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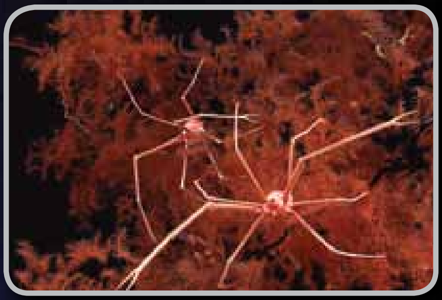

New Frontiers in Ocean Exploration

The E/V *Nautilus* and NOAA Ship *Okeanos Explorer* 2011 Field Season

GUEST EDITORS | KATHERINE L.C. BELL, KELLEY ELLIOTT, CATALINA MARTINEZ, AND SARAH A. FULLER

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FOREWORD

By John McDonough and Robert D. Ballard

This supplement to the March 2012 issue of *Oceanography* is dedicated to the continuing expeditions of the US National Oceanic and Atmospheric Administration (NOAA) Ship *Okeanos Explorer* and Exploration Vessel (E/V) *Nautilus*. The mission of these two ships is to explore the most unknown areas of the world's ocean, while engaging the interest of scientists, educators, students, and the general public in undersea exploration and discovery through active participation in real time. The March 2011 supplement to *Oceanography* chronicled the first series of missions undertaken by E/V *Nautilus*, and here we describe the following field season dedicated to this growing program. Our hope is to continue producing annual supplements to highlight the accomplishments of this systematic ocean exploration program.

Through a partnership that includes the NOAA Office of Ocean Exploration and Research, the Ocean Exploration Trust, the Institute for Exploration, the University of Rhode Island, the University of New Hampshire, and other institutions, teams of scientists and engineers are implementing the vision of President Clinton's Panel on Ocean Exploration (2000), which challenged the United States to develop assets dedicated to exploring remote ocean areas not routinely investigated by existing research vessels. With guidance and advice from the Ocean Exploration Advisory Working Group, a standing subcommittee of the NOAA Science Advisory Board, and the Nautilus Advisory Board, *Okeanos Explorer* and *Nautilus* operate under a new paradigm of "telepresence-enabled" expeditions that make it possible for interdisciplinary teams of experts, working in Exploration Command Centers (ECCs) at academic institutions and other locations around the United States and overseas, to participate in each mission.

Satellite and high-bandwidth Internet2 technology transmit data, including remotely operated vehicle (ROV) video feeds, to shore in real time, supporting the participation of science teams at the Inner Space Center at the University of Rhode Island Graduate School of Oceanography, and a growing ECC network. At ECCs, shore-based teams view information in real time and communicate with operational teams aboard the ships, helping to direct exploration activities. Significant progress has been made this year to stream the information on the World Wide Web over standard Internet1, enabling broader access and participation.

This dedicated network also makes it possible for educators, students, and the general public to participate in the missions. *Nautilus* engages "Educators-at-Sea" on every expedition to work with the shipboard team, preparing and transmitting high-definition video highlights and other products for posting on http://www.NautilusLive.org, making it possible for interested parties to pose questions to the scientists and engineers on board the ship. Likewise, professional educators and students engage in missions conducted by *Okeanos Explorer*, in real time through http://oceanexplorer.noaa.gov, and by accessing curriculum materials that meet national education standards and incorporating information and data generated by each mission.

Through this supplement, we hope to continue to generate interest in this unique program and encourage use of the preliminary results presented. Those who are interested in specific data and information from *Okeanos Explorer*, please visit http://explore.noaa.gov to access the digital atlas. For E/V *Nautilus* information, please visit http://www.oceanexplorationtrust.org.

INTRODUCTION

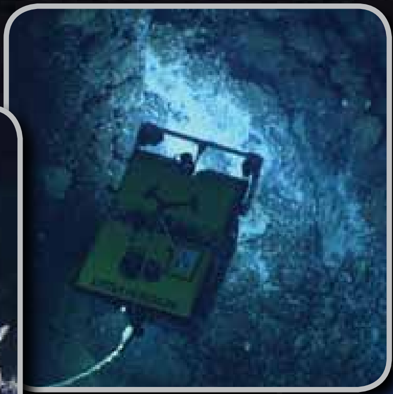
Advancing Scientific Knowledge, Technology Innovation, and Ocean Literacy Through Systematic Telepresence-Enabled Ocean Exploration

By Katherine L.C. Bell and Craig W. Russell

This 2012 "New Frontiers" *Oceanography* supplement highlights the *Okeanos Explorer* and *Nautilus* exploration programs as they provide a foundation of systematic telepresence-enabled exploration of the world's ocean. Both programs emerged from a national dialogue on ocean exploration, culminating in the 2000 report of President Clinton's Panel on Ocean Exploration, *Discovering Earth's Final Frontier: A US Strategy for Ocean Exploration*. (Full details appear in the March 2011 supplement available at http://tos.org/oceanography/archive/24-1_supp.html.) Ten years after this report, *Okeanos Explorer* and *Nautilus* exploration programs operate worldwide, fully involving scientists and members of the public who participate from shore via telepresence to advance ocean exploration, technology development, and literacy. This second *Oceanography* supplement finds our programs moving toward a national strategy for ocean exploration, partnering with academic, industry, government, and nongovernmental organizations to meet our primary goals of global ocean exploration; education, outreach, and training; and technology development.

The first section details the capabilities of *Nautilus* and *Okeanos Explorer*, specifically, the deep submergence vehicles, mapping capabilities, data management, and telepresence systems used to carry out systematic exploration aboard each ship. *Nautilus* uses side-scan sonar for the survey phase of exploration, and investigates targets of interest with the *Hercules-Argus* dual-body ROV system equipped with high-definition cameras, oceanographic sensors, and manipulators for collection of geological, biological, and water samples (see pages 8–11). One new tool currently in development for *Nautilus* integrates several sensors, including stereo imagery, structured light, and high-frequency multibeam sonars for making high-resolution maps that characterize geological, archaeological, and biological sites (see pages 42–45). *Okeanos Explorer* is equipped with an EM302 swath bathymetric mapping system as well as the *Little Hercules-Seirios* dual-body ROV system, which use high-definition cameras and oceanographic sensors (see pages 12–15). In 2011, *Okeanos Explorer* tested and proved the new *Seirios* camera sled and multibeam water column detection capabilities. Satellite dishes installed on both ships send video, sensor, and audio data from sea to a hub at the Inner Space Center, where it is relayed to Exploration Command Centers so that scientists ashore can investigate new ocean areas and phenomena simultaneously with the ship-based teams (see pages 16–17).

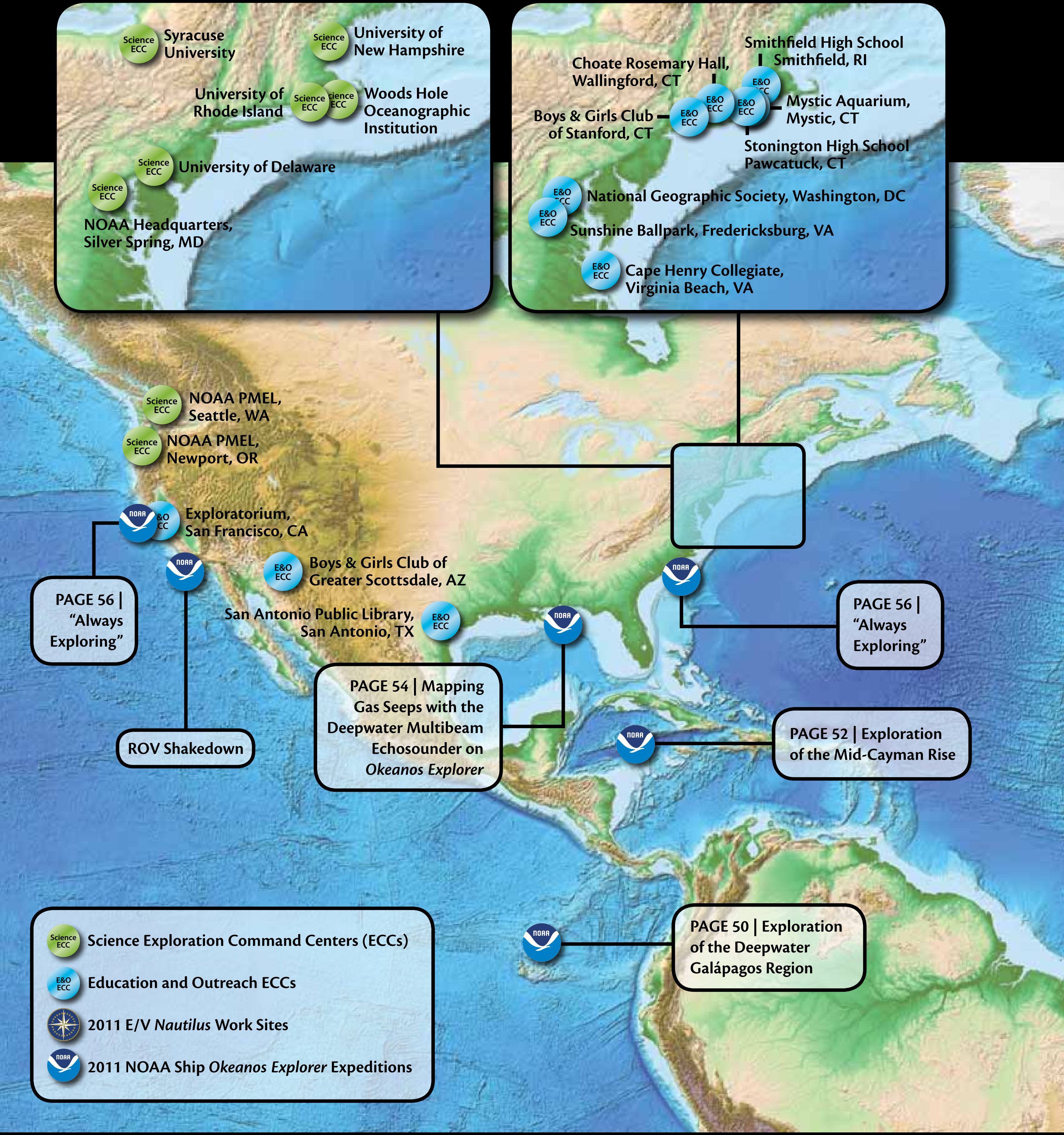
Next, we focus on our education and outreach programs, which engage millions of people around the globe by using telepresence technology to increase the ocean



literacy of people of all ages (see pages 18–23). Several levels of educational programming inspire and educate the next generation of explorers. At the broadest level, we use live Internet streaming, production of television specials, and partnerships with museums, aquariums, and science centers to reach the largest number of people possible. The next level involves more direct engagement through curriculum development for formal and informal education programs. We are working with several partners to develop standards-based curricula that are tied to expeditions and exploration. Finally, we use on-board and shore-based internship programs to train undergraduates and graduate students in science and engineering, addressing a lack of scientific and technical capacity identified by the oceanographic community.

The final section of this supplement reports on the results of over eight months of exploration by the *Nautilus* and *Okeanos Explorer* expedition teams. During the 2011 field season, *Nautilus* continued its work in the Black and Mediterranean Seas, and ventured into the North Atlantic Ocean for a total of 136 days at sea (see pages 24–45). The work this year was multidisciplinary, including geological, biological, chemical, and archaeological investigations in many regions of interest. In Turkey, the *Nautilus* team focused on seafloor imaging and studying the effects of Black Sea water chemistry on archaeological sites; in Greece and Italy, they investigated volcanically and hydrothermally active regions; off Portugal, they explored uplifted blocks of crust and mantle; and they targeted submarine canyons and other bathymetric features on the passive margins of Spain and Israel. The results of the *Okeanos Explorer* expeditions focus on the 2011 field season (see pages 46–59), when the ship was at sea for 138 days on expeditions along the Galápagos Rift, in the Gulf of Mexico, and in Mid-Cayman Rise region of the Caribbean. These expeditions targeted biological and geological exploration as well as mapping of these regions.

The *Nautilus* and *Okeanos Explorer* programs are fully engaged in obtaining a greater breadth of knowledge and understanding of the ocean's depths, and in sharing all that is learned in real time or in as close to real time as possible. We are working hard to expand our exploration programs in an effort to search for, locate, and describe new habitats and phenomena, establishing a rich foundation of information to catalyze further exploration, research, and education. Whether at sea or via the Internet, we invite you to share in the excitement of discovery through our ocean exploration programs during the 2012 field season.


Science ECC
Syracuse University
Science ECC
University of New Hampshire
University of Rhode Island
Science ECC
Science ECC
Woods Hole Oceanographic Institution
Science ECC
University of Delaware
Science ECC
NOAA Headquarters, Silver Spring, MD
Smithfield High School Smithfield, RI
Choate Rosemary Hall, Wallingford, CT
E&O ECC
Boys & Girls Club of Stanford, CT
E&O ECC
E&O ECC
Mystic Aquarium, Mystic, CT
Stonington High School Pawcatuck, CT
E&O ECC
National Geographic Society, Washington, DC
E&O ECC
Sunshine Ballpark, Fredericksburg, VA
E&O ECC
Cape Henry Collegiate, Virginia Beach, VA
Science ECC
NOAA PMEL, Seattle, WA
Science ECC
NOAA PMEL, Newport, OR
NOAA
Exploratorium, San Francisco, CA
NOAA
E&O ECC
Boys & Girls Club of Greater Scottsdale, AZ
San Antonio Public Library, San Antonio, TX
E&O ECC
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ROV Shakedown
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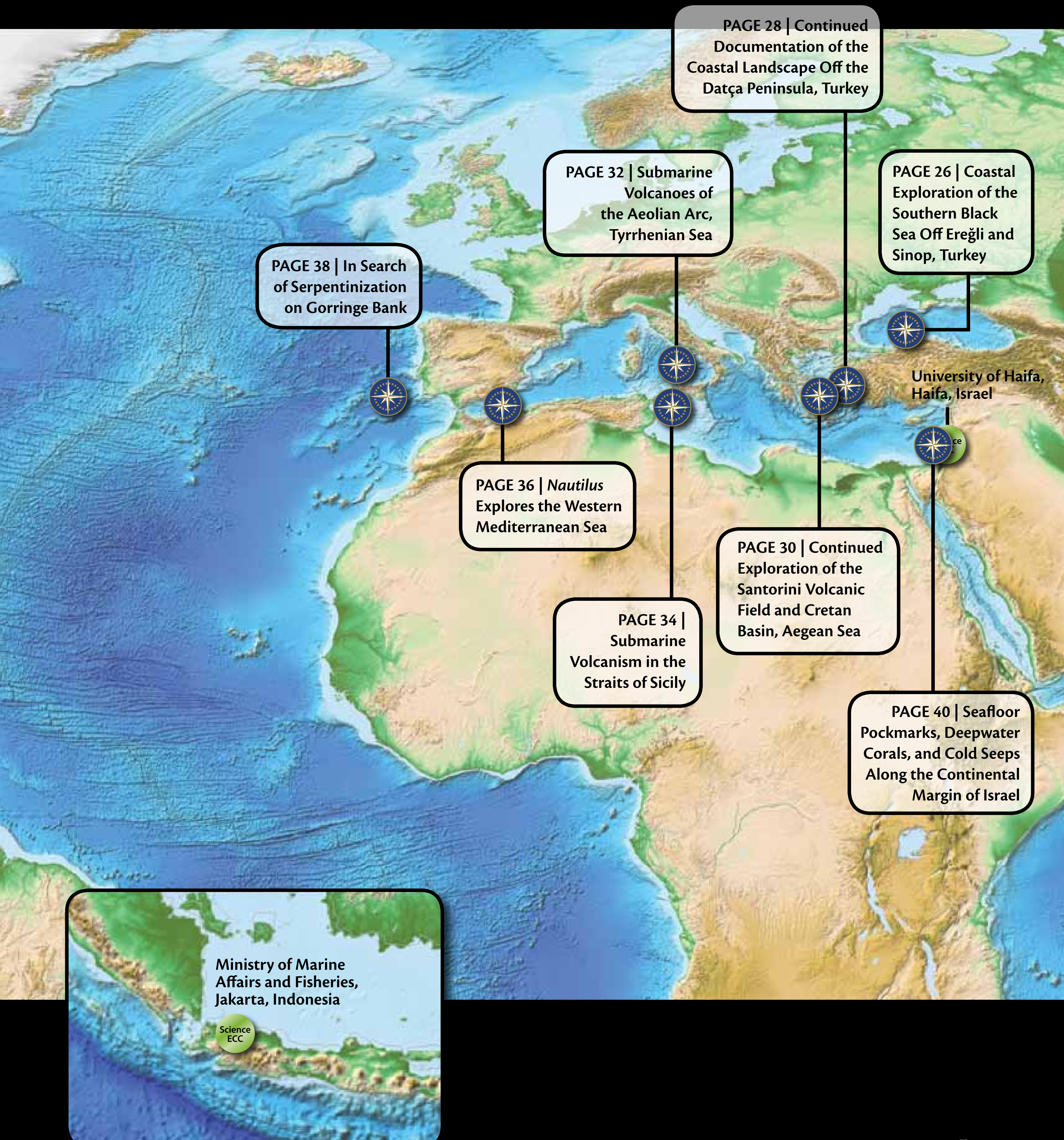
Science ECC
Science Exploration Command Centers (ECCs)
E&O ECC
Education and Outreach ECCs
2011 E/V Nautilus Work Sites
NOAA
2011 NOAA Ship Okeanos Explorer Expeditions

JOINT PROGRAM OVERVIEW MAP



Systematic Ocean Exploration Enabled by Telepresence Technology

By Catalina Martinez, Dwight F. Coleman, Katherine L.C. Bell, Webb Pinner, and Craig W. Russell

Background

Telepresence provides an individual or group of individuals with the data and information necessary for participation in an event or effort live when not physically present. This concept is not new, as telepresence technology has been applied in myriad ways for decades by government agencies and private industry. The vision of adapting this technology for oceanographic work was first conceived by Robert Ballard more than 25 years ago. He envisioned the use of telepresence to connect scientists, teachers, and students on shore to live images and real-time data from ships at sea, providing a portal into the excitement of oceanographic discovery, and demonstrating to a broad audience the importance of exploring and protecting our largely unknown ocean.

Development and Evolution of a Paradigm

Through many years of extensive collaborative efforts, the Institute for Exploration (IFE), the NOAA Office of Ocean Exploration and Research (OER), and the University of Rhode Island (URI) worked to determine the most effective and efficient application of this rapidly evolving technology for ocean science, exploration, education, and outreach. Each subsequent year brought new challenges and innovations. Over the years, we have developed and refined complex ship- and shore-based operating protocols, brought new ship- and shore-based telepresence systems online, and built the hub for this technology at URI, called the Inner Space Center (ISC). The ISC includes a production studio for live and post-produced education and outreach efforts and a "Mission Control Center" for ship-to-shore connectivity to support telepresence-enabled expeditions. Simultaneously, the NOAA Ship *Okeanos Explorer* and E/V *Nautilus* were extensively refitted to become the first two platforms customized for telepresence-enabled systematic ocean exploration.

Implementation and Efficiency

Traditional ship-based efforts evolve around a narrowly defined set of objectives and, in large part, begin and end with the team assembled on board the ship. Thus, berthing is a key limiting factor in terms of available expertise and opportunity for participation. Because it is not possible to fully predict discoveries during an ocean exploration mission, it is also not possible to determine the full spectrum of expertise that may be needed. The application of telepresence technology for ship-based work is extremely efficient as it permits unlimited access to personnel on shore, transcending schedules, expertise, skills, and abilities of traditional shipboard teams. Telepresence also enables the development of partnerships between geographically dispersed groups who otherwise might not have the opportunity to collaborate due to cost or logistics, and ultimately allows for the most efficient use of all resources, as access to data and information between ship and shore is immediate and sustained for the duration of an expedition.

Subtle differences in the way *Okeanos Explorer* and *Nautilus* are configured result in two slightly different, but complementary, staffing and operating models. *Okeanos Explorer* has extremely limited science/mission berthing, and thus relies heavily on daily input from teams on shore standing regular watches during ROV dives and during other major operations. With a maximum of three key science participants on board the ship for ROV cruises, shore-based participants are integral players in day-to-day decision making and planning. This model is referred to as "Doctors-on-Duty" and was most recently used during the 2011 exploration of the Mid-Cayman Rise (see pages 52–53), when a group of shore-based scientists was located at onshore Exploration Command Centers.

With greater berthing capacity, E/V *Nautilus* operates more autonomously with a team on board the ship. A multidisciplinary, international network of scientists is called

RIGHT | Diagram showing telepresence systems on board a ship of exploration and the pathways connecting live feeds from remotely operated vehicles to the Inner Space Center and onto the Internet. *Credit: K. Cantner*

BELOW | An Exploration Command Center at NOAA Headquarters in Silver Spring, Maryland, connected to the Internet2 to receive the live feeds of video, audio, and data from the remotely operated vehicles and the control room on board the ship.

upon when needed, making these individuals' expertise available almost immediately through the ship-to-shore access enabled by telepresence technology. "Doctors-on-Call" were used during several *Nautilus* projects in 2010 and 2011.

Web-based access to data, products, and information is essential for effective real-time collaboration. Recent improvements in video streaming via standard Internet and the advent of online chatting have enabled participation from any location that has Internet access. The continuing evolution of operating protocols, refinement of data management and distribution processes, and effective training of participants to operate between ship and shore are also key, along with the development and application of telepresence technology for education and outreach purposes. Each field season brings new challenges and opportunities to provide the most meaningful remote experience possible to those on shore, and to provide the most effective and efficient collaboration for operations at sea.

Through the different modes of operation associated with the application of telepresence-enabled systematic ocean exploration, we have connected researchers, educators, and the public to the excitement of discovering our largely unknown ocean in ways that just a few years ago were simply not possible, bringing Robert Ballard's initial vision to fruition in recent years. The Inner Space Center is the hub for this activity, where telepresence is facilitated; video, audio, and data streams are recorded and distributed in real time; and teams of participants are hosted during expeditions. As new technologies come online and new lessons are learned, the partners will continue to refine this operating paradigm, transcending the bounds of real-time access, increasing the pace and scope of discovery, and sharing the excitement of ocean exploration as quickly and as broadly as technology allows.

TECHNOLOGY

Exploration Vessel *Nautilus*

By Katherine L.C. Bell, Brennan Phillips, and Robert Knott

FORMERLY | *Alexander von Humboldt*

LENGTH | 64.23 meters (211 feet)

BEAM | 10.5 meters (34.5 feet)

DRAFT | 4.9 meters (14.75 feet)

TONNAGE | 1,249 gross, 374 net

MAIN PROPULSION | Single 1,286 kW (1,700 HP) controllable pitch

SPEED | 10 knots service, 12 knots maximum

ENDURANCE | 40 days at sea

RANGE | 24,000 kilometers (13,000 nautical miles)

DYNAMIC POSITIONING | Bow thruster and stern azimuth pump-jet

CLASSIFICATION | Germanischer Lloyd (GL) 100 A5 E1 (ice strengthened)

BUILT | 1967, Rostock, Germany

BERTHING | 48 persons (17 crew, 31 science/mission)

FLAG | St. Vincent and the Grenadines

HOME PORT | Bodrum, Turkey

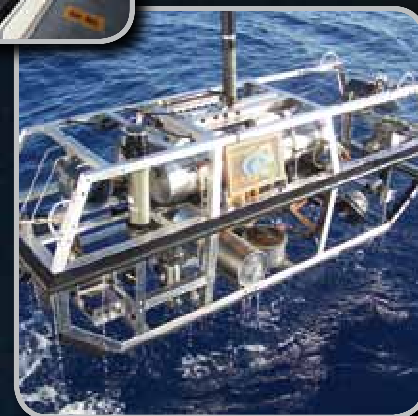
MISSION SYSTEMS | Custom 4,000 m rated dual-body remotely operated vehicles with high-definition video cameras; two side-scan sonar towfish (100/400 kHz and 300/600 kHz); 12 kHz Knudsen Chirp 3200 echo-sounder; 2.4 m tracking ELSP antenna capable of up to 20 Mbps (C-band circular or linear); four Tandberg SD encoders with multiplex for encapsulating real-time video streaming; RTS Telex intercom for real-time communications; Cisco C90 for video teleconferencing; two Omneon Mediadecks (MDM-5321 and SMD-2200-BB) for video recording, playback, and storage; 27 TB disk storage for nonvideo data.

Credit: T. Pierce

REMOTELY OPERATED VEHICLES

HERCULES is the primary vehicle of our two-body ROV system. *Hercules* is rated to a depth of 4,000 m, and is always deployed with *Argus*. Equipped with cameras, lights, instruments, manipulators, and a wide array of sampling tools, *Hercules* can take on virtually any exploration mission. The primary camera is a broadcast-quality high-definition system that is supplemented by six standard-definition cameras. Four powerful lights (over 60,000 lumens total) illuminate the forward working area, while smaller incandescent lights provide auxiliary illumination. Standard instrumentation includes a fast-profiling conductivity-temperature-depth (CTD) sensor, an oxygen probe, two high-resolution scanning sonars, a 1.2 MHz multibeam sonar, and a high-resolution stereo still camera system. The primary manipulator is a highly dexterous Kraft Predator arm with force feedback, complemented by a seven-function ISE Magnum manipulator for sample collection. *Hercules* is also equipped with a number of tools, including a suction sampler, sampling boxes with actuating trays, and sediment coring equipment, as well as several other purpose-built tools for different scientific objectives. Using a state-of-the-art navigation system in tandem with ultra-short baseline positioning, *Hercules* is capable of maneuvering and hovering on a centimeter-scale grid. Together with *Argus*, *Hercules* has completed over 200 dives in the Atlantic Ocean, Mediterranean Sea, and Black Sea.

ABOVE | *Hercules.* *Credit: T. Pierce*



RIGHT | *Argus.*

ARGUS was first launched in 2000 as a deep-tow system capable of diving as deep as 6,000 m. *Argus* is typically used in tandem with *Hercules*, where it hovers several meters above the seafloor and provides a bird's-eye view of *Hercules* on the seafloor, but can also be used as a stand-alone towsled. The electro-polished stainless steel frame carries a broadcast-quality high-definition camera, several standard-definition cameras, and two powerful 1,200 W arc lamps capable of producing over 100,000 lumens of light each. In addition to the cameras and lights, *Argus* supports a wide range of instrumentation, including a depth sensor, altimeter, CTD, subbottom profiler, scanning sonar, and side-scan sonar. *Argus* uses dual two-horsepower electric thrusters that permit heading adjustment and limited lateral movement.

MAPPING SYSTEMS

DIANA, one of two side-scan sonar systems on board *Nautilus*, is used to create maps of the seafloor and to identify targets of interest that ROVs *Hercules* and *Argus* investigate in more detail. *Diana* is an Edgetech 4200 MP side-scan sonar towfish that uses dual 300 and 600 kHz frequencies, with a range of approximately 200 m on either side of the towfish. The *Diana* system is capable of being towed to a depth of 2,000 m but is currently limited by cable length to 600 m. *Diana*'s transducers can also be installed on the *Argus* towsled, which greatly increases the maximum towing depth to 2,000 m.

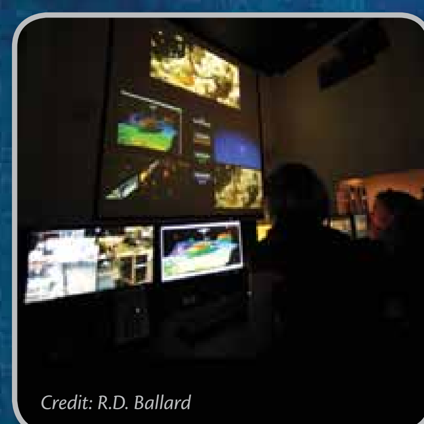
ECHO is a five-channel Benthos deep-tow side-scan sonar system rated to 3,000 m water depth. *Echo*'s operating frequencies are 100 and 400 kHz, which cover a total swath width up to 1,000 m. *Echo* is also equipped with a Chirp 2–7 kHz subbottom profiler that permits identification of subseafloor features.

ABOVE | *Diana.* *Credit: E. Martin*

LEFT | *Echo.* *Credit: D. Wright*

TELEPRESENCE SYSTEMS

The E/V *Nautilus* satellite system uses a very-small aperture terminal (VSAT) to enable two-way Internet connectivity between ship and shore. The maximum uplink capability is 46 Mbps, though the amount of satellite bandwidth is determined by the ship's location and the satellite being used. For the past two seasons, we have allocated 15 Mbps from ship to shore and 2 Mbps from shore to *Nautilus*. From the Mediterranean region, the signal is sent from *Nautilus* to a geosynchronous satellite, and then down to a ground station in Andover, Maine. The ground station then passes the signals to the Inner Space Center (ISC) at the University of Rhode Island Graduate School of Oceanography. At the ISC, the multicast video streams are distributed to the Internet and Internet2, and are used in highlight reels and webcasts. During expeditions, *Nautilus* is capable of sending up to four simultaneous broadcast-quality video streams and all associated intercom traffic and data back to shore in real time.



Credit: R.D. Ballard

All audio components of the telepresence network use a centralized intercom system for managing shipboard and ship-to-shore communications. This network facilitates communication between users working in the control van, the ship's officers on the bridge, and the various labs around the ship, as well as participants on shore. The intercom system is integrated with the *Nautilus* video streaming and video recording subsystems, which allow the intercom audio to be heard in the live video streams on shore and in the recorded video clips.

LIVE PRODUCTION STUDIO

A studio was built on board *Nautilus* this season to support live interactions and outreach production. Educators and scientists conduct interactive interviews with our outreach partners located at schools, museums, aquariums, and science centers around the world. Shore-based groups are able to communicate with the ship either with an intercom unit or via a telephone number that is bridged into the shipboard intercom system. Because of its success in facilitating live events and educational interactions, we will improve this facility for the upcoming season. Planned improvements include installation of a high-definition robotic camera, a production switcher, improved lighting, and an audio mixer and portable camera to enable interactions and interviews from the deck and other locations on the ship. These improvements will eventually be integrated into a new facility contained within our control room that will be constructed in 2014.

Katy Bell and Jim McMillan, President of the Board of the Monarch School, conducting a live interaction from the studio on board *Nautilus* with 7th and 8th grade students at Monarch, a K–12 school for children affected by homelessness in San Diego, California. *Credit: K. McMillan*

VIDEO SYSTEM

E/V *Nautilus* uses two Omneon MediaDecks broadcast-quality video servers to accommodate four channels of high-definition and standard-definition video signals. Each server can record up to 240 hours of high-definition video. Video files are transferred to an archive system that consists of a RAID hard-drive array and two tape drives. In addition to the video files, this system also archives all vehicle sensor data collected during expeditions. Two copies of the archived data are generated during each expedition. At the end of a cruise leg, one copy is sent to the Inner Space Center and the other is held on board *Nautilus* until the data on the original tapes are verified at the ISC.

Credit: A. Santos

Credit: A. Santos

Credit: M. Rosi

NOAA Ship *Okeanos Explorer*

By Craig W. Russell, Webb Pinner, David Lovalvo, Adam Skarke, Elizabeth Lobecker, Mashkoor Malik, and LT Megan Nadeau

FORMERLY | USNS *Capable*

LENGTH | 68 meters (224 feet)

BEAM | 13 meters (43 feet)

DRAFT | 4.6 meters (15 feet, 1 inch)

DISPLACEMENT | 2,312 LT

MAIN PROPULSION | Diesel electric with twin inboard turning screws (1,600 Shaft HP)

SPEED | 10 knots

ENDURANCE | 40 days at sea

RANGE | 17,780 kilometers (9,600 nautical miles)

DYNAMIC POSITIONING (DP-1) | 500 HP retractable azimuth bow thruster and two 250 HP stern thrusters

CLASSIFICATION | Stalwart-class ocean surveillance ship

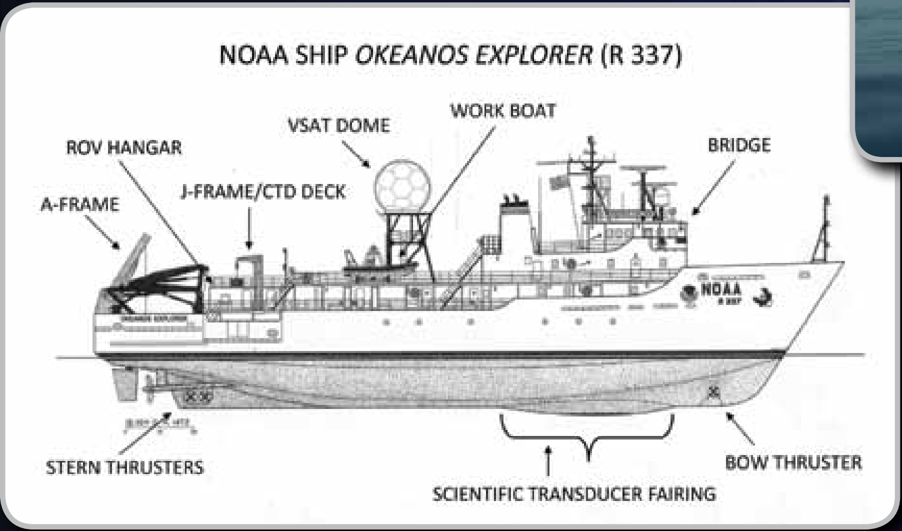
BUILT | 1987, Halter Marine in Pascagoula, MS, USA

BERTHING | 46 persons (27 crew, 19 mission/science)

FLAG | United States of America

HOME PORT | North Kingstown, RI, USA

MISSION SYSTEMS | Kongsberg EM 302 multibeam sonar; Kongsberg EK 60 fisheries sonar; Knudsen 3260 subbottom profiler; Sea-Bird Electronics 9/11+ CTD rosette with Sea-Bird SBE-32 carousel; in situ sensors (light scattering, dissolved oxygen, oxidation reduction potential); Sippican expendable bathythermograph sound velocity profiling; Custom 4,000 m rated dual-body remotely operated vehicles with high-definition video cameras; 3.7 m SeaTel tracking antenna capable of up to 46 Mbps Internet service; three Tandberg EN8090 high-definition video encoders for real-time video streaming; EVS XT2 high-definition, disk-based instant-replay video recorder; 130 TB disk storage; RTS Telex intercom for real-time audio communications.



REMOTELY OPERATED VEHICLES

LITTLE HERCULES is one part of *Okeanos Explorer's* two-body ROV system. Owned by the Institute for Exploration, *Little Hercules* was entirely retrofitted by NOAA's Ocean Exploration and Research Program in 2009 for use on board *Okeanos Explorer* through a partnership between the two programs. *Little Hercules* is rated to 4,000 m depth, and always operates in concert with a second vehicle. Communication with *Little Hercules* is conducted over fiber optic cable, and control of the vehicle and all onboard sensors is via surface computers located in the *Okeanos Explorer* control room. *Little Hercules* is very maneuverable, with four electric thrusters mounted in a configuration that allows it to move through the water much like a helicopter moves in air. *Little Hercules* carries a single high-definition video camera, two additional task video cameras, two high-intensity lights, a depth and altitude sensor, a CTD, and a full-color sector-scan imaging sonar system. An ultra-short baseline navigation system tracks the vehicle while it is underwater.

SEIRIOS is the second vehicle in *Okeanos Explorer*'s two-body, ROV system for exploring the ocean bottom with an impressive array of underwater cameras and sensors. It can operate as a stand-alone towed vehicle or in tandem, as a camera and light platform, to another ROV such as *Little Hercules*. In its dual role, *Seirios* can be towed in relatively close proximity to the seafloor or attached to the ROV to "fly" several meters above it. *Seirios* is currently rated to go as deep as 4,000 m, but future modifications will soon push that limit to 6,000 m. It is purposely designed to be negatively buoyant in water; thus, it carries no foam pack for flotation. It includes two high-definition cameras and 2,400 watts of broadcast-quality lighting. *Seirios* also carries two five-horsepower electric thrusters that allow it to move both rotationally and laterally. Depth sensors, an altimeter, a full-color sector scan imaging sonar, a CTD, and several other "task" cameras are additional standard equipment.

MAPPING SYSTEMS

Okeanos Explorer is equipped with three ocean mapping sonar systems: a 30 kHz multibeam sonar, an 18 kHz single-beam sonar, and a 3.5 kHz subbottom profiler. The multi-beam sonar yields high-resolution three-dimensional maps of the seafloor surface, the single beam sonar produces maps of water column acoustic reflectivity (Figures 1 and 2), and the subbottom profiler generates profiles of Earth's geological structure immediately beneath the seafloor.

Data collected with the sonar systems are initially spatially referenced with a differential global positioning system (GPS) and then corrected for the ships motions, such as pitching and rolling that occurred during collection. The data are then further corrected to account for vertical variability in the speed of sound in the ocean created

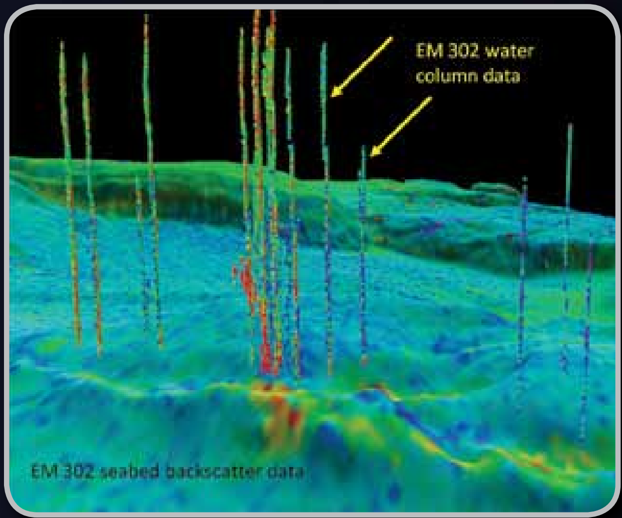


Figure 1. EM 302 multibeam seabed and water column data examples.

by changes in temperature and salinity with depth. These changes are precisely measured by conductivity and temperature sensing instruments deployed over the side of the ship at regular intervals of no more than six hours. All sonar data are collected, corrected, and processed in real time on board *Okeanos Explorer* with dedicated mapping computers and specialized software.

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 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 Geophysical Data Center (http://www.ngdc.noaa.gov), where they are archived and subsequently made available to the general public within 60 to 90 days.

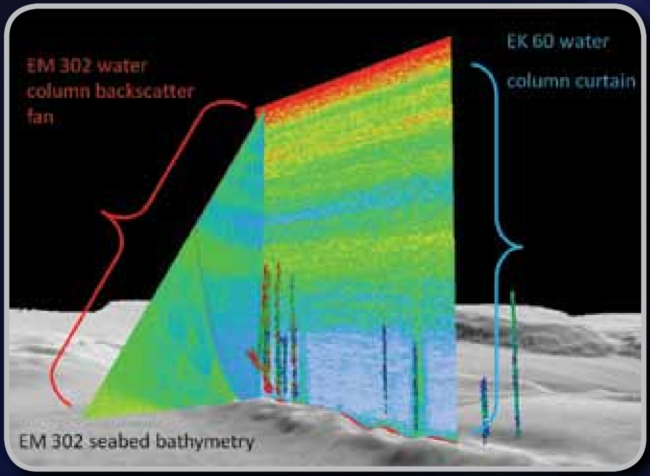


Figure 2. EM 302 multibeam sonar and EK 60 single-beam data examples. EK 60 and EM 302 provide similar data, but the multibeam sonar covers a much larger area of the seafloor.

TELEPRESENCE

VSAT

Okeanos Explorer uses VSAT to enable Internet and phone/fax connectivity at sea. This very prominent antenna is mounted on the mast aft of the bridge, and is capable of tracking a geostationary satellite even under moderate to heavy sea states.

REAL-TIME VIDEO STREAMING

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 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.

INTERCOM COMMUNICATIONS

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. 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.

INSTANT MESSAGING SERVICE FOR REAL-TIME COLLABORATION

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.

WEB-BASED ACCESS TO DATA AND OPERATIONAL INFORMATION

The *Okeanos Explorer* Program provides several additional web-based tools to ensure shore-side 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* FTP server is a shore-based file-server 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 extremely 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 RSS.

TECHNOLOGY

The URI Inner Space Center and Exploration Command Centers

By Dwight F. Coleman

Telepresence technology enables real-time participation in ocean exploration expeditions from shore. Although any participant can be a passive observer of the programs from anywhere with a broadband Internet connection, being a fully engaged participant requires additional infrastructure. The Inner Space Center at the University of Rhode Island Graduate School of Oceanography serves as the hub for supporting the technical and functional aspect of each Exploration Command Center (Figure 1). ECCs are multifaceted command stations that allow users to participate directly with shipboard operations (Figure 2).

The ISC connects to all ECCs and serves as the shore-based technical hub for all telepresence-enabled exploration on *Okeanos Explorer* and *Nautilus* (see page 6). The ISC manages all of the ECC intercom units, hosts the web-based access tools, and provides technical assistance to ECC users. This facility also serves as the dissemination point for all data collected from *Nautilus*. In addition to the ISC's support services, the Mission Control facility can physically host groups of scientists, students, and educators who participate in expeditions from shore. Although it currently works primarily with *Nautilus* and *Okeanos Explorer,* the ISC is capable of supporting three exploration vessels working simultaneously.

The Mission Control space within the ISC has several ECC-style workstations, or pods, where multiple users have access to all streaming data, video, and information, plus intercom keypanels for two-way voice communication with the ships and other ECCs. This space also represents an advanced data visualization laboratory for the display, analysis, and broadcast of live video feeds, maps, data sets, and other scientific results. One of the pods in Mission Control is equipped with video broadcast technologies so that an educator or scientist can "go live" to the Internet, to a classroom, or to informal science education facilities like

Figure 1. Dwight Coleman communicates with *Nautilus* and *Okeanos Explorer* simultaneously from Mission Control at the Inner Space Center (ISC) during a live media event to both ships. The Mission Control space at the ISC is equipped with a large projection screen that can handle displays of live feeds of video, data, and audio communications from multiple ships of exploration in real time.

Figure 2. Shore-based cruise participants at the NOAA Pacific Marine Environmental Laboratory in Seattle, Washington, staff an Internet2-enabled Exploration Command Center, Live video feeds streaming from *Okeanos Explorer* are decoded and displayed on the large screen monitors in real time. Access to data and other cruise information is managed through integrated personal computers, and voice communication is handled through the intercom keypanel.

aquariums, museums, and science centers. This location served as the hosting site for Nautilus Live broadcasts during the 2010 and 2011 field seasons (see page 20).

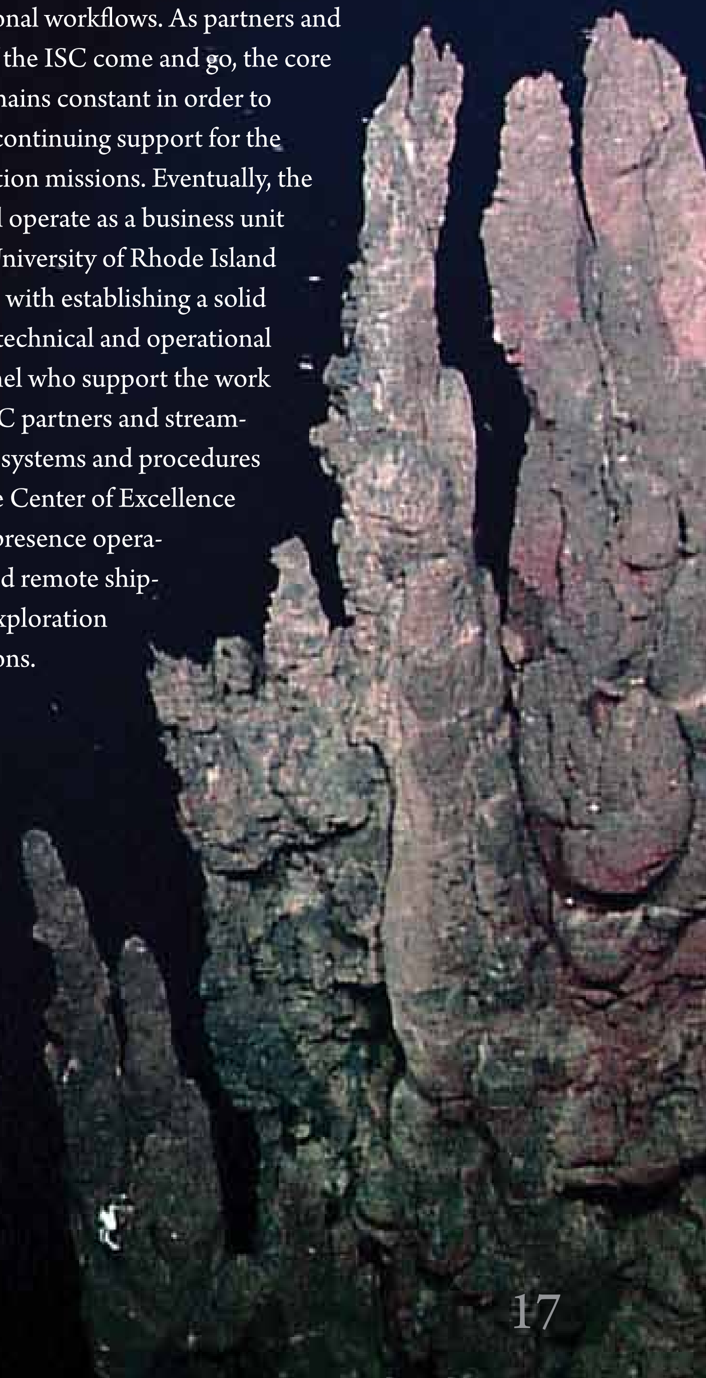
The video broadcast production control room and studio are used to produce live and recorded educational video content that supports the missions of the exploration ships in real time. This part of the facility also serves as a resource that supports the various educational programs associated with the missions and partner websites.

Scientific, technical, and educational personnel work at the ISC to support interactive exploration operations. The scientific and educational support staff can help users understand the capabilities and protocols that support the missions; technical staff maintain systems and train users. Equipped with technologies similar to those available on both ships, the facility is ideally suited for developing protocols for video and data management and for seamlessly supporting real-time technical and scientific operations, and it can serve as a shore-based training facility for new users of the shipboard technologies.

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* and *Nautilus.* The large monitors and video decoding hardware available to ECC participants display the same three primary video feeds seen on board the ships. 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* shore-side repository and on the ISC data and video servers and archival system. Where appropriate, processing software is also made available on the workstations to assist the ECC-based scientists with interpreting the real-time data.

Okeanos Explorer, Nautilus, and their programs' partners are currently the ISC's most frequent users. Depending on mission-specific requirements, the ISC's support staff can expand to accommodate the various projects. The Mission Control space is often used for nonlive video production where partners, for example, National Geographic Television, can film scientists interacting with pre-recorded or live video and data while they explain the work of the exploration missions.

The ISC has the flexibility to accommodate partners who have new sets of operating requirements. In that sense, the ISC is a constantly evolving laboratory for telepresence operations that require personnel to continually solve new problems and support changing operational workflows. As partners and users of the ISC come and go, the core staff remains constant in order to ensure continuing support for the exploration missions. Eventually, the ISC will operate as a business unit of the University of Rhode Island charged with establishing a solid base of technical and operational personnel who support the work of all ISC partners and streamline the systems and procedures of a true Center of Excellence for telepresence operations and remote ship-based exploration operations.



EDUCATION AND OUTREACH

EXPLORATION VESSEL *NAUTILUS*

Using *Nautilus* as a Platform for Lifelong Learning

By Alexandra Bell Witten, Katherine L.C. Bell, Amy O'Neal, Katrina Cubina, Jennifer Argenta, and Eleanor Smalley

In addition to its role as a platform for innovation in technology and ocean exploration, the *Nautilus* Exploration Program provides a vehicle for developing education and outreach programs to engage people of all ages. These programs encompass broad-scale outreach, K–12 science, technology, engineering, and mathematics (STEM) programs, undergraduate and graduate internships, and on-the-job training.

Nautilus inspires the explorer in almost everyone. Several organizational partners, including the National Geographic Society, Sea Research Foundation, and the JASON Project, present our work to the public using numerous types of media, including the Internet, film, television, magazines, and books, as well as live theater shows at aquariums and museums, to reach the broadest audience possible. These moments of discovery displayed through the various media allow us to capture the imaginations of millions of people, with the ultimate goal of leading them further down the path of higher education. In total, we estimate that we have reached approximately 14 million people since *Nautilus* first set sail in 2009.

Educators at Sea

The Educators-at-Sea Program is an effort to address the shortage of students entering STEM fields by bringing the excitement of ocean exploration to audiences of all ages. The program embeds two educators in each cruise to support all of our educational activities. During the 2011 field season, a total of 19 Educators-at-Sea joined expedition teams. They came from museums, aquariums, and public and private schools across the United States.

Educators-at-Sea posted 65 blogs and over 500 photographs on the Nautilus Live website, depicting everything from scientific activities, to vehicle operations and maintenance, to daily life and living conditions aboard *Nautilus*, and the many faces, personalities, and careers integral to the exploration program. Educators participated in 482 shows with the Nautilus Live Theater at Mystic Aquarium, and in live interactions with over 3,500 people around the world. Back on shore, the educators continue to work directly with over 2,000 of their own students, sharing their experiences on board *Nautilus*.

Classroom and After-School Programs

In 2011, we worked to turn inspiration into educational engagement at the middle and high school levels by infusing live elements into formal and informal curricular materials. These curricula cover the basic principles and standards required of STEM education programs serving middle school grades in all 50 states. The JASON Project continued to develop digital labs and curricular materials specific to *Nautilus* that are available at http://www.jason.org. These labs and materials were estimated to reach over 400,000 students in 2011.

In addition, nine JASON Student Argonauts and four JASON Educator Argonauts were selected to participate in transit legs on *Nautilus* (Figure 1). Five students were selected from high schools and technical schools, four were from Boys & Girls Clubs in the United States, and one internationally from Romania. These individuals attended a camp in July to prepare them for their oceanographic expedition. While on board, they participated in research projects and posted blogs and video updates to the JASON Project and Nautilus Live websites, and each group did two live webcasts, viewed by 1,700 people.

In 2011, Immersion Learning developed *Nautilus*-based programs in partnership with 55 youth-serving organizations. Immersion focused on inspirational career role models as part of its two new Immersion programs: *Nautilus Live* and *Remotely Operated Vehicles.* The programs consist of hands-on science, technology, engineering, and math activities, as well as multimedia resources related to *Nautilus* and remotely operated vehicles. Immersion held over 20 professional development

Figure 2. Dan Davis mentors honors student Kent Hamlin as a data logger in the Black Sea. *Credit: M. Blitzer*

Figure 1. Argonauts deploy an ad hoc Secchi disc to measure the visibility of the water in the Mediterranean Sea. *Credit: P. Haydock*

Figure 3. Marine Advanced Technology Center ROV Intern Rachel Gaines doing a pre-dive check on *Hercules. Credit: Cory Culbertson*

workshops, training a total of 376 program leaders.

The JASON Project and Immersion created a new series of live webcast events to enable tens of thousands of students to interact directly with world-renowned scientists. During each 45-minute webcast, they learn about the featured host's work and career path and vote in polls and ask questions. Live webcasts are archived for ongoing use at http://jason.org/live. In May 2011, 21,091 viewers participated in a live webcast entitled "Meet Ocean Explorers—Robert Ballard and Katy Croff Bell". In addition, the two scientists each did a live webcast from *Nautilus* during the cruise, and they were viewed by 2,300 people collectively.

Honors Program

In 2011, the Ocean Exploration Trust instituted an Honors Research Program for advanced high school students. Two students from Choate Rosemary Hall were selected to work with scientists at the University of Rhode Island Graduate School of Oceanography, and one student worked at the Cape Henry Collegiate School. The students developed summer research projects on oceanographic topics and processed 2010 *Nautilus* field program data, the products of which will serve as the basis for further research and exploration. The students joined a leg of the 2011 field season where they continued their research, later presenting their results at their schools. The 2012 program will build on this prototype and emphasize attracting honors students from underrepresented communities.

Science and Engineering Internships

Ten undergraduates and 36 graduate student interns participated in the 2011 *Nautilus* Exploration Program in order to be trained in oceanographic science and engineering. The interns join the at-sea team by serving as watch standers in the roles of vehicle and video engineers, navigators, and data loggers. Since 2009, *Nautilus* has trained 81 interns from 11 countries around the world, representing 29% of the expedition team.

Role Models and Lifelong Learning

Our aim is to offer lifetime learning opportunities to capitalize on interest sparked by live access to oceanographic expeditions. We emphasize role models from across the array of professions found on the ship and on shore. The essential element of our programs is the initial effort to engage and inspire children by giving them a compelling "view over the shoulder" of scientists and engineers at sea as they are making real time discoveries, and to show kids the path toward a future career of exploration.

EDUCATION AND OUTREACH

NAUTILUS LIVE

Inspiring the Next Generation Through Real-Time Access to Ocean Exploration

By Todd Viola, Alexandra Bell Witten, Patrick Shea, Susan Poulton, and Katherine L.C. Bell

Real-time streaming of video from the bottom of the ocean provides an excellent opportunity to engage the public. The central challenge of our outreach programming is to provide sufficient contextual information surrounding the video so that the viewer will quickly understand what is happening on the ship and immediately become an engaged participant. In a theater setting, the host/interpreter fills this important role. On the web, we need a layered strategy involving web interface design, content workflows, and interpretation by members of the *Nautilus* team.

Nautilus Live Website

The Nautilus Live website, http://www.NautilusLive.org, is designed to surround the live video stream coming from the ship with current information to help the audience identify and understand what is happening in the mission (Figure 1). The site displays the current status of operations, includes a map showing the ship's location, and provides a changing display of the notes being recorded by the watch Data Logger in real time. Also available are blogs, photos, and highlight videos, which are updated on the site multiple times per day. Beginning in August 2011, the website was embedded in the National Geographic Society's Oceans Portal. From July 20 to November 16, the website hosted 204,179 visits of which 97,696 were unique visitors from 173 countries. The number of unique visitors doubled over 2010 thanks in part to the National Geographic Society partnership to reach new global audiences. Website users are able to leave comments on posted blogs, images, and video, and to share Nautilus Live content with social networks using Facebook and Twitter.

The most widely used interactive feature of the website was "Send a Question." Visitors watching the live video on the site could submit a question without leaving the home page. Team members answered the questions live over the intercom audio, which accompanied the video on the website. Thus, web visitors could submit a question and get a response within moments. During the 2011 season, over 13,000 questions and comments were received through the Nautilus Live website. In several instances, website visitors used the "Send a Question" option to identify and/or provide research background on a discovery, for example, during the discovery of the shipwreck M/S *Dodekanisos* (see pages 28–29).

Another interactive feature launched this year enabled website viewers to identify great moments in the live video by submitting keyword "tags." These user-generated notes were recorded and time-stamped, enabling video production personnel to search for the viewer-tagged video segments and then include them in daily on-demand highlight clips.

The final addition to the Nautilus Live website in 2011 was the integration of a shore-based production team, which

Figure 1. The Nautilus Live home page includes live video, status updates, on-watch data logger observations, and links to photos, blogs, and on-demand videos.

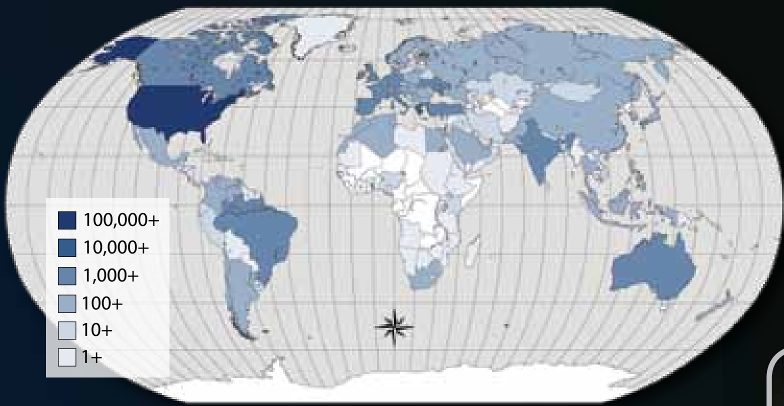


Figure 2. Approximately 100,000 unique visitors to the Nautilus Live website came from 173 countries around the world.

Figure 3. While aboard *Nautilus*, Educator-at-Sea Sharon Pearson (a) engages in a live interaction with her students (b) in Las Vegas, Nevada. *Credit T. Milliard*

focused on postproduction and interpretation for outreach audiences. The Inner Space Center-based team produced 235 on-demand videos, which included daily updates, expedition summaries, "Behind the Science" pieces, and "Meet the Team" videos that focused on individual team members, their work and/or educational backgrounds, and their jobs on the ship. These items complemented personnel profiles that were featured on the website.

Nautilus Live Theater at Mystic Aquarium

The premier venue for informal public outreach was at Mystic Aquarium, where a 50-seat Nautilus Live Theater was constructed in 2010. Over the course of the four-month 2011 field season, the theater hosted 486 live presentations, each of which included a live interaction with either the Educator-at-Sea on board *Nautilus* or the team at the Inner Space Center. Including the 2011 pre-expedition presentations beginning on July 1 through the end of the brief post-expedition show, over 29,000 guests participated in a theater show.

Visitors who came to the theater ranged from families and early childhood education classes to retirees; they represented partners, universities, and other aquariums, middle and high school classes, and local and international visitors. Many guests followed up their visits by going to the Nautilus Live website. Sample survey comments from guests included: "Got me interested in the expedition and made me go online and follow it live" and "Being able to speak with a crew member on board was really neat. I had so many questions that I could have asked."

Expanding beyond the Nautilus Live Theater is a network of 11 Exploration Command Centers designed for education and outreach purposes. They are located at schools, Boys & Girls Clubs, libraries, informal education sites, and science centers across the country. These centers displayed the live feeds in an immersive group setting configured to replicate the control van on board *Nautilus*. They featured the same displays and exclusive interactive opportunities as the Nautilus Live Theater. We also facilitated approximately 55 live interactions between educators, students, and scientists on the ship with schools and informal education sites on shore, reaching approximately 3,500 people from pre-kindergarten classes to retirees at public lectures.

Outreach and Media

An important part of the outreach story is the effort to help our partners reach audiences in the United States and abroad. In 2011, we held press and public events at Mystic Aquarium, in conjunction with the NOAA Office of Exploration and Research at the Inner Space Center, and at Exploration Command Center sites. Members of the press and dignitaries visited the ship in Turkey, Greece, and Israel; the latter two appeared to coincide with increased viewership on the Nautilus Live website in those countries. The partner countries also held live interactions with the ship in their native languages.

We will use the lessons learned during this year to implement a more robust communications plan for future years in an effort to increase live viewership all over the world.

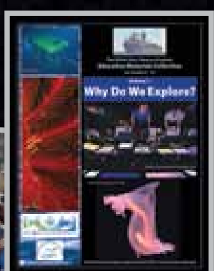
EDUCATION AND OUTREACH

NOAA SHIP *OKEANOS EXPLORER*

Enhancing Ocean Science Literacy Through NOAA Ocean Exploration Education

By Paula Keener and Mashkoor Malik

The NOAA Ship *Okeanos Explorer* is a national ocean-based asset through which a key recommendation from *The Report of the President's Panel on Ocean Exploration*[1]—"reaching out in new ways to learners of all ages to enhance ocean literacy"—is being implemented. The *Okeanos Explorer* 2011 field season provided opportunities to continue carrying out this recommendation at national and international levels. Exploration Education Modules developed for the Galápagos Rift and Mid-Cayman Rise expeditions delivered information about daily discoveries and the science behind the expeditions[2].



LEFT | Cover of *Volume 1: Why Do We Explore?* from the new NOAA Ship *Okeanos Explorer* Education Materials Collection (http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html).

ABOVE | Students learn how wavelengths of light travel to various depths in the deep ocean using special mask filters in an activity called "Light in the Deep Dark Ocean."

ABOVE | ROV team members Karl McLetchie, Tom Kok, and Joel De Mello (left to right) pose in front of *Little Hercules*.

LEFT | Educators learn about energy transfer through chemosynthesis in an activity called "Candy Chemosynthesis."

Professional development for educators using the new NOAA Ship *Okeanos Explorer* Education Materials Collection[3] was also launched in 2011. The collection encourages educators and students to become actively involved with the ship's voyages and discoveries. The collection is presented in two volumes: *Volume 1: Why Do We Explore?* focuses on climate change, ocean health, human health, and energy as important reasons for ocean exploration. *Volume 2: How Do We Explore?* targets systematic exploration methods and advanced technological assets and capabilities of *Okeanos Explorer*. Lessons are cross-referenced with *A Framework for K–12 Science Education Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and with the *Ocean Literacy Essential Principles and Fundamental Concepts*[4]. Both volumes have been offered as online courses in partnership with the College of Exploration and are archived at http://www.coexploration.org/oe. The online courses drew more than 1,500 participants representing all 50 US states and 29 countries.

Our efforts to educate the next generation of explorers also extend to the field. NOAA's Office of Ocean Exploration and Research (OER) supported eight hydrographic internships on board *Okeanos Explorer* during the 2011 field season, providing opportunities for undergraduates to work with ship's crew and scientists as an introduction to acoustics and multibeam data acquisition and processing. At-sea training opportunities were also provided to ROV pilots, data managers, and video production engineers, building critical capacity for future ocean exploration missions. In addition, OER developed shore billets at the University of Rhode Island and in Seattle, WA, to train NOAA Corps officers in support of shipboard and shore-based operations specific to *Okeanos Explorer*'s mission.

[1] http://explore. noaa.gov/media/http/pubs/pres_panel_rpt.pdf | [2] Ocean Explorer Expedition Education Modules are available at http://oceanexplorer.noaa.gov/edu/modules/welcome.html | [3] The NOAA Ship *Okeanos Explorer* Education Materials Collection is available at: http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html | [4] http://oceanliteracy.wp2.coexploration.org

Outreach: Communicating Benefits to Society

By Fred Gorell and Keeley Belva

In 2010, NOAA explored the Sulawesi Sea with its Indonesian partners, mapping a major seamount, discovering new ones, and imaging approximately 90 potentially new deep-sea species. Those observations and more were communicated via three news releases and press conferences, presentations to audiences in Indonesia and the United States, website updates, and media interviews. Additional benefits of this program included acquiring data for use by ocean resource managers and strengthening ties between the United States and Indonesia.

During *Okeanos Explorer*'s transit back to continental US waters, it supported the NOAA Fisheries Service by obtaining plastic and plankton samples from the ocean for research. Agency scientists are interested in learning whether plankton, at the base of the ocean food chain, may be ingesting toxins borne by plastic particles, and a news release emphasized this focus.

The 2011 Galápagos Rift expedition was the first in our program to feature live video available to audiences ashore via standard Internet. Combined with the follow-on expedition, standard Internet reached more than 250,000 unique visitors, part of NOAA's Office of Ocean Exploration and Research's goal to bring the excitement of ocean discovery to audiences in classrooms, newsrooms, and living rooms.

During the 2011 Mid-Cayman Rise expedition in the Caribbean Sea, scientists described fault systems that transported rocks from deep within Earth's interior to the ocean floor. Those deep faults may be the location of extensive hydrothermal systems that could host an abundant deep-sea and subsurface biosphere that draws its energy from these fluids rather than the sun. A NOAA news release covered mission discoveries. During this 2011 expedition, *Okeanos Explorer* and *Nautilus* in the Black Sea sent simultaneous live imagery to audiences, including media, at two Exploration Command Centers, showing the capabilities of telepresence technology to enable communications to multiple audiences ashore in exciting ways.

TOP | In 10 years of ocean exploration, 40 million individuals have visited NOAA's award-winning website http://oceanexplorer.noaa.gov, where the Mid-Cayman Rise expedition was featured in 2011. BOTTOM | Robert Ballard is interviewed about telepresence technology by 60 Minutes' reporter Lara Logan, ashore at the Inner Space Center at the University of Rhode Island. Filling the screen is live video of the wake of NOAA Ship *Okeanos Explorer* at sea, operating off Hawaii. *Credit: Joe Giblin, URI.*

The 2011 Gulf of Mexico expedition demonstrated the capability of *Okeanos Explorer*'s multibeam sonar to map gaseous seeps by imaging their "footprints" in the water column. The lead expedition scientist explained that this research will "increase knowledge of the marine environment, including the distribution of natural sources of methane input into the ocean and the identification of communities of life often associated with methane gas seeps." Again, NOAA issued a news release. Following this expedition, the ship visited Pascagoula, Mississippi, where outreach activities included ship tours and briefings for media, 40 students, and three US Congressional staffers.

In October, both US senators from Rhode Island, explorer Robert Ballard, and NOAA and University of Rhode Island leadership welcomed the crew and exploration team to *Okeanos*'s new home port in Rhode Island.

Okeanos Explorer expeditions were extensively covered by NOAA web and social media sites. For more about the *Okeanos Explorer* Program, visit http://www.oceanexplorer.noaa.gov, or connect with us at YouTube, Facebook, Twitter, iTunes, and Flickr.

E/V *NAUTILUS* 2011 FIELD SEASON

By Katherine L.C. Bell

The year 2011 marks the third field season for Exploration Vessel *Nautilus*. Over the past three years, we have worked with hundreds of people from all over the world to explore the deep sea, and have used telepresence technology to bring the excitement of our expeditions to millions of viewers worldwide. Our four-month field season built upon years of working in the Mediterranean and Black Sea regions, strengthening relationships with many of our partners, and building new ones as we look toward investigating unexplored areas. Our successful collaboration with 186 participants from 19 countries illustrates the diplomatic power of *Nautilus* and our common goal of exploring the world's ocean.

The 2011 season commenced in July off the Turkish Black Sea coast, where we collaborated with local geologists, biologists, and archaeologists to acoustically map the continental shelf and document evidence of internal wave dynamics and trawling activity, particularly as they affect the preservation of ancient shipwrecks (see pages 26–27). During this project, nine shipwrecks with varying degrees of preservation were discovered, the oldest dating to ca. 500 BCE. We continued our work in Turkish waters off the coast of Knidos in the southeastern Aegean Sea, where we investigated the coastal deep waters (see pages 28–29). We explored large areas of seabed, documenting marine geological features and 10 previously undiscovered shipwrecks. These discoveries, in combination with extensive seafloor mapping, are helping us study the effect of trawling on the destruction of shipwreck sites in deep water.

Exploration of volcanic centers in Greek and Italian waters led to exciting discoveries in geology, chemistry, and biology that will lead to a better understanding of past and present volcanic and hydrothermal systems in these areas. Our collaboration with Greek scientists expanded from Earth scientists to include water chemists and microbiologists as we continued our exploration of the Santorini and Kolumbo volcanoes, as well as the nearby Christiana group of four small islets and the deep Cretan Basin (see pages 30–31). New exploration in the Italian Aeolian Arc and Straits of Sicily offered a glimpse into vast hydrothermal systems, along with the vent site of a recent underwater volcanic eruption and the discovery of a World War II Italian airplane (see pages 32–35).

The passive margins of Spain and Israel proved to be amazingly dynamic targets of exploration. Off the coast of Spain, we found extensive deposits of ancient volcanic rocks, including pillow basalts, as well as deepwater coral reefs and an abundance of other biology (see pages 36–37). Continued exploration off the Israeli coast resulted in the discovery of seafloor vents, possibly releasing methane, and associated megafauna, including colonies of small tubeworms (see pages 40–41).

The 2011 season was the first time that *Nautilus* has worked in the Atlantic Ocean. Due west of the Strait of Gibraltar lies Gorringe Bank, a ridge composed of two uplifted blocks of oceanic crust and mantle (see pages 38–39). As its geological origin is similar to that of the Atlantic Massif on the Mid-Atlantic Ridge, we hypothesized

Credit: T. Pierce

Credit: T. Pierce

2011 *NAUTILUS* BY THE NUMBERS

19	Countries represented on *Nautilus*
24	Cultural sites discovered
67	Women on the Expedition Team
70	Collaborating institutions
186	Participants on the Expedition Team
1,080	Hours underwater

that it could have similar hydrothermal systems to those found at Lost City. Although we did not find evidence of active venting, we did recover samples of serpentinite and gabbro similar to those documented at Lost City. We also observed many species of coral, fish, and other benthic organisms, which were abundant at this intersection between the North Atlantic Ocean and Mediterranean Sea.

Throughout our expedition, we continued to develop and test new technologies to enhance our ability to characterize new regions as accurately and efficiently as possible. Our Mapping and Imaging Team continues to break new ground by developing techniques to map not only the seafloor, but also active seafloor venting, using stereo imagery, structured light, and high-frequency multibeam sonar (see pages 42–45). We are optimistic about the initial results and the broad range of potential applications of these new techniques. Two student projects were also developed this year, one to collect water samples under pressure, and the other to build a rock chipper to collect samples from outcrops.

In conjunction with our Advisory Board, the *Nautilus* team is now developing our cruise plans for 2012 and beyond. We expect to conduct a two-month field season in the summer of 2012, our last in the Mediterranean region for the foreseeable future. We will then install an EM302 multibeam system on *Nautilus* the following winter, giving us the capability to move out of previously studied areas into truly unexplored regions. A transit from Turkey to the Caribbean will be used to test the new multibeam system, and it will be followed by a full field season in the Caribbean region in 2013. We are looking forward to bringing our capabilities to new parts of the globe, forming new partnerships, and learning even more about our underexplored ocean.

Coastal Exploration of the Southern Black Sea Off Ereğli and Sinop, Turkey

By Michael L. Brennan, Dan Davis, Chris Roman, Ilya V. Buynevich, Alexis Catsambis, Meko Kofahl, Maureen Merrigan, Suna Tuzun, Muhammet Duman, Derya Urkmez, J. Ian Vaughn, and Tufan Turanli

The Black Sea is the largest anoxic basin on Earth. Below approximately 155 m depth, its waters become depleted in oxygen, and hydrogen sulfide is present in the water column. We returned to the Turkish Black Sea coast at the beginning of this year's expedition for the first time since 2007. Expeditions in 1999, 2000, 2003, and 2007 mapped and explored the area off Sinop between the 100 and 400 m isobaths to document the possible paleoshoreline that predated Black Sea flooding following the last ice age. During these surveys, four Byzantine-era amphora wrecks were found: three at 100 m depth, and one well-preserved wooden wreck with its mast still standing upright at 325 m depth (Ward and Ballard, 2004). In 2011, we returned to continue exploring the seabed across the oxic/anoxic interface where internal wave motion between these water layers affects sediment dynamics along the shelf. This internal wave action increases the preservation potential for shipwrecks that lie in water depths shallower than 155 m.

While conducting the side-scan sonar survey of the shelf along the Turkish coast, we observed a variety of seafloor features, including large sediment slumps along the steeper slope off Ereğli and waveforms below ~ 200 m depth off Sinop (Figure 1). We explored these bedform areas with the ROV *Hercules* (Figure 2) during a dive into the anoxic water layer to collect sediment cores. Push cores were collected in oxic and suboxic layers for comparisons between these environments (Figure 3). We collected a total of 12 cores, processed them on board, and then sent them to various institutions in Turkey and the United States for geological and biological analyses, including microbiology, grain size, porewater chemistry, and meiofauna. The resulting database will help us learn more about the biogeochemical processes occurring in these water layers.

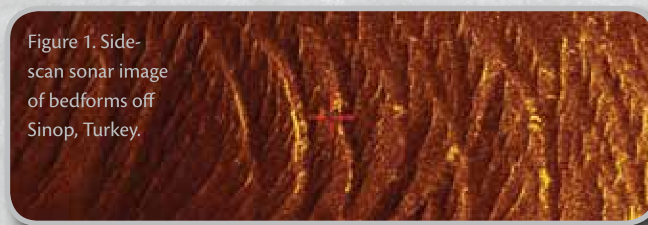


Figure 1. Side-scan sonar image of bedforms off Sinop, Turkey.

Using the dissolved oxygen (O_2) sensor on *Hercules* to locate coring sites in the suboxic zone (the interval at which O_2 is < 5 μM), we found that this layer began at 120 m depth. In a study done in the same area northwest of Sinop, Duman et al. (2006) reported the oxic/anoxic halocline to be between 100 and 110 m, with the suboxic transitional zone extending from 100 m down to ~ 200 m, which is

Figure 2. *Hercules* flying over a series of bedforms.

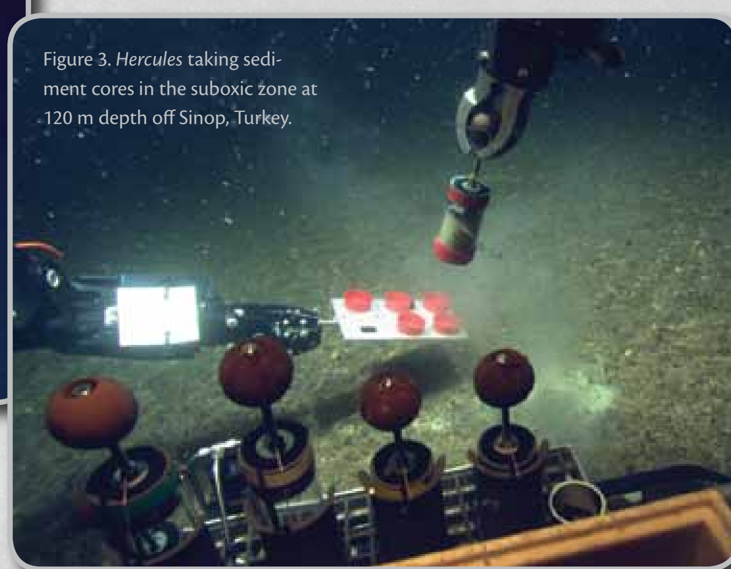


Figure 3. *Hercules* taking sediment cores in the suboxic zone at 120 m depth off Sinop, Turkey.

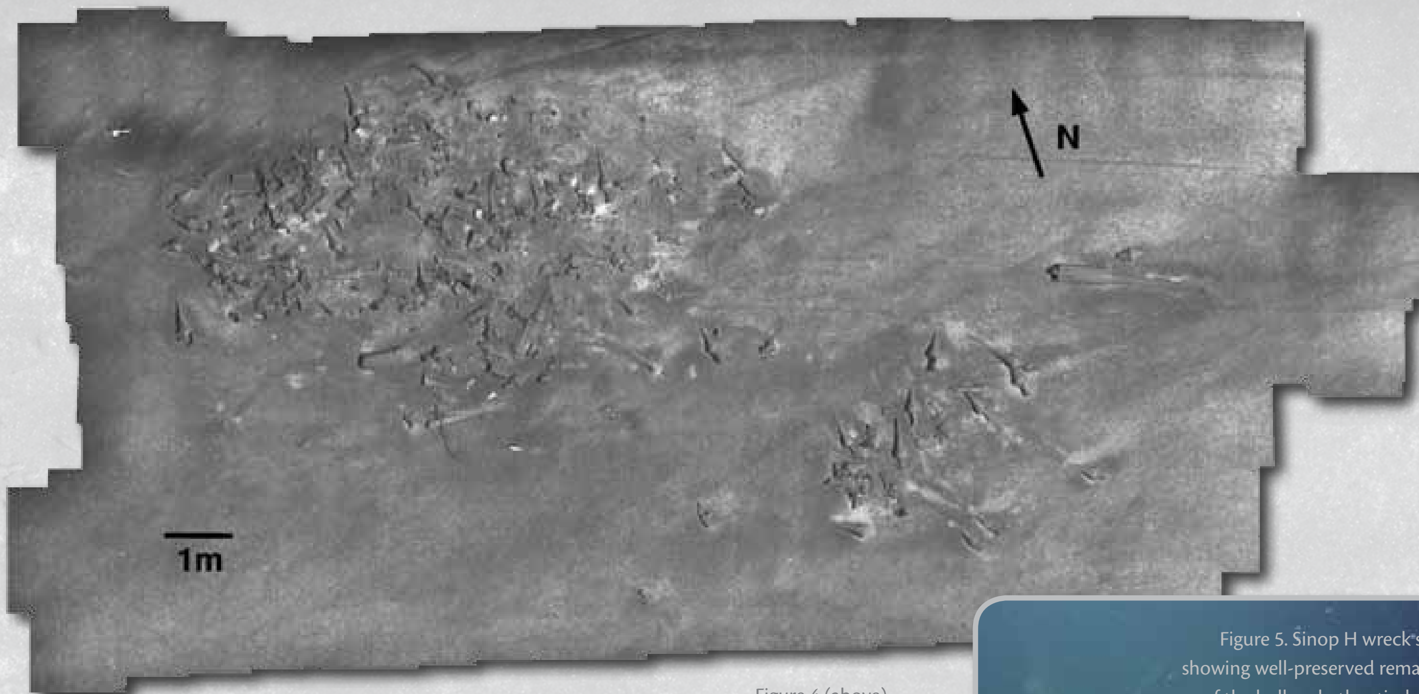


Figure 4 (above). Photomosaic of the Sinop A wreck site with trawl scars running in multiple directions.

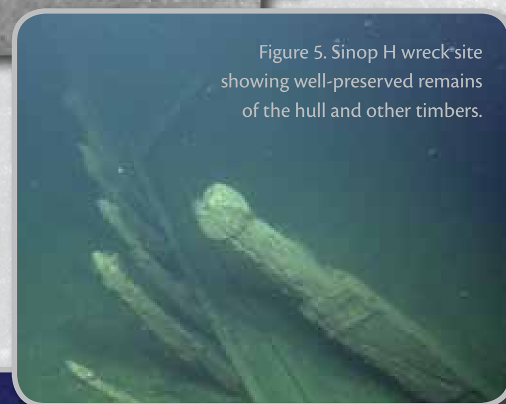


Figure 5. Sinop H wreck site showing well-preserved remains of the hull and other timbers.

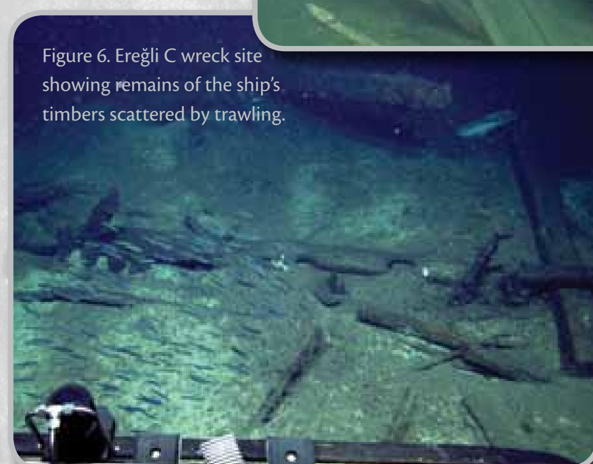


Figure 6. Ereğli C wreck site showing remains of the ship's timbers scattered by trawling.

the depth where we began documenting bedforms (megaripples with superimposed ripples). The observed onset of suboxic conditions at 120 m depth correlates well with the ranges cited by Duman et al. (2006), and with the preservation state of shipwreck sites located during this expedition.

During the acoustic surveys of the shelf, we located nine shipwrecks ranging in age from the 4th century BCE to the 19th century CE. These wrecks all lie between 100 and 115 m depth, as do Sinop A, B, and C, discovered in 2000. The wooden components of all of these ships remain preserved to varying extents. Those wrecks from 2000 and 2011 that lie along the 100 m depth contour largely contained cargoes of amphoras. Their timbers, however, are preserved better than expected when compared to ancient shipwrecks found in the Aegean Sea because of the low-oxygen content of the suboxic zone. In addition, internal waves caused by intense storms push suboxic waters up onto the shelf above 120 m depth, preventing wood-boring organisms from consuming the wooden parts of the shipwrecks.

The Black Sea shipwrecks have been damaged by trawl fishing, which we commonly observe at many sites in the Aegean Sea (Brennan, 2010). Sinop A, for example, has trawl scars running through the entire site from multiple directions. These scars are apparent in a photomosaic of the wreck (Figure 4). Many of the wrecks located in 2011 contain large amounts of wood. Some of them, such as Sinop H, still retain a vessel shape (Figure 5), whereas others, such as Ereğli C (Figure 6), have had their timbers ripped away and scattered on the seafloor, presumably by trawl fishing. Therefore, the current preservation state of each wreck site in the Black Sea reflects both human activities in the area and the presence of suboxic waters along the continental shelf. Further work over the next few years will focus on exploring and documenting new sites along this coastal area of northern Turkey to gain a broader understanding of the chemical processes in the water column, as well as the extent and intensity of trawl fishing in order to evaluate the preservation potential of cultural materials.

Continued Documentation of the Coastal Landscape Off the Datça Peninsula, Turkey

By Michael L. Brennan, Robert D. Ballard, Muhammet Duman, Gabrielle Inglis, Suna Tuzun, and Tufan Turanli

Since 2008, we have been documenting the coastal deep water (50–600 m) off southwestern Turkey around the Bodrum and Datça peninsulas. Over the past four years of expeditions, culminating in this past summer's work, we explored large areas of seabed and documented features such as rock ridges and slumps from the steep slopes of the peninsula, carbonate crusts from methane seeps, numerous ancient shipwrecks, and areas of seabed scarred by heavy bottom trawling activity (Brennan et al., 2011). Combining these data has allowed us to begin mapping the direct effect of trawling on the destruction of shipwreck sites in deep water. Wreck sites located in the rocky areas we documented west and northwest of Knidos are less damaged than those south of Knidos in flat terrain, where trawling is generally conducted parallel to isobaths. The 25 ancient wrecks found in these areas of the southeastern Aegean Sea comprise a sufficiently large database for initiating spatial comparisons between wrecks to help evaluate differences in the modern sites on the seabed.

The objectives of this year's expedition were to investigate some of the sonar targets located in 2010, fill in gaps in our side-scan sonar coverage in these areas, and conduct new mapping and imaging surveys of some of the previously discovered wrecks to evaluate them for recent trawl damage. Some of the sonar targets investigated over the past few years were identified as geological features, either rock outcrop exposures along the slope or crusts from gas seeps. Like shipwreck sites, these features are important for biological investigations, as the rocky substrates act as reefs on which benthic organisms colonize, and fish such as a boarfish, congregate (Figure 1). We also noted that some of the amphoras of several ancient shipwreck sites were slumped into a small depression within the site. Microbathymetric mapping of Knidos L illustrates such a feature (Figure 2). Such depressions at wreck sites may be the result of conger eels excavating sediments from around the artifacts to create burrows within the wreck (Figure 3). We observed these eels in similar depressions at multiple Aegean and Mediterranean wreck sites.

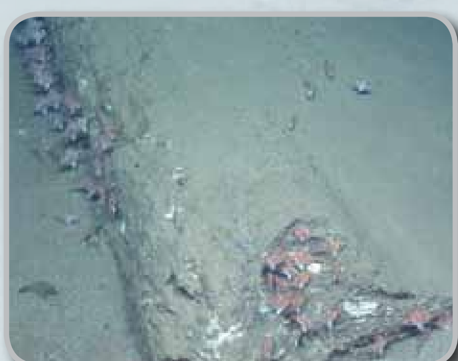


Figure 1. A school of boarfish *Capros aper*) congregate around a rock outcrop in the Aegean Sea off Knidos, Turkey.

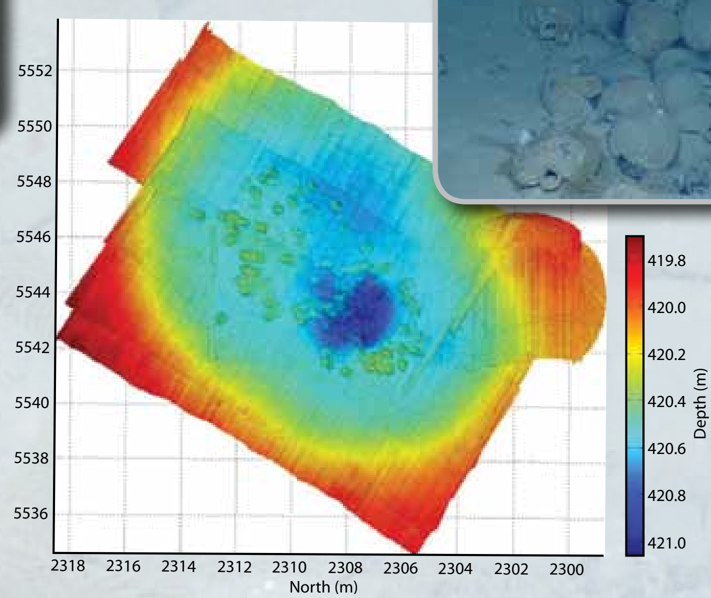


Figure 2. Multibeam microbathymetry map of the Knidos L shipwreck site showing depressed area of amphoras.

Figure 3. Knidos L wreck site with a conger eel (*Conger conger*) within the amphora pile.

Figure 5. Wreck of M/S *Dodekanisos*, with *Hercules* hovering over the bow.

We found 10 ancient wrecks this year near Knidos. Many of them are smaller than the large amphora wrecks that we found over the past few years, for example, Knidos T, located northwest of the peninsula (Figure 4). Such smaller wrecks were not carrying liquid cargo in amphoras, instead, they may have been carrying an organic cargo or no cargo at all, so their seafloor sites are smaller. These wreck sites are important to document carefully and completely because they contain a wide variety of small artifacts rather than uniform amphoras, and can tell us much about the ancient economy. Knidos T contains a multitude of small ceramic vessels, flat stone blocks, and metal chain, among other artifacts, much of which would be obscured by amphoras had this ship been carrying them.

Figure 4 (above). Knidos T wreck site showing a variety of artifacts, including small ceramics, flat blocks, and metal chain.

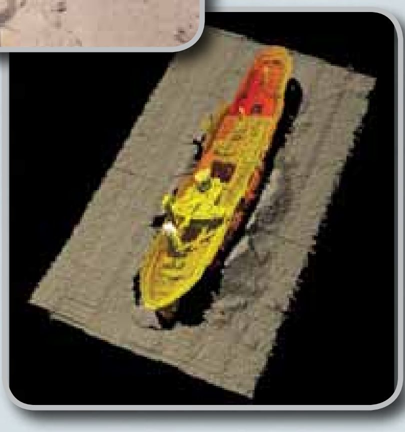


Figure 6 (right). Multibeam microbathymetry map of the ship *Dodekanisos*. Sediment mounds resulting from impact with the bottom are visible on the wreck's port side.

While side-scan sonar mapping a series of rock ridges and slumps just west of the Datça peninsula at 486 m depth, we also located the wreck of the Greek M/S *Dodekanisos*. The *Dodekanisos* sank in 1958 in a gale on its way to the Greek island of Kos, and was identified by viewers watching Nautilus Live in Greece (Figure 5). The ship settled on the seabed upright with a slight list to starboard, its bow facing northwest. We conducted a high-resolution multibeam survey of the wreck at 15 m altitude with *Hercules*. The microbathymetry map shows mounds of sediment on the port side that were pushed up by the ship upon landing on the seabed (Figure 6). Though the ship is intact, its residence underwater over the past 50 years has led to heavy deterioration. The wooden deck planking has rotted away in many places, and the steel is heavily corroded and degraded (Figure 5). This shipwreck illustrates the continued navigational hazard that the Datça cape has posed to mariners since ancient times.

Continued Exploration of the Santorini Volcanic Field and Cretan Basin, Aegean Sea

By Katherine L.C. Bell, Paraskevi Nomikou, Steven N. Carey, Eleni Stathopoulou, Paraskevi Polymenakou, Athanasios Godelitsas, Chris Roman, and Michelle Parks

The Hellenic Volcanic Arc lies in the southern Aegean Sea, formed by subduction of the African Plate below the European Plate. The Santorini complex, the most active volcanic center in the Hellenic Arc in recent times, is composed of three volcanic areas along the northeast-southwest Kameni and Kolumbo lines (Figure 1): the Kolumbo Volcanic Rift Zone in the northeast, Santorini in the center, and the Christiana islet group and submarine domes in the southwest (recent work of author Nomikou and colleagues). In 2011, we investigated the Santorini volcanic complex, as well as the back-arc Cretan Basin, continuing work that began in these regions in 2006 (Sigurdsson et al., 2006; Carey et al., 2011).

Kolumbo, which last erupted explosively in 1650 CE, is the largest volcano of the Kolumbo Volcanic Rift Zone. Its submarine cone is 3 km in diameter, and its crater floor is 500 m deep. In 2006, an active hydrothermal system venting hot gases and fluids at temperatures exceeding 200°C was discovered in the crater (Sigurdsson et al., 2006). In 2010, gas and geological samples were collected (Carey et al., 2011), and high-resolution mapping using multibeam, structured light, and stereo imagery was carried out (Roman et al., 2010b). In 2011, we returned to Kolumbo to focus on: (1) biogeochemical sampling of geological deposits, bacteria, water, and gases that exist in and around the hydrothermal vent field, and (2) high-resolution mapping of the hydrothermal vent field. We also tested two new gas sampling devices that are currently in development by URI Ocean Engineering Intern Mike Filimon.

In total, we collected 26 rock and sediment samples (with bacteria), 10 Niskin water samples, and 14 gas samples from the Kolumbo vent field. Samples of red-orange and white-grey bacterial mats from the crater floor were collected for metagenomic exploration of these newly discovered habitats in collaboration with the Joint Genome Institute, US Department of Energy. The first analytical data using pyrosequencing and illumina sequencing technology showed that a highly diverse microbial community inhabits this environment. Active and extinct chimneys are built of Fe, Pb, Cu, and Zn sulfides, and Ba and Ca sulfates. Iron-rich minerals and some arsenic-sulfur minerals

Figure 1. Swath bathymetry map of Santorini's volcanic field.

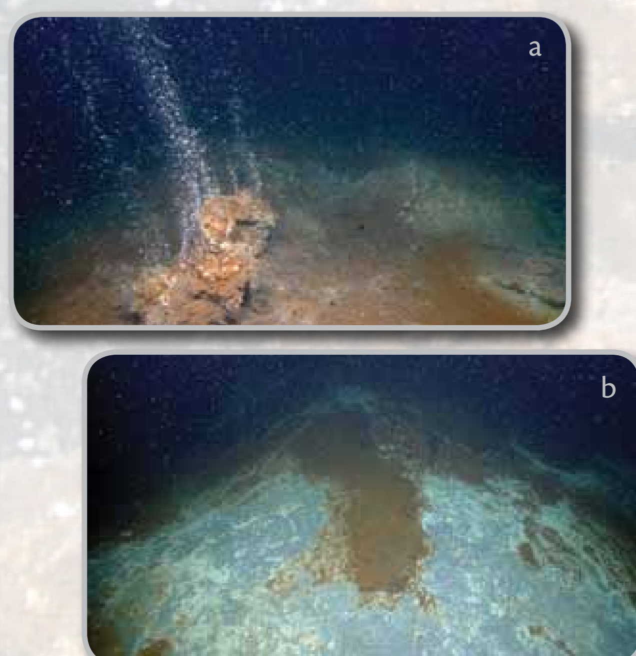


Figure 2. We are able to use different survey techniques to map out distributions of (a) bubbling and (b) nonbubbling vents inside the crater of Kolumbo Volcano.

Figure 3. *Hercules* collects a push core of a yellow bacterial colony and sediment from the hydrothermal vent field in the northern basin of Santorini.

Figure 4. *Hercules* inspects a large fracture on the slope of the Christiana domes.

Figure 5. Unidentified mounds in the Cretan Basin are a few meters in diameter, approximately 1 m high, and commonly have a small crater at the top.

that may be of biogenic origin cover some of the Kolumbo chimneys. Initial studies also indicate possible microbial microtextures in the cores of the chimneys (Kilias et al., 2011). Gas samples collected in 2010 showed that 99% of the gas being emitted from the hydrothermal vents is composed of CO_2 (Carey et al., 2011). Not surprisingly, preliminary onboard analysis of water samples in 2011 shows pH levels lower than average; detailed chemical analysis is currently in progress.

Kolumbo mapping efforts focused on two new ways to visualize active physical processes (Figure 2). First, we mapped the hydrothermal vent field and actively bubbling vents at high resolution. Second, we tested the use of structured light mapping over areas venting hot water without bubbles ("shimmery" water). The observed refraction of light can be used to visualize these venting areas (see pages 42–45). The preliminary results of both techniques were excellent, and we anticipate that these maps will contribute to a better understanding of Kolumbo's geological activity, and demonstrate the use of mapping temporal changes in biogeological systems. These techniques should also be useful in other exploratory applications.

Our work inside Santorini caldera focused on two regions: the hydrothermal vent field in the northern basin (Figure 3), and the north and east slopes of Nea Kameni Island. The low-temperature vent field in the northern basin, first discovered in 2006, is composed of small (1–4 m) mounds covered in yellow bacteria. Sediment samples were collected here to compare the microbial community to that in nearby Kolumbo. Since January 2011, interferometric synthetic aperture radar and GPS measurements[1] collected on the Kameni islands and Thera suggest caldera-wide uplift occurs at a fairly constant rate. This continued inflation may indicate the influx of new magma beneath Nea Kameni. ROV exploration along the northern slopes of Nea Kameni revealed lava flows and fractured lava blocks that were formed during the 1707–1711 and 1925–1928 CE eruptions. At the top of a volcanic dome, east of Nea Kameni, we also discovered a crater with shimmery water.

The Christiana group of four small islets belongs to a stand-alone volcanic cone that domed the seafloor at the junction of a pair of fault zones trending NNW-SSE and NNE-SSW. A group of submarine domes near the Christiana islets occur at an average depth of 500 m and are believed to be of volcanic origin (recent work of author Nomikou and colleagues). Until now, no visual observations had been made on the submarine domes; we conducted several *Hercules* dive transects up their slopes to study their origin, history, and relationship with the rest of the Santorini volcanic complex. We found evidence of faulting (Figure 4)—cliffs up to 100 m tall, and small colonies of yellow, presumably sulfur-reducing hydrothermal bacteria, as well as abundant benthic megafauna, including sponges, corals, sea cucumbers, and urchins.

The final area of interest was the Cretan Basin in the Sea of Crete, where we discovered an area of pockmarked mounds in 2006. Our goal in 2011 was to map the region with side-scan sonar to determine the geographic extent of the mound area, followed by visual reconnaissance with *Hercules*, and to collect sediment samples to investigate how these features formed (Figure 5). Unfortunately, failure of the side-scan system prevented us from carrying out the planned mapping, but we collected push cores from several of the mounds, and analysis is in progress.

[1] GPS measurements have been collected as a collaborative project that includes the University of Oxford, the National Technical University of Athens, the Georgia Institute of Technology, and the University of Patras.

Submarine Volcanoes of the Aeolian Arc, Tyrrhenian Sea

By Steven N. Carey, Katherine L.C. Bell, Mauro Rosi, Michael Marani, Paraskevi Nomikou, Sharon L. Walker, Kevin Faure, and Joshua Kelly

The southeast Tyrrhenian Sea off the western coast of southern Italy is one of the two areas of the Mediterranean basin where active subduction and associated volcanism occur. Rollback of westward-dipping Ionian oceanic lithosphere has created a small back-arc basin and the Aeolian Arc with seven subaerial volcanoes: Stromboli, Panarea, Vulcano, Lipari, Salina, Filicudi, and Alicudi volcanic islands (Figure 1). At least eight submarine volcanoes in the area have been explored to a limited degree. For several decades, the submarine centers in the arc and back-arc have been the target of geophysical, volcanological, and mineral exploration (e.g., Dekov and Savelli, 2004). Deep-sea dredging has collected evidence of hydrothermal activity at many of the submarine centers. CTD recordings in the water column, coupled with helium isotopic measurements, identified significant chemical signals at Palinuro, Enarete, Eolo, Marsili, Sisifo, and Secca del Capo that may result from hydrothermal venting (Lupton et al., 2011).

During the 2011 *Nautilus* field season, four submarine volcanoes, or seamounts, in the Aeolian Arc (Eolo, Enarete, Palinuro, and Casoni) were explored for evidence of recent volcanic activity and hydrothermal venting. Eolo is atypical of seamounts in the Aeolian Arc, having a complex structure that may be related to caldera collapse. We found sediment draping most of the volcano, suggesting a lack of recent volcanism, but we found evidence of hydrothermal venting at a number of sites—small patches (tens of centimeters across) of bright yellow-orange bacteria colonizing fractures in volcanic rock outcrops (Figure 2). In one locale, we encountered a small group of living tubeworms around a small outcrop of manganese-encrusted rocks.

On nearby Enarete, outcrops of manganese-encrusted lava flows and rocks broken off from lava domes were abundant. In some areas at the summit, fluids with temperatures up to 5°C above the ambient seawater were actively discharging. Bacteria were common in these areas, and small (a few tens of centimeters in height), fragile chimneys composed of iron oxides dotted the seafloor (Figure 3).

Palinuro Seamount is a complex feature, consisting of

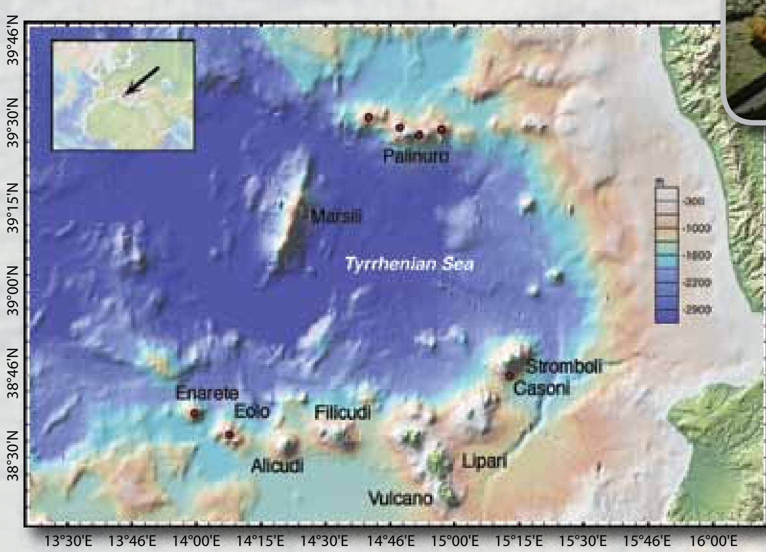


Figure 1. Bathymetric map of the Tyrrhenian Sea showing the location of the subaerial and submarine volcanic centers of the Aeolian Arc. Red circles indicate the submarine centers explored during the 2011 *Nautilus* field season.

Figure 2 (top photo). Yellow-orange bacteria colonizing an area of low-temperature hydrothermal fluid venting on Eolo Seamount, Tyrrhenian Sea.

Figure 3 (bottom photo). Yellowish-brown iron-oxide hydrothermal vent on the summit of Enarete Seamount, Tyrrhenian Sea.

Figure 4. Colony of living tubeworms (*Siboglinidae*) in the vicinity of high-temperature (54°C) venting on the western end of Palinuro Seamount. A small octopus is visible on the right-hand side of the image.

Figure 5. Tubular iron-oxide vent on the western side of Palinuro Seamount showing an interior composed of green nontronite.

five coalesced volcanic edifices lying along an east-west trending fault system extending seaward off the northern limit of Calabria (Figure 1). The seamount cluster spans a total length of 50 km, with a maximum width of about 25 km at its base. Previous seafloor observations show that sediment covers large parts of Palinuro Seamount, with outcrops of volcanic rocks being relatively rare in the upper portion of the coalesced volcanic edifices. Massive sulfide fragments had been recovered from the western portion of the seamount at approximately 600 m water depth by gravity coring, dredging, and video-guided grab sampling (Monecke et al., 2009). In this area, new exploration by the ROV *Hercules* revealed areas of fluids venting at temperatures up to 54°C. Large colonies of living tubeworms (*Siboglinidae*) surrounded the venting areas and were draped by cotton- and cobweb-like bacteria (Figure 4).

Figure 6. Bulbous iron-oxide vent on the eastern side of Palinuro Seamount showing an interior composed of green nontronite.

Near Palinuro in the high-temperature venting areas, honeycomb chimneys with interconnected globular spires were coated with brownish yellow bacteria (Figure 5). These fragile structures are likely constructed of iron-containing minerals, and many display a bright green core indicative of nontronite, an iron-rich clay common in low-temperature hydrothermal systems (Figure 6). On Palinuro's eastern end, there was also evidence of low-temperature hydrothermal venting from spires up to 30 cm in height. Interestingly, we observed small yellow tube-like structures that resembled some type of worm, but may instead be bacterial structures. The discovery of active venting at each summit along most of Palinuro's 50 km length explains the many strong water-column chemical signals observed by Lupton et al. (2011) in their CTD survey.

Figure 7. Inflated pillow basalt structure south of Stromboli Volcano on Casoni Seamount.

The final submarine center we explored was a small seamount south of Stromboli. We observed many small cones and ridges south-southwest of the island that are likely the submarine extensions of the Stromboli magmatic system. Previous dredging of Casoni Seamount recovered volcanic samples that were warm. No hydrothermal venting was discovered at Casoni, but a relatively fresh sequence of well-exposed pillow basalts and breccias indicate young submarine volcanism. Of particular interest were large mounds (Figure 7) that appear to have been inflation features on the submarine flows, likely analogous to uplifted crusts, or tumuli, often observed on subaerial basaltic lava flows, such as in Hawaii.

Submarine Volcanism in the Straits of Sicily

By Steven N. Carey, Katherine L.C. Bell, Michael Marani, Mauro Rosi, Edward T. Baker, Chris Roman, Marco Pistolesi, and Joshua Kelly

Tectonic extension during the late Miocene to Pliocene (about 10.5 to 2.5 million years ago) formed the Straits of Sicily, or Sicily Channel, between Sicily and the North African continental margin (Civile et al., 2010). Three principal elongated depressions in this deep intraplate rift zone—the Pantelleria, Linosa, and Malta grabens—occur along the length of the channel with maximum depths of 1,317, 1,529, and 1,731 m, respectively (Figure 1). Each graben is filled with thick (> 1,000 m) sedimentary sequences, so-called turbidites (Calanchi et al., 1989), and is generally bounded by northwest-southeast trending faults. The continental crust along the grabens is significantly thinned, with a minimum thickness of 17–18 km found beneath the Pantelleria and Linosa grabens. Subaerial and submarine volcanism occur at various locations within the Straits of Sicily as a result of crustal thinning. Subaerial volcanism is restricted to the islands of Pantelleria in the northwest and Linosa to the southeast (Figure 1).

In contrast, a large number of submarine volcanic centers (at least 10) have been identified within the grabens and along the shallower platforms adjacent to Sicily (Rotolo et al., 2006). New multibeam mapping around Pantelleria revealed the presence of at least 30 small volcanic cones in 100–650 m water depth (Bosman et al., 2007). Historical activity in the area was recorded as early as 264 BCE, and the last documented submarine eruption took place in 1891, several kilometers northwest of Pantelleria at Foerstner Volcano (Washington, 1909). The 1891 eruption was unusual because it produced meter-size basaltic scoria blocks that rose to the surface and degassed (sometimes exploding) before becoming saturated with seawater and then sinking back to the seafloor (Figure 2).

In 2011, E/V *Nautilus* scientists went to the area northwest of Pantelleria to investigate the location of the 1891 vent and to examine the structure, relative age, and composition of the numerous volcanic cones. We confirmed the location of the 1891 eruption vent about 4 km off the northwest coast (Figure 3). Surrounding the vent, a small mound with a peak at 255 m water depth, was an extensive field of large scoria blocks distributed on a seafloor mantled by fine-grained sediment (Figure 4). These blocks were likely transported briefly on the sea surface by local

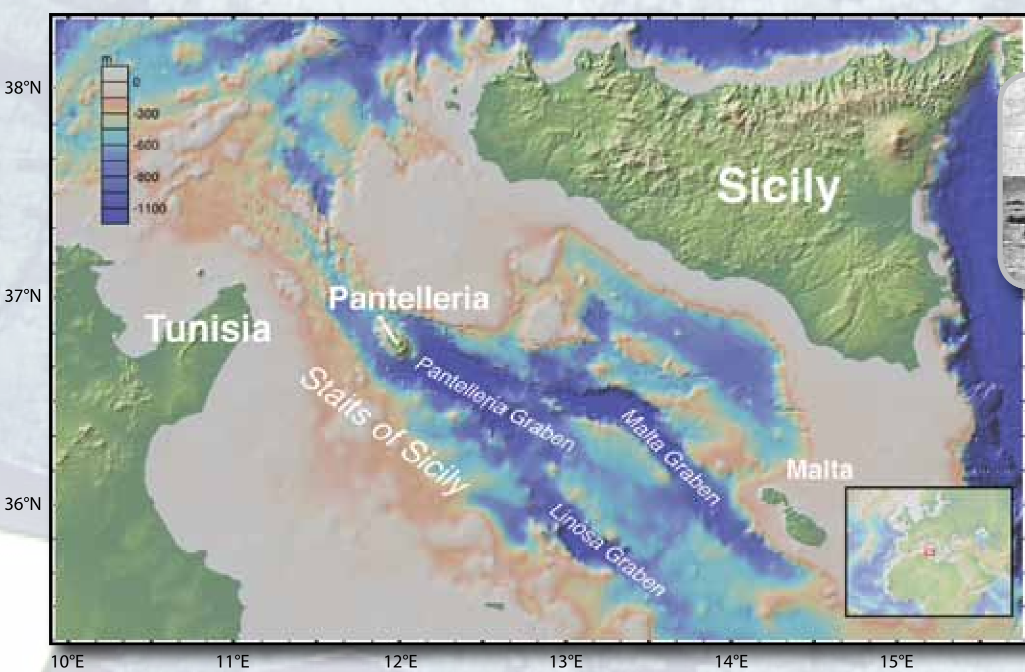


Figure 1 (left). Bathymetric map of the Straits of Sicily showing the location of the Pantelleria, Malta, and Linosa grabens.

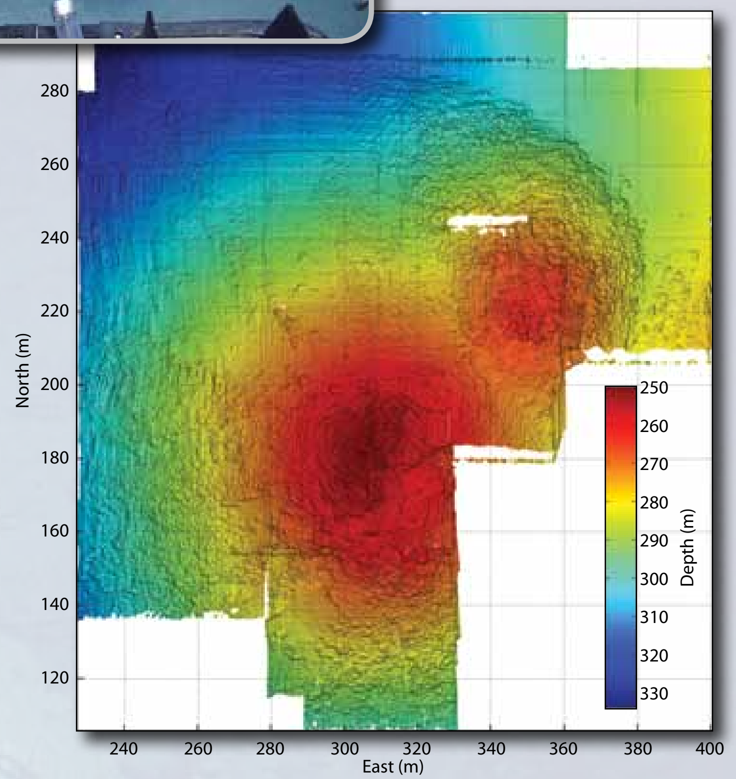
Figure 2 (above). Lithograph of floating scoria blocks from the 1891 submarine eruption of Foernster Volcano, Northwest Pantelleria. *From Butler (1892)*

Figure 3 (above). Vent area of the 1891 submarine eruption off the coast of Pantelleria, Italy. Pillow-like lava tubes are characterized by abundant decimeter-scale gas voids.

Figure 5 (right). Hollow scoria block from the 1891 submarine eruption off the coast of Pantelleria, Italy. Scale bar is 30 cm long. Note the large gas cavities that produced sufficient buoyancy for the blocks to rise to the sea surface.

Figure 4 (right). Scattered 1891 scoria blocks on fine-grained sediment at 350 m water depth off the coast of Pantelleria, Italy. The largest individual blocks are about 1 m in diameter.

Figure 6 (below). High-resolution bathymetric map of the 1891 submarine vent area and block field off the coast of Pantelleria, Italy.



currents before sinking back to the bottom. Many of the blocks were hollow and easily broken when grabbed with the manipulator arm of the ROV *Hercules* (Figure 5). We conducted a high-resolution multibeam mapping survey of the vent site and adjacent block field to help understand the nature of the submarine eruption processes and the dispersal pattern of the eruptive products (Figure 6). This first attempt at high-resolution imaging of a submarine vent system of this scale will likely lead to important insights into the evolution of this interesting eruption style.

Exploration of 11 other cones northwest of Pantelleria revealed only one with relatively fresh volcanic rocks. This cone was located just east of, and is significantly larger than, the 1891 vent site. Geochemical analyses of samples collected on this cone will be compared to the 1891 scoria to see whether this vent site may also have been associated with the most recent eruption. The other cones were characterized by the development of a biogenic mineralized crust covering outcrops of volcanic rock. Virtually all of these cones exhibited extensive areas of dead coral fragments, often coated with manganese precipitates, near their summits (Figure 7). This debris may represent drowned coral beds that developed during the last sea level low stand approximately 11,000 years before present. ^{14}C dating of sampled coral fragments will be used to assess this hypothesis.

Figure 7 (above). Dead coral beds being sampled by *Hercules*' manipulator arm at 400 m water depth on the slopes of a volcanic cone northwest of Pantelleria Island, Italy.

Nautilus Explores the Western Mediterranean Sea

By Dwight F. Coleman, James A. Austin Jr., Miquel Canals, David Amblas, Joan B. Company, and Michael L. Brennan

The southeastern and southern margins of Spain include the Mazarron Escarpment and several topographic features in the adjacent Alboran Sea (Figure 1), the two primary areas of interest for the E/V *Nautilus* team in the western Mediterranean Sea. We were interested in exploring the seafloor throughout these areas to (1) investigate the geological complexity associated with this tectonically active transform plate boundary system, (2) investigate active slope failure and sedimentary depositional environments associated with small submarine canyon systems that incise the continental shelf and slope off southern Spain, (3) inspect and sample several interesting submarine environments that were previously mapped with multibeam sonar systems, (4) document the benthic and pelagic marine life associated with these geological environments, and (5) investigate the oceanographic conditions associated with this westernmost basin of the Mediterranean Sea, where surface Atlantic water flows in above deeper outflowing Mediterranean water.

The Mazarron Escarpment is the remnant of an old, large transform fault system that now likely accommodates the northward push of the African Plate toward the Eurasian Plate. It is a steep, fault-bounded feature, which probably formed from east-west extensional tectonics along the transform system (Mauffret et al., 1992). We explored suspected volcanic seamounts associated with large pockmarks and rich hard-bottom biological communities, deformation structures related to regional tectonic stresses, and a possible mud volcano. This large mud volcano was explored in detail and found to be inactive. We completed several transects with the ROV *Hercules* along the base of the escarpment and out to deeper water in the vicinity of the mud volcano, while documenting and sampling depositional environments and benthic marine life.

The Alboran Sea is the westernmost basin in the Mediterranean Sea, and is being affected by the complex tectonic forces associated with continued convergence of the European and African Plates and the eastward extension of the Azores-Gibraltar Fracture Zone

Figure 2. Pillow basalts on the North Alboran Ridge.

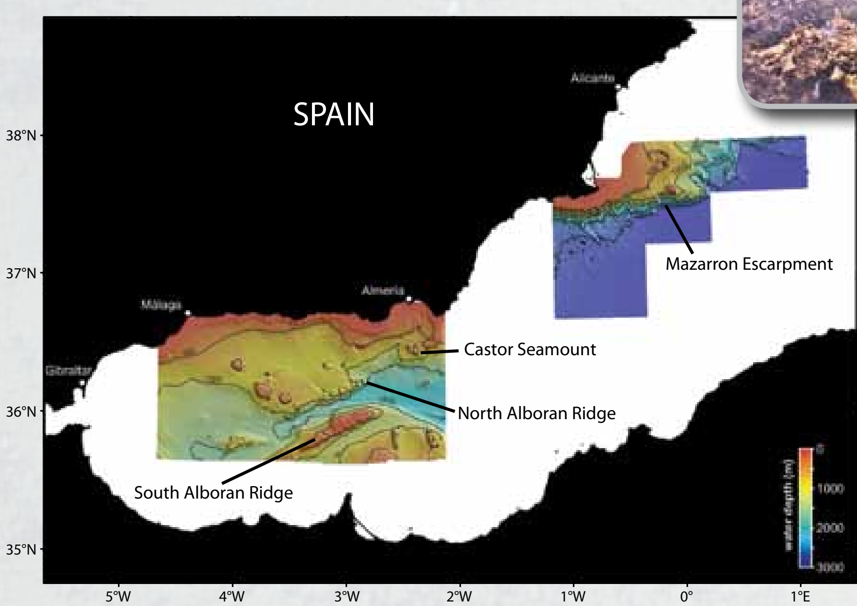


Figure 1. Multibeam bathymetric maps of the dive locations off southern Spain in the western Mediterranean Sea. *Multibeam data provided by the Spanish Institute of Oceanography*

(see pages 38–39). Dives on both the South and North Alboran Ridges, which flank a deepwater channel in the central Alboran Sea, confirmed that they are composed of submarine volcanic rocks, including pillow basalts (Figures 2 and 3). This volcanic terrain likely represents the remnants of Miocene rifting (~ 22 million years ago), which stretched and thinned the continental crust and opened the Alboran Basin along the east-west trending transform system (Muñoz et al., 2008). A side-scan sonar survey using the *Echo* towfish in the deeper portion near the Alboran Channel at the base of the Alboran Ridge supplemented dives along the north side of the ridge. This survey revealed a relatively flat seafloor with surprisingly heavy sedimentation, probably resulting from turbidite deposits related to mass-wasting processes on the adjacent steeper ridge flank.

The Alboran Sea is a very productive part of the Mediterranean; marine life abounds, including otherworldly siphonophores several meters long (Figure 4). In some of the intermediate-depth regions, especially where swift currents exist along steep rock faces on the Alboran Ridge, we found abundant benthic marine life, including oyster and deepwater coral communities. On an upslope transect of the South Alboran Ridge, from about 1,200 m to 500 m depth, we observed heavy and recent trawl marks scarring the seabed starting at 800 m. These furrows remained prevalent as we moved upslope. Few benthic biota were present near the furrows, probably as a result of the pervasive seafloor disruption by these fishing activities.


Figure 3. A squid swims near volcanic outcrops on the South Alboran Ridge.


Figure 4. A siphonophore inspected by *Hercules* in the Alboran Sea.


Figure 5. Glass sponges and soft corals on Castor Seamount in the Alboran Sea.

We also investigated portions of the submarine extension of the Carboneras Fault, which comes on shore in southern Spain. This active fault is part of the trans-Alboran shear zone, where the largest historical earthquakes in southeastern Spain have originated. Dives included portions of the Almeria Canyon and its tributaries. Another part of this zone is Castor Seamount, where we encountered more volcanic outcrops and associated biota, including glass sponges and soft coral communities (Figure 5). Along the Almeria Canyon transect, we visually inspected the seafloor at specific depth horizons to document the sedimentary geological character and benthic biology. This effort was part of an attempt to document and compare the canyons off southern Spain with canyons off eastern Spain, where similar ROV transect dives had been carried out previously. By comparing the nature of the canyons at specific depths with similar techniques, we established a baseline by which to gauge future changes in the seafloor environment and living communities. Similar comparisons could be made to other submarine canyons along the continental slopes and mid-basin ridges in other parts of the Mediterranean Sea.

Our dives in this part of the Mediterranean confirmed that it is tectonically complex, with many active faults and evidence of previous volcanic activity, and that its deepwater biota are rich and diverse, despite the negative impacts of intensive fishing in some areas. The complexity of the seafloor terrain, the dynamics of the oceanographic conditions through mixing of water masses, and the richness of the marine biology throughout the region made this exploration program off southern Spain truly worthwhile, and the *Nautilus* team agreed that future work in this area should be carried out through an expanded exploration program.

In Search of Serpentinization on Gorringe Bank

By Jeffrey A. Karson, Katherine L.C. Bell, Aleece Nanfito, Darcy Joyce, Marina Cunha, Javier Cristobo, and Eugenia Manjon

Gorringe Bank is a northeast-southwest elongated ridge on the floor of the eastern Atlantic Ocean that has been the site of diverse and ongoing geologic activity. Two distinctive seamounts mark the ridge, Gettysburg and Ormonde, both of which rise from the surrounding abyssal plain at > 5,000 m depth, to within a few tens of meters of sea level. Unlike most seamounts, which are extinct volcanoes, Gettysburg and Ormonde are uplifted blocks of oceanic crust and mantle created by seafloor spreading about 143 million years ago, during the early stages of opening of the Atlantic Ocean. Extreme faulting near the spreading center resulted in uplift and exposure of deep-seated rocks as an "oceanic core complex" (Karson et al., 2006; Smith et al., 2006). Later, diffuse compressional deformation along the eastern part of the Azores-Gibraltar transform plate boundary probably also contributed to uplift. In addition, the area passed over the Madeira hotspot, resulting in intrusion and extrusion of alkalic basalts. With summits presently fewer than 100 m below the sea surface, Gettysburg and Ormonde Seamounts emerged as rocky, wave-swept islands during the last glacial interval (~ 12,000 years ago). Gorringe Bank lies close to the epicenter of the Great Lisbon Earthquake of 1755 (M_b = 8.5). With this remarkable geologic history, it was no surprise to find complexities beyond those known from previous near-bottom studies in the area (Auzende et al., 1978; Girardeau et al., 1998).

Hercules and *Argus* plunged to their maximum depth ranges, approaching 4,000 m, for the first time since 2005 during the E/V *Nautilus* exploration of Gorringe Bank. Despite some technical challenges with the fiber-optic cable and the ship's propulsion system, four extended dives were completed, yielding spectacular images of the seafloor, a diverse suite of mantle and crustal rocks, and a wealth of exotic biological samples and images, including a number of potential newly discovered species.

Transects on the steep northwest slope of Gettysburg Seamount (named for the US vessel that discovered it in 1875) focused on previously unexplored exposures of upper mantle rocks called peridotites. Reactions with hot hydrothermal fluid has converted these rocks to serpentinites. Serpentinization is an exothermic (heat-producing) reaction that drives fluid circulation and venting at the Lost City Vent Field on the Mid-Atlantic Ridge (Kelley et al.,

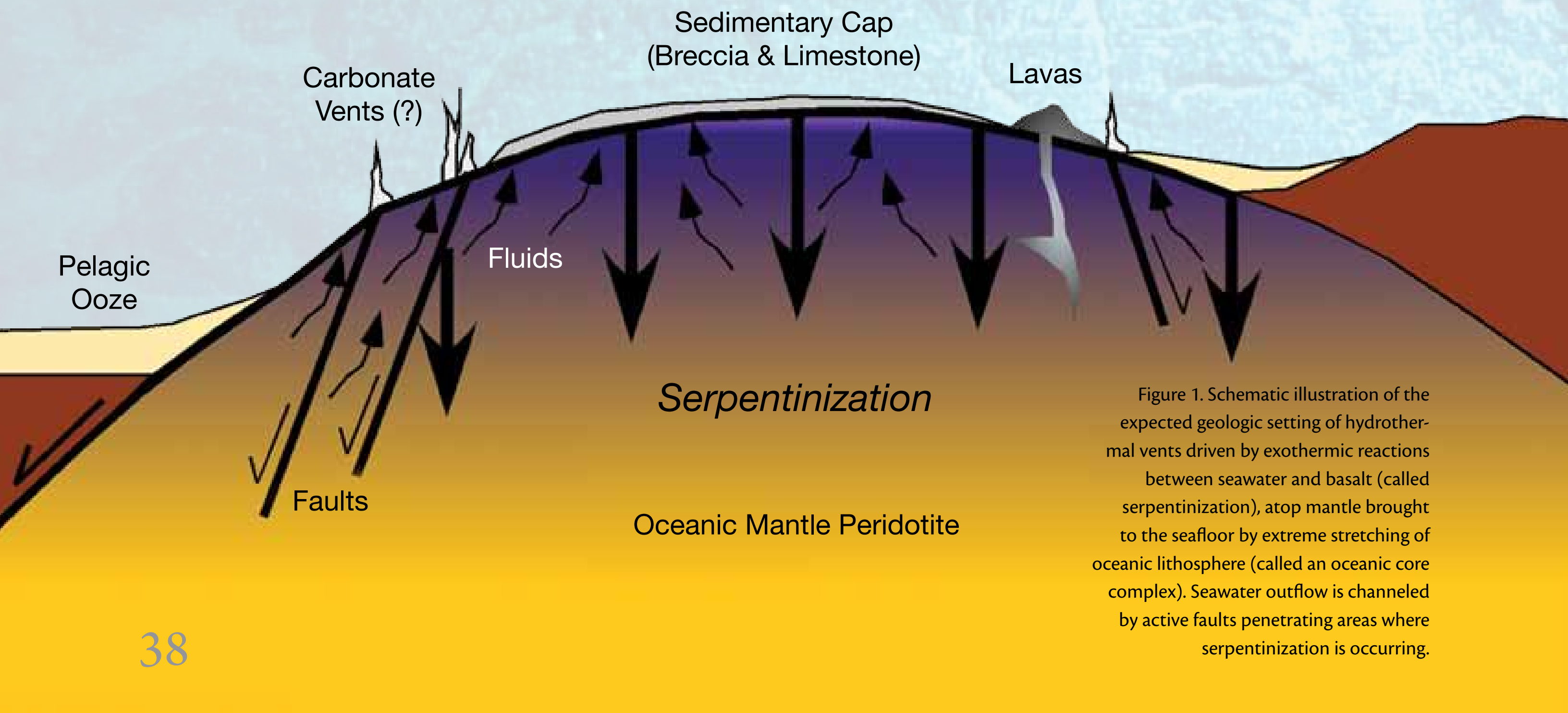


Figure 1. Schematic illustration of the expected geologic setting of hydrothermal vents driven by exothermic reactions between seawater and basalt (called serpentinization), atop mantle brought to the seafloor by extreme stretching of oceanic lithosphere (called an oceanic core complex). Seawater outflow is channeled by active faults penetrating areas where serpentinization is occurring.

Figure 2. ROV *Hercules* approaches a large outcrop of hydrothermally altered mantle rock (peridotite).

Figure 3. Sampling serpentinized peridotite (dark) and cross-cutting gabbroic veins (light).

Figure 4. A sample of gabbro, an intrusive rock, that has been altered by hydrothermal fluids.

2001, 2007). It is still the only known vent system of its kind on the seafloor. Unlike the well-known black smoker vents found along spreading centers such as the East Pacific Rise, Lost City is located 20 km off the spreading axis, on top of an oceanic core complex, with no volcanic activity. Could serpentinization-driven venting remain active even in very old mantle rock outcrops? Building upon the experience from Lost City, we targeted specific areas on Gettysburg Seamount to address that question (Figure 1). Although we found no evidence of active venting, we did find distinctive rock types, including serpentinites cut by veins of gabbro (an intrusive rock) altered by high-temperature water/rock reactions similar to those documented at Lost City (Figures 2–4). It is possible that any carbonate vent structures that once existed could have been eroded away when the seamount stood above sea level. Our initial exploration, focused on specific target areas, yielded interesting results that could set the stage for future work in this fascinating and enigmatic geologic setting.

Transects on Ormonde Seamount documented complex geology in previously unexplored areas. As anticipated from previous studies, we found highly fractured and altered lower crustal gabbroic rocks and overlying limestones, sedimentary breccias, and fresh-looking alkalic lavas.

Despite a mainly barren seafloor covered with smooth pelagic ooze, the lower slopes of both seamounts proved to be rich in exotic and, in some cases, previously unknown or poorly studied organisms, including sponges, corals, and fish. Direct observation and sampling targeted large organisms, but rock samples, and a particularly richly colonized slab of wood, also yielded a huge number of tiny sessile specimens as a bonus. Imagery and samples document a surprising degree of biological diversity in both mega- and macrofaunal assemblages. Microfauna were sampled from water and rock surfaces. On both seamounts, we observed several different species of gorgonian (soft) corals and collected samples for ongoing genetic connectivity work. Sponges were of special interest; we collected many specimens, including a possible new carnivorous species. Microscopic, elemental, and isotopic studies will continue in shore-based labs in the United States, Spain, and Portugal.

This cruise once again demonstrated the efficacy and future potential of *Nautilus*, *Hercules,* and *Argus* to explore and document seafloor features in deep waters of the Atlantic focusing on complex geological and biological frontiers.

Seafloor Pockmarks, Deepwater Corals, and Cold Seeps Along the Continental Margin of Israel

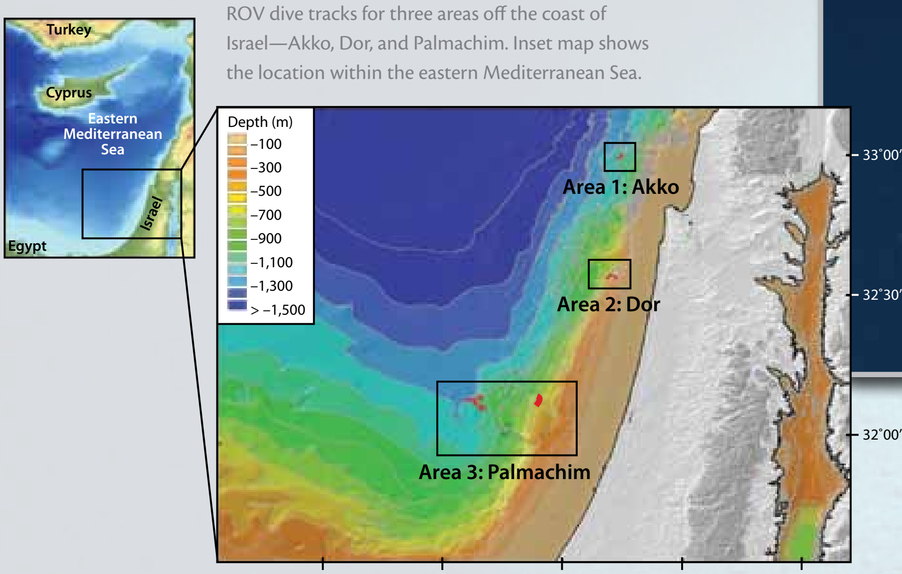
By Dwight F. Coleman, James A. Austin Jr., Zvi Ben-Avraham, Yizhaq Makovsky, and Daniel Tchernov

The E/V *Nautilus* 2011 field season culminated in a return to the Israeli continental margin to investigate regions of interest first explored during the 2010 *Nautilus* field season (Coleman et al., 2011). Two significant discoveries from the 2010 expedition were seafloor pockmarks at the base of a submarine canyon off Akko, northern Israel, and deepwater coral communities living on fossilized reef rock along the northern slump scar of the Palmachim Disturbance off southern Israel (Figure 1). We also investigated the toe of the Palmachim Disturbance in water depths of 1,000–1,100 m; there we discovered cold seeps consisting of carbonate mounds, seafloor encrustations, and disturbed sediment where we observed gas seepage (probably methane) and communities of tubeworms, mollusks, and other vent fauna. A multidisciplinary team explored these regions in detail using the *Hercules* and *Argus* ROV system to collect high-resolution video imagery, oceanographic data, and biological and geological samples.

Off Akko, at the base of a submarine canyon in water depths of 500–600 m, *Hercules* investigated large seafloor pockmarks, ranging in diameter from a few meters to several tens of meters, and up to several meters deep (Figure 2). We suspect these pockmark features are the result of gas and fluid escape, possibly associated with salt dissolution at depth that created negative pressure and zones of weakness in the subseafloor within which overlying sediments collapse. Pockmark walls were actively slumping. We discovered fossilized vent structures along the walls and sampled them. Live communities of tubeworms thrived on regions of dark, possibly methane-rich sediment. We sampled the sediment and biology of these areas using push corers. One short dive along the Dor Disturbance, off Haifa, Israel (Figure 1, Area 2), investigated several features mapped previously by Israeli scientists with multibeam sonar. During this dive, several sediment push cores were collected to help characterize the recent geological history of the disturbance related to sediment deposition at the base of a submarine canyon.

In a third region off southern Israel, along the edges of the Palmachim Disturbance, a large submarine landslide extending from the upper continental slope to the top of the continental rise, we explored two areas in water depths of approximately 1,100 m: the northern boundary, where there is a slump scar, and the toe of the Disturbance, where slide sediments are folded into gently undulating peaks and valleys. At the scar boundary, we further investigated

Figure 1. Map showing the survey locations and ROV dive tracks for three areas off the coast of Israel—Akko, Dor, and Palmachim. Inset map shows the location within the eastern Mediterranean Sea.



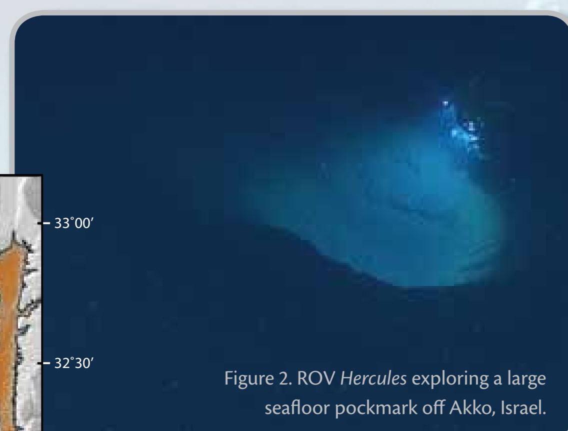


Figure 2. ROV *Hercules* exploring a large seafloor pockmark off Akko, Israel.

Figure 3. A deepwater black coral growing on an amphora (possibly from the Ottoman period) collected by *Hercules* near the northern scar of the Palmachim Disturbance off southern Israel.

a region of deepwater corals and other fauna living on fossilized carbonate reef deposits, which we discovered in 2010. The purpose of this dive was to delineate the extents of these reef features and coral communities, and to collect samples to understand the age and origin of the coral habitat. We discovered and sampled several large communities consisting of two types of coral (black coral variety *Antipatharia* and a cold-water bamboo coral variety *Isididae*), along with the material that makes up the substrate on which these corals grow. In several cases, coral was found growing on man-made objects—pottery shards, a large glass jar, and an ancient amphora (Figure 3). We collected these samples, as they constrain the age of the coral and can be correlated to nearby communities of similar age, size, and variety. We believe this interesting ecosystem is unique in this part of the Mediterranean, and by studying the biological character of the coral communities, we can understand more about their origins, distributions, and population dynamics.

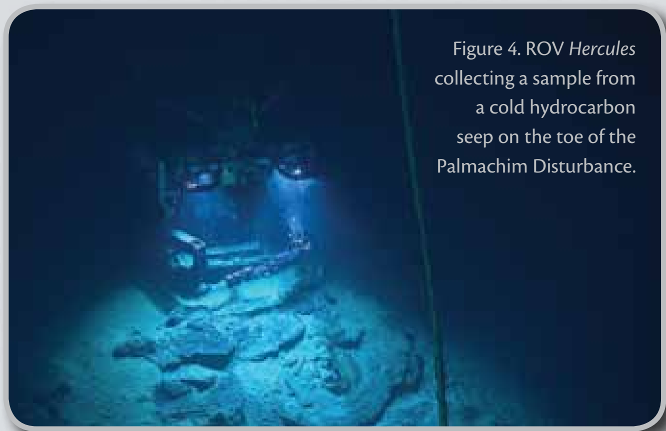


Figure 4. ROV *Hercules* collecting a sample from a cold hydrocarbon seep on the toe of the Palmachim Disturbance.

Finally, we conducted two ROV dives along the toe of the Palmachim Disturbance. Processed high-resolution seismic data from this area were used to create a base map of the bathymetry and structure of this geologic feature, which guided the dives. We noticed that the crests of some gentle fold features were breached, creating small pockmarks and gullies. In addition, we investigated small faults and scarps and we discovered an extensive area of cold seeps. Similar structures were documented by an expedition led by the Institute for Exploration in 1999 off Egypt and the Gaza Strip using the *Jason/Medea* ROV system (Coleman and Ballard, 2001). Large mounds and buildups of calcium carbonate, which characterize these seeps, precipitated out of solution as gas and fluid escape continued (Figure 4). Some buildups resemble sedimentary encrustations. We observed active gas venting along some perimeters of these buildup structures, which are filled with small holes presumably caused by large volumes of escaping gas/fluid at some previous time. Chemosymbiotic communities of polychaetes and mollusks live in proximity to these seeps (Figure 5). Samples of sediment, carbonate crust, and biological communities were collected. We propose that these features are prevalent along other areas on the Israeli continental margin, and may be indicative of gas/fluid-charged sediments emitting methane and other hydrocarbons, possibly associated with deeper reservoirs of natural gas, as have been recently discovered in deep water off the coast of Israel.

Figure 5. A small colony of tube worms and an urchin living around a cold hydrocarbon seep on the toe of the Palmachim Disturbance.

The Development of High-Resolution Seafloor Mapping Techniques

By Chris Roman, Gabrielle Inglis, J. Ian Vaughn, Clara Smart, Bertrand Douillard, and Stefan Williams

The 2011 field season continued the development of centimeter-level mapping techniques for marine geology, biology, and archaeology. The ROV *Hercules* is equipped with a suite of mapping instruments that enable detailed visual and acoustic seafloor surveys. The mapping sensors include a 1,375 kHz BlueView Technologies multibeam, verged color and black and white 12-bit 1360 × 1024 Prosilica stereo cameras, and a 100 mW 532 nm green laser sheet. The sensors are mounted near the rear of vehicle and arranged to image a common area. The vehicle navigation data comes from an RDI Doppler velocity log (DVL), IXSEA OCTANS fiber-optic gyroscope, and a Paroscientific depth sensor.

During the 2011 field season, one or more of the above sensors mapped 21 shipwrecks (see page 27, Figure 4). At many wrecks in the Black Sea, exceptionally turbid water prevented complete photographic surveys. However, the BlueView sonar worked in all cases and provided bathymetric data with multicentimeter-level resolution. We also continued the use of structured light laser imaging (Roman et al., 2010a) to obtain fine-scale, centimeter-level bathymetric maps of complete shipwrecks (Figure 1). This technique uses a camera to image a laser line projected on the seafloor. If the geometry between the laser and camera is known through calibration, a three-dimensional profile of the bottom can be measured to subcentimeter precision along the laser line. The laser system can produce bathymetry in turbid conditions where standard camera images become too contrast-limited for stereo vision techniques.

The laser system is set up by first calibrating the stereo cameras and then solving for the relationship between the image points on the laser line in the three-dimensional camera frame coordinate system. This year, we developed an in situ calibration procedure that can be used over

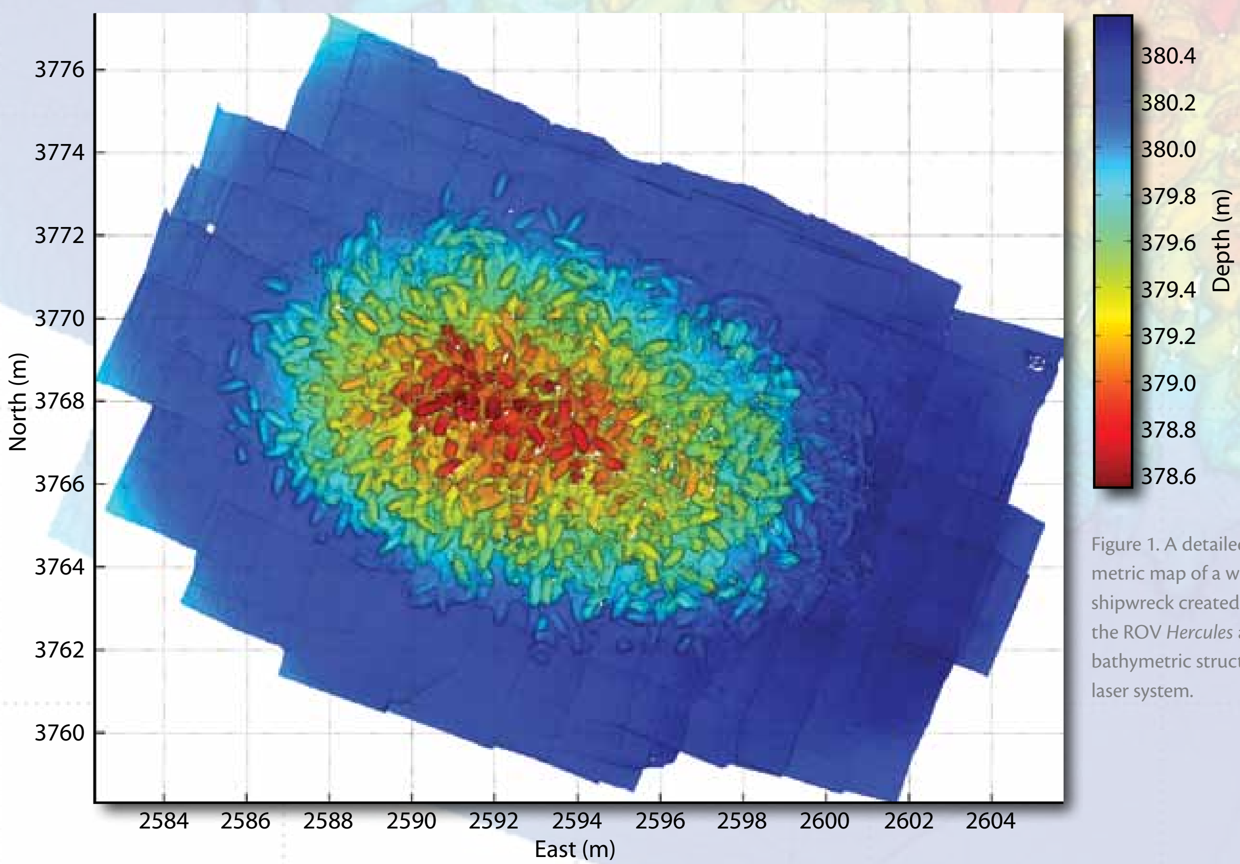


Figure 1. A detailed bathymetric map of a whole shipwreck created with the ROV *Hercules* and the bathymetric structured light laser system.

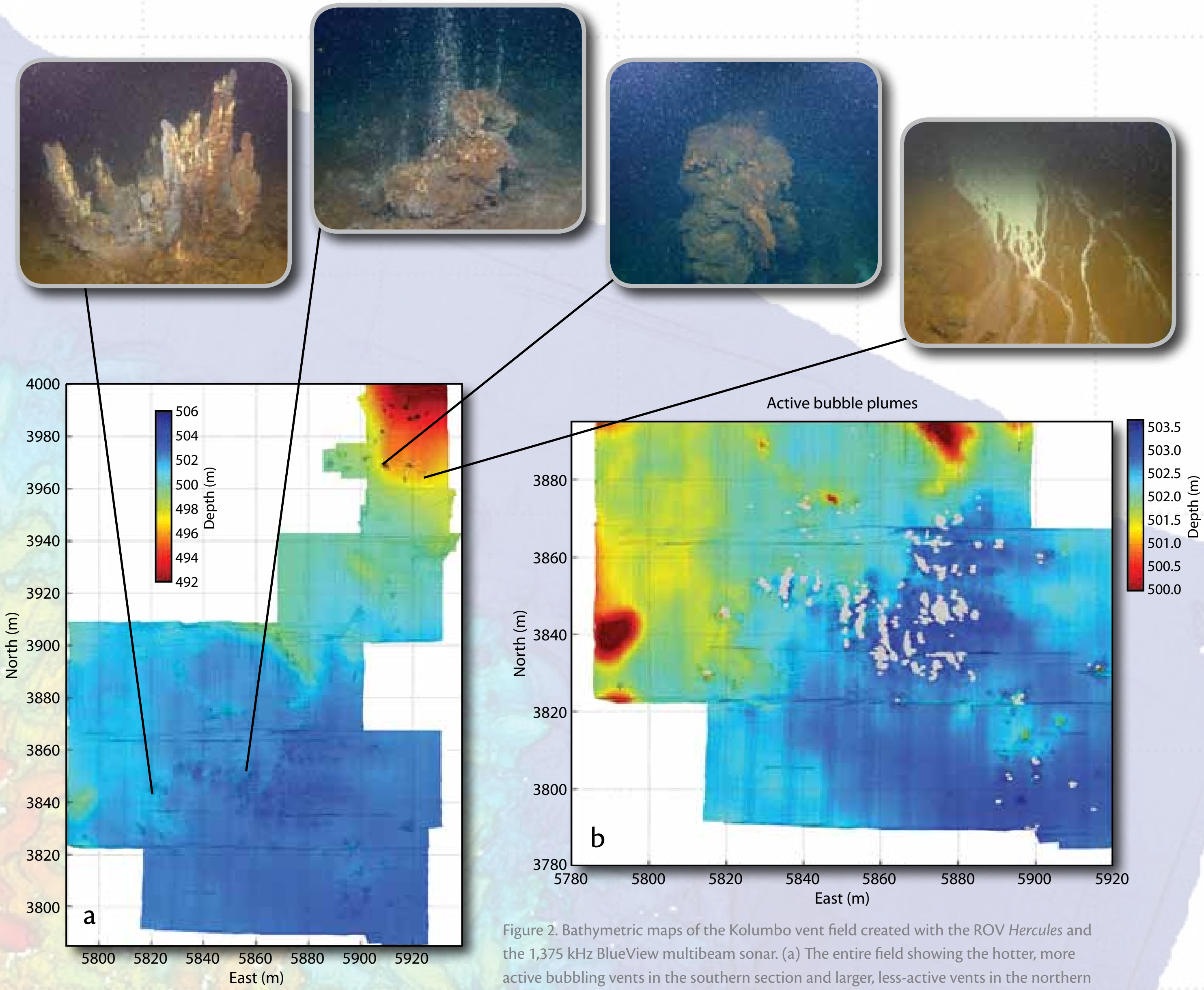


Figure 2. Bathymetric maps of the Kolumbo vent field created with the ROV *Hercules* and the 1,375 kHz BlueView multibeam sonar. (a) The entire field showing the hotter, more active bubbling vents in the southern section and larger, less-active vents in the northern section. (b) A close up of the southern section showing the distribution of active bubble plumes (gray patches) detected by the BlueView sonar (Figure 3).

natural terrain during operations. The approach uses paired feature points automatically extracted from stereo images of the laser line, and the stereo projection places these points in the three-dimensional camera frame. The drawback of this method is that it relies on the accuracy of the stereo calibration, which may be completed in a tank or using additional in situ methods.

To survey complete shipwrecks, we use a previously developed bathymetric simultaneous localization and mapping (SLAM) technique (Roman and Singh, 2007). This method relies on matching sections of the laser data across overlapping tracklines to help reduce the negative effects of position drift in the ROV's dead-reckoned navigation. Our goal is to produce such surveys of areas on the order of tens of meters per side, and at grid resolutions of 5 mm. The ability to make reliable across-track matches in an automated fashion over such complex scenes can be challenging and is a topic of ongoing research.

During exploration of the Hellenic Volcanic Arc, the BlueView sonar was used to create a large bathymetric map covering the known extent of the Kolumbo vent field. This survey was completed at an altitude of 9 m with a trackline spacing of 5 m. The narrow spacing ensured that a full volume at least 5 m above the seafloor was completely resolved. The data were then processed to both resolve the seafloor bathymetry (Figure 2a) and identify the active bubble plumes (Figure 2b). This survey altitude also reduced the navigation problems associated with corruption of the DVL velocity measurements by the bubble plumes.

To identify active plumes, the bubbles were segmented

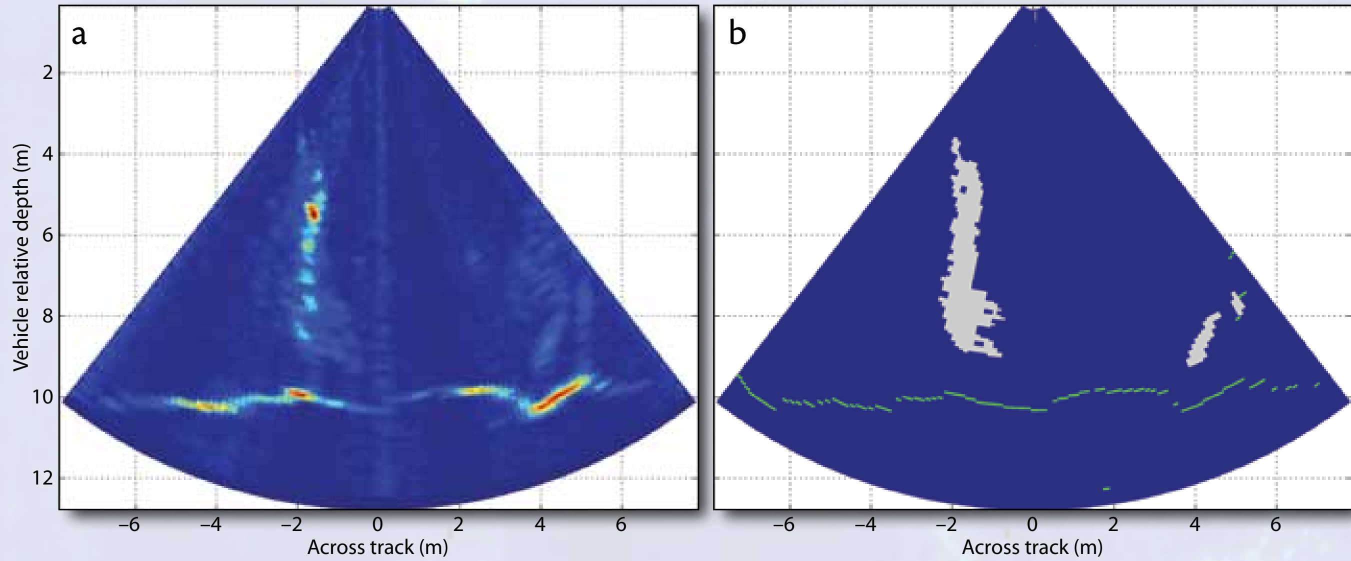
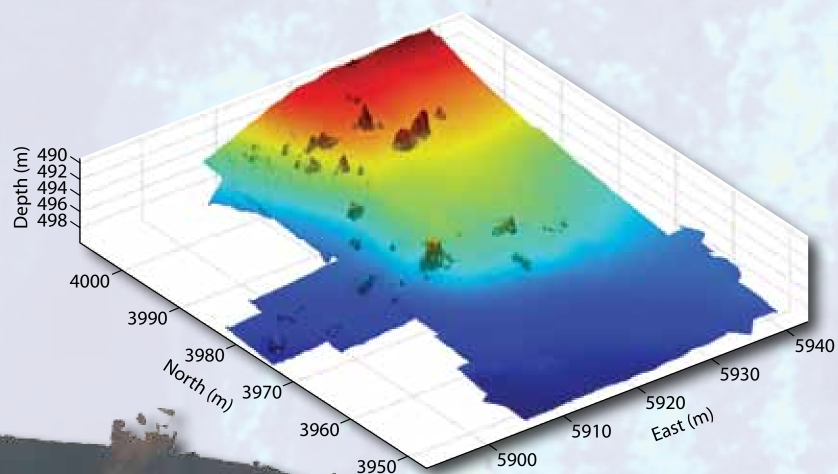
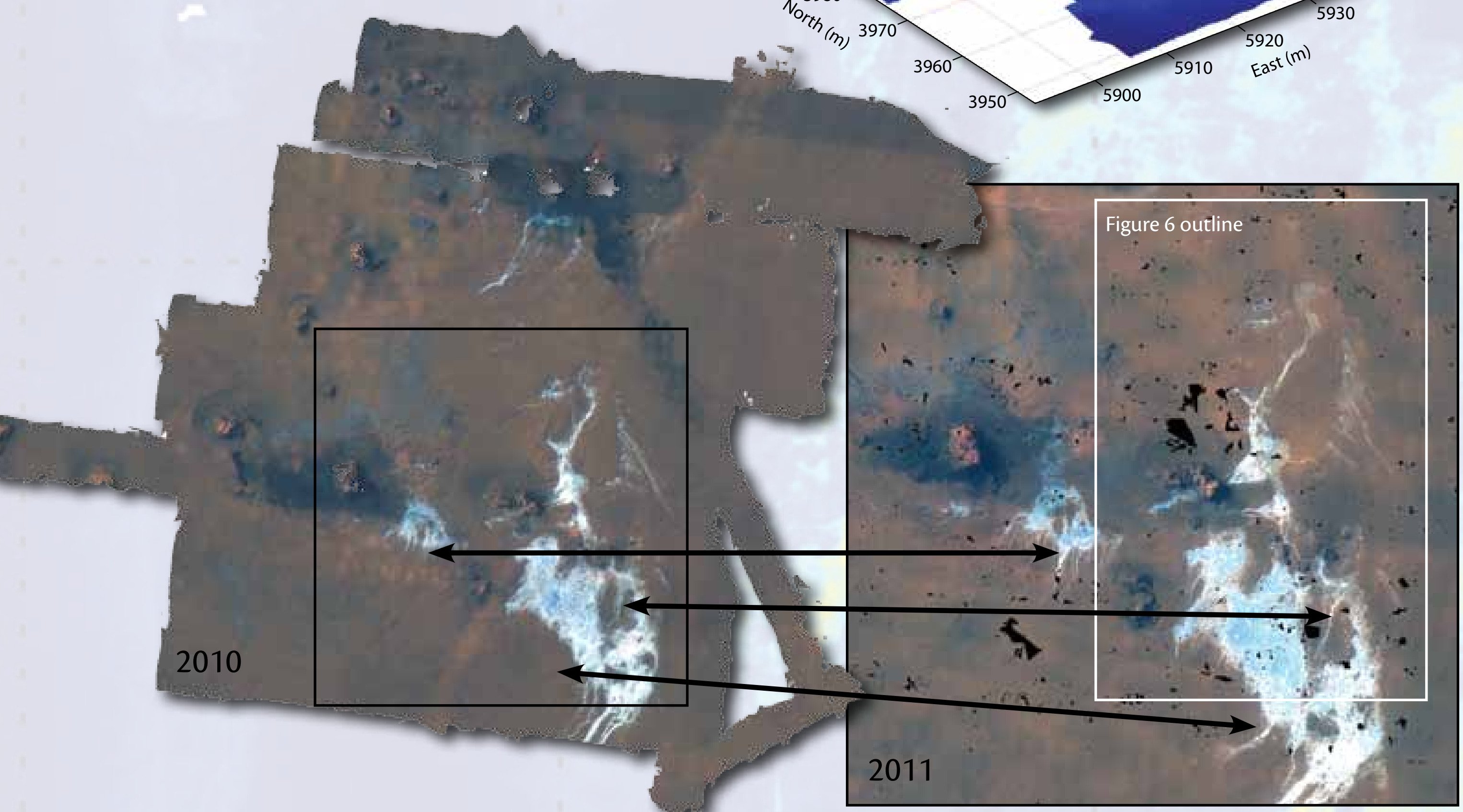


Figure 3. (a) A sample sonar image showing a large bubble plume rising approximately 6 m from the seafloor (left of center) and the edge of a smaller plume (right side). (b) The same ping processed to show the identified bottom (green) and bubbles isolated from water column (gray).

Figure 4. BELOW | Comparison between the 2010 (left) and 2011 (right) photomosaics of the northern vent field area. Differences in the bacterial mat coverage are highlighted. RIGHT | A high-resolution bathymetric map of the mosaic area created with the BlueView sonar during the 2.7 m altitude photomosaic surveys.





from the water column data (Figure 3a). The algorithm first looked for the bottom by searching back from the maximum range. Once detected, the bottom was then excluded from the sonar image so the bubbles could be identified by isolating the water column values above a multiple of the mean background signal level. The pixels identified as bubbles were then cleaned using several morphological filtering operations to consolidate the identified plumes and remove spurious points (Figure 3b). Passes over the most active areas of the field showed the largest bubble plumes extending approximately 12 m from the seafloor before being dissolved. The bubble plumes were found emanating from a subset of chimney features as well as some relatively flat areas of the seafloor (Figure 2a).

At the northern end of the vent field, a comparison between photomosaics completed in 2010 and 2011 shows a change in the bacterial mat covering the seafloor (Figure 4; Mahon et al., 2008; Johnson-Roberson et al., 2010). Some differences in the overall shape and several new streams of bacteria are evident. These surveys were completed at a 2.7 m altitude due to the persistent turbidity in the area (Figure 2).

A smaller bathymetric survey centered on the bacterial mat area was also completed using the green laser. This survey was used to map the fine-scale bathymetry of what seemed to be downhill flow channels and to locate areas of diffuse water venting over the bacterial mat. The presence of venting fluid can be detected by looking at the quality of the imaged laser line. The laser will refract as it passes through the warm water and appear blurred in the image (Figure 5). By batch processing the laser data and computing pixel intensity moments in the vertical image dimension about the center of the laser line, the amount of blur can be quantified and color-coded as a proxy for venting intensity (Figure 6). The basic spatial pattern of the bacterial map seen in the photomosaic (Figure 4) can also be seen here. Visual inspection confirmed varying amounts of shimmering water over the extent of the mat. Temperature probes taken with *Hercules* indicate vent temperatures between 30° and 60°C above ambient in the area.

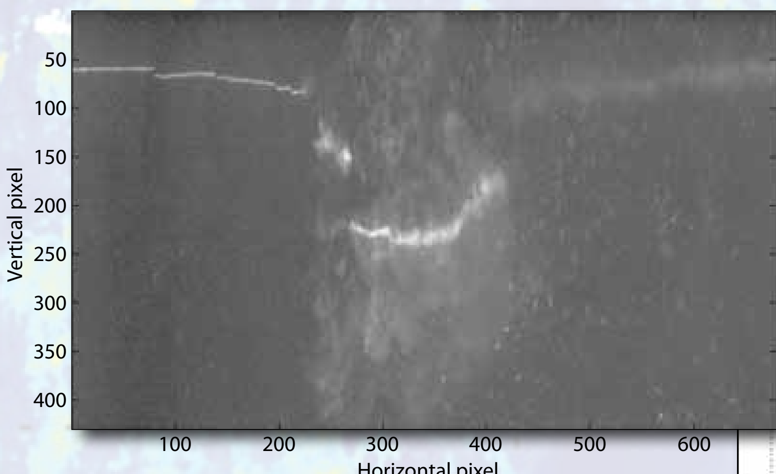


Figure 5. A 2 m wide sample image showing the laser line projected on the seafloor. The crisp line (left side) is undisturbed, while refraction due to hot water venting (center and right side) blurs the line.

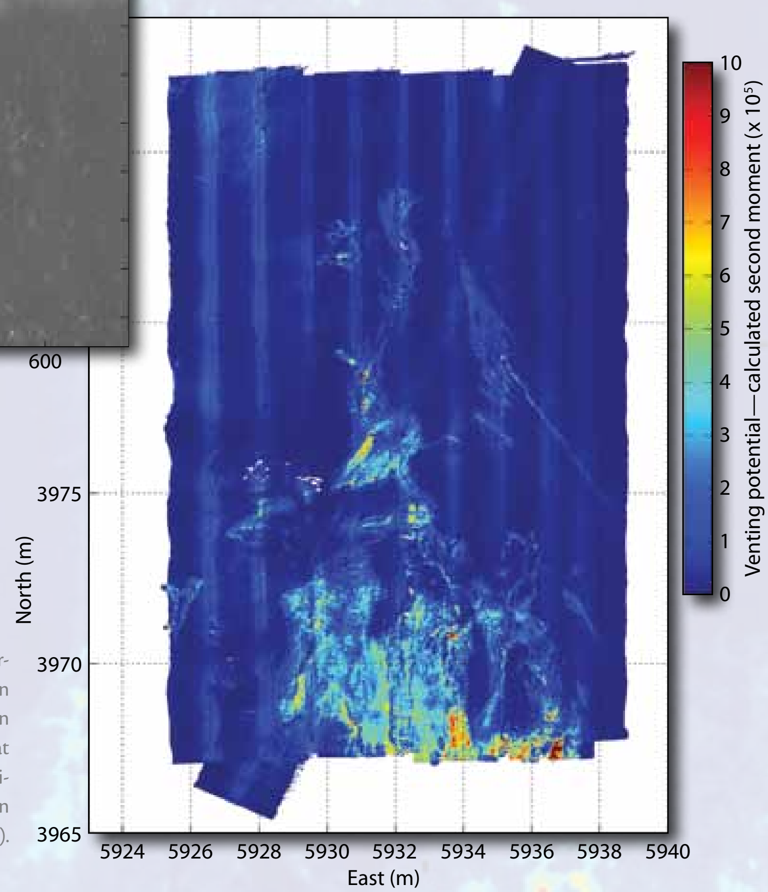


Figure 6. A seafloor map color-coded to show the distribution and intensity of active venting in the vicinity of the bacterial mat (Figure 4). The color scale indicates the degree of blurring seen in the laser line (Figure 5).

NOAA SHIP *OKEANOS EXPLORER* 2011 FIELD SEASON

By Craig W. Russell, Catalina Martinez, David McKinnie, CDR Robert Kamphaus, and CDR Joseph Pica

After several field seasons testing and assessing complex tools and systems, and training personnel for operations both at sea and on land, *Okeanos Explorer's* inaugural field season commenced in 2010 with a historic Indonesia-US exploration expedition in Indonesian waters. An international team (Figure 1) led by scientists from the United States and Indonesia explored the Sangihe Talaud Region in the North Sulawesi Sea. Scientists observed a remarkable abundance and biodiversity of marine life while working from two ships, the NOAA Ship *Okeanos Explorer* and the Indonesian research vessel *Baruna Jaya IV*, and at Exploration Command Centers on shore in Jakarta and Seattle. The expedition produced outstanding scientific results and was an important diplomatic success in advancing the two nations' science and technology partnership. During the return transit, we conducted a record-breaking trans-Pacific plankton tow from Guam to Hawaii to San Francisco, and we collected plastics through the Pacific "Garbage Patch," making efficient use of long transits.

In 2011, *Okeanos Explorer* conducted expeditions en route from San Francisco to its new home port in Davisville, Rhode Island, exploring targets in the Galápagos, Gulf of Mexico, and the Mid-Cayman Rise (Figure 2) region of the Caribbean. Community input solicited via workshops and discussions with partner agencies identified exploration targets. Multibeam mapping operations were conducted during all transits, along with surveys of opportunity where feasible, to make the most efficient use of each day at sea (see pages 56–57).

In May 2011, a workshop (Figure 3) was held to solicit community input and ideas for targets best explored through telepresence-enabled systematic exploration in the North Atlantic, Gulf of Mexico, Caribbean Sea, and South Atlantic. White papers were solicited in advance of the workshop, and approximately 50 participants joined NOAA and *Nautilus* program personnel to discuss ideas that fit the proposed model and available tools. Next steps include incorporating results into planning for 2012 and beyond, comparing objectives with budget realities and program priorities, and engaging the scientific community in planning and execution of missions. The full workshop report is available at http://explore.noaa.gov.

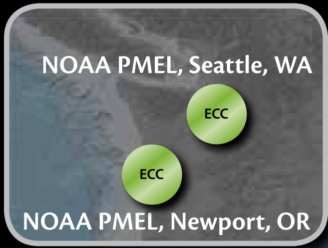
The *Okeanos Explorer* team is currently developing plans for the 2012 field season, incorporating the latest budget information, number of available days at sea, and target ideas from the May workshop, with additional organizational inputs. We look forward to sharing these plans as they unfold and hope you will join us in our explorations in 2012. Tune in at http://oceanexplorer.noaa.gov.

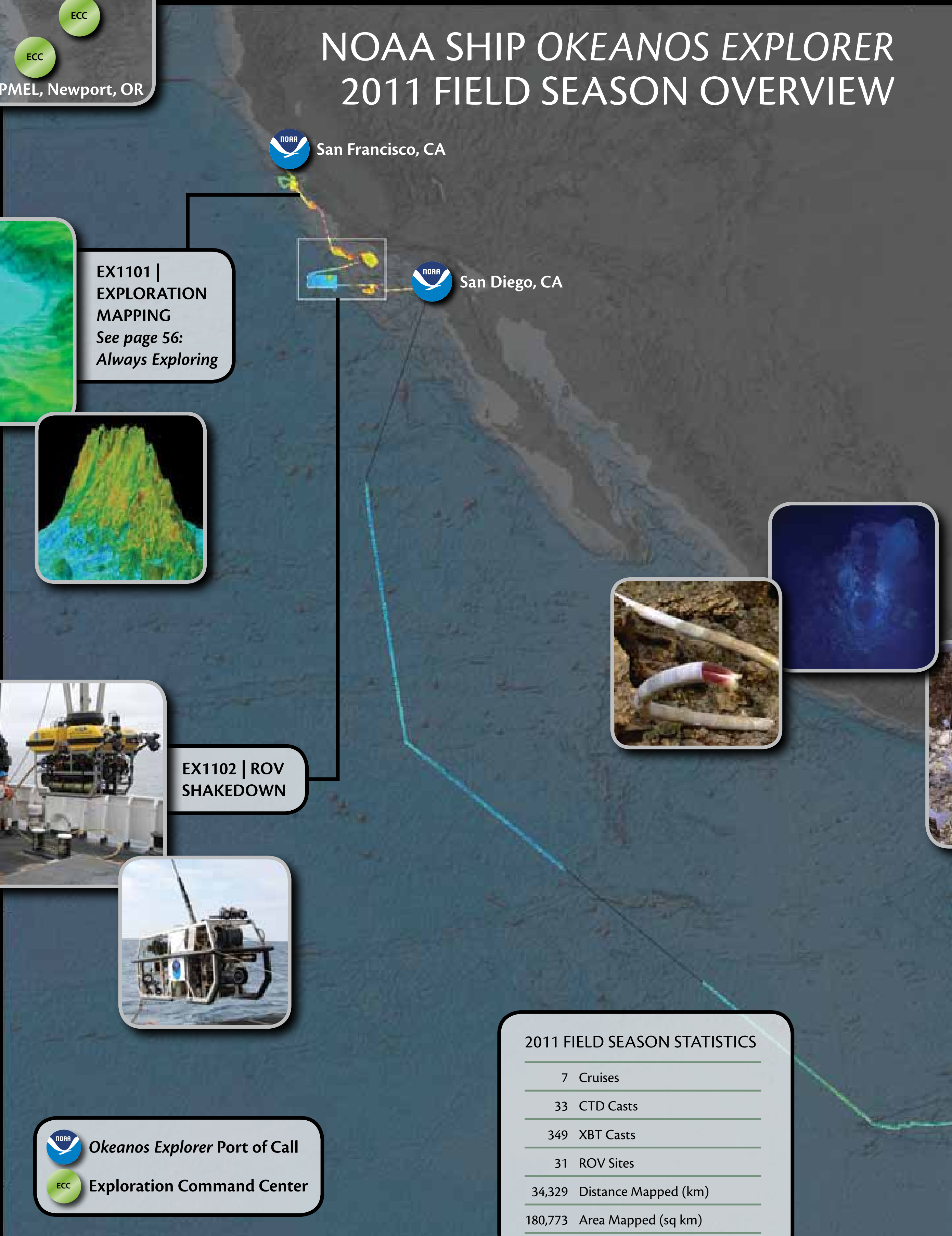
Figure 3. Andy Shepard leads a group discussion during a workshop held in May to glean input and ideas for future *Okeanos Explorer* and *Nautilus* exploration targets.

Figure 1. US and Indonesian expedition members pose in front of the NOAA Ship *Okeanos Explorer*, docked in Bitung, Indonesia, following completion of a 2010 joint expedition in Indonesia's waters.

Figure 2 (background). An active hydrothermal vent imaged during an August 2011 expedition to the Mid-Cayman Rise, Caribbean Sea. See pages 52–53 to learn more!

NOAA SHIP *OKEANOS EXPLORER* 2011 FIELD SEASON OVERVIEW





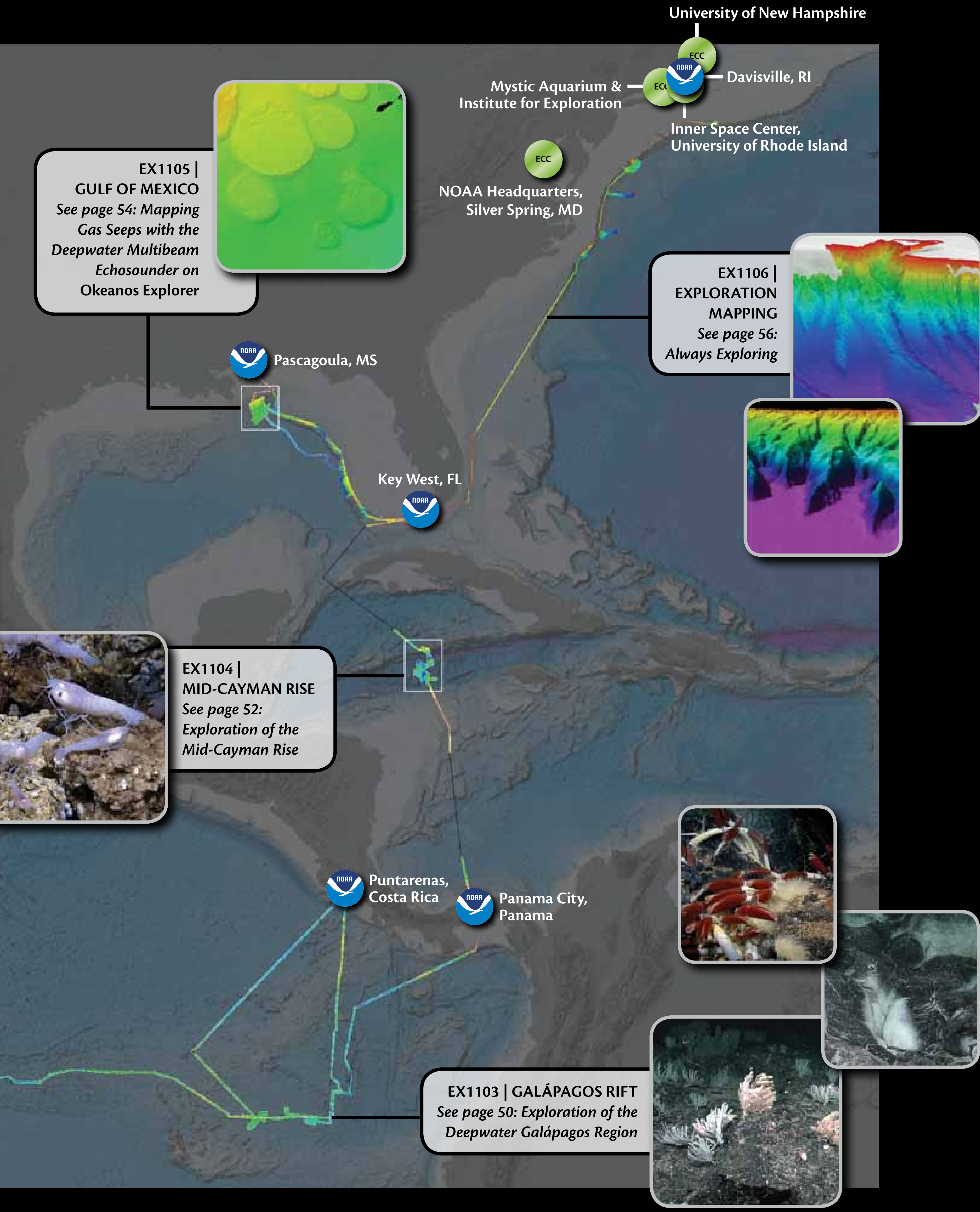
EX1101 | EXPLORATION MAPPING
See page 56: Always Exploring

EX1102 | ROV SHAKEDOWN

2011 FIELD SEASON STATISTICS

7	Cruises
33	CTD Casts
349	XBT Casts
31	ROV Sites
34,329	Distance Mapped (km)
180,773	Area Mapped (sq km)

Okeanos Explorer Port of Call
ECC Exploration Command Center


University of New Hampshire
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Inner Space Center,
University of Rhode Island
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NOAA Headquarters,
Silver Spring, MD
EX1105 |
GULF OF MEXICO
See page 54: Mapping
Gas Seeps with the
Deepwater Multibeam
Echosounder on
Okeanos Explorer
EX1106 |
EXPLORATION
MAPPING
See page 56:
Always Exploring
Pascagoula, MS
Key West, FL
EX1104 |
MID-CAYMAN RISE
See page 52:
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Deepwater Galápagos Region

Exploration of the Deepwater Galápagos Region

By Timothy M. Shank, Edward T. Baker, Robert W. Embley, Stephen Hammond, James F. Holden, Scott White, Sharon L. Walker, Miguel Calderón, Santiago Herrera, T. Jennifer Lin, Catriona Munro, Taylor Heyl, Lucy C. Stewart, Mashkoor Malik, Elizabeth Lobecker, and Jeremy Potter

In June and July 2011, *Okeanos Explorer* surveyed diverse habitats and geologic settings of the deep Galápagos region, including axial volcanic ridges, hydrothermal vents, off-axis sulfide mounds, and seamounts. During this expedition, the ship provided scientists, engineers, and the public an opportunity to explore unknown areas and revisit historical sites in the Galápagos Rift. The ship's multibeam sonar mapped more than 40,000 km^2 of seafloor, 11 CTD tows conducted along approximately 400 km of the unexplored eastern arm of the rift surveyed for hydrothermal plumes, and 12 ROV dives collected more than 90 hours of high-definition digital video. Broadband satellite transmitted data and ROV video feeds from the ship to a team of scientists on shore. The expedition team evaluated seafloor observations; directed seafloor ROV, CTD, and mapping operations in real time; and maintained a portal for outreach (http://oceanexplorer.noaa.gov).

The shipboard and shoreside expedition completed the first multibeam bathymetric map of the Galápagos Rift axis from 101.3°W to 98.0°W and conducted a continuous CTD and multibeam transect between 89.33°W and 85.75°W (Figure 1). Our survey revealed at least 20 distinct water-column anomalies along the eastern arm of the rift, corresponding to an overall spatial density of hydrothermal plumes about twice that of the central rift (Baker et al., 2008). Venting was concentrated in two distinct areas (Figure 1). One consisted of contiguous, intense plumes rising as high as 250 m above the seafloor. The other, hosting weaker plumes, was near the historical vent fields Rose Garden, discovered in 1979, and Rosebud, discovered in 2002 (Shank et al., 2003).

Five ROV dives near 88.3°W, the location of the largest hydrothermal plume signal (Figure 1), found recently erupted lava flows spread over at least 14 km, as well as several regions of vigorous diffuse venting. At two sites, white flocculent material—potentially microbial in origin—issued from the vents in a "snowblower" fashion. Two newly named vent fields, Uka Pacha and Pegasus, featured white microbial mats blanketing extensive areas along the base and sides of the axial graben

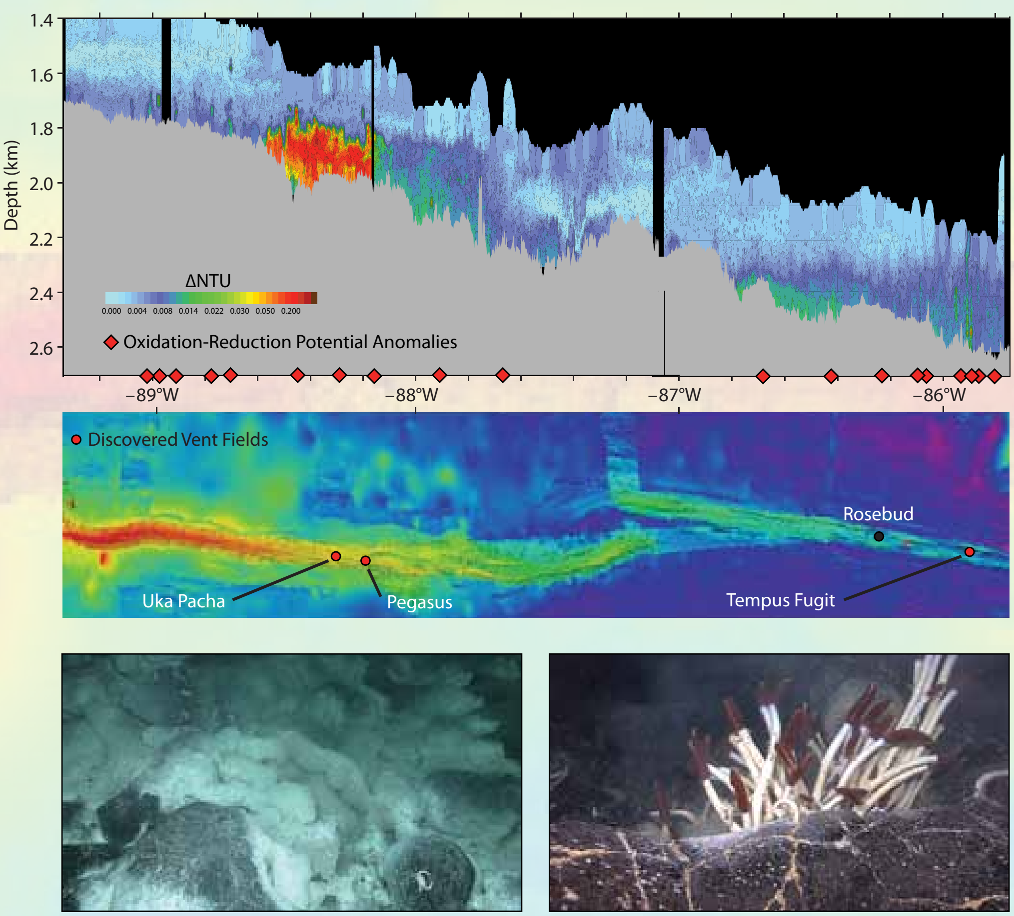


Figure 1. Hydrothermal plume survey (top) showing venting sites at 88.56°–88.09°W and 86.25°–85.87°W, bathymetric coverage (middle), and images of Uka Pacha (left) and Tempus Fugit (right) vent fields discovered during the expedition. In the top panel, ΔNTU corresponds to light backscattering by hydrothermal precipitates, and oxidation-reduction potential anomalies mark locations where reduced hydrothermal chemicals (e.g., H_2S, Fe^{+2}) were detected.

Figure 2. Extensive beds of Calyptogena clam shells hosting sparsely populated live clams (majority > 20 cm long) within and on the margins of the Tempus Fugit vent field.

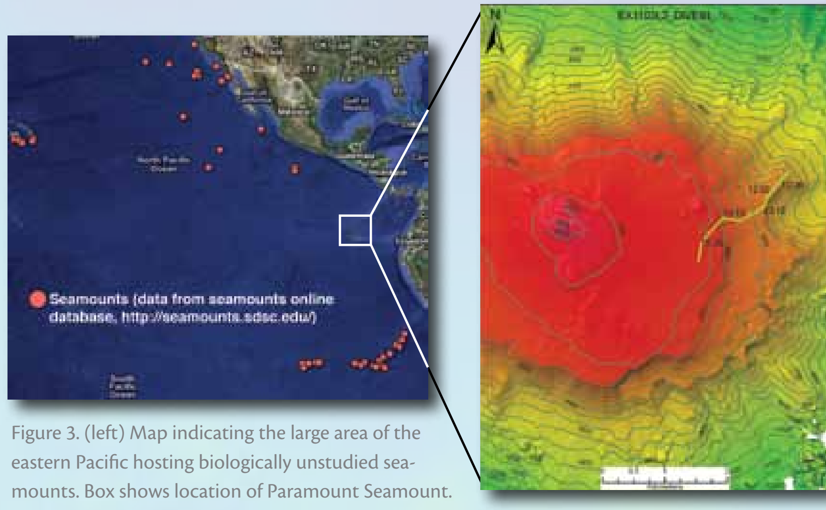


Figure 3. (left) Map indicating the large area of the eastern Pacific hosting biologically unstudied seamounts. Box shows location of Paramount Seamount. (right) Detail of Paramount Seamount bathymetry. Light green line indicates the track line of the ROV dive.

(Figure 1). Sessile fauna were not observed and mobile organisms were scarce, suggesting insufficient time since the creation of the vents for new colonists to arrive (Shank et al., 1998). Extinct hydrothermal sulfide chimneys over 30 m tall were discovered within 2 km of the active vents, indicating that the region previously experienced a substantial period of intense high-temperature venting.

Three ROV dives at plume sites near 86°W discovered one of the largest vent fields known on the rift (120 m × 40 m). The field, named Tempus Fugit, was characterized by diffuse venting in a once-massive clam bed thought to be more than 20 years old (Figure 2). In addition to mature live vesicomyid clams, siboglinid tubeworms, and mytilid mussels, the high abundance of juveniles suggests that this site has had multiple colonization events over time (Figure 1). Clusters of scavenging dandelion siphonophores demarcated the site's periphery. We observed active colonization on relatively older pillow and lobate lavas ringed by large beds of dead clams. There were at least 13 species of vent-endemic fauna at the site, including potentially three species of tubeworms. The lack of biota and presence of vitreous, unsedimented lobate lava flows observed at the Rosebud diffuse vent field (86.2°W) suggests that there may have been an eruption at this site after 2005 when this site was last visited.

Results of this cruise indicate abundant and recent hydrothermal and volcanic activity on two adjacent tectonic ridge segments, spanning more than 200 km of spreading axis. These findings not only reveal recent eruptive activity between 85°W and 89°W, they also indicate the rates of hydrothermal habitat turnover via eruption, dike intrusion, or cessation of venting may be considerably higher than previously thought along the Galápagos Rift.

In addition to exploring the rift, the expedition visited a previously unmapped and biologically unknown seamount region (Figure 3). We discovered that Paramount Seamount hosts: (1) abundant and diverse deepwater coral communities (including many potential new species), (2) a strongly pronounced break in faunal composition with depth (Figure 4), and (3) distinct faunal communities likely influenced by the seamount's summit having been subject to wave erosion when sea level was lower, and by the presence of drowned reefs after sea level rose.

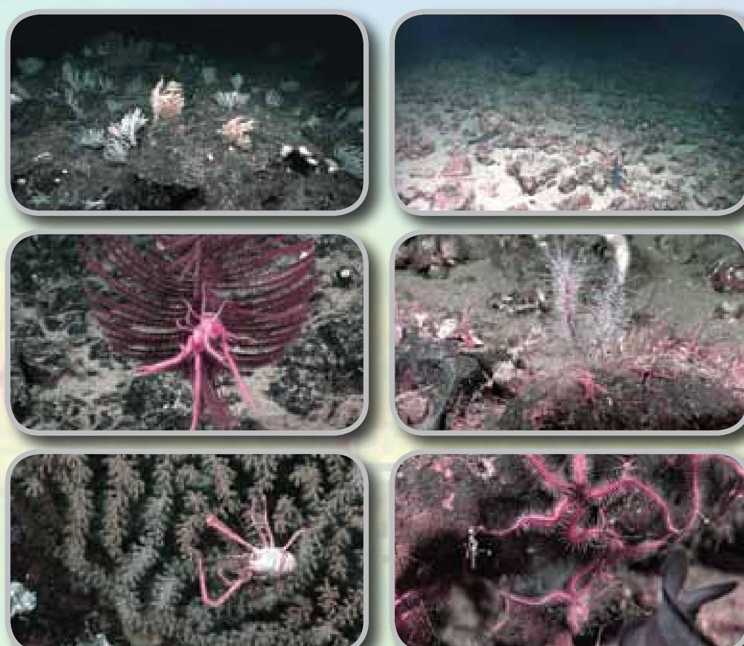


Figure 4. (left column) The deep slope of the seamount harbors a high abundance of primnoid and paramuricid gorgonians and antipatharians, and their galatheid crab associates. (right column) The shallow zone harbors a high diversity of different species of small primnoid gorgonians, bubblegum corals, and antipatharians. High abundances of ophiuroid brittle stars occupy the surface of red minerals, which presumably are the remnants of an ancient shallow-water coral reef.

Exploration of the Mid-Cayman Rise

By Christopher R. German, Paul A. Tyler, Cameron McIntyre, Diva Amon, Michael Cheadle, Jameson Clarke, Barbara John, Jill McDermott, Sarah Bennett, Julie Huber, James Kinsey, Jeff Seewald, Cindy Van Dover, and Kelley Elliott

Discovery of deep-sea hydrothermal vents and associated biological communities on the Galápagos Rift in 1977 was one of the major scientific breakthroughs of the past century, informing our understanding of key issues in the Earth, ocean, and life sciences. More than 100 different vent sites have been found in different ocean basins worldwide since then, and everywhere scientists have looked, new species have been collected. Most recently, scientists were surprised to find that water-rock interactions during hydrothermal circulation at the least volcanically active mid-ocean ridges could give rise to the synthesis of organic compounds in vent fluids that may reveal insight into the origins of life—on Earth and beyond. The August 2011 expedition to the Mid-Cayman Rise, one of Earth's deepest and slowest spreading ridges, followed recent data suggesting there are multiple vent sites present in shallow and deep settings along this ridge axis (German et al., 2010; Connelly et al., 2012).

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 oceanic core complexes (OCCs; John and Cheadle, 2010). We 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, we collected detailed ROV seafloor observations (Figure 1), including novel vent sites and the ecosystems they host.

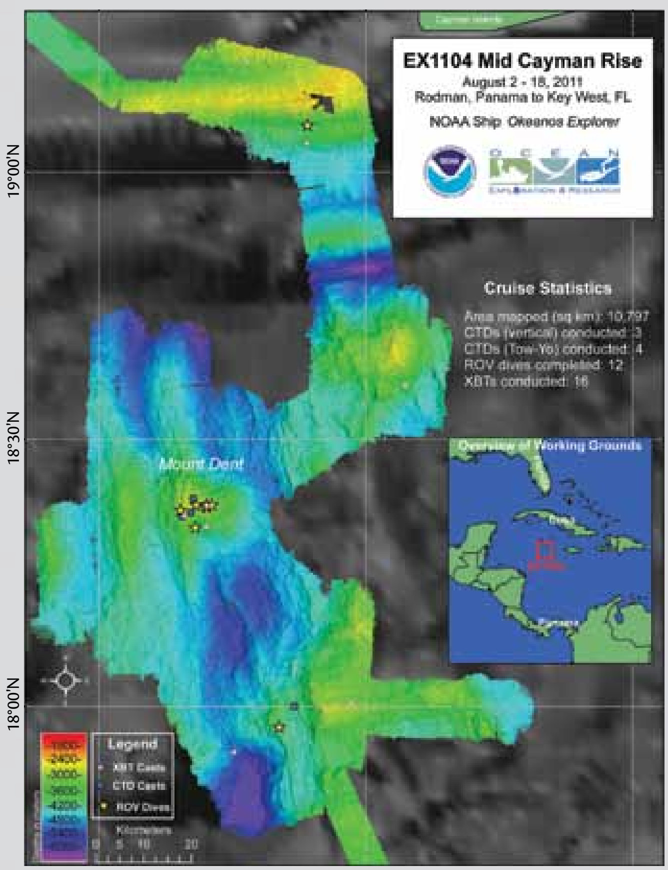


Figure 1. Overview map from the 2011 expedition showing the locations of mapping surveys conducted, ROV dives, and CTD rosette operations.

Enabled by satellite and high-bandwidth Internet2 telepresence technology, data and ROV video feeds were transmitted to shore in real time, supporting the participation of an international team of scientists primarily at the University of Rhode Island, but also Woods Hole Oceanographic Institution and NASA's Jet Propulsion Laboratory. Scientists around the world 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.

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 our UK colleagues, we were able to locate the central spire of the Von Damm hydrothermal field at the start of our first dive and were astonished to find a chimney orifice that was approximately 1 m wide (Figure 2), along with shrimp 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.

During the second dive, we documented the first live

Figure 2 (left). ROV *Little Hercules* examining the ~ 1 m diameter vent-orifice at the summit of the Von Damm central spire.

Figure 3 (above). Image of the first live tubeworm photographed at a vent site in Atlantic waters.

Figure 4. Location where active fluid flow, microbial mats, vent shrimp, gastropods, and tubeworms were all observed together at a single site.

tubeworm at an Atlantic hydrothermal field (Figure 3). Our shore-based colleagues confirmed that while these tubeworms were distinct from those seen at hydrothermal vents on the Galápagos 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. Continuing our exploration of the Von Damm site we found 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 (Figure 4).

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 our investigation, we used ROV cameras to explore the south wall of Mount Dent, located beneath the vent site. Our mission also included an extensive nighttime multibeam program, enabling us to map the bathymetry of three OCCs rising from the rift valley floor.

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 5) confirmed that lava emission rates, even on an ultraslow-spreading ridge, can be impressive.

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 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 we know, this was the first deep-submergence investigation of this particular feature.

This exploratory expedition was extremely productive and successful. We 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 our CTD and mapping programs, we investigated the fate of fluid discharge from the site, tested for the location of other sites, and investigated geologic 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.

Figure 5. Ropey "pahoehoe" lava textures from more than 3,000 m deep at the Mid-Cayman Rise (above) are identical to those associated with fresh flows at Chain of Craters Road, Hawaii Volcanoes National Park (right).

Mapping Gas Seeps with the Deepwater Multibeam Echosounder on *Okeanos Explorer*

By Thomas C. Weber, Larry Mayer, Jonathan Beaudoin, Kevin Jerram, Mashkoor Malik, Bill Shedd, and Glen Rice

The Gulf of Mexico has long been known to contain large reservoirs of oil and gas. Some of these hydrocarbons make their way up through faults to the seabed surface (Roberts and Carney, 1997), providing an energy source for chemosynthetic communities (Fisher et al., 2007). Methane bubbles at these sites are sometimes released into the seawater where they dissolve or, occasionally, rise to the sea surface and into the atmosphere (MacDonald et al., 2002). Detecting the presence of gas seeps and mapping their locations are critical steps toward refining our understanding of the complex geological and biological processes occurring in the deep Gulf of Mexico, as well as our understanding of background conditions in light of events such as the Deepwater Horizon spill.

Gas bubbles in seawater are acoustically strong targets because they respond like simple harmonic oscillators with a strong resonance when excited by acoustic waves. We exploited this behavior to map gas seeps in the northern Gulf of Mexico using a multibeam echosounder during a cruise aboard the NOAA Ship *Okeanos Explorer* in the late summer of 2011. Multibeam echosounders insonify a large swath (typically an across-track fan that is four to six times the water depth) of the ocean on each ping (Figure 1), making large-scale mapping of a region a realistic possibility. These echosounders are traditionally designed with a focus on mapping the seafloor, and several manufacturers now routinely provide a capability for collecting acoustic backscatter data that can also be used for "midwater" mapping. Gas seeps have been mapped previously with multibeam echosounders (e.g., Nikolovska et al., 2008; Gardner et al., 2009), but we did not know how well the 30 kHz system (a Kongsberg EM302) on *Okeanos Explorer* would perform for our work in the Gulf of Mexico (Figure 2).

Initial results from the multibeam echosounder are quite promising. We observed hundreds of seeps—some repeatedly—in our survey area. We identified seeps mainly from their "continuous" returns, which were quite narrow in comparison to their vertical extent (e.g., Figure 1). Typically, the acoustic backscatter anomalies that we associated with these seeps were not observed shallower than 500 m, a depth that coincides with the methane hydrate stability zone (Milkov and Sassen, 2000). Given the depth and temperature of the deep Gulf of Mexico, it is likely that methane bubbles rising from the seafloor form methane hydrates, inhibiting gas transfer into the methane-undersaturated ocean during bubble ascent.

Working in 1,200–2,500 m water depth, we were able to most reliably detect seeps over a swath width that was approximately twice the water depth; outside of this detection window, reverberation from the seafloor tended to mask most of the seeps. Given this seep detection capability

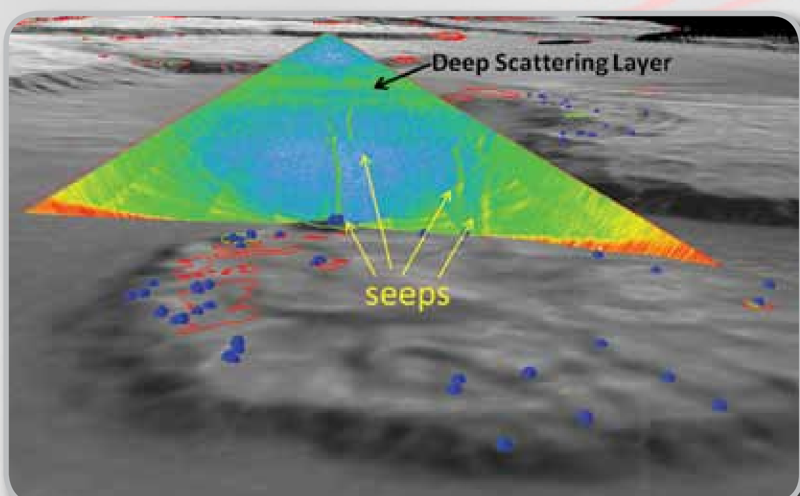


Figure 1. Backscatter data in the shape of a fan collected from a single ping of the 30 kHz multibeam echosounder, along with gas seep targets extracted from hundreds of pings during a survey over Dauphin Dome in the northern Gulf of Mexico.

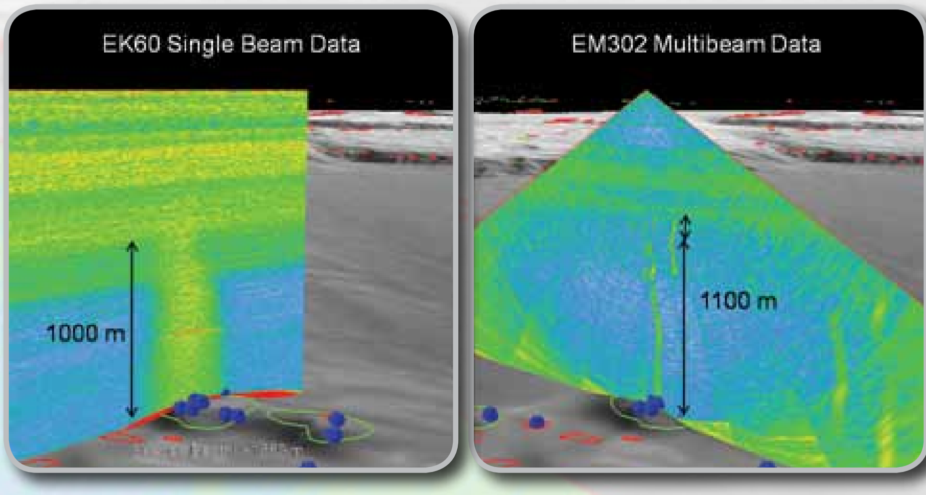


Figure 2. A contrast in backscatter: a seep simultaneously mapped with the both an 18 kHz single-beam echo sounder (left) and the 30 kHz multibeam echosounder (right). The echogram shown for the single-beam echosounder is constructed from hundreds of pings as the ship travels over the seeps. The data from the multibeam echosounder are from a single ping.

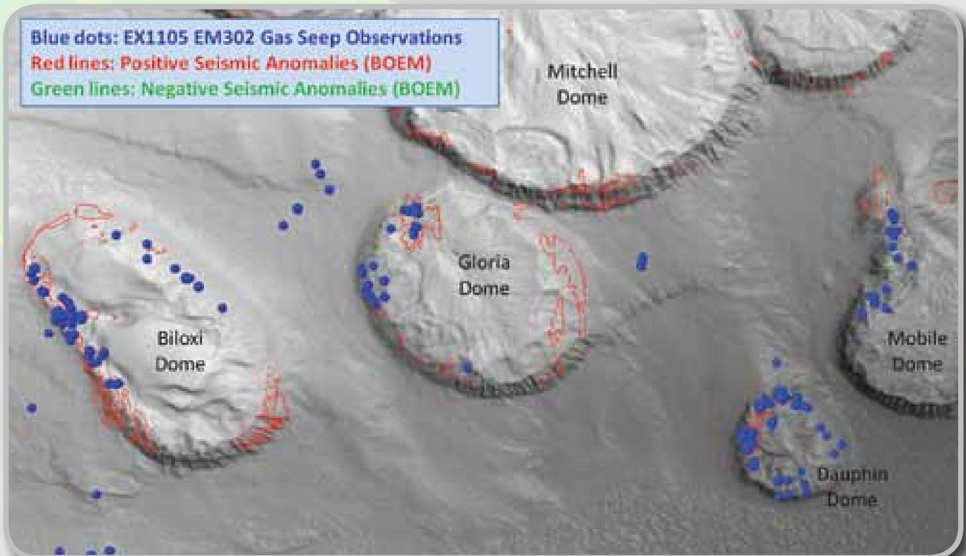


Figure 3. Seeps (blue dots) mapped with the multibeam echosounder overlaid on bathymetry (gray scale) along with seismic anomalies provided by the Bureau of Ocean Energy Management.

and assuming a water depth of 1,500 m and a speed of 10 kts, it is possible to survey more than 50 km^2 of seafloor each hour for potential seep locations.

Most of the seep-like structures we observed acoustically with the multibeam echosounder were on the edges of salt domes, which are common in the Gulf of Mexico's oil and gas province. Often, the seep observations were within suspected "hardground" anomalies mapped using three-dimensional seismic data (http://www.boemre.gov/offshore/mapping/SeismicWaterBottomAnomalies.htm). These positive anomalies possibly indicate past carbonate or hydrate structures, whereas negative seismic anomalies possibly indicate young, high-flux gas seeps or hydrate formations at or just below the seabed interface. However, as Figure 3 shows, we also observed seeps on the edges of salt domes where there were no seismic anomalies (e.g., the eastern edge of Dauphin Dome) and sometimes did not observe seeps where positive seismic anomalies existed (e.g., the eastern side of Gloria Dome). Together, the seismic anomaly maps and the multibeam echosounder water-column detection of seeps offer clues regarding which areas were historically active but are now inactive, which areas have been active long enough to form carbonate hardgrounds, and which areas may be locations of newer events that have not yet formed carbonate structures substantial enough to be detected as seismic anomalies.

“Always Exploring”

By Elizabeth Lobecker, Craig W. Russell, and Kelley Elliott

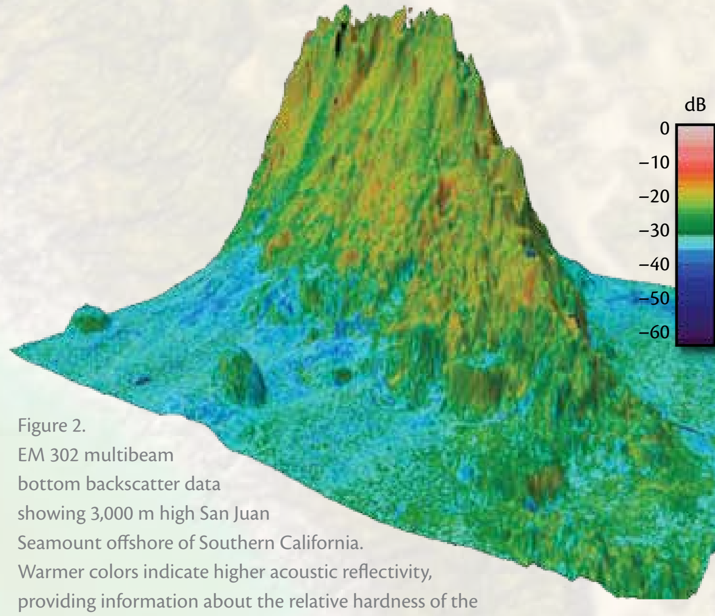


Figure 2. EM 302 multibeam bottom backscatter data showing 3,000 m high San Juan Seamount offshore of Southern California. Warmer colors indicate higher acoustic reflectivity, providing information about the relative hardness of the seafloor, with implications for erosion and habitat.

NOAA's *Okeanos Explorer,* “America's ship for ocean exploration,” systematically explores the ocean every day of every cruise to maximize public benefit from the ship's unique capabilities. “Always Exploring” is a guiding principle. With 95% of the ocean unexplored, we pursue every opportunity to map, sample, explore, and survey at planned destinations as well as during transits. Throughout the ship's geographically diverse 2010 and 2011 field seasons, multiple opportunities arose to transform standard operational transit cruises into interdisciplinary explorations by acquiring high-quality, innovative scientific data around the clock, and rapidly disseminating those data to the public.

Planning Efficient Cruise Tracks and Complementary Operations

During cruise planning, transits are optimized to allow mapping of unexplored or unmapped regions. We review input received from ocean science and management communities to identify unexplored regions for possible inclusion. We also consult those scientists and managers to verify that potential targets remain a high priority and were not recently explored.

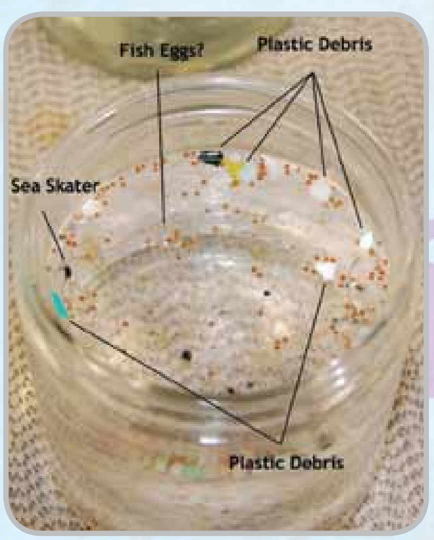


Figure 1. A sample of marine life and plastics collected during the transit cruise from Hawaii to California. Most debris concentrated in the “Garbage Patch” is composed of small bits of plastic not immediately visible to the naked eye.

The *Okeanos Explorer* Program also supports surveys of opportunity to add layers of scientific value to cruises. We conduct nonmapping surveys of opportunity and include well-defined exploratory operations that help transform standard ship shakedown and transit mapping cruises into multilayered voyages of discovery. Surveys selected are those that reflect the exploration mission or provide an opportunity to test additional capabilities that could be incorporated into systematic exploration operations.

Technology

An integral element of *Okeanos Explorer's* “Always Exploring” model is the ship's seafloor and water column mapping capability. The principal mapping sensor, the EM 302 multibeam sonar, is staffed on all transit cruises for 24-hour seabed and water column data collection and processing. As appropriate on a cruise-by-cruise basis, the ship's Kongsberg EK 60 fisheries sonar and Knudsen 3260 subbottom profiler provide additional data sets. The low resolution of bathymetric data derived from satellite altimetry allows recognition of very large features and the general character of the seafloor. At full ocean depths, the ship's multibeam bathymetric data are at least 40 times finer resolution than satellite data. This capability allows imaging of previously unknown features and visualizing a truer picture of the seafloor and water column. Since commissioning,

BACKGROUND IMAGE | *Okeanos Explorer* West Coast 2011 field season EM 302 multibeam data.

BACKGROUND IMAGE | *Okeanos Explorer* Gulf of Mexico and US East Coast 2011 field season EM 302 multibeam data.

the *Okeanos Explorer* team has collected more than 88,000 linear kilometers of bathymetry stretching from Indonesia's Sulawesi Sea to the North Atlantic, mapped a number of seamounts not found in existing bathymetry or charts, successfully tested its mapping system to 7,954 m depth over the Mariana Trench, and demonstrated the multibeam sonar's ability to detect gaseous and physical features in wide areas of the water column. Notably, this ability resulted in the discovery of 1,400 m high plumes, confirmed to be methane gas, off the coast of northern California. Gas hydrate scientists at Monterey Bay Aquarium Research Institute conducted discovery follow-up work in the summer of 2011, and the initial results analyzing the vent source geomorphology were presented at the 2011 fall meeting of the American Geophysical Union (Gwiazda et al., 2011).

"Always Exploring" During the 2010 and 2011 Field Seasons

During the 2010 field season, the *Okeanos Explorer* Program partnered with NOAA's National Marine Fisheries Service to conduct two surveys of opportunity during *Okeanos Explorer's* return transits from Indonesia. A Continuous Plankton Recorder collected plankton from Guam to Hawaii, and on to San Francisco, across these historically undersampled regions. Surface water samples collected in Manta nets during the transit from Hawaii to San Francisco were analyzed for plastics (Figure 1) to gain a greater understanding of the extent of the Pacific "Garbage Patch." Plankton sample data will help scientists better understand the nature of the plankton community in these regions (http://go.usa.gov/Q4F). Combined with the plastics data, insights may be gained into the effect of plastics on the marine food web (http://go.usa.gov/QRI).

During the 2011 field season, the *Okeanos Explorer* Program added additional days to operational transits to define unexplored features and map areas identified as high-priority exploration targets and areas of interest by the science and management community. Examples include transits along the Florida Escarpment, near a subset of the thousands of unmapped seamounts in the Pacific Ocean (Figure 2), along the deep canyons at the continental shelf break off the US East Coast (Figure 3, left), along significant portions of several National Marine Sanctuaries, including the Channel Islands and Monterey Bay, and along America's coasts where historically important shipwrecks rest (Figure 3, right). Results of these cruises are expected to be incorporated into future explorations by *Okeanos Explorer*, the Bureau of Ocean Energy Management, and the NOAA Office of National Marine Sanctuaries.

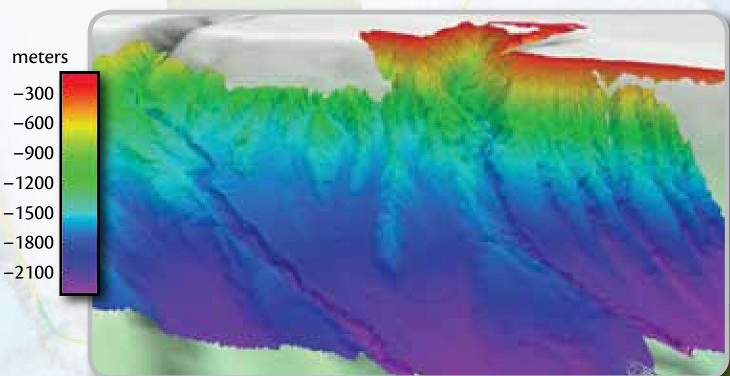
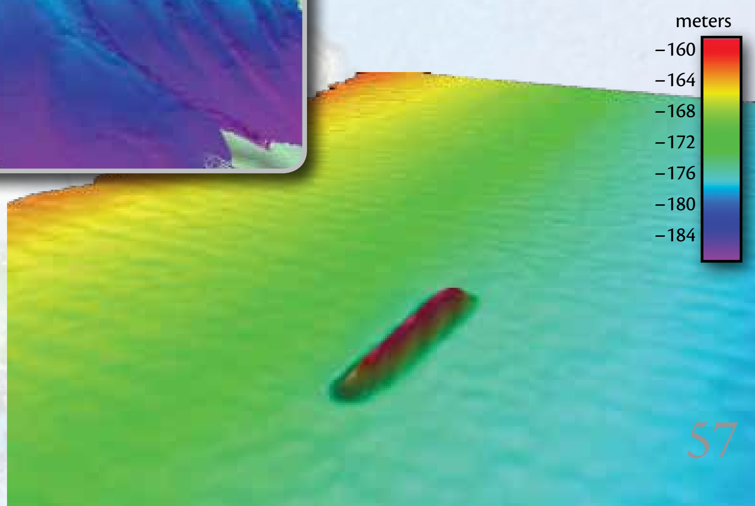


Figure 3. (above) Screen shot looking west over Baltimore and South Wilmington Canyons on the US Continental Shelf Break. (right) Screenshot of an unidentified shipwreck mapped off the Atlantic coast of Florida.



Exploring New Frontiers in Information Management

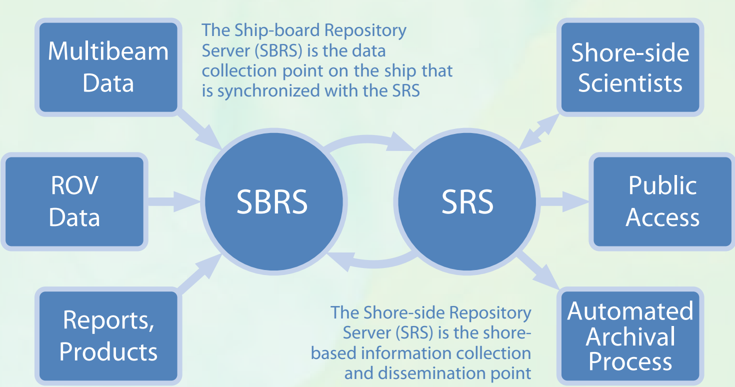
By Sharon Mesick, Elizabeth Lobecker, Webb Pinner, Susan Gottfried, and Brendan Reser

NOAA's exploration flagship, *Okeanos Explorer,* is equipped to incorporate information management objectives into multidisciplinary data collection and processing operations in real time. A constant stream of data and information shared between shipboard and shore-based participants via satellites and high-bandwidth Internet2 (called telepresence technology) enables a geographically distributed expedition team to jointly and dynamically manage ongoing exploration activities. This information management strategy couples the ship's unique telepresence-enabled capabilities with shore-side partner resources and efficient work-flow management to produce three primary benefits: (1) success of the scientific mission is enhanced by sharing data with shore-side partners in near-real time; (2) educators and the public can rely on timely access to information in support of education and outreach initiatives; and (3) environmental data management mandates for data dissemination, accessibility, and long-term user understanding of information are addressed.

Near Real-Time Data Sharing Services

Scientific data collection and ship-to-shore data flow commence when *Okeanos Explorer* sails. Data products, reports, and other mission information created by shipboard personnel are stored in the Ship-Board Repository Server (SBRS) in a standardized directory structure.

The Shore-Side Repository Server (SRS) is an information collection/dissemination point that synchronizes hourly with the SBRS to provide near-real-time access to cruise data and information products (e.g., daily updates, dive reports, mapping products, videos). Shipboard and shore-based personnel use the SRS as a data exchange location to access and review the previous day's data, discuss results, and make planning decisions.



The SRS system is also integral to maintaining public awareness of expedition progress. Information is presented in the *Okeanos Explorer* Atlas, a publicly accessible Internet map that displays ship location and expedition information in mission-specific context. Daily updates posted to the map include daily highlights, ROV dive locations, oceanographic data, and seafloor mapping imagery. The atlas links educators to Exploration Education Materials so that data can be incorporated into lesson plans for classroom use.

Automated procedures are used to manage and document data while the cruise is underway, improving data standardization, reliability, and throughput time for metadata documentation, data, and information products in three primary categories:

1. VIDEO AND STILL IMAGERY MANAGEMENT

Okeanos Explorer and its ROVs are equipped with eight high-definition and 21 standard-definition video cameras. Video is recorded digitally in full resolution, and is processed based on feedback from the expedition science team. Compressed versions of the videos are created for easy transmittal and web viewing. Still imagery is created from recorded video clips during post-processing. The video data and products are transmitted to the SRS where they are shared with expedition participants and the public via Internet access points. Images and videos are preserved in the NOAA Central Library and many are also accessible from the library's online catalog.

2. SEAFLOOR MAPPING DATA MANAGEMENT

Okeanos Explorer is equipped with a suite of acoustic mapping sensors, including a Kongsberg EM302 multibeam sonar system. High-resolution data are developed into a standard suite of quality-controlled mapping products, including gridded bathymetry and bottom backscatter data. These products are shared via SRS and are used for decision making in the field through collaboration with shore-based cruise participants. After the cruise, the mapping data are reviewed and are submitted to the National Geophysical Data Center for long-term stewardship.

"… I was called back to the conference party line, out at sea, because the team working ashore had come up with new interpretations based on the most recent multibeam data that meant we should reconsider and, we all quickly agreed, completely re-plan the very next day's ROV dive."

—Chris German, WHOI,
Mid-Cayman Rise Expedition Science Team Lead

3. OCEANOGRAPHIC DATA MANAGEMENT

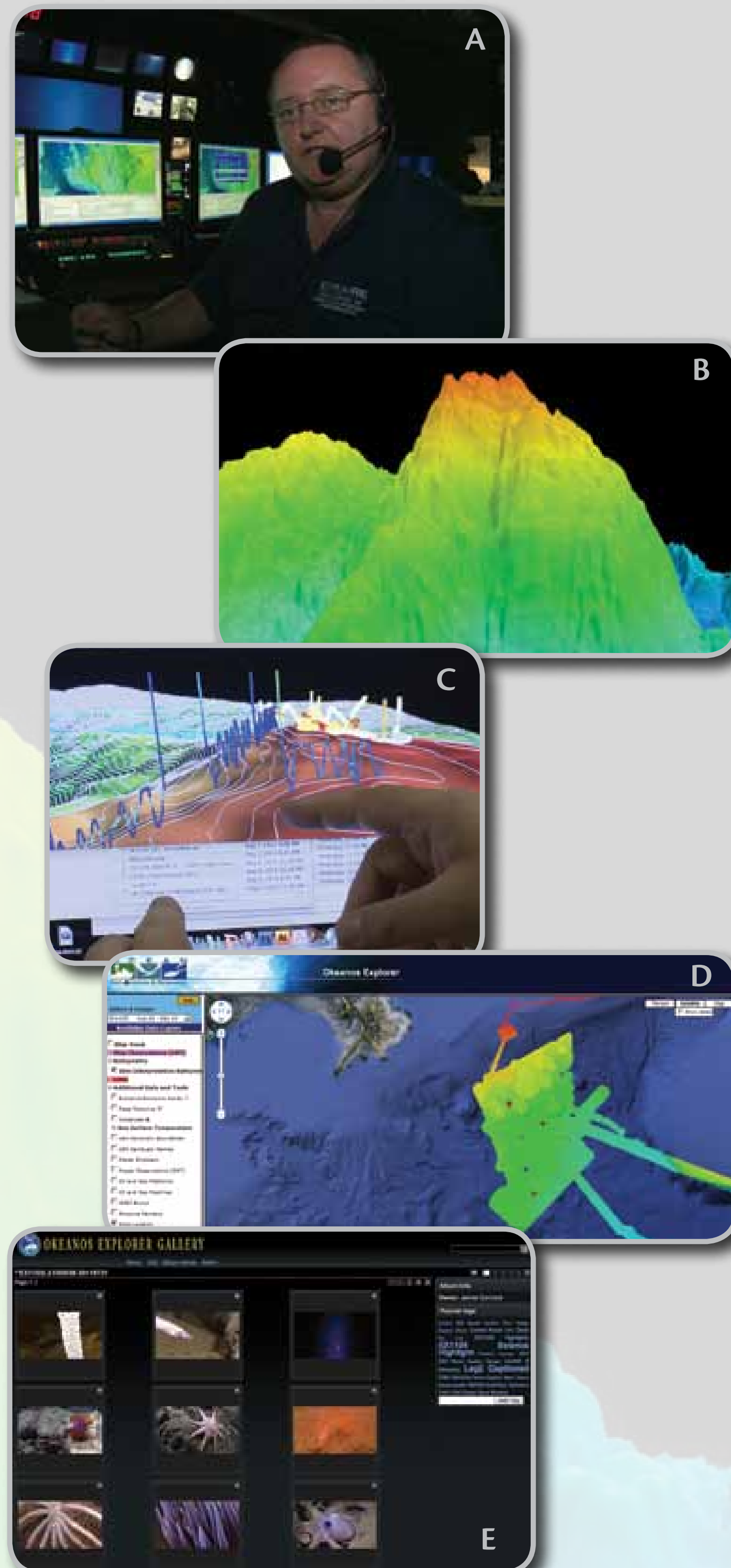
The ship and ROVs are equipped with CTD sensors. These data are used to calibrate the multibeam sensor, characterize the physical properties of the water column, and identify potential ROV dive locations. They are included in SRS updates, and are displayed in the *Okeanos Explorer* Atlas, where profile data may be compared to historical profiles in the World Ocean Atlas.

Navigational, meteorological, and oceanographic data collected from ship sensors are recorded in the NOAA Scientific Computing System (SCS). Daily SCS data transmissions to the SRS are converted to an Open Geospatial Consortium (OGC) compliant NetCDF3 format for direct public access. Oceanographic data are preserved at the National Oceanographic Data Center.

Short- and Long-Term Benefits

In the remote exploration paradigm, ready access to information onshore within 24 hours of data collection enables shoreside and shipboard scientific teams to jointly manage exploration efforts. The program's well-managed data facility makes *Okeanos Explorer* a responsive and efficient exploration platform.

In addition to short-term operational improvements, benefits from this data management approach accrue to all NOAA partners over the long term. The information management strategy and practices used aboard *Okeanos Explorer* serve as an example for Rolling Deck to Repository (R2R) programs in both the academic and NOAA fleet, and provide a proof-of-concept for NOAA's environmental data management policies and procedures. As a result of these practices, exploration results are widely disseminated to have maximum impact in the research, commercial, regulatory, and educational realms, and to excite the public imagination and encourage public involvement in exploration.



(A) Christopher German, Mid-Cayman Rise Expedition Science Team Leader. (B) EM302 multibeam data collected over Mount Dent, a seamount explored during the Mid-Cayman Rise Expedition. (C) Fledermaus visualization showing CTD Tow-Yo data collected over the Mid-Cayman Rise while searching for hydrothermal vent activity (post-processed data courtesy of Sarah Bennett, NASA-JPL, and James Kinsey and Christopher German, WHOI) (D) The *Okeanos Explorer* Atlas digital map allows the public to follow expedition activities in near-real time. (E) The *Okeanos Explorer* Image Gallery provides highlight images of each day's ROV dive.

EPILOGUE

During the last several years, we have been successfully implementing this new telepresence-enabled paradigm for ocean exploration. From initial forays using ships of opportunity and the Institute for Exploration's "fly-away" system, to recent missions using dedicated platforms, we explored new areas in the far western Pacific north of Indonesia, the west coast of North and South America, the Caribbean Sea and Gulf of Mexico, the US East Coast, the Lost City hydrothermal vent field on the Mid-Atlantic Ridge, and the Mediterranean and Black Seas. We have only begun to scratch the surface of ocean areas that we know little about.

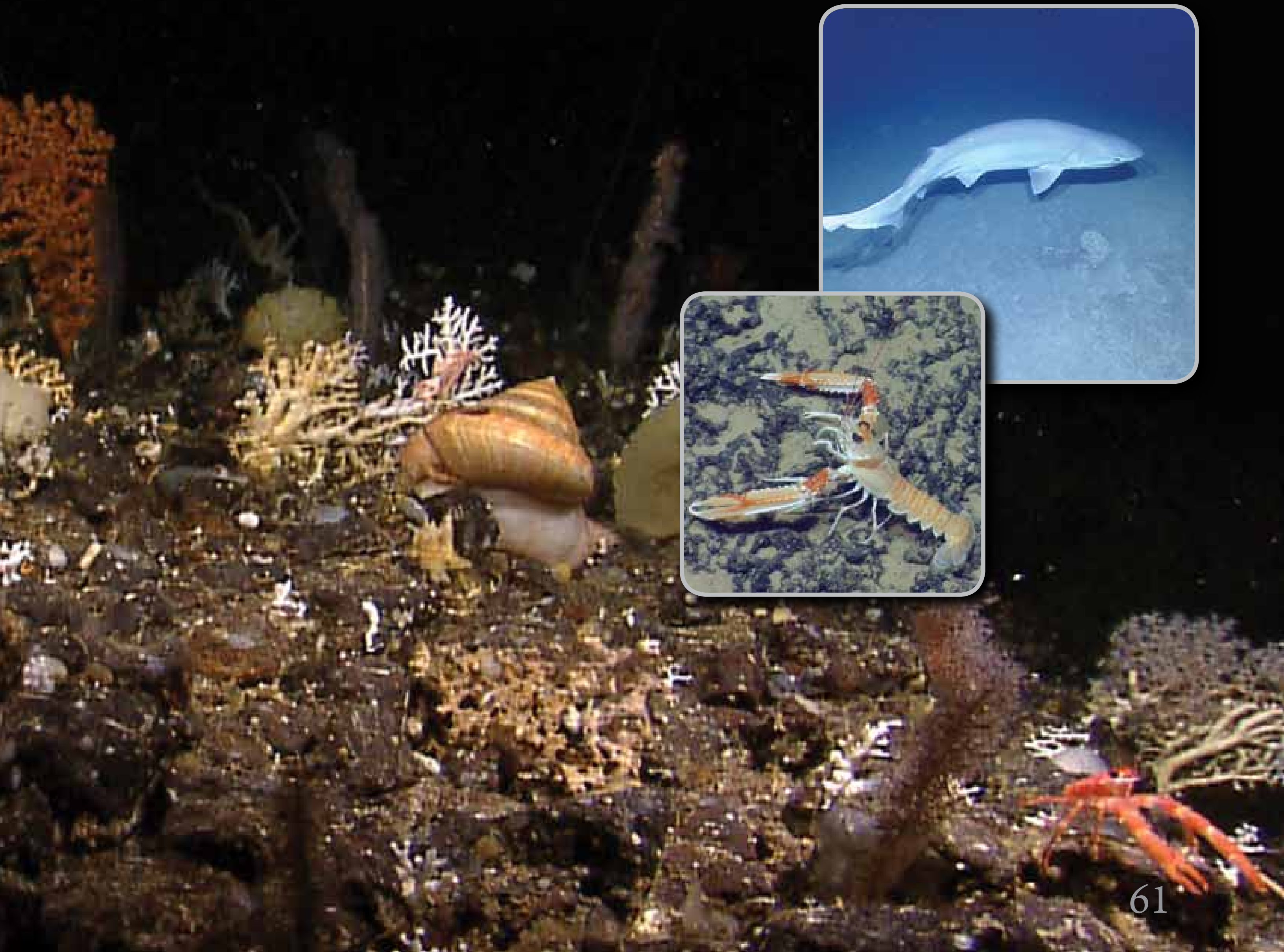
The program is growing. Two dedicated ships of exploration, the NOAA Ship *Okeanos Explorer* and E/V *Nautilus*, the new Inner Space Center at the University of Rhode Island Graduate School of Oceanography, Internet2-enabled Exploration Command Centers at academic institutions and other facilities in the United States and overseas, and an ever-increasing number of remote consoles allow almost unlimited access to real-time exploration. As we continue to investigate new methods for using standard Internet and social media, we anticipate a growing community of ocean explorers will be watching every mission.

What does the future hold? The success of these missions proves that the telepresence-enabled approach yields new discoveries, stimulates new lines of inquiry, catalyzes changes and advancements in technologies, provides information valuable for addressing immediate ocean management challenges, and acts as a springboard for engaging the next generation of ocean scientists and explorers.

To guide our exploration missions in 2012 and 2013, we conducted a workshop in May 2011, which provided an opportunity for scientists to identify targets in the Atlantic basin, including the Gulf of Mexico and Caribbean Sea. We plan to conduct a more in-depth workshop focused on the Caribbean in 2012. E/V *Nautilus* will transit through the Atlantic and Caribbean to the Pacific in 2013, while *Okeanos Explorer* will continue to concentrate on the Atlantic, Gulf of Mexico, and Caribbean.

We have been working with the ocean science and engineering communities on the installation of a multi-beam sonar system on E/V *Nautilus*, and on expanding to 6,000 m the depth capabilities of the ROV dedicated to *Okeanos Explorer*. We will continue to engage these communities in discussions concerning new sensors and systems to continue to improve ship-based systems and the growing shore-based network.

During challenging economic times, this new paradigm for ocean exploration continues to demonstrate great value. Through telepresence technology, we can now explore remote regions with a far greater number of experts compared to traditional means, and deliver data, information, and preliminary findings in real and near-real time. And, most importantly, by maintaining our focus on truly unknown ocean areas, we have an opportunity to make significant discoveries that could, perhaps, stimulate new areas of the economy.



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