America, The Geology of North America*, v. I-2, pg. 269-290.
- Harrison, W., Malloy, R.J., Rusnak, G.A., Terasmae, J., (1965), "Possible late Pleistocene uplift: Chesapeake Bay Entrance," *Journal of Geology*, vol. 73(2), p. 201-229.
- Hobbs III, C.H., (1997), *Sediments and Shallow Stratigraphy of a Portion of the Continental Shelf of Southeastern Virginia*, Contract Report for U.S. Department of Interior, Minerals Management Service, Cooperative Agreement 14-35-0001-30740, August 1997.
- Kimball, S.M., Dame II, J.K and Hobbs III, C.H. et al (1991), "Investigation of Isolated Sand Shoals on the Inner Shelf of Southern Virginia, Final Report," Virginia Institute of Marine Science, College of William and Mary, April 1991.
- Meisburger, E.P. (1972), "Geomorphology and Sediments of the Chesapeake Bay Entrance," *Technical Memorandum No. 38*, U.S. Army Corps of Engineers, Coastal Engineering Research Center, p. 1-61.
- Minerals Management Service (MMS) (2005), Digital Offshore Cadastre (DOC) - Atlantic83 - OCS Blocks. MMS Mapping and Boundary Branch, Lakewood, Colorado, February 28, 2005.
- Mixon, R.B., (1985), "Stratigraphic and geomorphic framework of Uppermost Cenozoic Deposits in the Southern Delmarva Peninsula, Virginia and Maryland," U.S. Geological Survey Professional Paper, vol. 1067-G, p. 53.
- National Geophysical Data Center (NGDC) (2011), U.S. Coastal Relief Model, Retrieved 2011, <http://www.ngdc.noaa.gov/mgg/coastal/crm.html>
- National Geophysical Data Center (NGDC) and National Oceanic and Atmospheric Administration (NOAA) (1937-2007), Hydrographic Survey Digital Sounding Data, Retrieved 2011, <http://maps.ngdc.noaa.gov/viewers/bathymetry/>
- National Geophysical Data Center (NGDC) and National Oceanic and Atmospheric Administration (NOAA) (2007), "Virginia Beach, VA 1/3 arc-second MHW DEM," NOAA Tsunami Inundation, <http://www.ngdc.noaa.gov/mgg/inundation/>
- Nordfjord, S., Goff, J. A., Austin, J. A. Jr., Sommerfield, C. K., (2005), "Seismic geomorphology of buried channel systems on New Jersey shelf: assessing past environmental conditions," *Marine Geology*, vol. 214, p. 339-364.
- Oertel, G.F., and Foyel, A.M. (1995), "Drainage Displacement by Sea-Level Fluctuation at the Outer Margin of the Chesapeake Seaway," *Journal of Coastal Research*, vol. 11, no. 3, p. 583-604.
- S&ME (2009), "Craney Island Eastward Expansion, Geotechnical Evaluation of Potential Offshore Borrow, Atlantic Ocean Channel, Thimble Shoals Channel, Newport News Channel and Anchorages." Prepared by S&ME, Inc., July 29, 2009 for the USACE.

- Snedden, J.W., Kreisa, R.D., Tillman, R.W., Culver, S.J., and Schweller, W.J. (1999), "An expanded model for modern shelf sand ridge genesis and evolution on the New Jersey Atlantic Shelf," *in* Bergman, K.M., Snedden, J.W. (Eds.), *Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation*, SEPM Special Publication, vol. 64, p. 147-163.
- Swift, D.J.P., Duane, D.B., and McKinney, T.F. (1973), "Ridge and swale topography of the middle Atlantic bight: Secular response to Holocene hydraulic regime," *Marine Geology*, vol. 14, p. 1-43.
- Swift, D.J.P., Nelsen, T., McHone, J., Holliday, B., Palmer, H., and Shideler, G. (1977) Holocene Evolution of the Inner Shelf of Southern Virginia. *Journal of Sedimentary Petrology*, vol. 47, no. 4, pp. 1454 – 1474.
- Swift, D.J.P., Moir, R., and Freeland, G.L. (1980), Quaternary Rivers on the New Jersey Shelf: Relation of Seafloor to Buried Valleys. *Geology*, vol. 8, pp. 276 – 280.
- Swift, D.J.P., Parsons, B.S., Foyle, A., and Oertel, G.F. (2003), Between beds and sequences: stratigraphy organization at intermediate scales in the Quaternary of the Virginia coast, USA. *Sedimentology*, vol. 50, pp. 81 – 111.
- Swift, D.J.P. (2010), personal communication.
- Toscano, M.A., Kerhin, R.T, York, L.L., Cronin, T.M. and Williams, S.J. (1989), Late Quaternary stratigraphy of the inner continental shelf of Maryland. *Maryland Geological Survey Report of Investigations*, vol. 50, p. 116.
- Uptegrove, J., Hall, D.W., Waldner, J.S., Sheridan, R.E., Lubchansky, B.J., Ashley, G.M. (1999) Geologic Framework of the New Jersey Inner Shelf: Results from Resource-based Seismic and Vibracore Studies. In Puffer, J.H. "New Jersey Beaches and Coastal Processes from Geologic and Environmental Perspectives, Geological Association of New Jersey, Proceedings Volume 16."

## FIGURES



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_03\_VA\_DMME\_DTS\mxd\Fig-1-01\_ProjectLocation.mxd, 04/03/13, jfisher



CBBT = Chesapeake Bay Bridge-Tunnel

**LEGEND**

- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Meteorological Tower Aliquot
- Demonstration Project Lease Aliquot
- + Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**PROJECT LOCATION MAP**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 1-1

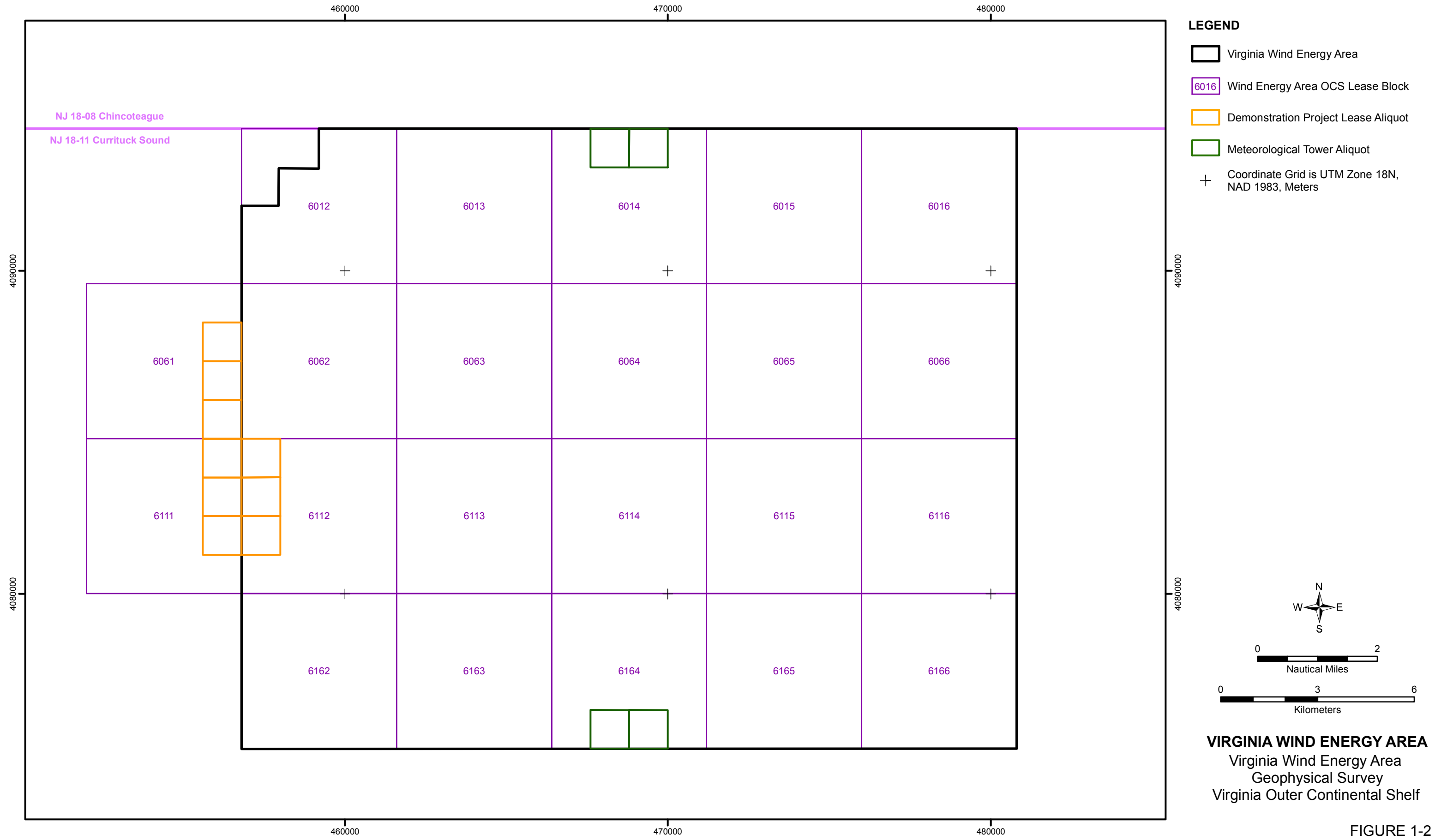
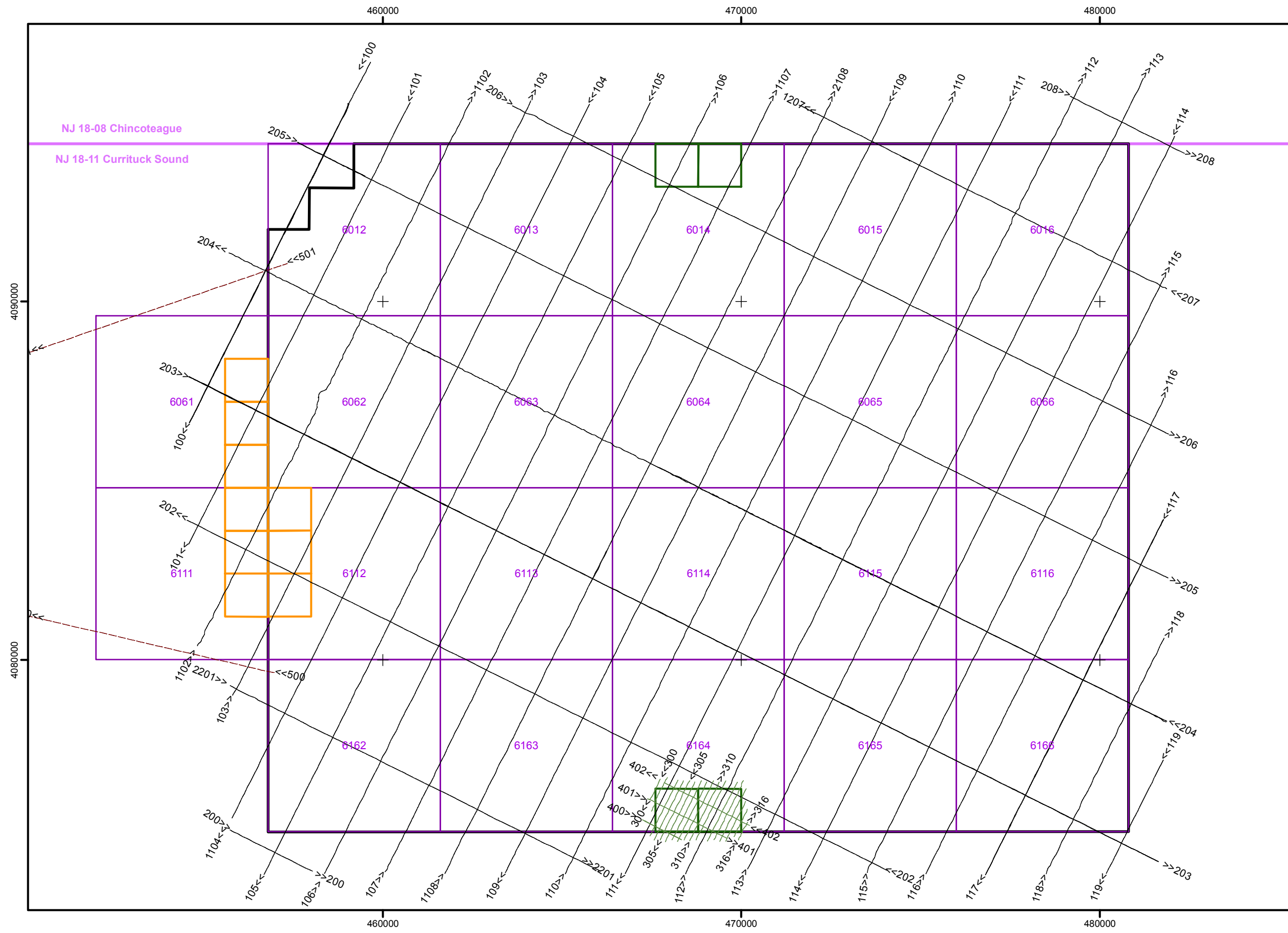


FIGURE 1-2

N:\Projects\3671\_Bluewater\Wind-DESurvey\Outputs\2013-Aug\_Data\_Transmittal\02-Digital\_Maps\Fig-1-03b\_VAWEA\_SurveyArea\_PostPlot.mxd, 8/19/2013, abowman



**LEGEND**

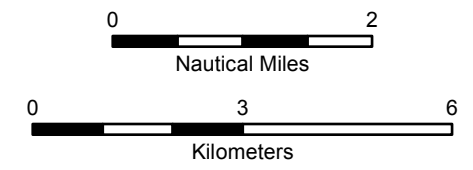
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**Fugro 2013 Survey Tracklines**

- WEA Survey Line (100 and 200 series)
- Met Tower Survey Line (300 and 400 series)
- Regional Survey Line (500 series)

**Notes:**

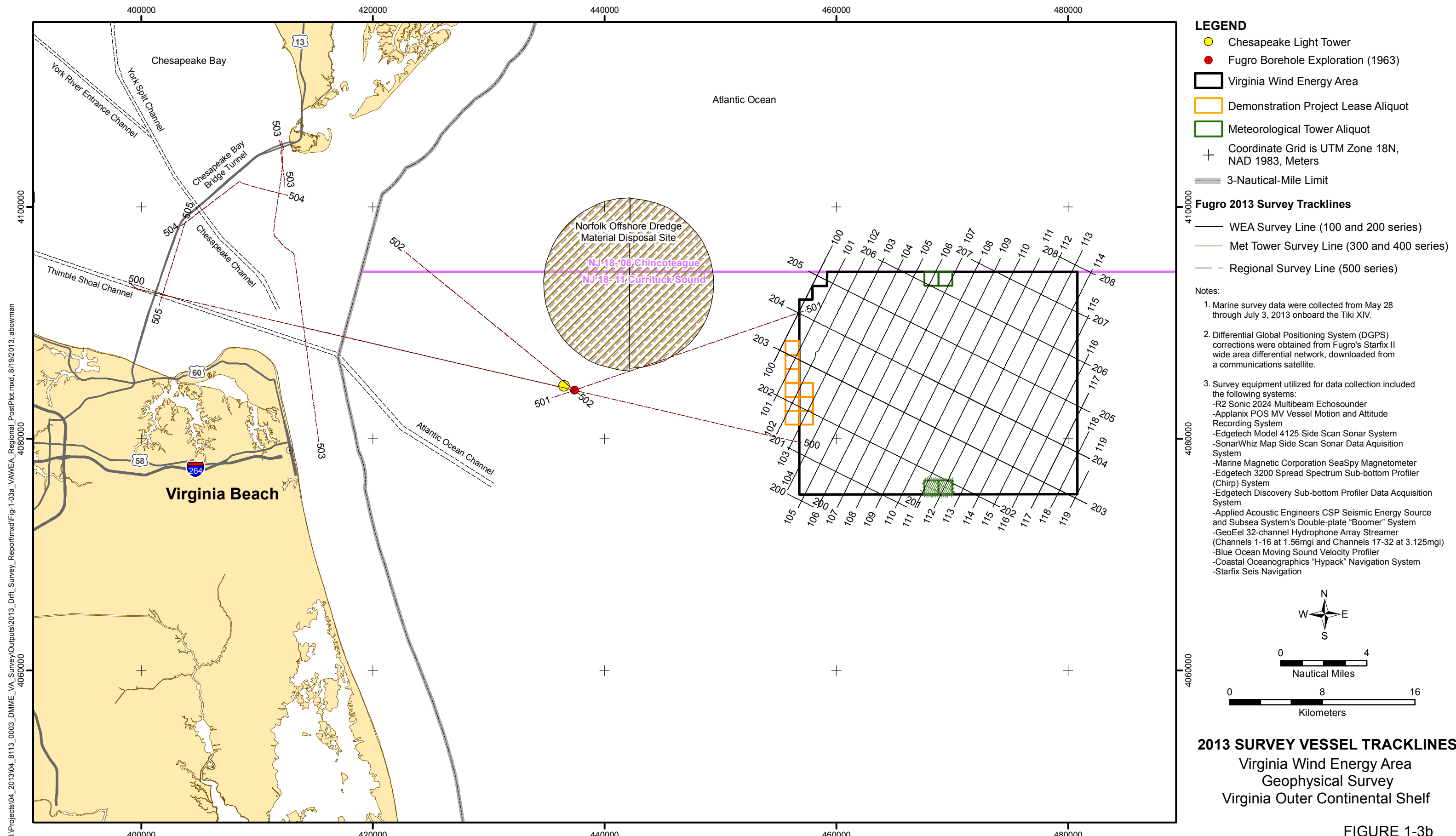
1. Marine survey data were collected from May 28 through July 3, 2013 onboard the Tiki XIV.
2. Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starfix II wide area differential network, downloaded from a communications satellite.
3. Survey equipment utilized for data collection included the following systems:
  - R2 Sonic 2024 Multibeam Echosounder
  - Applanix POS MV Vessel Motion and Attitude Recording System
  - Edgetech Model 4125 Side Scan Sonar System
  - SonarWhiz Map Side Scan Sonar Data Acquisition System
  - Marine Magnetic Corporation SeaSpy Magnetometer
  - Edgetech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) System
  - Edgetech Discovery Sub-bottom Profiler Data Acquisition System
  - Applied Acoustic Engineers CSP Seismic Energy Source and Subsea System's Double-plate "Boomer" System
  - GeoEel 32-channel Hydrophone Array Streamer (Channels 1-16 at 1.56mgi and Channels 17-32 at 3.125mgi)
  - Blue Ocean Moving Sound Velocity Profiler
  - Coastal Oceanographics "Hypack" Navigation System
  - Starfix Seis Navigation



**2013 SURVEY VESSEL TRACKLINES**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 1-3a

N:\Projects\3671\_Bluewater\Wind-DESurvey\Outputs\2013-Aug\_Data\_Transmittal\02-Digital\_Maps\Fig-1-03b\_VAWEA\_SurveyArea\_PostPlot.mxd, 8/19/2013, abowman



**LEGEND**

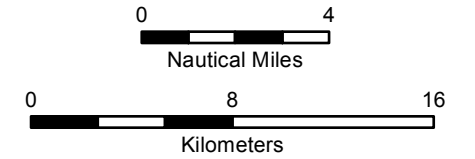
- Chesapeake Light Tower
- Fugro Borehole Exploration (1963)
- Virginia Wind Energy Area
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- +
 Coordinate Grid is UTM Zone 18N, NAD 1983, Meters
- 3-Nautical-Mile Limit

**Fugro 2013 Survey Tracklines**

- WEA Survey Line (100 and 200 series)
- Met Tower Survey Line (300 and 400 series)
- Regional Survey Line (500 series)

**Notes:**

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2. Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starfix II wide area differential network, downloaded from a communications satellite.
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  - Edgetech Model 4125 Side Scan Sonar System
  - SonarWhiz Map Side Scan Sonar Data Acquisition System
  - Marine Magnetic Corporation SeaSpy Magnetometer
  - Edgetech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) System
  - Edgetech Discovery Sub-bottom Profiler Data Acquisition System
  - Applied Acoustic Engineers CSP Seismic Energy Source and Subsea System's Double-plate "Boomer" System
  - GeoEel 32-channel Hydrophone Array Streamer (Channels 1-16 at 1.56mgi and Channels 17-32 at 3.125mgi)
  - Blue Ocean Moving Sound Velocity Profiler
  - Coastal Oceanographics "Hypack" Navigation System
  - Starfix Seis Navigation



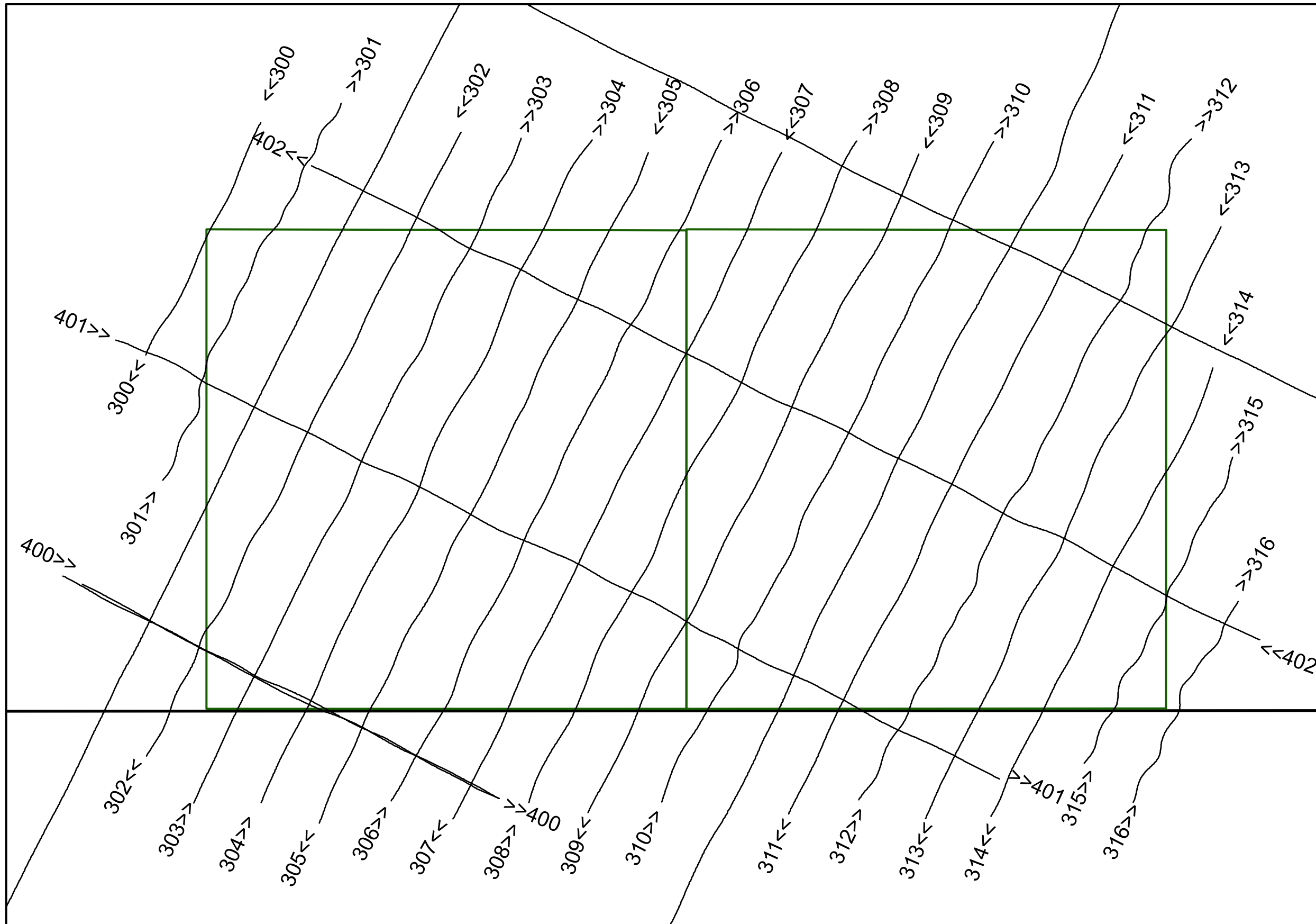
**2013 SURVEY VESSEL TRACKLINES**

Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 1-3b

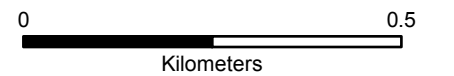
N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-1-03a\_VAWEA\_Regional\_PostPlot.mxd, 8/19/2013, abowman

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-1-03a\_VAWEA\_Regional\_PostPlot.mxd, 8/19/2013, abowman



**LEGEND**

- >>300 Survey Vessel Navigation Trackline
- ▭ Virginia Wind Energy Area
- ▭ Meteorological Tower Aliquot
- + Coordinate Grid is UTM Zone 18N, NAD 1983, Meters



**2013 SURVEY VESSEL TRACKLINES**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 1-3c

### SOIL TYPES

	Well graded GRAVEL (GW)		Clayey SAND (SC)		Clayey SILT (ML/CL)
	Poorly graded GRAVEL (GP)		Silty SAND (SM)		High Plasticity ORGANICS (OH)
	GRAVEL with sand (GP or GW)		SAND with silt (SP-SM)		Low Plasticity ORGANICS (OL)
	GRAVEL with clay (GP or GW)		Fat CLAY (CH)		SANDSTONE (Rx)
	Clayey GRAVEL (GC)		Sandy Fat CLAY (CH)		SILTSTONE (Rx)
	GRAVEL with silt (GP or GW)		Lean Clay (CL)		CLAYSTONE (Rx)
	Silty GRAVEL (GM)		Sandy Lean CLAY (CL)		BASALT
	Well graded SAND (SW)		Silty CLAY (CL-ML)		Interlayered SILTSTONE (Rx) and SANDSTONE (Rx)
	Poorly graded SAND (SP)		Elastic SILT (MH)		BOULDERS and COBBLES
	SAND with gravel (SP or SW)		SILT (ML)		Asphalt Concrete
	SAND with clay (SP-SC)		Sandy SILT (ML)		Base Material

### SAMPLERS

	Thin-Walled Shelby Tube		Rock Core (interior symbol represents percent recovery)		SPT
	Piston Sampler		(32) 3-inch Diameter Shelby Tube		
	Wireline		Thick-Wall Wireline		

Note: For the 3-inch shelly tube (driven), the number in parentheses indicates the number of blows required to advance the sampler 12 inches, after a 6-inch seating interval, using a 140-lb hammer with a 30-inch drop.

### CLASSIFICATION TEST/BLOW COUNTS/ ROCK QUALITY AND CORING RATE

- Percent Passing No. 200 Sieve
- Water Content (%)
- Submerged Unit Weight (KCF)
- Theoretical Submerged Unit Weight (KCF)
- Plastic Limit                  Liquid Limit
- +-----+-----+
- Non-Plastic
- ×
- ⊙ Blow Count
- Rock Quality Designation (RQD)
- ===== Rock Recovery Percent
- Coring Rate

### STRENGTH TESTS

- ⊗ Pocket Penetrometer
- ⊕ Torvane
- ◇ Remote Vane
- ◆ Miniature Vane                  ◇ Residual Vane
- ▲ Unconsolidated Undrained Triaxial
- Unconfined Compression (soil)
- ⊙ Point Load Test
- Unconfined Compression (rock)
- ◇ △ (Open symbols indicate remolded tests)
- + Strength exceeds capacity of measuring device
- Fractures Per Foot
- CPT (Nk = 12 and 15)

## KEY TO TERMS AND SYMBOLS USED ON BORING LOGS

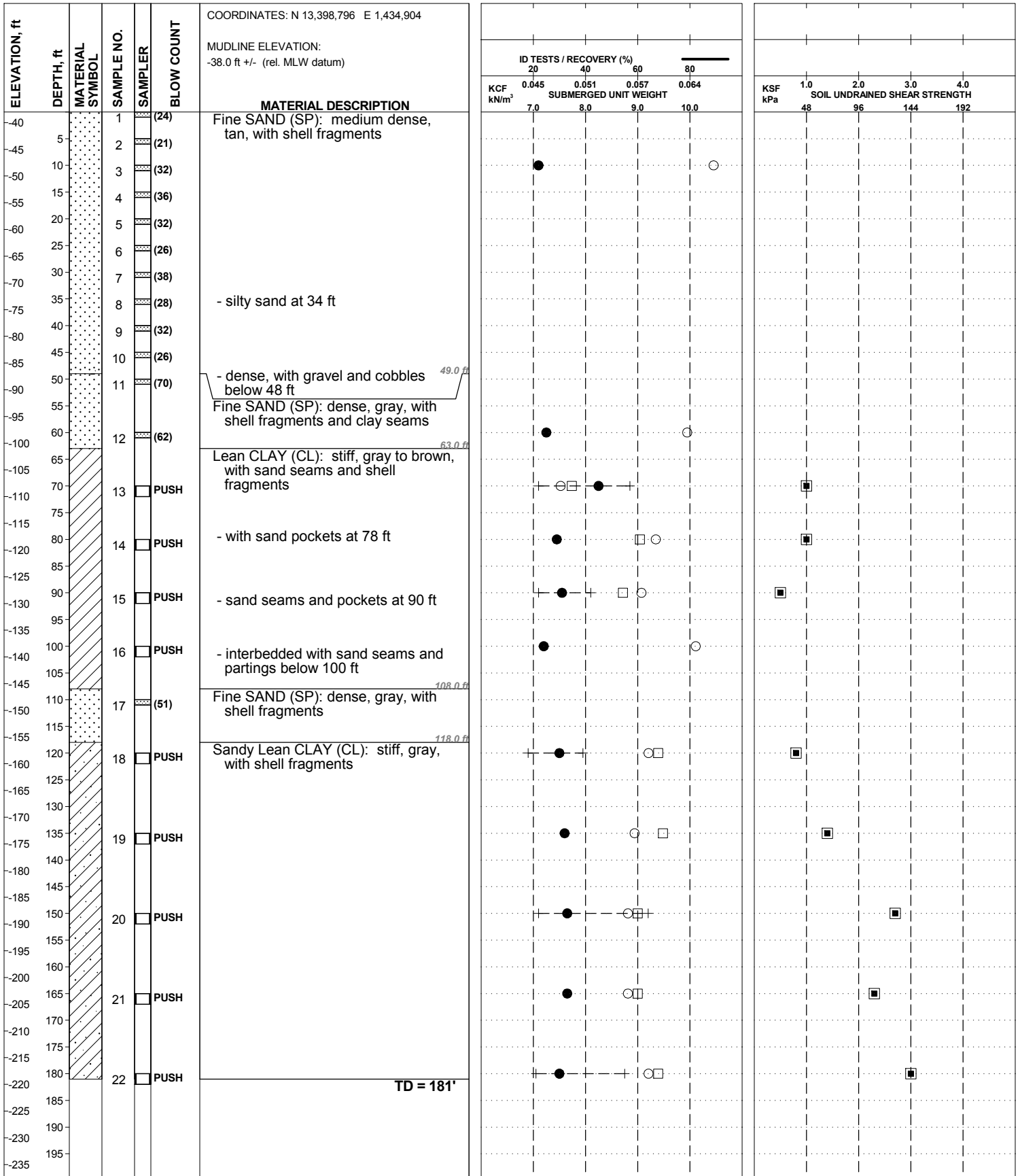
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

01-60-11027/2190

**PROJECT NO:** 04.81130003  
**BORING:** B-1 (1963)

**START DATE:** 5/30/1963  
**COMPLETION DATE:** 5/31/1963

**DRILLER:** Fugro McClelland  
**DRILLING METHOD:** Mud Rotary Wash, Wireline



The log and data presented are a simplification of actual conditions encountered at the time of sampling at the sample location. Subsurface conditions may differ at other locations and with the passage of time.

For symbol identification, refer to Key to Terms & Symbols Used on Logs.

### LOG OF BORING B-1 (1963)

Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



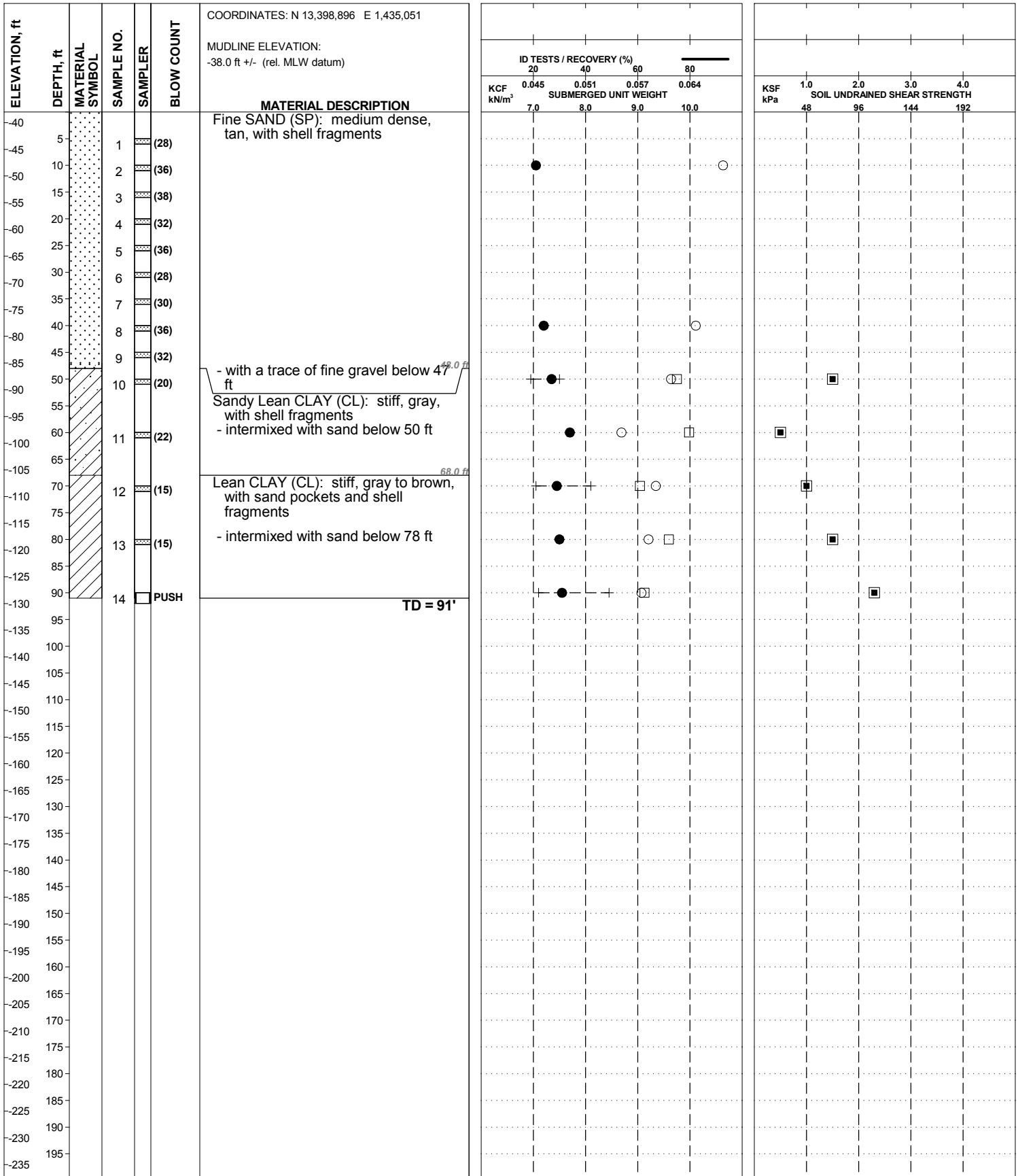
FIGURE 1-4b

01-60 31027/2190

**PROJECT NO:** 04.81130003  
**BORING:** B-2 (1963)

**START DATE:** 5/31/1963  
**COMPLETION DATE:** 6/1/1963

**DRILLER:** Fugro McClelland  
**DRILLING METHOD:** Mud Rotary Wash, Wireline



**LOG OF BORING B-2 (1963)**

Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



FIGURE 1-4c

The log and data presented are a simplification of actual conditions encountered at the time of sampling at the sample location. Subsurface conditions may differ at other locations and with the passage of time.

For symbol identification, refer to Key to Terms & Symbols Used on Logs.

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Draft\_Survey\_Report\Fig-1-05\_NOAA\_Bathymd\_8/28/2013\_kspencer

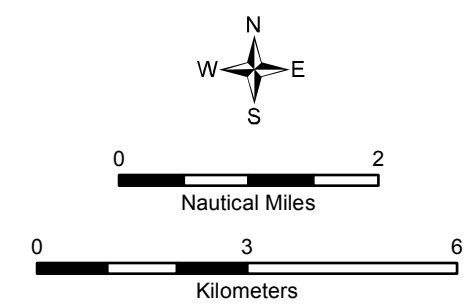


**LEGEND**

- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- NOAA Hydrographic Survey Extents**
- H12309 (Surveyed from 4/15/2011 to 5/10/11)
- H12502 (Surveyed from 9/7/2012 to 9/28/2012)
- H12503 (Surveyed from 9/23/2012 to 12/13/2012)
- Boundary Between 1981 and 1935 Data
- +
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**Notes:**

1. The 1981 sounding data were obtained with Ross #5000 echosounder (single beam). Data spacing is approximately 80 meters within rows and 200 meters between rows.
2. The 1935 sounding data were obtained with the 515 type hammer oscillator fathometer. Data spacing is approximately 150 meters within rows and 950 meters between rows.



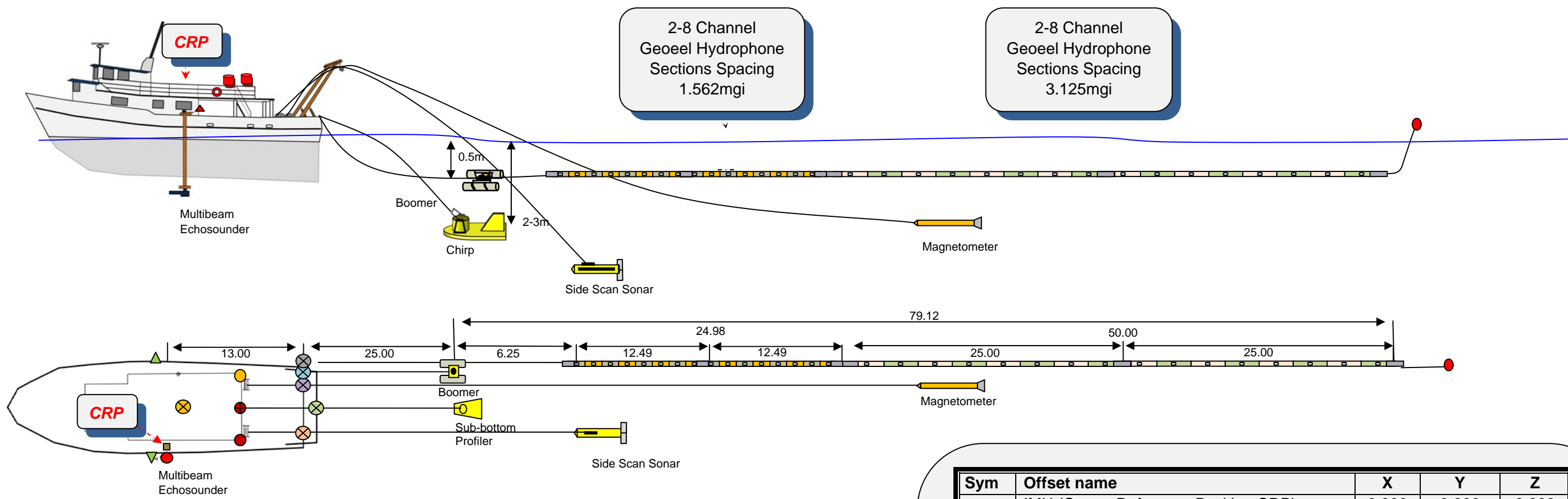
**HISTORICAL BATHYMETRIC DATA COVERAGE**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 1-5

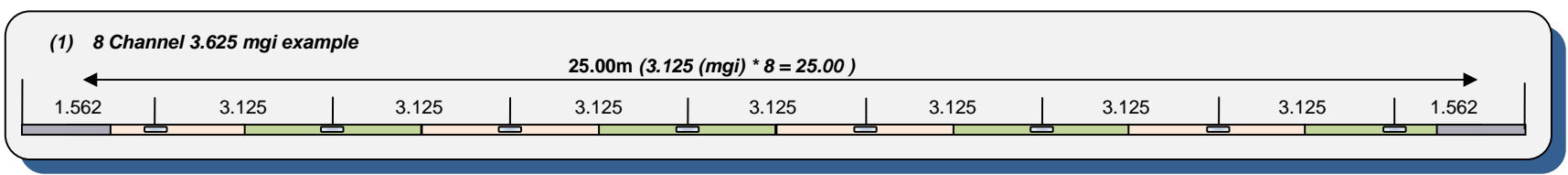
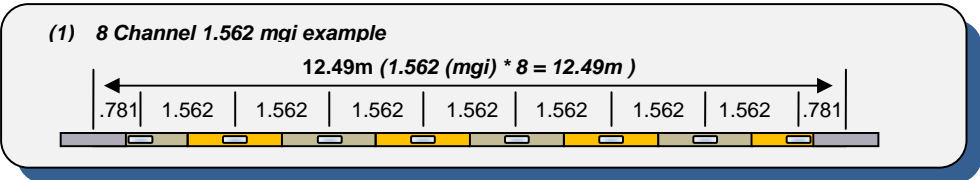


The Tiki XIV is owned and operated by Tiki Adventures.

**SURVEY VESSEL TIKI XIV**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf



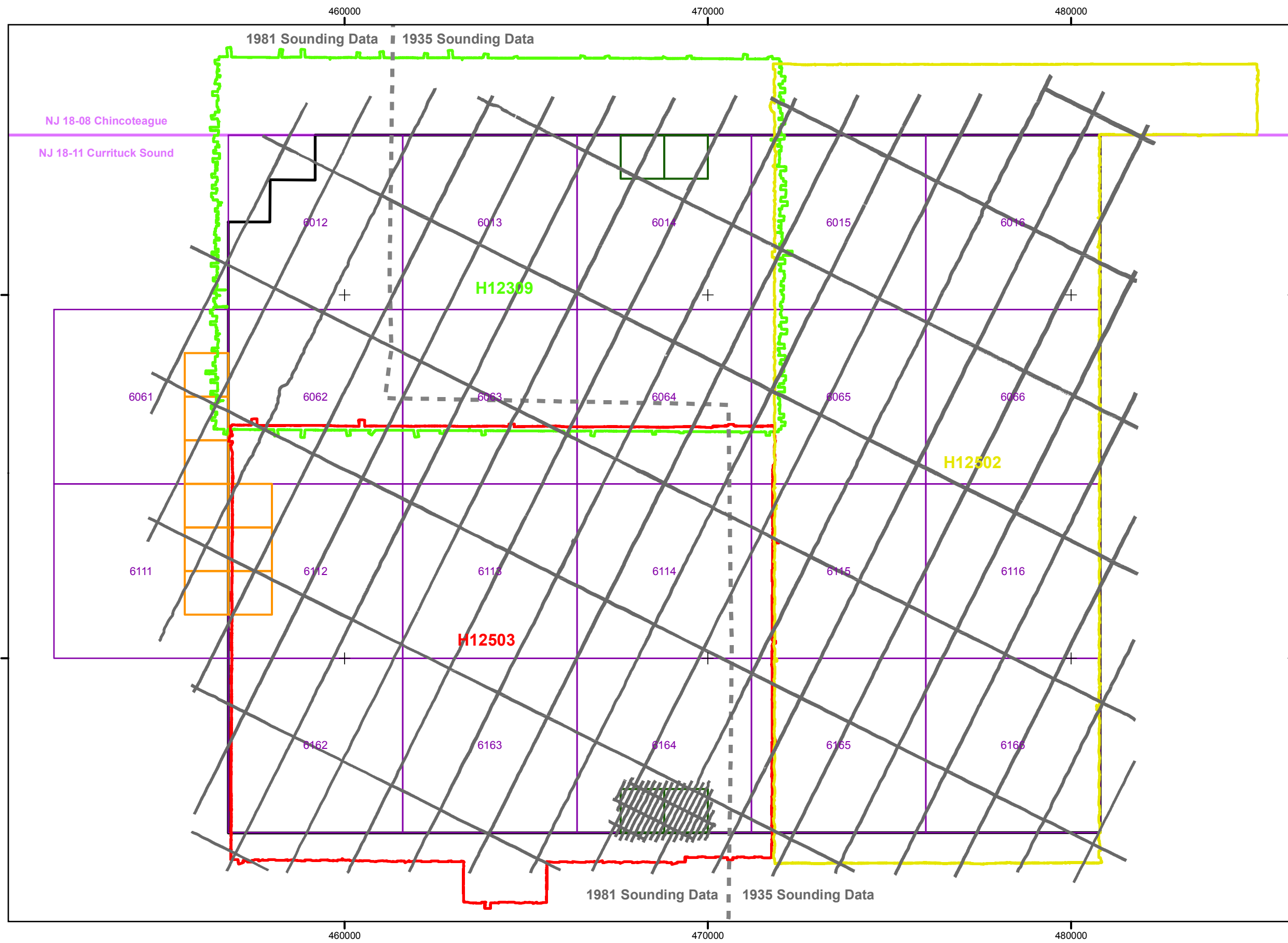
**\*\*Dimensions in Meters\*\***  
**\*\*Not to Scale\*\***



Sym	Offset name	X	Y	Z
■	IMU (Center Reference Position CRP)	0.000	0.000	0.000
●	MBE Acoustic Center	-.752	.186	-5.454
●	Port POSMV (Primary Antenna)	.614	-6.521	2.202
●	Starboard POMV Antenna (Vector Antenna)	2.574	-6.521	2.221
●	Trimble 461 Antenna (Secondary Nav)	5.284	-6.330	2.267
⊗	Trimble 461 Antenna (Vector Antenna)	3.446	-1.282	3.410
⊗	Side Scan Sonar Tow point / Cable Counter	1.658	-11.515	2.000
⊗	Sub Bottom Profiler Tow Point	2.862	-11.483	-.148
⊗	Magnetometer Tow Point /Cable Counter	4.365	-11.509	2.00
⊗	Boomer Tow Point	5.601	-11.517	0.00
⊗	Streamer Tow Point	5.799	-11.510	0.00
▽	Port Ultrasonic Sensor (Static Draft)	-.752	.531	-.246
△	Starboard Ultrasonic Sensor (Static Draft)	6.553	.291	-.251
<b>All Units are in Meters</b>				

**MV TIKI XVI GEOPHYSICAL SYSTEM TOW CONFIGURATION**  
**Multibeam, Seismic Reflection, Sub Bottom Profiler, Side Scan Sonar and Magnetometer Systems**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Draft\_Survey\_Report\mxd\Fig-1-05\_NOAA\_Bathymxd\_8/28/2013\_kspencer



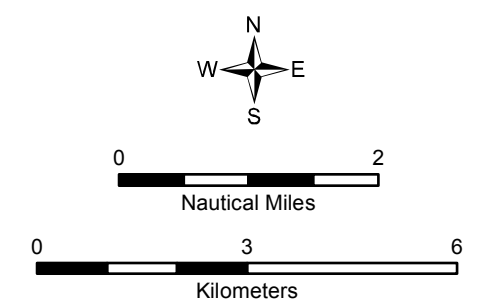
**LEGEND**

- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Fugro (2013) Bathymetric Extent

**NOAA Hydrographic Survey Extents**

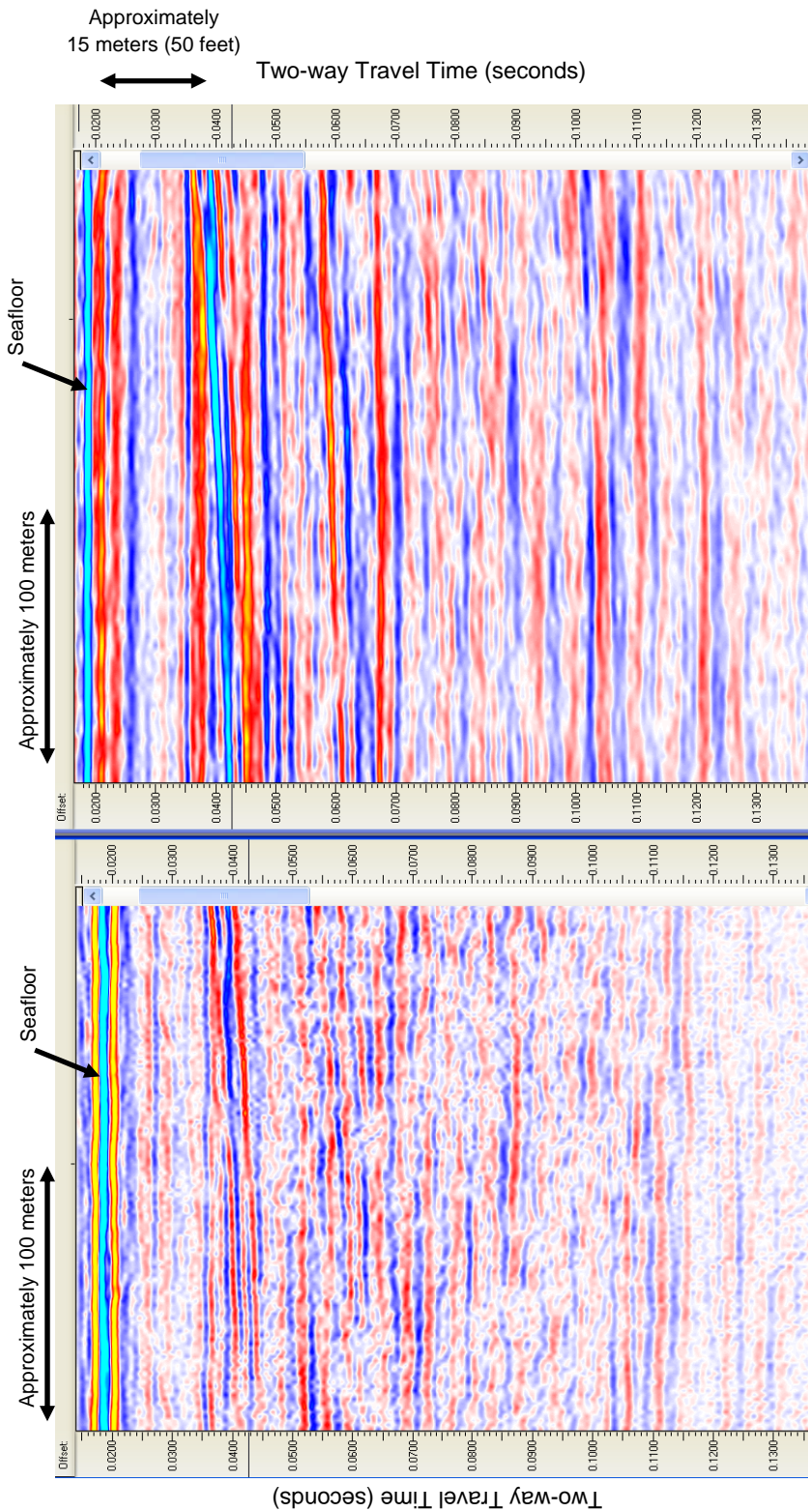
- H12309 (Surveyed from 4/15/2011 to 5/10/11)
- H12502 (Surveyed from 9/7/2012 to 9/28/2012)
- H12503 (Surveyed from 9/23/2012 to 12/13/2012)
- Boundary Between 1981 and 1935 Data
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

- Notes:
1. The 1981 sounding data were obtained with Ross #5000 echosounder (single beam). Data spacing is approximately 80 meters within rows and 200 meters between rows.
  2. The 1935 sounding data were obtained with the 515 type hammer oscillator fathometer. Data spacing is approximately 150 meters within rows and 950 meters between rows.
  3. Fugro (2013) - Bathymetric data are from a multibeam survey conducted from may 28 through July 3, 2013.



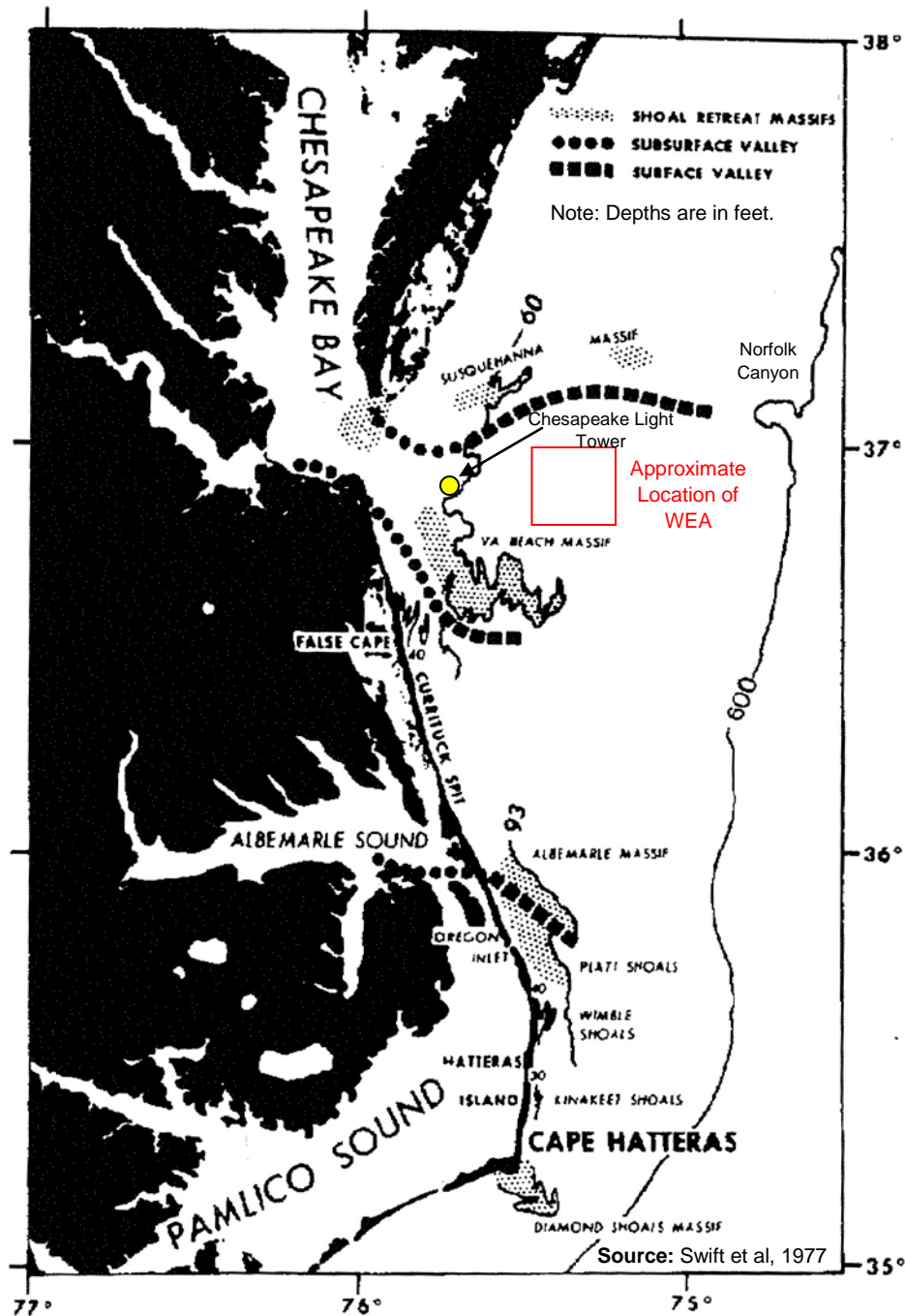
**HISTORICAL BATHYMETRIC DATA COVERAGE**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 2-3



The images provide processed data examples from the two different hydrophone array configurations used in the 2013 survey. Data from the shorter group interval hydrophone array (16-channel at 1.56mgi) reveal more detail in the shallow section (upper 20ms below the seafloor); note the distinct reflector at 26ms in the 1.56mgi streamer that does not appear as distinct in the 3.125mgi data. In contrast, the larger group interval with twice as many channels shows better coherency in the signal in the deeper section of the data (20 to 110ms). For this study, we deemed that the 32 channel dataset provided the best source for interpreting the regional geology. We note that the 1.56 mgi streamer can be used to refine the shallow section of the data (e.g. upper 15 to 20 meters).

**1.56-MGI AND 3.125-MGI SEISMIC DATA COMPARISON**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf



The graphic above depicts major physiographic features of the inner continental shelf offshore southeastern Virginia. This area has similar features as with other locations in the Middle Atlantic Bight, which include a shelf valley, shoal retreat massif (compound bathymetric high consisting of smaller-scale highs), and sand ridges/shoals (shoreface-connected, nearshore, and offshore). In general, nearshore sand ridges trend north-south with relief up to approximately 35 feet (10 meters). These features extend 15 kilometers offshore toward well-defined southwest-trending scarp whose toe lies at roughly 141 feet. The Virginia Beach Massif is an east-west trending bathymetric high segmented into north-south trending sand ridges and swales. This feature has a “comblike pattern” with “teeth” extending from the spine of the massif towards the north. Modified from Swift et al. (1977).

**PHYSIOGRAPHY**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



HOLO. PLEISTOCENE	WESTERN SHORE		EASTERN SHORE	CHRONOLOGY	SHELF SEISMIC STRATIGRAPHIC RECORD		
	Poquoson Member	Unnamed	Wachapreague Formation		TR-2 Trans. Ravinement	Depositional Sequence I	Seismic Unit A
LATE	Lynnhaven Formation	Joynes Neck Sand	Stage 2 18 - 40 ka.	FES-3 Fluvial Unconformity	Depositional Sequence II	Seismic Unit B	
		(Butlers Bluff Member) Nassawadox Formation (Stumptown Member)	Stage 5a 82 - 128 ka.?	RR-8 Regr. Ravinement	Depositional Sequence III	Seismic Unit C	
	Tabb Formation	Omar Formation	Stage 5c?	FES-5 Fluvial Unconformity TR-6 Tr. Ravinement FES-7 Fluvial Unconformity	Depositional Sequence IV	Seismic Unit E	
			Stage 5e 125 ka.	MFS-8a Max. Fl. Surface	Depositional Sequence V	Seismic Unit G2	
	Shirley Fm.	(Accomack Member)	Stage 6 150 ka.	TR-8 Transgr. Ravinement	Depositional Sequence VI	Seismic Unit G1	
	Chuckatuck Fm.		Stage 7 or 11 200 - 400 ka.	FES-9 Fluvial Unconformity	Depositional Sequence VII	Seismic Unit H	
	Charles City Fm.		Stage 8 or 12 270 - 450 ka.	FES-10 Fluvial Unconformity	Depositional Sequence VIII	Seismic Unit I	
	Windsor Fm.			SR-11 Fluvial Unconformity	Depositional Sequence IX	Seismic Unit J	
	Bacon's Castle Fm.						

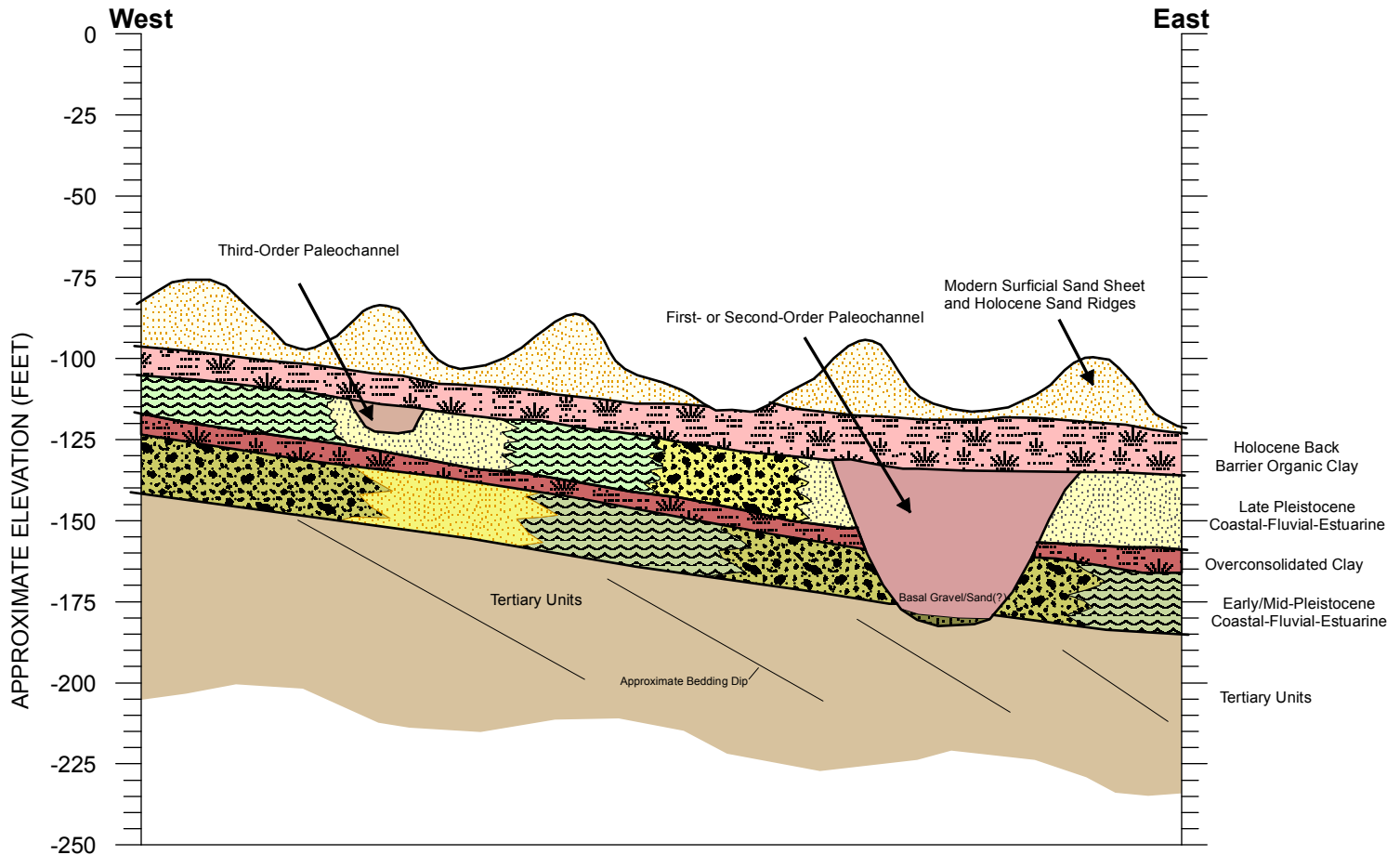
Correlation chart for the shallow seismic stratigraphy of southeastern Virginia and the inner continental shelf. (Swift et al., 2003)

AGE	SOUTHERN & CENTRAL DELMARVA — CHESAPEAKE BAY			
	VIRGINIA MARYLAND CENTRAL, WESTERN, CHES. BAY	VIRGINIA EASTERN PART	MARYLAND EASTERN PART	
BRUNHES NORMAL MAGNETIC INTERVAL	LATE PLEISTOCENE POST - 140,000 years B.P.	KENT ISLAND FORMATION	WACHAPREAGUE FORMATION	SINEPUXENT & IRONSHIRE FORMATIONS
		OCCOHANNOCK MBR	JOYNES NECK SAND	?
		BUTLERS BLUFF MBR		
		STUMPTOWN MBR		
PLIOCENE	PRE - 140,000 years B.P.	OMAR FORMATION (ACCOMACK MBR)	OMAR FORMATION (ACCOMACK MBR)	OMAR FORMATION (AS RESTRICTED BY OWENS & DENNY, '79)
	"YADKIN BEDS"			WALSTON SILT & BEAVERDAM SAND
	YORKTOWN FORMATION	UPPER YORKTOWN F.M. LOWER	U. SHELLY SAND TUNNELS MILL MBR L. SHELLY SAND MBR	NOT RECOGNIZED

AFTER MIXON (1985)  
Regional correlation chart for the Virginia inner continental shelf. (Toscano et al., 1989)

## STRATIGRAPHIC CHART

### Virginia Wind Energy Area Geophysical Survey Virginia Outer Continental Shelf



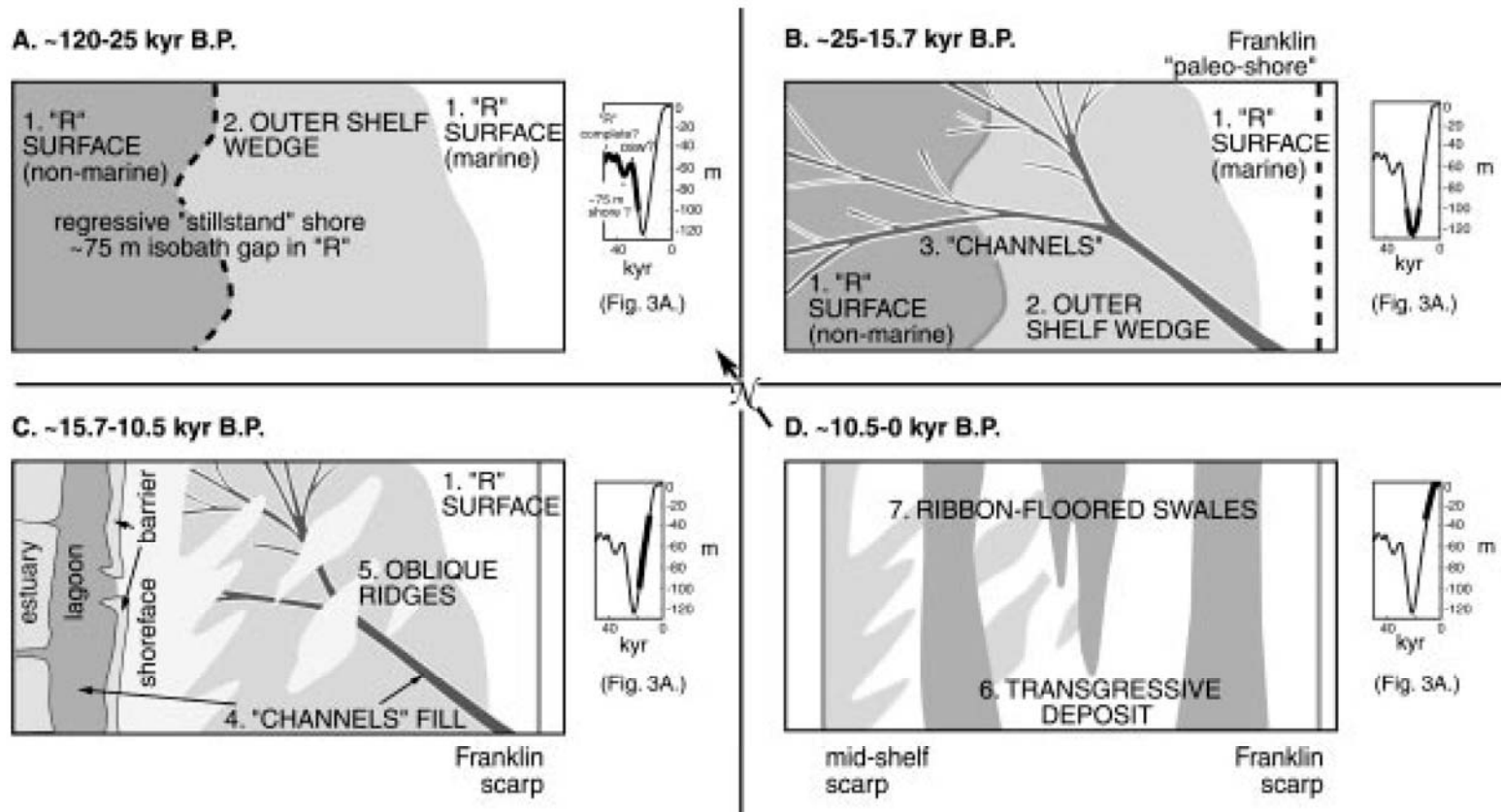
**LEGEND**

- Holocene - Predominantly fine and medium sand
- Holocene Back Barrier - Predominantly soft, organic clay
- Paleochannel Infill - Predominantly fine-grained
- Paleochannel Infill - Lag gravel and sand; may or may not be present
- Early and Late-Pleistocene Sequences - May not be present or one, two, or up to three sequences preserved.
- Late Pleistocene Estuarine - Predominantly fine-grained
- Late Pleistocene Barrier - Sand
- Late Pleistocene Alluvium - Sand and gravel
- Early Pleist Back Barrier - Overconsolidated organic, clay
- Early Pleistocene Estuarine - Predominantly fine-grained
- Early Pleistocene Barrier - Sand
- Early Pleistocene Alluvium - Sand and gravel
- Tertiary Strata

**Note:**

The stratigraphic conditions depicted on this figure represent a geologic model. Actual thickness and number of stratigraphic layers may differ from those shown on this schematic drawing. Subsurface investigation (geotechnical borings and/or CPTs and geophysical data) will be required to characterize subsurface conditions for

**SCHEMATIC GEOLOGIC PROFILE**  
**Virginia Outer Continental Shelf**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

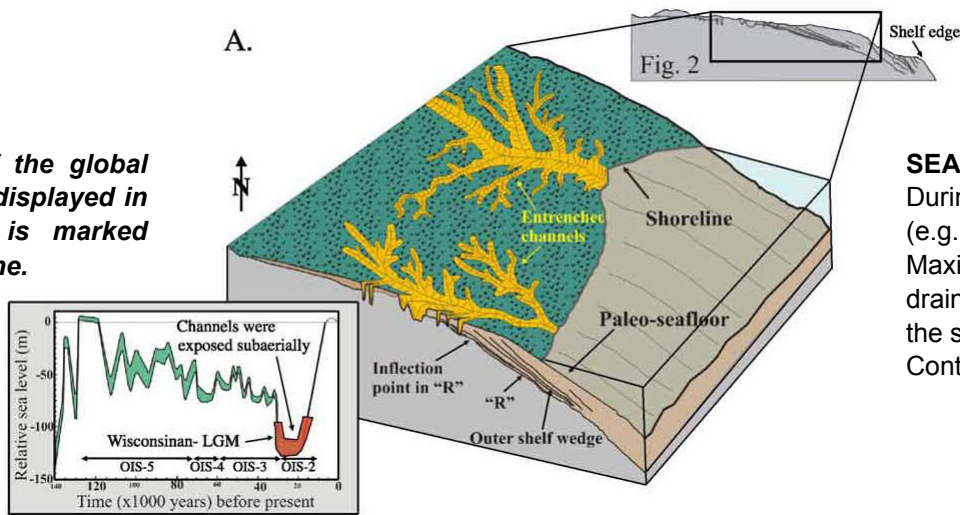


Schematic geologic evolution of the mid-shelf corridor since ~120 kyr B.P. The portion of the global eustatic curve (inset Fig. 3A above) displayed in each cartoon is marked with a heavy black line. (A) Depicts period when the shoreline moved seaward across the mid-shelf corridor during the last regression (~120-25 kya); (B) shows the Wisconsin glacial maximum, when the mid-shelf corridor was subaerially exposed, and "channels" were carved (~25-15.7 kya); (C) illustrates the portion of the Holocene transgression when the shoreline moved from the Franklin "paleo-shore" to the mid-shelf scarp, and "channels" were infilled with an upward-deepening succession of lagoonal and estuarine muds; estuaries, lagoons, shoreface barriers, and nearshore shores/oblique ridges comprised the various depositional environments in this cartoon (~15.7-10.5 kya); (D) shows the modern seafloor of the mid-shelf corridor (10.5 kyr to Present). Shelf currents have reworked and winnowed the oblique ridges, creating the surficial unit. "Channels" and other subsurface features (e.g. deltas, unconformities, etc.) have no seafloor bathymetric expression, and the ribbon-floored swales represent erosion of the surficial unit.

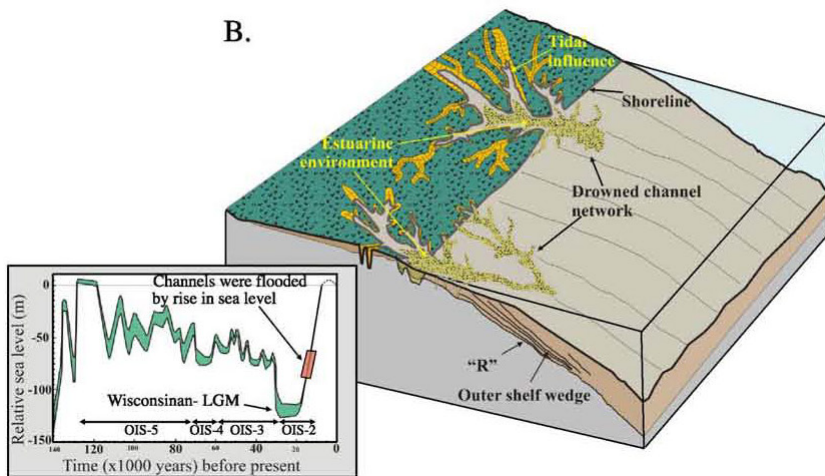
Source: Duncan et al. (2000)

**GEOLOGIC EVOLUTION OF MID-SHELF CORRIDOR**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

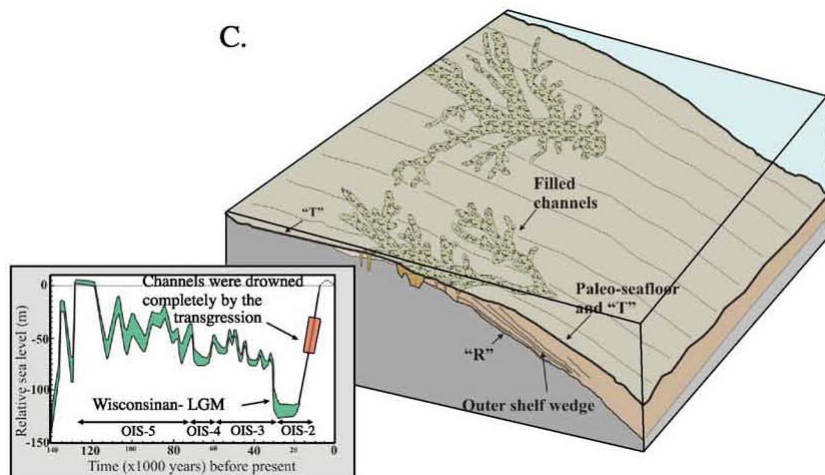
The portion of the global eustatic curve displayed in each cartoon is marked with a red outline.



**SEA LEVEL LOWSTANDS**  
During Sea Level Lowstands (e.g. Wisconsin – Last Glacial Maximum ~25-15.7 kya), drainage systems developed on the subaerially exposed Continental Shelf.



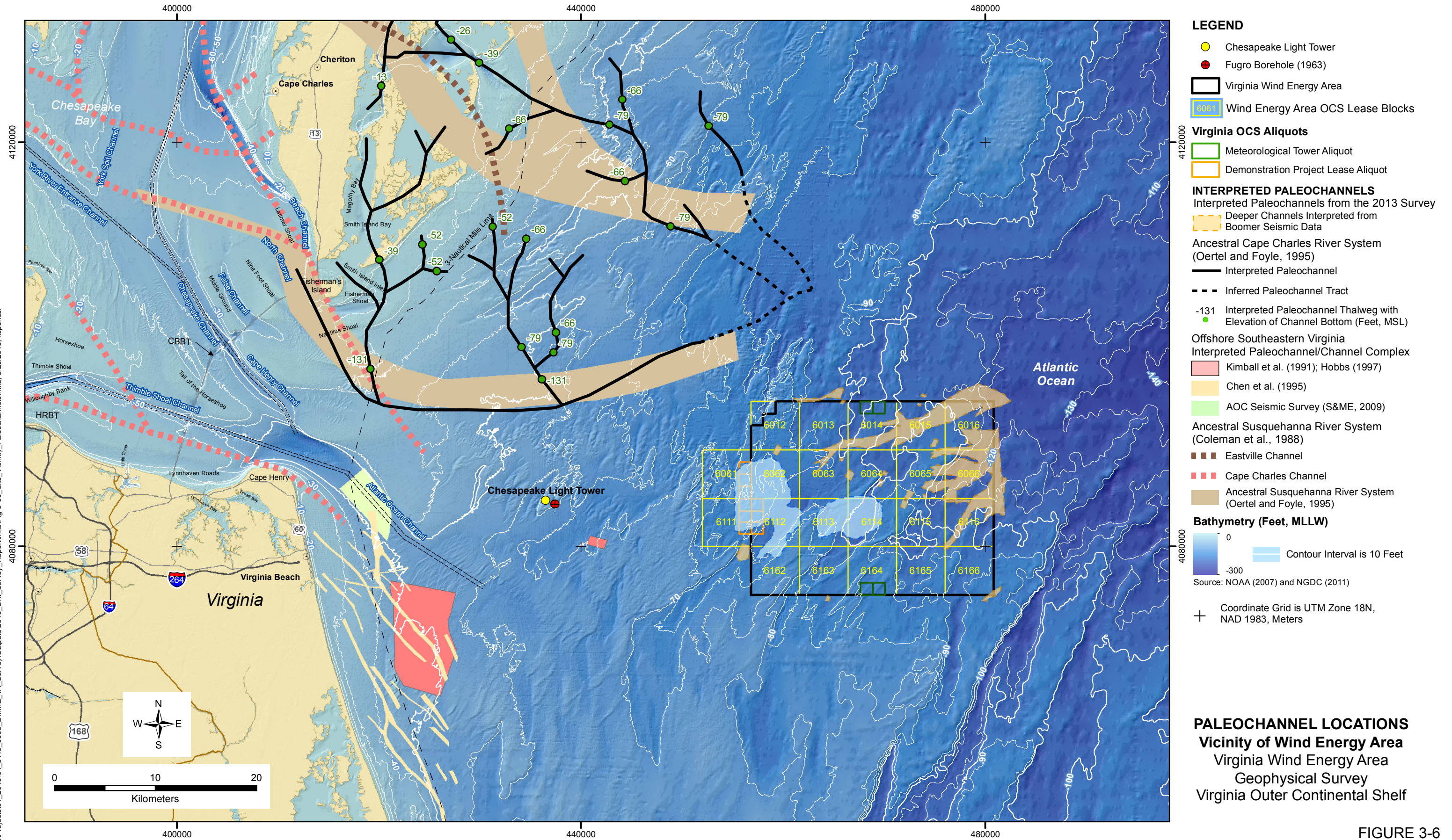
**MARINE TRANSGRESSION**  
As sea level rose, the shoreline transgressed across the shelf which resulted in: 1) fluvial channels transitioning to estuarine environments, and 2) drowning, infilling, and burial of channels; channels infilled with upward deepening succession of lagoonal and estuarine muds.



**CONDITIONS TODAY**  
Following transgression, Holocene-age marine sediments mask the location of channels and the materials that infill them. Conditions also underlie barrier spit prograding deposits along the Delmarva Peninsula.

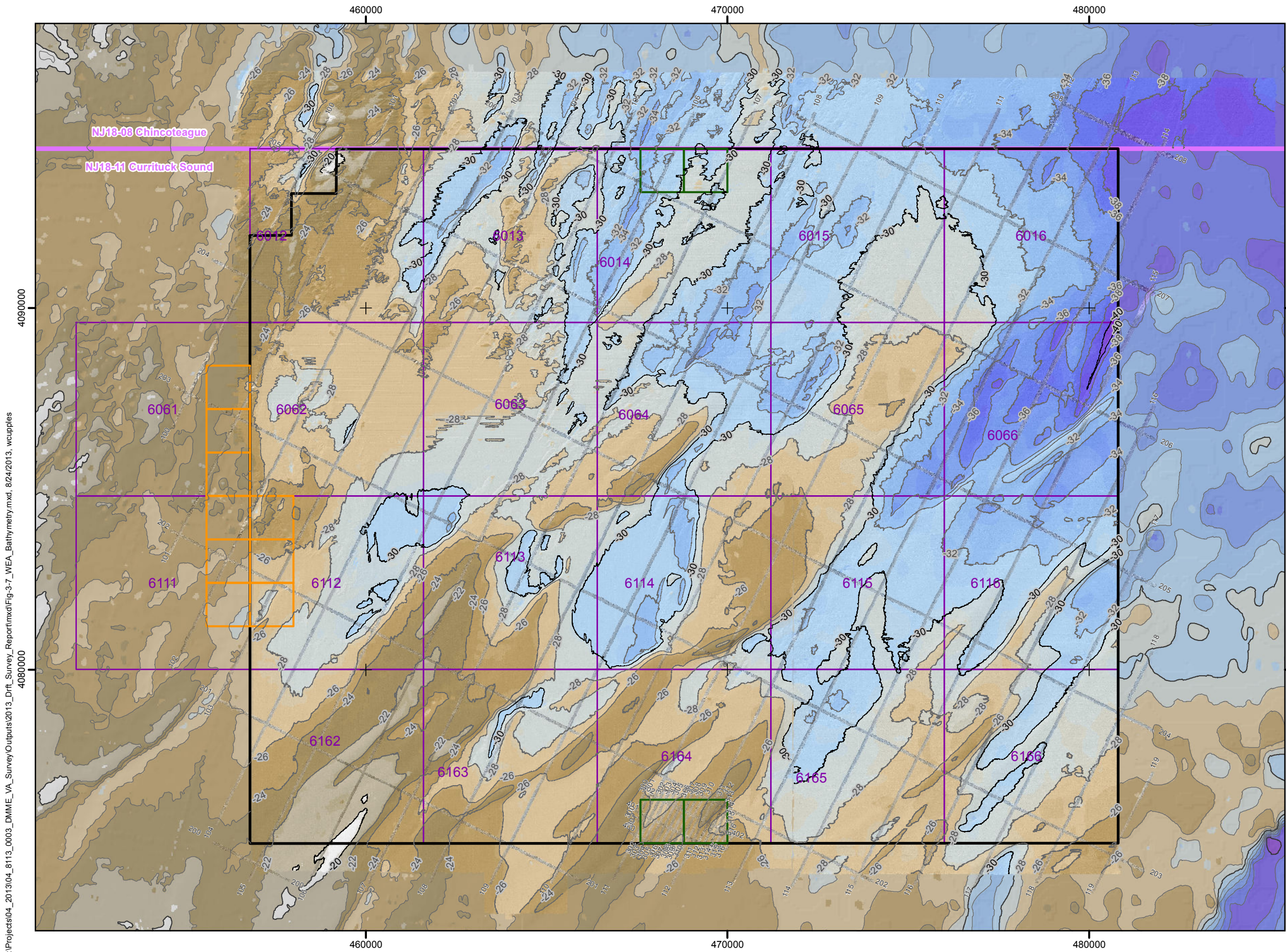
Source: Nordfjord et al. (2005)

**CHANNEL INCISION AND BURIAL EXAMPLE**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-3-06\_Site\_Vicinity\_Paleochannels.mxd, 8/29/2013, kspencer

FIGURE 3-6



**LEGEND**

- 100 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

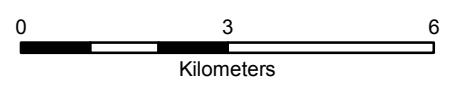
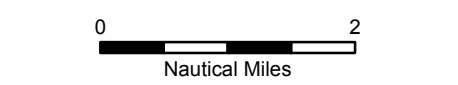
**Bathymetry (Meters, MLLW)**  
Source: NOAA Bathymetric Data  
Darker swath indicates extent of Fugro 2013 survey.

	-18 to -20		-30 to -32
	-20 to -22		-32 to -34
	-22 to -24		-34 to -36
	-24 to -26		-36 to -38
	-26 to -28		-38 to -40
	-28 to -30		-40 to -42

Major contour interval is 10 meters.  
Minor contour interval is 2 meters.

**Notes:**

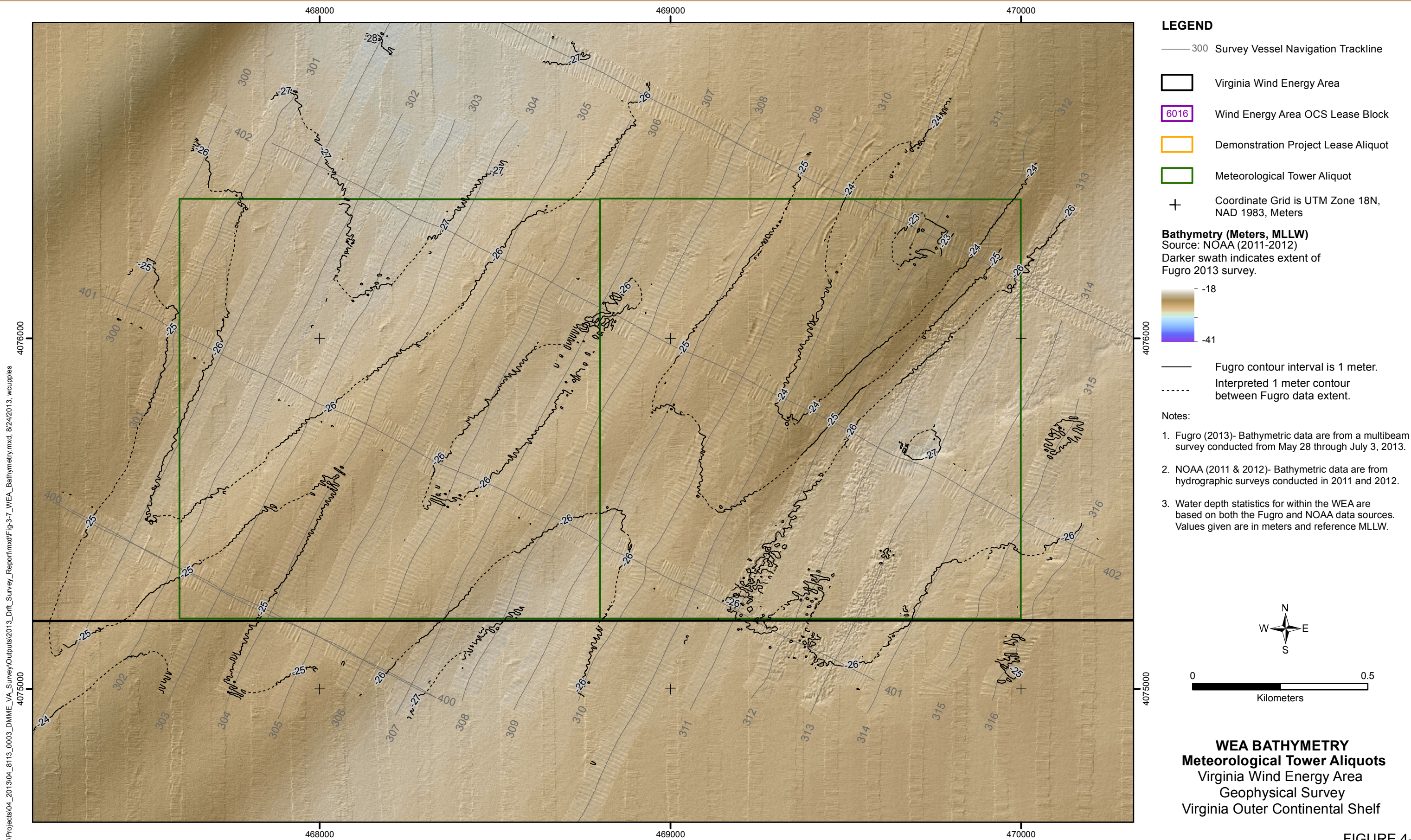
1. Fugro (2013)- Bathymetric data are from a multibeam survey conducted from May 28 through July 3, 2013.
2. NOAA (2011 & 2012)- Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
3. Water depth statistics for within the WEA are based on both the Fugro and NOAA data sources. Values given are in meters and reference MLLW.
4. Regional NOAA data are hydrographic surveys conducted by NOAA in 1935 and 1981.



**WEA BATHYMETRY**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

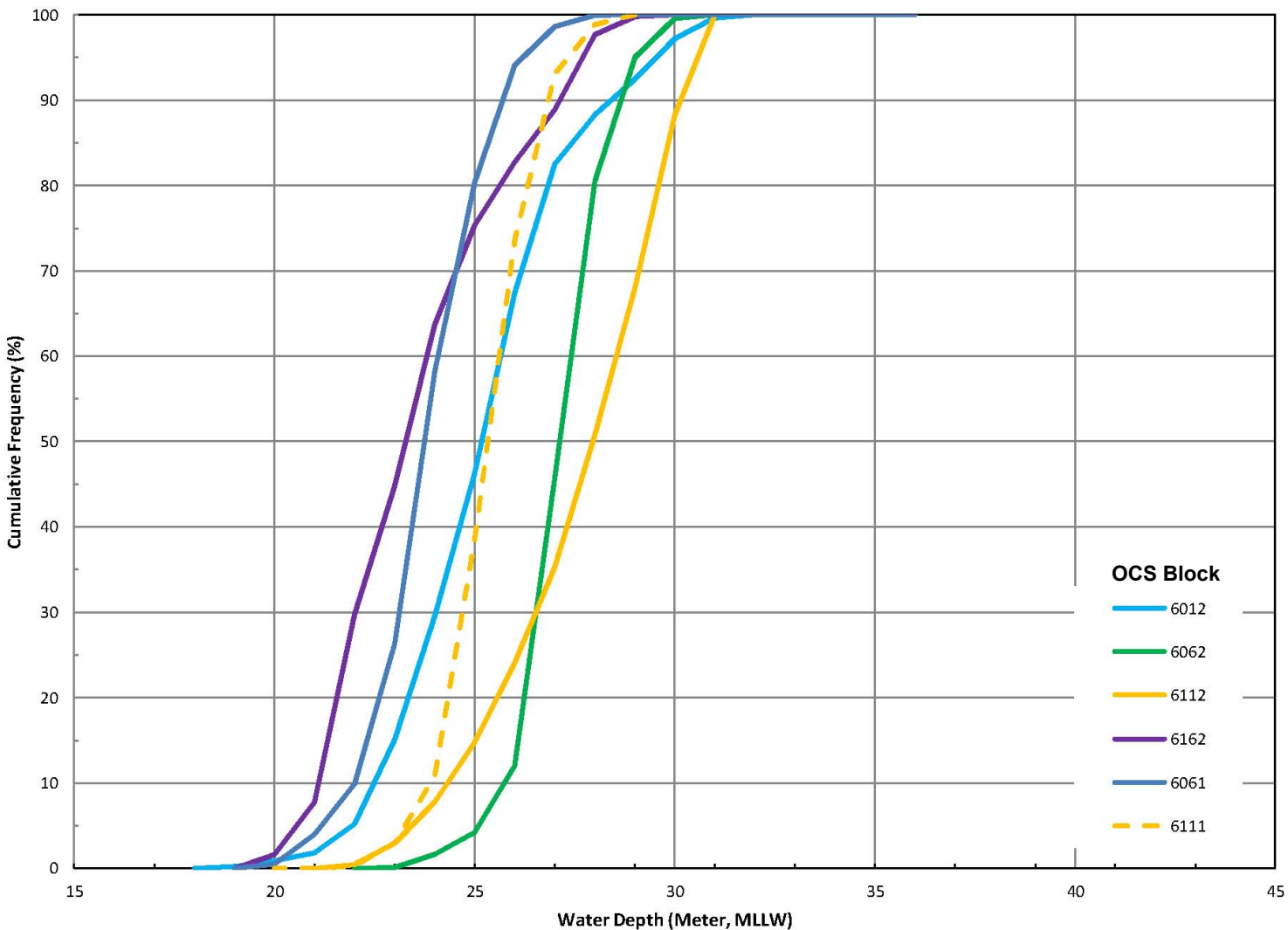
N:\Projects\04\_2013\04\_8113\_003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\Fig-3-7\_WEA\_Bathymetry.mxd, 8/24/2013, wcupples

FIGURE 4-1a



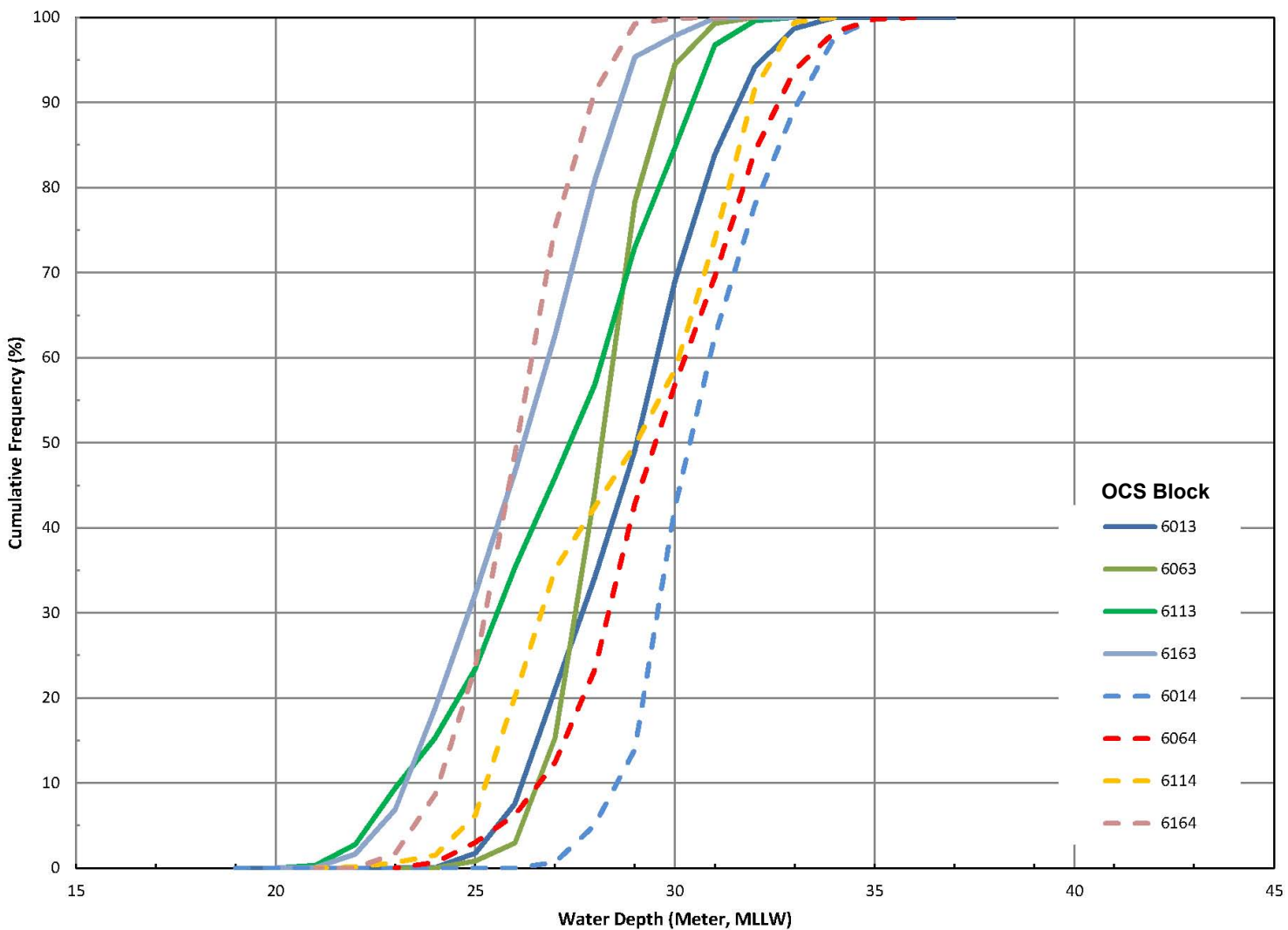
N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-3-7\_WEA\_Bathymetry.mxd, 8/24/2013, wcupplies

FIGURE 4-1b



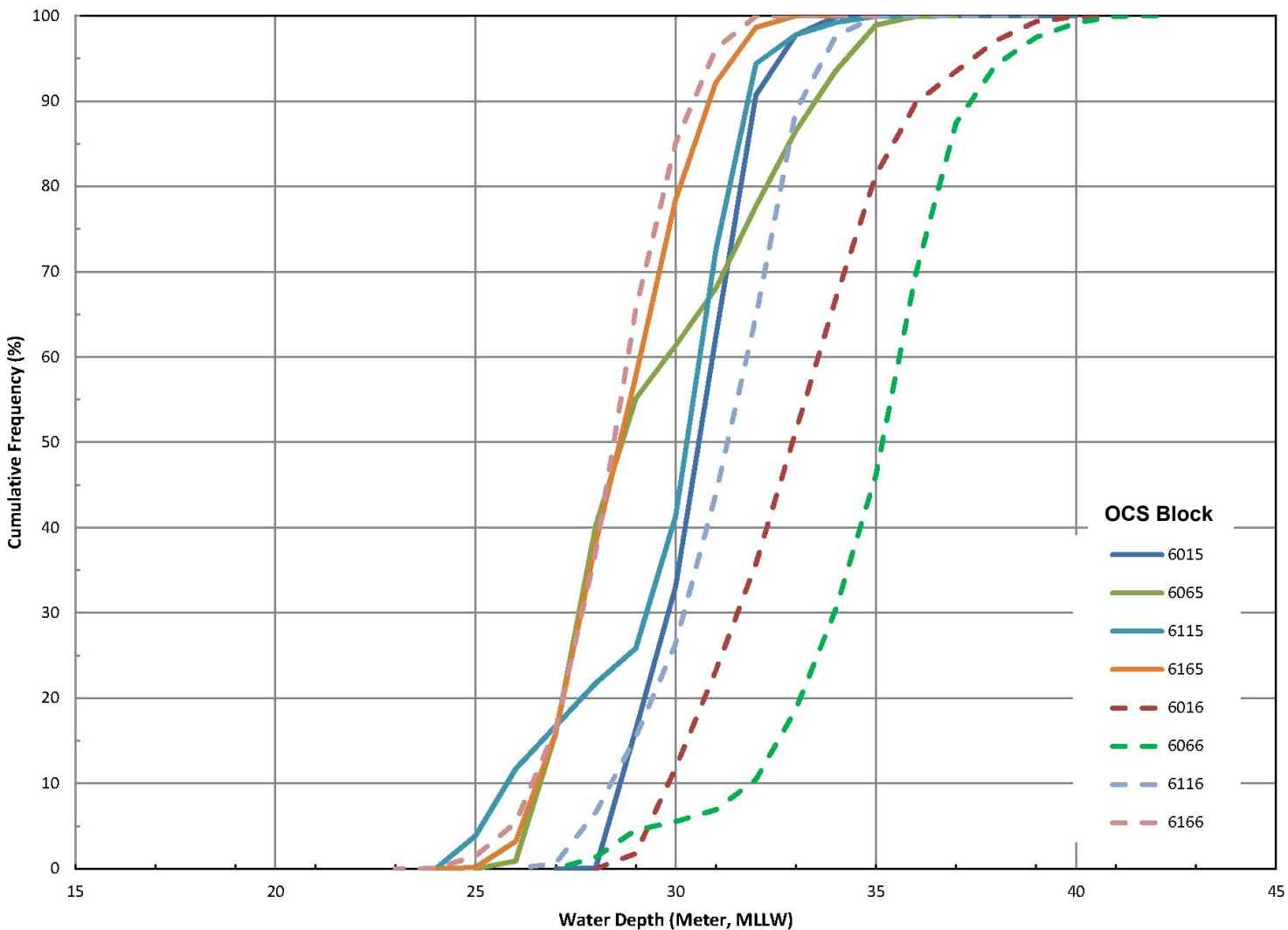
Note: 1) Water depth statistics for OCS blocks 6061, 6111, and 6012 are representative of the entire block area.  
2) Water depth statistics of OCS Blocks 6061 and 6111 are based on Fugro (2013) and Regional NOAA data (1981). All others are based on Fugro (2013) and NOAA (2011-2012) data sources shown on Figure 1-5.

**STATISTICAL SUMMARY OF WATER DEPTHS**  
**Nearshore Two Columns of OCS Blocks**  
Virginia Wind Energy Area Desktop Study  
Virginia Outer Continental Shelf



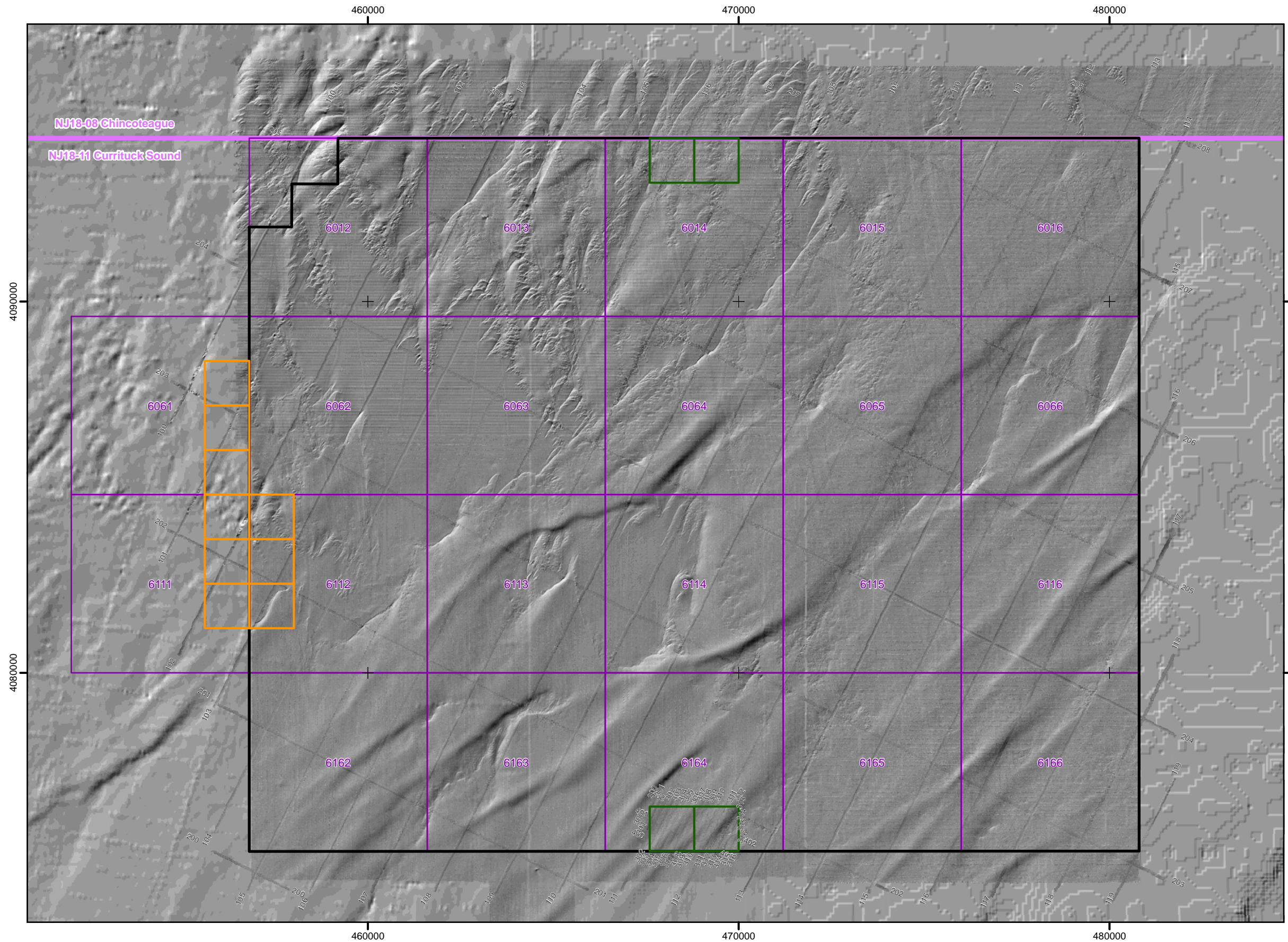
Note: Water depth statistics for OCS blocks are based on Fugro (2013) and NOAA (2011-2012) data sources shown on Figure 1-5.

**STATISTICAL SUMMARY OF WATER DEPTHS**  
**Middle Two Columns of OCS Blocks**  
Virginia Wind Energy Area Desktop Study  
Virginia Outer Continental Shelf



Note: Water depth statistics for OCS blocks are based on Fugro (2013) and NOAA (2011-2012) data sources shown on Figure 1-5.

**STATISTICAL SUMMARY OF WATER DEPTHS**  
**Offshore Two Columns of OCS Blocks**  
Virginia Wind Energy Area Desktop Study  
Virginia Outer Continental Shelf



**LEGEND**

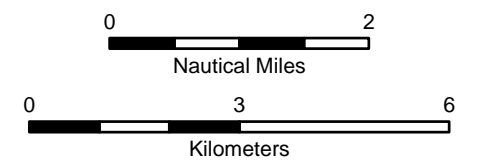
- <sup>100</sup> Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**Sun-Illuminated Hillshade Rendering Parameters**

Illumination Altitude: 45°  
Illumination Azimuth: 315°

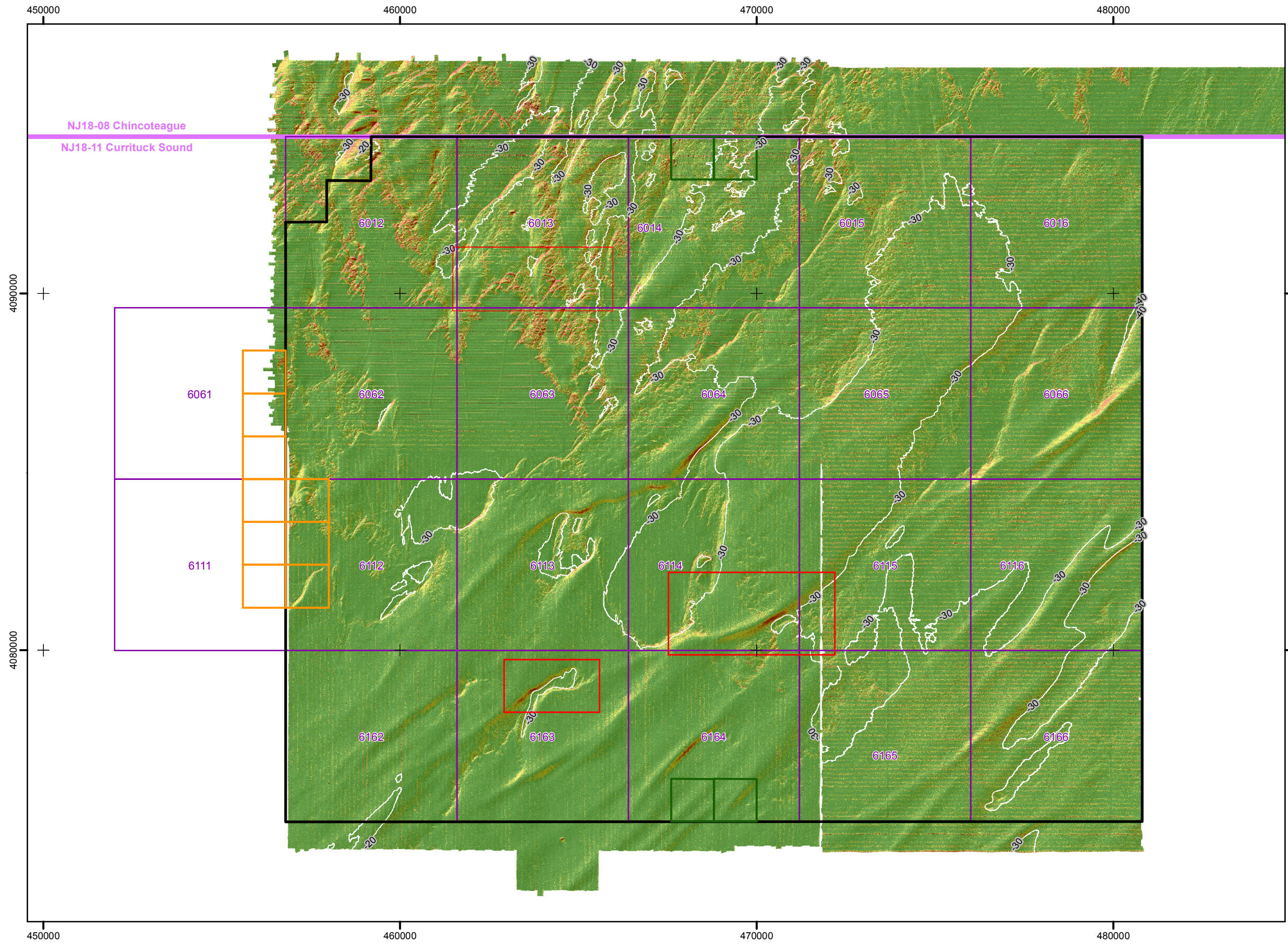
**Notes:**

1. Fugro (2013)- Bathymetric data are from a multibeam survey conducted from May 28 through July 3, 2013.
2. NOAA (2011 & 2012)- Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
3. Water depth statistics for within the WEA are based on both the Fugro and NOAA data sources. Values given are in meters and reference MLLW.
4. Regional NOAA data are hydrographic surveys conducted by NOAA in 1935 and 1981.



**WEA HILLSHADED RELIEF**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-2



**LEGEND**

- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**Seafloor Slope Gradient (degrees)**

- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 10
- 10+

**Bathymetric Contours (MLLW)**

- Major contour interval is 10 meters.

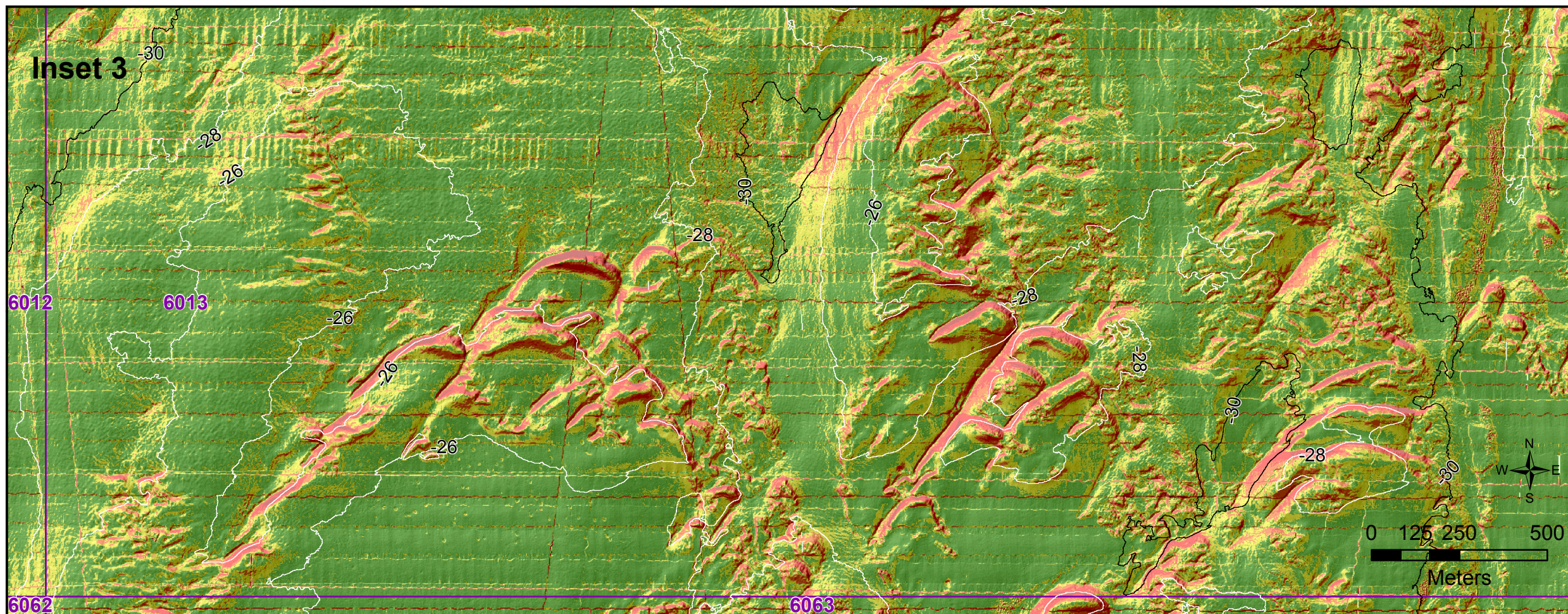
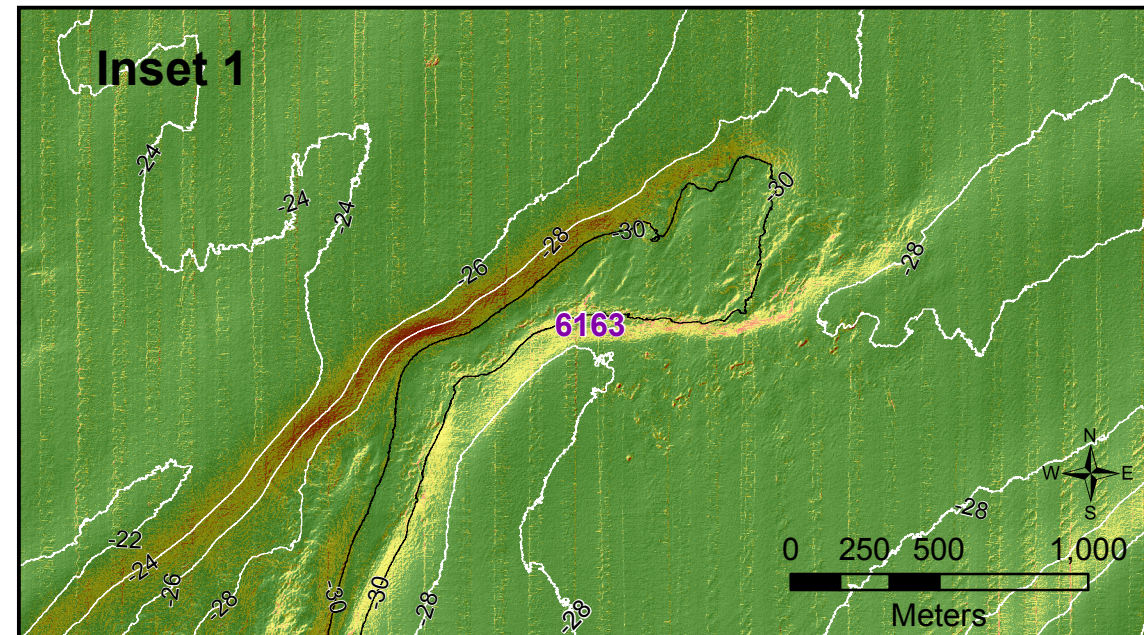
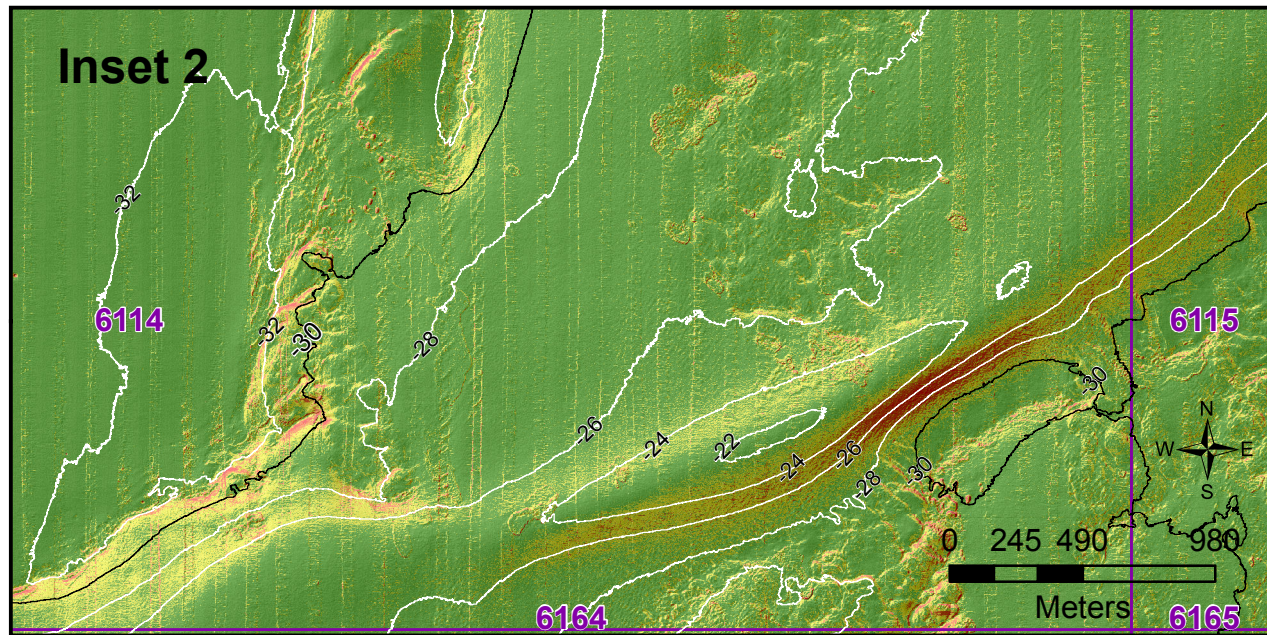
Note:

- The seafloor slope gradient was calculated using a compilation of data sets from NOAA (2011 and 2012).

**WEA SEAFLOOR SLOPE GRADIENT**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-3a

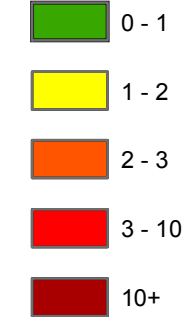
N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\_Reports\Outputs\2013\_Draft\_Survey\_Report\mxd\Fig-4-3\_WEA\_SlopeGradient.mxd\_8/26/2013\_wcupples



**LEGEND**

6061 Wind Energy Area OCS Lease Block

**Seafloor Slope Gradient (degrees)**



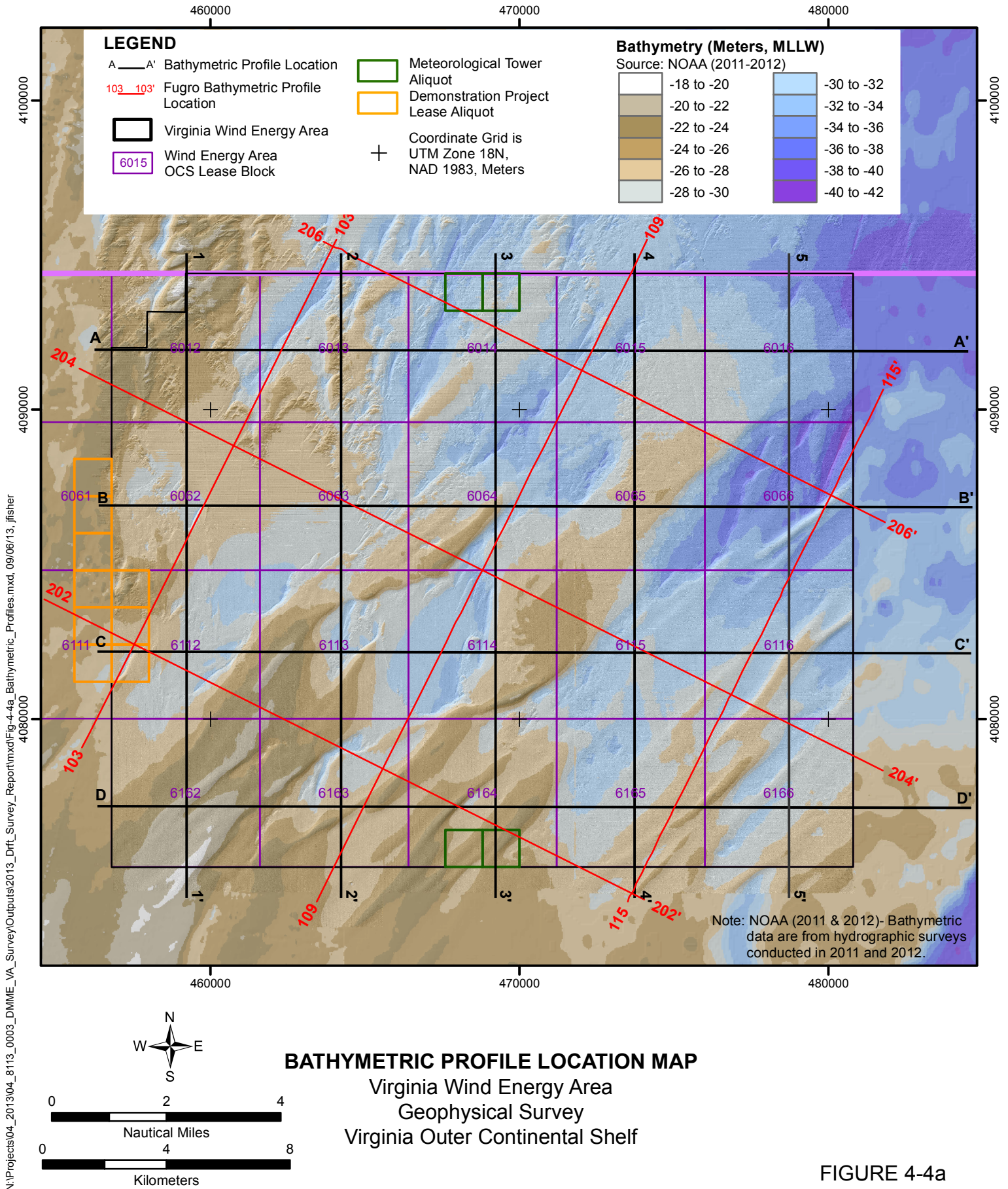
**Bathymetric Contours (MLLW)**

Major contour interval is 10 meters.  
Minor contour interval is 2 meters.

**Note:**

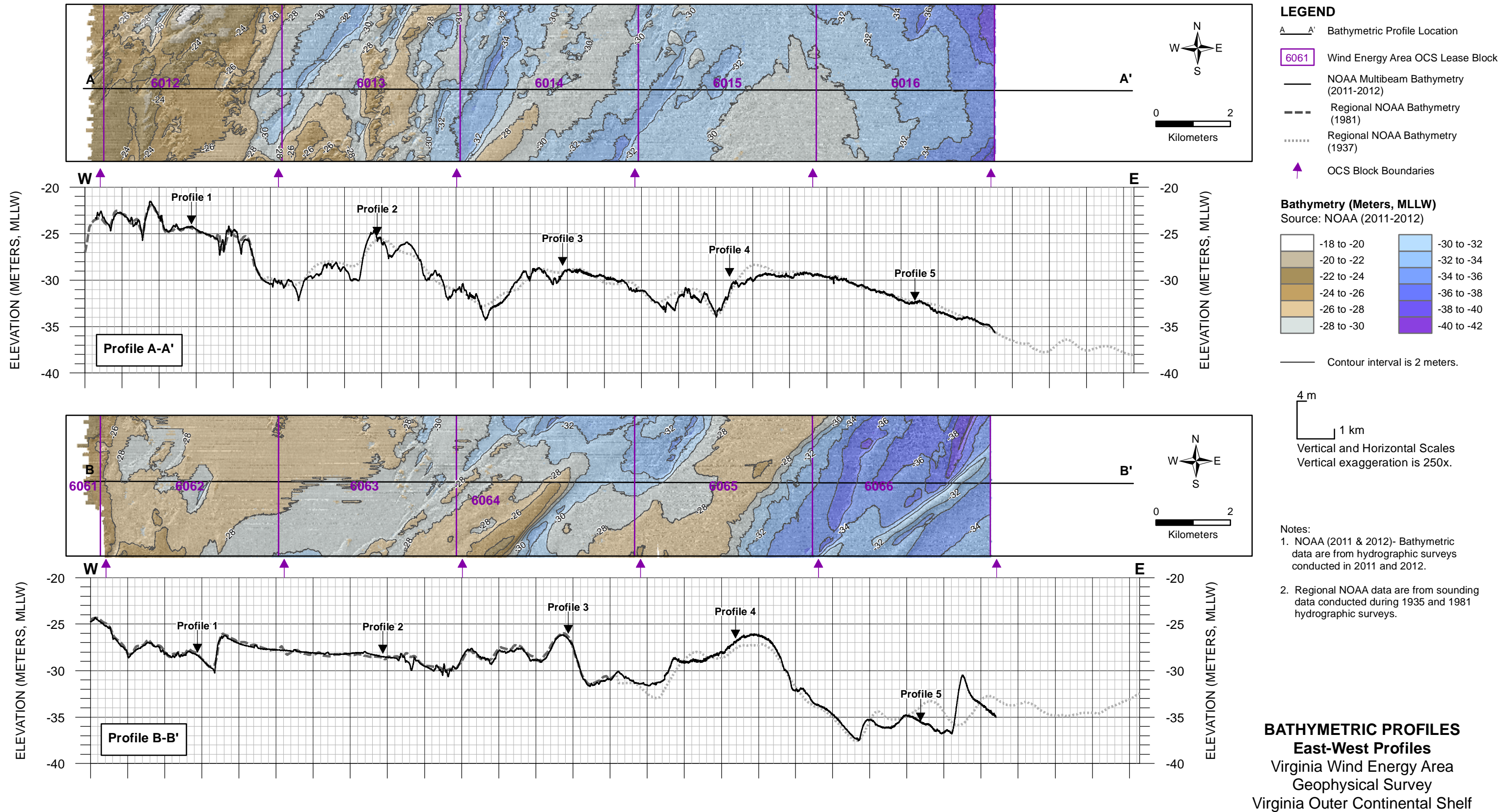
1. The seafloor slope gradient was calculated using a compilation of data sets from NOAA (2011 and 2012).
2. Refer to Figure 4-3a for locations of these detailed inset views.

**WEA SEAFLOOR SLOPE GRADIENT FEATURES**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf



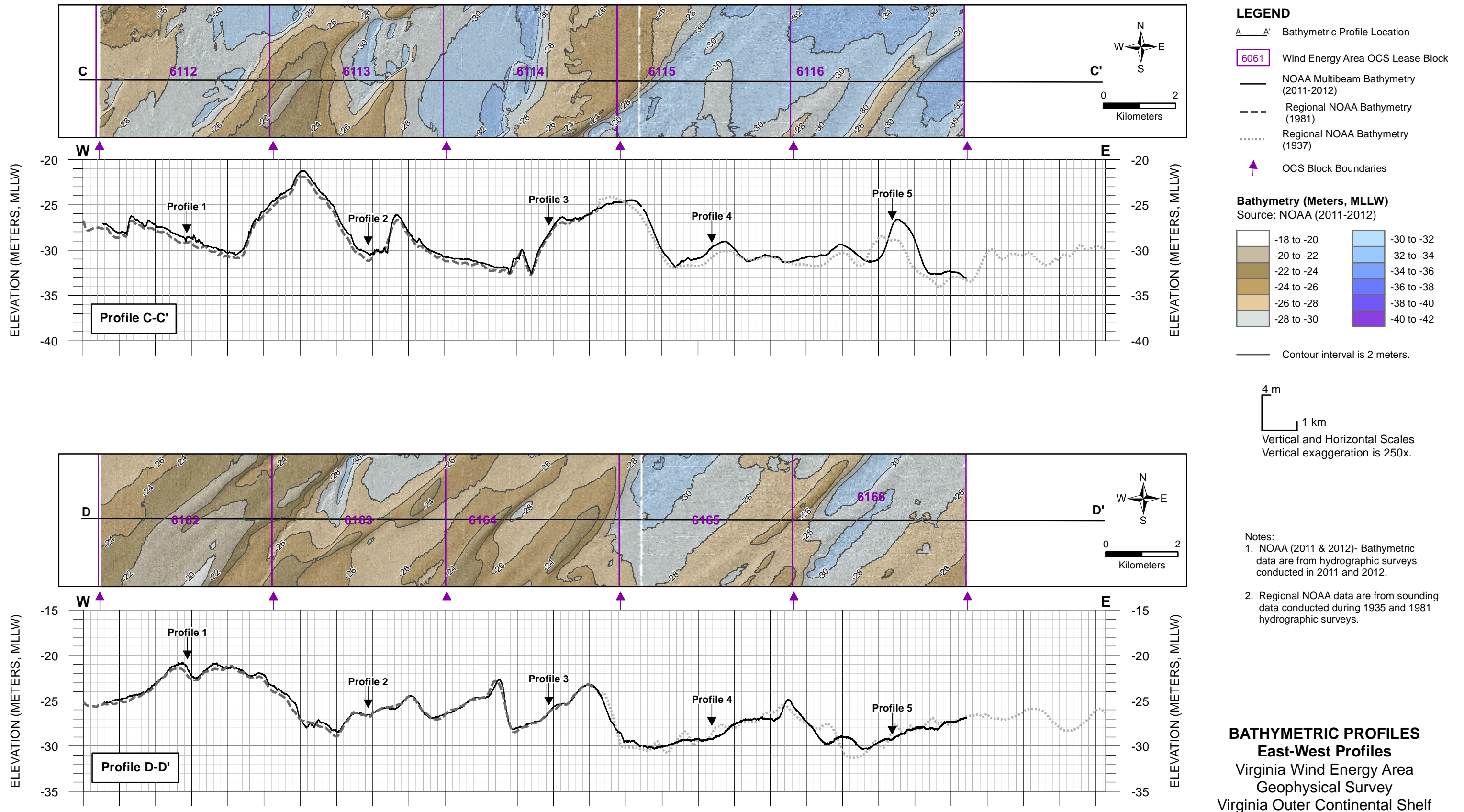
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FIGURE 4-4a



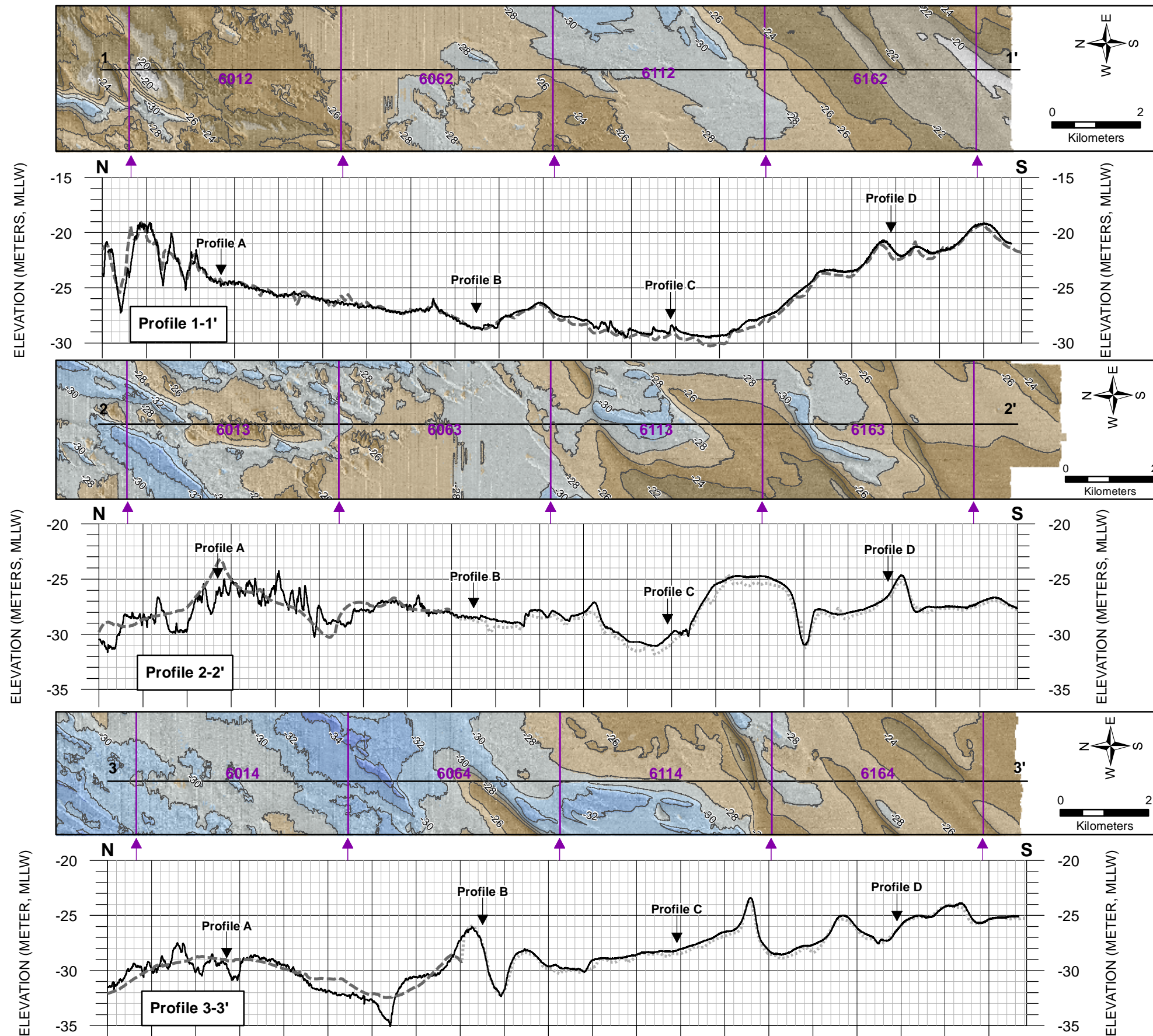
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FIGURE 4-4b



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-4-4c\_Bathymetric\_Profiles\_EW\_2.mxd, 09/09/13, ifisher

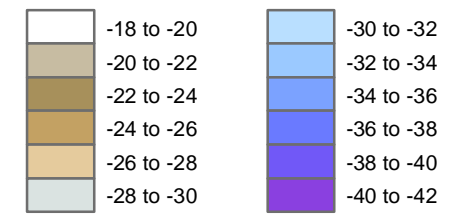
FIGURE 4-4c



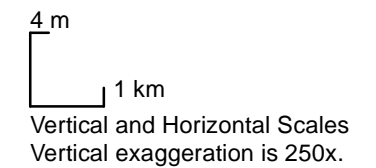
**LEGEND**

- A—A' Bathymetric Profile Location
- 6061 Wind Energy Area OCS Lease Block
- NOAA Multibeam Bathymetry (2011-2012)
- - - Regional NOAA Bathymetry (1981)
- ..... Regional NOAA Bathymetry (1937)
- ▲ OCS Block Boundaries

**Bathymetry (Meters, MLLW)**  
Source: NOAA (2011-2012)



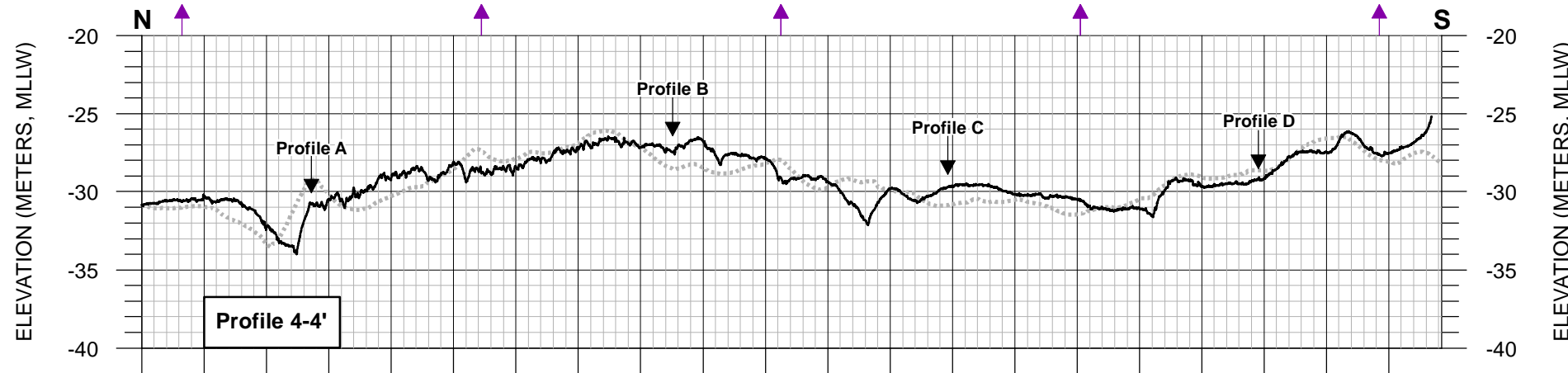
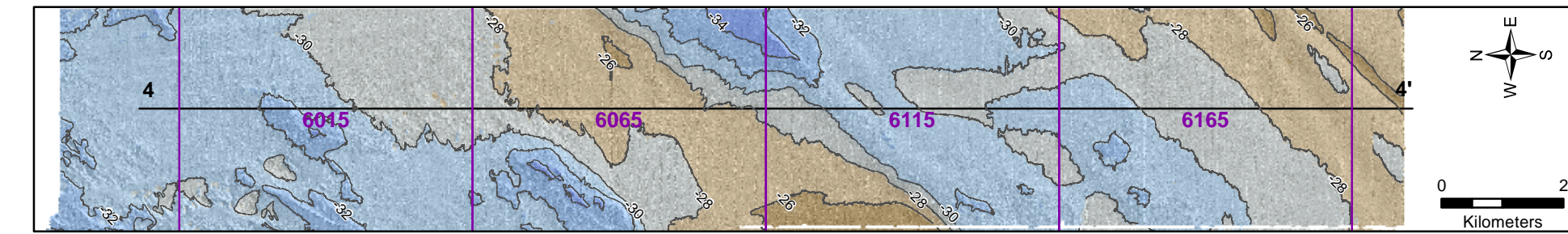
— Contour interval is 2 meters.



- Notes:
- Plan view maps have been rotated 90 degrees so north is on the left side (to match the profile view). Profiles are numbered from left to right starting from the nearshore area (1-1') and moving offshore (5-5').
  - NOAA (2011 & 2012)- Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
  - Regional NOAA data are from sounding data conducted during 1935 and 1981 hydrographic surveys.

**BATHYMETRIC PROFILES**  
**North-South Profiles**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

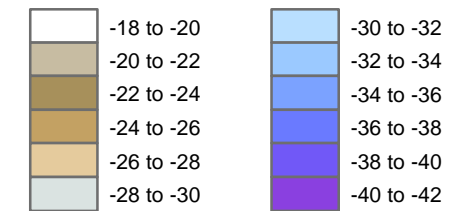
FIGURE 4-4d



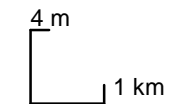
**LEGEND**

- A—A' Bathymetric Profile Location
- 6061 Wind Energy Area OCS Lease Block
- NOAA Multibeam Bathymetry (2011-2012)
- ..... Regional NOAA Bathymetry (1937)
- ▲ OCS Block Boundaries

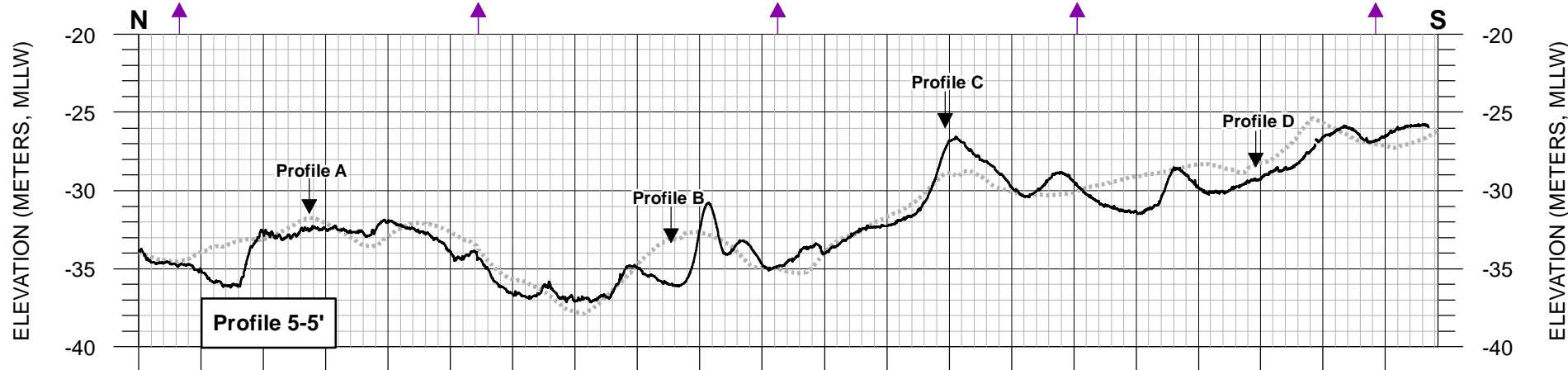
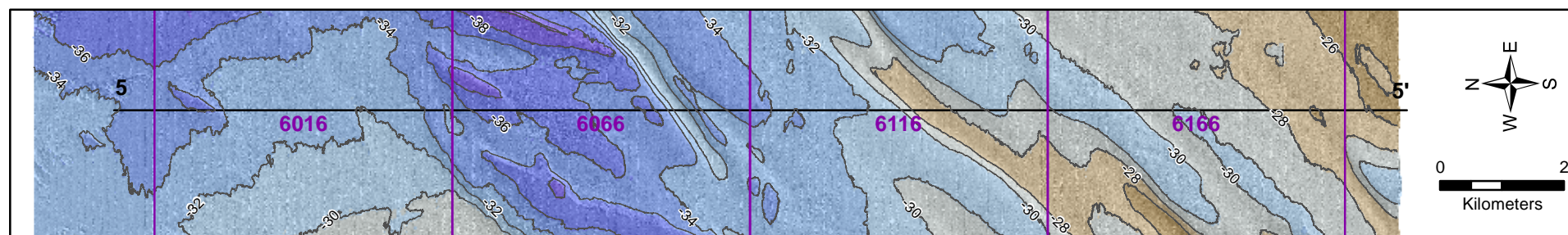
**Bathymetry (Meters, MLLW)**  
Source: NOAA (2011-2012)



— Contour interval is 2 meters.



Vertical and Horizontal Scales  
Vertical exaggeration is 250x.

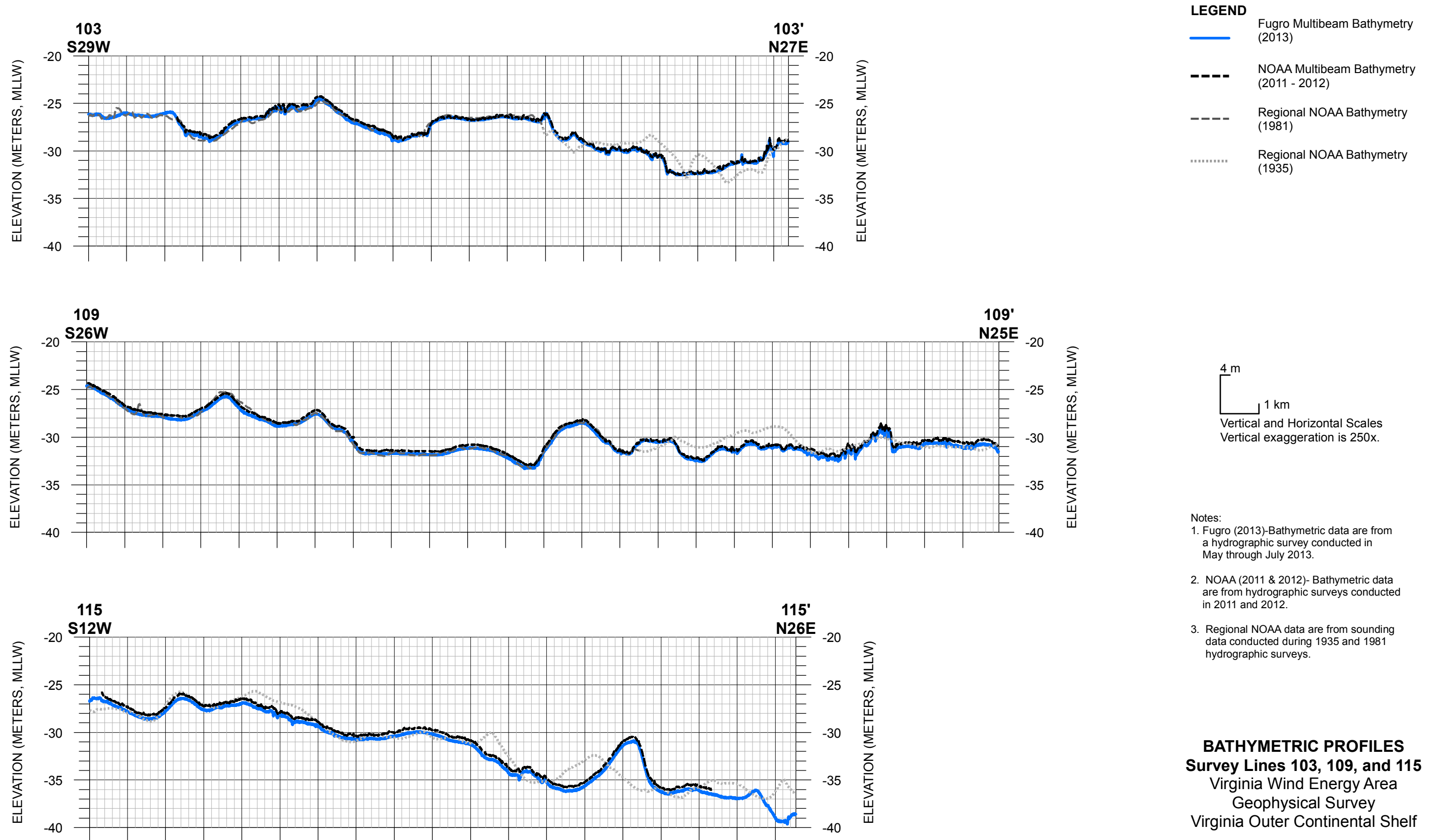


**Notes:**

1. Plan view maps have been rotated 90 degrees so north is on the left side (to match the profile view). Profiles are numbered from left to right starting from the nearshore area (1-1') and moving offshore (5-5').
2. NOAA (2011 & 2012)- Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
3. Regional NOAA data are from sounding data conducted during 1935 and 1981 hydrographic surveys.

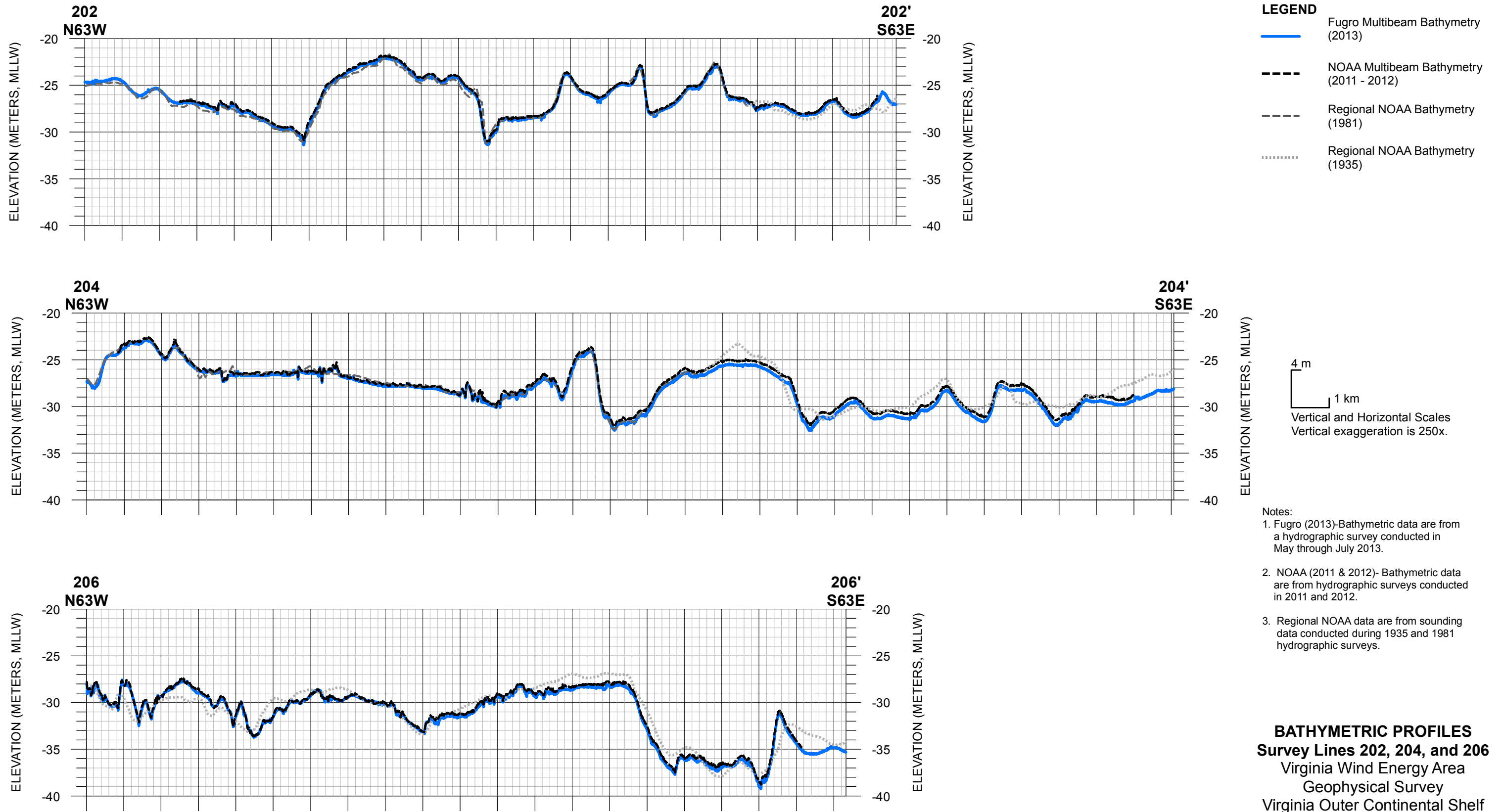
**BATHYMETRIC PROFILES**  
**North-South Profiles**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-4e



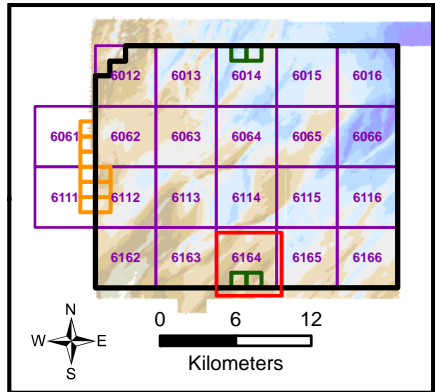
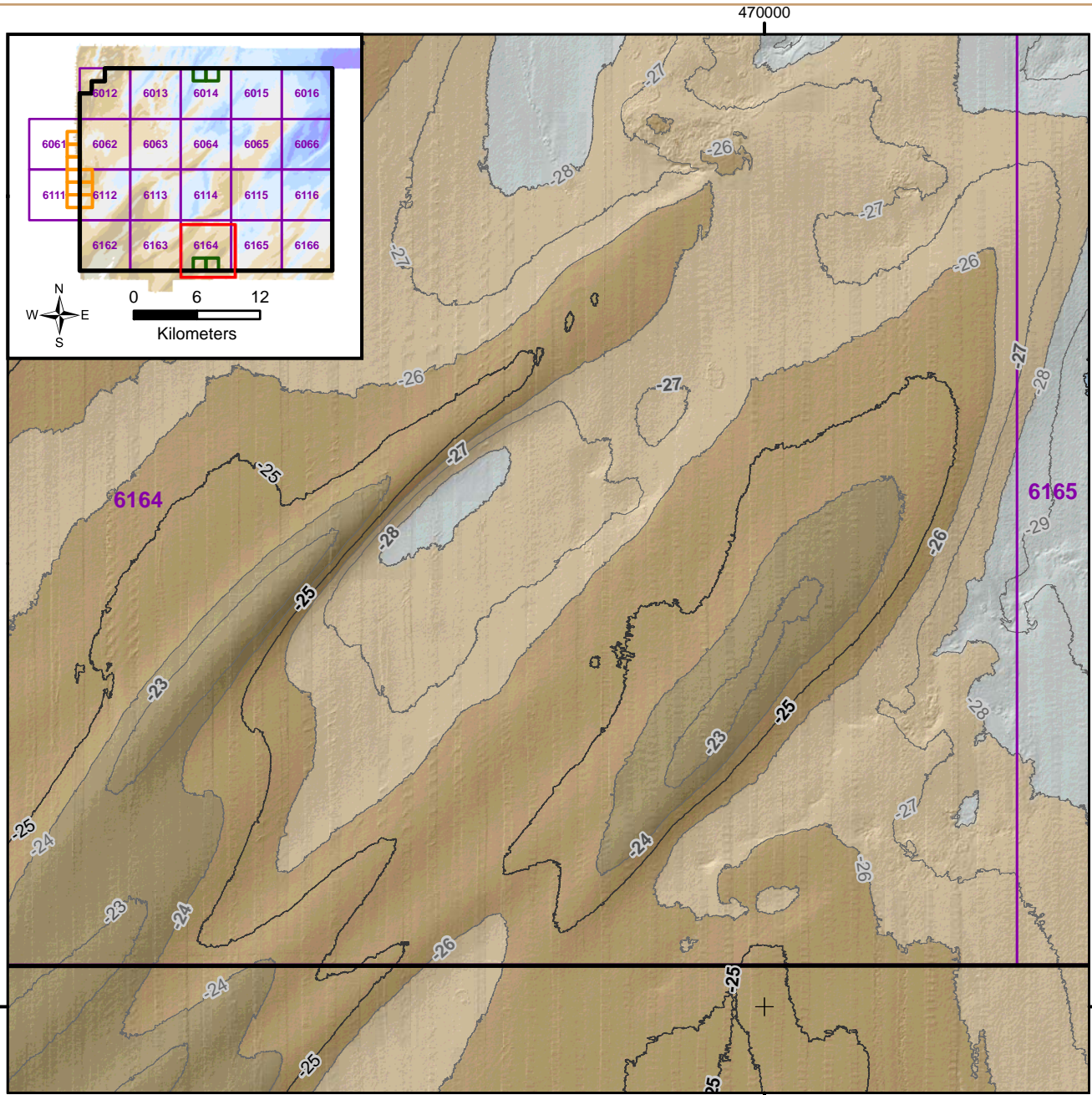
N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Output\2013\_Draft\_Survey\_Report\mxd\Fig-4-4f\_Bathymetric\_Profiles\_100series.mxd, 09/09/13, jfisher

FIGURE 4-4f



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Draft\_Survey\_Report\mxd\Fig-4-g\_Bathymetric\_Profiles\_200series.mxd, 09/09/13, jfisher

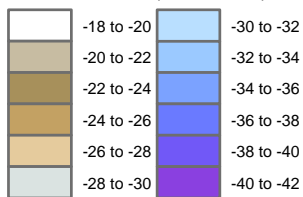
FIGURE 4-4g



**LEGEND**

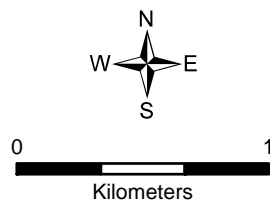
**Bathymetry (Meters, MLLW)**

Source: NOAA (2011-2012)



— Major contour is 5 meters.  
— Minor contour is 1 meter.

Note:  
NOAA (2011 & 2012)- Bathymetric data  
are from hydrographic surveys c  
onducted in 2011 and 2012.

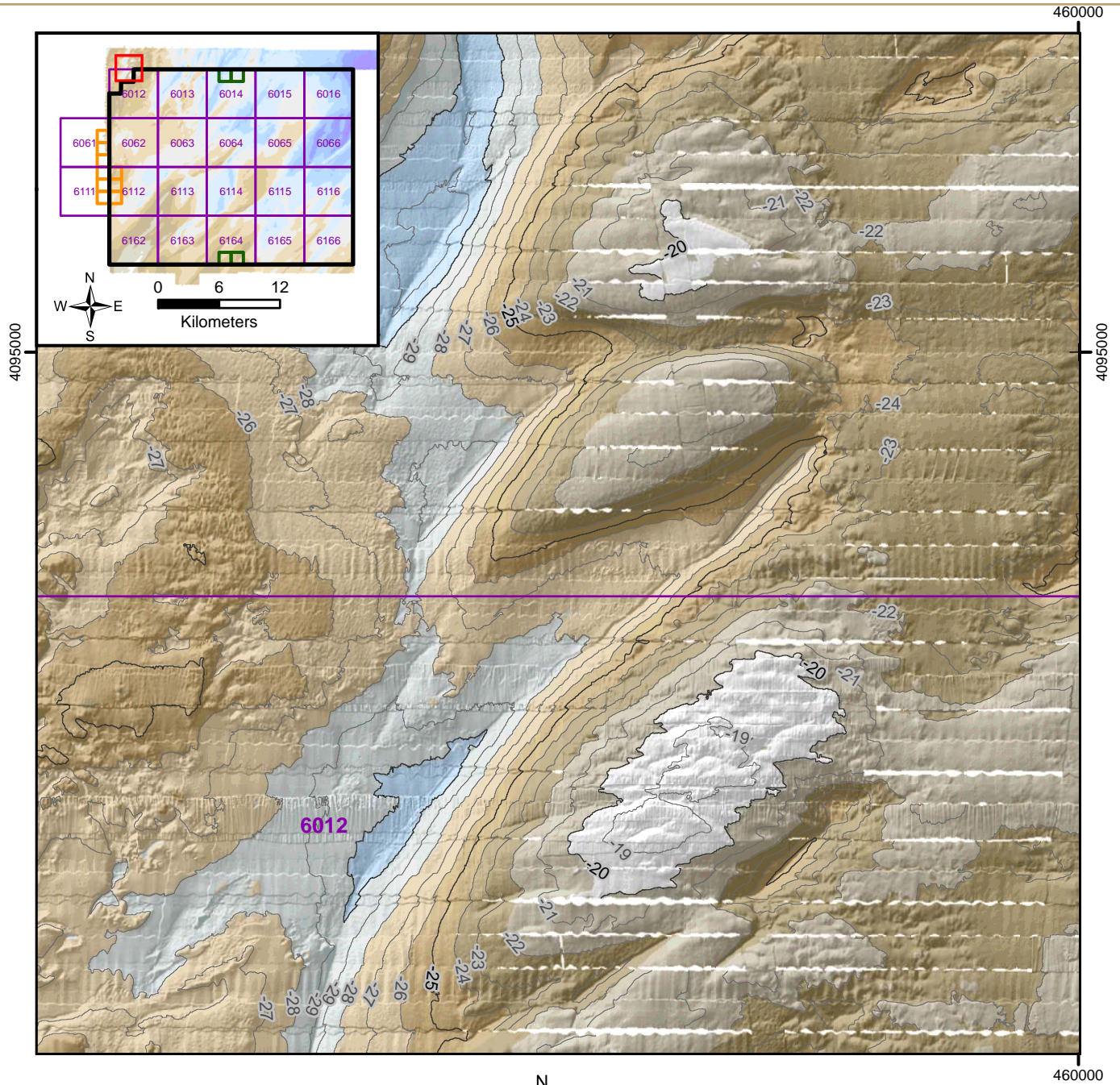


- Virginia Wind Energy Area
- 6061 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**WEA BATHYMETRY SAND RIDGE FEATURES**

Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-5



**LEGEND**

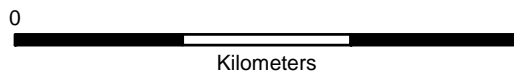
**Bathymetry (Meters, MLLW)**

Source: NOAA (2011-2012)

-18 to -20	-30 to -32
-20 to -22	-32 to -34
-22 to -24	-34 to -36
-24 to -26	-36 to -38
-26 to -28	-38 to -40
-28 to -30	-40 to -42

— Major contour is 5 meters.  
— Minor contour is 1 meter.

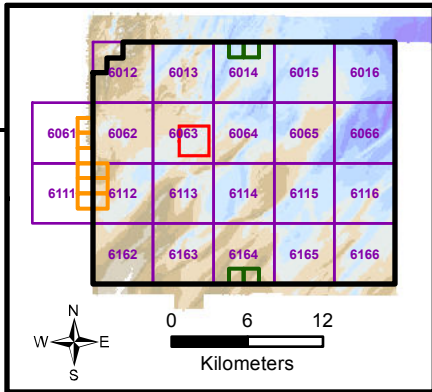
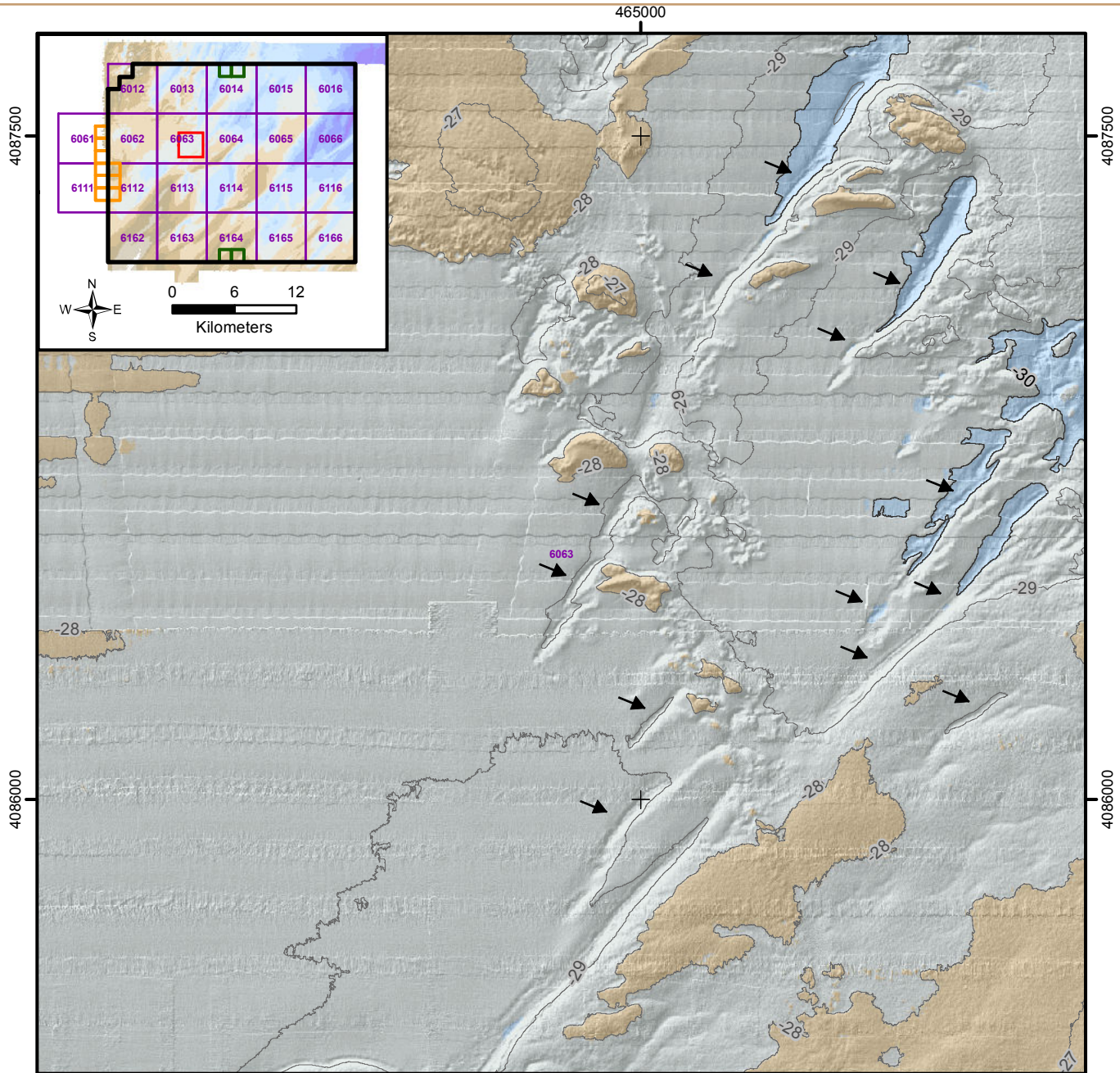
Note:  
NOAA (2011 & 2012)- Bathymetric data  
are from hydrographic surveys c  
onducted in 2011 and 2012.



- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- + Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**LARGER BATHYMETRY DUNE FEATURES**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

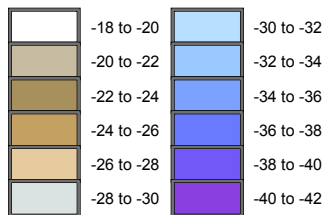
FIGURE 4-6a



**LEGEND**

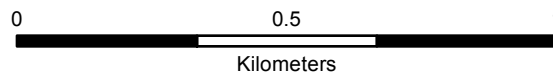
**Bathymetry (Meters, MLLW)**

Source: NOAA (2011-2012)



— Major contour is 5 meters.  
— Minor contour is 1 meter.

Note:  
NOAA (2011 & 2012)- Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.



- Virginia Wind Energy Area
- 6061 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**BATHYMETRY LINEAR FEATURES**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-6b

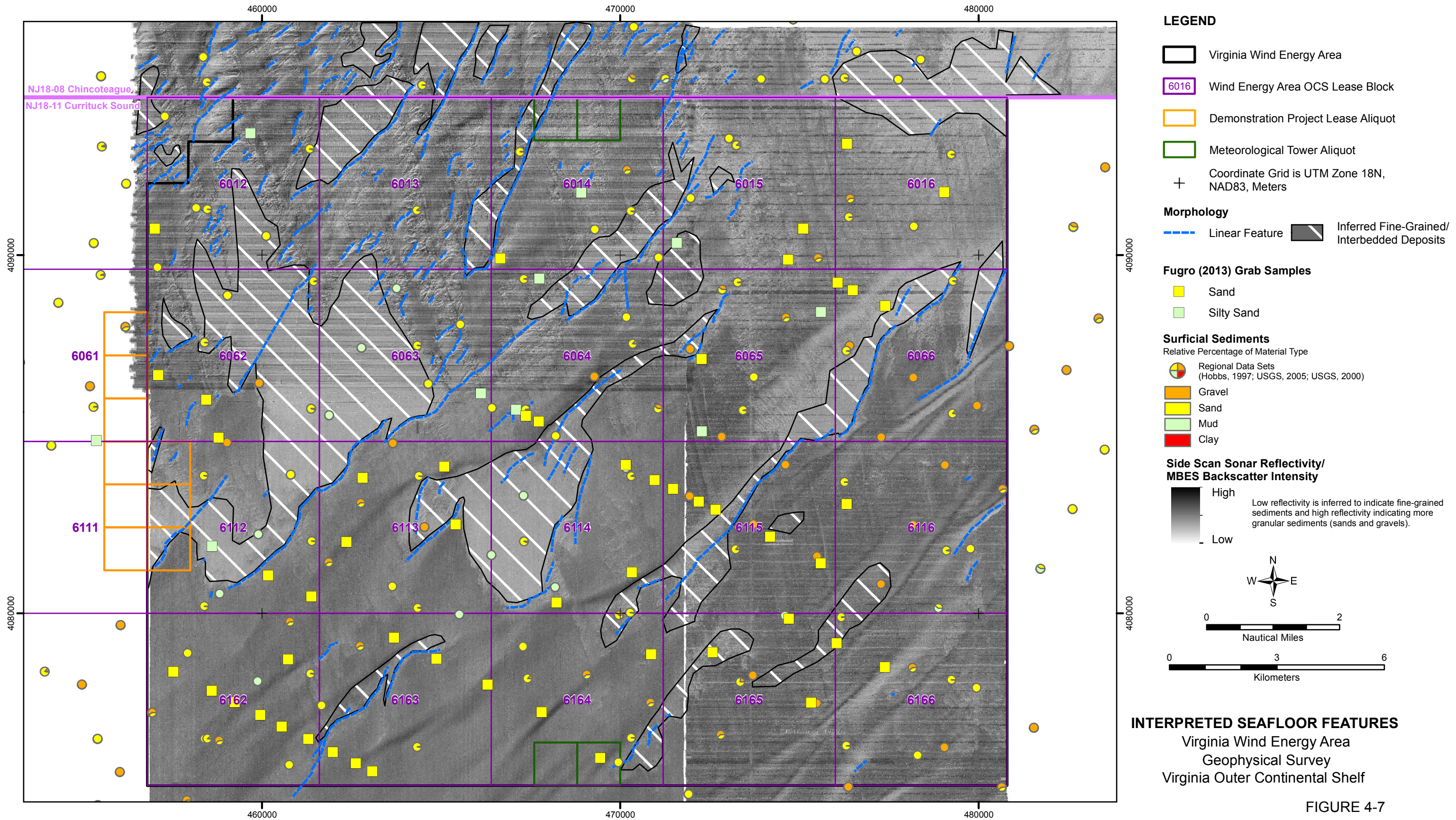


FIGURE 4-7

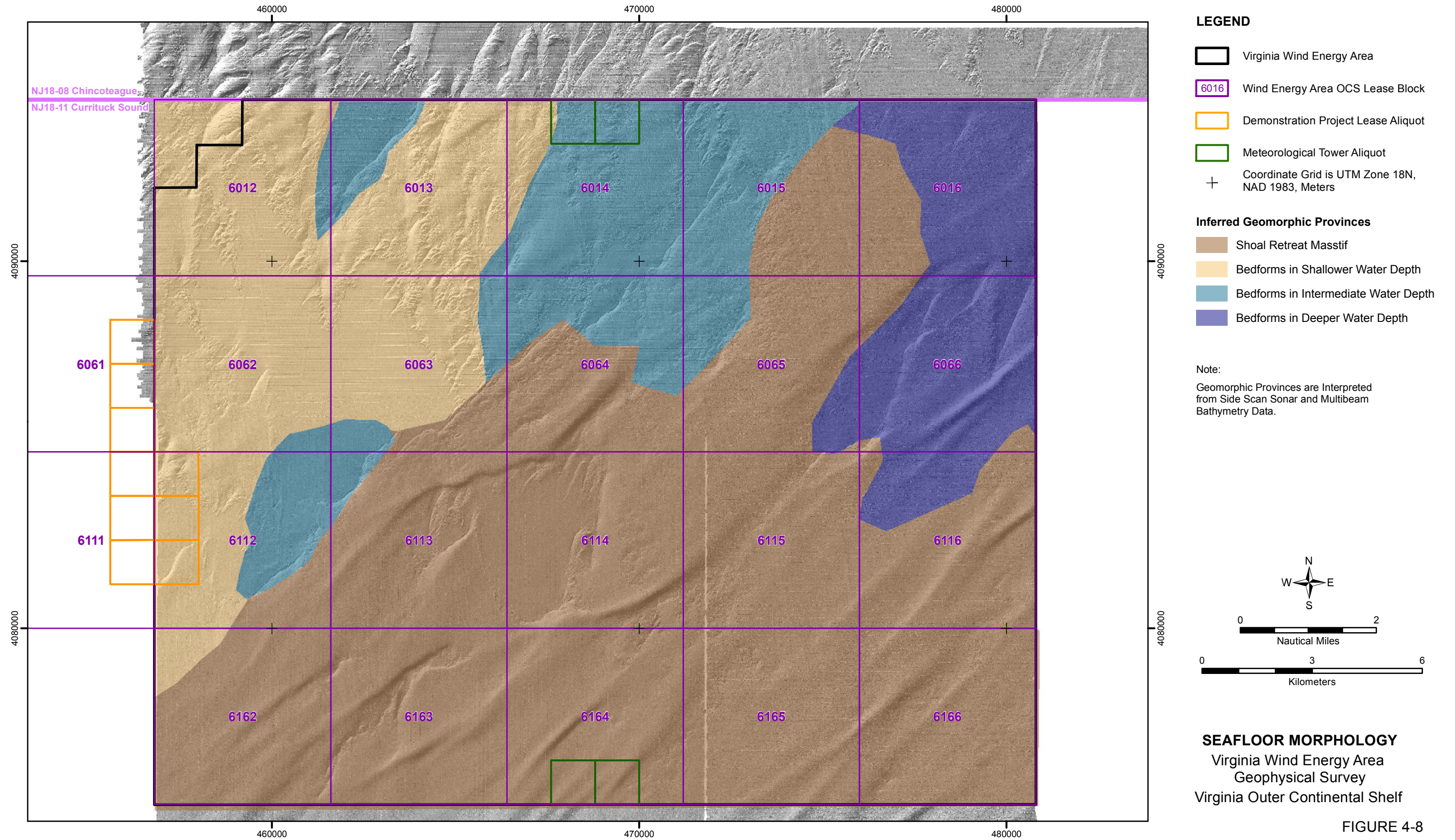
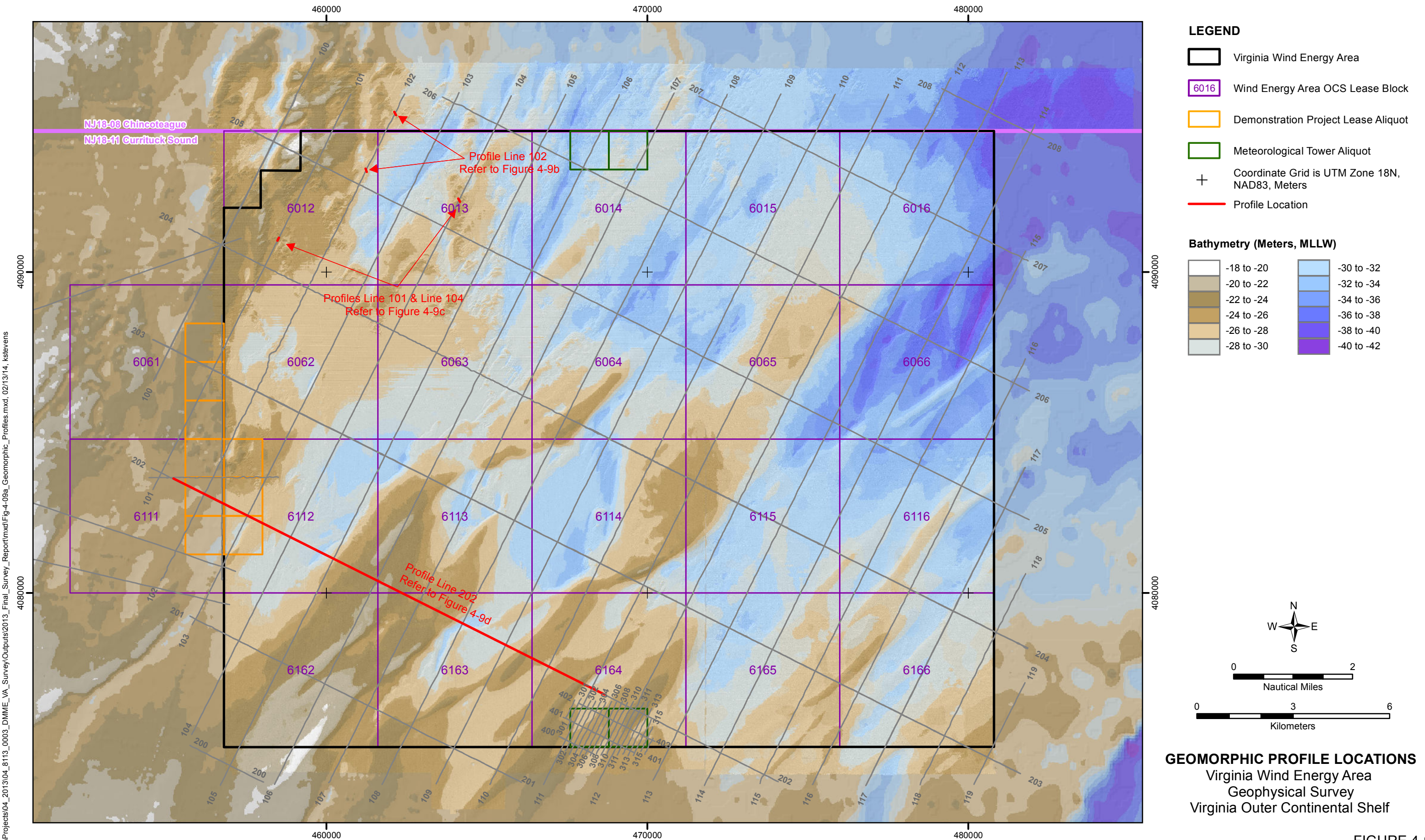


FIGURE 4-8



**LEGEND**

- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD83, Meters
- Profile Location

**Bathymetry (Meters, MLLW)**

	-18 to -20		-30 to -32
	-20 to -22		-32 to -34
	-22 to -24		-34 to -36
	-24 to -26		-36 to -38
	-26 to -28		-38 to -40
	-28 to -30		-40 to -42

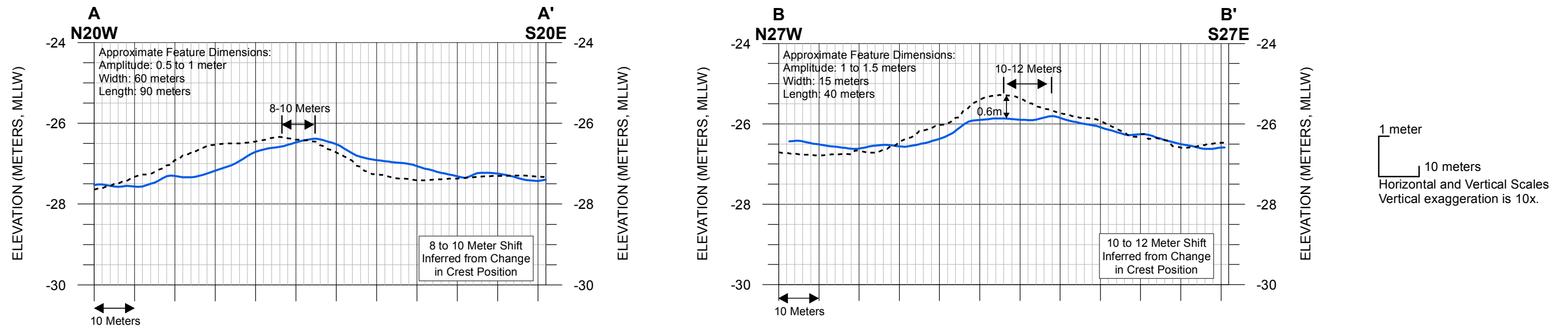
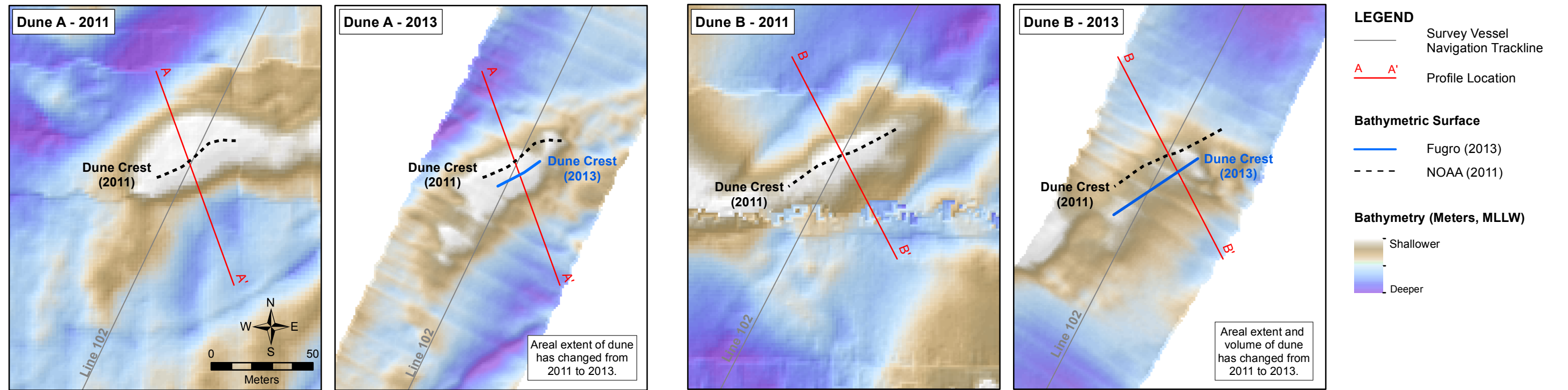
0 2  
Nautical Miles

0 3 6  
Kilometers

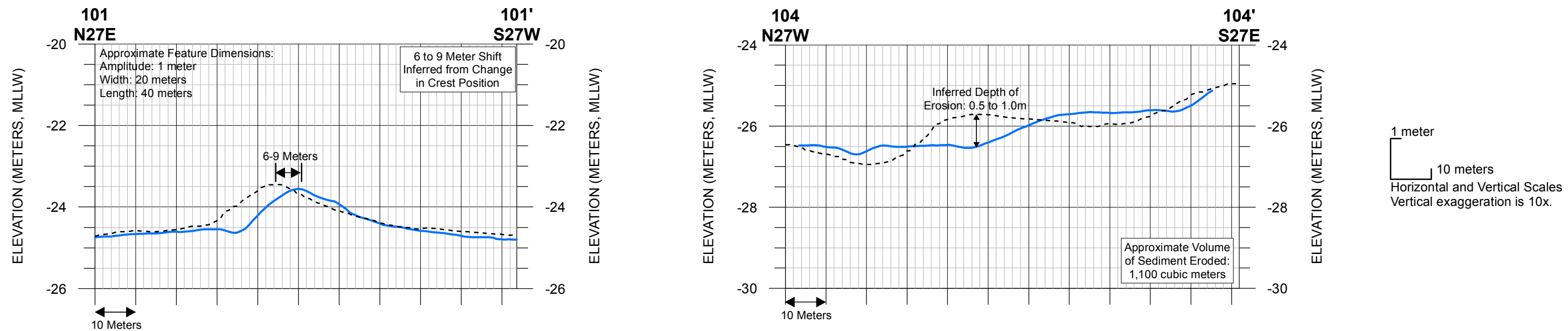
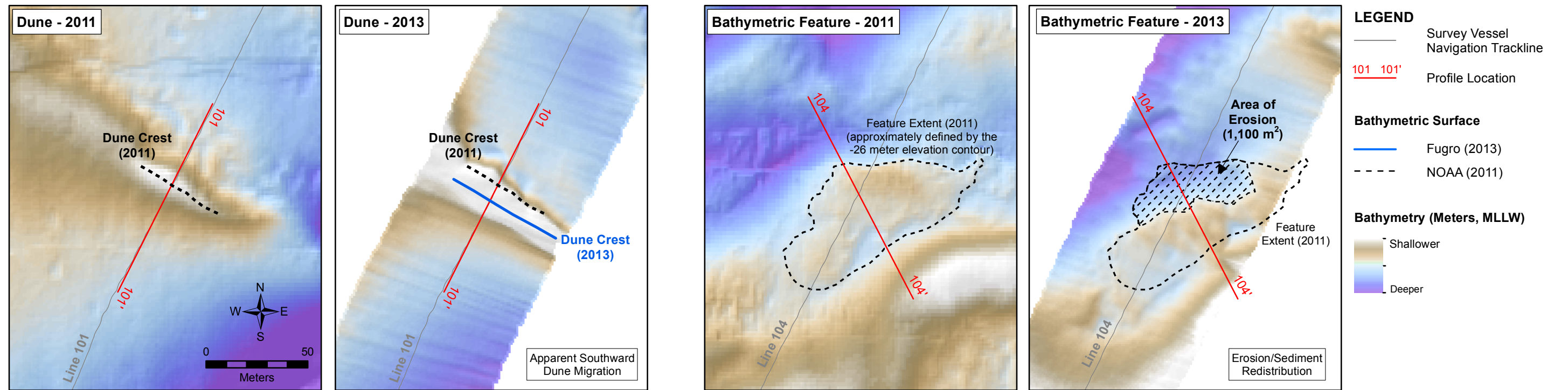
**GEOMORPHIC PROFILE LOCATIONS**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-9a

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Final\_Survey\_Report\mxd\Fig-4-09a\_Geomorphic\_Profiles.mxd, 02/13/14, kstevens

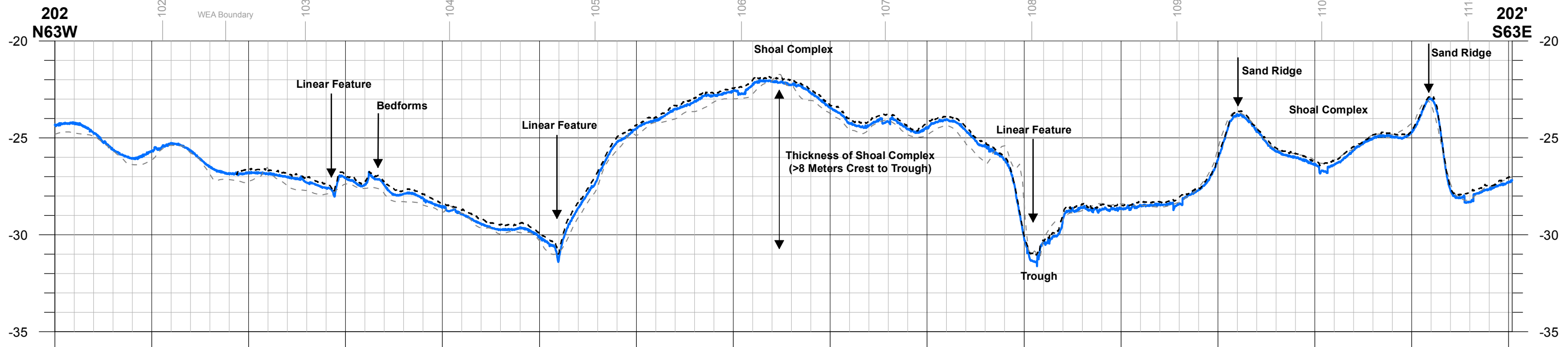
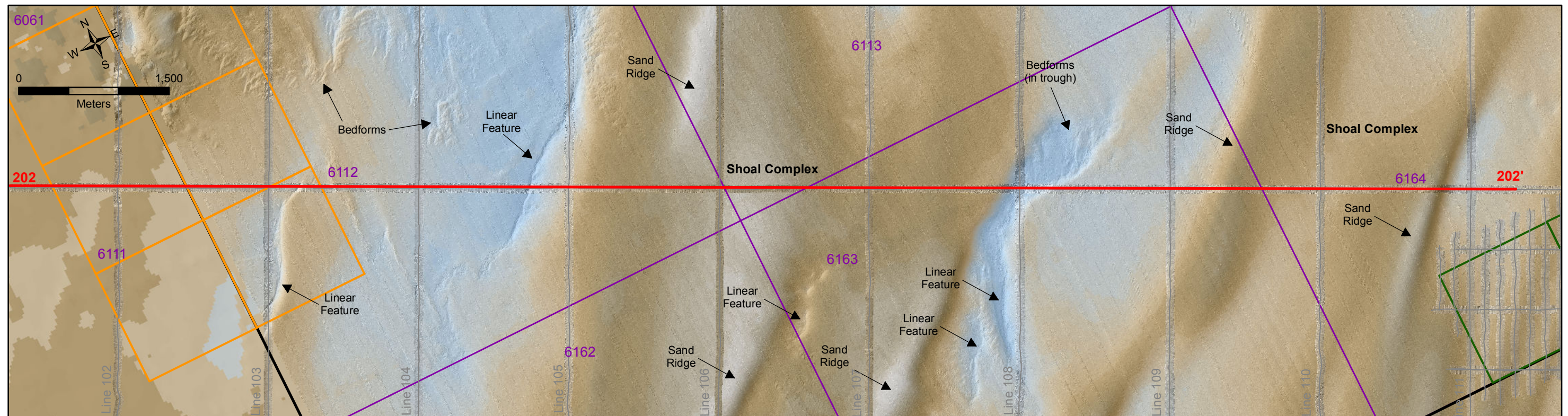


**GEOMORPHIC PROFILE**  
**Dune Migration - Line 102**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf



**GEOMORPHIC PROFILES**  
**Lines 101 & 104**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

N:\Projects\04\_2013\04\_8113\_DMME\_VA\_Survey\Outputs\2013\_Final\_Survey\_Report\mxd\Fig-4-9c\_Geomorphic\_Profile\_Dunes\_101\_104.mxd, 02/13/14, kstelevens

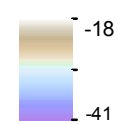


2 meters  
400 meters  
Horizontal and Vertical Scales  
Vertical exaggeration is 200x.

**MAP LEGEND**

- Survey Vessel Navigation Trackline
- Profile Location
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot

**Bathymetry (Meters, MLLW)**

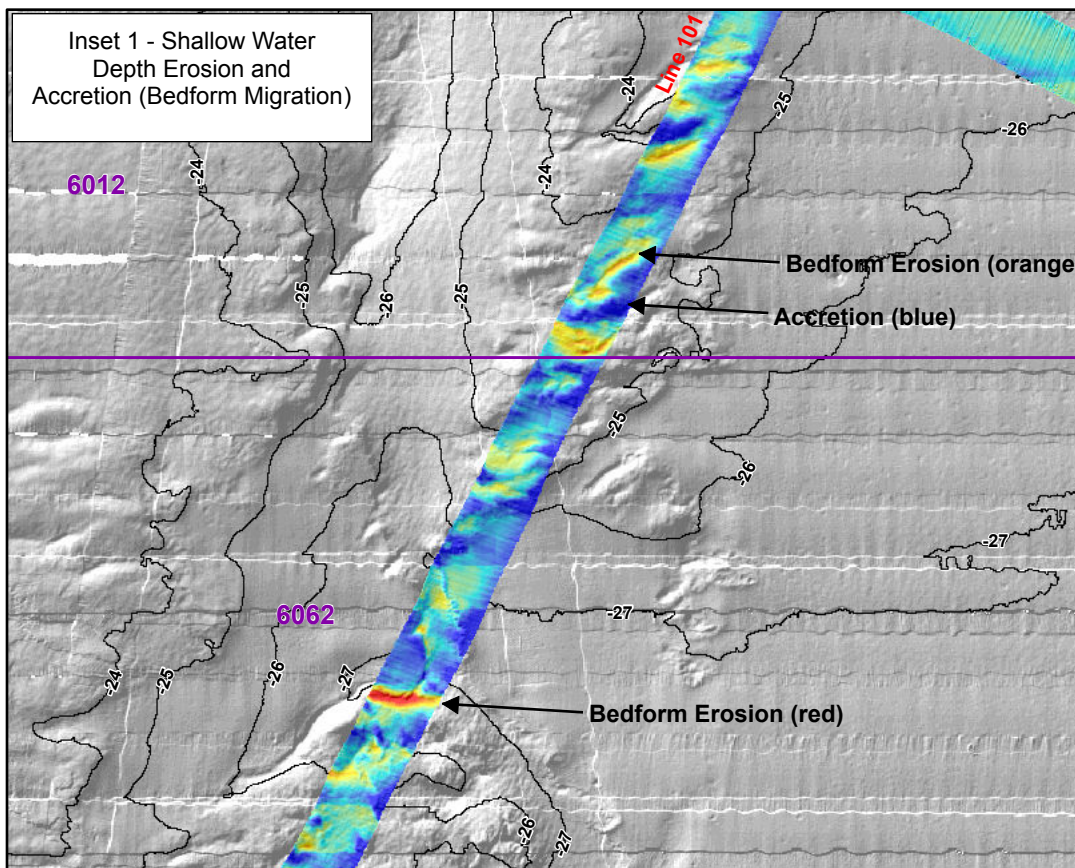
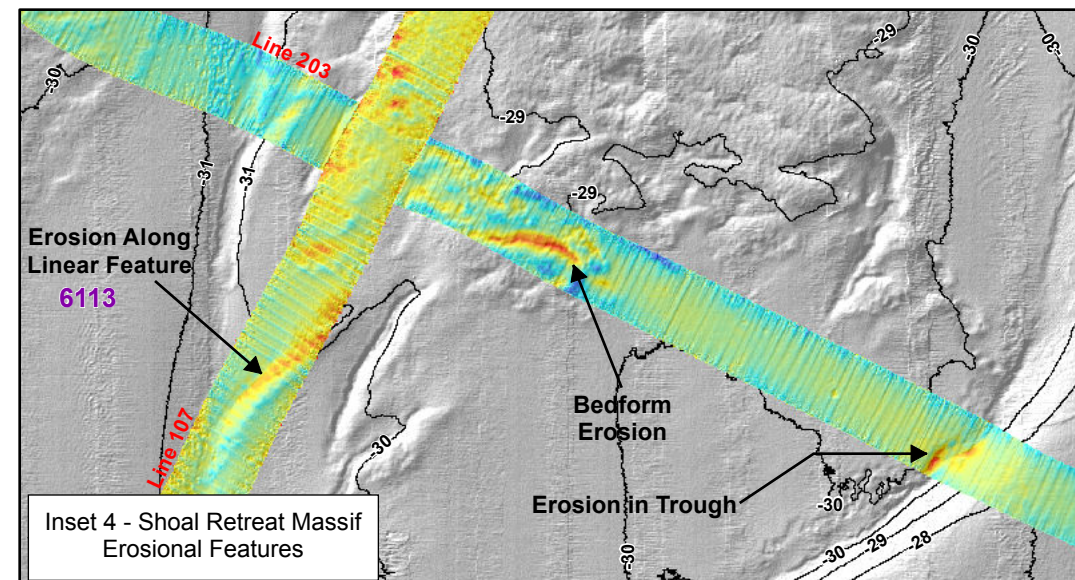
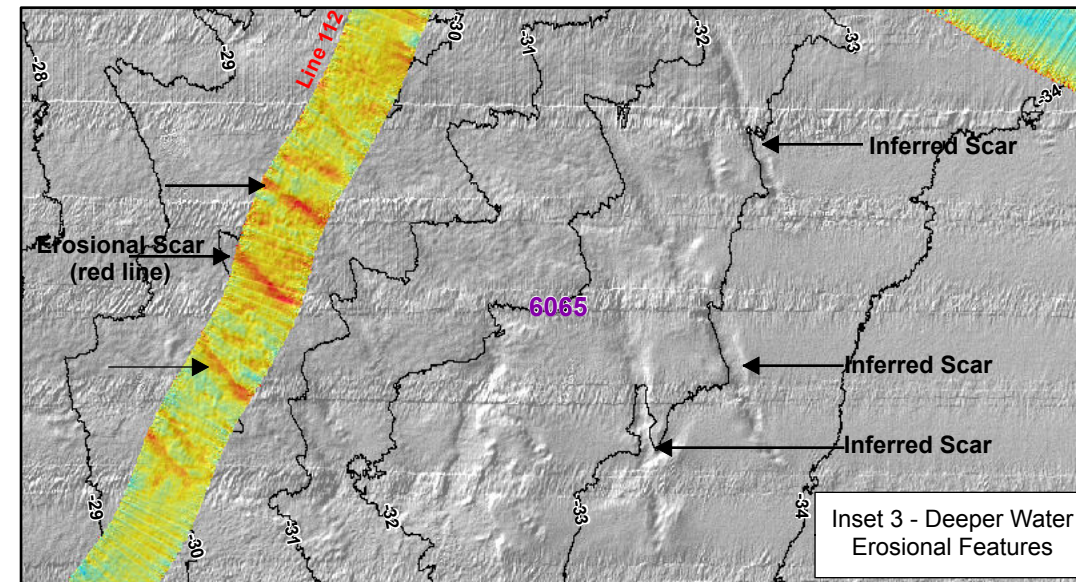
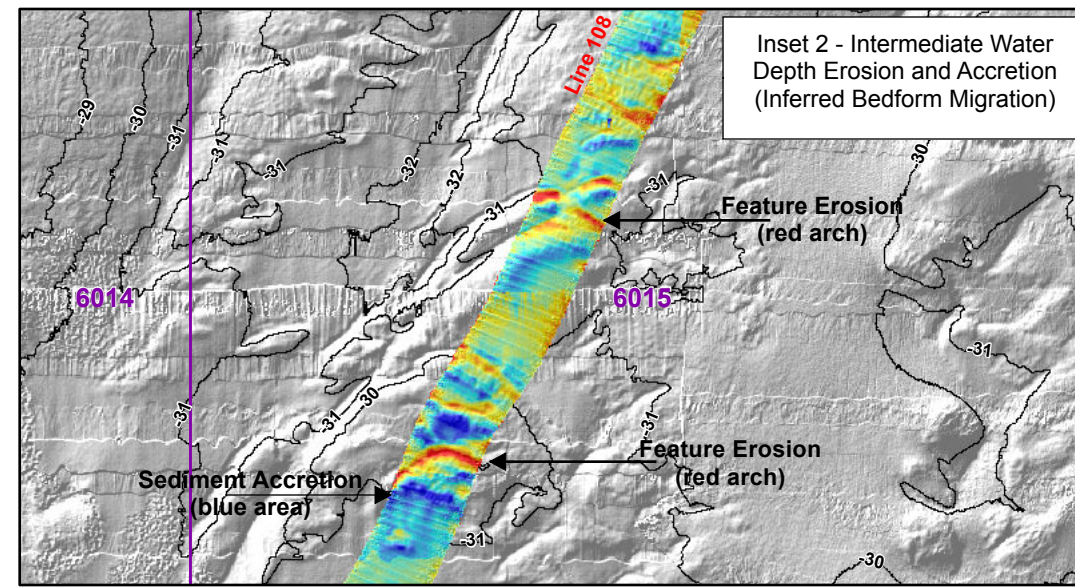
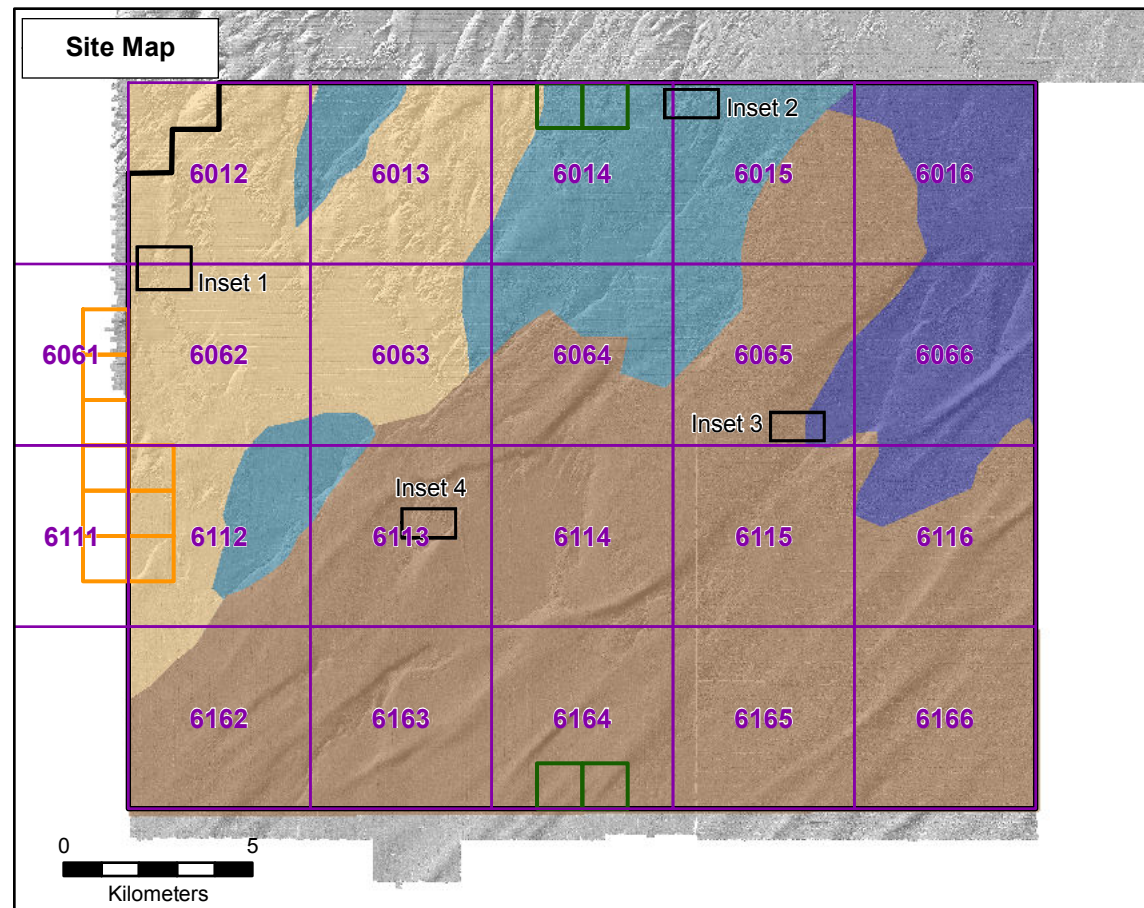


**PROFILE LEGEND**  
**Bathymetric Surface**

- Fugro (2013)
- NOAA (2011)
- Regional NOAA (1981)

**GEOMORPHIC PROFILE**  
**Geologic Features - Line 202**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 4-9d



**LEGEND**

- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot

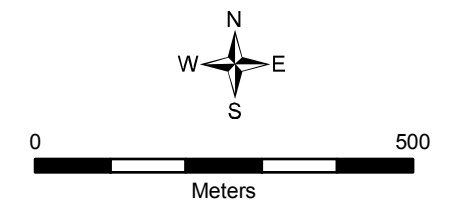
**Inferred Geomorphic Provinces**

- Shoal Retreat Massif
- Bedforms in Shallower Water Depth
- Bedforms in Intermediate Water Depth
- Bedforms in Deeper Water Depth

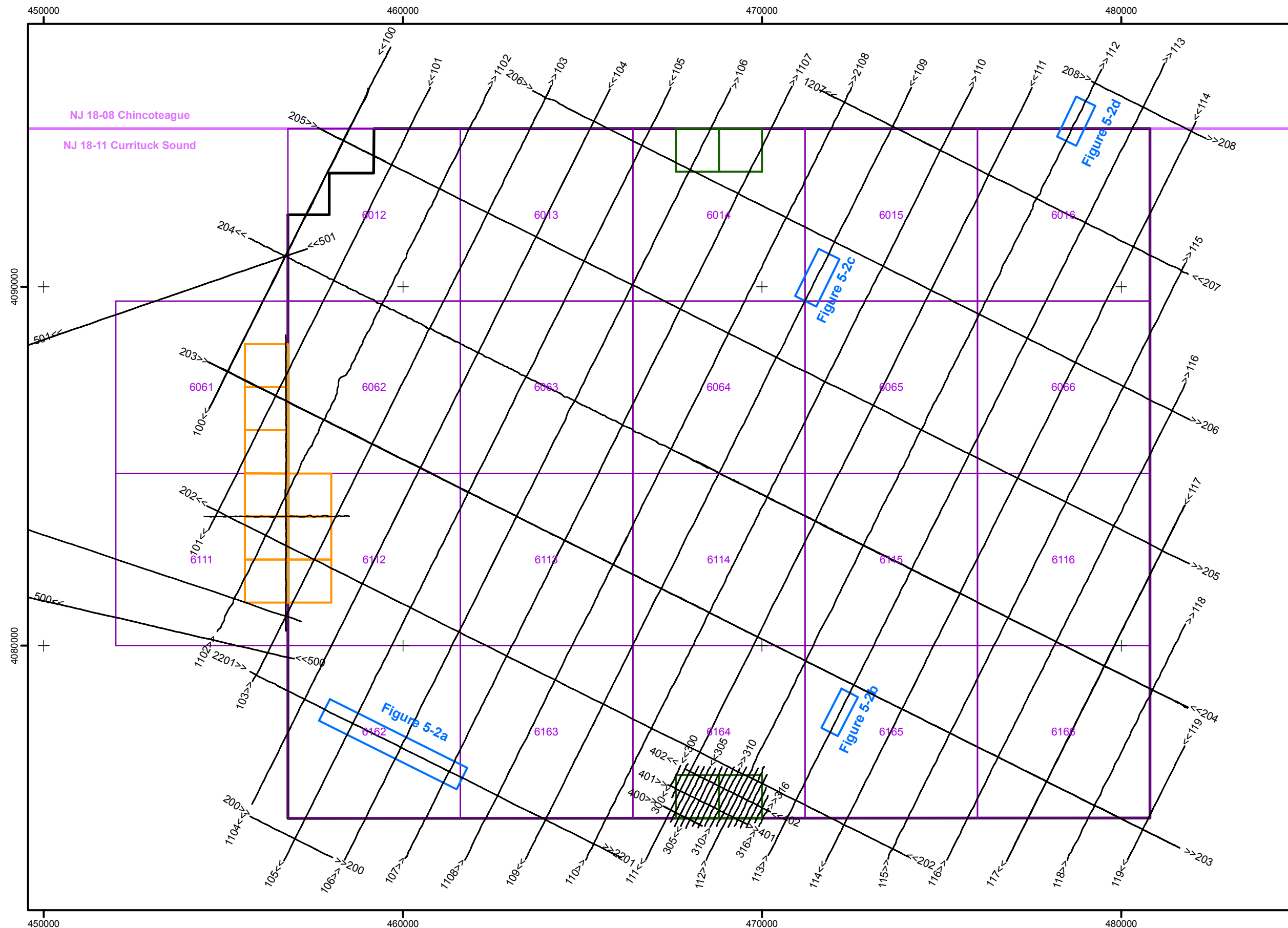
**Comparison Between Fugro and NOAA MBES**

- Accretion
- No Change
- Erosion

- Bathymetric Contour
- Contour interval is 1 meter



**DIFFERENCE MAP EROSION EXAMPLES**  
Comparison of NOAA and Fugro MBES Data  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

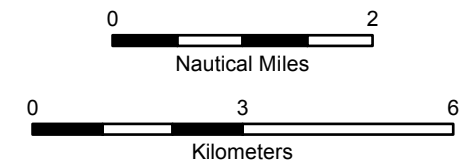


**LEGEND**

- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- CHIRP Profile Locations
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

Note:

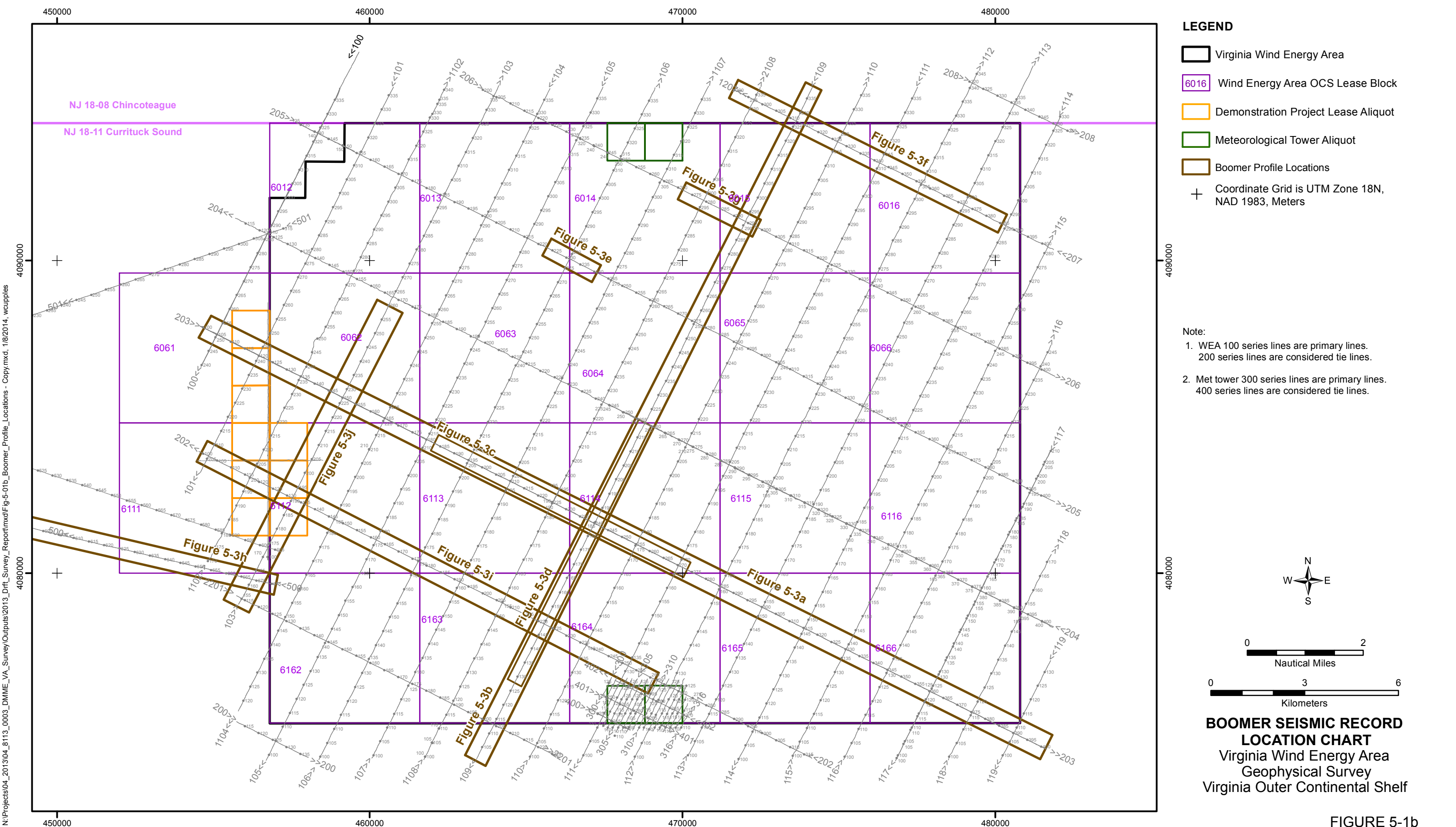
1. WEA 100 series lines are primary lines. 200 series lines are considered tie lines.
2. Met tower 300 series lines are primary lines. 400 series lines are considered tie lines.



**CHIRP SEISMIC RECORD  
LOCATION CHART**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 5-1a

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\_Reports\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-1-04\_Seismic\_Profile\_Locations.mxd, 8/28/2013, wcupplies



**LEGEND**

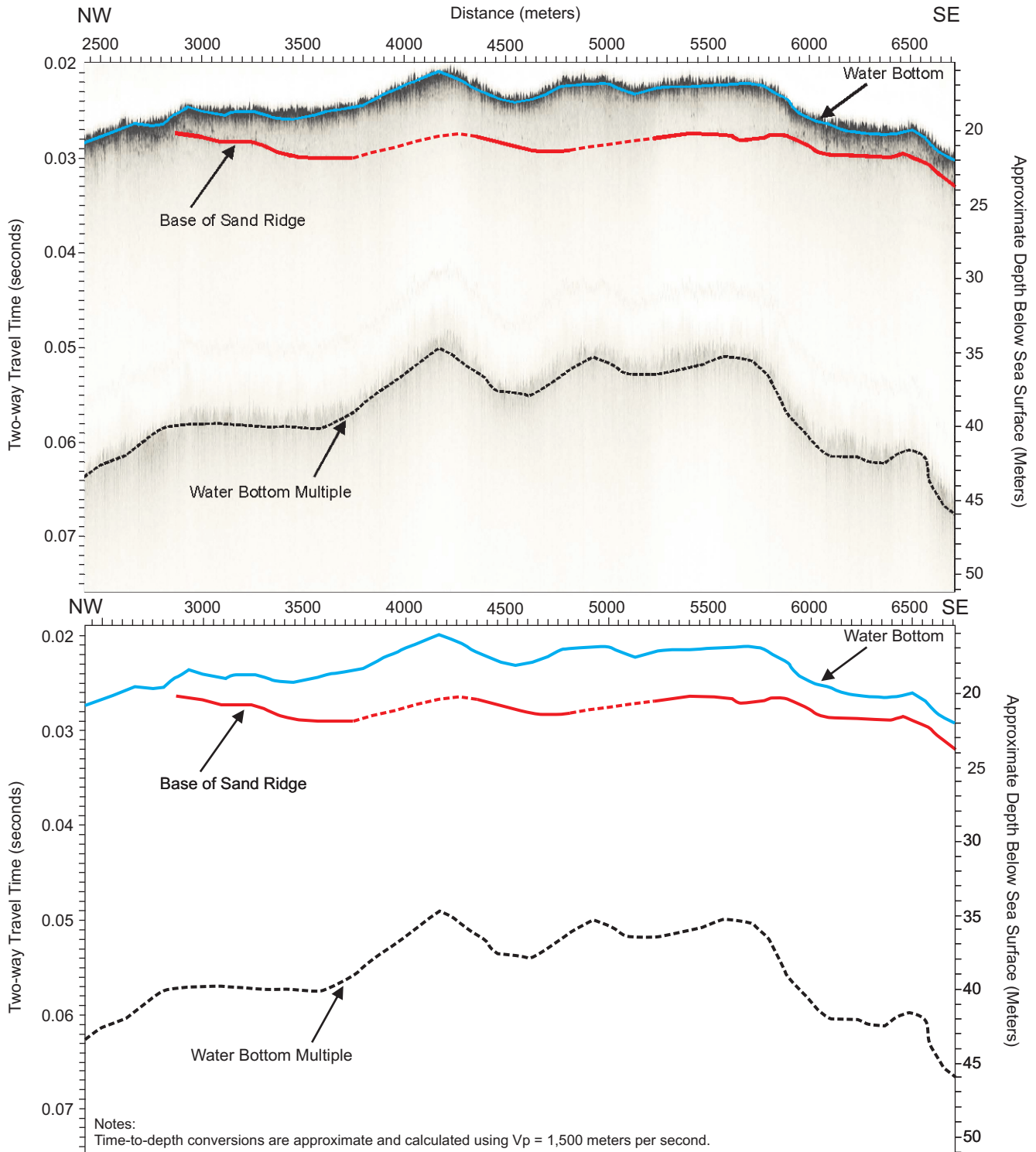
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Boomer Profile Locations
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

- Note:
1. WEA 100 series lines are primary lines. 200 series lines are considered tie lines.
  2. Met tower 300 series lines are primary lines. 400 series lines are considered tie lines.

**BOOMER SEISMIC RECORD  
LOCATION CHART**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

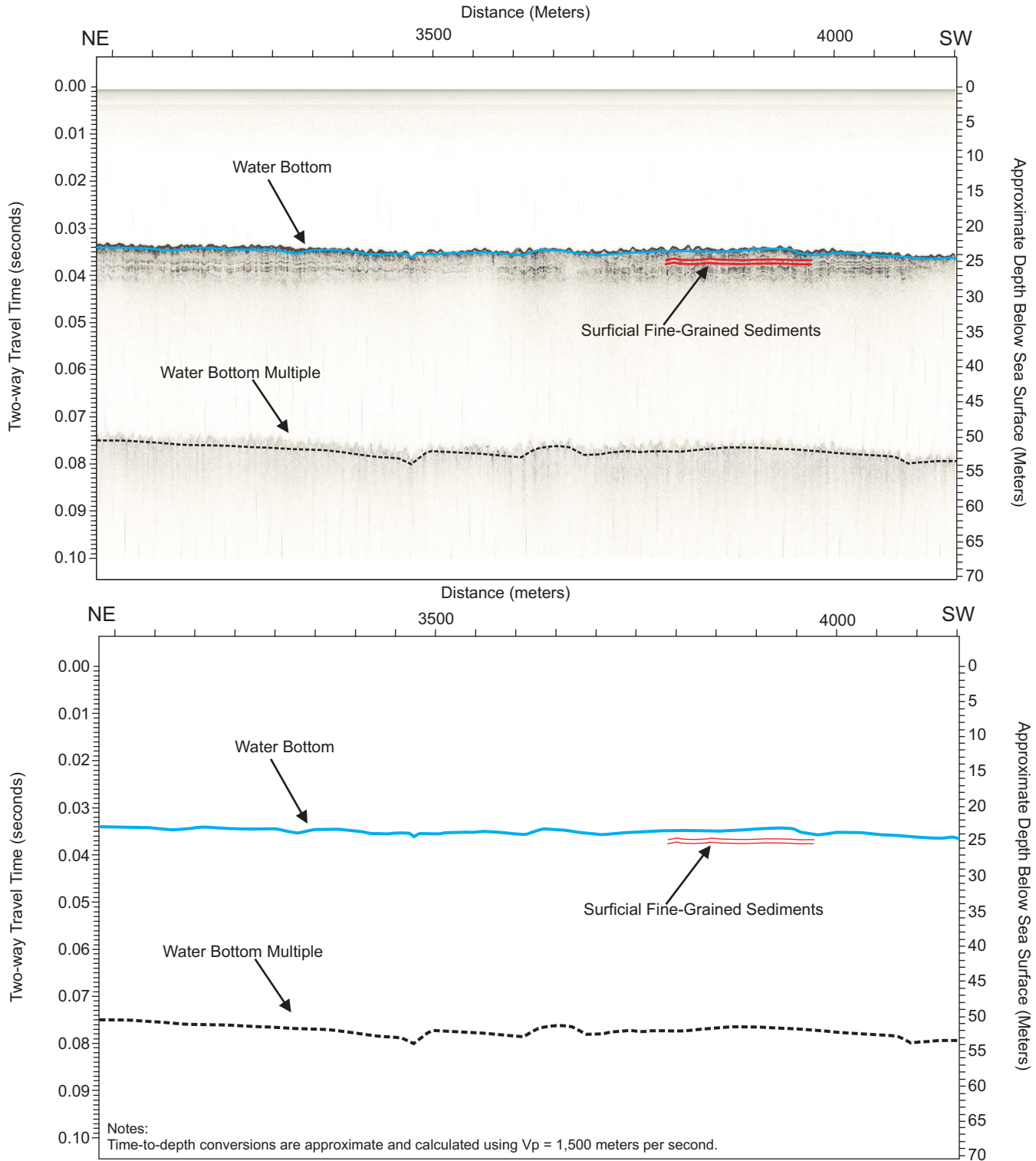
FIGURE 5-1b

N:\Projects\04\_2013\04\_8113\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-5-01b\_Boomer\_Profile\_Locations - Copy.mxd, 1/8/2014, wcupples



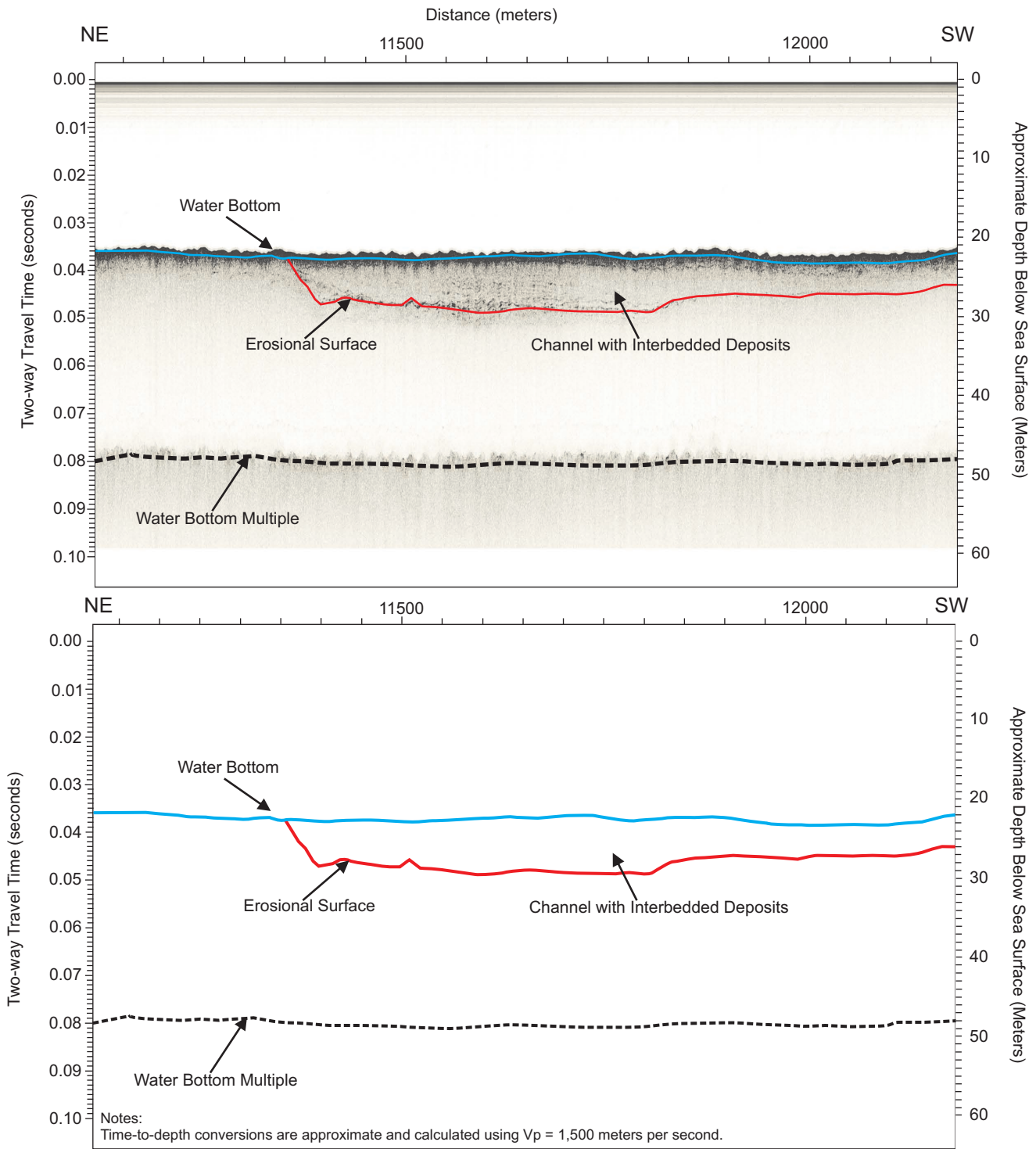
Base of sand ridge (red erosional surface) located along Chirp Line 2201.  
For location see Figure 1-04.

**CHIRP SEISMIC RECORD, LINE 2201**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf



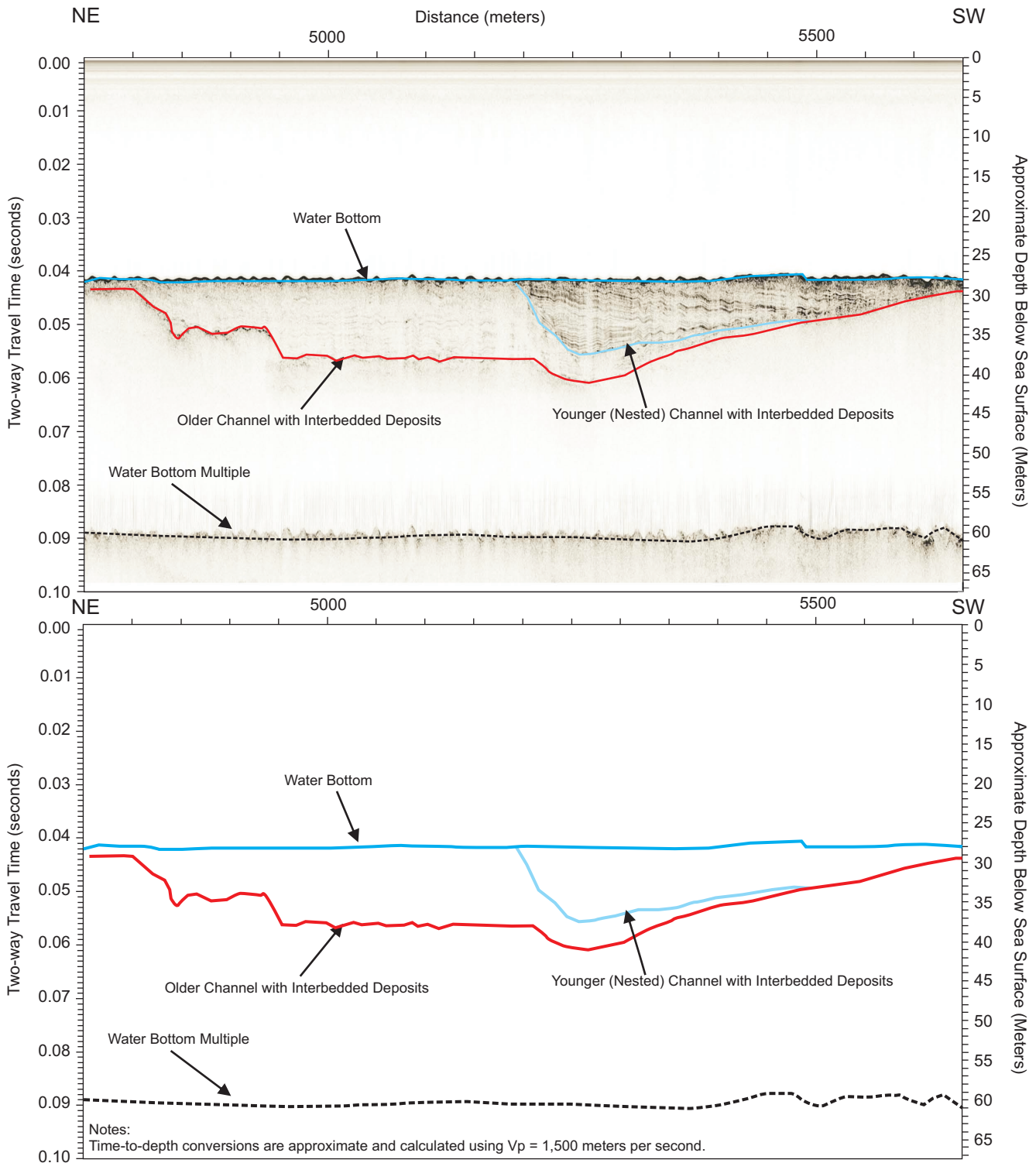
This profile shows surficial fine-grained interbedded sediments along CHIRP Line 1113. For the location of this profile see Figure 1-04.

**CHIRP SEISMIC RECORD, LINE 1113**  
 Virginia Wind Energy Area  
 Geophysical Survey  
 Virginia Outer Continental Shelf



Channel with flat lying interbedded deposits along Chirp Line 109 (SW corner of OCS block 6015). Note that interbedded deposits are not laterally extensive. For the location of this profile see Figure 1-04.

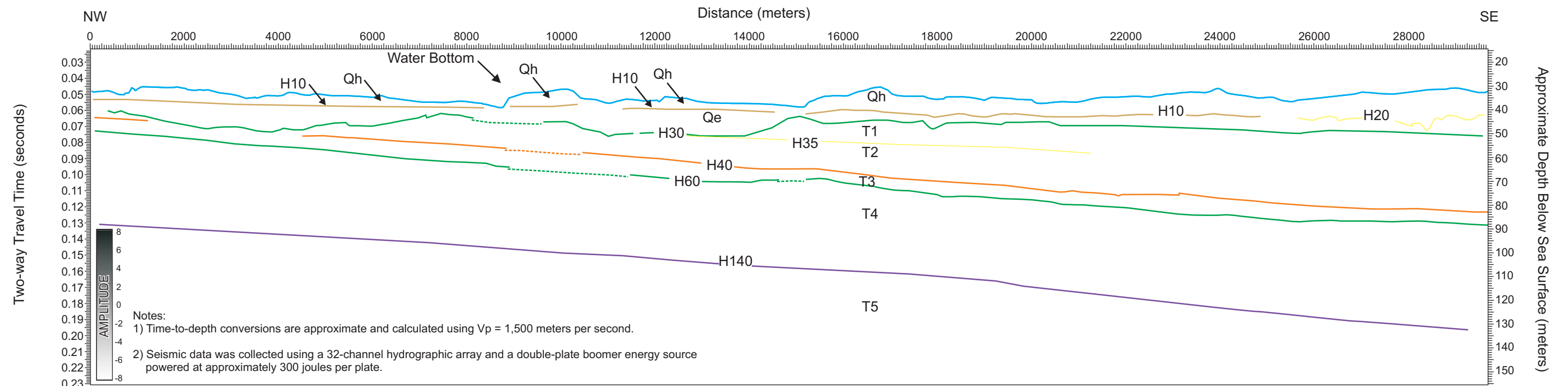
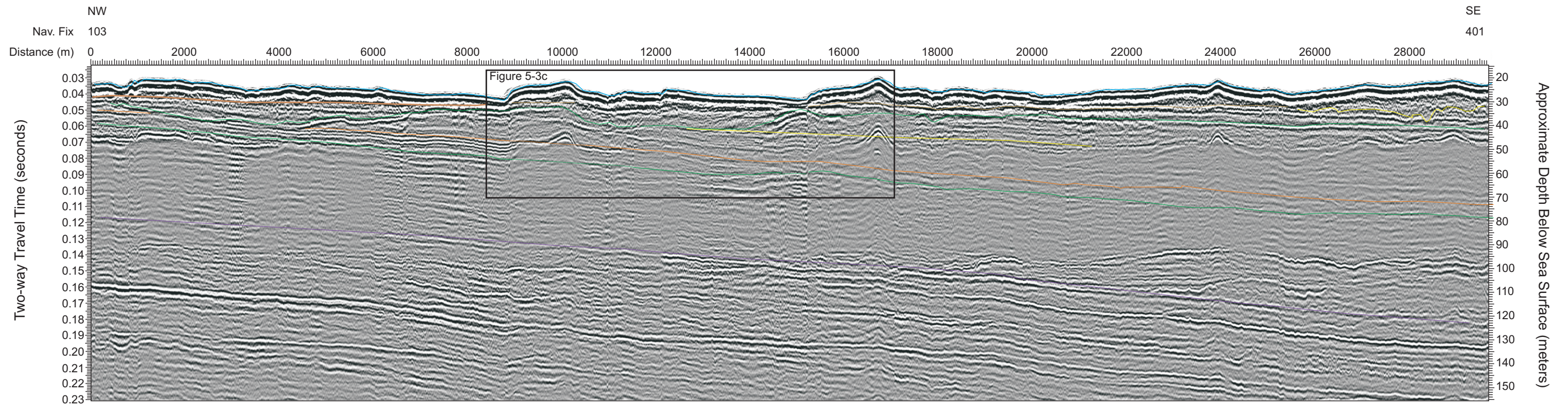
**CHIRP SEISMIC RECORD, LINE 109**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf



Notes:  
Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.

This figure shows a older channel (red) containing interbedded deposits that are essentially flat lying. Inset in the older channel is a younger (nested) channel (light blue) which contains interbedded deposits dipping down to the northeast. For the location of this profile see Figure 1-04.

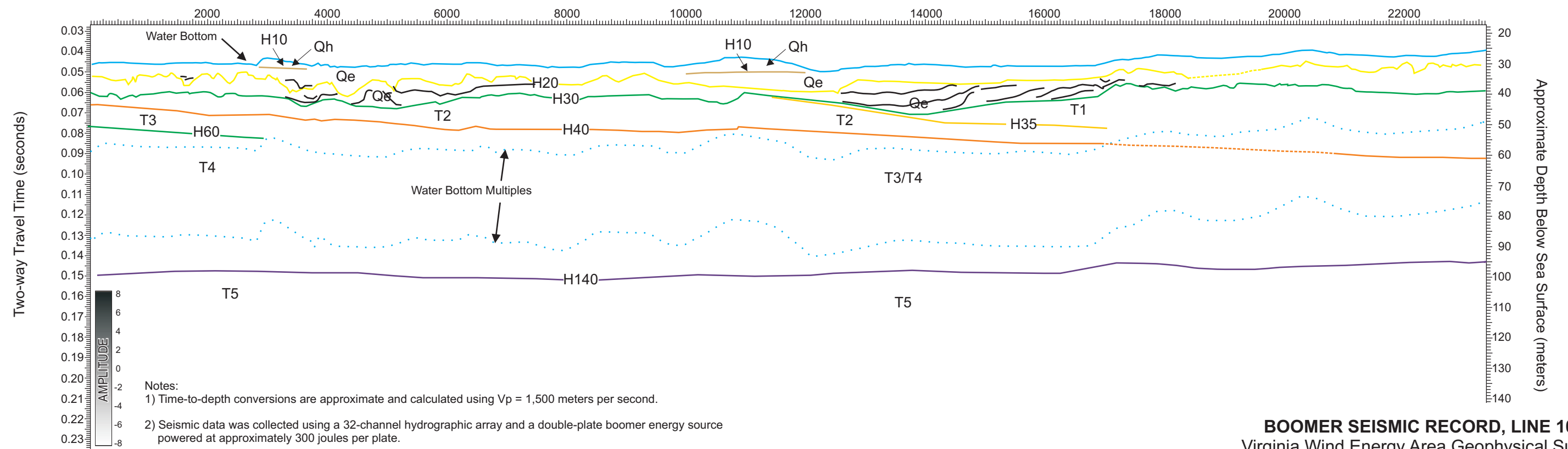
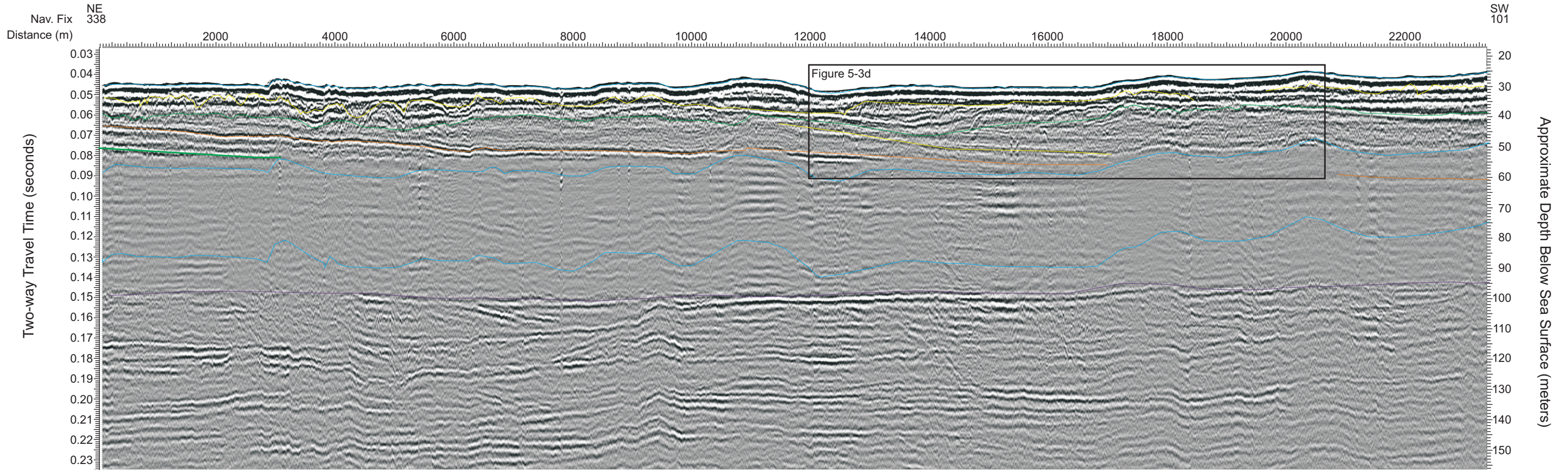
**CHIRP SEISMIC RECORD, LINE 112**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf



Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
 Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
 T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment

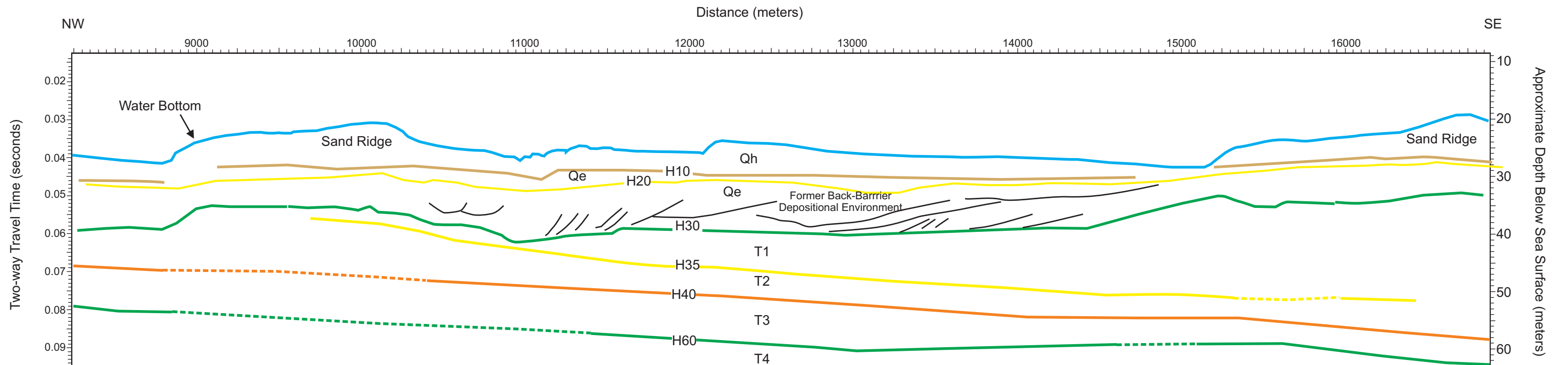
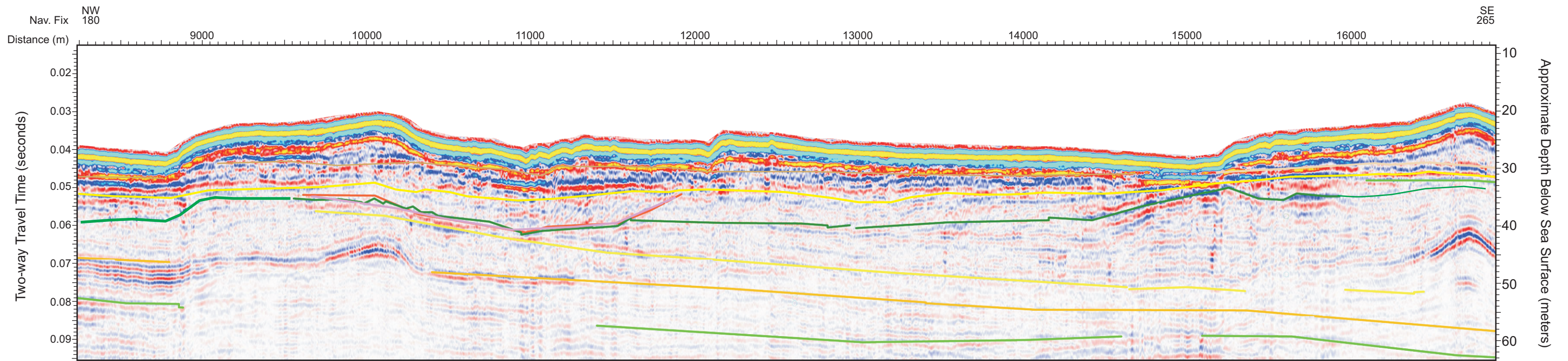
**BOOMER SEISMIC RECORD, LINE 203**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

FIGURE 5-3a



**BOOMER SEISMIC RECORD, LINE 109**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment



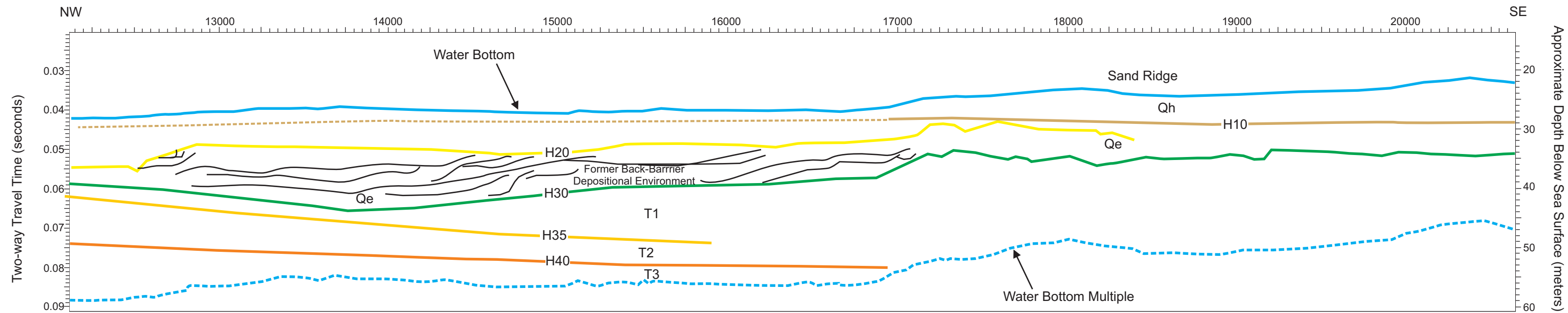
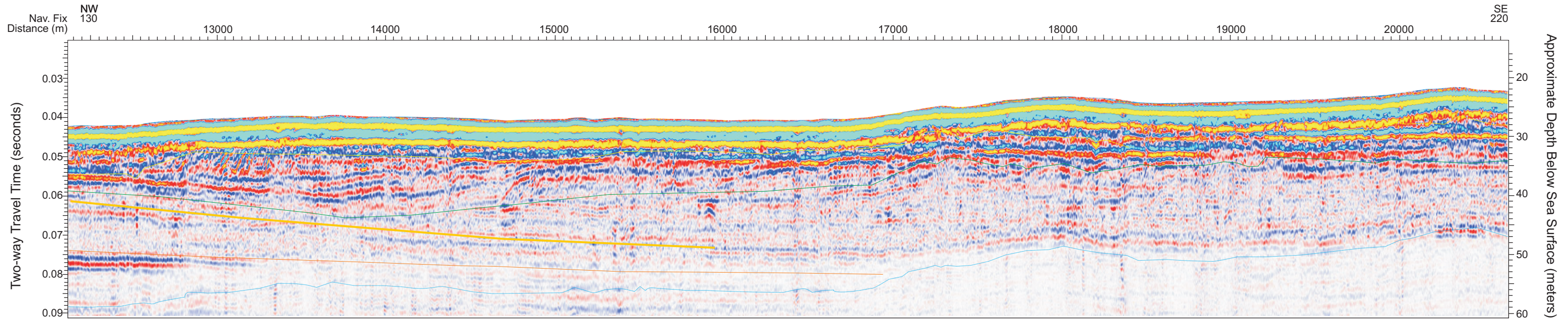
Notes:  
1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.

2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
 Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
 T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment

**BOOMER SEISMIC RECORD, LINE 203 SAND RIDGE**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

FIGURE 5-3c



Notes:  
 1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.  
 2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
 Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
 T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment

**BOOMER SEISMIC RECORD, LINE 109 Sand Ridge**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

FIGURE 5-3d

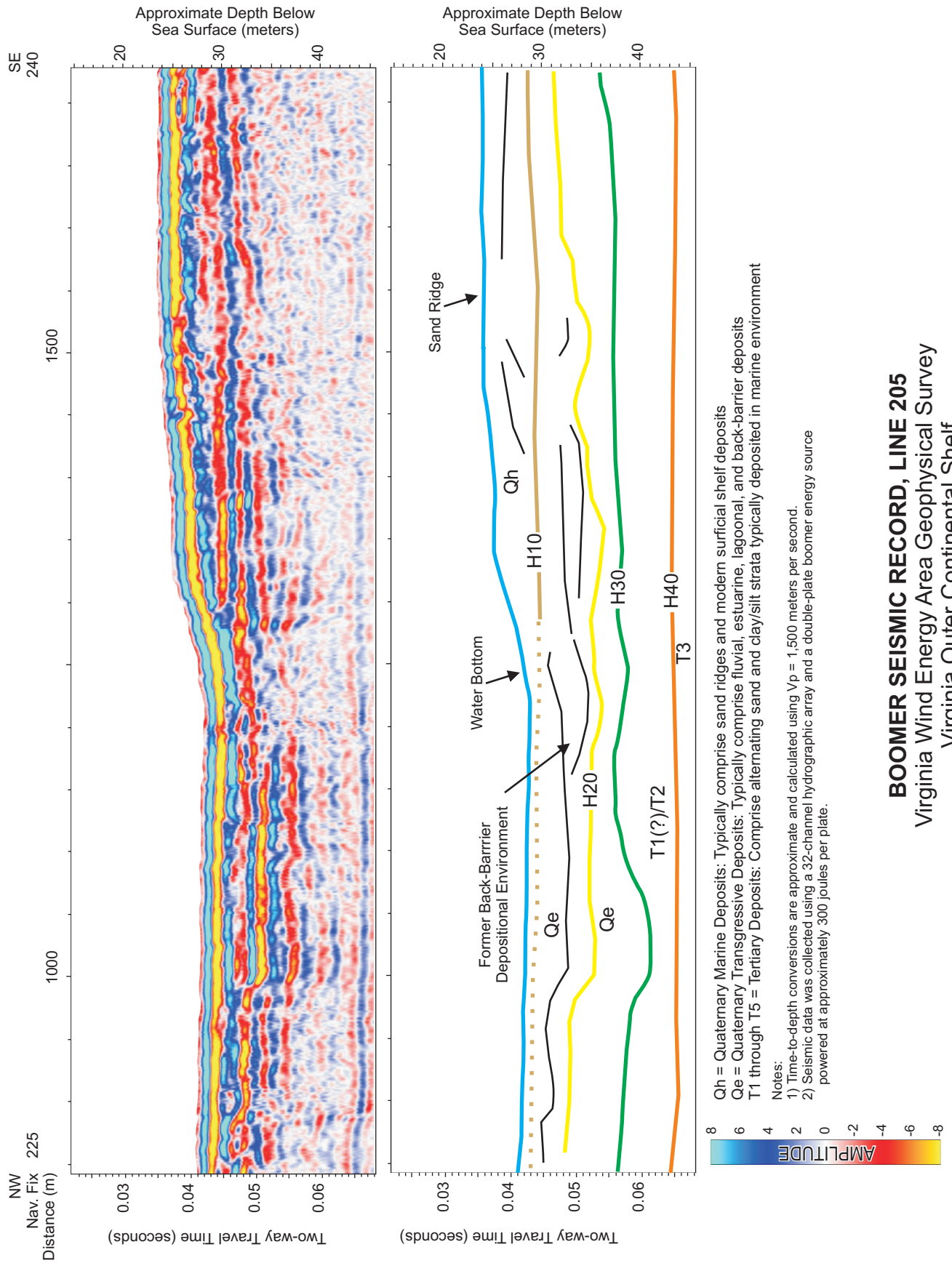
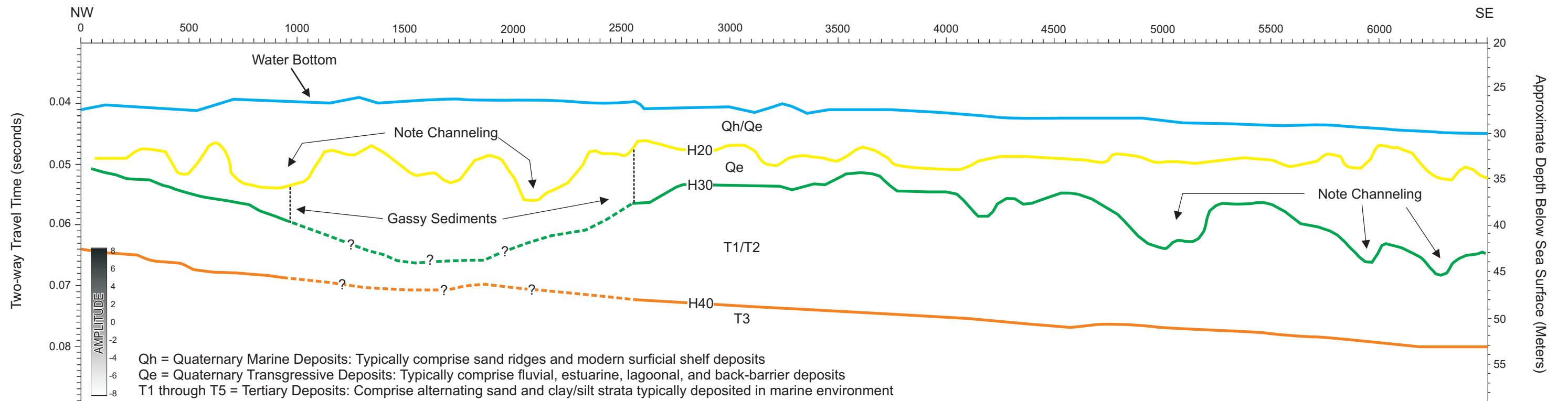
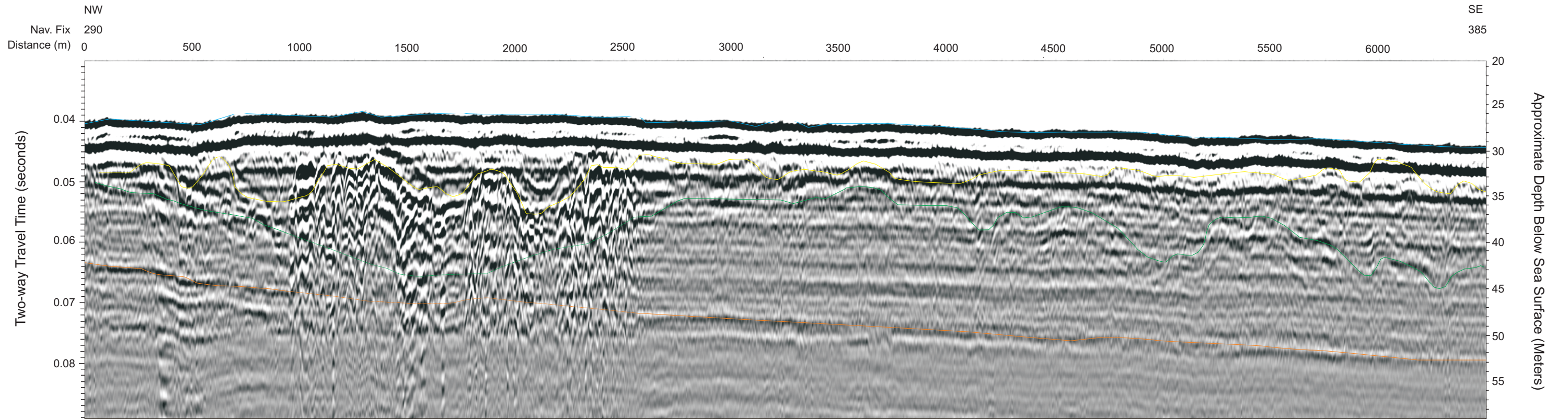


FIGURE 5-3e



- Notes:
- 1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.
  - 2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.
  - 3) Interpreted horizons are dashed where masked by gassy sediments and interpolated across the masked data zone.

**BOOMER SEISMIC RECORD, LINE 207**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

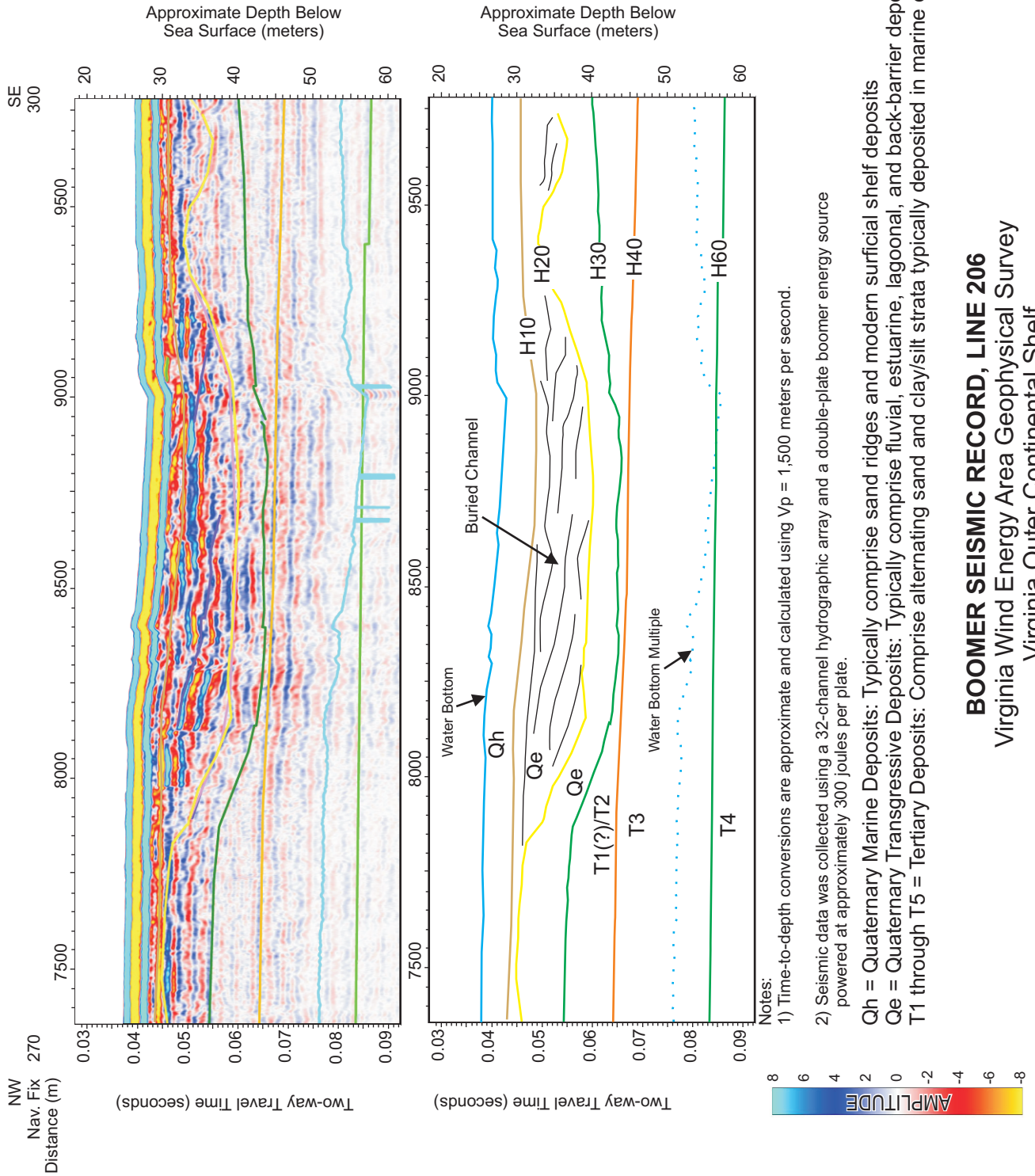
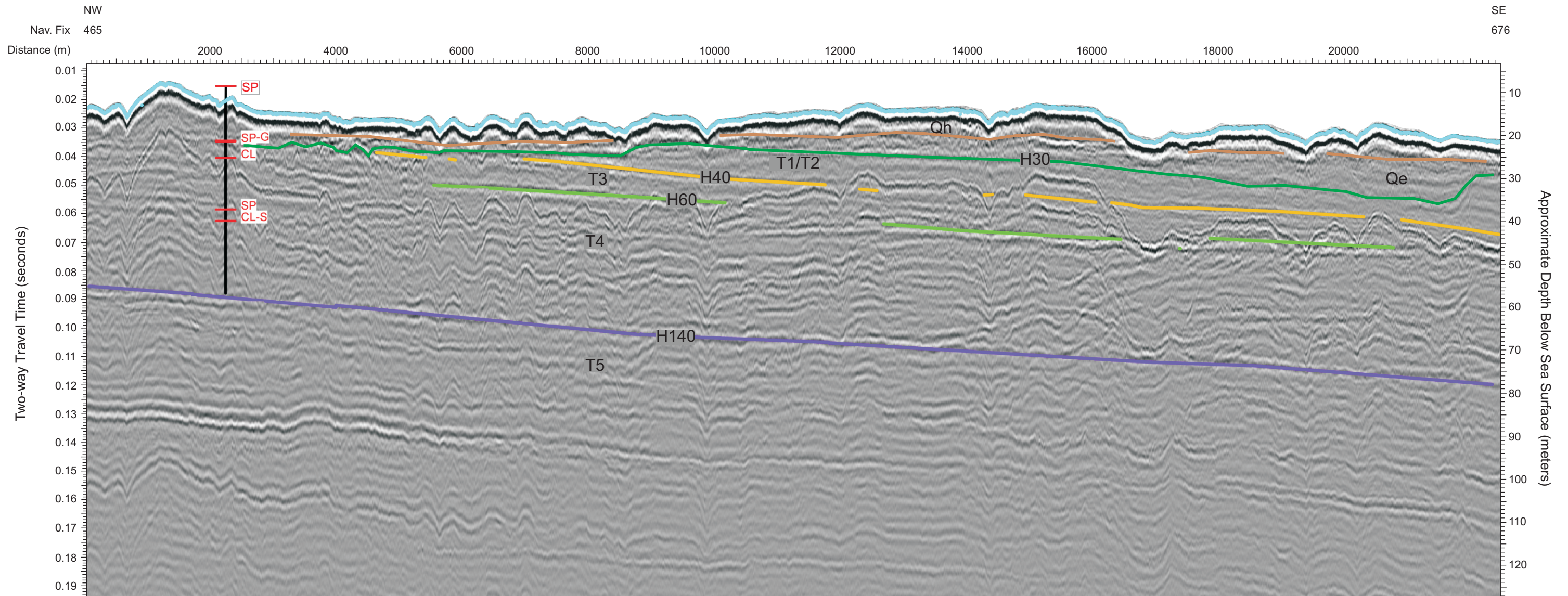


FIGURE 5-3g

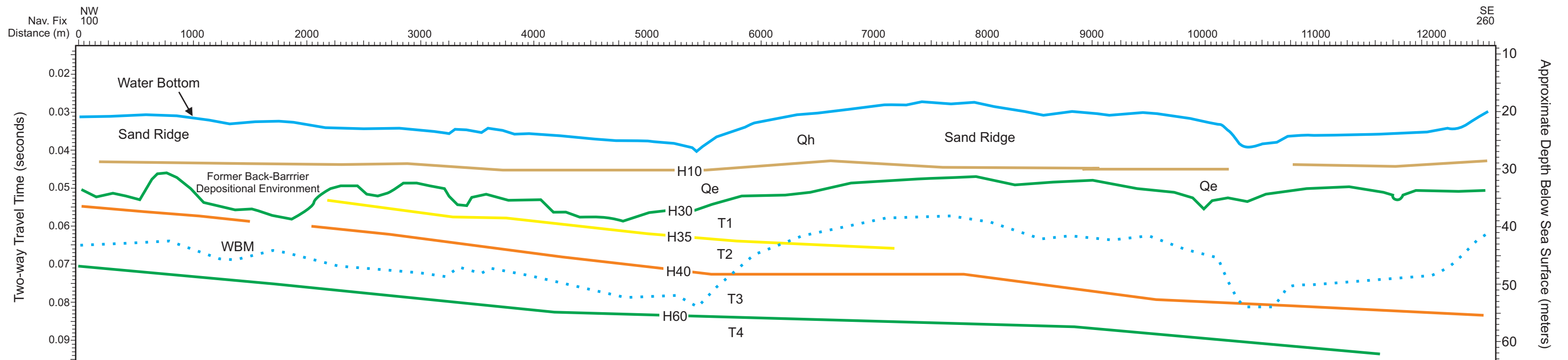
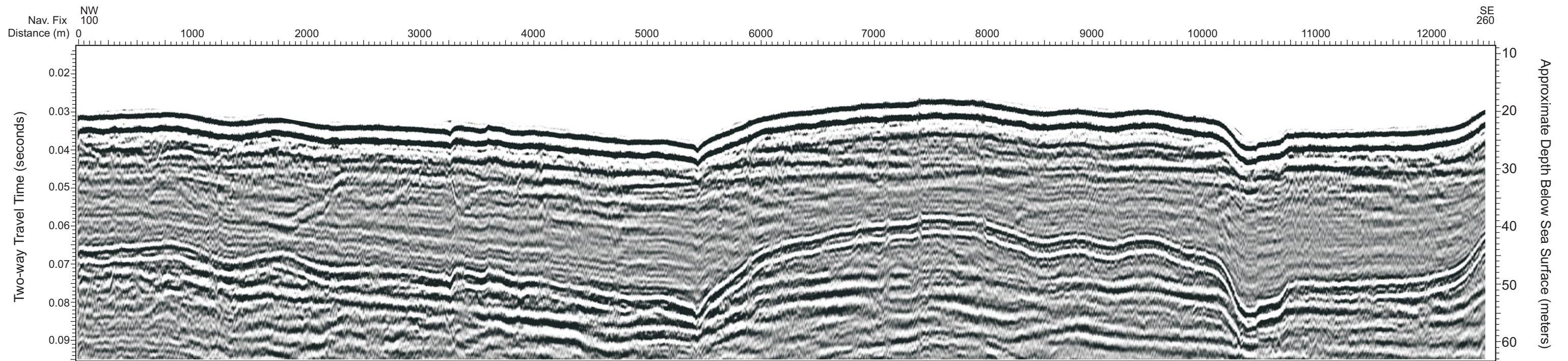


Notes:

- 1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.
- 2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.
- 3) Interpreted horizons are dashed where masked by gassy sediments and interpolated across the masked data zone.

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
 Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
 T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment

**BOOMER SEISMIC RECORD, LINE 500**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



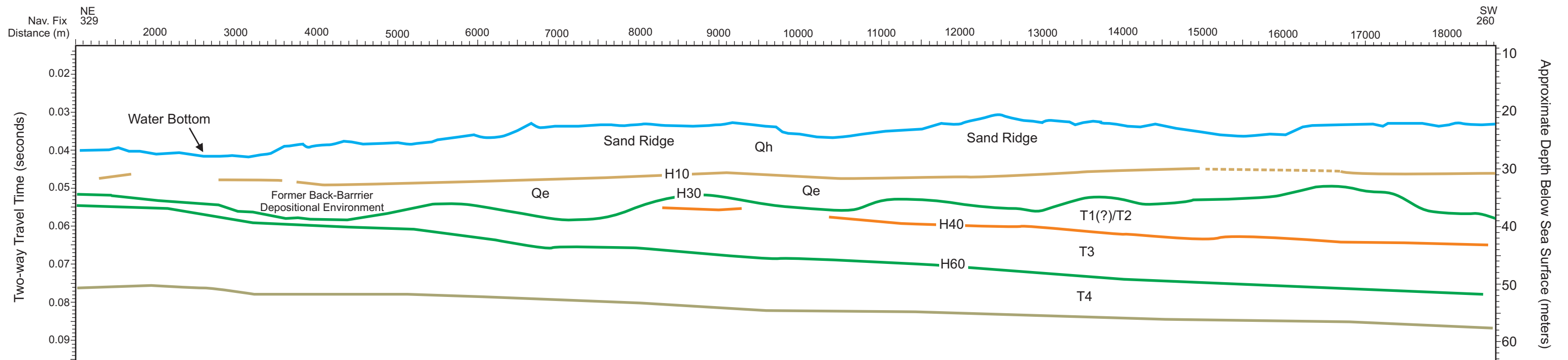
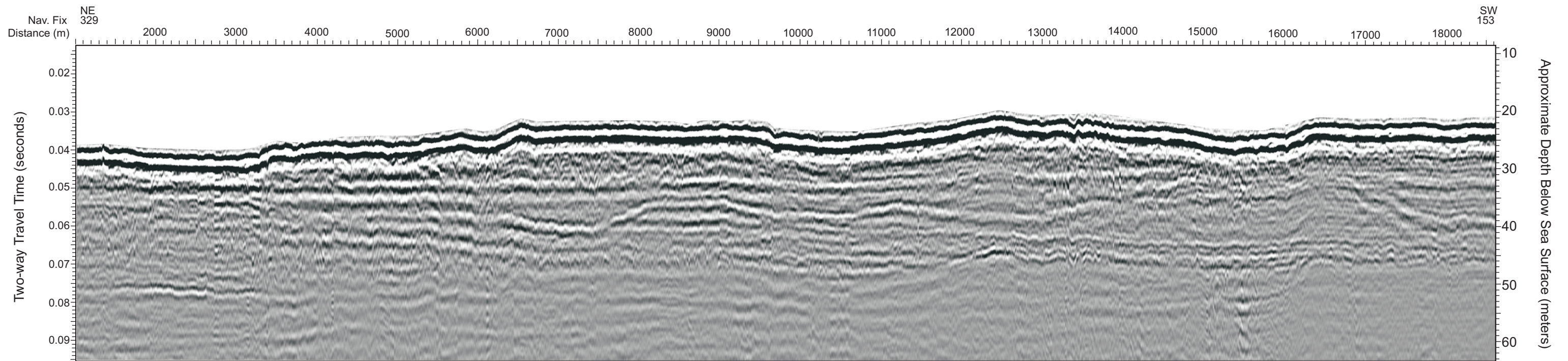
Notes:  
 1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.  
 2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.  
 3) Surface-related multiple suppression (SRMS) was not conducted on this record. Although SRMS was conducted on the data, this record was selected for display because it is judged to provide a better depiction of H40.

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
 Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
 T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment



**BOOMER SEISMIC RECORD, LINE 203**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

FIGURE 5-3i

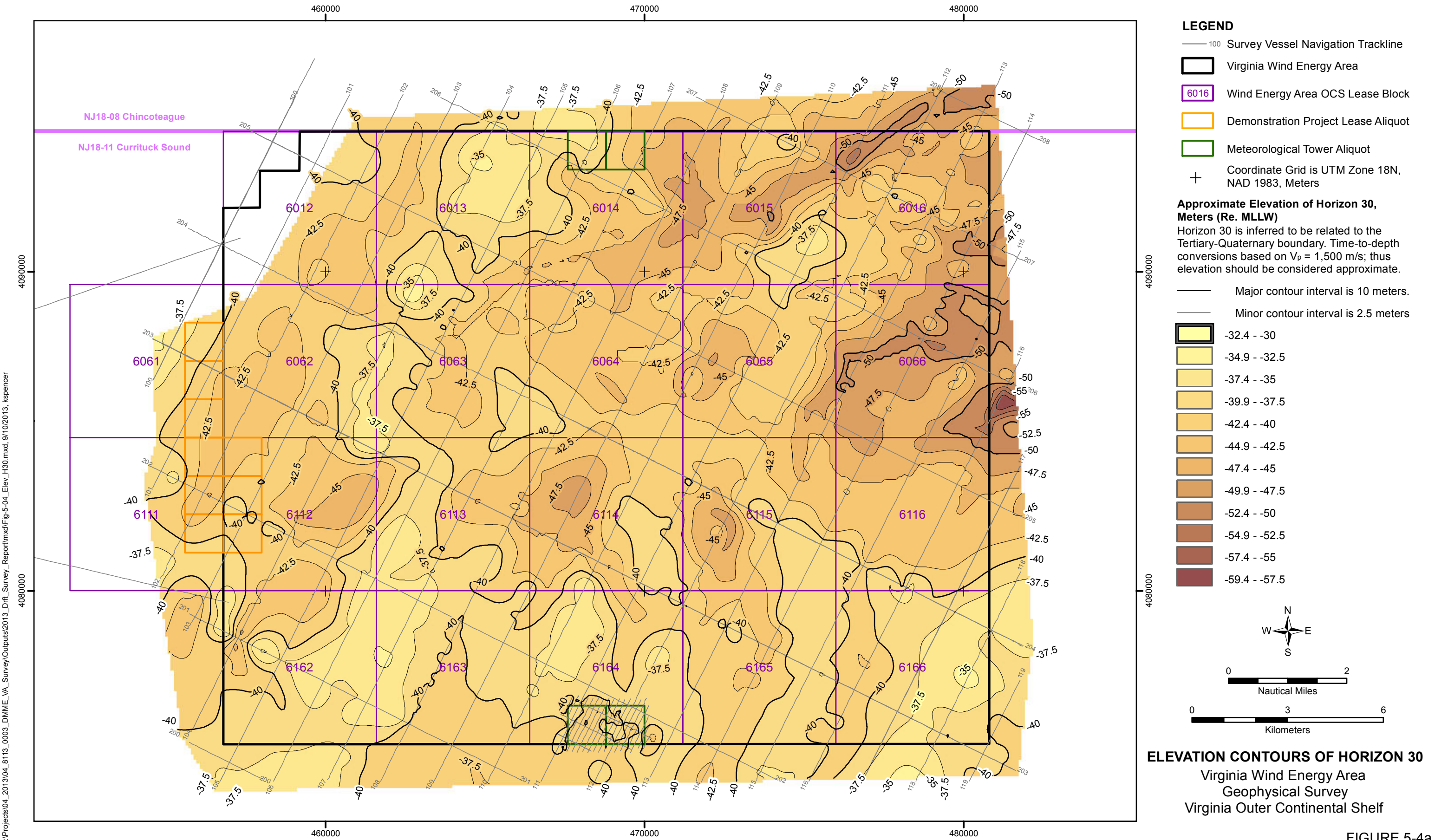


Notes:  
1) Time-to-depth conversions are approximate and calculated using  $V_p = 1,500$  meters per second.  
2) Seismic data was collected using a 32-channel hydrographic array and a double-plate boomer energy source powered at approximately 300 joules per plate.

Qh = Quaternary Marine Deposits: Typically comprise sand ridges and modern surficial shelf deposits  
Qe = Quaternary Transgressive Deposits: Typically comprise fluvial, estuarine, lagoonal, and back-barrier deposits  
T1 through T5 = Tertiary Deposits: Comprise alternating sand and clay/silt strata typically deposited in marine environment

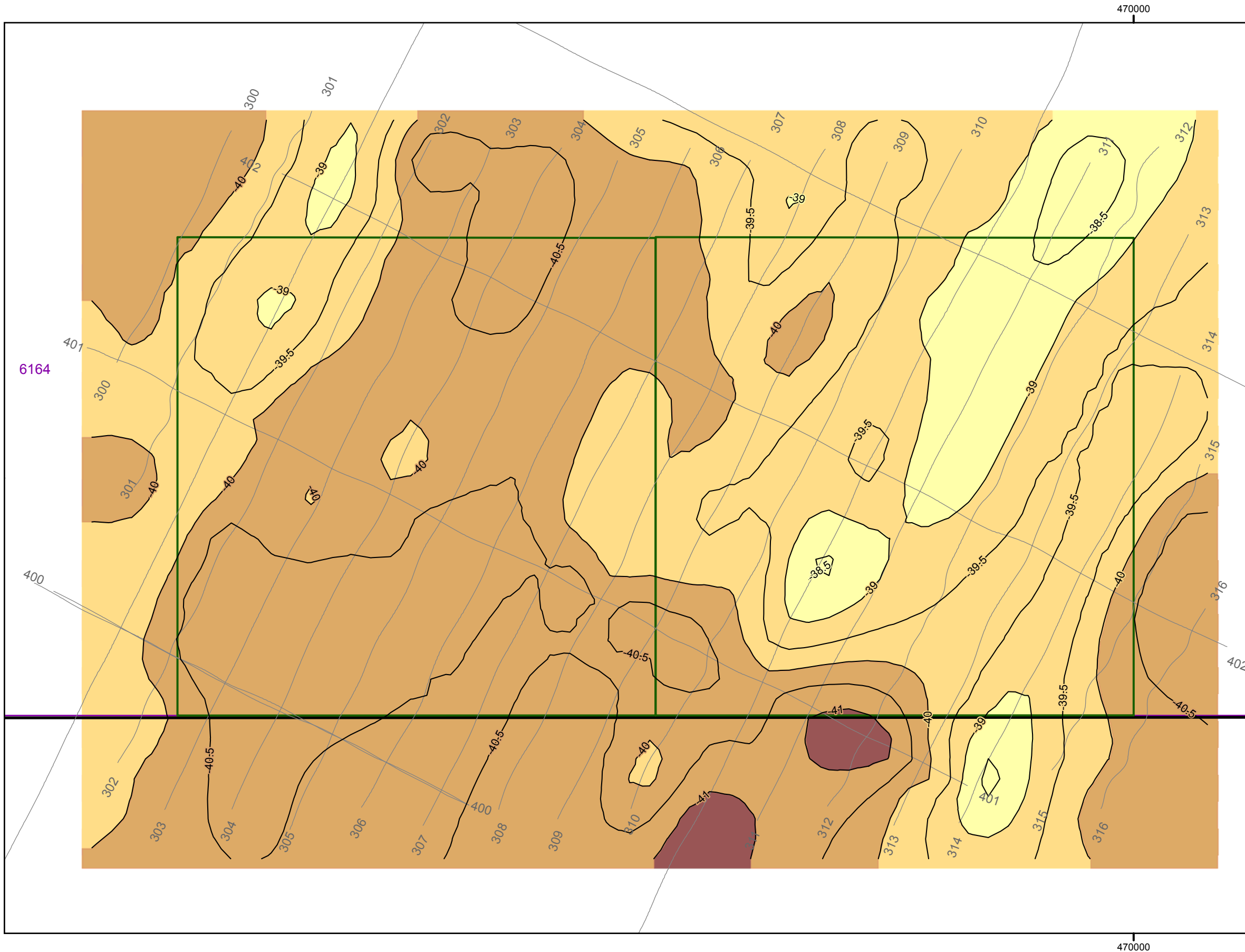
**BOOMER SEISMIC RECORD, LINE 103**  
Virginia Wind Energy Area Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 5-3j



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_SurveyOutputs\2013\_Drift\_Survey\_Report\mxd\Fig-5-04\_Elev\_H30.mxd, 9/10/2013, kspencer

FIGURE 5-4a



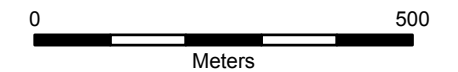
**LEGEND**

- 300 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6164 Wind Energy Area OCS Lease Block
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

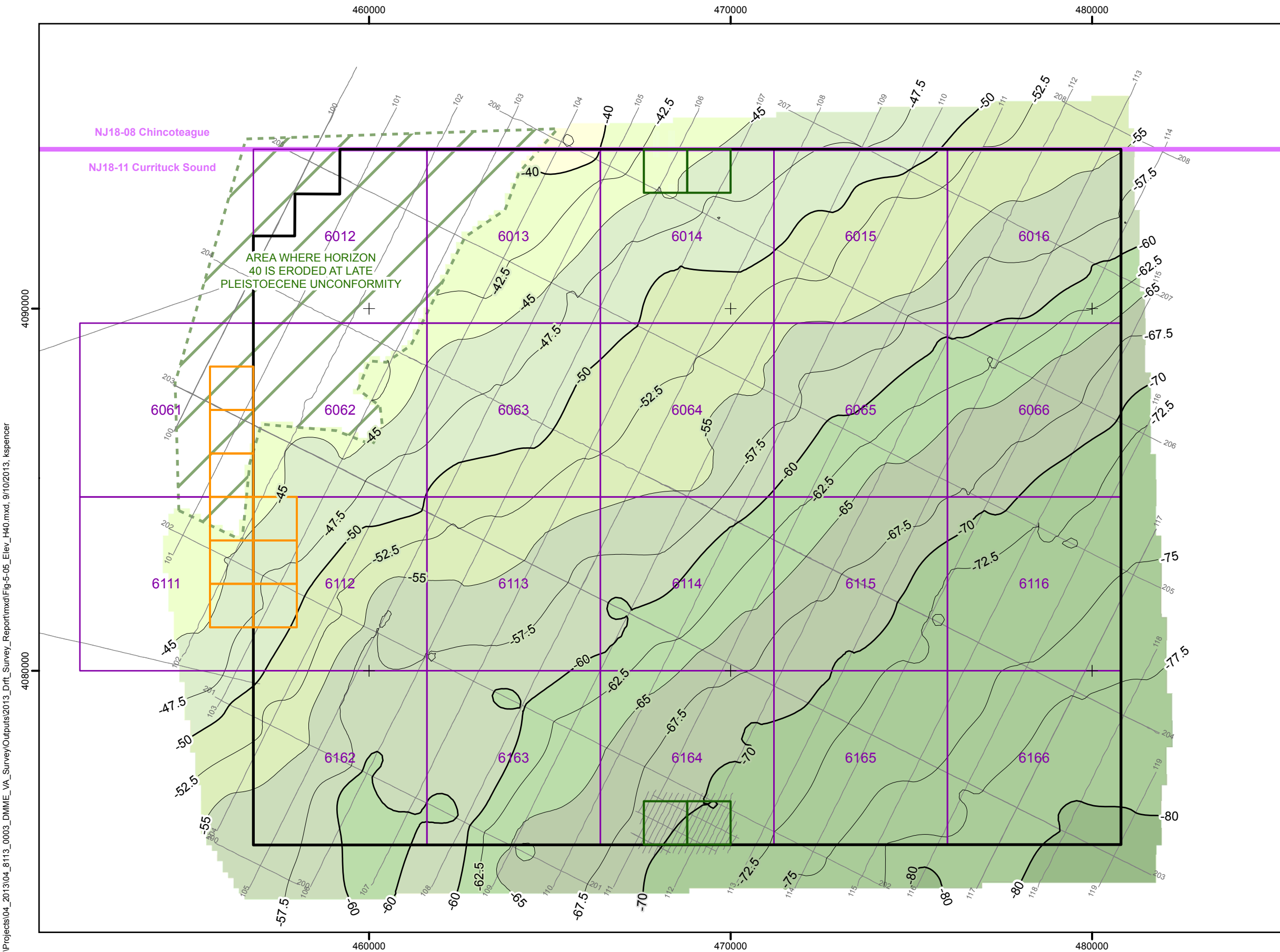
**Approximate Elevation of Horizon 30, Meters (Re. MLLW)**

Horizon 30 is inferred to be related to the Tertiary-Quaternary boundary. Time-to-depth conversions based on  $V_p = 1,500$  m/s; thus elevation should be considered approximate.

- Contour interval is 0.5 meters.
- 38.9 - -38
- 39.9 - -39
- 40.9 - -40
- 41.3 - -41



**ELEVATION CONTOURS OF HORIZON 30**  
**Meteorological Tower Aliquots**  
 Virginia Wind Energy Area  
 Geophysical Survey  
 Virginia Outer Continental Shelf

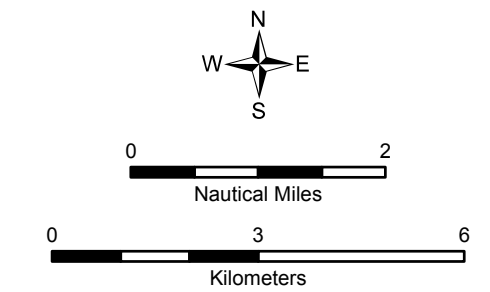


**LEGEND**

- 100 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

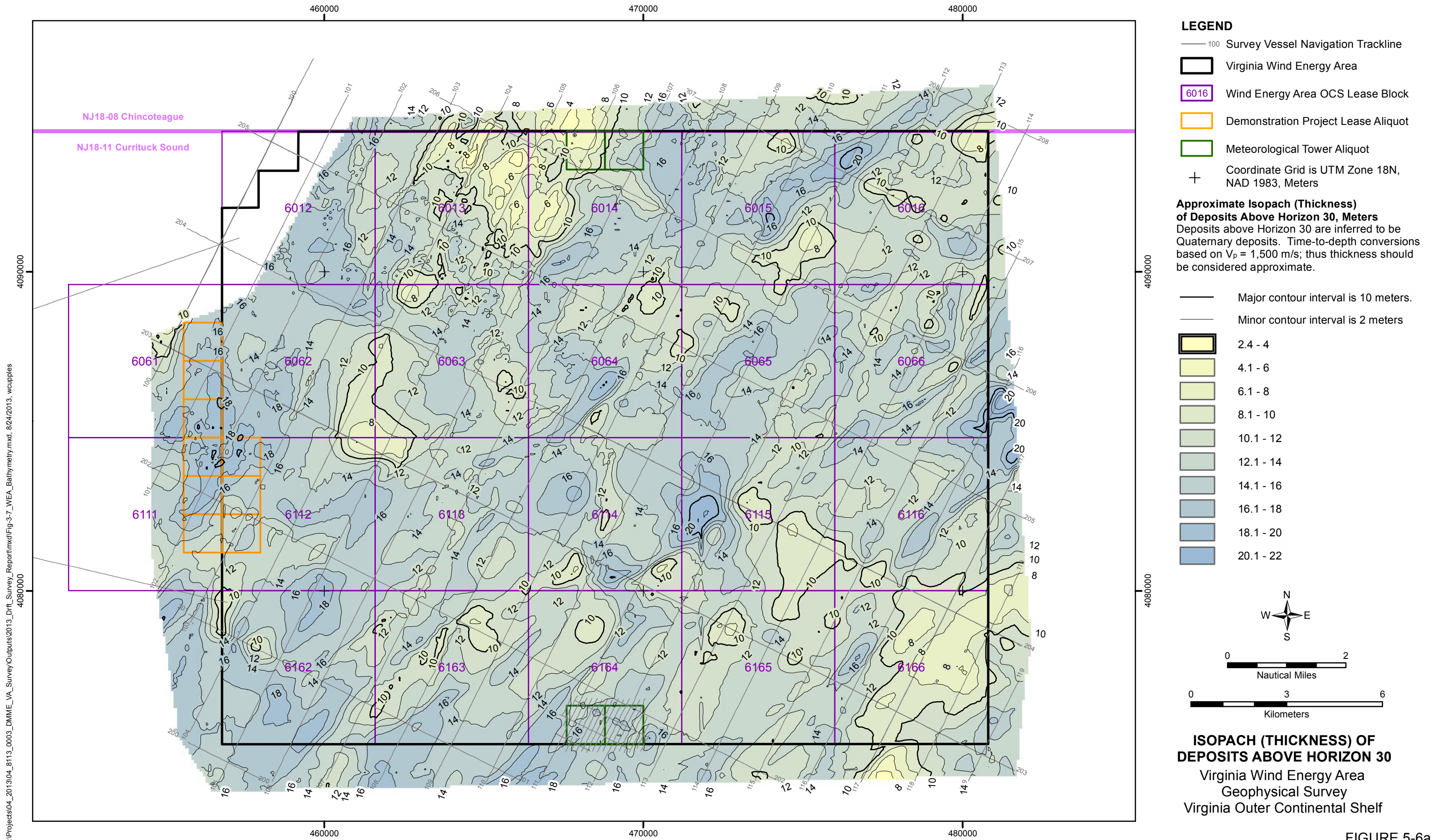
**Approximate Elevation of Horizon 40, Meters (Re. MLLW)**  
Horizon 40 is inferred to be related to a Tertiary strata. Time-to-depth conversions based on  $V_p = 1,500$  m/s; thus elevation should be considered approximate.

- Major contour interval is 10 meters.
- Minor contour interval is 2.5 meters
- 39.9 - -35
- 44.9 - -40
- 49.9 - -45
- 54.9 - -50
- 59.9 - -55
- 64.9 - -60
- 69.9 - -65
- 74.9 - -70
- 79.9 - -75
- 82.5 - -80



**ELEVATION CONTOURS OF HORIZON 40**  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

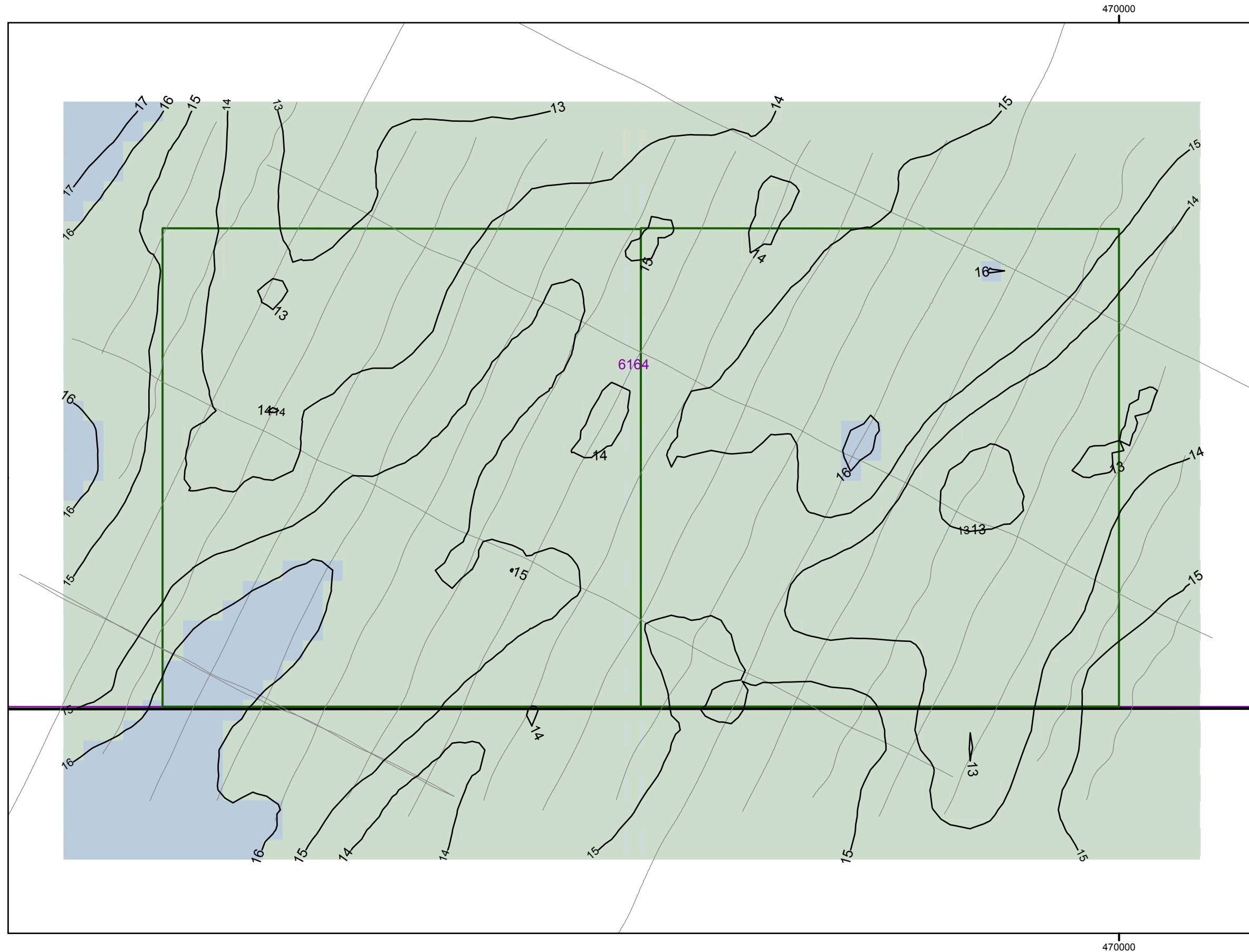
FIGURE 5-5



N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\Fig-3-7\_WEA\_Bathymetry.mxd, 8/24/2013, wcupples

FIGURE 5-6a

N:\Projects\04\_2013\04\_8113\_0003\_DMME\_VA\_Survey\Outputs\2013\_Drift\_Survey\_Report\mxd\Fig-3-7\_WEA\_Bathymetry.mxd, 8/24/2013, wcupplies



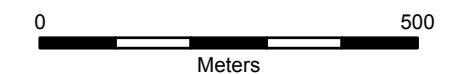
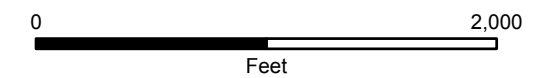
**LEGEND**

- 100 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot
- Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

**Approximate Isopach (Thickness) of Deposits Above Horizon 30, Meters**  
Deposits above Horizon 30 are inferred to be Quaternary deposits. Time-to-depth conversions based on  $V_p = 1,500$  m/s; thus thickness should be considered approximate.

Major contour interval is 1 meter.

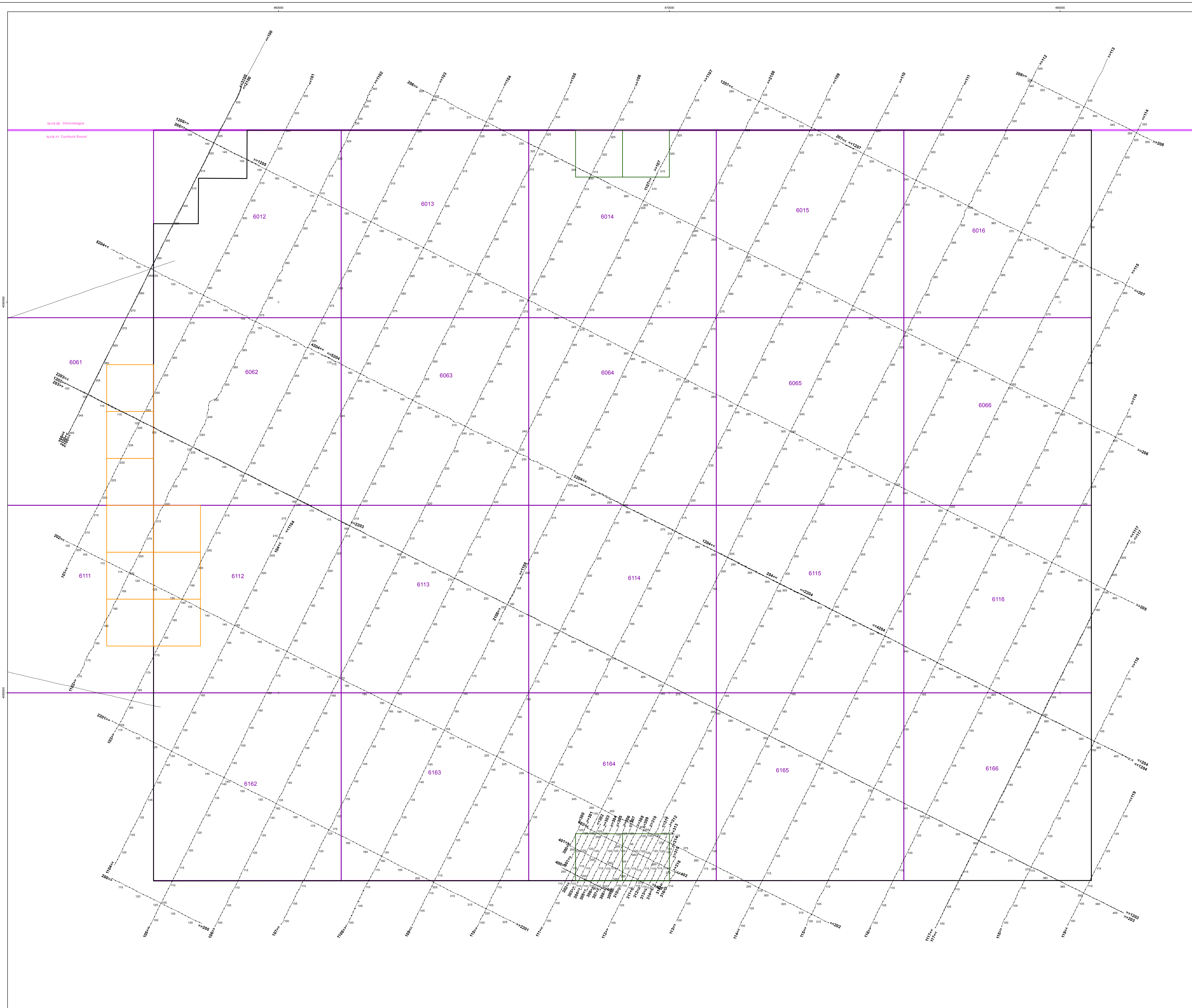
- 5.7 - 6
- 6.1 - 8
- 8.1 - 10
- 10.1 - 12
- 12.1 - 14
- 14.1 - 16
- 16.1 - 18
- 18.1 - 20
- 20.1 - 22



**ISOPACH (THICKNESS) OF DEPOSITS ABOVE HORIZON 30 (QUATERNARY DEPOSITS)**  
Meteorological Tower Aliquots  
Virginia Wind Energy Area  
Geophysical Survey  
Virginia Outer Continental Shelf

FIGURE 5-6b

## CHARTS



**LEGEND**

**Survey Vessel Navigation Trackline**  
 Survey line number in bold  
 Navigation event mark number  
 Arrows on line indicate direction of vessel travel.

Virginia Wind Energy Area  
 Wind Energy Area OCS Lease Block  
 Demonstration Project Lease Area  
 Meteorological Tower Alquot

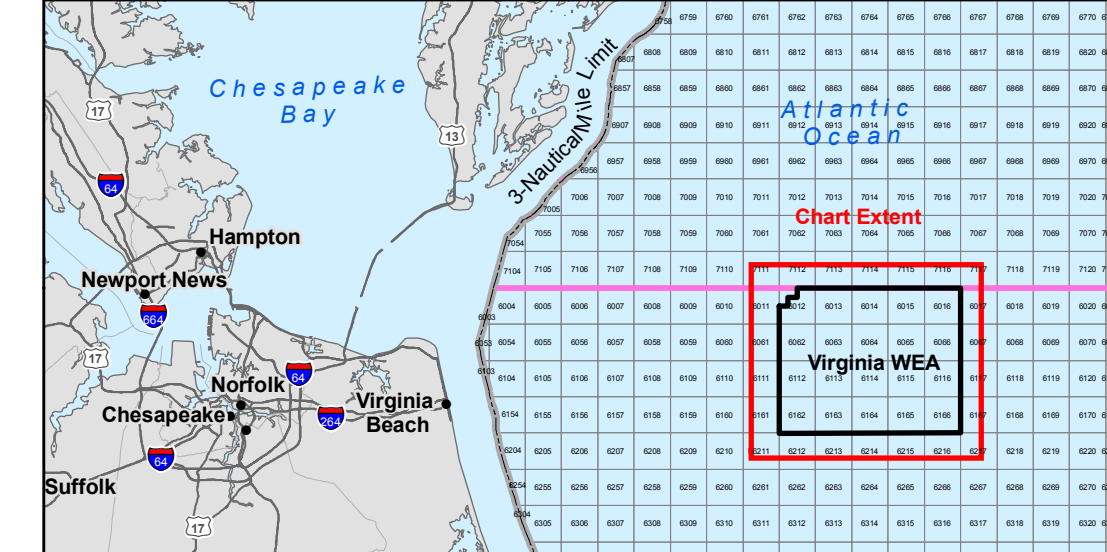
- Notes:
- Fugro marine survey data were collected from May 28 through July 3, 2013 onboard the TAI XIV.
  - Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starix II wide area differential network, downloaded from a communications satellite.
  - Survey equipment utilized for data collection included the following systems:  
 - IBC Sonic 2004 Multibeam Echosounder  
 - Applanis POS MV Vessel Motion and Attitude Recording System  
 - EdgeTech Model 4200 Side Scan Sonar System  
 - Sonotek Marine Side Scan Sonar Data Acquisition System  
 - Marine Magnetic Corporation SeaSway Magnetometer  
 - EdgeTech 2000 Serial Directional Sub-bottom Profiler (CHIP) System  
 - EdgeTech Discovery Sub-bottom Profiler Data Acquisition System  
 - Applied Acoustic Equipment (AAE) Seismic Energy Source and Subsea System's Double-pulse "Boomer" System  
 - Geotek 50 Channel Hydrophone Array Streamer (Channels 1-16 at 1.5m and Channels 17-32 at 3.125m)  
 - Blue Ocean Mapping Sound Velocity Profiler  
 - Coastal Oceanographics "Hyack" Navigation System  
 - Starix Data Navigation

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**GEODETTIC INFORMATION**

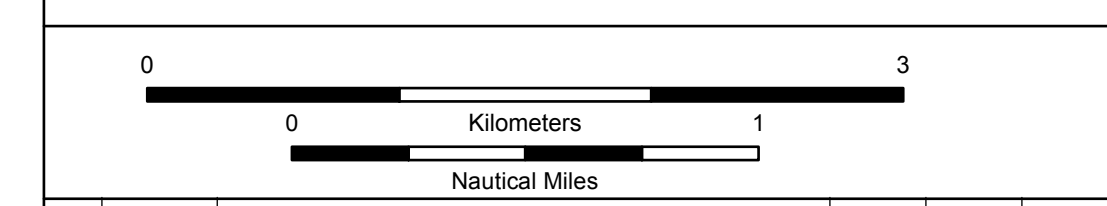
SPHEROID: GRS 80  
 SEMI-MAJOR AXIS: 6378137.000  
 SEMI-MINOR AXIS: 6356752.314  
 INVERSE FLATTENING: 298.25722101  
 ECCENTRICITY: 0.08181875  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18N  
 UNIT: Meter  
 FALSE EASTING: 500000  
 FALSE NORTHING: 0

Coordinate Grid is UTM Zone 18N, NAD 83, Meter

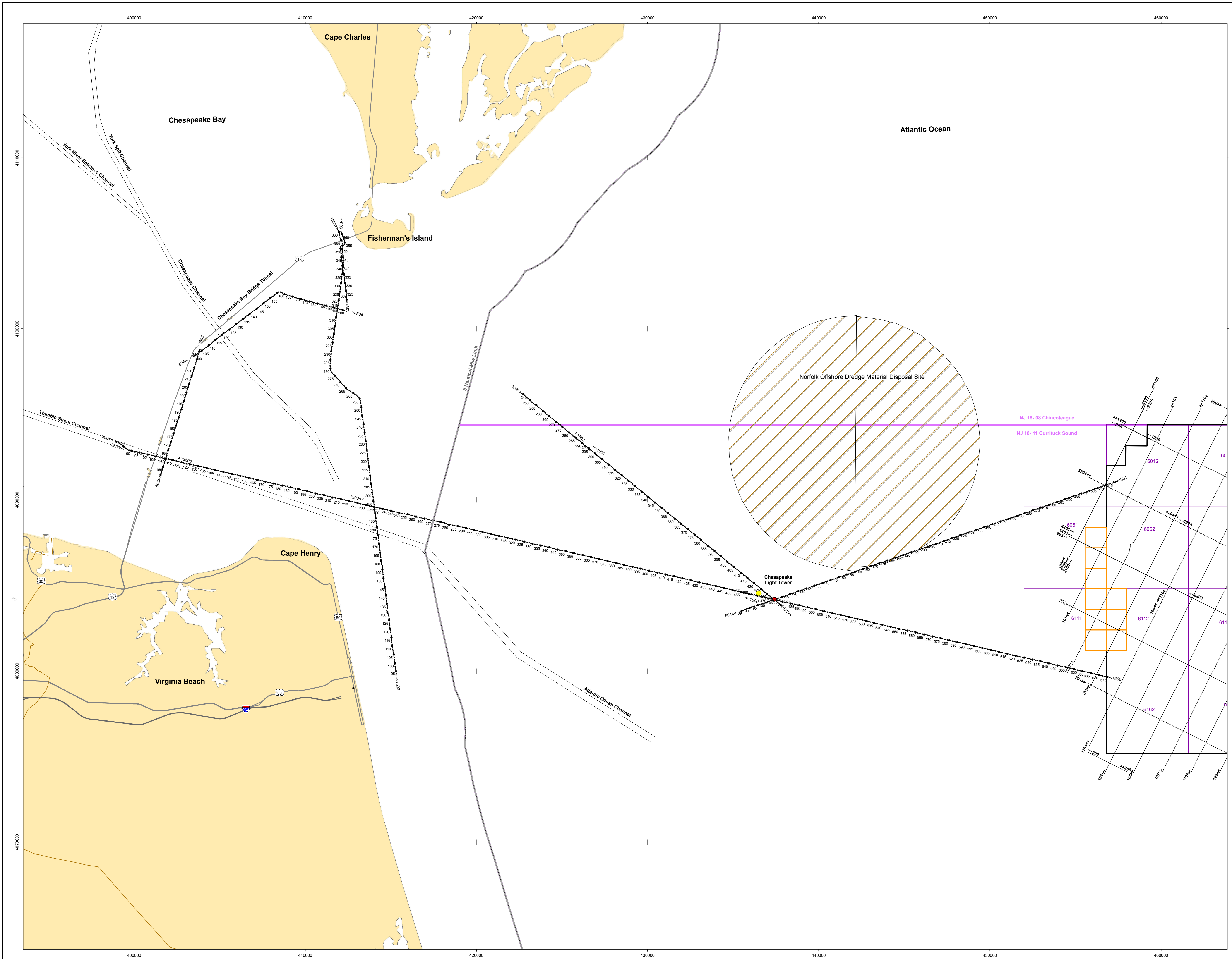


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**SURVEY VESSEL TRACKLINES**  
**Wind Energy Area**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHECK	APPR.
1	Sept 2013	Survey Report	AEB	KCS	KRS
2					
3					



**LEGEND**

**Survey Vessel Navigation Trackline**  
 Survey line number in bold.  
 Navigation event mark number.  
 Arrows on line indicate direction of vessel travel.

- Chesapeake Light Tower
- Fugro Borehole Exploration (1963)
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Area
- Meteorological Tower Aliquot

**Notes:**

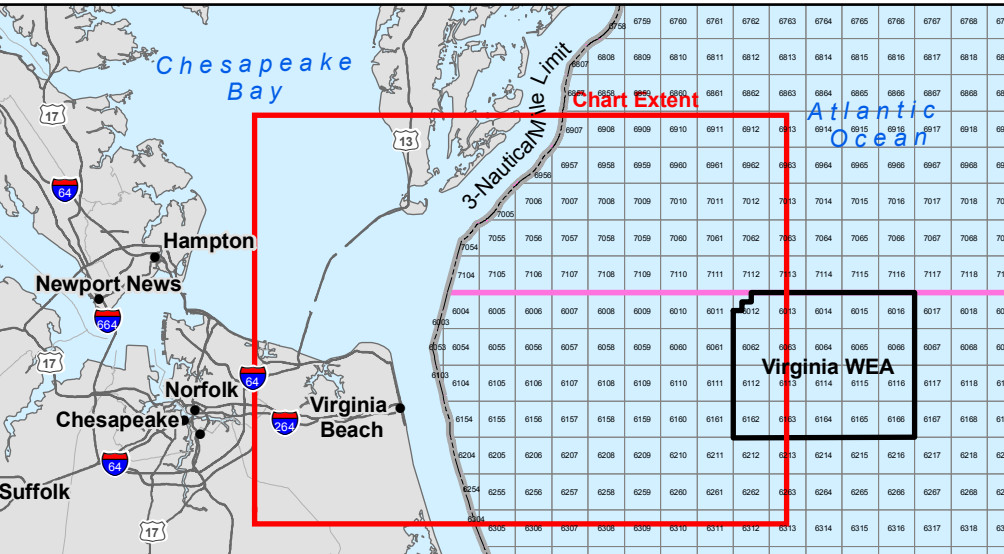
- Fugro marine survey data were collected from May 28 through July 3, 2013 onboard the Tiki XIV.
- Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starfix II wide area differential network, downloaded from a communications satellite.
- Survey equipment utilized for data collection included the following systems:
  - R2 Sonic 2024 Multibeam Echosounder
  - Applanix POS MV Vessel Motion and Attitude Recording System
  - Edgetech Model 4125 Side Scan Sonar System
  - SparNav Map Side Scan Sonar Data Acquisition System
  - Marine Magnetic Corporation SeaSpy Magnetometer
  - Edgetech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) System
  - Edgetech Discovery Sub-bottom Profiler Data Acquisition System
  - Applied Acoustic Engineers CSP Seismic Energy Source and Subsea System's Double-plate "Boomer" System
  - GeoEast 12-channel Hydrophone Array Streamer (Channels 1-16 at 1.56mgi and Channels 17-32 at 3.125mgi)
  - Blue Ocean Moving Sound Velocity Profiler
  - Coastal Oceanographics "Hyack" Navigation System
  - Starfix Seis Navigation

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**GEOIDIC INFORMATION**

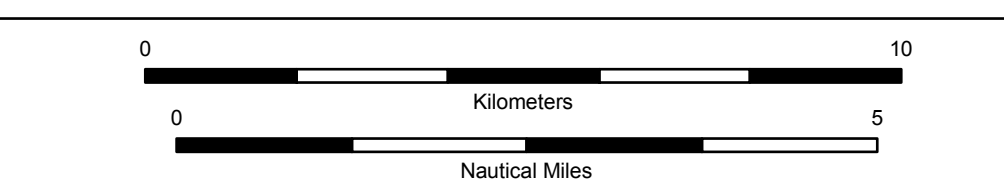
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 SEMI-MINOR AXIS: 6,356,752.314  
 INVERSE FLATTENING: 298.2572101  
 ECCENTRICITY: 0.00694380  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0

Coordinate Grid is UTM Zone 18N, NAD 1983, Meters



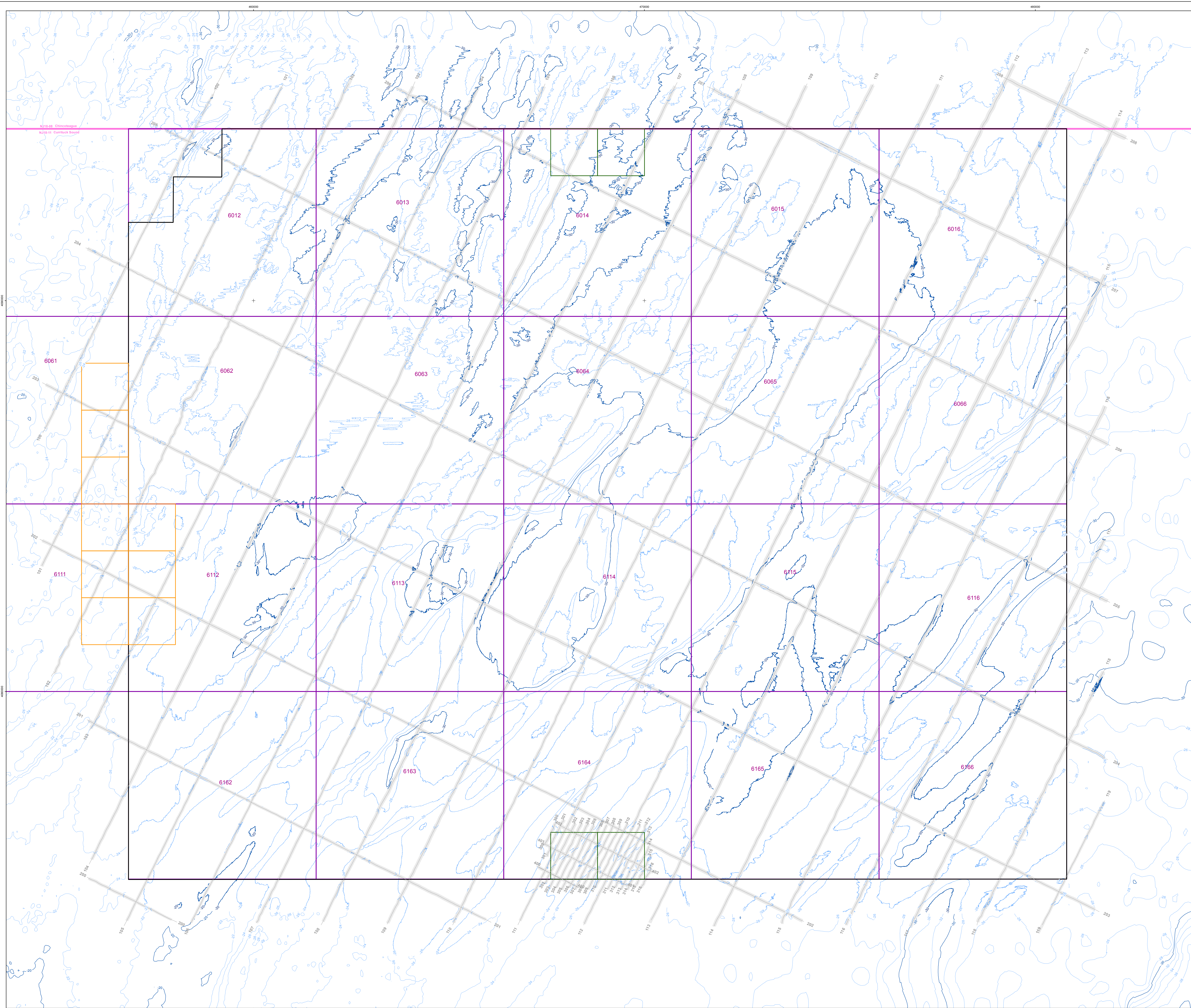
**FUGRO CONSULTANTS, INC.**  
 World Trade Center, Suite 350  
 101 West Main Street  
 Norfolk, Virginia 23510  
 Tel: (757) 625-3350  
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**SURVEY VESSEL TRACKLINES**  
**Regional Tracklines**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR
1	Sept. 2013	Survey Report	AEB	KCS	KRS
2					
3					

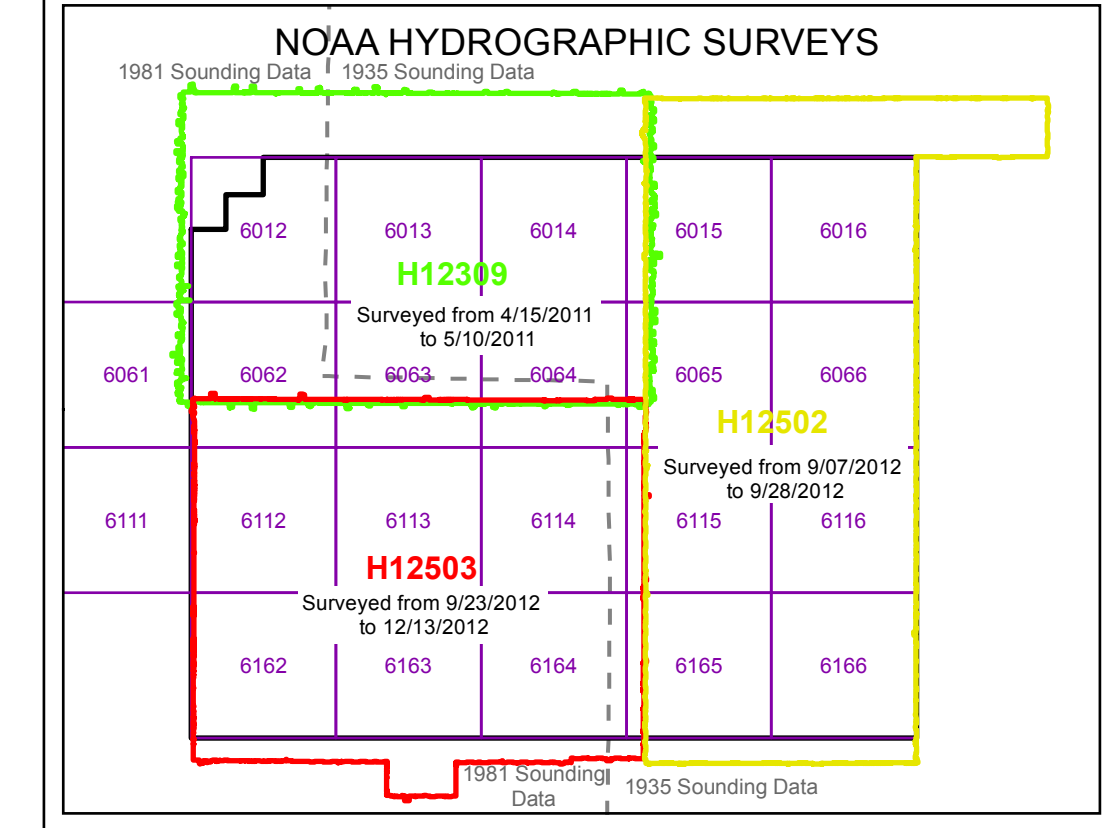
JOB NUMBER: 04.81130003 CHART NO.: 1b



**LEGEND**

- 100 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Allotment
- Meteorological Tower Allotment

Bathymetric Contours (Meters, MLLW)  
 Source: Fugro (2013) and NOAA (2011-2012)  
 Major contour interval is 10 meters.  
 Minor contour interval is 2 meters.  
 Fugro (2013) bathymetric extent.

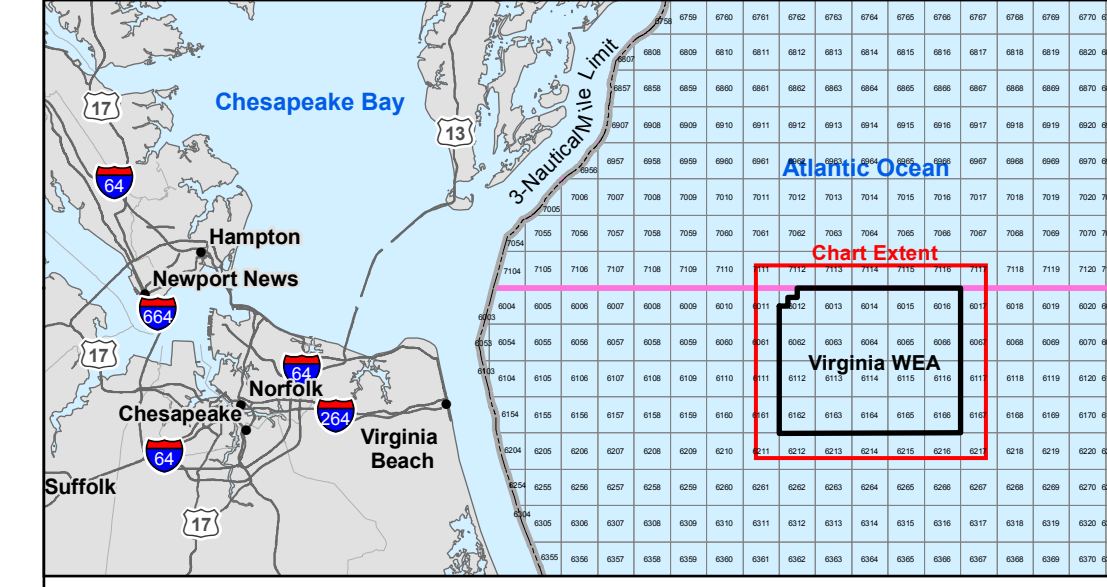


- Notes:
1. High-resolution multibeam bathymetry data within the WEA were acquired by Fugro (2013) and NOAA (2011 & 2012).
  - 2a. Fugro 2013 - Bathymetric data are from a multibeam survey conducted from May 28 through July 3, 2013.
  - 2b. Fugro's survey equipment utilized for bathymetric data collection included the following systems:  
 - R2 Sonic 2024 Multibeam Echosounder  
 - Agiptron PDS MV Inertial Motion and Attitude Recording System  
 - Blue Ocean Moving Sound Velocity Profiler  
 - Coda Octopus "Hypack" Navigation System
  3. NOAA (2011 & 2012) - Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
  4. Regional NOAA data are from hydrographic surveys conducted by NOAA in 1935 and 1981.
  5. Fugro hydrographic and geophysical survey data were acquired from May 28 through July 3, 2013 onboard the T/R XIV.
  6. Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Swift In-Water Area Differential Network, downloaded from a communications satellite.

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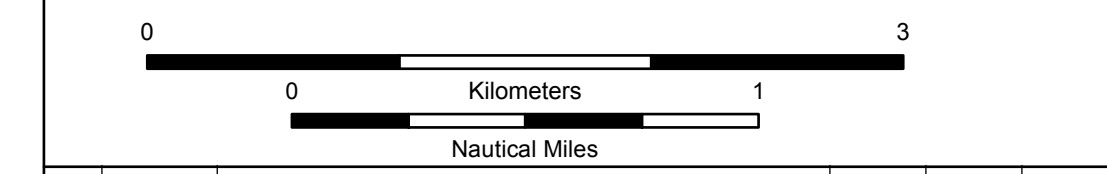
**GEODETTIC INFORMATION**

SPHEROID: GRS 1980  
 SEMI-MAJOR AXIS: 6378137.000  
 SEMI-MINOR AXIS: 6356752.314  
 INVERSE FLATTENING: 298.257222101  
 ECCENTRICITY: 0.004471015868973393  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18N  
 UNIT: METERS  
 FALSE EASTING: 500000  
 FALSE NORTHING: 0  
 Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

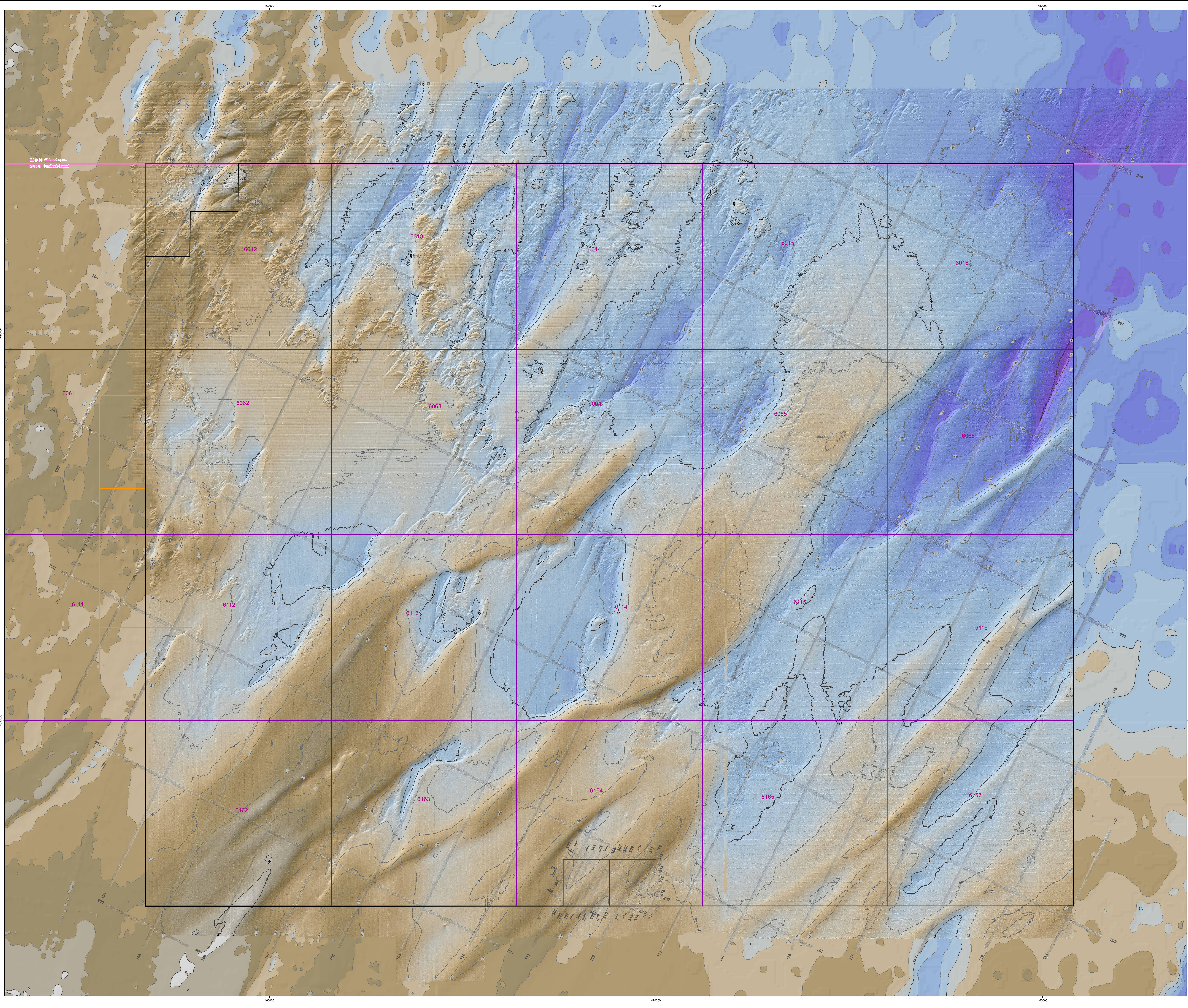


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**WEA BATHYMETRY Contour Chart**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHECKED	APPROVED
1	Sept 2013	Survey Report	ARB	KCS	KRS
2					
3					



**LEGEND**

- 100 Survey Vessel Navigation Tracking
- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot

**Bathymetry (Meters, MLLW)**  
 Source: Fugro (2013) and NOAA (2011-2012)  
 Darker swath indicates swath of Fugro 2013 survey

-18  
-41

Major contour interval is 10 meters.  
 Minor contour interval is 2 meters.

**Water Depth Statistics**

Wind Energy Area	Southern Meteorological Aliquot
Minimum: -41 m	Minimum: -27 m
Maximum: -18 m	Maximum: -23 m
Mean: -29 m	Mean: -25 m
Standard Deviation: 3 m	Standard Deviation: 0.8 m

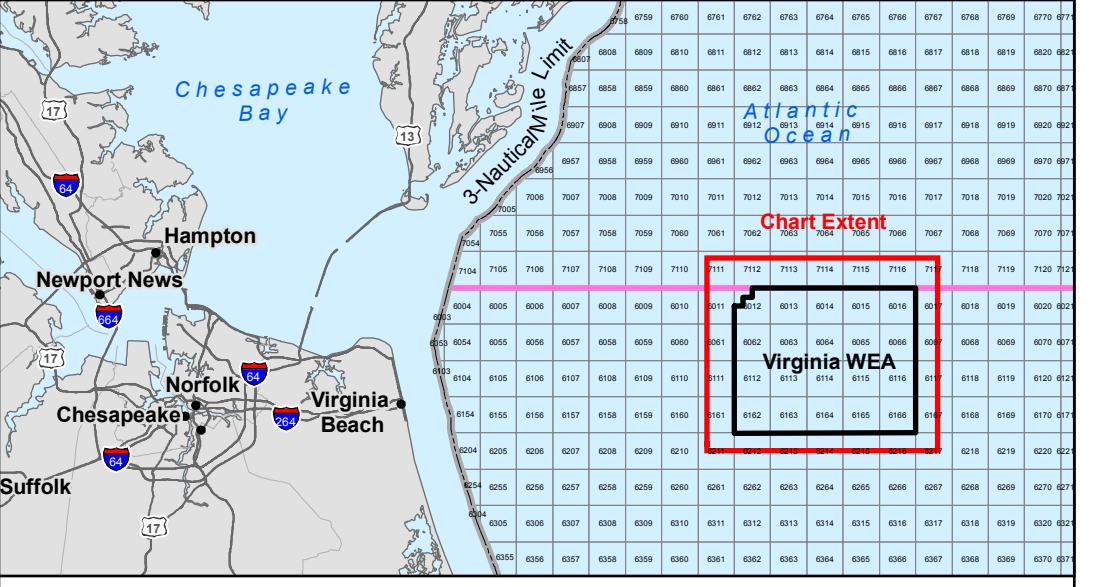
- Notes:**
- 1a. Fugro 2013 - Bathymetric data are from a multibeam survey conducted from May 28 through July 3, 2013.
  - 1b. Survey equipment utilized for data collection included the following systems:
    - H2 Sona 3024 Multibeam Echosounder
    - Applanac POS MV Vessel Motion and Attitude Recording System
    - Blue Ocean Moving Sound Velocity Profiler
    - Coastal Oceanographic "Hypank" Navigation System
    - NOAA OCS 18-2013 - Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
  3. Water depth statistics for within the WEA are based on both the Fugro and NOAA data sources. Values given are in meters and reference MLLW.
  4. Fugro hydrographic and geophysical survey data were acquired from May 28 through July 3, 2013 onboard the T/S 317.
  5. Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starlink wide area differential network, downloaded from a communications satellite.

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**GEODETTIC INFORMATION**

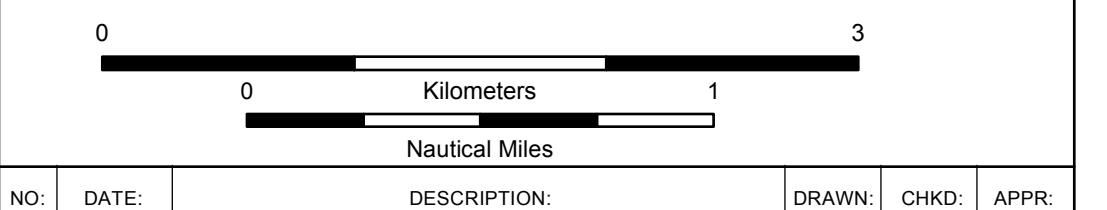
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 SEMI-MINOR AXIS: 6,356,752.144  
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 ECCENTRICITY: 0.004414481541  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 DATUM: WGS 84  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0

Coordinate Grid is UTM Zone 18N, NAD 1983, Meters

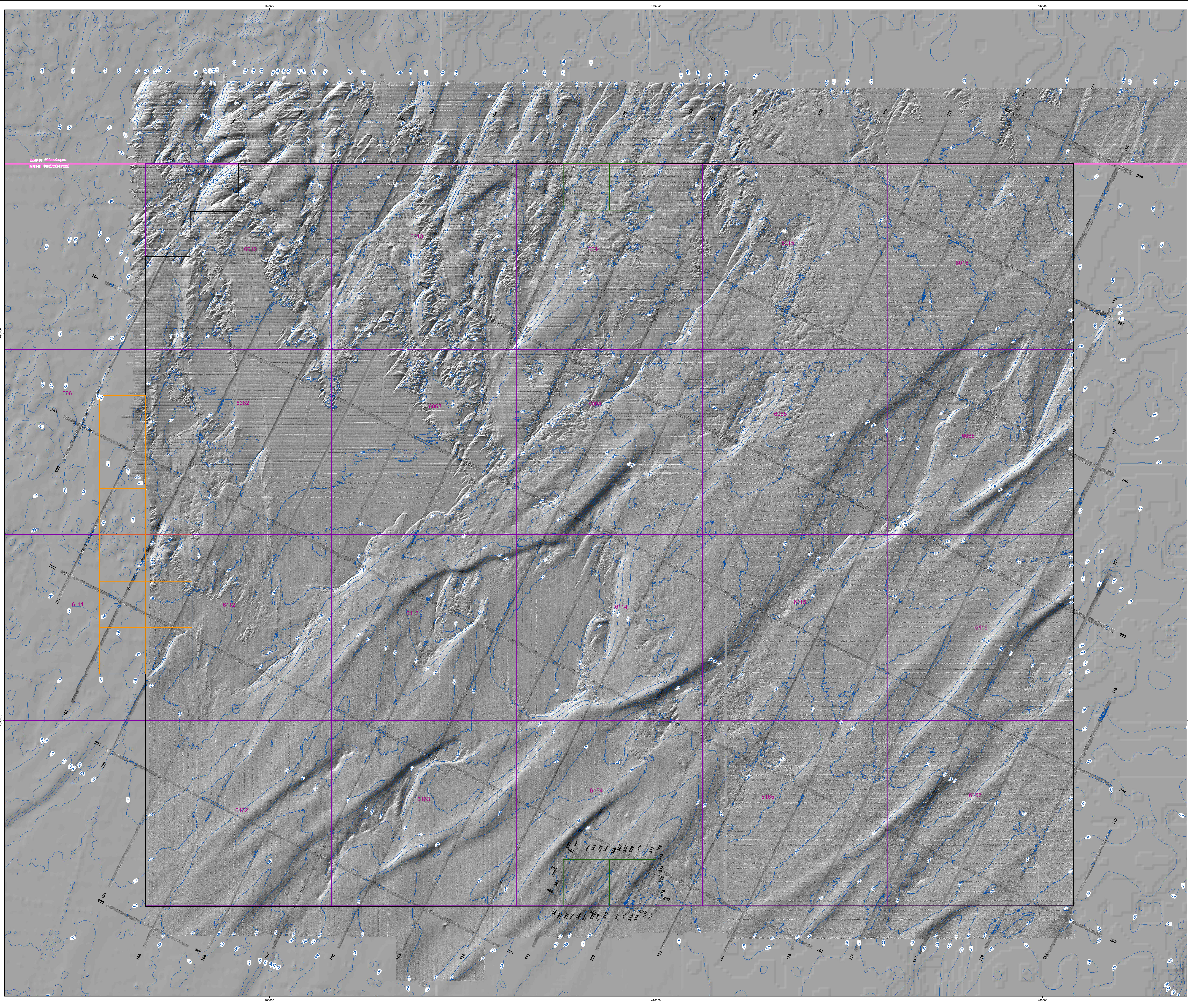


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**WEA BATHYMETRY**  
**Color-shaded Relief**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



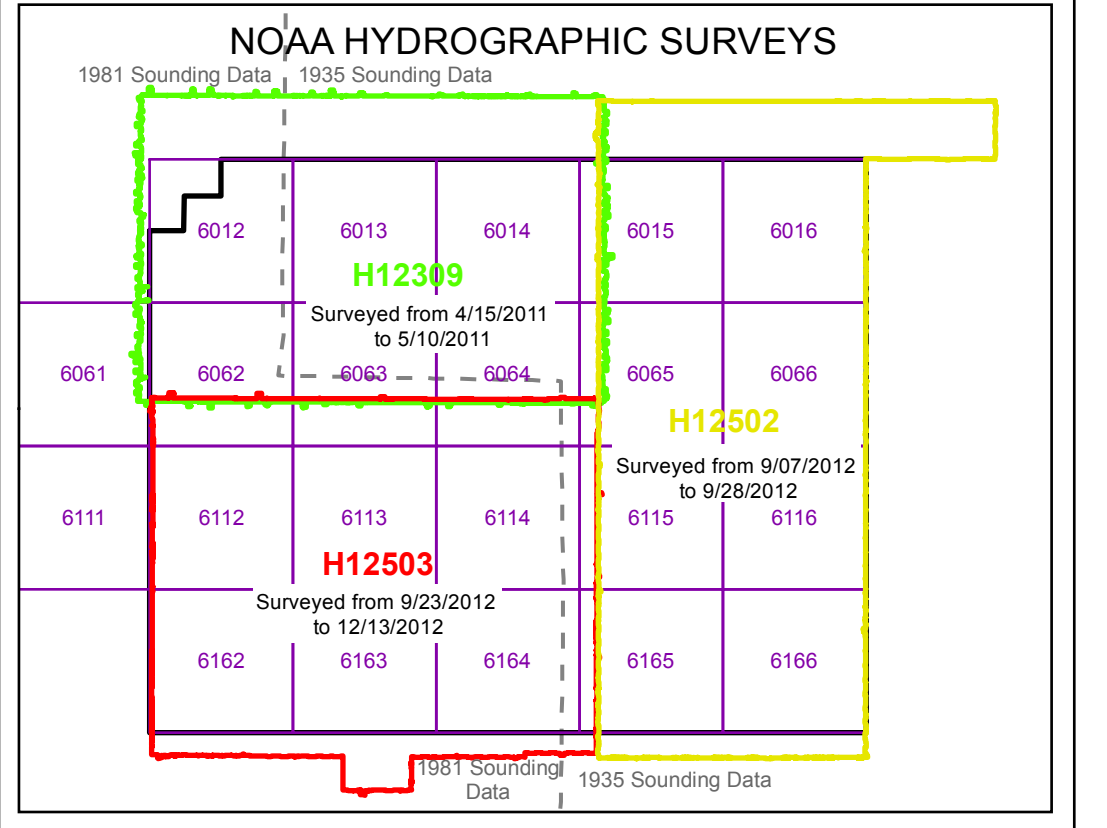
NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Sept 2013	Survey Report	AEB	KCS	KRS
2					
3					



**LEGEND**

- Virginia Wind Energy Area
- Wind Energy Area OCS Lease Block
- Demonstration Project Lease Aliquot
- Meteorological Tower Aliquot

Bathymetric Contours (Meters, MLW)  
 Source: Fugro (2013) and NOAA (2011-2012)  
 Contour Interval is 2 meters.



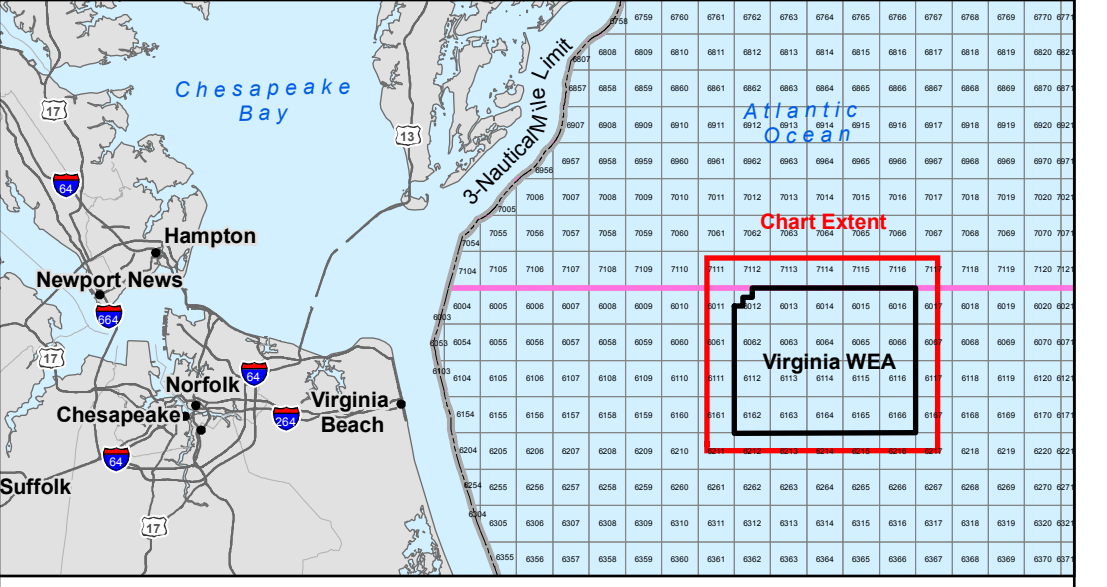
- Notes:
1. High-resolution multibeam bathymetry data within the WEA were acquired by Fugro (2013) and NOAA (2011 & 2012).
  - 2a. Fugro 2013 - Bathymetric data are from a multibeam survey conducted from May 28 through July 3, 2013.
  - 2b. Fugro's survey equipment utilized for bathymetric data collection included the following equipment:  
 - 40 Sonic 2024 Multibeam Echosounder  
 - Aquarius PDS MV Heave Motion and Attitude Recording System  
 - Blue Ocean Moving Sound Velocity Profiler  
 - Coastal Oceanographic "Hyposol" Navigation System
  3. NOAA (2011 & 2012) - Bathymetric data are from hydrographic surveys conducted in 2011 and 2012.
  4. Regional NOAA data are from hydrographic surveys conducted by NOAA in 1935 and 1951.
  5. Fugro hydrographic and geophysical survey data were acquired from May 28 through July 3, 2013 onboard the T/R XIV.
  6. Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starlink wide area differential network, downloaded from a communications satellite.

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**GEODETIC INFORMATION**

GRID SYSTEM	GCS NAD 83
SEMI-MAJOR AXIS	6378137.000
SEMI-MINOR AXIS	6356752.314
INVERSE FLATTENING	298.2572201
ECCENTRICITY	-0.004672857
PROJECTION	UNIVERSAL TRANSVERSE MERCATOR
ZONE	ZONE 18 NORTH
UNIT OF MEASURE	METERS
FALSE EASTING	500,000
FALSE NORTHING	0

Coordinate Grid is UTM Zone 18N, NAD 1983, Meters



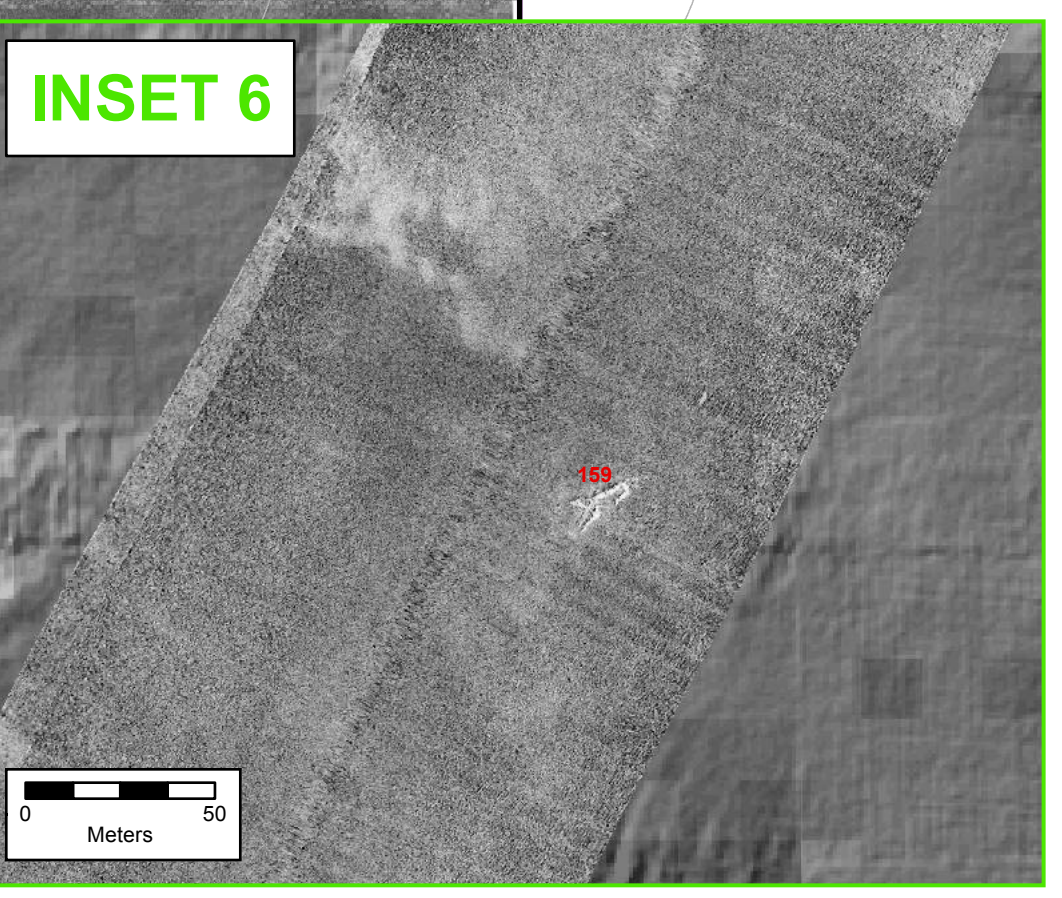
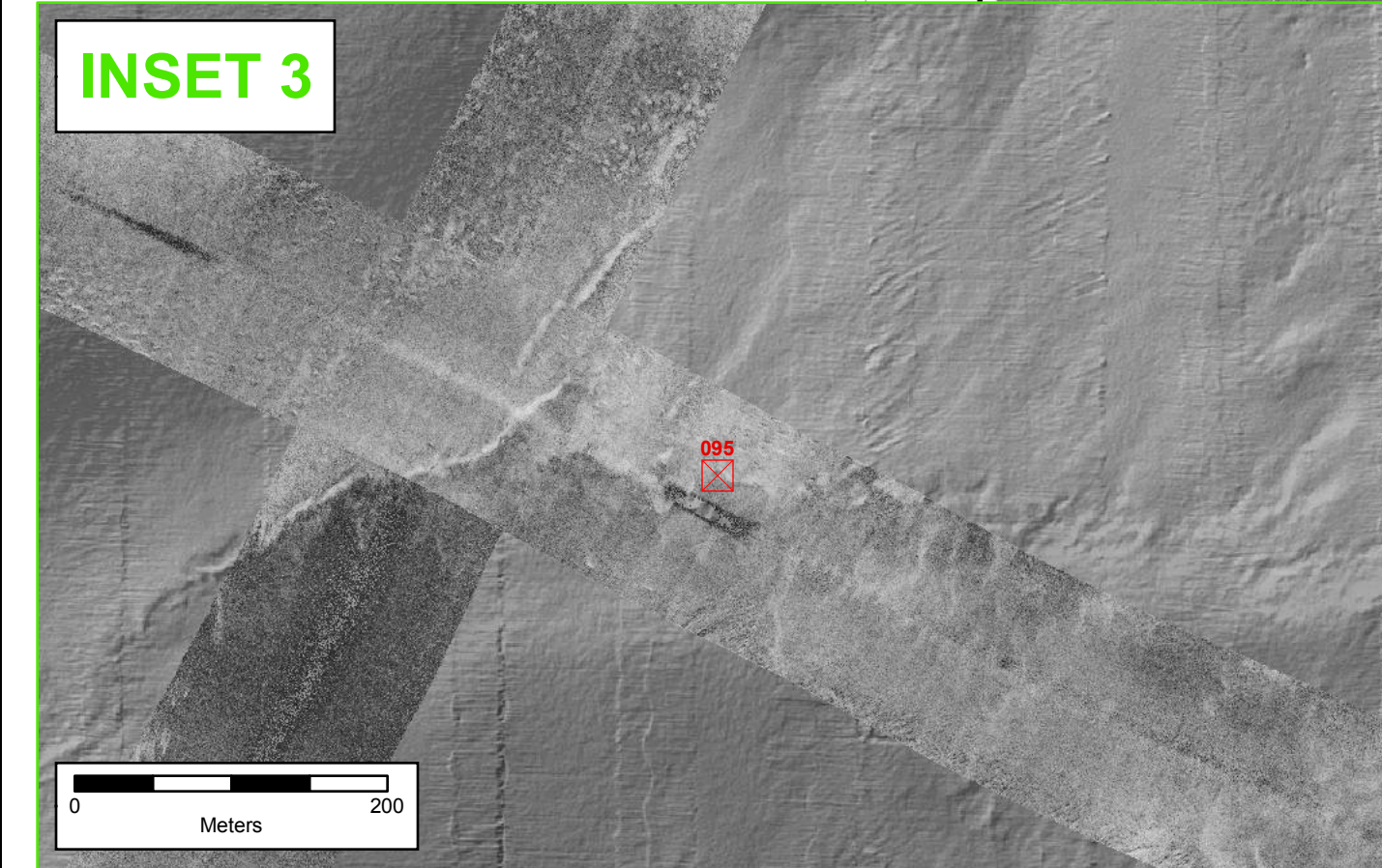
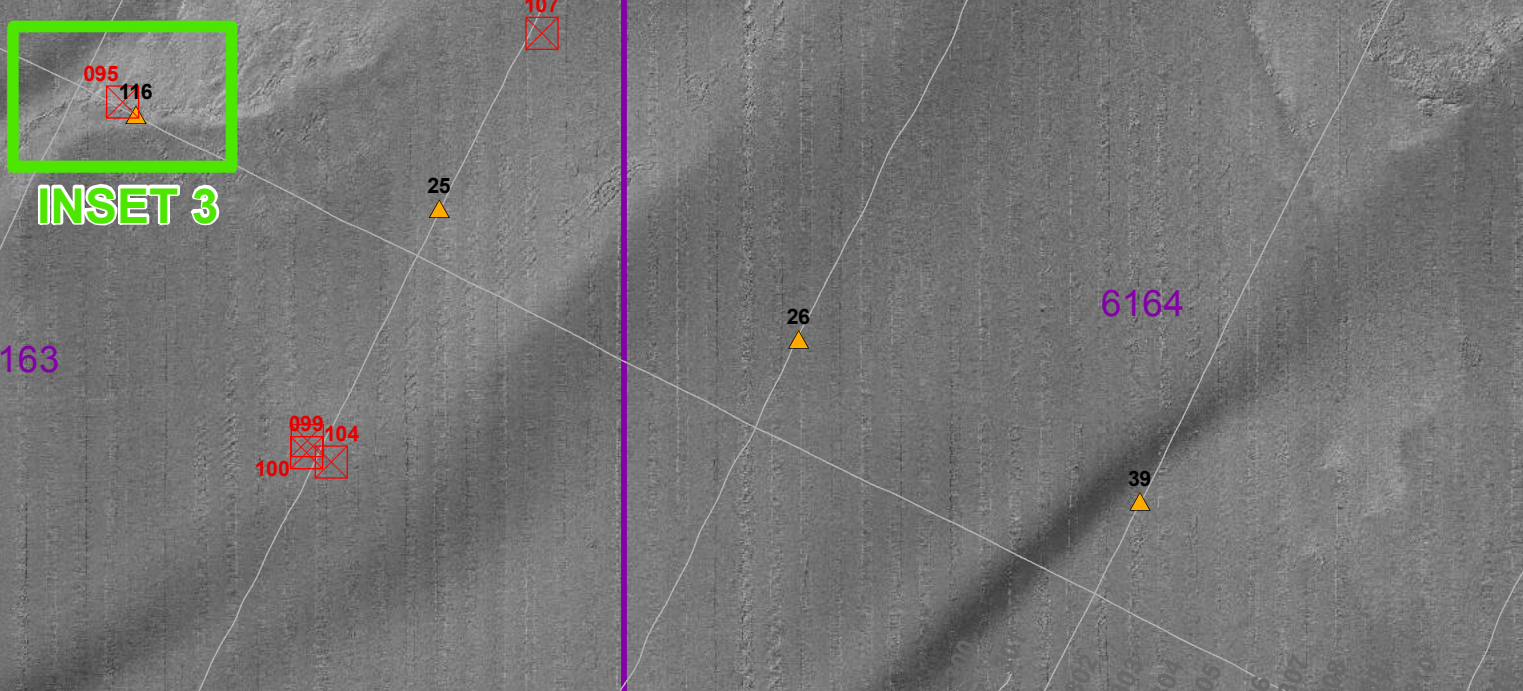
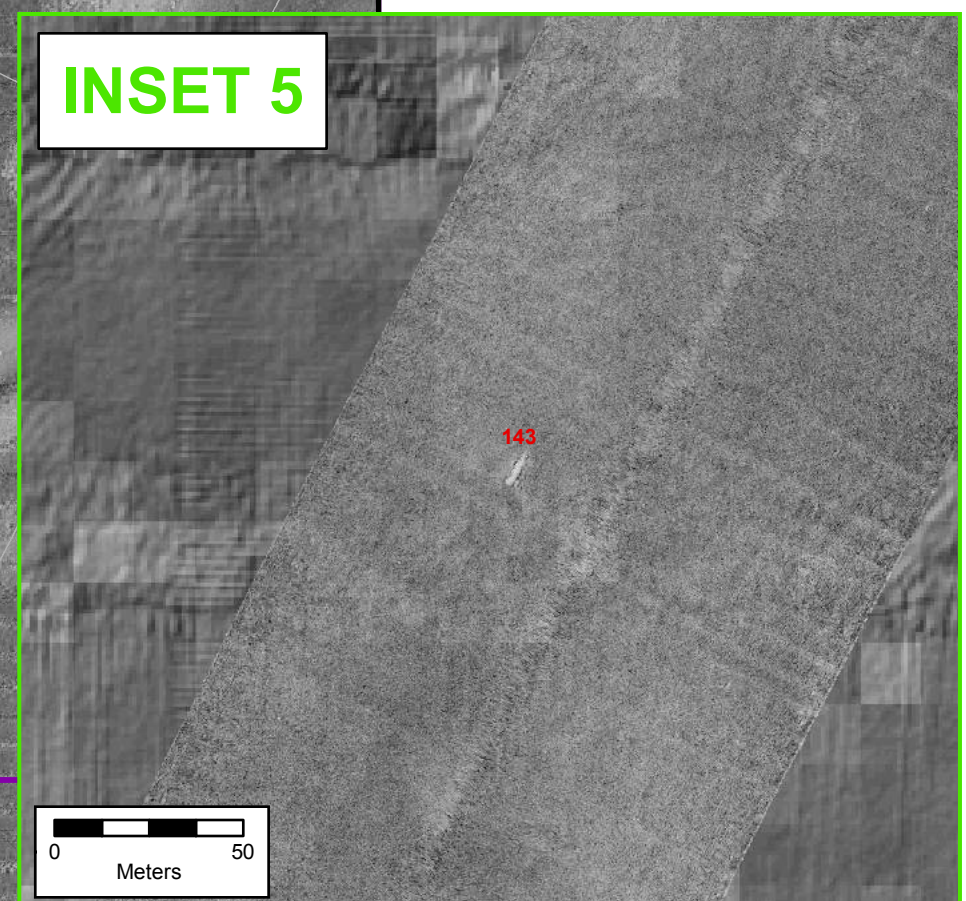
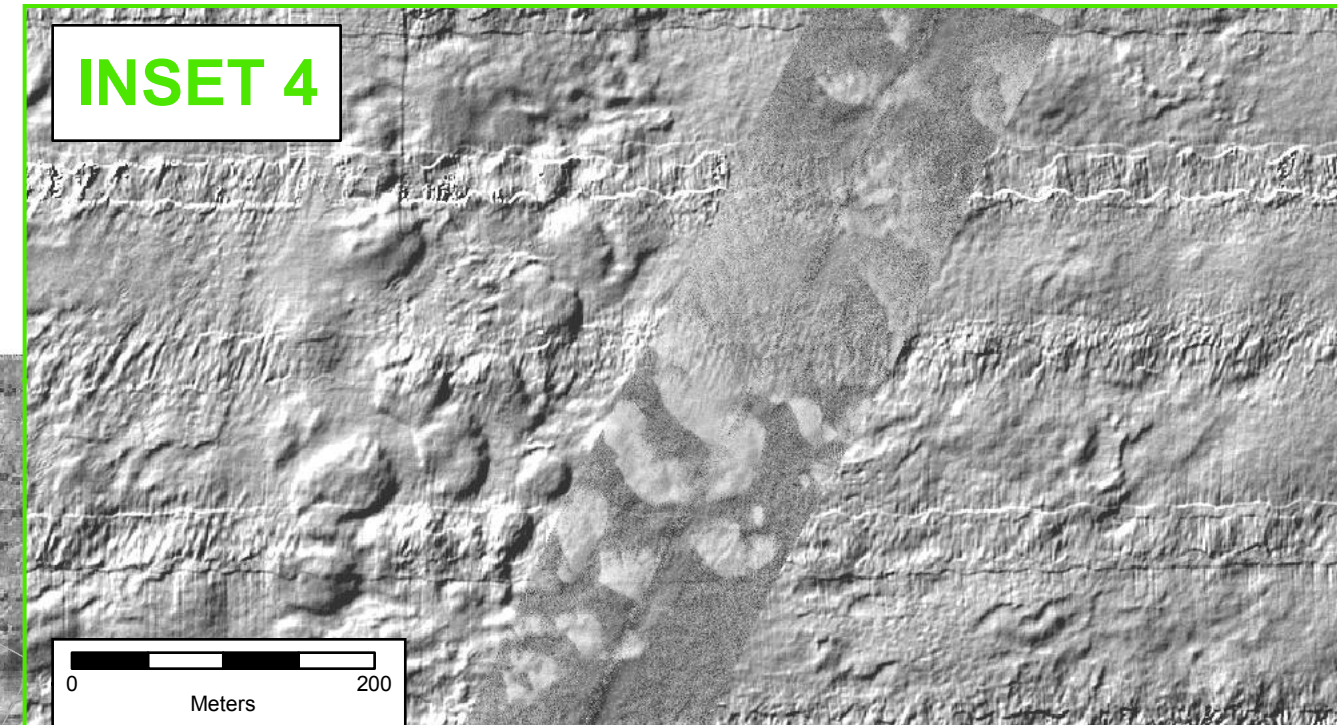
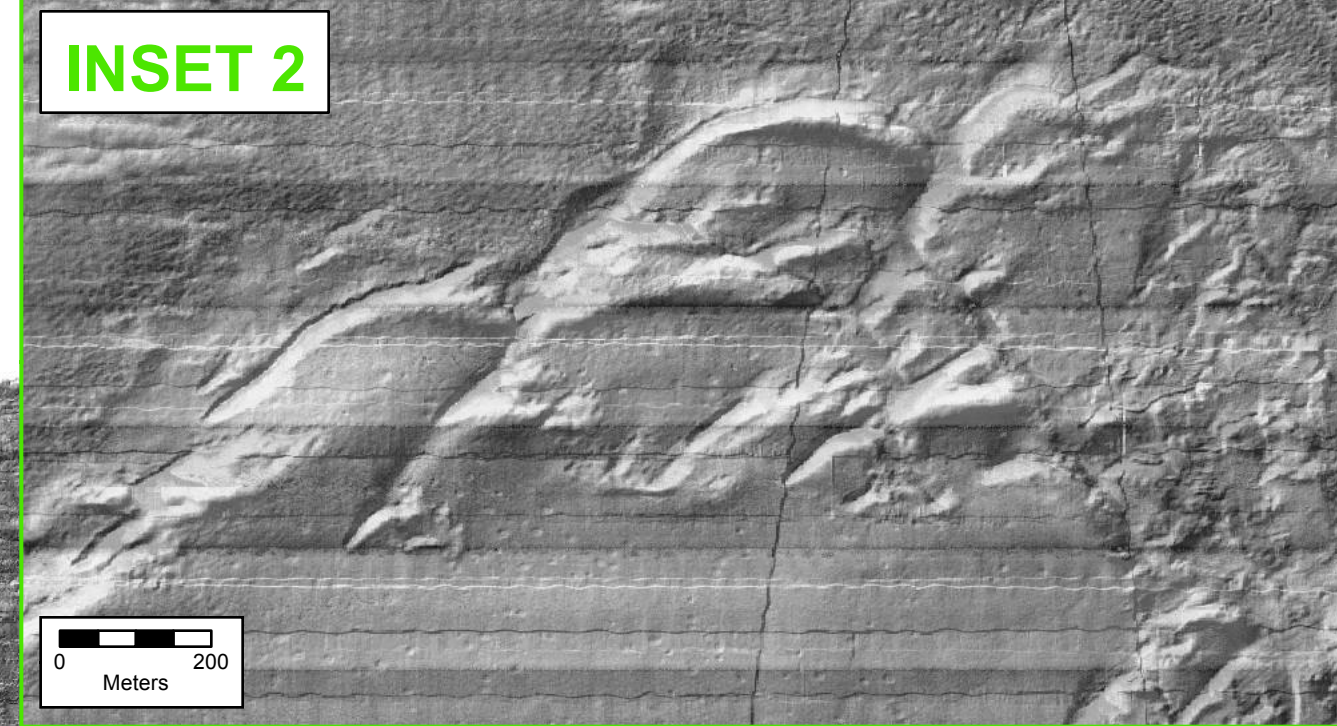
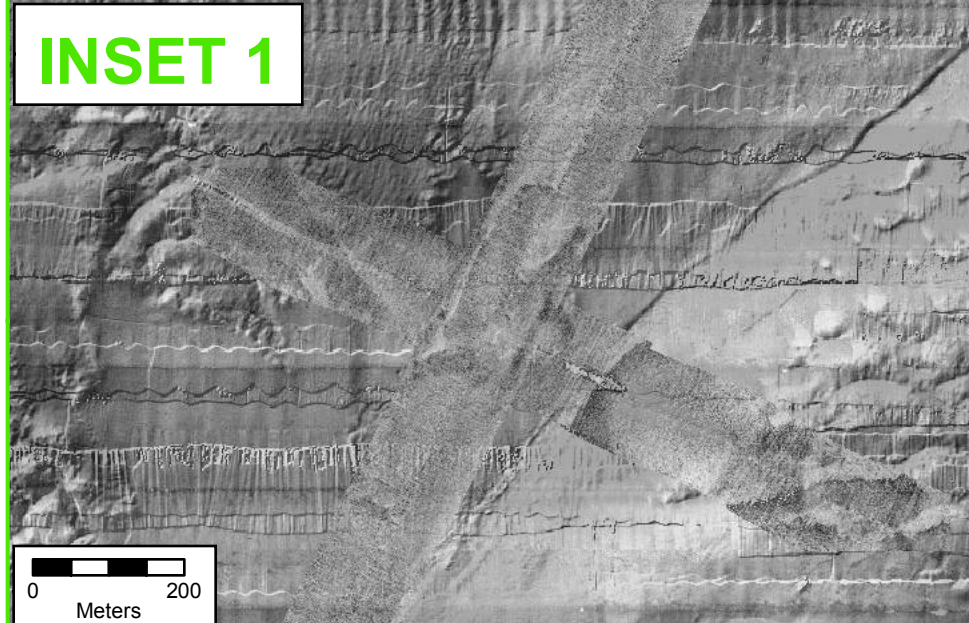
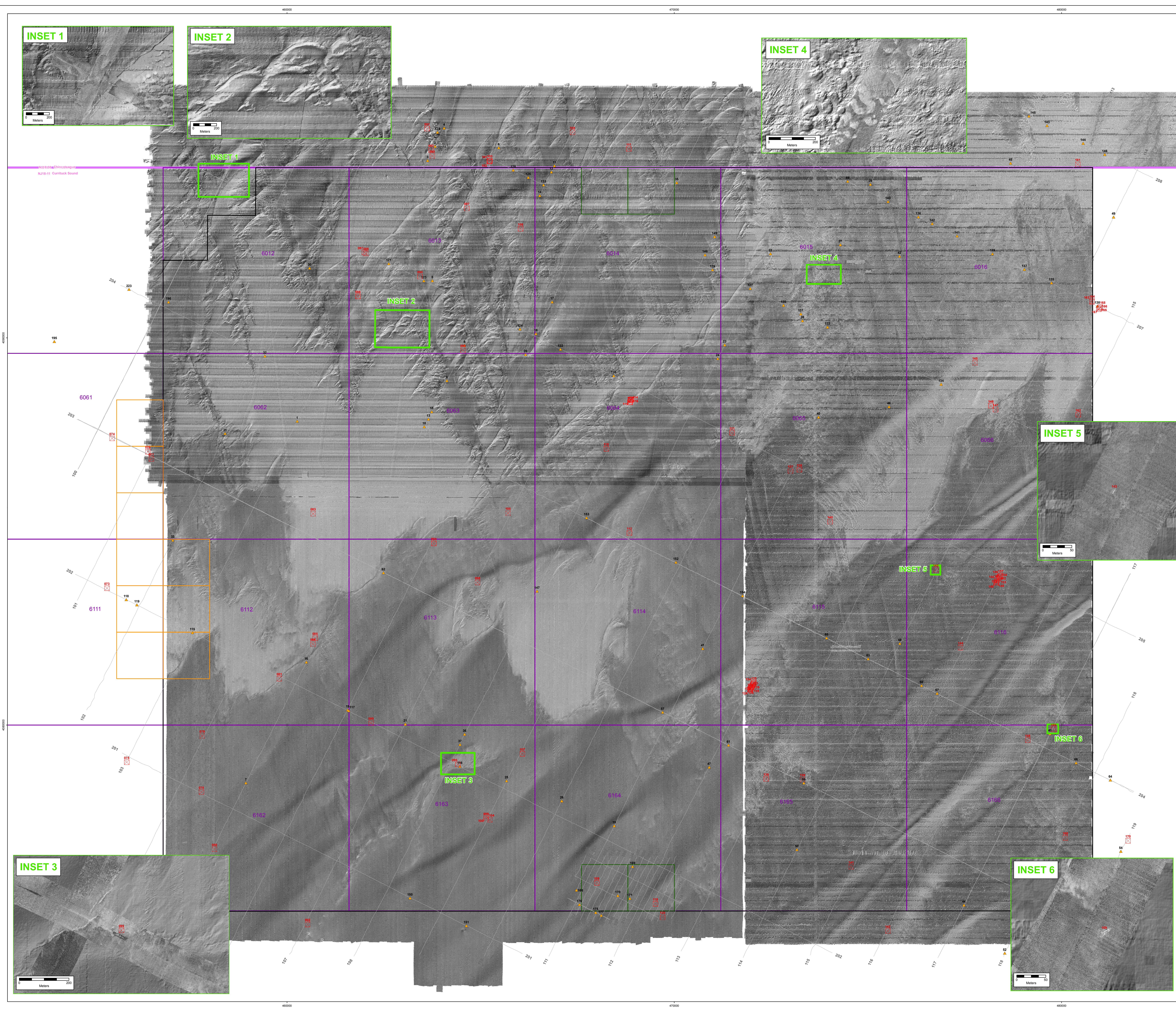
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**WEA HILLSHADED-RELIEF**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

0 1 2 3  
 Kilometers  
 Nautical Miles

NO.	DATE	DESCRIPTION	DRAWN	CHECK	APPROV.
1	Sept 2013	Survey Report	JEF	KCS	KRS
2					
3					

JOB NUMBER: 04.81130003 CHART NO.: 3



**LEGEND**

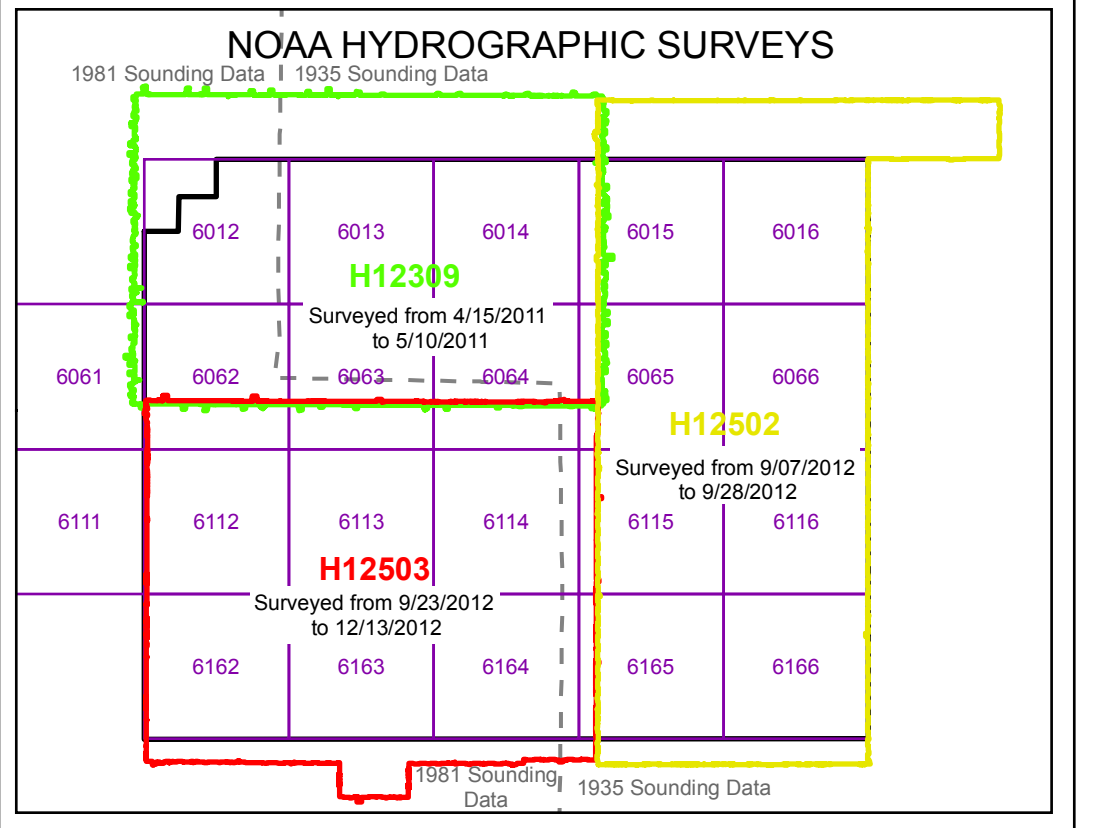
- 100 Survey Vessel Navigation Trackline
- Virginia Wind Energy Area
- 6016 Wind Energy Area OCS Lease Block
- Demonstration Project Lease Allotment
- Meteorological Tower Allotment
- 100 Side Scan Sonar Target
- 30 Interpreted Magnetic Anomaly

**Side Scan Sonar Reflectivity**

- High Reflectivity
- Low Reflectivity

**Multibeam Backscatter Intensity**

- High Intensity
- Low Intensity



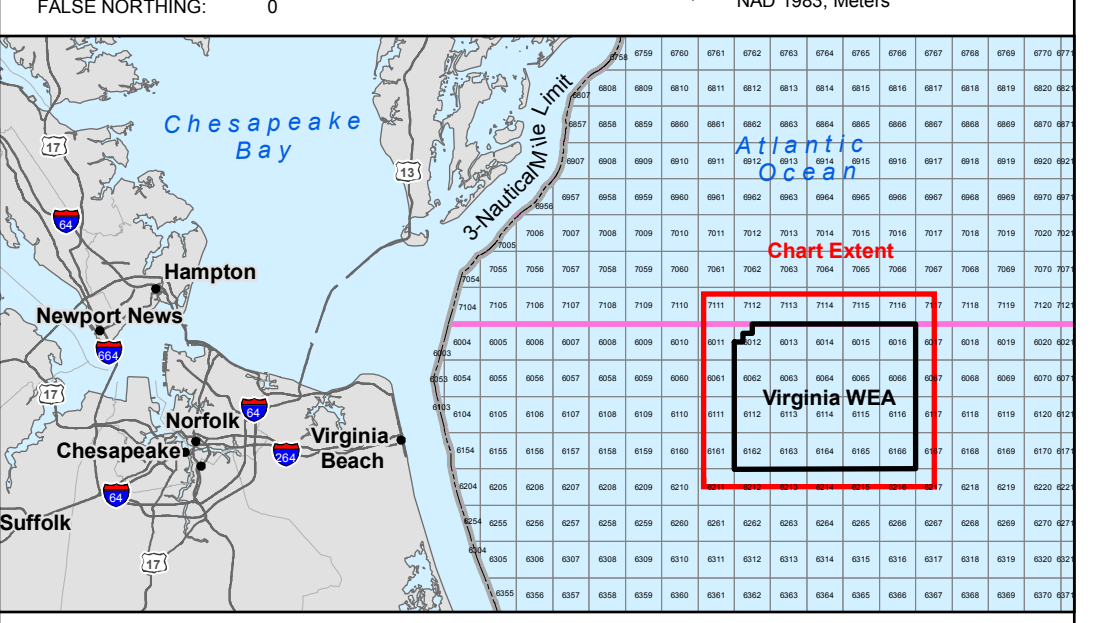
- Notes:
19. Fugro (2013) - Marine survey data was collected from May 28 through July 3, 2013.
  20. Survey equipment utilized for data collection included the following systems:
    - Agiplex PDS MV Vessel Motion and Attitude Recording System
    - Etophon Model 125 Side Scan Sonar System
    - SoranWhiz Mag Side Scan Sonar Data Acquisition System
    - Marine Magnetic Corporation Stability Measurement
    - Coastal Oceanographic's "Hyppack" Navigation System
  21. Bathymetric Global Positioning System (DGPS) corrections were obtained from Fugro's Starfix II wide area differential network, downloaded from a communications satellite.
  22. NOAA (2011 & 2012) - Side scan sonar and multibeam backscatter data are from hydrographic surveys conducted in 2011 and 2012.

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**GEODETTIC INFORMATION**

CRS: NAD 83  
 SEMI-MAJOR AXIS: 6378137.000  
 SEMI-MINOR AXIS: 6356752.314  
 INVERSE FLATTENING: 298.257222101  
 ECCENTRICITY: 0.00441448224252  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 ORIGIN: 960000  
 FALSE EASTING: 960000  
 FALSE NORTHING: 0

Coordinate Grid is UTM Zone 18N  
 MGD 18N Meters



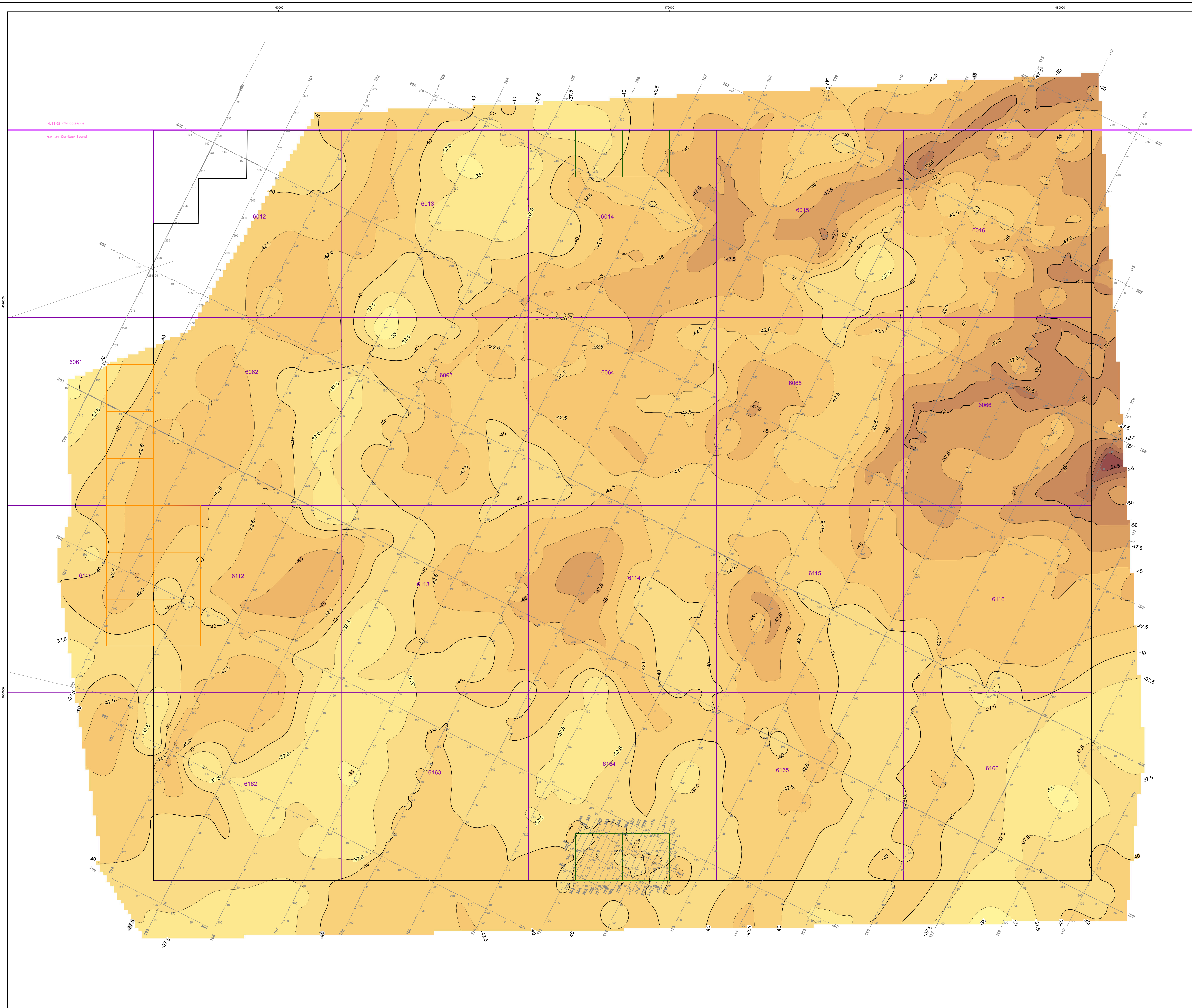
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**SIDE SCAN SONAR TARGETS AND MAGNETIC ANOMALIES**  
**Side Scan Sonar and Backscatter with Hill-shaded Relief**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

0 1 2 3  
 Nautical Miles

NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Sep 2013	Survey Report	KWS	KRS	KRS
2					
3					

JOB NUMBER: 04.81130003 CHART NO.: 4



**LEGEND**

**Survey Vessel Navigation Trackline**  
 Survey line number in bold  
 Navigation event mark number  
 Arrows on line indicate direction of vessel travel.

Virginia Wind Energy Area  
 Wind Energy Area OCS Lease Block  
 Demonstration Project Lease Area  
 Meteorological Tower Aliquot

Approximate Elevation of Horizon 30, Meters (Re. MLLW)  
 Horizon 30 is inferred to be related to the Tertiary-Quaternary boundary.  
 Time-to-depth conversions based on  $V_s = 1,500$  m/s; thus elevation should be considered approximate.

Major contour interval is 10 meters.  
 Minor contour interval is 2.5 meters

- 32.4 - -30
- 34.9 - -32.5
- 37.4 - -35
- 39.9 - -37.5
- 42.4 - -40
- 44.9 - -42.5
- 47.4 - -45
- 49.9 - -47.5
- 52.4 - -50
- 54.9 - -52.5
- 57.4 - -55
- 59.4 - -57.5

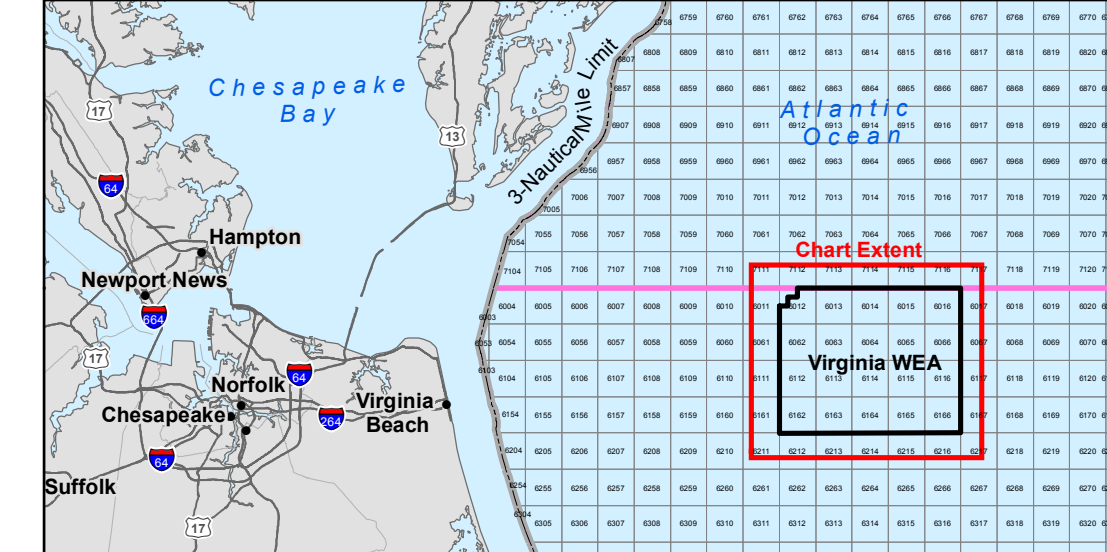
- Notes:
- Fugro marine survey data were collected from May 28 through July 3, 2013 onboard the Titi XIV.
  - Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starlink II wide area differential network, downloaded from a communications satellite.
  - Survey equipment utilized for data collection included the following systems:  
 - Applanix POS MV Inertial Motion and Attitude Recording System  
 - Edgetech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) System  
 - Edgecraft Oceanic Sub-bottom Profiler Data Acquisition System  
 - Applied Acoustic Electronics' CSP® Seismic Energy Source and Subsea System's Double-plate "Boomer" System  
 - Oceanic 50 Channel Hydrographic Array System  
 - Chirp 1-16 at 1.56mg and Channels 17-32 at 3.125mg)  
 - Blue Ocean-Marking Sound Velocity Profiler  
 - Coastal Oceanographics' "Hypack" Navigation System  
 - Starlink Sea Navigation

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**GEODETIC INFORMATION**

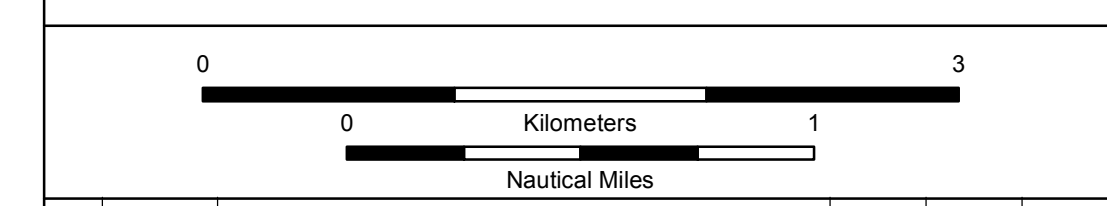
CRS: NAD 83  
 SEMI-MAJOR AXIS: 6,378,137.000  
 SEMI-MINOR AXIS: 6,356,752.314  
 INVERSE FLATTENING: 298.257222101  
 ECCENTRICITY: 0.004414481541  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 DATUM: GRS 80  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0

Coordinate Grid is UTM Zone 18N, NAD 83, Meters



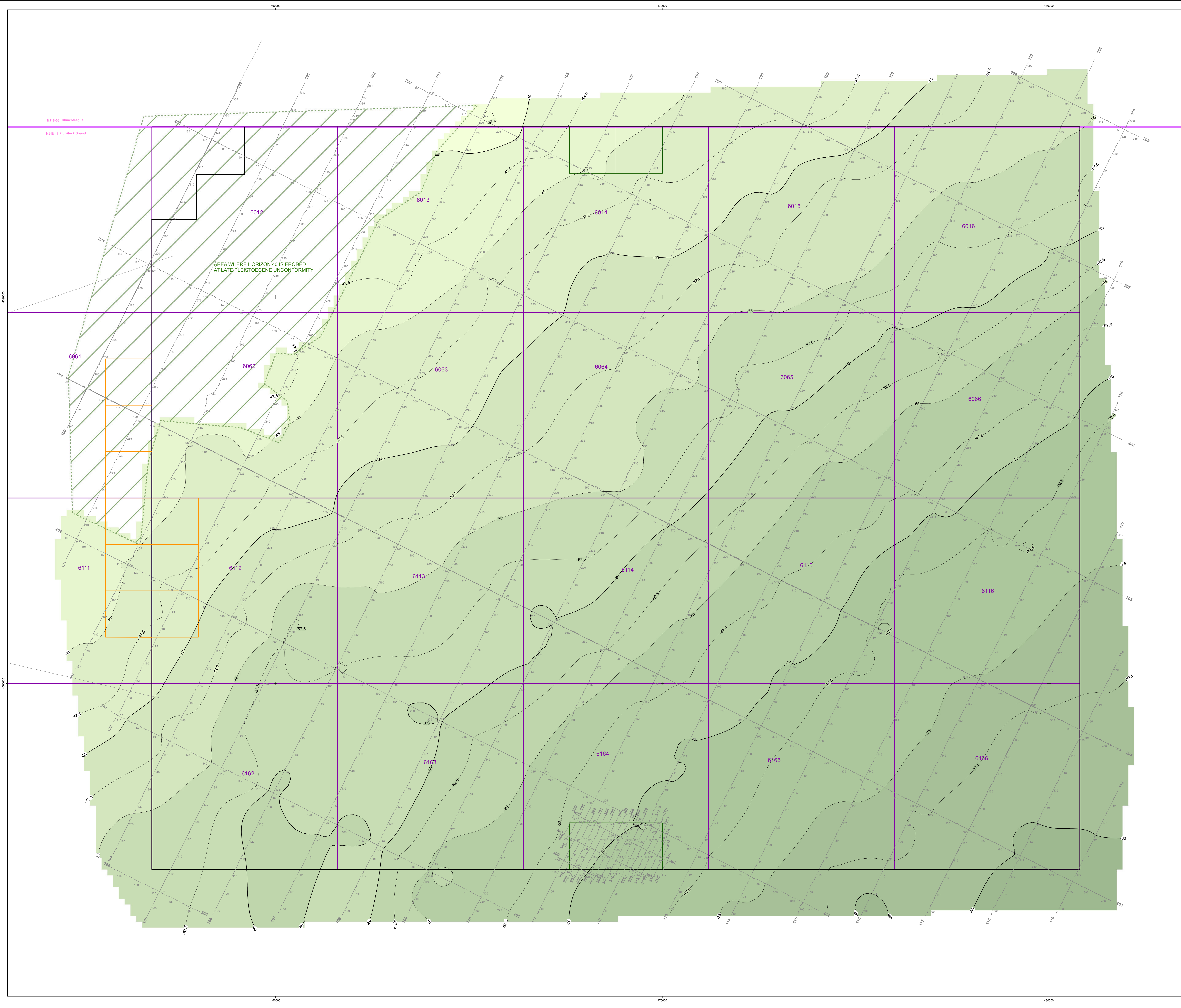
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**ELEVATION CONTOURS OF HORIZON 30 (Quaternary-Tertiary Boundary)**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Sept 2013	Survey Report	KWS	KCS	KRS
2					
3					

JOB NUMBER: 04.8130003 CHART NO.: 5



**LEGEND**

- Survey Vessel Navigation Trackline**  
 Survey line number in bold  
 Navigation event mark number  
 Arrows on line indicate direction of vessel travel.
- Virginia Wind Energy Area
  - Wind Energy Area OCS Lease Block
  - Demonstration Project Lease Area
  - Meteorological Tower Aliquot

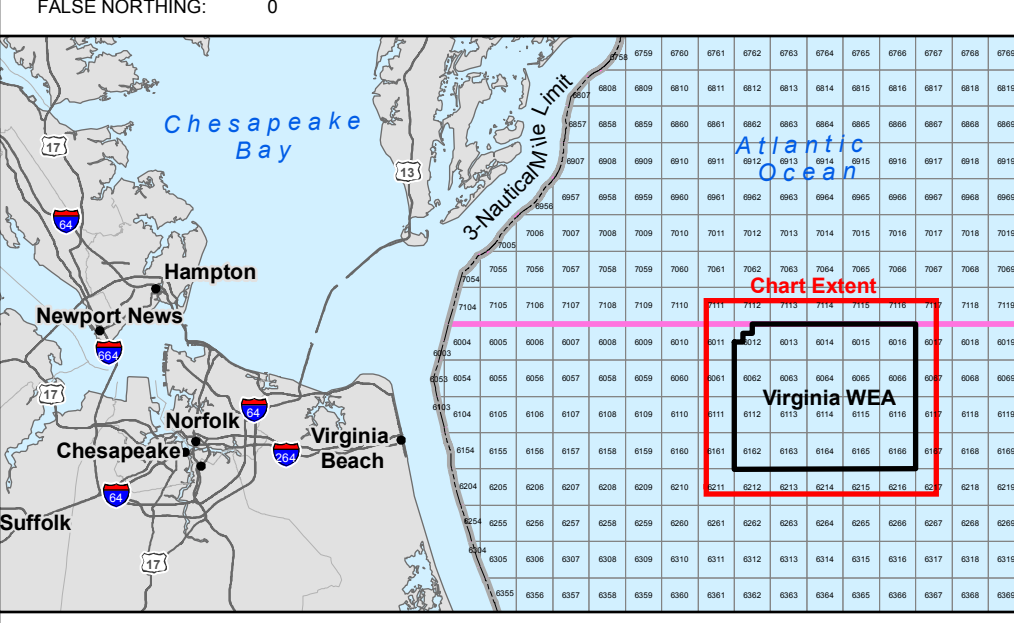
**Approximate Elevation of Horizon 40, Meters (Re. MLLW)**  
 Horizon 40 is inferred to be related to a Tertiary age strata.  
 Time-to-depth conversions based on  $V_p = 1,500$  m/s, thus elevation should be considered approximate.

- Major contour interval is 10 meters.
- Minor contour interval is 2.5 meters.
- 39.9 - -35
- 44.9 - -40
- 49.9 - -45
- 54.9 - -50
- 59.9 - -55
- 64.9 - -60
- 69.9 - -65
- 74.9 - -70
- 79.9 - -75
- 82.5 - -80

- Notes:**
- Fugro marine survey data were collected from May 28 through July 3, 2013 onboard the T41 XIV.
  - Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starfix II wide area differential network, downloaded from a communications satellite.
  - Survey equipment utilized for data collection included the following systems:  
 Agiplex F100 MV Inertial Motion and Attitude Recording System  
 Edgetech 2000 Synthetic Aperture Sonar (Chirp) System  
 Edgetech Chirpplus Sub-bottom Profiler Data Acquisition System  
 Applied Acoustics Corporation CIP Synthetic Energy Source and Subsea System's Double-plate "Boomer" System  
 General 50-channel Hydroacoustic Array (Dynamac)  
 (Channels 1-16 at 1.56mg and Channels 17-32 at 3.125mg)  
 Blue Ocean Mapping Sound Velocity Profiler  
 Coastal Oceanographics "Hypack" Navigation System  
 Starfix Sora Navigation

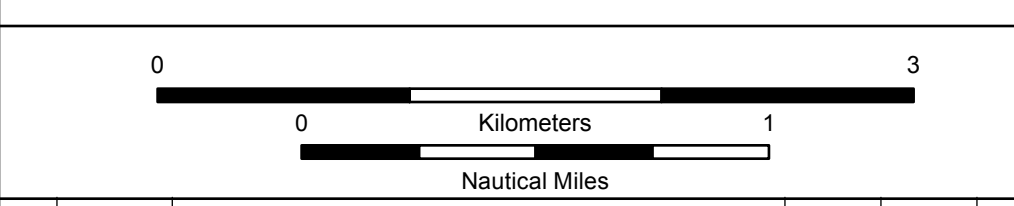
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**GEODETTIC INFORMATION**  
 DATUM: GRS 80  
 SEMI-MAJOR AXIS: 6,378,137.000  
 SEMI-MINOR AXIS: 6,356,752.144  
 INVERSE FLATTENING: 298.25722101  
 ECCENTRICITY: 0.00443441  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 UNIT: Meter  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0  
 Coordinate Grid is UTM Zone 18N, WGS 1984, Meter



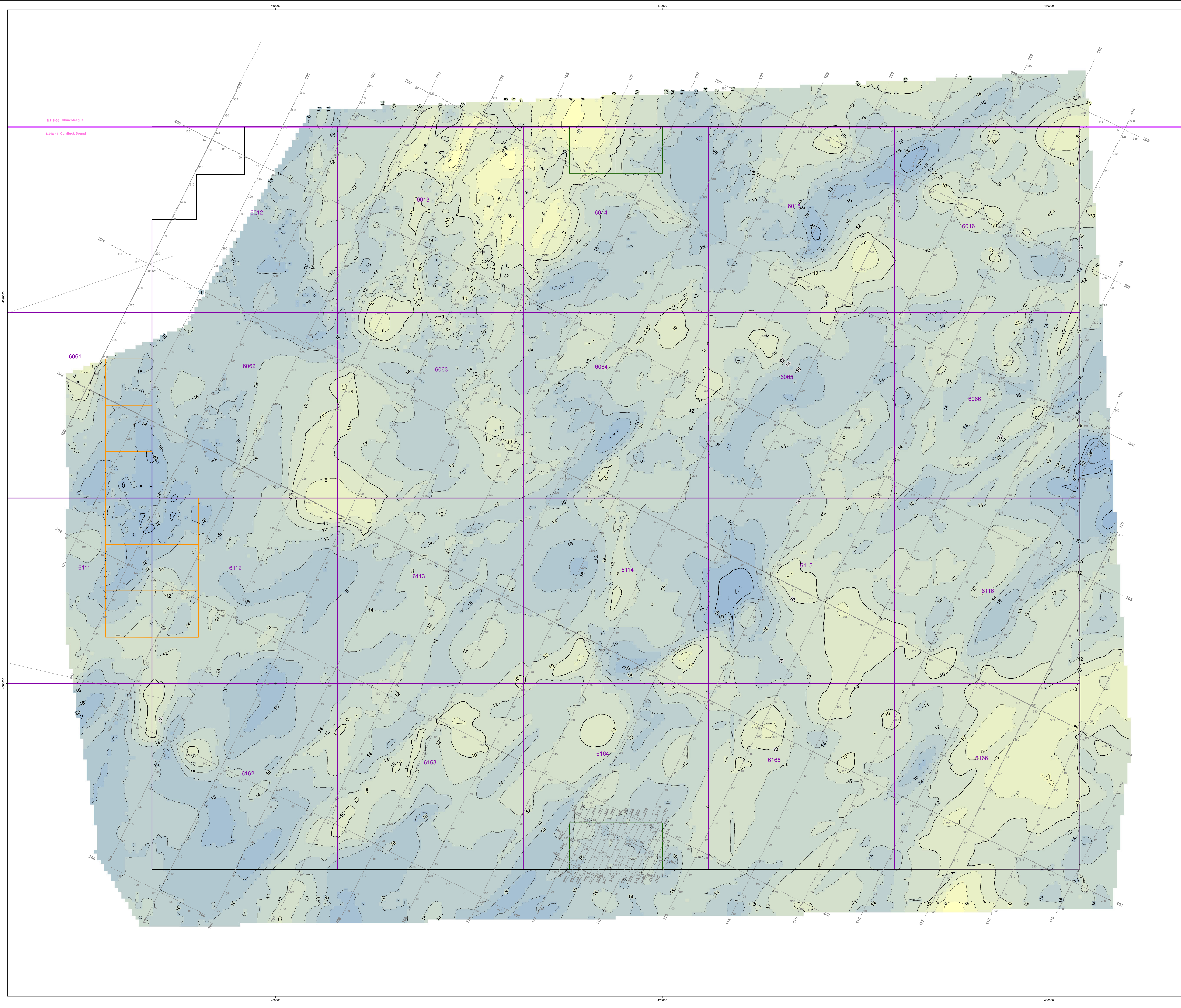
**FUGRO CONSULTANTS, INC.**  
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 101 West Main Street  
 Norfolk, Virginia 23510  
 Tel: (757) 825-3200  
 Fax: (757) 825-3352  
 www.fugro.com

**ELEVATION CONTOURS OF HORIZON 40**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Sept 2013	Survey Report	KWS	KCS	KRS
2					
3					

JOB NUMBER: 04.81130003 CHART NO.: 6



**LEGEND**

**Survey Vessel Navigation Trackline**  
 Survey line number in bold  
 Navigation event mark number  
 Arrows on line indicate direction of vessel travel.

Virginia Wind Energy Area  
 Wind Energy Area OCS Lease Block  
 Demonstration Project Lease Area  
 Meteorological Tower Aliquot

Approximate Isopach (Thickness) of Deposits Above Horizon 30, Meters  
 Deposits above Horizon 30 are inferred to be Quaternary deposits.  
 Time-to-depth conversions based on  $V_s = 1,500$  m/s; thus thickness should be considered approximate.

Major contour interval is 10 meters.  
 Minor contour interval is 2 meters.

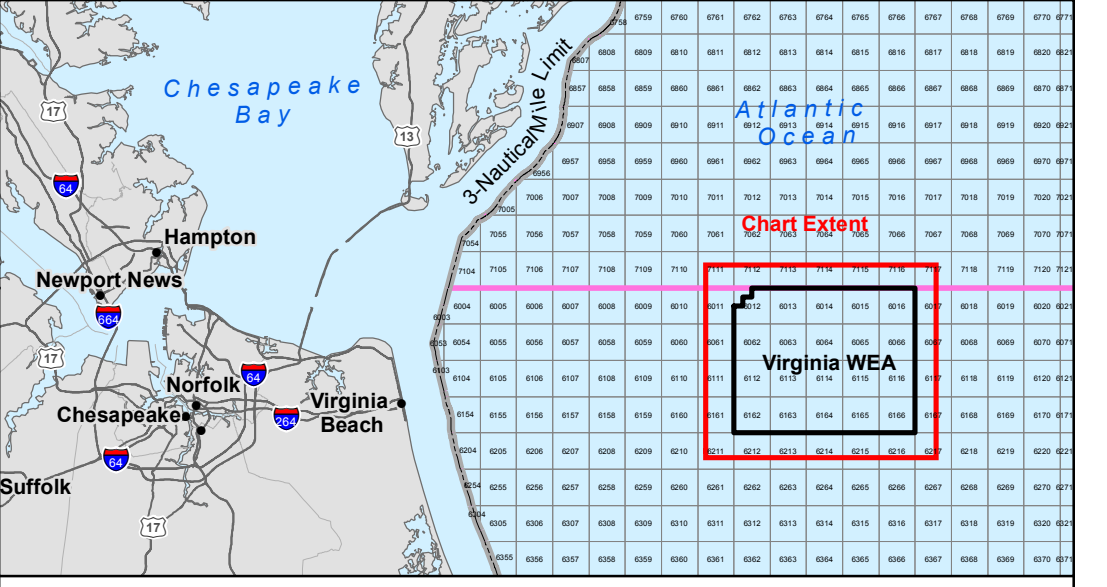
2.4 - 4  
 4.1 - 6  
 6.1 - 8  
 8.1 - 10  
 10.1 - 12  
 12.1 - 14  
 14.1 - 16  
 16.1 - 18  
 18.1 - 20  
 20.1 - 22

**Notes:**

- Fugro marine survey data were collected from May 28 through July 3, 2013 onboard the Tiki XV.
- Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Starlink II wide area differential network, downloaded from a communications satellite.
- Survey equipment utilized for data collection included the following systems:  
 - Applanix POS MV Inertial Motion and Attitude Recording System  
 - Edgetech 3000 Spread Spectrum Sub-bottom Profiler (Chirp) System  
 - Edgetech Discovery Sub-bottom Profiler Data Acquisition System  
 - Applied Acoustic Electronics' CSP® Seismic Energy Source and Subsea System's Double-plate "Boomer" System  
 - Okeanos 30 Channel Hydracoustic Array System  
 - Channels 1-16 at 1.56m/s and Channels 17-32 at 3.125m/s  
 - Star Ocean-Marking Sound Velocity Profiler  
 - Coastal Oceanographics' "Hippack" Navigation System  
 - Starlink Sea Navigation

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**GEOIDETIC INFORMATION**  
 DATUM: GRS80  
 SEMI-MAJOR AXIS: 6,378,137.000  
 SEMI-MINOR AXIS: 6,356,752.314  
 INVERSE FLATTENING: 298.257222101  
 ECCENTRICITY: 0.0044318488  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18 NORTH  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0  
 Coordinate Grid is UTM Zone 18N, NAD 83, Meters

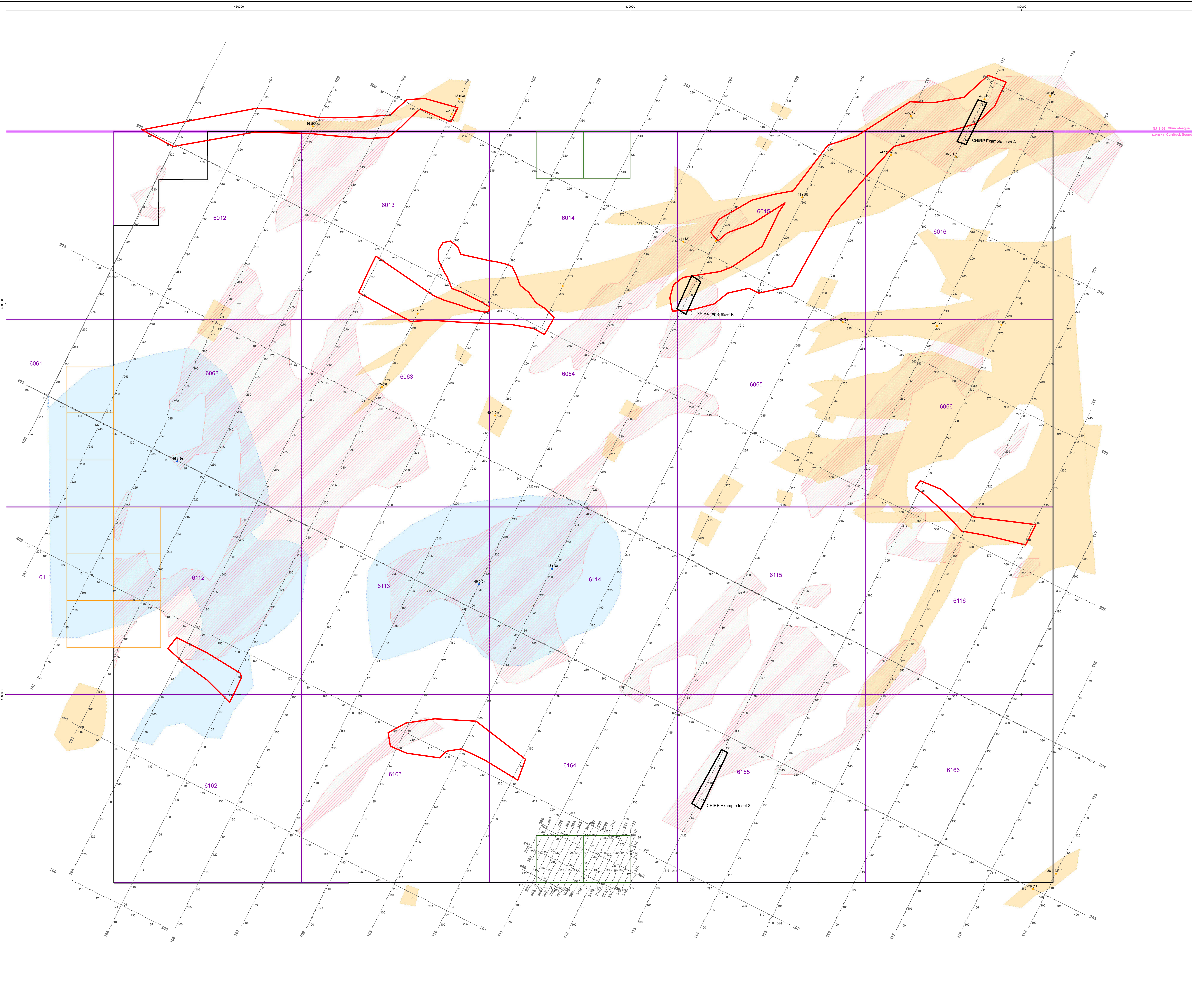


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**ISOPACH (THICKNESS) OF DEPOSITS ABOVE HORIZON 30**  
 Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf

NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Sept 2013	Survey Report	KWS	KCS	KRS
2					
3					

JOB NUMBER: 04.8130003 CHART NO.: 7



### LEGEND

**Survey Vessel Navigation Trackline**

- Survey line number in bold
- Navigation event mark number
- Arrows on the indicate direction of vessel travel.

Virginia Wind Energy Area

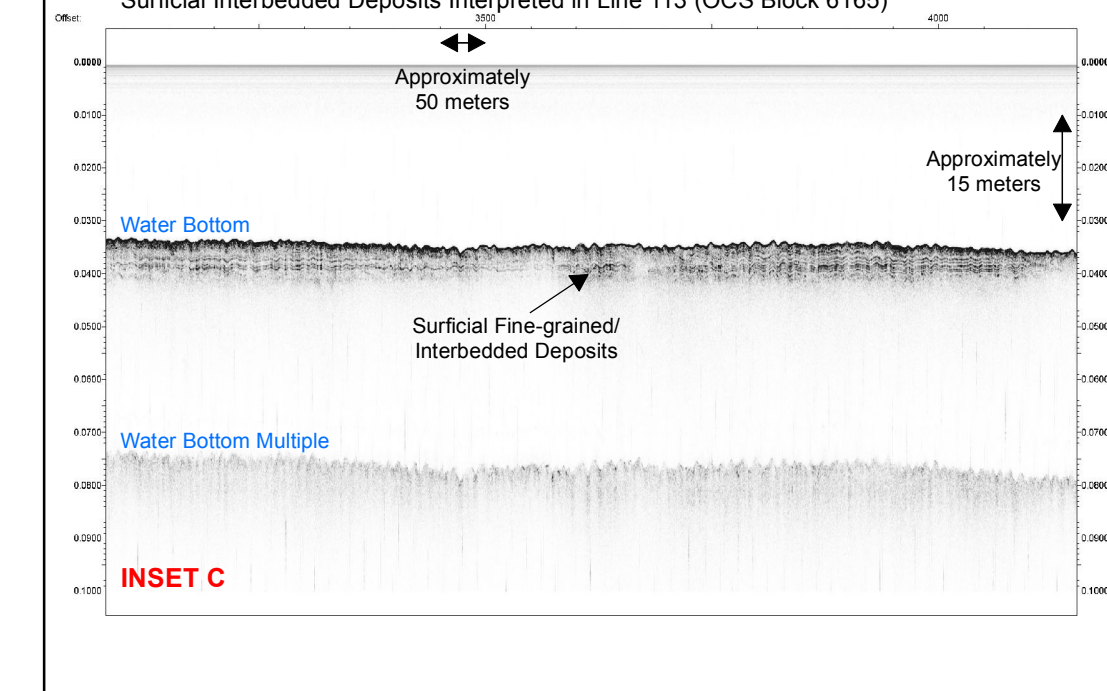
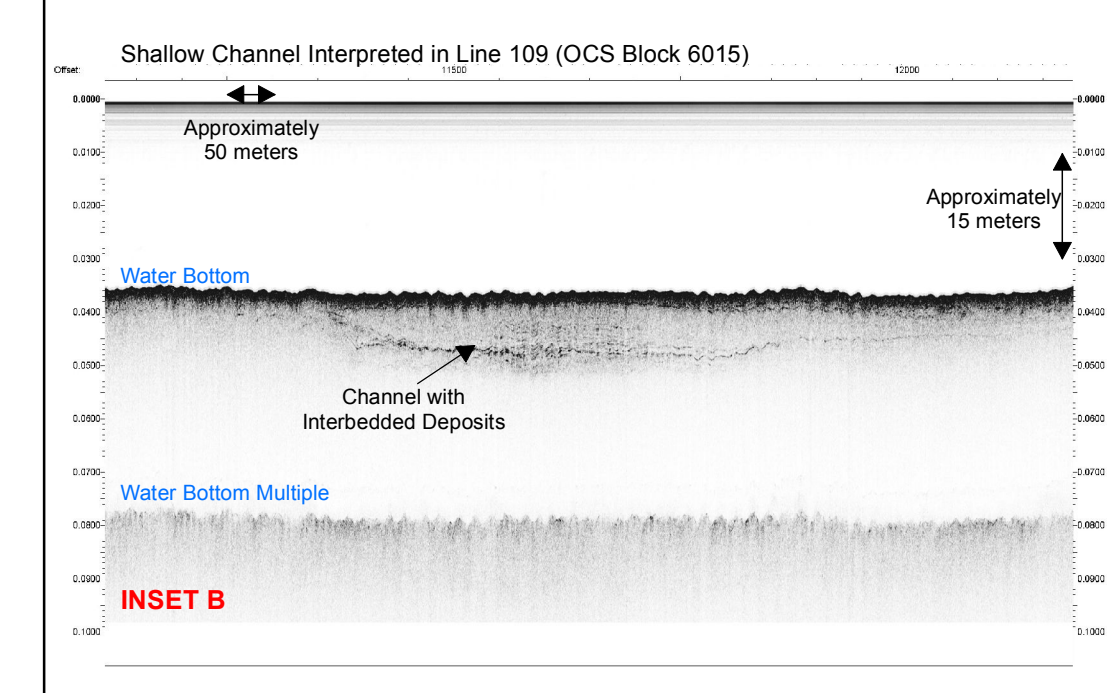
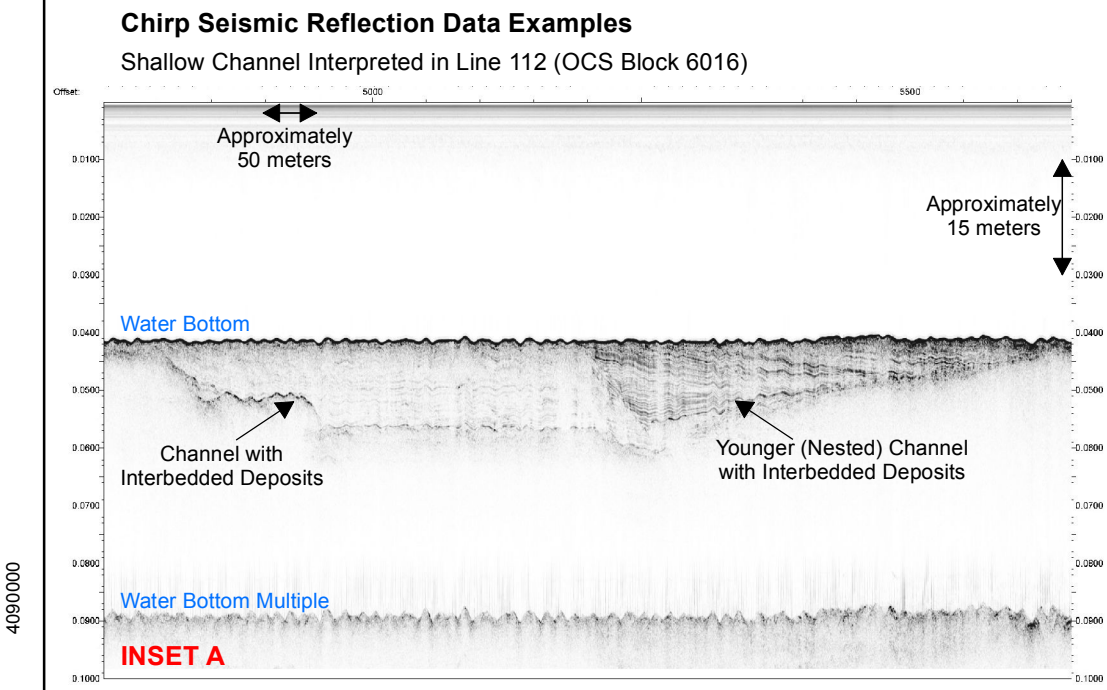
Wind Energy Area OCS Lease Block

Demonstration Project Lease Alquot

Meteorological Tower Alquot

### Subsurface Channels

- Shallow channels interpreted from Chirp data
- Deep channels interpreted from boomer data
- Approximate thalweg elevation (m) and depth below seafloor (m) labeled
- Back-barrier fluvial estuarine environment interpreted from boomer data
- Approximate thalweg elevation (m) and depth below seafloor (m) labeled
- Areas delineated indicate approximate extent of deeper areas. Outflow paths and return routes to some open ocean are not delineated.
- Surficial fine-grained interbedded deposits interpreted in the Chirp data.
- Areas mapped based on low side scan sonar reflectivity and deep (3 to 5m) Chirp signal penetration that reveal layering, acoustical surfaces that suggest possible embayment and fluvial estuarine deposits. Areas commonly correspond to bathymetric lows in between sand ridges.
- See Chirp data examples below for typical seismic records in these areas.

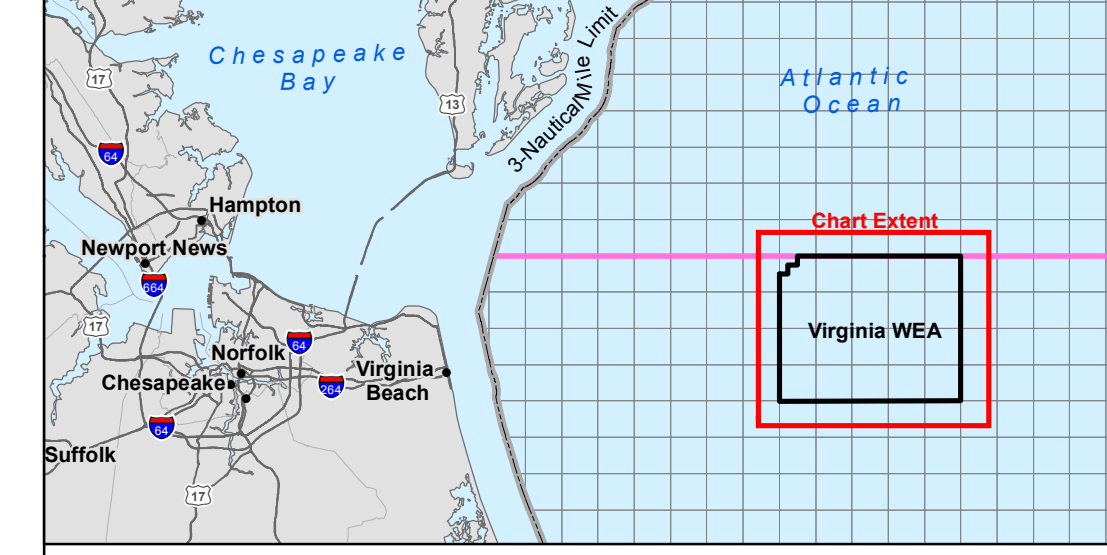


- Notes:
- Marine survey data were collected from May 28 through July 3, 2013 onboard the TAI XIV.
  - Differential Global Positioning System (DGPS) corrections were obtained from Fugro's Startix II wide area differential network, downloaded from a communications satellite.
  - Survey equipment utilized for data collection included the following systems:
    - RG Sonic 2024 Multibeam Echosounder
    - Apollon FCS 8000 Motion and Attitude Recording System
    - EdgeTech Model 4123 Side Scan Sonar System
    - Sonotek Mark 5000 Side Scan Sonar Data Acquisition System
    - Marine Magnetic Corporation SeaSoy Magnetometer
    - EdgeTech 3200 Spread Spectrum Sub-bottom Profiler (Chirp) System
    - EdgeTech Discovery Sub-bottom Profiler Data Acquisition System
    - Applied Acoustics Engineers CDP Seismic Energy Source and Babcock System's Double-plate 'Boomer' System
    - Geotech Seafloor Hydrophone Array Streamer
    - Channels 1-16 at 1.50mg and Channels 17-32 at 3.125mg
    - Blue Ocean Moving Sound Velocity Profiler
    - Cosmos Oceanographics 'ThyPack' Navigation System
    - Startix Sea Navigation

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#### GEODETTIC INFORMATION

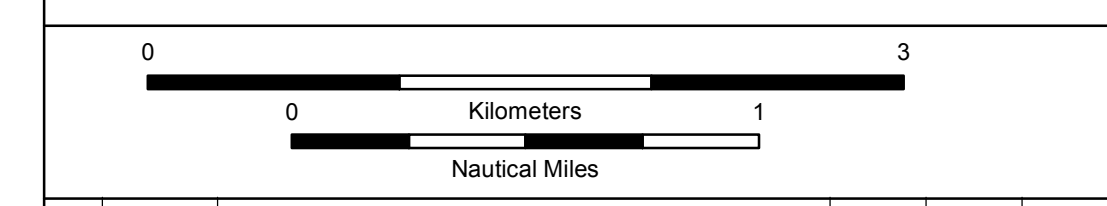
DATUM: NAD 83  
 SEMI-MAJOR AXIS: 6378137.000  
 SEMI-MINOR AXIS: 6356752.314  
 INVERSE FLATTENING: 298.257222101  
 ECCENTRICITY: 0.004474609273  
 PROJECTION: UNIVERSAL TRANSVERSE MERCATOR  
 ZONE: 18N  
 FALSE EASTING: 500,000  
 FALSE NORTHING: 0  
 Coordinates are UTM Zone 18N, NAD 1983, Meters.



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### SUBSURFACE FEATURES

Virginia Wind Energy Area Geophysical Survey  
 Virginia Outer Continental Shelf



NO.	DATE	DESCRIPTION	DRAWN	CHKD	APPR.
1	Aug 2013	Survey Report	JEF	KRS	KRS
2					
3					

**APPENDIX A**  
**SEISMIC DATA PROCESSING**

## APPENDIX A – SEISMIC DATA PROCESSING

Fugro acquired high resolution geophysical data aboard the *Tiki XIV* vessel (Figure 2-1) from May 28<sup>th</sup> through July 3<sup>rd</sup>, 2013 with the Virginia Wind Energy Area (WEA). This appendix describes the seismic reflection data acquisition and processing procedures.

### MULTI-CHANNEL SEISMIC REFLECTION SURVEY

#### Data Collection

An Applied Acoustics Engineering's CSP seismic energy source was used to power the Subsea Systems d-plate "boomer" system. The power source was operated at approximately 1000 joules during this survey. The boomer plate(s) is an electro-mechanical transducer made of an insulated aluminum plate and a rubber diaphragm adjacent to a flat wound electrical coil. A short duration high-energy pulse is discharged from the energy source into the coil and the resulting magnetic field repels the plate in the transducer. The plate motion is transferred to the water by the rubber diaphragm, generating a broadband acoustic pulse that does not have strong cavitation or ringing.

The reflected acoustic signal was received using Geometrics seismic acquisition system 32-channel, Ethernet-based GeoEel digital hydrophone arrays. A single 32-channel hydrophone streamer sorted in two sections. The front section is arranged with 16 channels spaced at an interval of 1.562 meter group interval (MGI). The aft section consisted of 16 channels hydrophones with an MGI of 3.125. Data was recorded. The 16-channel array was configured with a group interval of 1.56 meters (5.126 feet) and was towed approximately 1.5 feet below the water surface. Raw data from the digital streamers were recorded using a. Data were stored on hard disk in SEG Y format for later post-processing. Data were also backed up on DVD and an external hard drive.

#### Data Processing

Data processing of the multichannel seismic reflection profiles acquired followed the basic premise of the wavelet processing method used in the petroleum exploration industry. A single-plate boomer source type was used combined with a 16-channel mini-streamer. The boomer produced a source energy level of about 300 Joules over a broad bandwidth ranging from about 100 Hertz to more than 1,000 Hertz. The 16-channel mini-streamer has a group interval of 1.5625 meters (5.126 feet) and a near trace to source offset of 6.25 meters (20.505 feet). The short offset and group interval of the mini-streamer provides high-resolution imaging of the seafloor and shallow sub-bottom. For the shallow water depth of about 15 meters (50 feet), the total streamer length of 37.5 meters (120 feet) is sufficient to provide some water bottom multiple suppression. The relatively short hydrophone group intervals of each streamer are very important for avoiding spatial aliasing of these digitally sampled data, thereby improving the overall signal-to-noise ratio of the seismic data.

Basic seismic data processing consists of filtering in both time and space, deconvolution to provide a sharper and more consistent seismic wavelet for interpretation, correction of normal move-out due to varying subsurface velocity structure, stacking of data traces to increase the signal-to-noise ratio, and migration to put the reflecting horizons back into their proper lateral positions. A firing rate (pop interval) of 0.5 sec was used for this survey. This provided an

average shot point interval of 1.0 to 1.1 meters, which is about midway between the nominal CMP binning interval of 0.78 meters (2.6 feet) and the 1.56 meters (5.126 feet) hydrophone group interval. To provide the best image resolution for these acquisition parameters, a final binning interval of 0.39 meters (1.3 feet), equal to one-half the nominal binning interval for the streamer group interval was used. To increase fold and signal-to-noise ratio for this short CMP spacing, a three-element source mix was used with weights of 1-2-1 to form an acoustic beam focused downward with minimal side-lobes in the radiation pattern. Further random noise attenuation was accomplished after stacking, but before migration, by applying an F-X predictive filter with a high-cut frequency set to 900 Hertz. The remainder of the processing steps and the specific parameters used are typical for multichannel high-resolution seismic data as described below.

### **Step 1. Trace Editing, Scaling and Filtering**

The first step used in both processing flows, after loading the segy data into the processing workstation, is to filter and scale the data. Preliminary review of data traces to edit or "kill" bad traces is performed. An antialias filter is used as a band-pass filter to avoid aliasing in the time domain above the Nyquist frequency (2,000 Hertz for 0.25-millisecond sample rate) and to remove low-frequency streamer noise, like bulge waves and water wave motion. An Ormsby filter (trapezoid band-pass shape) was used with parameters of 10/15-1500/1800 Hertz for the mini-streamer data. Scaling was then applied in two parts: first to remove the geometrical spreading attenuation with a time varying exponential function with exponent of 0.7, and second to equalize the average amplitudes of each trace in the data set, using an RMS scaling factor for a window of data with reasonable signal-to-noise ratio. The window was set between 40 milliseconds and 200 milliseconds for the data recorded to 250 milliseconds (shallow water). The 1-2-1 weighted trace mix was applied to the data sorted into common offset (channel number) groups providing a downward-focused source array.

### **Step 2. Spiking Deconvolution**

Spiking deconvolution is applied to shrink the original source wavelet down to an "ideal" zero-phase wavelet that is consistent from trace-to-trace and record to record. With infinite bandwidth, this ideal trace would be a delta function, or spike at the appropriate arrival time. For real band-limited data, a Ricker or similar symmetrical wavelet with minimal side-lobes is desired. For these high-resolution data, spiking deconvolution used an operator length of 20-millisecond, and was designed using the same window as for trace scaling above, where good signal-to-noise ratio exists. Another Ormsby filter is applied after deconvolution to eliminate high-frequency noise, using the same parameters of 10/15-1500/1800 Hertz.

### **Step 3. Spatial Filter Design and Velocity Analysis**

After the first trace processing and editing steps, frequency-wavenumber (FK) analysis is done on select shot records to design FK filters to attack spatial aliasing. Aliasing due to inadequate sampling in the spatial domain is often overlooked and may result in data artifacts from aliased high-frequency events that may appear as real reflection events. For marine data, where the velocity of sound in water is about 1,500 meters per second (5,000 feet per second), we can predict the frequencies where coherent noise traveling through the water past the streamer may become aliased: for the 1.56-mgi streamer, the spatial Nyquist frequency is 480 Hertz. These frequencies are lower than much of the source energy, and so array forming in

the streamer must be accomplished to attenuate noise traveling horizontally in the water column. Direct source to streamer wave propagation produces this coherent noise energy as does propeller noise in the water from the shooting vessel as well as from other ships passing through the area. An FK filter is well-suited to this, as it can preserve more of the vertically-incident high-frequency reflection signal. We tried a four-element, uniform weighted, mix of traces in shot gathers to create a hydrophone group array with group length twice the group interval-such an array puts a notch exactly at the spatial alias frequencies- but the mix tends to attenuate other high-frequency signal, including the water bottom in shallow areas where near hydrophone offsets exceed water depths. The FK filters were designed to attenuate the low velocity energy, assumed to be noise in the water column, and preserve high velocity energy from subsurface reflections. The FK filter is followed by another Ormsby band-pass frequency filter set from 50/75 to 640/960 Hertz for the 32-channel mini-streamer data.

Velocity analysis was performed to determine stacking velocities for subsurface reflection events on two profiles. Our processing software utilizes semblance and constant velocity stacked traces to aid in picking stacking velocities, as well as providing predictions of hyperbolic move-out plotted directly on offset gathers of seismic traces. The results of stacked data using the velocity function were virtually identical to that for the constant velocity stacks at 5,000 feet per second. Consequently, no additional velocity analyses were performed for the mini-streamer data, and a constant stacking velocity of 5,000 feet per second was used. Water-saturated sediment velocities in these shallow areas are very close to that of the water column, and sometimes slower due to gas content.

#### **Step 4. Normal Move-out Correction and Stack**

The deconvolved and filtered traces were sorted into the CMP order, spatially filtered (FK filter) and stacked to produce a CMP stack record section. A static shift to correct for elevation (depth) of streamer and source, as well as the tidal elevation was also applied. For a few noisy lines, acquired during the inclement weather, an Alpha-Trim stack summing trace values within 90<sup>th</sup> percentile from the median was applied to reduce noise bursts from water waves and cable jerks. However, most data were acquired during good weather conditions and the full stack with 1/N weighting was applied. For the mini-streamer, nominal fold used in the stack is 1200 percent (i.e., 12 traces per CMP gather were summed based on the 1.1-meter shot spacing and the 0.39 meters [1.3 feet] bin spacing). With the 1-2-1 source array mix the actual fold of the 24-channel mini-streamer stack is closer to 2,400 percent and provided a sharper image of the shallow subsurface including some attenuation of the first water bottom multiple. The post-stack F-X prediction (signal enhancement) step further attenuated random noise providing a more coherent image of the deeper reflections allowing more confident interpretation of subbottom structure and stratigraphy. Navigation and tidal static corrections were written to the trace headers of the stacked data, which then were filtered and output in SEG-Y format for loading into the interpretation workstation. Ormsby filter parameters used after stack were: 80/120-600/900 Hertz for the mini-streamer data.

#### **Step 5. Post-Stack Migration**

Stacked data contain hyperbolic reflections and diffractions that need to be collapsed into proper spatial locations to further sharpen the image of subsurface reflection horizons and faults. We used a simple frequency-wave number migration, which works for all dip angles.

Because these high-resolution data involve shallow, mostly water-saturated subsurface sediments, a constant velocity of 4800 feet per second was used for the migration. Migration velocities are generally lower than stacking velocities because the latter are affected by horizon dip, and migration depends on the actual velocity of the geologic layers (i.e., interval velocities). Data were filtered after migration and saved as SEG-Y data for loading into the interpretation workstation. Ormsby filter parameters were: 25/50-560/840 Hertz for the mini-streamer. The high-cut for these filters is designed to avoid spatial aliasing and remove high-frequency noise from the image. The low-cut for these filters is designed to provide a higher resolution image for the mini-streamer and to maintain at least two octaves bandwidth.

#### **Step 6. Post-Migration Predictive Deconvolution**

Because some reverberation or "ringing" of reflective horizons may appear, a post-migration predictive deconvolution was tested in some areas. Predictive deconvolution in theory operates on zero-offset, vertical-incidence reflection data; the migrated record section is our best approximation to such a reflection profile. Predictive deconvolution is used to attenuate multiples; from the water bottom and from interbed reverberations. Parameters used for the predictive deconvolution were a 16-millisecond prediction distance and a 32-millisecond operator length. Filtering to remove high-frequency noise after deconvolution was applied during initial processing of the seismic data, but resulted in noticeable reduction in signal quality.

**APPENDIX B**  
**SURVEY LINE LOGS**

















## LINE SUMMARY LOG



Client: BOEM	Project No.: 4.81130003	Date:	Wednesday, June 05, 2013
Project Name: VAWEA	Vessel: Tiki 14	Page 5 of 20	Julian Date: 156
Surveyor: FUGRO	Location: Offshore VA	Devices:	SSS, Mag, SBP, Seismic

Survey Date	Line Number	Azimuth	First Shot Point		Last Shot Point		Mag Layback Start		Mag Layback End		Line Number	SSS Layback Start		SSS Layback End		Line Number	SBP Layback Start		SBP Layback End		Seismic Line
			Event No.	Time	Event No.	Time	Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time	
5-Jun	206	116°	200	12:49	404	15:34	61.312	SOL			206	34.464	SOL	37.653	EOL	206	10	SOL	10	EOL	206
							61.312	13:24	78.050	13:25	206.001	31.161	13:24	38.085	13:25	206.001					6173
							78.050	13:32	69.968	13:33	206.002	38.085	14:24	33.758	14:25						
							69.968	14:24	61.601	14:25	206.003	33.758	14:50	42.125	14:51						
							61.601	14:50	77.037	14:51	206.004	42.125	15:15	45.876	15:16						
												45.876	15:18	37.653	15:19						
	207	297°	404	16:19	322	17:24	84.539	SOL			207	37.797	SOL			207	10	SOL	10	SOL	207
							84.539	16:23	89.877	16:24	207.001	37.797	16:23	56.551	16:24						
							89.877	17:10	73.863	17:11		56.551	17:10	50.348	17:11						
	1207	297°	324	17:40	290	18:07	74.007	SOL			1207	47.607	SOL	47.751	EOL	1207	10	SOL	10	EOL	1207
	105	206°	339	18:41	98	21:57	74.007	SOL	66.217	EOL	105	37.364	SOL			105	10	SOL	10	EOL	105
							74.007	19:37	67.083	19:38	105.001	37.364	21:32	26.256	21:33	105.001					6072
							67.083	20:51	66.217	20:52	105.002										12039
											105.003										
											105.004										
	200	116°	112	22:21	137	22:41	66.217	SOL	62.755	EOL	200	26.256	SOL	26.256	EOL	200	10	SOL	10	EOL	200
							66.217	22:38	62.755	22:29											
	106	26°	99	22:54	339	2:09	56.984	SOL			106	16.157	SOL			106	10	SOL	10	EOL	106
							56.984	0:22	65.063	0:23	106.001	16.157	23:27	20.774	23:28	106.001					6073
							65.063	0:35	68.525	0:37	106.002	20.774	0:22	26.833	0:23						
							68.525	1:10	72.998	1:11	106.003	26.833	0:35	32.459	0:37						
							72.998	1:23	77.181	1:24	106.004	32.459	1:10	39.961	1:11						



































### LINE SUMMARY LOG



Client: BOEM	Project No.: 4.81130003	Date: Saturday, June 22, 2013
Project Name: VAWEA	Vessel: Tiki 14	Page 14 of 20      Julian Date: 173
Surveyor: FUGRO	Location: Offshore VA	Devices: SSS, Mag, SBP, Seismic

Survey Date	Line Number	Azimuth	First Shot Point		Last Shot Point		Mag Layback Start		Mag Layback End		Line Number	SSS Layback Start		SSS Layback End		Line Number	SBP Layback Start		SBP Layback End		Seismic Line
			Event No.	Time	Event No.	Time	Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time	
22-Jun	3204	116.3°	112	10:50	122	10:59	70.689	SOL			3204	35.056	SOL			3204	10	SOL	10	EOL	3204
							70.690	10:58	63.188	10:59	3204.001	35.060	10:58	25.679	11:00						9171
							63.190	11:06	20.344	11:07	3204.002	25.678	11:19	33.469	11:20						
							20.340	11:15	37.360	11:16		33.469	12:11	39.240	12:12						
							37.364	11:22	46.886	11:23		39.240	12:38	34.767	12:39						
							46.890	12:11	51.069	12:12		34.767	12:42	41.836	12:43						
22-Jun	1113	26.4°	100	15:24	339	18:38	25.251	SOL		N/A	1113	2.862	SOL			1113	10	SOL	10	EOL	1113
							25.251	15:40	51.351	15:41	1113.001	2.862	15:38	36.931	15:39	1113.001					7080
							51.310	15:53	71.421	15:54	1113.002	36.930	15:52	46.597	15:53						13047
							71.421	17:01	82.591	17:02	1113.003	46.597	17:00	58.725	17:01						
							82.591	18:24	93.473	18:25	1113.004	58.725	18:23	68.093	18:24						
22-Jun	114	206.5°	330	19:03	100	22:10	101.249	SOL			114	76.027	SOL			114	10	SOL	10	EOL	114
							101.249	19:28	94.519	19:29	114.001	76.027	19:26	69.824	19:27	114.001					6081
							94.519	19:37	84.521	19:38	114.002	69.824	19:35	59.725	19:37						12048
							84.521	20:56	73.641	20:57	114.003	59.725	20:55	48.473	20:56						
											114.004										
22-Jun	115	26.4°	99	22:30	284	0:56	75.254	SOL			115	40.971	SOL			115	10	SOL	10	EOL	115
							75.254	22:57	72.010	22:58	115.001	40.970	22:56	48.328	22:57						6082
							72.010	23:57	84.069	23:59	115.002	48.328	23:55	59.148	23:56						
							84.069	0:05	75.518	0:06	115.003	59.148	0:01	50.492	0:02						
											50.492	0:39	57.994	0:40							







## LINE SUMMARY LOG



Client: BOEM	Project No.: 4.81130003	Date: Tuesday, June 25, 2013
Project Name: VAWEA	Vessel: Tiki 14	Page 16 of 20      Julian Date: 176
Surveyor: FUGRO	Location: Offshore VA	Devices: SSS, Mag, SBP, Seismic

Survey Date	Line Number	Azimuth	First Shot Point		Last Shot Point		Mag Layback Start		Mag Layback End		Line Number	SSS Layback Start		SSS Layback End		Line Number	SBP Layback Start		SBP Layback End		Seismic Line
			Event No.	Time	Event No.	Time	Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time		Cable Out (M)	Time	Cable Out (M)	Time	
25-Jun	116	26.5°	99	13:12	247	15:08	67.660	SOL			116	22.216	SOL		EOL	116	10	SOL	10	EOL	116
							67.660	13:39	75.594	13:40	116.001	22.216	13:21	34.912	13:22						6083
							75.594	14:40	94.637	14:41	116.002	34.912	13:37	42.413	13:38						
												42.413	14:41	51.069	14:42						
25-Jun	1117	206.5°	210	15:42	99	17:12	91.464	SOL			1117	50.492	SOL		EOL	1117	10	SOL	10	EOL	1117
							91.464	15:46	78.335	15:47	1117.001	50.492									7084
											1117.002	50.492									
25-Jun	316	26.4°	109	18:08	114	18:13	73.575	SOL	73.575	EOL	316	35.633	SOL	35.633	EOL	316	10	SOL	10	EOL	316
25-Jun	315	26.4°	109	18:46	110	18:47	69.679	SOL	69.679	EOL	315	26.833	SOL	26.833	EOL	315	10	SOL	10	EOL	312
25-Jun	1315	26.4°	109	19:01	117	19:08	69.679	SOL	69.679	EOL	1315	30.295	SOL	30.295	EOL	1315	10	SOL	10	EOL	315
25-Jun	314	206.4°	121	18:27	109	18:37	73.575	SOL	73.575	EOL	314	35.777	SOL	35.777	EOL	314	10	SOL	10	EOL	314
25-Jun	313	206.4°	125	19:21	109	19:34	69.679	SOL	69.679	EOL	313	30.295	SOL	30.295	EOL	313	10	SOL	10	EOL	313
25-Jun	312	26.4°	109	19:44	127	19:59	69.679	SOL	69.679	EOL	312	30.295	SOL	30.295	EOL	312	10	SOL	10	EOL	1312
25-Jun	311	206.4°	127	20:11	109	20:25	69.679	SOL	69.679	EOL	311	30.295	SOL	30.295	EOL	311	10	SOL	10	EOL	311
25-Jun	310	26.4°	109	20:36	127	20:51	69.679	SOL	69.679	EOL	310	30.295	SOL	30.295	EOL	310	10	SOL	10	EOL	310
25-Jun	309	206.4°	127	21:00	109	21:15	69.679	SOL	69.679	EOL	309	30.295	SOL	30.295	EOL	309	10	SOL	10	EOL	309
25-Jun	308	26.4°	109	21:25	90	21:40	69.679	SOL	69.679	EOL	308	37.220	SOL	37.220	EOL	308	10	SOL	10	EOL	308
25-Jun	307	206.4°	127	21:49	109	22:04	69.679	SOL	69.679	EOL	307	37.220	SOL	37.220	EOL	307	10	SOL	10	EOL	307
25-Jun	306	26.4°	109	22:15	127	22:29	69.679	SOL	69.679	EOL	306	37.220	SOL	37.220	EOL	306	10	SOL	10	EOL	306
25-Jun	305	206.4°	127	23:24	109	23:39	69.679	SOL	69.679	EOL	1305	37.220	SOL	37.220	EOL	1305	10	SOL	10	EOL	1305
25-Jun	304	26.4°	109	23:00	127	23:15	69.679	SOL	69.679	EOL	304	37.220	SOL	37.220	EOL	304	10	SOL	10	SOL	304
25-Jun	303	206.4°	109	23:48	127	0:03	69.679	SOL	69.679	EOL	303	37.220	SOL	37.220	EOL	303	10	SOL	10	EOL	303
25-Jun	302	206.4°	127	0:10	110	0:24	69.679	SOL	69.679	EOL	302	37.220	SOL	37.220	EOL	302	10	SOL	10	EOL	302
25-Jun	301	26.4°	118	0:33	128	0:41	69.679	SOL	69.679	EOL	301	37.220	SOL	37.220	EOL	301	10	SOL	10	EOL	301
25-Jun	300	206.4°	127	0:51	121	0:56	69.679	SOL	69.679	EOL	300	37.220	SOL	37.220	EOL	300	10	SOL	10	EOL	300













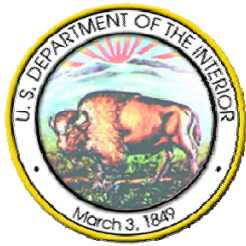


**APPENDIX C**

**MAGNETIC ANOMALY TABLE**

**APPENDIX D**

**SIDE SCAN SONAR TARGET TABLE**



### **The Department of the Interior Mission**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.



### **The Bureau of Ocean Energy Management**

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.