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MAPPING DATA ACQUISITION AND PROCESSING SUMMARY REPORT

CRUISE EX-12-06 Northeast and Mid-Atlantic Canyons Exploration (Mapping)

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1. Introduction

The NOAA Office of Ocean Exploration and Research (OER) is the only federal program dedicated to exploring our deep ocean, closing the prominent gap in our basic understanding of U.S. deep waters and seafloor and delivering the ocean information needed to strengthen the economy, health, and security of our nation.

Using the latest tools and technology, OER **explores** previously unknown areas of our deep ocean, making discoveries of scientific, economic, and cultural value. Through live video streams, online coverage, training opportunities, and real-time events, OER allows scientists, resource managers, students, members of the general public, and others to actively **experience** ocean exploration, expanding available expertise, cultivating the next generation of ocean explorers, and engaging the public in exploration activities. From this exploration, OER makes the collected data needed to **understand** our ocean publicly available, so we can maintain the health of our ocean, sustainably manage our marine resources, accelerate our national economy, and build a better appreciation of the value and importance of the ocean in our everyday lives.

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2. Report Purpose

The purpose of this report is to briefly describe the acoustic seafloor and water column mapping data collection and processing methods used during exploration expedition EX-12-06, and to present a summary of the overall mapping results and mapping related cruise activities.

3. Cruise Objectives

NOAA Ships Nancy Foster, Henry B. Bigelow, Ronald H.Brown, and *Ferdinand R. Hassler Collaboration*

The shelf break and slope off the northeastern US support a diversity of habitats including more than 70 canyons ranging from depths of ~100 meters to ~3500 meters. The canyons provide a refuge for a variety of fauna including species of deep water corals, fish and other animals. While some canyons have been studied previously, most are poorly known and are of high interest to federal and state agencies with research and management responsibilities. OER's previous work on northeast canyons includes "Deep Water Mid-Atlantic Canyon Exploration" in 2011 which focused on Norfolk, Washington, Accomac and Baltimore canyons. Other NOAA programs (e.g., National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) and NMFS Deep Sea Coral Research and Technology Program (DSCRTP) also have a stated interest in understanding the geomorphology and habitat complexity of these canyons. In 2012, NOAA OER initiated a program, the Atlantic Canyons Undersea Mapping and Explorations (ACUMEN), to explore these canyons in partnership with NOAA NMFS, NOAA National Ocean Service (NOS), NOAA Office of Marine and Aviation Operations (OMAO), Virginia Sea Grant, and the Mid Atlantic Regional Council on the Ocean (MARCO). A majority of this exploration work was completed by the EX during EX-12-01, EX-12-04, and EX-12-05 Leg 2, and was supplemented by coordinated mapping efforts conducted by NOAA Ships *Henry B. Bigelow* and *Ferdinand R. Hassler* in July of 2012. EX-12-06 will focus on mapping all canyon and shelf priority areas not addressed in EX-12-01, EX-12-04, EX-12-05 Leg2, or by NOAA Ships *Bigelow* or *Hassler*. This work will include, but is not limited to, surveys of priority area margins and previous survey data holidays. Survey mapping during EX-12-06, in concert with existing data, resulted in near complete multibeam coverage of the seafloor between the ~ 400 meter contour and Extended Continental Shelf (ECS) survey between Cape Hatteras and the US-Canadian maritime territorial boundary.

Additionally, it is expected that multibeam data collected on EX-11-06, EX-12-01, EX-12-04, EX-12-05 Leg 2, and EX-12-06 will inform planning by OER, NMFS, and other NOAA science partners, for telepresence enabled ROV expeditions to the continental shelf canyons scheduled for the summer of 2013 on *Okeanos Explorer*.

Training

An ancillary objective was training of mapping personnel new to the ship, including contracted watch leads and three Explorers-in-Training.

The objectives for this cruise are further detailed in the EX-12-06 Project Instructions, which are archived in the NOAA Central Library.

4. Summary of Mapping Results

Cruise Overview Map

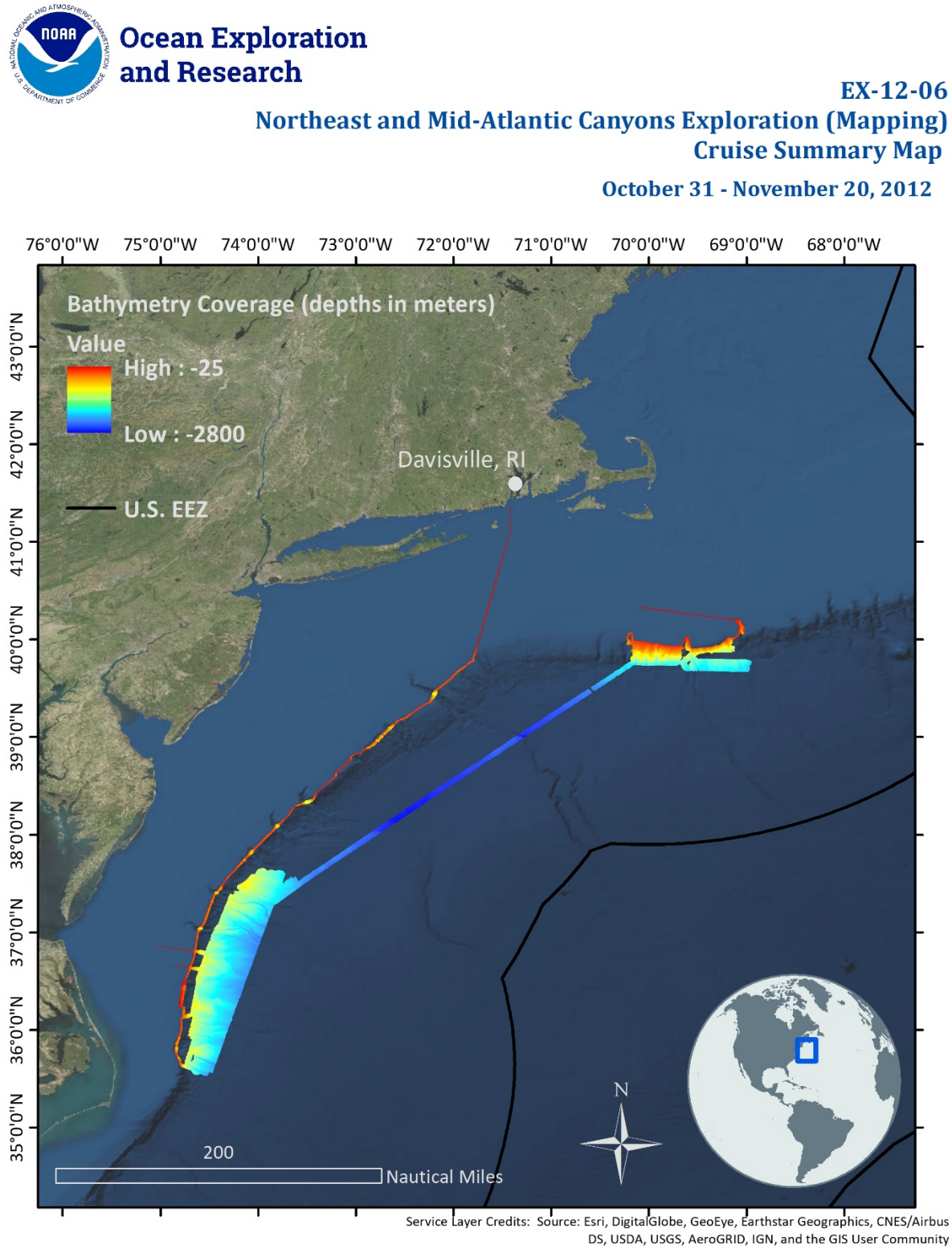

Figure 1. Cruise map showing overall EX-12-05 Leg 2 bathymetry coverage. Map generated in ArcMap.

Features Mapped

Approximately 165 kilometers to the east of Cape Henry, Virginia the EM 302 multibeam sonar recorded acoustic water column targets consistent with gas plume activity (Figure 2). The location was recorded and then resurveyed three times. Analysis of the resulting water column data indicates that the targets are likely gas plumes. Initial field processing of data indicates that there are 10-15 individual seeps in a linear orientation over a discrete area of high backscatter amplitude which would be consistent with the existence of associated chemosynthetic communities. Field consideration of surrounding data did not reveal any additional plumes proximal to this field. A cursory review of available scientific literature suggest that this feature was not previously known to exist, however further consideration of the record is necessary to confirm.

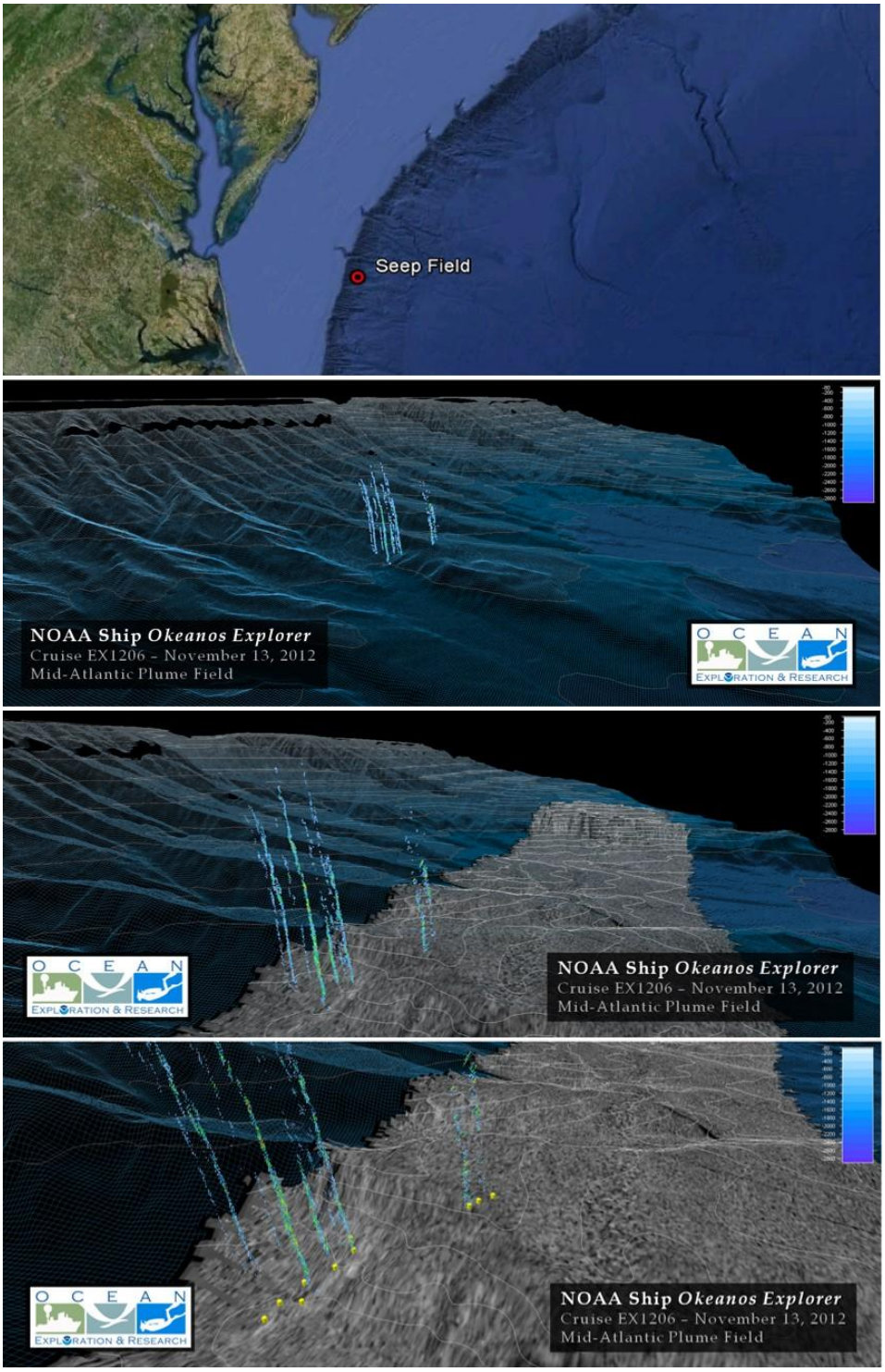

Figure 2. November 13, 2012. Water column anomaly targets, likely gaseous plumes (seep field #1). Google Earth location map and water-column and seafloor backscatter scene in QPS, Fledermaus software.

From November 17 to 19, several more water column anomalies were detected. See Figure 3 for locations of the seep fields temporarily referred to as #2 and #3.

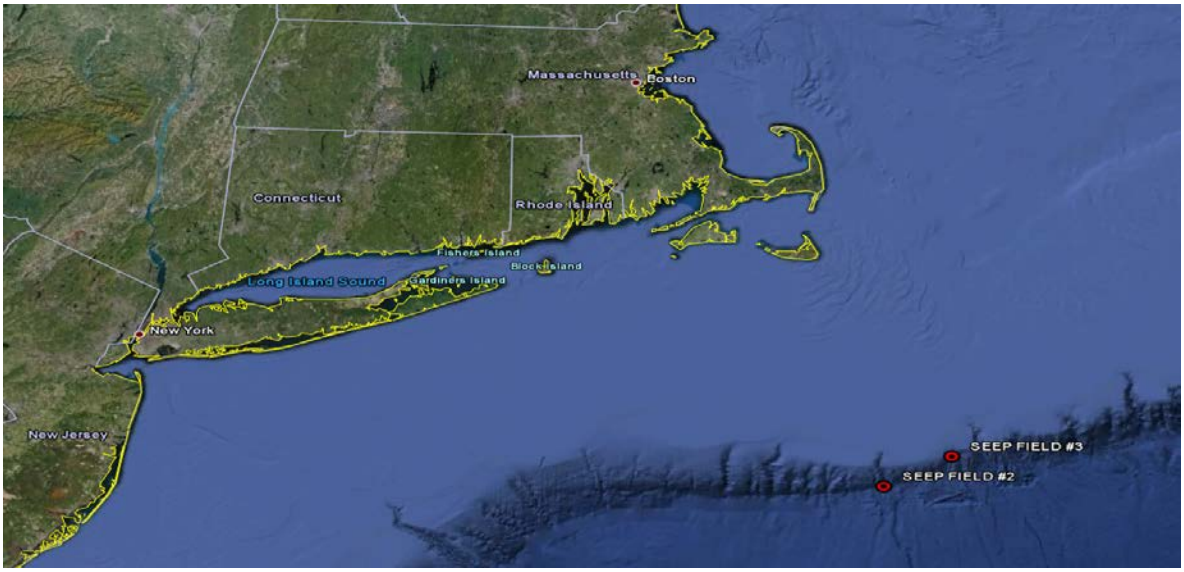

Figure 3. November 17-19 2012. Water column anomaly targets, likely gaseous seep fields.

On November 17, 2012, the EM 302 multibeam sonar recorded an acoustic water column target consistent with gas plume activity. Analysis of the resulting water column data indicates that the targets are likely gas plumes (see Figure 5). Initial consideration of data indicates that there are at least two individual seeps adjacent to Veatch Canyon and proximal to a discrete area of high backscatter amplitude which would be consistent with the existence of associated chemosynthetic communities. A cursory review of available scientific literature suggest that this feature was not previously known to exist, however further consideration of the record is necessary to confirm.

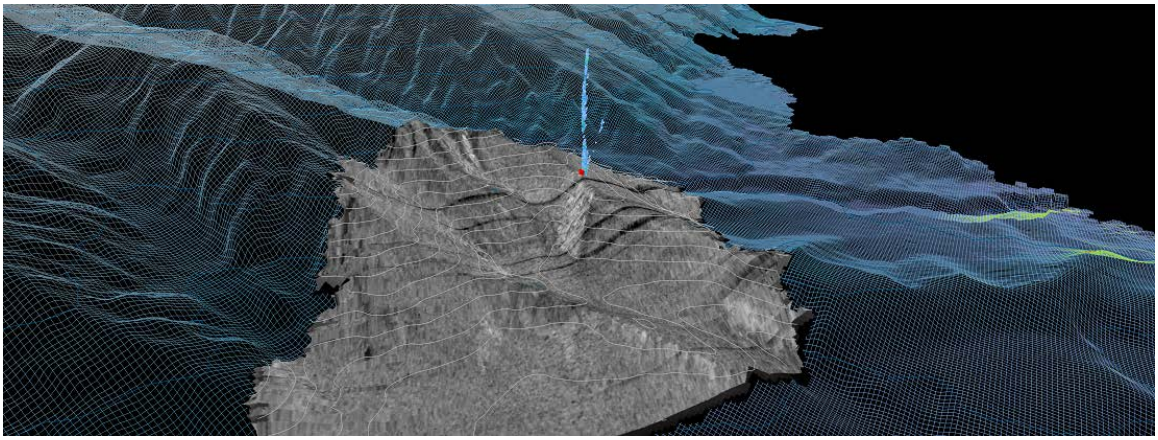

Figure 4. November 17, 2012. Water column anomaly targets, likely gaseous plumes. Seep field #2.

On November 18, the EM 302 multibeam sonar recorded an acoustic water column target consistent with gas plume activity. Analysis of the resulting water column data indicates that the targets are likely gas plumes (see Figure 6). Initial consideration of data indicates that there are at least fifteen individual seeps. The seeps are located in water depths of 300-400 meters. A cursory review of available scientific literature suggest that this feature was not previously known to exist, however further consideration of the record is necessary to confirm.

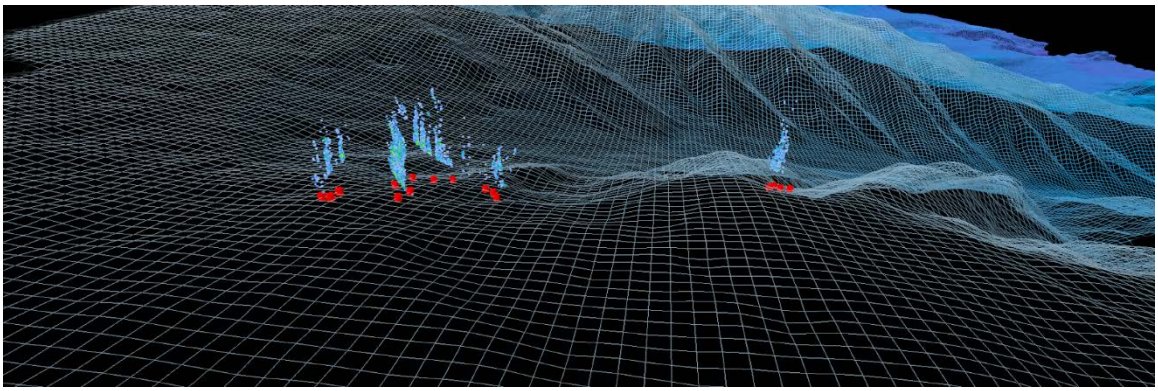

Figure 5. November 18, 2012. Water column anomaly targets, likely gaseous plumes. Seep field #2.

On November 19, the EM 302 multibeam sonar recorded an acoustic water column target consistent with gas plume activity. Analysis of the resulting water column data indicates that the targets are likely gas plumes (see Figure 7). Initial consideration of data indicates that there are at least five individual seeps. The seeps are located in water depths of 1000-1100 meters. A cursory review of available scientific literature suggests that this feature was not previously known to exist, however further consideration of the record is necessary to confirm.

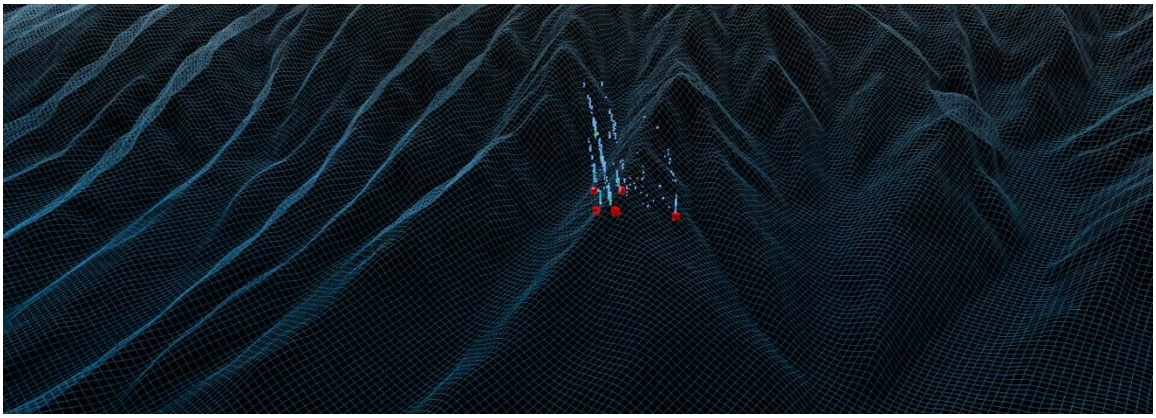

Figure 6. November 19, 2012. Water column anomaly targets, likely gaseous plumes. Seep field #3.

5. Mapping Statistics

Dates of cruise	**November 2– November 20, 2012**
Ship's draft Start of cruise End of cruise	**Fore: 15' 0", Aft: 14' 8" Fore: 13' 9"; Aft: 15' 0.5"**
Linear kilometers of survey with EM 302	**5,231**
Square kilometers mapped with EM 302	**15,467**
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files (.all)	**310 files/ 42.2 GB**
Number / Data Volume of EM 302 water column multibeam files	**307 files / 143 GB**
Number / Data Volume of EK 60 water column split beam files (.raw)	**207 / 3.2 GB**
Number / Data Volume of sub-bottom sonar files (.segy, .kea, .keb)	**67 / 1.5 GB**
Number of XBT casts	**109**
Number of CTD casts (including test casts)	**0**

6. Mapping Sonar Setup

Kongsberg EM 302 Multibeam Sonar

The NOAA Ship *Okeanos Explorer* is equipped with a 30 kHz Kongsberg EM 302 multibeam sonar capable of detecting the seafloor in up to 10,000 meters of water. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters less than 3300 meters, the system is operated in multi-ping, or dual swath mode, and obtains up to 864 soundings per ping, by generating two swaths per ping cycle. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter. Backscatter represents the strength of the acoustic signal reflected from a target, such as the seafloor or bubbles in the water column.

Kongsberg EK-60 Split-Beam Sonar

The ship is also equipped with one Kongsberg EK 60 split-beam fisheries sonar. The 18 kHz transducer and transmits a 7° beam fan. This sonar is a quantitative scientific echosounder calibrated to identify the target

strength of water column acoustic reflectors - typically biological scattering layers, fish, or gas bubbles – providing additional information about water column characteristics and anomalies.

Knudsen Sub-bottom Profiler

Additionally, the ship is equipped with a Knudsen 3260 sub-bottom profiler that produces a frequency-modulated chirp signal with a central frequency of 3.5 kHz. This sonar is used to provide echogram images of shallow geological layers underneath the seafloor to a maximum depth of about 80 meters below the seafloor. The sub-bottom profiler is normally operated to provide information about sub-seafloor stratigraphy and features while the bottom bathymetry is simultaneously being mapped by the multibeam sonar. The data generated by this sonar is fundamental to helping geologists interpret the shallow geology of the seafloor.

7. Data Acquisition Summary

Mapping operations included EM 302 multibeam, EK 60 split-beam, and Knudsen 3260 sub-bottom profile data collection.

Survey lines were planned to maximize either bathymetry edge matching of existing data or data gap filling in areas where existing bathymetry coverage existed. In regions with no existing data, lines were planned to optimize potential exploration discoveries.

Throughout the cruise, multibeam data quality was monitored in real-time by acquisition watch standers. Ship speed was adjusted to maintain data quality as necessary and line spacing was planned to ensure at least ¼ swath width overlap between lines. Cutoff angles in SIS were generally left wide open for maximum exploration data collection and were adjusted on both the port and starboard side to ensure the best data quality and coverage. Data were corrected for sound velocity in real-time using the Reson SVP-70 data at the sonar head, and profiles from Expendable Bathythermographs (XBTs) that were conducted at intervals no greater than 6 hours, or as dictated by local oceanographic conditions.

Simrad EK 60 18 kHz split-beam water column sonar data were collected continuously during the cruise. The screenshot below shows data holdings in www.ncei.noaa.gov (last accessed 4 April 2019).

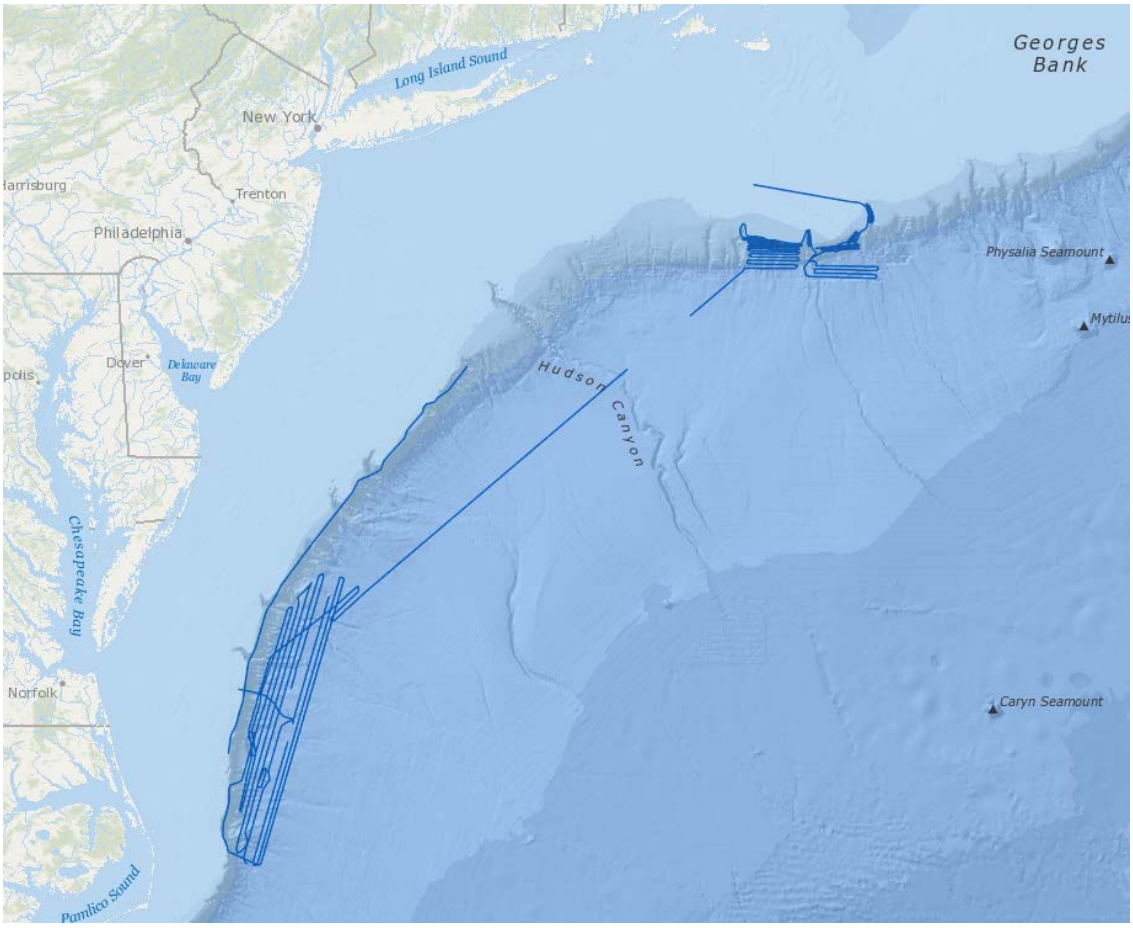

Figure 2. Screenshot of Simrad EK 60 18 kHz split-beam sonar data tracklines in blue collected during EX-12-06.

Knudsen 3260 sub-bottom profiler data were collected daily from 1000 – 1800 local ship time. The screenshot below shows data holdings in www.ncei.noaa.gov (last accessed 4 April 2019).

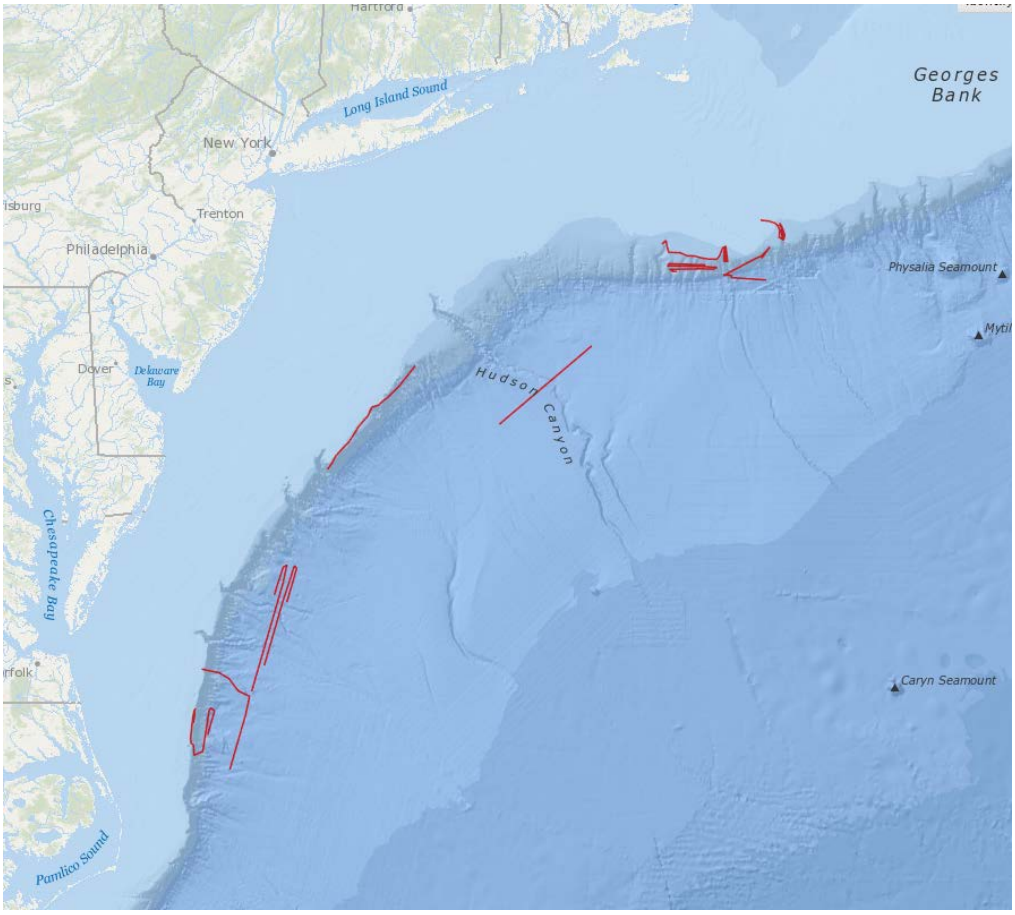

Figure 3. Screenshot of sub-bottom profiler data tracklines in red collected during EX-12-06.

8. Multibeam Sonar Data Quality Assessment and Data Processing

EM 302 Built-in Self Tests (BISTs) were run throughout the cruise to monitor multibeam sonar system status and are available as ancillary files in the sonar data archives. Raw multibeam bathymetry data files were acquired by SIS, then imported into Caris HIPS and SIPS for processing. In Caris, attitude and navigation data stored in each file were checked, and erroneous soundings were flagged off. Gridded digital terrain models were created and posted to the ship's ftp site for daily transfer to shore. Final bathymetry QC was completed post-cruise onshore at the Center for Coastal and Ocean Mapping at the University of New Hampshire. With the vast majority of surveying completed in deep water, depth measurements were not adjusted for tides, as they are an essentially insignificant percent of the overall water depth.

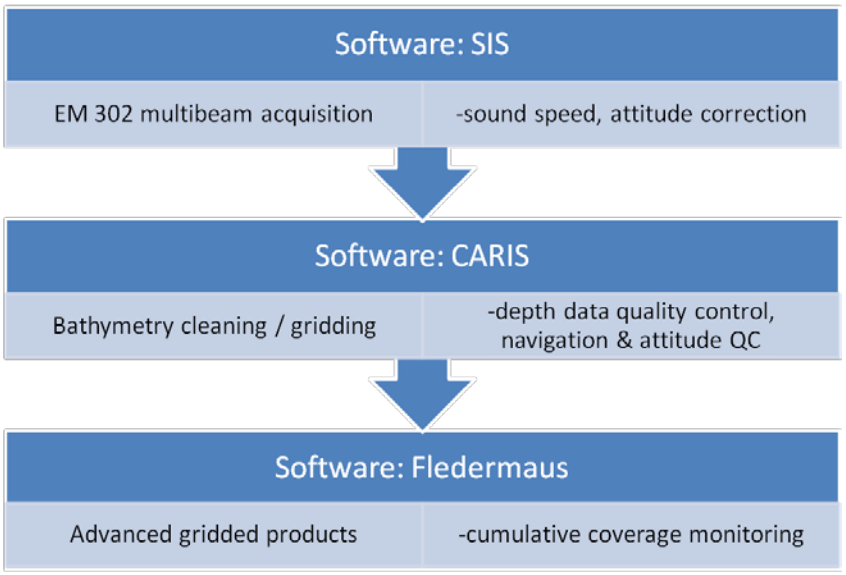

Figure 16. Shipboard multibeam data flow.

Crosslines

Two crosslines were run during this cruise. Crossline analysis was completed using Qimera Crosscheck, and the results against the requirements for an International Hydrographic Organization Special Order survey are shown below. It is noted that the survey working grounds were far deeper than typical Special Order survey working depths, indicating excellent data quality.

The first crossline was run on November 9. The crossline was lines 0086 and 0087; the mainscheme lines were lines 0118, 0130, 0145, 0148, 0155, and 0163.

621445 # Number of Points of Comparison
-1647.451896 # Data Mean
-1646.900428 # Reference Mean
-0.551468 # Mean
46.939978 # Median
3.443451 # Std. Deviation
-2029.89 -1044.87 # Data Z - Range
-2017.33 -1045.18 # Ref. Z - Range
-59.75 155.31 # Diff Z - Range
7.438370 # Mean + 2*stddev
53.826879 # Median + 2*stddev
12.354283 # Special Order Error Limit
0.007082 # Special Order P-Statistic
4401 # Special Order - # Rejected
1 **# Special Order Survey ACCEPTED**

A second crossline was run on November 14. The crossline was lines 0170, 0171, and 0172. The mainscheme lines were 0068, 0071, 0101, 0104, 0105, 0106, 0112, 0132, 0142, 0143, 0144, 0150, and 0154.

1319257 # Number of Points of Comparison
-1760.968485 # Data Mean
-1744.523509 # Reference Mean
-16.444976 # Mean
-678.014066 # Median
108.655484 # Std. Deviation
-3333.90 -1274.78 # Data Z - Range
-2139.51 -1344.16 # Ref. Z - Range
-1811.30 353.78 # Diff Z - Range
233.755944 # Mean + 2*stddev
895.325034 # Median + 2*stddev
13.086314 # Special Order Error Limit
0.047199 # Special Order P-Statistic
62267 # Special Order - # Rejected
1 **# Special Order Survey ACCEPTED**

EM 302 Patch Test

The annual multibeam patch test was conducted during cruise EX-12-01 and the results are available in the 2012 NOAA Ship *Okeanos Explorer* Survey Readiness Report which is available in the NOAA Central Library.

EM 302 Multibeam Water Column Backscatter Data Processing

Water column data was reviewed daily throughout the cruise to examine for the presence of seeps and other water column anomalies.

EM 302 Built In System Tests (BISTs)

BISTs were run throughout the cruise to monitor multibeam sonar system status and are available as ancillary files in the sonar data archives.

9. Data Archival Procedures

All mapping data collected by the NOAA Ship *Okeanos Explorer* are archived and publicly available within 90 days of the end of each cruise via the National Centers for Environmental Information (NCEI) online archives. The complete data management plan (which describes the raw and processed data formats

produced for this cruise) is available as an appendix in the project instructions which is available in the NOAA Central Library.

Ancillary and supporting files are archived with the sonar datasets. These include:

EM 302 Multibeam bathymetry and bottom backscatter dataset:

- Mapping watchstander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit

Simrad EK split-beam water column dataset:

- Mapping watchstander log
- Weather log
- EK data log

Knudsen 3260 Sub-bottom Profiler dataset:

- Mapping watchstander log
- Weather log
- Sub-bottom data log

EM 302 Multibeam water column dataset:

- Mapping watchstander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit

- MB WCD review log if data were reviewed for presence of seeps in Fledermaus MidWater

At the time of writing this report, the following DOIs were available as permanent links to sonar datasets:

EM 302 water column data http://doi.org/10.7289/V53B5X3W

EK 60 data http://doi.org/10.7289/V5GH9FVM

Sub-bottom data, supporting data, and informational logs are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 3/21/2019).

EM 302 bathymetry data, supporting informational logs, and ancillary files are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 3/21/2019).

10. Cruise Calendar

All times listed are local ship time, which was -4 hours from UTC on Nov 2 and 3, and -5 hours from UTC from Nov 4 to Nov 20.

October/November 2012						
Sun	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**
		30	31 Personnel arrive at ship	1 Personnel arrive at ship	2 Depart Davisville, RI. Scheduled ABS engineering inspection. Began mapping operations in 30 m of water	3 Normal mapping survey operations
4 Normal mapping survey operations	5 Normal mapping survey operations	6 Morning mapping operations. Afternoon suspended mission	7 No mission operations	8 No mission operations	9 Normal mapping survey operations	10 Normal mapping survey operations.

		operations and proceeded to the Chesapeake Bay to seek shelter from storm				
11 Normal mapping survey operations. Some vessel traffic interrupted operations	12 Normal mapping survey operations. Some vessel traffic interrupted operations	13 Normal mapping survey operations. Detected anomaly in water column backscatter	14 Normal mapping survey operations	15 Normal mapping survey operations. Completed southern priority area, commenced transit mapping	16 Normal mapping survey operations, northern priority area	17 Normal mapping survey operations. Detected anomaly target in water column backscatter
18 Normal mapping survey operations. Detected anomaly in water column backscatter	19 Normal mapping survey operations. Detected anomaly in water column backscatter	20 Pulled alongside in Davisville, RI				

11. Daily Cruise Log Entries

Generated from the daily expedition situation reports. All times listed are local ship time, which was -4 hours from UTC on Nov 2 and 3, and -5 hours from UTC from Nov 4 to Nov 20.

November 2, 2012

Okeanos Explorer (EX) departed Davisville Depot, North Kingstown, RI at 1020 bound for the Atlantic Ocean and cleared the Narragansett Bay sea buoy at approximately 1400 after a scheduled ABS engineering inspection. Multibeam sonar data collection commenced at 1600 in approximately 30 meters of water. EX collected mapping data for the remainder of the day while transiting across the continental shelf to the south of Block Island. Initial mapping watches were focused on training mission personnel in control room operations as well as the acquisition of multibeam data and sound velocity profiles.

November 3, 2012

Continuous multibeam and single-beam data collection is being conducted during transit mapping. Multibeam bathymetry data quality is fair, with generally consistent bottom detection and wide swath coverage. Due to significant observed variability in sea water salinity and temperature, XBT profiles are being collected every three hours, or more often as dictated by physical oceanographic conditions.

November 4, 2012

EX is presently mapping the continental shelf break approximately 100 kilometers northeast of Cape Hatteras, North Carolina. Continuous multibeam and single-beam data collection is being conducted during transit mapping. Multibeam bathymetry data quality is high, with consistent bottom detection and wide swath coverage. Due to significant observed variability in sea water salinity and temperature, XBT profiles are being collected every three hours, or more often as dictated by physical oceanographic conditions.

November 5, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of North Carolina and Virginia throughout the day. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1800 ship time.

November 6, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of North Carolina and Virginia until 1400. Multibeam and single-beam sonar data were collected continuously, and sub-bottom sonar data were collected between 1000 and 1700 ship time. At 1400 the ship suspended mission operations and proceeded to the Chesapeake Bay to seek shelter from an impending nor'easter storm. The EX set its anchor at Lynnhaven Roads inside of Cape Henry, Virginia at 0125 on 11/07.

November 7, 2012

No mapping operations took place on 11/07. The ship remained at anchor to wait for weather conditions to improve offshore and to complete the necessary repairs to anchor capstan.

November 8, 2012

No mapping operations took place on 11/08. The ship remained at anchor to wait for weather conditions to improve offshore and to complete the necessary repairs to anchor capstan.

November 9, 2012

EX departed Naval Amphibious Base Little Creek, VA at 0800 and proceeded offshore to the southern EX1206 survey mapping area. Multibeam and single-beam sonar data collection commenced at 1600 in approximately 50 meters of water. The EX rejoined the survey mapping line at approximately 2345. Multibeam bathymetry data quality is high, with consistent bottom detection and wide swath coverage.

November 10, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of North Carolina and Virginia throughout the day. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1800 ship time.

November 11, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of North Carolina and Virginia throughout the day. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1800 ship time. Survey mapping operations were interrupted due to sailing vessel traffic early in the day, resulting in a significant data holiday. Filling this holiday required approximately two hours of ship time.

November 12, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of North Carolina and Virginia throughout the day. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1800 ship time. Survey mapping operations were interrupted due to fishing vessel traffic and drifting nets twice, resulting in significant data holidays.

November 13, 2012

EX is presently mapping the continental slope approximately 165 kilometers to the east of Cape Henry, Virginia. Continuous multibeam and single-beam data collection is being conducted during survey mapping. At approximately 12:50 the EX multibeam sonar recorded acoustic water column targets consistent with gas plume activity. The location was recorded and then resurveyed three times early on 11/14.

November 14, 2012

Okeanos Explorer (EX) conducted survey mapping to the east of the continental shelf break offshore of Virginia and Delaware throughout the day. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1800 ship time.

November 15, 2012

Okeanos Explorer (EX) completed the southern survey area and conducted transit mapping to the east of the continental shelf break offshore of Delaware, New Jersey, New York, and Rhode Island throughout the day.

November 16, 2012

Okeanos Explorer (EX) conducted survey mapping to the south of the continental shelf break offshore of Massachusetts and Rhode Island throughout the day. Multibeam bathymetry data quality is moderate, with intermittent bottom detection due to sea state conditions.

November 17, 2012

Okeanos Explorer (EX) conducted survey mapping to the south of the continental shelf break offshore of Massachusetts and Rhode Island throughout the day. Collected survey lines further defined the bathymetry of Atlantis and Veatch Canyons which are both NEFSC exploration priorities. Multibeam bathymetry data quality is moderate, with intermittent bottom detection due to sea state conditions. At approximately 1905 EST the EX multibeam sonar recorded an acoustic water column target consistent with gas plume activity. The location was recorded and will be resurveyed on 11/18/12. Analysis of the resulting water column data indicates that the targets are likely gas plumes.

November 18, 2012

Okeanos Explorer (EX) conducted survey mapping to the south of the continental shelf break offshore of Massachusetts and Rhode Island throughout the day. Multibeam bathymetry data quality is moderate, with intermittent bottom detection due to sea state conditions. At approximately 1700 EST the EX multibeam sonar recorded an acoustic water column target consistent with gas plume activity. Analysis of the resulting water column data indicates that the targets are likely gas plumes.

November 19, 2012

Okeanos Explorer (EX) conducted survey mapping to the south of the continental shelf break offshore of Massachusetts and Rhode Island until 1400 on 11/19. Multibeam and single-beam sonar data were collected continuously, and sub bottom sonar data were collected between 1000 and 1700 ship time. Multibeam bathymetry data quality is moderate, with intermittent bottom detection due to sea state conditions. At approximately 1620 EST on 11/19 the EX multibeam sonar recorded an acoustic water column target consistent with gas plume activity. Analysis of the resulting water column data indicates that the targets are likely gas plumes.

November 20, 2012

EX transited to Narragansett Bay and came alongside at Davisville Depot at 0900. A change of command ceremony was held at 1400 on 11/20 and command of the EX was transferred from CDR Kamphaus to CDR Ramos.

12. References

The 2012 NOAA Ship *Okeanos Explorer* Survey Readiness Report can be obtained in the NOAA Central Library or by contacting the NOAA OER mapping team at oar.oer.exmappingteam@noaa.gov.

The EX-12-06 Project Instructions can be obtained from the NOAA Central Library. The EX-12-06 Data Management Plan is an appendix of the project instructions.

EM 302 water column data http://doi.org/10.7289/V53B5X3W

EK 60 data http://doi.org/10.7289/V5GH9FVM

Sub-bottom data, supporting data, and informational logs are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 3/21/2019).

EM 302 bathymetry data, supporting informational logs, and ancillary files are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/ (last accessed 3/21/2019).

The following was used for reference throughout the cruise:

Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, J. Geophys. Res., 114, B01411, doi:10.1029/2008JB006008, 2009.

NOAA Nautical Charts