**Agreement: M14AC00006 Massachusetts Geological Survey/University of Massachusetts; Hurricane Sandy Coastal Recovery and Resiliency - Sand Resources Needs Assessment at Critical Beaches on the Massachusetts Coast - Supplement**

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**Technical Report**

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**Abstract**

A total of 210 km (126 miles) of geophysical data, 8 vibracores and 7 grab samples were collected by CB&I of Boca Raton, FL, in 2015, to aid in determining the extent, character, thickness, volume (if feasible) and suitability of sand resources for beach nourishment in six areas located in federal waters off the coast of Massachusetts. The six areas analyzed were selected by the Massachusetts Office of Coastal Zone Management (CZM) based on proximity to potential beach nourishment projects. The six areas include: Buzzards Bay 8.8 km (5.5 miles) southwest of Cuttyhunk; Nomans Land approximately 11.7 km (7 miles) south southwest of Squibnocket Point on Martha's Vineyard; Muskeget Channel located at the south end of the channel separating Nantucket and Martha's Vineyard; Nantucket 8 km (5.5 miles) due south of Surfside on Nantucket Island; Marshfield 11.2 km (7 miles) due east of Scituate; and Plum Island located 5.6 to 8 km (3.5 to 5 miles) east of the Plum Island barrier beach in Newburyport and Ipswich. Seismic profile data were processed in SIOSEIS and SeisUnix and interpreted in conjunction with existing bathymetry, side scan sonar, surface grab sample and vibracore data.

The lack of data in some locations and the quality of much of the CB&I seismic reflection profile data did not allow estimation of sand volumes except for Marshfield. Rather, estimates of sand thickness were determined along individual tracklines when possible and not without the aid of other geophysical data collected in previous studies.

The Muskeget Channel, Nantucket and Plum Island sites show the greatest promise as sources of sand for beach nourishment projects. At Muskeget Channel, recent sands overlie marine fan deposits and have a combined total thickness ranging from 0 to 10 meters (0 to 33 feet). Underlying the fan deposit are sandy outwash deposits of unknown thickness. No lake or glacial till deposits are expected at this site as it lies outboard of the last glacial terminal moraine. The sediment is consistently fine and fine-to-medium sand with 1-10% coarse sand. The sediments at Muskeget Channel are slightly finer than the deposits found on nearby Miacomet and Low beaches on Nantucket.

The Nantucket site consists of a modern bar complex but a lack of data precludes estimating thickness. Based on the limited vibracore and grab sample data the sediment at the Nantucket site consists of fine and fine-to-medium sand with occasional pebbles and gravel. These sediments are also slightly finer in texture than the sediment at adjacent beaches on Nantucket Island.

Plum Island has the greatest sand potential because it is located near an extensive low-stand delta deposit. The site consists of a highly eroded and undulating fluvial channel system feeding the delta and is overlain by a thin but variable thickness marine sand sheet that changes morphology with each storm event. These fluvial deposits are underlain by fine-grained marine sediments. Total thickness of the sand sheet and fluvial sediments varies from 6 to 12 meters (20 to 39 feet) in the western two-thirds of the site and thickens to 14 to 22 meters (46 to 79 feet) in the eastern third of the site, with the thickest area occurring just east of the site boundary. The sediments consist of fine and fine-to-medium sand with pockets of medium-to-coarse sand and very coarse sand and gravel. The beach at nearby Plum Island has median grain sizes in the coarse to very coarse sand range and are generally comparable to the offshore sediments.

Marshfield contains a lenticular body of sand and gravel up to 12 meters (39 feet) thick that overlies lake bottom and glacial till deposits.  The estimated volume of this material is 40,000,000 cubic meters (52,000,000 cubic yards).  The areal extent of the sand and gravel body is approximately 7 square km (2.7 square miles).  The deposit is very rocky with medium to coarse quartz sand and was most likely derived from the nearby glacial till deposits.  This site may be a suitable supply for Humarock, Scituate, Peggotty and Plymouth beaches on the mainland, which have coarse, very coarse and gravelly to cobbly substrates.

Buzzards Bay is mostly all glacial till or lake bottom sediments and is not considered a suitable site for sand.  The thickness of the till and lake bottom sediments is unknown.  The till deposits contain numerous large boulders up to 9 meters (30 feet) in size.  However, there is evidence of a channel fill deposit at the northeast end of the site that may have been part of a channel system draining glacial lakes in Rhode Island Sound and Buzzards Bay.  Thickness of the channel fill may range from 5 to 13 meters (16 to 42 feet) and may warrant further investigation.

The Nomans Land site lies on the terminal moraine of the last glaciation and consists entirely of glacial till of unknown thickness.  Large surface boulders up to 3 to 9 meters (10 to 30 feet) are observed on the side scan sonar imagery.  Occasional and discontinuous pockets of medium to coarse sand may occur within the deposit occupying < 10% of the area of the unit.  The site is not considered suitable as a source of sand.

## Introduction

The following is the technical report for Agreement M14AC00006: Massachusetts Geological Survey/University of Massachusetts – Sand Resources Needs Assessment at Critical Beaches in Massachusetts - Supplement. The purpose of this report is to summarize the results of work conducted to process and evaluate geophysical data collected in conjunction with vibracore and grab samples to determine the extent, character, volume (if feasible) and suitability of sand resources for beach nourishment in six areas located in federal waters off the coast of Massachusetts. The six areas analyzed were selected by the Massachusetts Office of Coastal Zone Management (CZM) based on proximity to potential beach nourishment projects. The six areas include: Buzzards Bay, Nomans Land, Muskeget Channel, Nantucket, Marshfield, and Plum Island (Figure 1).

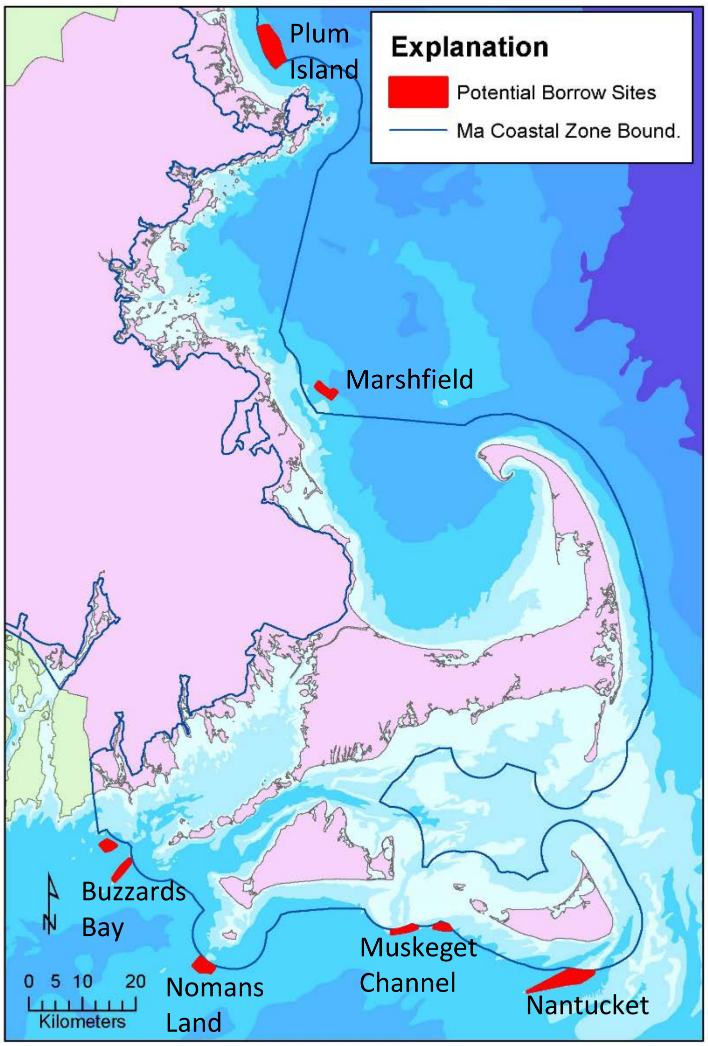


*Figure 1. Location of potential offshore borrow areas with the assigned names corresponding to the text.*

## Background

The results presented in this technical report represent the second phase of a larger, two-part project. In 2014, UMass Amherst, in cooperation with CZM, entered into a 2-year cooperative agreement (Phase 1) with the Bureau of Ocean Energy Management (BOEM) to assess the condition of 18 Massachusetts public beaches that are experiencing erosion and which have infrastructure that is at risk. For that project, a total of 234 topographic profiles (winter and summer combined) surveyed normal to the beaches plus 889 sediment samples and 86 pebble counts (winter and summer combined) were collected and analyzed for the following beaches: 1) Barges Beach, Gosnold, East and Horseneck Beaches, Westport, Low and Miacomet Beaches, Nantucket, Surf Beach, Falmouth, Town Beach, Oak Bluffs (also referred to as Pay and Inkwell beaches) and Sylvia State Beach, Oak Bluffs and Edgartown during August/September 2014 and March, 2015; and, 2) Humarock Beach, Scituate, Nahant Beach, Nahant, Nantasket Beach, Hull, Peggotty Beach, Scituate, Plum Island, Newbury and Newburyport, Long Beach, Plymouth (referred to as Plymouth), Revere Beach, Revere, Long Beach, Rockport (referred to as Rockport), Fieldston/Brant Rock Beach, Marshfield (collectively referred to as Marshfield) and Salisbury Beach, Salisbury during August/September, 2015 and March, 2016. Sediment samples/pebble counts were collected at low tide, mid tide, and high tide positions, the berm crest and dune, if present. Between 2 and 10 profiles were surveyed at each beach, depending on the length of the beach, using a Topcon GTS 210 total station and/or a real time kinematic Trimble R8 Global Navigation Satellite System (GNSS) connected to the cellular network. Spacing between profiles ranged from 80 to 600 meters. The final report and all of the data from Phase 1 can be found at: [ftp://eclogite.geo.umass.edu/pub/stategeologist/BOEMData/](ftp://eclogite.geo.umass.edu/pub/stategeologist/BOEMData/)

In 2015, BOEM contracted with CB&I to collect geophysical data, vibracores, and grab samples in offshore areas selected by each of the Atlantic Coast states. In Massachusetts, CB&I collected a total of 210 km of seismic reflection profile data, swath bathymetry, magnetometer and side scan sonar data, 8 vibracores and 7 grab samples in the project areas shown in Figure 1. The geophysical data were not processed by CB&I. The vibracores, however, were split, photographed, described and sub-sampled by CB&I for grain size analysis along with the grab samples. The geophysical and geological data were bundled together by CB&I and provided to the states by BOEM in September 2016.

The purpose of this second phase of the project (Phase 2) and the subject of this technical report is to: 1) process and interpret the geology from seismic profile data; 2) evaluate and interpret the side scan sonar and bathymetric data; 3) determine the areal extent and volume (if possible) of any sand resources; 4) review the vibracore and grab samples to evaluate the character and suitability of any sand resources for nourishment; and, 5) examine other sources of data to assist with the sand resource assessment.

## Relevance of This Project

Coastal communities in Massachusetts are vulnerable to erosion and relative sea level rise. Extensive development and armoring of shorelines, largely prior to coastal management regulations, have contributed to a severe reduction in the natural supply of sediment to beach systems, resulting in shoreline erosion and loss of dunes—which magnifies the vulnerability of the natural and built environment to coastal storms now and in the future. With accelerated rates of sea level rise and more frequent and intense storms, low-lying coastal areas are increasingly vulnerable to erosion and inundation.

Nourishment has significant appeal over armoring approaches that interrupt natural sediment transport and littoral cells. Massachusetts sediment assets, within its nearshore navigation channels and offshore ocean areas, as well as adjacent federal waters, offer great potential for addressing the sediment deficit on beaches. While marine sediments are routinely extracted for beach nourishment and shoreline stabilization projects in other areas of the United States and across the globe, Massachusetts' experience has been limited primarily to the beneficial re-use of compatible dredged material and nourishment using upland sources.

The Commonwealth of Massachusetts is now proactively promoting beach nourishment throughout the state. For example, the importance of this issue was recognized by the Coastal Hazards Commission, which was mandated by the state legislature to develop recommendations for addressing coastal hazards issues in Massachusetts. In 2007, the Commission recommended that Massachusetts should ***implement a program of regional sand management through policies, regulations, and activities that promote nourishment as the preferred alternative for coastal hazard protection*** (https://www.mass.gov/files/documents/2016/08/rv/chc-final-report-2007.pdf for background, more information, and the full list of recommendations). The 2011 Massachusetts Climate Change Adaptation Report also explicitly promotes the use of soft engineering approaches that supply sediment to resource areas, such as beaches and dunes, to manage the risk to existing coastal development while minimizing adverse impacts to coastal processes (see https://www.mass.gov/files/documents/2017/11/29/Full%20report.pdf for the complete report). In addition, the scope for updating CZM's 2009 Ocean Management Plan includes ***a task to identify appropriate locations for offshore sand resource areas for use as sources of sand for beach nourishment projects***.

**Methods**

Chirp Sub-Bottom Data

Chirp sub-bottom data were collected by CB&I with an EdgeTech 3200 sub-bottom profiler with a 512i towfish. Chirp sub-bottom data were collected using a sweep frequency pulse between 0.5 to 12 kHz. This instrumentation generates cross-sectional images of the seabed capable of resolving bed separation resolutions of 0.06 to 0.10 meters (depending on selected pulse/ping rate). The tapered waveform spectrum results in images that have virtually constant resolution with depth. These data were collected and recorded in the system's native EdgeTech .jsf format. Navigation and horizontal positioning for the sub-bottom profiler system were provided by the C-Nav 3050 DGNSS system (system accuracy of 10 to 15 cm) via Hypack 2015 utilizing the Hypack standard towfish layback driver. Forward/aft and port/starboard fish tow point offsets were measured (to within 25 cm) in relation to the C-Nav DGNSS antennae and input to the Hypack towfish driver as offsets. In addition, a catenary factor (to account for tow cable tow angles/depths) together with the measured amount of "cable out" deployed from the tow point (to within 25 cm) were input to the Hypack standard towfish layback driver. The Hypack standard towfish layback driver calculated the towed position of the sub-bottom profiler towfish and supplied this position to the sub-bottom profiler system at 1 Hz. These layback-corrected positions were recorded within the raw sub-bottom profile digital .jsf file. Thus, data have been corrected for navigational offsets and towed laybacks. These data were collected July 20, 2015 to

July 26, 2015 and are presented in the NAD 1983 Universal Transverse Mercator (UTM) Zone 19N projection.

Sub-bottom profile data were analyzed at UMass Amherst by Dr. William P. Clement, a geophysicist in the Department of Geosciences. SIOSEIS was used to process the .jsf files. Step one in processing involved removing large “spikes” from the data. Then two adjacent traces were summed into one trace to enhance signal to noise. Summing was accomplished with the median stacking algorithm in SIOSEIS. Median stacking finds the median value of the amplitude of the traces to be stacked and sums a percentage of the trace values relative to the median value. The influence of ocean waves was removed by applying a filter that dampens the effects of ship heave. The process computes the average time of the water bottom arrival time of 51 traces and corrects the water bottom arrival time of the middle trace by shifting it by the difference between the middle trace water bottom arrival time and the average water bottom arrival time of the 51 traces. Two gain enhancements were applied. First, a simple gain where the amplitude is increased based on the travel time raised to the 1.5 power. Second, an automatic gain control (AGC) was applied, a commonly used gain designed to enhance low amplitude events. The final step involved converting two-way travel time to depth using a velocity of 1500 m/s for the speed of sound through saltwater. Final plots of the data were made using SeisUnix software. Plots were converted to jpegs (Figure 2). All seismic data were sent to Ralph Lewis, marine geologist, for interpretation. His findings are provided in Appendix A of this technical report.

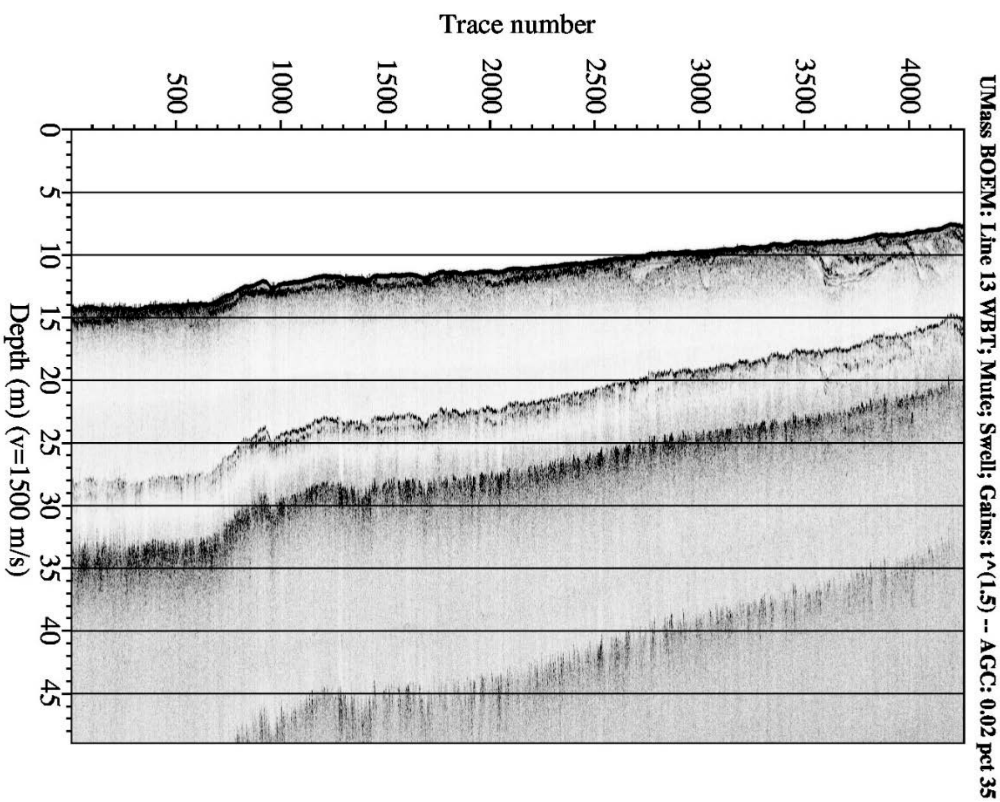


*Figure 2. Example of processed seismic profile (Line MA_013) located in Muskeget Channel.*

Swath Bathymetry Data (Bathymetry and 550 kHz Side Scan Sonar)

Interferometric bathymetry data were collected by CB&I using an EdgeTech 6205, a fully integrated swath bathymetry and dual frequency sidescan sonar system that uses chirp pulse modulation for both the swath hydrographic and seafloor backscatter data collection. The system's configuration included an over-the-side vessel pole mount and sound velocity sensor at the sonar head integrated with a standard motion reference unit and sound velocity profiler. The bathymetric sonar data were collected using a frequency of 550 kHz, which is the optimal setting for shallower water depths and higher resolution data collection. Patch tests were conducted to precisely determine the static position of the sonar head and to quantify any residual roll, pitch, and yaw biases with respect to the vessel reference frame. Latency tests were conducted to verify time synchronization of the navigation and bathymetric systems. All bathymetric data have been corrected for navigational offsets. Post-processing of the raw bathymetry data was done in Hysweep 2015 MBMAX64 Editor. Navigation and horizontal positioning for the EdgeTech 6205 interferometric sonar bathymetry data was provided by an Applanix POS m/v 320 with an Auxiliary C-Nav GPS with SBAS corrections. These data were collected July 22, 2015 to July 27, 2015 and provided in the NAD 1983 Universal Transverse Mercator (UTM) Zone 19N projection. Final vertical data are provided in meters relative to the North American Vertical Datum of 1988. All bathymetry data are provided as ASCII XYZ format and the 550 kHz side scan sonar data are provided as .jsf files.

The bathymetry data were imported into ArcGIS 10.4.1 and converted to a raster using the mean for the cell assignment, none for the priority setting and 3 m for the cell size. Once converted, the raster was hillshaded using a sun azimuth of 315° and altitude of 45°. No vertical exaggeration was assigned. There were some issues with the bathymetry data collected by CB&I. The edges of each swath were clipped due to poor quality resulting in non-overlapping swaths. This resulted in gaps between adjacent tracklines. Contact was made with CB&I but they were unable to resolve the issue. Accordingly, other sources of bathymetric data were examined to help fill in the gaps although none were at a 3-meter resolution.

Side Scan Sonar Data (300 kHz)

The 300 kHz side scan sonar data were collected with an EdgeTech 4200-HFL sonar system. This system uses full-spectrum chirp technology to deliver wide-band, high-energy pulses coupled with high resolution and superb signal-to-noise ratio echo. The portable sidescan sonar package included a laptop computer running the Discover® acquisition software and 300 kHz frequency towfish running in high definition mode. At 300 kHz, the maximum range scale is 150 meters. The sensor was towed from a marine grade hydraulic winch in order to adjust for changes in the seafloor and maintain a depth that is 10-20% of the range of the instrument per BOEM guidelines. The frequency of this system is capable of identifying seafloor objects and features of at least one (1) meter in diameter. Navigation and horizontal positioning for the sidescan sonar system were provided by the C-Nav 3050 DGNSS system (system accuracy of 10 to 15 cm) via Hypack 2015 utilizing the Hypack standard towfish layback driver. Forward/aft and port/starboard fish tow point offsets were measured (to within 25 cm) in relation to the C-Nav DGNSS antennae and input to the Hypack towfish driver as offsets. A catenary factor (to account for tow cable tow angles/depths) together with the measured amount of "cable out" deployed from the tow point (provided in real time by a digital cable counter) were input to the Hypack standard towfish layback driver. The Hypack standard towfish layback driver calculated the towed position of the sidescan sonar towfish, and supplied this position to the sidescan sonar system at 1 Hz. These layback-corrected positions were recorded within the raw sidescan sonar digital .jsf file. These data were collected July 20, 2015 to July 26, 2015 and are provided in NAD 83 UTM Zone 19N projection.

Processing of 300 and 550 kHz Side Scan Sonar Data

Jsf files of the sidescan sonar data were imported into SonarWiz 7.0 using the default settings for scaling and auto bottom tracking. Some bottom-tracking edits to clean up edges were completed manually. Other post-processing steps included TVG (time-varying gain) adjustments to generate a uniform brightness across the full swath width, EGN (empirical gain normalization) adjustments to normalize the data to produce better contrast ratios and more uniform appearance, and a nadir filter to reduce artifacts associated with nadir look angles (e.g., effects of the water column). The de-striping filter was tried but found to degrade image quality by reducing image contrast without significantly improving interpretability; it was disabled and the final images show moderate striping.

Four mosaics were composed at each of the six study areas: one for each sonar frequency and for each tow direction. As needed, gains on individual tracks were tweaked within each mosaic at each study area to remove any remaining variations in average brightness. The auto-scaling feature was turned off and the color ramp was scaled manually for each mosaic to minimize clipping of higher-valued pixels. This approach preserves the full color range when exported to ArcGIS, maximizing the interpretability of the images. The 550 kHz sonar data also required a 4.14-meter navigational offset correction (to starboard) that was applied under the file manager function in SonarWiz.

Filtered sonar data were exported to ArcGIS at very high spatial resolution (0.25 m/pixel) to preserve spatial detail. In ArcMap, pyramids were built with bilinear resampling for smooth appearance for zoomed-in display. Gamma values were tweaked to optimize readability without saturating or starving the image, and to balance overall brightness in the mosaic for each site. A custom color ramp was built to replicate the SonarWiz Mst Bronze palette. This palette is designed to provide good visual discrimination of features at the low ("dark") end of the spectrum, which enhances low-amplitude ripples and fishing drag lines. These final processed mosaics (Figure 3) were used in conjunction with the bathymetry, sub-bottom profile data, vibracores and grab samples to map the surficial geology of the seafloor.

Magnetometer Data

Magnetometer data were collected using a Geometrics G-882 Digital Cesium Marine Magnetometer provided in .RAW Hypack file format. These data were collected July 20, 2015 to July 26, 2015 and are provided in the NAD 1983 Universal Transverse Mercator (UTM) Zone 19N projection. The magnetometer was run on 110/220 volts alternating current (VAC) power and capable of detecting and aiding the identification of any ferrous, ferric or other objects that may have a distinct magnetic signature. Factory set scale and sensitivity settings were used for data collection (0.004 nT/ πHz rms [nT = nanotesla or gamma]). Typically, 0.02 nT P-P [P-P =

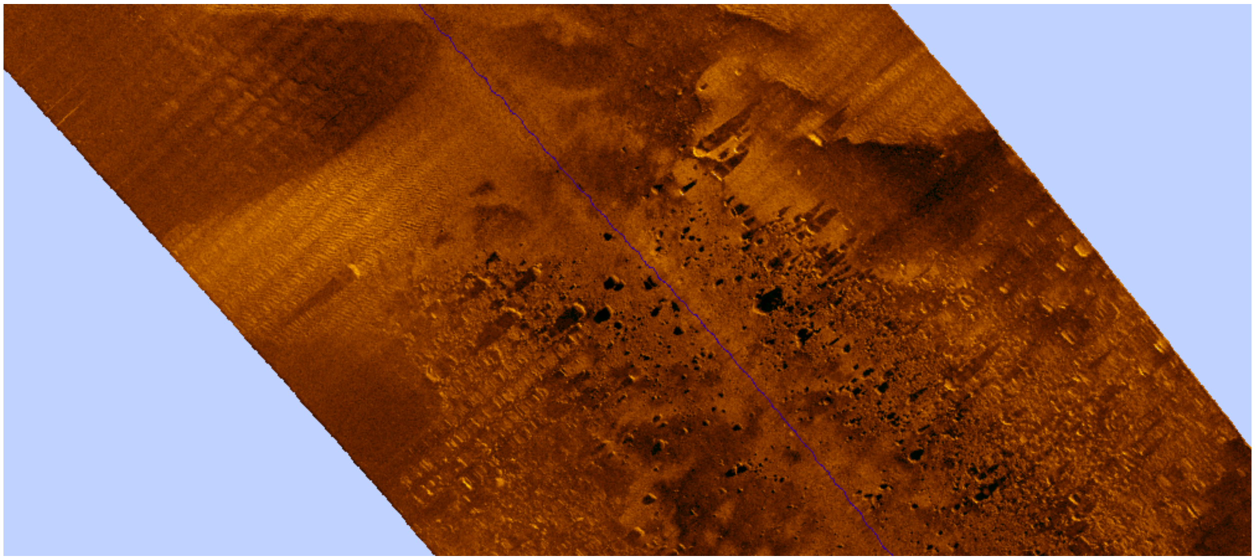

*Figure 3. Example of processed 300 kHz side scan sonar image of Line MA-001. Boulders up to 5 m are evident in the till deposit (lower 2/3 of image) and there is a veneer of sand with bedforms over lake bottom deposits (upper third of image). Image is from the Buzzards Bay site. Scale approximately 1 inch = 2000 feet.*

peak to peak] at a 0.1 second sample rate or 0.002 nT at 1 second sample rate). Sample frequency is factory-set at up to 10 samples per second. The instrument sensitivity is 1 gamma.

The magnetometer was towed in tandem with and 10 meters behind the primary sidescan sonar towfish. The tandem system was attached to a marine grade hydraulic winch to adjust for changes in water depth and maintain an altitude of no greater than 6 meters above the seafloor. Horizontal positioning was supplied by a C-Nav 3050 DGNSS system via Hypack 2015. A navigational correction of -8 meters was applied to the data to account for the 10 meters of magnetometer cable layback behind the side scan sonar towfish allowing for an 80% catenary in that cable.

The magnetometer files were imported into SonarWiz 6.0 version 6.05.0025, using the Hypack raw file magnetometer template and down-sampling to 1 Hz. The data were exported as ASCII CSV files with columns for date, time, latitude, longitude, easting, northing, and gamma value. Profiles of magnetic intensity (gamma units) versus record number were created in SonarWiz 6.0 with no smoothing (Figure 4). The magnetic intensity data were converted to a shapefile in ArcGIS version 10.3.1 and plotted (Figure 5). Magnetometer results and a report summarizing those results are provided in Appendix B of this technical report.

<u>Vibracore and Grab Sample Collection and Analysis</u>

All vibracore and grab samples were collected and analyzed by CB&I as follows: The vibracores were collected using a 271B Alpine Pneumatic vibracore, configured to collect undisturbed sediment cores up to 6 meters (20 feet) in length. This self-contained, freestanding pneumatic vibracore unit contains an air-driven vibratory hammer assembly, an aluminum H-beam which

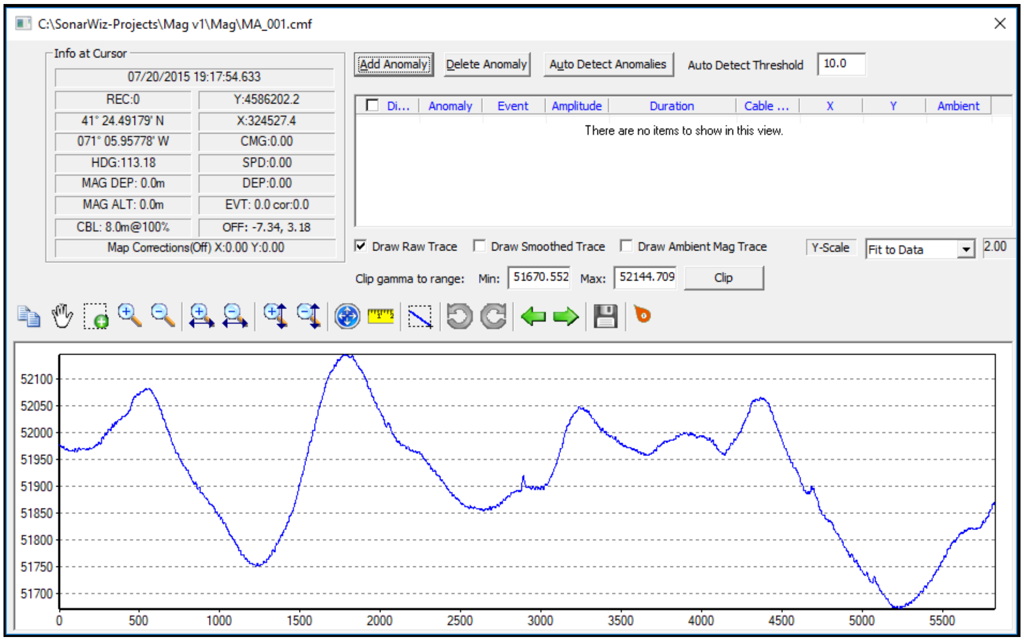


*Figure 4. Magnetic intensity (gamma, y-axis) versus record number for track line 001 in the Buzzards Bay region.*

acts as the vertical beam upright on the seafloor, 6-meter long steel tubes measuring 10.2 cm (4 inches) in diameter (with a plastic core liner), and a drilling bit with a cutting edge.

An air hose array provides compressed air from the compressor on deck to drive the vibracore. The vibracore unit was deployed from an A-frame on the M/V Thunderforce. The desired penetration depth was 6 meters (20 feet). However, maximum penetration was not always achieved at all sample locations. A minimum of 80 percent of the expected penetration was required through the unconsolidated strata. When located over a boring site, every reasonable effort was made to reach the required depth or to reach penetration refusal. Penetration refusal was completed when less than 30.5 cm (1 foot) of advance was accomplished after 5 minutes of vibration. When refusal was met at less than 80 percent of the desired depth of penetration, the sampled portion was removed and a new core pipe was set up. A jet pump hose was attached to the tip of the core pipe just below the vibrator. The rig was lowered to the bottom and jetted down to a depth 61 cm (2 feet) above where the first attempt met refusal. The jet was then turned off and the vibrator turned on, taking the additional part of the core and 61 cm (2 feet) of overlap. Retries were accomplished until penetration had reached the required depth, until refusal, or until three (3) retries were attempted, whichever occurred first. The jetted cores were labeled with an “A” for the first jetted section and a "B" for the second jetted section after the core name. The vibracores were then removed from the vibracore unit. They were measured, marked and cut into 5 foot sections. The total length of recovery was measured and compared to the measured depth of penetration to calculate percent recovery. Penetration was determined with the use of a penetrometer and chart recorder. Depth of penetration beneath the surface of the bottom was known to be within plus or minus 15 cm (0.5 feet) of actual penetration. Each vibracore was labeled onboard the vessel.

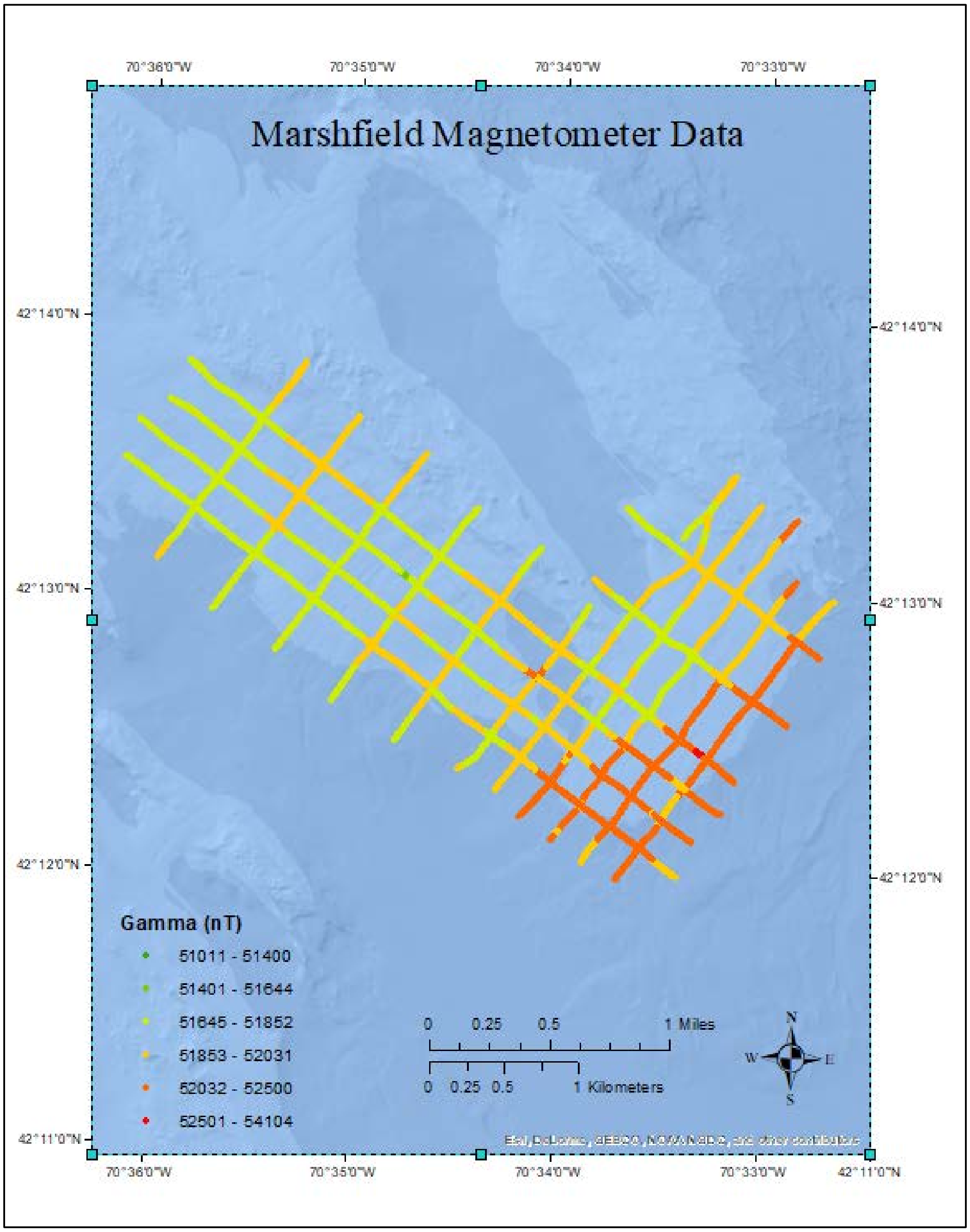


*Figure 5. Plot of magnetometer values in Marshfield.*

A Ponar petite grab sampler was used for collection of unconsolidated surface samples. The Ponar was lowered by hand over the side to the seafloor at pre-determined and pre-approved sample locations. Once near the seafloor, the Ponar was allowed to free fall, triggering the sampling device to penetrate and close into the seafloor, collecting a surface sediment sample. The Ponar was then retrieved to the deck of the vessel, and the sample placed in secure sample bags for transport back to CB&I's geotechnical laboratory for visual description, photographing and sediment analysis.

Upon completion of field operations, all vibracores were transported to CB&I's office in Boca Raton, Florida. The vibracores were split lengthwise and logged in detail by describing sedimentary properties by layer in terms of layer thickness, color, texture (grain size), composition and presence of clay, silt, gravel, or any other identifying features in accordance with American Society for Testing and Materials (ASTM) standard procedure D 2488-09a. The vibracores were photographed in 61 cm (2.0 foot) intervals using an Olympus C-765 digital camera that was mounted on a frame directly above the vibracores. The photographs were taken using full spectrum overhead lighting and an 18% gray background, which provides a known reference color and is the standard reference value against which camera light meters are calibrated. Sediment samples were extracted from the vibracores at irregular intervals based on distinct stratigraphic layers in the sediment sequence. The vibracores were then wrapped and boxed for transfer to a BOEM-designated archive facility according to that facility's requirements.

Sedimentary properties of the grab samples were also described. Each grab sample was split into two representative sub-samples, one sub-sample was used to conduct the laboratory analysis and the other sub-sample was provided to the BOEM-approved archive facility. All sediment samples were analyzed to determine color and grain size distribution. During sieve analysis, the wet, dry and washed Munsell colors were recorded. Grain size was determined through sieve analysis in accordance with ASTM Standard Materials Designation D422-63 for particle size analysis of soils. This method covers the quantitative determination of the distribution of sand particles. Sediment finer than the No. 230 sieve (4.0 phi) was analyzed following ASTM Standard Test Method Designation D1140-00. Mechanical sieving was conducted using calibrated sieves with a gradation of half phi intervals. Additional sieves representing key ASTM sediment classification boundaries were also included to meet appropriate beach-compatible mineral characterization. Weights retained on each sieve were recorded cumulatively. Grain size results were entered into the gINT® software program, which computes the mean and median grain size, sorting, silt/clay percentages for each sample using the moment method.

<u>Other Geophysical Data</u>

For this study, several other sources of data were used to augment the data collected by CB&I. These other sources of data include bathymetric, side scan sonar and seismic profile data (Tables 1, 2, and 3). There are two reasons why this information was needed. First, the bathymetric data collected by CB&I was limited because the edges of each swath were clipped, leaving gaps between tracklines. Second, the Chirp data collected by CB&I was not very useful. No amount of processing improved discrimination of seismic units. This limits data interpretation. In addition, the data density is low, further limiting confident interpretation. There are several locations with no vibracore or grab samples to confirm substrate materials. Accordingly, interpretation must rely on other sources of data. However, even with the inclusion of outside sources of data, it is not possible to construct isopach maps for each area. In most areas it was only possible to determine whether sand exists. In some cases, a minimum thickness is provided if there is vibracore data or if the quality of the seismic data is sufficient to interpret seismic units along individual tracklines.

*Table 1. Listing of Other Bathymetric Data Sources Including Links to the Data and Accompanying Reports*

| | |
|---|---|
| Marshfield | Pendleton, E.A., Baldwin, W.E., Barnhardt, W.A., Ackerman, S.D., Foster, D.S., Andrews, B.D., and Schwab, W.C., 2013, Shallow geology, seafloor texture, and physiographic zones of the Inner Continental Shelf from Nahant to northern Cape Cod Bay, Massachusetts: U.S. Geological Survey Open-File Report 2012–1157, 53 p., https://pubs.usgs.gov/of/2012/1157/ |
| Plum Island | Barnhardt, W.A., Andrews, B.D., Ackerman, S.D., Baldwin, W.E., and Hein, C.J., 2009, High-resolution geologic mapping of the inner continental shelf; Cape Ann to Salisbury Beach, Massachusetts: U.S. Geological Survey Open-File Report 2007-1373, variously paged, DVD-ROM and available online at https://pubs.usgs.gov/of/2007/1373/ |
| Buzzards Bay | Foster, D.S., Baldwin, W.E., Barnhardt, W.A., Schwab, W.C., Ackerman, S.D., Andrews, B.D., Pendleton, E.A., 2016, Shallow geology, sea-floor texture, and physiographic zones of Buzzards Bay, Massachusetts (ver. 1.1, June 2016): U.S. Geological Survey Open-File Report 2014–1220, https://dx.doi.org/10.3133/ofr20141220. Just reaches the east side of Buzzards Bay site. |

*Table 2. Listing of Other Side Scan Sonar Data Sources Including Links to the Data and Accompanying Reports*

| | |
|---|---|
| Marshfield | Pendleton, E.A., Baldwin, W.E., Barnhardt, W.A., Ackerman, S.D., Foster, D.S., Andrews, B.D., and Schwab, W.C., 2013, Shallow geology, seafloor texture, and physiographic zones of the Inner Continental Shelf from Nahant to northern Cape Cod Bay, Massachusetts: U.S. Geological Survey Open-File Report 2012–1157, 53 p., https://pubs.usgs.gov/of/2012/1157/ |
| Plum Island | Barnhardt, W.A., Andrews, B.D., Ackerman, S.D., Baldwin, W.E., and Hein, C.J., 2009, High-resolution geologic mapping of the inner continental shelf; Cape Ann to Salisbury Beach, Massachusetts: U.S. Geological Survey Open-File Report 2007-1373, variously paged, DVD-ROM and available online at https://pubs.usgs.gov/of/2007/1373/ |

## Processing of Sand Thicknesses

Sand thicknesses were determined from seismic profiles where discrimination of seismic units was reasonable. To ensure consistency, precision, and accuracy, copies of the interpreted profile images were edited using semi-automated tools to trace the seafloor and interpreted contacts in distinct colored lines; the origin and last-labeled trace number and depth were also marked on the image as specific-colored points on the profile axes.

A MATLAB image-processing script was then applied to each image to find the axis ticks (for scaling pixels to trace numbers and depths), and to find each surface trace; together this information was used to output a table of average depth-below-seafloor -- i.e., thickness -- vs. average trace number across uniform trace intervals; the trace interval was every 100 traces for profiles having more than 6000 total traces, and every 50 traces for the shorter ones.

The tracklines for the seismic profiles were used to create ArcGIS "routes" measured in units of trace-number, allocating trace positions uniformly along the line-length of each trackline. The tables of thicknesses for trace intervals were applied as ArcGIS "events" to the "routes", resulting in a feature layer that can be symbolized (e.g., using color) to indicate thicknesses along the tracklines.

*Table 3. Listing of Other Sources of Seismic Data Including Links to the Data and Accompanying Reports*

| | |
|---|---|
| Marshfield | Raytheon Company, Ocean Systems Center, 1972, Final Report of the Massachusetts Coastal Mineral Inventory Survey, prepared for the Commonwealth of Massachusetts, Department of Natural Resources, Division of Mineral Resources, Seismic lines 8, 9, 10. |
| Plum Island | Oldale Data: https://cmgds.marine.usgs.gov/fan_info.php?fan=1980-010-FA<br>Oldale Report: Oldale, R.N. and Wommack, L.E., 1987, Maps and seismic profiles showing geology of the inner Continental Shelf, Cape Ann, Massachusetts to New Hampshire, U.S. Geological Survey, Miscellaneous Field Studies Map MF-1892, 2 plates, https://pubs.er.usgs.gov/publication/mf1892<br><br>Barnhardt Data: https://pubs.usgs.gov/of/2007/1373/GIS/hyperlink_images/SeismicProfiles.zip<br>Barnhardt Report: Barnhardt, W.A., Andrews, B.D., Ackerman, S.D., Baldwin, W.E., and Hein, C.J., 2009, High-resolution geologic mapping of the inner continental shelf; Cape Ann to Salisbury Beach, Massachusetts: U.S. Geological Survey Open-File Report 2007-1373, variously paged, DVD-ROM and available online at https://pubs.usgs.gov/of/2007/1373/<br><br>Hein Data: https://www.geo.umass.edu/stategeologist/Products/Surficial_Geology/Newburyport_East/Newburyport_East_GIS.zip<br>Hein Maps: https://mgs.geo.umass.edu/biblio/onshore-offshore-surficial-geologic-map-newburyport-east-and-northern-half-ipswich |
| Buzzards Bay | O'Hara Data: https://cmgds.marine.usgs.gov/fan_info.php?fan=1975-011-FA<br>O'Hara Report: O'Hara, C.J. and Oldale, R.N., 1980, Maps showing geology and shallow structure of eastern Rhode Island Sound and Vineyard Sound, Massachusetts, Miscellaneous Field Studies Map- U.S. Geological Survey, Report: MF-1186, 5 sheets. https://pubs.er.usgs.gov/publication/mf1186 |
| Nomans Land | O'Hara Data: https://cmgds.marine.usgs.gov/fan_info.php?fan=1980-012-FA<br>O'Hara Report: McMullen, K.Y., Poppe, L.J., and Soderberg, N.K., 2009, Digital seismic-reflection data from eastern Rhode Island Sound and vicinity, 1975–1980: U.S. Geological Survey Open-File Report 2009–1003, 2 DVD-ROMs. (Also available at https://pubs.usgs.gov/of/2009/1003/) |
| Nantucket | Oldale Data: https://cotuit.er.usgs.gov/data/1976-036-FA/SE/Scans/Sparker/FA76036_256-257_1245-0438_MSP_L5.tif (last accessed spring 2018, no longer accessible)<br>Oldale Cruise Report: https://cotuit.er.usgs.gov/data/1976-036-FA/NL/001/01/76036rpt.pdf (last accessed spring 2018, no longer accessible) |
| Muskeget Channel | Oldale Data: https://cotuit.er.usgs.gov/data/1976-036-FA/SE/Scans/Sparker/FA76036_256-257_1245-0438_MSP_L5.tif (last accessed spring 2018, no longer accessible)<br>Oldale Cruise Report: https://cotuit.er.usgs.gov/data/1976-036-FA/NL/001/01/76036rpt.pdf (last accessed spring 2018, no longer accessible) |

## Results

### Surficial Geologic Mapping and Characteristics and Estimated Thickness of Sand Resources

All data sources were examined and used to create a surficial geologic map of each site, to identify whether sand is present or not, to evaluate the character of any sand and, where possible, to estimate the thickness of the sand resource. All vector, raster and source data used or created as part of this project to evaluate sand resources – along with any images and all accompanying reports – are provided with their associated metadata, at the following site: ftp://eclogite.geo.umass.edu/pub/stategeologist/BOEM2data/.

#### *Buzzards Bay*

The Buzzards Bay site is located about 8.8 km (5.5 miles) southwest of Cuttyhunk and 12.8 to 16 km (8 to 10 miles) due south of Westport, MA (see Figure 1). Four tracklines were run in this area. MA_001 and MA_002 are located about 3.2 km (2 miles) north of tracklines MA_003 and MA_004 (Figure 6). No vibracores or grab samples were acquired at this site. In 1975, O'Hara

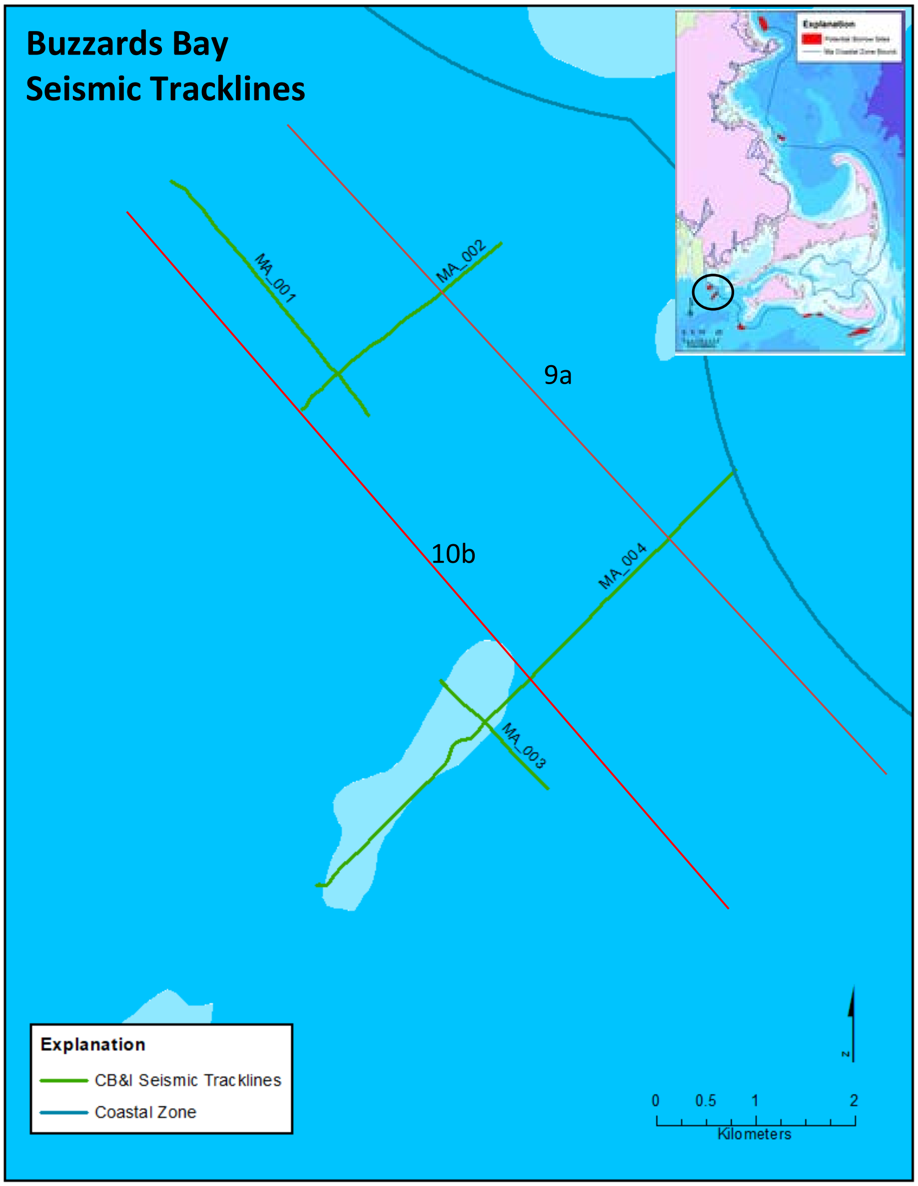


*Figure 6. Tracklines for Buzzards Bay site. Lines MA_001 to MA_004 (green) collected by CB&I. Lines 9a and 10b (red) collected in 1975 by O'Hara (see Table 3 for reference).*

and Oldale (1980) collected "boomer" data in Buzzards Bay as part of a survey by USGS Woods Hole (see Table 3 for link to reference). They made 33 traverses: 27 in a NW-SE orientation with a line spacing of 1.85 km (1 nautical mile) and 6 in a SW-NE direction and line spacing of approximately 5.6 km (3 nautical miles). A total of 663 km (398 miles) of seismic data were collected with a penetration of up to 125 meters (410 feet). Lines 9a and 10b pass through the Buzzards Bay study area and helped with the interpretation (Figure 6). The seismic lines collected by CB&I were of poorer quality and difficult to interpret.

Four surficial geologic units were identified at the Buzzards Bay site (Figure 7):

**Moraine Deposits** – About 75% of the area at this site is located in moraine deposits. This includes all of line MA-002, the south half of line MA-001, and nearly all of line MA-003 and the southern 70% of line MA-004 (Figure 7). The moraine deposits fall on topographic highs, correlate with two recessional moraines as shown on a draft of the Quaternary map of Massachusetts (Stone and Lewis, person. commun., 2018) and correlate well with the interpretation of O'Hara and Oldale (1980) (Figure 8). The moraine is comprised of an unsorted, non-stratified heterogeneous mixture of sand, silt, clay with pebble, cobble and boulder clasts. Large surface boulders up to 3 to 9 m (9.8 to 30 feet) are also common in this unit. The deposit has been substantially reworked during Holocene marine transgression and by modern currents and storm activity leaving behind a boulder lag on the seabed (Figure 7).

**Lake Bottom Deposits** – Lake bottom deposits underlie about 10% of the area at the site. This includes the northern 30% of line MA-001 and the northern 10% of line MA-003 (Figure 7). The lake bottom deposits correlate well with the lake bottom deposits as shown on the draft Quaternary map of Massachusetts (Stone and Lewis, person. commun., 2018). The deposits consist of very fine sand, silt, and clay that may occur as well-sorted, thin layers of alternating silt and clay (varves), or as thicker layers of very fine sand and silt. Very fine to fine sand may occur at the surface of these lake-bottom deposits and grade downward into rhythmically bedded silt and clay varves. The deposit occurs inboard of recessional moraines in ice-dammed glacial lakes, locally in Buzzards Bay, and overlie glacial till or coastal plain deposits.

**Channel Fill Deposits** – Channel fill deposits occupy about 15% of the area at the site and occur along the northern 2 km (1.2 miles) of line MA-004. This unit was deposited in a channel that provided a drainage pathway during isostatic rebound and lower relative sea level and may be part of a post glacial drainage network that drained temporary glacial lakes in Buzzards Bay and Block Island Sound. The unit is most likely composed of sand and gravel of unknown thickness carved into coastal plain or lake bottom deposits. No textural data are available. Occasional and discontinuous pockets of sand overlie the deposit occupying 10% of the area of the unit.

**Mobile Sand Sheet** – This deposit represents sand, most likely Holocene in age, occurring as a thin, discontinuous sheet overlying approximately 10% of moraine and channel fill units and 20-25% of lake bottom deposits. Although no sediment samples or vibracores are available, the unit most likely consists of fine to medium and fine to coarse, quartz sand, with 1-35% gravel, 1-10% shell hash, 1-10% silt that partially overlies channel fill deposits and occurs sporadically over lake bottom and moraine deposits. Deposit contains bedforms with wavelengths from 1 to 3 m (3.3 to 10 feet). These bedforms likely migrate and change morphology after storm events.

The potential for economically valuable sand resources at the Buzzards Bay site is poor. While the area has a veneer of Holocene sand in places, the sand sheet is mobile, discontinuous and very thin, and it locally overlies glacial till, fine-grained lake bottom or coastal plain deposits. The only area that may have potential is the channel fill deposit. Line MA-004 shows a minimum thickness of at least 5 m (16 feet) but may be as thick as 13 m (42 feet) (Figure 9).

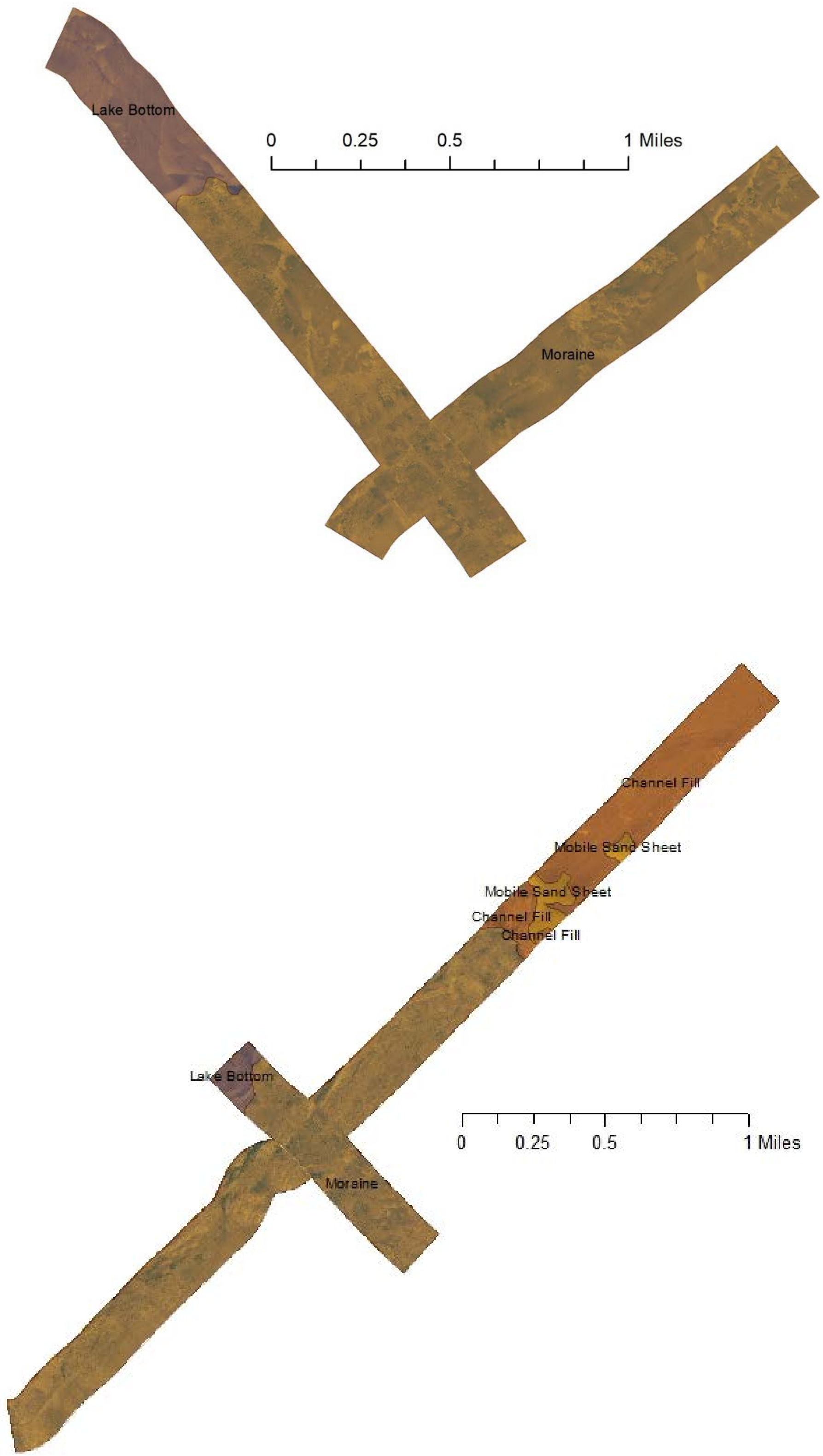


*Figure 7. Surficial geologic map of the Buzzards Bay site. Note – figure does not represent actual geographic position of tracklines, for illustration purposes only.*

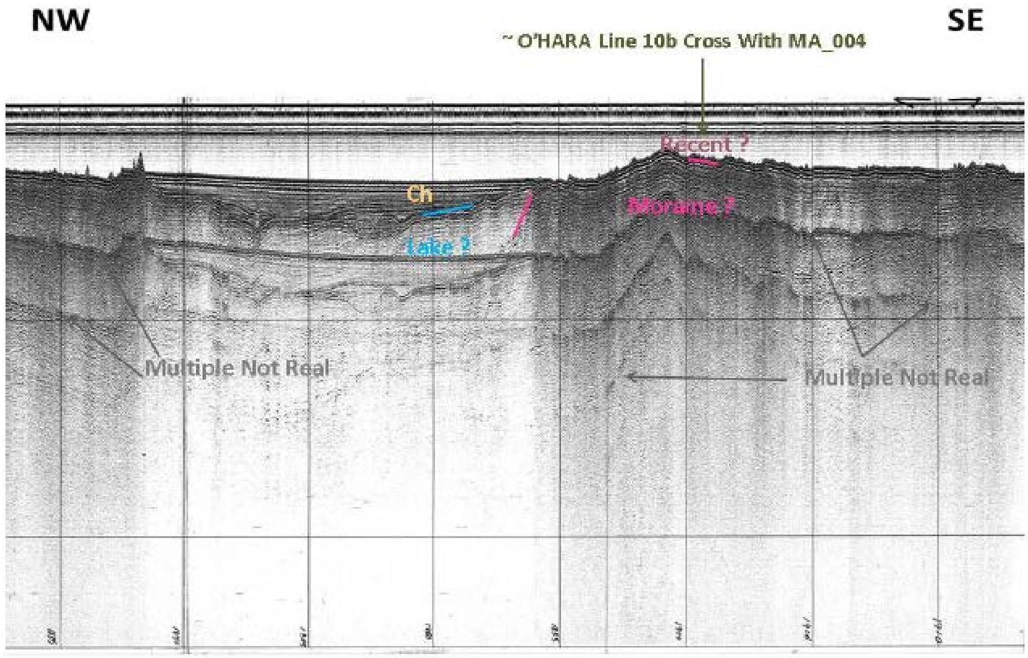


*Figure 8. Line 10b from O'Hara and Oldale (1980) showing the moraine deposit and channel fill deposits cut into lake bottom deposits. See Figure 6 for location of trackline with respect to the Buzzard Bay site. Ch = channel fill deposits.*

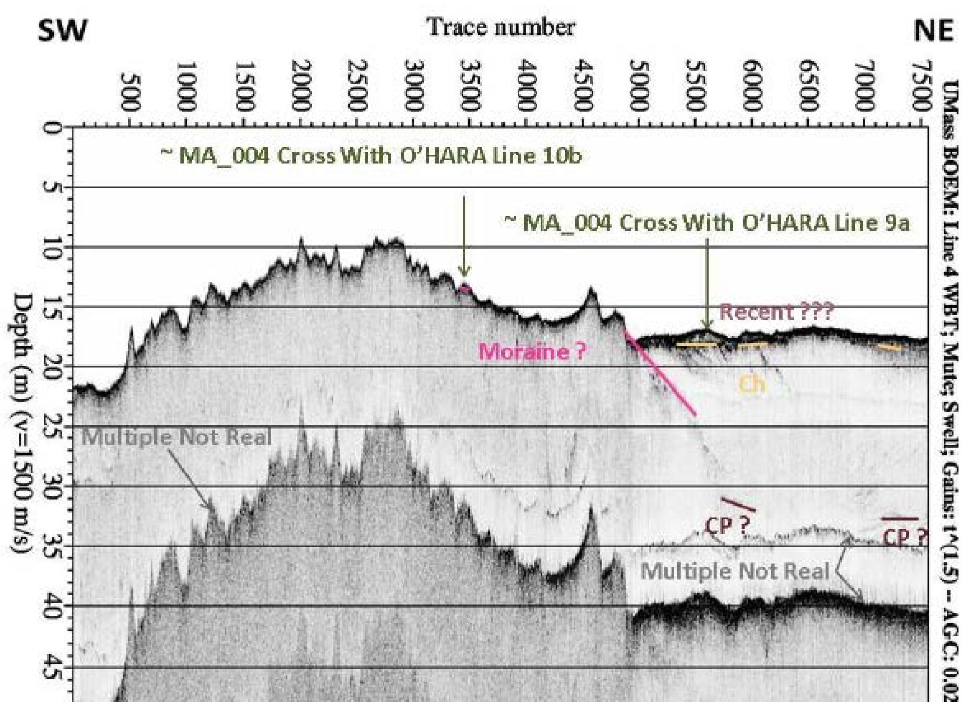


*Figure 9. Interpreted seismic record of Line MA-004 showing channel fill deposit (Ch on map). Precise thickness is unknown and no sediment samples or vibracore data are available. CP = Coastal Plain deposits.*

Based on mapping by Stone and Lewis (person. commun., 2018) and a review of other seismic data, the channel heads west from Line MA-004 toward Rhode Island Sound and northeast toward Buzzards Bay (Figure 10). This area may warrant additional investigation.


*Figure 10. Area outlined in blue shows the location of channel fill deposits in the Buzzards Bay area that may warrant additional investigation. Also shown is 300 kHz side scan sonar data collected as part of this study overlain on the draft Quaternary geologic map of Massachusetts (colored polygons).*

## Nomans Land

The Nomans Land site is located about 6.4 km (4 miles) southwest of Nomans Land, a small island located 5.3 km (3.3 miles) southwest of Squibnocket Point on Martha's Vineyard (see Figure 1). Four tracklines were run in this area. Lines MA_005 and MA_006 trend NW to SE whereas lines MA_007 and MA_008 are oriented SW to NE (Figure 11). Tracklines are spaced about 1.3 km (0.8 miles) apart. One grab sample was collected along Line MA_008 (MA-BOEM-2015-SS01). The sediment in the grab sample consists of 31% gravel and 69% sand. Nearby data from the usSeaBed database also indicate either gravel or sand in the sediment description. In 1980, the USGS collected 226 km (136 miles) of high resolution uniboom seismic data in southern Rhode Island Sound under the direction of Charles O'Hara (see Table 3 for links to these data) and was summarized by McMullen et al. (2009). Line 1 from this cruise

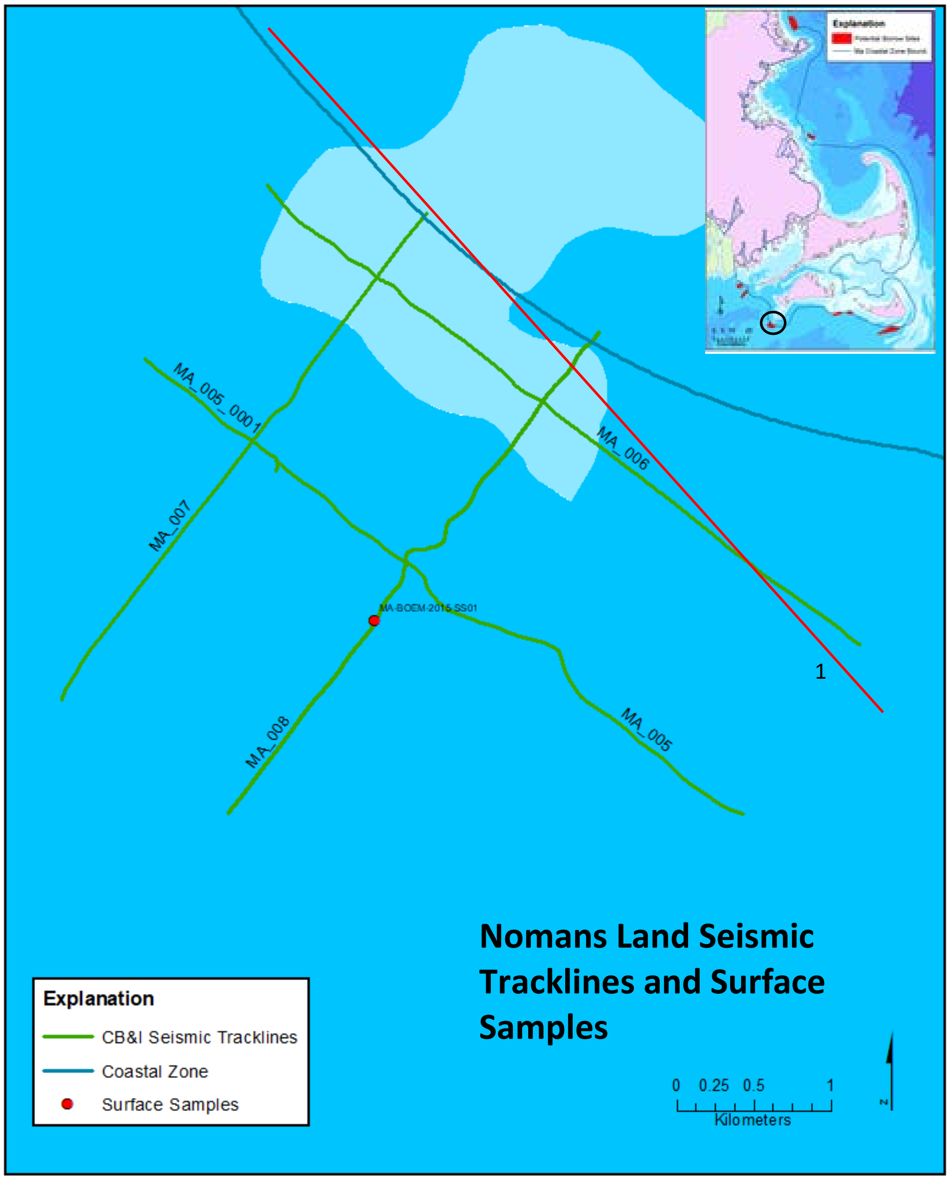


*Figure 11. Map showing the location of seismic lines collected by CB&I (green) and the 1980 cruise by O'Hara (red) (McMullen et al., 2009) at the Nomans Land site.*

passes through the Nomans Land site (Figure 11) and helped with the interpretation. The seismic data collected by CB&I were of poorer quality and difficult to interpret.

The entire Nomans Land site is mapped as glacial till of unknown thickness deposited as a moraine over coastal plain deposits and is considered unsuitable as a "sand" resource (Figure 12). The material consists of a non-sorted, non-stratified heterogeneous mixture of sand, silt, clay with pebble, cobble and boulder clasts; large surface boulders up to 3 to 9 m (10 to 30 feet) are also common. The site is located in relatively high topographic relief formed as part of the last glacial maximum terminal moraine (Figure 13). The deposit has been substantially reworked during Holocene marine transgression and by modern currents and storm activity leaving behind a boulder lag on the seabed (Figure 14). Occasional and discontinuous pockets of medium to coarse sand may occur within the deposit occupying < 10% of the area of the unit.

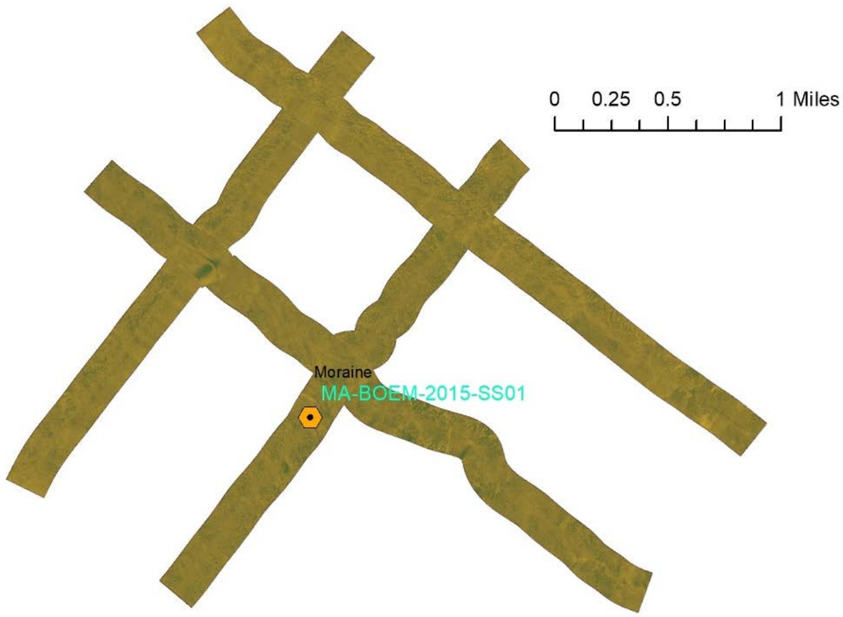


*Figure 12. Surficial geologic map of Nomans Land superimposed over the 300 kHz side scan sonar images. Entire area is a moraine comprised of glacial till deposited over coastal plain deposits.*

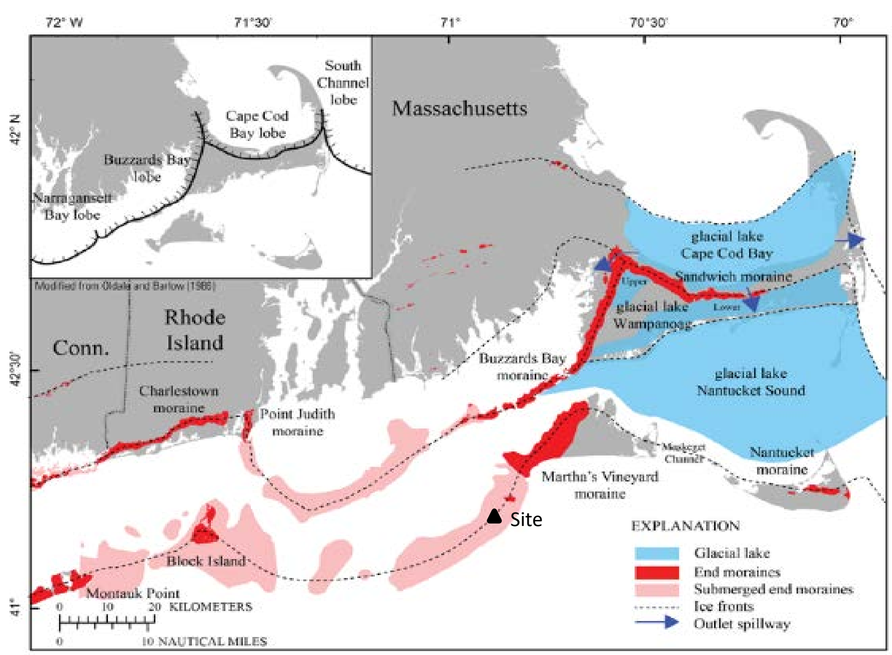


*Figure 13. Location of Nomans Land site (black triangle) with respect to last glacial maximum terminal moraine. Adapted from Baldwin et al., 2016.*

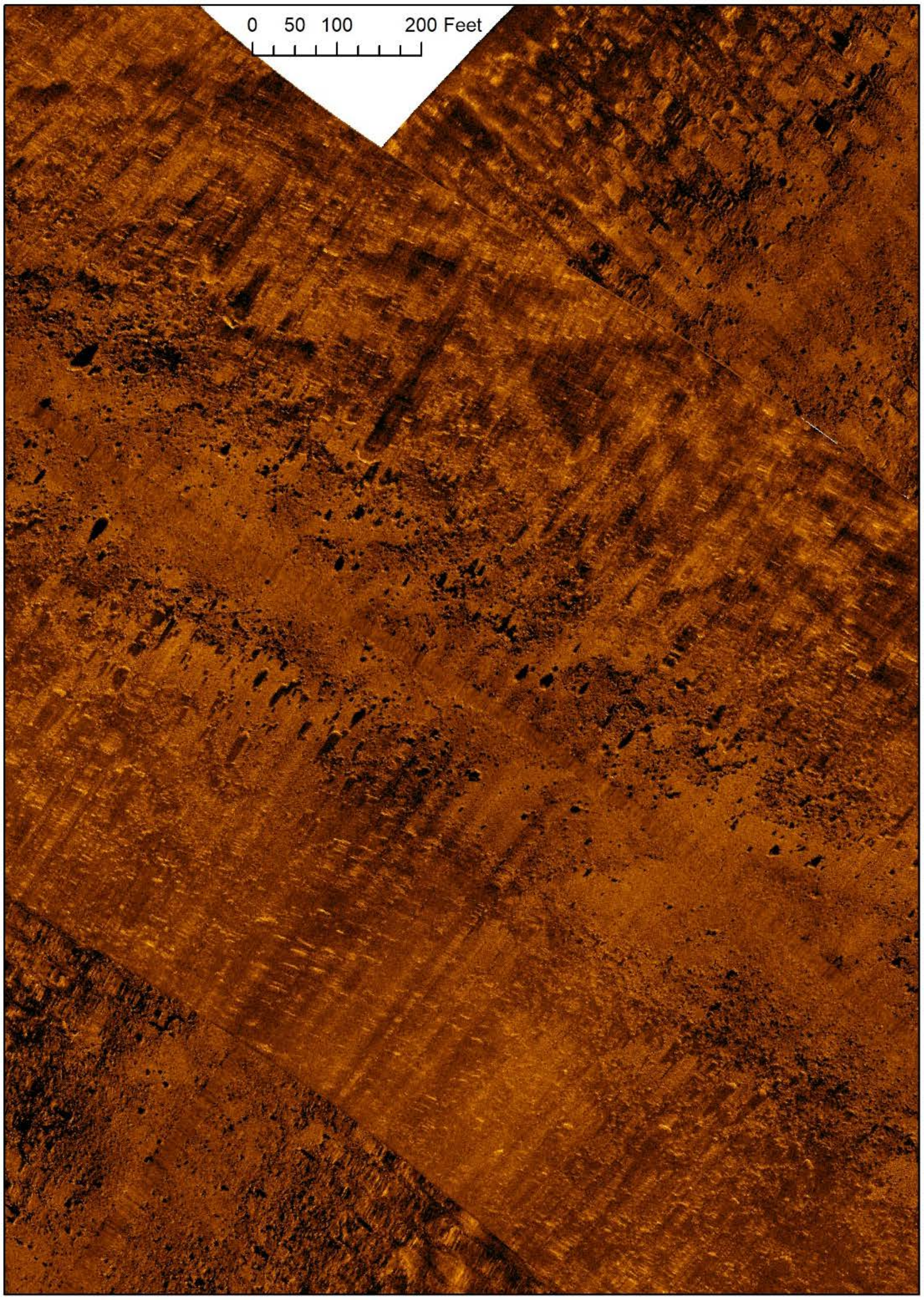


*Figure 14. Close up view of Nomans Land site depicting the boulder lag deposit on the seabed. Boulders up to 9 m (30 feet) are observed. This is a 0.25 m (0.8 foot) resolution 300 kHz side scan sonar image.*

This resource is considered unsuitable as a source of sand. If coarse sand, gravel and cobbles are desired, then the material may be suitable. However, there are numerous boulders with which any kind of dredging operation must contend.

*Muskeget Channel*

The Muskeget Channel site is located at the south end of Muskeget Channel, which separates Martha's Vineyard and Nantucket. The west end of the site is located 9.6 km (6 miles) south of Wasque Point on Chappaquiddick, Martha's Vineyard. The east end of the site is located approximately 6.4 km (4 miles) southwest of Tuckernuck Island off the west end of Nantucket (see Figure 1). Approximately 34 km (20 miles) of seismic profile data were collected by CB&I (Lines MA_009 through MA_019) (Figure 15). Two vibracores and one grab sample were collected at the site (Figure 15). Vibracore MA-BOEM-2015-VC02 penetrated a depth of 5.2 m (17.9 feet) and Vibracore MA-BOEM-2015-VC4 and 4A penetrated a total depth of 5.5 m (18 feet). The seismic data collected by CB&I were of better quality at this site and useful in interpreting the subsurface seismic units.

The surficial materials at the site consist of a sand sheet and fan deposits overlying glacial outwash. The sand and fan deposits include predominantly fine and fine-to-medium, well sorted, quartz sand with 1-10% coarse sand, 1-10% silt and 1-10% shell hash and shell fragments. A pebble layer in core MA-BOEM-2015-VC02 is inferred to be a buried seafloor. This boundary exhibits a strong seismic reflection (Figure 16). This reflection (reflector 1) ranges from 1-3 meters (3.3 to 10 feet) deep in the western end of lines MA_009 and MA_010 and 8-10 meters (26 to 33 feet) deep at the eastern end of these seismic lines. In contrast, in the eastern portion of the site along lines MA_011, MA_012 and MA_013, the depth to reflector 1 is generally 1-4 meters (3.3 to 13 feet), with a maximum depth of 4-6 meters (13 to 20 feet) at the west end of lines MA_011 and MA_012 (Figure 17). This reflector is interpreted as the top of the older outwash plain deposited distally from the last glacial maximum terminal moraine.

A second seismic reflector is interpreted to be the top of a marine fan developed as part of a large ebb tidal delta complex prograding southward from the constriction between Martha's Vineyard and Nantucket (Figure 16). The fan deposit is generally less than 2 m (6.6 feet) thick in the eastern portion of the area and thickens northwestward to a maximum of 4.5 meters (14.8 feet) thick, averaging about 2-3 meters (6.6 to 10 feet) thick along seismic line MA_017 (Figure 17). The fan deposits reach a maximum thickness of 8-10 meters (26 to 33 feet) along the east end of Line MA_010 but thin westward to 2-3 meters (6.6 to 10 feet) or less. In some places along the western end of the site, the fan deposits are not present (Figure 17).

Up to 5.5 meters (18 feet) of recent sand lies over the fan deposits in the western portion of the area but is generally less than 4 meters (13 feet) thick. In the eastern portion of the site, the recent sands are discontinuous and sometimes absent (Figure 17). The recent sands are interpreted to be a modern bar derived from reworking of the underlying fan deposits. In some locations, removal of the recent sand deposits and reworking of the thinner fan deposits has exposed the underlying outwash deposits.

The Muskeget Channel site offers a consistent, uniform and fairly thick deposit of fine and fine-to-medium sand and includes both a mobile sand sheet and underlying marine fan deposits. Vibracore MA-BOEM-2015-4 and 4A penetrated into the outwash deposits. Below the gravel lag deposit (0.3 to 0.5 meters [1 to 1.5 feet] thick), which contains upwards of 60%

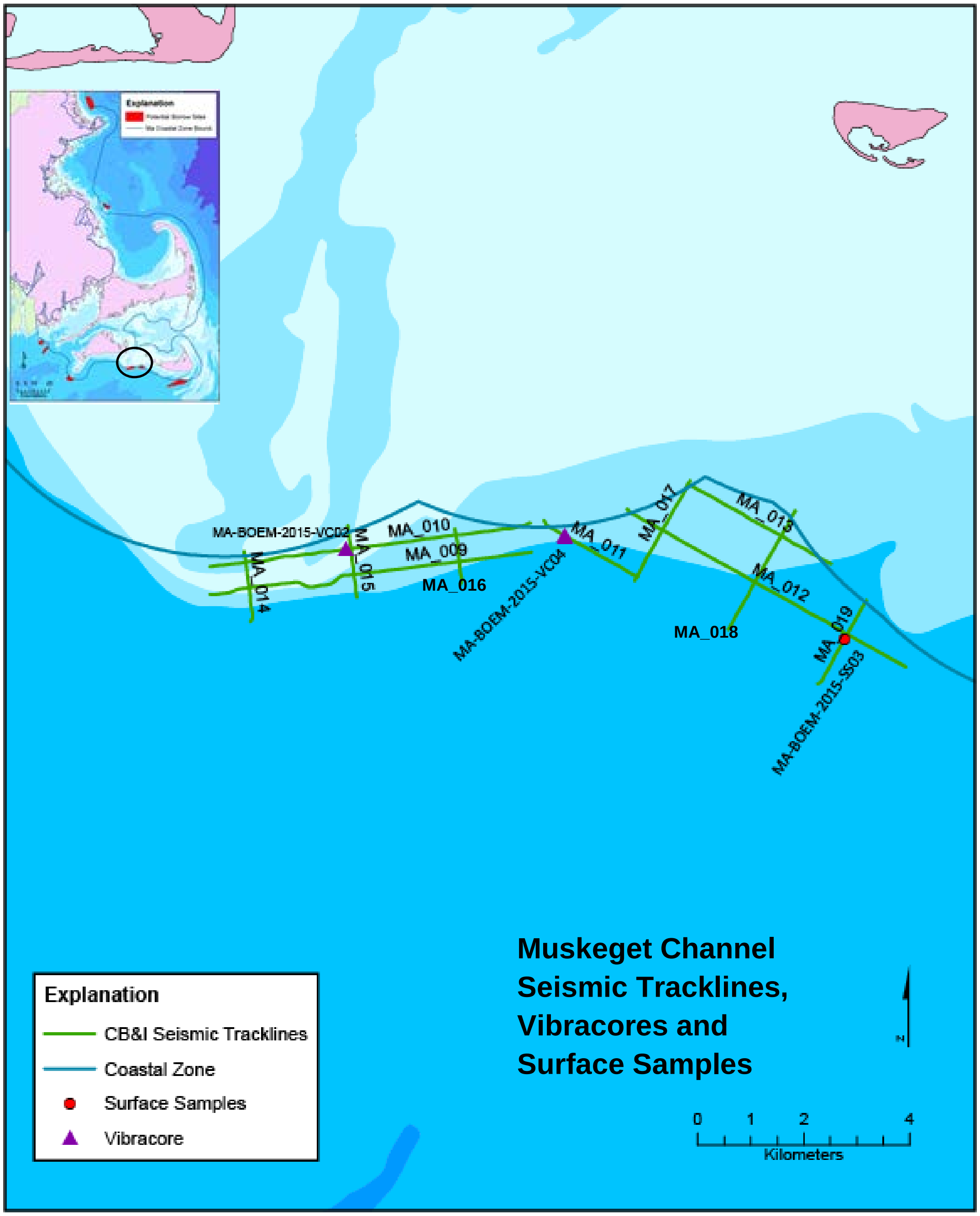


*Figure 15. Map showing the location of tracklines, vibracores and grab samples for the Muskeget Channel site.*

gravel, the sediment returns to fine-to-medium sand. The thickness of the underlying outwash deposits is unknown. Muskeget Channel certainly warrants additional investigation.

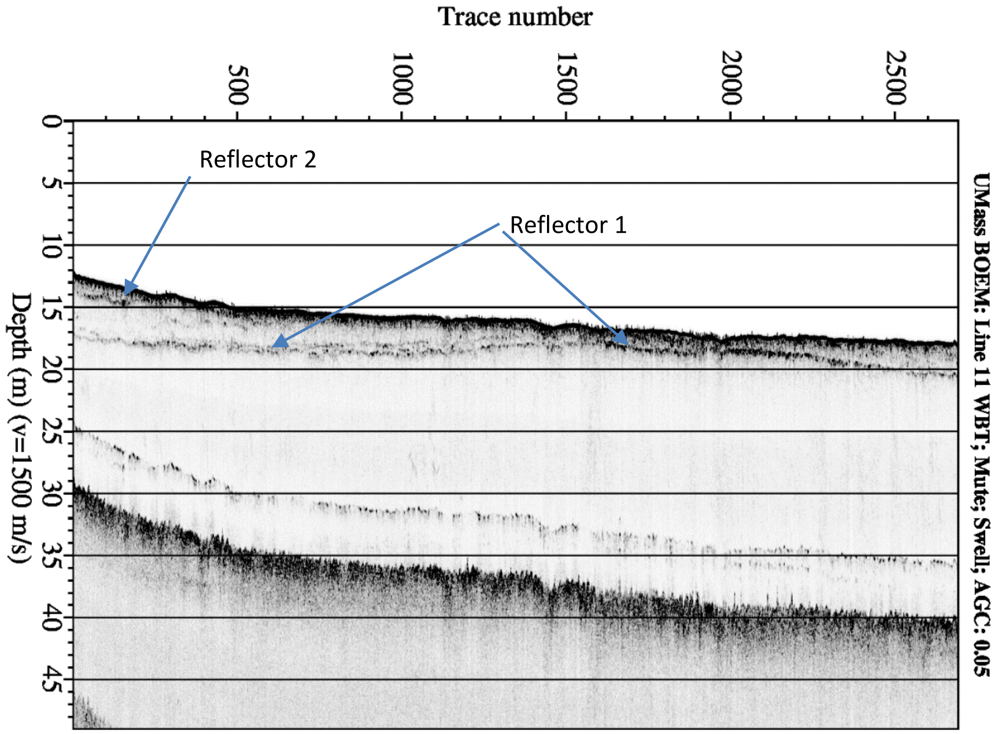


*Figure 16. Seismic profile MA_011 showing strong seismic reflectors 1 and 2. Reflector 1 is interpreted to be the top of the Quaternary outwash plain migrating southward from the terminal moraine to the north and is marked by a gravel lag deposit. Reflector 2 is interpreted to be the contact between marine fan and recent marine sand deposits.*

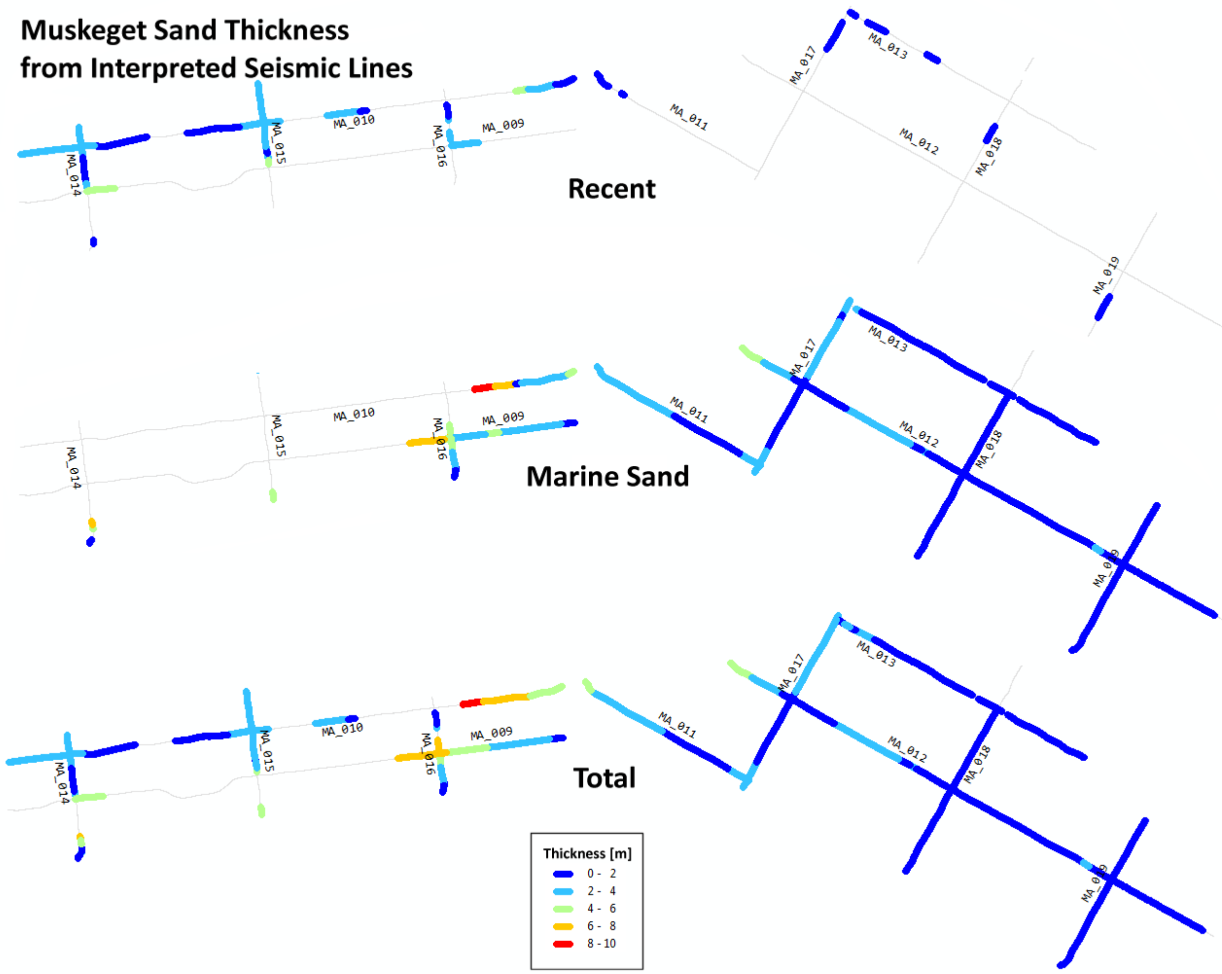


*Figure 17. Map showing the estimated thickness and distribution of the upper recent sands and underlying marine fan deposits derived from CB&I seismic data. The bottom figure is the sum of the recent and fan deposits and represents the depth to the underlying outwash deposits. The thickness of the underlying outwash deposits in unknown but also contains sand.*

*Nantucket*

The Nantucket site is located about 8 km (5 miles) due south of Nantucket (see Figure 1). Approximately 29 km (17.4 miles) of seismic profile data were collected by CB&I (Lines MA_020 through MA_022) (Figure 18). One vibracore and one grab sample were collected at the site (Figure 18). Vibracore MA-BOEM-2015-VC06 penetrated to a depth of 5.5 meters (18 feet). The seismic data collected by CB&I were of poor quality making it difficult to interpret the seismic units. Most of the interpretation is based on a general knowledge of the stratigraphy and review of the side scan sonar data.

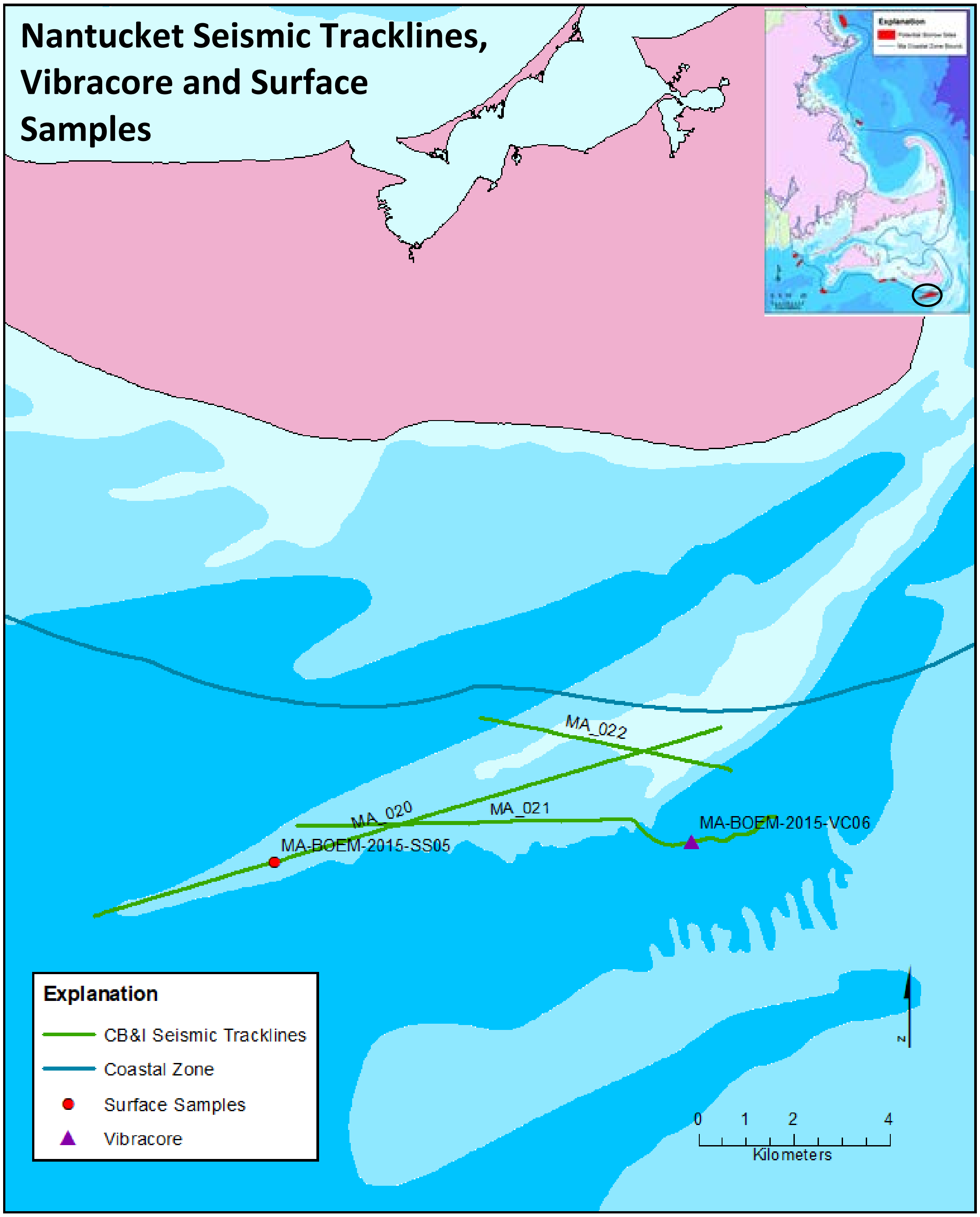


*Figure 18. Seismic tracklines, vibracore and sediment sample locations for the Nantucket site.*

The surficial material at the site consists entirely of sand and is interpreted as a modern marine bar complex. The bar complex was most likely derived from reworking of underlying outwash deposits since the site is outboard of the late Wisconsinan terminal moraine. Sediment characteristics exhibited in vibracore MA-BOEM-2015-VC06 are similar down core and consist of fine and fine-to-medium quartz sand with 1-10% coarse sand, 1-10% shell hash and/or shell fragments, and 1-10% silt. Occasional gravel and pebbles ranging from 6.4 to 12.7 mm (0.25 to 0.5 inches) in size also occur. Grab sample MA-BOEM-2015-SS05 are similar to vibracore sediments, containing 98% fine quartz sand with 1-10% shell hash. Surface sands show two families of bedforms evident within side scan imagery. One trending NE-SW with wavelengths of 60 to 85 meters (196 to 279 feet) and amplitudes of 1 to 3 meters (3.3 to 10 feet) and a second set of bedforms trending north-south with wavelengths of 8 to 16 meters (26 to 52.5 feet) (Figure 19). Although data are limited, this site has potential as a source of fine to medium sand and warrants additional investigation.

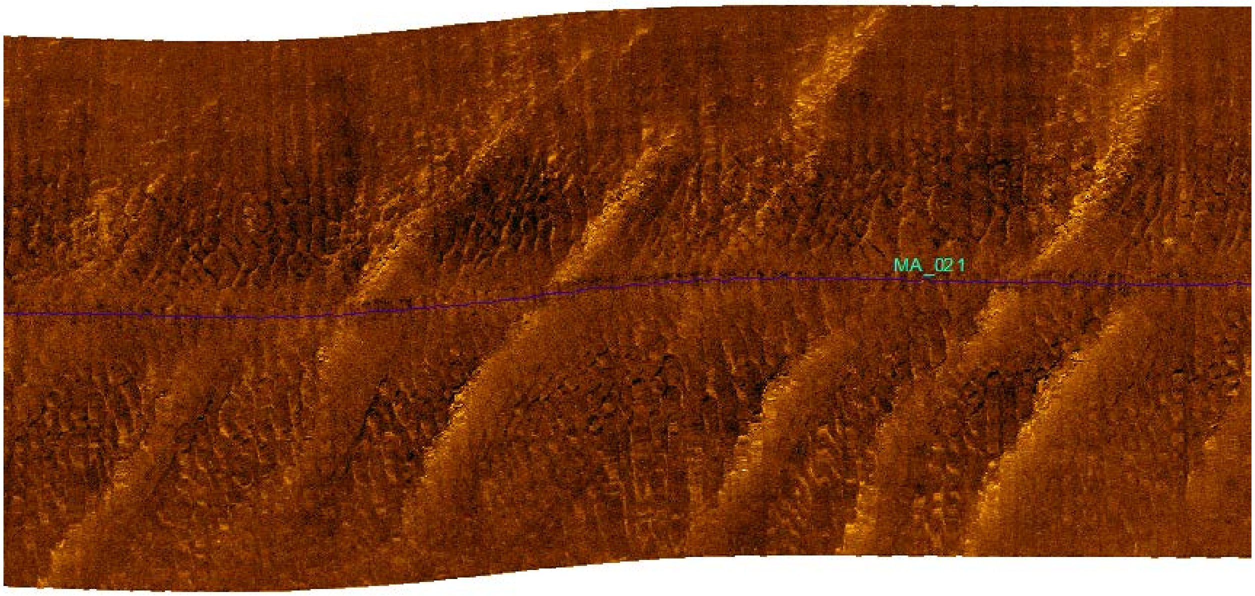


*Figure 19. 300 kHz side scan sonar image showing examples of two sets of bedforms along seismic line MA_021.*

*Marshfield*

The Marshfield site is approximately 11.2 km (7 miles) due east of Scituate, MA and encompasses an area of about 9.3 square km (3.6 square miles) (see Figure 1). Approximately 44 km (26.4 miles) of seismic profile data were collected by CB&I. Lines MA_023 to MA_033 are oriented NE-SW and lines MA_034 to MA_039 trend NW-SE. Line spacing ranges from 260 to 520 meters (853 to 1706 feet) (Figure 20). In 1972, Raytheon collected boomer data as part of a Massachusetts coastal mineral inventory survey (see Table 3) (Raytheon, 1972). Lines 8, 9 and 10 cross the Marshfield site (Figures 20, 21, 22, and 23). Two vibracores were collected also from this site, MA-BOEM-2015-VC11 and MA-BOEM-2015-VC12. VC11 penetrated 2.6 m (8.6 feet) and VC12 penetrated 1.4 m (4.5 feet). In addition, two grab samples were collected, MA-BOEM-2015-SS13 and MA-BOEM-2015-SS14 (Figure 20).

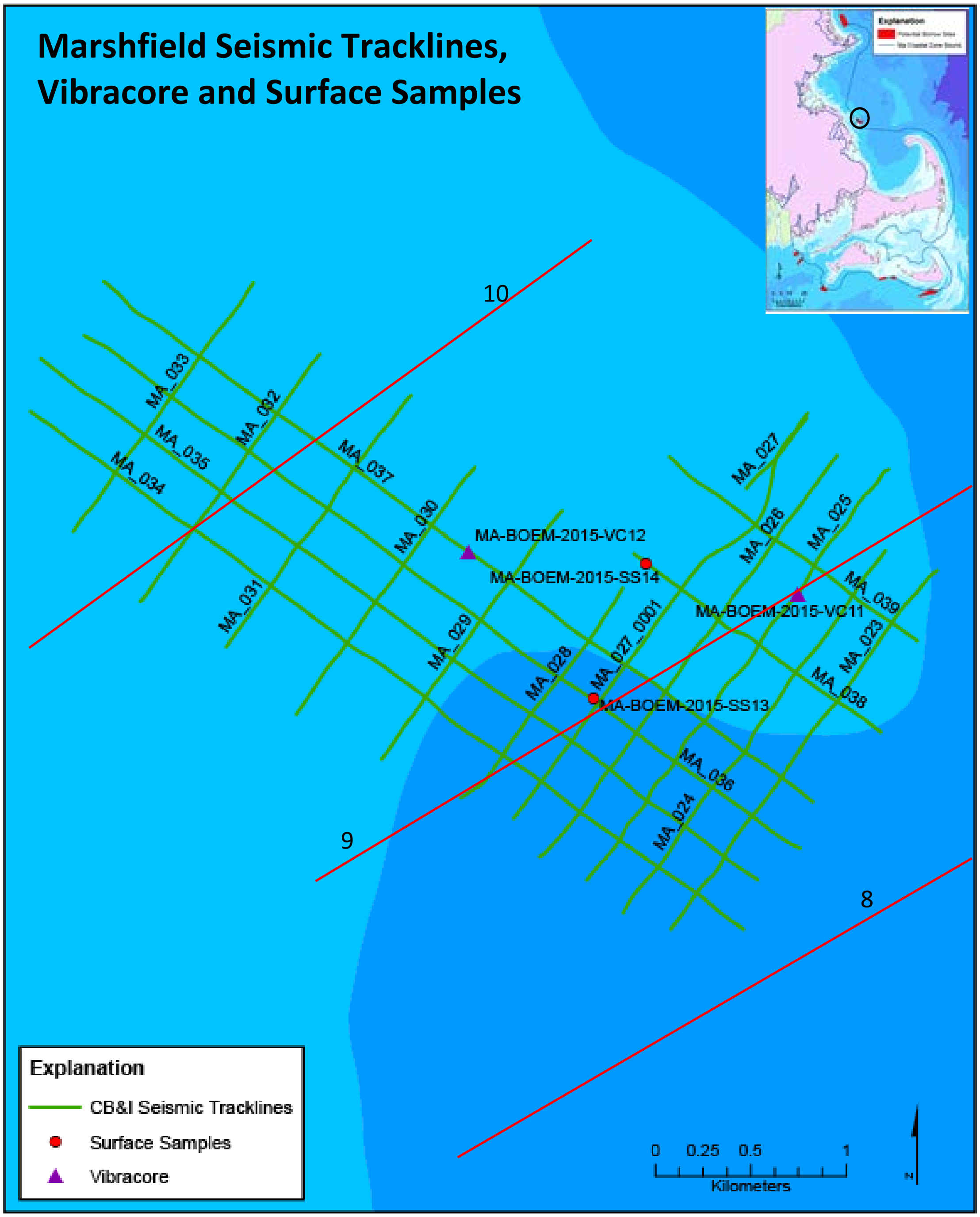


*Figure 20. Location of seismic tracklines, vibracores and grab samples for the Marshfield site. Red lines represent location of seismic tracklines from the Raytheon (1972) study.*

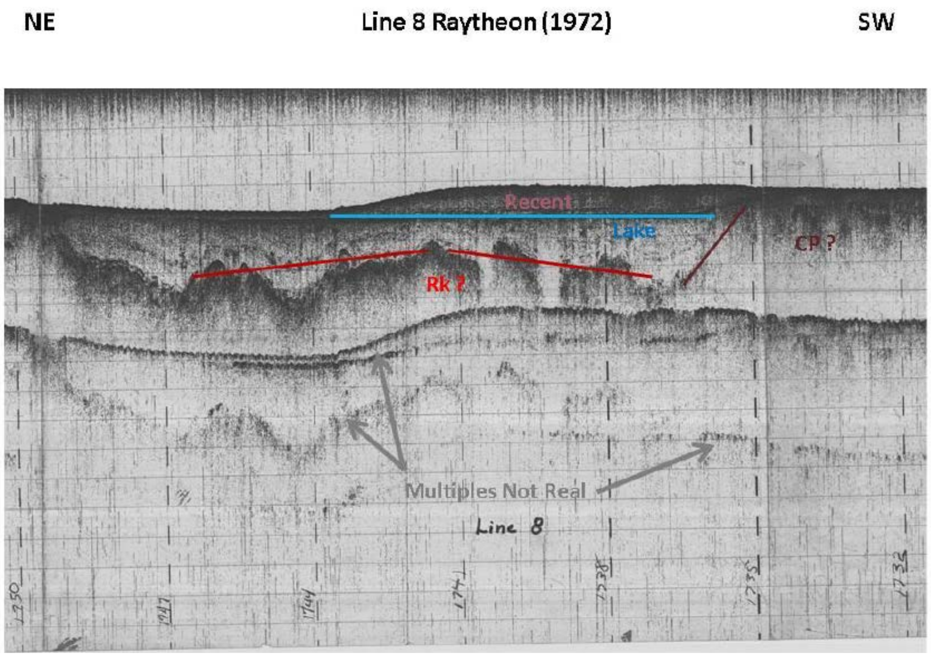


*Figure 21. Interpreted Raytheon Seismic Line 8. CP = Coastal Plain, Rk?=Bedrock, Recent=recent sand and gravel deposits. Vertical and horizontal scales unknown.*

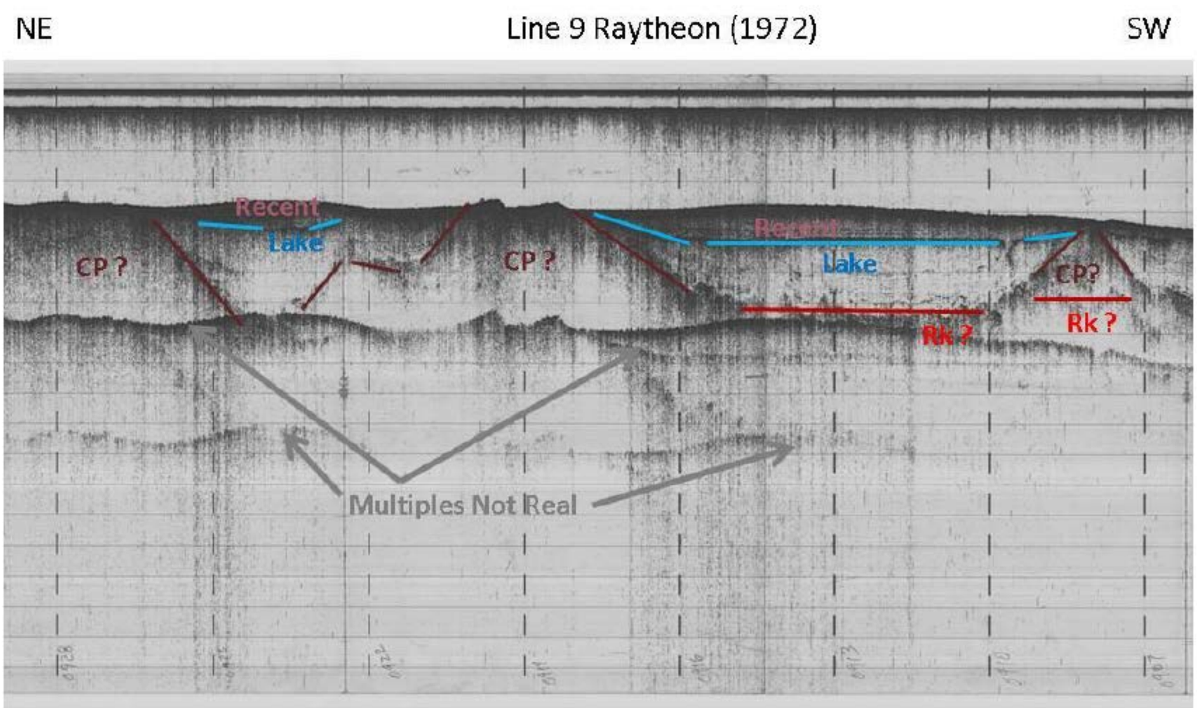


*Figure 22. Interpreted Raytheon Seismic Line 9. CP = Coastal Plain, Rk?=Bedrock, Recent=recent sand and gravel deposits. Vertical and horizontal scales unknown.*

SW Line 10 Raytheon (1972) NE

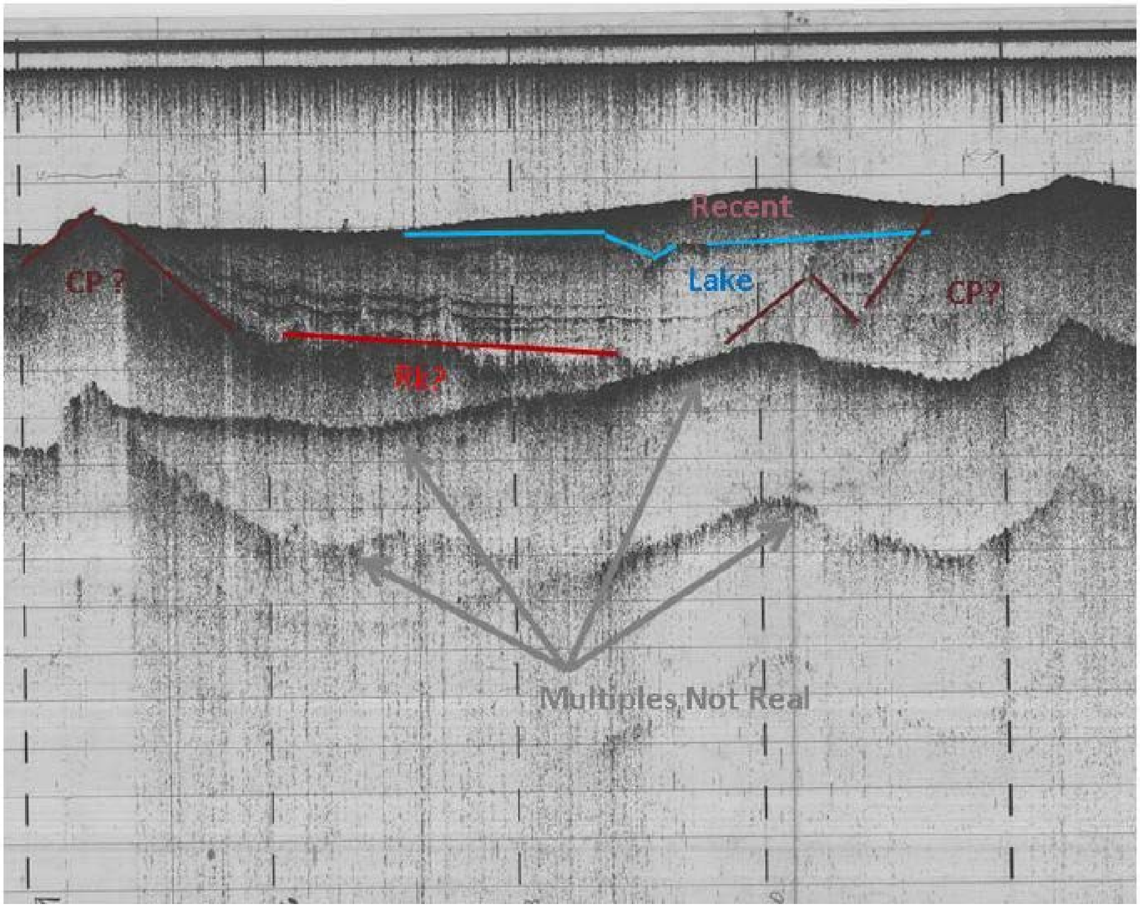


*Figure 23. Interpreted Raytheon Seismic Line 10. CP = Coastal Plain, Rk?=Bedrock, Recent=recent sand and gravel deposits. Vertical and horizontal scales unknown.*

The seismic data collected by CB&I are difficult to interpret. As a result, surficial geologic mapping relied on side scan sonar imagery and the 1972 Raytheon data whereas thickness estimates relied solely on interpretation of the CB&I data. Accordingly, there is significant disparity between the isopach contouring and the distribution of surficial geologic deposits because of the uncertainty in interpreting the seismic units. However, it was felt there was enough information to provide at least a first-order estimate of thickness and volume.

The surficial geology consists of three units (Figure 24). The northern edge of the site is glacial till over thrusted blocks of coastal plain deposits. The till deposits occupy a bathymetric high that corresponds to a recessional moraine position. The extent of the till deposit is mapped based on the presence or absence of boulders on the seafloor. Boulders up to 4.5 meters (15 feet) in size are observed. The material consists of a non-sorted, non-stratified heterogeneous mixture of sand, silt, clay with pebble, cobble and boulder clasts.

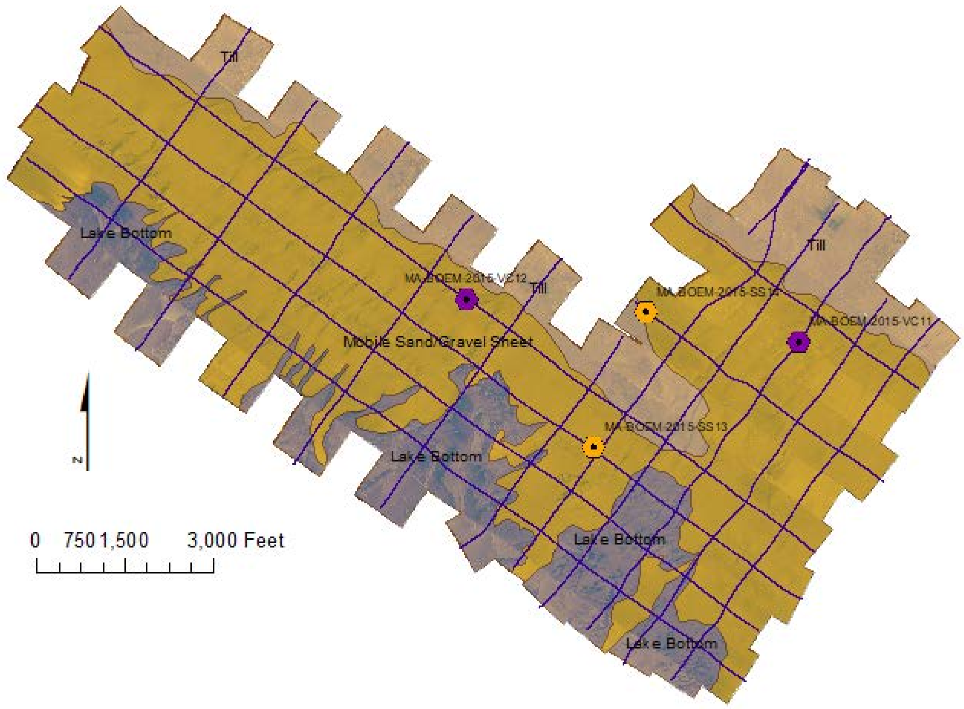


*Figure 24. Surficial geology of the Marshfield site.*

Along the western edge of the site are lake deposits. These laminated sediments are clearly visible in the Raytheon seismic profiles (Figures 21-23). The deposits consist of very fine sand, silt, and clay that may occur as well-sorted, thin layers of alternating silt and clay (varves), or as thicker layers of very fine sand and silt. Very fine to fine sand may occur at the surface of these lake-bottom deposits and grade downward into rhythmically bedded silt and clay varves. The deposit occurs inboard of recessional moraines in ice-dammed glacial lakes, locally in Cape Cod Bay, and overlie glacial till or coastal plain deposits. Occasional and discontinuous pockets of sand overlie the deposit occupying up to 30 to 40% of the area of the unit. Where present, the sand occurs as a thin sheet and exhibits bedforms with dimensions similar to previously mentioned regions (i.e., wavelengths from 2 to 3 meters or 6.6 to 10 feet) and likely migration and modification during storms.

Overlying the lake bottom sediments and concentrated on the southwest slope of the till deposits is a lenticular body of sand and gravel. This deposit is thickest to the northeast and thins to the southwest (Figure 25). Utilizing the CB&I seismic data exclusively, up to 12 meters (39 feet) of material exists here. The total estimated volume of material is 40 million cubic meters (52 million cubic yards). The vibracores indicate the material is predominantly rocky sand with medium-to-coarse quartz sand, 1-10% shell hash, 1-10% silt, and cobbles up to 76 mm (3 inches) in size. The grab samples are similar. It is likely this deposit was derived locally from the reworking of nearby glacial till.

This site provides a reasonable supply of medium to coarse sand, gravel and cobbles for those beaches that require coarser materials.

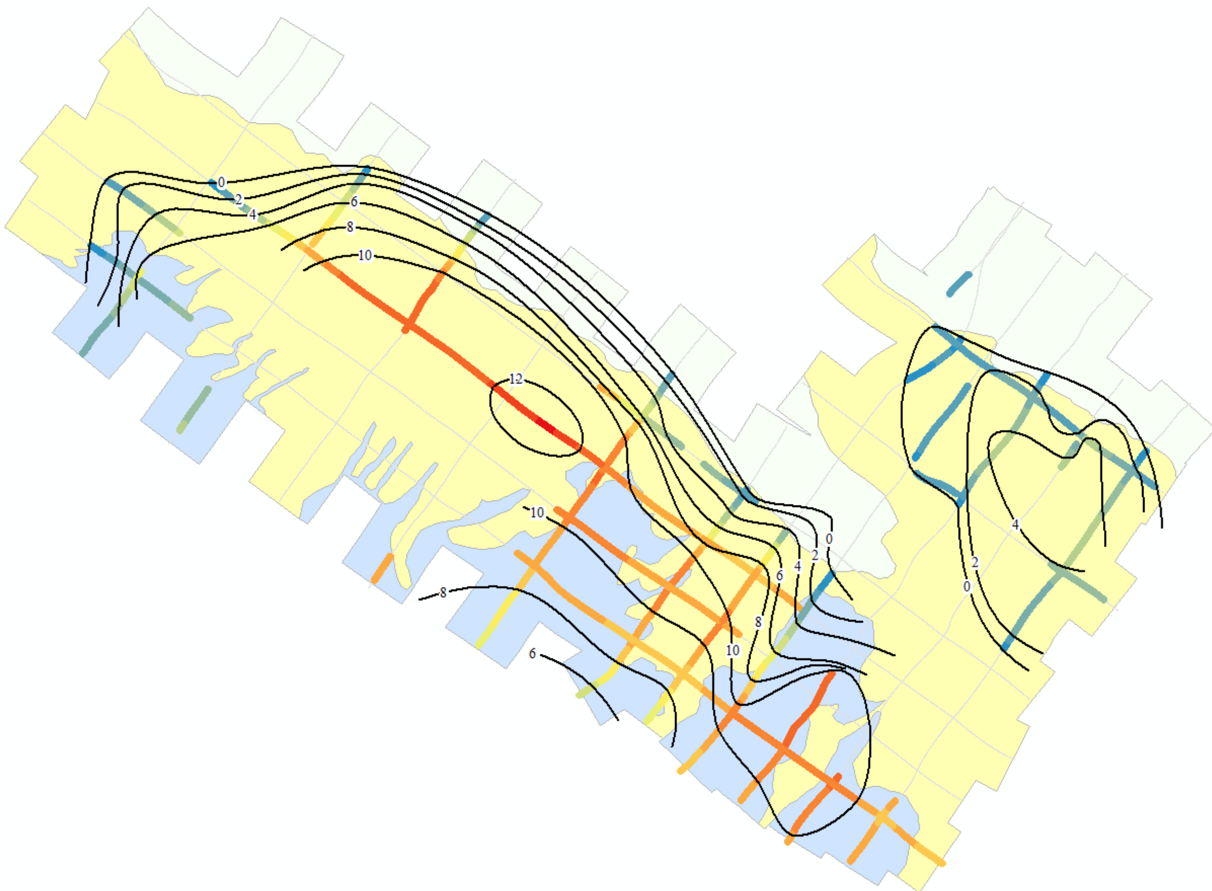

*Figure 25. Isopach map of the sand and gravel lens (black contours) for the Marshfield site based solely on 2015 CB&I sub-bottom seismic data (colored lines denote sediment thickness along seismic lines). Geology (colors) also provided based on 2015 side scan sonar data and interpretation of 1972 Raytheon seismic data. Note discrepancies exist between the two data sets due in part to limitations associated with interpretations of seismic reflection data particularly along lake bed exposures where no core samples exist for ground-truthing. Yellow=sand and gravel, blue=lake, light green=till over coastal plain. Units in meters.*

*Plum Island*

The Plum Island site lies between 5.6 and 8 km (3.5 and 5 miles) east northeast of Plum Island, MA and is about 18 square km (7 square miles) in area (see Figure 1). Approximately 75 km (45 miles) of seismic profile data were collected by CB&I. Lines MA_040 to MA_047 are oriented NW-SE and lines MA_048 to MA_057 trend NE-SW. Line spacing ranges from 240 to 1000 meters (787 to 3281 feet) (Figure 26). Two vibracores were collected also from this site, MA-BOEM-2015-VC07 and MA-BOEM-2015-VC08. VC07 penetrated 2.93 m (9.6 feet) and VC08 penetrated 2.77 m (9.1 feet). In addition, two grab samples were collected, MA-BOEM-2015-SS09 and MA-BOEM-2015-SS10 (Figure 26).

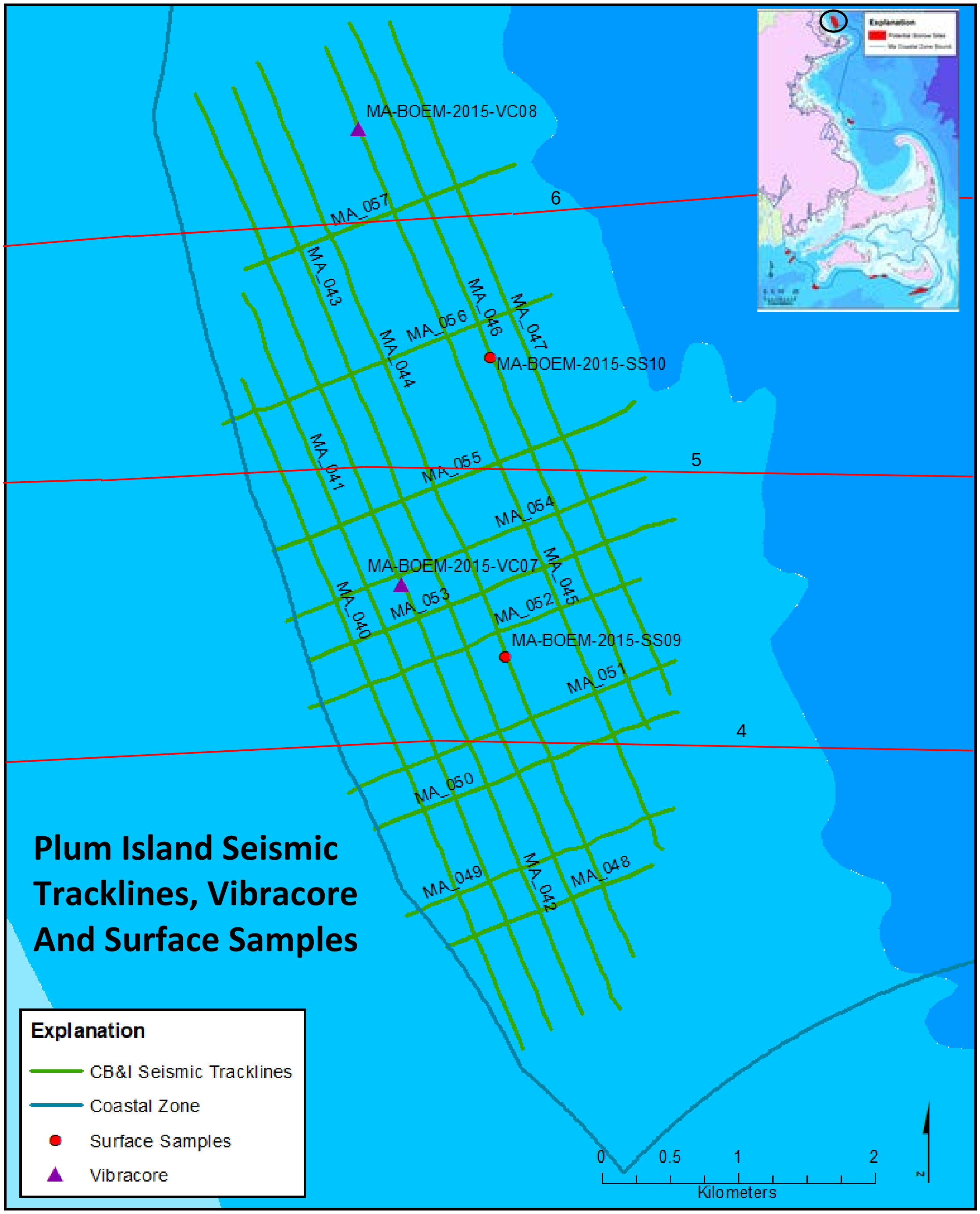


*Figure 26. Location of seismic lines, vibracores and grab samples collected by CB&I for the Plum Island site. Red lines are the seismic tracklines from Oldale and Wommack (1987).*

Oldale and Wommack (1987) collected seismic data in 1980 to map the geology of the inner continental shelf from Cape Ann, Massachusetts to New Hampshire (see Table 3). Lines 4, 5, and 6 pass through the Plum Island site (Figure 26). These early seismic profiles indicated a complex stratigraphy of glacial till, bedrock exposures, glacial marine sediments deposited during early post glacial submergence, fluvial sedimentation and formation of a low-stand delta following post-glacial rebound, and Holocene marine transgression, which eroded the fluvial sediments and deposited a thin and discontinuous mobile sand sheet on top.

Barnhardt et al. (2009) collected approximately 1100 km (660 miles) of high-resolution chirp seismic-reflection profiles in the Merrimack River embayment in 2007 (see Table 3 for reference). Twelve seismic lines that pass through the Plum Island site were selected and the geology re-interpreted (Figure 27). The 12 seismic profiles from Barnhardt et al. (2009) and the 18 seismic profiles from CB&I were combined with recent mapping and data collected by Hein et al. (2010) (see Table 3 for link to data) to interpret the geology and estimate the thickness of sand resources.

The surficial geology consists of three units (Figure 28). In the northern quarter of the site there are a few small bedrock exposures that protrude through the sediment cover. At the far southern end of the site there is a gravel and boulder lag deposit that has been mapped as eroded glacial till (Figure 28). This is either the remnant of a drumlin or a recessional moraine. The remainder of the site consists of an undulating, variable thickness mobile sand sheet overlying a fluvial-deltaic deposit of sand and gravel. In some areas the mobile sand sheet is eroded exposing the underlying fluvial sediments; distinguishing between the sand sheet and fluvial sediments could not be made at a regional scale and are not shown on the surficial geologic map. There are also buried channel fill deposits at the south end of the site that are not shown the surficial geologic map but appear in the map by Hein et al. (2010) and in Barnhardt et al. (2009) seismic data.

It is unclear if the vibracores penetrated through the mobile sand sheet into the underlying fluvial sediments. Core VC07 contains mostly fine and fine-to-medium quartz sand, 1-10% coarse sand, 1-10% silt, 1-10% shell hash with occasional pebbles and gravel up to 12.7 mm (0.5 inches) in size. Core VC08 contains medium to coarse sand from 0 to 0.84 m (0 to 3.2 feet) below the seafloor grading downward to fine and fine-to-medium sand. Grab samples SS09 and SS10 also show fine and fine-to-medium quartz sand, 1 to 20% coarse sand, 1-10% silt and 1-10% shell hash and shell fragments with occasional pebbles and gravel up to 12.7 mm (0.5 inches) in size.

Seven sediment grab samples collected by Barnhardt et al. (2009) in 2005 also lie within the Plum Island site. Grain size is variable but is mostly fine sand but contains pockets of medium to coarse sand and very coarse sand with gravel up to 18% by weight (Figure 29). In addition, grab samples from the usSeaBed data base were also examined (Figure 29). Nearly all the samples in the vicinity of the site are classified as 100% sand with a few pockets of gravelly sand.

Estimated thicknesses of the various sand units were determined two ways. First, estimates of the mobile marine sand sheet thickness, fluvial-deltaic deposit thickness and the thickness of a channel fill deposit that occurs in the subsurface at the south end of the site were determined from the Barnhardt et al. (2009) chirp data. These data are of much higher quality, allowing depths of the various units to be determined along the seismic trackline. These data were then combined to provide a map of the total sand thickness.  Second, the CB&I data was used to create a thickness map of the mobile sand sheet where it could be clearly identified in the seismic

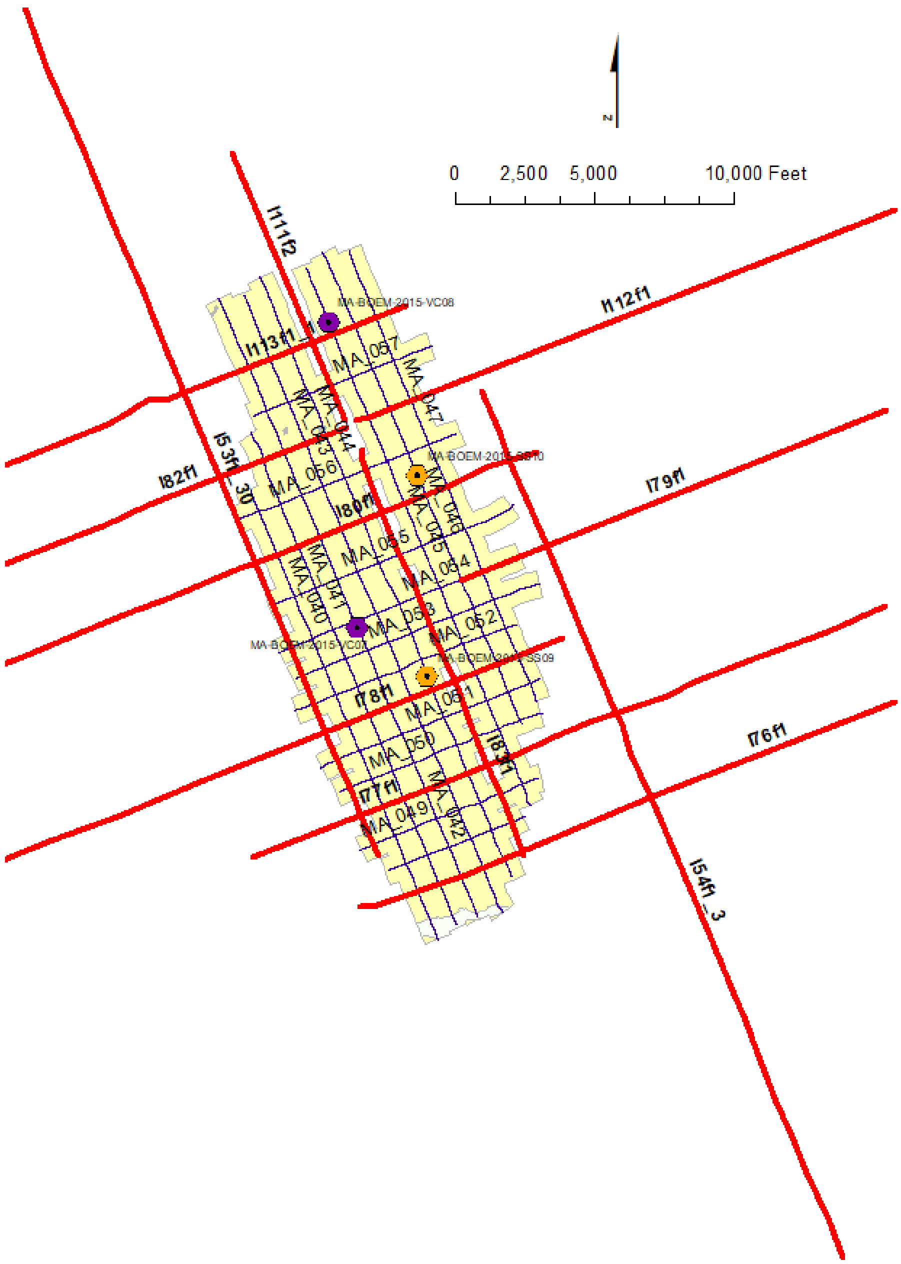


*Figure 27. Location of high-resolution chirp seismic profiles for the Plum Island site collected by Barnhardt et al. (2009) shown in red with respect to seismic lines collected by CB&I (purple). Location of vibracores and sediment samples collected by CB&I also shown.*

data.  Lack of data coverage did not warrant attempting to create a surface of each sand unit for volume calculations.

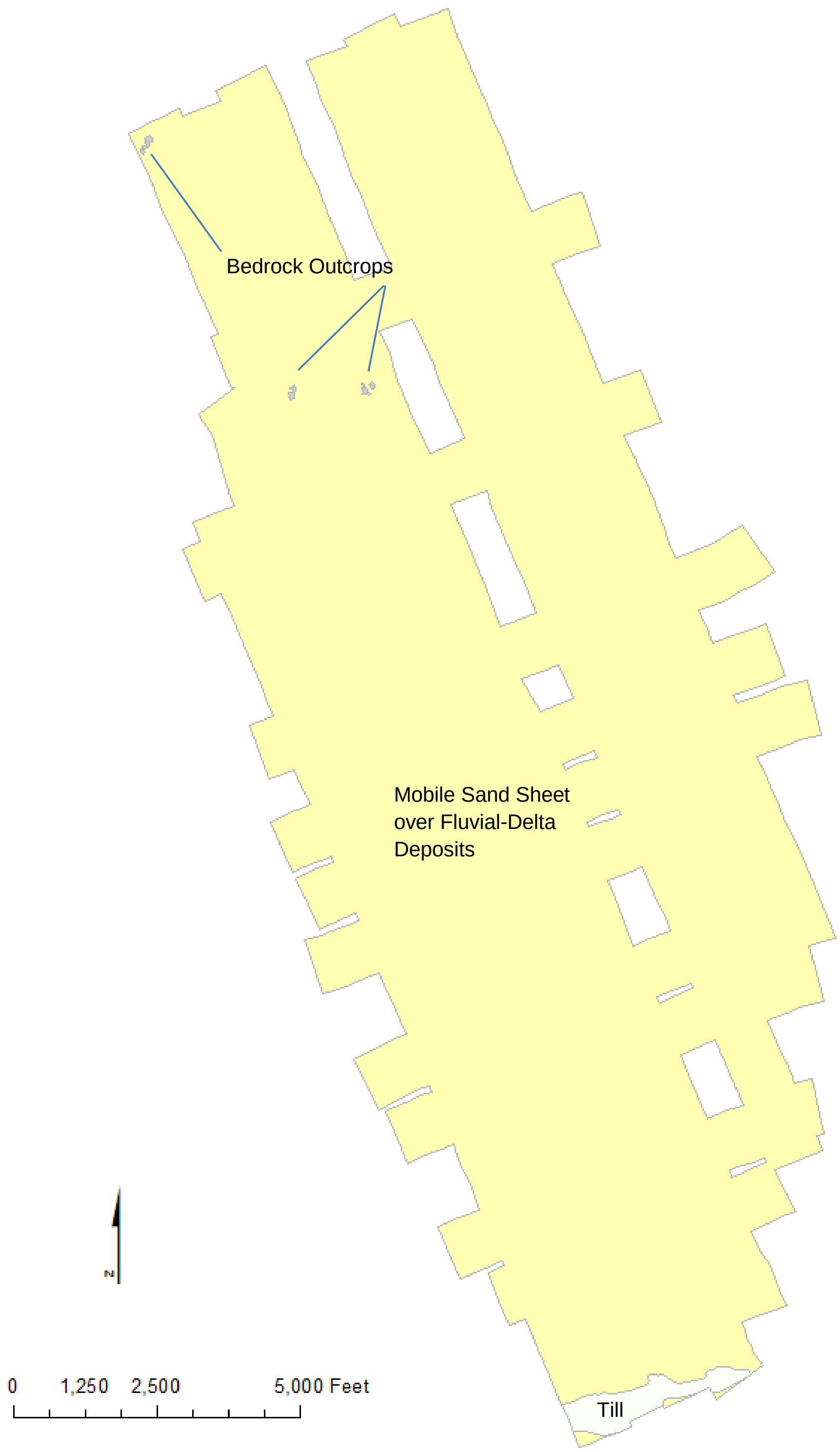


*Figure 28. Surficial geologic map of the Plum Island site.*

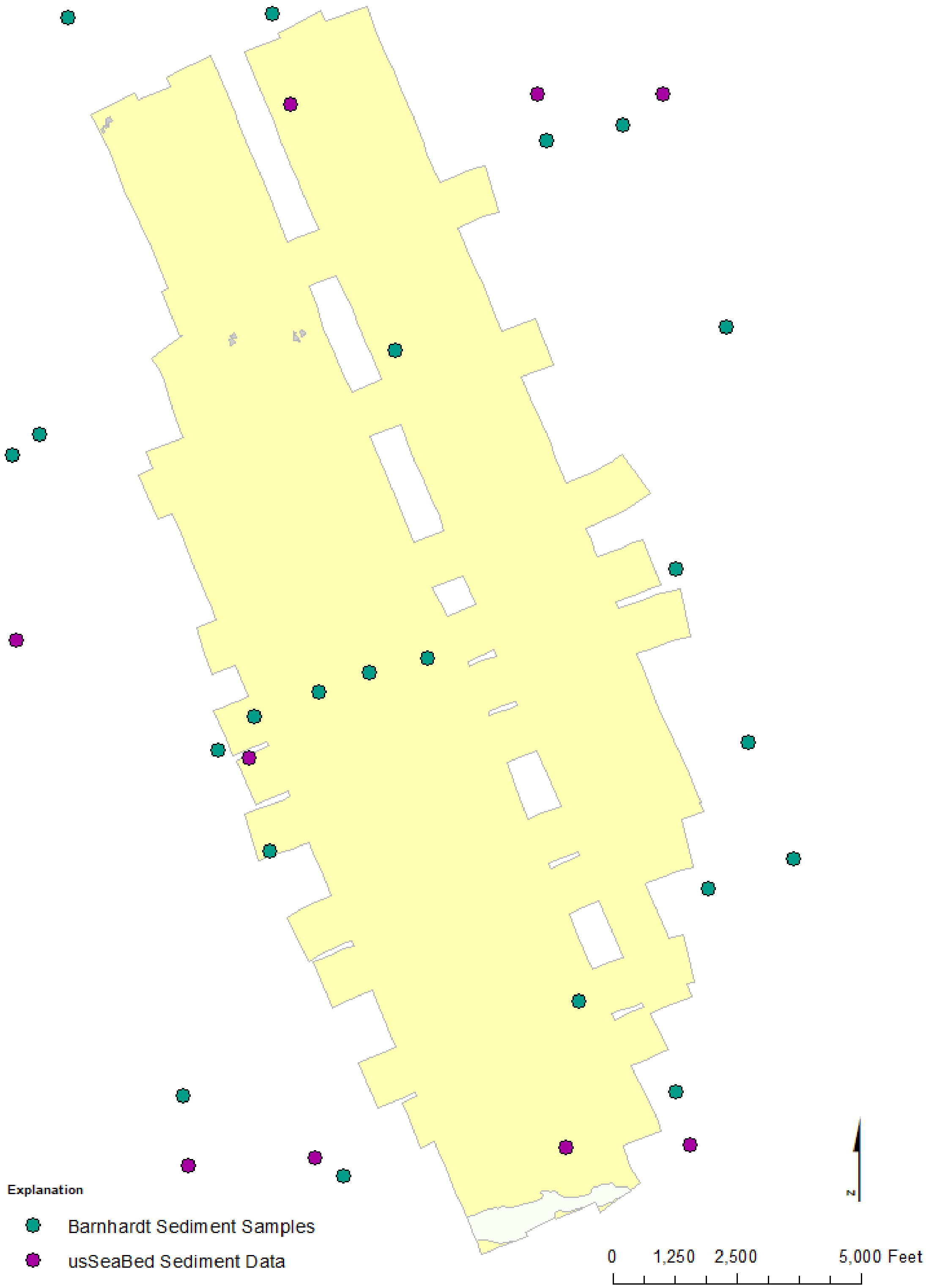


*Figure 29. Location of other sediment grab samples in the vicinity of the Plum Island site.*

The marine mobile sand sheet, on average, is 0 to 2 meters (0 to 6.6 feet) thick with occasional areas where it is up to 4 to 6 meters (13 to 20 feet) thick (Figure 30). The surface of the sand sheet is quite undulating with pockets where the sand has been eroded exposing the underlying fluvial sediments. The fluvial deposits are substantially thicker ranging from 0 to 10 meters (0 to 32.8 feet) thick over the western two-thirds of the site (Figure 31). The fluvial sediments thicken considerably to the east over the main portion of the former low-stand delta. Foreset beds are observed in the seismic profiles. The channel fill deposits are located in the southern portion of the site immediately north of the till exposure (Figure 32). The channel deposits are generally 1 to 5 meters (3.3 to 16.4 feet) thick and show a maximum thickness of 8 to 10 meters (28.6 to 32.8 feet). Total sand thickness is estimated to be 6 to 12 meters (20 to 39 feet) in the western two-thirds of the site and thickens to 14 to 22 meters (46 to 79 feet) in the eastern third of the site, with the thickest area occurring just east of the site boundary (Figure 33). Seismic profiles collected by CB&I show the upper mobile sand sheet is 0 to 4 meters (0 to 13 feet) thick (Figure 34) and within the same range as that observed previously by Barnhardt et al. (2009).

## Conclusions

A total of 210 km (126 miles) of swath bathymetry, side scan sonar, magnetometer and chirp seismic reflection profile data, along with 8 vibracores and 7 grab samples were collected by CB&I in six areas located off the coast of Massachusetts and analyzed to determine the extent, estimated thickness, character and suitability of any sand resources for potential beach nourishment projects. The six sites are Buzzards Bay, Nomans Land, Muskeget Channel, Nantucket, Marshfield and Plum Island. The lack of data in some locations and the poor quality of the CB&I seismic reflection profile data did not allow for estimates of sand volumes with the exception of Marshfield. Rather, estimates of sand thickness are provided along individual tracklines where possible.

The sites that show the greatest promise as a source for sand are Muskeget Channel, Nantucket and Plum Island. At Muskeget Channel, recent sands lay over a marine fan deposit, and combined, these have total thicknesses ranging from 0 to 10 meters (0 to 30 feet). Underlying the fan deposit are sandy outwash deposits of unknown thickness. However, the site is outboard of the terminal moraine so no glacial till or fine lake bottom sediments are expected. The same conditions apply to the Nantucket site. Nantucket consists of a modern bar complex but a lack of data precludes estimating thickness. Based on the limited vibracore and grab sample data the sediment consists of fine and fine-to-medium sand with occasional pebbles and gravel. Plum Island has the greatest sand potential because it is located near an extensive low-stand delta. The site consists of a highly eroded and undulating fluvial channel system feeding the delta that is overlain by a thin but variable thickness sand sheet. The sand sheet is mobile, and most likely changes morphology after major storm events. The fluvial deposits are underlain by fine-grained marine sediments. Total thickness of the sand sheet and fluvial sediments varies from 6 to 12 meters (20 to 39 feet) in the western two-thirds of the site and thickens to 14 to 22 meters (46 to 79 feet) in the eastern third of the site, with the thickest area occurring just east of the site boundary. The sediments consist of fine and fine-to-medium sand


*Figure 30. Estimated thickness of mobile marine sand sheet at the Plum Island site based on re-interpreted seismic data collected by Barnhardt et al. (2009).*


*Figure 31. Estimated thickness of fluvial deposits at the Plum Island site based on re-interpreted seismic data collected by Barnhardt et al. (2009). Note there is some mismatch of thicknesses at line intersections due to differences in the interpretation of unit thickness on individual seismic lines.*

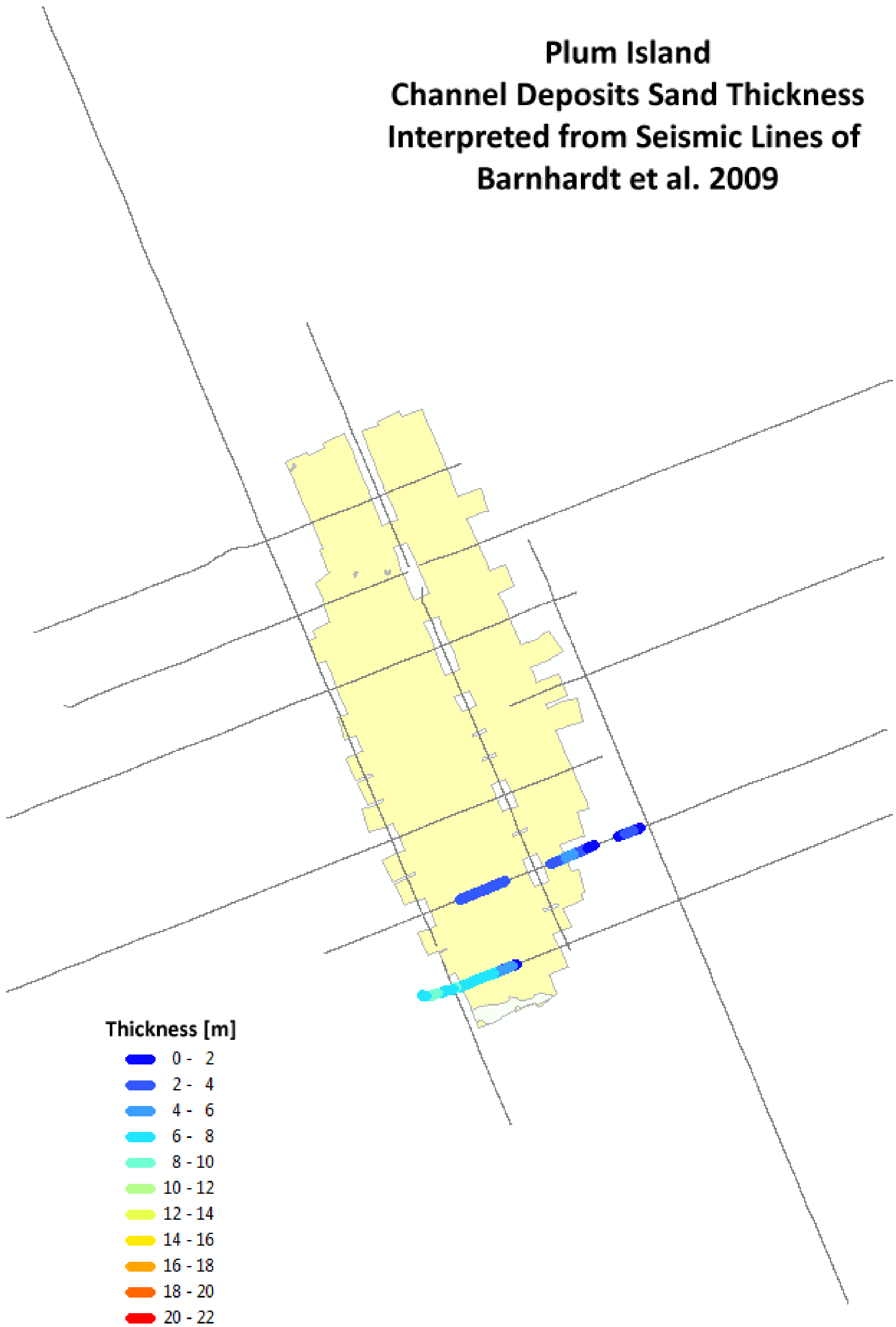


*Figure 32. Estimated thickness of channel fill deposits at the Plum Island site based on re-interpreted seismic data collected by Barnhardt et al. (2009).*

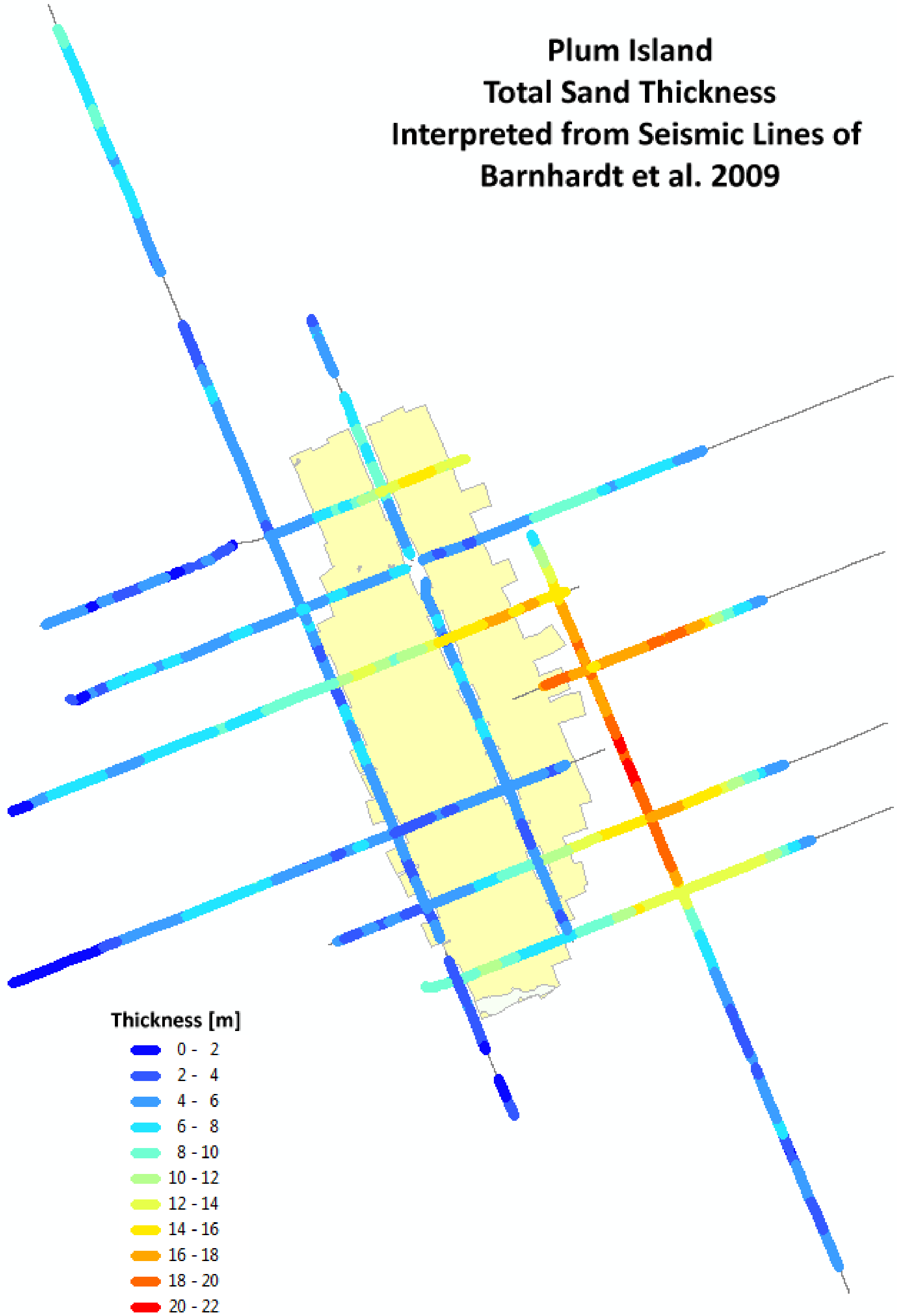


*Figure 33. Estimated total thickness of sand and gravel deposits at the Plum Island site. Represents the sum of the sand sheet, fluvial and channel fill deposits. Note there is some mismatch of total thicknesses at line intersections due to differences in the interpretation of unit thicknesses on individual seismic lines.*

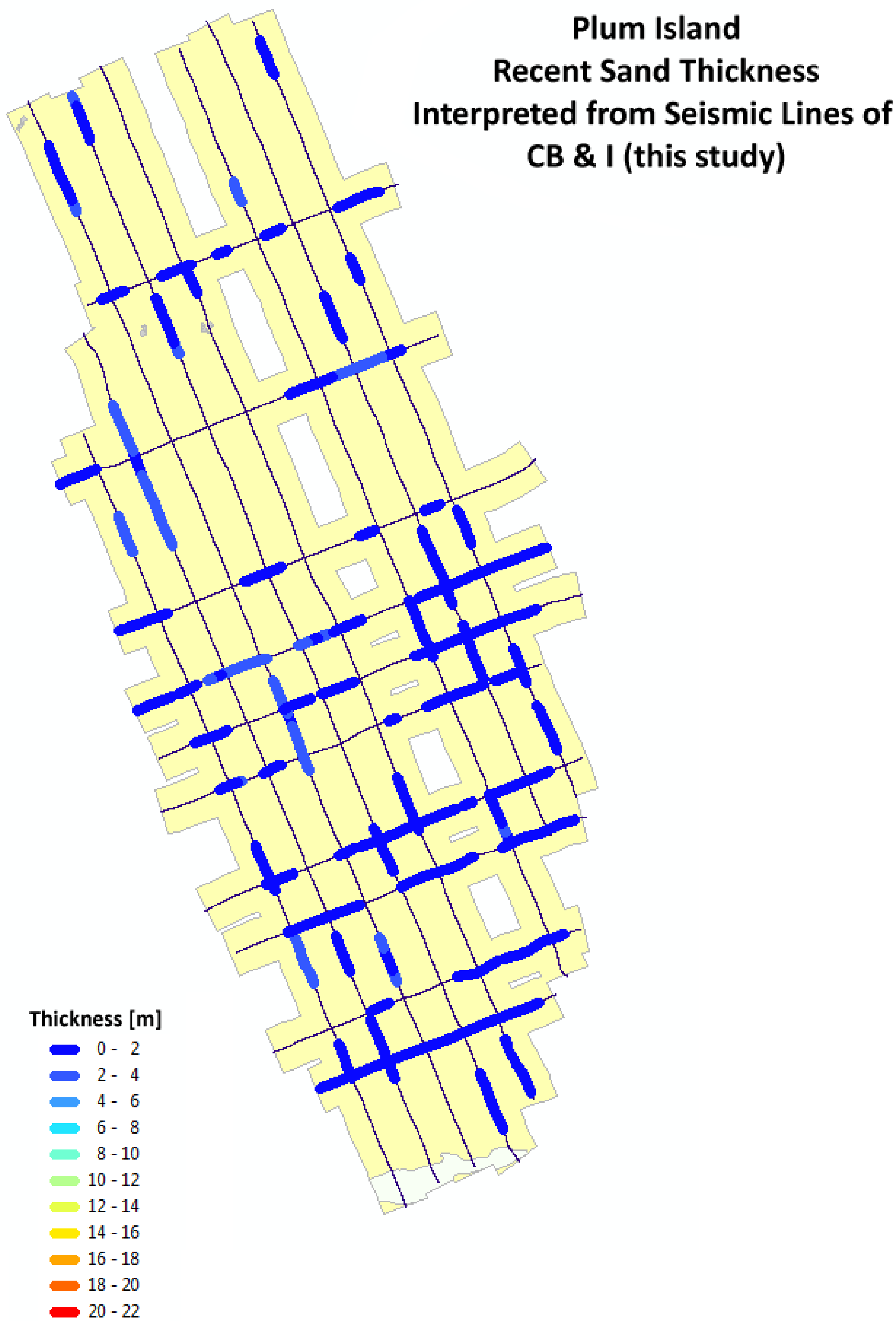


*Figure 34. Estimated thickness of mobile marine sand sheet at the Plum Island site based on interpreted seismic data collected by CB&I in 2015.*

with pockets of medium-to-coarse sand and very coarse sand and gravel. In general, Plum Island is coarser than Muskeget Channel and Nantucket. Clearly, these three sites warrant more detailed investigation.

Marshfield contains a lenticular body of sand and gravel up to 12 meters (39 feet) thick that overlies lake bottom and glacial till deposits. The estimated volume of this material is 40,000,000 cubic meters (52,000,000 cubic yards). The areal extent of the sand and gravel body is approximately 7 square km (2.7 square miles). The deposit is very rocky with medium to coarse quartz sand and was most likely derived from the nearby glacial till deposits. This site may be a suitable supply for those beaches requiring coarser materials and may warrant additional investigation.

Buzzards Bay is mostly all glacial till or lake bottom sediments and is not considered a suitable site for sand. The thickness of the till and lake bottom sediments is unknown. The till deposits contain numerous large boulders up to 9 meters (30 feet) in size. However, there is evidence of a channel fill deposit at the northeast end of seismic line MA_004 that may have been part of a channel system draining glacial lakes in Rhode Island Sound and Buzzards Bay. Thickness of the channel fill may range from 5 to 13 meters (16 to 42 feet) and may warrant further investigation.

The Nomans Land site lies on the terminal moraine of the last glaciation and consists entirely of glacial till of unknown thickness. Large surface boulders up to 3 to 9 meters (10 to 30 feet) are observed on the side scan sonar imagery. Occasional and discontinuous pockets of medium to coarse sand may occur within the deposit occupying < 10% of the area of the unit. The site is not considered suitable as a source of sand.

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# Appendix A

## Interpretation of BOEM Chirp and Sample Data

**Report by**

**Ralph Lewis**
**March 7, 2017**

# Interpretation of BOEM Chirp Seismic and Sample Data From Selected Potential Sand and Gravel Resource Areas in Massachusetts Waters

# 2017- March 7th Draft

By Ralph Lewis

## Introduction:

"Chirp" seismic-reflection profiles from 38 survey lines, collected in six areas of interest regarding their sand and gravel resource potential, were processed and supplied to the author by the Massachusetts Geological Survey. These data were supplemented by accompanying sample analyses and photographs from seven shallow cores and seven surface samples.

As noted in the results section, the "chirp" system chosen for the surveys was not up to the task of clearly imaging most of the deposits of interests (the Nantucket West Survey Area, where the data were a bit better, being an exception), and the interpretations of the BOEM profiles attempted in this report relied heavily on the existing mapped regional geology, and other existing seismic and bathymetric data from in and around each survey area. Where possible, tracklines for the BOEM study have been superimposed on existing geologic map drafts that are being prepared as part of the production of the Quaternary Geologic Map of Massachusetts. These maps (Figures 2, 26, 50, 58) also show the location  of the other seismic profiles that were relied on for the BOEM interpretations attempted, the BOEM core locations, and multibeam "swath" bathymetry where available.

In the case of the Marshfield Survey Area, "boomer" data collected by Raytheon for a 1972 Massachusetts Coastal Mineral Inventory Survey (Figures 1 and2), and the swath bathymetry, were extremely helpful. EG&G "Uniboom" data collected by the USGS (Oldale- 80010) in 1980 (Figures 26-29) and the swath bathymetry guided the attempt to interpret the BOEM data in the Plum Island area. In Buzzards Bay the BOEM data are close to "boomer" data (Figures 50-

53) from a 1975 USGS “O’Hara” cruise (ASTR-75) but existing swath bathymetry was of limited use.  Two“boomer” lines from a 1980 USGS Oldale cruise (AST-80-6B) lie close to the Noman’s Land BOEM data (Figures 59 and 60). The Nantucket and Nantucket West survey areas are close to “sparker” Line 5, USGS Cruise Fay 036 (1976), and a helpful general DEM bathymetric view of these survey areas exists (Figures 66, 67 and 73, 74). Interpreted seismic records from the supporting Raytheon and USGS cruises are included as figures in each survey area results section if they were helpful with the BOEM data interpretations.

## Seismic Unit Interpretive Designations:

The following designations have been used:

**Recent**- Modern marine deposits consisting of sand and or sand and gravel (such as bars, bed forms, reworked older material, etc.)

**Marine Fan (F?)-** Deposits of a marine fan inferred to be prograding southward from Nantucket Sound

**Channels (Ch) -** Channels cut into underlying glacial and coastal plain deposits during low stand

**Delta-** Glaciomarine deltaic deposits of the Merrimack Delta

**Marine-** Glaciomarine deposits that overlie till, coastal plain deposits and/or bedrock

**Lake-** Glaciolacustrine deposits that overlie till, coastal plain deposits and/or bedrock

**Outwash (QO) -** Outwash deposits that emanated from the terminal moraine of the Wisconsinan glacier.

**Coastal Plain Deposits (CP)** - Deposits associated with the Atlantic Coastal Plain (generally Cretaceous and/or Tertiary in age)

**Rock (Rk)-** Bedrock of various ages (acoustic basement)

# Survey Area Sections 1-6:

## Section 1 - Marshfield Results

Combining the BOEM Marshfield seismic  profiles with the mapped geology, swath bathymetry, and existing 1972 “boomer” data (Figure 1- red rectangle, Figure 2 Geologic Map, Figures 3-5 Raytheon lines) yielded a map of the inferred “Recent” deposit of interest (pink speckled area Figure 2). The inferred “Recent” deposit shown on the interpreted BOEM seismic lines (Figures 8-25) was penetrated by two cores (VC 11 and VC 12) that contained sand and gravel mixed with shell hash (see Figures 6,7,10 and 23). The presence of shell hash indicates this is a marine deposit.

The spotty quality of the Marshfield “chirp” data makes their interpretation difficult. The interpretations shown on Figures 8-25 have been made with a low confidence level. As a “stand-alone” data set these seismic profiles are not sufficient to support a confident assessment of this resource. The Raytheon profiles (Figures 3-5) show that the deposit in question has a lenticular cross-section (Figures 3-5) indicating it is probably a bar that has been reworked from older glacial and coastal plain deposits by modern marine processes. The swath bathymetry helped in outlining the extent of the deposit as shown on Figure 2.

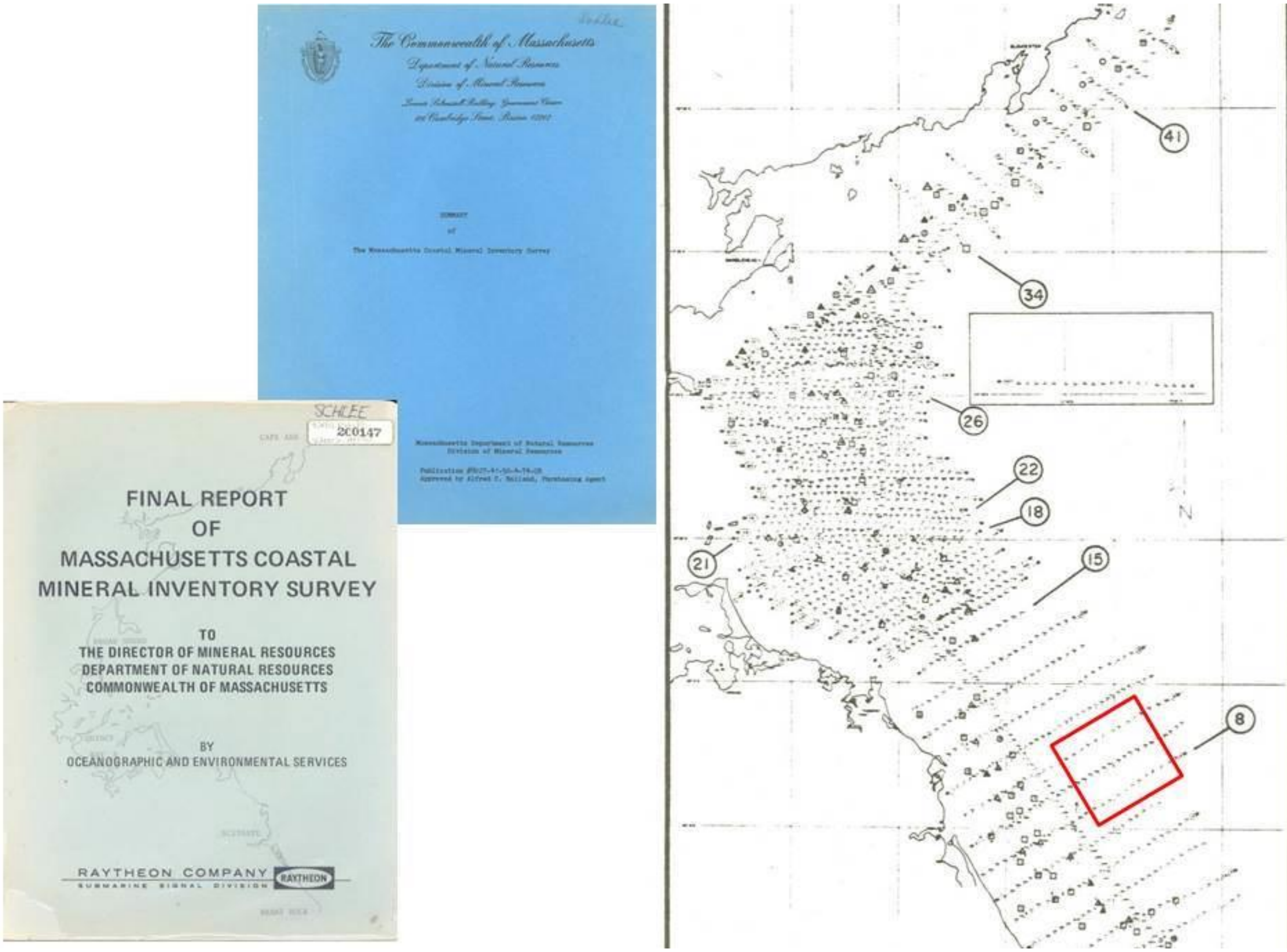



**Figure 1: Showing the two 1972 reports produced for the Massachusetts Coastal Mineral Inventory Survey. The seismic profiles used for Figures 3-5 are shown in the red rectangle.**

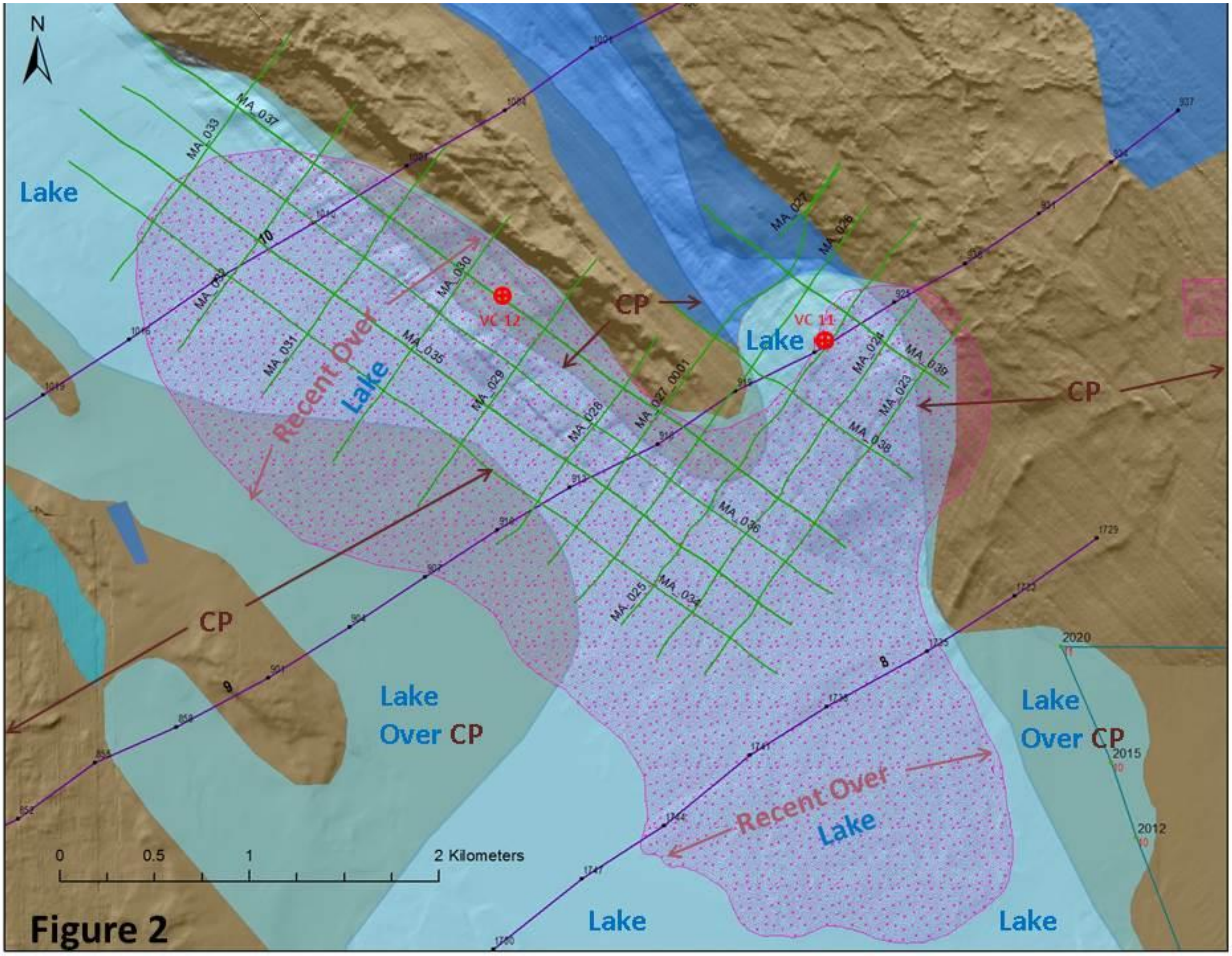



**Figure 2: A draft geologic map produced as part of the production of the Quaternary Geologic Map of Massachusetts with Raytheon tracklines 8-10 (in purple), BOEM tracklines 23-39 and cores VC 11 and VC 12 shown in their geologic/bathymetric context. The multibeam bathymetry augmented the seismic data and helped to better define the extent of the "Recent" deposit of interest shown in pink speckles.**

NE Line 8 Raytheon (1972) SW

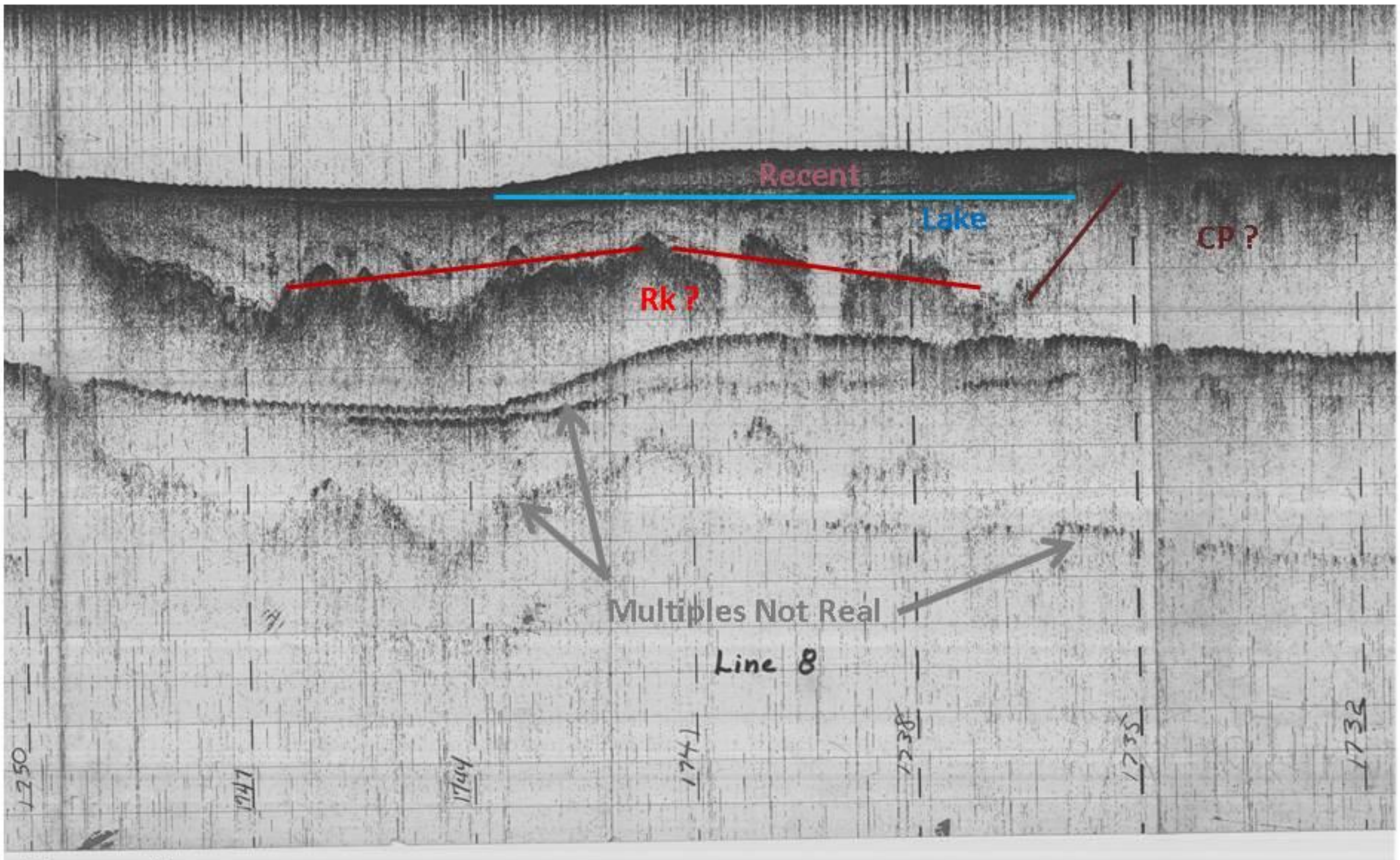



**Figure 3**

NE Line 9 Raytheon (1972) SW

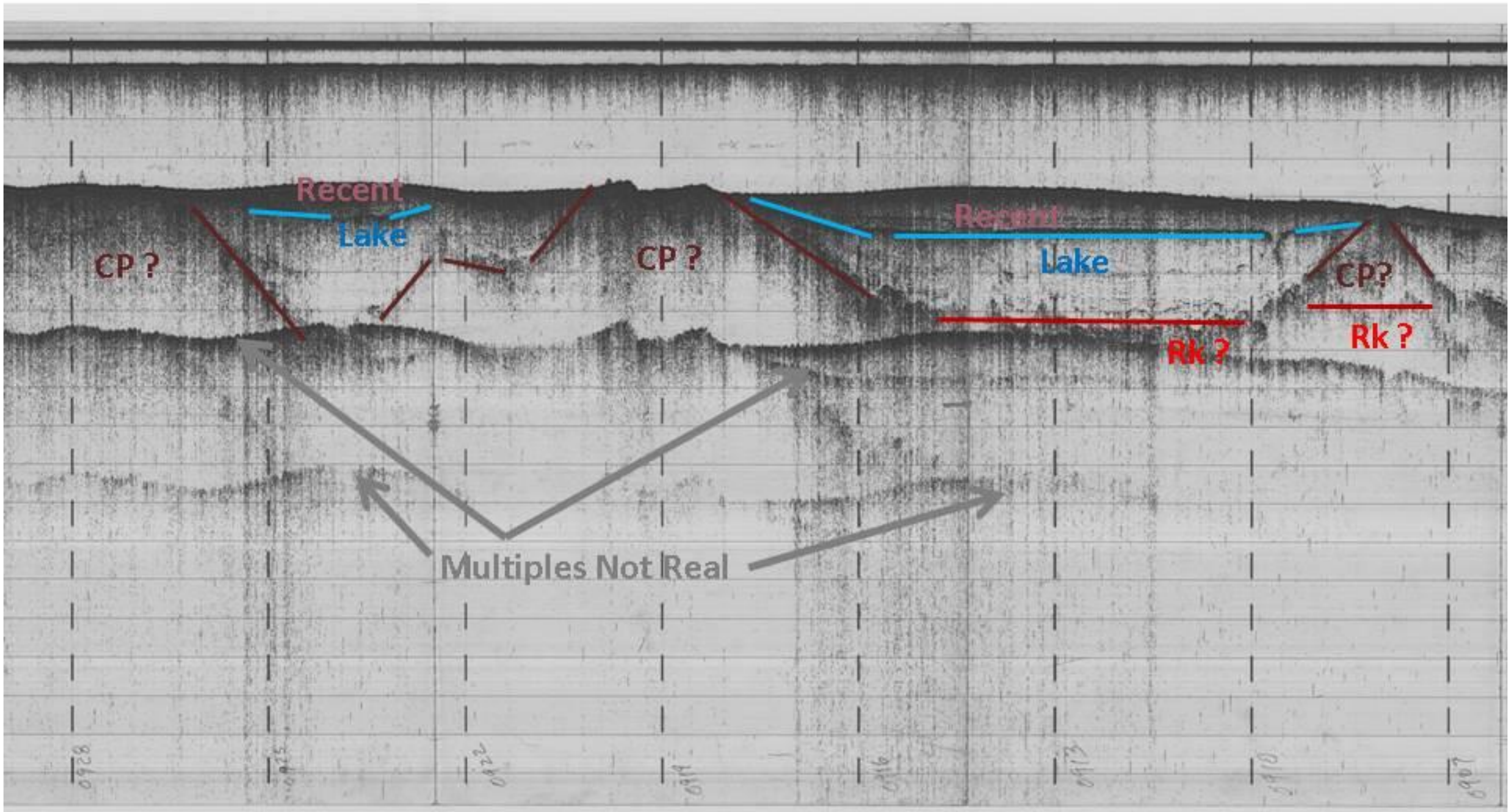



**Figure 4**

**SW** Line 10 Raytheon (1972) NE

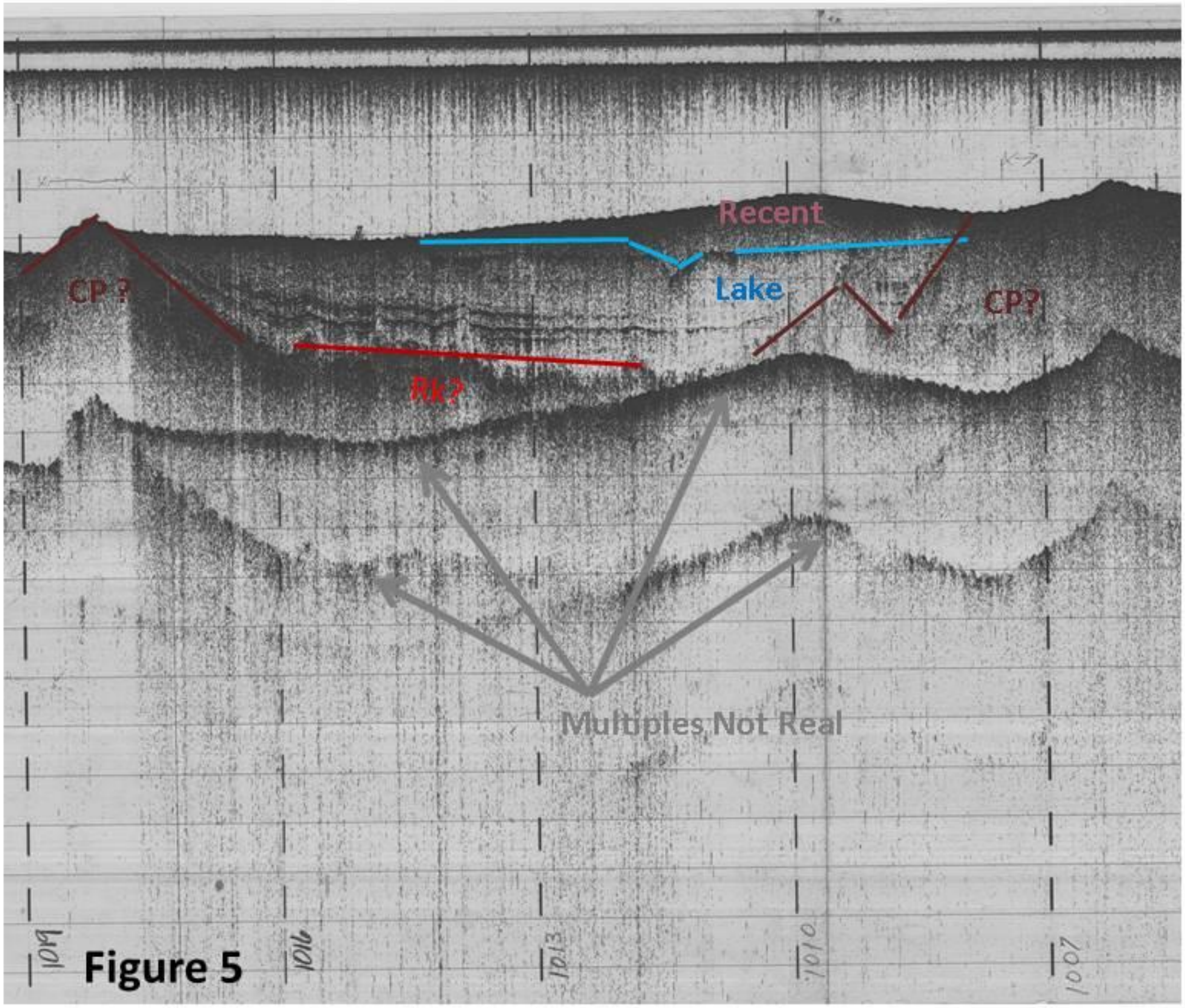



**Figure 5**

# Core VC 11

(Unsorted S&G with Shell Hash)

| ELEV. (ft) | DEPTH (ft) | LEGEND | CLASSIFICATION OF MATERIALS Depths and elevations based on measured values | % REC. | BOX OR SAMPLE | REMARKS |
|---|---|---|---|---|---|---|
| -115.6 | 0.0 | | | | | |
| -116.0 | 0.4 | | SAND, fine to medium grained, quartz, trace clay, trace coarse grains, trace rock, rock up to (0.5" x 0.25"), dark grayish brown (2.5Y-4/2), (SW). | | 1 | Sample #1, Depth = 0.2' Mean (mm): 0.48, Phi Sorting: 0.93 Fines (230): 2.95% (SW) |
| -116.8 | 1.2 | | | | 2 | Sample #2, Depth = 0.8' Mean (mm): 7.16, Phi Sorting: 2.17 Fines (230): 0.44% (GW) |
| -117.9 | 2.3 | | Rocky SAND, medium to coarse grained, quartz, trace shell hash, trace silt, rock up to (2.0" x 1.25"), (0.75" x 0.5") shell fragment @ 0.5', 2.5" rock @ 0.6', dark grayish brown (2.5Y-4/2), (GW). | | 3 | Sample #3, Depth = 1.7' Mean (mm): 4.03, Phi Sorting: 2.54 Fines (230): 0.47% (GW) |
| -120.4 | 4.8 | | SAND, medium to coarse grained, quartz, some rock, trace silt, rock up to (2.0" x 1.25"), 3.0" rock @ 2.2', grayish brown (2.5Y-5/2), (GW). | | 4 | Sample #4, Depth = 3.5' Mean (mm): 4.17, Phi Sorting: 2.29 Fines (230): 0.42% (GW) |
| | | | Rocky SAND, medium to coarse grained, quartz, trace silt, rock up to (2.25" x 1.5"), grayish brown (2.5Y-5/2), (GW). | | 5 | Sample #5, Depth = 6.7' Mean (mm): 2.25, Phi Sorting: 2.09 Fines (230): 0.92% (SW) |
| -124.2 | 8.6 | | Rocky SAND, medium to coarse grained, quartz, trace silt, rock up to 1.5", (3.0" x 2.0") rock @ 6.3', (2.25" x 1.5") rock @ 7.2', 2.5" rock @ 7.9', Bit Sample from 8.4' to 8.6', dark gray (5Y-4/1), (GW). | | | |
| | | | End of Boring | | | |






**Figure 6**

# Core VC 12

(Unsorted S&G with Shell Hash)



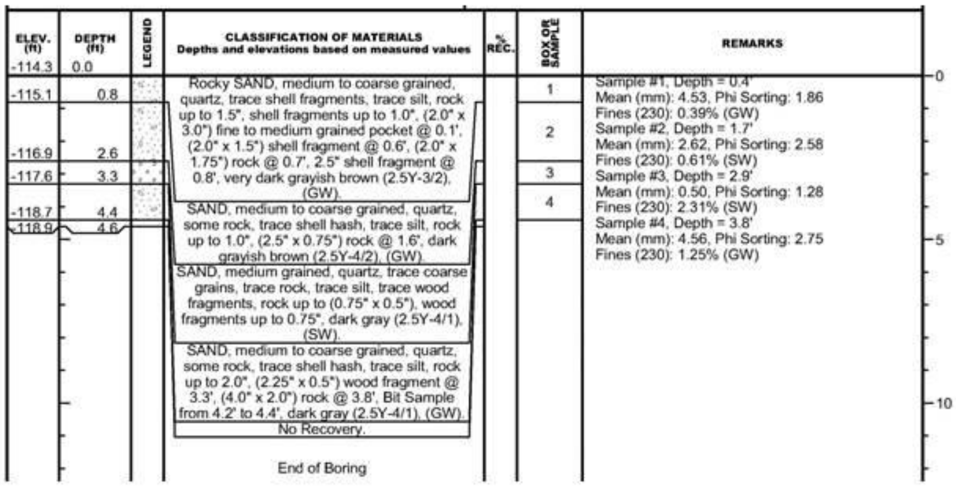




**Figure 7**

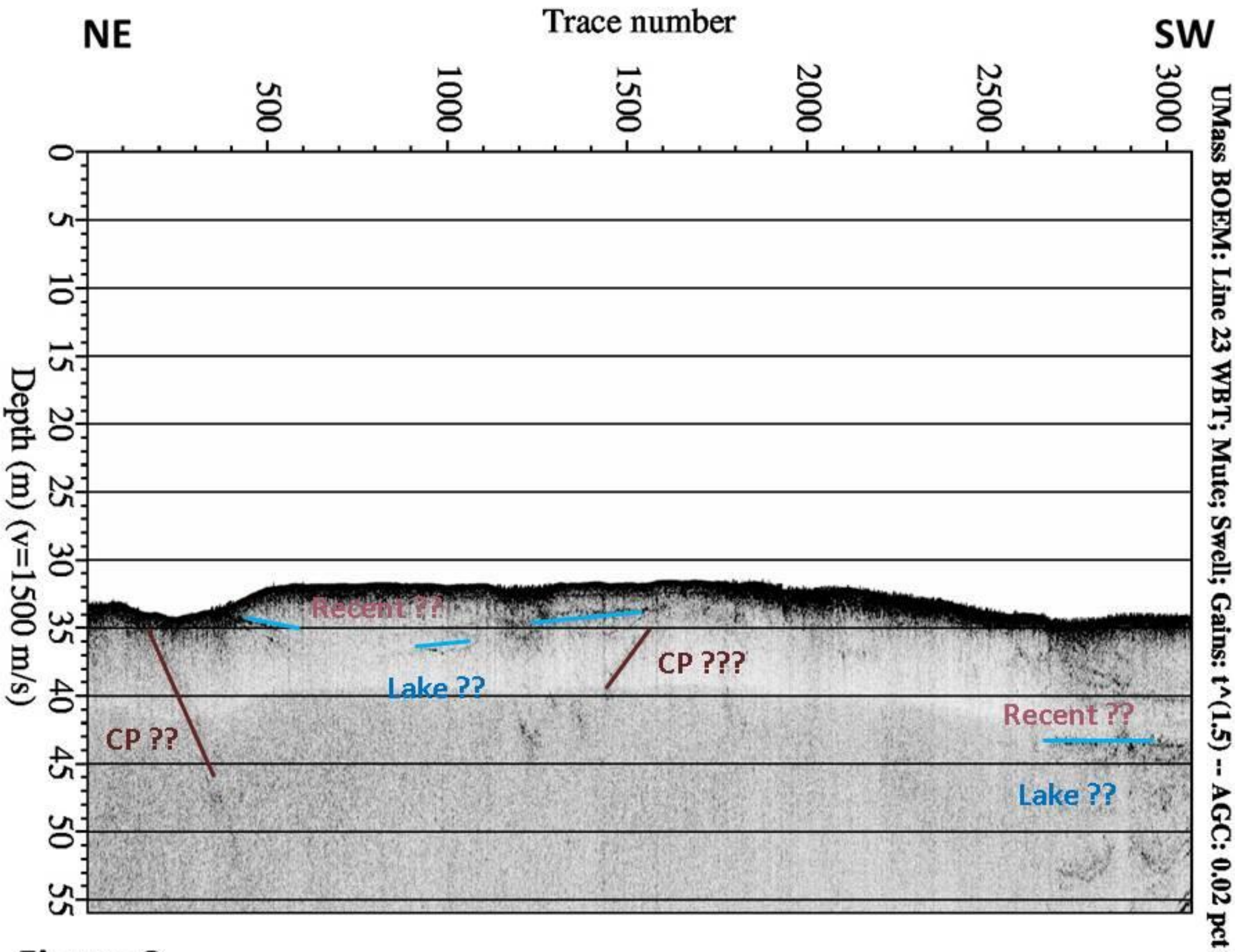

NE
Trace number
SW
500
1000
1500
2000
2500
3000
UMass BOEM: Line 23 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
Recent ??
CP ???
Lake ??
CP ??
Recent ??
Lake ??

Figure 8

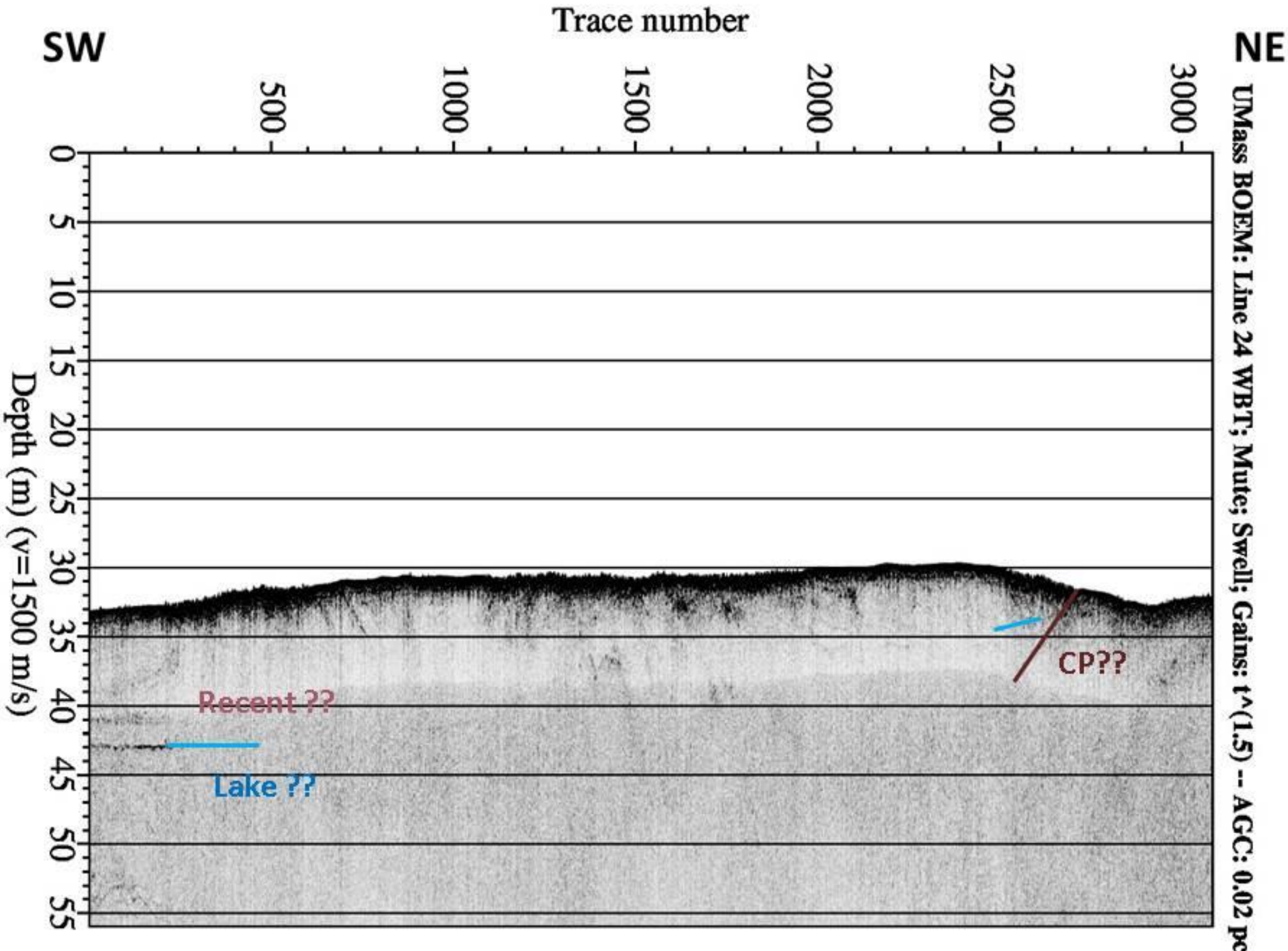

SW
Trace number
NE
500
1000
1500
2000
2500
3000
UMass BOEM: Line 24 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
Recent ??
Lake ??
CP??

Figure 9

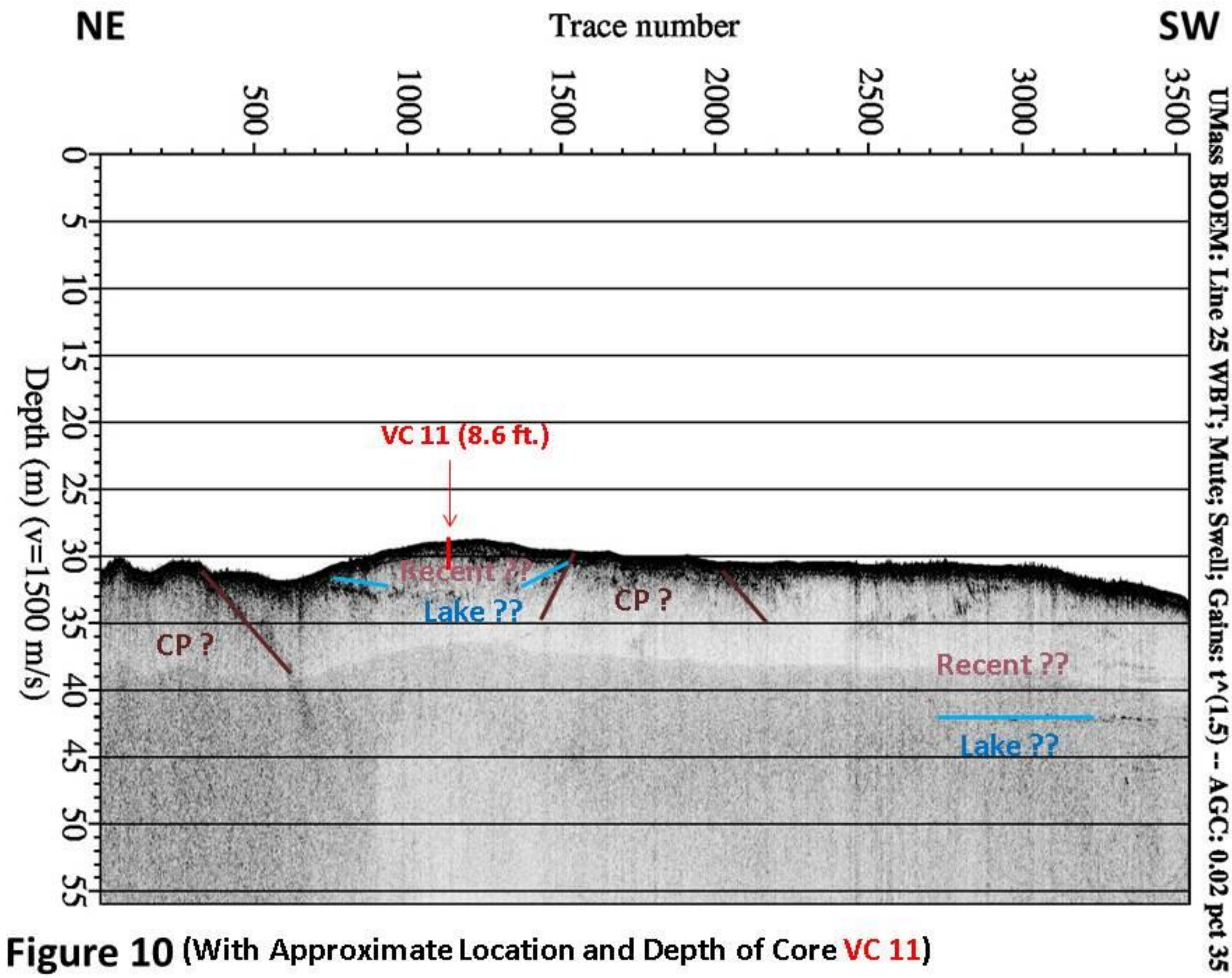



**Figure 23: Showing the approximate location and depth of Core VC 11 along "chirp" line 25**

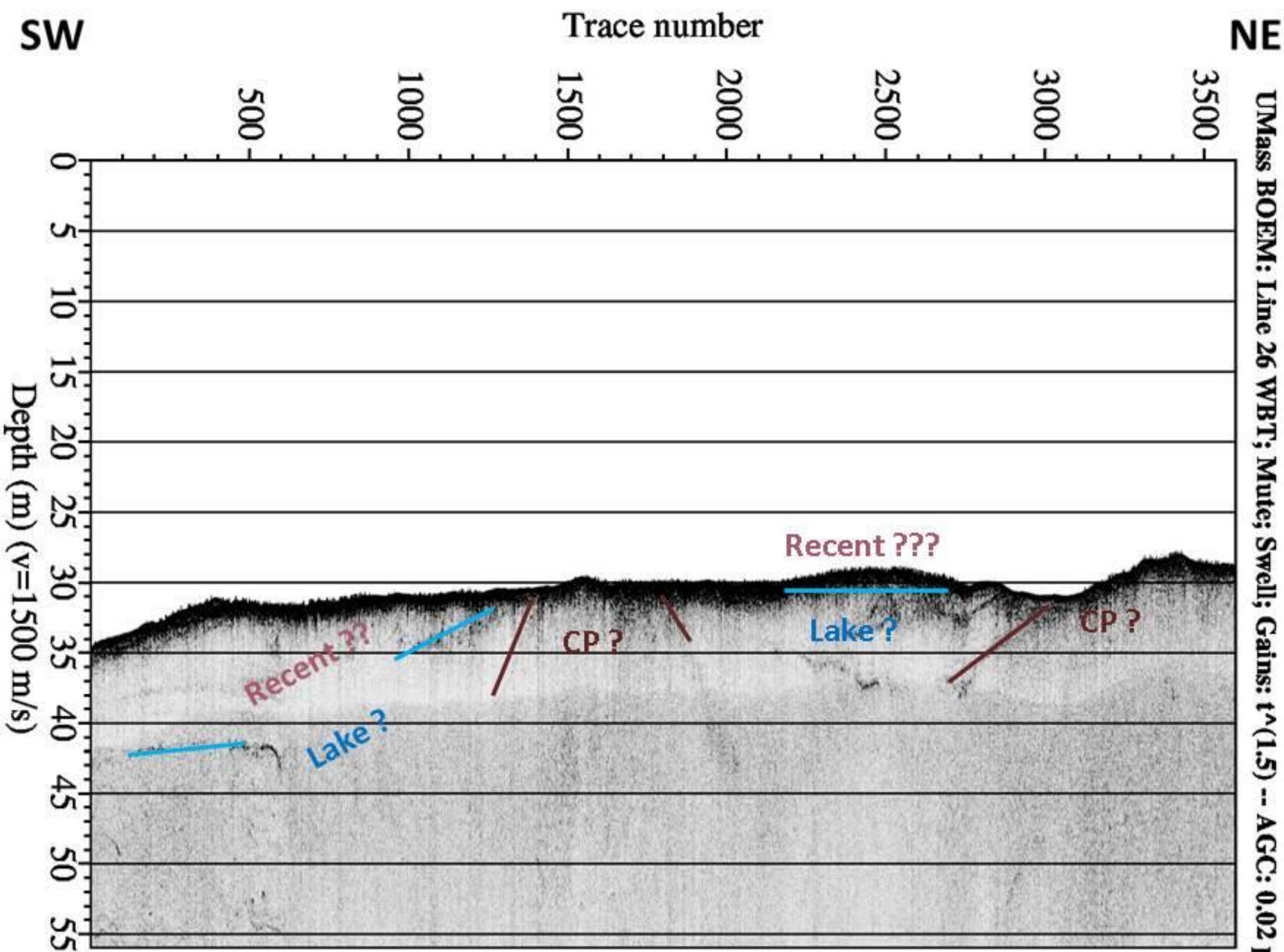

SW
Trace number
NE
500
1000
1500
2000
2500
3000
3500
UMass BOEM: Line 26 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
Recent ???
Lake ?
CP ?
CP ?
Recent ??
Lake ?
CP ?

**Figure 11**

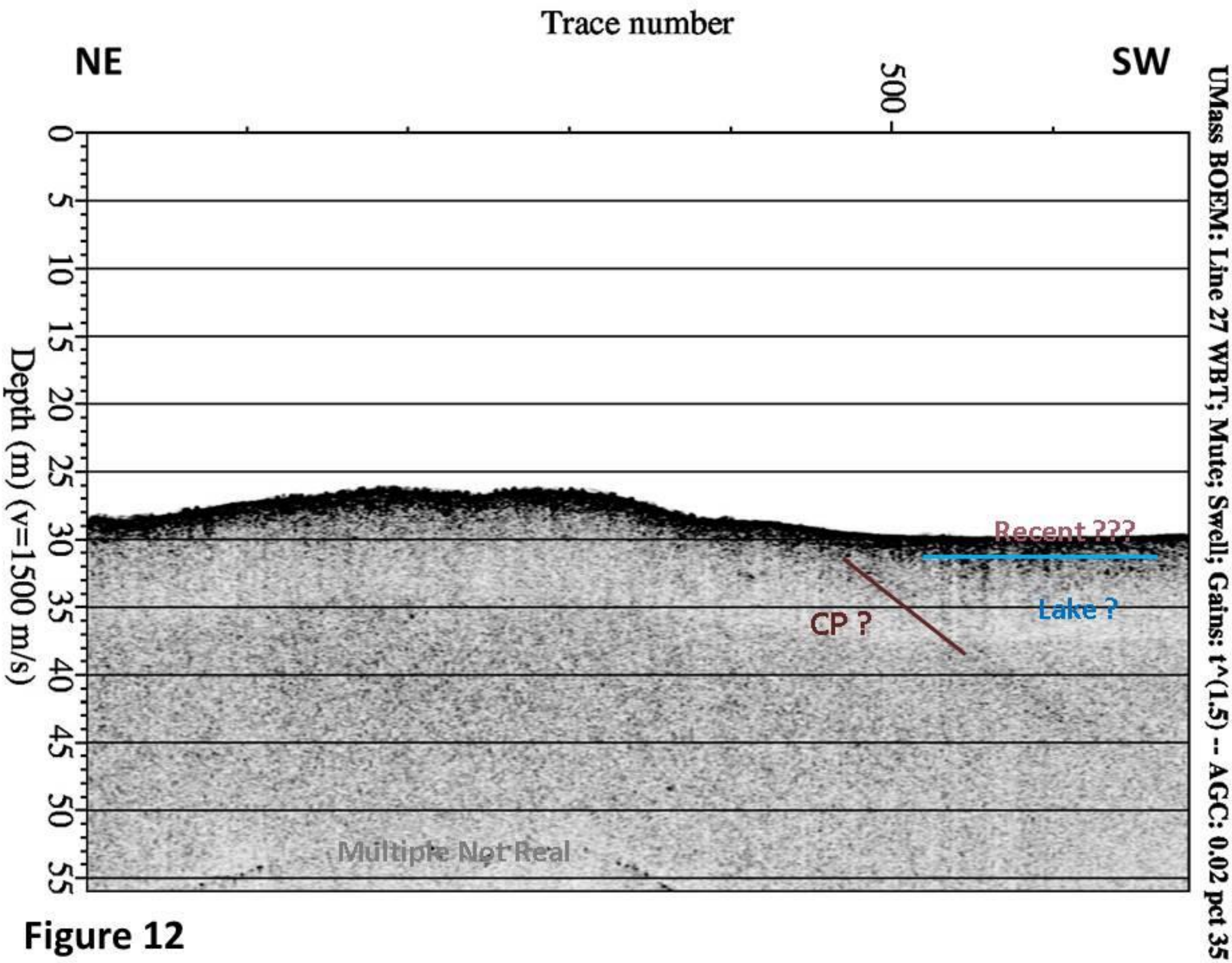
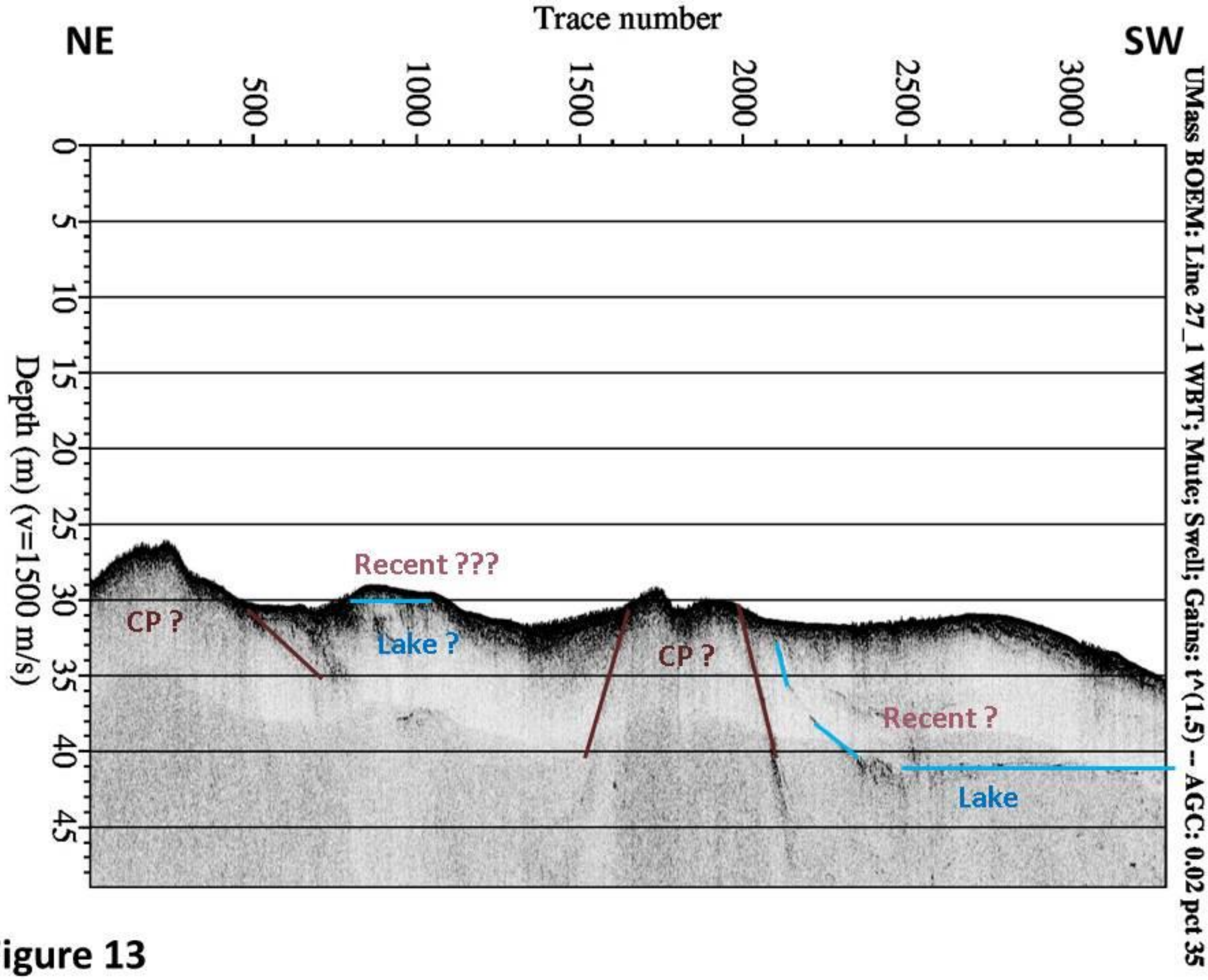

Trace number
NE
SW
500
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
UMass BOEM: Line 27 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ???
Lake ?
CP ?
Multiple Not Real

Figure 12



Trace number
NE
SW
UMass BOEM: Line 27_1 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
Recent ???
CP ?
Lake ?
CP ?
Recent ?
Lake


**Figure 13**

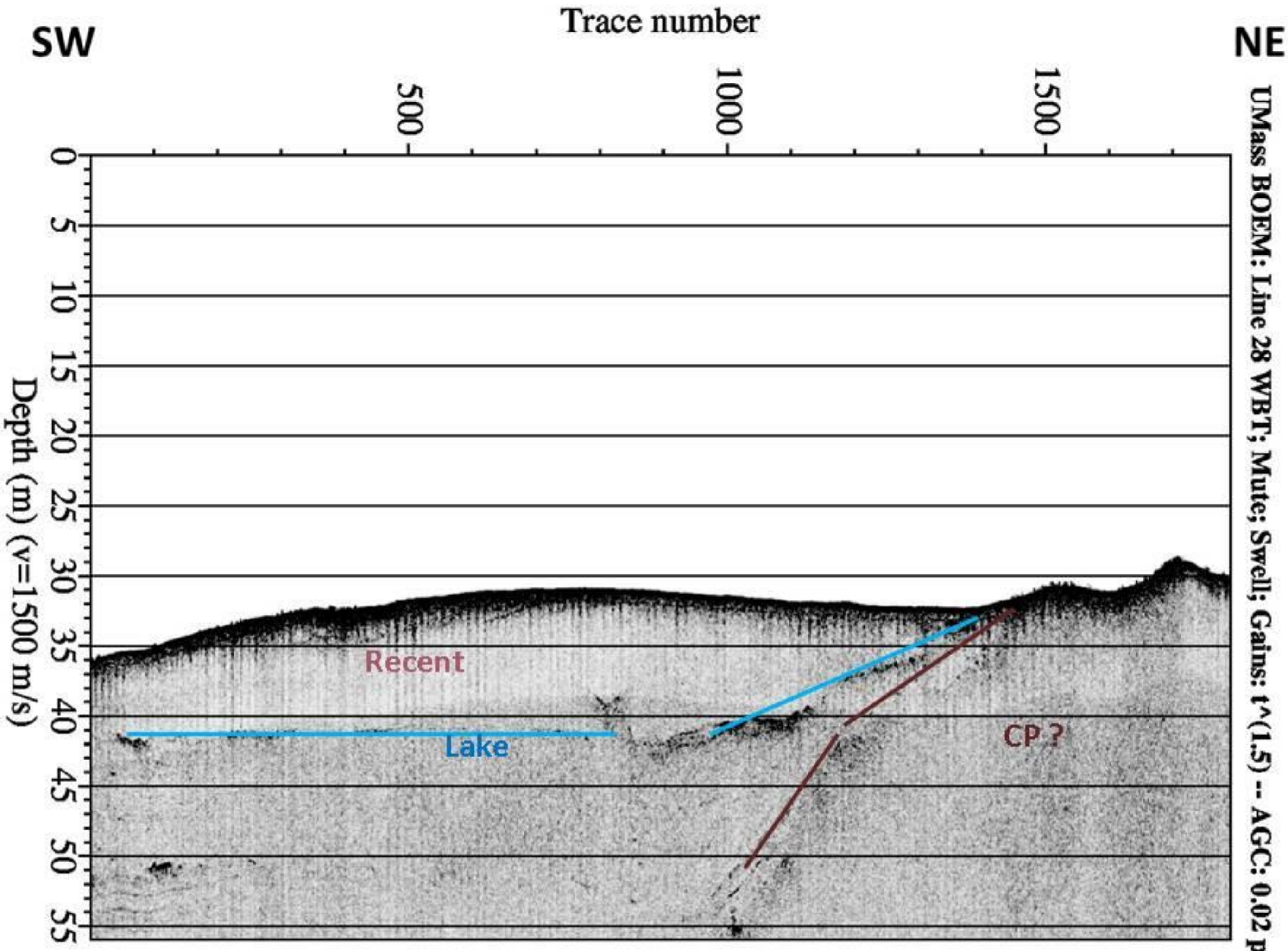

SW
Trace number
NE
500
1000
1500
UMass BOEM: Line 28 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
Recent
Lake
CP ?

**Figure 14**

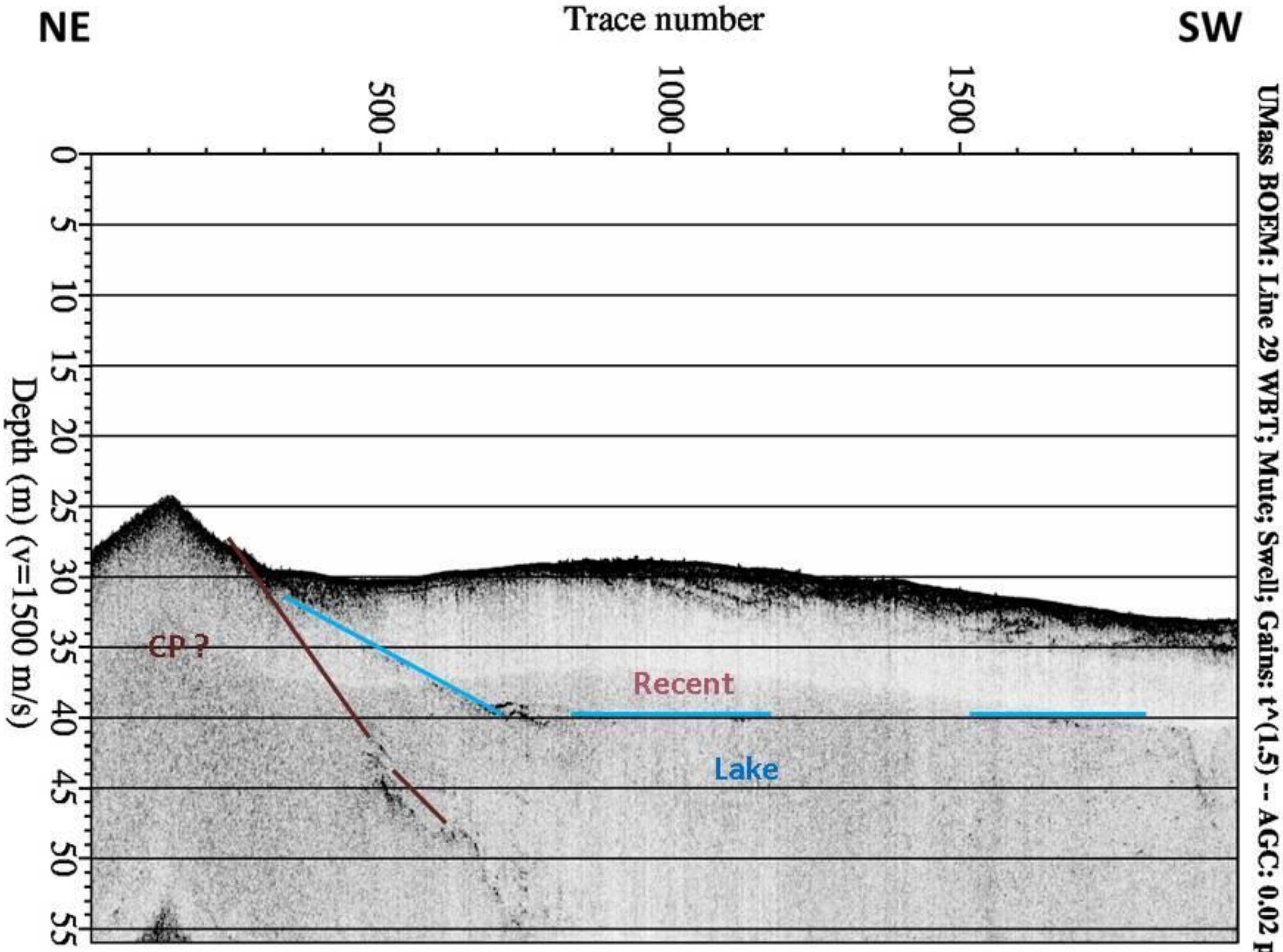

NE
SW
Trace number
500
1000
1500
UMass BOEM: Line 29 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
CP ?
Recent
Lake

Figure 15

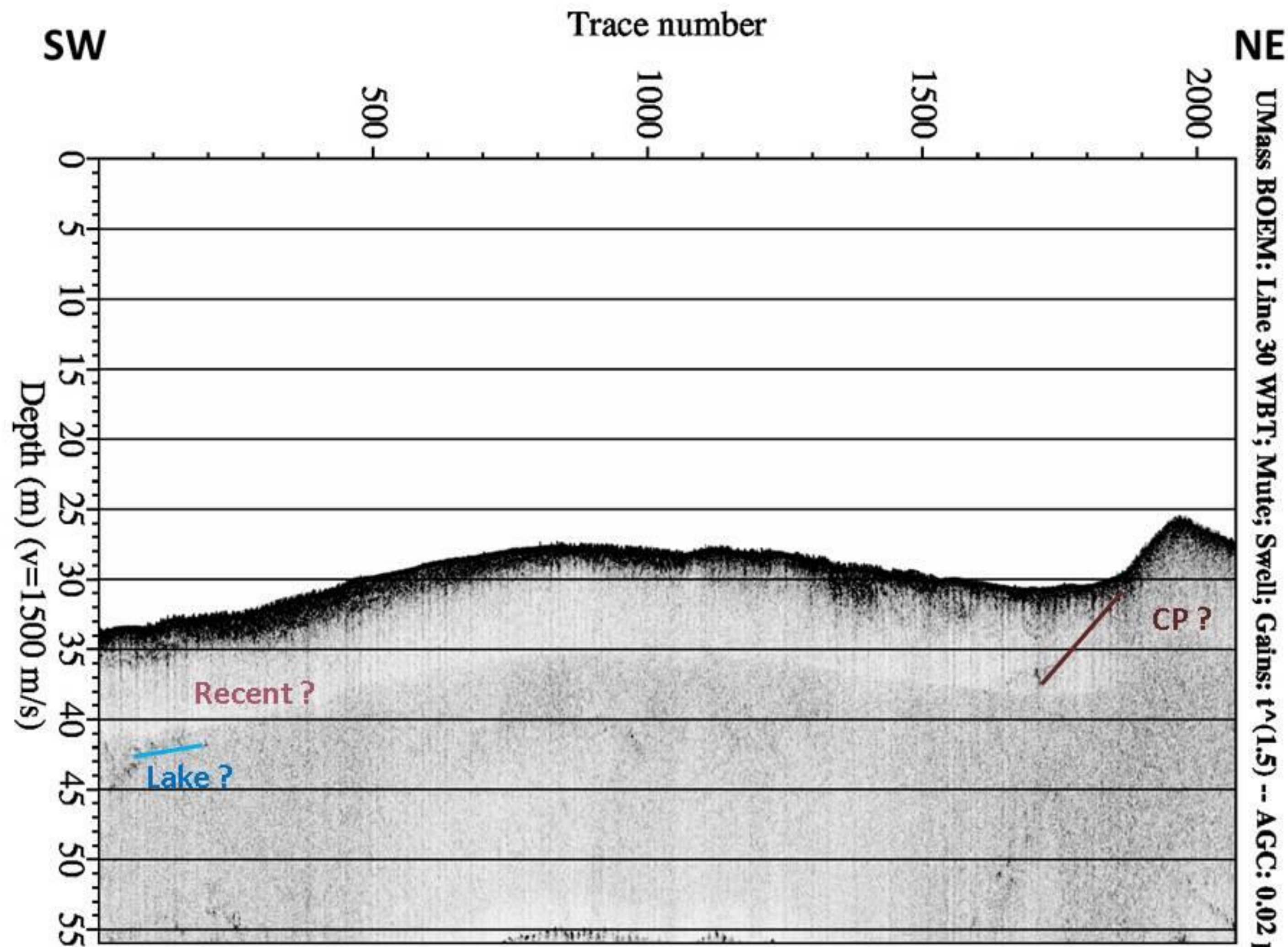

SW
Trace number
NE
500
1000
1500
2000
UMass BOEM: Line 30 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
Recent ?
Lake ?
CP ?

Figure 16

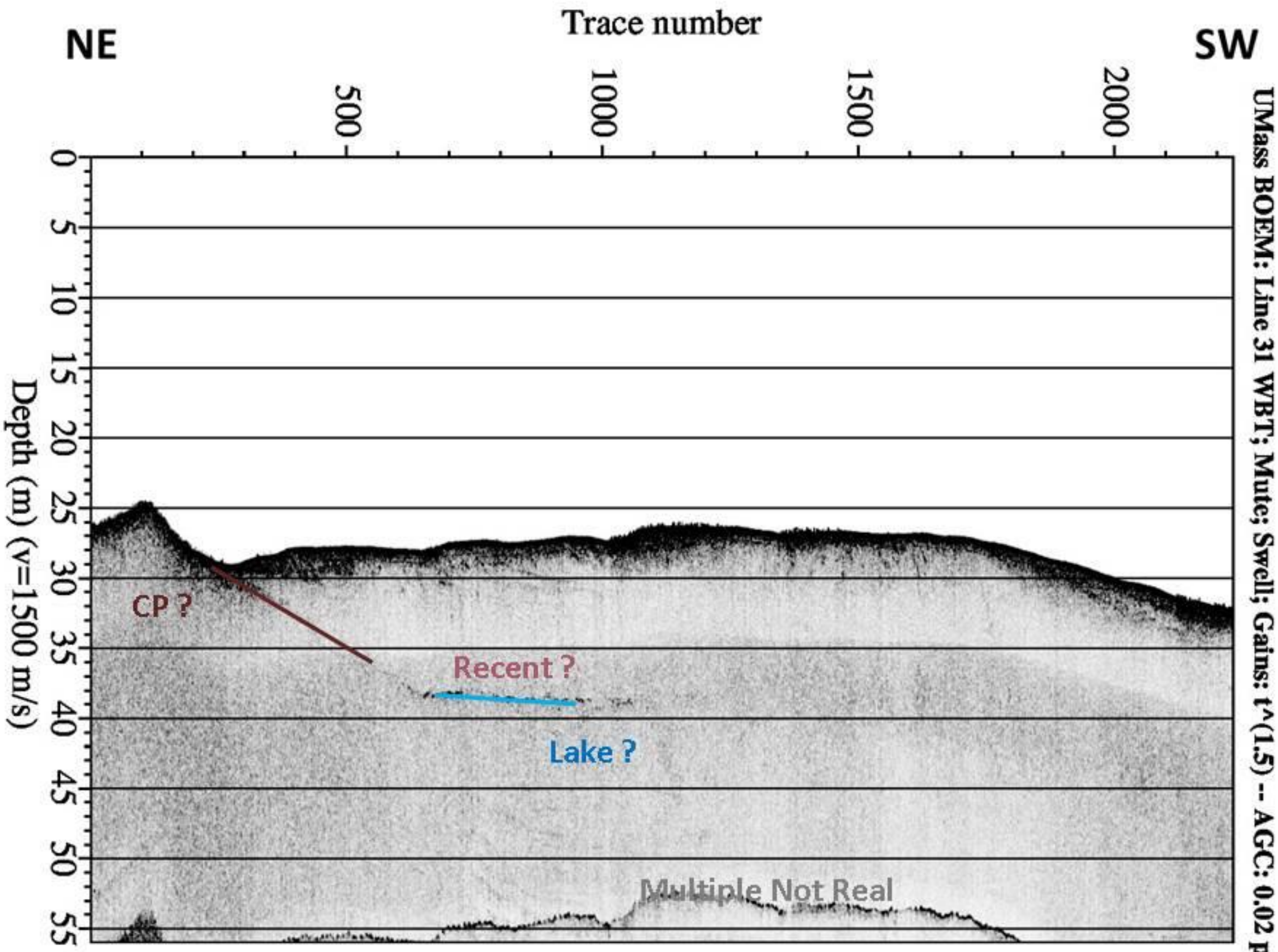

NE
Trace number
SW
500
1000
1500
2000
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
UMass BOEM: Line 31 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
CP ?
Recent ?
Lake ?
Multiple Not Real

**Figure 17**

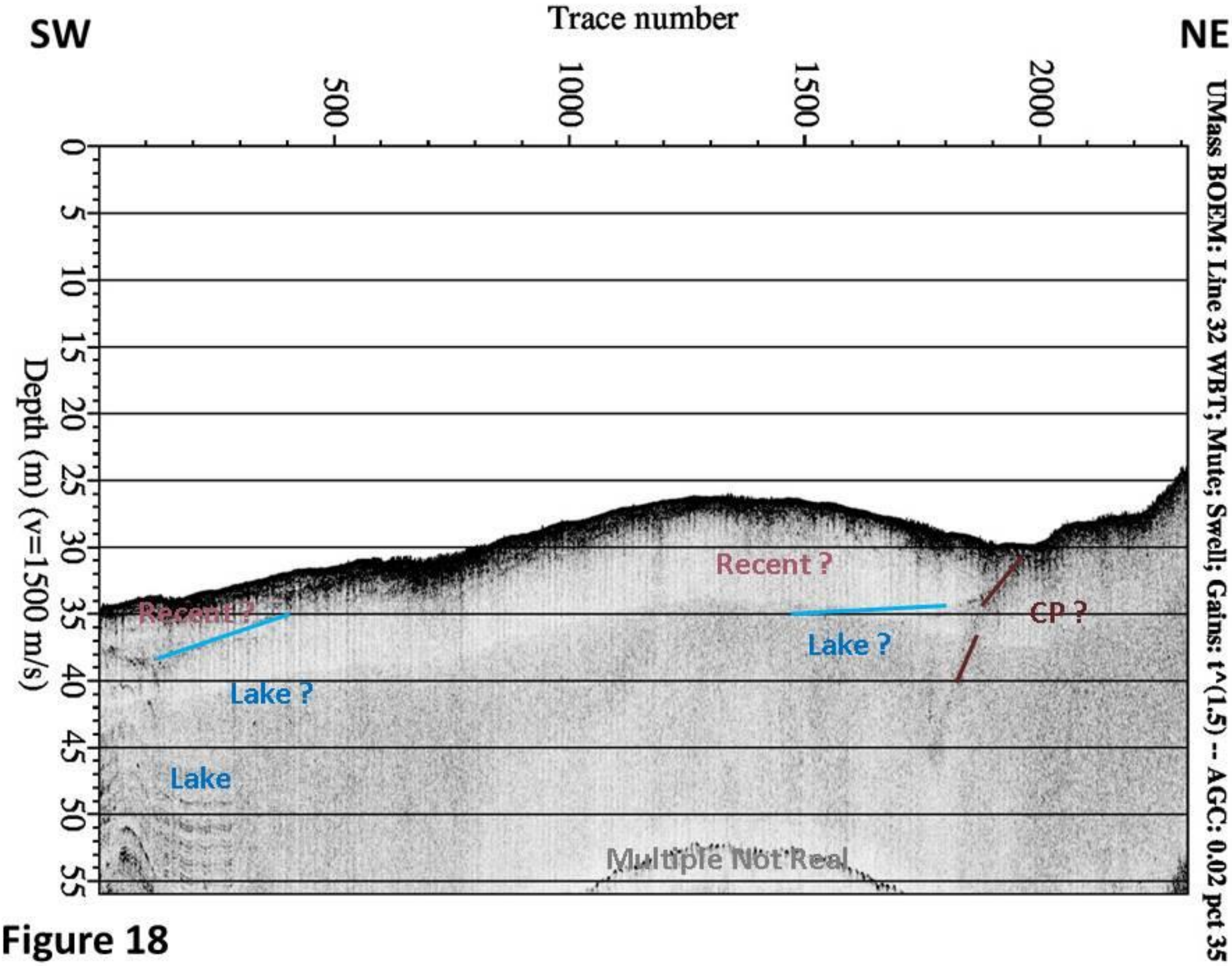

SW
Trace number
NE
500
1000
1500
2000
UMass BOEM: Line 32 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
Recent ?
Recent ?
Lake ?
Lake ?
CP ?
Lake
Multiple Not Real

**Figure 18**

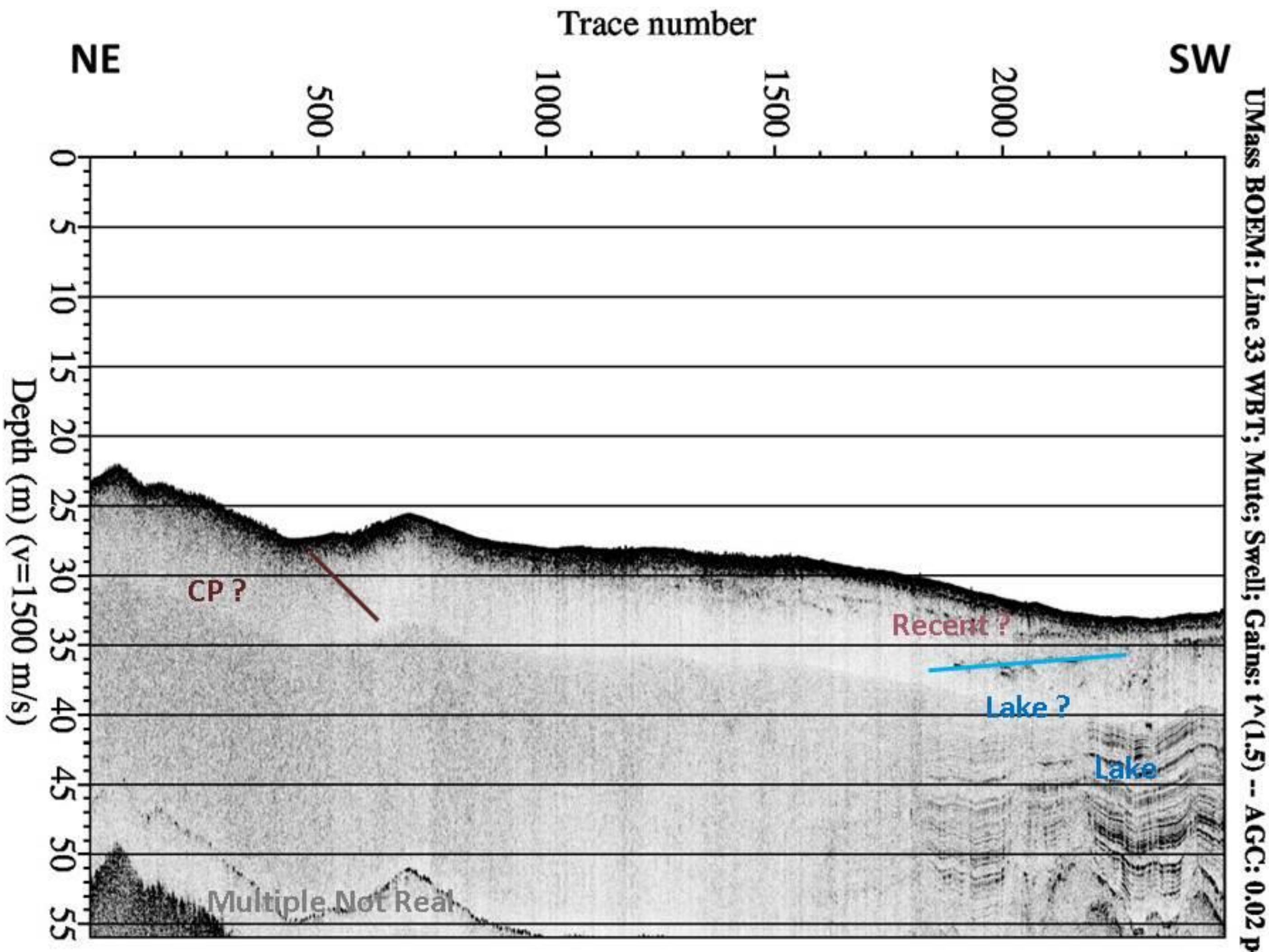
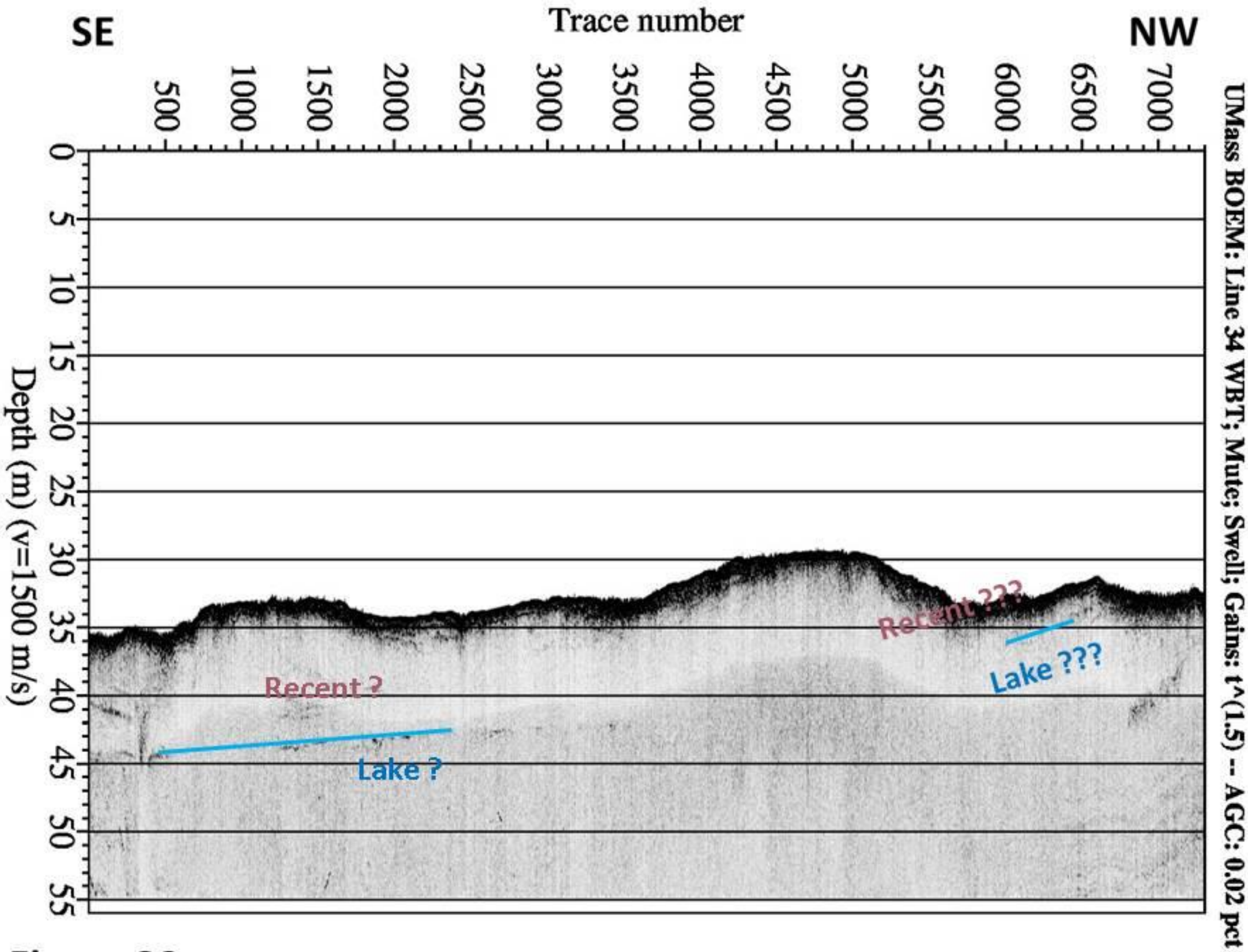

Trace number
NE
SW
500
1000
1500
2000
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
UMass BOEM: Line 33 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
CP ?
Recent ?
Lake ?
Lake
Multiple Not Real

Figure 19



SE
Trace number
NW
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
UMass BOEM: Line 34 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
Recent ???
Lake ???
Recent ?
Lake ?


**Figure 20**

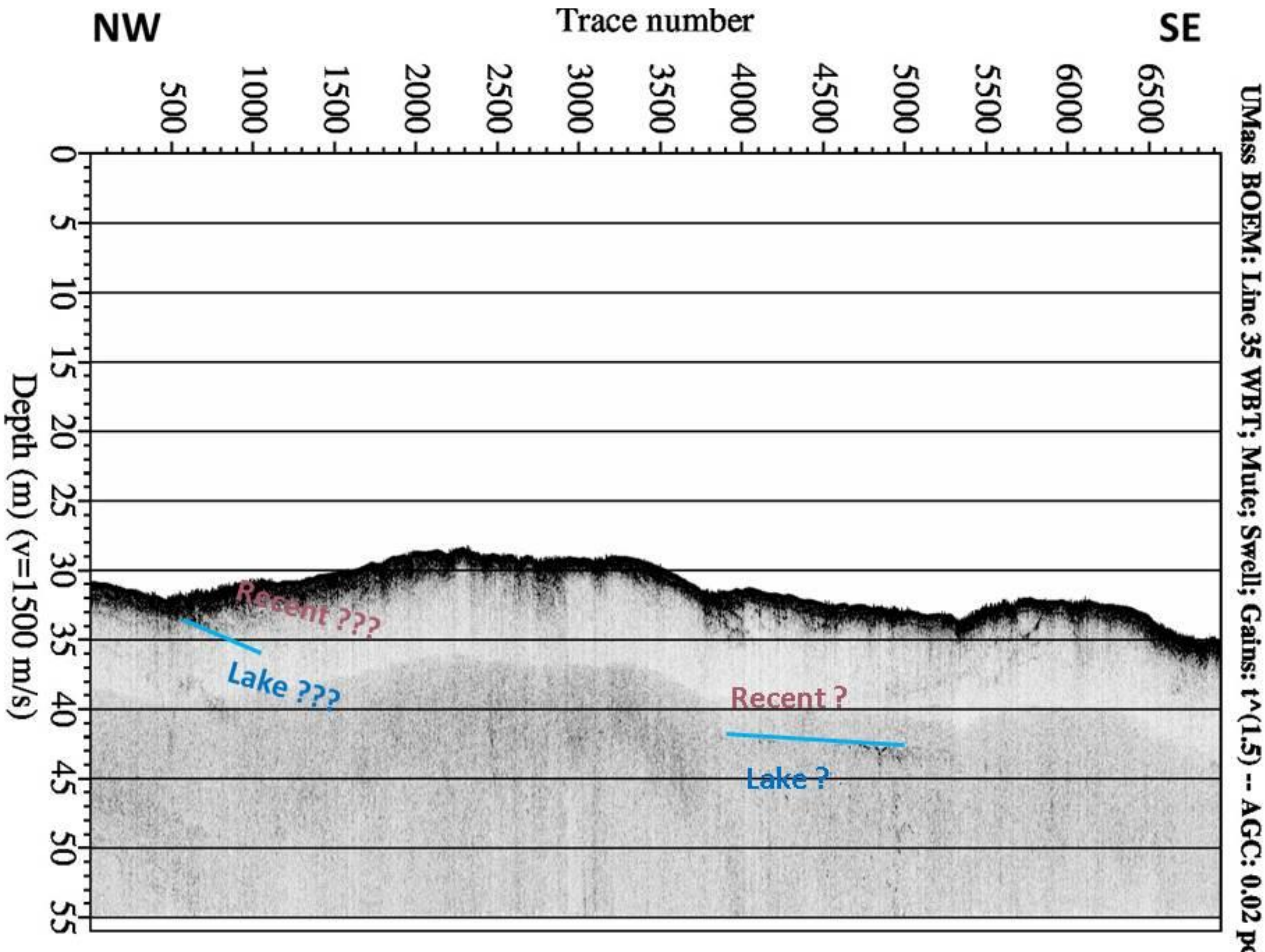

NW
Trace number
SE
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
UMass BOEM: Line 35 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
50
55
Recent ???
Lake ???
Recent ?
Lake ?

Figure 21

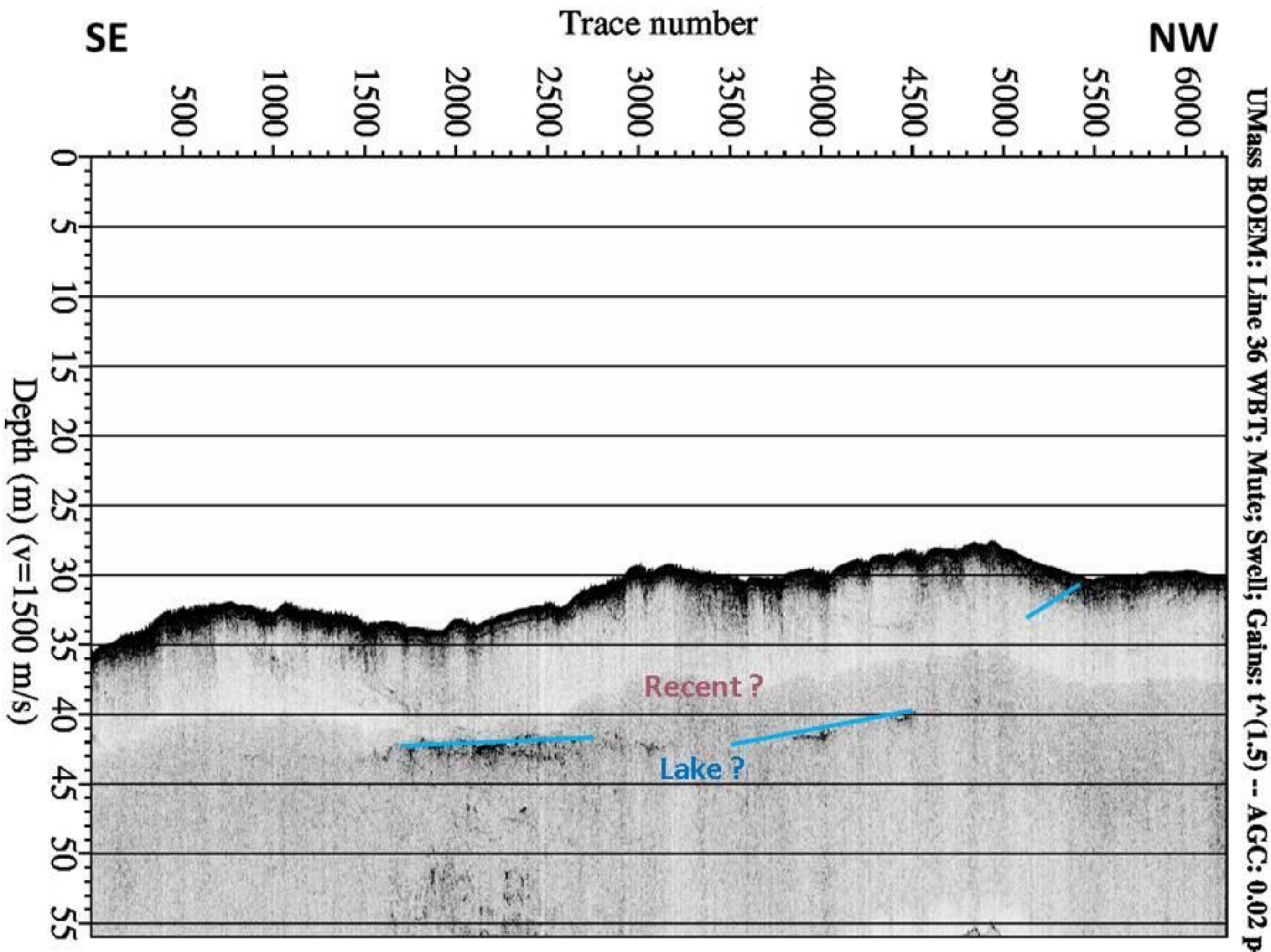

Trace number
SE
NW
Recent ?
Lake ?
Depth (m) (v=1500 m/s)
UMass BOEM: Line 36 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

**Figure 22**

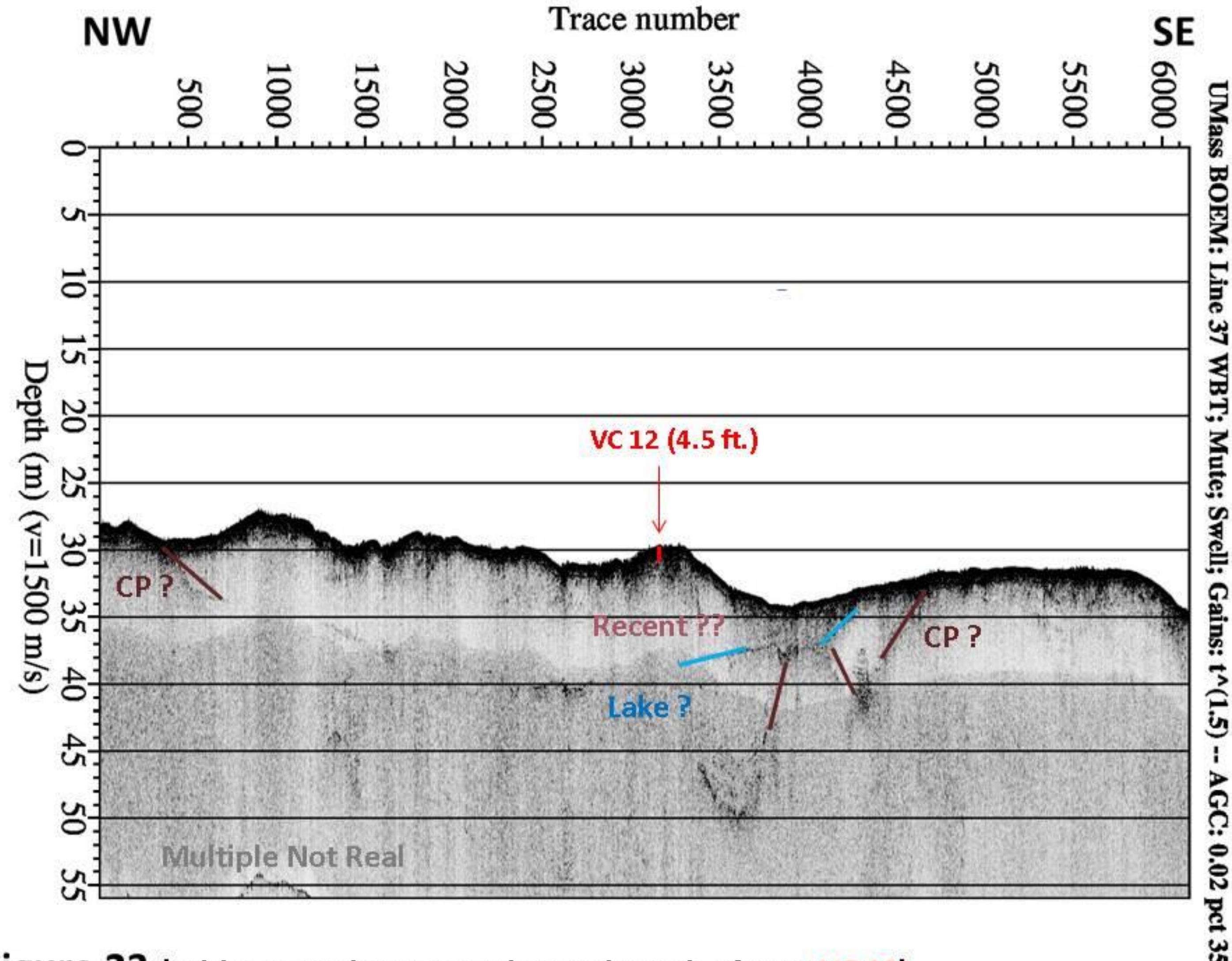
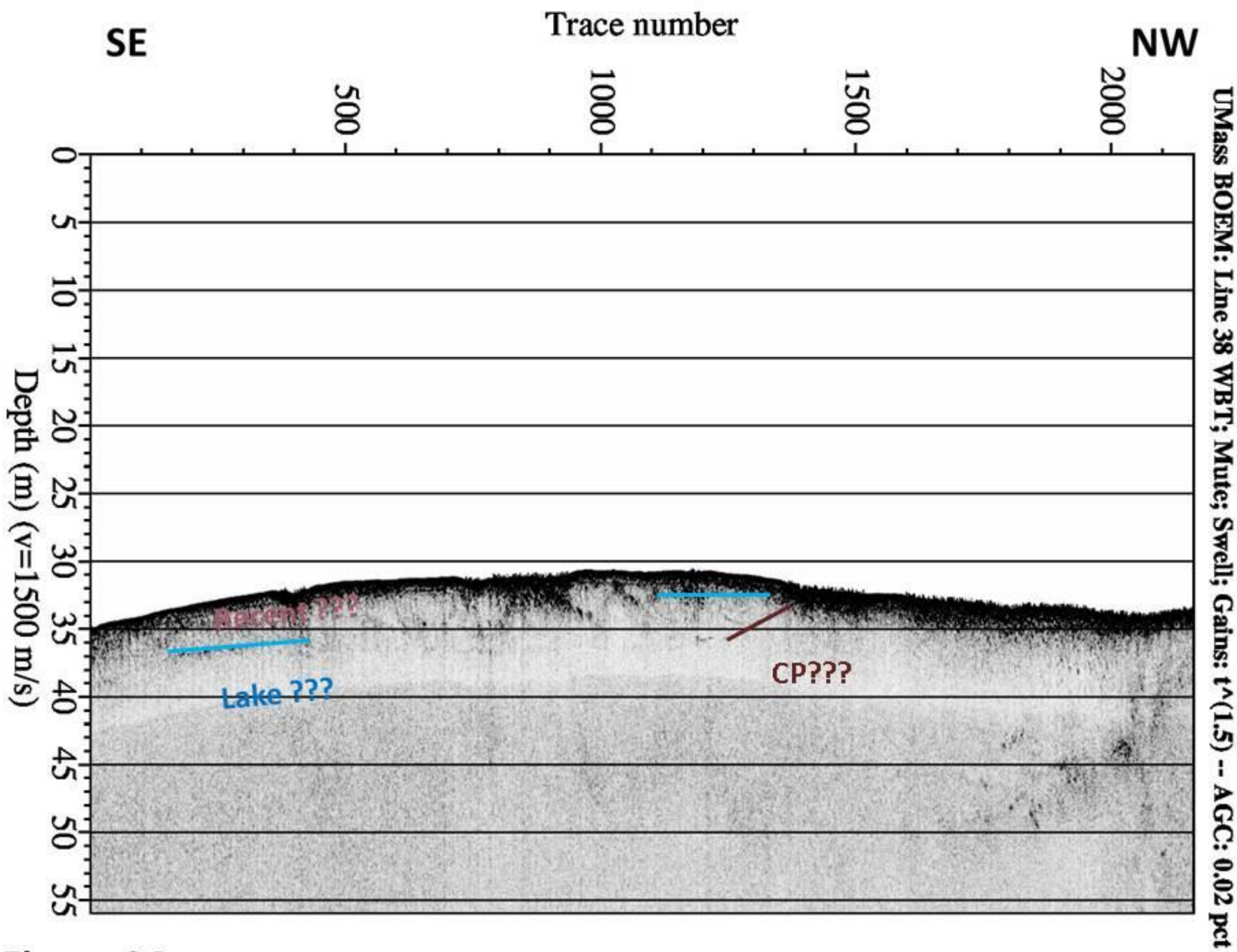



**Figure 23** (With Approximate Location and Depth of Core VC 12)

**Figure 23: Showing the approximate location and depth of Core VC 12 along "chirp" line 37**



Trace number
SE
NW
500
1000
1500
2000
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
UMass BOEM: Line 38 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ???
Lake ???
CP???


**Figure 24**

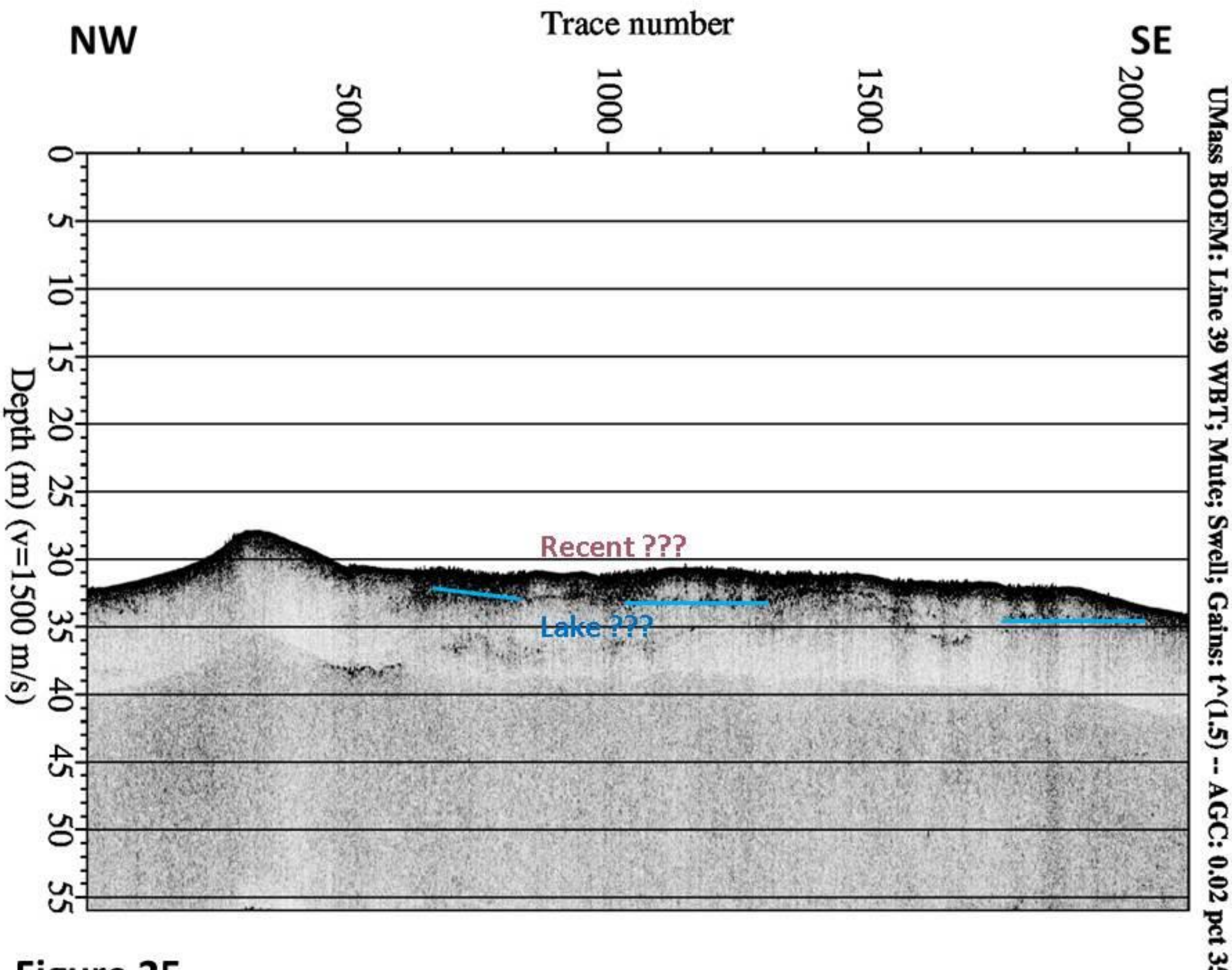

NW
Trace number
SE
500
1000
1500
2000
0
5
10
15
20
25
30
35
40
45
50
55
Depth (m) (v=1500 m/s)
Recent ???
Lake ???
UMass BOEM: Line 39 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

**Figure 25**

## Section 2 - Plum Island Results

Combining the BOEM Plum Island “chirp” seismic lines with the existing mapped geology, swath bathymetry, and the existing 1980 USGS “boomer” data [Figure 26, Figures 27, 28, 29 (Oldale 80010)] proved useful to this effort.

The “Recent” deposit identified on the interpreted BOEM seismic lines (Figures 32-49) was penetrated by two cores (VC 07 and VC 08, Figure 26 and Figures 34, 37). Core VC 07 contained well-sorted fine to medium-grained sand with shell hash while Core VC 08 contained sands that ranged from fine to coarse- grained with shell hash (Figures 30 and 31). There was a prominent shell and pebble layer at about 7ft. in Core VC 08.

The shell hash in both cores indicates this is a marine deposit. Asymmetrical bed forms imaged on the swath bathymetry (Figure 26) are moving a bit north of westward across the delta (steep sides to the west). The shell and pebble layer encountered at about 7’ in Core VC 08 is inferred to be a former sea floor surface that has been overridden by mobile marine sediment.

Although the “chirp” data are of poor quality and the spotty interpretations shown on Figures 32-49 have been made with little confidence, some inferences can be made from the Oldale “boomer” data and the swath bathymetry. Evidence provided by these sources leads to the conclusion that the deposit in question at the Plum Island site is a sand sheet (probably reworked from underlying Merrimack Delta deposits) that is moving, as bed forms, generally westward across the scoured delta surface. The irregular scouring of the underlying delta surface and the crests and troughs of the sand sheet (Figures 26, 27, 28, 29) combine to introduce some variability in the thicknesses of the deposit.

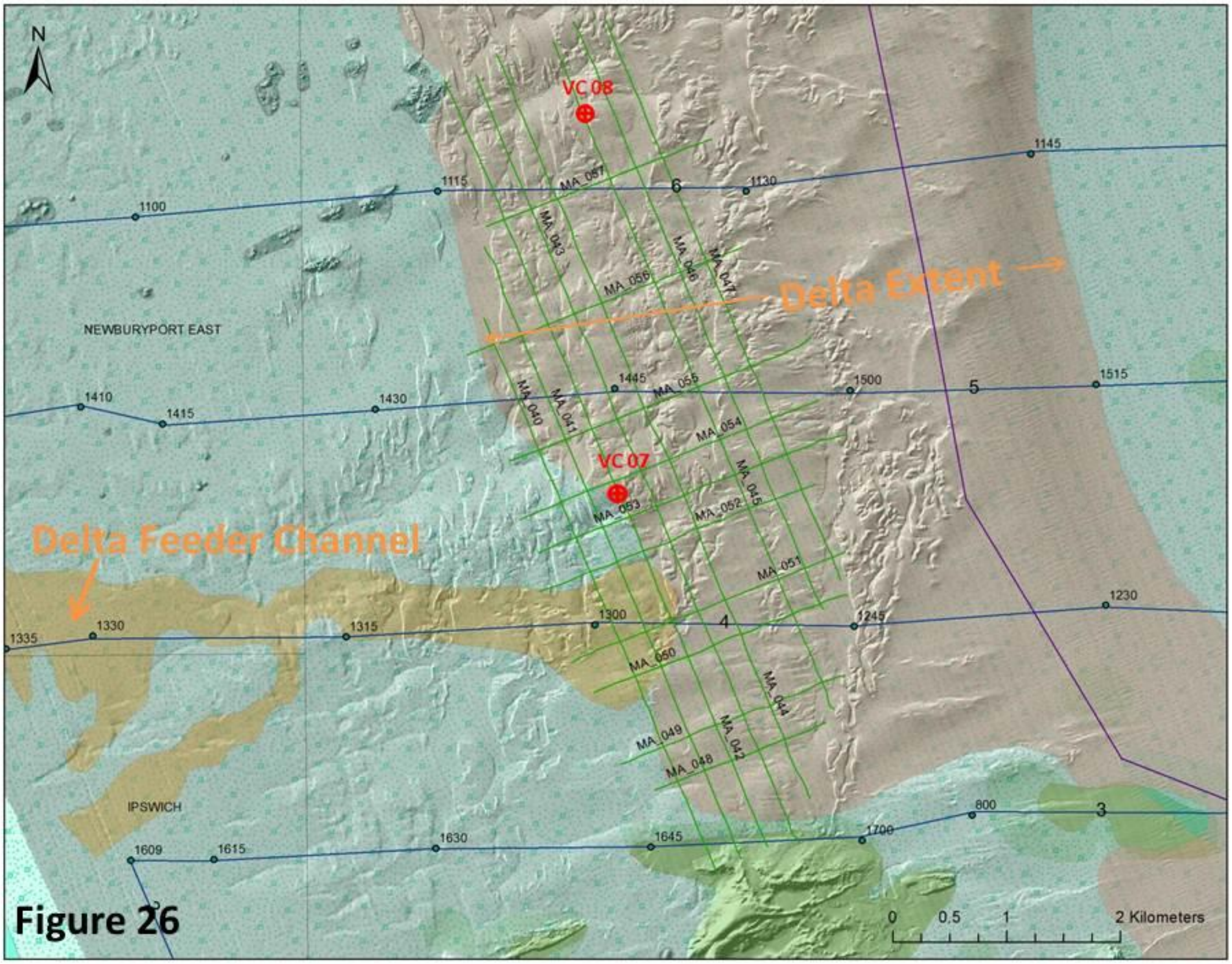
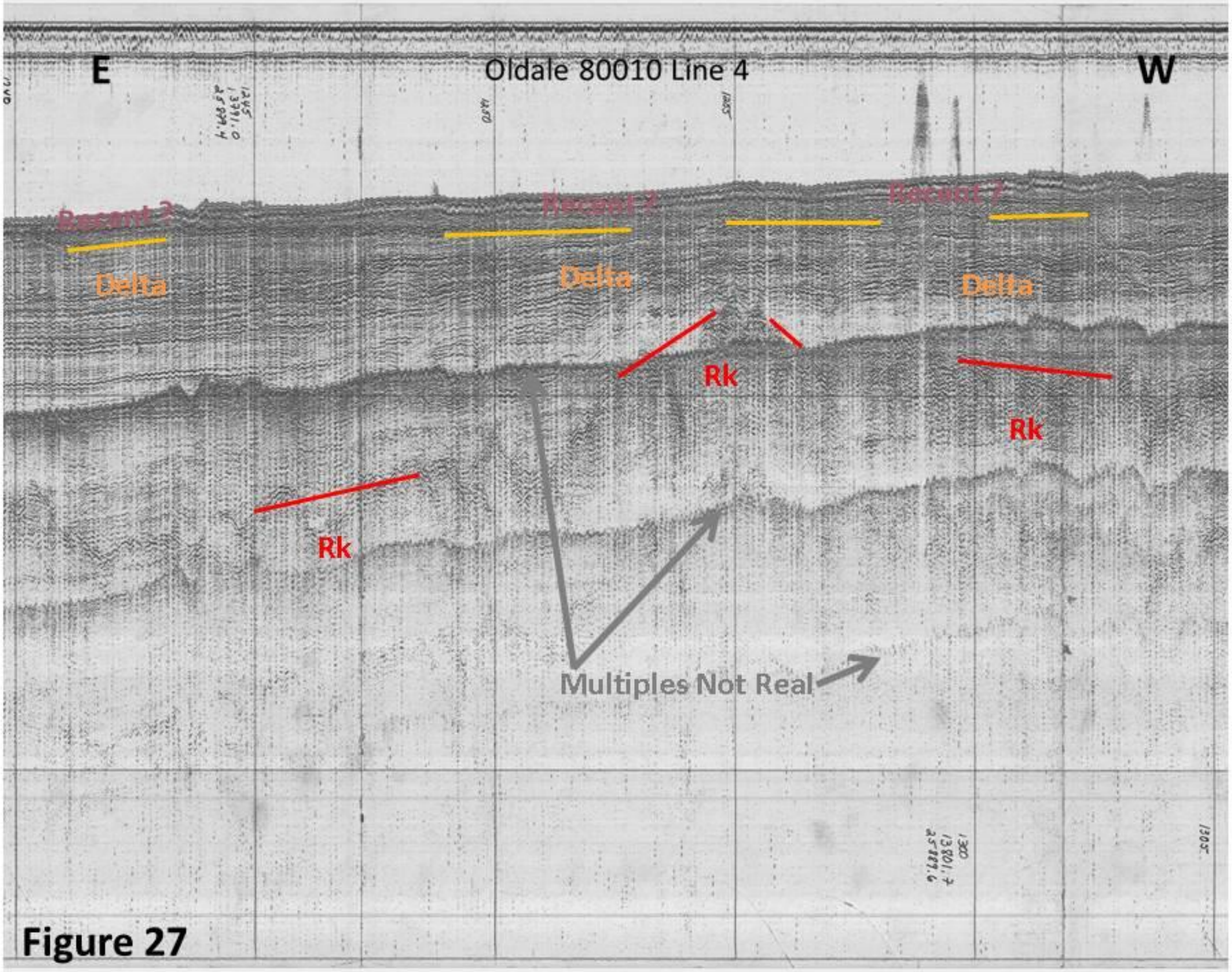



**Figure 26: A draft geologic map produced as part of the production of the Quaternary Geologic Map of Massachusetts with Oldale tracklines 4-6 (in blue), BOEM tracklines 40-57 and cores VC 07 and VC 08 shown in their geologic context. The swath bathymetry shown above indicates that the bed forms typifying the BOEM survey area are moving a bit north of westward across the delta (steep sides to the west). Cores VC 07 and VC 08 appear to have penetrated this mobile marine deposit.**


E
Oldale 80010 Line 4
W
Recent ?
Recent ?
Recent ?
Delta
Delta
Delta
Rk
Rk
Rk
Multiples Not Real
Figure 27

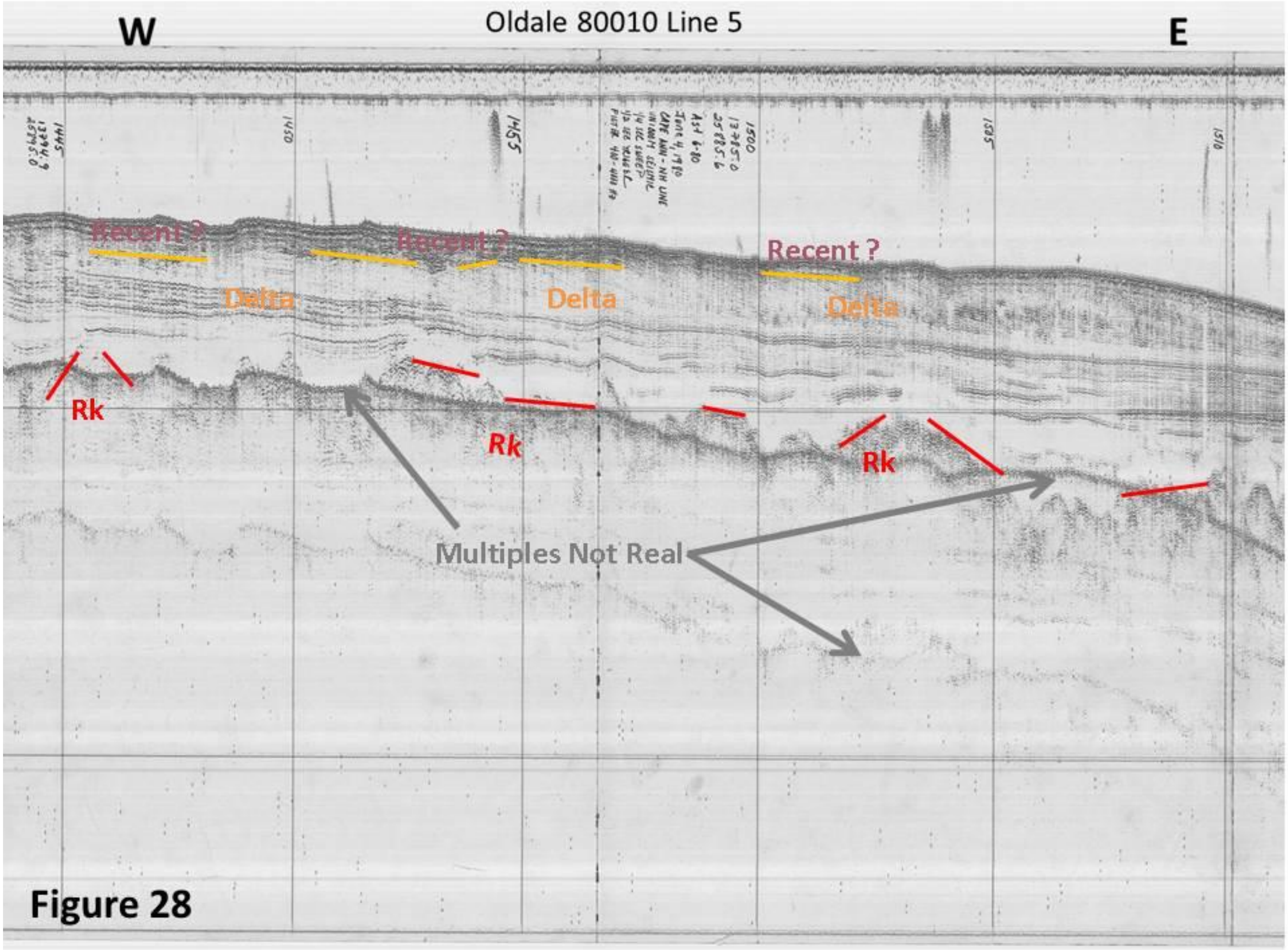
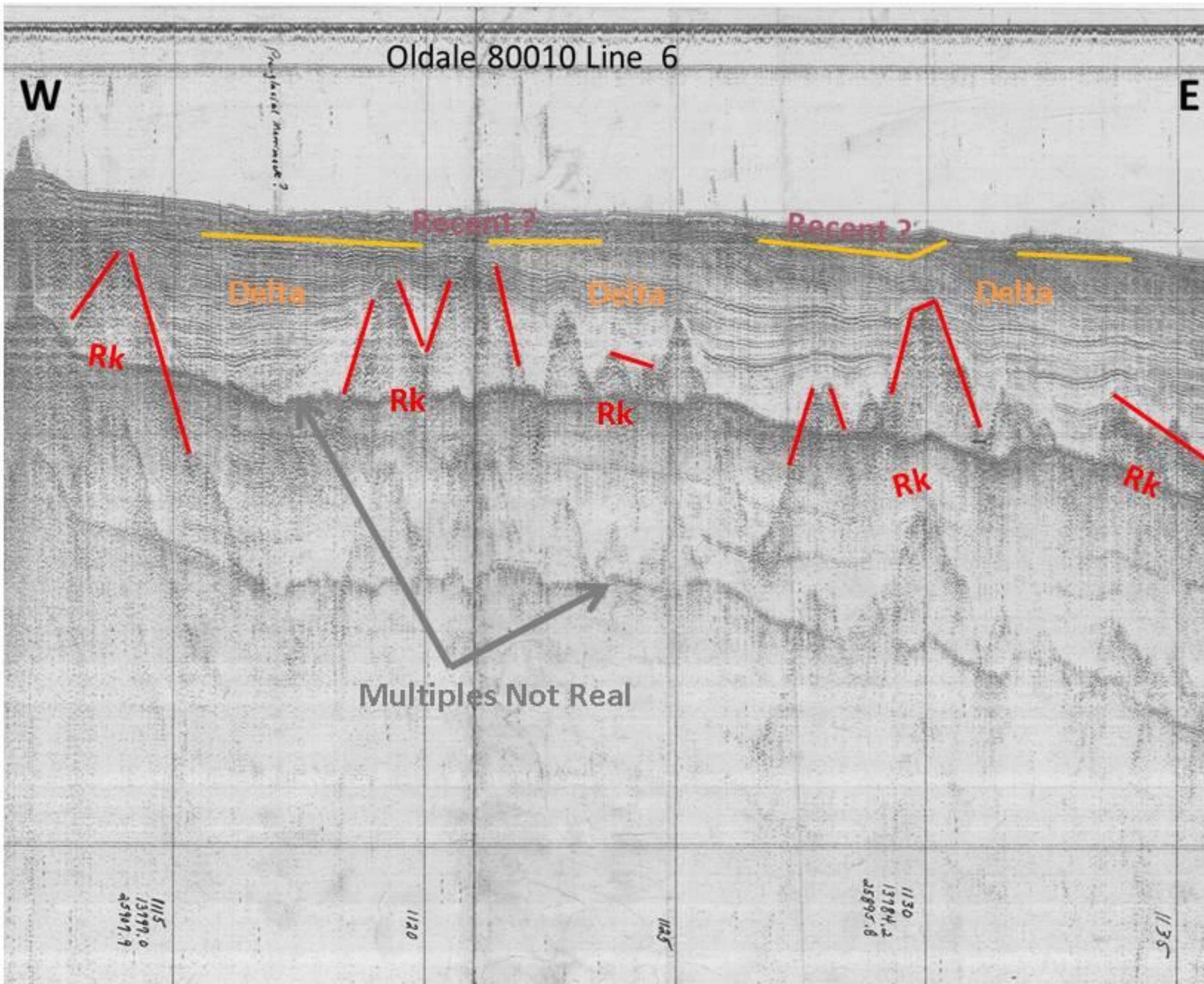

Oldale 80010 Line 5
W
E
Recent ?
Recent ?
Recent ?
Delta
Delta
Delta
Rk
Rk
Rk
Multiples Not Real

Figure 28



Oldale 80010 Line 6
W
E
Recent ?
Recent ?
Delta
Delta
Delta
Rk
Rk
Rk
Rk
Rk
Multiples Not Real
1115
1120
1125
1130
1135


**Figure 29**

# Core VC 07

(Well-Sorted Fine to Medium-Grained Sand + Shell Hash)

| ELEV. (ft) | DEPTH (ft) | LEGEND | CLASSIFICATION OF MATERIALS Depths and elevations based on measured values | % REC. | BOX OR SAMPLE | REMARKS |
|---|---|---|---|---|---|---|
| -95.6 | 0.0 | | | | | |
| -97.6 | 2.0 | | SAND, fine to medium grained, quartz, trace coarse grains, trace shell fragments, trace shell hash, trace silt, shell fragments up to (0.5" x 0.75"), dark grayish brown (2.5Y-4/2), (SW). | | 1 | Sample #1, Depth = 1.0' Mean (mm): 0.40, Phi Sorting: 0.91 Fines (230): 0.93% (SW) |
| -99.2 | 3.6 | | SAND, fine to medium grained, quartz, little coarse grains, trace rock, trace shell fragments, trace shell hash, trace silt, rock up to (0.5" x 0.25"), shell fragments up to 0.5", 1.0" shell fragment @ 2.5', olive brown (2.5Y-4/3), (SW). | | 2 | Sample #2, Depth = 2.8' Mean (mm): 0.43, Phi Sorting: 0.98 Fines (230): 0.92% (SW) |
| -99.8 | 4.2 | | SAND, fine to medium grained, quartz, trace shell hash, trace silt, 0.75" and (2.75" x 0.75") shell fragments @ 3.7', dark gray (2.5Y-4/1), (SW). | | 3 | Sample #3, Depth = 3.9' Mean (mm): 0.34, Phi Sorting: 0.88 Fines (230): 1.21% (SW) |
| -100.2 | 4.6 | | SAND, fine to medium grained, quartz, trace coarse grains, trace shell fragments, trace shell hash, trace silt, shell fragments up to (0.5" x 0.25"), dark grayish brown (2.5Y-4/2), (SW). | | 1 | |
| -103.1 | 7.5 | | SAND, fine grained, quartz, trace coarse grains, trace shell hash, trace silt, grayish brown (2.5Y-5/2), (SP). | | 4 | Sample #4, Depth = 6.1' Mean (mm): 0.23, Phi Sorting: 0.63 Fines (230): 0.95% (SP) |
| -105.2 | 9.6 | | SAND, fine grained, quartz, trace coarse grains, trace shell hash, trace silt, 2 (0.5") rocks @ 8.7', Bit Sample from 9.4' to 9.6', gray (2.5Y-5/1), (SP). | | 5 | Sample #5, Depth = 8.5' Mean (mm): 0.18, Phi Sorting: 0.50 Fines (230): 1.60% (SP) |
| | | | End of Boring | | | |

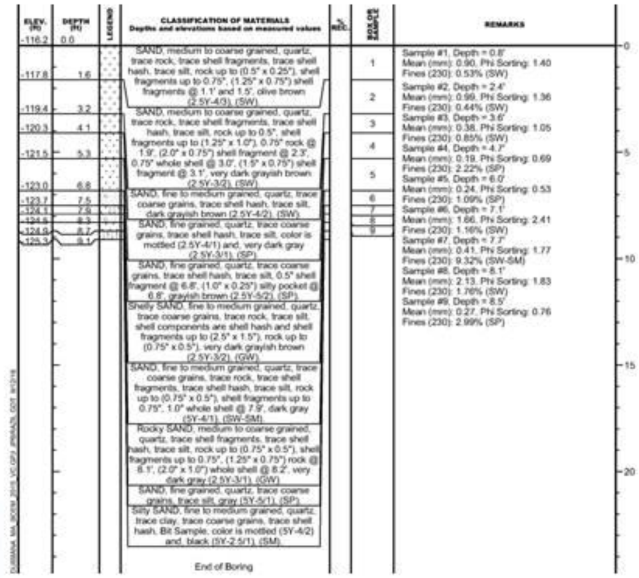





**Figure 30**

# Core VC 08

(Fine to Medium to Coarse- Grained Sand
+ Shell Hash- Shell Layer and Rocky Sand at ~ 7')



| ELEV. (ft) | DEPTH (ft) |
|---|---|
| -116.2 | 0.0 |
| -117.8 | 1.6 |
| -119.4 | 3.2 |
| -120.3 | 4.1 |
| -121.5 | 5.3 |
| -123.0 | 6.8 |
| -123.7 | 7.5 |
| -124.1 | 7.9 |
| -124.5 | 8.3 |
| -124.9 | 8.7 |
| -125.3 | 9.1 |

**CLASSIFICATION OF MATERIALS**
Depths and elevations based on measured values

- SAND, medium to coarse grained, quartz, trace rock, trace shell fragments, trace shell hash, trace silt, rock up to (0.5" x 0.25"), shell fragments up to 0.75", (1.25" x 0.75") shell fragments @ 1.1' and 1.5', olive brown (2.5Y-4/3), (SW)
- SAND, medium to coarse grained, quartz, trace rock, trace shell fragments, trace shell hash, trace silt, rock up to 0.5", shell fragments up to (1.25" x 1.0"), 0.75" rock @ 1.9', (2.0" x 0.75") shell fragment @ 2.3', 0.75" whole shell @ 3.0', (1.5" x 0.75") shell fragment @ 3.1', very dark grayish brown (2.5Y-3/2), (SW)
- SAND, fine to medium grained, quartz, trace coarse grains, trace shell hash, trace silt, dark grayish brown (2.5Y-4/2), (SW)
- SAND, fine grained, quartz, trace coarse grains, trace shell hash, trace silt, color is mottled (2.5Y-4/1) and, very dark gray (2.5Y-3/1), (SP)
- SAND, fine grained, quartz, trace coarse grains, trace shell hash, trace silt, 0.5" shell fragment @ 6.8', (1.0" x 0.25") silty pocket @ 6.8', grayish brown (2.5Y-5/2), (SP)
- Shelly SAND, fine to medium grained, quartz, trace coarse grains, trace rock, trace silt, shell components are shell hash and shell fragments up to (2.5" x 1.5"), rock up to (0.75" x 0.5"), very dark grayish brown (2.5Y-3/2), (GW)
- SAND, fine to medium grained, quartz, trace coarse grains, trace rock, trace shell fragments, trace shell hash, trace silt, rock up to (0.75" x 0.5"), shell fragments up to 0.75", 1.0" whole shell @ 7.9', dark gray (5Y-4/1), (SW-SM)
- Rocky SAND, medium to coarse grained, quartz, trace shell fragments, trace shell hash, trace silt, rock up to (0.75" x 0.5"), shell fragments up to 0.75", (1.25" x 0.75") rock @ 8.1', (2.0" x 1.0") whole shell @ 8.2', very dark gray (2.5Y-3/1), (GW)
- SAND, fine grained, quartz, trace coarse grains, trace silt, gray (5Y-5/1), (SP)
- Silty SAND, fine to medium grained, quartz, trace clay, trace coarse grains, trace shell hash, Bit Sample, color is mottled (5Y-4/2) and, black (5Y-2.5/1), (SM)

End of Boring

**REMARKS**

| BOX OR SAMPLE | REMARKS |
|---|---|
| 1 | Sample #1, Depth = 0.8' Mean (mm): 0.90, Phi Sorting: 1.40 Fines (230): 0.53% (SW) |
| 2 | Sample #2, Depth = 2.4' Mean (mm): 0.99, Phi Sorting: 1.36 Fines (230): 0.44% (SW) |
| 3 | Sample #3, Depth = 3.6' Mean (mm): 0.38, Phi Sorting: 1.05 Fines (230): 0.85% (SW) |
| 4 | Sample #4, Depth = 4.7' Mean (mm): 0.19, Phi Sorting: 0.69 Fines (230): 2.22% (SP) |
| 5 | Sample #5, Depth = 6.0' Mean (mm): 0.24, Phi Sorting: 0.53 Fines (230): 1.09% (SP) |
| 6 | Sample #6, Depth = 7.1' Mean (mm): 1.66, Phi Sorting: 2.41 Fines (230): 1.16% (SW) |
| 7 | Sample #7, Depth = 7.7' Mean (mm): 0.41, Phi Sorting: 1.77 Fines (230): 9.32% (SW-SM) |
| 8 | Sample #8, Depth = 8.1' Mean (mm): 2.13, Phi Sorting: 1.83 Fines (230): 1.76% (SW) |
| 9 | Sample #9, Depth = 8.5' Mean (mm): 0.27, Phi Sorting: 0.76 Fines (230): 2.99% (SP) |






**Figure 31**

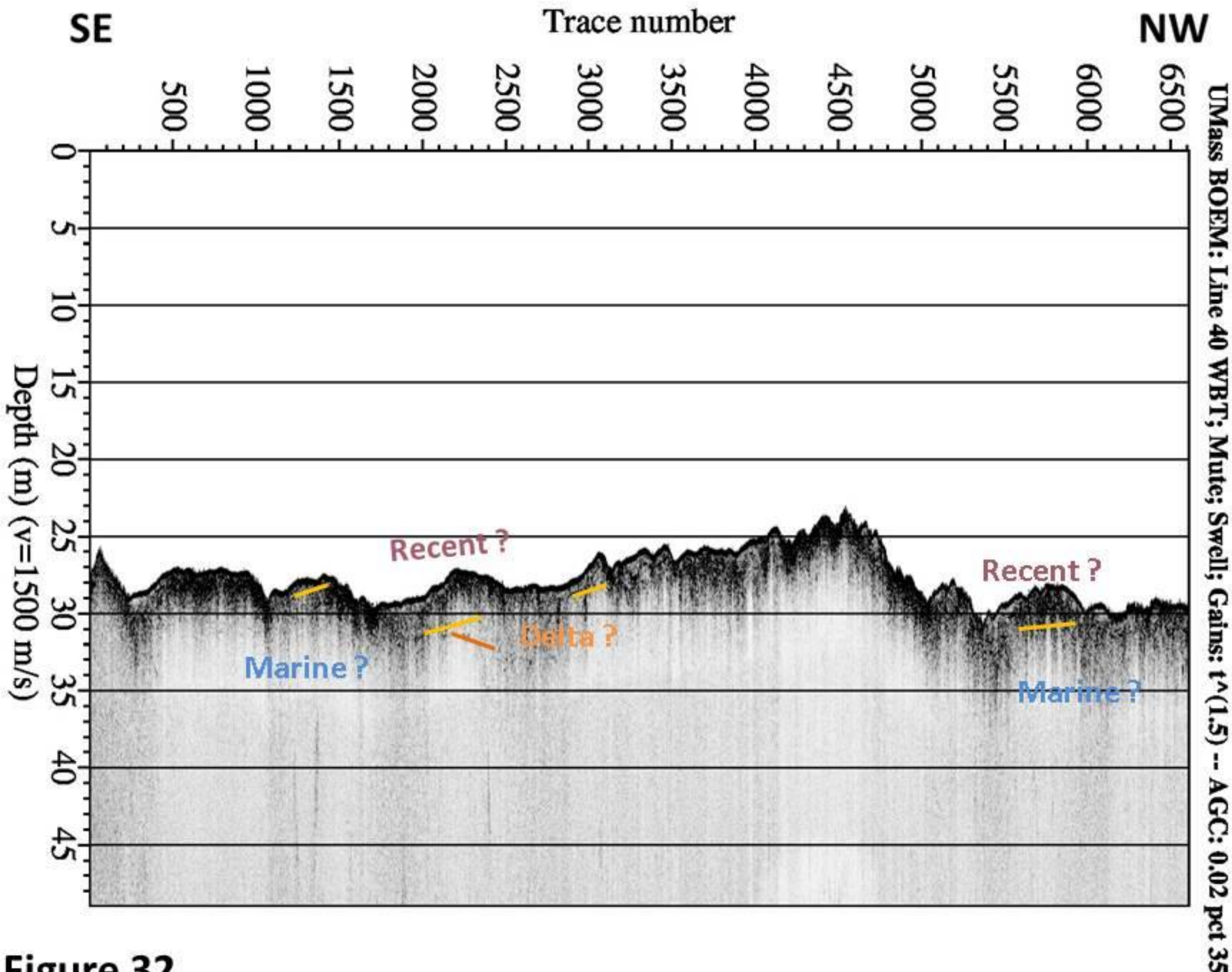

SE
Trace number
NW
Recent ?
Recent ?
Delta ?
Marine ?
Marine ?
Depth (m) (v=1500 m/s)
UMass BOEM: Line 40 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

Figure 32

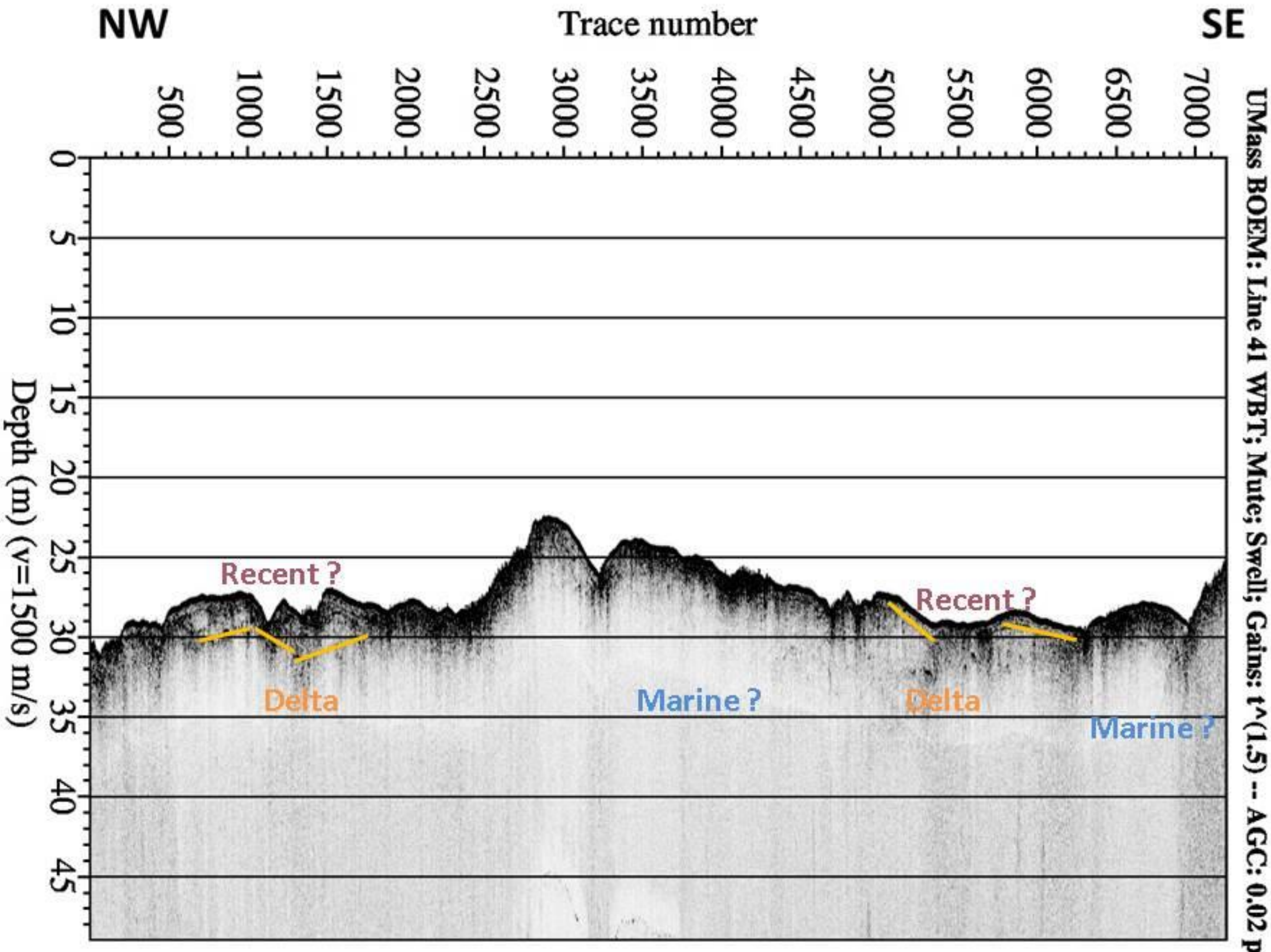

NW
Trace number
SE
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 41 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ?
Delta
Marine ?
Recent ?
Delta
Marine ?

Figure 33

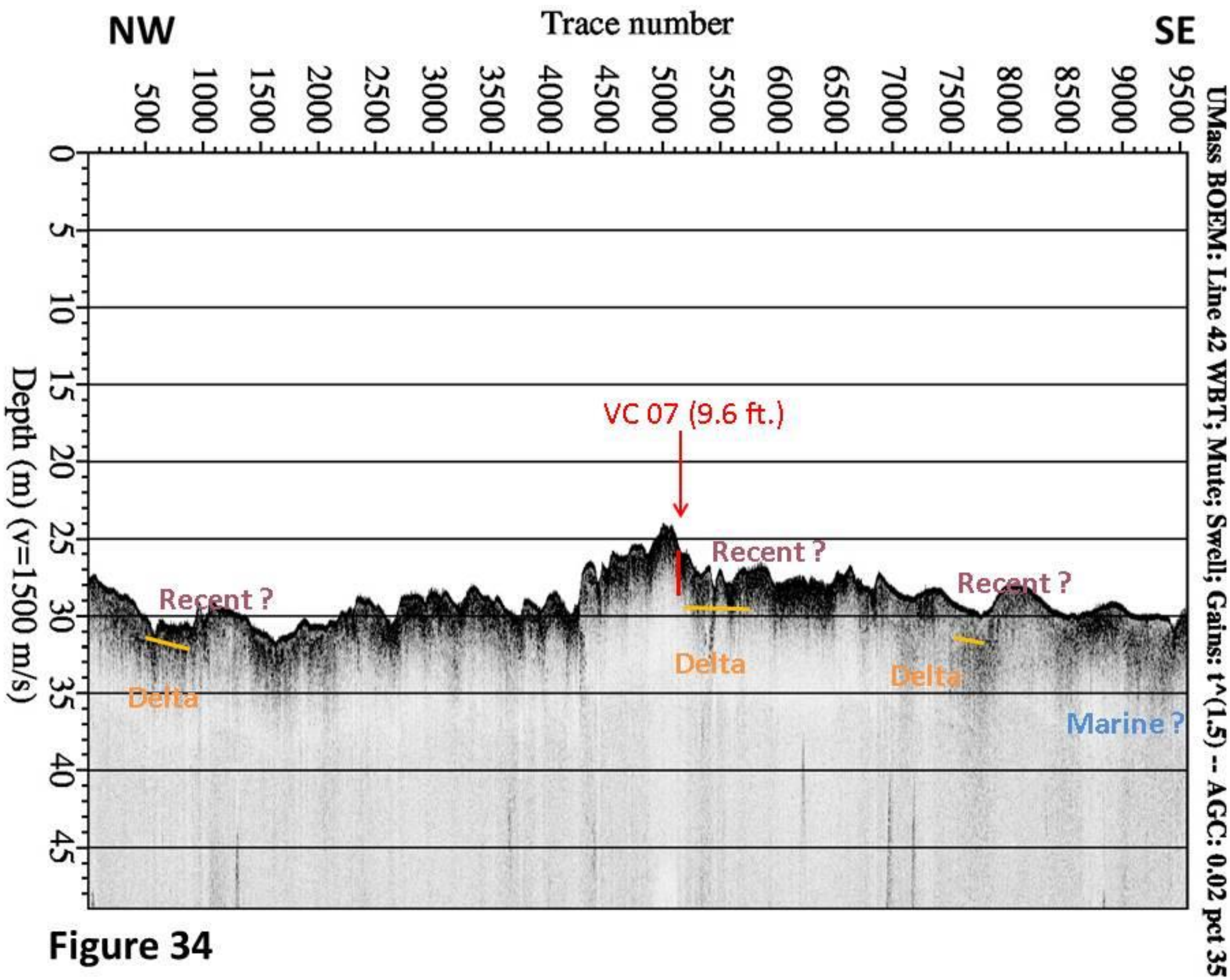
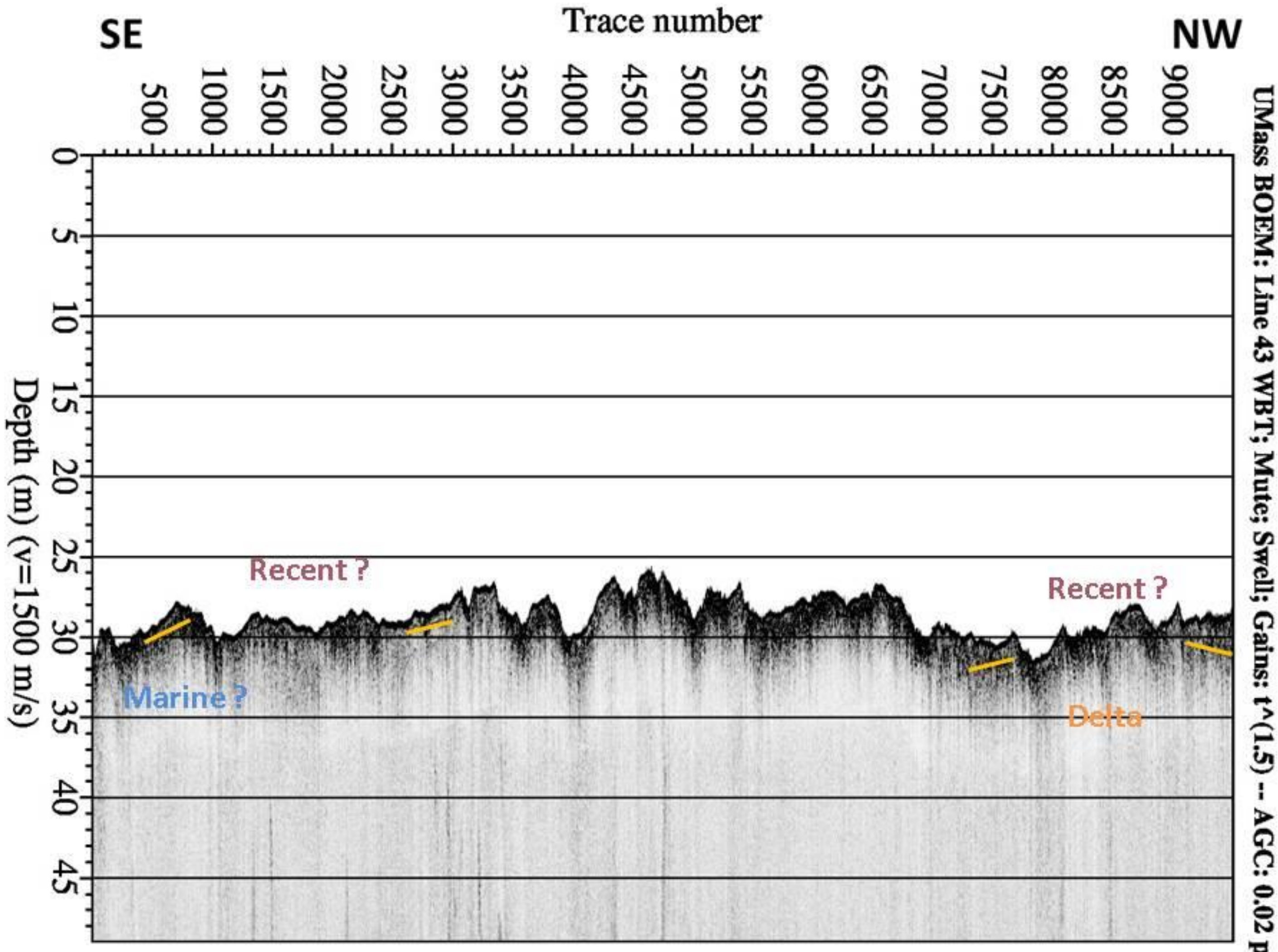



Figure 34

**Figure 34: Showing the approximate location and depth of Core VC 07 along "chirp" line 42**



SE
Trace number
NW
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500 9000
0 5 10 15 20 25 30 35 40 45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 43 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ?
Marine ?
Recent ?
Delta


Figure 35

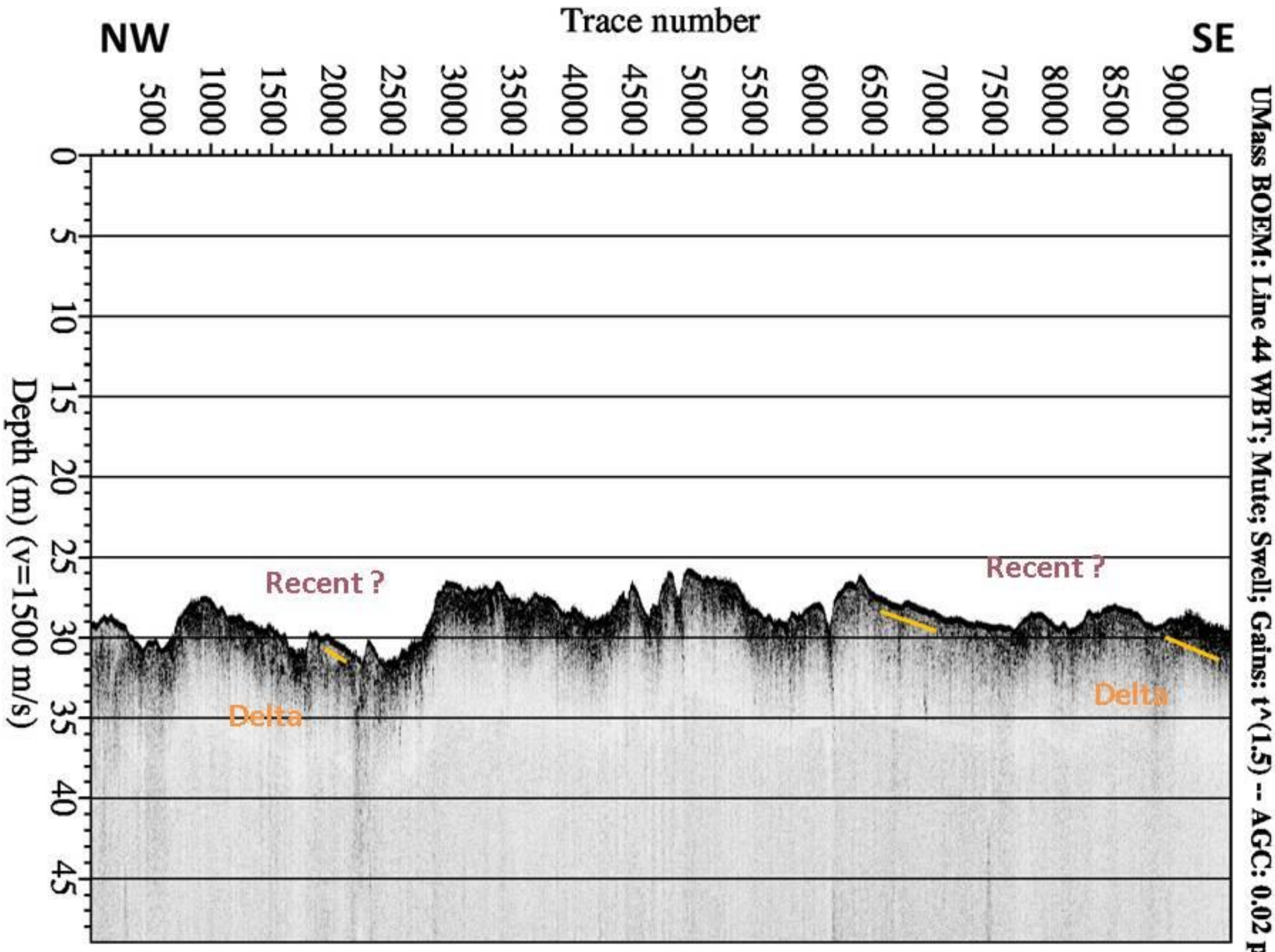

Trace number
NW
SE
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
Recent ?
Recent ?
Delta
Delta
UMass BOEM: Line 44 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

**Figure 36**

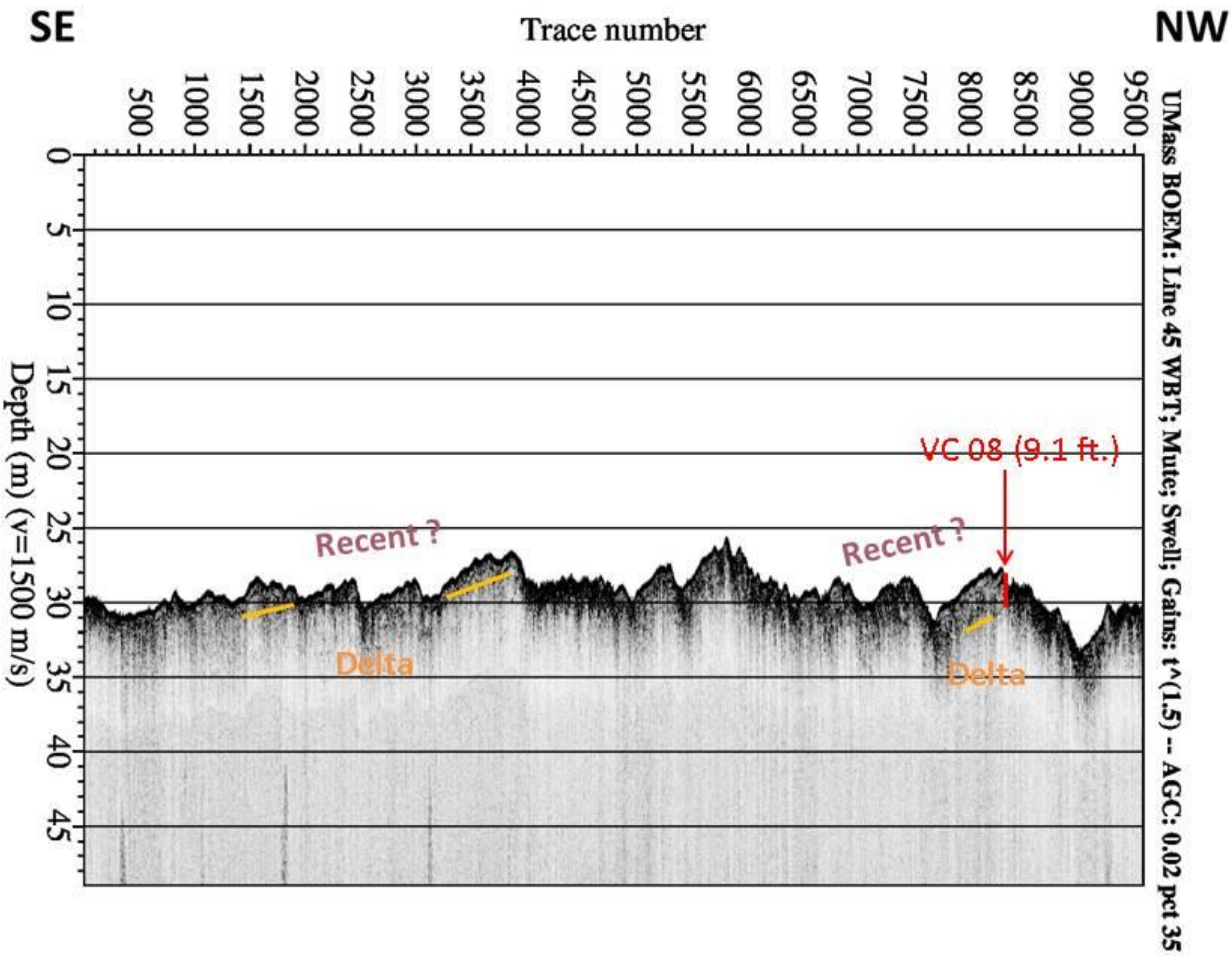
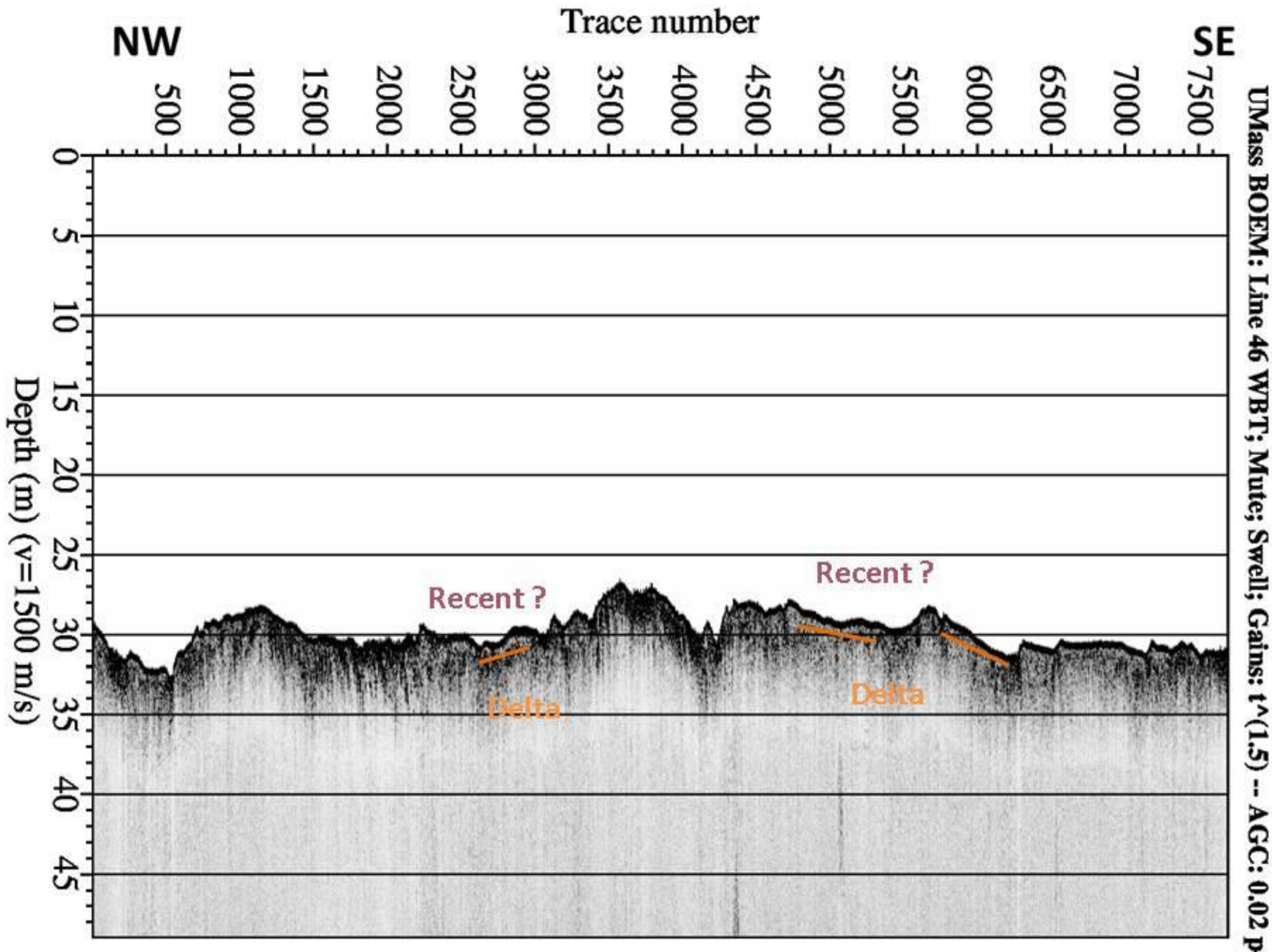



**Figure 37**

**Figure 37: Showing the approximate location and depth of Core VC 08 along "chirp" line 45**



Trace number
NW
SE
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500
0 5 10 15 20 25 30 35 40 45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 46 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ?
Recent ?
Delta
Delta


Figure 38

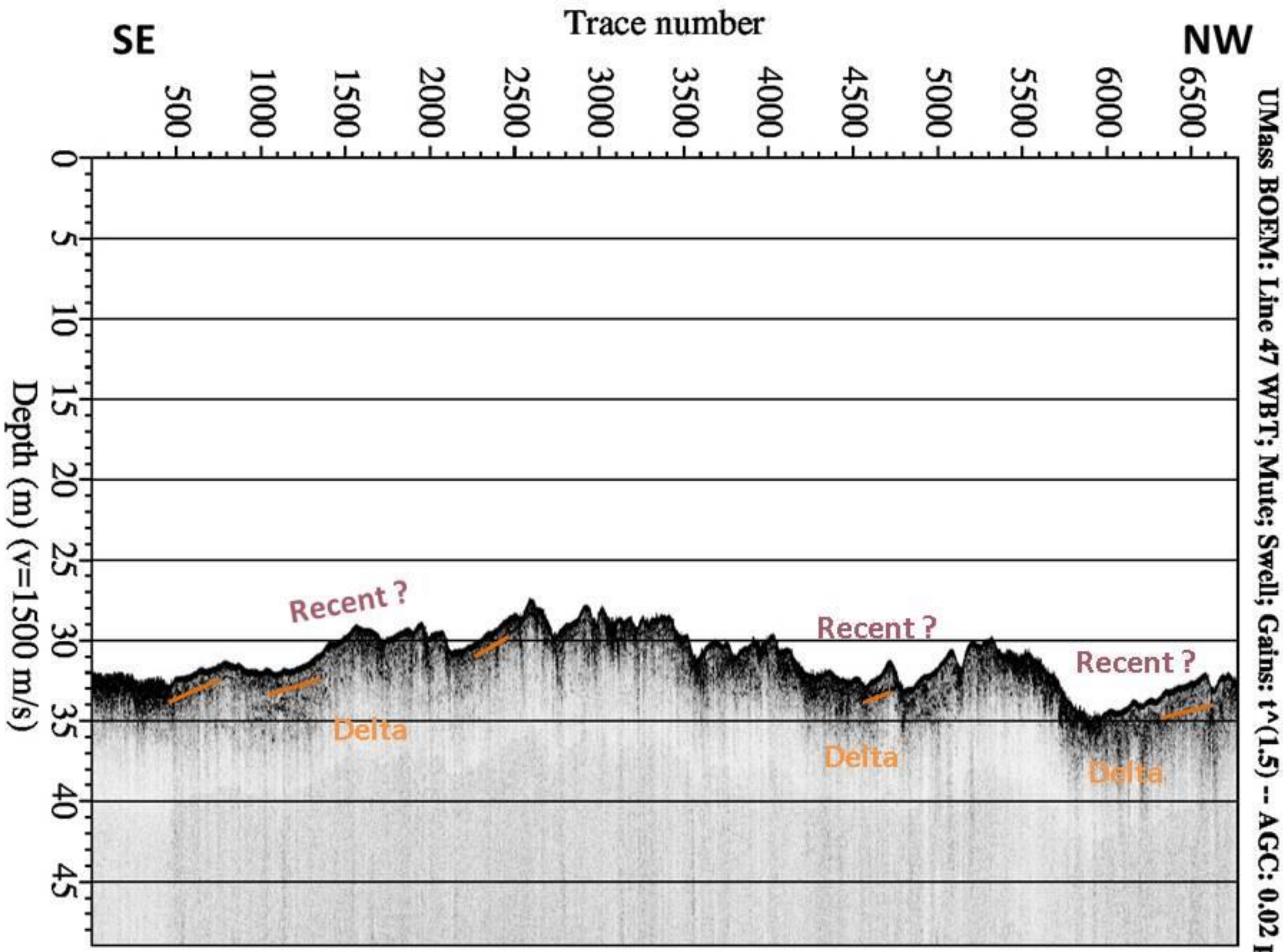
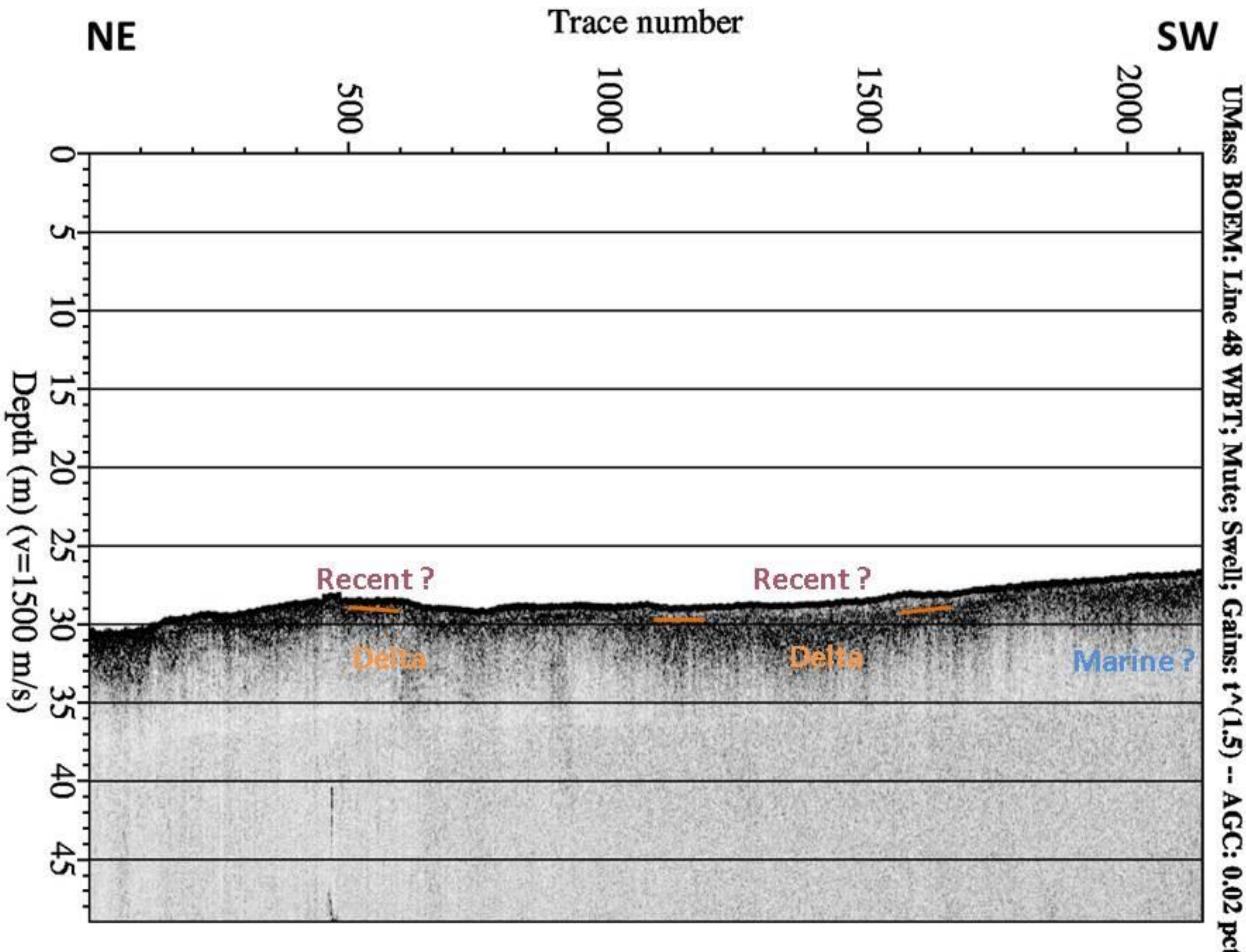

Trace number
SE
NW
UMass BOEM: Line 47 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
Recent ?
Recent ?
Recent ?
Delta
Delta
Delta

Figure 39



NE
Trace number
SW
500
1000
1500
2000
UMass BOEM: Line 48 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
Recent ?
Recent ?
Delta
Delta
Marine ?


Figure 40

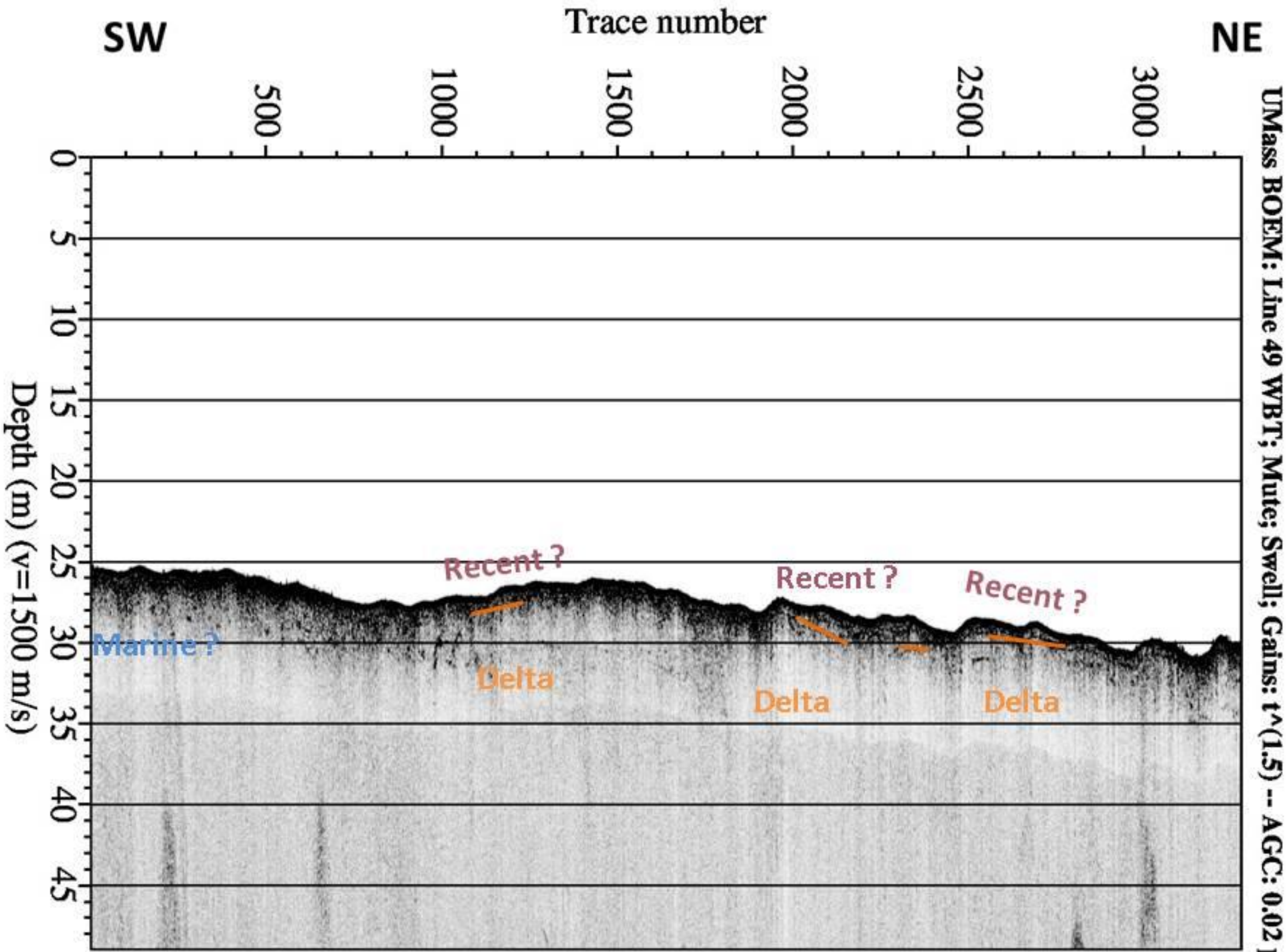

SW
Trace number
NE
UMass BOEM: Line 49 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
Recent ?
Recent ?
Recent ?
Marine ?
Delta
Delta
Delta

**Figure 41**

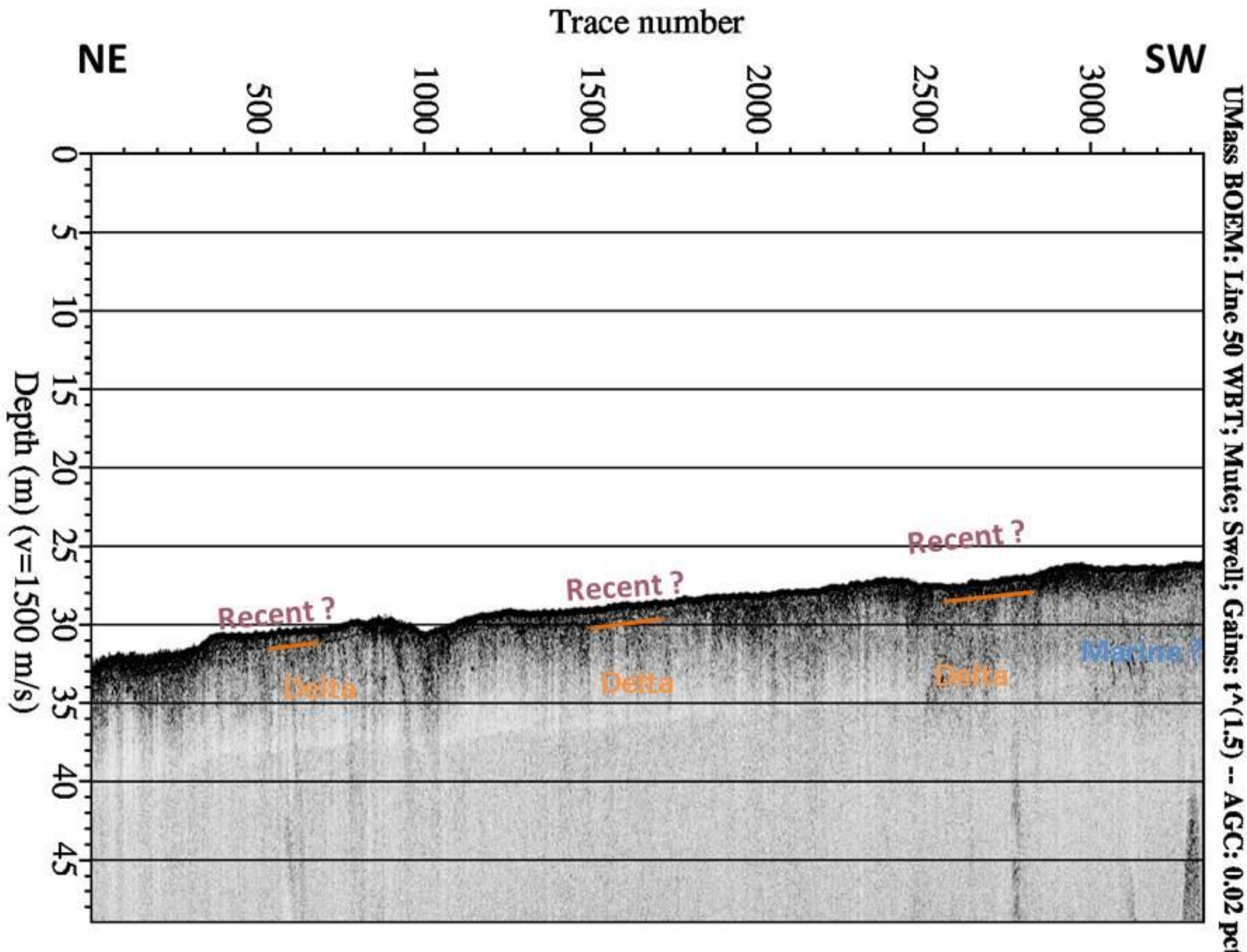

Trace number
NE
SW
500
1000
1500
2000
2500
3000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 50 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ?
Recent ?
Recent ?
Delta
Delta
Delta
Marine ?

Figure 42

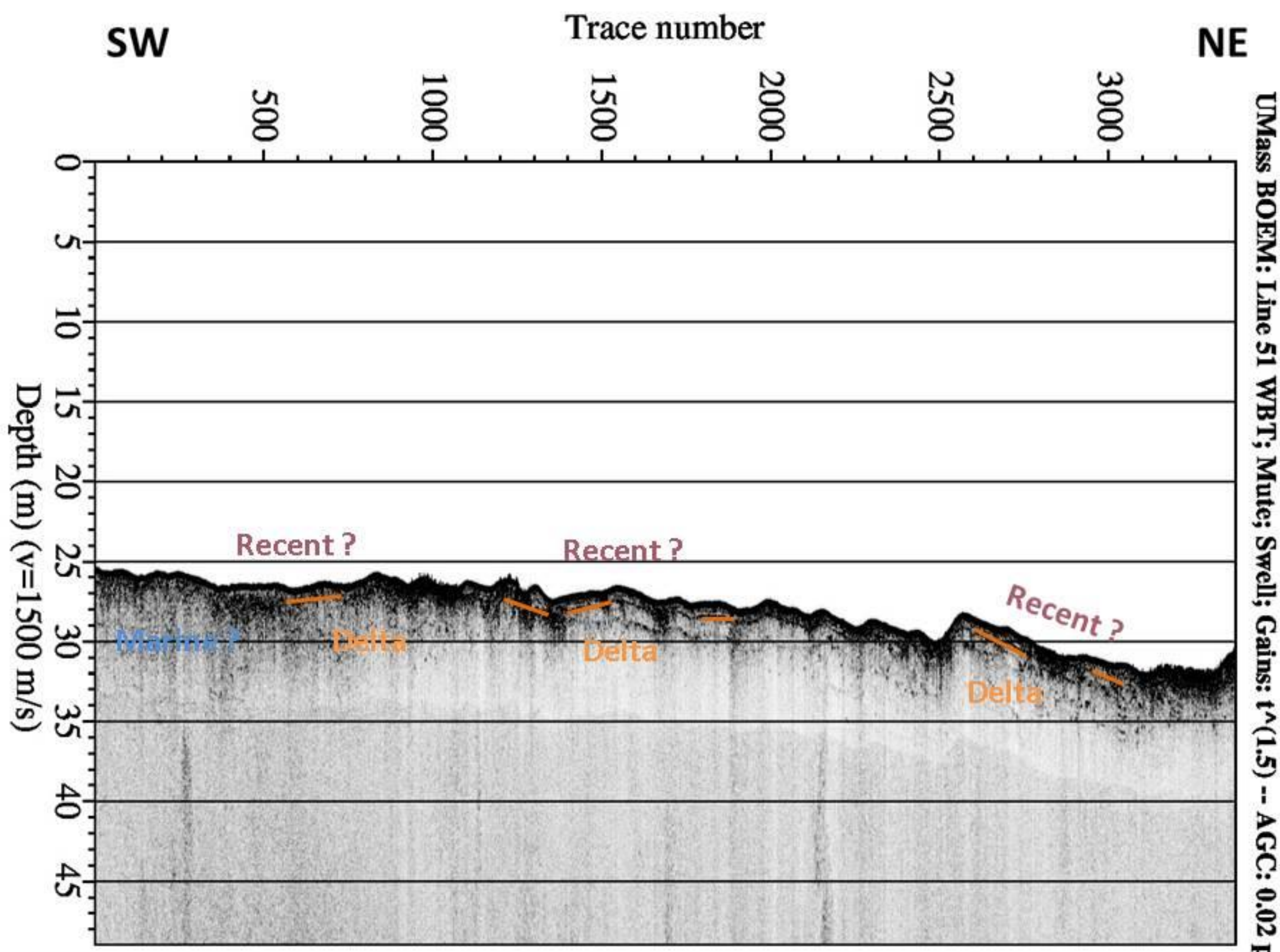

SW
Trace number
NE
500
1000
1500
2000
2500
3000
UMass BOEM: Line 51 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent ?
Recent ?
Recent ?
Marine ?
Delta
Delta
Delta

Figure 43

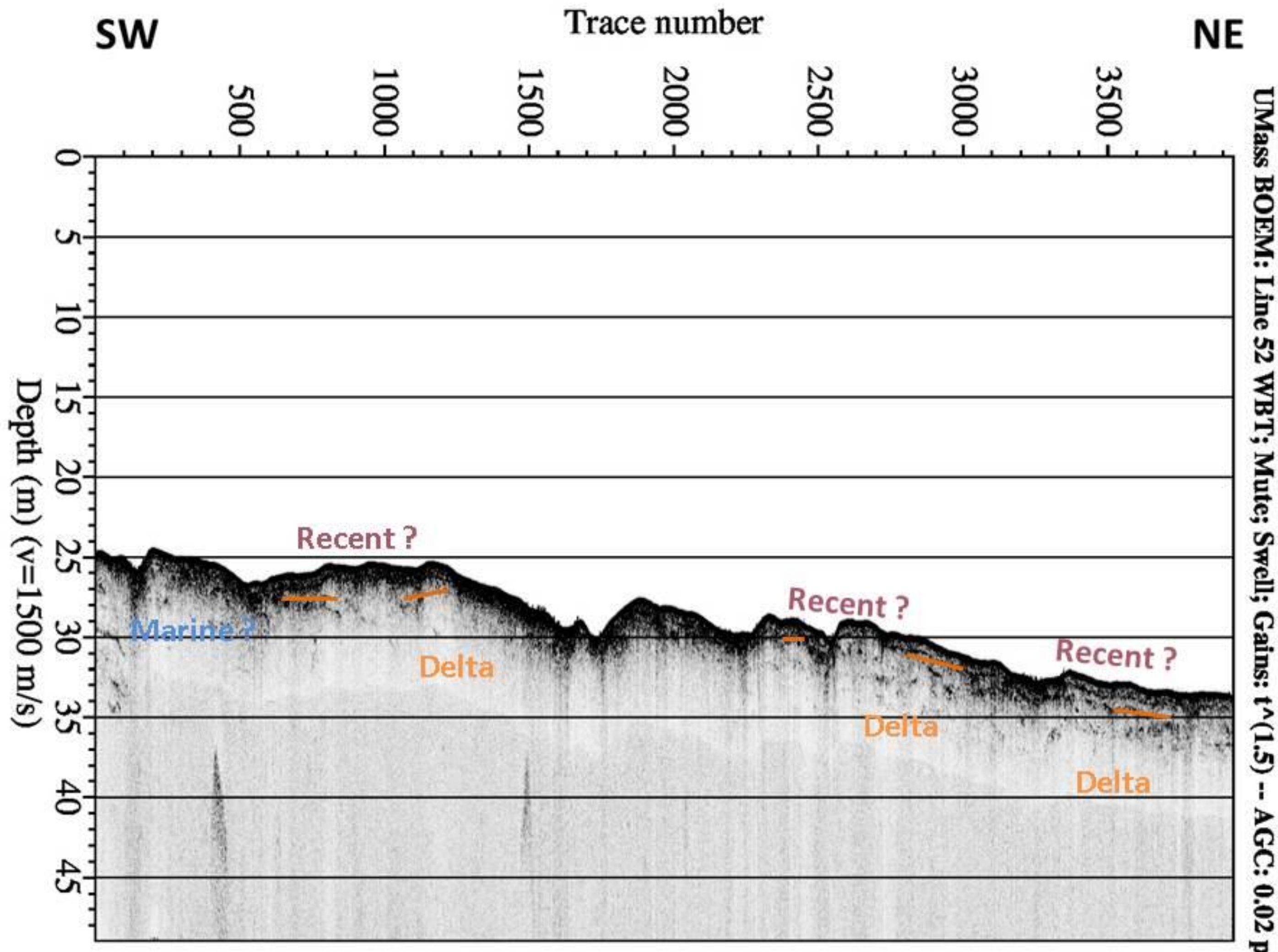

SW
Trace number
NE
500
1000
1500
2000
2500
3000
3500
UMass BOEM: Line 52 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
Recent ?
Recent ?
Recent ?
Marine ?
Delta
Delta
Delta

**Figure 44**

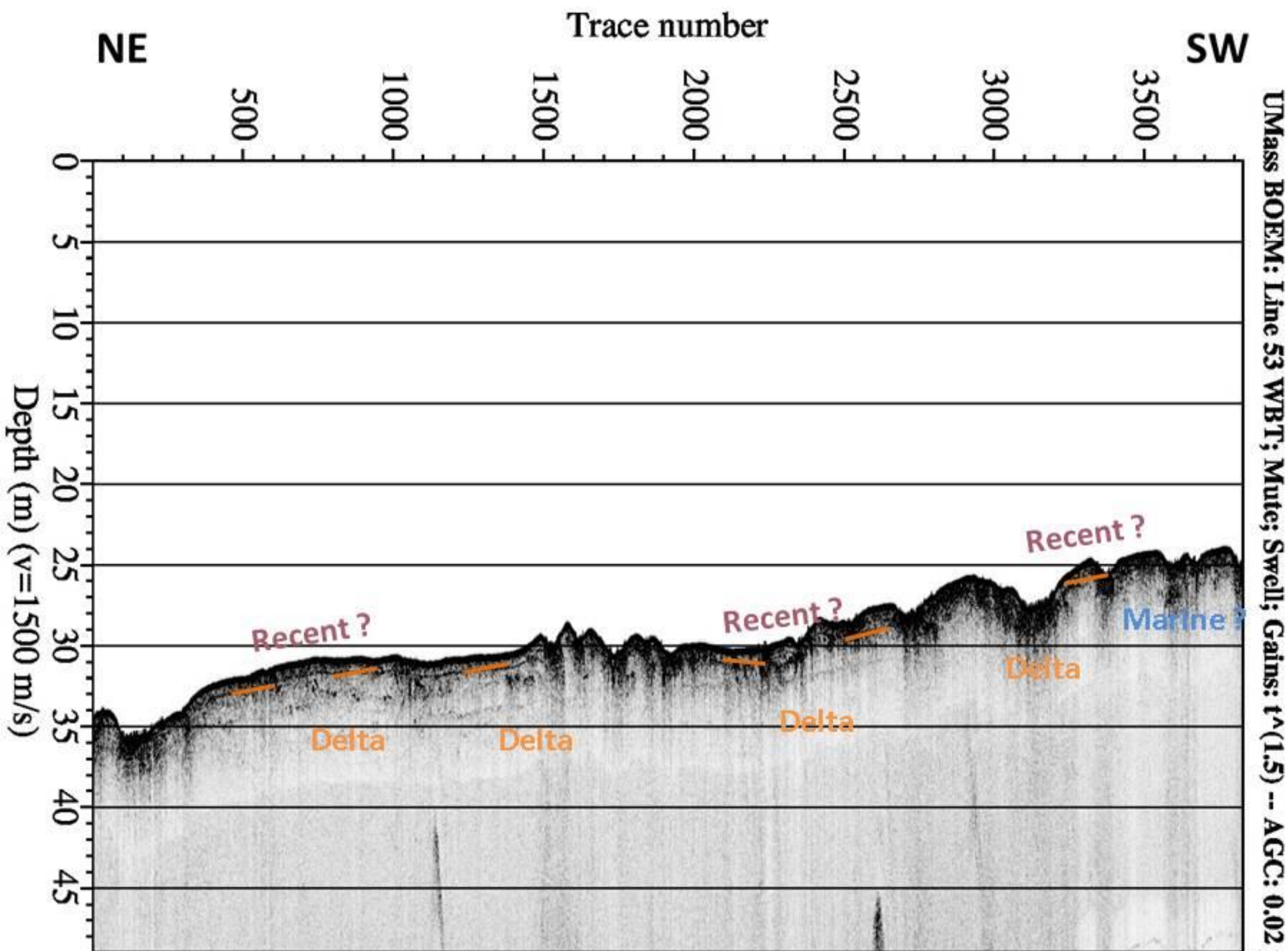

Trace number
NE
SW
500
1000
1500
2000
2500
3000
3500
UMass BOEM: Line 53 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent ?
Recent ?
Recent ?
Marine ?
Delta
Delta
Delta
Delta

**Figure 45**

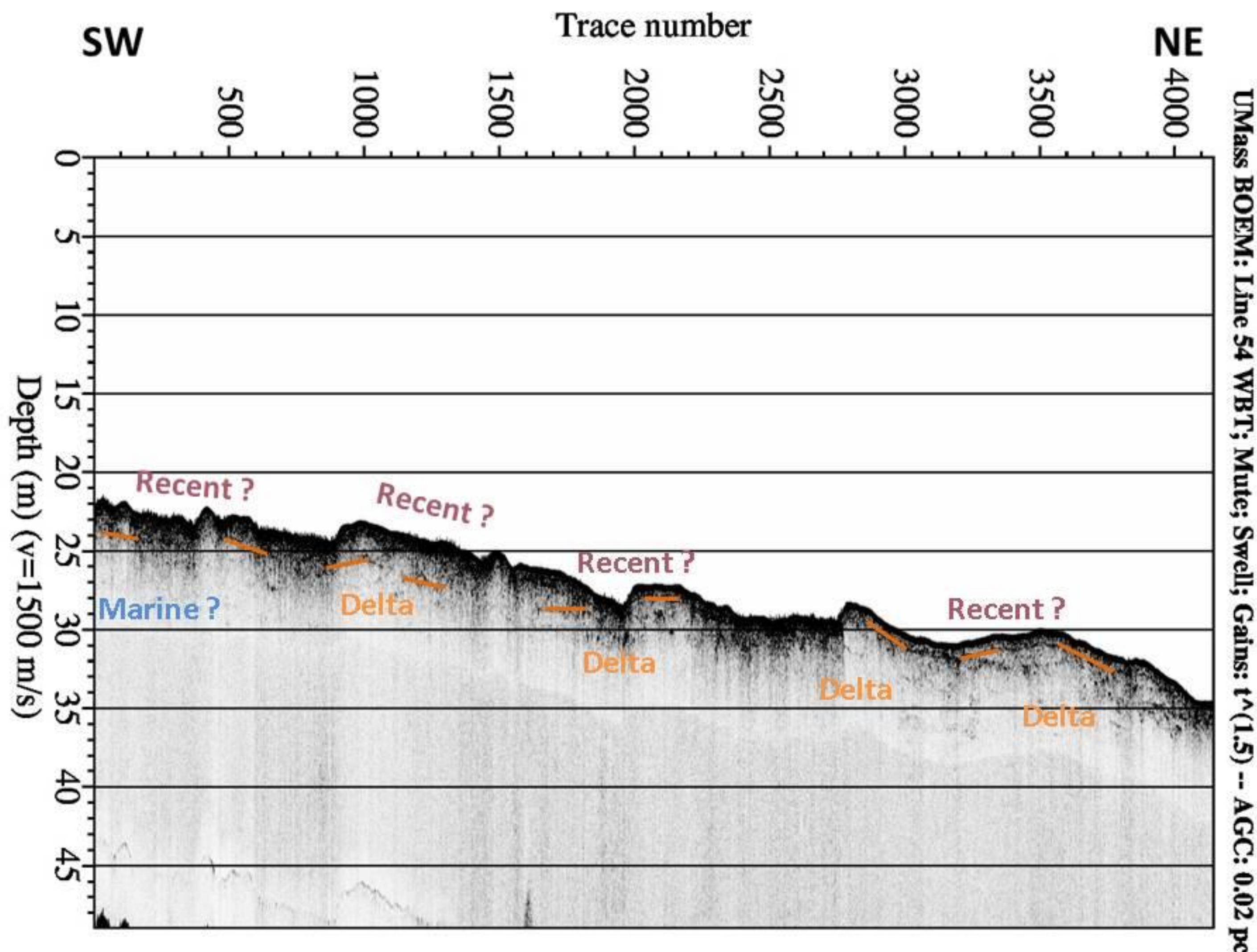

SW
NE
Trace number
500
1000
1500
2000
2500
3000
3500
4000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 54 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ?
Recent ?
Recent ?
Recent ?
Marine ?
Delta
Delta
Delta
Delta

**Figure 46**

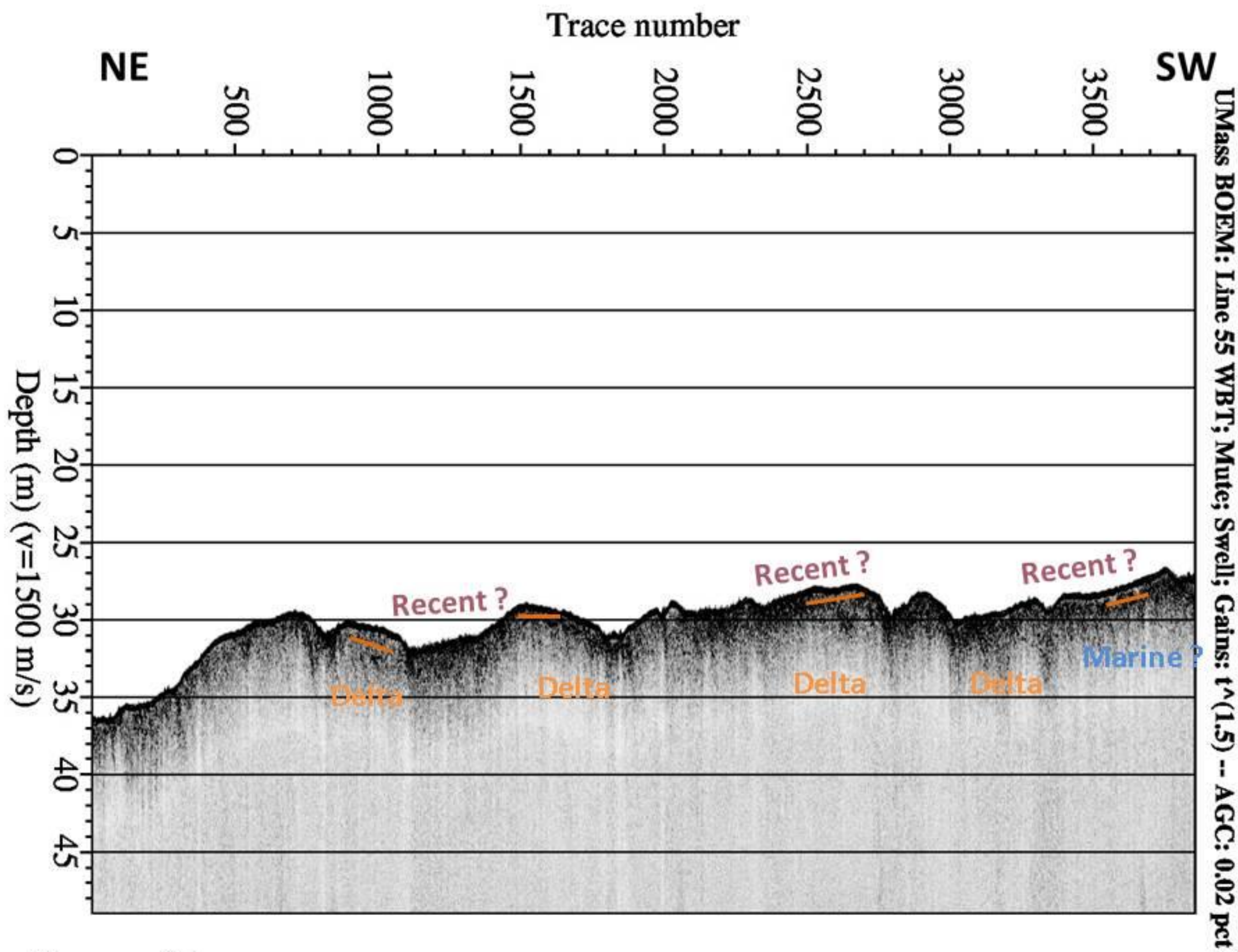

Trace number
NE
SW
500
1000
1500
2000
2500
3000
3500
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent ?
Recent ?
Recent ?
Recent ?
Delta
Delta
Delta
Delta
Marine ?
UMass BOEM: Line 55 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

Figure 47

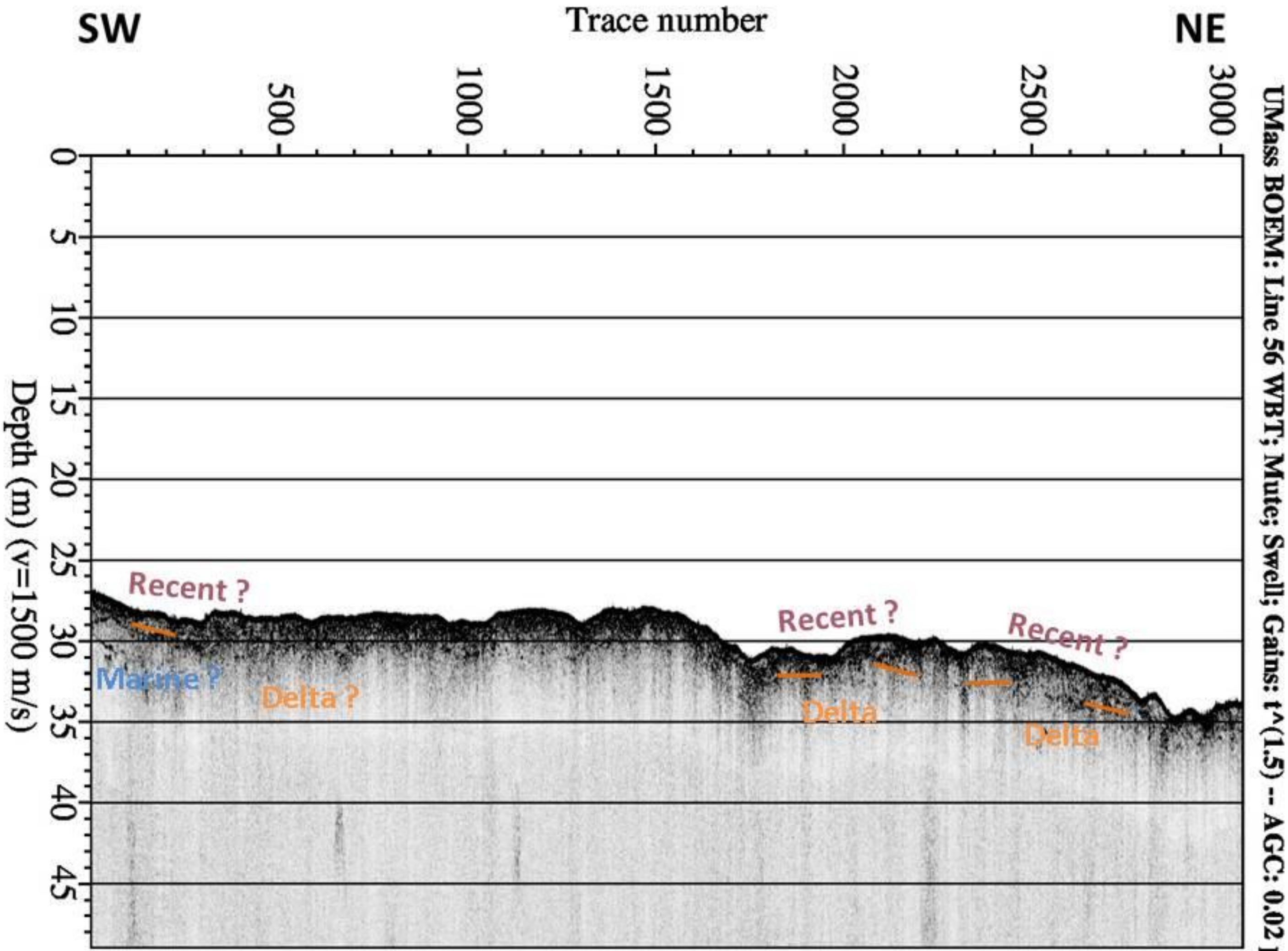

SW
Trace number
NE
500
1000
1500
2000
2500
3000
UMass BOEM: Line 56 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
Recent ?
Marine ?
Delta ?
Recent ?
Delta
Recent ?
Delta

Figure 48

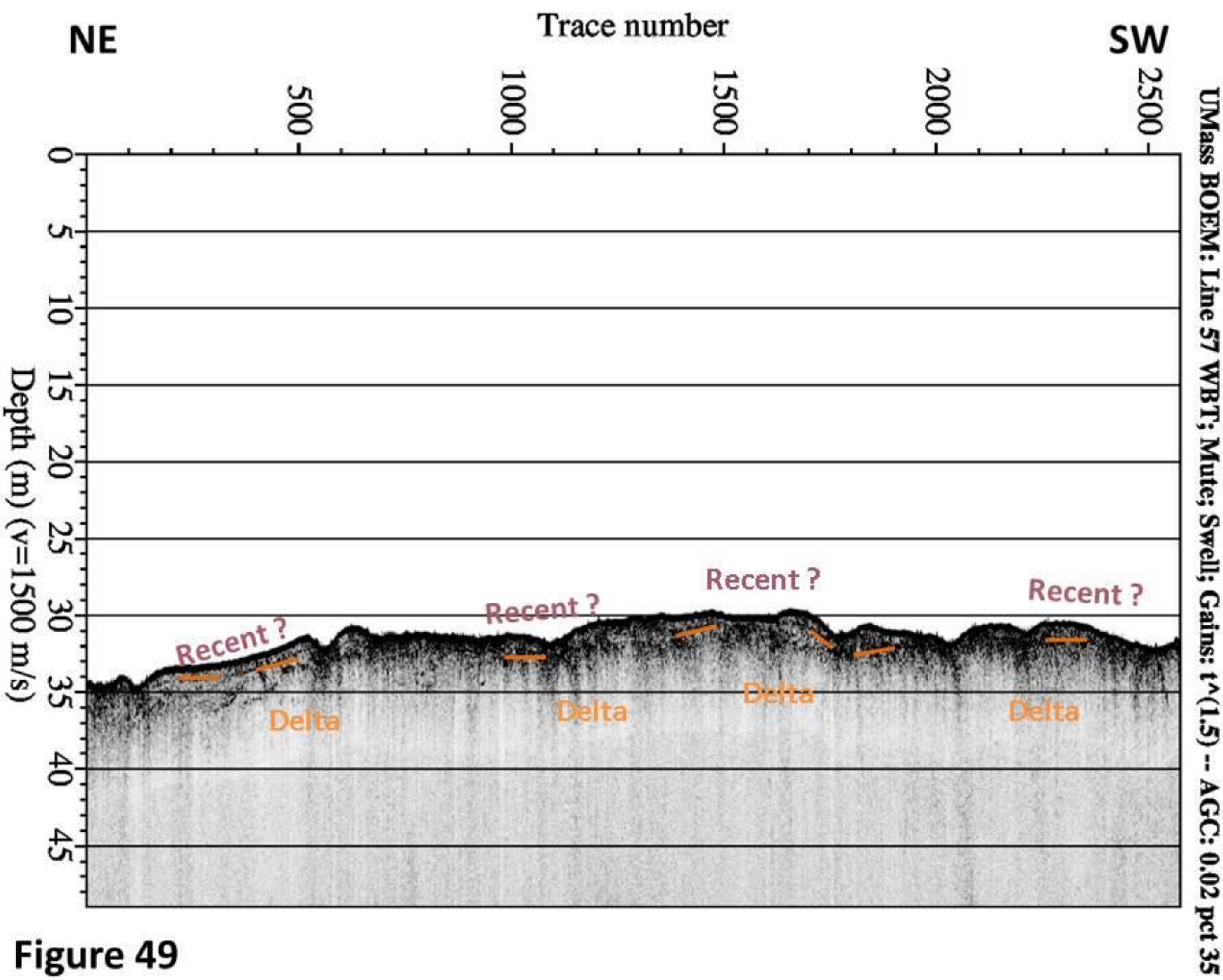



Figure 49

## Section 3 – Buzzards Bay Results

Combining the BOEM Buzzards Bay "chirp" seismic lines with the existing mapped geology and the existing 1975 USGS "boomer" data (O'Hara-ASTR-75) proved somewhat useful to this effort (Figures 50-53). The interpretations shown on Figures 54-57 have been made with little confidence. Although some inferences can be made from the 1975 "boomer" data the lack of cores is a hindrance. It appears that the deposits of interest in the two small areas surveyed are composed of reworked material derived from the underlying till, lake or channel deposits (Figures 50-57).

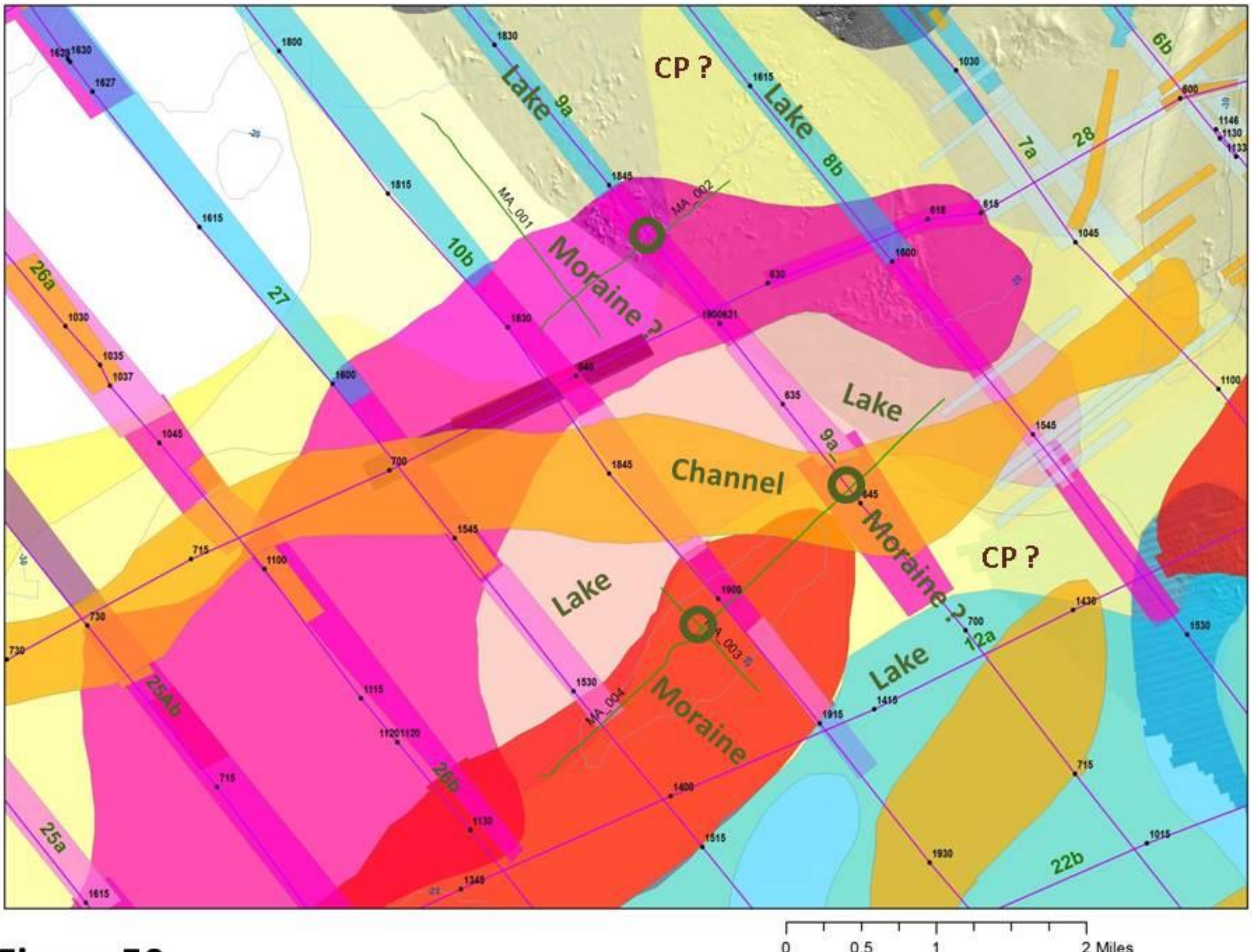
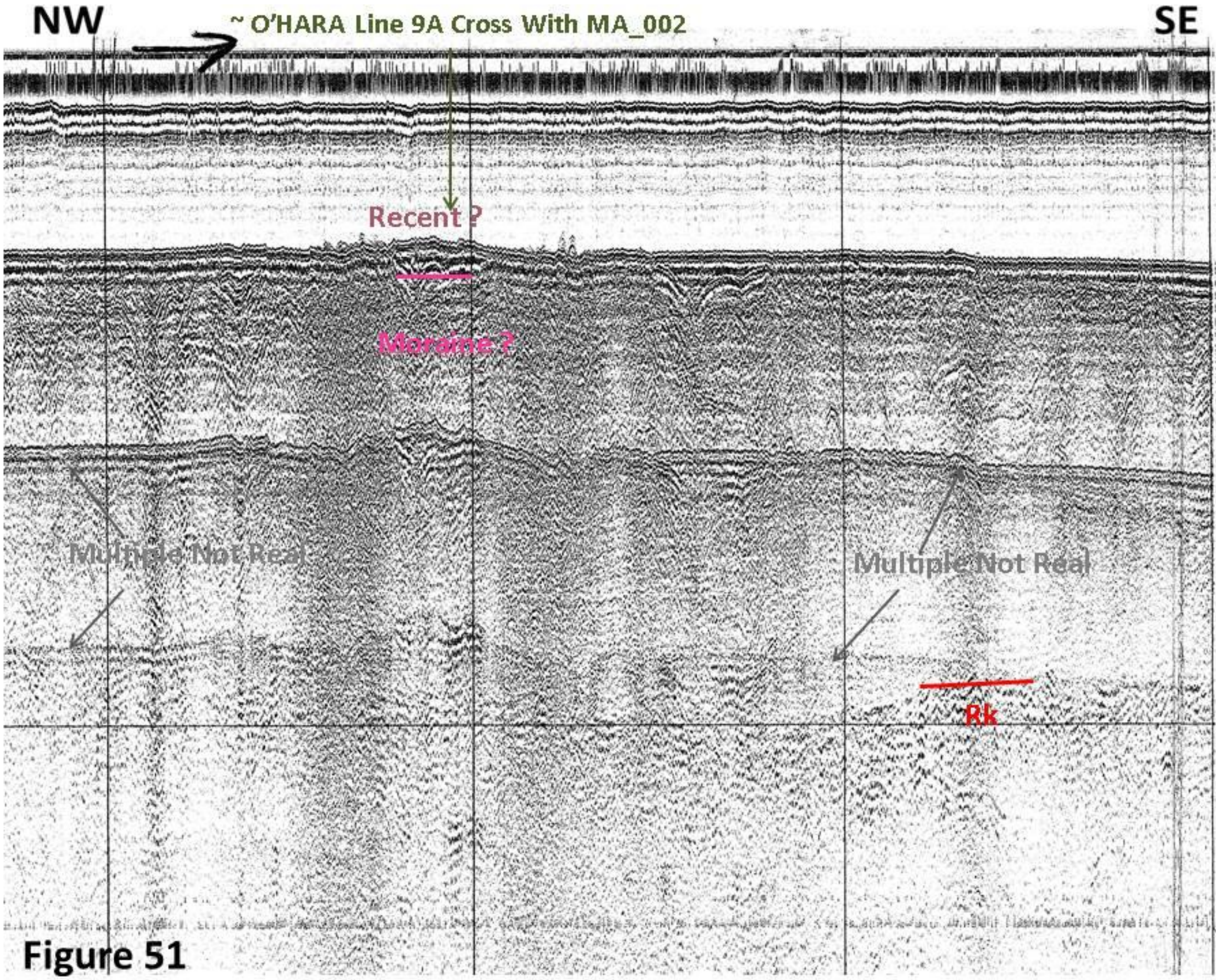
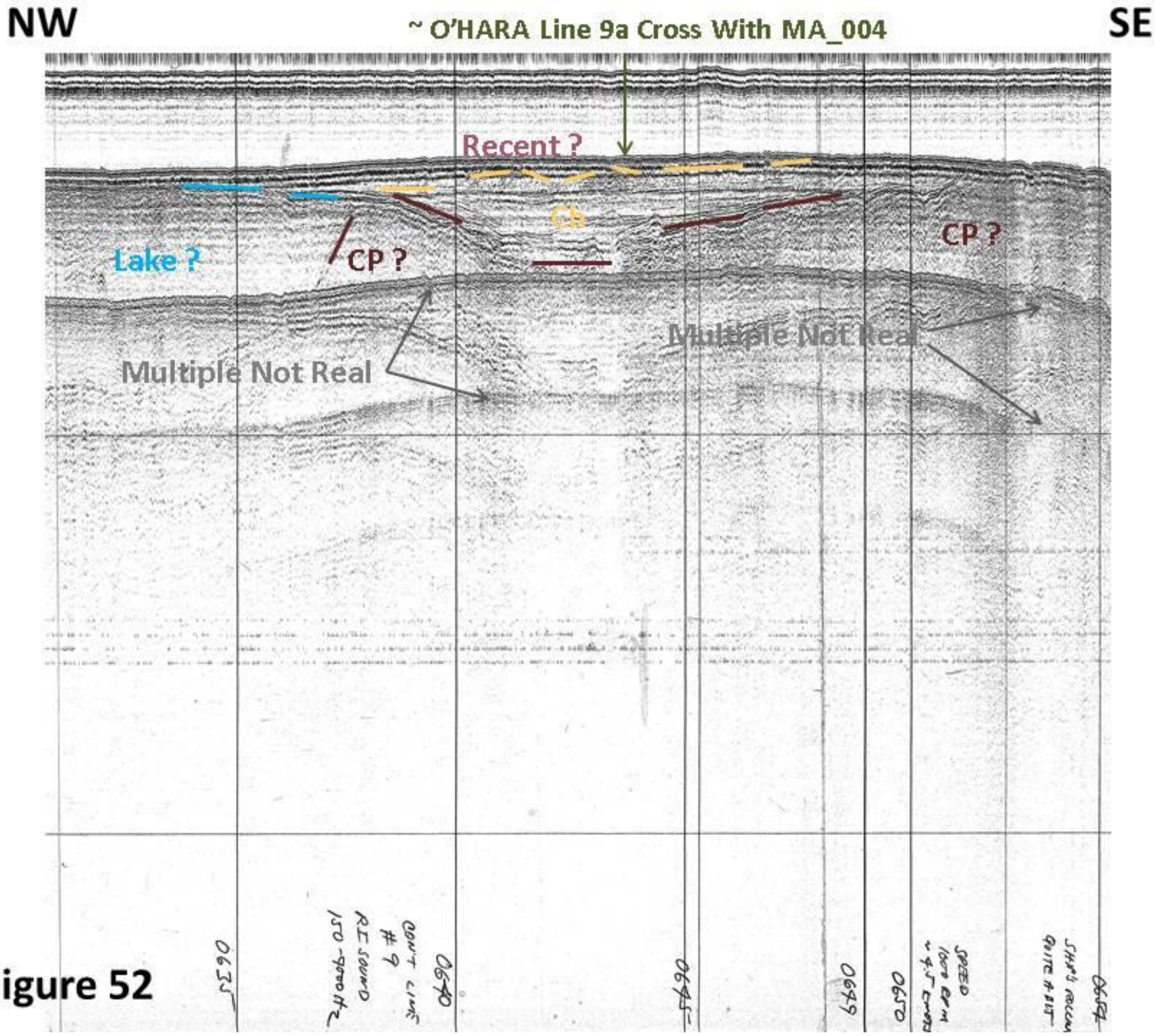



**Figure 50**

**Figure 50: A draft geologic map produced as part of the production of the Quaternary Geologic Map of Massachusetts. The 1975 tracklines 9a and 10b (in purple), BOEM tracklines 1-4 (in green) are shown in their geologic context. Map units representing coastal plain (CP), Moraine, Lake, and Channel deposits are shown around each survey area. Crossings of the BOEM and O'Hara tracklines are highlighted by green circles and are shown on appropriate seismic profiles (Figures 51, 52, 53, 55, 57).**


NW
~ O'HARA Line 9A Cross With MA_002
SE
Recent ?
Moraine ?
Multiple Not Real
Multiple Not Real
Rk
Figure 51



NW
~ O'HARA Line 9a Cross With MA_004
SE
Recent ?
Ch
Lake ?
CP ?
CP ?
Multiple Not Real
Multiple Not Real
0635
0640
0645
0649
0650


Figure 52

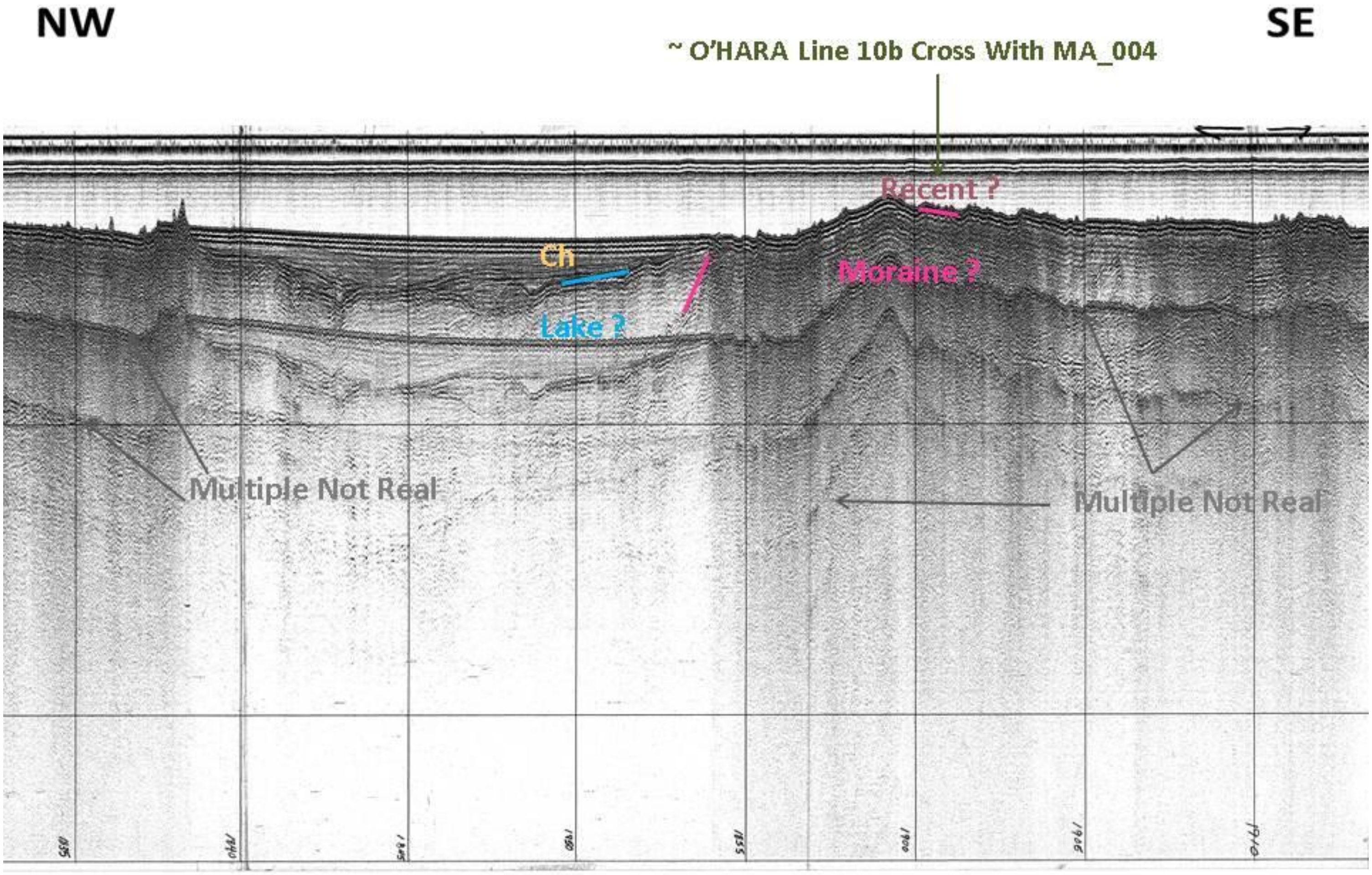
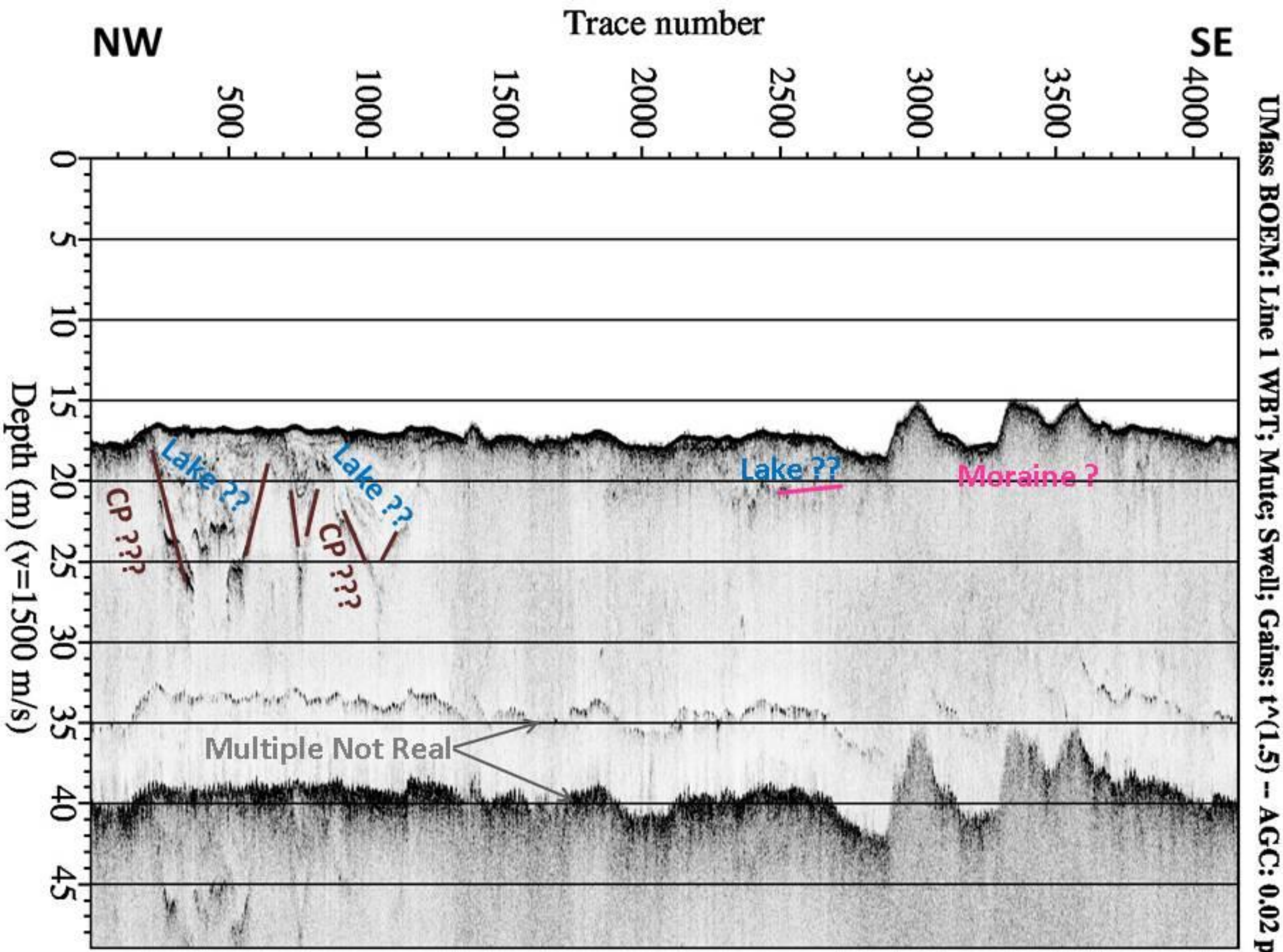
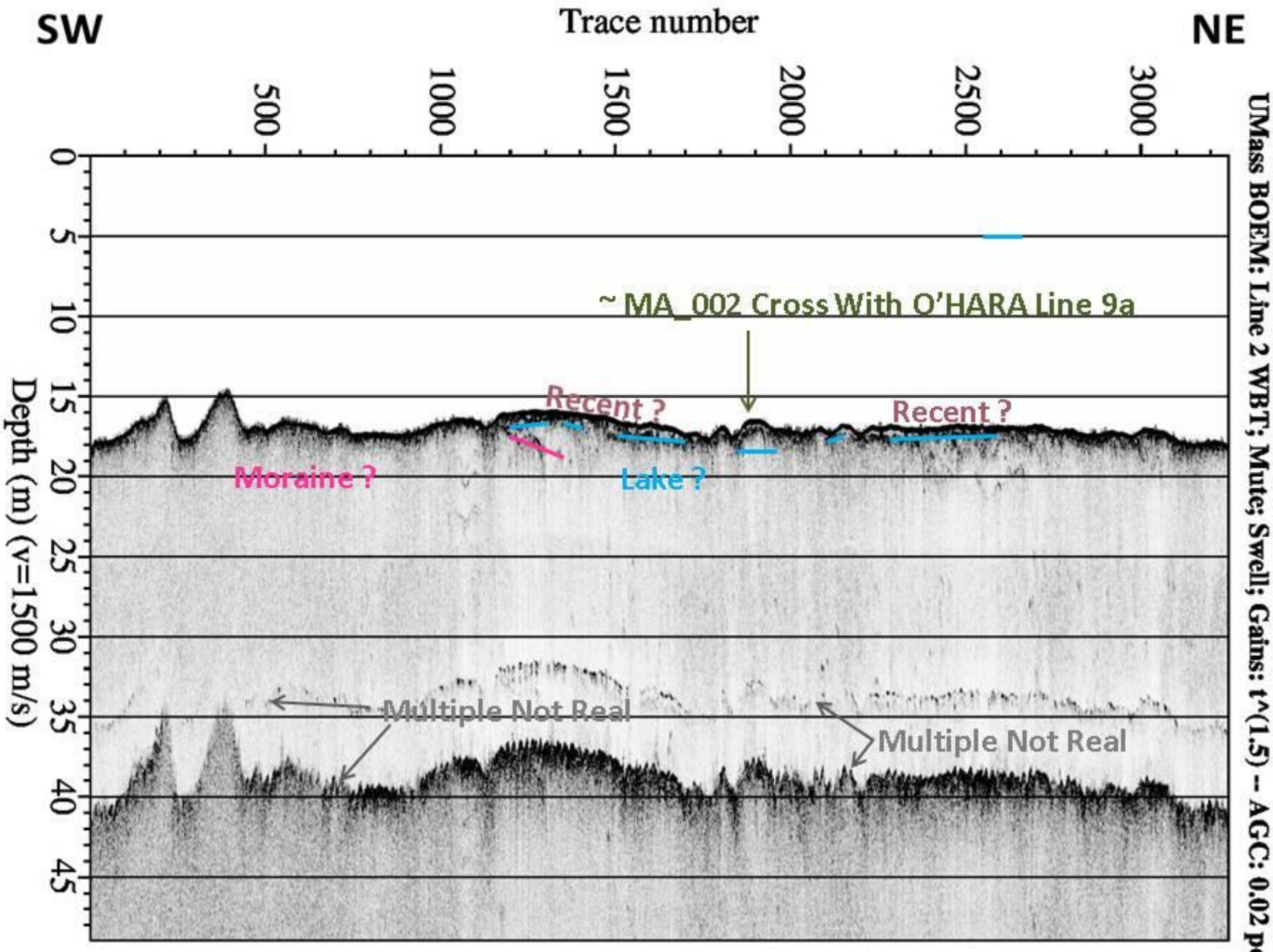

NW
SE
~ O'HARA Line 10b Cross With MA_004
Recent ?
Ch
Moraine ?
Lake ?
Multiple Not Real
Multiple Not Real

Figure 53



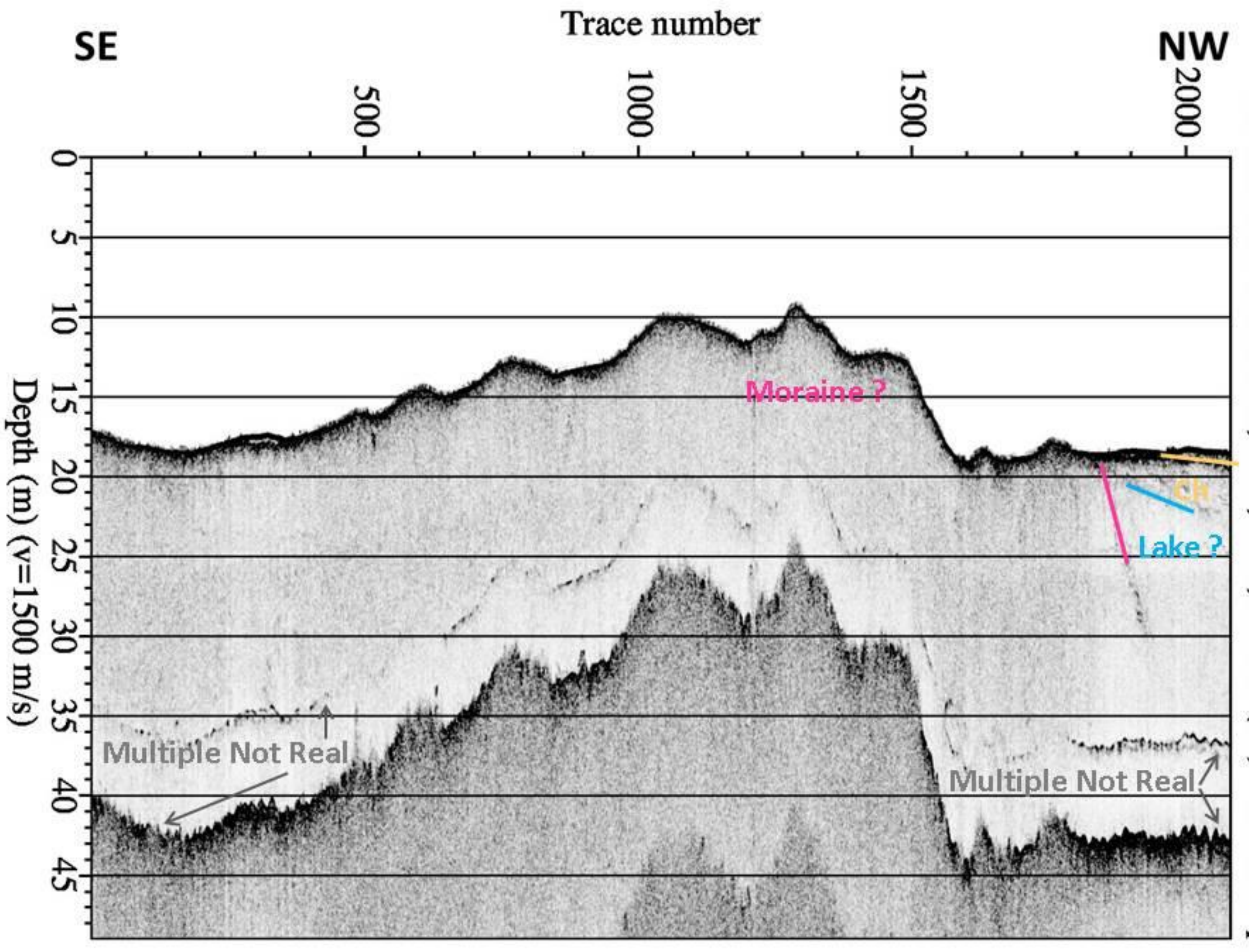
UMass BOEM: Line 1 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Trace number
NW
SE
500
1000
1500
2000
2500
3000
3500
4000
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Lake ??
Lake ??
Lake ??
CP ???
CP ???
Moraine ?
Multiple Not Real


Figure 54



SW
Trace number
NE
UMass BOEM: Line 2 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
~ MA_002 Cross With O'HARA Line 9a
Recent ?
Recent ?
Moraine ?
Lake ?
Multiple Not Real
Multiple Not Real


**Figure 55**



Trace number
SE
NW
500
1000
1500
2000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
Moraine ?
Ch
Lake ?
Multiple Not Real
Multiple Not Real
UMass BOEM: Line 3 WBT; Mute; Swell; Gains: t^(1.5) – AGC: 0.02 pct 35


Figure 56

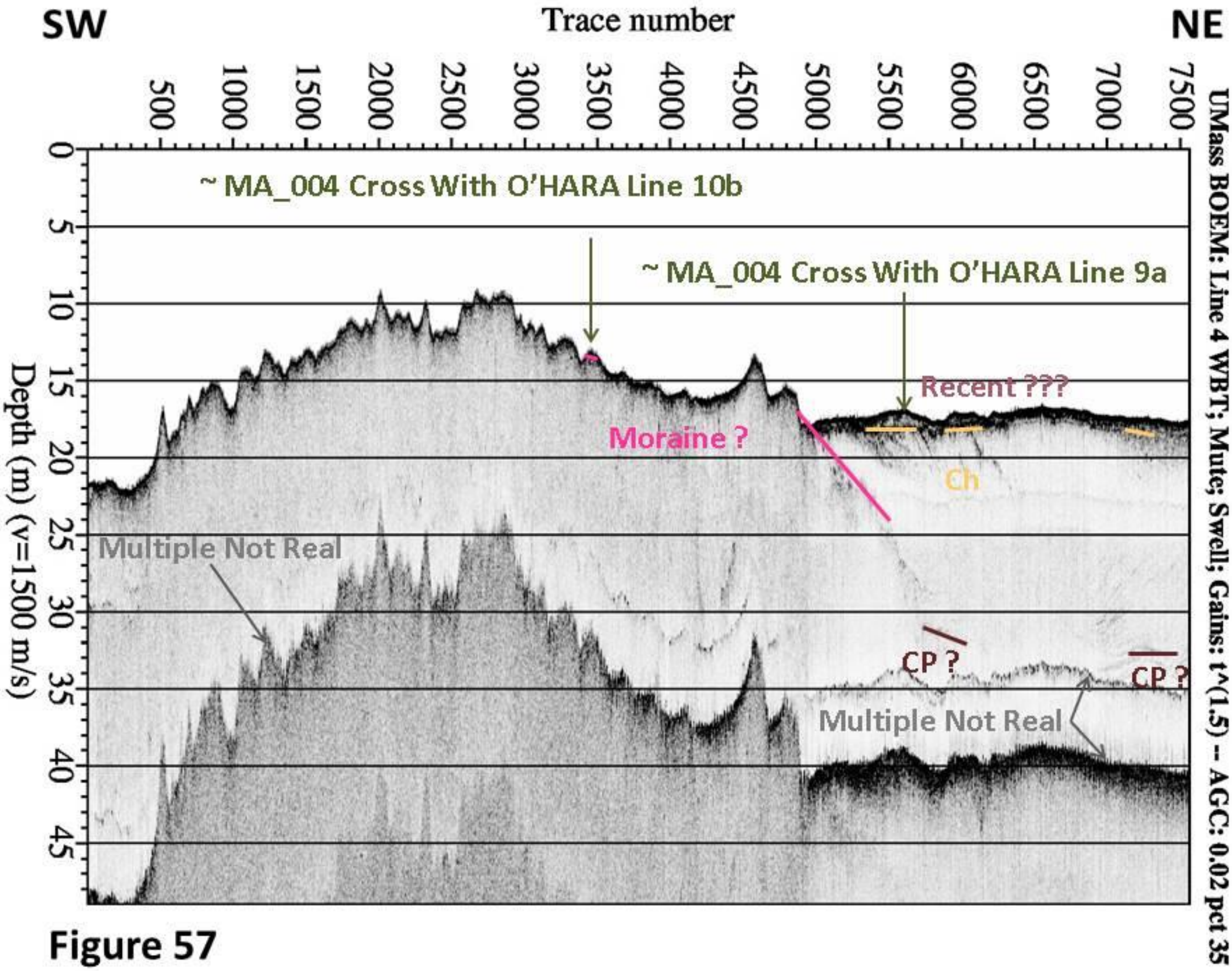
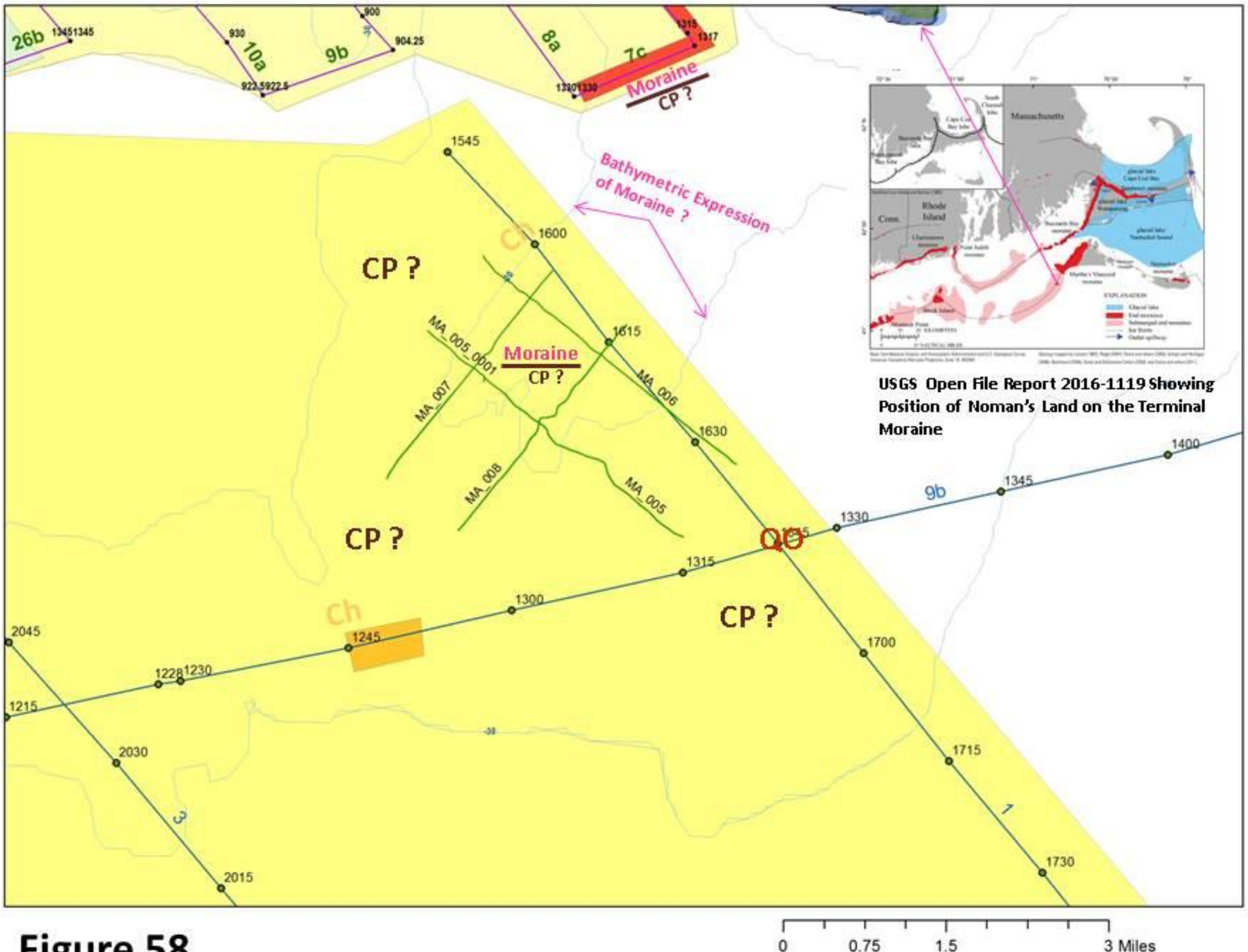


Figure 57

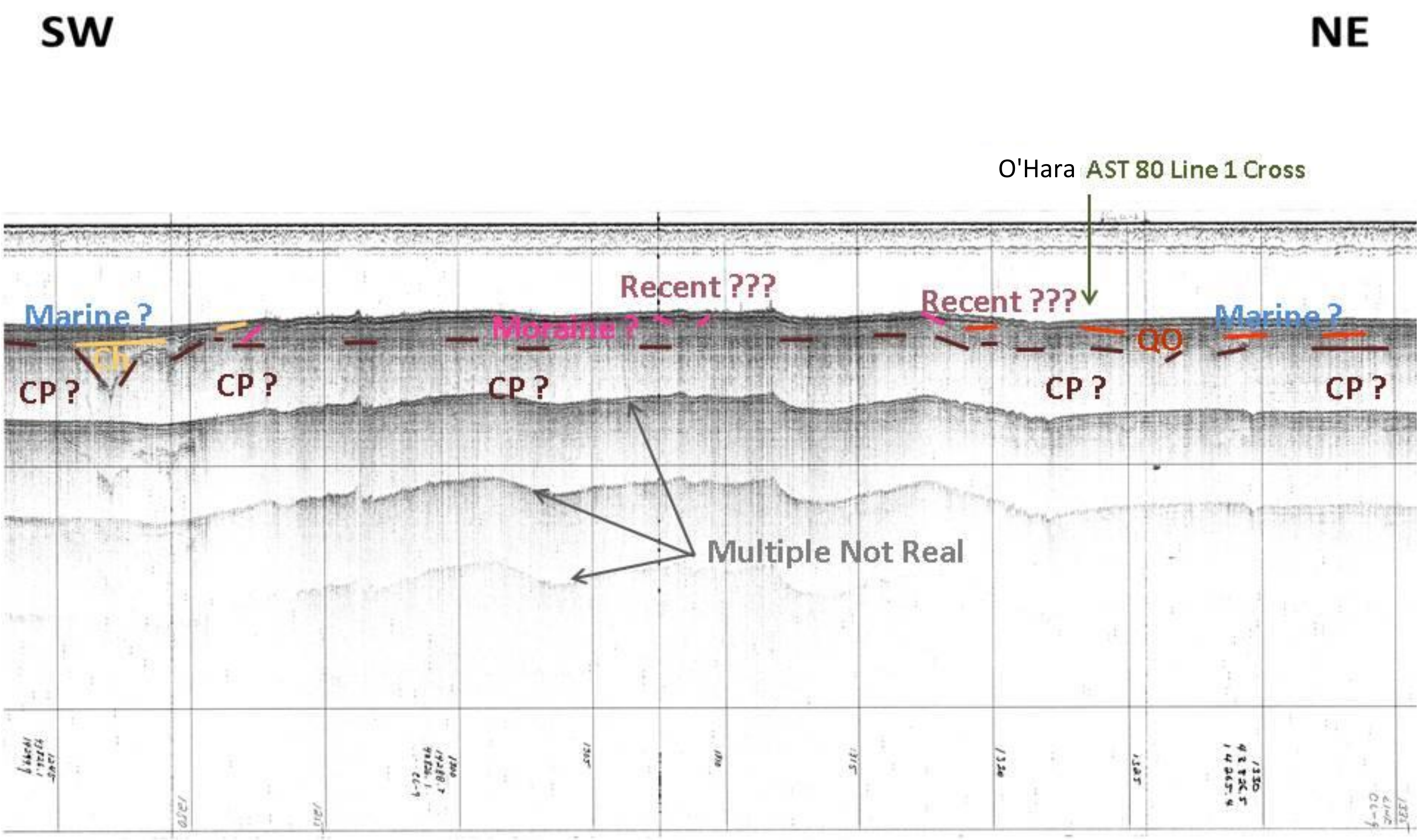
## Section 4 – Noman's Land Results

Combining the BOEM Noman's Land "chirp" seismic lines with the existing mapped geology and the existing 1980 USGS "boomer" data (O'Hara-ASTR-80-6B) proved somewhat useful to this effort (Figures 58-65). The interpretations shown on Figures 61-65 have been made with little confidence. Although some inferences can be made from the 1980 "boomer" data the lack of cores is a hindrance. It appears that the deposits of interest in the small area surveyed are composed of reworked material derived from the underlying till, outwash, channel and or glaciomarine deposits (Figures 61-65).




# Figure 58

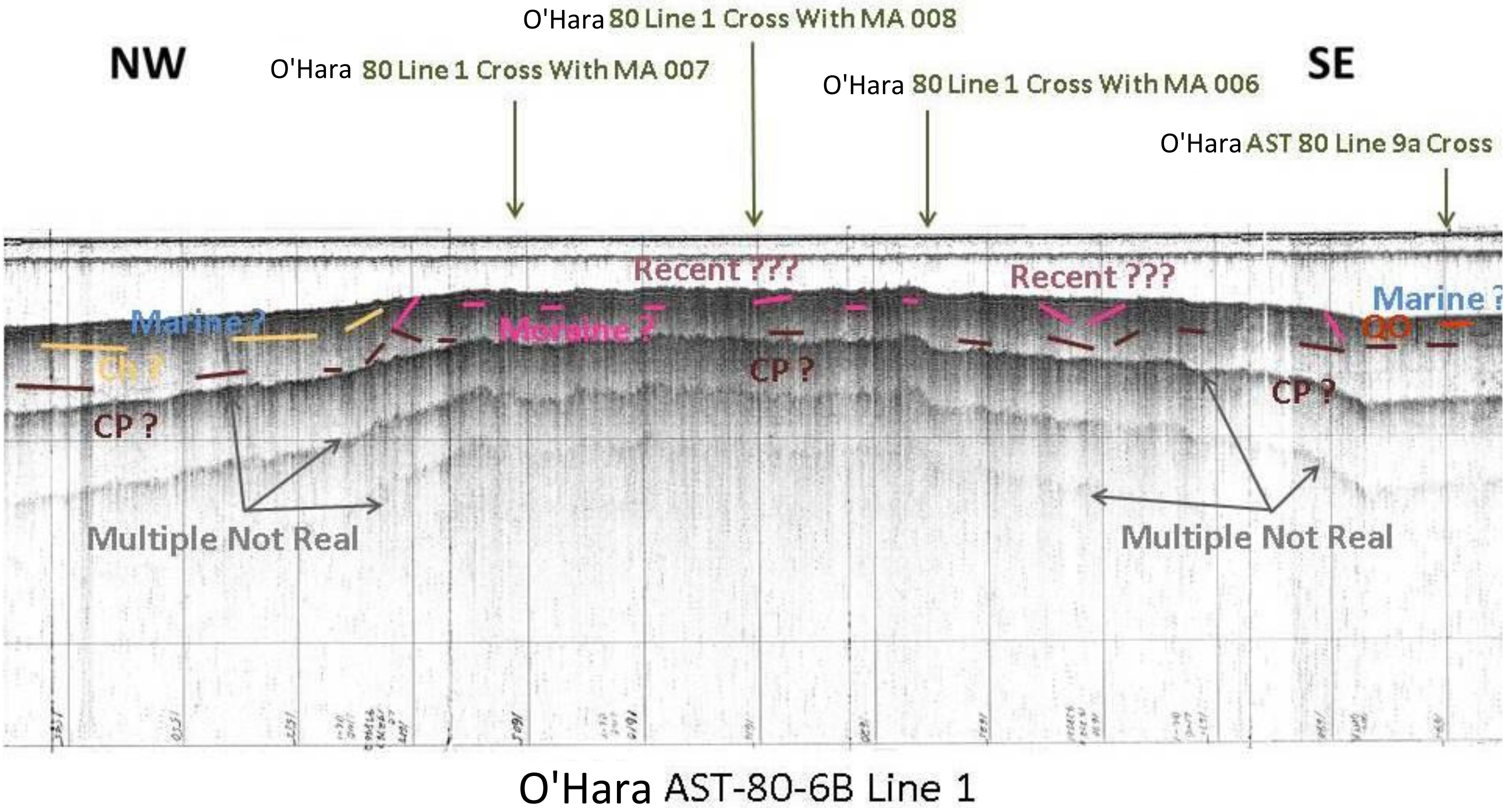
**Figure 58: A draft geologic map produced as part of the production of the Quaternary Geologic Map of Massachusetts. The 1980 O'Hara tracklines 1 and 9b (in blue), BOEM tracklines MA 005, and MA 0005.1- MA 008 (in green) are shown in their geologic context. Map units representing coastal plain (CP), Moraine, Channel (Ch) and Outwash (QO) deposits are shown around each survey area. The inset USGS map shows the position of Noman's Land relative to the offshore moraines of the area. Crossings of the BOEM tracklines with the O'Hara lines and the crossing of O'Hara line 1 with O'Hara line 9b are shown on the appropriate seismic profiles (Figures 59, 60, 63, 64, 65).**




O'Hara AST-80-6B Line 9b

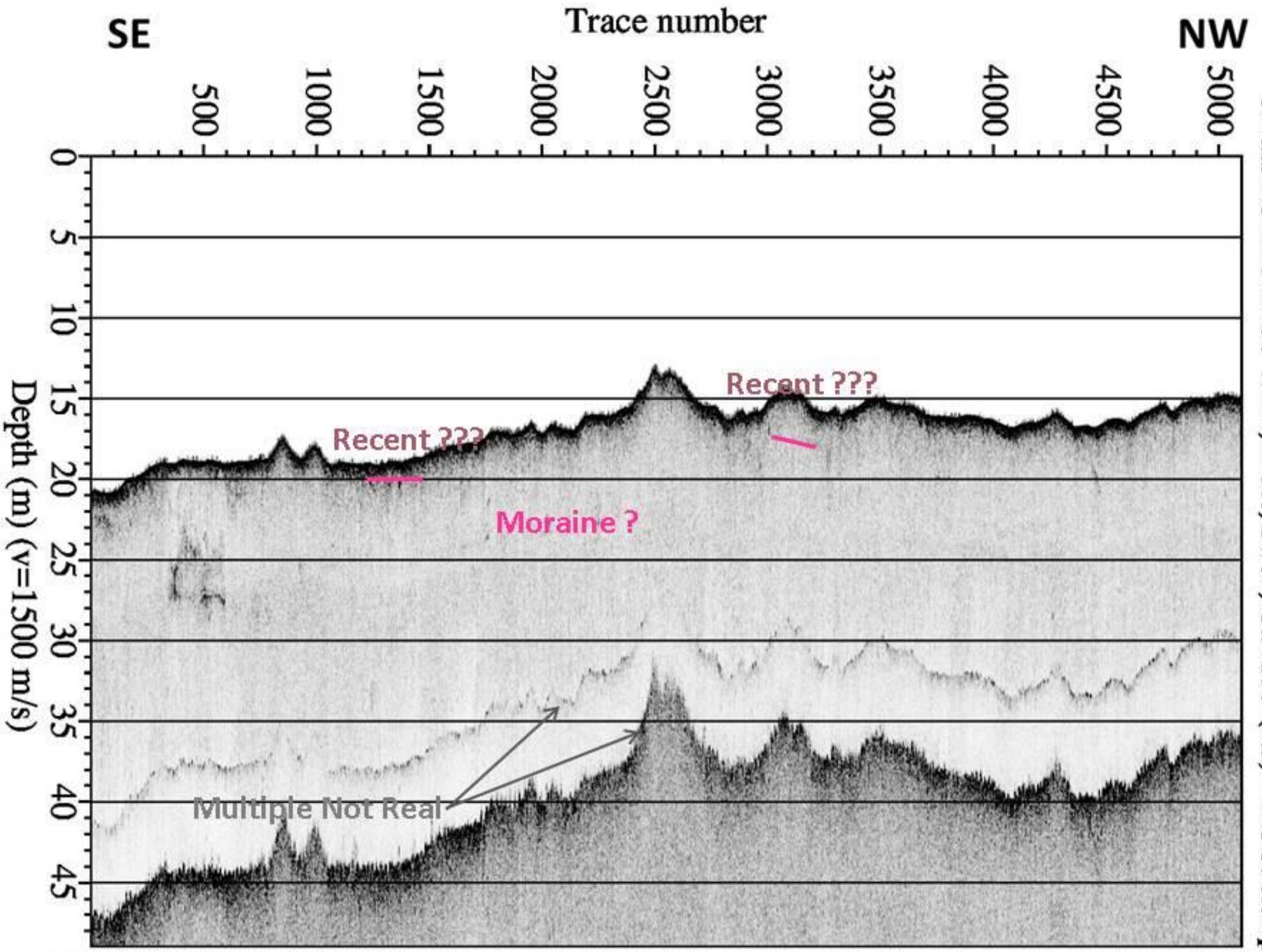
**Figure 59**

**Figure 59: Showing the approximate location of the cross with O'Hara AST 80 Line 1**




# Figure 60

**Figure 60: Showing the approximate location of the cross with O'Hara AST 80 Line 9a and the crosses with BOEM Lines MA 006, 007, and 008**



SE
Trace number
NW
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 5 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent ???
Recent ???
Moraine ?
Multiple Not Real


Figure 61

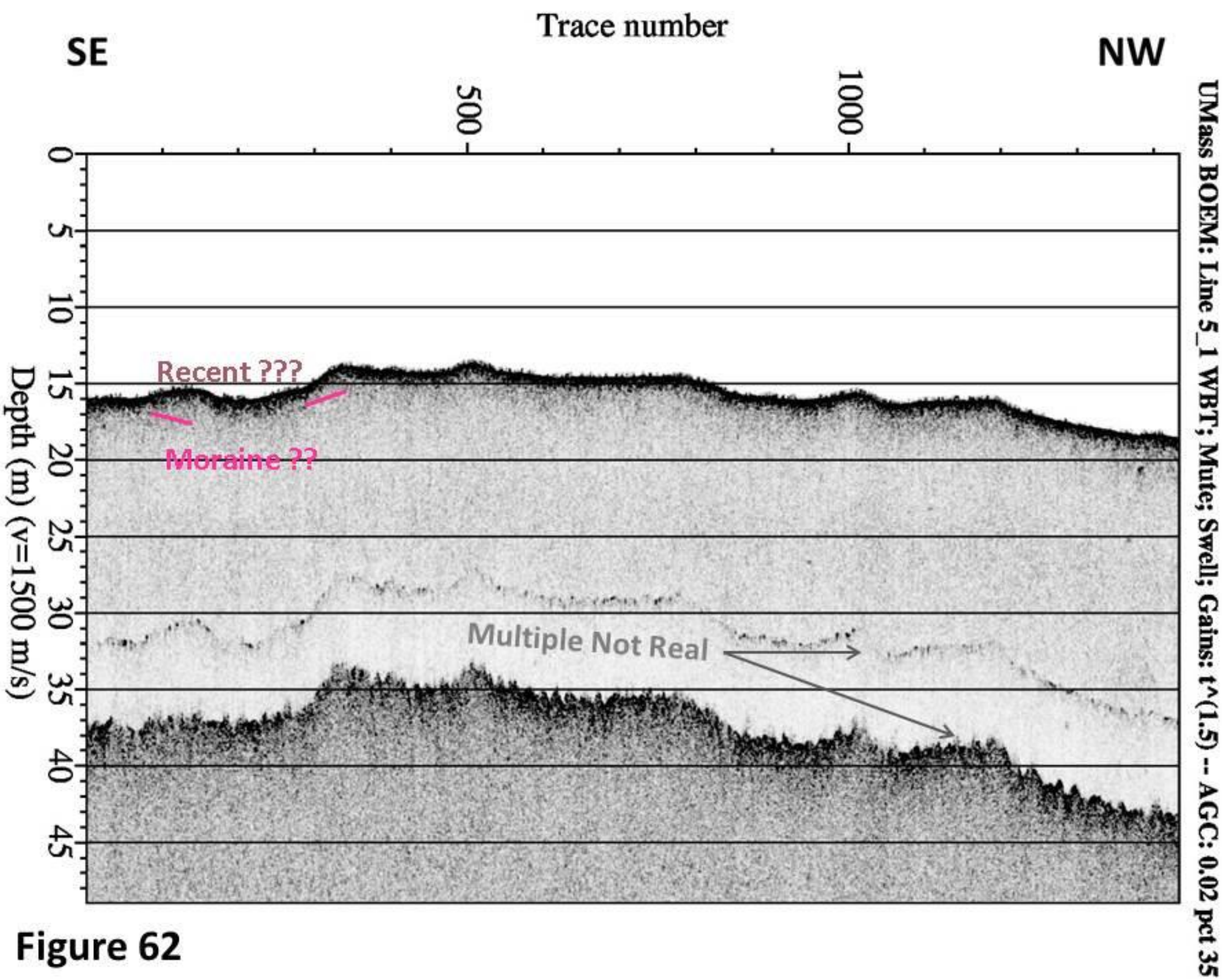

Trace number
SE
NW
500
1000
UMass BOEM: Line 5_1 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent ???
Moraine ??
Multiple Not Real

Figure 62

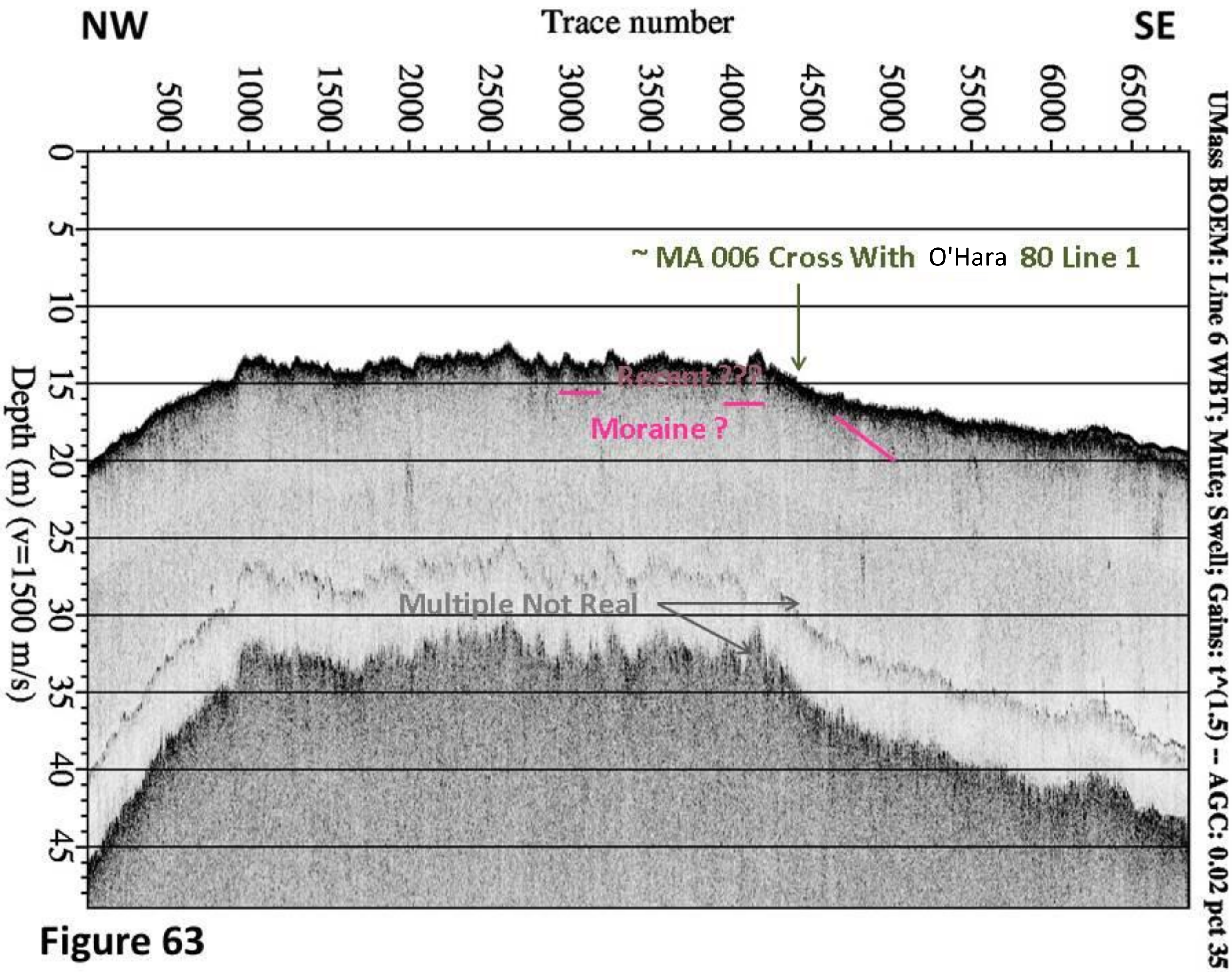



**Figure 63: Showing the approximate location of the cross with O'Hara AST 80 Line 1**

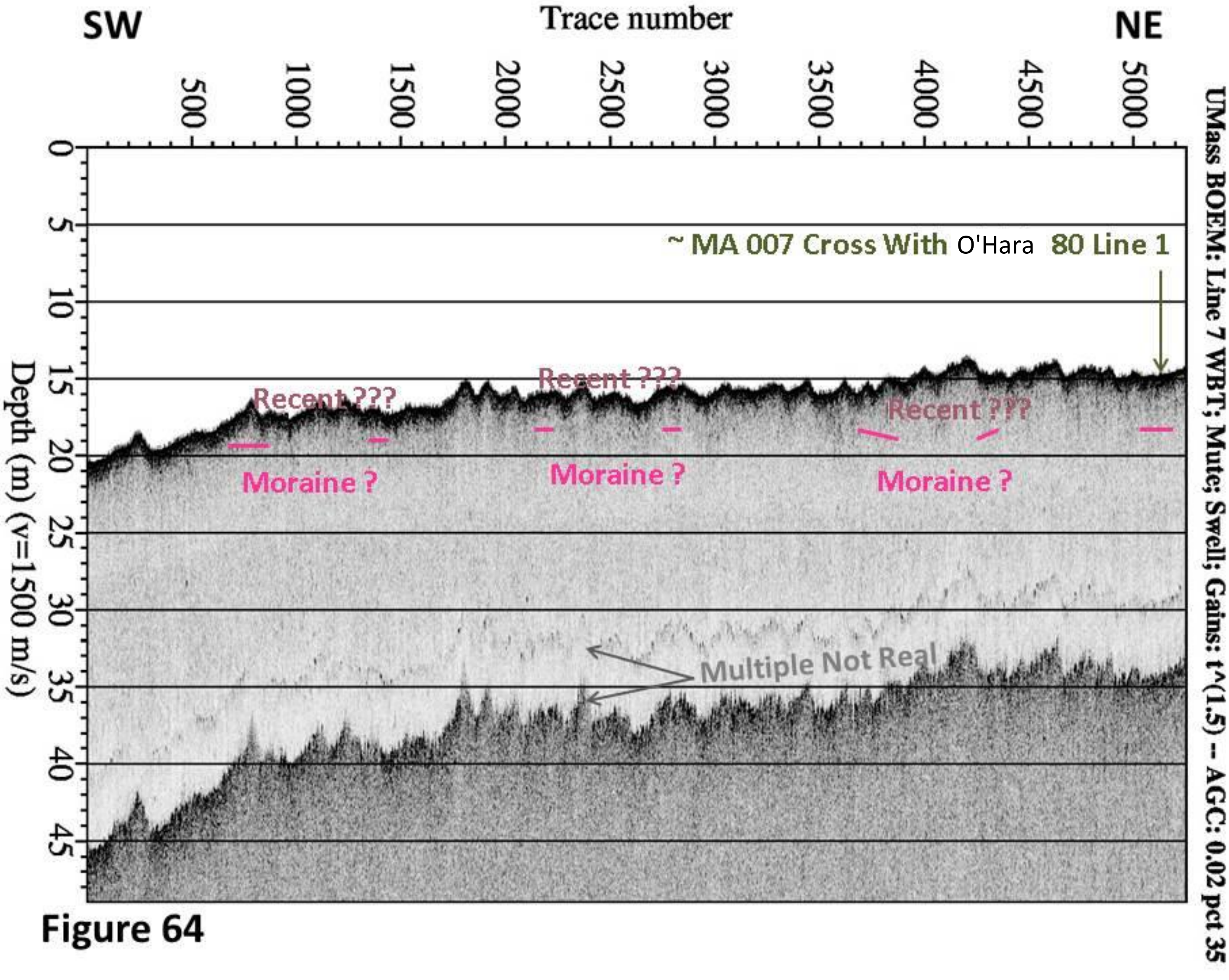



**Figure 64: Showing the approximate location of the cross with O'Hara AST 80 Line 1**

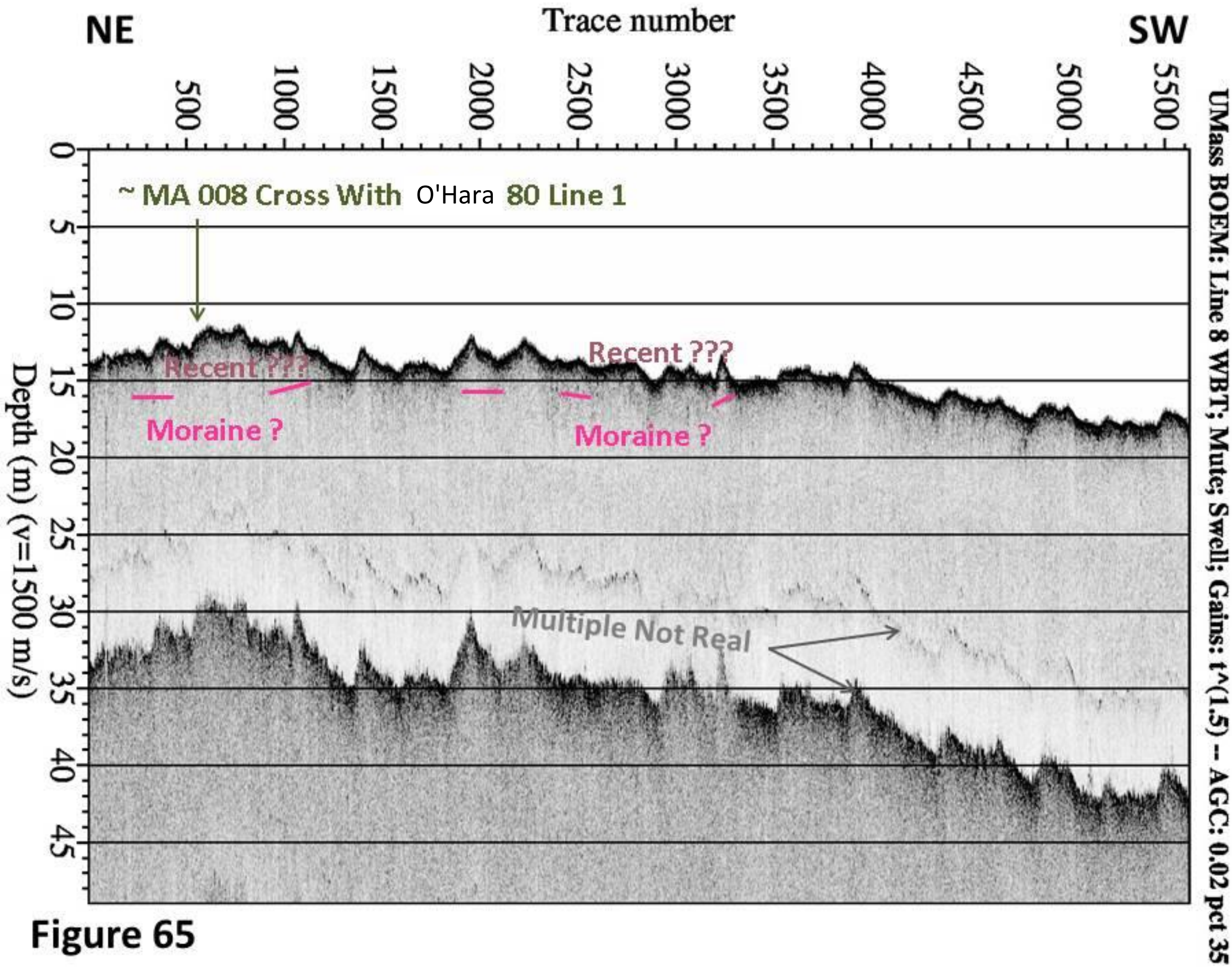



**Figure 65: Showing the approximate location of the cross with O'Hara AST 80 Line 1**

## Section 5 - Nantucket Results

A USGS "sparker" line (Fay 23 Line 5, 1976) lies to the west of, but does not traverse, the BOEM Nantucket survey area (Figure 66). As the DEM of the bathymetry shows (Figure 67) the seafloor in the vicinity of Fay 23 Line 5 is much less modified by modern reworking than the survey area is. The interpretation offered for Fay 23 Line 5 was made with little supporting information other than a general knowledge of the stratigraphy that would be expected in the area. When combined with the DEM bathymetric image shown on Figure 67, the Fay 23 “sparker” line does, however, provide some insight regarding the geologic setting of the survey area and was somewhat helpful with the BOEM line interpretations (Figures 70- 72). Owing to the poor quality of the BOEM seismic data these interpretations have been made with little confidence.

The inferred “Recent” deposit identified on the interpreted BOEM seismic line MA-021 (Figure 71) was penetrated by Core VC 06 (Figure 69). Core VC 06 contained well-sorted fine to medium-grained sand with shell hash.

The shell hash indicates this is a marine deposit and the morphology of the deposit depicted on the DEM bathymetry suggests it is part of a modern bar complex that is probably composed of reworked outwash and possible coastal plain deposits. The thickness of the bar deposit cannot be reliably assessed from the BOEM seismic data but at one spot along Line MA_021 it is at least 18.1 feet thick and it probably thins to the west.

Figure 66

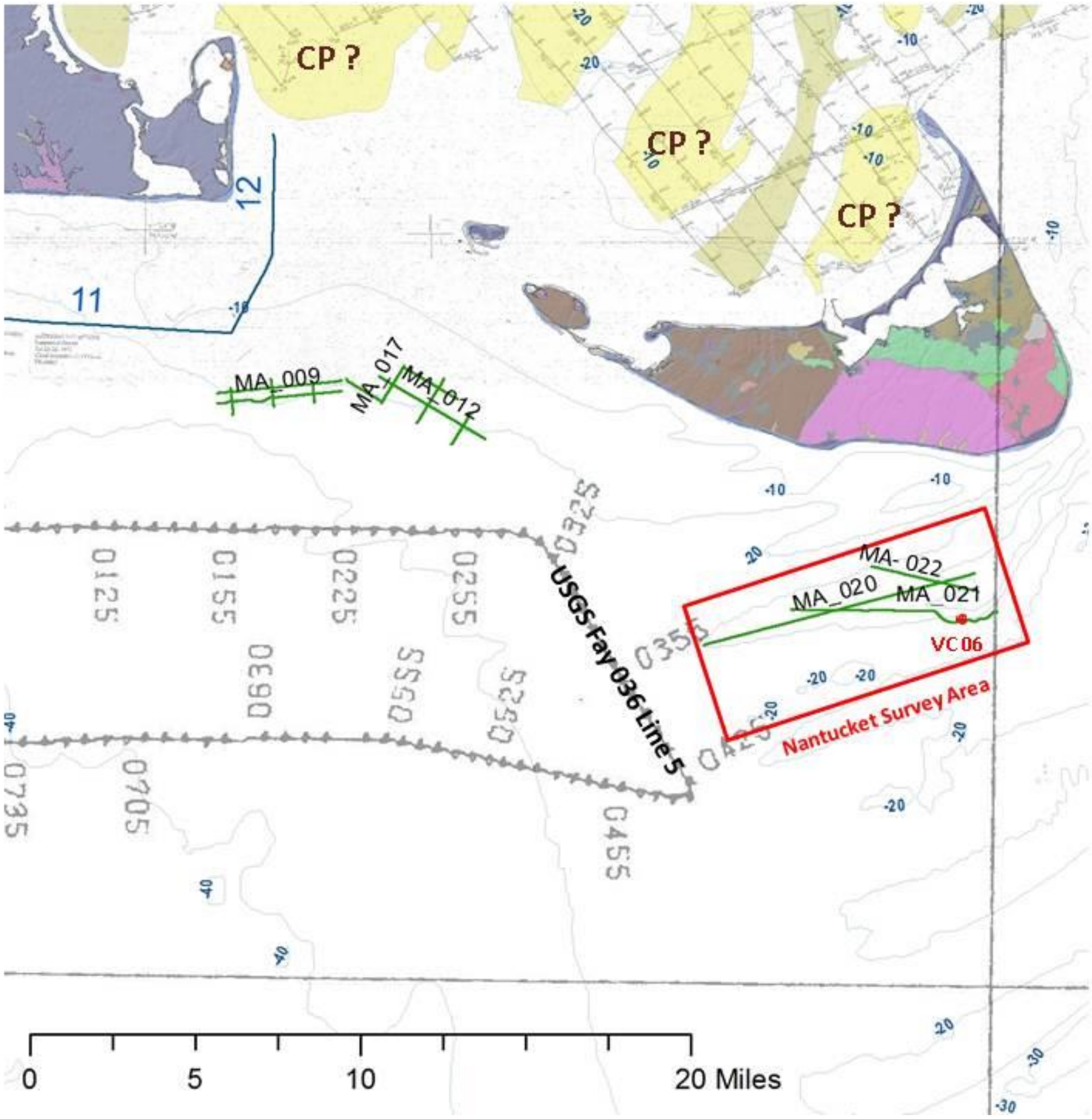
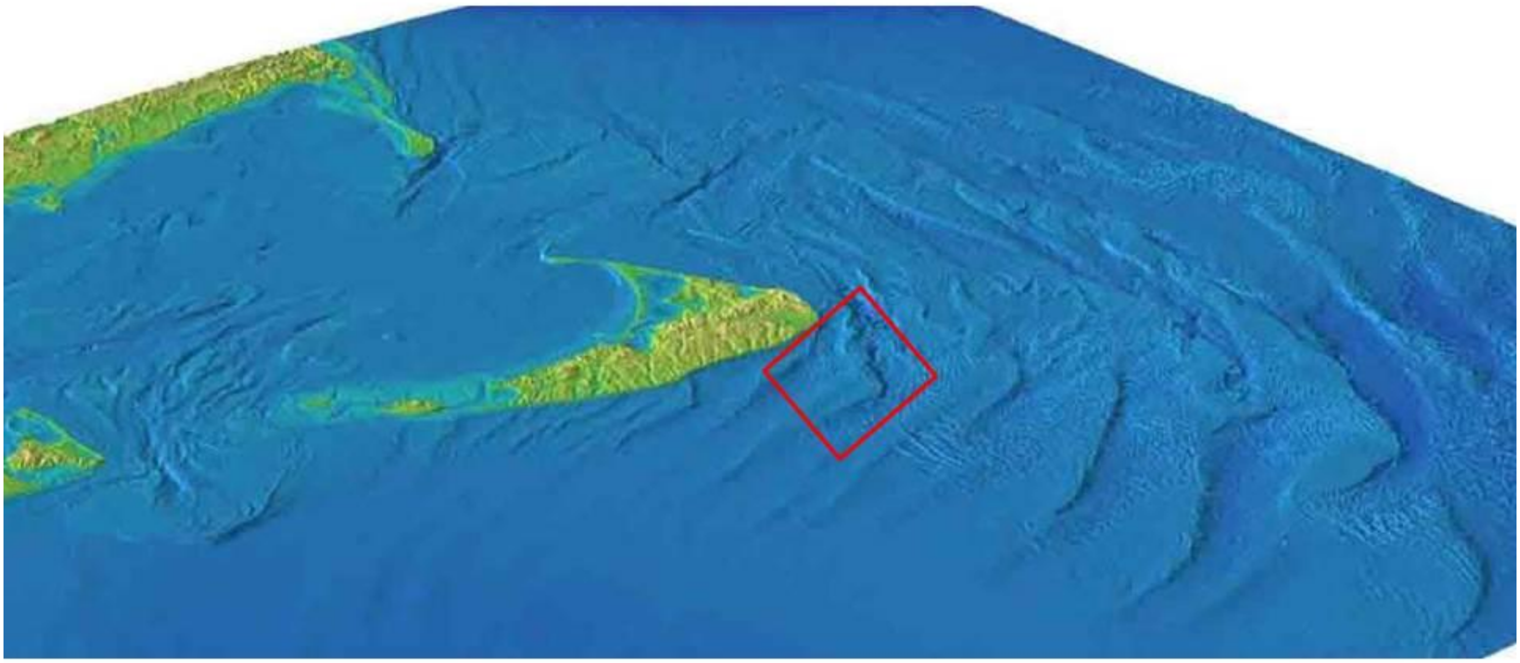


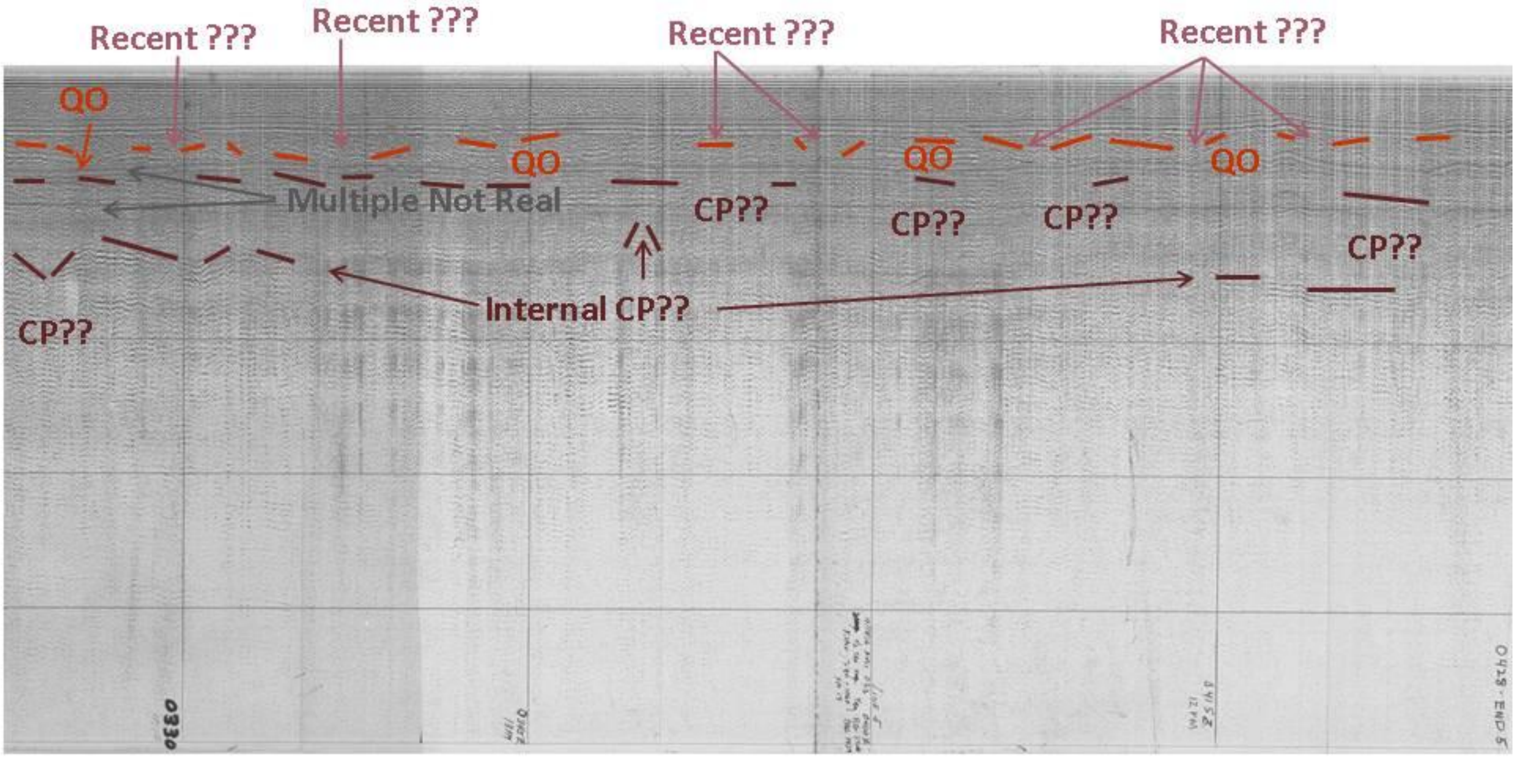

**Figure 66: A map showing the published geology of a portion of Martha's Vineyard, Nantucket, and Nantucket Sound (O'Hara and Oldale, 1987); Fay 23 "sparker" Line 5 is shown in relationship to the Nantucket Survey Area (red box); BOEM tracklines 20-22 and core VC 06). Note: Line 5 should read Fay 23.**



# Figure 67

**Figure 67: The DEM bathymetry shown above appears to indicate that bed forms are moving southwestward (steep sides to the southwest) over a series of modern bars. Core VC 06 penetrated the bar outlined by the red box. This area is probably underlain by outwash deposits that overlie coastal plain deposits (Figure 68). Modern reworking of these older deposits is inferred to have created the bars.**

NW SE




USGS Cruise Fay 23 Sparker Line 5

**Figure 68**

# Core VC 06

(Well-Sorted Fine to Medium-
Grained Sand + Shell Hash)

| ELEV. (ft) | DEPTH (ft) | LEGEND | CLASSIFICATION OF MATERIALS Depths and elevations based on measured values | % REC. | BOX OR SAMPLE | REMARKS |
|---|---|---|---|---|---|---|
| -32.7 | 0.0 | | | | | |
| -34.3 | 1.6 | | SAND, medium grained, quartz, little coarse grains, trace shell hash, trace silt, light olive brown (2.5Y-5/3), (SP). | | 1 | Sample #1, Depth = 0.8' Mean (mm): 0.50, Phi Sorting: 0.75 Fines (230): 0.84% (SP) |
| -37.0 | 4.3 | | SAND, fine to medium grained, quartz, trace coarse grains, trace rock, trace shell hash, trace silt, rock up to 0.25", color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 2 | Sample #2, Depth = 3.0' Mean (mm): 0.38, Phi Sorting: 0.67 Fines (230): 1.14% (SP) |
| -38.7 | 6.0 | | SAND, fine grained, quartz, trace shell hash, trace silt, dark gray (2.5Y-4/1), (SP). | | 3 | Sample #3, Depth = 5.1' Mean (mm): 0.31, Phi Sorting: 0.51 Fines (230): 1.59% (SP) |
| -40.9 | 8.2 | | SAND, fine to medium grained, quartz, trace coarse grains, trace rock, trace shell hash, trace silt, rock up to 0.25", 0.5" shell fragment @ 6.6', color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 2 | |
| -43.7 | 11.0 | | SAND, fine to medium grained, quartz, trace coarse grains, trace rock, trace shell hash, trace silt, rock up to (0.5" x 0.25"), grayish brown (2.5Y-5/2), (SP). | | 4 | Sample #4, Depth = 9.6' Mean (mm): 0.37, Phi Sorting: 0.81 Fines (230): 1.73% (SP) |
| -45.0 | 12.3 | | SAND, fine grained, quartz, trace coarse grains, trace shell hash, trace silt, gray (5Y-5/1), (SP). | | 5 | Sample #5, Depth = 11.6' Mean (mm): 0.25, Phi Sorting: 0.51 Fines (230): 1.59% (SP) |
| -50.8 | 18.1 | | SAND, fine to medium grained, quartz, trace coarse grains, trace shell fragments, trace shell hash, trace silt, shell fragments up to 0.5", (2.0" x 0.75") silty pocket @ 14.0', (1.5" x 1.0") whole shell @ 12.9', color is mottled (2.5Y-5/3) and, dark gray (2.5Y-4/1), (SP). | | 6 | Sample #6, Depth = 15.2' Mean (mm): 0.44, Phi Sorting: 0.66 Fines (230): 2.71% (SP) |
| | | | End of Boring | | | |

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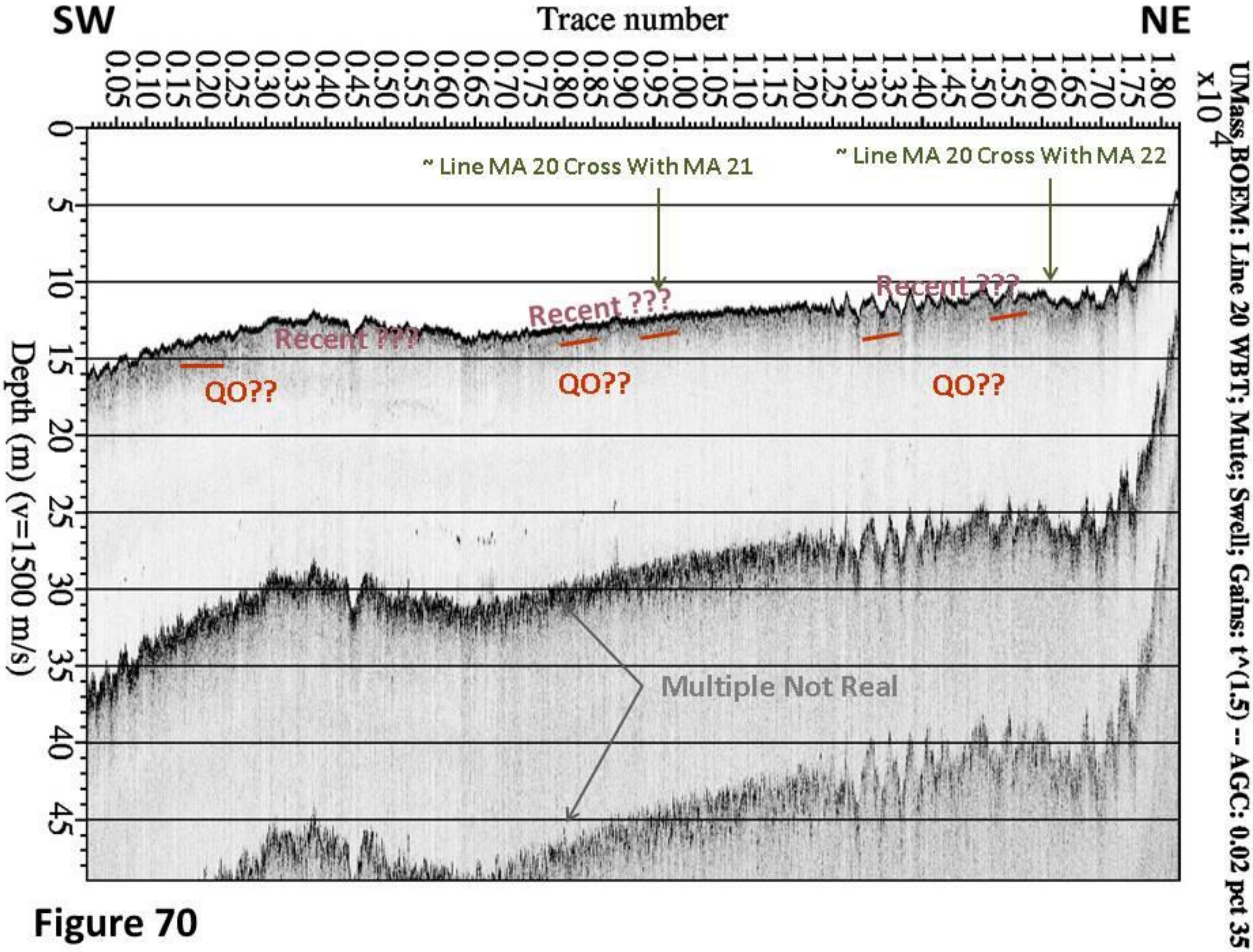
**Figure 69**



SW
Trace number
NE
UMass BOEM: Line 20 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
x10^4
~ Line MA 20 Cross With MA 21
~ Line MA 20 Cross With MA 22
Recent ???
Recent ???
Recent ???
QO??
QO??
QO??
Multiple Not Real
Depth (m) (v=1500 m/s)


**Figure 70**

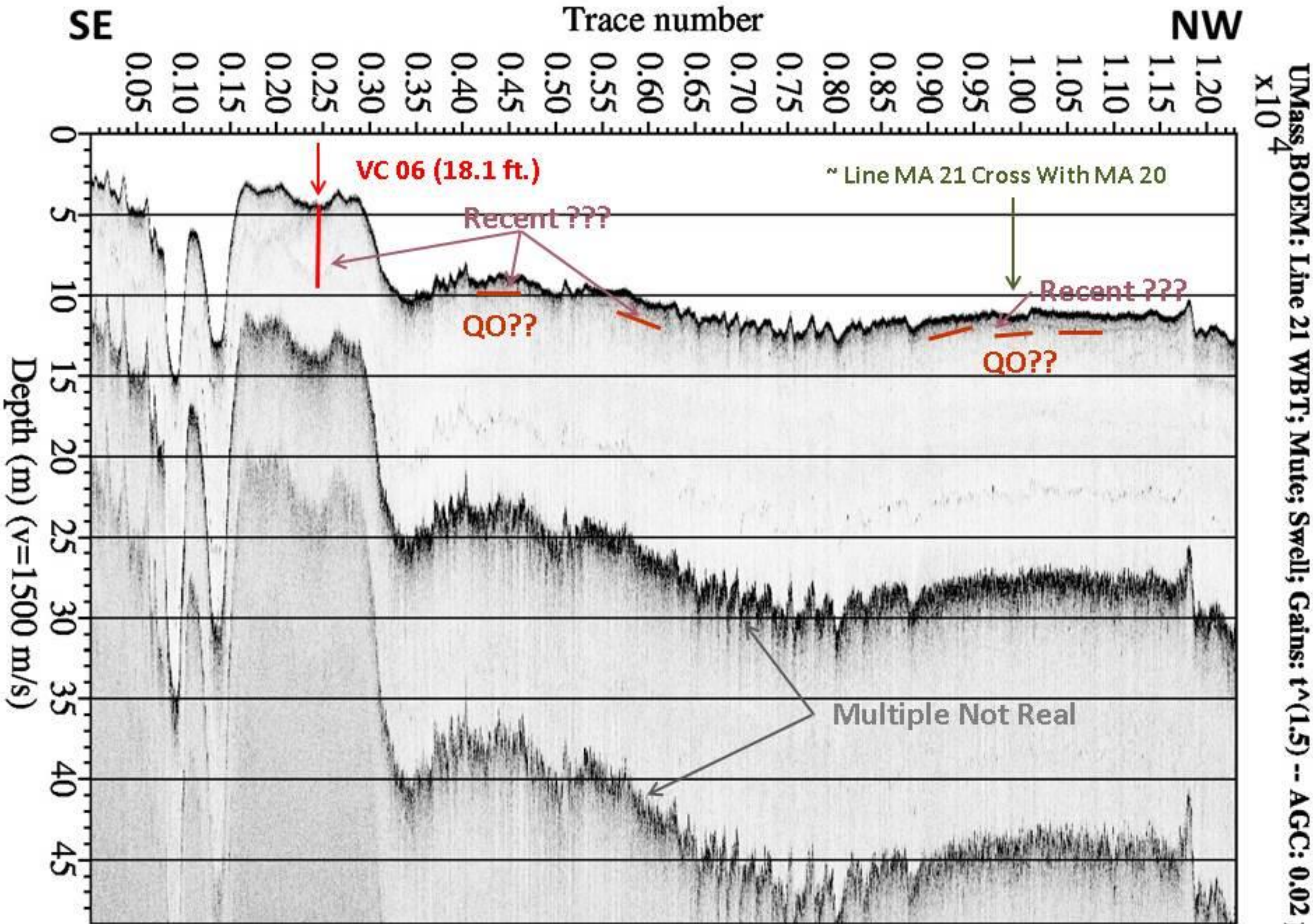



**Figure 71**

**Figure 71: Showing the approximate location and depth of Core VC 06 along “chirp” line 21**

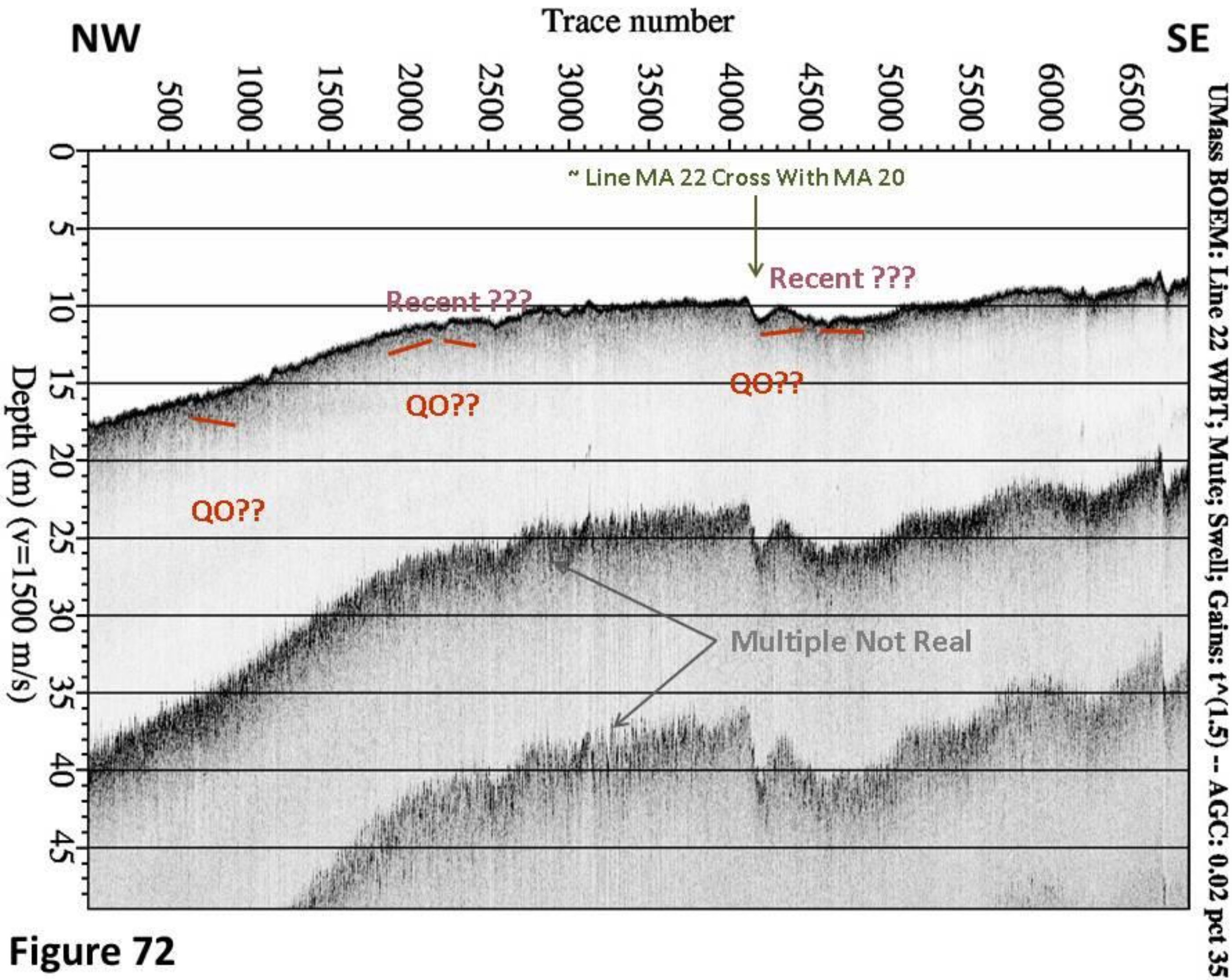



Figure 72

## Section 6 - Muskeget Channel Results

A 1976 USGS "sparker" line (Figure 68, Fay 23 Line 5) lies to the southeast of, but does not traverse, the BOEM Muskeget Channel survey area (Figure 73). As the DEM of the bathymetry shows (Figure 74) the seafloor in the vicinity of Fay 23 Line 5 is much less modified by modern reworking than the survey area is. The interpretation offered for Fay 23 Line 5 was made with little supporting information other than a general knowledge of the stratigraphy that would be expected in the area. Combining the seismic stratigraphy inferred from the Fay 23 "sparker" line with the DEM bathymetric image shown on Figure 74 has provided some helpful insight regarding the geologic setting of the survey area. The bathymetric expression of the “fan” that can be recognized on Figure 74 allowed for a new seismic stratigraphic unit to be added to the Fay 23 mix, and this helped with the BOEM line interpretations (Figures 77- 87). Owing to the better quality of the BOEM Nantucket West seismic data, and the availability of helpful core data, interpretations of the BOEM seismic profiles for this area are have been made with a slightly higher level of confidence than in the five previous survey areas.

The deposits of interest were penetrated by Cores VC 02 (Figure 75) and VC 04/04a (Figure 76) along BOEM “chirp” Lines MA_010 and MA_011 respectively (Figures 78, 79). Both cores contained well-sorted fine to medium-grained sand with shell hash, and Core VC 04a penetrated a pebbly layer at 12.8 ft.. Sediments below ~16 ft. in core VC 04a appear to be a bit finer and slightly better sorted than those above the pebbly layer (Figure 76). Shell is not reported below ~ 16ft. in the VC 04a core description.

Shell, where present, indicates a marine deposit and the morphology of the deposit depicted on the DEM bathymetry (Figure 74) suggests it is, at least partly, a modern bar that is probably composed of reworked older (fan?) deposits. The pebbly layer at 12.8 ft. in Core VC 04a (Figure 79) is inferred to be an old sea floor that has been buried. Owing to its depth relative to the core, Reflector sf1 on Line MA_011 is inferred to represent that buried sea floor.

In the eastern portion of the survey area Reflector sf1 shallows from SW (~ 20m depth) to NE (~10m depth) on Lines MA_ 017-019, and from SE ( ~ 15- 20 m depth) to NW (~ 10-12m depth) on Lines MA_ 011-013). In western portions of the survey area Reflector sf1 is best represented on Line MA_016 where it shallows slightly from SE (~24 m depth) to NW (~ 22m depth). On Lines MA_ 009, 010 and MA_ 014-016 Reflector sf1 is generally poorly represented and appears to variously lie between ~18-24m depth. The gentle southward slope of reflector sf1 (~ 2.5m/km in the eastern portion of the survey area) is greatly exaggerated on the seismic profile figures.

At the depths noted, Reflector sf1 could represent the top of coastal plain (CP) or the top of outwash (QO). O’Hara and Oldale (1987) have mapped the top of coastal plain at -30m in southern Nantucket Sound and the interpretation of Fay 23 Line 5 shown on

Figure 68 would put the top of coastal plain at no higher than about -25m at the NW end of Line 5. The interpreted top of outwash at the same end of Line 5 ranges from ~ -8m to ~ -20m. For the purposes of the BOEM line interpretations offered here, Reflector sf1 seems too shallow for the top of coastal plain and is inferred to better fit the interpreted depths for the top of outwash on Fay 23 Line 5. The gentle southward slope of Reflector sf1 would be consistent with the surface of an outwash deposit emanating from the terminal moraine to the north. The rounded pebbles encountered at the depth of Reflector sf1 in Core VC 04a and the lack of shell at the bottom of the core would also be consistent with a "top of outwash" assignation for Reflector sf1.

In eastern portions of the survey area, where Reflector sf1 is clearly represented on the BOEM profiles, the extent and thickness of an overlying seismic unit (F?) is apparent. Unit F? is thin (~1 meter or less), patchy and its surface looks scoured on Lines MA_ 018 and 019 (Figures 86 and 87). The unit thickens northwestward from essentially nothing to about 5m thick along Lines MA_ 012 and 013. Line MA_ 017 crosses Lines MA_ 012 and 013 near their NW ends, and along this SW to NE line (Figure 85) seismic unit F? is continuous, has a fairly smooth surface, and is up to 3m thick. At core site VC 04a along Line MA_011 the unit is ~ 3.9m (12.8 ft.) thick and appears to be thickening to the NW (Figure 79).

The picture is less clear to the west where Reflector sf1 is not detected everywhere. Along the western and northern margins of the survey area, Reflector sf1 is not detected and Reflector sf2 is inferred to represent the top of seismic unit F?. On western portions of Lines MA_ 009,010 (Figures 77 and 78) and northern portions of Lines MA_014-016 (Figures 82-84) the difference between a projected probable depth for Reflector sf1 and the inferred depth of Reflector sf2 would yield a thickness of up to 15m for seismic unit F?. Along the eastern and southern margins of the western survey area Reflector sf1 is only detected at the NE ends of Lines MA_ 009 and 010 (Figures 77 and 78) at the SE ends of Lines MA_ 014,015 and 016 (Figures 82-84). Where Reflector sf1 is detected up to 5m of unit F? is inferred to overlie it.

The bathymetric image on Figure 74 indicates the presence of a fan-like deposit (similar to a large ebb tidal delta) that appears to be prograding southward from the constriction between Nantucket and Martha's Vineyard. If that is true, the fan deposit would be composed of material removed from Nantucket Sound and core data from Line MA_011 indicate that seismic unit F? is marine. The inferred southward and eastward thinning of seismic unit F? would be consist with the sediment distributions expected on the southeastern side of such a prograding marine fan. Based on this reasoning, Seismic unit F? is interpreted to be a marine fan deposit.

Where Reflector sf2 is present it is inferred to represent the reworked surface of the marine fan. On “chirp” Lines MA_ 009, 010, 014, 015, and 016 (Figures 77, 78, 82,83,84) this surface is overlain by up to 5.5m of “Recent” material that is inferred to represent a modern bar derived from reworking of the fan deposit. Core VC 02 penetrated 17.9 ft. of the inferred bar as shown on Line MA_010 (Figure 78). To the east (Lines MA_ 011, 012, 013. 017, 018, 019) reworking of much thinner fan deposits appears to have locally exposed the underlying outwash or created thin, patchy “Recent” deposits that locally overlie remnants of the fan.

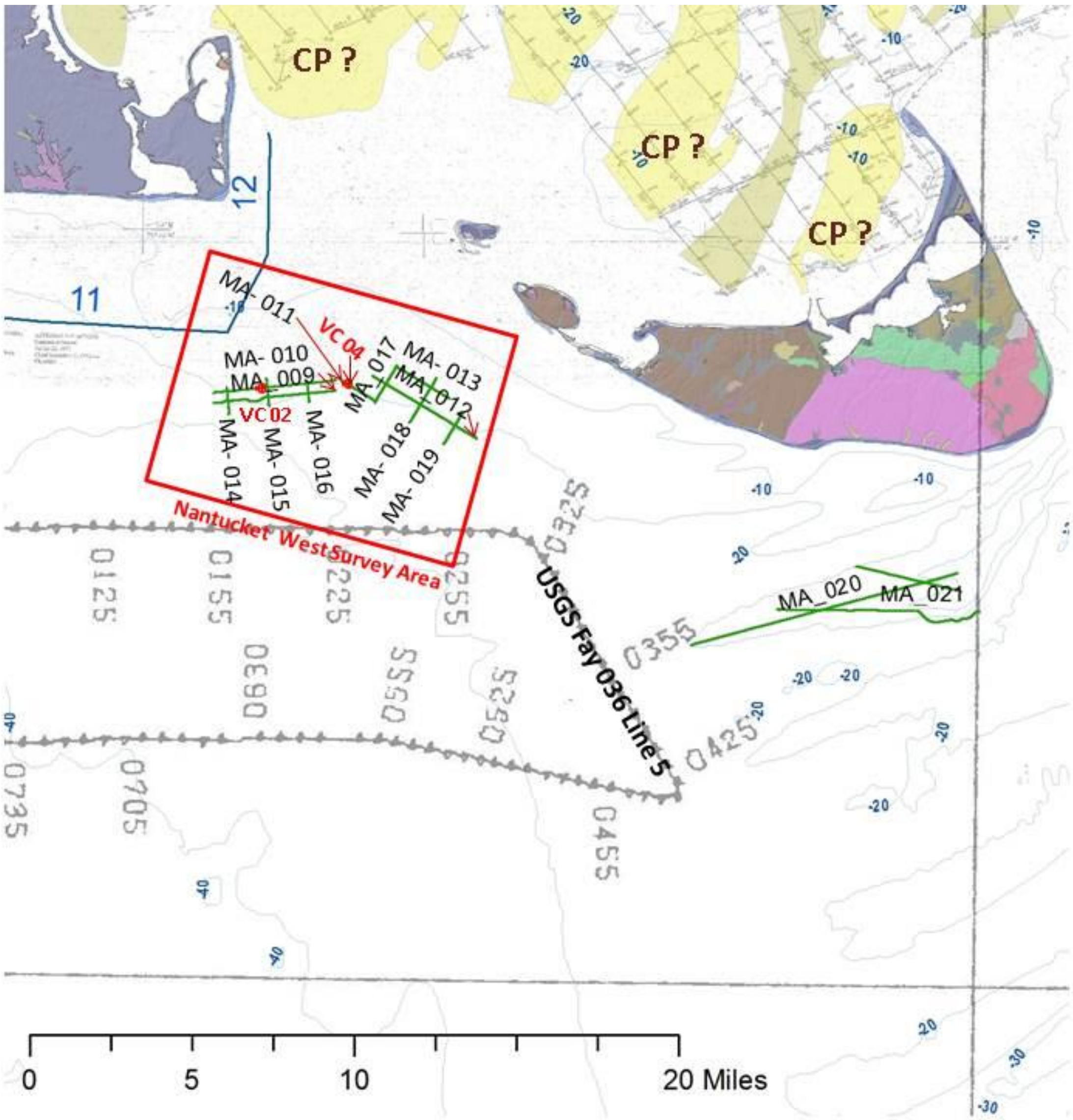
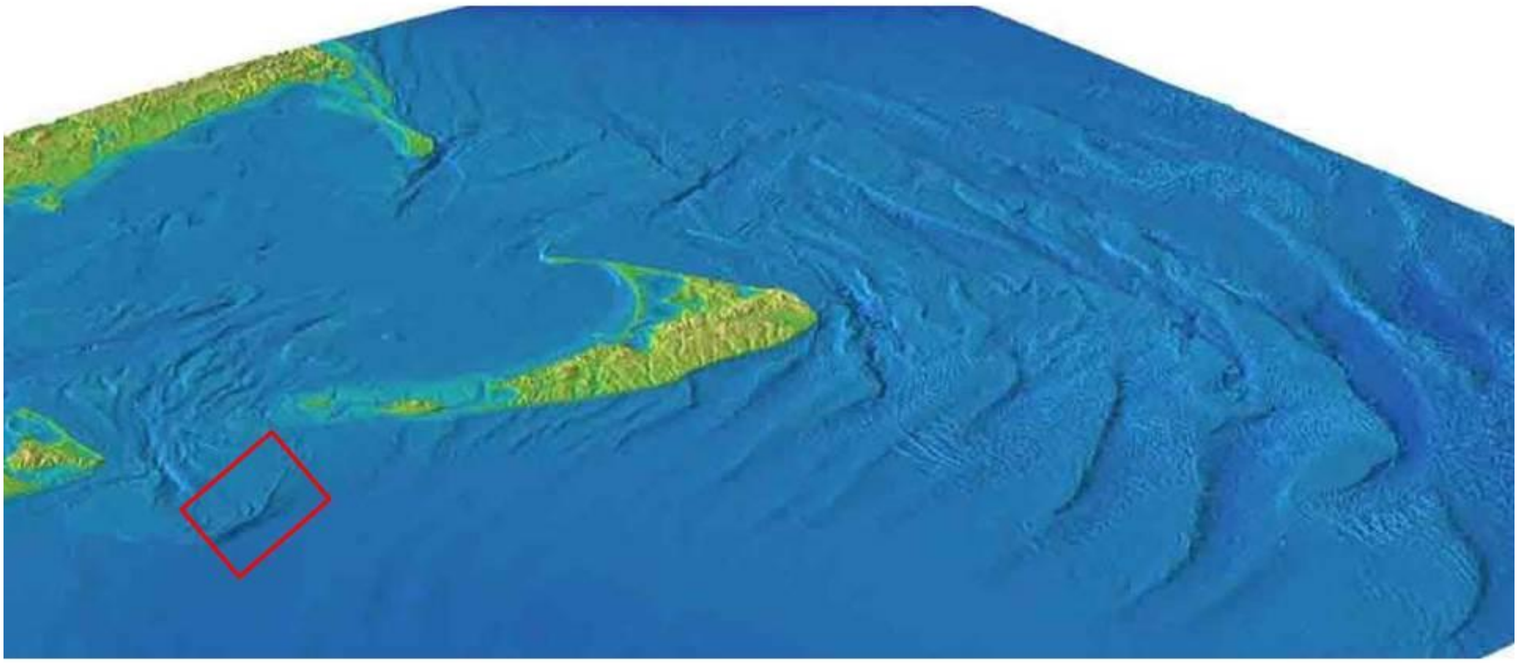



**Figure 73**

**Figure 73: A map showing the published geology of a portion of Martha's Vineyard, Nantucket, and Nantucket Sound (O'Hara and Oldale, 1987); Fay 036"sparker" Line 5 is shown in relationship to the Nantucket West Survey Area (red box); BOEM tracklines 009-019 and cores VC 02 and VC 04).**



## Figure 74

**Figure 74: The DEM bathymetry image above nicely shows the modern bar surveyed in the Nantucket West area (red box). This bar overlies and fringes the southeastern margin of a sediment fan(lighter blue shading in, and just west of, the red box) that appears to be building southward from the constriction between Martha's Vineyard and Nantucket (much like a large ebb tidal delta). This sediment fan is inferred to be composed of material being swept seaward from Nantucket Sound. The bar developed on it is inferred to be the result of modern reworking of the fan. Core VC 02 is inferred to have penetrated the bar and Core VC 04/04 is inferred to have penetrated the fan deposit.**

# Core VC 02

(Well-Sorted Fine to Medium-
Grained Sand + Shell Hash)

| ELEV. (ft) | DEPTH (ft) | LEGEND | CLASSIFICATION OF MATERIALS Depths and elevations based on measured values | % REC. | BOX OR SAMPLE | REMARKS |
|---|---|---|---|---|---|---|
| -31.1 | 0.0 | | | | | |
| -33.9 | 2.8 | | SAND, medium grained, quartz, trace coarse grains, trace shell hash, trace silt, gray (2.5Y-5/1), (SP). | | 1 | Sample #1, Depth = 1.4' Mean (mm): 0.70, Phi Sorting: 0.63 Fines (230): 0.83% (SP) |
| -38.8 | 7.7 | | SAND, medium grained, quartz, trace coarse grains, trace shell hash, trace silt, color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 2 | Sample #2, Depth = 5.2' Mean (mm): 0.56, Phi Sorting: 0.64 Fines (230): 0.71% (SP) |
| -41.5 | 10.4 | | SAND, fine to medium grained, quartz, trace shell hash, trace silt, color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 3 | Sample #3, Depth = 9.0' Mean (mm): 0.37, Phi Sorting: 0.56 Fines (230): 0.98% (SP) |
| -47.0 | 15.9 | | SAND, medium grained, quartz, trace coarse grains, trace shell fragments, trace shell hash, trace silt, shell fragments up to (0.5" x 0.25"), color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 4 | Sample #4, Depth = 13.2' Mean (mm): 0.50, Phi Sorting: 0.63 Fines (230): 0.67% (SP) |
| -47.7 | 16.6 | | SAND, medium grained, quartz, trace coarse grains, trace shell hash, trace silt, gray (2.5Y-5/1), (SP). | | 1 | |
| -49.0 | 17.9 | | SAND, medium grained, quartz, trace coarse grains, trace shell fragments, trace shell hash, trace silt, shell fragments up to (0.5" x 0.25"), color is mottled (2.5Y-5/2) and, dark gray (2.5Y-4/1), (SP). | | 4 | |
| | | | End of Boring | | | |

2015_VC.GPJ JPBRAZIL.GDT 9/12/16





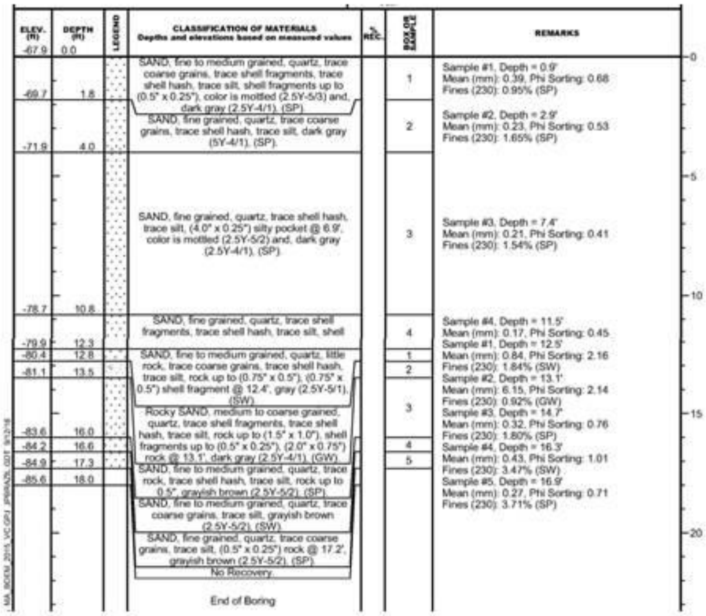





**Figure 75**

# Core VC 04/04a

(Well-Sorted Fine to Medium-Grained Sand + Shell Hash, Pebbly layer at 12.8 ft.)



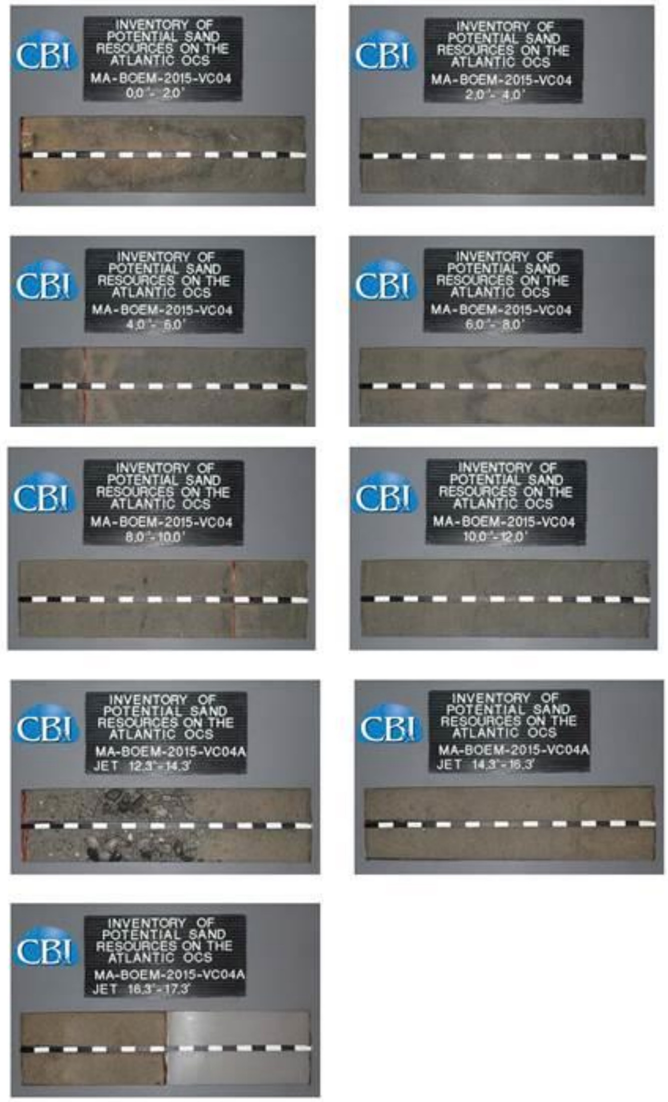




**Figure 76**

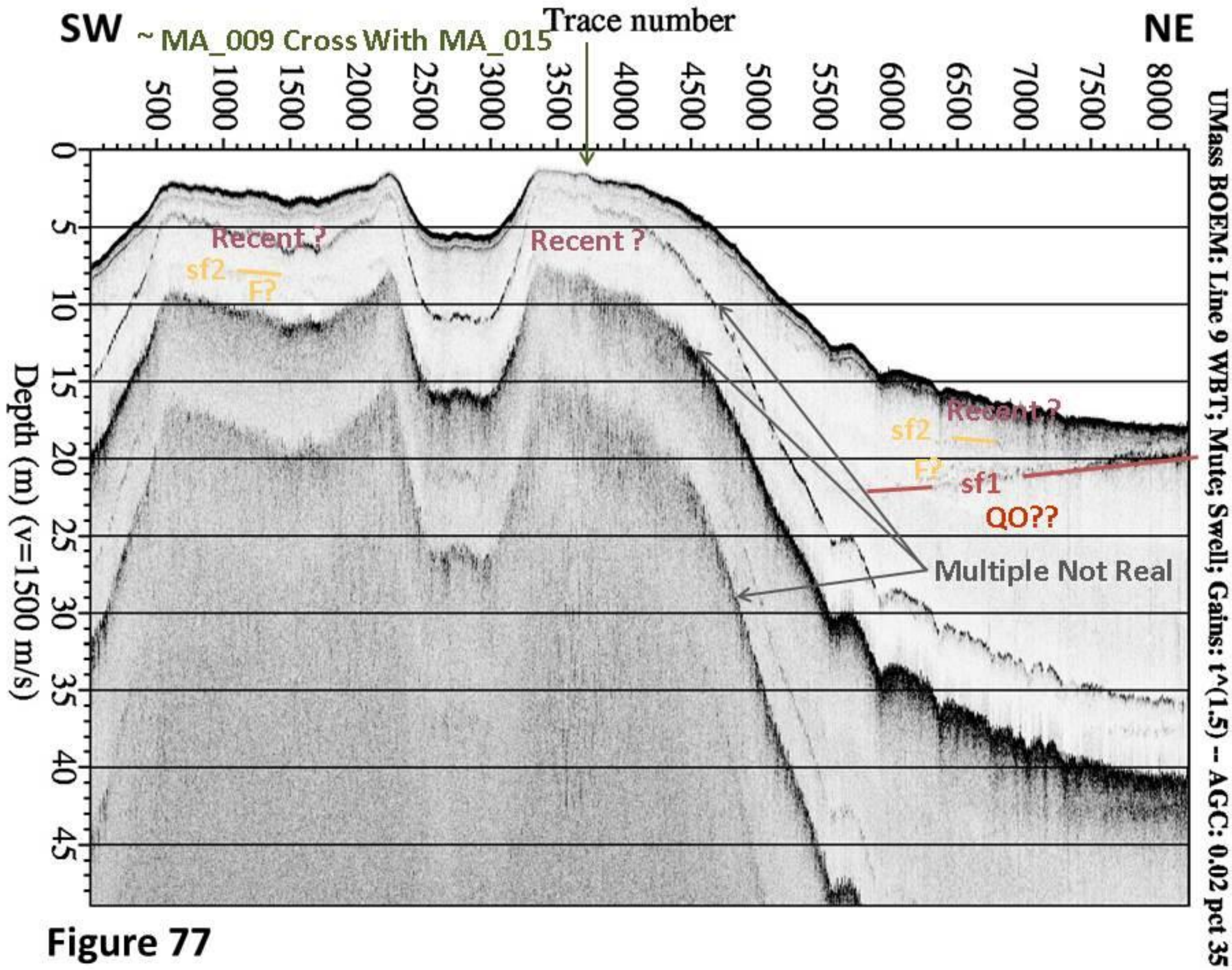

SW
~ MA_009 Cross With MA_015
Trace number
NE
Recent ?
sf2
F?
Recent ?
Recent ?
sf2
F?
sf1
QO??
Multiple Not Real
Depth (m) (v=1500 m/s)
UMass BOEM: Line 9 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35

**Figure 77**

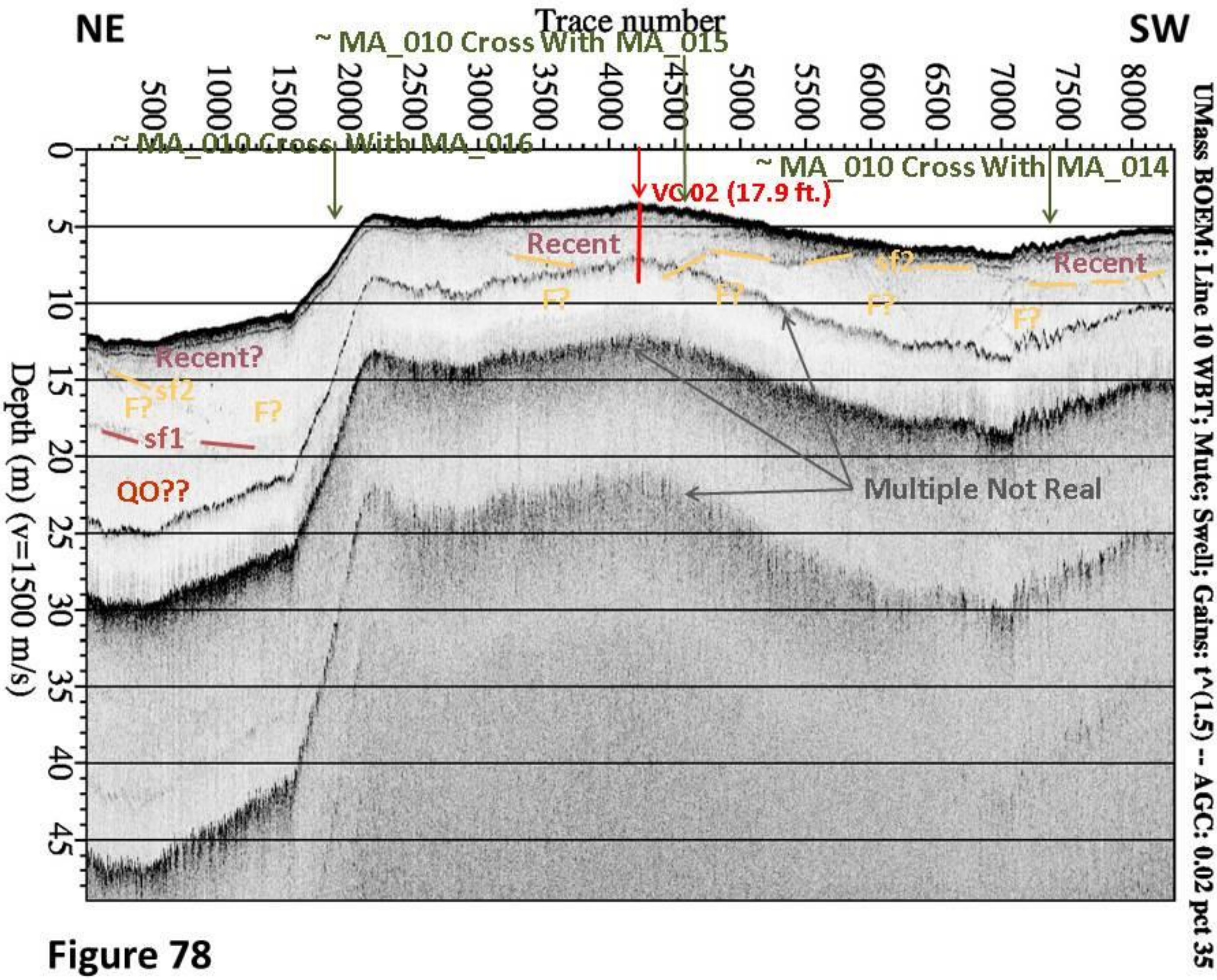



**Figure 78**

**Figure 78: Showing the approximate location and depth of Core VC 02 along "chirp" line 10**

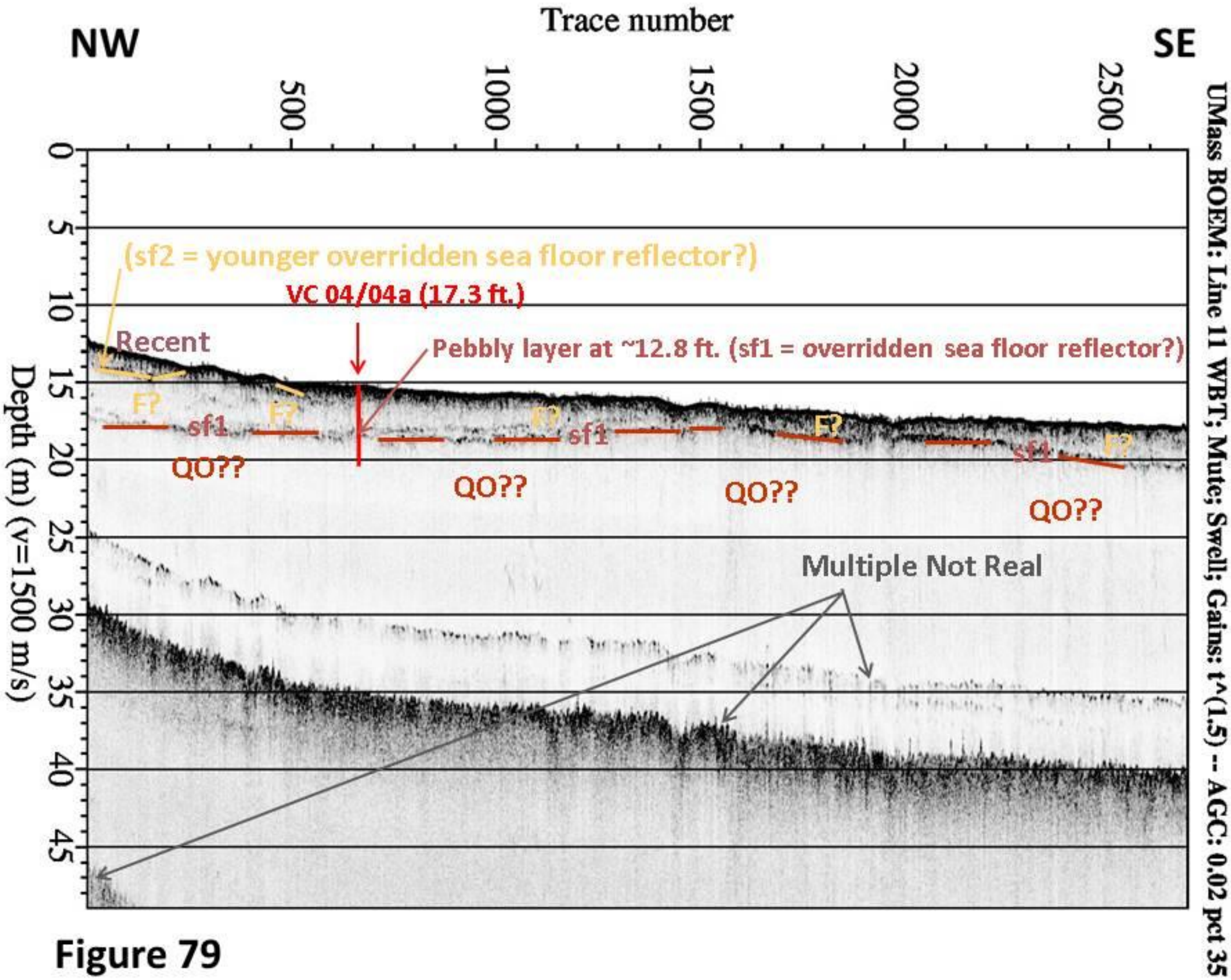
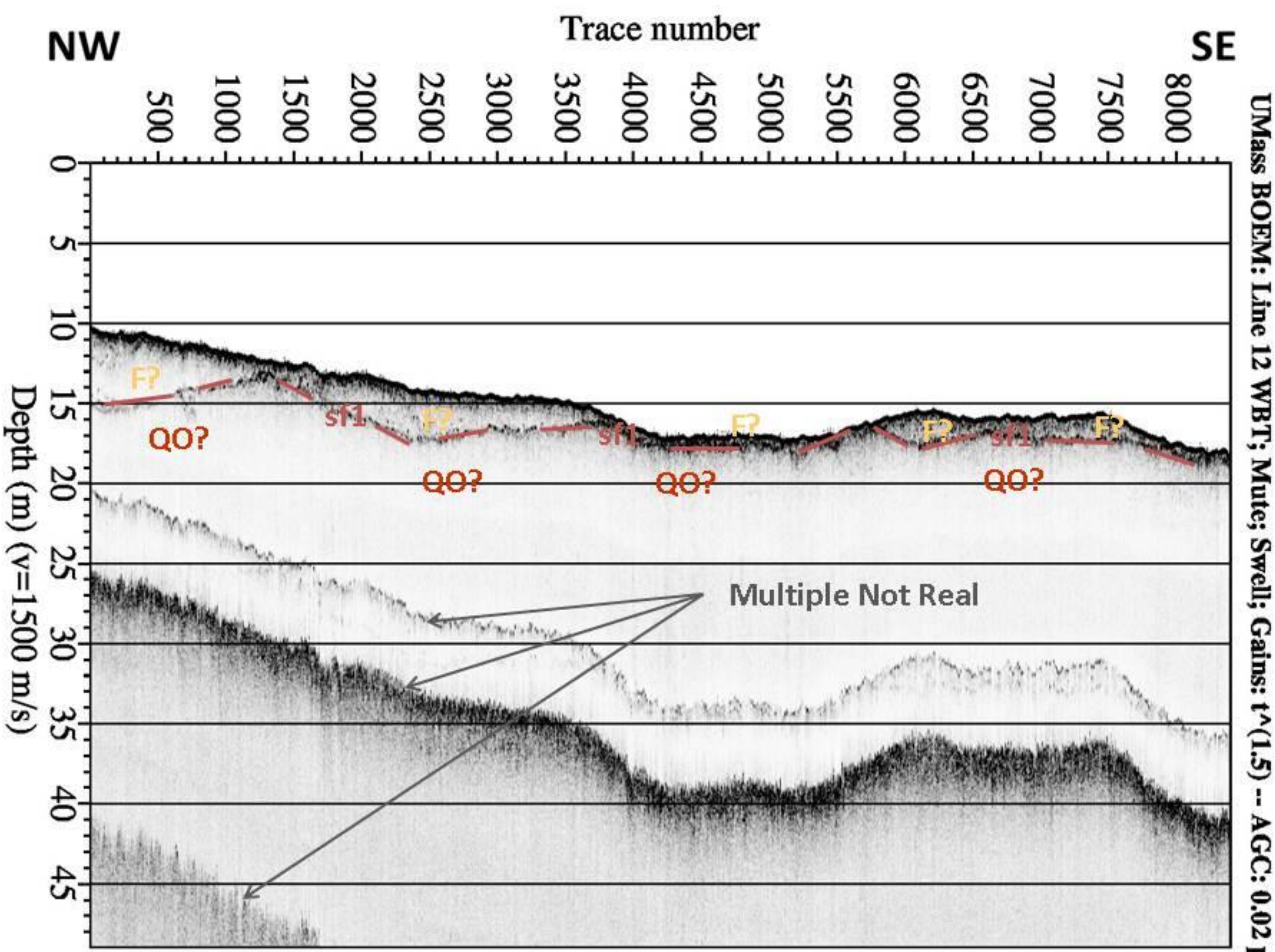
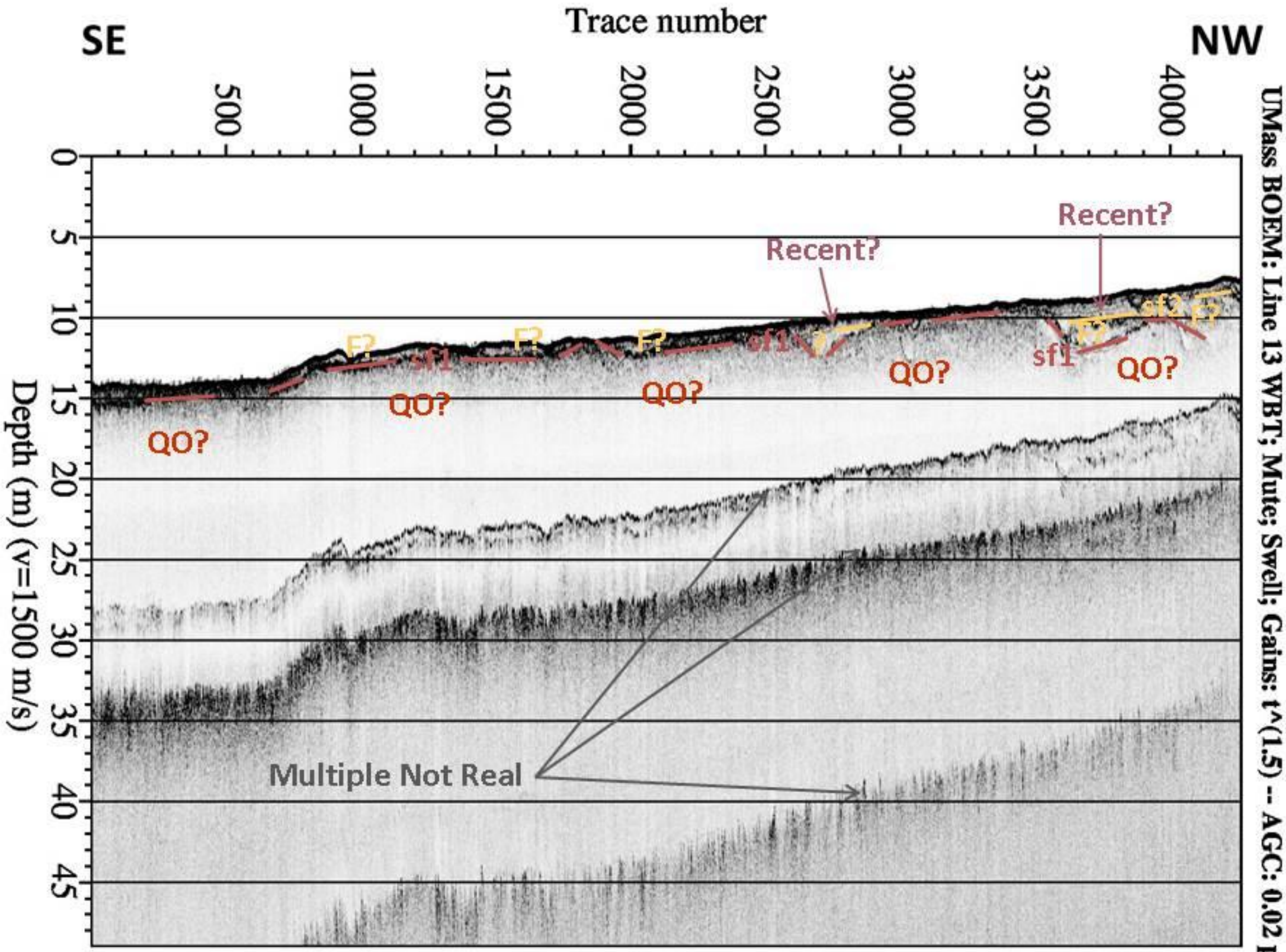



**Figure 79: Showing the approximate location and depth of Core VC 04/04a8 along "chirp" line 11**



NW
Trace number
SE
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
UMass BOEM: Line 12 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
F?
QO?
sf1
Multiple Not Real


Figure 80



SE
NW
Trace number
500
1000
1500
2000
2500
3000
3500
4000
UMass BOEM: Line 13 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent?
Recent?
F?
F?
F?
sf1
sf1
sf1
QO?
QO?
QO?
QO?
QO?
Multiple Not Real


Figure 81

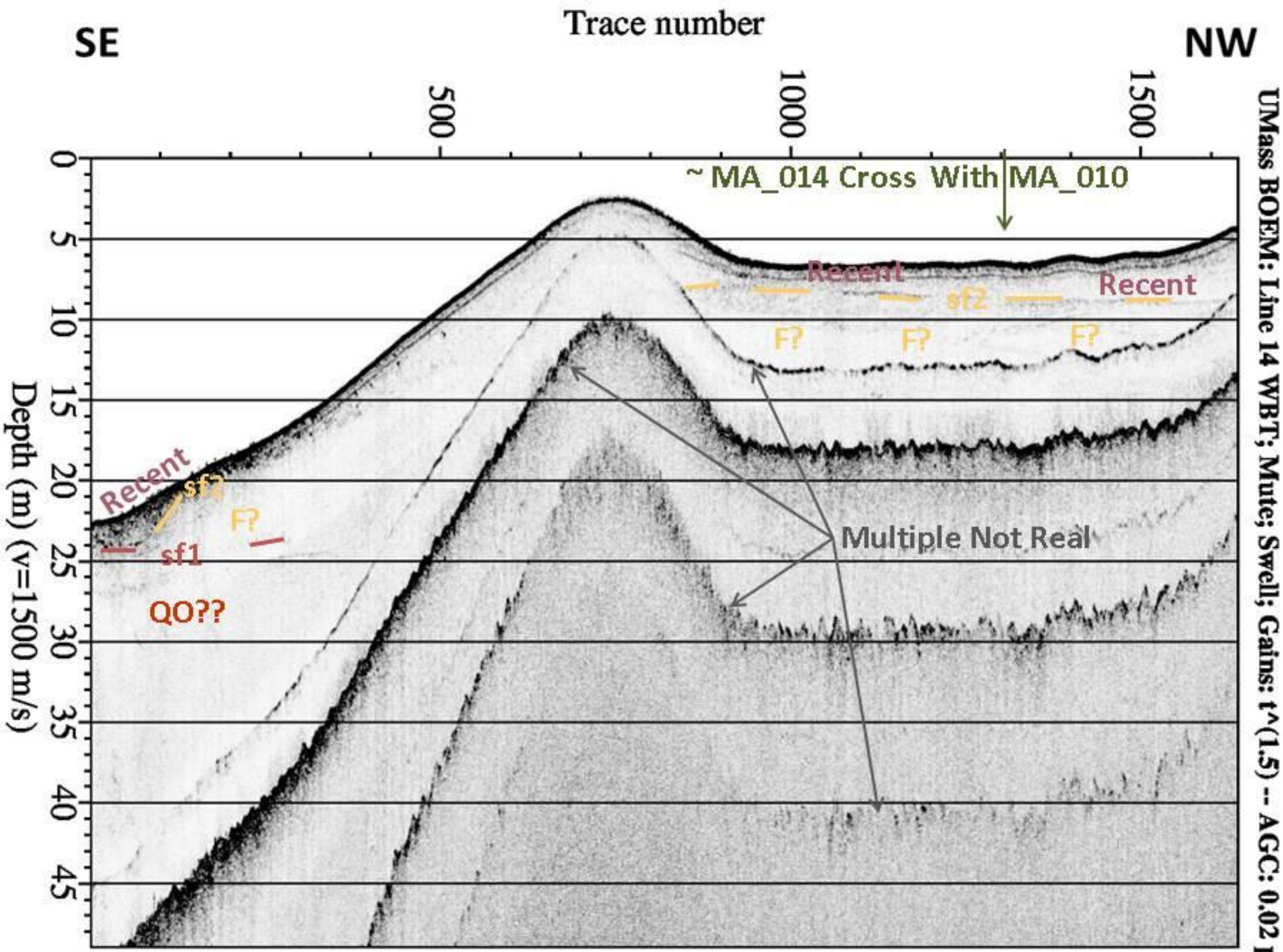
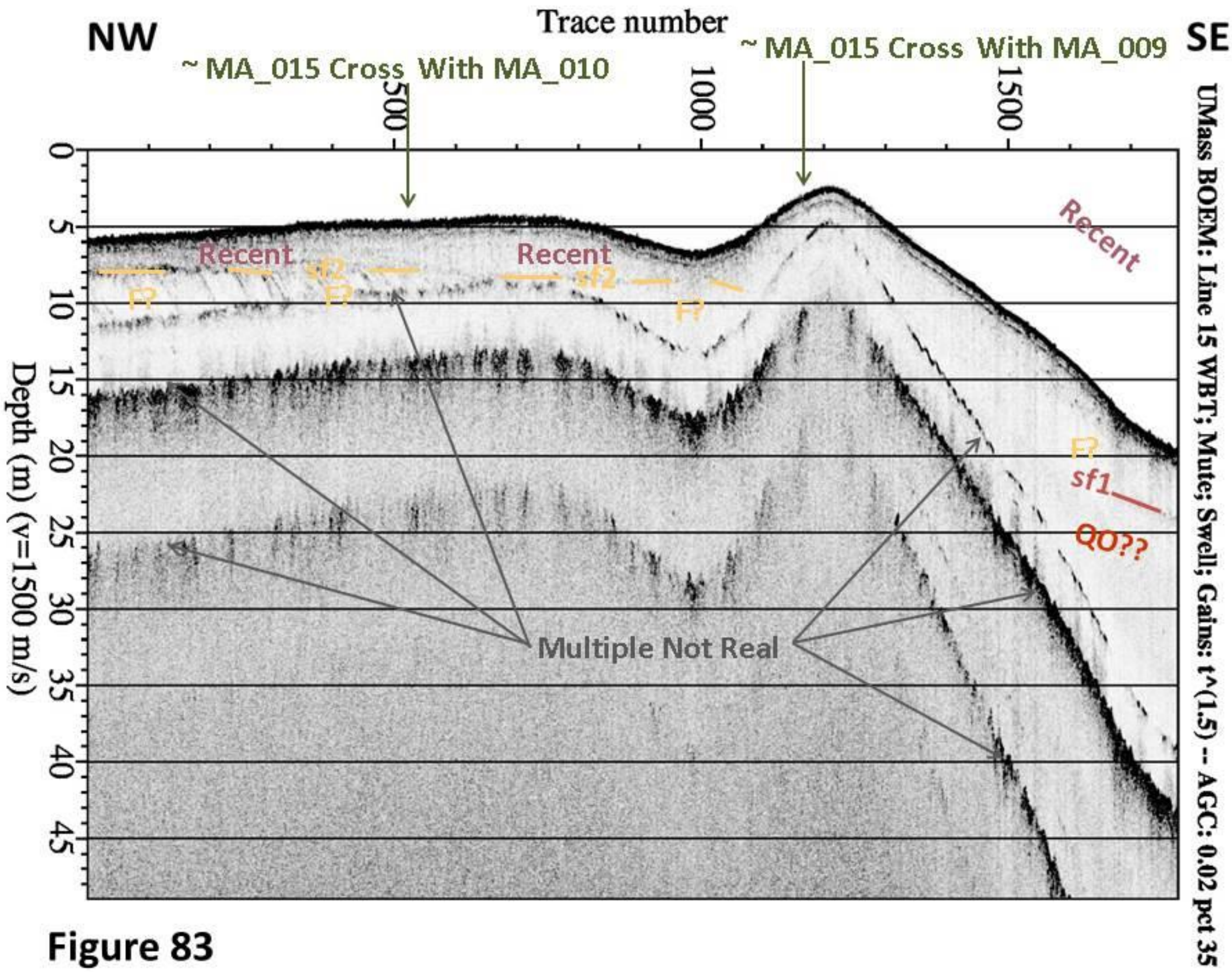

Trace number
SE
NW
500
1000
1500
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 14 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
~ MA_014 Cross With MA_010
Recent
sf2
Recent
F?
F?
F?
Recent
sf2
F?
sf1
QO??
Multiple Not Real

**Figure 82**



NW
SE
Trace number
~ MA_015 Cross With MA_010
~ MA_015 Cross With MA_009
500
1000
1500
0
5
10
15
20
25
30
35
40
45
Depth (m) (v=1500 m/s)
UMass BOEM: Line 15 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Recent
Recent
Recent
sf2
sf2
F?
F?
F?
F?
sf1
QO??
Multiple Not Real


Figure 83

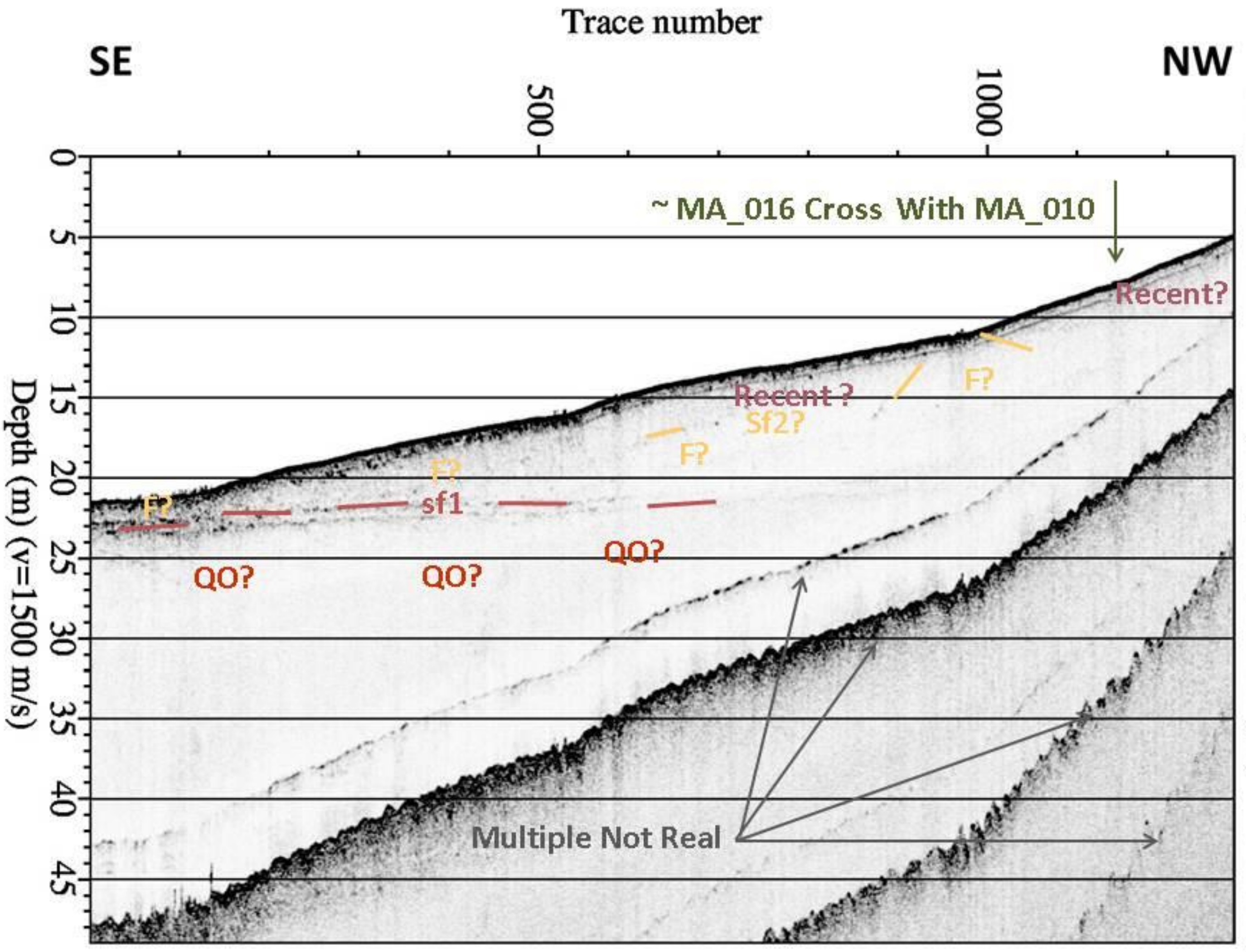

Trace number
SE
NW
500
1000
UMass BOEM: Line 16 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
~ MA_016 Cross With MA_010
Recent?
F?
Recent ?
Sf2?
F?
F?
F?
sf1
QO?
QO?
QO?
Multiple Not Real

Figure 84

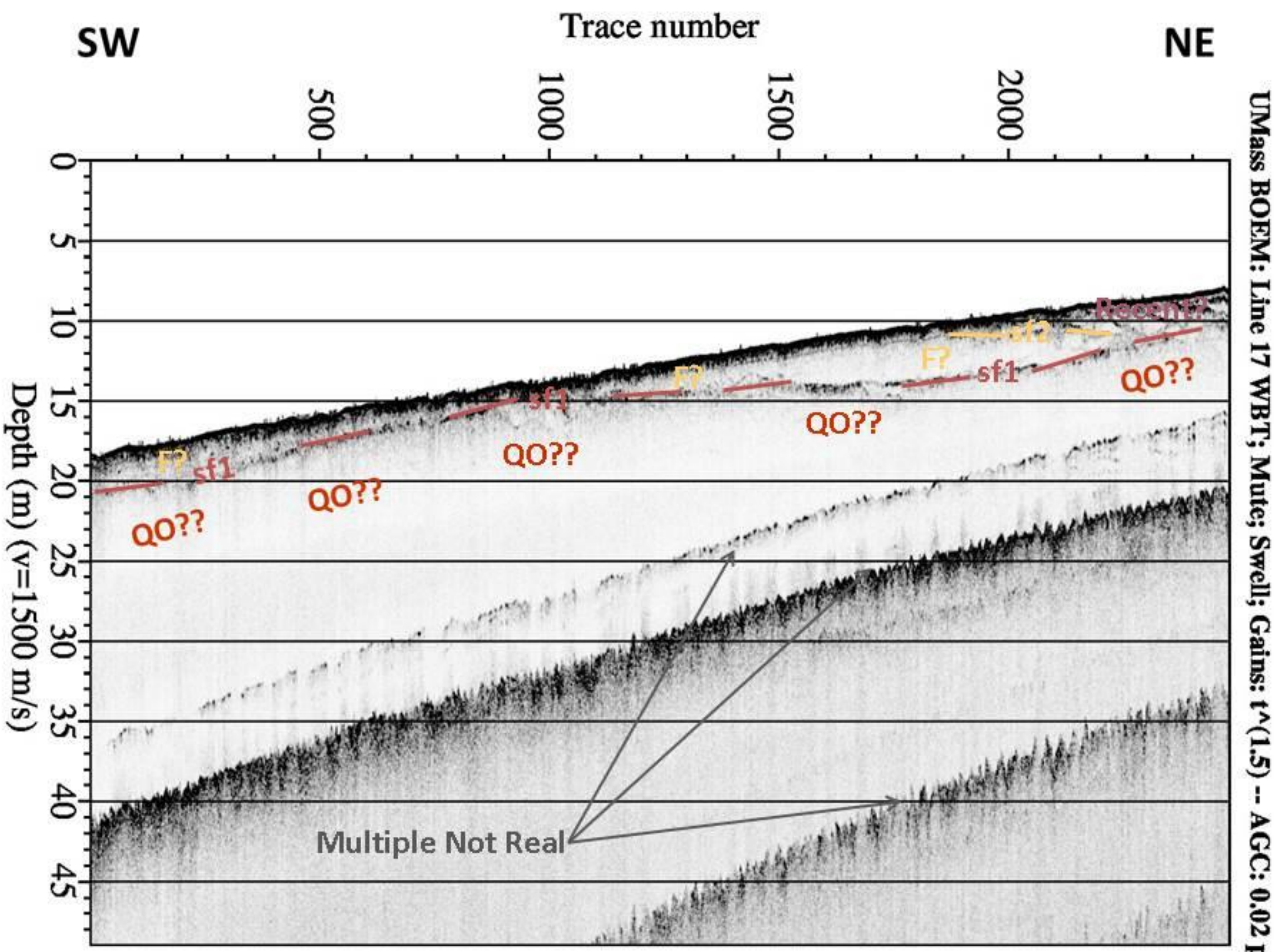
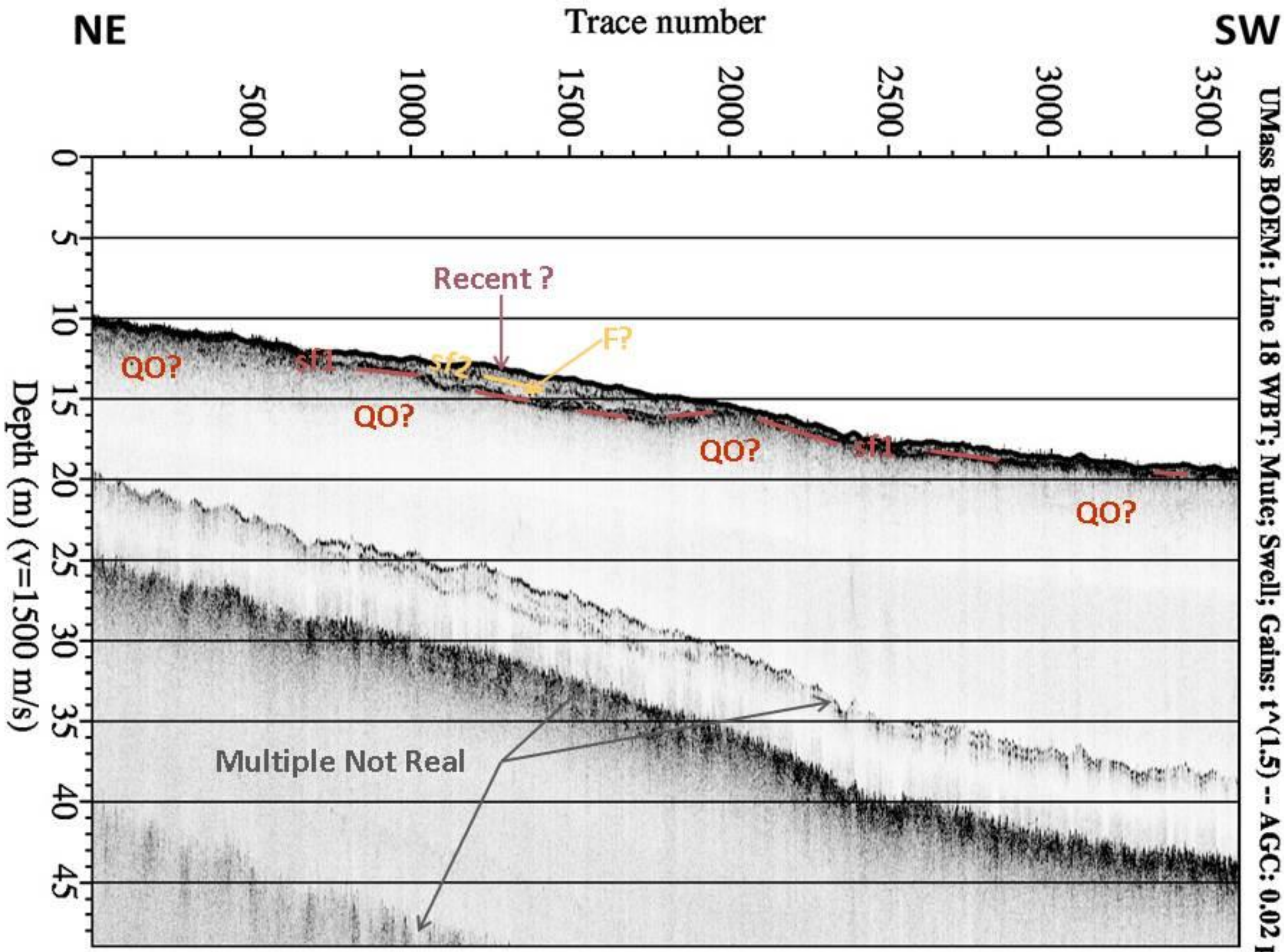
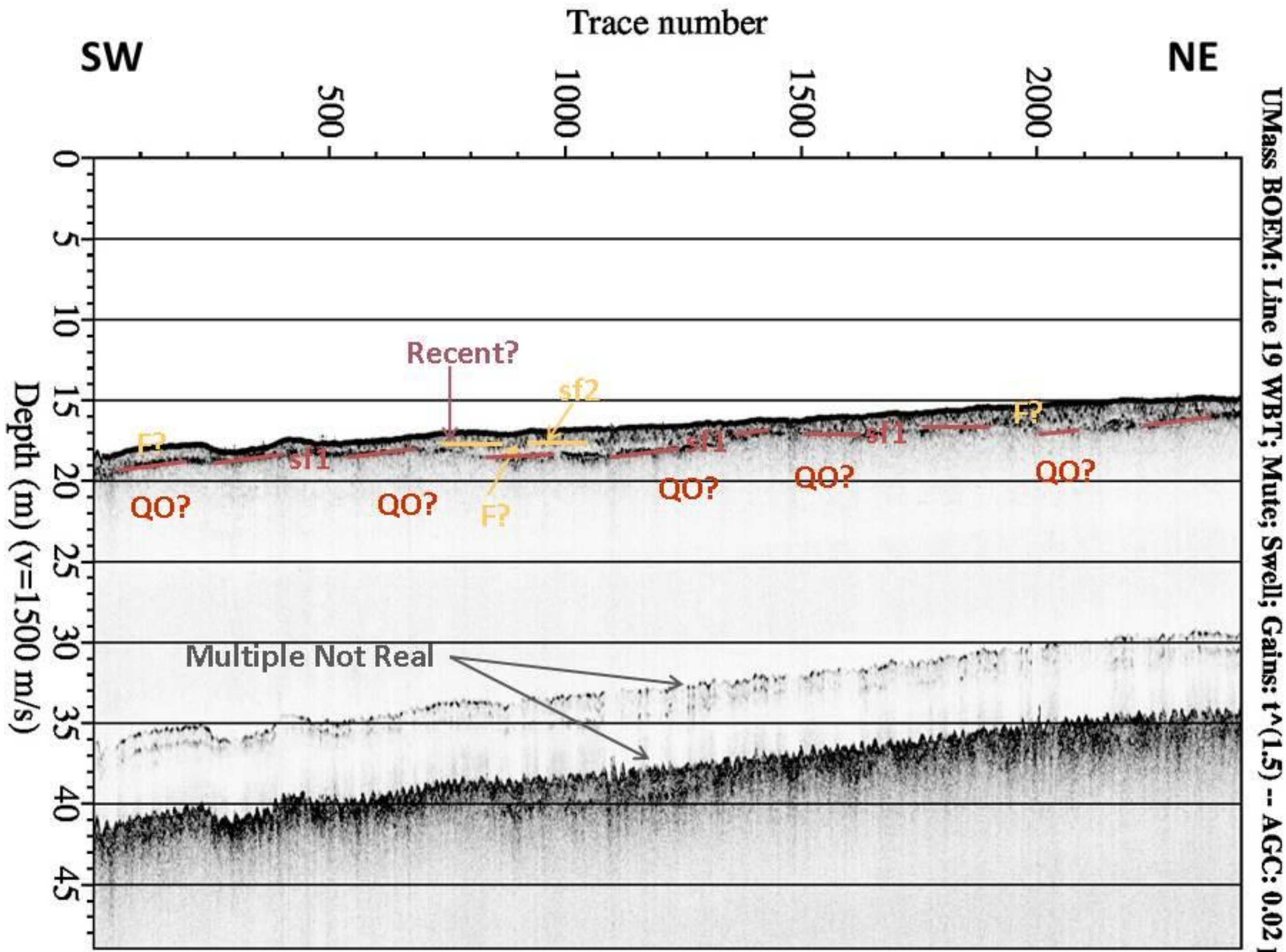

SW
NE
Trace number
500
1000
1500
2000
UMass BOEM: Line 17 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
0
5
10
15
20
25
30
35
40
45
Recent?
sf2
F?
sf1
QO??
F?
sf1
QO??
F?
sf1
QO??
QO??
QO??
Multiple Not Real

**Figure 85**



NE
SW
Trace number
UMass BOEM: Line 18 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Depth (m) (v=1500 m/s)
Recent ?
F?
sf1
sf2
QO?
Multiple Not Real


Figure 86



UMass BOEM: Line 19 WBT; Mute; Swell; Gains: t^(1.5) -- AGC: 0.02 pct 35
Trace number
SW
NE
Depth (m) (v=1500 m/s)
Recent?
sf2
F?
sf1
QO?
Multiple Not Real


Figure 87

# Appendix B

# BOEM Magnetometer Data Processing and Results

**Report by**

**John Gartner**
**May 25, 2018**

**BOEM Magnetometer Data Processing and Results, Draft**

John Gartner, PhD, UMass Amherst, Department of Geosciences

8/10/2018

**Executive summary:** The magnetometer surveys suggest no metallic objects of human origin, such as shipwrecks, pipelines, or discarded materials, on the seabed along the 57 track lines across 6 regions off the Massachusetts coast. There may be small or non-magnetic items present, for example anchor lines and wooden hulls. There also may be objects just beyond or adjacent to the track lines that could have historic importance or interfere with machinery for sand removal.

**Project Overview**

Beach nourishment and coastal restoration is being considered in Massachusetts following storm events that have eroded beaches along the Commonwealth's coastline, including in areas that have increased human activity near homes, ports, and popular visitor locations. Many questions arise around beach nourishment, including how much of the observed changes in beach topography is within natural range of variations, how long-lasting is beach nourishment, will it cause hard-to-predict changes to beach profiles and ecological resources, how much will it cost and benefit Massachusetts, and where will the sand and gravel come from? This project focuses on the last question—how feasible are off-shore and near-shore sand and gravel resources that could be used for beach nourishment and replenishment? To answer this, we must answer several technical questions. For example, where, how large, and how thick are the sand resources on the sea bed floor? What is their origin, and can they be replenished by natural process that move sand and gravel across the sea bed? Are there human artifacts such as shipwrecks and pipelines that could hinder the extraction of the sand and gravel resources on the sea bed floor? This report shows how we use magnetometer data and sonar data, coupled with our geologic understanding of the region to estimate the extent, depth, and quality of the sand and gravel resources off the coast of Massachusetts. More broadly, this information is coupled with other surveys and geologic interpretation compiled in companion reports to give a broader view on the costs, benefits, and concerns of beach nourishment and replenishment. Overall this is part of a large project spearheaded by the Bureau of Ocean and Energy Management (BOEM) to identify, characterize and delineate potential sand resources on the Atlantic Outer Continental Shelf (OCS) for use in future coastal restoration, beach nourishment, and/or wetland restoration efforts.

**Magnetometer background**

Magnetometer data has been used in a variety of settings to interpret the presence of human artifacts at and under the seabed floor. It has also been used to interpret rock type and geologic resources. Historically it was one of the key observations that supported the theory of plate tectonics. For a simple overview, the intensity of a magnetometer reading is influenced by the (a) earth's overall magnetic field which changes from a higher intensity near the poles to a lower intensity near the equator, (b) magnetic properties of underlying rock types due to the varying presence of magnetic minerals, primarily magnetite, and (c) the presence of metallic objects. A metallic object will cause an anomaly in magnetic intensity, with an excursion of high and low intensity near the object. The amount of this anomaly is a function of proximity and amount of ferromagnetic material in the object, with the principle concern being how close the magnetometer is to the object. Magnetic intensity is most often reported in gamma units (γ) or nanotesla units (nT) in geologic surveys, where 1 gamma = 1 nanotesla = $10^{-9}$ Tesla = $10^{-5}$ gauss = $10^{-5}$ oersted = $10^{-9}$ weber/$M^2$. The typical maximum anomaly for various objects is about 40 nT for an automobile at 30 feet, 50-200 gamma for a 12-inch diameter pipeline at 25 feet, and 300-700 nT for a 1,000 ton shipwreck at 100 ft (see Table 1)

*Table 1. Magnetic anomalies of common objects, reproduced from Briener, 1999, Applications Manual for Portable Magnetometers, ftp://geom.geometrics.com/pub/mag/Literature/AMPM-OPT.PDF*

Table of Anomalies of Common Objects
Typical Maximum Anomaly

| OBJECT | Near Distance | Far Distance |
|---|---|---|
| Automobile (1 ton) | 30 feet<br>40 gammas | 100 feet<br>1 gamma |
| Ship (1000 tons) | 100 feet<br>300 to 700 gammas | 1000 feet<br>0.3 lo 0.7 gammas |
| Light Aircraft | 20 feet<br>10 to 30 gammas | 50 feet<br>0.5 lo 2 gammas |
| File (10 inch) | 5 feet<br>50 to 100 gammas | 10 feet<br>5 lo 10 gammas |
| Screwdriver (5 inch) | 5 feet<br>5 to 10 gammas | 10 feet<br>0.5 to 1 gamma |
| Revolver (38 special or 45 automatic) (induced approximately equal to permanent, see text) | 5 feet<br>10 to 20 gammas | 10 feet<br>1 to 2 gammas |
| Rifle | 5 feet<br>10 to 50 gammas | 10 feet<br>2 to 10 gammas |
| Ball Bearing (2mm) | 3 Inches<br>4 gammas | 8 inches (0.5 feet)<br>0.5 gamma |
| Fenceline | 10 feet<br>15 gammas | 25 feet<br>1 to 2 gammas |
| Pipeline (12 inch diameter) | 25 feet<br>50 to 200 gammas | 50 feet<br>12 to 50 gammas |
| DC Train | 500 feet<br>5 to 200 gammas | 1000 feet<br>1 to 50 gammas |
| 'Cow' magnet (½"W,3" L) | 10 feet<br>20 gammas | 20 feet<br>2 gammas |
| Well casing and wellhead | 50 feet<br>200 to 500 gammas | 500 feet<br>2 to 5 gammas |

(Note anomalies are only representative and may vary by a factor of 5 or even 10 depending upon the many factors described herein)

## Methods

In this project, a Geometrics G-882 Digital Cesium Marine Magnetometer was towed behind a research motor vessel overseen by CB&I, Inc., on surveys from July 20, 2015 to July 26, 2015 off the coast of Massachusetts. The research vessel simultaneously collected data for Chirp sub-bottom sonar, side scan sonar, and swath bathymetry. The magnetometer instrument offset was 8 m. A total of 59 track lines were surveyed (Table 2), each with a unique data file formatted in the .RAW Hypack file format, presented in NAD 1983 Universal Transverse Mercator (UTM) Zone 19N projection. Magnetometer readings were taken about every 0.5 seconds. These files were imported to the SonarWiz 6 program V6.05.0025, using the "Hypack Raw File Magnetometer" template and down sampling to 1 Hz. The data were exported to ASCII CSV files with columns for date, time, latitude, longitude, easting, northing, and gamma value. Profiles of magnetic intensity (gamma units) versus record number were created in SonaWiz 6 with no smoothing of the data. The location and magnetic intensity data were converted to a shapefile in ArcMap version 10.3.1 and plotted with the World Ocean Base map, downloaded from ESRI, Inc. The base map data are sourced from ESRI, DeLorme, GEBCo, NOAA NGDC, and other contributors. The base map is intended to give a broad sense of setting, not precise bathymetry. The bathymetry data collected by the research vessel is higher resolution, but the base map covers a larger region.

*Table 2. Survey location and track line numbers*

| **Region** | **Track line** | | |
|---|---|---|---|
| Buzzards Bay | MA_001 | to | MA_004 |
| Nomans Land | MA_005&5_1 | to | MA_008 |
| Nantucket West | MA_009 | to | MA_019 |
| Nantucket East | MA_020 | to | MA_022 |
| Marshfield | MA_023&27_1 | to | MA_039 |
| Plum Island | MA_040 | to | MA_057 |

**Results and Interpretation**

The results are available in three associate files:

1. An excel document, BOEM_MAG_data_table.xlsx, which tabulates information for each of the 386,474 magnetometer readings, including site area, line number, date, time, magnetometer position (in Latitude-Longitude and in UTM Coordinates, Zone 18, WGS 1984), and gamma reading (found in project file – [ftp://eclogite.geo.umass.edu/pub/stategeologist/BOEM2Data/](ftp://eclogite.geo.umass.edu/pub/stategeologist/BOEM2Data/))
2. A powerpoint file, BOEM_MAG_line_graphs.pptx, that plots gamma reading vs record number for each survey line (attached)
3. A powerpoint file, BOEM_MAG_maps.pptx, that provides maps of the gamma readings along each survey line (attached)

The results show that the range of magnetometer data is from 51010 to 54104 gamma. A typical line graph profile is shown in Figure 1, for survey line MA_001. The values rise and fall over the 4.4 km length of this track line, with no abrupt anomalies of 20 gamma or more over a distance of the characteristic size of a pipeline, sunken ship, or other large metallic objects. With 4 peaks in gamma values over the 4.4 km of this track line, the approximately km length scale is consistent with the approximately km length scale of gamma variations observed in geologic materials from airborne magnetometer surveys in this region (Daniels and Snyder, 2004, New England states aeromagnetic and gravity maps and data, U.S. Geological Survey Open-File Report 2004-1258, https://mrdata.usgs.gov/catalog/cite-view.php?cite=59). The range of values and rate of change for survey line 001 is similar to the 58 other line surveys in the BOEM project.

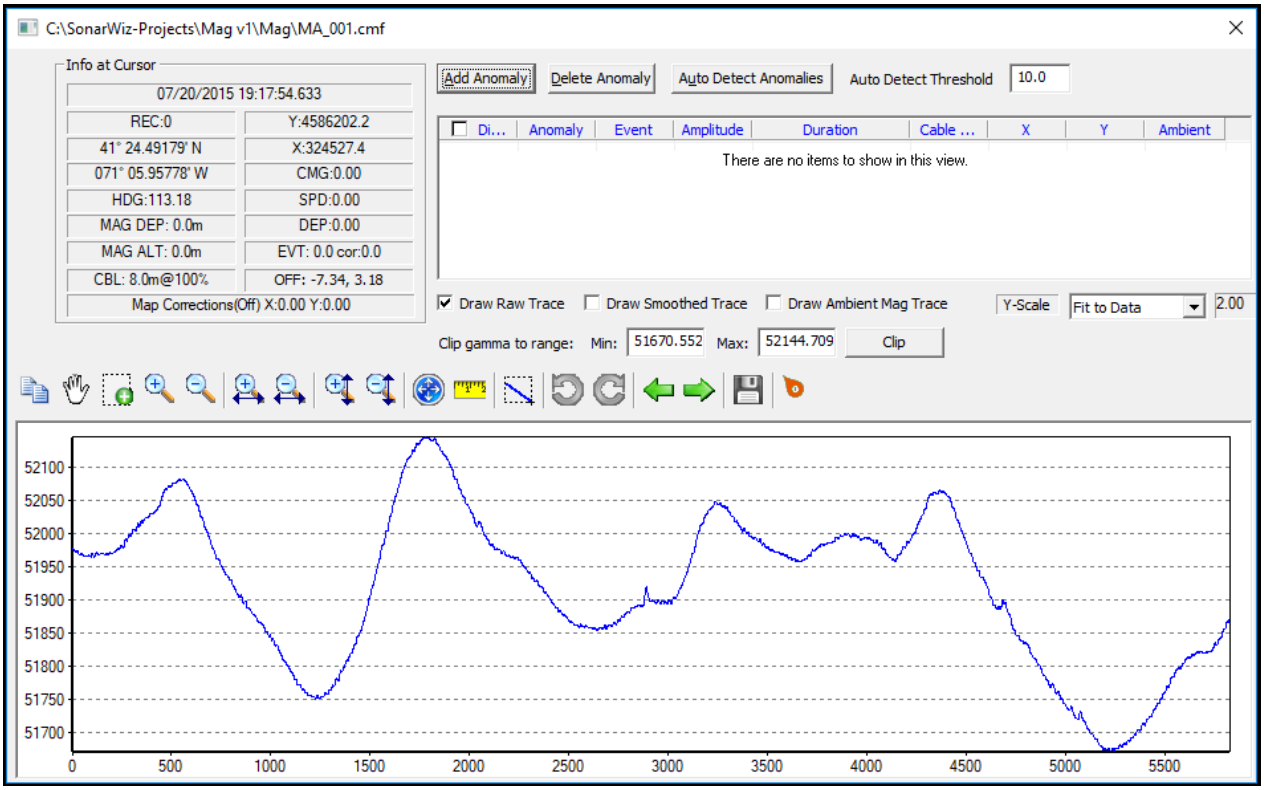



*Figure 1. Magnetic intensity (gamma) versus record number for track line MA_001 in the Buzzards Bay region.*

Figure 2 maps the magnetometer readings for the Marshfield region. The 16 track lines are consistent with the data shown in Figure 1. There is a narrow range of magnetic intensity (5,100 to 5,400 gamma), with variations occurring over km length scales consistent with the length scale of geologic materials. There are no anomalies on the spatial scale of human artifacts.

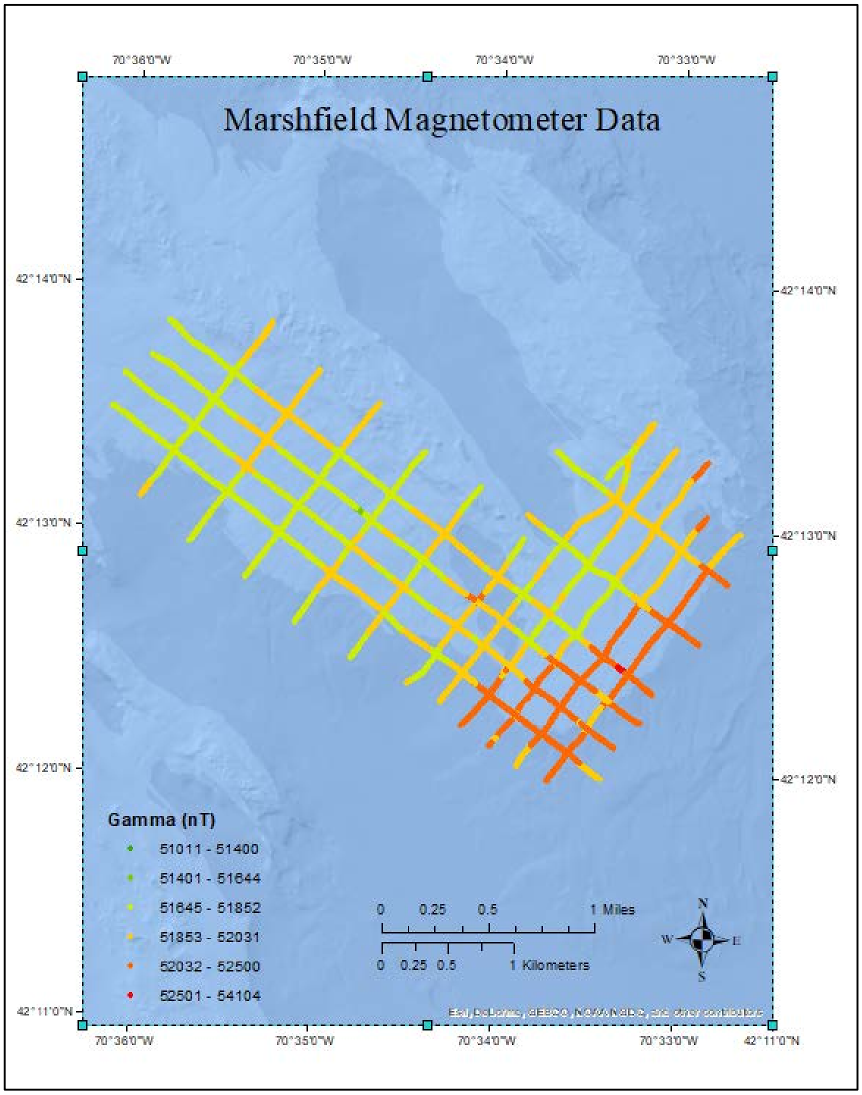


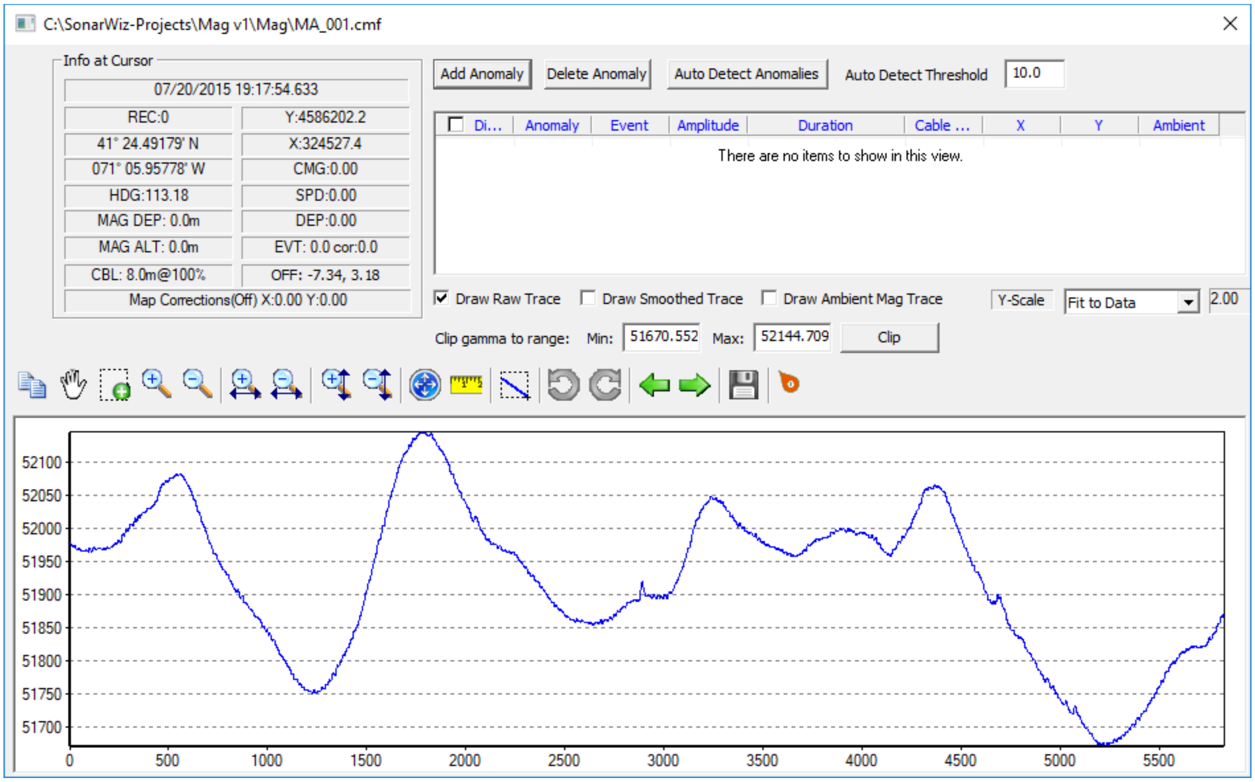

*Figure 2. Magnetometer values in Marshfield region*

**Summary**

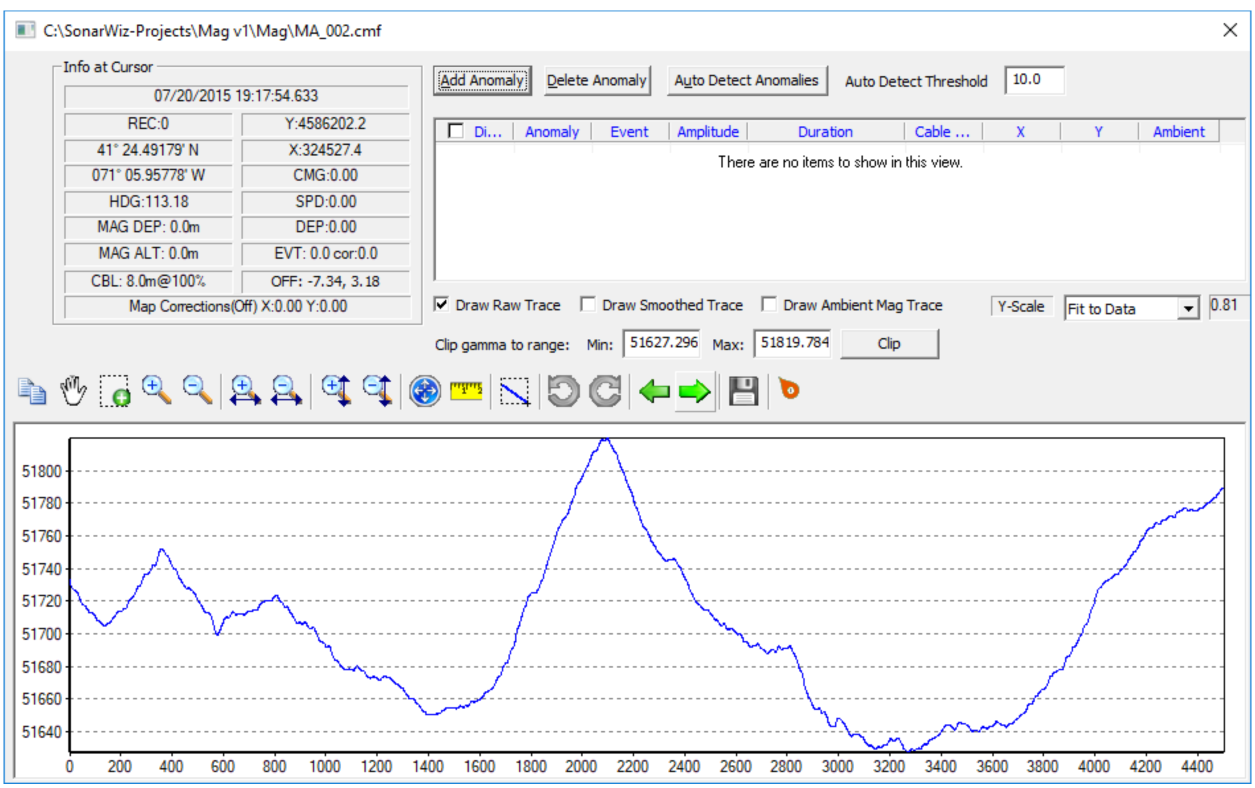
In sum, the observations suggest no metallic objects of human origin, such as shipwrecks, pipelines, or discarded materials, along the track lines. There may be small or non-magnetic items present, for example anchor lines and wooden hulls. These human artifacts might be detectable in side scan sonar data. Is important to note that these data only characterize conditions along the track lines, and there may be objects just beyond or adjacent to the track lines that could have historic importance or interfere with machinery for sand and gravel removal.

These are line graphs of magnetometer data from the BOEM Project. Data were collected in July 2015 off the coast of Massachusetts. Compiled by John Gartner, PhD, UMass Amherst, Department of Geosciences

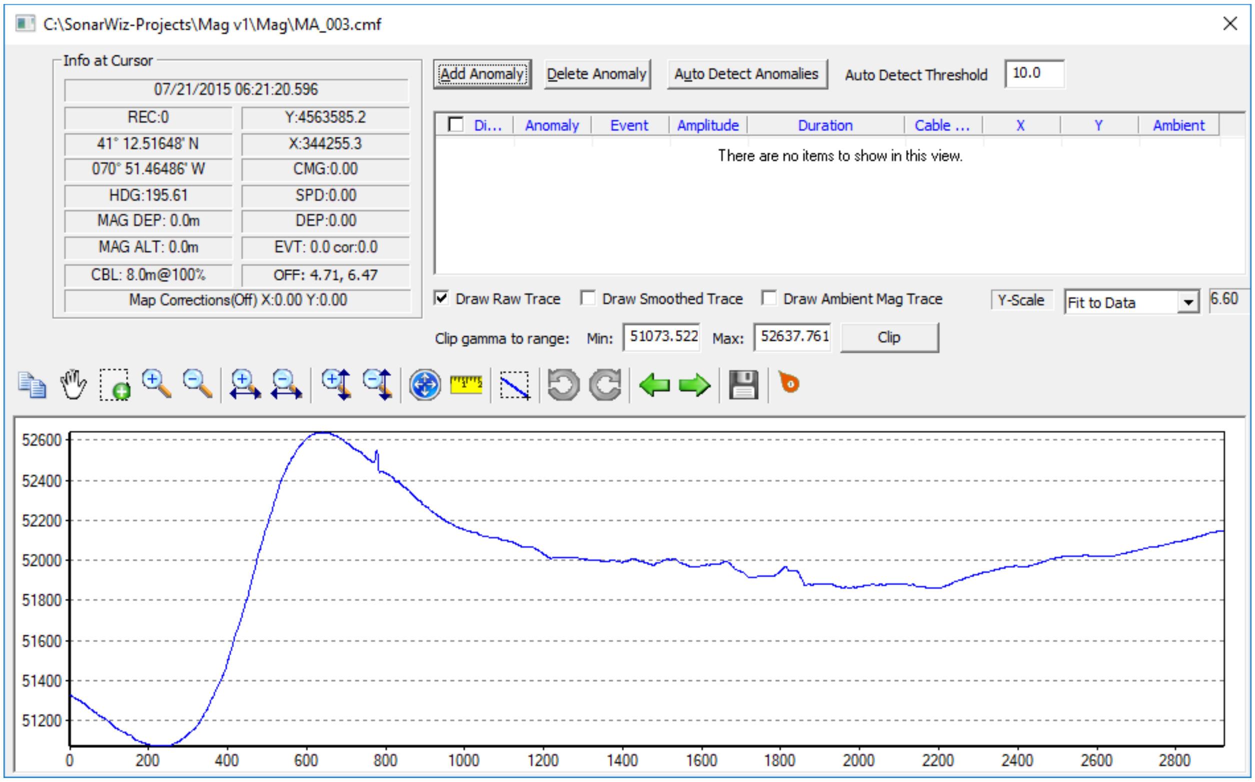
# MA_001 Buzzards Bay



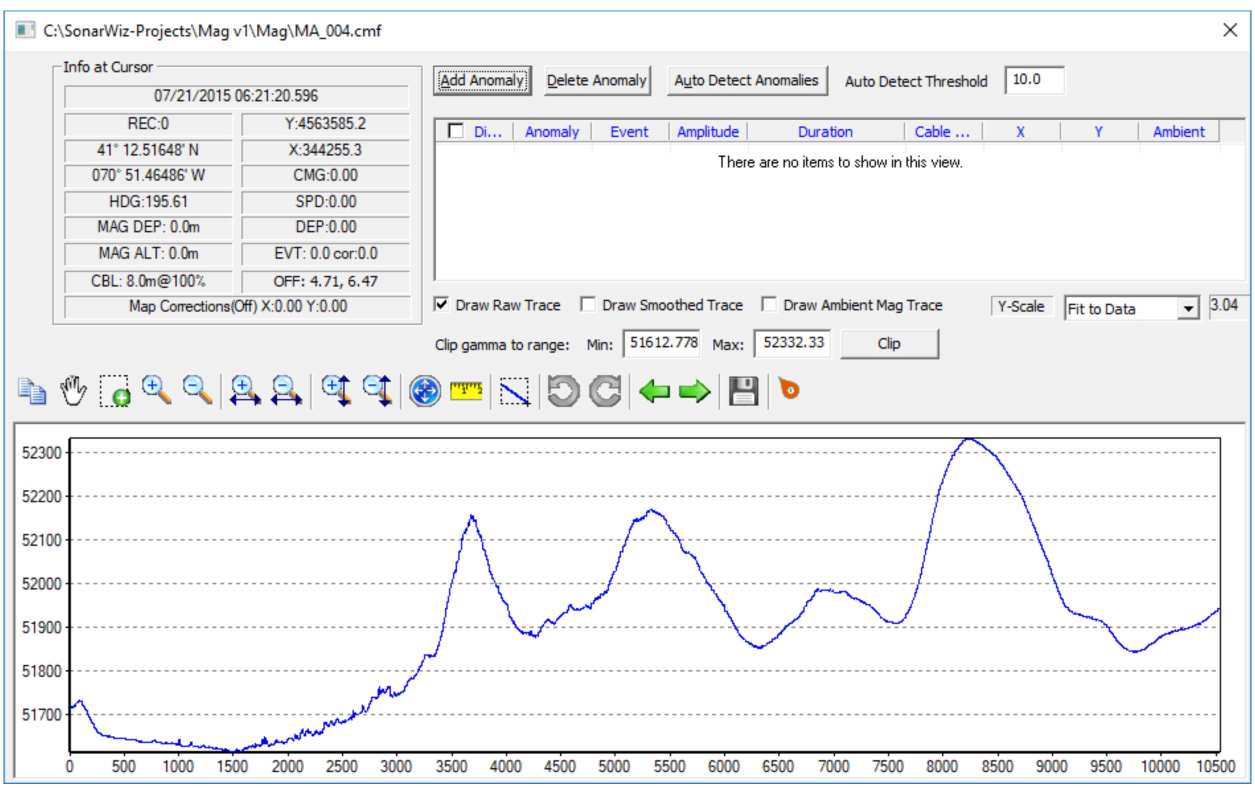

# MA_002 Buzzards Bay



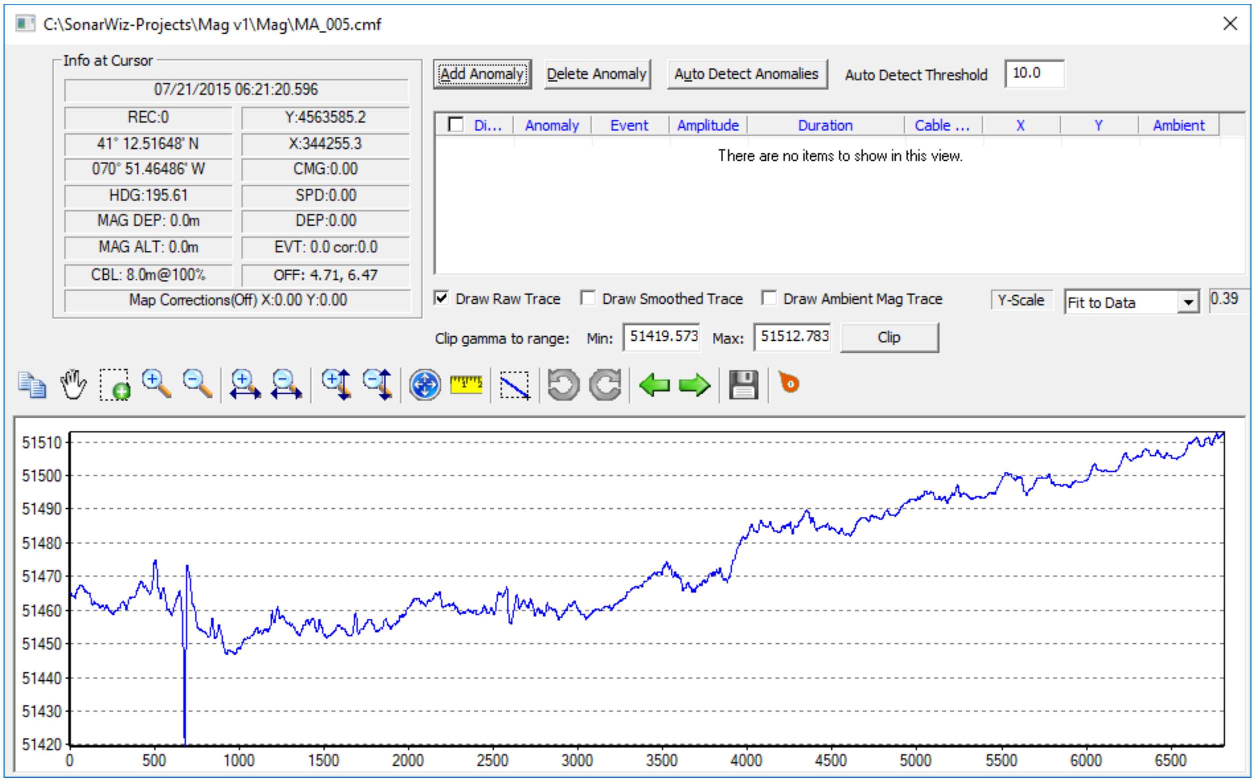
# MA_003 Buzzards Bay



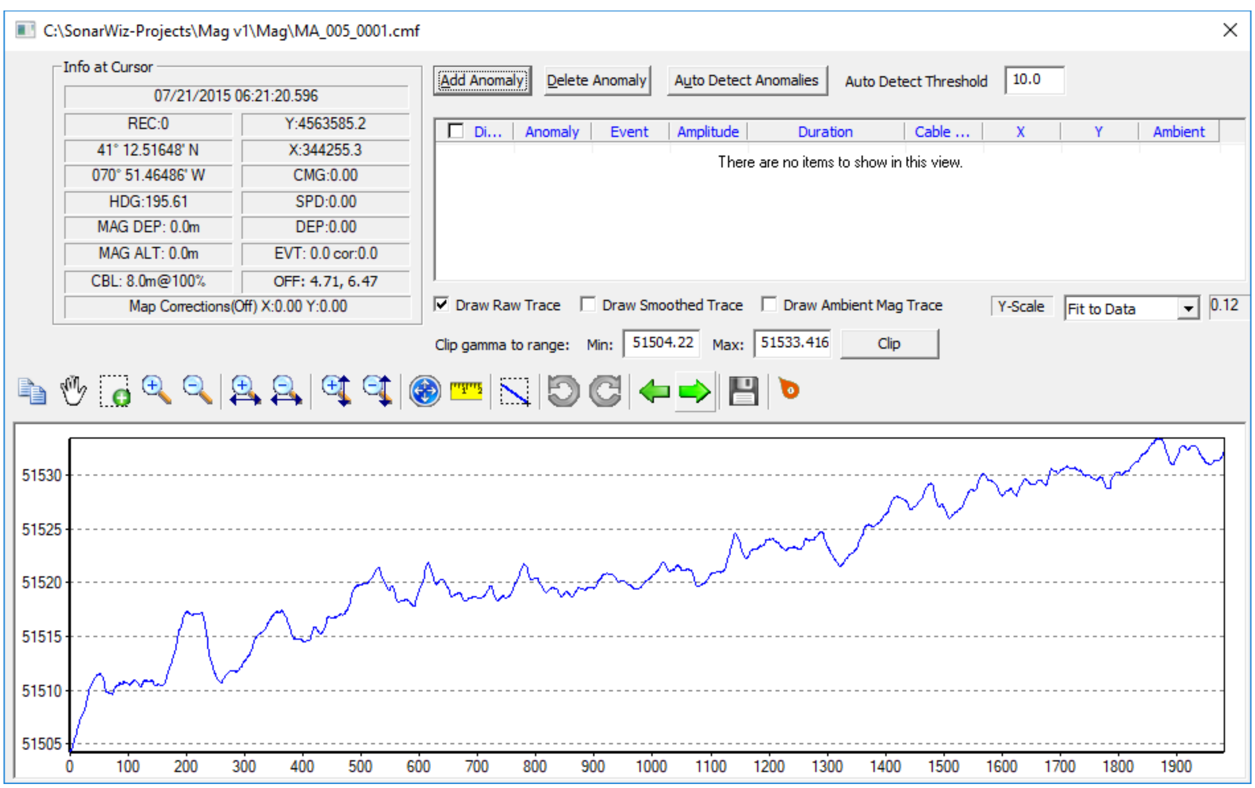

# MA_004 Buzzards Bay



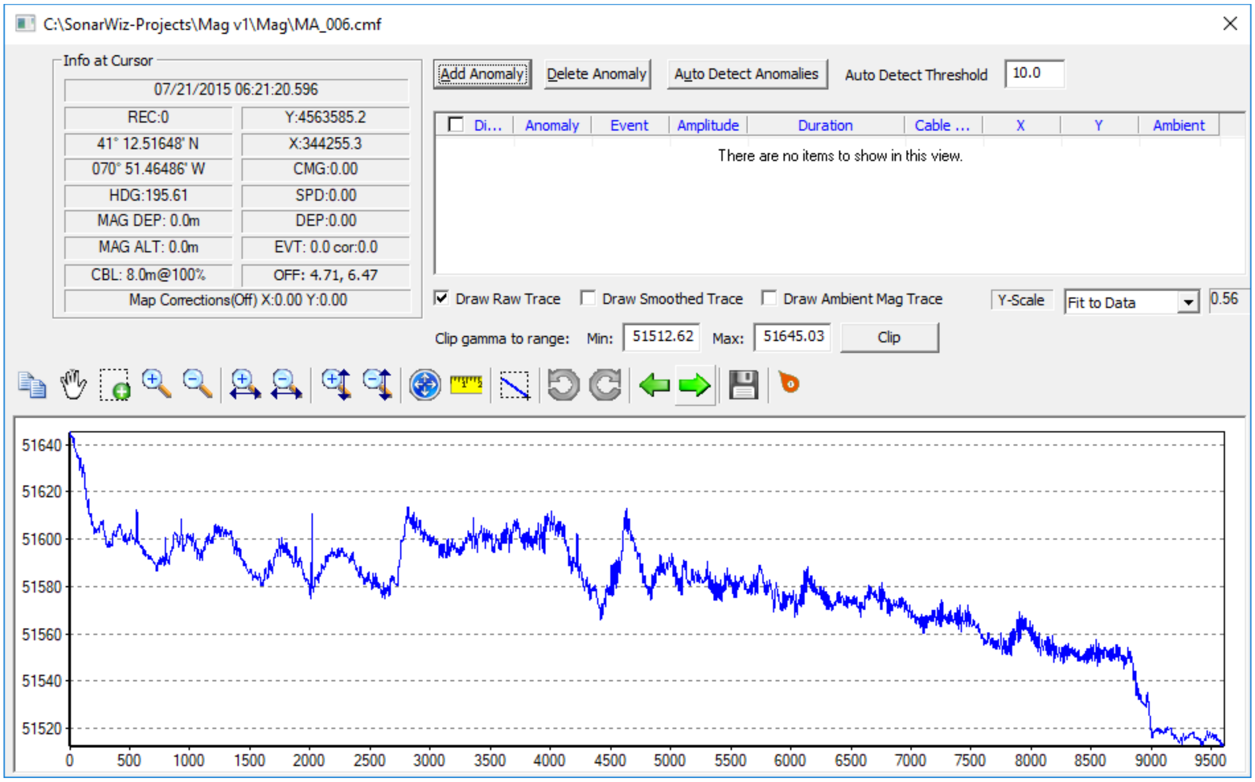
# MA_005 Nomans Land



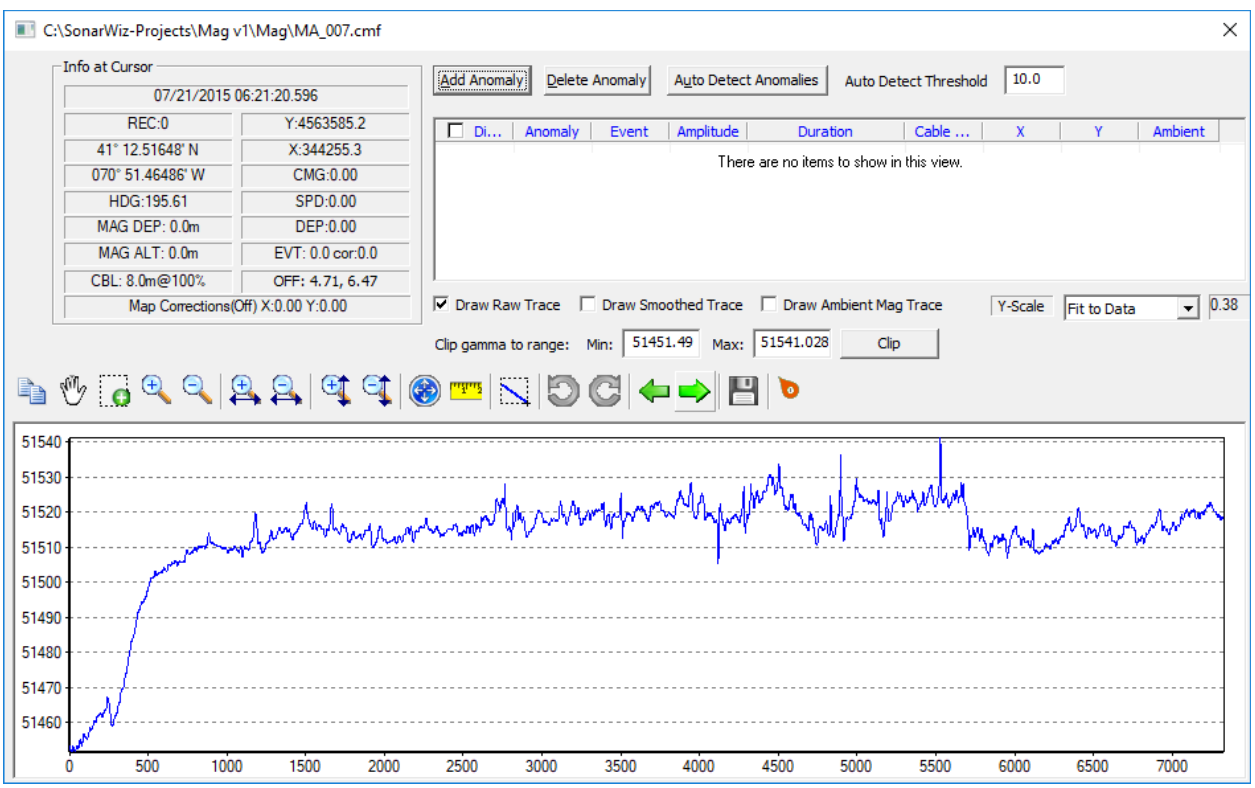

# MA_005_0001 Nomans Land



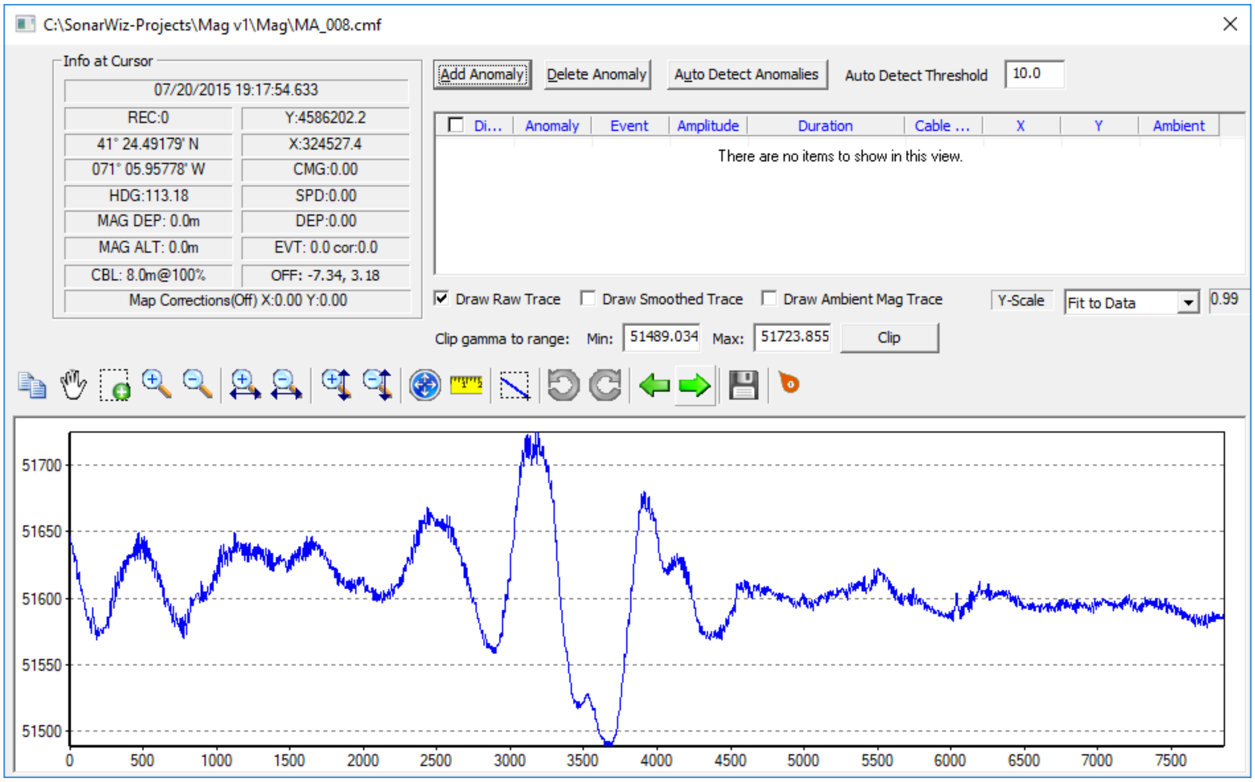
# MA_006 Nomans Land



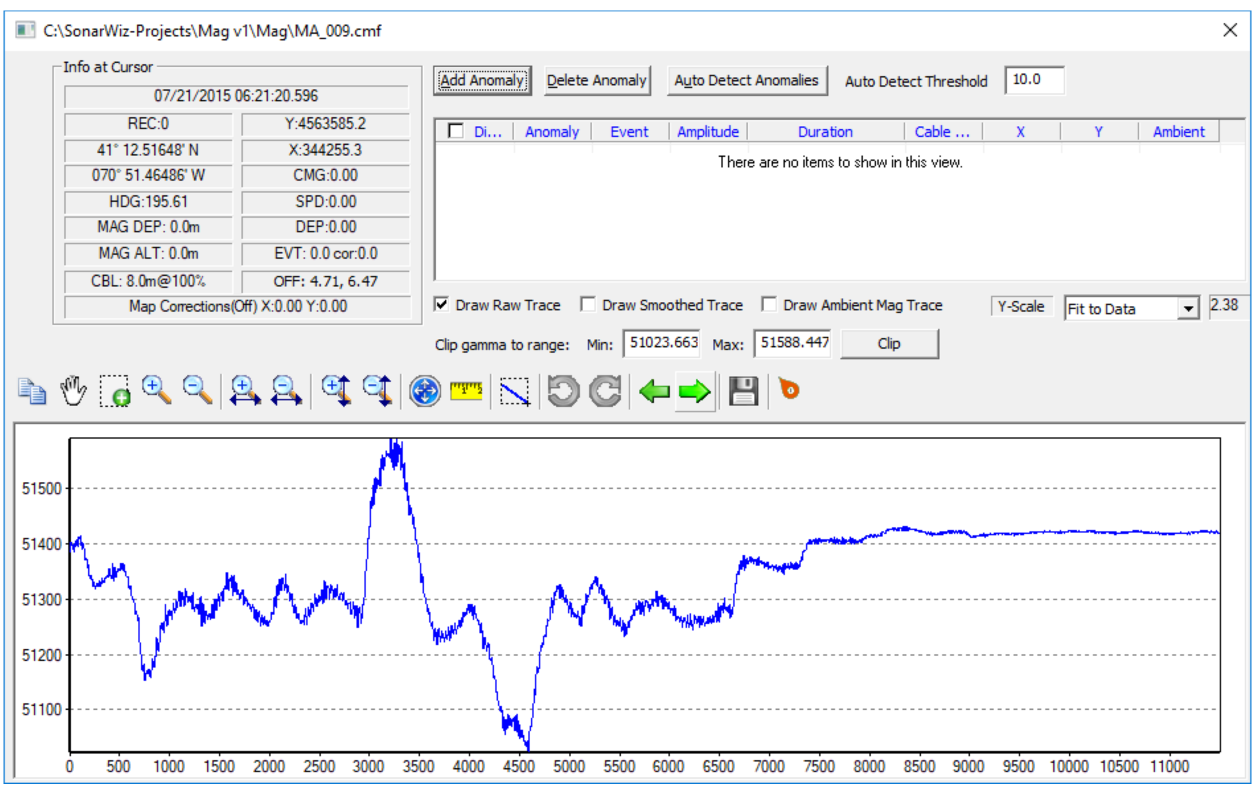

# MA_007 Nomans Land



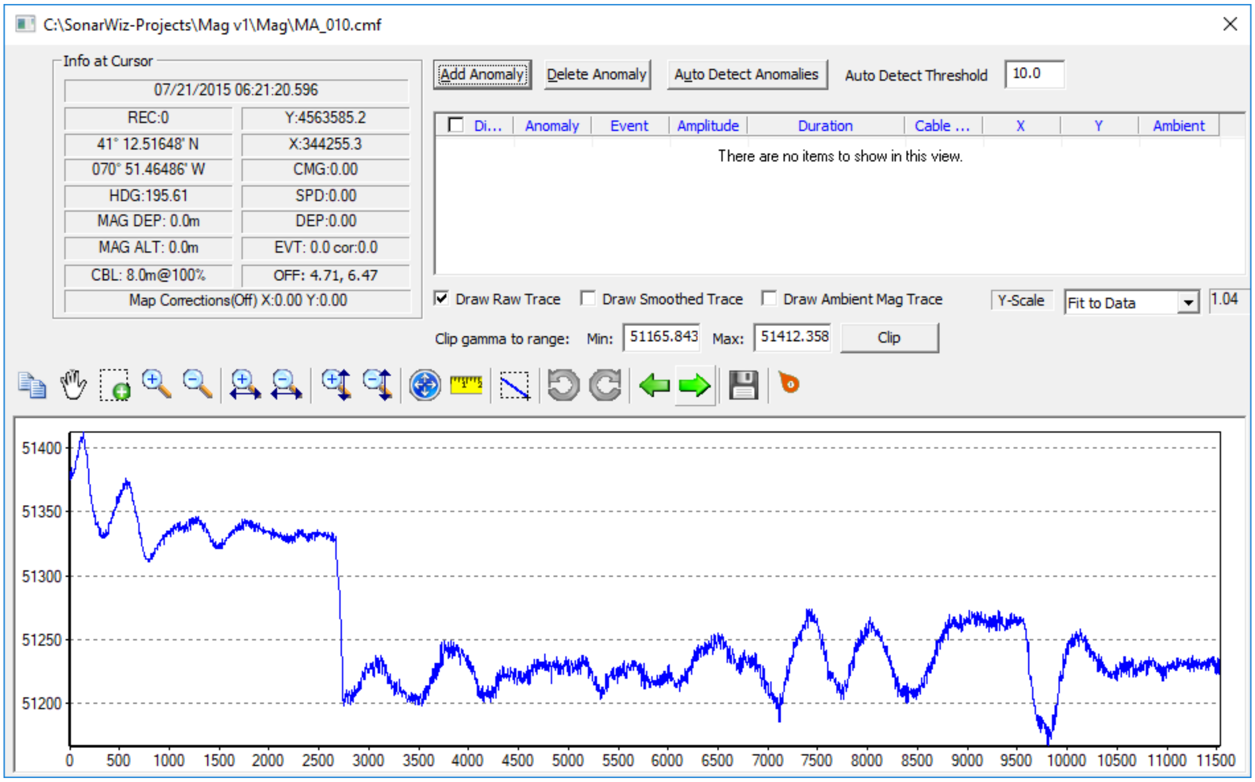
# MA_008 Nomans Land




# MA_009 Muskeget Channel



# MA_010 Muskeget Channel

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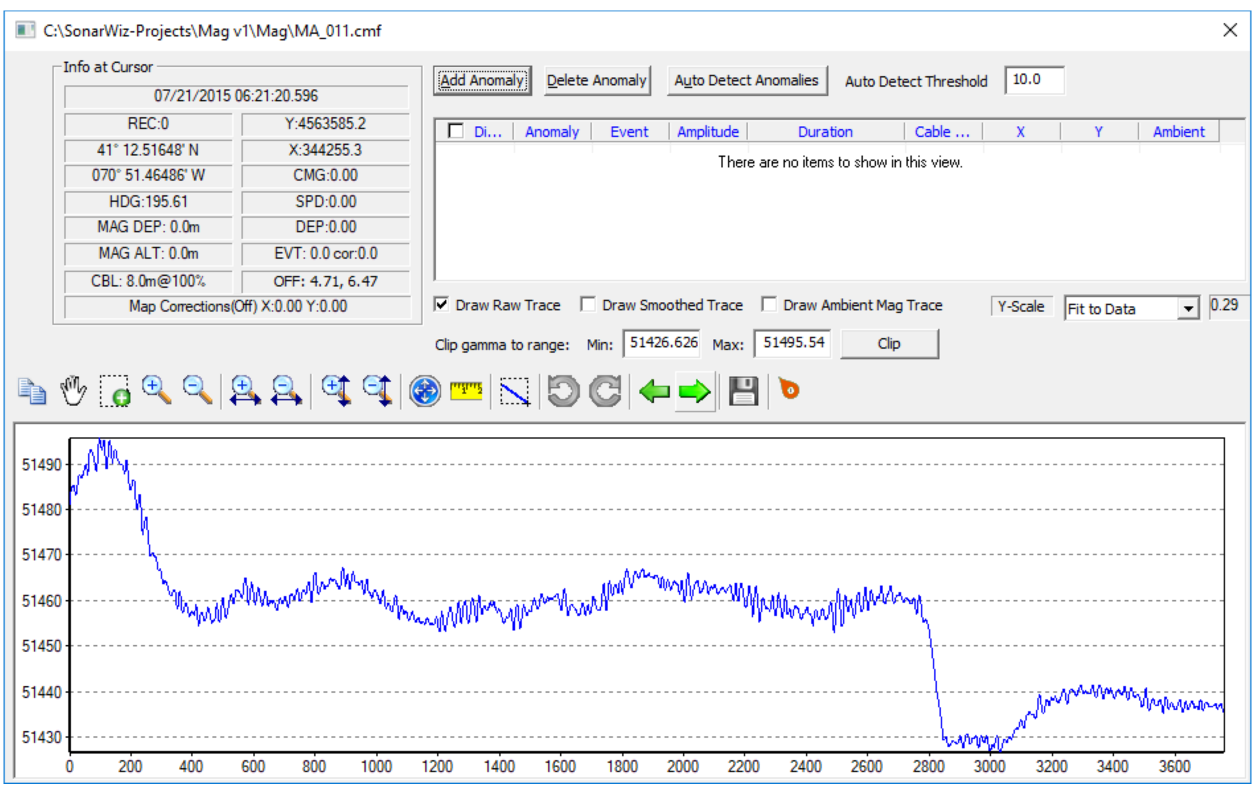
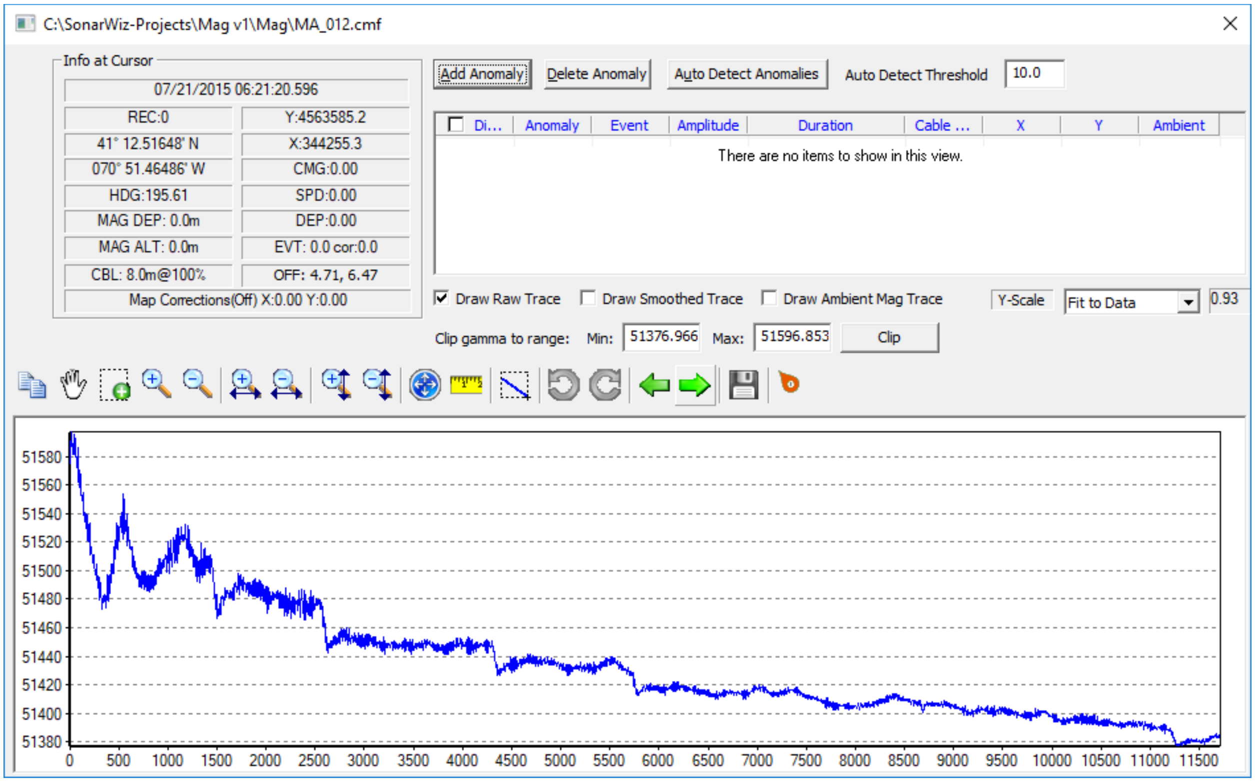


# MA_012 Muskeget Channel

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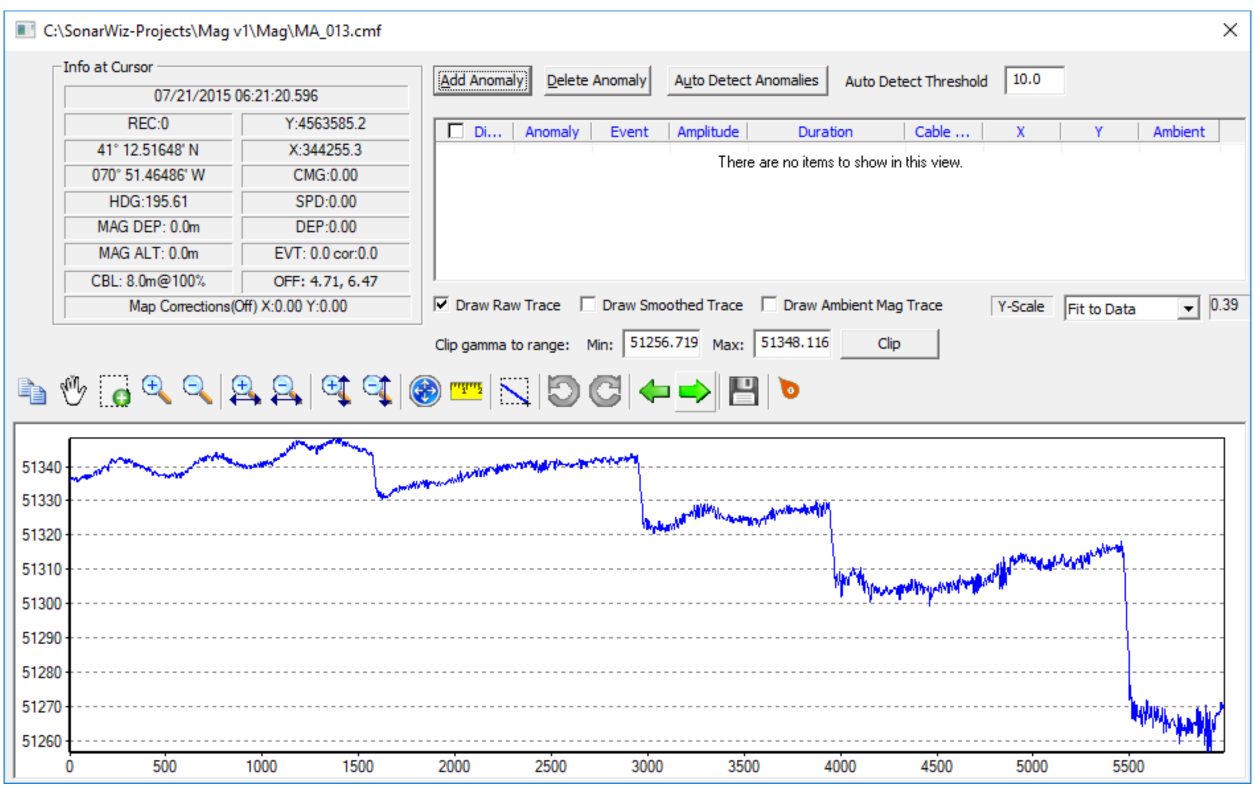

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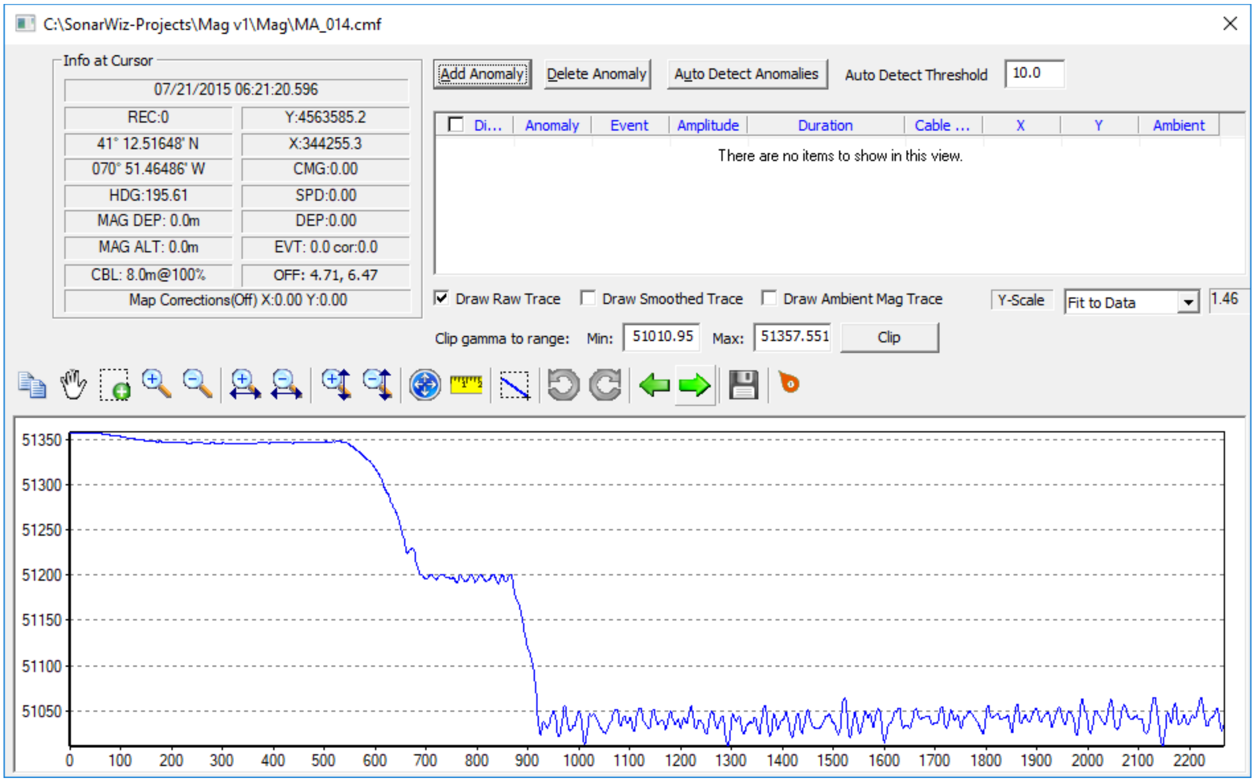
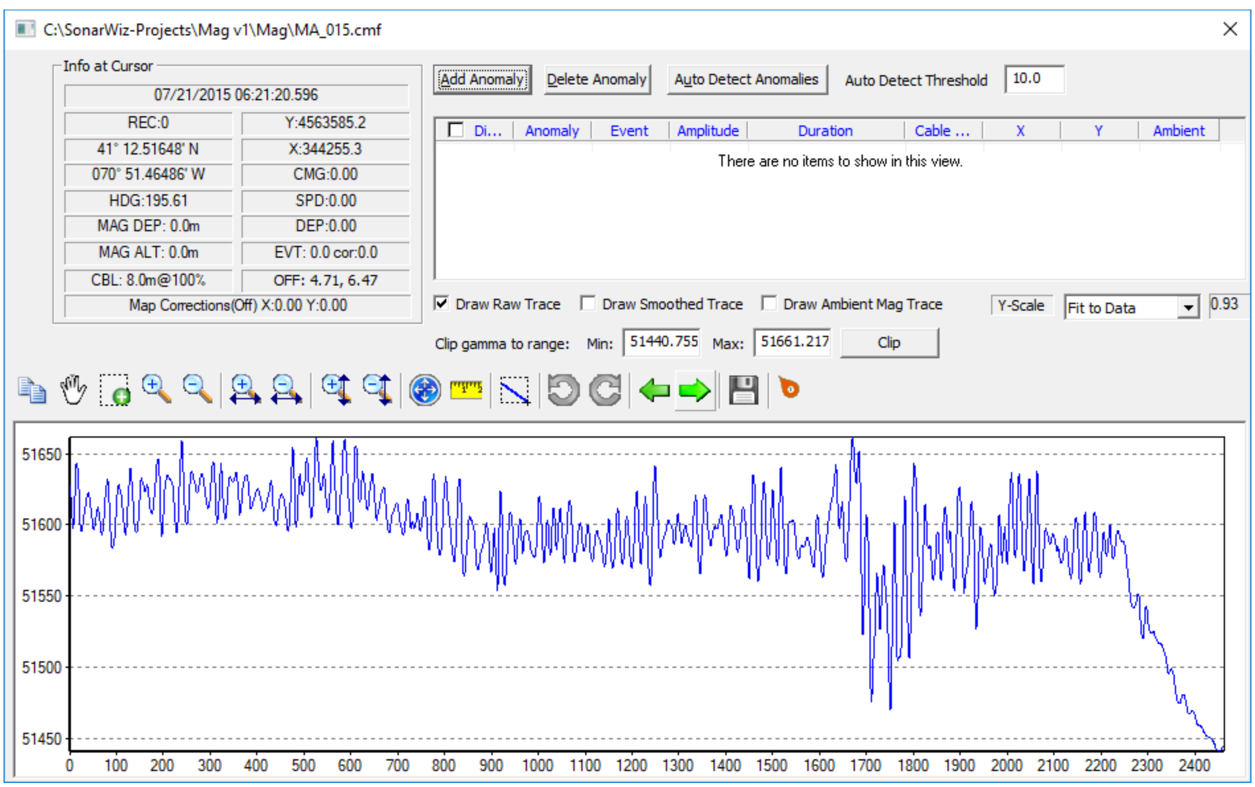
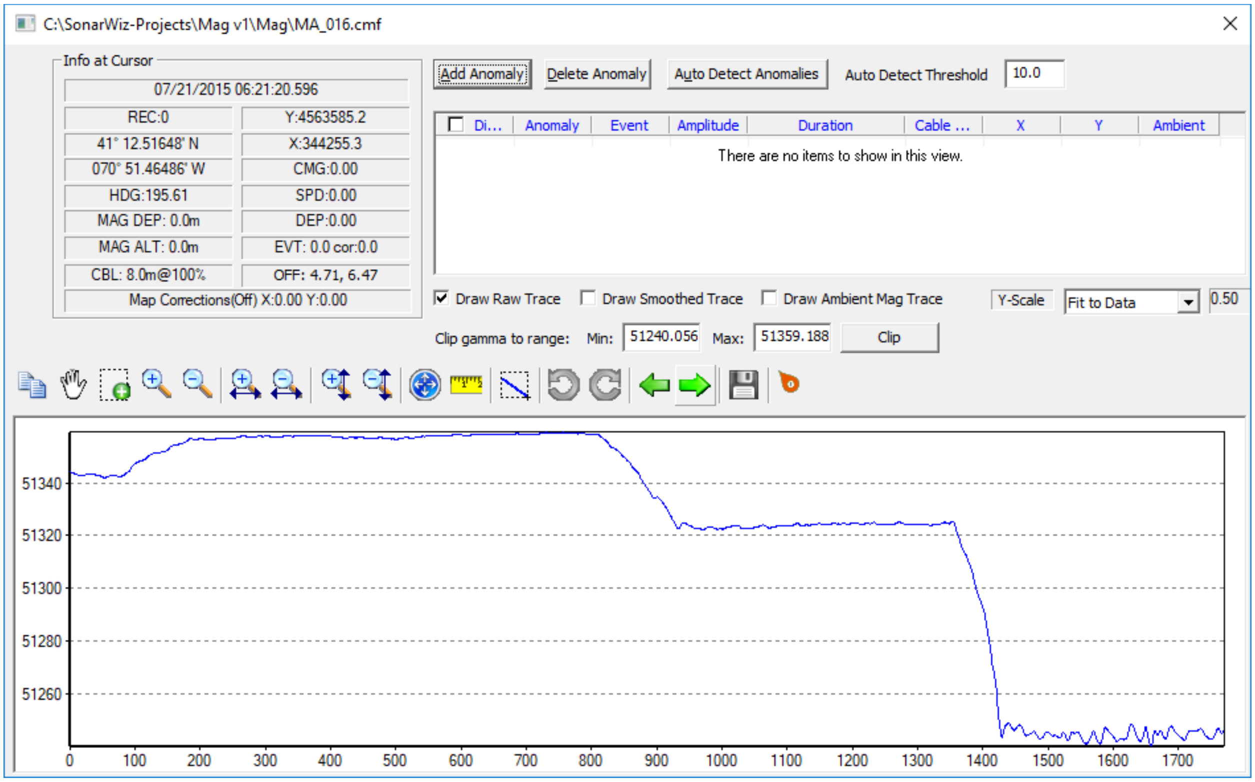


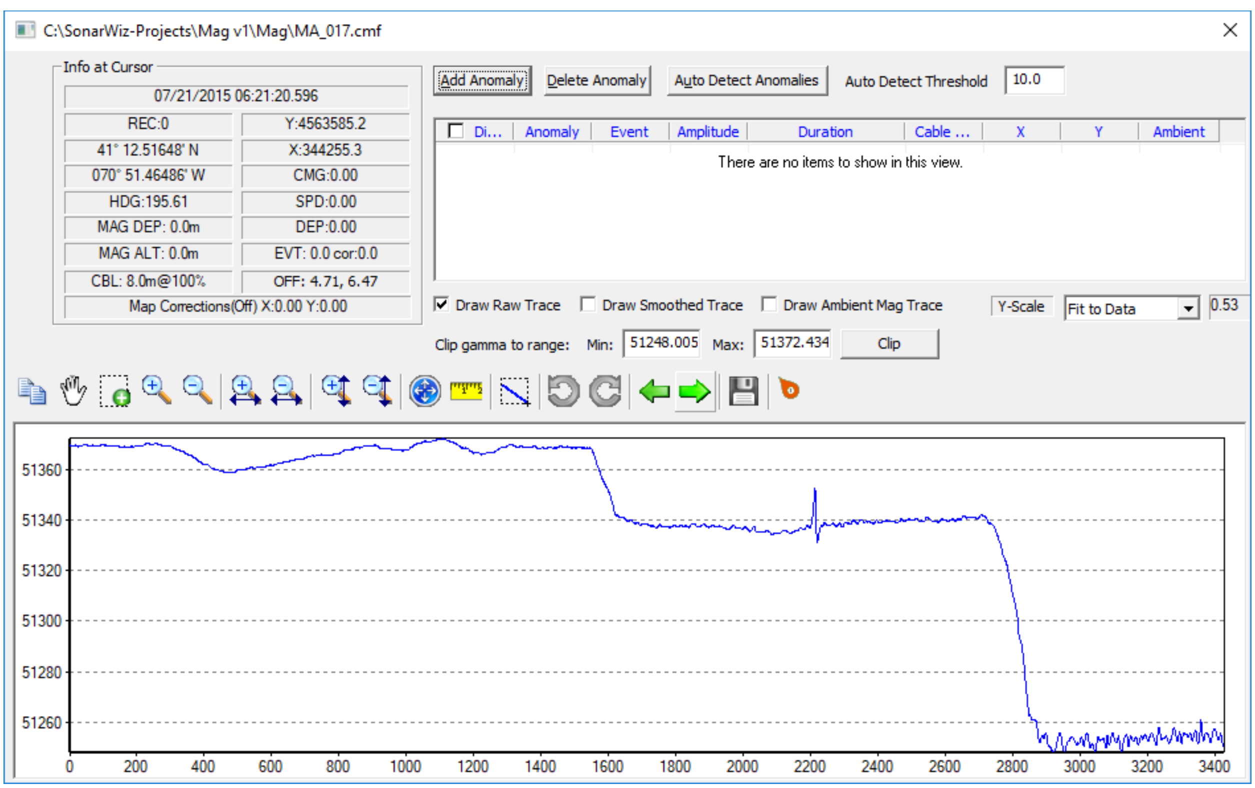

# MA_015 Muskeget Channel



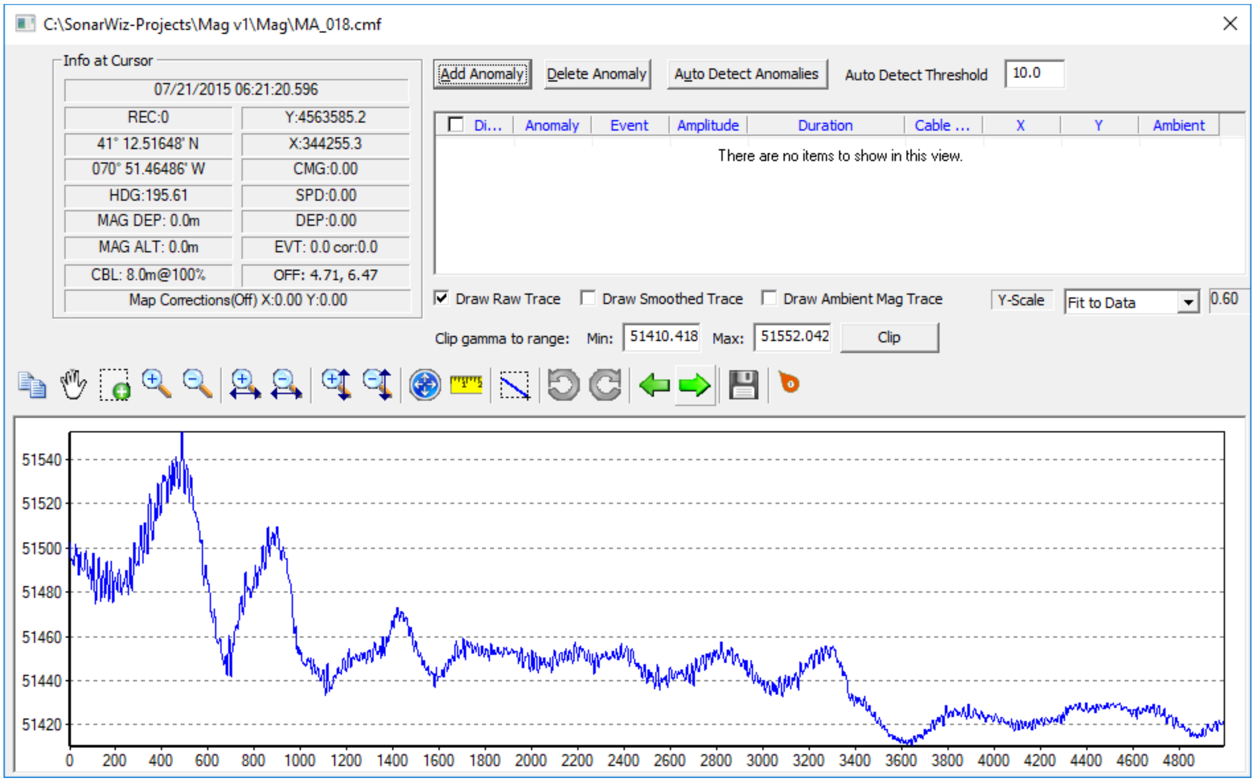
## MA_016 Muskeget Channel



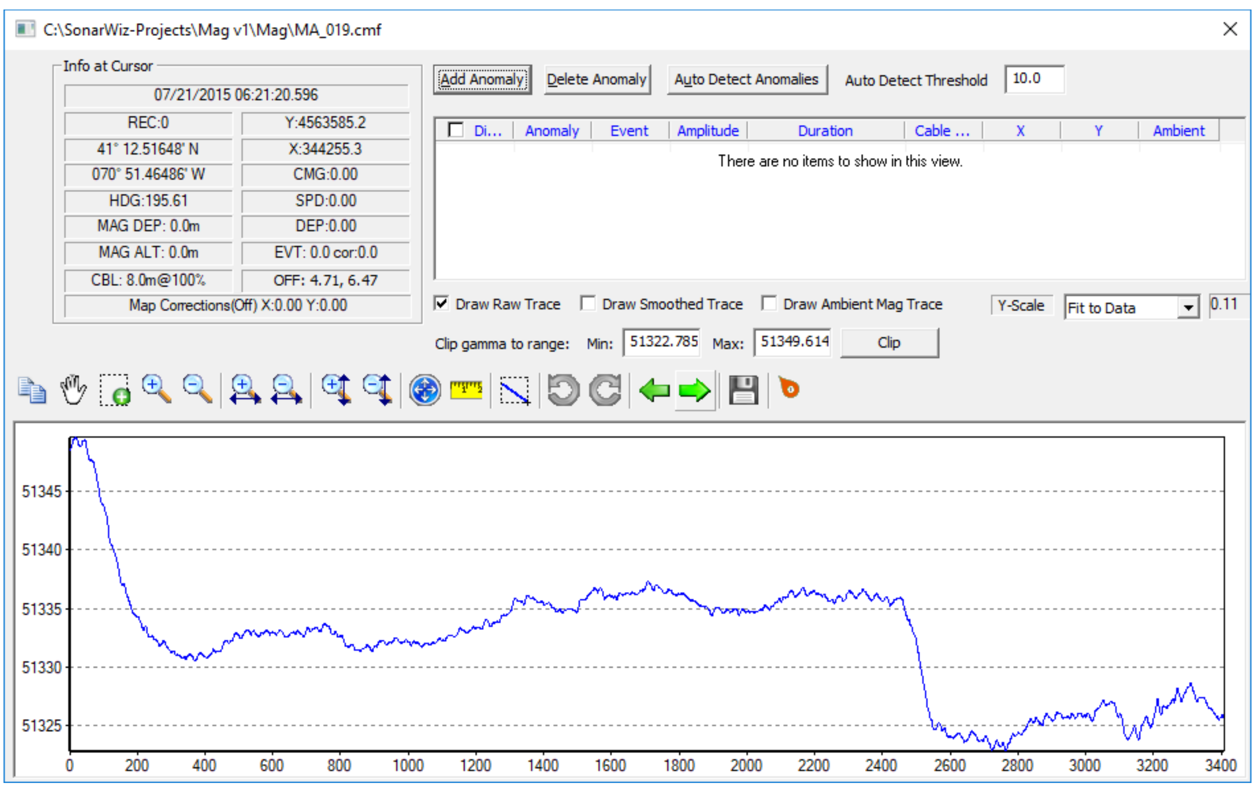

## MA_017 Muskeget Channel



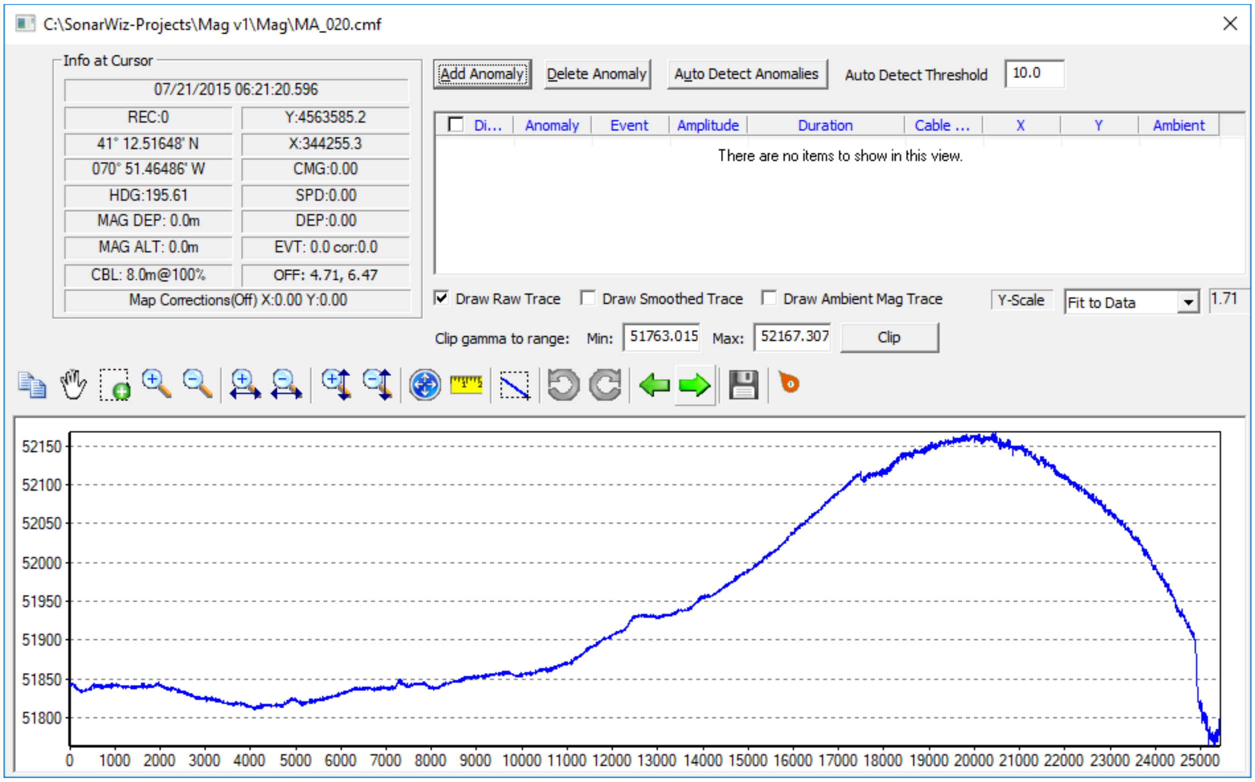
# MA_018 Muskeget Channel



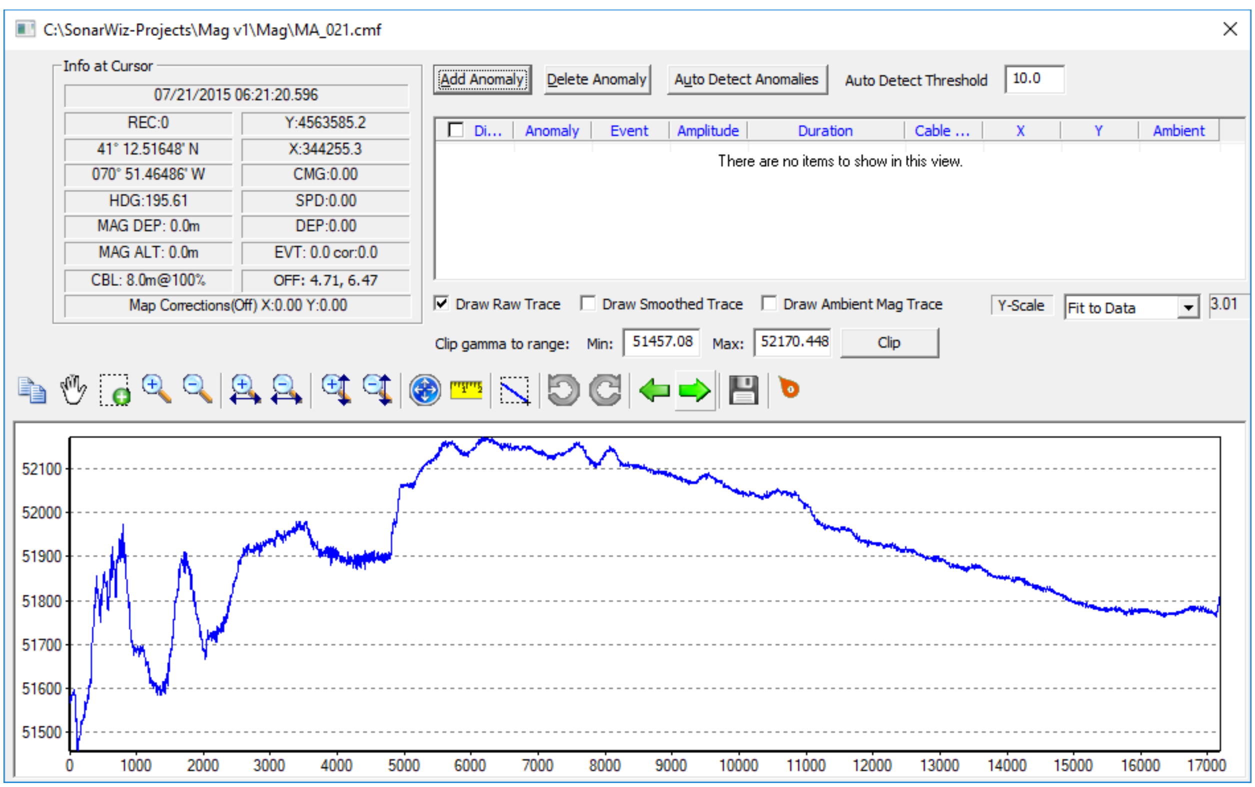

# MA_019 Muskeget Channel



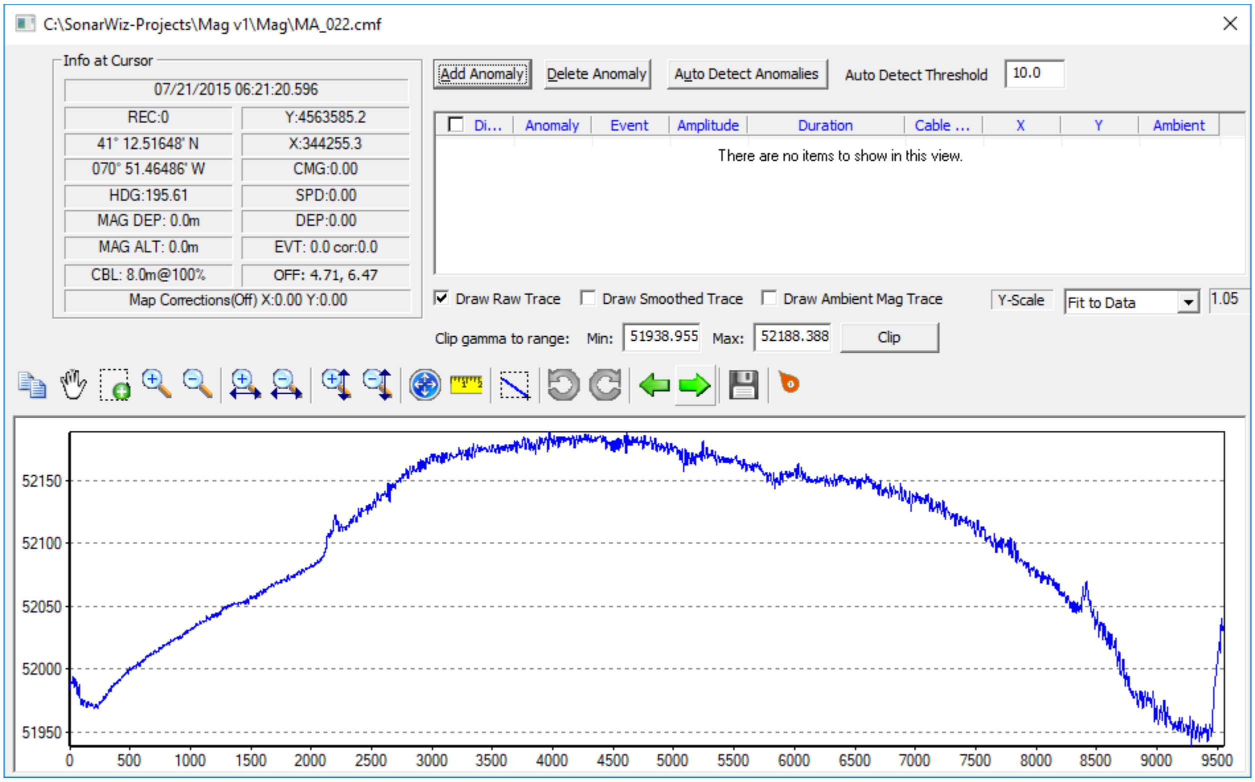
# MA_020 Nantucket



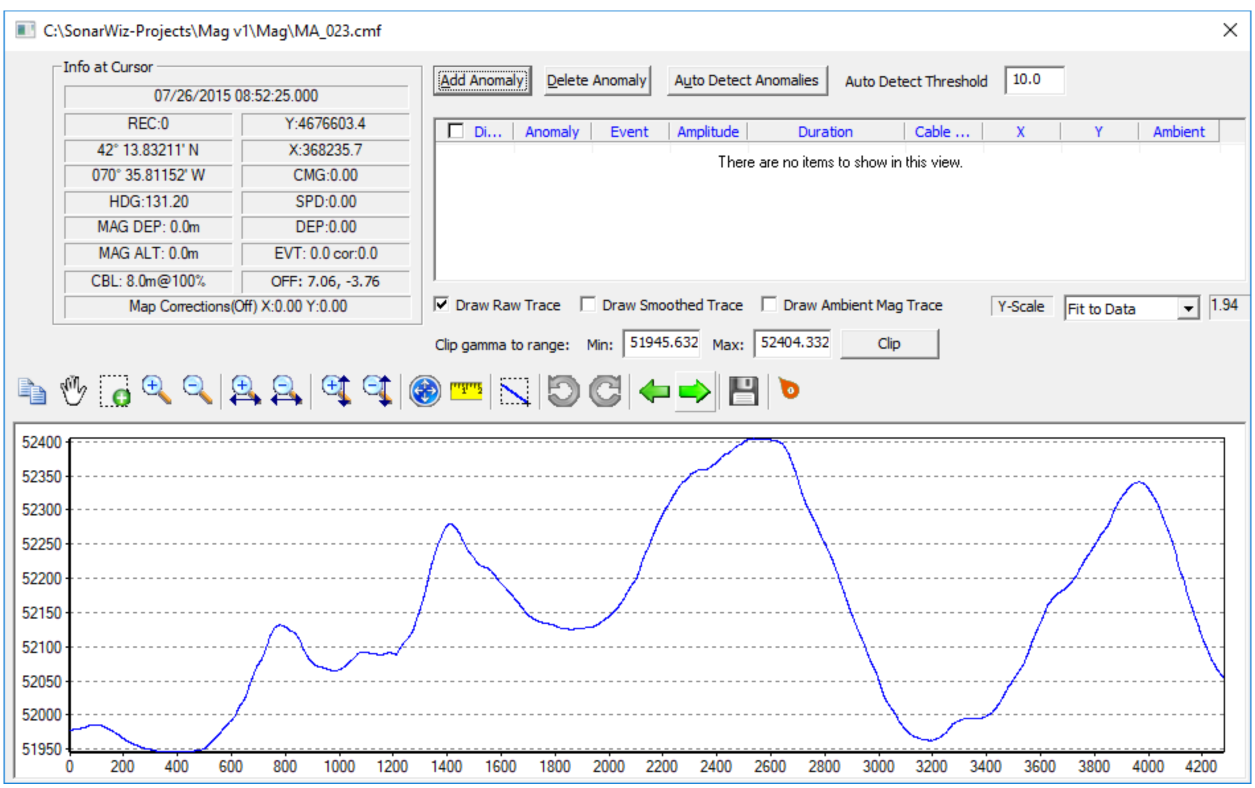

# MA_021 Nantucket



# MA_022 Nantucket




# MA_023 Marshfield



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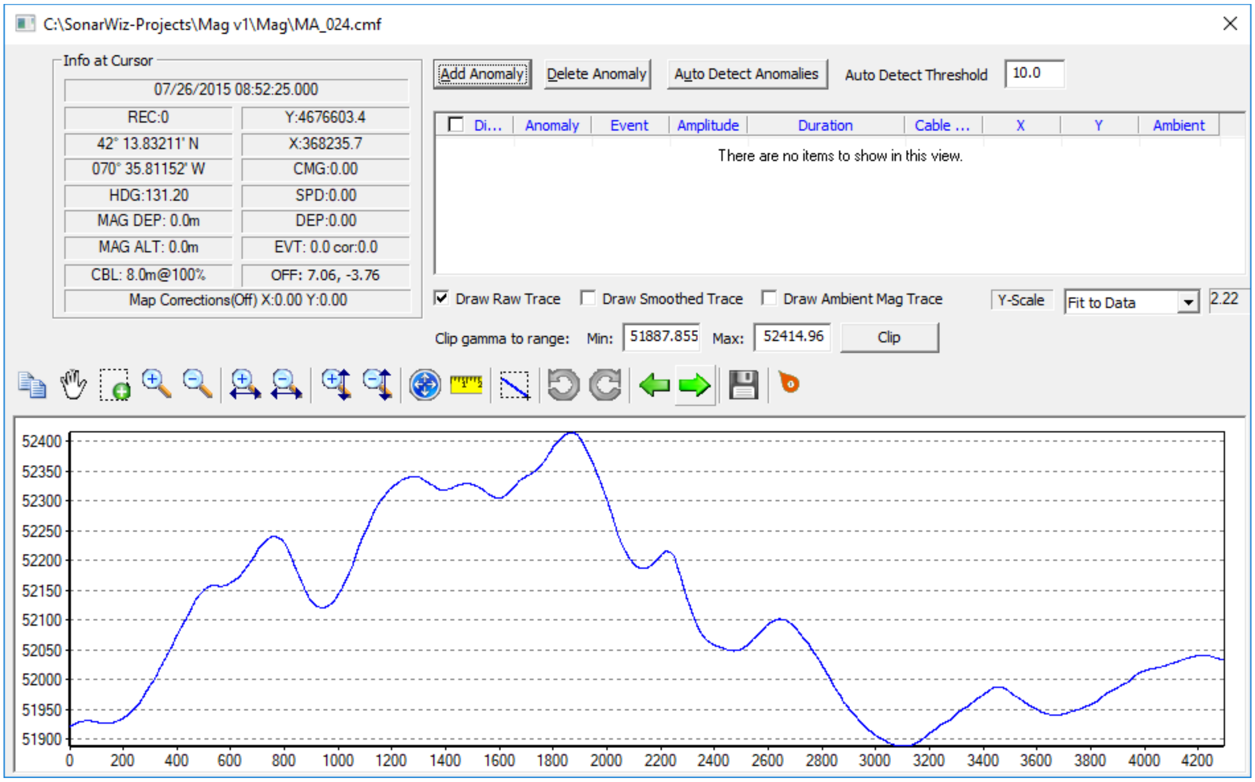


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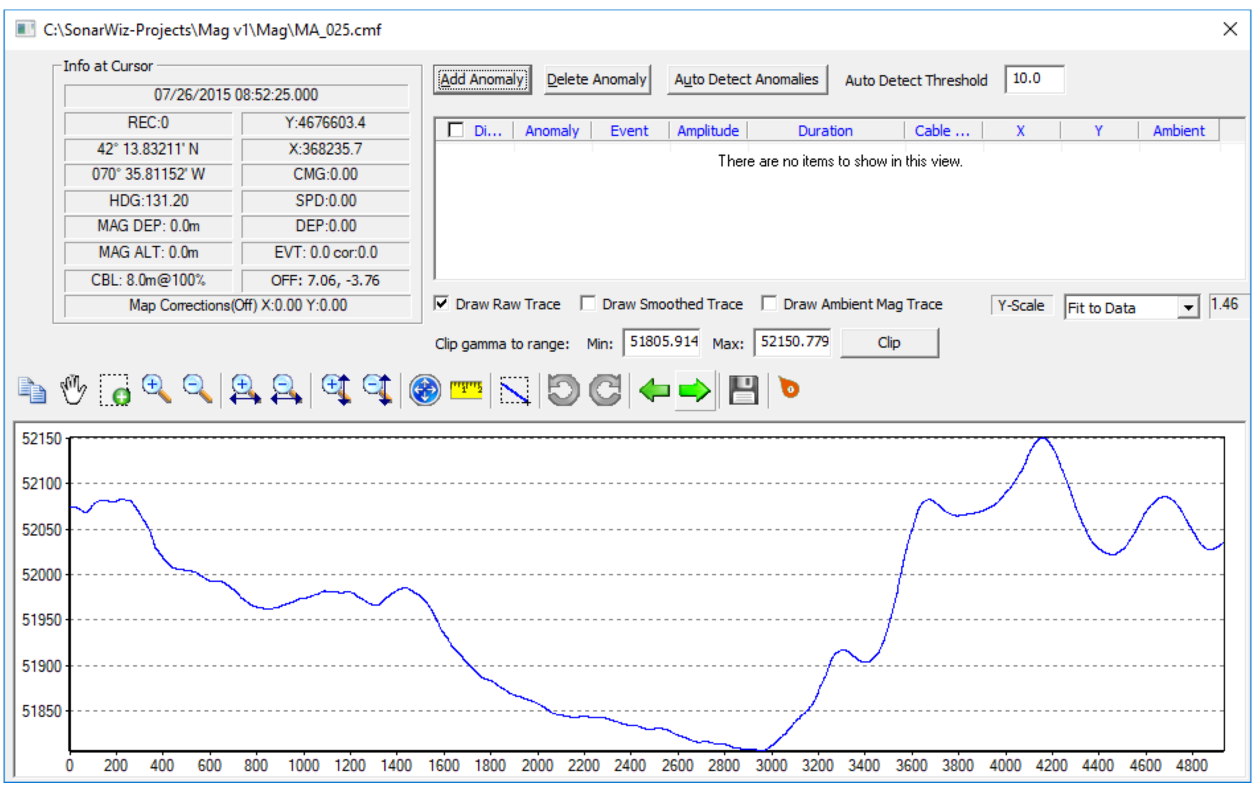

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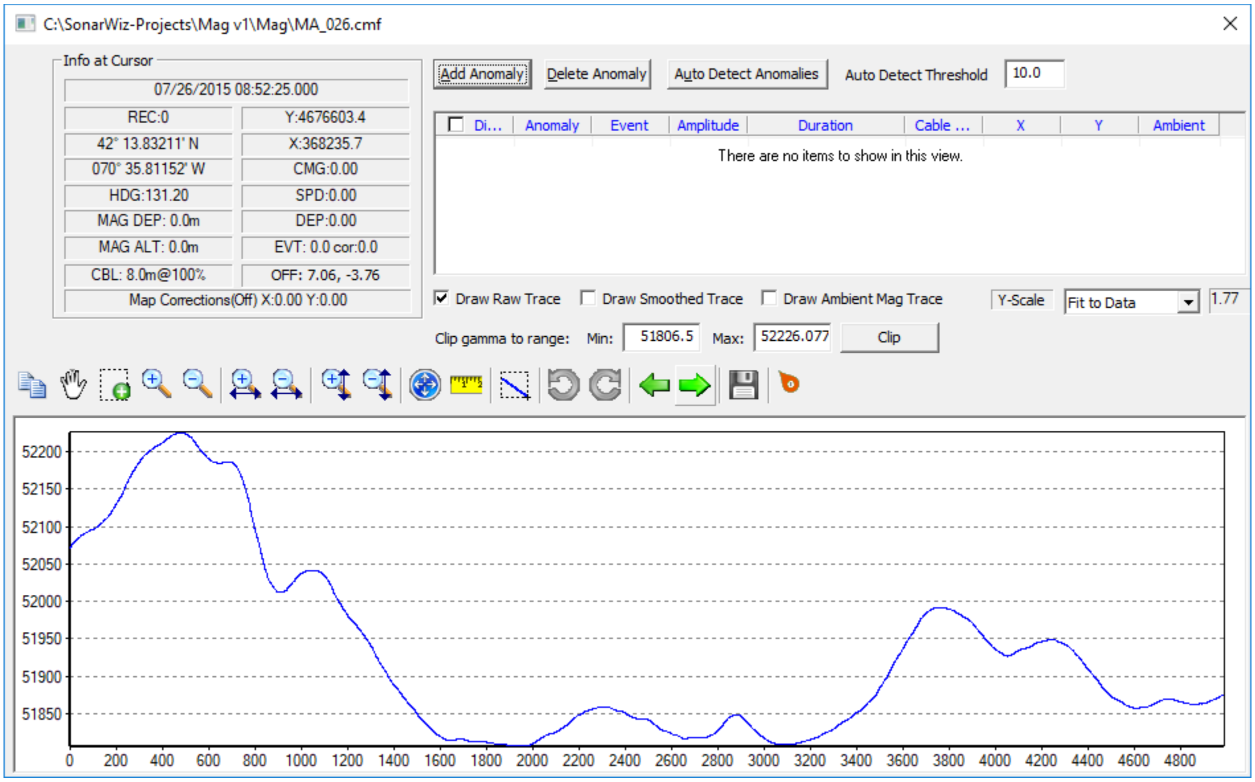


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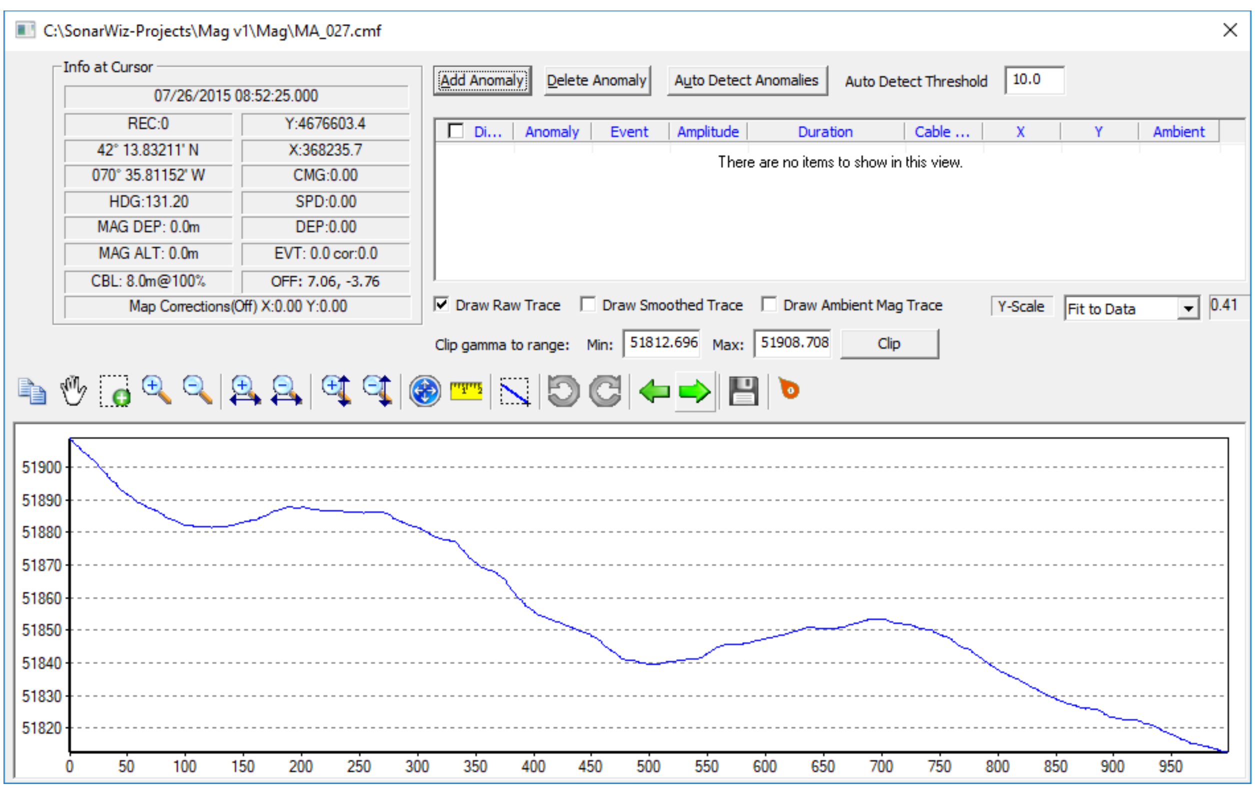
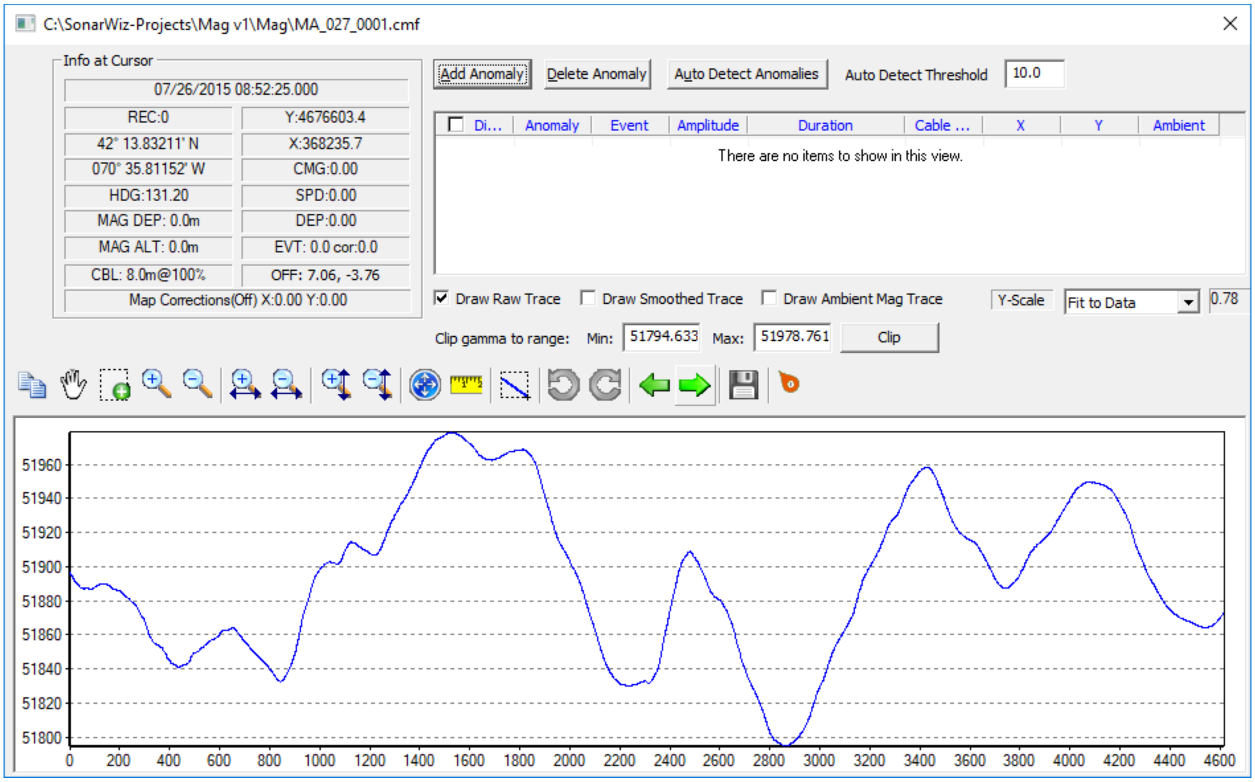


# MA_027_0001 Marshfield

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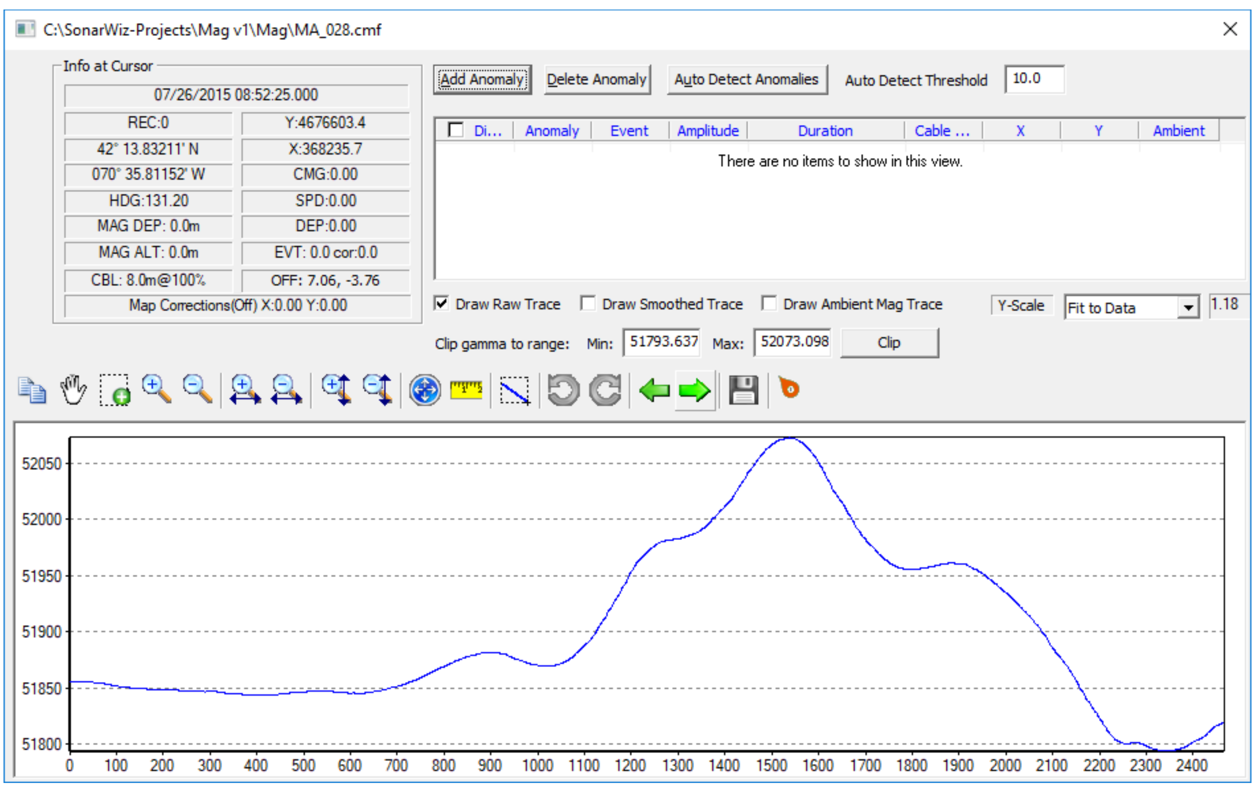

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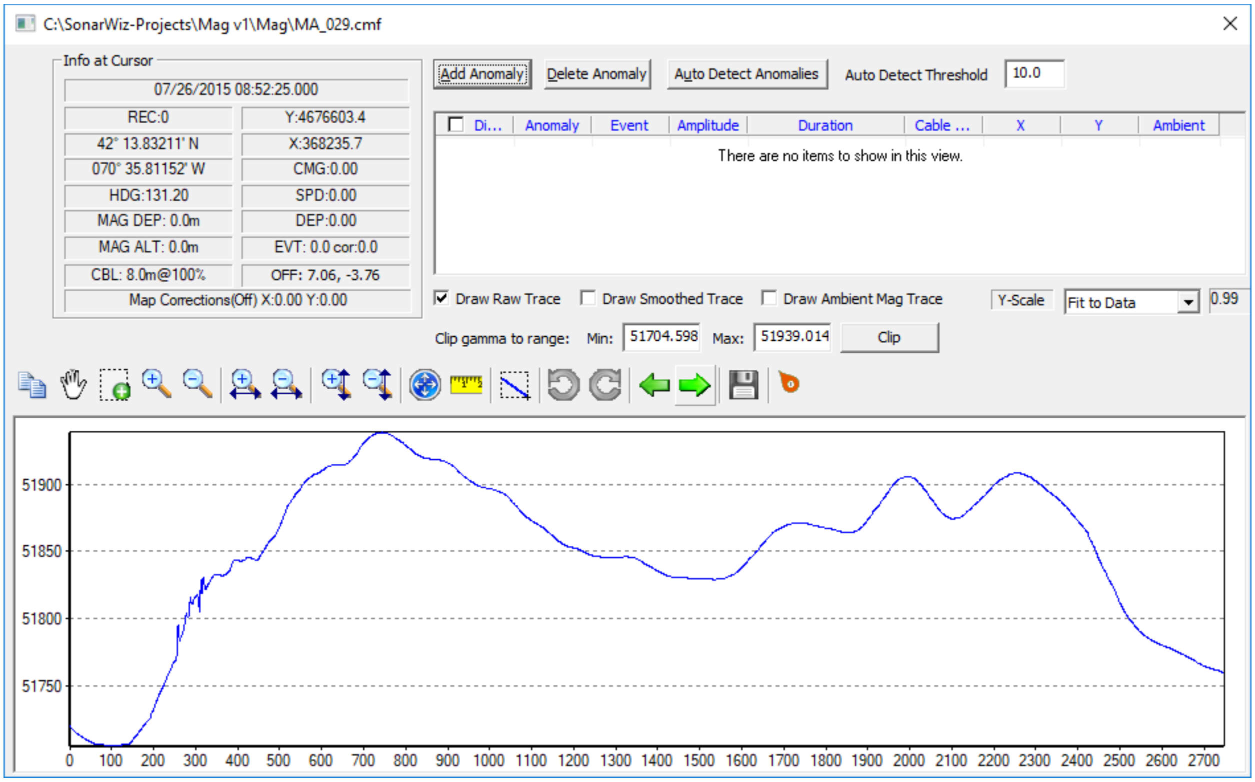


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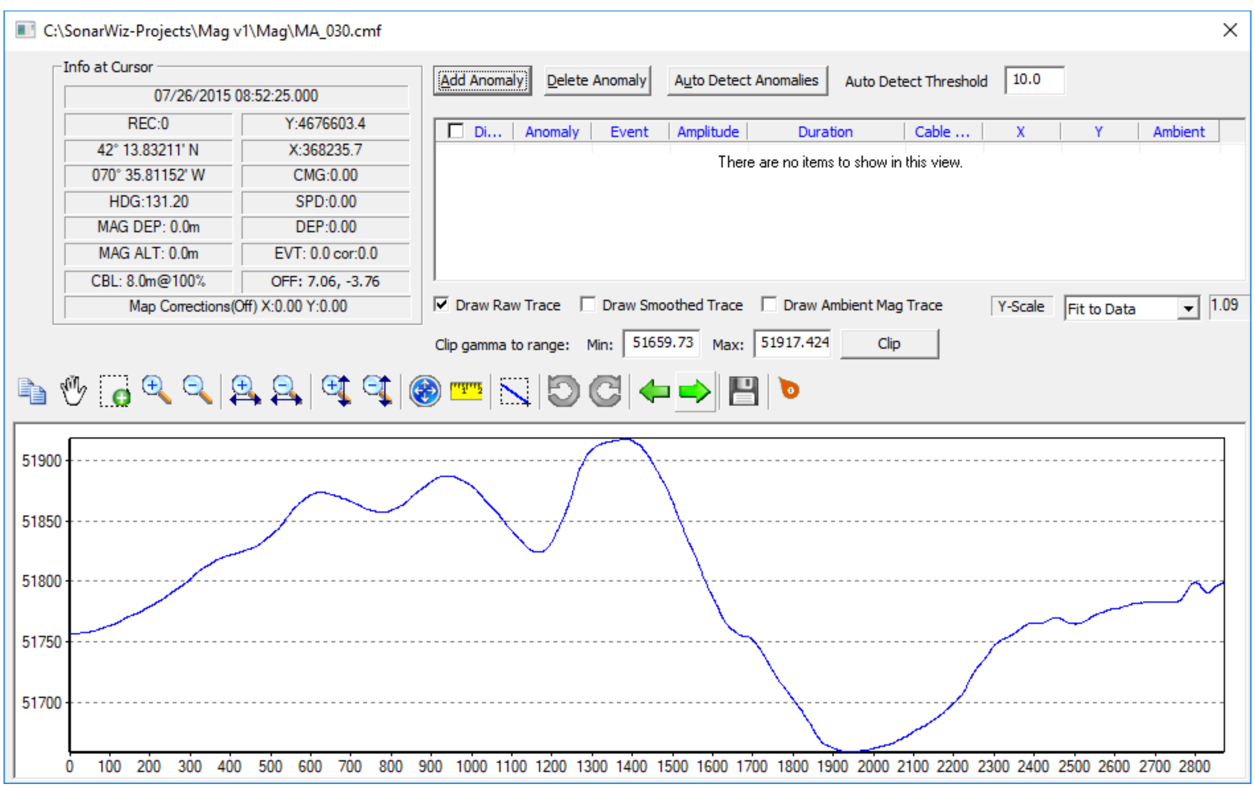

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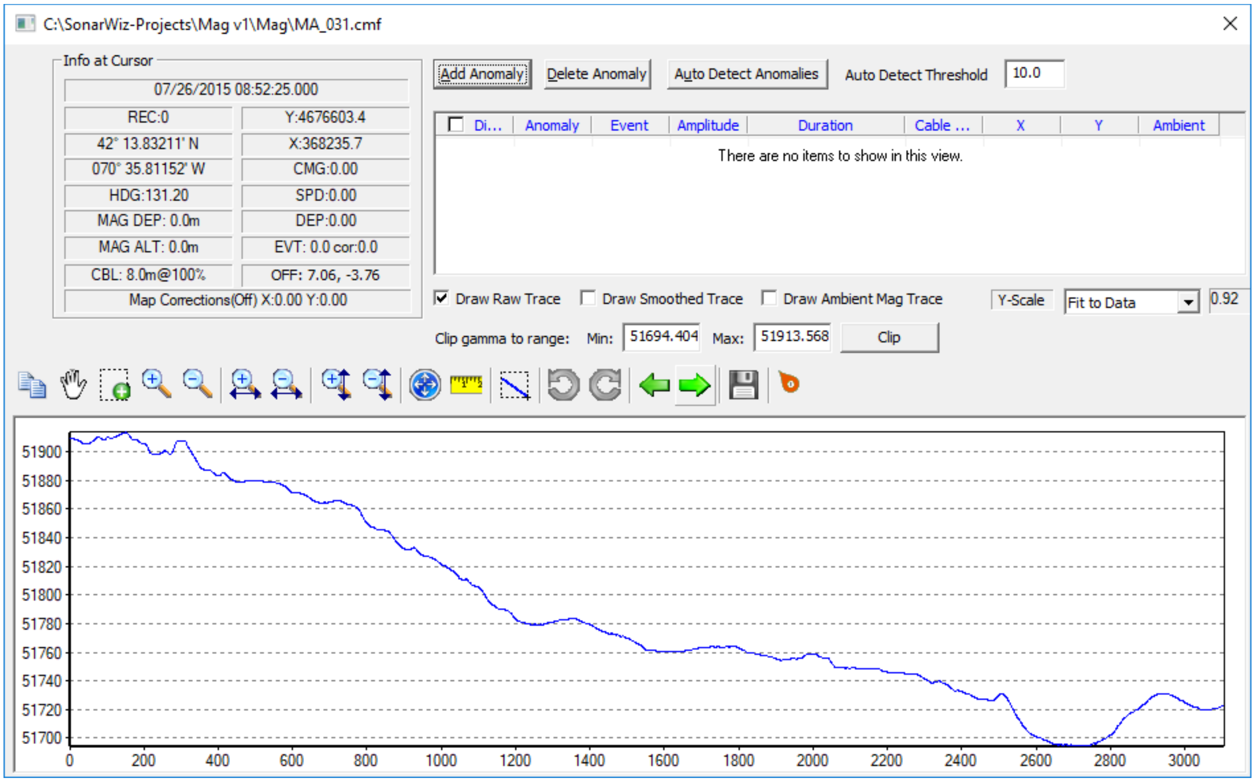


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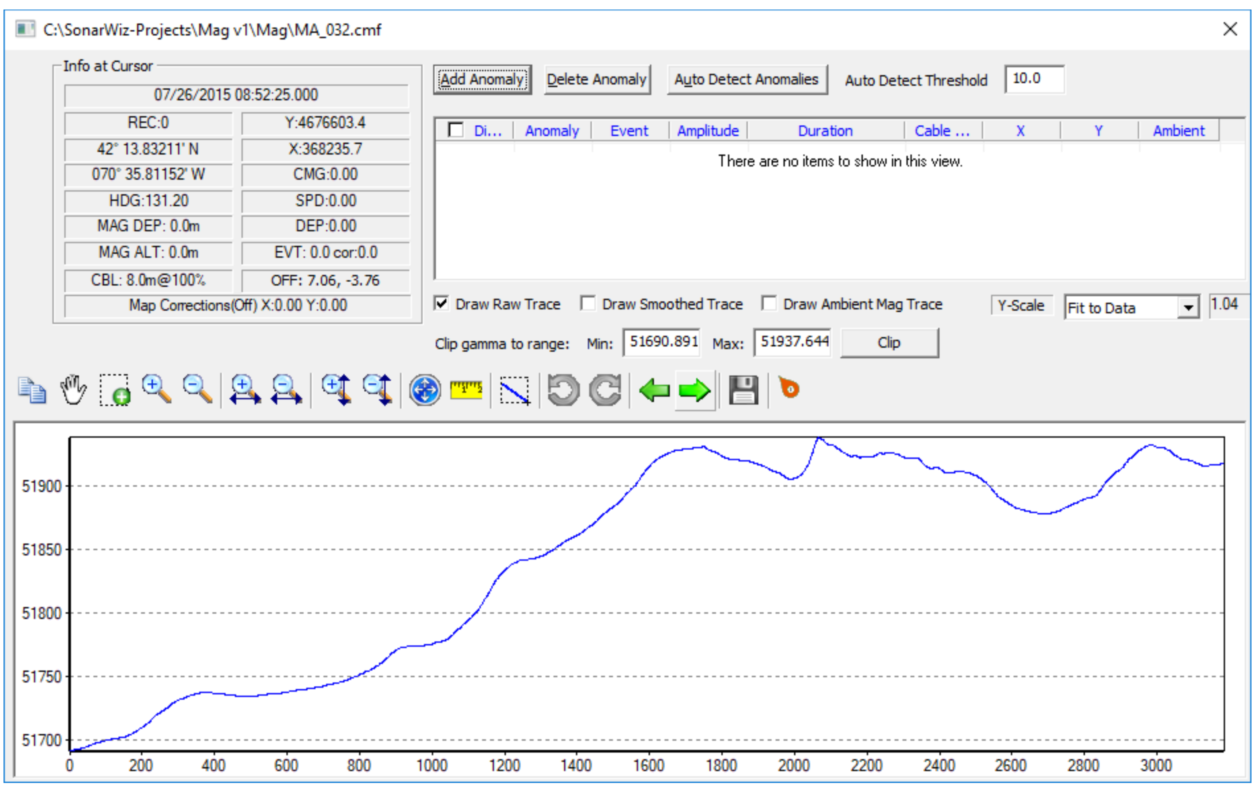

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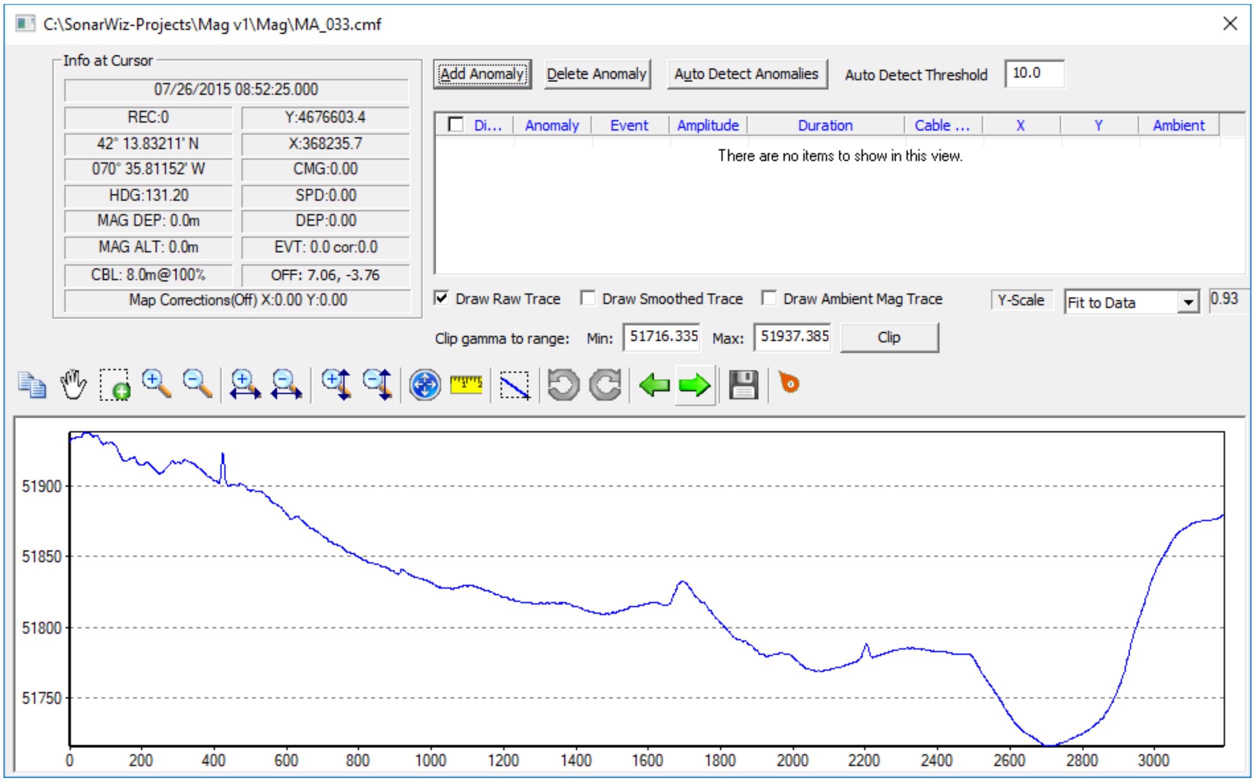


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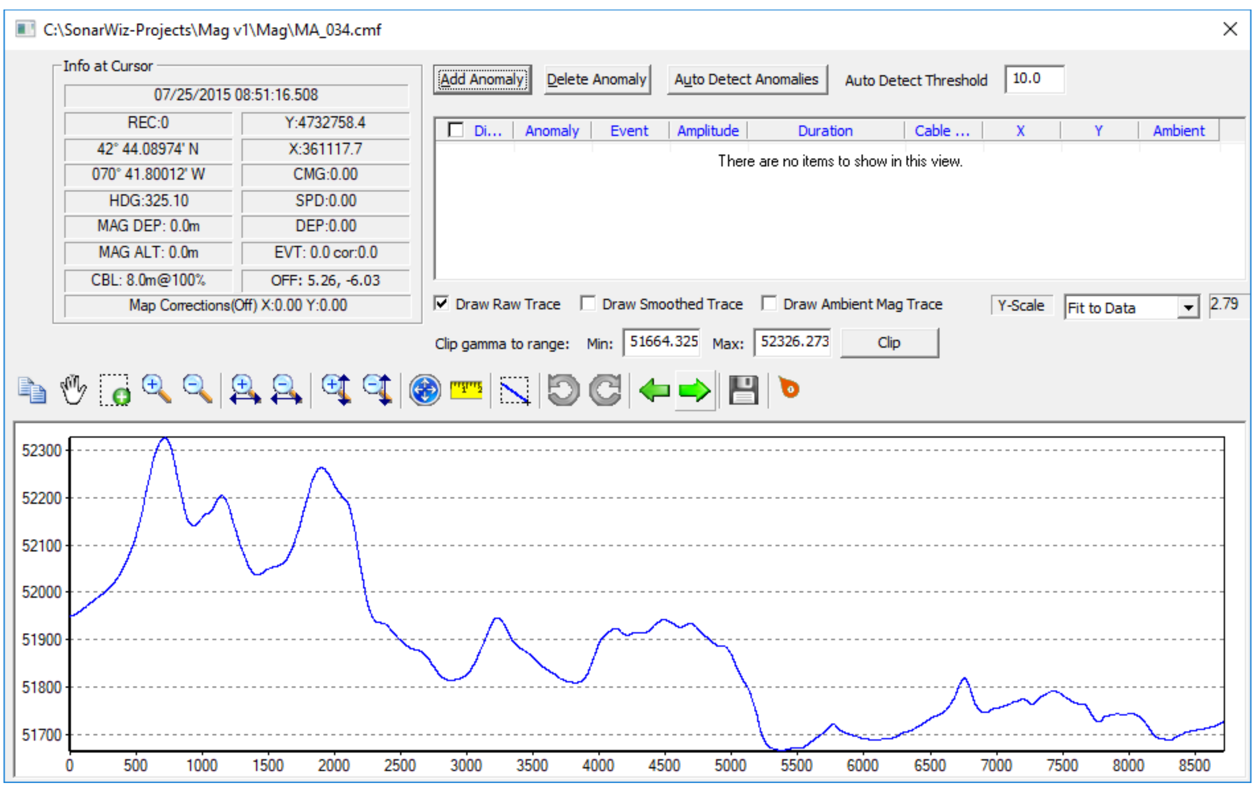

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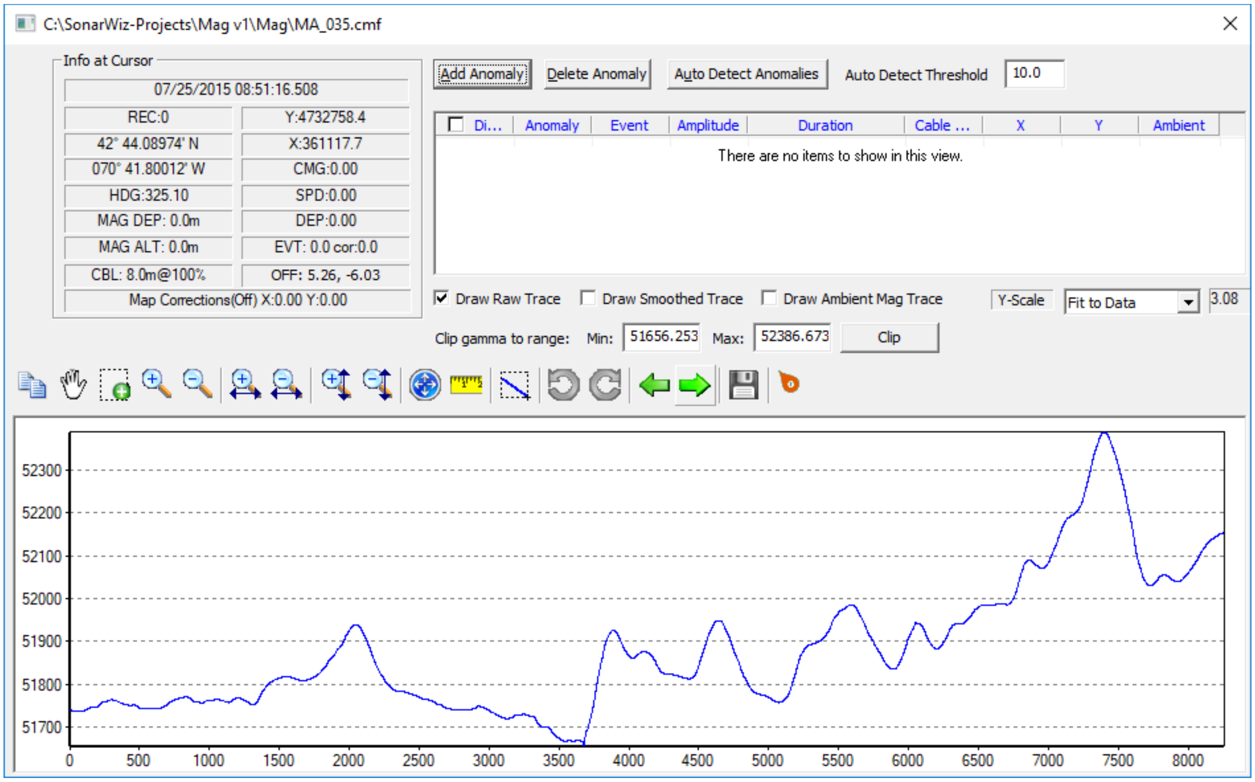


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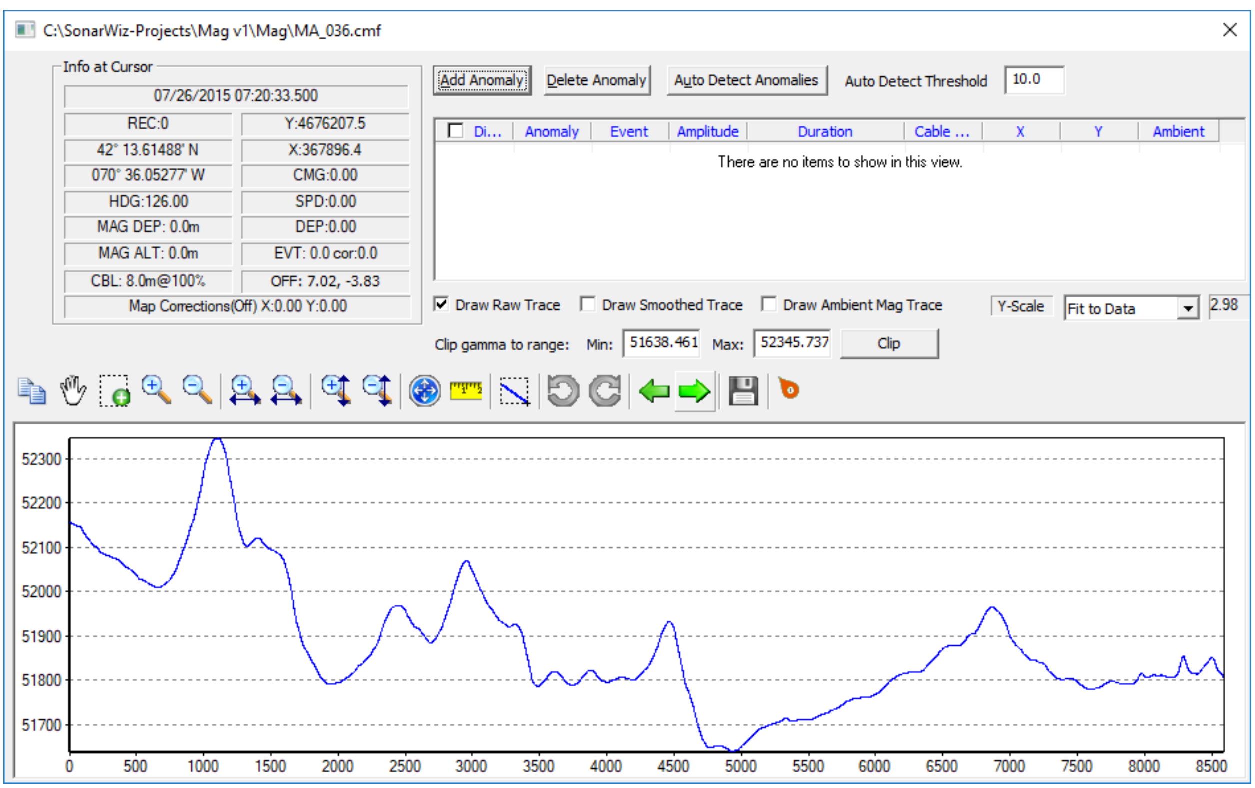

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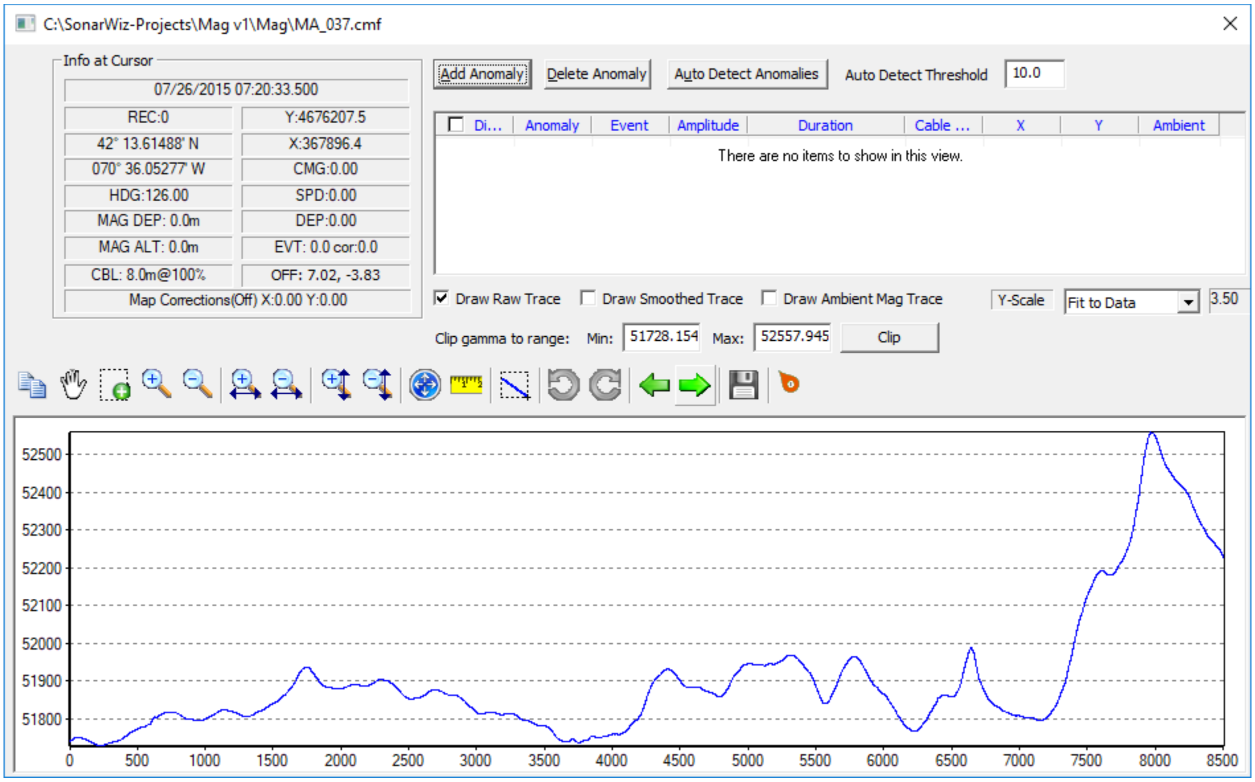


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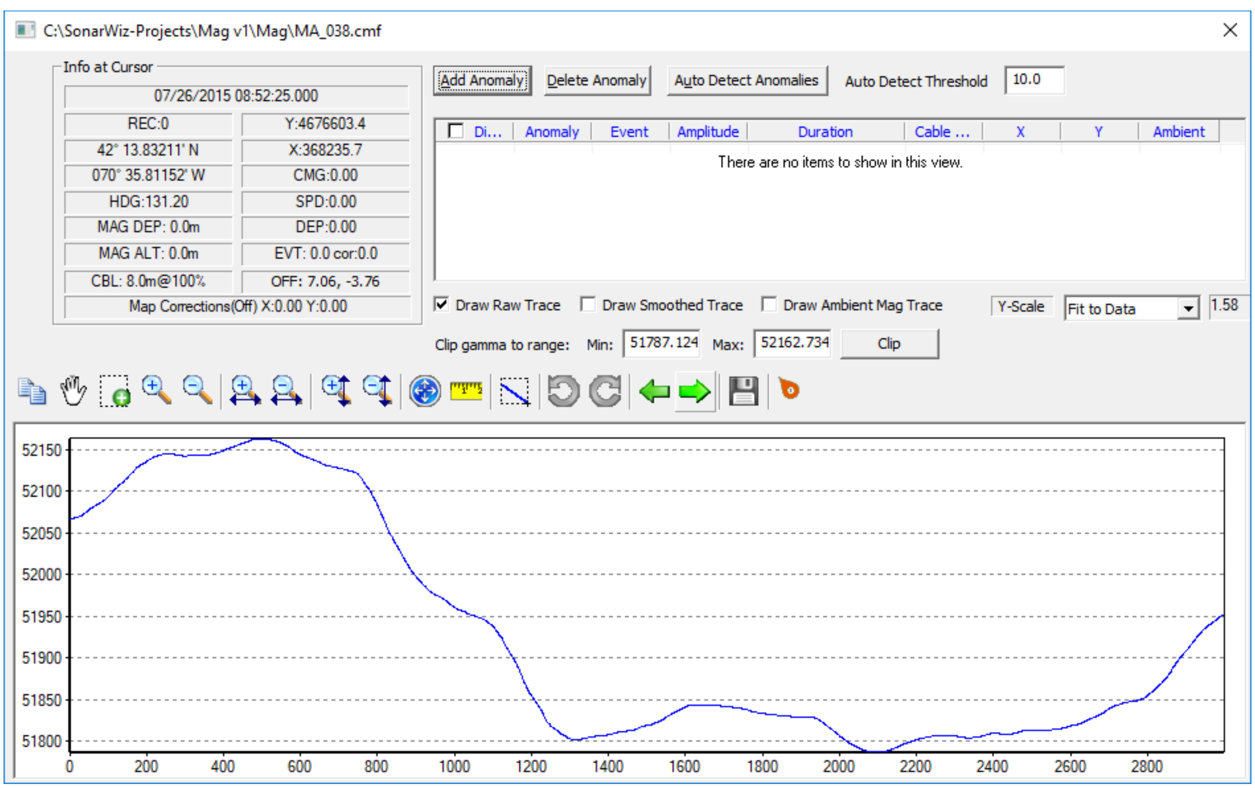

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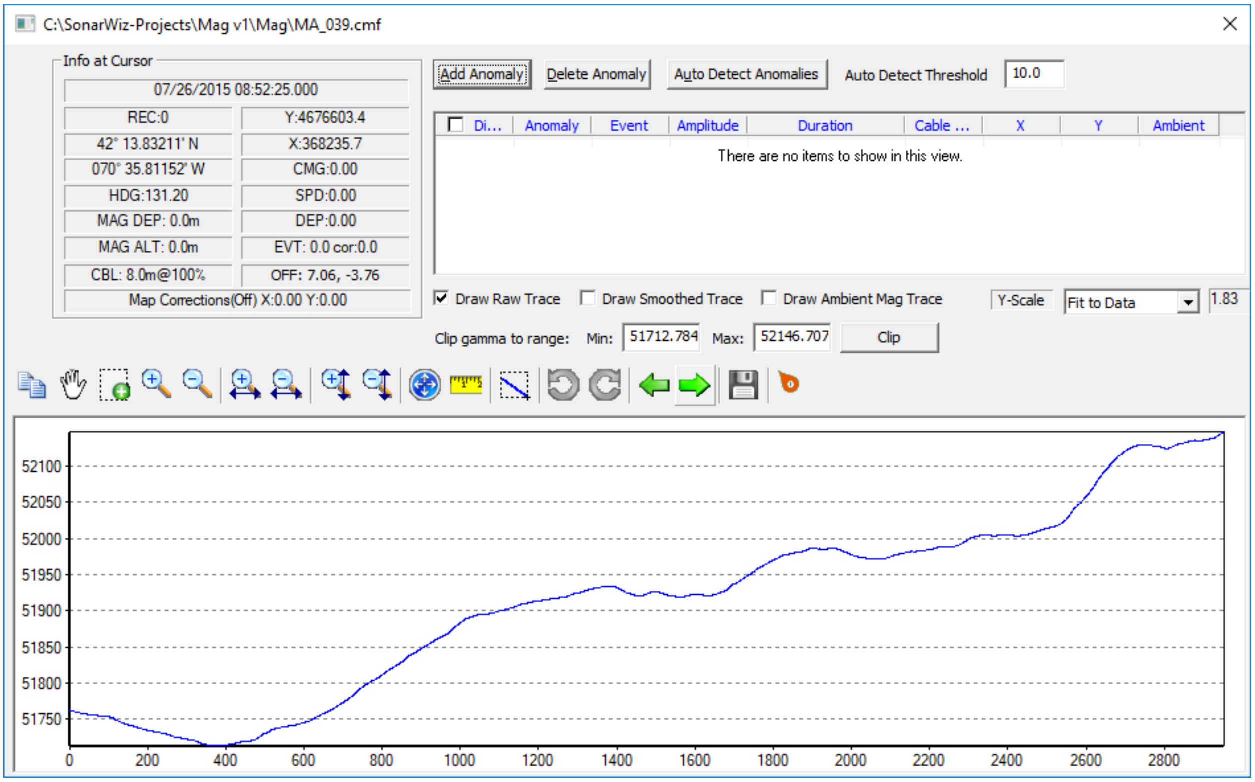
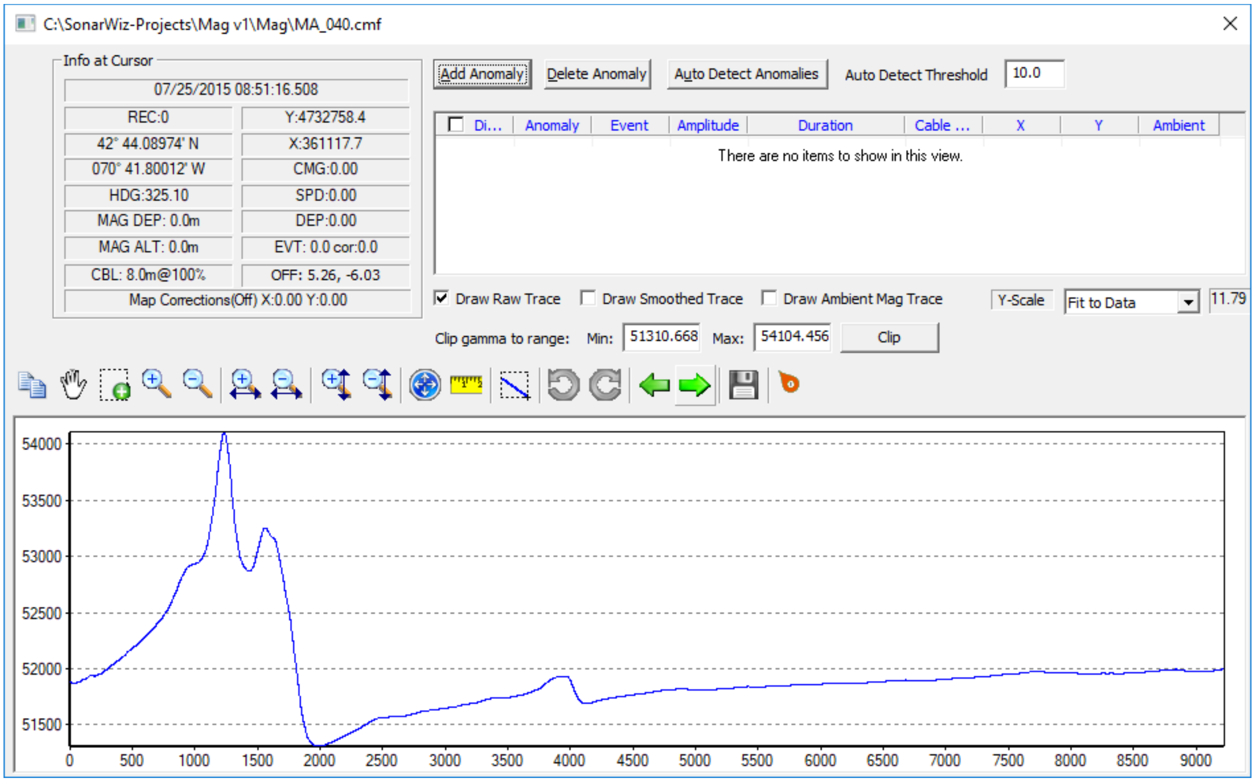



# MA_040 Plum Island



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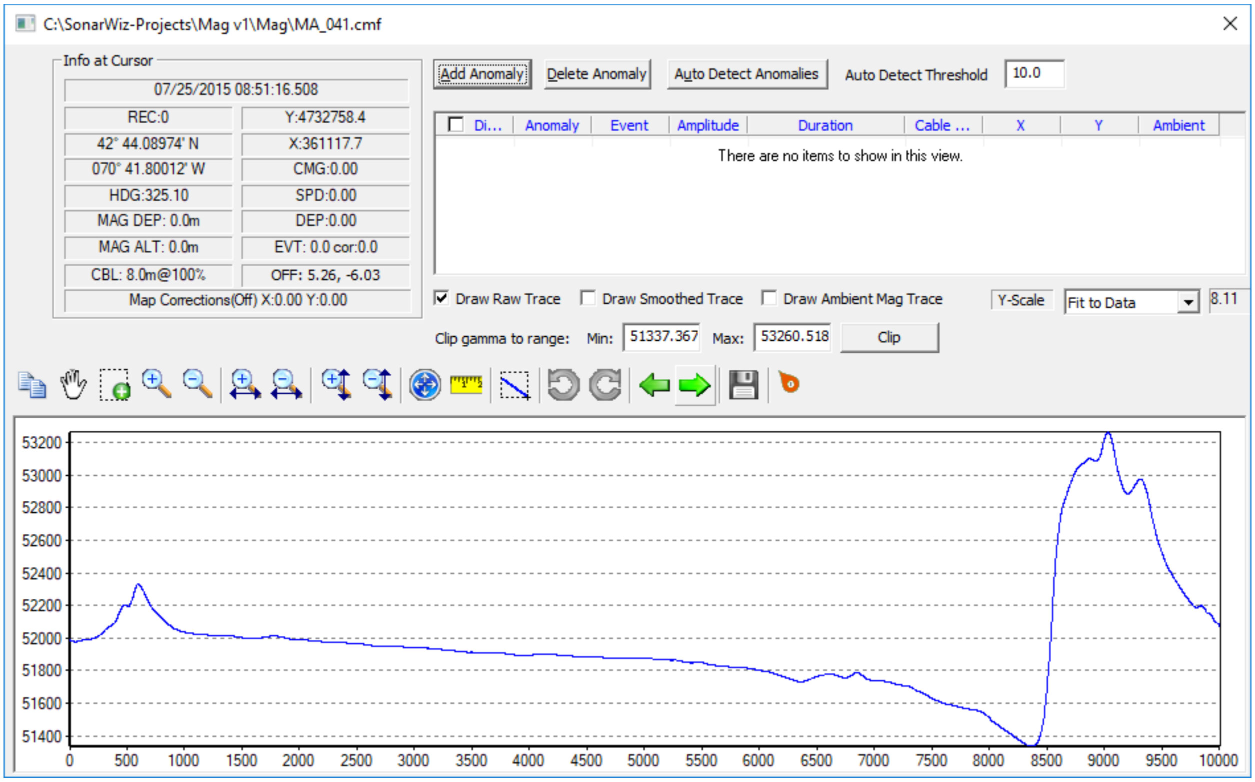


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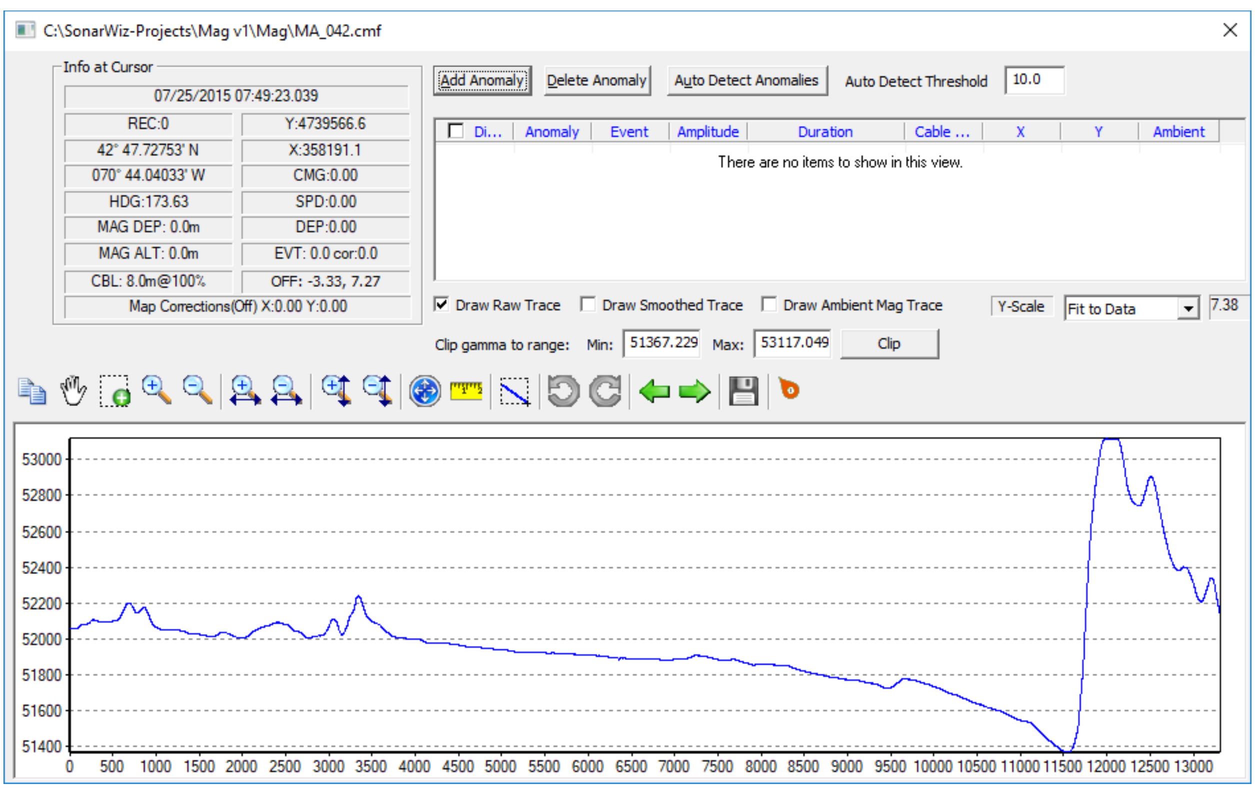

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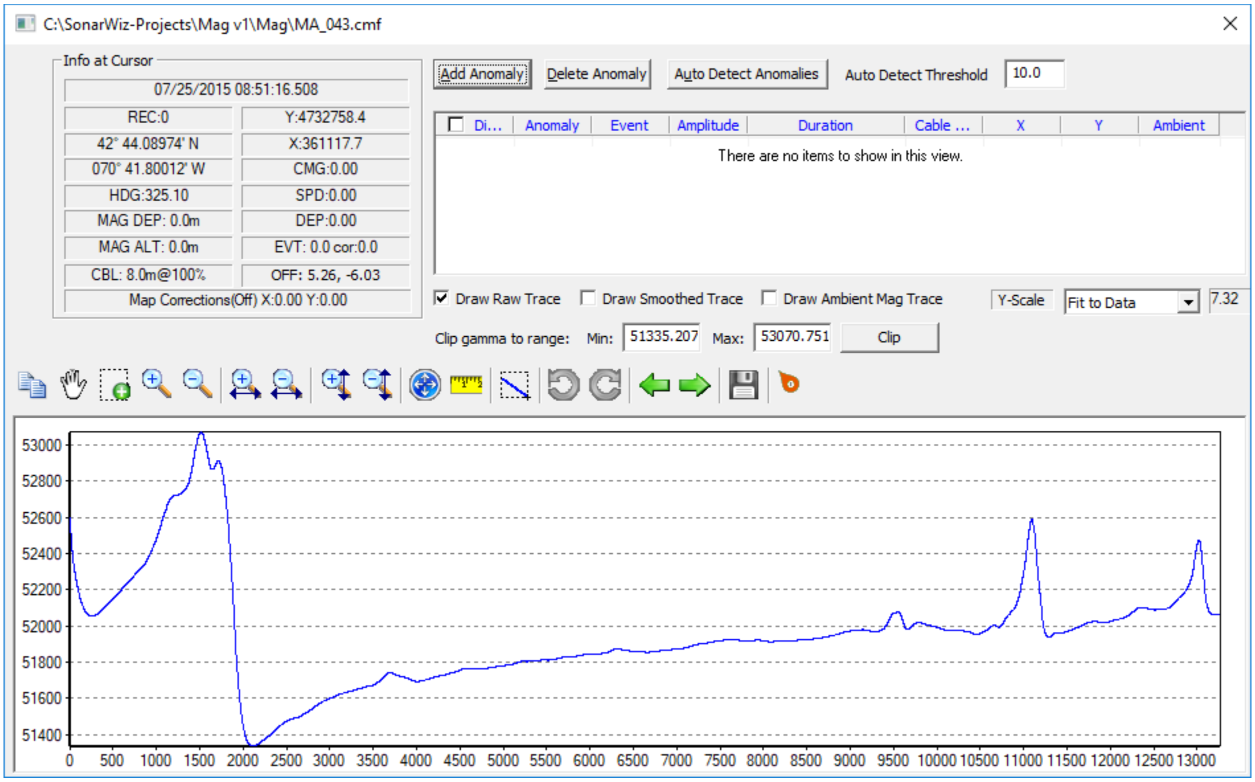


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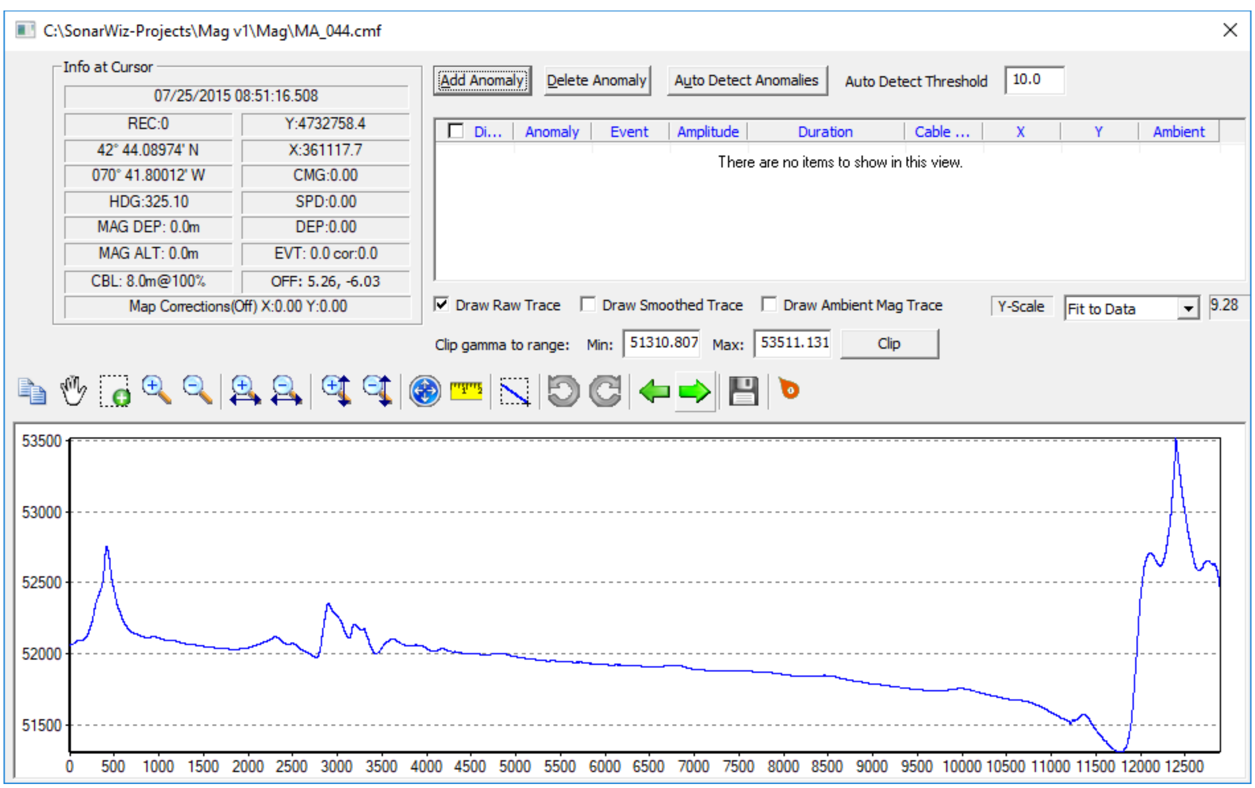

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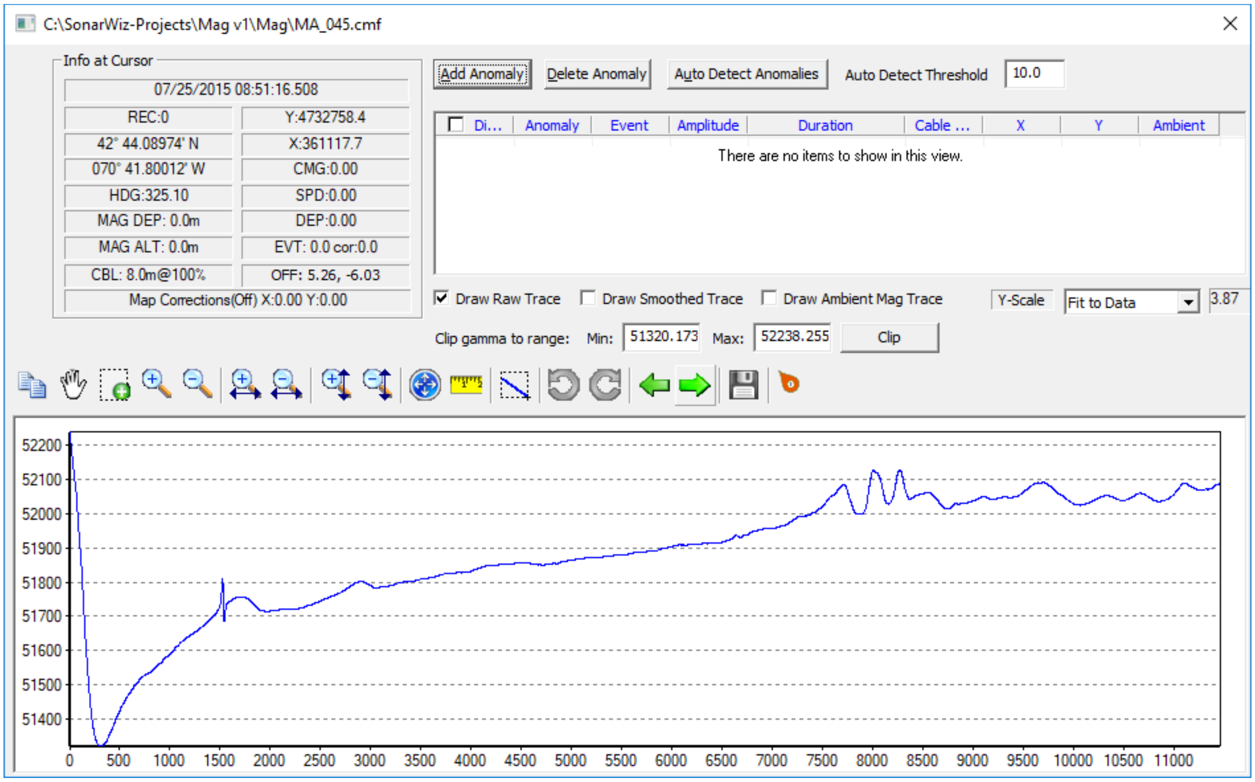


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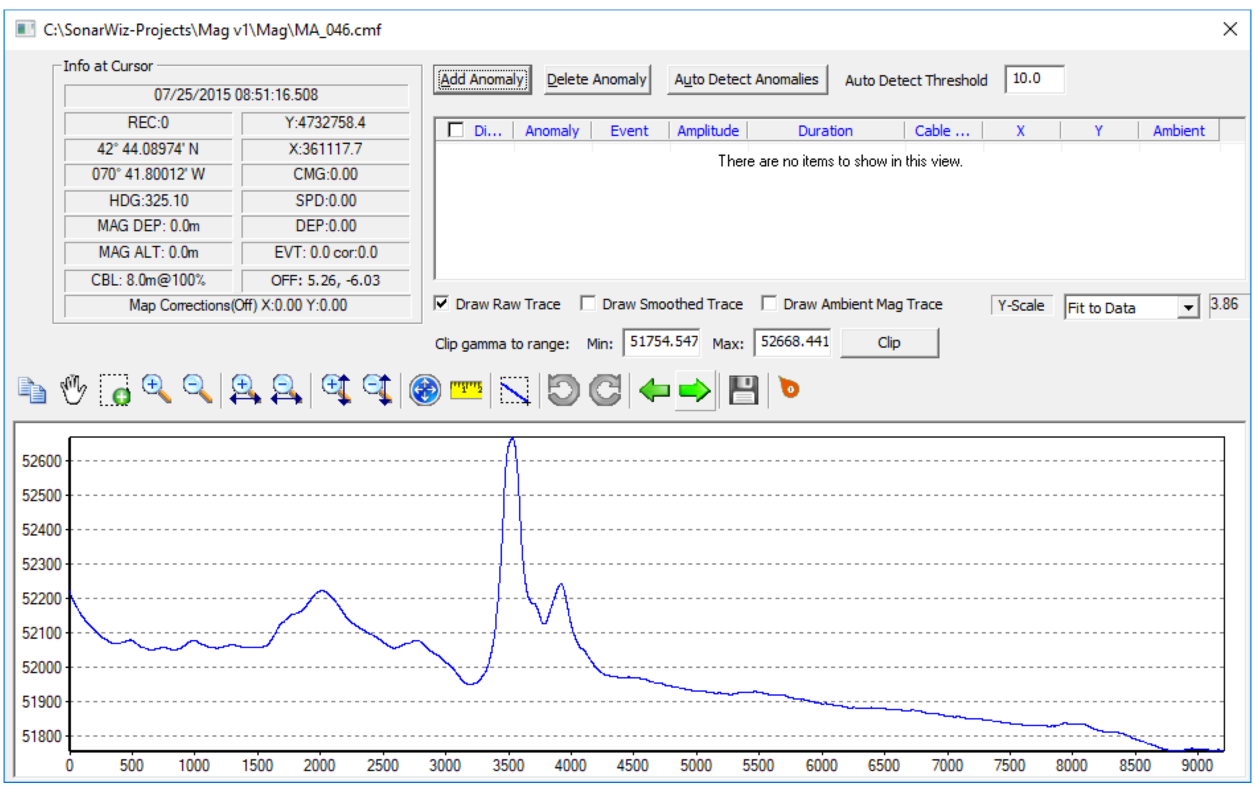

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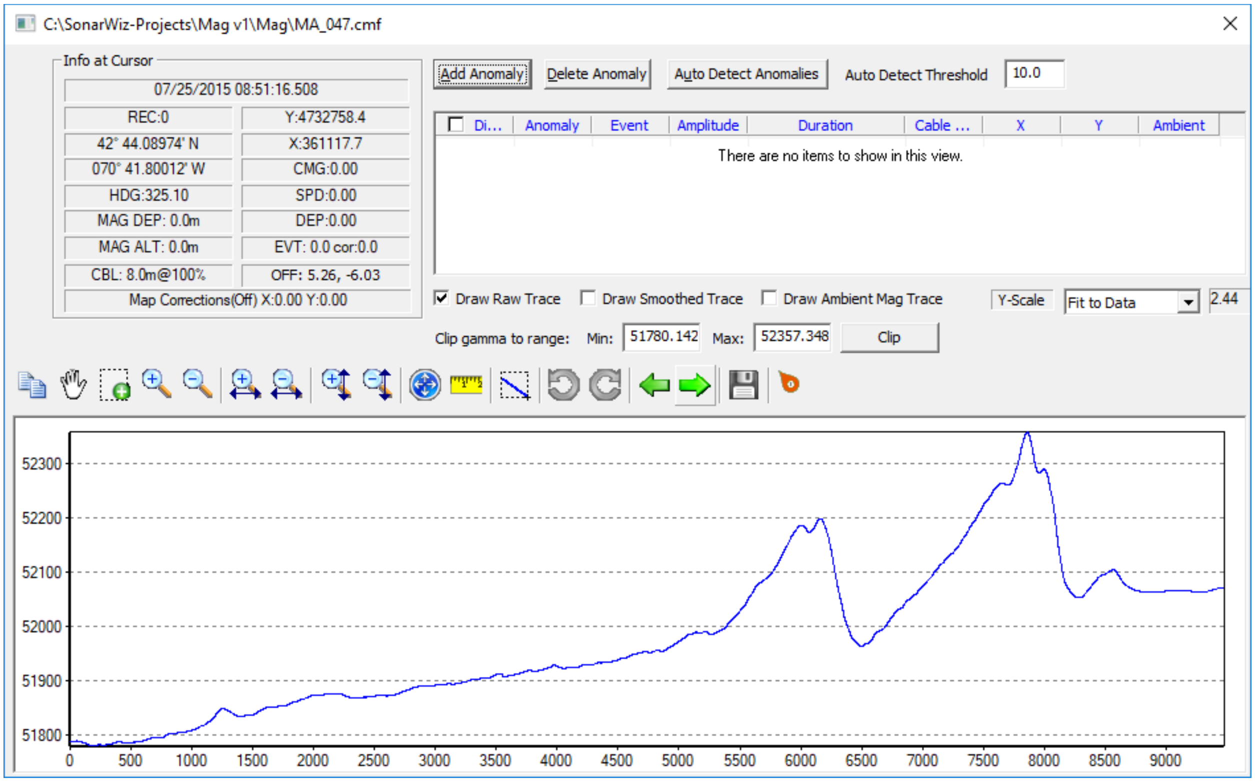


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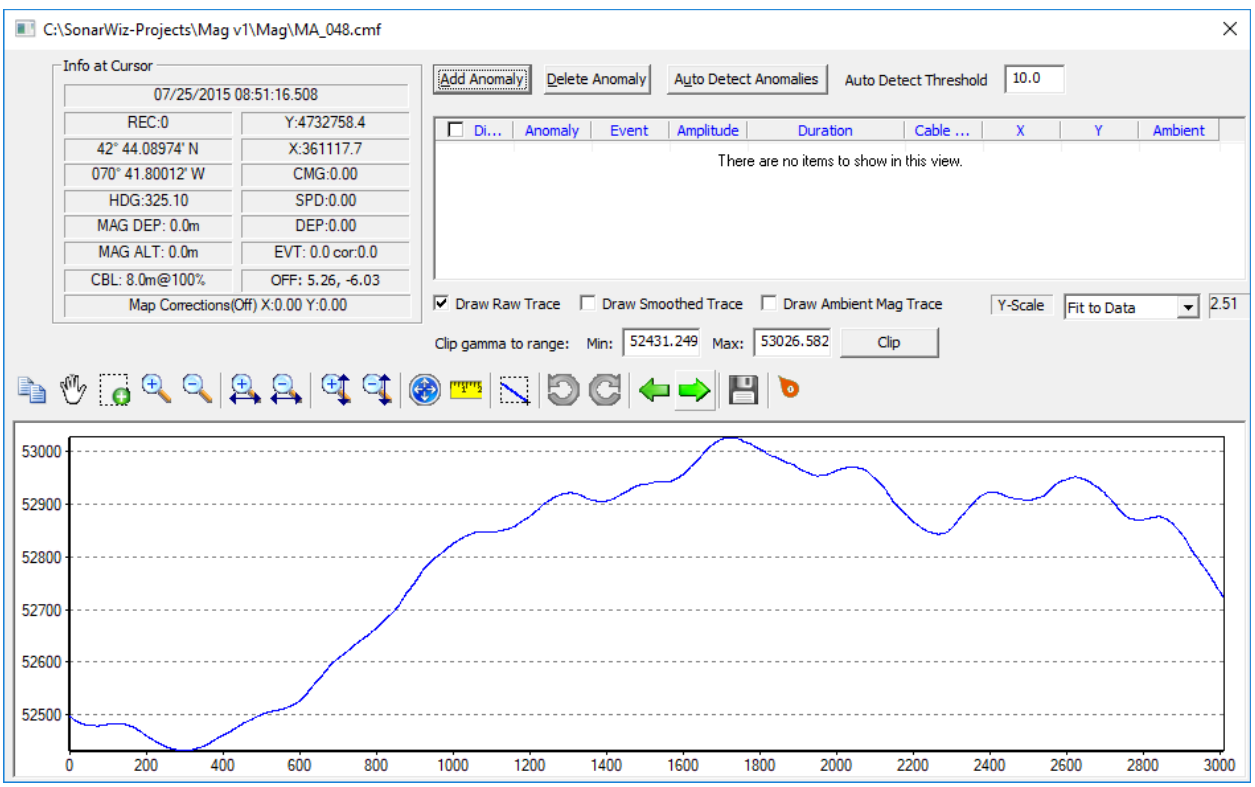

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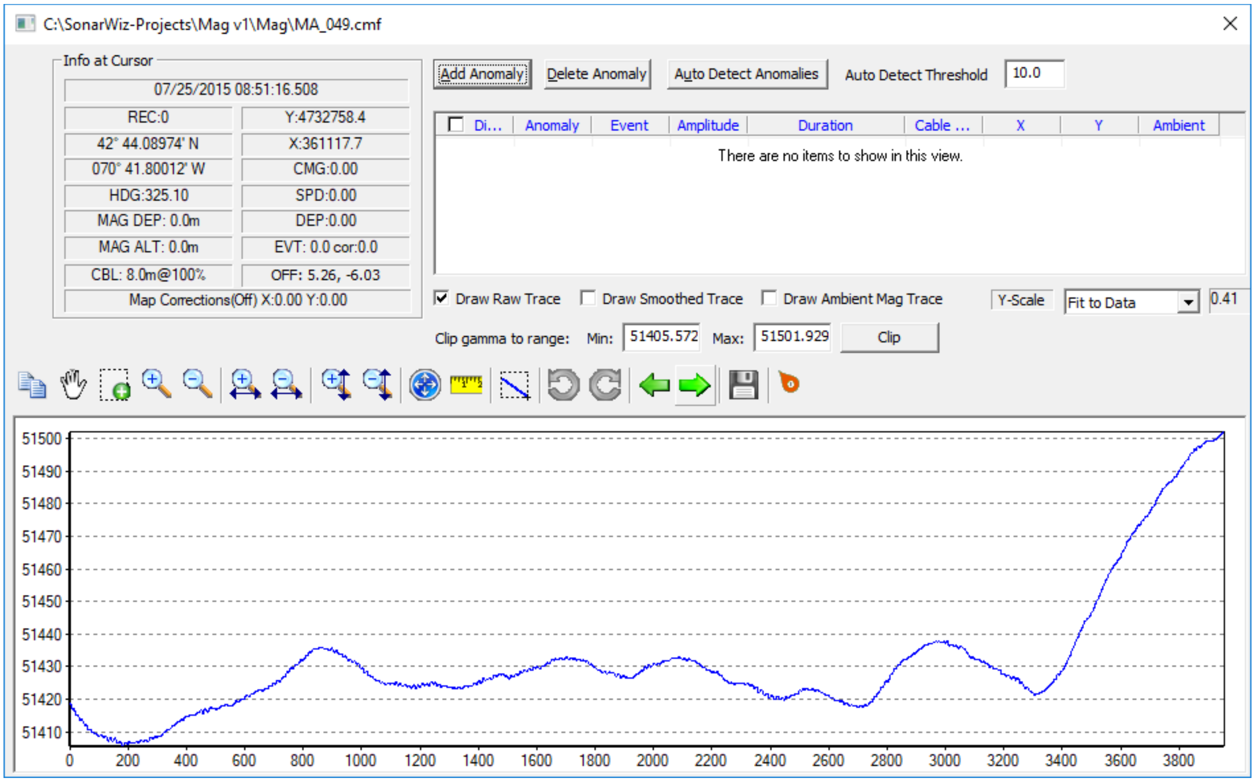


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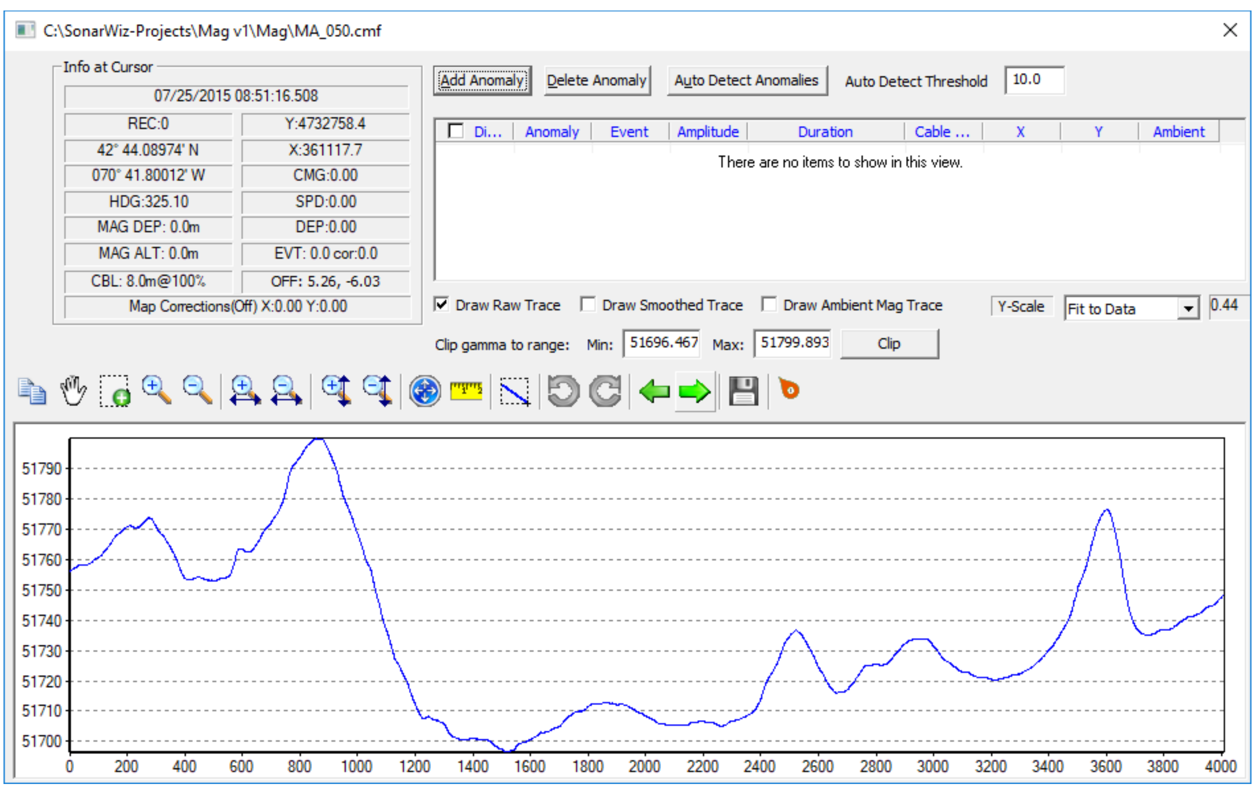

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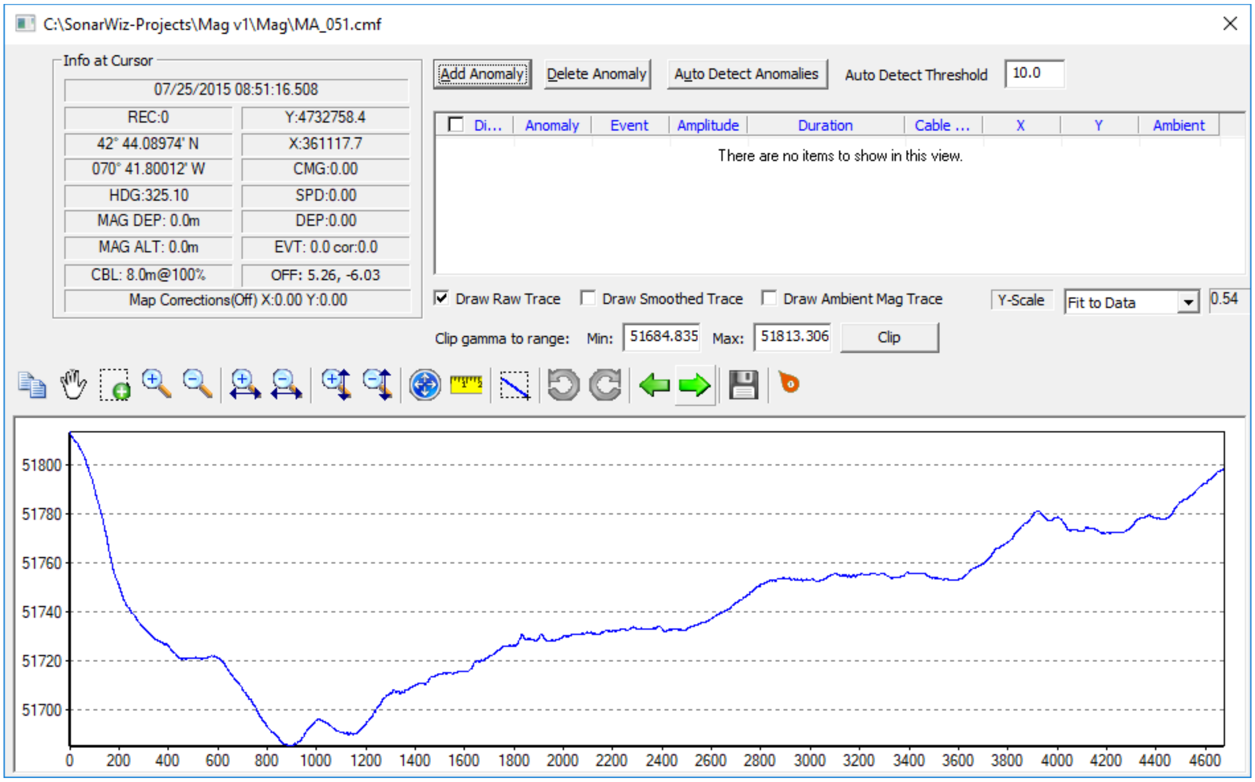


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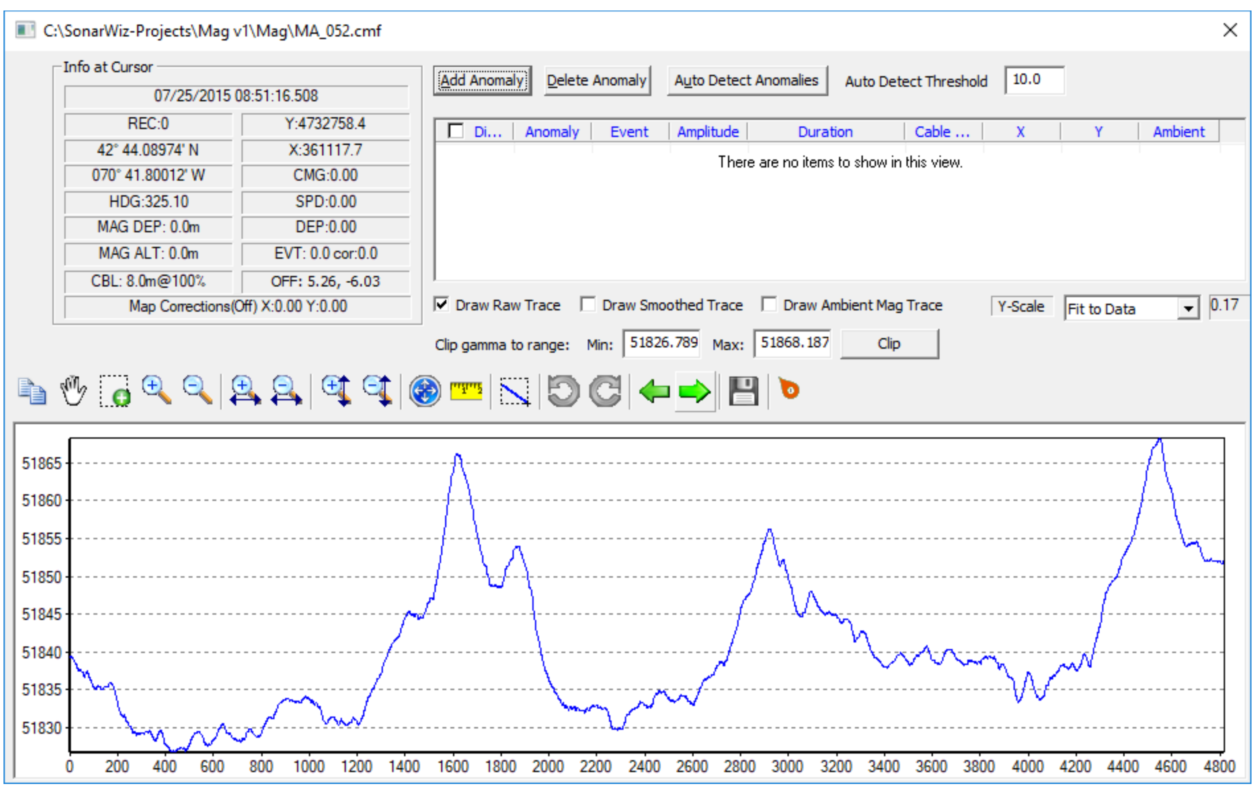

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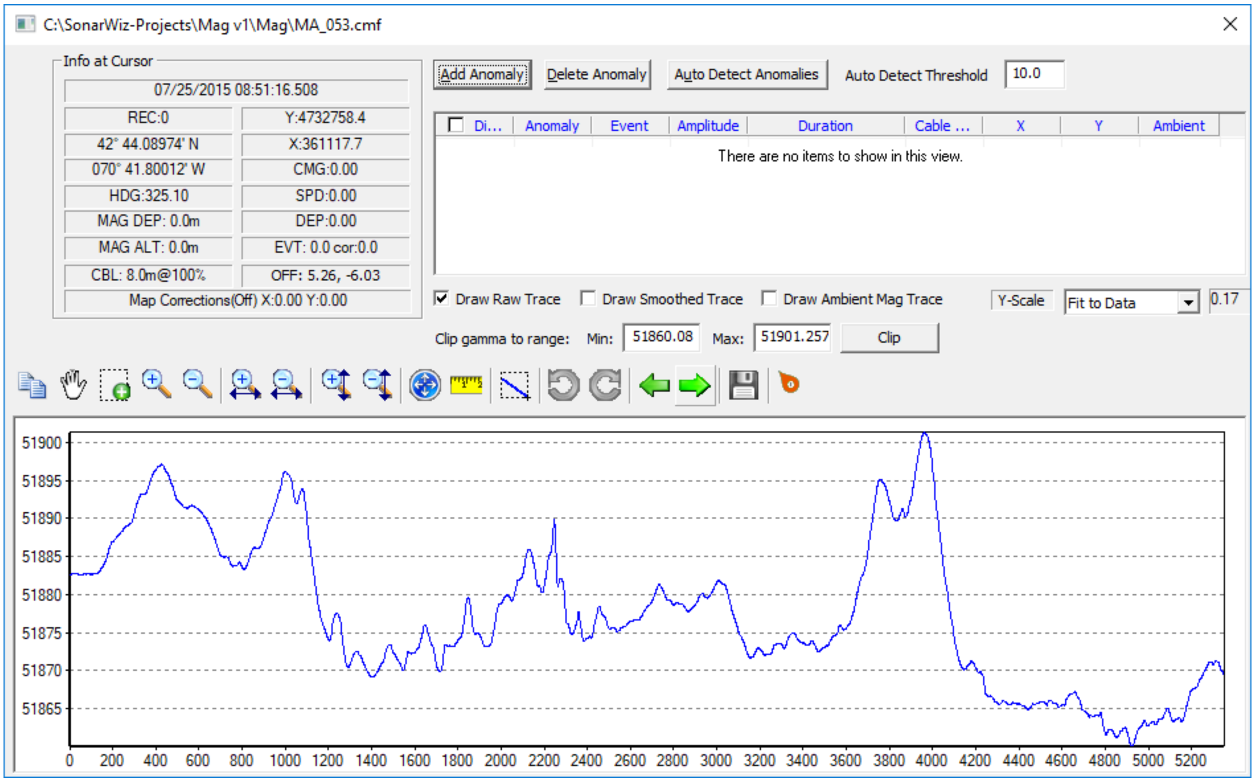


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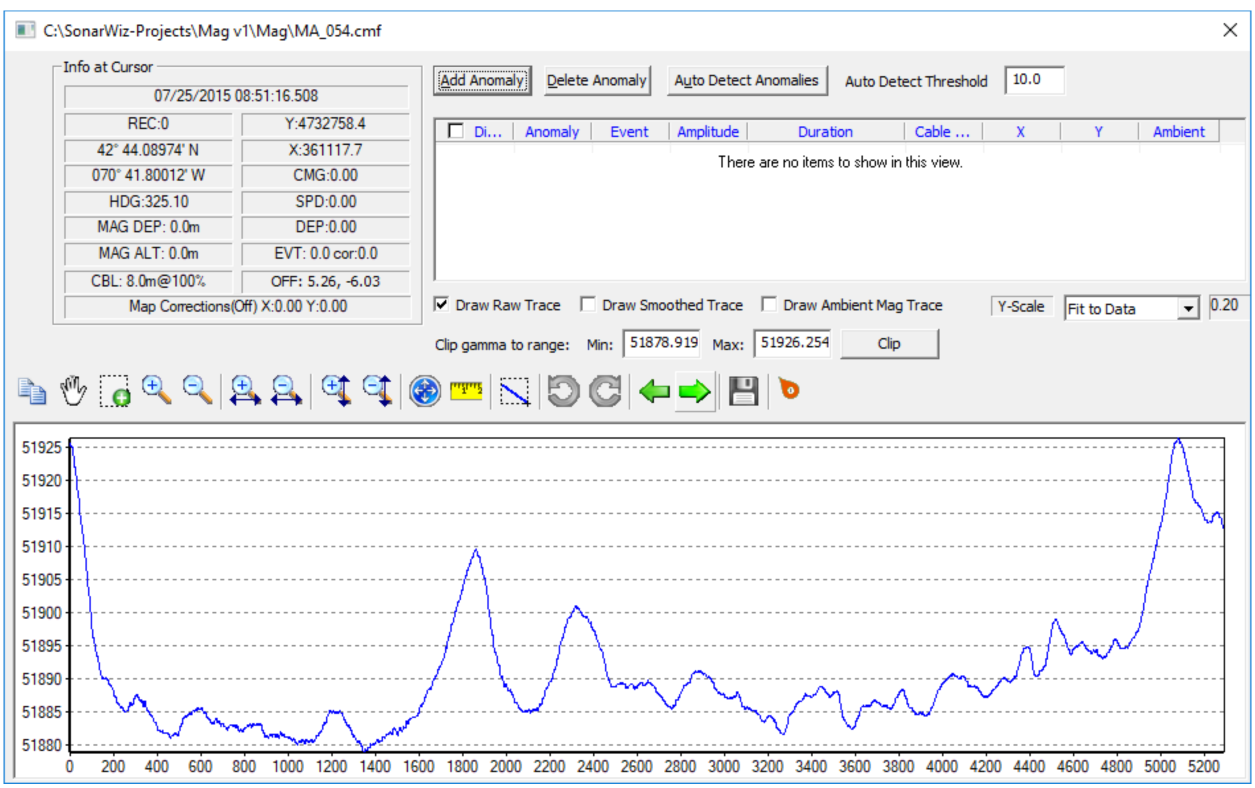

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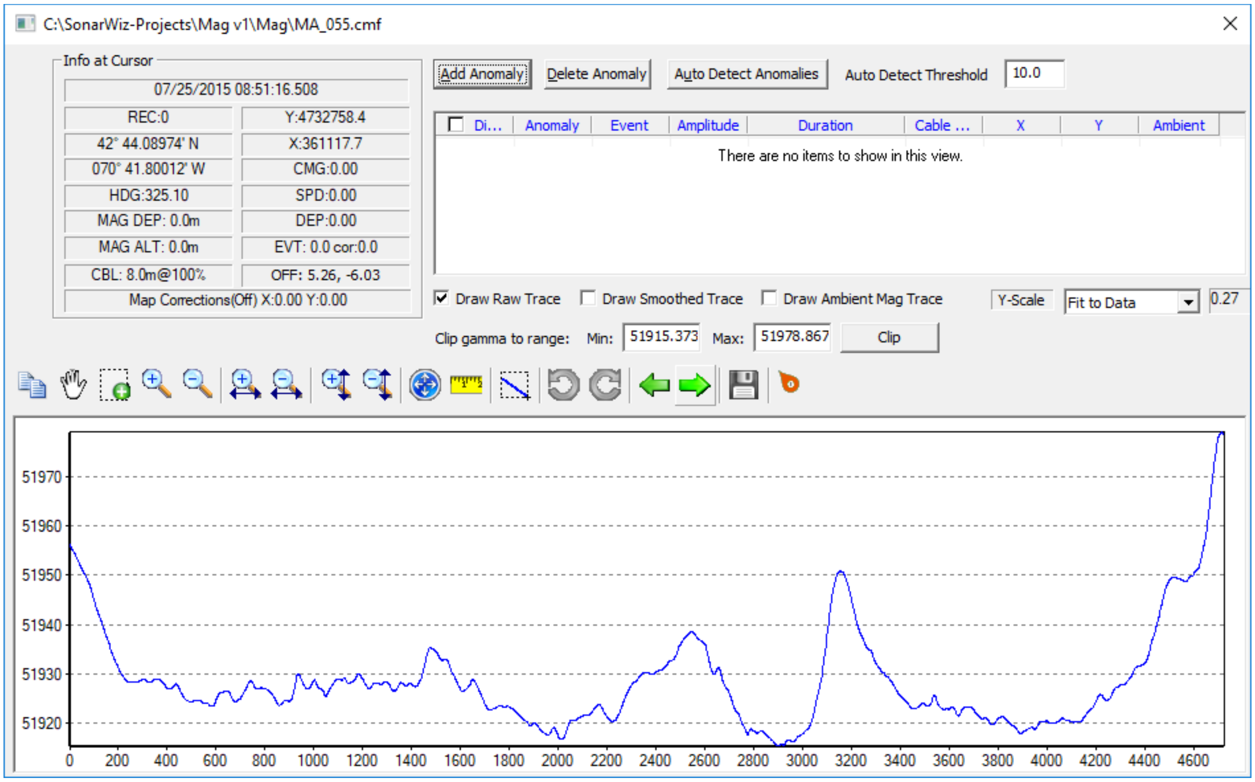
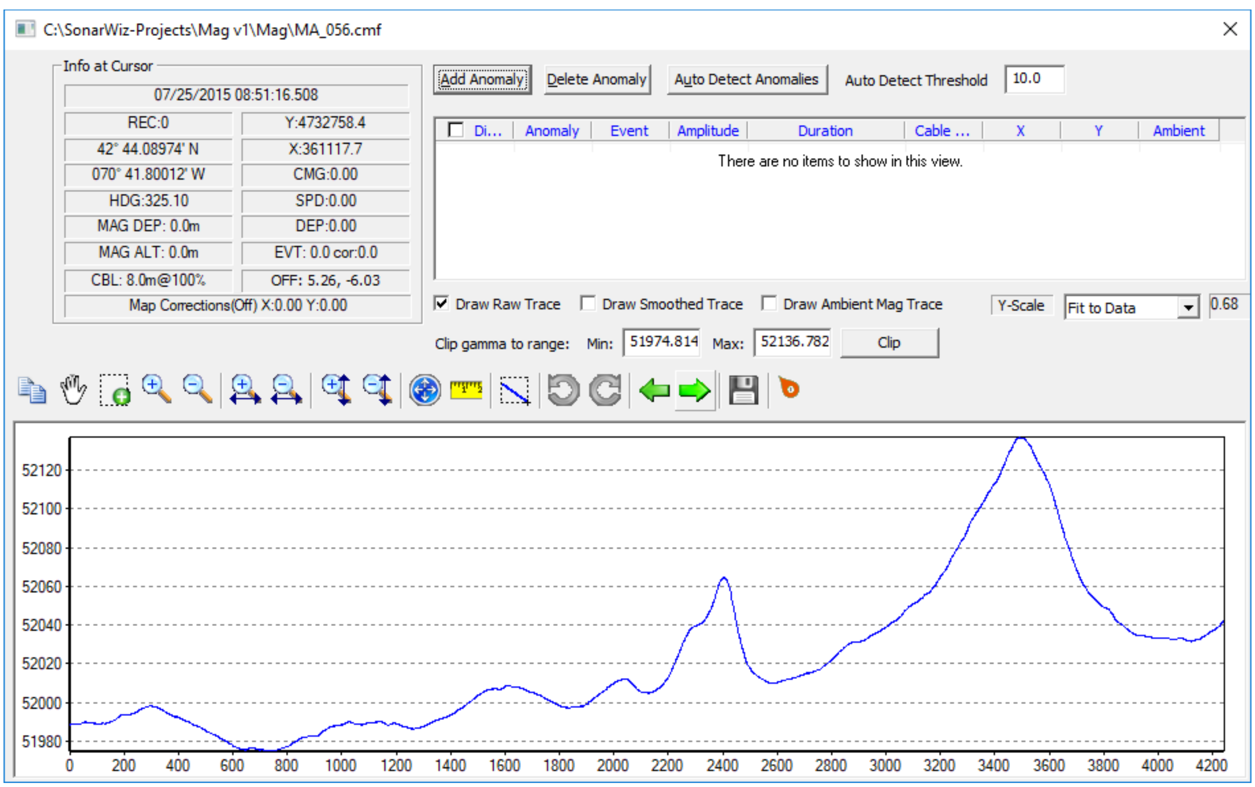
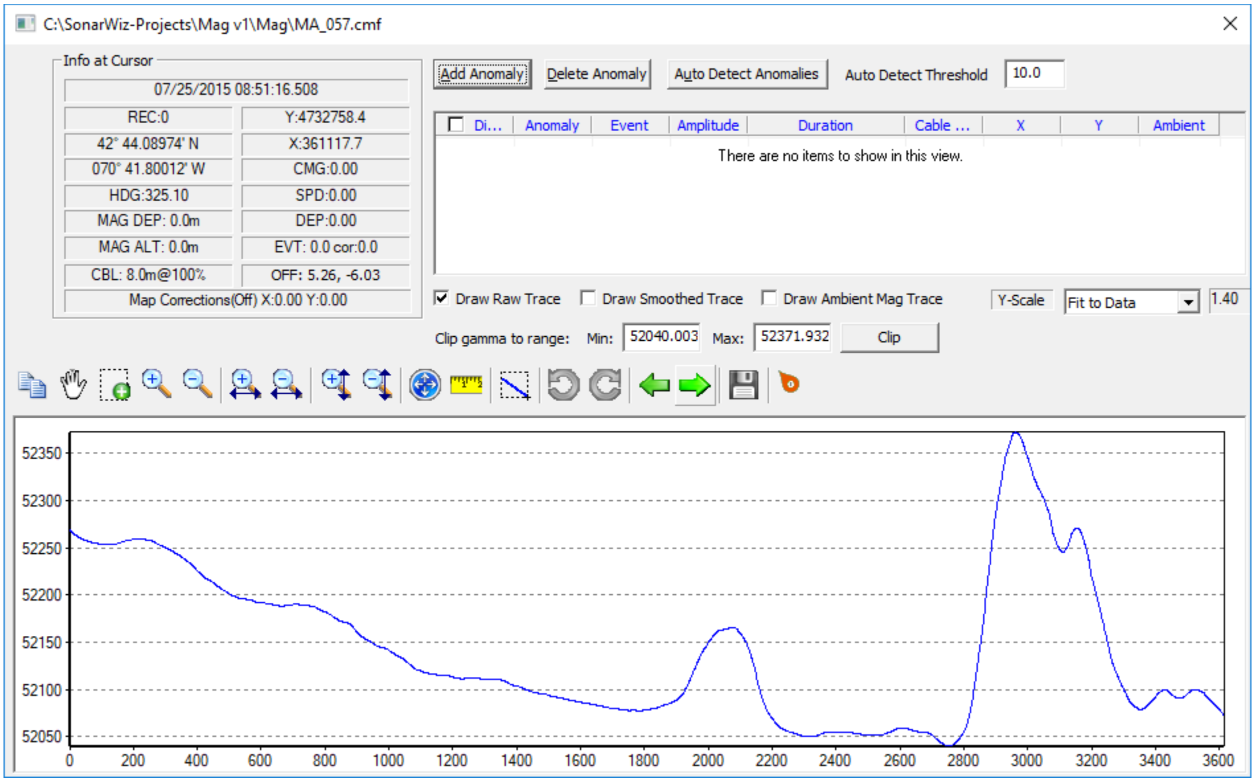


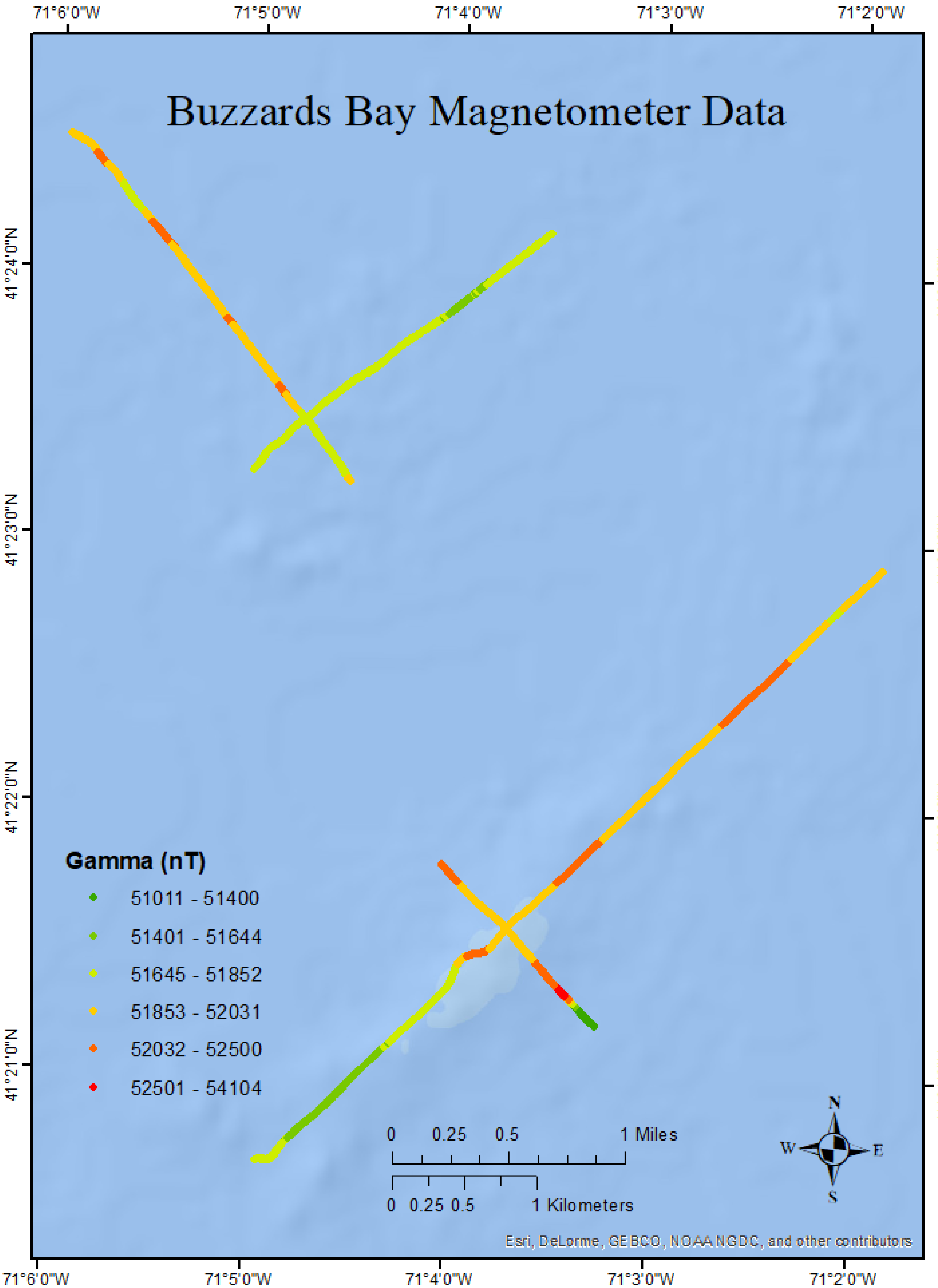

# MA_056 Plum Island



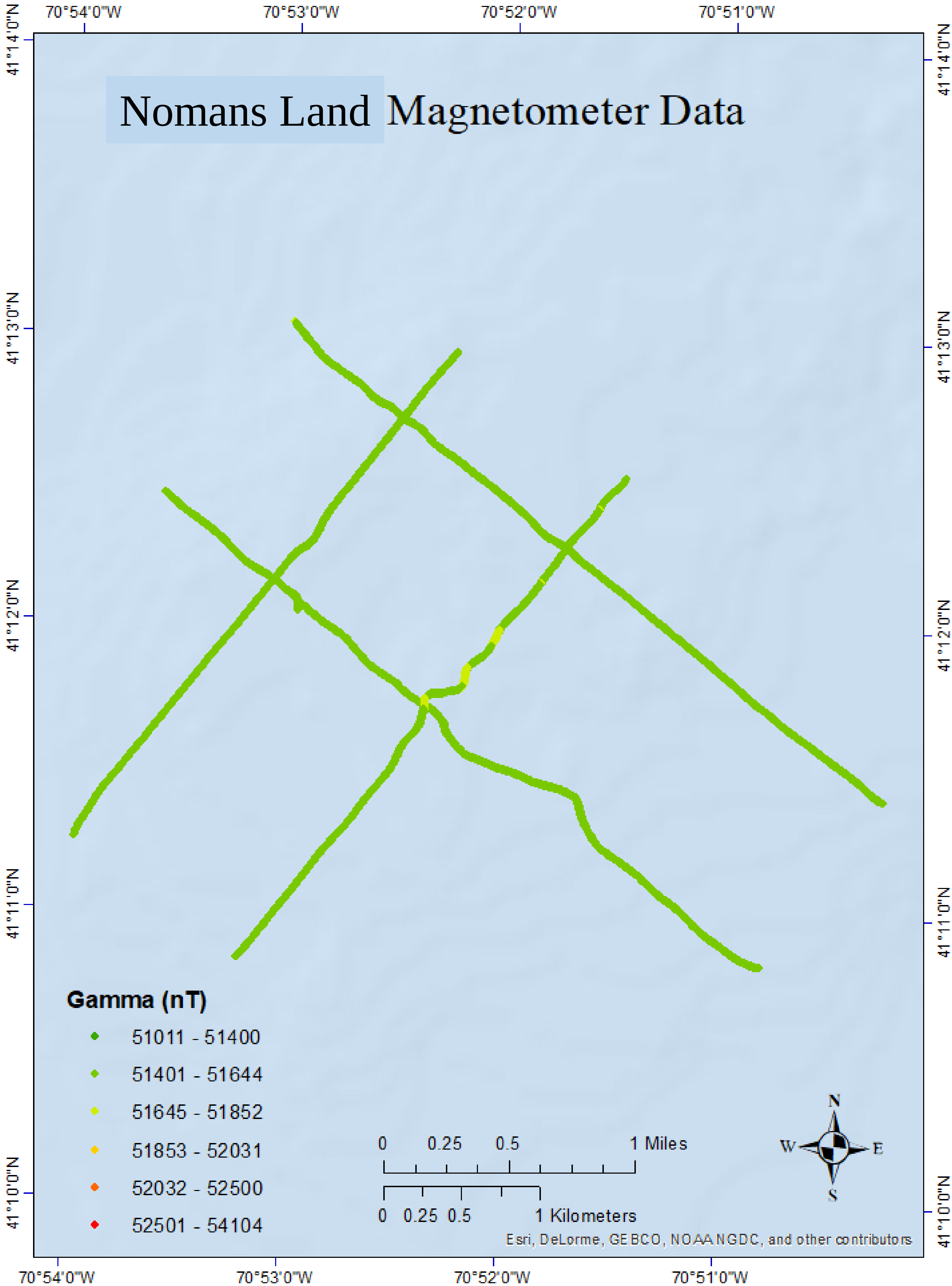
# MA_057 Plum Island



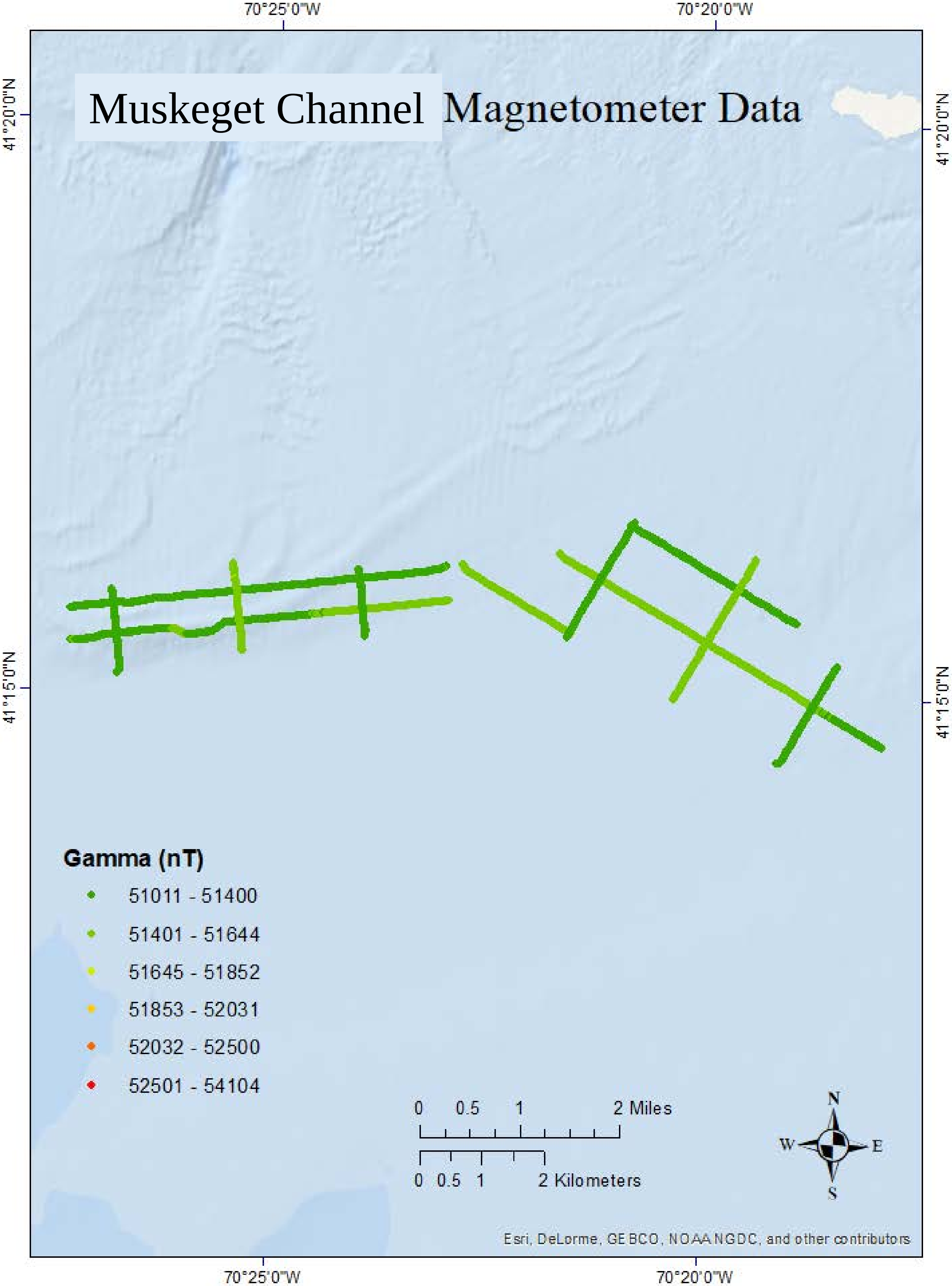
These are maps show magnetometer data from the BOEM Project. Data were collected in July 2015 off the coast of Massachusetts. Compiled by John Gartner, PhD, UMass Amherst, Department of Geosciences.



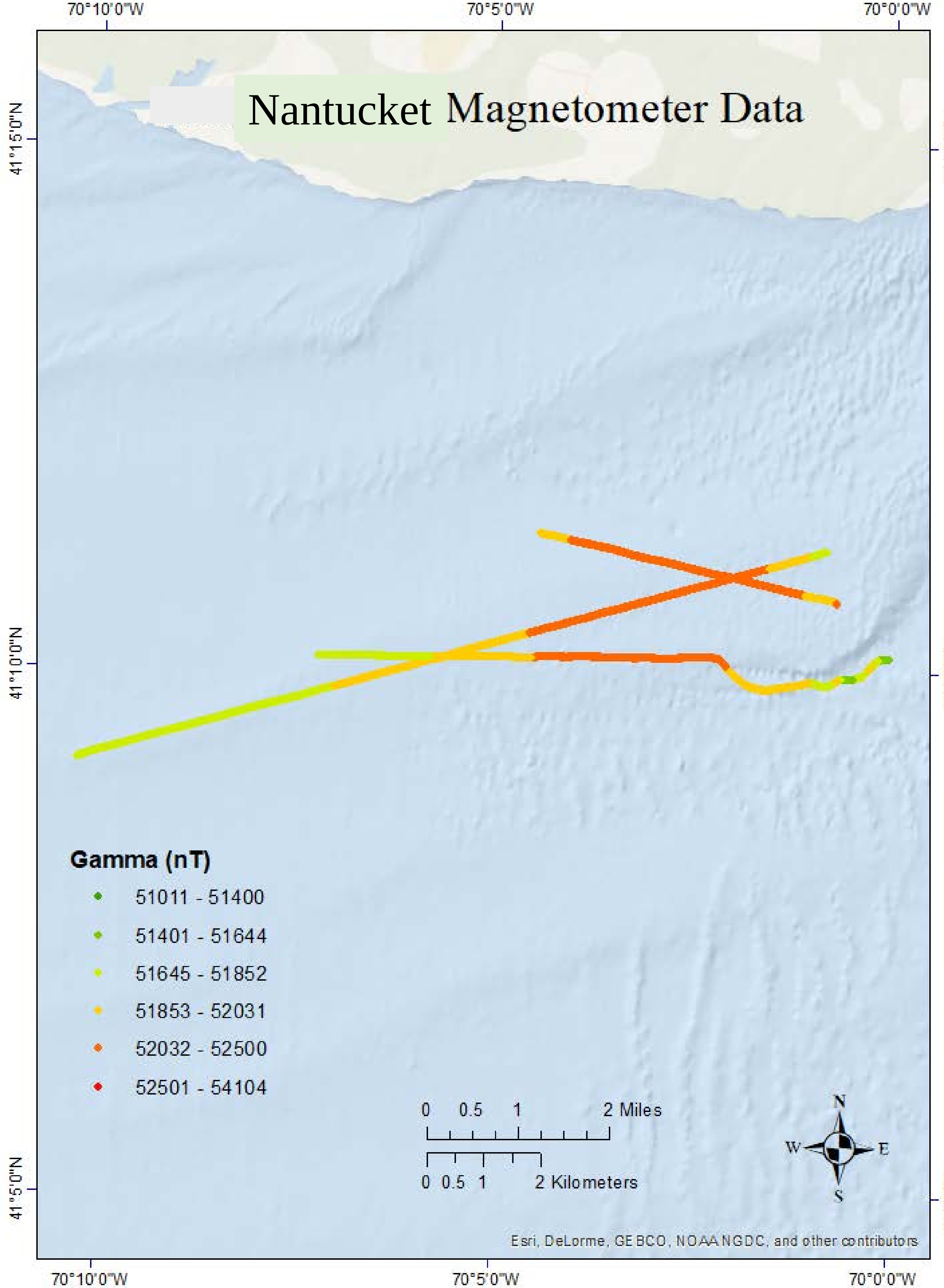
Buzzards Bay Magnetometer Data
71°6'0"W
71°5'0"W
71°4'0"W
71°3'0"W
71°2'0"W
41°24'0"N
41°23'0"N
41°22'0"N
41°21'0"N
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.25 0.5 1 Miles
0 0.25 0.5 1 Kilometers
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



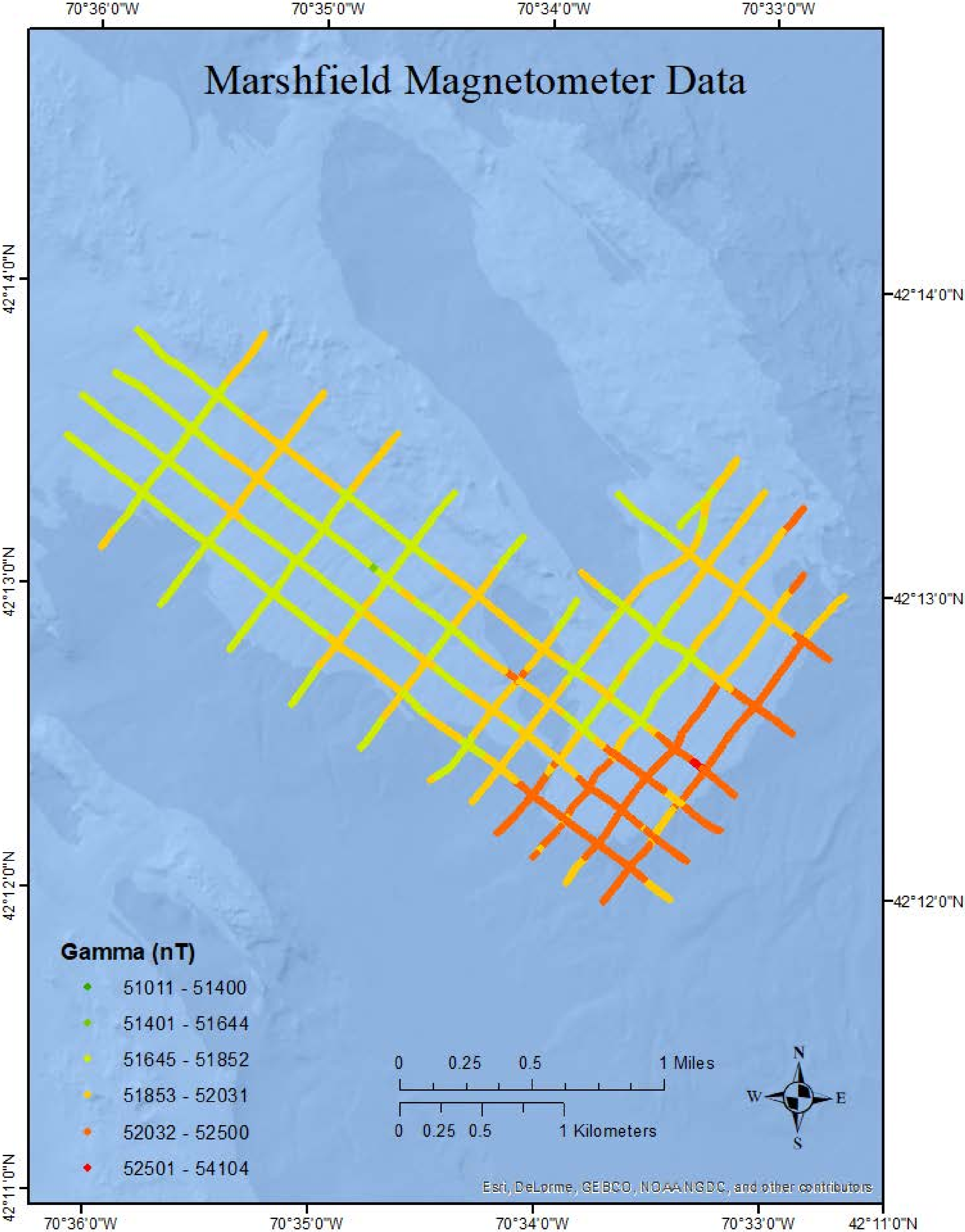
Nomans Land Magnetometer Data
70°54'0"W
70°53'0"W
70°52'0"W
70°51'0"W
41°14'0"N
41°13'0"N
41°12'0"N
41°11'0"N
41°10'0"N
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.25 0.5 1 Miles
0 0.25 0.5 1 Kilometers
N
S
W
E
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



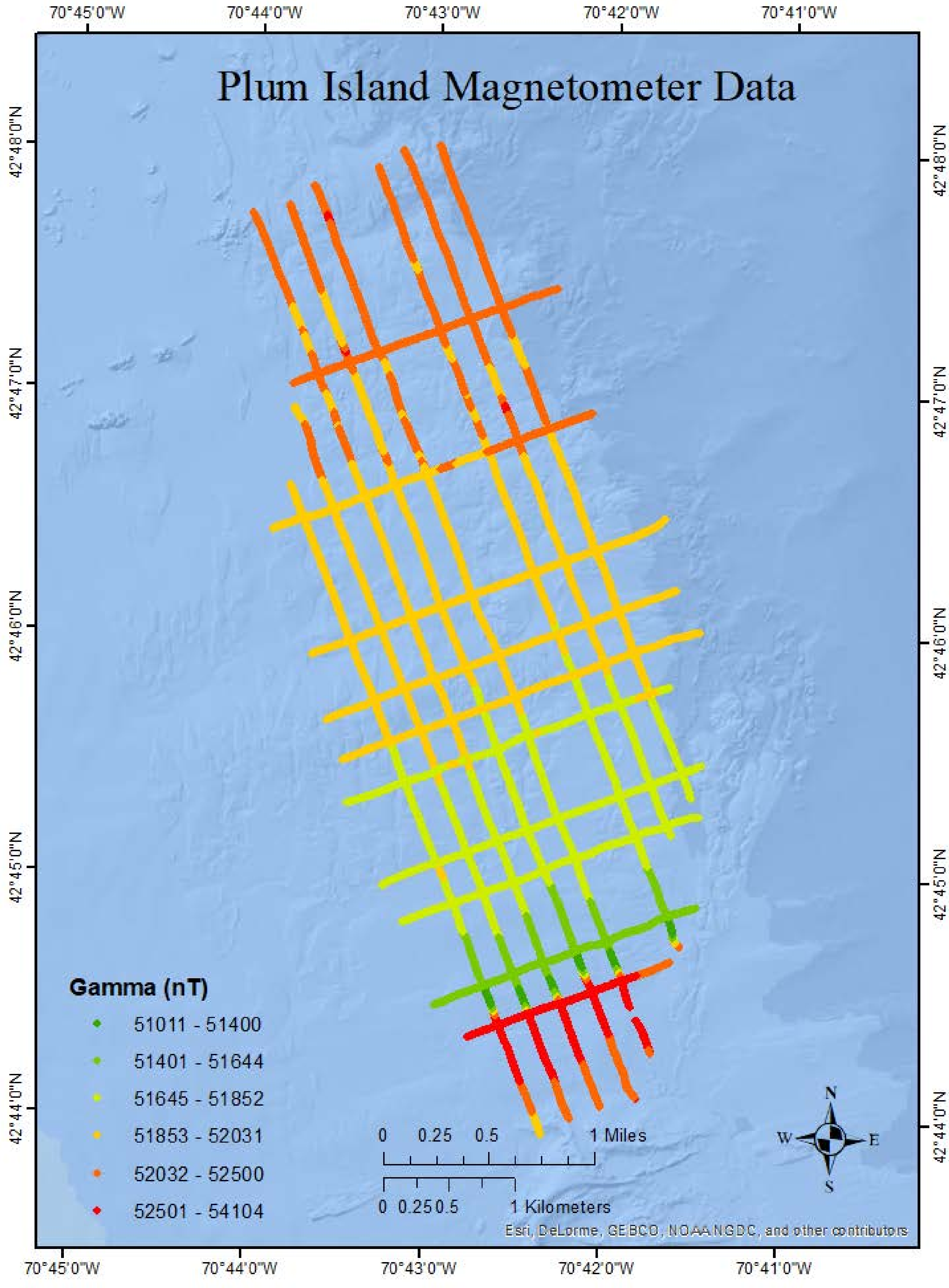
70°25'0"W
70°20'0"W
41°20'0"N
41°15'0"N
Muskeget Channel Magnetometer Data
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.5 1 2 Miles
0 0.5 1 2 Kilometers
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



Nantucket Magnetometer Data
70°10'0"W
70°5'0"W
70°0'0"W
41°15'0"N
41°10'0"N
41°5'0"N
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.5 1 2 Miles
0 0.5 1 2 Kilometers
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



Marshfield Magnetometer Data
70°36'0"W
70°35'0"W
70°34'0"W
70°33'0"W
42°14'0"N
42°13'0"N
42°12'0"N
42°11'0"N
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.25 0.5 1 Miles
0 0.25 0.5 1 Kilometers
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



Plum Island Magnetometer Data
70°45'0"W
70°44'0"W
70°43'0"W
70°42'0"W
70°41'0"W
42°48'0"N
42°47'0"N
42°46'0"N
42°45'0"N
42°44'0"N
Gamma (nT)
51011 - 51400
51401 - 51644
51645 - 51852
51853 - 52031
52032 - 52500
52501 - 54104
0 0.25 0.5 1 Miles
0 0.25 0.5 1 Kilometers
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors