doi: 10.25923/q0tt-bw71

Ocean Exploration and Research

Cruise Report: EX-11-04
2011 Mid-Cayman Rise Expedition
(ROV and Mapping)

Caribbean Sea

Rodman, Panama, to Key West, FL, USA

02, August 2011 – 18, August 2011

Contributors:

Kelley Elliott, Expedition Coordinator, NOAA Office of Ocean Exploration and Research
Elizabeth Lobecker, Mapping Team Lead, NOAA Office of Ocean Exploration and Research
Chris German, Science Team Lead, Woods Hole Oceanographic Institution
Paul Tyler, Co-Science Team Lead, University of Southampton
David Lovalvo, The Global Foundation for Ocean Exploration

September 21, 2021

Office of Ocean Exploration and Research, NOAA
1315 East-West Hwy, SSMC3 RM 10210
Silver Spring, MD 20910

Abstract

EX-11-04 was a combined seafloor mapping and remotely operated vehicle (ROV) cruise to the Mid-Cayman Rise in the Caribbean Sea that took place between August 02-18, 2011. The 17-day expedition included 10 days of operations at the Mid-Cayman Rise and one day at the Cayman Trough fracture zone, southwest of the Cayman Islands and located entirely within their Exclusive Economic Zone (EEZ). The expedition conducted 24-hour operations, with daily surveys focused on the exploration of seafloor habitats using the Institute for Exploration's (IFE's) *Little Hercules* ROV, and conductivity, temperature, and depth (CTD) rosette and mapping operations conducted in the evening and through the night. Over the course of 11 days, nearly 11,000 km^2 of seafloor were mapped at the Mid-Cayman Rise, primarily focused on the oceanic core complexes (OCCs) comprising much of the rift valley walls and the Cayman Trough fracture zone to the north. The expedition team conducted 12 ROV dives from 1,192 to 3,542 m; 10 of these focused on locating and characterizing the full extent of the Von Damm hydrothermal vent field and exploring further afield on "Mount Dent" to understand its geologic setting, one dive was conducted on the southeastern rifted OCC, and the final ROV dive conducted a vertical transect up the south-facing slope of the Cayman Trough fracture zone. CTD rosette chemical sampling conducted over the Von Damm vent field (VDVF) revealed that the hot fluids there, escaping from the rocks of the Mid-Cayman Rise, were hugely enriched in methane and other, more complex organic compounds. The ROV dives revealed extensive tubeworm communities of differing size and shape across the length and breadth of the VDVF, and, for the first time, chemosynthetic shrimp and tubeworms were observed inhabiting the same hydrothermal vent site. The ROV dive on the southeastern rifted OCC observed sheet flow textures on lava flows greater than 3,000 m deep on one of the slowest spreading ridges on Earth, a lava flow morphology unanticipated in a deep, slow-spreading environment. The expedition team used an emerging model of telepresence-enabled ocean exploration. Scientists and the team onboard NOAA Ship *Okeanos Explorer* worked with a larger team of scientists participating ashore at a network of Exploration Command Centers (ECCs) and other locations. Scientists ashore participated from centers at the University of Rhode Island (URI) and Woods Hole Oceanographic Institution (WHOI), while other scientists in California, Pennsylvania, Germany, Canada, Portugal, and the United Kingdom (U.K.) participated via live video feeds and some through online instant messaging. They played a key role by identifying biological, chemical, and geological features shown in ROV imagery or revealed in data from ocean sensors thousands of miles away.

This report can be cited as follows:

Elliott, K., Lobecker, E., German, C., Tyler, P. & Lovalvo, D. (2021). Cruise Report: EX-11-04, 2011 Mid-Cayman Rise Expedition (ROV and Mapping). Office of Ocean Exploration and Research, Office of Oceanic and Atmospheric Research, NOAA, Silver Spring, MD 20910. OER Expedition Rep. 11-04. doi: 10.25923/q0tt-bw71

For further information, direct inquiries to:

NOAA Office of Ocean Exploration and Research
1315 East-West Hwy, SSMC3 RM 10210
Silver Spring, MD 20910
Phone: 301-734-1014
Email: oceanexplorer@noaa.gov

Table of Contents

Summary of Figures

Summary of Tables

1. Introduction

By leading national efforts to explore the ocean and make ocean exploration more accessible, the NOAA Office of Ocean Exploration and Research (OER) is filling gaps in basic understanding of deep waters and the seafloor, and providing deep-ocean data, information, and awareness. Using the latest tools and technology, OER explores unknown areas of the deep ocean. NOAA Ship *Okeanos Explorer* is one such tool. Working in close collaboration with government agencies, academic institutions, and other partners, OER conducts deep-sea exploration expeditions using advanced technologies on *Okeanos Explorer*, mapping and characterizing areas of the ocean that have not yet been explored. Collected data about deep waters and the seafloor—and the resources they hold—establishes a foundation of information and fills gaps in the unknown. As the only federal program dedicated entirely to ocean exploration, OER is uniquely situated to lead partners in delivering critical deep-ocean information to managers, decision makers, scientists, and the public.

All data collected during *Okeanos Explorer* expeditions adhere to federal open-access data standards and are publicly available shortly after an expedition ends. This ensures the delivery of reliable scientific data needed to identify, understand, and manage key elements of the ocean environment.

2. Expedition Overview

Discovery of the first deep-sea vents and their associated biological communities on the Galápagos Rift in 1977 (Corliss et al., 1979) represented one of the major scientific breakthroughs of the past century and revolutionized our understanding of earth, ocean, and life sciences. Since then, hydrothermal vent sites have been found worldwide along the global seafloor spreading systems, and everywhere scientists have looked, new species have been found. Most recently, scientists have been surprised to find that the rocks that make up the seafloor at the least volcanically active mid-ocean ridges affect the chemistry of the resulting vent fluids such that they are uniquely relevant to studying the origins of life—on Earth and beyond. This cruise to the Mid-Cayman Rise, one of Earth's deepest and slowest spreading ridges, conducted exploration based on the latest data—suggesting there are multiple vent sites present in a range of shallow and deep settings along this ridge axis (German et al., 2010; Connelly et al., 2012).

During August 2011, a team of scientists and technicians, both at sea and on shore, conducted exploratory interdisciplinary investigations on the geology, marine life, and hydrothermal systems at the Mid-Cayman Rise and Cayman Trough fracture zone. The 17-day expedition included 10 days of operations in this region (**Figure 1**), located southwest of the Cayman Islands and entirely within their Exclusive Economic Zone (EEZ). The expedition conducted 24-hour operations, with daily surveys focused on the exploration of seafloor habitats and geological processes using the Institute for Exploration's (IFE's) *Little Hercules* remotely operated vehicle (ROV), and mapping and conductivity, temperature, and depth (CTD) rosette operations conducted in the evening and through the night.

- August 02 – Departed Rodman, Panama, and began passage through the Panama Canal.
- August 03 – Commenced transit to the primary operating area. Acquired transit mapping data while in the Panama EEZ and conducted a test CTD rosette cast. The multibeam system was secured while in the Columbia EEZ.
- August 04 – Acquired transit mapping data within the Nicaragua and Honduras EEZs.
- August 05-12 – Entered the primary operations area in the Cayman Islands EEZ. Exploration of "Mount Dent" and the Von Damm vent field (VDVF).
- August 09 – VIP/Media telepresence event conducted with shore.
- August 13 – Exploration of a rifted oceanic core complex (OCC) towards the southeast corner of the Mid-Cayman Rise operating area.
- August 14 – Exploration of "Mount Doom" and Von Damm.
- August 15 – Exploration of an interior wall of the north Cayman Trough fracture zone.
- August 16 – Departed the primary operating area and commenced transit to Florida. The multibeam system was secured during transit through the Cuban EEZ.
- August 17 – The ship crossed into the U.S. EEZ and commenced transit mapping data acquisition.
- August 18 – Ship arrived in Key West, FL. Expedition ended.

In 2011, *Okeanos Explorer* was one of the newest additions to the NOAA fleet. She was recommissioned in 2008 and provides accommodations for up to 46 crew and technicians. Unique to this ship is that most of the scientists remain ashore. Via telepresence, live images from the seafloor and other science data flow over satellite and high-speed Internet pathways to scientists standing watches in Exploration Command Centers (ECCs). During this expedition, core scientists worked from ECCs at the University of Rhode Island (URI) and a Remote Command Center at Woods Hole Oceanographic Institution (WHOI). Scientists also participated via Internet and instant messaging. These scientists added their expertise in real time to operations at sea.

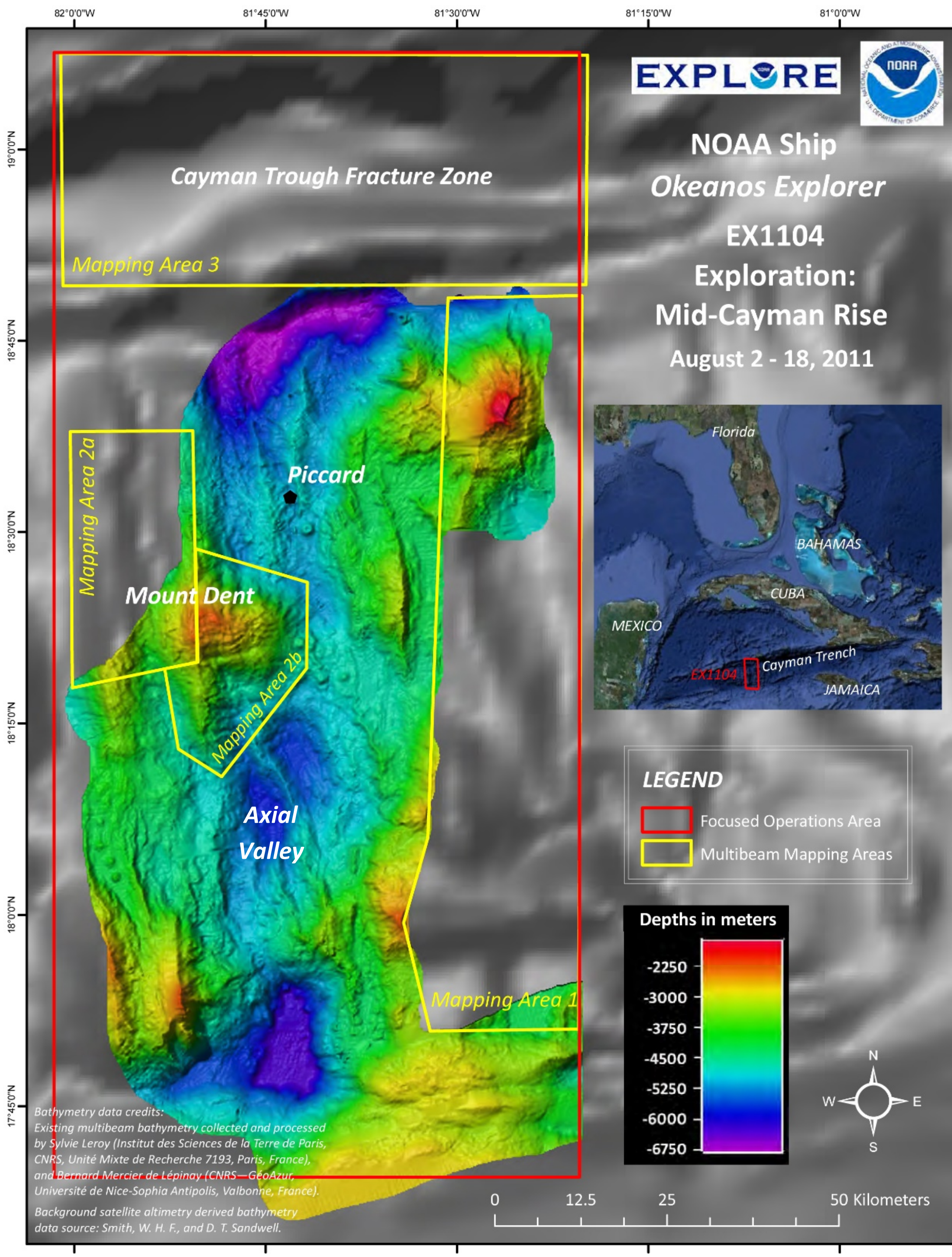


Figure 1. Map showing the general area of the Mid-Cayman Rise. The expedition focused along the eastern and western walls bounding the rift valley, where long-lived fault systems lift rocks from deep within Earth's interior up to the ocean floor along so-called "oceanic core complexes". The expedition also explored to the north where the ridge axis is truncated by the deep east-west trending Cayman Trough fracture zone.

The purpose of this expedition was to conduct exploratory investigations on the OCCs that appear to dominate construction of the rift valley walls along much of the Mid-Cayman Rise, and an inner wall of the Cayman Trough fracture zone immediately to the north (**Figure 1**).

Specifically, the team investigated the geology, marine life, and hydrothermal systems that these areas might host. Key objectives included:

- Precisely locate Von Damm, the first hydrothermal field to be found on “Mount Dent”, characterize its geologic setting and obtain the first high-quality, high-definition (HD) video of both the geology of the site and the biological community present.
- Explore the summit of “Mount Dent” to understand its geologic setting, and, ideally, locate Europa, a second hydrothermal field, for which preliminary evidence exists (predicted to be of a “Lost City” type), to compare and contrast with the Von Damm site.
- Continue exploring off-axis to define the size and shape of the multiple other OCCs that are geologically similar to “Mount Dent”, and line the walls of the Mid-Cayman Rise.
- Use the CTD system, its in situ sensors, and shipboard analysis of samples for their dissolved methane concentrations to seek clear indications of additional hydrothermal sources that may be located elsewhere along the Mid-Cayman Rise, including on top of the other OCCs the team planned to map.
- Track any additional hydrothermal sites to source using the CTD and ROV in concert.
- Explore the top of at least one other OCC, even if the team found no evidence for more hydrothermal activity.
- Map the north wall of the Cayman Trough fracture zone, immediately north of the Mid-Cayman Rise.
- Explore the cliff face of the Cayman Trough fracture zone to examine the types of exposed rocks and which animals exist on the cliff face.

3. Participants

Various personnel from different organizations participated in the expedition. The list of participants is below:

NOAA SHIP OKEANOS EXPLORER OFFICERS AND CREW	
Officers	
Kamphaus, Robert CDR	Commanding Officer (CO)
Peltzer, Thomas LCDR	Executive Officer (XO)
Nadeau, Megan LT	Operations Officer (Ops)
O'Leary, Matthew LTJG	Navigation Officer (Nav)
Kennedy, Brian ENS	Junior Officer (JO) & ROV Nav
Rivera, Felix ENS	Junior Officer (JO)
Anthony, Michael LT	U.S. Public Health Service (USPHS) Medical Officer
Deck Department	
VerPlanck, Carl	Chief Boatswain (CB)
Mancinelli, Dana	Boatswain Group Leader (BGL)

Baird, Kelson	Able Bodied Seaman Day Worker - AB (D)
Vickers, Liam	Able Bodied Seaman Day Worker - AB (D)
Hozendorf, Jerrod	Able Bodied Seaman Day Worker - AB (D)
Deeton, James	General Vessel Assistant (GVA)
Hocko, Michael	General Vessel Assistant (GVA)
Survey Department	
Peters, Colleen	Senior Survey Technician (SST)
Stuart, Elaine	Senior Survey Technician (SST)
Engineering Department	
Dennis, Robert	Chief Mechanical Engineer (CME)
Gabona, Ricardo	1st Assistant Engineer (1 A/E)
Van Dyke, Timothy	2nd Assistant Engineer (2 A/E)
Clark, Joe (Augmentor)	Junior Unlicensed Engineer (JUE)
Collins, Margret	Engineer Utilitywoman
Weber, Steve	General Vessel Assistant
Electronic Technicians (ETs)	
Conway, Richard	Chief ET
Andreopoulos, Kirk	ET
Steward Department	
Wells, Kenneth	Chief Steward
Capati, Rainier	Chief Cook
Gahr, Ed (Augmentor)	2nd Cook

ON-BOARD MISSION PERSONNEL LEG II	
Elliott, Kelley	Expedition Coordinator
German, Chris	Science Team Lead
Lovalvo, Dave	ROV Team Lead
Lobecker, Meme	Mapping Team Lead
Pinner, Webb	Telepresence lead
Wright, Dave	ROV Pilot/Co-pilot
Kok, Tom	ROV Pilot/Co-pilot
Mohr, Bobby	ROV Pilot/Co-pilot
Ritter, Chris	ROV Pilot/Co-pilot
McLetchie, Karl	ROV Pilot/Co-pilot
Williams, Jeff	ROV Pilot/Co-pilot

Howard, Vincent	ROV Nav/Mechanical Engineer
Mefford, John	ROV Nav/Mechanical Engineer
Brian, Roland	ROV Video Engineer
Biscotti, Joe	ROV Video Engineer
Brinkman, Brian	ROV Video Engineer
Diffendele, Gregg	Data
Tyler, Paul	Scientist
McIntyre, Cameron	Science Technician

PRIMARY SHORESIDE SCIENCE TEAM MEMBERS	
Amon, Diva	URI ECC
Bennett, Sarah	National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), Pasadena, CA
Cheadle, Mike	URI ECC
Clarke, Jameson	URI ECC
Hammond, Steve	NOAA Pacific Marine Environmental Laboratory (PMEL), Newport ECC
John, Barbara	URI ECC
McDermott, Jill	URI ECC
Kinsey, James	WHOI

4. Ship Capabilities

NOAA Ship *Okeanos Explorer*, R 337 (call letters WTDH), is NOAA's only ship dedicated exclusively to ocean exploration. *Okeanos Explorer* is one of the five former U.S. Navy T-AGOS ships acquired and converted by NOAA for use as scientific research ships. Originally built for anti-submarine warfare, former U.S. Naval Ship (USNS) *Capable* was commissioned as NOAA Ship *Okeanos Explorer* on August 13, 2008. Prior to commissioning, the vessel underwent extensive refurbishment from 2005-2008 by Todd Pacific Shipyards Corporation, including adding mission space for the ROV hanger, bow and stern thrusters, fairings for mapping sensors, and bridge upgrades. The ship has been outfitted with dynamic positioning (DP), a hull-mounted deep-water multibeam echo sounder (MBES), a single-beam echo sounder (SBES), and a sub-bottom profiler (SBP), along with host of ancillary equipment. In 2011, the ship was integrated with dual-body ROV system (*Little Hercules* and *Seirios*) with a depth rating of 4,000 m.

4.1 Vessel Specifications

The most recent vessel specifications are available online at https://www.omao.noaa.gov/learn/marine-operations/ships/okeanos-explorer/about/specifications.

Hull Number	337	Cruising speed	10 knots
Call letters	WTDH	Mapping speed	8 knots
Builder	VT Halter Marine, Inc., Moss Point, MS	Berthing	46
Launched	Oct 28, 1988	Commissioned Officers	6
Delivered to NOAA	Sept 10, 2004	Licensed engineers	3
Commissioned	Aug 14, 2008	Crew	18
Length overall (LOA)	68.3 m (224 feet)	Scientists	19
Breadth	13.1 m (43 feet)	Ambar Rigid Hull Inflatable Boat (RHIB)	2
Draft	4.6 m (15 feet)	Full Load displacement	2,312 long tons
Range	9,600 nm	Light ship displacement	1,616 long tons
Endurance	40 days		

4.2 Remotely Operated Vehicle (ROV) System

Okeanos Explorer is equipped with a 4,000-meter rated dual-body ROV system composed of the camera sled, *Seirios* (**Figure 2**), and ROV, *Little Hercules* (LH) (**Figure 3**). During dives, *Seirios* is suspended from the A-frame by the primary umbilical, while LH is free to explore to the extent of its neutrally buoyant 40-meter tether. *Seirios* serves as lighting and imaging platform, looking down on LH, while LH, decoupled from the ship's motion, can collect stable HD imagery of the seafloor.

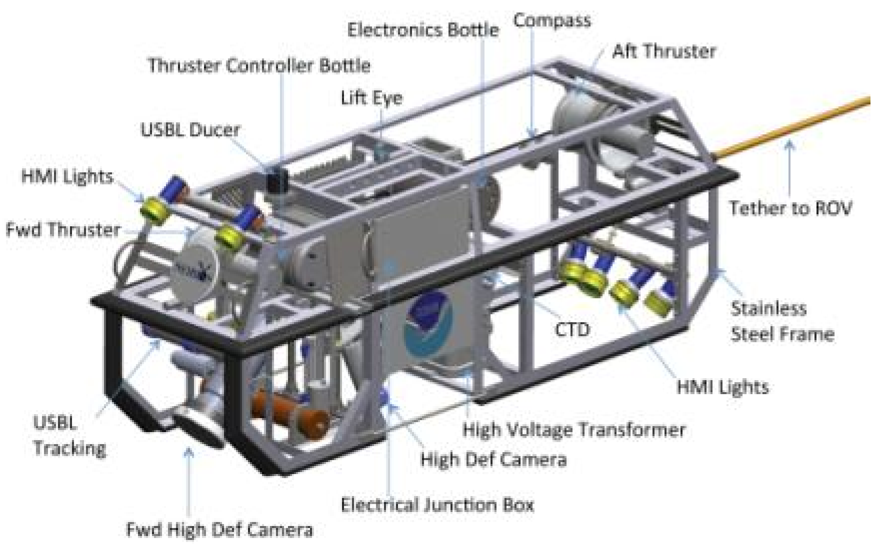


Figure 2. *Seirios*, a camera sled and sensor platform developed for the NOAA Ship *Okeanos Explorer* and implemented as a standalone tow-body or as an in-tandem system with an ROV.

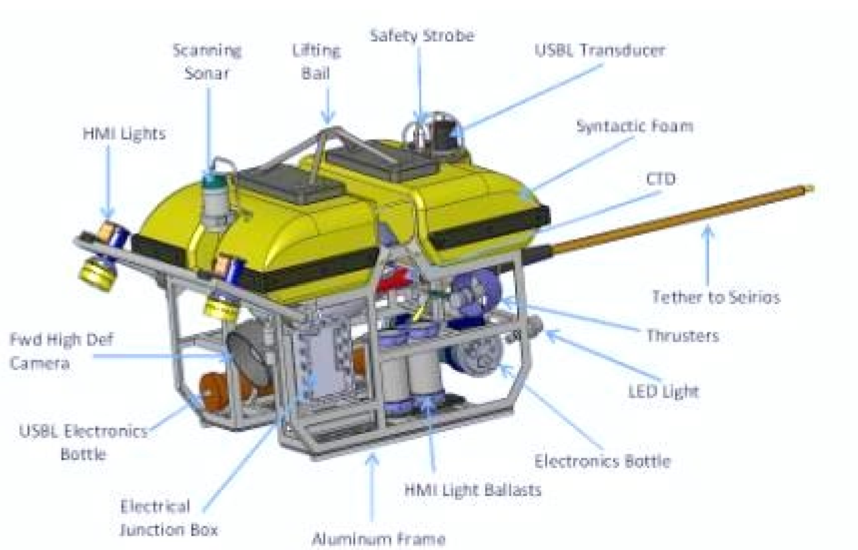


Figure 3. Diagram of IFE's *Little Hercules* ROV detailing the location of key components.

The main scientific data product returned from the vehicles is the HD video and still imagery. LH is equipped with an HD camera (Insite Zeus Plus) mounted on a rotator unit (Remote Ocean Systems R-25-FB), which allows it to tilt from viewing straight ahead to straight down. *Seirios* is equipped with an identical main HD camera/rotator system that is also oriented to tilt from straight ahead to straight down. In addition to its main camera, *Seirios* has a smaller HD camera (Insite Mini Zeus) mounted on a pan and tilt unit (ROS PT-25-FB). The Mini Zeus assembly is mounted on passive, pressure actuated slide. At depth, the Mini Zeus extends below the *Seirios* frame and can pan and tilt around with an unobstructed view of everything below.

Both vehicles rely on high-intensity hydrargyrum medium-arc iodide (HMI) lights to illuminate their surroundings. LH is equipped with a pair of HMI lights with flood reflectors–both are DeepSea Power & Light (DSPL) 400W Sea Arc 2 lights. *Seirios* is equipped with six similar lights, except, for more focused light, they contain spot reflectors. Finally, to provide scale to the imagery, LH has a pair of parallel, camera mounted red lasers (DSPL Micro SeaLasers), separated by 10 cm.

LH carries a CTD, the Sea-Bird Electronics, Inc. (SBE) 49 FastCAT, that returns only conductivity, temperature, and depth measurements. *Seirios* carries a more complex instrument (SBE 9plus), which in addition to conductivity, temperature, and depth sensors has ports to integrate a variety of other water sampling sensors. During the previous cruise, EX-11-03 Leg 2, *Seirios*'s CTD was equipped with a dissolved oxygen (DO) sensor, and, for dives near possible hydrothermal venting sites, an Oxidation-Reduction Potential (ORP) sensor.

The remaining sensors on the vehicles are dedicated to navigating and positioning during dives. These sensors include depth gauges, altimeters, inertial measurement unit (on LH), pitch roll compensated magnetic compass (on *Seirios*), scanning sonars, and ultra-short baseline (USBL) tracking transponders. Specifically, each vehicle has a LinkQuest TrackLink TN10010CR transponder, which is queried and tracked by the ship's hull mounted LinkQuest TrackLink 10000HA transceiver.

4.3 Mapping Systems

At the time of this expedition, *Okeanos Explorer* was equipped with a 30 kilohertz (kHz) Kongsberg EM 302 MBES, a 3.5 kHz Knudsen 3260 SBP, and an 18 kHz Kongsberg EK 60 SBES. During this cruise, EM 302 seabed bathymetry and backscatter data were collected. Additionally, EK60 and EM 302 water column data were continuously monitored by mapping watchstanders, and the water column data were logged if anomalies of interest were observed in those data.

The ship used a Position and Orientation System for Marine Vessels (POS MV), Applanix ver. 4, to record and correct multibeam data in real time for any ship's motion. The satellite service C-Nav Global Positioning System (GPS) system provided Differential GPS (DGPS) correctors to the POS MV with positional accuracy expected to be better than two meters.

All the corrections (motion, sound speed profile, sound speed at sonar head, vessel draft, and sensor offsets) were applied during real-time data acquisition in Kongsberg's data acquisition software, Seafloor Information System (SIS) ver. 3.6.4 build 176. Sippican expendable bathythermograph (XBT) casts (Deep Blue, maximum depth 760 m) were conducted every six hours, and more frequently if needed. XBT cast data were converted to SIS-compliant format using Velocipy, the NOAA in-house tool for XBT processing. Please consult the Mapping Data Report (http://doi.org/10.7289/V5/MDR-OER-EX1104, last accessed June 24, 2021) for details about parameters and settings used for EM 302 data acquisition.

Onboard processing of bathymetric data was performed using Teledyne Computer Aided Resource Information System (CARIS) Hydrographic Information Processing System (HIPS), version 6.1. Data were cleaned using the CARIS 'Swath Editor' and 'Subset Editor' tools. Bathymetry grids were generated at a resolution of 50 m. Onboard processing of seabed and water column backscatter data was conducted using Geocoder and Interactive Visualization Systems (IVS) Fledermaus, respectively, limited only to specific targets where water column anomalies were noted during data collection. Detailed processing of seabed and water column backscatter data for sites of interest was completed onboard using IVS Fledermaus suite, version 7.

Angular offsets (based on patch test conducted in – Check Shakedown results) are tabulated as below.

	Roll	**Pitch**	**Heading**
Tx Transducer	0.0	0.0	359.98
Rx Transducer	0.0	0.0	0.03
Attitude	0	0.0	0.0

Table 1. Angular offsets for Transmit (Tx) and Receive (Rx) transducer as determined during a patch test conducted in May 2010.

Summary map products created with the processed acoustic data are generated on a daily basis and immediately made available to collaborating scientists on shore via the ship's Very Small Aperture Terminal (VSAT) satellite system (see Telepresence section below). At the conclusion of each cruise, all collected raw sonar data and finalized summary map products, as well as associated metadata, are delivered to the National Centers for Environmental Information (NCEI), https://www.ncei.noaa.gov/ (last accessed June 24, 2021), where they are archived and subsequently made available to the general public within 60 to 90 days.

Further details on the mapping systems are available in the 2011 NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report available at https://doi.org/10.25923/5edq-a645 (last accessed June 17, 2021).

4.4 CTD Rosette, XBT, and Water Sampling

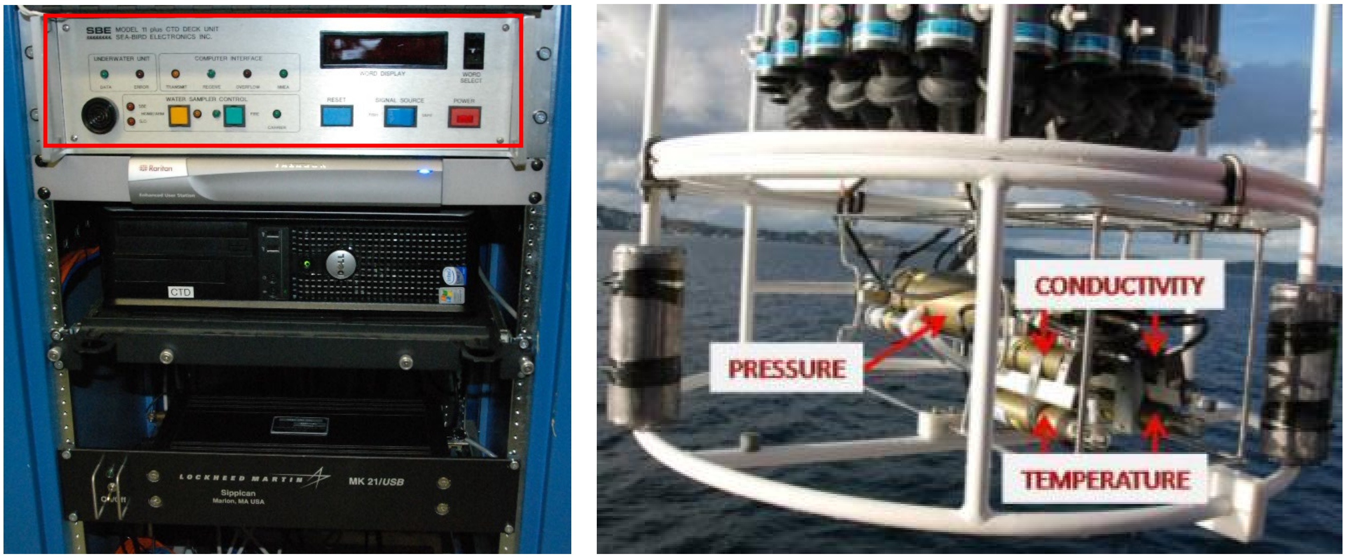


Figure 4. (Left) Deck Unit (SBE 11) for acquisition of real time sound speed profile from SBE 9 plus CTD (Right) Horizontal mounted CTD with dual temperature and conductivity sensors and SBE 32 carousel for 24-bottle water sampling.

At the time this expedition was outfitted, *Okeanos Explorer* had two SBE 9/11Plus CTDs, each with dual “3Plus Temperature” and “4C Conductivity” sensors. This unit (**Figure 4**) is capable of collecting temperature, conductivity, and pressure in real time and depth. Depth, salinity, and sound velocity are calculated in real time via SBE Seasave acquisition software. One complete package was used to collect data and the other was kept as a spare. The ship must hold station using DP mode to conduct a CTD cast. The CTD was lowered through the water column at 60 m/min.

Sippican Expendable BathyThermograph (XBT) casts were conducted on the aft deck with a portable launcher (**Figure 5**). Sippican Expendable Sound Velocity (XSV) probes were also used to measure sound velocity directly. The data were collected in real time with Lockheed Martin Sippican, Inc., WinMK21 acquisition software.

Figure 5. Sippican XBT launch from the aft deck (left). Deck unit for Sippican XBT (right).

Sound speed profiles obtained from CTD/XBT casts can be converted to SIS-compliant data format using Velociwin, version 8.92 Plus. The SBE 9/11Plus CTD was connected to the SBE 32 Carousel. The SBE 32 was rigged with 24 2.5 L water sampling bottles. The bottles can be triggered to close at any depth during a cast through the Seasave acquisition software on the CTD computer in the dry lab.

During this expedition, the CTD rosette was also equipped with an ORP, DO, Light Scattering Sensor (LSS), and an altimeter. Vertical CTD casts, and combination vertical cast/tow-yo operations, termed "pogos", were conducted off the J-Frame during the cruise.

Water Sample Analysis using a Gas Chromatograph

EX-11-04 included the addition of a Hewlett Packard (now Agilent) 5890 Gas Chromatograph to process water samples. Previous work conducted by science teams in the region (2009, 2010) revealed onboard methane analysis, using a gas chromatograph, to be the key to identifying the presence of some types of hydrothermal activity whose chemical signals are not detected by the in situ sensors on the CTD rosette. This additional survey of opportunity (Appendix A) was approved to provide OER a field test of this operation and learn how it could be applied to future *Okeanos Explorer* expeditions. Data processing of methane concentrations was conducted by the shipboard science team.

Water samples for methane (CH_4) analysis (20 milliliters [mL]) were drawn from the Niskin bottles mounted on the CTD in 60 mL plastic syringes. Dissolved CH_4 concentrations were determined by gas chromatography using a Hewlett Packard 5890 II gas chromatograph fitted with a six-foot, five-angstrom (Å) molecular sieve column and a flame ionization detector following a headspace extraction. The headspace extraction involved connecting the 60-mL plastic syringe containing the water sample to a purpose-built interface connected directly to the gas chromatograph and drawing ~40 mL of nitrogen into the syringe. The headspace was allowed to equilibrate with the water sample before depressing the plunger to transfer the headspace gas into a sample loop for injection onto the chromatography column for chromatographic separation.

Water Samples for Microbiology

Microbial communities are often enriched in hydrothermal plumes, meaning the number of cells is elevated above background seawater due to all the energy sources in the plume, making them another good indicator of hydrothermal activity. Water samples were collected from, and in the vicinity of, potential plume sites and preserved for microbial community analysis by Julie Huber with the Marine Biological Laboratory. Water samples were preserved in duplicate with 37% formaldehyde (final concentration 3.7%) and stored at 4 ^{o}C. More information and the process for total organic carbon (TOC) sample collection and preservation is available in Appendix B.

Water Samples for Total Organic Carbon (TOC)

Hydrothermal systems represent a biological niche, which has been considered independent from the rest of the ocean. However, hydrothermal systems can act as a transport mechanism of organic carbon from within the crust and surrounding areas of diffuse flow, out into the water column. Very few studies exist on the presence of organic carbon in hydrothermal plumes, so water samples were collected for post-cruise analysis of TOC by Sarah Bennett with NASA JPL. Water samples were collected from, and in the vicinity of, potential plume sites and preserved for post-cruise analysis. From these samples, 40 mL of water were transferred into TOC glass vials and acidified with trace metal grade hydrochloric acid (HCl) to 0.1% (i.e., 40 microliters [µL] in a 40-mL sample). More information on the TOC sample justification and preservation is available in Appendix C.

4.5 Telepresence Technology

Okeanos Explorer is equipped with satellite communication equipment, video ingestion/routing/ recording/streaming equipment, and audio ingestion/routing/recording equipment to support the vessel's telepresence mission. More information on how these technologies enabled remote science participation during EX-11-04 is in Section 5.5 Telepresence Operations of this report.

VSAT System

The vessel's VSAT tracking antennae is capable of supporting network connectivity speeds of up to 20 megabits-per-second (Mbps) ship-to-shore and up to five Mbps shore-to-ship. The SeaTel 14300 3.7m C-Band tracking antenna sits atop the vessel's main mast to minimize physical obstructions and is enclosed in a climate-controlled radome to protect the equipment from the elements. During mapping-only cruises, the system operates at five Mbps ship-to-shore and 1.5 Mbps shore-to-ship. During ROV operations the ship-to-shore link is increased to 20 Mbps to support simultaneous streaming of three HD video feeds. This bandwidth allows data transfers and use of real-time voice intercom communications between the ship and shore-based ECC.

Real -Time Video Streaming (Russell et al, 2012)

"*Okeanos Explorer* is capable of streaming up to three simultaneous high-definition video feeds to shore with a total delay of fewer than three seconds. These simultaneous feeds are accomplished using the same high-definition video encoder technology used throughout the broadcast industry for streaming television, news, and live sporting events. The encoders compress the raw high-definition video to a more manageable size and format, allowing it to be transmitted over computer networks. This compressed, but still full, high-definition video is only accessible at locations connected to Internet2. Additional video encoders located at the Inner Space Center (ISC) compress the full high-definition video by roughly 75%, allowing the feed to be distributed over standard Internet connections for public viewing on web pages and mobile devices" (Russell et al, 2012).

Intercom Communications (Russell et al., 2012)

"All shipboard and shore-based audio components of the telepresence network use a centralized intercom system for managing shipboard and ship-to-shore communications. Also adapted from the broadcast industry, this Internet-enabled intercom network facilitates communication between users working in the *Okeanos Explorer* control room, the ship's officers on the bridge, the deck department (via wireless headsets), and participants on shore." During EX-11-04, an intercom system was also set-up in the scientists' stateroom. "The intercom system is integrated with *Okeanos Explorer*'s video streaming and video recording subsystems, allowing the intercom audio to be heard in the live video streams and in the recorded video clips" (Russell et al, 2012).

Instant Messaging Service for Real-Time Collaboration (Russell et al, 2012)

"*Okeanos Explorer* uses a private instant messaging (IM) service to provide a real-time, text-based collaboration tool. A small portion of the IM traffic is person-to-person collaboration. The majority of the traffic is associated with the *Okeanos* Eventlog, a dedicated group chat room for recording real-time observations from the entire participating team. The resulting Eventlog file is time-stamped to match the ship's clocks and serves as a complete record for all cruise events and science observations" (Russell et al, 2012).

Web-based Access to Data and Operational Information (Russell et al, 2012)

"The *Okeanos Explorer* Program provides include several additional web-based tools to ensure shoreside participants stay informed and have direct access to the most up-to-date data and operational information 24/7.

- The *Okeanos Explorer* Portal is a web portal for posting and accessing operational information, including daily ship status reports, ROV dive plans, ROV dive summaries, participant contact information, background information, news, and general documentation about how to use the collaboration tools.
- The *Okeanos Explorer* File Transfer Protocol (FTP) server is a shore-based fileserver dedicated to *Okeanos Explorer*. All data collected by the vessel are transmitted to the FTP server every hour. This server provides participants with access to the latest data and information.
- The *Okeanos Explorer* Gallery is a website that provides quick access to the latest still imagery collected by the vessel. This website is useful to members of the media and educational teams who require updated still imagery for news articles and press releases.

- *Okeanos Explorer* also leverages Web 2.0 technologies to inform participants and the general public, including social media venues such as Twitter and Facebook, and web syndication tools such as Really Simple Syndication (RSS)" (Russell et al, 2012).

Exploration Command Centers (ECCs)

Shoreside participants interact with the shipboard team through ECCs, allowing explorers to join in the ongoing exploration from shore. ECCs are also an education and outreach venue and used for live events with the vessel.

"A standard ECC includes a console big enough for two participants, three large display monitors, speakers, an intercom keypanel, video decoding hardware, and computer workstations. ECCs can be as elaborate or as minimal as required by the hosting facility. The only requirement is that the hosting facility must have direct access to Internet2 to receive the high-bandwidth multicast video streams. Once configured, the ECC mimics the layout and functionality of the control rooms on board *Okeanos Explorer*… The large monitors and video decoding hardware available to ECC participants display the same three primary video feeds seen on board the ship. The intercom unit enables direct two-way communication between the watch leader in the shipboard control room and the scientists at the ISC and ECCs. The intercom station also enables shipboard personnel to listen to shore-based conversations, and vice versa. The additional computer workstations in each ECC provide Internet access to web-based tools that include the data stored on the *Okeanos Explorer* shoreside repository… Where appropriate, processing software is also made available on the workstations to assist the ECC-based scientists with interpreting the real-time data" (Coleman, 2012).

The primary role of the ECCs is to provide a broader base of intellectual capital to exploration and allow explorers to explore from shore. During EX-11-04, six ECCs were installed around the country. They were located at:

- NOAA PMEL, Sand Point, Seattle, WA
- NOAA PMEL, Newport, OR
- NOAA Headquarters (HQ), Silver Spring, MD
- University of New Hampshire (UNH), New Durham, NH
- URI's ISC, Narragansett, RI
- Mystic Aquarium's IFE, Mystic, CT

University of Rhode Island's Inner Space Center (ISC)

The ISC is equipped with a mission control center, telepresence-related support equipment, and dedicated personnel to support multiple telepresence-enabled oceanographic vessels simultaneously. The ISC consists of mission control room, video studio, video production room, audio booth, offices, and meeting spaces.

The mission control room is for hosting scientists, engineers, students, and other personnel participating in ongoing expeditions. The space consists of multiple large projection screens that can display multiple live video feeds and supporting information. Participants have proper work surfaces, access to dedicated computer workstations for viewing and manipulating incoming data, and intercom stations for communicating with the personnel on the vessel. The ISC could host up to 15 personnel.

The mission control room is also used as a training facility for staff, undergraduate students, and graduate students, and it is a visually appealing backdrop for tours and events given to the general public.

The video studio, video production room, and audio booth provide production support for live events and post-cruise product development. These spaces also support scientific operations and are used to record the live feed from vessels.

5. Operations

5.1 Diplomatic Clearances

Pursuant to the National Environmental Policy Act (NEPA), OER is required to include in its planning and decision-making processes appropriate and careful consideration of the potential environmental consequences of actions it proposes to fund, authorize, and/or conduct. The Companion Manual for NOAA Administrative Order 216-6A (https://www.nepa.noaa.gov/docs/NOAA-NAO-216-6A-Companion-Manual-03012018.pdf, last accessed June 24, 2021) describes the agency's specific procedures for NEPA compliance.

Permission to conduct Marine Scientific Research was obtained for Panama, Honduras, Nicaragua, and the Cayman Islands EEZs (U.S. Department of State Cruise ID F2011-043, Appendix D). Operations were conducted only in the EEZs of these countries' waters, as well as the United States. Permission was also received to acquire data in the Florida Keys National Marine Sanctuary.

5.2 Expedition Track

The ship departed Rodman, Panama, on the evening of August 02, 2011, and passed through the Panama Canal. After exiting the Canal, multibeam data acquisition commenced during passage through Panama's EEZ. A CTD cast was conducted before exiting the Panama's EEZ to test and calibrate the gas chromatograph. The multibeam system was secured during transit through Columbia's EEZ, then data acquisition recommenced upon entrance into Nicaragua's EEZ and continued through Honduras's and the Cayman Islands' EEZs. The ship arrived at the primary expedition operating area the morning of August 5th and commenced 24-hour combined ROV/CTD rosette/mapping operations. The ROV dives were conducted during daylight and evenings, and nights were utilized to glean more information about the operating area using the CTD rosette and multibeam. The last two nights of mapping operations, and the final ROV dive of the expedition, were conducted on the north Cayman Trough fracture zone, immediately north of the Mid-Cayman Rise. Following completion of several mapping lines along the north Cayman Trough fracture zone, the ship departed the primary operating area early morning on August 16th and began her return transit to Key West, FL. The multibeam system was secured the morning of August 16th when the ship entered the Cuban EEZ. Multibeam data acquisition recommenced upon entering the U.S. EEZ in the early evening of August 17th and continued until the ship approached Key West, FL. *Okeanos Explorer* pulled into the U.S. Coast Guard (USCG) sector Key West Navy Base at Trumbo Point, Key West, FL, early the morning of August 18th, bringing the cruise to an end.

The maps below (**Figures 6** and **7**) provide an overview of the expedition, showing the location of multibeam operations, CTD rosette operations, and ROV dives. **Tables 2 through 5** in the next section provide operational summaries of the multibeam mapping, ROV and CTD rosette operations conducted during the expedition.

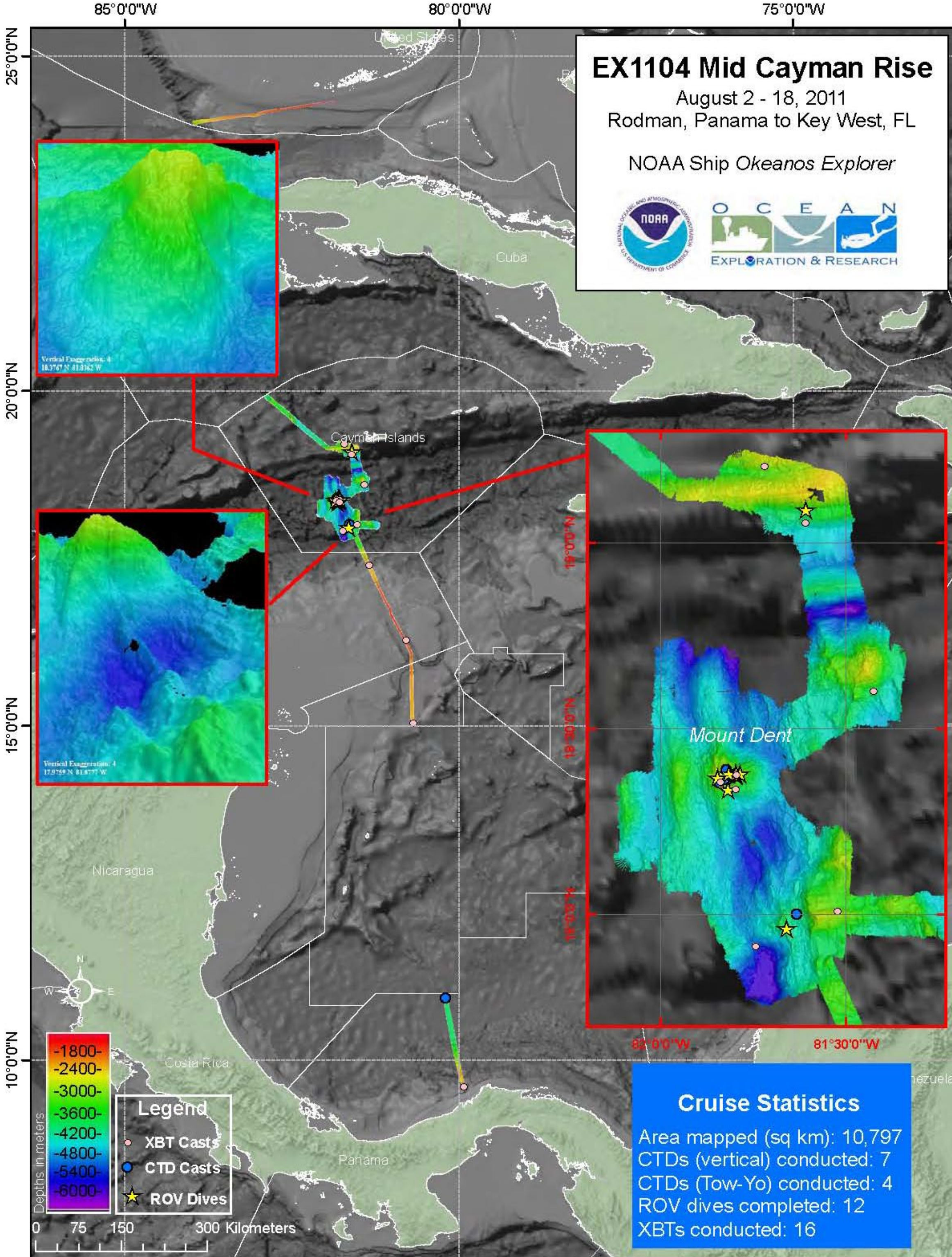


Figure 6. Map showing an overview of multibeam, CTD rosette, and ROV dive operations during EX-11-04. Underway data were not acquired in the Columbian and Cuban EEZs. Background image is from Smith and Sandwell, 1997.

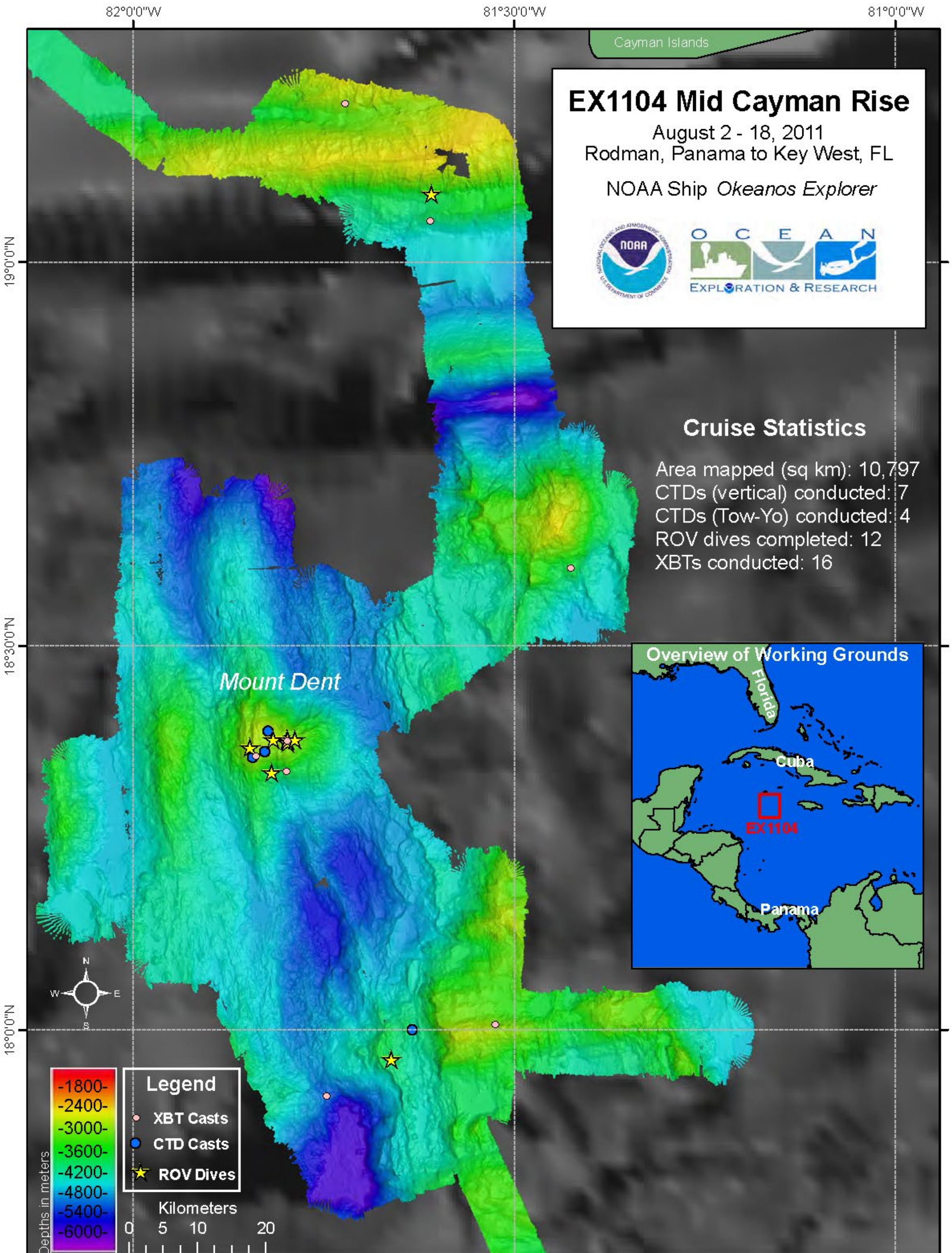


Figure 7. Overview map summarizing the multibeam operations, CTD rosette, and ROV dive locations during EX-11-04. Background image is from Smith and Sandwell, 1997.

5.3 Summary Tables of Operations and Dive Site Map

The tables below provide high level summaries and statistics of the primary science operations conducted during the expedition. **Table 2** provides an overview of the multibeam mapping activities, data, and operational statistics from the expeditions. **Tables 3 and 4** summarize the CTD rosette operations conducted during the expeditions. **Table 3** provides the statistics of the C TD "Pogo" operations (a combination of a tow-yo with vertical casts at key points, due to ship limitations preventing normal tow-yo operations) including the start and end location, speed and distance covered. **Table 4** provides the dates, locations and types of data acquired during the vertical CTD casts conducted during the expedition. **Table 5** provides a high level summary of the ROV dives conducted during the expedition, and is accompanied by an overview map (**Figure 8**) map showing these locations overlaid on top of bathymetry acquired during the expedition.

Table 2. Statistics of mapping operations conducted during the EX-11-04 expedition.

Dates	August 2 - 18, 2011
Weather delays	0 days
Total non-mapping days	2 days
Total survey mapping days	9 partial days
Total transit mapping days	5 partial days
Line kilometers of survey	2,554 km
Square kilometers mapped	10,994
Number of bathymetric multibeam files	106
Data volume of raw multibeam data files	11.1 GB
Number of water column multibeam files	0
Data volume of water column multibeam files	0
Number of XBT casts	18
Number of CTD casts - tow-yo	4
Number of CTD casts - vertical	3
Average ship speed for survey	9.5 kts

Table 3. Summary table of CTD rosette operations conducted during the EX-11-04 expedition.

CTD Stations	Type of Operation	Date	From (Position)	To (Position)	Speed	Sensors	Distance covered	Water Samples?
CTD_02	"Pogo" combo	08052011	18° 22.591, -81° 47.892	18° 22.328, -81° 48.388	0.5	LSS, ORP, Altimeter	1 m	Yes (2,296 -1,900 m)
CTD_03	"Pogo" combo	08072011	18° 21.706, -81° 49.632	18° 22.134, -81° 48.768	0.5	LSS, ORP, Altimeter	1.71 km	Yes (2,400 -1,900 m)
CTD_04	"Pogo" combo	08082011	18° 21.265, -81° 50.576	18° 22.659, -81° 48.723	0.5	LSS, ORP, Altimeter	2.98 km	Yes (2,400 -1,900 m)

CTD_05	"Pogo" combo	08092011	18° 23.31, -81° 49.35	18° 22.661, -81° 48.881	0.5	LSS, ORP, Altimeter	1.44 km	Yes (2,203 -1,698 m)
TOTAL							7.13 km	

Table 4. Location and description of vertical CTD cast conducted during EX-11-04 expedition.

CTD station	Date	Position	Sensors	Water Samples Collected (Depth/m)
EX1104_CTD_01	08032011	10° 55.428, -80° 11.910	LSS, ORP, Altimeter	Yes (995-20 m)
EX1104_CTD_06	08132011	17° 59.994, -81° 37.992	LSS, ORP, Altimeter	Yes (3,737-2,300 m)
EX1104_CTD_07	08142011	18° 22.59, -81° 47.896	LSS, ORP, Altimeter	Yes (2,300-1,800 m)

Table 5: Summary of ROV dives conducted during the EX-11-04 expedition. The dive purpose, overview and scientific highlights are available in Table 7.

Dive Number #	Date (GMT)	Site Name	Latitude (N)	Longitude (W)	Max Depth (m)	Total time on bottom	Total linear km observed*
01	08-05-2011	Von Damm	18° 22.664'	081° 47.734'	2,343.9	4:43:46	2.20
02	08-06-2011	Von Damm	18° 22.667'	081° 47.864'	1,192.0	N/A	N/A
03	08-06-2011	Von Damm	18° 22.667'	081° 47.864'	2,372.1	4:57:17	2.51
04	08-07-2011	Von Damm	18° 22.668'	081° 47.965'	2,339.4	5:40:38	3.30
05	08-08-2011	Southern slopes of Mt. Dent	18° 20.226'	081° 49.244'	3,461.8	4:39:25	4.14
06	08-09-2011	South Slope of the Von Damm vent site	18° 22.490'	081° 47.906'	2,421.9	6:26:02	4.10
07	08-10-2011	NW from Von Damm	18° 22.805'	081° 47.935'	2,356.0	7:35:38	2.41
08	08-11-2011	Bumpland	18° 22.738'	081° 49.076'	2,202.6	6:24:01	3.68
09	08-12-2011	Europa	18° 22.072'	081° 51.149'	2,298.0	6:29:50	4.32
10	08-13-2011	SE Corner	17° 57.783'	081° 39.859'	3,541.6	6:17:23	4.20
11	08-14-2011	Mt Doom	18° 22.750'	081° 47.284'	2,520.6	6:41:43	4.35
12	08-15-2011	Cayman Trough	19° 05.362'	081° 36.564'	3,267.6	5:32:51	4.48
TOTAL						**65:28:34**	**39.69**

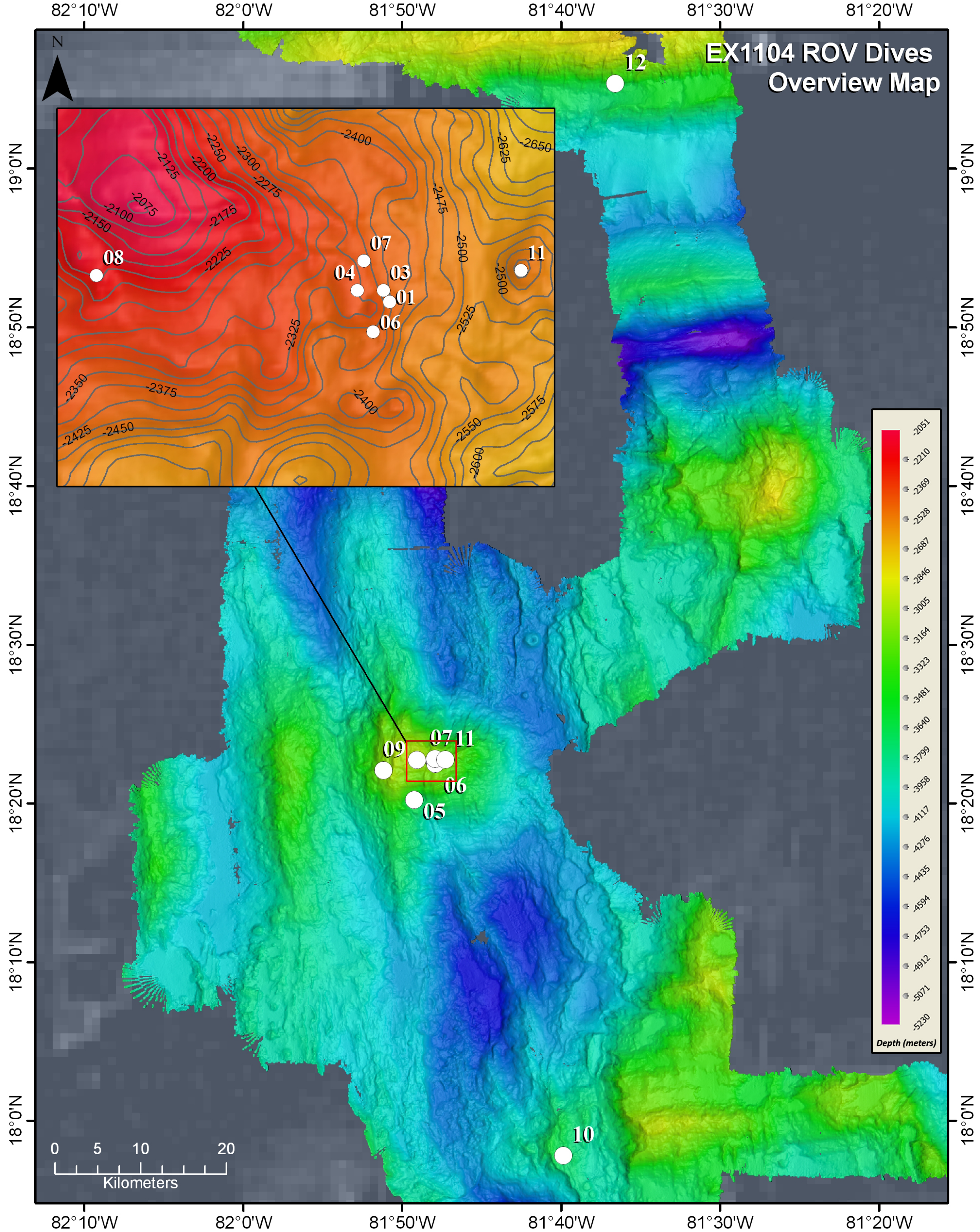


Figure 8. Overview map of the Mid-Cayman Rise showing the location of ROV dives (by dive number) overlaid on multibeam bathymetry acquired during EX-11-04. Close-up maps of the bathymetry and

ROV dive sites are available in **Figures 18-20.** Dives 01 and 03 indicate the general location of the Von Damm vent site.

5.4. Calendar of Events

- Depart Rodman, Panama: 20110802 – 1400 UTC
- Exit Panama Canal: 20110803 – 0000 UTC
  Enter Columbia EEZ: 20110803 – 1845 UTC
- Enter Nicaragua: 20110804 – 1700 UTC
- Enter Honduras: 20110804 – 2130 UTC
- Enter Cayman Islands EEZ: 20110805 – 0640 UTC
- Enter Cuban EEZ: 20110816 – 1340 UTC
- Enter U.S. EEZ: 20110817 – 2115 UTC
- Arrive in Key West, FL: 20110818 – 1215 UTC

August 2011						
Sun	**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**
	1 • Ship in port: Balboa, Panama	2 • Depart dock at 1830 for Panama Canal, transit through Canal overnight.	3 • Complete transit through Canal. • Multibeam transit mapping in Panama EEZ. • CTD 01 test cast. • No data collected in Colombian EEZ.	4 • Continue transit multibeam mapping to Mid-Cayman Rise operations area. • Data collected in Nicaragua and Honduras EEZs.	5 • Transit exploration mapping to Mid-Cayman Rise operations area. • ROV Dive 01. • Hull SCUBA dive (non-science). • CTD 02 “pogo” combo.	6 • Morning multibeam mapping. • ROV Dive 02 (aborted) and 03. • Evening mapping.
7 • Overnight mapping. • ROV Dive 04. • CTD 03 “pogo” combo.	8 • Overnight mapping. • ROV Dive 05. • CTD 04 “pogo” combo.	9 • Overnight mapping. • ROV Dive 06. • CTD 05 “pogo” combo.	10 • Overnight mapping. • ROV Dive 07. • Evening mapping. • ET work on VSAT.	11 • Overnight mapping. • ROV Dive 08. • CTD termination failure • Evening mapping. • ET work on VSAT.	12 • Overnight mapping. • ROV Dive 09. • Evening mapping. • ET work on VSAT.	13 • Overnight mapping. • ROV Dive 10. • CTD test cast & CTD 06 cast. • ET work on VSAT.
14 • Overnight mapping.	15 • Overnight mapping.	16 • No data collection	17 • Mapping in US EEZ	18 • Arrive Key West, FL	19	20

• ROV Dive 11. • CTD 07 cast.	ROV Dive 12. • Mapping in Cayman Islands EEZ. • No mapping in Cuba EEZ.	while in Cuba EEZ.				

5.5. Telepresence Operations

Okeanos Explorer is a dedicated ocean exploration ship, with a mission and goal to travel to places where little to nothing is known in order to make discoveries. Since the team does not know what they will find, they cannot always plan to have the right experts onboard the ship. Therefore, as a ship dedicated to exploration, *Okeanos Explorer* is equipped with "telepresence" technology–allowing the team onboard to remotely engage with a theoretically unlimited shoreside intellectual capital.

5.5.1 Telepresence Overview

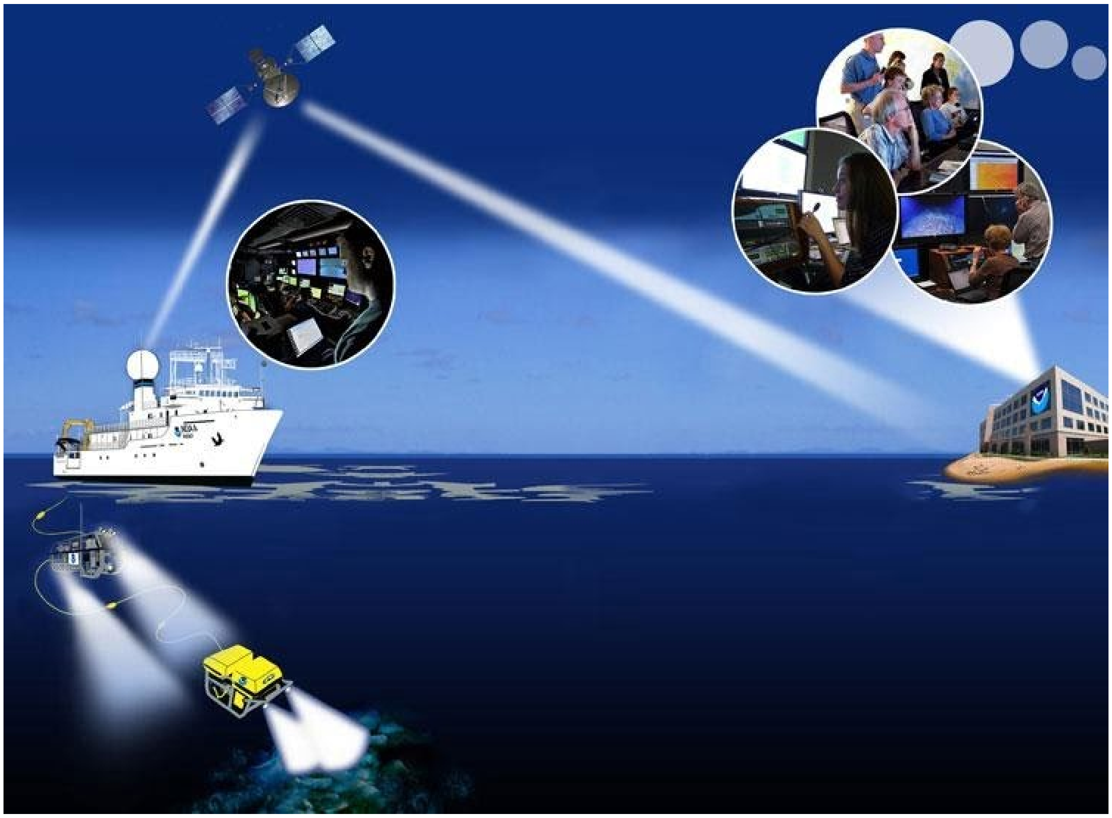


Figure 9. A telepresence-enabled platform: satellite technology enables data and video to be transmitted in real time from NOAA Ship *Okeanos Explorer* and ROVs working at depth to a shore-based hub where the video is transmitted in high definition out on Internet2 to a variety of receiving stations on shore include a number of Exploration Command Centers located around the country. A lower resolution, higher latency version is also available via standard Internet. Access

to the video and a suite of Internet-based collaboration and communication tools allows scientists located on shore to join the operation in real time.

Via telepresence (**Figure 9**), live images from the seafloor and other science data flow over satellite and high-speed Internet pathways to scientists standing watches in ECCs or other Internet-enabled locations. Telepresence enables a shore-based team of scientists, students, and the public to join the expedition in real time.

Okeanos Explorer provides accommodations for up to 46 crew and technicians. Of these, 26 are crew who run, maintain, and operate the ship; the remaining 20 berths are “mission” berths–intended for personnel sailing who will support the ocean exploration “mission” operations. The majority of those berths are dedicated to technicians to run the equipment. Typically, only two scientists sail onboard the ship (a third scientist was allowed during EX-11-04 to conduct gas chromatograph analysis), and the majority of the science team participates from shore (**Figure 10**).

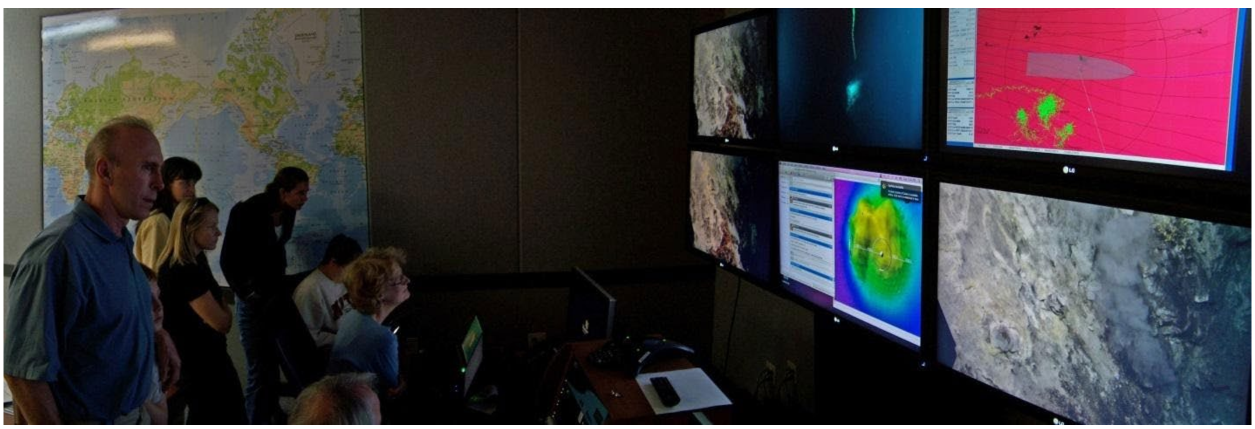


Figure 10. Scientists participate in an ROV dive remotely from the Seattle ECC.

5.5.2 Telepresence Technology

Remote participation in the seagoing operations is made possible through several technologies. The primary is a 3.7-meter C-band VSAT antenna capable of streaming up 20 Mbps of data to shore. A VSAT is used to transmit and receive data such as video, voice, and computer information from the ship to a satellite in space that then transmits the data to a shoreside hub. The 20 Mbps bandwidth allows up to three HD video feeds and data to be streamed from the ship to shore in near-real time. The video feeds can include the cameras on the ROVs while underwater, or one of more than a dozen cameras in mission spaces onboard the ship–showing equipment deployments and recoveries, personnel at work, or even computer data acquisition screens of ongoing operations. These HD video feeds are sent from the ship to a satellite in space, then down to a shoreside hub at URI’s ISC before being broadcast worldwide on

Internet2. On Internet2, the video feed can be seen with less than a two-second delay to what is happening onboard the ship. Once on shore at the ISC, the video feeds are also run through an encoder and a lower resolution version is streamed online to be made available to anyone with standard Internet connection, albeit with a longer latency. Making the feeds publicly available on standard Internet enables scientists to participate from anywhere with an Internet connection and allows the general public to follow along and take a front-row seat as discoveries are made in real time. EX-11-04 was the first *Okeanos Explorer* expedition enabling the live video feeds to be viewable on standard Internet through NOAA's Ocean Explorer website (http://oceanexplorer.noaa.gov, last accessed June 24, 2021).

The bandwidth also allows data to be sent to shore in near-real time. The ship has an integrated, end-to-end data management protocol that includes both a ship and shoreside data repository server that are continuously compared via a synchronization process to mirror each other. This process ensures the latest data and data products collected onboard the ship are automatically transferred to shore. The remote sync (Rsync) process is run hourly, 24/7 during the cruise, and makes the data onboard the ship available to shoreside science participants within an hour to a few days after being collected.

A number of ECCs around the country tap into these Internet2 feeds, and include access to additional tools and equipment allowing scientists to participate in the cruise from shore. ECCs typically have three large monitors displaying each of the video feeds coming off the ship (**Figure 10**) and are equipped with an RTS Systems, Inc., intercom unit (**Figure 11**) or conference phone and computers. The RTS intercom units use Voice over Internet Protocol (VoIP) technology to allow the shoreside scientists to communicate directly with the scientists onboard the ship and scientists located at other ECCs that are equipped with this same technology.

5.5.3 Shoreside Participation

Scientists are able to participate from shore by viewing these live feeds online and talking directly with the onboard and fellow remote scientists in real time through RTS intercom units or a phone call (**Figure 11**). At the same time, instant messaging is used to facilitate communication and logging of science observations. A group chat room called the Eventlog is set up to enable science participants both to communicate with each other, but also to log observations during science operations. Each entry includes the participant's name and is given a UTC date and time code. All of the systems onboard the ship are synced to UTC date and time, and to allow correlation of any entries in the Eventlog with datasets collected onboard the ship.

Figure 11. Voice communication between *Okeanos Explorer* and shoreside ECCs uses a VoIP-enabled RTS intercom system. The intercom system leverages the *Okeanos Explorer's* Internet connectivity to connect all of the ship-based and shore-based intercom units into a single system.

Participation is also facilitated by daily ship-to-shore science meetings, focused on discussing the latest data and operational updates, and also collaboratively planning the next ROV dive. Just like during a webinar, computer data screens are sent off the ship as a live feed during these meetings so everyone on the call is looking at the same view and can collaboratively discuss and refine operations and dive plans for the next day. During EX-11-04, two daily science meetings were held with the ship and shore-based science teams to discuss the latest findings and plan the next step of the expedition.

Finally, the latest datasets and products transferred from the ship to the shoreside repository server can be accessed by the shoreside science team using an FTP site. This way, the shoreside science team can download and review the latest data and be prepared to provide input on the next steps of the expedition during the next cruise planning meeting.

During EX-11-04, the majority of the science team participated in the expedition from the ECC located at URI's ISC; however, additional scientists provided input from around the country and the world. Sarah Bennett participated via instant messaging and by accessing the Internet2 feed from NASA's JPL in Pasadena, CA. Notably, Sarah participated remotely in CTD rosette operations by watching the live data acquisition screens from shore, chatting with onboard scientists via the Eventlog, and providing input (e.g., when to collect water samples). James Kinsey joined from an informal ECC set up at WHOI in Woods Hole, MA. Other scientists joined from Pennsylvania, Germany, Canada, Portugal, and the United Kingdom (U.K.)–participating by watching the live video feeds online and sharing expertise via instant messaging and e-mail. They played a key role by identifying biological, chemical, and geological features shown in ROV images or revealed in data from ocean sensors thousands of miles away.

5.5.4 Open Data

Catalyzing follow-on work is best accomplished through an open data model. The data acquired and products developed are shared in real time, both during and after a cruise. Within 60-90 days following cruise completion, the data and products are sent to the National Archives. This way, the data collected meets the needs of many different stakeholders and helps achieve the goal of enabling follow-on research and management activities.

6. Results

6.1 Summary of Results

During August 2011, a team of scientists and technicians, both at sea and on shore, conducted exploratory interdisciplinary investigations on the geology, marine life, and hydrothermal systems at the Mid-Cayman Rise. The 17-day expedition included 10 days of operations at the Mid-Cayman Rise and one day at the Cayman Trough fracture zone, southwest of the Cayman Islands and located entirely within their EEZ. Over the course of 11 days, nearly 11,000 km^2 of seafloor were mapped at the Mid-Cayman Rise, primarily focused on the OCCs comprising much of the rift-valley walls and the Cayman Trough fracture zone to the north. The team conducted 12 ROV dives (**Table 5**, **Figure 8**): 10 were focused on locating and characterizing the full extent of the Von Damm hydrothermal site and exploring further afield on "Mount Dent" to understand its geologic setting; one dive was conducted on the southeastern rifted OCC; and the final ROV dive was conducted a vertical transect up the south-facing slope of the Cayman Trough fracture zone.

Initial results from the expedition were summarized in the March 2012 Oceanography Supplement publication, "New Frontiers in Ocean Exploration: The E/V *Nautilus* and NOAA Ship *Okeanos Explorer* 2011 Field Season" (Bell et al, 2012). The summary below is largely excerpted from the "Exploration of the Mid-Cayman Rise" article by German et al., 2012.

The expedition implemented an innovative operating paradigm, enabled by telepresence technology, using satellites and high-bandwidth Internet2 to transmit data and video feeds to shore in real time. This supported the participation of an international team of scientists, primarily at the URI ECC, but also at WHOI and NASA's JPL. Scientists around the world (Pennsylvania, Germany, Canada, Portugal and the U.K.) also participated via standard Internet. With only three scientists on board the ship, the shore-based team was an integral part of the expedition, providing comments during daily ROV dives and CTD casts, evaluating transmitted data in real time, and helping to plan and direct daily operations.

The expedition focused on mapping the shallow outer "walls" bounding the Mid-Cayman Rise rift valley where long-lived fault-systems lift rocks from deep within Earth's interior to the ocean floor to form OCCs (John and Cheadle, 2010). The team also investigated the water column overlying the ridge axis for telltale chemical signals of venting using a CTD rosette, in situ sensors, and onboard gas chromatograph analyses. Finally, the expedition collected detailed ROV seafloor observations (**Figures 12**-**18**), including novel vent sites and the ecosystems they host.

Ten ROV dives focused on locating and characterizing the full extent of the Von Damm hydrothermal site and on exploring further afield on "Mount Dent" to understand its geologic setting. Thanks to input from U.K. colleagues, the team was able to locate the central spire of the Von Damm hydrothermal field at the start of Dive 01 and were astonished to find a chimney orifice that was approximately one meter wide (**Figure 12**), along with shrimp (**Figures 13** and **14**) that were substantively different in appearance from other Mid-Atlantic Ridge species, but exhibiting features characteristic of shrimp from other known vent sites that host chemosynthetic bacteria.

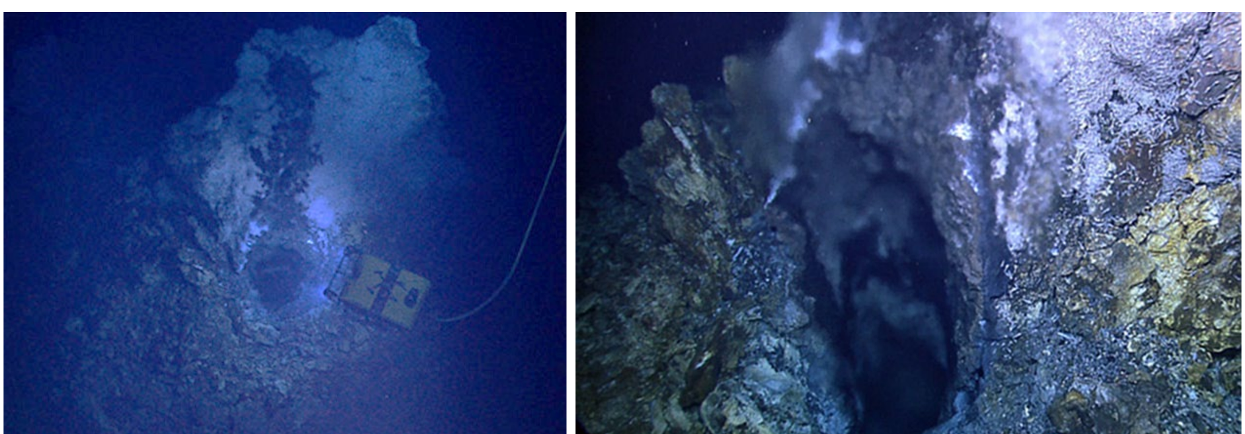


Figure 12. ROV *Little Hercules* examining the vent-orifice at the summit of the eight-meter tall spire on the summit of the central Von Damm hydrothermal vent field (left). This contained an orifice more than ~one meter (right)–about the same size as ROV *Little Hercules*–emitting hot fluids near the summit of the spire. Images captured during Dive 04.

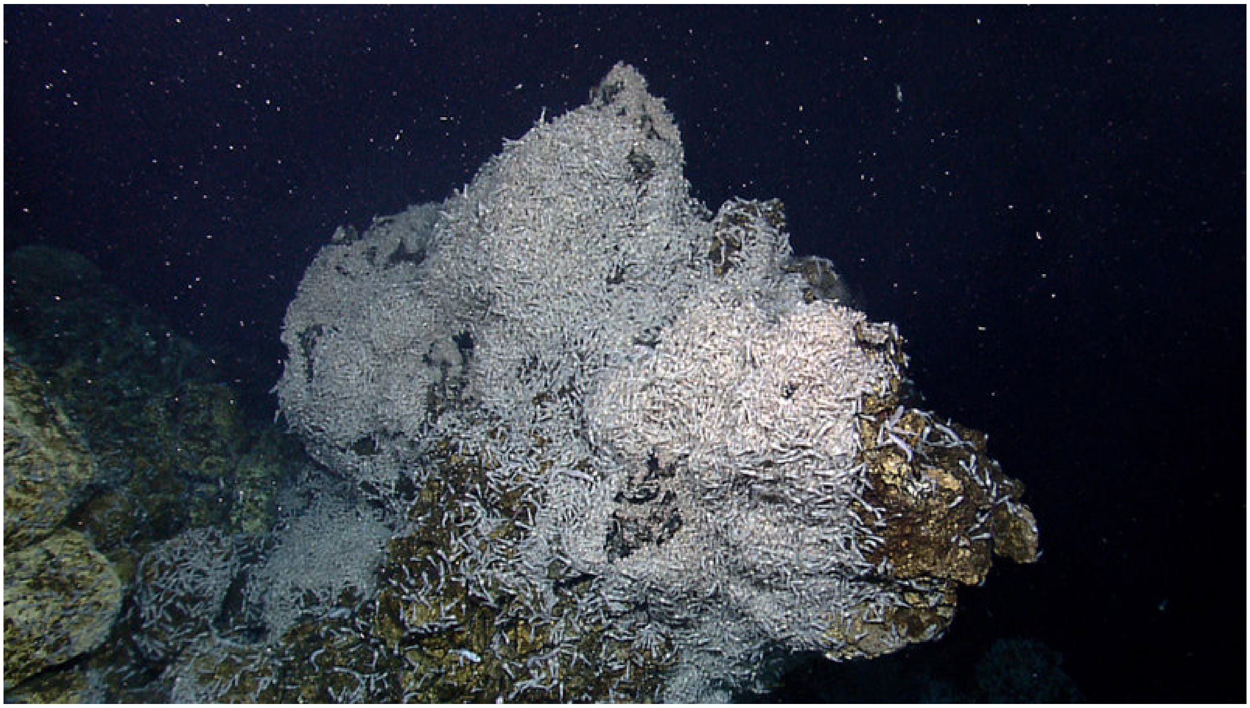


Figure 13. One of the "shrimp spires" found during the first few dives at the Von Damm hydrothermal vent field. The shrimp (possibly *Rimicaris* sp.) were crawling all over the rocks, likely attracted by the warm fluid seeping from the spire's surface.

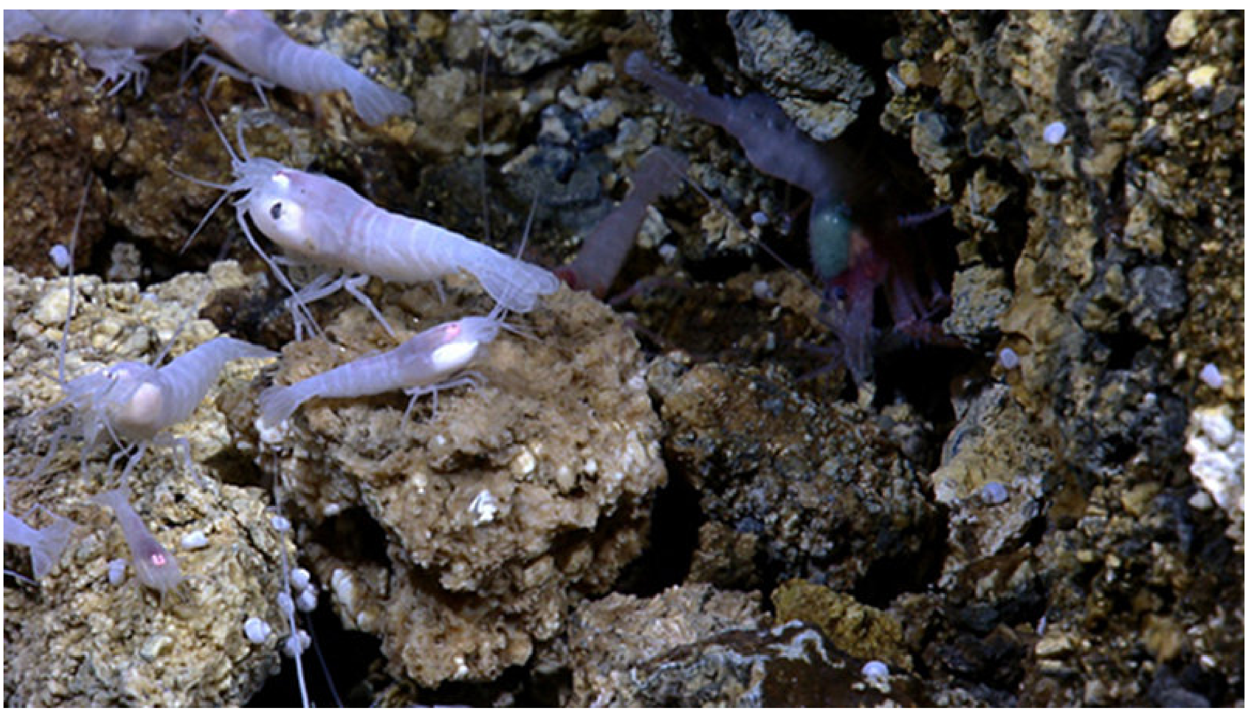


Figure 14. Still frame from video captured during Dive 01. At least two species of shrimp were found at the Von Damm hydrothermal vent site. One relies on chemosynthesis for food, and the other may be a predator.

During Dive 03, the first live tubeworm at an Atlantic hydrothermal field was documented (**Figure 15**). The shore-based science team confirmed that while these tubeworms were distinct from those seen at hydrothermal vents on the Galapagos Rift, they appeared similar to species found in the Gulf of Mexico, where they live in association with cold hydrocarbon seeps, and at vent fields as far afield as Marsili Seamount off the coast of Italy and the Lau Basin near Tonga. Continued exploration of the Von Damm site revealed additional venting sites and tubeworm aggregations. In one location, microbial mats, vent shrimp, tubeworms, and gastropods were all observed coexisting in an area of hydrothermal fluid flow (**Figures 16** and **17**).

Figure 15. Close-up image showing the first live tubeworm seen during the expedition during Dive 03 at a hydrothermal vent site in the Von Damm vent field. At the time of the EX-11-04 expedition, hydrothermal tubeworms at a vent site in the Atlantic Ocean had only been noted at Marsili Seamount in Italy. Chemosynthetic bacteria living inside the tubeworms derive energy from chemicals emitted in the hot water of hydrothermal vents.

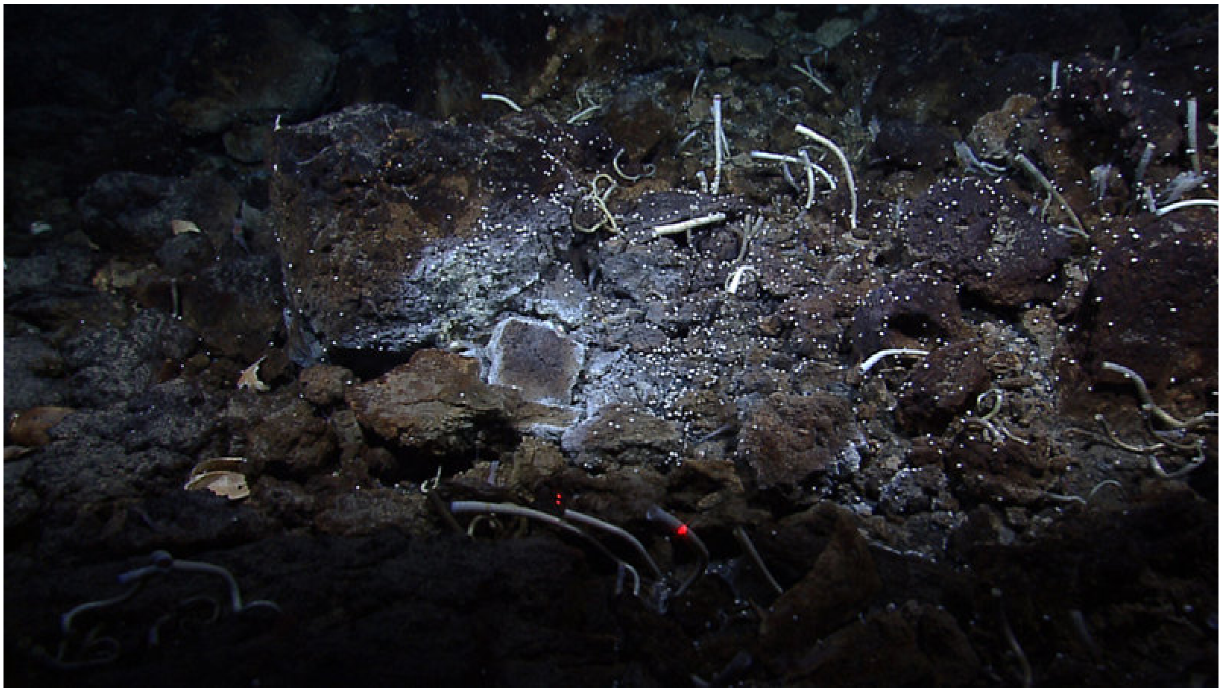


Figure 16. The "moment of discovery" happened at this site during Dive 06, where active fluid flow, microbial mats, vent shrimp, gastropods, and tubeworms were all observed together at a single site.

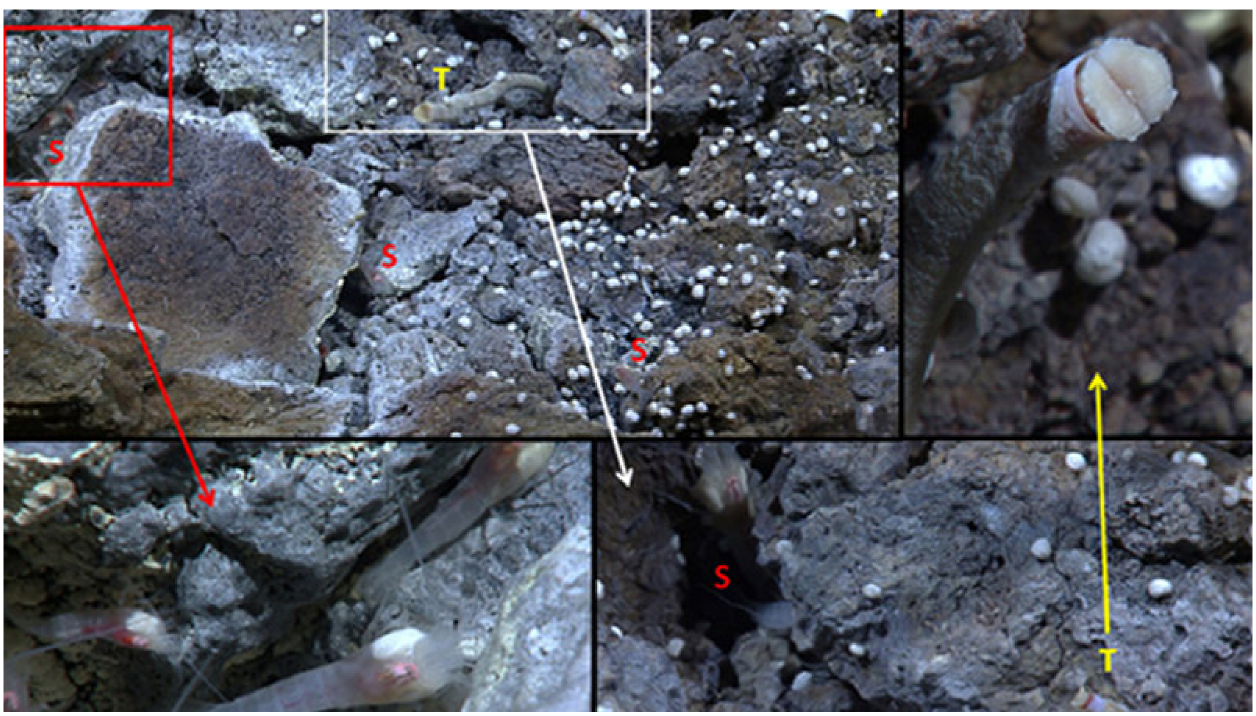


Figure 17. Close-up images showing the Dive 06 discovery: the top-left and bottom-right images show close-up views of the site hosting chemosynthetic tubeworms (T) and shrimp (S) containing chemosynthetic bacteria. The numerous small conical animals are gastropods (marine snails) that also appear to be associated with vent activity.

A second expedition objective was to understand tectonic processes associated with OCC formation and evolution, and to answer the question: why does the Von Damm field occur where it does? For this investigation, the team used ROV cameras to explore the south wall of "Mount Dent", located beneath the vent site. This mission also included an extensive nighttime multibeam program, enabling the team to map the bathymetry of three OCCs rising from the rift valley floor (**Figure 7**).

Toward the end of the cruise, an ROV dive was conducted in the southeast corner of the Mid-Cayman Rise to explore a suspected axial volcanic ridge. The ROV dive revealed interleaved pillow basalts and sheet flows at the first outcrop. There was no evidence of recent volcanic activity, nor active venting or associated vent fauna. Nonetheless, identification of ropey "pahoehoe" lava textures (**Figure 18**) confirmed that lava emission rates, even on an ultraslow-spreading ridge, can be impressive.

Figure 18. Ropey "pahoehoe" lava-flow textures from Dive 10 (left) deeper than 3,000 m on the Mid-Cayman Rise, and (right) Chain of Craters Road, Hawai'i Volcanoes National Park (*credit: Chris German*).

The final ROV dive of the expedition conducted a geological and biological transect from south to north up the interior wall of the north Cayman Trough fracture zone. Although fracture zones represent one of the three major types of plate tectonic boundary, they have received relatively little attention, and, as far as is known, this was the first deep submergence investigation of this particular feature.

This exploratory expedition was extremely productive and successful. The team documented the full extent of the Von Damm vent field (approximately 150 m on a side), identified the major sites of active venting, and located new biological communities. Using the ship's CTD and mapping programs, the team investigated the fate of fluid discharge from the site, tested for the location of other sites, and investigated geological processes that underpin hydrothermal venting. This work provides an invaluable legacy for further internationally coordinated research beginning with an ROV *Jason* sampling program in January 2012 (German et al. 2012).

6.2 CTD Results

A total of 7.13 linear km was surveyed using a CTD tow-yo configuration to conduct combination vertical cast/ tow-yo, or "pogo", operations. The data were processed by Sarah

Bennett at NASA's JPL. Water samples were immediately processed onboard through a gas chromatograph to search for the presence of methane (Section 4.4 – Water Sample Analysis using a Gas Chromatograph). The results from these analyses are available both in the table below and the CTD Rosette summary forms in Appendix E.

Table 3 and Table 4 (pages 27-28) provide more information on the CTD operations from the expedition, including "pogo" start and end locations, speed, distance covered, and data types. The following table (**Table 6**) provides a summary description of the data/results of the CTD operations conducted during EX-11-04.

Table 6. summary description of the data/results of the CTD operations conducted during EX-11-04. Additional CTD operations data are available in tables 3 and 4.

CTD Stations	Type of CTD Operation	Latitude (N):	Longitude (W):	Water Samples Collected?	Remarks
CTD_01	Vertical Cast	10° 55.428	-80° 11.910	Yes (20) – Methane analysis	A test cast.
CTD_02	Combination or "Pogo"	18° 22.591, -81° 47.892	18° 22.328, -81° 48.388	Yes (20) – Methane, TOC, Microbiology	Strong ORP signals at near bottom depths and plume height (2,000 m). LSS and potential temperature (POTEMP) at plume height only. LSS, POTEMP and CH_4 traced to 1 km from source by tow-yo.
CTD_03	Combination or "Pogo"	18° 21.706, -81° 49.632	18° 22.134, -81° 48.768	Yes (20) – Methane, TOC, Microbiology	No signals in LSS for entire cast. Signal in final ORP upcast only. CH_4 anomalies at all three "pogo" legs. Plume traced to end point, 4 km from source.
CTD_04	Combination or "Pogo"	18° 21.265, -81° 50.576	18° 22.659, -81° 48.723	Yes (20) – Methane, TOC, Microbiology	No signals in LSS or ORP but significant CH_4 anomalies throughout cast.
CTD_05	Combination or "Pogo"	18° 23.31, -81° 49.35	18° 22.661, -81° 48.881	Yes (20) – Methane, TOC, Microbiology	No in situ ORP or LSS anomalies observed. Shipboard methane showed above background concentrations at all three stations of "pogo" (strongest at center).
CTD_06	Vertical Cast	17° 59.994	-81° 37.992	Yes (20) – Methane analysis	No plumes observed from in situ sensors. All CH_4 samples yielded background values ($\leq$1 nM).
CTD_07	Vertical Cast	18° 22.59	-81° 47.896	Yes (20) – Methane, TOC, Microbiology	No LSS signal but lots in ORP sensor. CH_4 analyses very high. Three plumes. Also, positive near bottom T° anomalies.

6.3 Mapping Results

Transit exploration multibeam mapping using the EM 302 was conducted in the EEZs of Panama, Nicaragua, Honduras, the U.K. (Cayman Islands), and the U.S. (**Figure 6**). New data acquisition files were started for each country to ease international data delivery requirements. The ship transited through the EEZs of Colombia and Cuba, but did not collect mapping data, as marine scientific research clearance was not requested. Focused exploration mapping was conducted over the Cayman Trough (**Figure 7**).

EM 302 multibeam data collection was conducted for 2,553.5 linear km of the seafloor, and a total of 10,994 km^2, was mapped during this expedition using the EM 302 multibeam, including mapping over previously unmapped areas of the Mid-Cayman Rise and Cayman Trough fracture zone. Focused EK60 18 kHz split-beam fisheries sonar operations were conducted over the Cayman Trough fracture zone where seeps were potentially present, but ultimately none were detected.

XBTs were collected every two to four hours to correct multibeam data for changes in sound speed in the water column and were applied in real time using SIS. A thermosalinograph (TSG) seawater intake mounted on the hull at the EM 302 transducers was used to determine sound speed at the sonar head and was applied in real time using SIS.

Further details on the mapping results are available in the EX-11-04 Mapping Data Acquisition and Processing Report available at http://doi.org/10.7289/V5/MDR-OER-EX1104 (last accessed June 23, 2021).

6. ROV Dive Overviews

Table 7 (below) summarizes the purpose, overview, and scientific highlights of each dive. **Figure 7** provides an overview map showing the location of each successful ROV dive conducted during EX-11-04 overlaid on bathymetry data acquired during EX-11-04. Several close-up maps (**Figures 19-21**) showing ROV dive locations (by number) overlaid on EX-11-04 bathymetry are below. Detailed summaries of all ROV dives conducted during EX-11-04, along with associated products including dive track maps, dive imagery, and sensor data, are available online at: https://www.ncei.noaa.gov/waf/okeanos-rov-cruises/ex1104/, last accessed September 15, 2021).

Table 7. EX-11-04 ROV dive summary listing the dive purpose, overview, and highlights.

Date	Dive #	Site name	Dive Purpose and Overview
8/5	01	Von Damm	**Purpose:** Locate and characterize the full extent of the Von Damm site in a systematic survey. **Summary:** Immediately located the Von Damm vent site at ~2,300 m. The vent had an ~8 m spire emitting diffuse hydrothermal outflow, and more focused clear fluid flow from an ~1 m orifice on its north side; the spire was covered by dense populations of a hydrothermal shrimp cf. *Rimicaris* sp. Conducted systematic video survey surrounding vent site and identified “hotspots” of activity for next dive.
8/6	02	Von Damm	Port vertran died at 1,100 m. Dive aborted. Vehicles returned to surface.
8/6	03	Von Damm	**Purpose:** Complete characterization of the Von Damm vent-site and, as time permits, commence off-site reconnaissance. **Summary:** Completed characterization of Von Damm area planned during Dive 01 with additional survey coverage along the southern and eastern flanks. Commenced off-site reconnaissance. Discovery of a live hydrothermal tubeworm at a vent site in the Atlantic Ocean (only one is previously known in the Atlantic–at Marsili Seamount offshore Italy).

8/7	04	Von Damm	**Purpose:** Conduct detailed biological characterization of hotspot areas identified at Von Damm, and conduct fluid flow experiment. **Summary:** Conducted detailed observations of the biology and other “hot spots” of the Von Damm hydrothermal field. Incredible images of the vents and animals living at the sites were captured by the cameras on the ROV. Used LH to measure flow of hydrothermal fluid out of a 5-6 cm orifice on the side of the main spire.
8/8	05	Southern slopes of Mt. Dent	**Purpose:** Conduct a south to north geologic transect up the south flank of Mt. Dent. **Summary:** Conducted a vertical transect starting at 3,461 m along highly varied seafloor, from ooze to huge angular boulders up to tens of meters across on steep overhanging slopes. Exposure of moderately south dipping rock did crop out at several depths. Toward the end of the dive, meter-scale pock-mark sediment was noted. Fauna observed were distributed infrequently along the dive.
8/9	06	South Slope of the Von Damm vent site	**Purpose:** Traverse from SSE of Von Damm toward the base of the mound, conduct a VIP event at the central Von Damm spire, and then continue exploration onward to the W of that vent site. **Summary:** The dive traversed an area to the SSE of the Von Damm site, discovering extensive new biological communities–including both tubeworms and shrimp–hosted in diffuse hydrothermal flow. Found new chimney structures in the same area, emitting hot clear fluid in a much more focused manner. Conducted a VIP event with the Silver Spring ECC and ISC. Then explored new seafloor areas and investigated sonar targets identified from a prior autonomous underwater vehicle (AUV) survey. At these three sonar targets, the team found rocks outcropping, at least some measure of fluid flow out of the seafloor, and extensive deep sea coral communities and other fauna.
8/10	07	NW from Von Damm	**Purpose:** Examine “bright” spots in JC44 Autosub backscatter. **Summary:** Most of Dive 07 explored rocky and sedimented areas with relatively low levels of biota. At the end of the dive, the team discovered a habitat with dense biota, corals, and very diffuse fluid flow. The dive was extended to investigate.
8/11	08	“Bumpland”	**Purpose:** Determine rock type of mounds, test if orientation is controlled by faulting, and search for vents. **Summary:** Dive 08 was conducted west of the summit of Mt. Dent, following a series of topographic highs at the base of a steep west-facing scarp. Imaged fantastic geological imagery, including video of a double fissure.
8/12	09	“Europa”	**Purpose:** Locate the source of CH_4 and E_h anomalies in water column. **Summary:** Dive 09 was conducted at “Europa”, a suspected low-temperature “Lost-City” type hydrothermal field toward the SW limit of Mt. Dent’s summit. Much of the dive was spent traversing biogenic carbonate sediment and basaltic rock types. A geological highlight was finding what appeared to be intercalated sediment and lava flows, but no active venting was found.
8/13	10	SE Corner	**Purpose:** Explore the axial volcanic ridge (AVR) of Mid-Cayman Rise and look for vents. **Summary:** Dive 10 was conducted towards the SE corner of the Mid-Cayman Rise, transecting NNW across the rifted OCC. Much of the dive was spent traversing biogenic sediment; however, highlights included fresh basalt pillow lavas and examples of frozen sheet flow lavas.
8/14	11	“Mt Doom”	**Purpose:** Investigate “Mt. Doom” and traverse west to investigate slope.

			Summary: Dive 11 started with a visit to “Mt. Doom”–a tall conical mountain about 1,000 m from the Von Damm vent site and similar in size and shape. Although no active venting was encountered on “Mt. Doom”, a return trip to the Von Damm site approaching from the east encountered more tubeworms and a new site of active venting outside the previously explored area, almost doubling the total extent of venting now known at the site.
8/15	12	Cayman Trough	**Purpose:** Transect south to north up the interior wall of the north Cayman Trough fracture zone. **Summary:** Dive 12 was conducted up the interior (south-facing) wall of the north Cayman Trough fracture zone. Geological highlights included a 40-foot-high sheer vertical cliff face thousands of meters deep. Despite the steep slope of about 30-40º from horizontal, the remainder of the dive was spent over thick biogenic carbonate sediment but interspersed with an array of biological highlights.

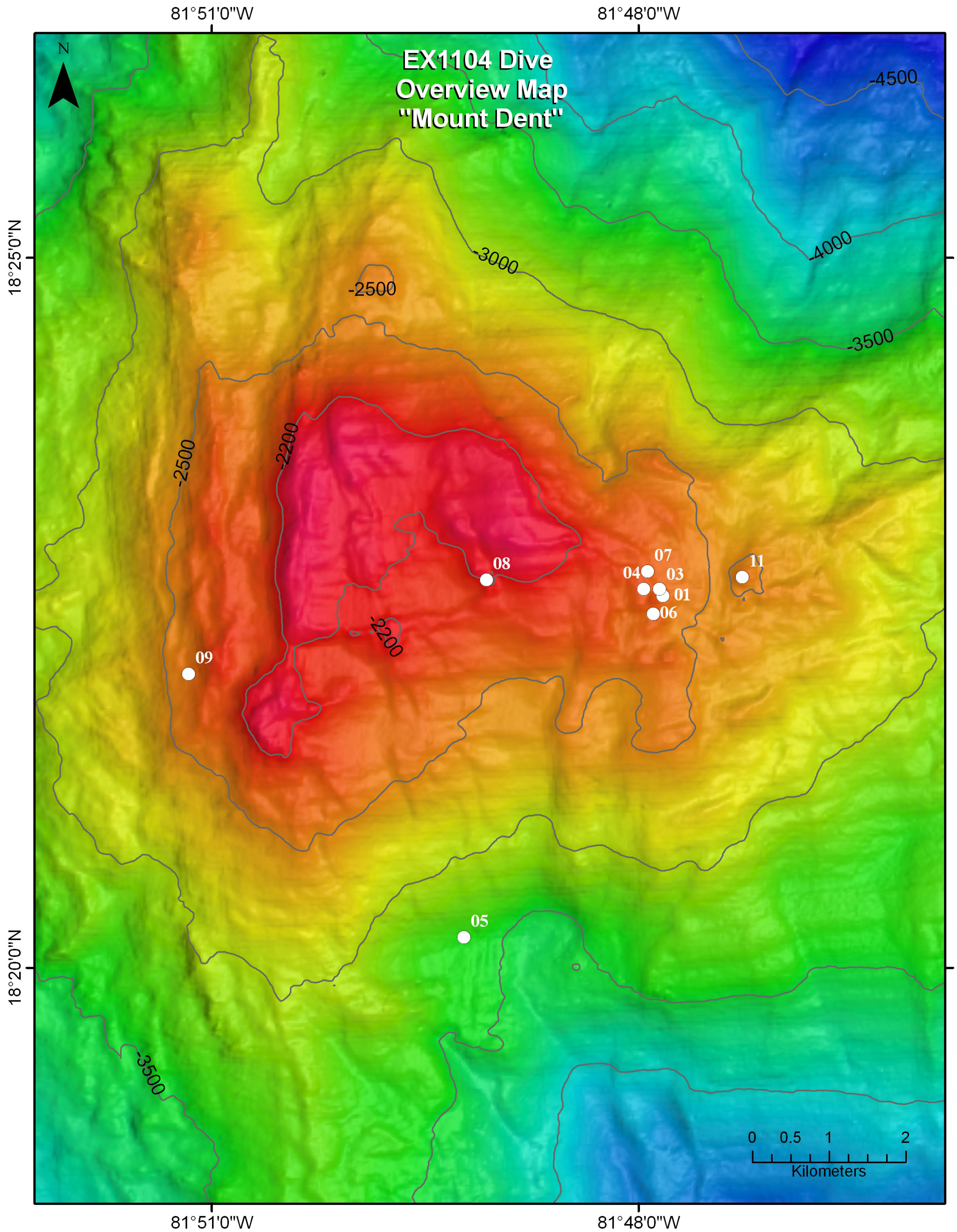


Figure 19. Close-up map showing EX-11-04 bathymetry of Mount Dent and the location of ROV dives successfully conducted during EX-11-04. Dives 01 and 03 indicate the general location of the Von Damm

vent site. The bathymetry colors represent depths. Red is the most shallow, transitioning to blue at the deepest. The grey lines are bathymetric contours at 500 m intervals.

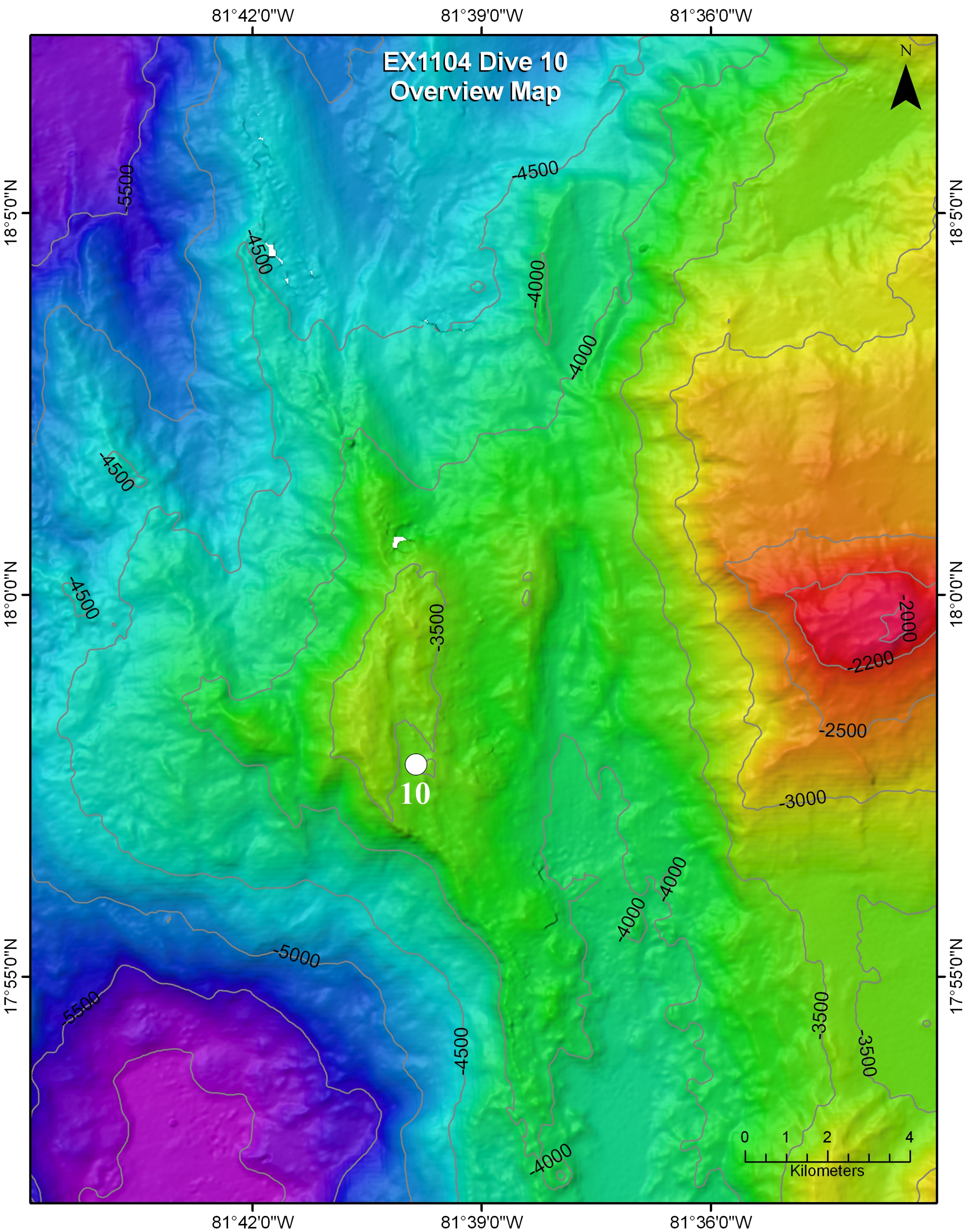


Figure 20. Close-up map showing the location of ROV Dive 10, overlaid on bathymetry of the axial volcanic ridge toward the southeast corner of the Mid-Cayman Rise. The bathymetry colors

represent depths. Red is the most shallow, transitioning to purple at the deepest. The grey lines are bathymetric contours at 500 m intervals.

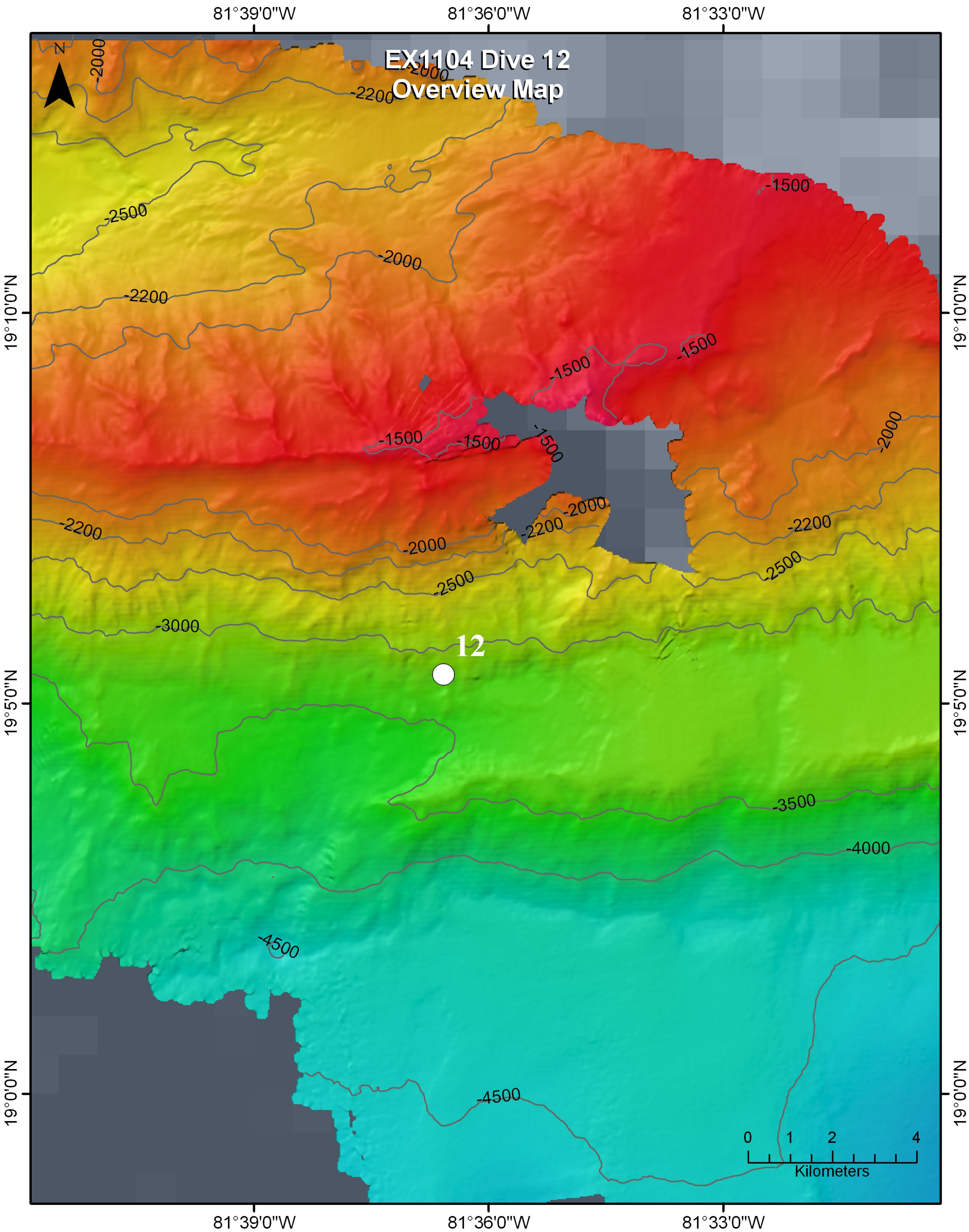


Figure 21. Close-up map showing the location of ROV Dive 12, overlaid on bathymetry of the interior (south-facing) wall of the north Cayman Trough fracture zone. The bathymetry colors represent depths. Red is the most shallow, transitioning to teal at the deepest. The grey lines are bathymetric contours at 500 m intervals.

7. Data Disposition and Archival

The EX-11-04 Data Management Plan can be found in Appendix I of the EX-11-04 project instructions (cruise plans), available in the NOAA Central Library Ocean Exploration Institutional Repository at: https://repository.library.noaa.gov/view/noaa/10584 (last accessed June 23, 2021).

7.1 OER Data Discoverability Tools

All data collected by *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. Data can be accessed via the following websites:

- OER Digital Atlas at https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm (last accessed June 23, 2021).
- OER ROV Data Archives at https://www.ncei.noaa.gov/waf/okeanos-rov-cruises/, (last accessed June 23, 2021).

Additional data requests are handled through the NOAA Ocean Exploration and Research Program Data Access Request Form, available here: https://docs.google.com/a/noaa.gov/forms/d/1pU3jbcV5ffunMKUbYgnA2OK-ZT9qj2Dh6JgZ79TTORM/viewform?formkey=dHAycC1MyndJb0hTdGRaYXAzVTVBdWc6MA&fromEmail=true (last accessed June 23, 2021).

7.2 Sonar Data

Sonar data collected onboard *Okeanos Explorer* undergoes quality assurance/quality control (QA/QC) after a cruise and is then made publicly available through the OER Data Discoverability Tools, the National Archives, and the following websites:

- All sonar data is permanently discoverable at: https://www.ncei.noaa.gov/ (last accessed June 23, 2021).
- NCEI Interactive Bathymetry Data Viewer: http://maps.ngdc.noaa.gov/viewers/bathymetry/ (last accessed June 23, 2021).

8. References

Bell, K.L.C., Elliott, K., Martinez, C. & Fuller, S.A. eds. (2012). New Frontiers in Ocean Exploration: The E/V Nautilus and NOAA Ship Okeanos Explorer 2011 Field Season. *Oceanography 25*(1), Supplement, 68 pages. http://dx.doi.org/10.5670/oceanog.2011.supplement.01

Coleman, D. (2012). Technology: The URI Inner Space Center and Exploration Command Centers. In Bell, K.L.C., Elliott, K., Martinez, C. & Fuller, S.A. (Eds.) New Frontiers in Ocean Exploration: The E/V Nautilus and NOAA Ship Okeanos Explorer 2011 Field Season. *Oceanography 25*(1), Supplement, pages 16-17. http://dx.doi.org/10.5670/oceanog.2011.supplement.01

Corliss, J.B., Dymond, J., Gordon, L.I., Edmond, J.M., von Herzen, R.P., Ballard, R.D., Green, K., Williams, D., Bainbridge, A., Crane, K. & van Andel, T.H. (1979). Submarine Thermal Springs on the Galapagos Rift*. Science 203*(4385), pages 1073-1083. http://dx.doi.org/10.1126/science.203.4385.1073

Connelly, D.P., Copley, J.T., Murton, B.J., Stansfield, K., Tyler, P.A., German, C.R., Van Dover, C.L., Amon, D., Furlong, M., Grindlay, N., Hayman, N., Hühnerbach, V., Judge, M., Le Bas, T., McPhail, S., Meier, A., Nakamura, K., Nye, V., Pebody, M., Pedersen, R.B., Plouviez, S., Sands, C., Searle, R.C., Stevenson, P., Taws, S. & Wilcox, S. (2012). Hydrothermal vent fields and chemosynthetic bacteria on the world's deepest seafloor spreading centre*. Nature Communications 3*. http://dx.doi.org/10.1038/ncomms1636

German, C.R., Bowen, A., Coleman, M.L., Honig, D.L., Huber, J.A., Jakuba, M.V., Kinsey, J.C., Kurz, M.D., Leroy, S., McDermott, J.M., Mercier de Lépinay, B., Nakamura, K., Seewald, J.S., Smith, J.L., Sylva, S.P., Van Dover, C.L., Whitcomb, L.L. & Yoerger, D.R. (2010). Diverse styles of submarine venting on the ultra-slow spreading Mid-Cayman Rise. *Proceedings of the National Academy of Sciences of the United States of America 107*(32), pages 14,020-14,025. http://dx.doi.org/10.1073/pnas.1009205107

German, C.R., Tyler, P.A., McIntyre, C., Amon, D., Cheadle, M., Clarke, J., John, B., McDermott, J., Bennett, S. Huber, J., Kinsey, J., Seewald, J., Van Dover, C. & Elliott, K. (2012). Exploration of the Mid-Cayman Rise. In Bell, K.L.C., Elliott, K., Martinez, C. & Fuller, S.A. (Eds.) New Frontiers in Ocean Exploration: The E/V Nautilus and NOAA Ship Okeanos Explorer 2011 field season. *Oceanography 25*(1), Supplement, pages 52-53. http://dx.doi.org/10.5670/oceanog.2011.supplement.01

John, B.E., and Cheadle, M.J. (2010). Deformation and Alteration Associated with Oceanic and Continental Detachment Fault Systems: Are They Similar? In P.A. Rona, C.W. Devey, J. Dyment, & B.J. Murton (Eds.), *Diversity of Hydrothermal Systems on Slow Spreading Ocean*

Ridges (pp. 175-205). Geophysical Monograph Series, Volume 188. American Geophysical Union, Washington, DC. https://dx.doi.org/doi/10.1029/2008GM000772

Lobecker, E., Nadeau, M., Stuart, E., Peters, C., Howard, V. & Mefford, J. (2014). Mapping Data Acquisition and Processing Report. Cruise EX1104, Cayman Trench, August 2-18, 2011, Balboa, Panama to Key West, Florida. NOAA Institutional Repository. Office of Ocean Exploration and Research, Office of Oceanic and Atmospheric Research, NOAA, Silver Spring, MD 20910. http://doi.org/10.7289/V5/MDR-OER-EX1104

Russell, C.W., Pinner, W., Lovalvo, D., Skarke, A., Lobecker, E., Malik, M. & Nadeau, M. (2012). Technology: NOAA Ship Okeanos Explorer. In Bell, K.L.C., Elliott, K., Martinez, C. & Fuller, S.A. (Eds.) New Frontiers in Ocean Exploration: The E/V Nautilus and NOAA Ship Okeanos Explorer 2011 field season. *Oceanography 25*(1), Supplement, pages 12-15. http://dx.doi.org/10.5670/oceanog.2011.supplement.01

Smith, W. H. F., and Sandwell, D.T. (1997). Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings. *Science 277*(5334), pages 1957-1962. http://dx.doi.org/10.1126/science.277.5334.1956

9. Appendices

Appendix A: Water Sampling for Shipboard Methane Determination

How to Preserve CTD Fluids for Total Cell Counts

Julie Huber
jhuber@mbl.edu

Microbial communities are often enriched in hydrothermal plumes, meaning the number of cells is elevated above background seawater due to all the yummy energy sources in the plume, making them another good indicator of hydrothermal activity. We like to visually examine the fluids with microscopy to look for particles and interesting cells, as well as count the cells and compare them to background seawater. During our plume search, any sample that has any indication of a plume should be preserved, as well as the 2-3 samples on either side of it, to get background levels. Every sample needs to be preserved in duplicate. The water gets preserved in 37% formaldehyde (final concentration 3.7%) and stored at 4 ºC. Formaldehyde should be used in a hood if one is available. You can pour 50 ml into a 50 ml falcon tube and use that as a working solution, leaving the large bottle in the HazMat cabinet.

- Scintillation vials for samples
- 25 ml disposable sterile pipettes and bulb for distributing CTD sample water
- 1 ml pipette and tips for dispensing formaldehyde
- Labels for scintillation vials

1. Fill scintillation vial with CTD sample water directly off the Niskin bottle. Use the 25 ml pipette and bulb to remove 18 ml, dump out remainder, and distribute the 18 ml back into the vial. For each sample, you will have 2 vials of 18 ml each and you can use the same pipette for the duplicates.

2. Add 1.8 ml of 37% formaldehyde to the vial using the 1 ml pipette (set it to 900 µl and dispense 2x).

3. Cap, invert a few times, label. You can write on the top with a sharpie, and for duplicates, please label samplename-1, samplename-2. We usually only count -1 but like to have -2 in case we have problems. We will also supplied labels that can stick on in case you want to pre-label or your sharpie appears to be rubbing off or whatever.

4. Store at 4 ºC.

Let me know if you have any questions!

Thanks,
Julie

Appendix B: Water Sample Preservation for Total Cell Counts

Subject: Sampling of the CTD for DOC on the EX
From: "Bennett, Sarah A (382D-CalTech)" <Sarah.A.Bennett@jpl.nasa.gov>
Date: Thu, 09 Jun 2011 12:23:57 -0700
To: "Kelley.Elliott@noaa.gov" <Kelley.Elliott@noaa.gov>, "cgerman@whoi.edu" <cgerman@whoi.edu>, "Coleman, Max (382D)" <max.coleman@jpl.nasa.gov>

Hi Kelley and Chris,

Sorry I didn't make it for the CTD call, Max filled me in on the details and today's call also gave me a good overview. I believe Max mentioned our interest in organic carbon and we have discussed and would like the possibility of sampling for total organic carbon (TOC) in plume samples collected by the CTD rosette. It is relatively simple and we have chosen TOC rather than DOC/POC (dissolved and particulate organic carbon), due to sample processing issues and the amount of water required (10L). So our requirements would be the following:

1) Samples from 'juicy' plumes - i.e. Eh anomalies, along with background samples above and below the plume, AND samples from directly above a vent site - if carried out at Von Damm and Europa

2) 40 ml taken directly from the CTD bottle into TOC glass vials (we will provide)

3) Samples acidified with trace metal grade HCl - 0.1%, i.e. 40 ul in 40ml sample (Again we will send the acid out to the ship)

We are interested in TOC because hydrothermal systems represent a biological niche which has been considered independent from the rest of the ocean. However, hydrothermal systems can act as a transport mechanism of organic carbon from within the crust and surrounding areas of diffuse flow, out into the water column. However, very few studies exist on the presence of organic carbon in hydrothermal plumes. I have carried out two studies, one at the East Pacific Rise and one at the Loihi Seamount. At the EPR, I found very little elevation in DOC, but at Loihi the DOC concentrations were elevated. I think this is due to differences in the chemistry and biology of these two environments. If indeed we have different venting environments in the Cayman Trough, it would be interesting to compare the plumes from different sites for organic carbon. This in itself will be an interesting study, but will also guide us on our return to the Cayman in January.

Let me know what you think,

Best wishes,
Sarah

PS Please update your email to this JPL address - Thanks!

Appendix C: Water Sample Preservation for Total Organic Carbon

SURVEYS OF OPPORTUNITY - INITIAL REQUEST FORM

A surveys of opportunity is a small, exploratory expedition that takes advantage of the elastic schedules of ocean-going, research vessels, - in this case, the Okeanos Explorer - by maximizing transit times between ports or projects, or by filling smalls gaps in the ship's calendar.

Given the ship's unique technology and capabilities, NOAA's Office of Ocean Exploration and Research (OER) invites regional researchers to help acquire additional data within the vessel's operating areas to assess specific but poorly known sites, adding to an inventory of submerged resources. In circumstances where individuals cannot serve on a "survey of opportunity", then OER ensures that acquired data and any other pertinent information are transferred to the appropriate researchers after the expedition. Previously successful surveys of opportunity have included mapping geological features, locating and characterizing shipwrecks, and defining marine protected areas. Some surveys are completed in only a few hours, while others last a couple days.

Although exploration potential and scientific merit play a role in which opportunistic surveys are conducted, they are not chosen through a peer-reviewed process. Rather, their selection is based more on the vessel operating in the right place with the right equipment at the right time, and the ship's calendar and on-board resources allow for the added work. All requests for a survey of opportunity are archived with OER and the ship, and expire only when the survey work is completed. There is no guarantee that any request for a survey will be accomplished, nor is there any system of prioritization or ranking. Keep in mind that this proposal may be available to the public upon request except for privileged information and material that is personal, proprietary or otherwise exempt from disclosure under law.

Survey or Project Name

Shipboard methane determination during exploration of the Mid-Cayman Spreading Center

Points of Contact (POC)

Lead POC or Principle Investigator (PI & Affiliation)	*Supporting Team Members*
Jeffrey Seewald	**Jill McDermott** **Chris German**

Activities Description(s) *(Include goals, objectives and tasks)*

Buoyant plumes of high temperature hydrothermal fluids rise hundreds of meters above the seafloor before being dispersed laterally by deep-ocean currents (Lupton, 1995). In part, due to their high initial methane (CH4) concentrations, such plumes can be traced over long distances (tens of km) through the water column (e.g. Lilley et al., 1995). Our goal is to conduct shipboard dissolved CH4 analysis on seawater samples collected with the CTD rosette. The objective is to identify hydrothermal vent plumes in the water column, in order to idenitfy seafloor targets for further exploration and identification of active vent fields.

PROCEDURE FOR SHIPBOARD METHANE ANALYSIS

Water samples for methane (CH4) analysis (20 ml) will drawn from the Niskin bottles mounted on the CTD in 60 mL plastic syringes. Dissolved methane concentrations will be determined by gas chromatography using a Hewlett Packard 5890 II gas chromatograph fitted with a 6-foot 5 Å molecular sieve column and a flame ionization detector following a headspace extraction. The headspace extraction involves connecting the 60 ml plastic syringe containing the water sample to a purpose built interface connected directly to the gas chromatograph and drawing ~40 ml of nitrogen into the syringe. The headspace is allowed to equilibrate with the water sample before depressing the plunger to transfer the headspace gas into a sample loop for injection onto the chromatography column for chromatographic separation.

The compressed gases necessary for this analysis include nitrogen (N2), air, and hydrogen (H2) all

at an initial cylinder pressure of 2000 PSIA. The nitrogen is used as a carrier gas for the gas chromatography column and is connected directly to the gas chromatograph with 1/8" copper tubing. The flow rate is set to ~30 mL/min and flow is continuous for the duration of the cruise once the instrument is set up in port. The air and hydrogen are used as fuels for the flame ionization detector. They are connected directly to the gas chromatograph with 1/8" copper tubing. The flow rates are 400 mL/min for the air and 30 mL/min for the hydrogen. These gases are only flowing when the instrument is in use and serve as a fuel for a very small flame that is fully enclosed within the detector of the gas chromatograph. When not in use these gases are turned off at the compressed gas cylinder valve. The only other chemicals involved in this analysis are gas standards used for calibration of the gas chromatograph detector. These consist of trace concentrations of methane (~100 ppm) in nitrogen at relatively low pressure (~200 PSIA). At this concentration of methane, the gases are non-flammable due to the balance being nitrogen. Due to the relatively small cylinder size (~1 liter) and quantity of gas contained within, they do not represent a suffocation risk for normal laboratory conditions.

List of Participating Organizations

Woods Hole Oceanographic Institution

Duration *(specific start and end dates, or expected length of survey)*

Approximately 10 nights during CTD rosette operations.

Area of Survey and Cruise Track Descriptions *(please attach appropriate charts and include chart reference numbers)*

Mid-Cayman Spreading Center. Location of CTD casts to be determined during future discussions that consider scientific objectives of all cruise participants.

Conditions and Dependencies *(e.g, water depths, special sea conditions, time constraints, etc)*

Will collect samples to depths of ~5000 m.

Equipment/Systems Needed

☐DP	☐Sled
☐A-Frame	☐xBot
☐Traction Winch	☐Seawater flow-through system
☐Hydro Winch	☐Fluorometer
☐ROV Crane	☒CTD (deck unit)
☐General Purpose Crane	☒CTD Rosette
☐EM302	☐SCS Outputs
☐Deep Water Echo Sounder	☐Hazardous Storage
☐VSAT Pipe Mbps # days full pipe	Describe:
☐Cameras ☐Telepresence ☐CCTV	☐Other ship's equipment(s):
☐ROV	Describe All:

Special Equipment *(identify any PI-supplied gear that the ship will be requested to deploy)*

Gas chromatograph. This is a stardard Hewlett Packard (now Agilent) 5890 GC that takes up approximately 60 sq inches (30"x30") with access required at the front and left side.

Three size K compressed gas cylinders - one nitrogen, one hydrogen, and one compressed air. Tanks are approximately 4.5 feet tall and 10 inches wide, weighing roughly 80 lbs. (The tanks could be located at a distance from the GC if there is a sufficient chase available to run 1/8" copper lines). The gases will be used by connecting them via a regulator and running them through the GC for the various needs.

Lead Time and Long Lead Time Items *(e.g., permits, etc)*

Shore-side support *(besides staffing, what other coordination is needed, e.g. telepresence center)*

Telepresence with other shore-based members of the science team.

The gases will be delivered to the ship or ship's agent (whichever you prefer) by Praxair. Currently, this is set up for Puntarenas, but could be changed to Panama if necessary. At the end of the cruise, the cylinders will be vented to the atmosphere and disposed of in a dumpster. Alternatively, if possible, the science team may make arrangements for the the cylinders to be stored in Key West until their NSF/NASA cruise in January 2012 that will be departing out of Key West.

Data, Products and Outputs *(requested shipboard data processing, archiving and product generation, such as sonar processing, GIS layer creation, mosaic, video archiving, etc)*

Data processing of methane concentrations will be conducted by the shipboard science team. The resulting data will become part of the Okeanos Explorer data/product suite and will go through the standard EX data pipeline to public archive.

QUALITATIVE PARAMETERS

Why is this project considered "exploration"?

Hydrothermal alteration of ultramafic rocks, such as those found in the Mid-Cayman Spreading Center, is of special interest to Astrobiologists bacause both high- and low- temperature ultramafic systems can host abiotic organic synthesis that may be important to pre-biotic chemistry and the origins of life on early Earth (Holm & Charlou, 2001; Proskurowski et al., 2008). While the eruption of komatiitic lavas may have made such vent-systems common on early Earth (e.g. Brasier et al., 2002), it is only under the tectonic controls peculiar to slow and ultra-slow ridges that ultramafic rocks are likely to be exposed to hydrothermal reactions today (German & Von Damm, 2004). To date, relatively few areas of hydrothermal activity hosted in ultramafic crust have been studied. This is exactly what has been identified at 18°21-24'N, 81°44-50'N and, potentially, elsewhere along the rift-valley walls of the Mid-Cayman Spreading Center. Exploring this area for the extent and nature of hydrothermal systems represents a substantial opportunity to contribute to our understanding of a broad range of processes associated with serpentinization at present-day ridge crest hydrothermal systems and on early Earth.

In many cases, plume signals are dispersed by lateral currents, and temperature anaomalies are too weak to be detected by conventional CTD sensors. Shipboard determination of CH4 is a particalry sensitive technique that will provide three-dimensional information concerning the nature and location of seafloor hydrothermal vent targets, which enables most effective use of the Little Hercules ROV. Methane determination is a particularly good exploration tool because it facilitates the idenitification of low- temperature serpentinization reactions at the rift-valley walls. The latter do not release high concentrations of dissolved metals at the seafloor like conventional "black smokers" (e.g. Kelley et al., 2001), but instead can be readily detected from the high dissolved methane concentrations they release into the adjacent water column (Charlou et al., 1998). Accordingly, shipboard CH4 measurement will broaden the range of vent styles that can be detected during water column surveys at the Mid-Cayman Spreading Center and substantially increase the potential for new discoveries.

How is this survey multidisciplinary? *(Will various types of data be acquired by different user groups during the survey? Will the data products will be used by different users after the survey?)*

Identification of the location of hydrothermal activity is a primary goal for biologists, geologists, geochemists, and geophysicists, examining chemical, physical, and biological processes associated with crustal generation at the ultra-slow Mid-Cayman Spreading Center.

What is the public outreach potential for this project?

Locating hydrothermal vents on the seafloor is not a trivial task. Through real-time blogs, the public can follow the sequence of events that leads to the discovery of new vent fields on the seafloor.

What will become of the data, imagery, information and samples after this survey?

(Who is responsible for data archiving? How will the information be archived? Are there any intended publications from this survey? Will this data be used as leverage for follow-up investigation?)

Data will be made publicly available via the standard Okeanos Explorer data pipelines, and will be provided to other researchers working in the area upon request. The data represents valuable information that will be used to direct future oceanographic research cruises in the area during 2012.

What restrictions of confidentiality are placed on this request?

(Can this request be shared with OER partners operating in the area who might be able to acquire these data? Is any part of this intended dataset sensitive and restricted? Are you willing to work with NOAA public affairs officials to report any discoveries made by this survey?

The resultant dataset will be made publicly available via the standard Okeanos Explorer data pipeline.

Through real-time blogs on the oceanexplorer.noaa.gov website, the public can follow the sequence of events that leads to the discovery of new vent fields on the seafloor.

If this project is maritime archeologically-focused, what is the site's archaeological or historical importance?

N/A

If this project is maritime archeologically-focused, who has jurisdiction over the site, and have the appropriate agencies been contacted?

N/A

Procedure for Shipboard Methane Analysis

Water samples for methane (CH_4) analysis (20 ml) will drawn from the Niskin bottles mounted on the CTD in 60 mL plastic syringes. Dissolved methane concentrations will be determined by gas chromatography using a Hewlett Packard 5890 II gas chromatograph fitted with a 6-foot 5 Å molecular sieve column and a flame ionization detector following a headspace extraction. The headspace extraction involves connecting the 60 ml plastic syringe containing the water sample to a purpose built interface connected directly to the gas chromatograph and drawing ~40 ml of nitrogen into the syringe. The headspace is allowed to equilibrate with the water sample before depressing the plunger to transfer the headspace gas into a sample loop for injection onto the chromatography column for chromatographic separation.

The compressed gases necessary for this analysis include nitrogen (N_2), air, and hydrogen (H_2) all at an initial cylinder pressure of 2000 PSIA. The nitrogen is used as a carrier gas for the gas chromatography column and is connected directly to the gas chromatograph with 1/8" copper tubing. The flow rate is set to ~30 mL/min and flow is continuous for the duration of the cruise once the instrument is set up in port. The air and hydrogen are used as fuels for the flame ionization detector. They are connected directly to the gas chromatograph with 1/8" copper tubing. The flow rates are 400 mL/min for the air and 30 mL/min for the hydrogen. These gases are only flowing when the instrument is in use and serve as a fuel for a very small flame that is fully enclosed within the detector of the gas chromatograph. When not in use these gases are turned off at the compressed gas cylinder valve. The only other chemicals involved in this analysis are gas standards used for calibration of the gas chromatograph detector. These consist of trace concentrations of methane (~100 ppm) in nitrogen at relatively low pressure (~200 PSIA). At this concentration of methane, the gases are non-flammable due to the balance being nitrogen. Due to the relatively small cylinder size (~1 liter) and quantity of gas contained within, they do not represent a suffocation risk for normal laboratory conditions.

Appendix D: Marine Scientific Research Clearance – Cayman Islands EEZ

Foreign & Commonwealth Office

Date: 10th June 2011

Ref: 049/2011

The Maritime Policy Unit (Legal Advisers) of the Foreign and Commonwealth Office presents its compliments to the Embassy of the United States of America and has the honour to refer to the US Embassy's application requesting permission to undertake a research cruise by the **Okeanus Explorer** in **the territorial waters of the Cayman Islands**.

The appropriate United Kingdom authorities have been informed of the research cruise **OKEANUS EXPLORER F2011-43** of **1st AUGUST** to **31st AUGUST 2011** and hereby give clearance for the cruise, subject to the following conditions.

It is requested that the vessel should at all times comply with the International Regulations for Preventing Collisions at Sea 1972 (as amended) as set out in the Schedule to the Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations 1989 (SI 1989 No 1798). In particular, the vessel should comply with the requirements of Rule 10 of the Collision Regulations when operating within the vicinity of traffic separation schemes approved by the IMO. In this connection, the Embassy's attention is drawn to the Admiralty Notice to Mariners No 17 of 99 and Merchant Shipping Notice M1448.

Attention is also drawn to: a) the safety zone established in accordance with international law and extending to 500 metres around all water off-shore installations (it is an offence to enter such safety zones without permission from the Minister of State for Energy (Part III of the Petroleum Act 1987)) and b) oil and gas Development Areas which are marked on Admiralty Charts.

The Department for Environment, Food and Rural Affairs would like the following to be brought to the US Embassy's attention; the master of the cruise vessel must be made aware of the possibility of encountering fixed, poorly lit and marked, fixed fishing gear. Care should be taken not to interfere with the activities of commercial fishing vessels when undertaking scientific trials. In the event of any fouling the vessel should report details direct to the Marine Fisheries Agency at the earliest opportunity.

The cruise is planned in an area of possible live cables. The master should obtain the latest Cable Awareness charts from www.kisca.org.uk and should not bottom trawl within 500m of any in-use cables.

The appropriate United Kingdom authorities have been informed of the proposed testing and hereby give clearance for said testing to proceed subject to the following conditions.

Please provide copies of the original cruise reports including that resulting from the above mentioned test data, in digital format if possible, to:

- Foreign and Commonwealth Office, Maritime Policy Unit
- Ministry of Defence: Lt Cdr P R Newell RN, DI ICSP MARPLANS02, Room 252, Old War Office Building, Whitehall, London SW1A 2EU / colin.thomson923@mod.uk (please also provide all raw and processed data and resulting research within the UK Exclusive Economic Zone).
- Director of the Fisheries Research Services, Marine Scotland Science, 101 Victoria Road, Torry, Aberdeen AB9 8DB / Iain.Gibb@scotland.gsi.gov.uk
- UK Hydrographic Office: Nick.Weaver@UKHO.gov.uk / Head of MEIC, UK Hydrographic Office, Taunton, Somerset TA1 2DN (please also provide all raw and processed data and resulting research).
- British Oceanographic Data Centre: gaev@bodc.ac.uk / Dr Gaynor L Evans, Proudman Oceanographic Laboratory, Joseph Proudman Building, 6 Brownlow Street, Liverpool L3 5DA.
- Jane Thompson, RSU Operations, NERC Research Ship Unit, National Oceanographic Centre, Empress Dock, Southampton SO14 3ZH / rvsops@sea.noc.soton.ac.uk
- As a condition of entry, in accordance with article 249 of UNCLOS, the Joint Nature Conservation Committee requests that access to all data collected from within waters under UK jurisdiction is granted. Pre-reports should be forwarded to the Joint Nature Conservation Committee when they are immediately ready. In addition, the scientist in charge of that part of the expedition taking place within waters under UK jurisdiction will submit to the JNCC Offshore Survey Programme Manager, JNCC, Monkstone House, City Road, Peterborough, PE1 1JY, UK when it is immediately ready, 2 copies of a short expedition narrative describing the expedition and its preliminary results and the ships expedition track chart (Latitude and Longitude positions to be supplied as MS Excel spreadsheet or ArcGIS shapefile). Subsequently, 2 copies of the full expedition report including an assessment of the results of the expedition and two copies of all publications arising out of the expedition should be provided to: - JNCC Offshore Survey Programme Manager, JNCC, Monkstone House, City Road, Peterborough. PE1 1JY.

The Maritime Policy Unit avails itself of this opportunity to renew to the Embassy of the United States of America the assurances of its highest consideration.

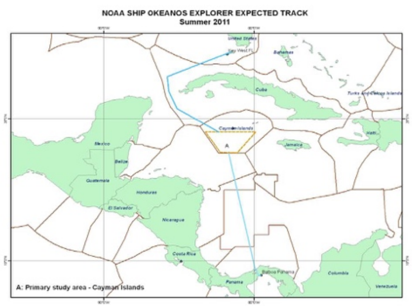
MARITIME POLICY UNIT
LEGAL ADVISERS
FOREIGN AND COMMONWEALTH OFFICE
LONDON
SW1A 2AH

10th June 2011

Appendix E: CTD Rosette Summary Forms

EXPLORE

CTD Cast Name	Cruise		CTD Number		Date	
	EX1104		CTD01		08/03/11	
Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German					
General Area Descriptor	North of Panama					
Site Name	Caribbean					
Type of CTD Operation	☒ Vertical Cast					
	☐ Tow-Yo					
Target Position	>1000m	Along transit				
Deployment Time & Location	UTC Time	1728				
	Latitude	10	º	55.428	′	N
	Longitude	80	º	11.910	′	W
Time & Location At Depth	UTC Time	174839	Target Depth/Range	1000 m		
	Latitude	10	º	55.807	′	N
	Longitude	80	º	11.995	′	W
Recovery Time & Location	UTC Time	1825	Maximum Depth (m)	1000		
	Latitude	10	º	56.406	′	N
	Longitude	80	º	12.036	′	W
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451					
	☒ ORP 08 Votage Channel 05					
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06					
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00					
	☐ Other (*specify*) ___________ Voltage Channel __ ___________ Voltage Channel __					
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: 20					
Sample Processing	Sample Type(s): Shipboard Dissolved Methane					
	Method: ☒ Processed on EX ☐ Preserved, Chemicals used ___________ ☐ None					
	Storage: ☒ None ☐ Room Temp Storage ☐ -80 Freezer ☐ -20 Freezer					
Data Archival	Tethys FTP site					



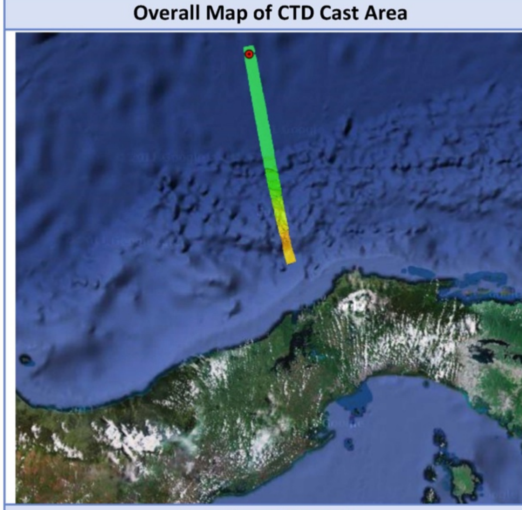
NOAA SHIP OKEANOS EXPLORER 1

Equipment Malfunctions	None.
Special Notes	None.
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI) Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL), *Sharon.l.Walker@noaa.gov* & *Edward.Baker@noaa.gov* (NOAA-PMEL)

Purpose of the CTD operation: 1) Collect water samples to test Gas Chromatograph operation on ship. 2) Acquire data to test shore-based processing pipeline at NASA-JPL.

Description of the Data/Results:

Vertical cast to 1000m. All real time data look good. Data processing pipeline ashore was tested and verified by science lead, back aboard ship. All niskin bottles fired correctly and yielded good samples for methane analysis.

Overall Map of CTD Cast Area	Screen Grab of Data
	
Overview of Cast site	*SeaSave Data Acquisition Screen*
Please direct inquiries to:	**NOAA Office of Ocean Exploration & Research** **1315 East-West Highway (SSMC3 10th Floor)** **Silver Spring, MD 20910** **(301) 734-1014**

CTD Cast Name	Cruise	CTD Number	Date
	EX1104	CTD02	8/5/11
Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German		
General Area Descriptor	Cayman Islands		
Site Name	Von Damm		
Type of CTD Operation	☐ Vertical Cast ☐ Po-Go ☐ Tow-Yo ☒ Combination		
Target Position	18° 22.592'N / 081° 47.884'W	18° 22.591'N / 081° 47.892'W	

Deployment Time & Location	UTC Time	00:40			
	Latitude	18	º	22.591 ʻ	N
	Longitude	81	º	47.892 ʻ	W
Time & Location At Depth	UTC Time	01:23:27	Target Depth/Range	20 mab	
	Latitude	18	º	22.591 ʻ	N
	Longitude	81	º	47.892 ʻ	W
Recovery Time & Location	UTC Time	04:22	Maximum Depth (m)	2291 m	
	Latitude	18	º	22.328 ʻ	N
	Longitude	81	º	48.388 ʻ	W

CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451
	☒ ORP 08 Votage Channel 05
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00
	☐ Other (*specify*) ____________ Voltage Channel __ ____________ Voltage Channel __
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: 20
Sample Processing	Sample Type(s): Methane, TOC, Microbiology
	☒ Processed on board ☒ Preserved ☒ Chemicals Formalin
	☐ None ☐ Room Temp Storage ☐ -80 Freezer ☒ -20 Freezer ☒ Refrigerator
Data Archival	Tethys FTP site

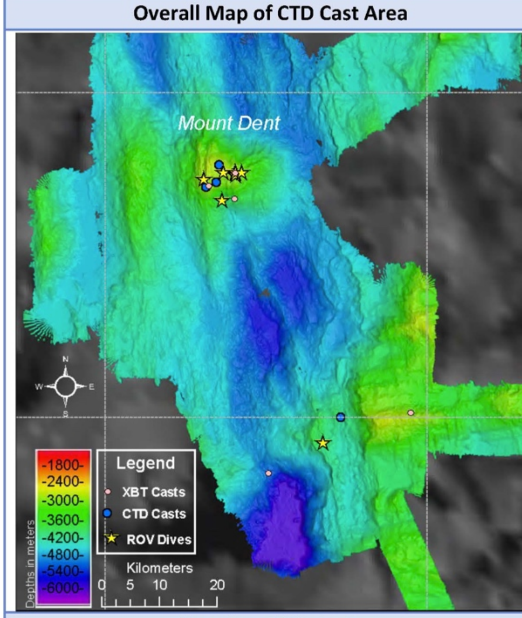
Equipment Malfunctions	Bottle 11 did not close—o-ring popped off bottom of bottle
Special Notes	
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI) Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL), J. Kinsey (WHOI), J. Huber (MBL)

Purpose of the CTD operation: dispersing plume tracking at Von Damm vent site

Description of the Data/Results:

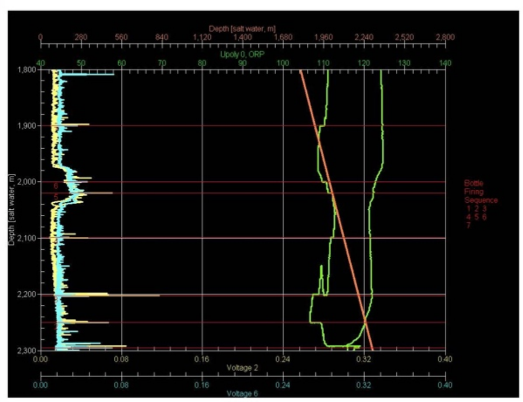
Strong ORP signals at near bottom depths and plume height (2000m).
LSS and POTEMP at plume height only.
LSS, POTEMP and CH_4 traced to 1km from source by tow yo.

Overall Map of CTD Cast Area



Overview of Cast site

Screen Grab of Data



SeaSave Data Acquisition Screen

EXPLORE

CTD Cast Name	Cruise	CTD Number	Date
	EX1104	CTD03	8/7/11

Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German				
General Area Descriptor	Cayman Islands				
Site Name	Von Damm				
Type of CTD Operation	☐ Vertical Cast ☐ Po-Go				
	☐ Tow-Yo ☒ Combination				
Target Position	18° 21.71'N	18° 21.706'N			
	081° 49.63'W	081° 49.632'W			
Deployment Time & Location	UTC Time	00:00			
	Latitude	18	º	21.706	' N
	Longitude	81	º	49.632	' W
Time & Location At Depth	UTC Time	0045	Target Depth/Range	20 mab	
	Latitude	18	º	21.706	' N
	Longitude	81	º	49.631	' W
Recovery Time & Location	UTC Time	0456	Maximum Depth (m)	2410	
	Latitude	18	º	22.134	' N
	Longitude	81	º	48.768	' W
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451				
	☒ ORP 08 Votage Channel 05				
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06				
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00				
	☐ Other (*specify*) ___________ Voltage Channel __ ___________ Voltage Channel __				
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: 20				
Sample Processing	Sample Type(s): Methane, TOC, Microbiology				
	☒ Processed on board ☒ Preserved ☒ Chemicals Formalin				
	☐ None ☐ Room Temp Storage ☐ -80 Freezer ☒ -20 Freezer ☒ Refrigerator				
Data Archival	Tethys FTP site				

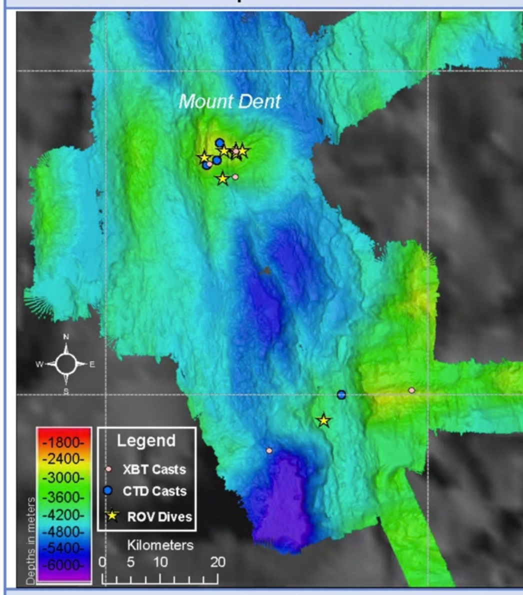
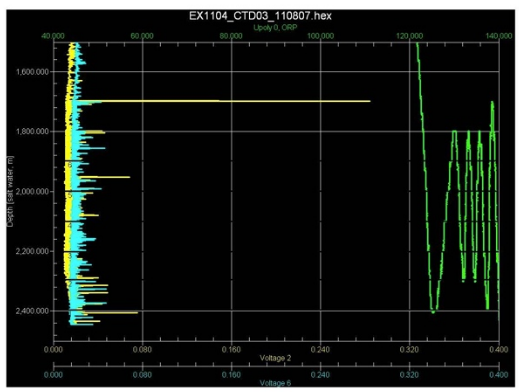
NOAA SHIP OKEANOS EXPLORER 1

Equipment Malfunctions	Bottle 11 did not close, position 15 did not fire.
Special Notes	Tow yo reversed (SW-NE) due to weather
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI) Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL), J. Kinsey (WHOI), J. Huber (MBL)

Purpose of the CTD operation: Tracking the Von Damm plume toward Europa.

Description of the Data/Results:

No signals in LSS for entire cast.
Signal in final ORP upcast only.
CH_4 anomalies at all 3 Pogo legs.
Plume traced to end point, 4 km from source.

Overall Map of CTD Cast Area	**Screen Grab of Data**
	
Overview of Cast site	*SeaSave Data Acquisition Screen*

EXPLORE

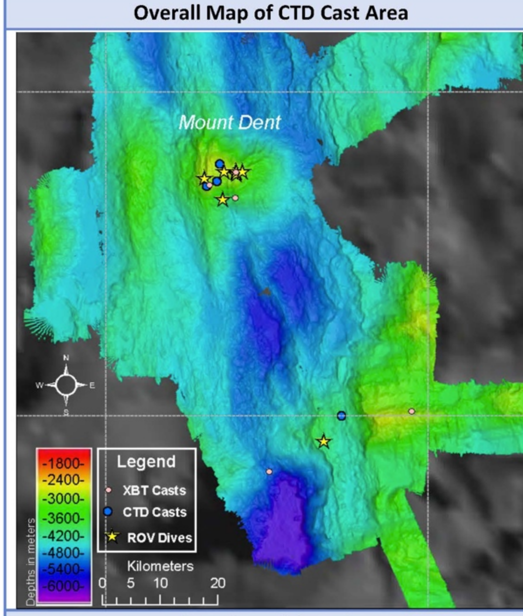
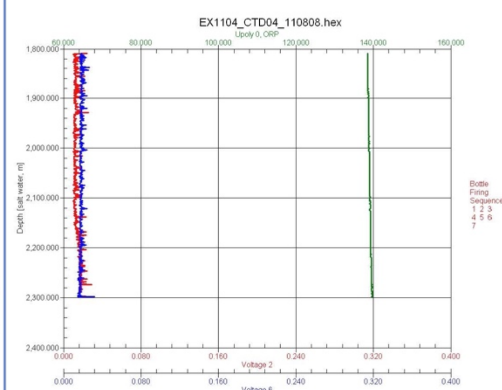
CTD Cast Name	Cruise	CTD Number	Date		
	EX1104	CTD04	8/8/11		
Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German				
General Area Descriptor	Cayman Islands				
Site Name	Europa				
Type of CTD Operation	☐ Vertical Cast	☐ Po-Go			
	☐ Tow-Yo	☒ Combination			
Target Position	18° 21.27'N	18° 21.26'N			
	081° 50.57'W	081° 50.576'W			
Deployment Time & Location	UTC Time	23:57			
	Latitude	18	º	21.265	' N
	Longitude	81	º	50.576	' W
Time & Location At Depth	UTC Time	00:47	Target Depth/Range	20 mab	
	Latitude	18	º	21.264	' N
	Longitude	81	º	49.576	' W
Recovery Time & Location	UTC Time	04:53	Maximum Depth (m)	2360	
	Latitude	18	º	22.659	' N
	Longitude	81	º	48.723	' W
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451				
	☒ ORP 08 Votage Channel 05				
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06				
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00				
	☐ Other (*specify*) ___________ Voltage Channel __ ___________ Voltage Channel __				
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: ____20_________				
Sample Processing	Sample Type(s): ___Methane, TOC, Cell counts___________________________				
	☒ Processed on board ☒ Preserved ☒ Chemicals __Formalin_______________				
	☐ None ☐ Room Temp Storage ☐ -80 Freezer ☒ -20 Freezer ☒ Refrigerator				
Data Archival	Tethys FTP site				

Equipment Malfunctions	Bottle 11 did not close, position 15 did not fire.
Special Notes	Replicate samples from bottle 4, bottle 5 → proves no leak on bottle 4.
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI) Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL), J. Kinsey (WHOI), J. Huber (MBL)

Purpose of the CTD operation: Plume dispersion & C-ORG cycle study, Von Dam plume.

Description of the Data/Results:

No signals in LSS or ORP but significant CH_4 anomalies throughout cast.

Overall Map of CTD Cast Area	Screen Grab of Data
	
Overview of Cast site	*SeaSave Data Acquisition Screen*

EXPLORE

anCTD Cast Name	Cruise	CTD Number	Date
	EX1104	CTD05	8/9/11

Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German
General Area Descriptor	Cayman Islands
Site Name	Da Bumps
Type of CTD Operation	☐ Vertical Cast ☐ Po-Go ☐ Tow-Yo ☒ Combination
Target Position	18° 23.30'N / 18° 23.81'N 081° 49.36'W / 081° 49.35'W

Deployment Time & Location	UTC Time	00:10				
	Latitude	18	º	23.31	'	N
	Longitude	81	º	49.35	'	W
Time & Location At Depth	UTC Time	00:50	Target Depth/Range	20 mab		
	Latitude	18	º	23.294	'	N
	Longitude	81	º	49.360	'	W
Recovery Time & Location	UTC Time	04:21	Maximum Depth (m)	2117		
	Latitude	18	º	22.661	'	N
	Longitude	81	º	48.881	'	W

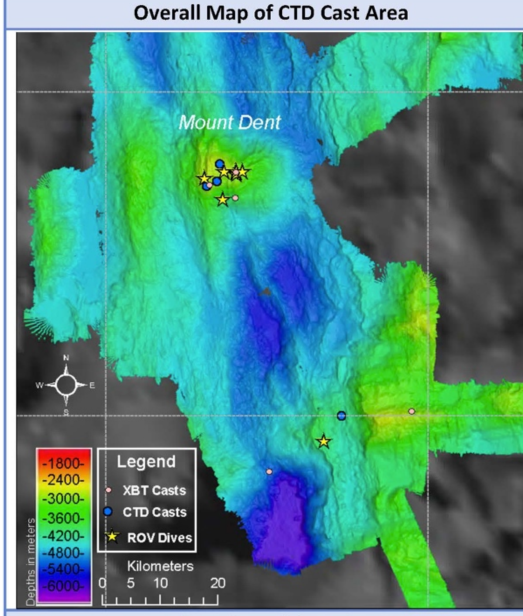
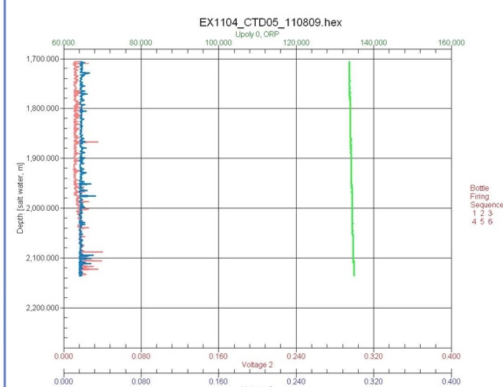
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451 ☒ ORP 08 Votage Channel 05 ☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06 ☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00 ☐ Other (*specify*) ____________ Voltage Channel __ ____________ Voltage Channel __
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: ___20_________
Sample Processing	Sample Type(s): ___Methane, TOC, Cell counts______________________________ ☒ Processed on board ☒ Preserved ☒ Chemicals __Formalin___________________ ☐ None ☐ Room Temp Storage ☐ -80 Freezer ☒ -20 Freezer ☒ Refrigerator
Data Archival	Tethys FTP site

Equipment Malfunctions	None.
Special Notes	None.
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI) Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL), J. Kinsey (WHOI)

Purpose of the CTD operation: Prospecting for hydrothermal plumes near summit of Mt Dent.

Description of the Data/Results:

No in situ ORP or LSS anomalies observed.
Shipboard methane showed above background concentrations at all three stations of PoGo. (Strongest at center).

Overall Map of CTD Cast Area	Screen Grab of Data
	
Overview of Cast site	*SeaSave Data Acquisition Screen*

EXPLORE

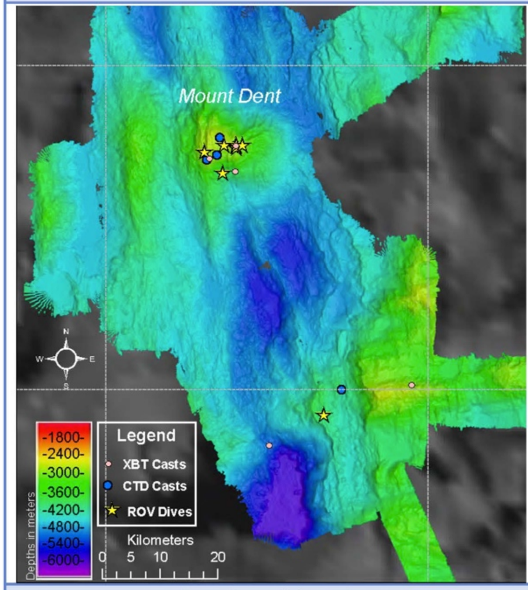
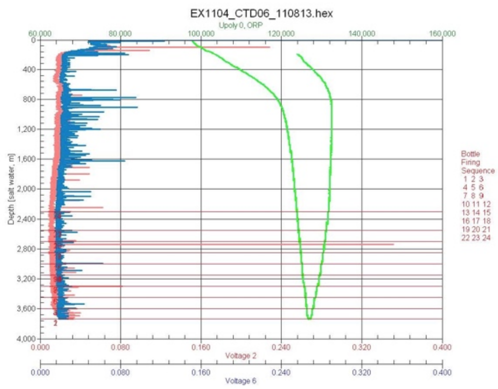
anCTD Cast Name	Cruise		CTD Number		Date
	EX1104		CTD06		8/13/11
Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German				
General Area Descriptor	Cayman Islands				
Site Name	Mt Hudson				
Type of CTD Operation	☒ Vertical Cast	☐ Po-Go			
	☐ Tow-Yo	☐ Combination			
Target Position	18° 00.00’N				
	081° 38.00’W				
Deployment Time & Location	UTC Time	0123			
	Latitude	17	º	59.994 ‘	N
	Longitude	81	º	37.992 ‘	W
Time & Location At Depth	UTC Time	0232	Target Depth/Range	20 mab	
	Latitude	17	º	59.995 ‘	N
	Longitude	81	º	37.991 ‘	W
Recovery Time & Location	UTC Time	0358	Maximum Depth (m)	3736	
	Latitude	17	º	59.996 ‘	N
	Longitude	81	º	37.990 ‘	W
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451				
	☒ ORP 08 Votage Channel 05				
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06				
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00				
	☐ Other (*specify*) ___________ Voltage Channel __ ___________ Voltage Channel __				
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: ____20________				
Sample Processing	Sample Type(s): ___Methane _______________________________				
	☒ Processed on board ☐ Preserved ☐ Chemicals ___________________				
	☒ None ☐ Room Temp Storage ☐ -80 Freezer ☐ -20 Freezer ☐ Refrigerator				
Data Archival	Tethys FTP site				

Equipment Malfunctions	None.
Special Notes	None.
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI)

Purpose of the CTD operation: Exploring for hydrothermal plume signals, SE of MCR

Description of the Data/Results:

No plumes observed from in situ sensors.
All CH_4 samples yielded background values (≤1nM).

Overall Map of CTD Cast Area	Screen Grab of Data
	
Overview of Cast site	*SeaSave Data Acquisition Screen*

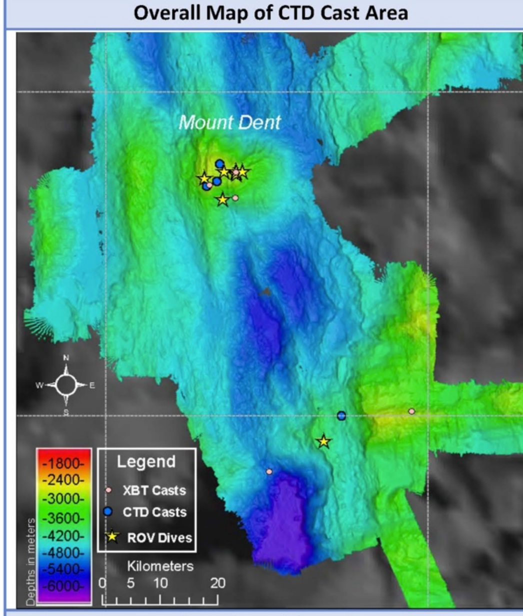
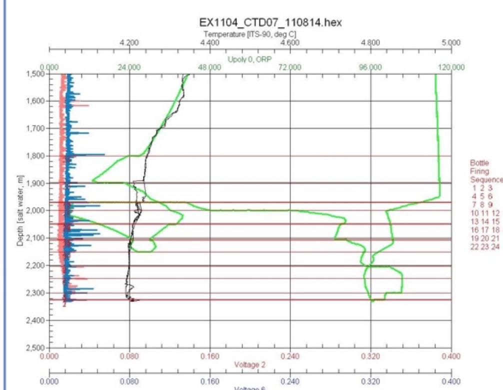
anCTD Cast Name	Cruise		CTD Number		Date	
	EX1104		CTD07		8/14/11	
Expedition Coordinator/ Science Team Lead	Kelley Elliott/Chris German					
General Area Descriptor	Cayman Islands					
Site Name	Mt Doom					
Type of CTD Operation	☒ Vertical Cast		☐ Po-Go			
	☐ Tow-Yo		☐ Combination			
Target Position	18° 22.59'N					
	081° 47.91'W					
Deployment Time & Location	UTC Time	2351				
	Latitude	18	º	22.59	'	N
	Longitude	81	º	47.896	'	W
Time & Location At Depth	UTC Time	0037	Target Depth/Range		2300/20 mab	
	Latitude	18	º	22.589	'	N
	Longitude	81	º	47.896	'	W
Recovery Time & Location	UTC Time	0358	Maximum Depth (m)		2324	
	Latitude	18	º	22.589	'	N
	Longitude	81	º	47.900	'	W
CTD Sensor Data Acquired	☒ CTD **P** 0905 **T1** 5001 **T2** 5017 **C1** 3449 **C2** 3451					
	☒ ORP 08 Votage Channel 05					
	☐ LSS 12790 Voltage Channel 02 ☒ LSS 12791 Voltage Channel 06					
	☐ Dissolved Oxygen Voltage Channel __ ☒ Altimeter Voltage Channel 00					
	☐ Other (*specify*) ____________ Voltage Channel __ ____________ Voltage Channel __					
Water Samples Collected?	☒ Yes ☐ No If Yes, Number of Bottles Tripped: ____20________					
Sample Processing	Sample Type(s): ___Methane, TOC, Microbes (cell counts)_____________________					
	☒ Processed on board ☒ Preserved ☒ Chemicals __Formalin________________					
	☐ None ☐ Room Temp Storage ☒ -80 Freezer ☒ -20 Freezer ☒ Refrigerator					
Data Archival	Tethys FTP site					

Equipment Malfunctions	None.
Special Notes	Forgot bottle vs. carousel position is offset by USBL placement. Double-dip required, 2000-2200m.
Scientists Involved *(name / location / affiliation / email)*	cgerman@whoi.edu & cmcintyre@whoi.edu (WHOI), jhuber (MBL, Sarah.A.Bennett@jpl.nasa.gov (NASA-JPL)

Purpose of the CTD operation: C-org cycling and plume exploration above Van Damm site.

Description of the Data/Results:

Stunning. No LSS signal but lots in ORP sensor.
CH_4 Analyses very high. 3 plumes.
Also, positive near bottom T° anomalies.

Overall Map of CTD Cast Area	Screen Grab of Data
	
Overview of Cast site	*SeaSave Data Acquisition Screen*

Appendix F: Acronyms

1 A/E—1st Assistant Engineer
2 A/E—2nd Assistant Engineer
Å—Angstrom
AB (D)—Able Bodied Seaman Day Worker
AUV—Autonomous underwater vehicle
AVR—Axial volcanic ridge
BGL—Boatswain Group Leader
CARIS—Teledyne Computer Aided Resource Information System
CB—Chief Boatswain
CH4—Methane
CME—Chief Mechanical Engineer
CO—Commanding Officer
CTD—Conductivity, temperature, and depth
DGPS—Differential GPS
DO—Dissolved oxygen
DP—Dynamic positioning
DSPL—DeepSea Power & Light
ECC—Exploration Command Center
EEZ—Exclusive Economic Zone
Eh—Redox potential
ET—Electronic Technician
FTP—File Transfer Protocol
GPS—Global Positioning System
GVA—General Vessel Assistant
HCl—Hydrochloric acid
HD—High-definition
HIPS—Hydrographic Information Processing System
HMI—Hydrargyrum medium-arc iodide
HQ—Headquarters
IFE—Institute for Exploration
IM—Instant messaging
ISC—Inner Space Center
IVS—Interactive Visualization Systems
JO—Junior Officer
JPL—NASA Jet Propulsion Laboratory
JUE—Junior Unlicensed Engineer
kHz—Kilohertz
km—Kilometers
L—Liter
LH—ROV Little Hercules
LOA—Length overall
LSS—Light Scattering Sensor

MBES—Multibeam echo sounder
Mbps—Megabits-per-second
µL—Microliter
mL—Milliliter
NASA—National Aeronautics and Space Administration
NAV—Navigation Officer
NCEI—NOAA National Centers for Environmental Information
NEPA—National Environmental Policy Act
nm—Nautical miles
nM—Nanometer
NOAA—National Oceanic and Atmospheric Administration
OCC—Oceanic core complexes
OER—NOAA Office of Ocean Exploration and Research
Ops—Operations Officer
ORP—Oxidation-Reduction Potential
PMEL—NOAA Pacific Marine Environmental Laboratory
POTEMP—Potential temperature
QA/QC—Quality assurance/quality control
RHIB—Rigid Hull Inflatable Boat
ROV—Remotely operated vehicle
RSS—Really Simple Syndication
Rsync—Remote sync
Rx—Receive transducer
SBE—Sea-Bird Electronics, Inc.
SBES—Single-beam echo sounder
SBP—Sub-bottom profiler
SIS—Seafloor Information System
SST—Senior Survey Technician
TOC—Total organic carbon
TSG—Thermosalinograph
Tx—Transmit transducer
UK—United Kingdom
UNH—University of New Hampshire
URI—University of Rhode Island
USBL—Ultra-short baseline
USCG—U.S. Coast Guard
USNS—U.S. Naval Ship
USPHS—U.S. Public Health Service
UTC—Coordinated Universal Time
VDVF—Von Damm vent field
VoIP—Voice over Internet Protocol
VSAT—Very Small Aperture Terminal
WHOI—Woods Hole Oceanographic Institution
XBT—Expendable bathythermograph

XSV—Expendable Sound Velocity
XO—Executive Officer