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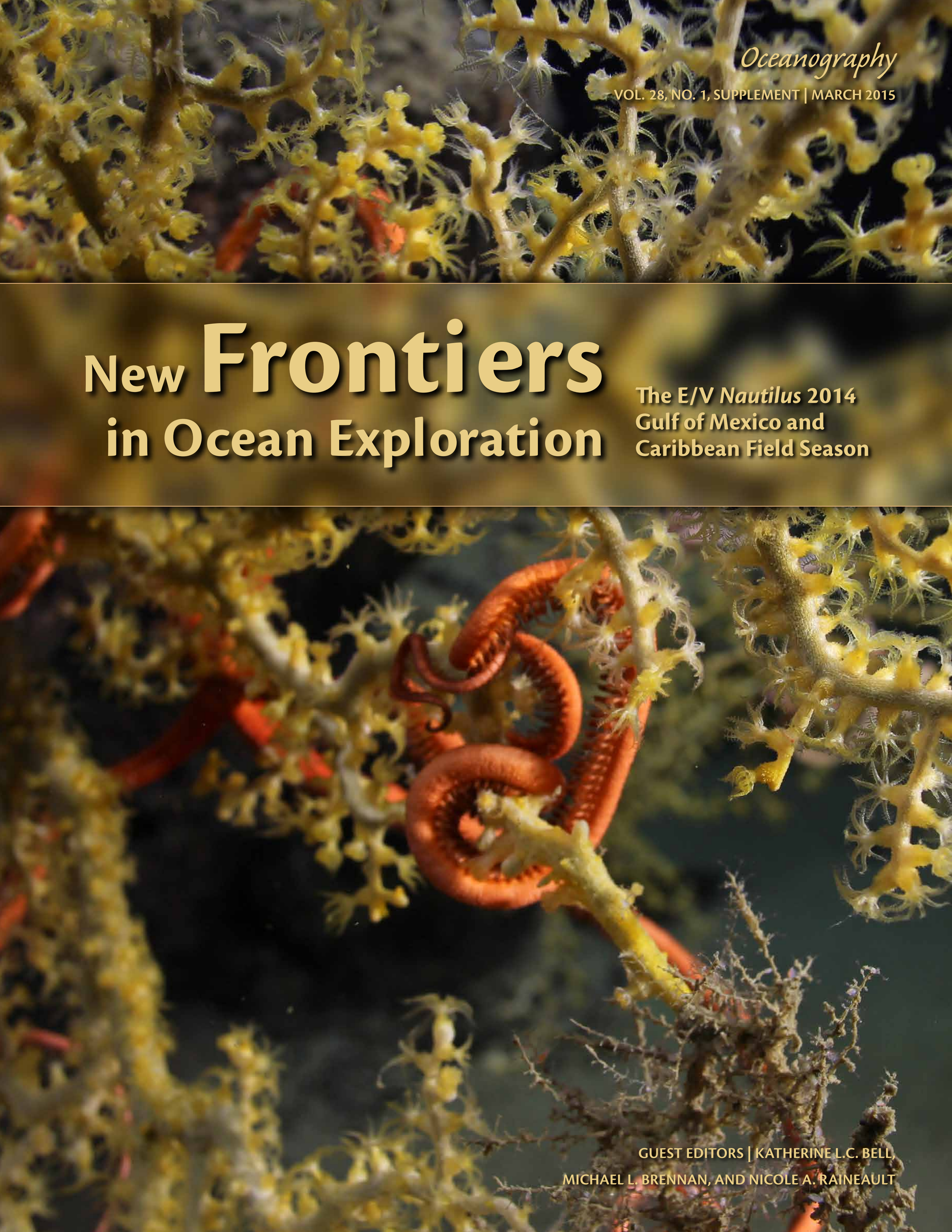
New Frontiers in Ocean Exploration

The E/V *Nautilus* 2014 Gulf of Mexico and Caribbean Field Season



GUEST EDITORS | KATHERINE L.C. BELL,
MICHAEL L. BRENNAN, AND NICOLE A. RAINEAULT

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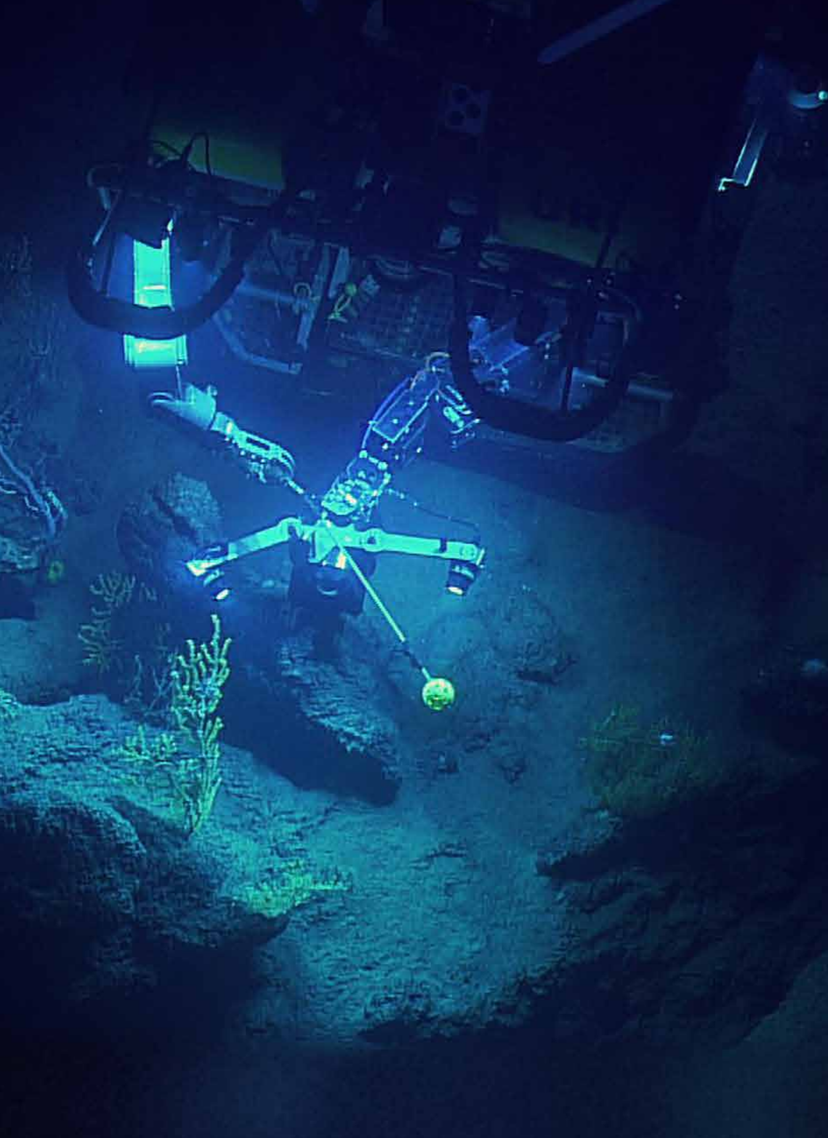
INTRODUCTION

By Robert D. Ballard and Katherine L.C. Bell

The Ocean Exploration Trust (OET) Workshop on Telepresence-Enabled Exploration of the Caribbean Region was convened in November 2012 to plan for the 2013 field season with the idea that Exploration Vessel (E/V) *Nautilus* and its Corps of Exploration would spend only one year working in the Gulf of Mexico and the Caribbean Sea. However, the strong showing of interest in the area from the international group of marine scientists who submitted white papers to and participated in that workshop was so impressive the Trust and its Nautilus Advisory Board decided to schedule a second year in this area of the world before moving on to the Pacific Ocean, as originally planned.

This fifth *Oceanography* supplement chronicles the 2014 field season: four months of exploration in the Gulf of Mexico and the Caribbean Sea, as well as rapid growth in our science, technology, engineering, and mathematics (STEM) education and outreach programs and continued research on best practices of telepresence and archaeological oceanography.



The first section of this supplement (pages 4–15) describes the technology used on board *Nautilus* to explore the deep sea and to make our expeditions accessible globally to the public, students, and scientists alike. The biggest technology strides during 2014 were made in data management and accessibility. On board *Nautilus*, we completely renovated the Data Processing & Visualization Laboratory in advance of the 2014 field season, creating a space for scientists, students, and engineers to process and analyze data during expeditions and share them with scientists on shore. Our Data Team was hard at work creating online collaboration tools that now make it significantly easier to access *Nautilus* data in real time or near-real time on board the ship, on shore at the Inner Space Center, and in scientists' homes and laboratories. Continued emphasis on data management in the coming years will result in easier collaboration among scientists at sea and ashore, and will accelerate the pace of discovery and research.

The area of largest growth for the Nautilus Exploration Program in 2014 was in education and outreach (pages 16–23). In June, we launched our first Community STEM Program (CSP) in South Florida, sponsored by the Florida Panthers Foundation. This new initiative focuses our STEM education efforts in select geographical regions, allowing single communities to engage their members in all of the educational programs OET offers, thereby increasing the impact these programs can have in any individual location. By working at the intersection of education and ocean exploration, our goal is to promote STEM fields using the excitement of exploration and technological innovation. Our programs range from the public website Nautilus Live (http://www.nautiluslive.org), to live interactions with museums, aquariums, and science centers, to K12 Learning modules for schools and out-of-school programs, to seagoing opportunities for high school, college, and graduate students. By the beginning of the 2015 field season, CSP will have grown to more than 10 communities, and we expect further expansion to 15–20 communities by the 2017 field season.

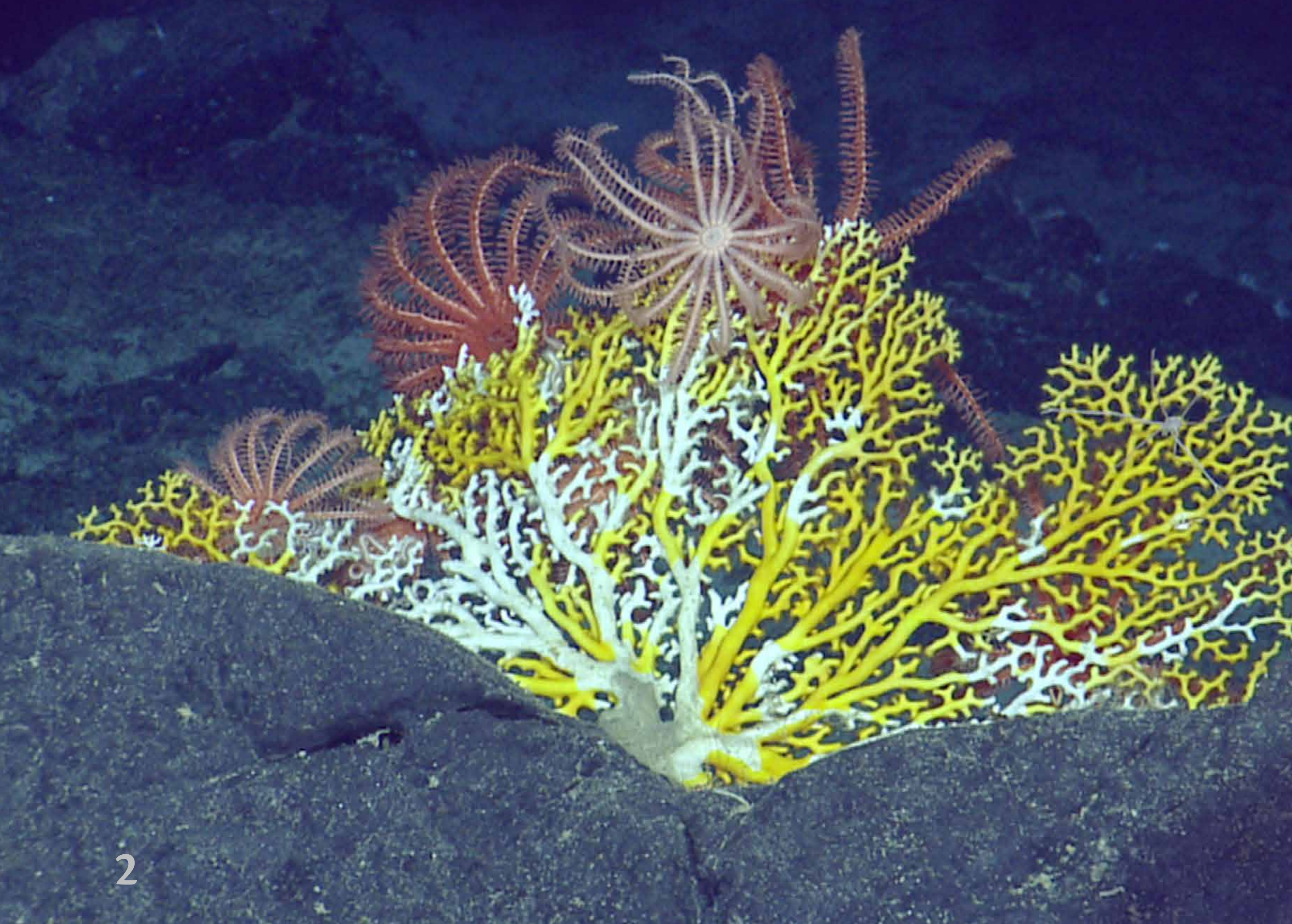
The first exploratory program of 2014 was carried out at Great Bahama Bank and in the Straits of Florida, two High Priority Target Areas identified during the 2012 Caribbean Workshop because of their potential geohazards and sinkholes (pages 26–27). This cruise was followed by a series of exploratory transits in and around the Dry Tortugas, including documentation of a German U-boat supporting a dense concentration of invasive lion fish that is threatening the shallow- and deepwater communities in the Gulf of Mexico and the Caribbean Sea.

Approximately one month was devoted to conducting four missions in the Gulf of Mexico. Two of these projects were continuing efforts to (1) document how natural and accidental oil and gas inputs affect deep-sea coral communities, working with the Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) Consortium (pages 28–29), and (2) study the fate and transport of gas bubbles from natural seeps, in conjunction with the Gulf Integrated Spill Response (GISR) Consortium (pages 32–33).

The other two projects were concerned with investigating a series of shipwrecks that were involved in "Operation Drumbeat," when, in 1941, Adolph Hitler sent a wolfpack of U-boats to the East Coast and into the Gulf of Mexico to disrupt US shipping routes and transport of oil and other commodities of critical importance to the war effort (pages 30–31). These two expeditions resulted in a *NOVA*/National Geographic program aired on Public Television in May 2015 as well as a second show aired on CBS's *60 Minutes* that highlighted not only the human history preserved in the depths of the Gulf of Mexico, but also the natural resources contained within the US Exclusive Economic Zone.

Following our efforts in the Gulf of Mexico, *Nautilus* continued to explore the Caribbean Sea, further responding to the recommendations of the 2012 Caribbean Workshop. Targets of exploration in 2014 included the deep waters of the Mesoamerican Reef off the coast of Belize, the second largest barrier reef system in the world (pages 34–35), and the Windward Passage between Jamaica and Haiti (pages 36–37). The geological and biological aspects of both locations were investigated using the *Nautilus* EM302 multibeam sonar system to create maps of the seafloor before diving on selected targets with the remotely operated vehicles (ROVs) *Hercules* and *Argus*.

The expedition then continued on to the Anegada Passage in the eastern Caribbean to follow up on successful exploration there during the 2013 field season. The 2014 cruise, which included collection of new rock and core samples, was again led by US Geological Survey scientist Amanda Demopoulos and funded by a Targeted Research RFP solicited by the US National Oceanic and Atmospheric Administration (NOAA)



Office of Ocean Exploration and Research.

Nautilus completed the 2014 field season by continuing exploration of Kick'em Jenny volcano west of Grenada and the Barbados Cold Seep Province in Trinidad and Tobago (pages 38–39). The 2013 exploration of Kick'em Jenny revealed debris avalanche-induced cold seeps and their unique ecosystems dominated by giant chemosynthetic mussels and associated communities. In 2014, we continued to explore this area, resulting in the discovery of many more cold seeps, as well as what is believed to be the largest *B. boomerang* mussel ever found. Our work on the Barbados mud volcanoes was the first ROV exploration in this area, following manned submersible research nearly 20 years ago. Through the combined use of the shipboard EM302 multibeam to detect bubble plumes and ROV dives, we discovered cold seep sites that had not been previously explored, including large areas with methane hydrates and associated biological communities.

In addition to scientific exploration, the final expedition included ethnographic and educational components through a study called Transforming Remotely Conducted Research Through Ethnography, Education & Rapidly Evolving Technologies (TREET), funded by the Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) program (pages 40–43). The primary goals of this project are to use ethnography to study how telepresence can be best used in the context of oceanographic and other research, and to determine how to best engage groups of undergraduates through remote but authentic research experiences. The results of this study will be useful not only for the Nautilus Exploration Program but also for the University-National Oceanographic Laboratory System (UNOLS, the organization that coordinates the US academic research fleet), NOAA, and other organizations as they continue to develop their own telepresence-enabled capabilities.

Following up on our previous archaeological work in the Black, Aegean, and Mediterranean Seas, OET held a symposium to present our findings to the public and academic communities in October 2014. A summary of the symposium proceedings and plans for continued research is presented on pages 44–45.

This volume concludes with a view toward the future of the Nautilus Exploration Program through a summary of the Workshop on Telepresence-Enabled Exploration of the Eastern Pacific Ocean, held in December 2014 in San Francisco (pages 46–51). This workshop hosted nearly 70 scientists at the Exploratorium to identify key oceanography questions about the eastern Pacific that need answers, as well as 33 High Priority Target Areas that are poorly understood or completely unexplored. The results of this workshop will be used to plan the *Nautilus* 2015–2018 field seasons.

Since 2009, *Nautilus* has been home to 656 scientists, engineers, students, filmmakers, songwriters, artists, and guests, 40% of whom are women, representing 38 countries. We have spent 610 days at sea, mapping over 126,000 square kilometers of seafloor and exploring the water column and seafloor for 4,254 hours (177+ days). Nearly 2,000 geological, biological, and chemical samples have been collected, more than 200 of which have been requested for follow-up research, and more than 50 publications, theses, and dissertations have resulted from our expeditions. We are very proud of all that has been accomplished in six short years, and we look forward to what the Pacific Ocean has in store for *Nautilus* and her Corps of Exploration.

TECHNOLOGY

Exploration Vessel *Nautilus*

BUILT | 1967, Rostock, Germany

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

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

ENDURANCE | 40 days at sea

SPEED | 10 knots service, 12 knots maximum

FUEL CAPACITY | 330 cubic meters

PROPULSION | Single 1,286 kilowatt (1,700 hp) controllable pitch main thruster; 250 kW bow thruster; 350 kW jet pump stern thruster

SHIP SERVICE GENERATORS | Two 500 kVa generators, one 350 kVa generator, and one 450 kVa shaft generator

PORTABLE VAN SPACE | One 20-foot van

COMPLEMENT | 17 crew; 31 science and operations

FLAG | St. Vincent and the Grenadines

HEAVY EQUIPMENT |

- Dynacon 421 ROV winch with 4,500 meter (14,764 feet) Rochester A302351 1.73 centimeter (0.68 inch) diameter cable
- DT Marine 210 winch with 1,200 m Rochester A320327 0.82 centimeter (0.322 inch) diameter wire
- Bonfiglioli knuckle-boom crane, 4.2 ton capacity, two extensions
- A-frame, 6 ton capacity

Data Processing & Visualization Lab

AREA | 44.5 square meters (480 square feet)

WORKSTATIONS | Seven workstations for data manager, data loggers, navigators, educators, data engineers, satellite engineer, video engineer; high-resolution map, multibeam, and side-scan sonar processing; flexible bench space

Telepresence Technology

VSAT | 2.4 meter tracking antenna capable of up to 20 Mbps (C-band circular or linear)

REAL-TIME VIDEO STREAMING |

- Four Tandberg standard definition encoders with multiplex for encapsulating real-time video
- Harmonic Electra 7000 high definition encoder

CAMERAS | One Sony BZR-800 high definition pan/tilt/zoom camera mounted in the Control Van and on the aft deck; one Marshall Electronics VS-570-HDSDI high definition camera with pan/tilt/zoom, and microphone for interaction with shore, mounted in Wet Lab and ROV hangar

COMMUNICATIONS |

- Ship-wide RTS Telex intercom system for real-time communications between ship and shore
- Handheld UHF radios are interfaced with the RTS intercom system for deck, bridge, and Control Room communications

Control & Imaging Vans

AREA | 28 square meters (301.4 square feet)

WORKSTATIONS | Nine; typical configuration for ROV operations: two to three scientists, data logger, *Hercules* pilot, *Argus* pilot, navigator, video engineer, Science Communication Fellow

Rack Room

AREA | 17.3 square meters (185 square feet)

VIDEO STORAGE | Two Omneon Mediadecks (MDM-5321 and SMD-2200-BB) for video recording, playback, and storage

DATA STORAGE | 16 TB online storage for non-video data; 28 TB disk storage for video data

EMERGENCY COMMUNICATIONS | Iridium phone

ELECTRONICS WORKBENCH | 80 cu ft of storage

Wet Lab

AREA | 19 square meters (204.5 square feet) with 5-meter-long (16-foot) stainless steel worktop

REFRIGERATION |

- Panasonic MDF-C8V1 ULT –80/–86°C scientific freezer, 0.085 cubic meters (3 cubic feet)
- Science refrigerator/freezer, approximately 0.57 cubic meters (20 cubic feet)

MICROSCOPE |

- Nikon SMZ800 trinocular microscope, 6.3× zoom, Vari-Mag C-mount camera adapter with additional 2.5× ocular
- Dual output cold light source
- Nikon D300 SLR camera
- HDMI out for sharing microscope video with shore

HAZMAT |

- Fume hood
- HAZMAT locker for chemical and waste storage
- Carry-on, carry-off chemical policy

Production Studio

AREA | 12 square meters (130 square feet)

CAMERA | Remote controllable high definition Sony BRC-H700

SWITCHER | Ross CrossOver16 with ability to switch underwater, topside, or scaled computer video streaming to the Inner Space Center for live interactions

ROV Hangar

AREA | 24 square meters (258.3 square feet)

POWER | 110/60 Hz and 220/50 Hz available

PERSONAL PROTECTIVE EQUIPMENT | Hard hats, PFDs, high voltage gloves

LIFTS | 2 × 2-ton overhead manual chainfall lifts

STORAGE | Storage for spares and other equipment

ROV Workshop

AREA | 18 square meters (193.8 square feet)

TOOLS | Complete set of hand tools, cordless tools, electrical and fiber optic test equipment, mill-drill combination machine

STORAGE | Storage for spares and other equipment

Acoustic Systems

Kongsberg EM302 Multibeam Echosounder

FREQUENCY | 30 kHz

DEPTH RANGE | 10–7,000 meters (33–22,966 feet)

SWATH WIDTH | Up to 5.5 times water depth, to approximately 8,000 meters (26,247 feet)

PULSE FORMS | CW and FM chirp

BEAMWIDTH | 1° × 1°

APPROXIMATE GRID RESOLUTION | 10% water depth (e.g., 10 m at 1,000 m depth)

SOUNDINGS PER PING | Up to 864

SWATHS PROFILES PER PING | 1 or 2

Knudsen Subbottom Profiler and Echosounder

PROFILER | Knudsen 3260 Chirp subbottom profiler and echosounder

OPERATING FREQUENCY | Dual frequency, 3.5 kHz and 15 kHz

POWER | 4 kW on Channel 1 and up to 2 kW on Channel 2

RANGE | 50 to 5,000 meters (164 to 16,404 feet)

Ultra-Short Baseline Navigation System

SYSTEM | TrackLink 5000MA system for USBL tracking of ROVs *Hercules* and *Argus*

RANGE | Up to 5,000 meters (16,404 feet)

POSITIONING ACCURACY | 1° (better than 2% of slant range)

OPERATIONAL BEAMWIDTH | 120°

OPERATING FREQUENCY | 14.2 to 19.8 kHz

TARGETS TRACKED | Up to eight

Side-Scan Towfish *Diana*

SIDE-SCAN SONAR | EdgeTech 4200 MP CHIRP side-scan sonar with depressor wing

DEPTH CAPABILITY | 2,000 m (6,561.7 ft), currently limited by 1,000 m (3,280.8 ft) cable

TOWFISH SIZE | 125.6 centimeters × 11.4 centimeters (49.5 inches × 4.5 inches)

FREQUENCY | 300 and 600 kHz dual simultaneous

OPERATING RANGE | 230 meters (300 kHz), 120 meters (600 kHz)

HORIZONTAL BEAMWIDTH | 0.54° and 0.34° (high speed mode), 0.28° and 0.26° (high definition mode)

VERTICAL BEAMWIDTH | 50°

DEPRESSION ANGLE | Tilted down 20°

RESOLUTION ALONG TRACK (High Speed Mode) | 300 kHz: 1.9 meters @ 200 meters; 600 kHz: 0.6 meters @ 100 meters

RESOLUTION ALONG TRACK (High Definition Mode) | 300 kHz: 1.0 meter @ 200 meters; 600 kHz: 0.45 meters @ 100 meters

RESOLUTION ACROSS TRACK | 3 centimeters (300 kHz), 1.5 centimeters (600 kHz)

SENSORS | Heading, pitch, roll, pressure

Remotely Operated Vehicle *Argus*

General

DEPTH CAPABILITY | 6,000 meters (19,685 feet), currently limited to 4,000 meters

CABLE | 4,000 meters, 0.681 electro-optical, 3x #11 conductors, 3x SM fibers

SIZE | 3.8 meters long × 1.2 meters wide × 1.3 meters high

WEIGHT | 1,800 kilograms (4,000 pounds)

MAXIMUM TRANSIT SPEED | 2 knots

ASCENT/DESCENT RATE | 30 meters/minute (98.4 feet/minute)

PROPULSION | Two Deep Sea Systems International 404 brushless DC thrusters for heading control

Imaging & Lighting

CAMERAS |

- One Insite Pacific Zeus Plus high definition camera with Ikegami HDL-45A tilt head with Fujinon HA 10×5.2 lens -1080i SMPTE 292M output format – 2 MP still image capable
- Three Insite Pacific standard definition mini utility cameras (fixed mounted) 480 line NTSC format
- One Insite Pacific low-light "fish-eye," downward-looking standard definition camera (fixed mounted)

LIGHTING |

- Two Deep Sea Power & Light 1,200 Watt HMI, 100,000 lumens each
- Two Deep Sea Power & Light 400 Watt HMI
- Two Deep Sea Power & Light 250 Watt Incandescent

Vehicle Sensors & Navigation

USBL NAVIGATION | TrackLink 5000 system, acoustically triggered

PRIMARY HEADING | Crossbow high resolution magnetic motion and attitude sensor

SECONDARY HEADING | TCM2 solid state fluxgate compass

PRESSURE SENSOR | Paroscientific Digiquartz 8CB series

ALTIMETER | Benthos PSA-916

FORWARD-LOOKING SONAR | Mesotech 1071, 675 kHz, 100 meters range

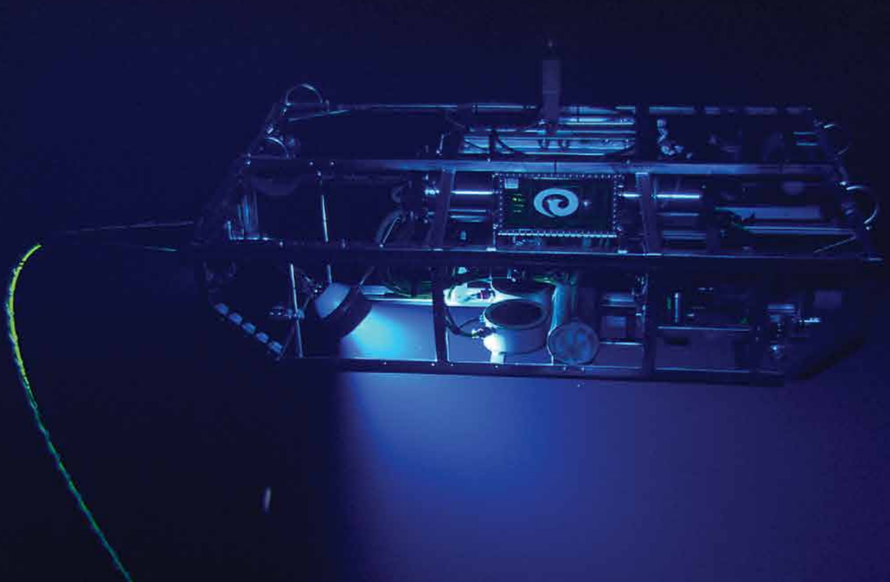
SIDE-SCAN SONAR | EdgeTech 4200 MP

SUBBOTTOM PROFILING SONAR | TriTech SeaKing Parametric Subbottom Profiler (10–30 kHz)

Scientific Instrument Support

POWER | 110 V 60 Hz AC, 24 VDC, 12 VDC, 5 VDC power options

DIGITAL DATA CHANNELS | Three RS-232, one 100base-T Ethernet



Remotely Operated Vehicle *Hercules*

General

DEPTH CAPABILITY | 4,000 meters (13,123 feet)

TETHER | 30–45 meters (98.4–147.6 feet), 20 millimeters (0.79 inches) diameter, neutrally buoyant

SIZE | 3.9 meters long × 1.9 meters wide × 2.2 meters tall (12.8 feet long × 6.2 feet wide × 7.2 feet tall)

MASS | ~ 2,500 kilograms (5,500 pound-mass) in air

MAXIMUM VEHICLE SPEED | 0.77 meters/second (1.5 knots) forward, 0.25 meters/second (0.5 knots) lateral, 0.5 meters/second (1 knots) vertical (on site, within tether range)

MAXIMUM TRANSIT SPEED | 1 meter/second (2 knots), no sampling, in layback mode

MAXIMUM ON-BOTTOM TRANSIT SPEED | 0.5 meters/second (1 knot), no sampling

MAXIMUM SAMPLING TRANSIT SPEED | 0.25 meters/second (0.5 knots) on flat seafloor; < 0.13 meters/second (< 0.25 knots) over featured terrain

ROV CLOSED LOOP POSITION CONTROL | Station Keep, X/Y step, Auto Depth, Auto Altitude, X/Y/Z step and hold velocity control

DESCENT/ASCENT RATE | 30 meters/minute (98.4 feet/minute)

PROPULSION |

- Six hydraulic thrusters powered by 15 kW (20 hp), 207 bar (3,000 psi) hydraulic system
- Fore/Aft & Vertical – Four 27.94 cm (11 inch) ducted thrusters, each providing 900 N (200 lbf) thrust
- Lateral – Two 22.86 cm (9 inch) ducted thrusters, each providing 450 N (100 lbf) thrust

Vehicle Sensors & Navigation

HEADING AND ATTITUDE |

- Primary Heading – IXSEA Octans III north-seeking fiber-optic gyrocompass (0.1° secant latitude accuracy with 0.01° resolution)
- Secondary Heading – TCM2 solid state fluxgate compass

PRESSURE SENSOR | Paroscientific Digiquartz 8CB series

CTD | Seabird FastCAT 49

OXYGEN OPTODE | Aanderaa 3830

TEMPERATURE PROBE | WHOI high temperature probe (0°–450°C, .1°C resolution)

USBL NAVIGATION | LINKQUEST TrackLink 5000

DOPPLER NAVIGATION & ALTITUDE | RDI Workhorse Navigator Doppler Velocity Log 600 kHz, 0.7–90 meter range (2.3–295.3 feet)

FORWARD-LOOKING SONARS |

- Kongsberg Mesotech 1071 profiling sonar, 300 kHz, 200 meter range (164 feet)
- TriTech Super SeaPrince 675 kHz, 50 meter range (164 feet)

Imaging & Lighting

STANDARD IMAGING SUITE | One high definition video channel on fiber optic, four standard definition video channels on coax, generally configured as:

- Insite Pacific, 6,000 msw rated, Zeus Plus with 10× zoom lens, Ikegami HDL-45A with zoom/pan/tilt/extend –1080i SMPTE 292M output format
- Insite Pacific, 6,000 msw rated, Titan Rotate-Tilt standard definition camera (bubble camera) 480 line NTSC format
- Three Insite Pacific NOVA utility cameras, mounted to view the starboard sample box, 480 line NTSC format
- One Insite Pacific Aurora utility camera, NTSC format

LIGHTING |

- Two Deep Sea Power & Light 400 Watt HMI with dual-ballast, 12,000 lumens, forward mounted
- Two Deep Sea Power & Light Matrix-3 LED lamps, 20,000 lumens, forward mounted
- Six to twelve Deep Sea Power & Light Sphere LED lamps, 6,000 lumens mounting configurable

SCALING | Two red Deep Sea Power & Light Micro Sea-Lasers, mounted 10 cm (3.94 inches) apart, HD camera only

HIGH-RESOLUTION MAPPING SUITE |

- Available for nonstandard mapping products
- Typical configuration is downward looking; custom configurations possible
- 1375 kHz BlueView multibeam, 90° total swath, 30 meter range, centimeter resolution capable
- Two stereo Prosilica still cameras, one black & white, one color; 1,024 × 1,360 pixels; 29° × 39° field of view; strobe lighting
- Green laser sheet with dedicated laser camera; 532 nanometers; 100 mW; 45° line generating head; inclined plane

Manipulators and Sampling

MANIPULATORS |

- Kraft Predator: Hydraulic, seven function spatially correspondent, force feedback, 200 lb lift
- ISE Magnum: Hydraulic, seven function, 300 lbs lift

SUCTION SYSTEMS |

- Suction sampling system, two × 8 liter discrete samples
- Jet-suction excavation system

SAMPLING TOOLS | Mission configurable

- Up to eight 6.35 centimeter (2.5 inch) inner diameter, 28 centimeter (11 inch) long push cores
- Up to six 5 liter Niskin bottles, manually triggered
- Custom tools can be integrated with prior notice

SAMPLE STORAGE |

- Forward sample tray (inboard): 45 cm × 33 cm × 25 cm (17.7 inches × 13 inches × 9.8 inches)
- Forward sample tray (outboard): 68 cm × 35 cm × 30 cm (26.8 inches × 13.8 inches × 11.8 inches)
- Starboard sample drawer: 65 cm × 50 cm × 30 cm (25.5 inches × 19.7 inches × 11.8 inches)
- Payload: Up to 300 lbs depending on sensor package
- Custom configuration of boxes, crates, and containers

ELEVATORS | Mission configurable; free ascent; maximum standard payload 70 kg (150 lb)

Scientific Instrument Support

SWITCHED POWER |

- 110 V, 60 hz AC
- 24 VDC
- 12 VDC
- 5 VDC

DIGITAL DATA CHANNELS |

- RS-232: 115 Kbauds
- RS-485/422: 2.5 Mbauds
- Ethernet: 10/100/1,000 mbps links available
- TTL: one TTL link

HYDRAULIC | Proportional and solenoid hydraulic functions

- 1,150 psi at 10 GPM
- 1,850 psi at 10 GPM
- 3,000 psi at 10 GPM (advance notice needed)

EXAMPLES OF USER-INSTALLED SENSORS |

- Harvard in situ mass spectrometer
- Fluorometer
- pH sensor
- PMEL MAPR eH sensor
- Kongsberg M3 multibeam sonar
- 18MP Ethernet connected digital still camera

DATA MANAGEMENT

New Tools for Data Visualization and Dive Planning

By Ethan Gold and Nicole Raineault

Digital and video data collected aboard *Nautilus* are essential to a successful expedition. Oceanographic sensor data, video and images, observational notes, and mapping and navigation data form the scientific legacy of the Nautilus Exploration Program. In order to meet scientific, educational, and outreach goals, data accessibility both during and after an expedition is a high priority and is continually being improved.

Synopsis 2014

Building on shipboard data management infrastructure work carried out in 2013, the Data Team focused on data quality and formats, ship/shore infrastructure, and visualization tools during the 2014 field season. Much of the vehicle navigation system was upgraded in the spring, providing greater stability and accuracy. *Nautilus* and the Inner Space Center (ISC) now use a symmetrical set of software to log and visualize current and historical data sets for situational awareness, quality control, and cruise planning.

In order to provide a centralized introduction for our cruise participants, we supply descriptions of our primary tools on a single Web page on the ship and a similar page on shore. Although this landing page was simple this season, we plan to expand our visitor's environment into a more comprehensive portal. We have expanded and updated system documentation, such as multibeam survey protocols and shipboard-specific instrument operations manuals. Symmetrical authentication, file sharing, and matching file system structures on ship and shore allow us to provide a well-integrated cruise experience. Sitting in the ISC Situation Room on shore is now quite similar to sitting in the Data Lab on the ship itself, with transparent access to current cruise data. All generated geospatial (KML) and dive report (HTML) products are stored permanently as part of the cruise archive.

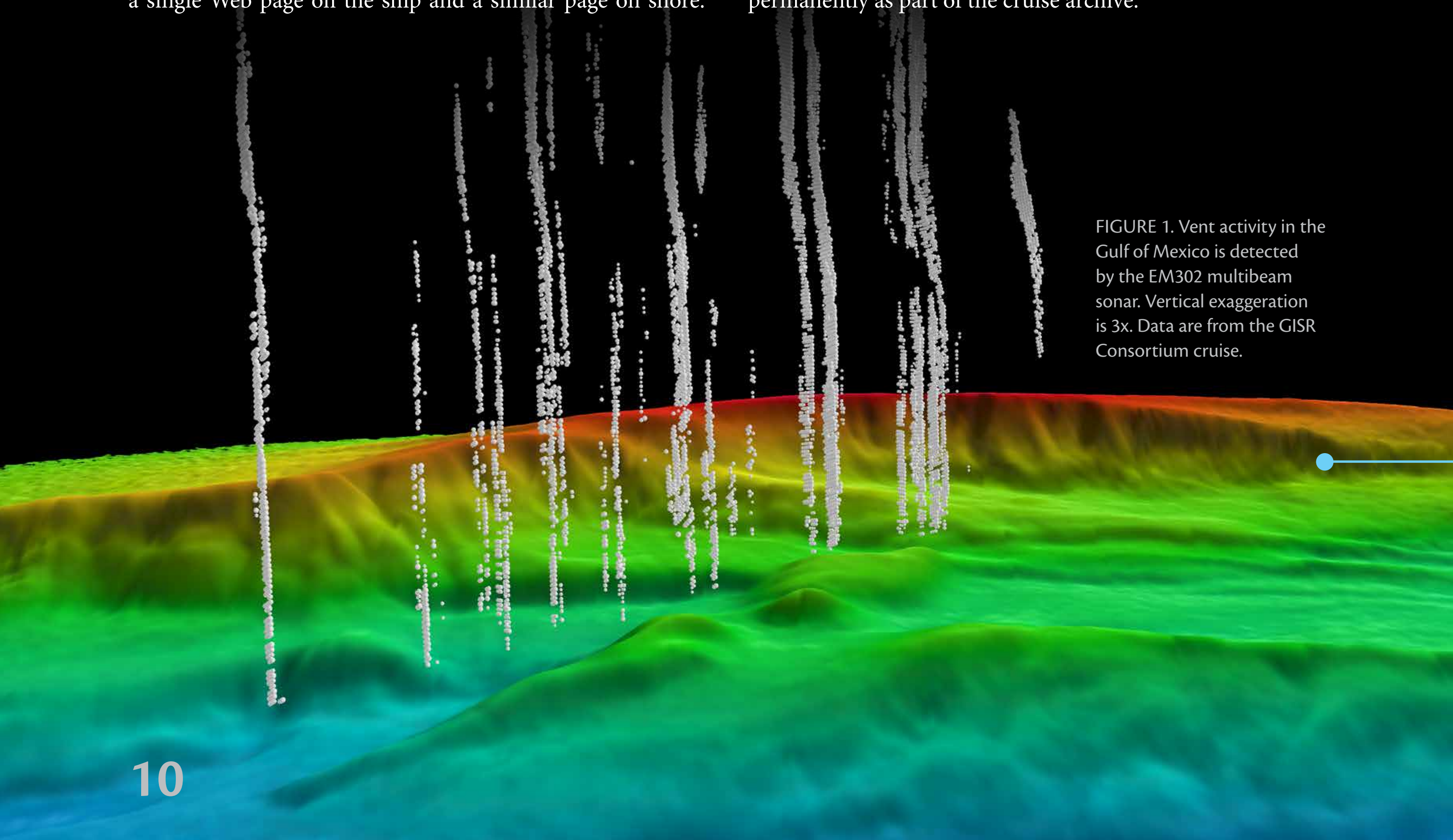


FIGURE 1. Vent activity in the Gulf of Mexico is detected by the EM302 multibeam sonar. Vertical exaggeration is 3x. Data are from the GISR Consortium cruise.

New Tools Fielded in 2014

The **Live Science Chat Dashboard** displays real-time ship/shore chat, subsampled graphs of vehicle data, and a history of the dive observations made by watchstanders on *Nautilus* (Figure 2). The Dashboard provides an immersive experience to scientists on shore by improving situational awareness via live feeds of vehicle depth, temperature, salinity, and ship heading, course, and wind speed. These elements are crucial for helping those on shore understand or make science and operational decisions.

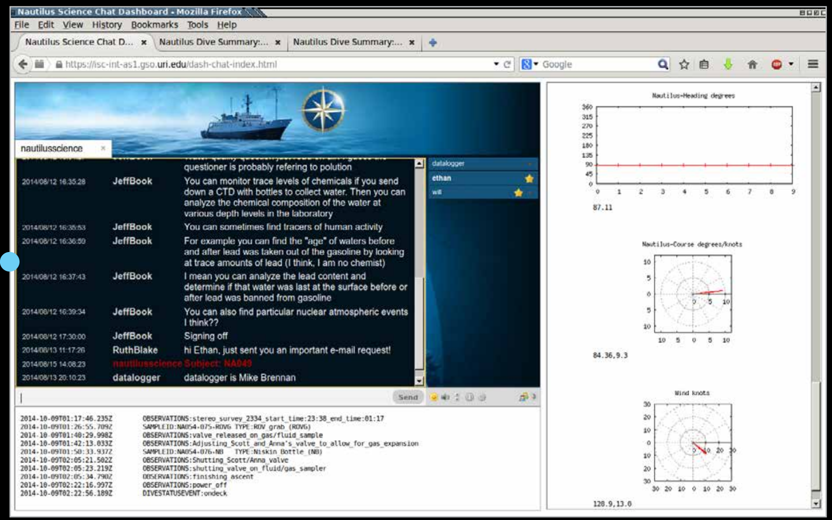


FIGURE 2. The Live Science Chat Dashboard is a Web page for scientists participating on shore and at sea to provide real-time vehicle and ship information to contextualize the video (right), along with the observation and chat logs to enhance communications between participants (left).

Another product is the **daily plot of the ship track, subsea vehicle navigation (seafloor clamped), and optional timecode flags in KML** (Figure 3). These auto-generated files help scientists quickly review where the ship and vehicles have surveyed, which is particularly useful for planning future dives. We use KML format for plotting geospatial data because it is viewable in the freely available and user-friendly Google Earth software.

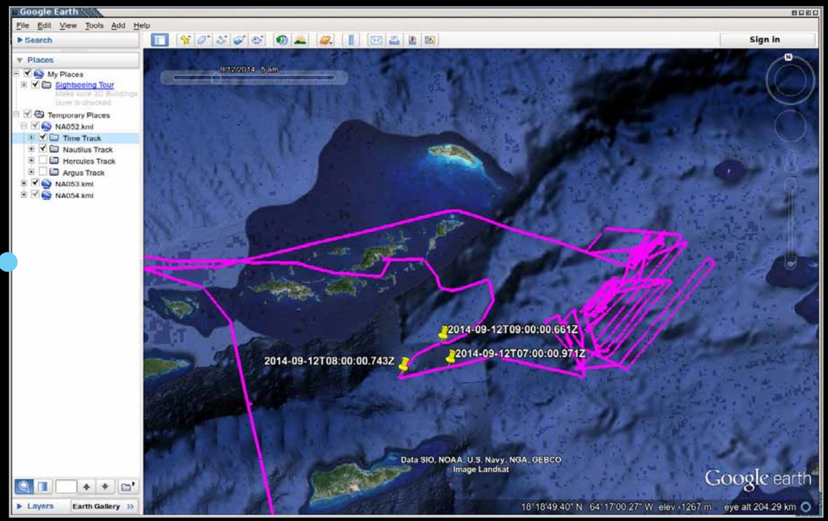


FIGURE 3. Daily KML plots show ship and vehicle navigation and optional time stamps, which are useful for planning or parsing selections of video and digital data.

Automated dive metadata summaries improve upon the human-generated spreadsheets by increasing the accuracy of entries (Figure 4). The new computer-generated summaries include the same important dive metadata (e.g., start/end and on bottom/off bottom date, time, location, and depth), but automation reduces the likelihood of errors. Now, the Data Team triggers the computer-produced summary by indicating a start and end date and time. They then review the summary as a quality control measure and add in relevant engineering notes. The HTML dive summaries are much more user-friendly and aesthetically pleasing than the spreadsheets. Additionally, the HTML page also contains links to the dive report, geospatial KML files, and sample information.

FIGURE 4. Automated dive summaries are an easy way for scientists to quickly recap the important dive metadata and access links to relevant data products.

With the addition of new vendor tools, we are now able to offer **rapid water column analysis** to look for bubble seeps in the water column with our EM302 multibeam sonar (Figure 1).

The dive metadata are, in turn, used to produce **three-dimensional KML renderings of each dive**, with observations, samples, and other logged information depicted as markers (Figure 5). The markers are time-correlated with image captures to provide a comprehensive dive review experience. This new product makes it easy to quickly review the terrain in a given area or to relocate interesting features. Instant replay via geospatially referenced images improves the transition between watches on the ship by allowing the science team to quickly review what past watches have seen and done. These renderings are also critical to scientists reviewing data long after the cruise is over. Scientists often want to associate seafloor type, depth, or another physical characteristic (e.g., salinity or temperature) with the types and quantities of organisms they encounter. Currently, each georeferenced observation also contains images from the video and *Hercules* ROV depth. In the future, we plan to add other time-correlated measurements, including salinity and temperature, and links to video clips.

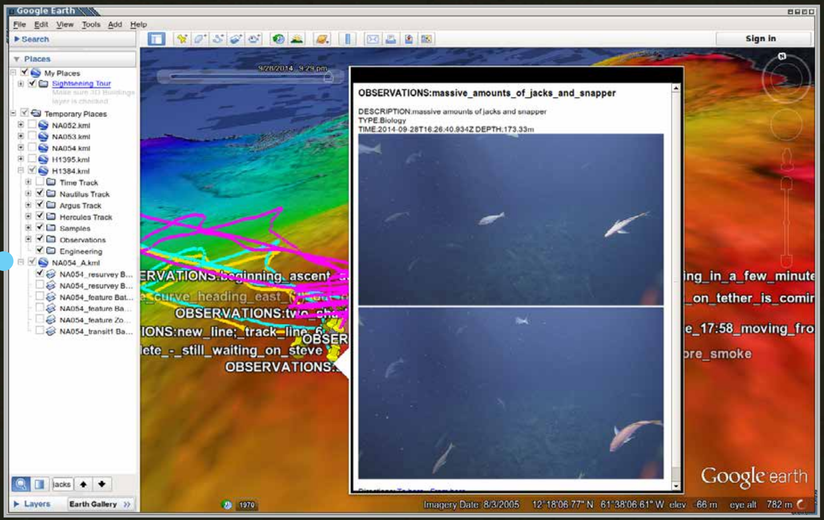


FIGURE 5. Three-dimensional geospatial dive rendering is a valuable tool for viewing observations, samples, and time-associated images on an interactive platform.

Future Improvements

Challenges for next season include linking mapping data products (digital elevation models, backscatter images, and water column anomalies/plume locations) with the geospatial dive KMLs. We also plan to make some products that are currently only available on *Nautilus* or at the Inner Space Center accessible to scientists participating remotely via authenticated network services. Currently, these products are included in the cruise archive and are available upon request.

NAUTILUS SAMPLES

By Nicole Raineault, Connor Marr, Barbara John, Mike Cheadle, Jason Chaytor, Peter Etnoyer, and Leigh Marsh

While the vast majority of data *Nautilus* collects are digital—high-definition video, still photos, sensor, measurements, and navigation—physical samples are invaluable to scientists. Biological samples are critical in determining the species of an organism and may lead to the discovery of a new organism or new knowledge that extends a species' range or adaptations. Biological samples also permit scientists to study food web and reproductive dynamics as well as growth rates, which are critical for research on fisheries and other natural marine resources. Rock and sediment samples are key to learning more about sedimentation rates, geological formation and history, and marine geohazards that may impact coastal communities.

Nautilus has been collecting samples since 2010. From then until 2012, samples were primarily geological and many were archived by the cruise Lead Scientists; however, individual sample ownership limits use of the sample to a smaller pool of scientists. Since 2013, we changed our policy to store all samples at larger repositories, increasing their availability and visibility to researchers. Rock samples and sediment cores are stored at the University of Rhode Island's Marine Geological Samples Lab (MGSL). Scientists can request splits or subsamples of cores or rocks for further research. In addition, *Nautilus* routinely collects two types of biological samples: voucher samples (intact/whole organisms) and tissue samples (subsamples of a population or whole organism) that are used for DNA analysis. These biological samples are archived at Harvard University's Museum of Comparative Zoology (MCZ).

In 2014, *Nautilus* collected 1,763 unique subsamples from a total of 602 samples. Just under 500 samples were sent to the MCZ and 82 were sent to the MGSL. So far, partnering scientists have requested 27 rock and nine core subsamples from the 2014 season. Requests for the 2013 geological samples include 74 rock and 35 core subsamples. Biological sample requests include 17 invertebrate and one ichthyology sample. Below we illustrate several examples of how scientists are using Nautilus samples collected in the last two years.

Example 1. Mid-Cayman Rise Spreading Rates (Connor Marr, Barbara John, Mike Cheadle)

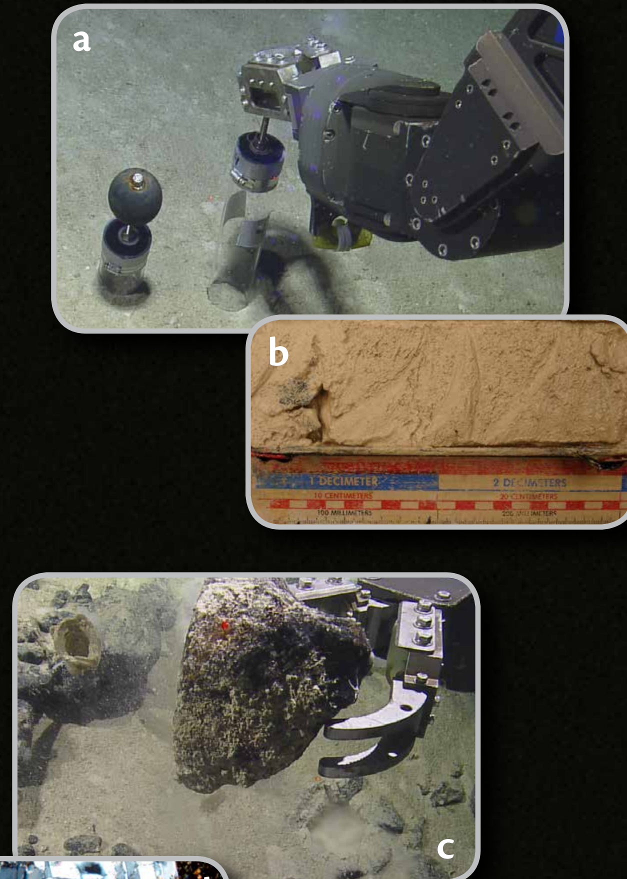
During the 2013 cruise to the Mid-Cayman Rise, gabbros were collected on the western side of Mt. Dent, the feature on which the Von Damm hydrothermal vent site was discovered by the NOAA Ship *Okeanos Explorer* in 2011. Zircons were separated from these samples as well as from samples previously collected by the submersible *Alvin* on the eastern side of Mt. Dent and dated at the Stanford University/USGS SHRIMP facility. Together, the two sample sets provide a sufficiently long baseline to permit the ages to be used to accurately estimate the rate at which the Mt. Dent oceanic core complex grew (i.e., the rate at which the detachment fault was slipping). The exciting result is that the detachment fault was and may still be moving much faster than expected. This estimate of the rate of detachment faulting could not have been made without *Nautilus* sampling on the western side of Mt. Dent.

Figure 1. (a) Cathodoluminescence image of zoned zircon grains from a (b) proto-mylonitic gabbro collected on the western side of Mt. Dent.

Example 2. Puerto Rico and Anegada Passage (Jason Chaytor)

Because the Northeast Caribbean is a complex geological environment dominated by subduction tectonics and volcanism, a wide diversity of rock types were collected during cruise NA035 around Puerto Rico and the Virgin Islands in 2013 (Figure 2). Thin section and geochemical analyses of the precisely located and diverse set of rock samples—limestone, marble, schist, granodiorite, basalt, and highly altered andesite—highlight the region's complexity. Radiometric geochronology analysis ($^{40}Ar/^{39}Ar$) is being performed on basaltic clasts from volcanoclastic breccias exposed along Desecheo Ridge (Mona Passage) and Barracuda Bank (Anegada Passage). These rock samples, along with a new suite of rocks collected from seamounts in the Anegada Passage during cruise NA052 in September 2014, will add to our understanding of the geologic history and tectonic/volcanic processes of the Northeast Caribbean.

Sediment push cores collected during NA035 and preserved intact for shipment to the repository were split and visually described to identify lithologic intervals, sedimentary structures, and variations in sediment deposition processes. Samples taken at specific locations in each core were analyzed to determine sediment texture (grain size) and composition. Micropaleontological analysis and radiocarbon (AMS ^{14}C) dating has been carried out on additional core samples to determine the geochronology of recent sedimentation across the Northeast Caribbean.



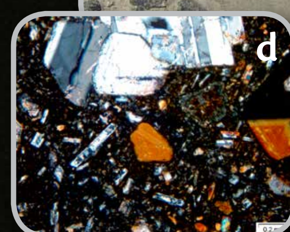


Figure 2. Photos of core and rock samples from the waters around Puerto Rico and Anegada Passage: (a) Taking a short core that was later (b) cut in half. (c) Collecting an andesite that was (d) sliced into a thin section.

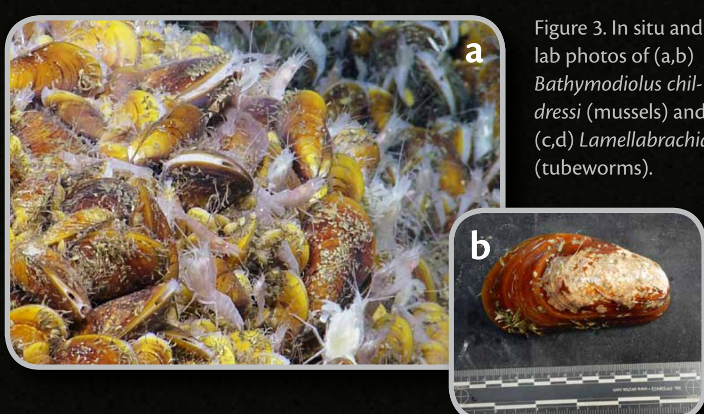
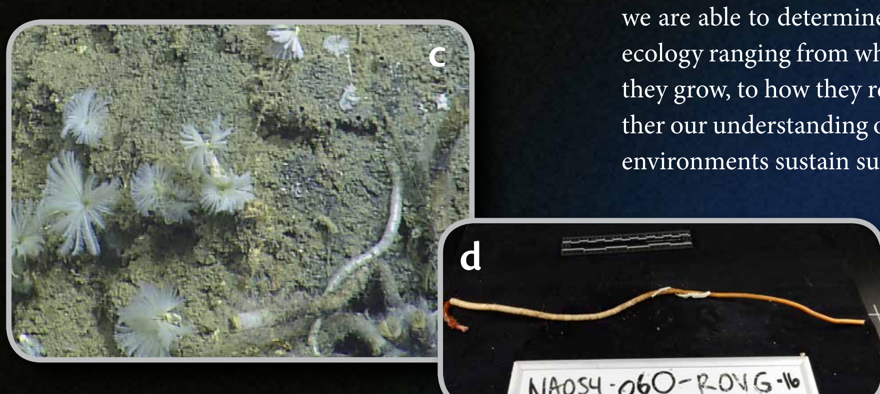


Figure 3. In situ and lab photos of (a,b) *Bathymodiolus childressi* (mussels) and (c,d) *Lamellabrachia* (tubeworms).

Example 3. Kick'em Jenny Seep Samples (Leigh Marsh)

Bathymodiolus childressi (mussels) and *Lamellabrachia* (tubeworms) were the most sampled organisms at the Kick'em Jenny cold seep sites (Figure 3). A tissue sample was extracted from each for genetic analysis work to be carried out by Duke University scientists. The remainder of the animal was preserved in a variety of ways to examine the autecology (the ecological study of a particular species) of each of the dominant taxa associated with these cold seep environments. Using a variety of techniques and analyses, we are able to determine many different aspects of species ecology ranging from what the organisms eat, to how much they grow, to how they reproduce. This knowledge will further our understanding of how these insular and ephemeral environments sustain such oases of life in the deep ocean.



Example 4. Mesoamerican Reef (Peter Etnoyer)

Corals and sponges provide structure, refuge, and habitat to deep-sea fish, crustaceans, and sea stars, but very few deep-sea coral colonies have ever been collected from the Mesoamerican Reef. In 2014, *Nautilus* collected the first ever samples of the stony corals *Enallopsammia* and *Madrepora* from Belizean waters (Figure 4). Although we logged the first observation of *Lophelia pertusa*, we did not collect samples because it was too small was and observed only once. We also collected the first samples of *Chrysogorgia fewkesii* (a deep-sea octocoral) and *Paracalyptrophora carinata* (a sea fan) from Belize. Each sample is precious, as every collection represents another step forward in our ability to describe, predict, and protect vulnerable deep-sea coral ecosystems.

The samples are used as reference material after matching expert-level species identifications to images. High-quality identifications are possible because the samples are preserved multiple ways, barcoded by their DNA, and then archived. Each image is tagged with its scientific name, geo-position, depth, temperature, salinity, and dissolved oxygen, and then shared online through NOAA's growing National Database of Deep-Sea Corals and Sponges.

Some coral specimens are collected for studies of age and growth rate. Sea fan colonies are useful for this purpose because these organisms have woody stems with concentric growth rings. Radioisotope and stable isotope studies of these rings allow for some interpretation of age and change over the life history of the animal. Deep-sea corals can yield hundreds, even thousands, of years of information about climate change in the deep sea.

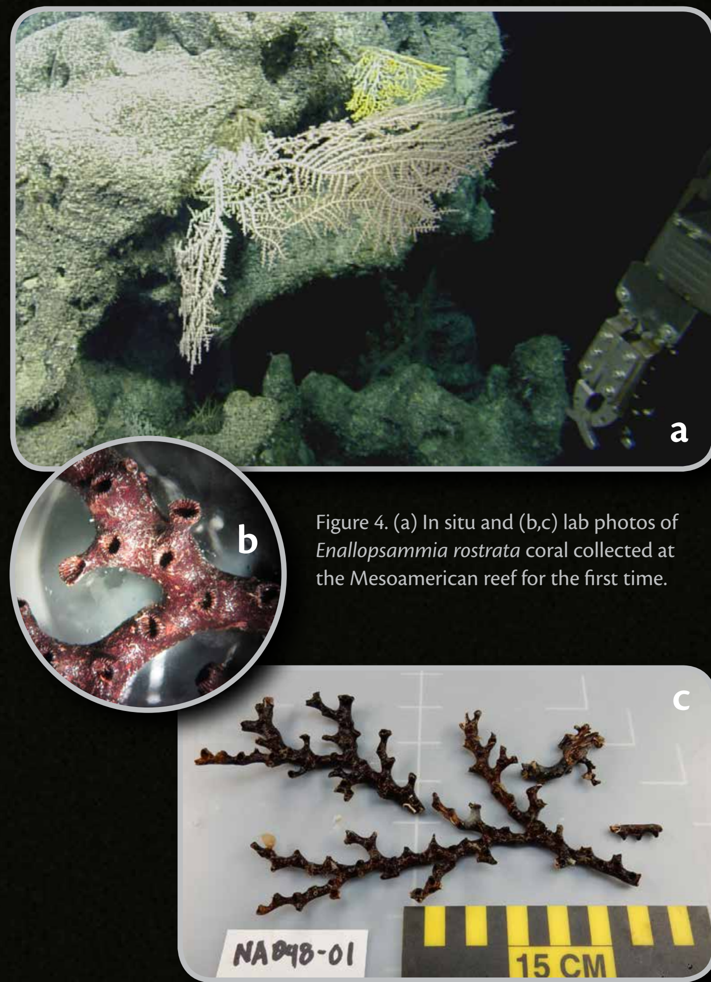


Figure 4. (a) In situ and (b,c) lab photos of *Enallopsammia rostrata* coral collected at the Mesoamerican reef for the first time.

Future of Sampling on *Nautilus*

One of the most coveted types of sample is a piece of hard rock, which helps geologists understand the origin of the seafloor. Loose rocks are often transported from other locations and cannot be used to determine local geological history. Currently, sampling hard rocks in situ is nearly impossible. In the past, we have employed hard objects to fracture rocks from more massive exposures, but this technique is unreliable. To improve our repertoire of geological tools, OET issued an Engineering Design Challenge to students at several universities, inviting them to design and propose tools that can break or core hard rock. The winning team from McNeese State University in Lake Charles, LA, will build their sampler, and it will be tested in the field during the 2015 *Nautilus* season.

EDUCATION & OUTREACH

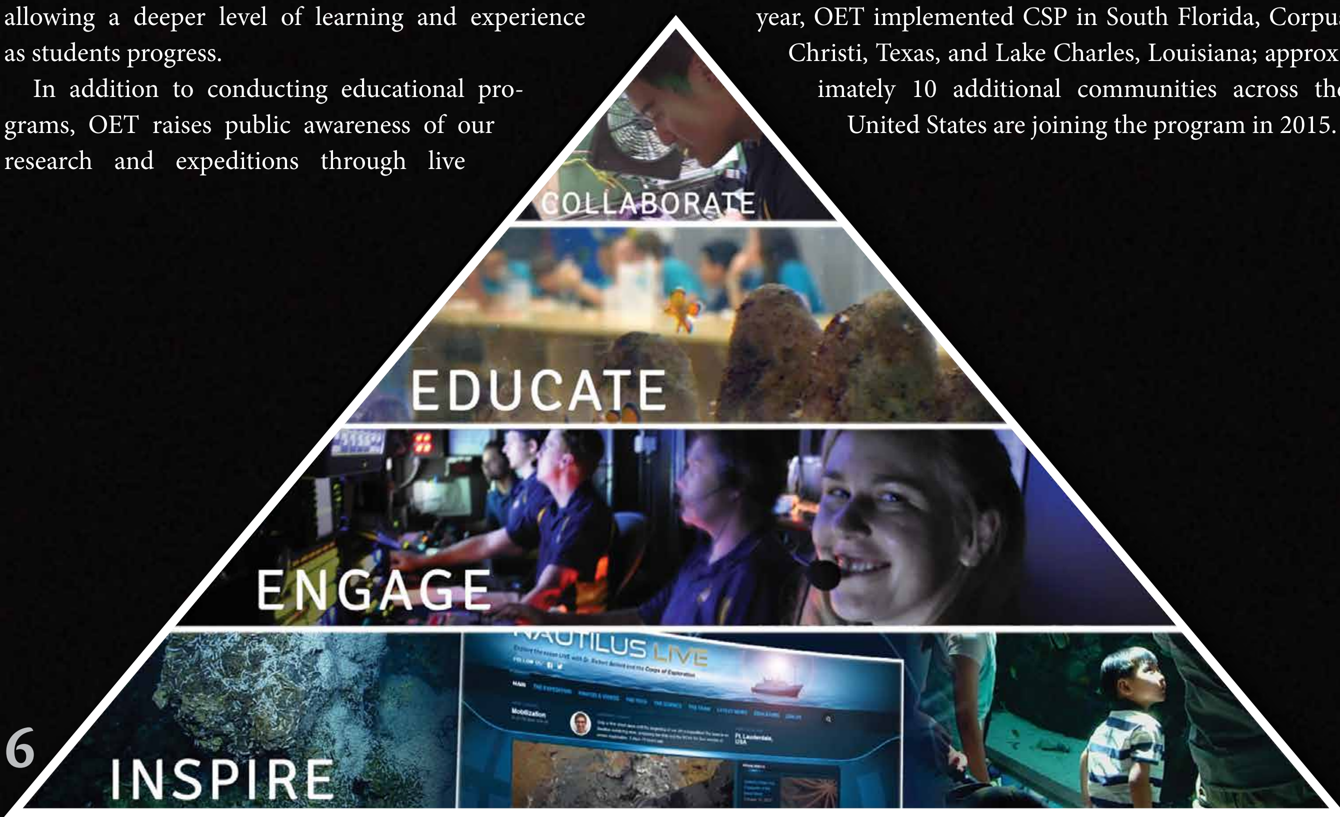
Ocean Exploration as a Platform for STEM Education & Outreach

By Allison Fundis, Samuel Garson, Scott Munro, Susan Poulton, Todd Viola, and Katherine L.C. Bell

By sparking interest in scientific inquiry and engineering design at a young age through exposure to ocean exploration and innovative technologies, and building on that interest throughout students' educational careers, the Ocean Exploration Trust hopes to motivate more students to be lifelong learners and pursue careers in STEM fields. Using research conducted aboard E/V *Nautilus,* the ship's associated technologies, and shore-based facilities at the University of Rhode Island (URI)—including the Graduate School of Oceanography (GSO) and the Inner Space Center (ISC)—we guide young students to early career professionals through a series of educational programs focused on STEM disciplines and vocational skills. The series uses a four-tiered approach—inspire, engage, educate, collaborate—where each step and subsequent program builds on the previous one, allowing a deeper level of learning and experience as students progress.

In addition to conducting educational programs, OET raises public awareness of our research and expeditions through live streaming video and interactions with scientists and engineers from the ship 24 hours a day via the Nautilus Live website (http://www.nautiluslive.org). Annually, our outreach efforts bring research launched from *Nautilus* to tens of millions worldwide and allow the public, students, and scientists to participate in expeditions virtually from shore.

In 2014, OET began targeting its suite of education and outreach programs to specific communities through a new initiative, the Community STEM Program. The CSP allows partner communities to engage community members in all of the educational programs OET offers, increasing the impact these programs can have in any individual location. OET's focus on the CSP represents a new approach that forges relationships across community partners with the common goal of increasing STEM literacy and proficiency. In the inaugural year, OET implemented CSP in South Florida, Corpus Christi, Texas, and Lake Charles, Louisiana; approximately 10 additional communities across the United States are joining the program in 2015.



TIER 1. INSPIRE

OET emphasizes the importance of role models in inspiring young people to pursue particular career paths and aims to highlight the variety of opportunities and STEM-related careers available, as well as the diversity of backgrounds of the participants in the Nautilus Exploration Program. Members of the Corps of Exploration who have joined *Nautilus* expeditions since 2009 use our growing online presence, television specials, and outreach at museums, aquariums, and science centers around the world to reach out to learners of all ages. Anyone with an Internet connection can join the Corps of Exploration in real time as we investigate the ocean and make discoveries.

The winning 2014 *Nautilus* patch design by Krisheree Shimamoto.

Robert Ballard and Katy Croff Bell connect to AMHQ with Sam Champion on the Weather Channel live from onboard *Nautilus*.

Outreach via Nautilus Live, News Media, and Social Media

OET's outreach goals include introducing a broad and diverse global audience to the wonders of ocean exploration. During the 2014 *Nautilus* expedition, the Nautilus Live website reached over 850,000 unique visitors, generating more than 2.5 million page views. The site featured 24-hour live streaming video of expedition operations and dives through cameras on the ship and on the ROVs, accompanied by live audio commentary from scientists, engineers, educators, and students. Nautilus Live's Facebook audience more than doubled to 27,000 followers, with an extended reach of 5.9 million. On Twitter, @EVNautilus also doubled its following to 4,800. During the expedition, Instagram and YouTube became prominent outreach platforms to reach younger audiences, and several of our most viewed videos brought our YouTube traffic up to 5.1 million video views in just two months.

The work of the scientists and engineers aboard *Nautilus* was featured in over 750 news media reports in print, television, radio, and online. Media outlets included *National Geographic*, The Weather Channel, CNN, BBC, NBC, Fox News, ABC, CBS, *The Atlantic*, and *The Houston Chronicle*. Stories covered many topics, from exploration of a German U-boat sunk in 1942, to finding a beautiful siphonophore and dumbo octopus, to sampling underwater volcanoes. Two television specials were filmed on board, including a National Geographic/PBS co-production of *NOVA* and a *60 Minutes* segment, both set to air in 2015. In addition, an ongoing partnership with The Weather Channel brought weekly updates to the morning show *AMHQ with Sam Champion* live from the ship, highlighting research being done throughout the five-month expedition. Scientists, educators, and students were often featured in local and national media stories.

By establishing strong relationships with journalists, social media influencers, and the outreach departments of affiliated universities and institutions, Nautilus Live reached more members of the public than all previous years combined and provided a prominent platform to feature participating partners and scientists. The total estimated extended audience for outreach efforts in 2014 was more than 70 million.

	2014	2013	2012
NAUTILUS EXPEDITION			
Global Audience Reach (estimated)	70 million	10 million	3 million
Articles in Press	750	85	15
NAUTILUS LIVE WEBSITE			
Unique Visitors	775 thousand	460,351	110,735
Page Views	2.2+ million	1,622,828	470,745
# of Questions Submitted by Viewers to E/V Nautilus	44 thousand	35,724	11,103
SOCIAL MEDIA			
Facebook Annual Growth (new followers)	14+ thousand	7,873	1,434
Twitter Annual Growth (new followers)	2.6 thousand	1,136	997
YouTube Views	5.2 million	35,254	14,589

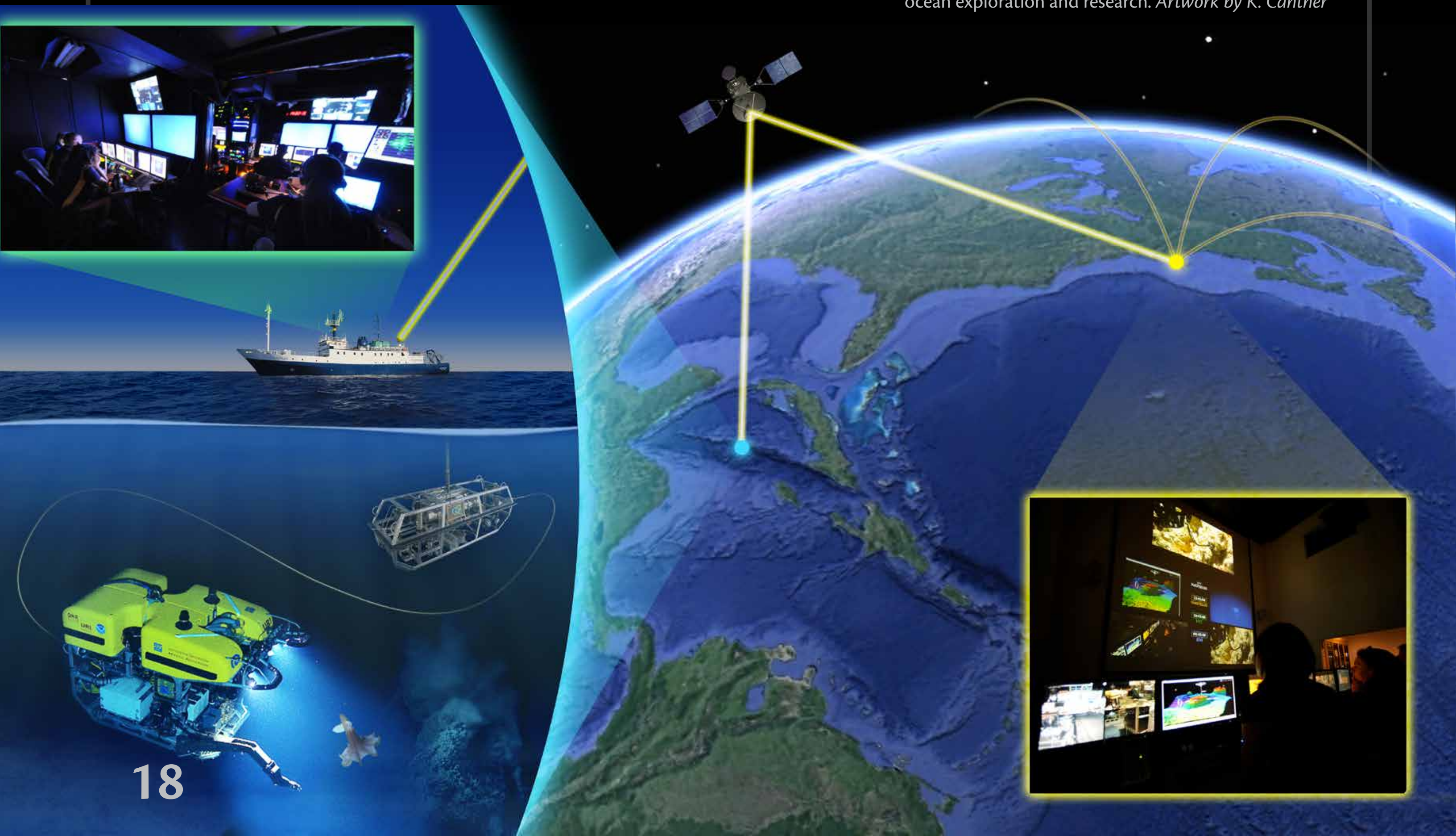
The *Nautilus* Exploration Program has increased its audience and reach significantly since 2012.

BOX 1. Telepresence and University of Rhode Island's Inner Space Center

By Dwight Coleman

The Inner Space Center at the University of Rhode Island Graduate School of Oceanography is the technical facility that supports all telepresence-related activities for E/V *Nautilus*. The primary requirement for establishing ship-to-shore telepresence activities is a high bandwidth Internet connection that is usually satellite based. The ISC is the telepresence hub for receiving, recording, and redistributing all streaming video, audio, and data, in addition to being the hub through which remote user participation occurs. The telepresence paradigm involves live interactive involvement by shore-based participants in the active ship-based exploration program. Shore participation takes many forms, including, but not limited to, remote scientific decision making and leadership, scientific data transfers for near-real-time processing, recording of scientific observations through online voice communications and instant messaging, delivery of interactive educational programming with live audiences, and remote participation by vast audiences through hosted websites. The year 2014 represented the fifth full year of operations at the ISC, primarily supporting the telepresence operations of both *Nautilus* and the NOAA Ship *Okeanos Explorer*. In addition to these two vessels, the ISC has been supporting telepresence projects on a number of other ships, primarily research vessels that are part of the UNOLS fleet. These ships use a mobile telepresence unit to allow switching and distribution of various video and audio sources. These feeds are streamed ashore to the ISC through a satellite Internet connection where they are recorded, transcoded for distribution through partner websites, and used for educational outreach programming, similar to the way Nautilus Live is run. The ISC is constantly being maintained and upgraded to support the technical equipment and evolving protocol requirements to support successful telepresence operations.

Telepresence technologies are used aboard E/V *Nautilus* to connect shore-based audiences to live ocean exploration and research. *Artwork by K. Cantner*



TIER 2. ENGAGE

The telepresence technology installed on E/V *Nautilus* allows the public to engage in a unique two-way dialogue with onboard team members connecting directly with onshore audiences through special programming at venues such as universities, museums, and science centers. Shipboard broadcast capabilities enable educators, scientists, engineers, and students to participate in live interactions with tens of thousands of guests per year at these venues and with online audiences via the Nautilus Live website.

Engaging Shoreside Audiences Through Live Ship-to-Shore Interactions

Building on a successful 2013 season, OET continued its robust program of live interactions during the 2014 expedition, conducting over 350 interactions with more than 60 locations worldwide. Through this program, guests at partner museums, aquariums, and science centers engage with members of the Corps of Exploration directly from E/V *Nautilus* through facilitated shows at partner sites. Major venue partners during the 2014 expedition included Mystic Aquarium in Connecticut, Exploratorium in San Francisco, Titanic Belfast Museum in Northern Ireland, and Museum of Discovery and Science in Fort Lauderdale, Florida. OET also continued outreach programs with a variety of schools, universities, and out-of-school programs, including Boys and Girls Clubs.

Another key engagement point for students and the public is the "Send a Question" feature on the Nautilus Live website. Enhancements made after the 2013 season resulted in submission of approximately 45,000 questions to our scientists and engineers in 2014. These questions, submitted by onshore viewers, were answered over the audio accompanying the live streaming video feed. This format also allowed the public to play a role in identifying archaeological and biological discoveries made throughout the expedition season, creating a crowd-sourced participatory experience that encouraged the public to dive deeper into the content and research being conducted on board.

TIER 3. EDUCATE

By establishing partnerships with schools, out-of-school programs, and curriculum developers, OET has developed and implemented a series of educational programs that has exposed hundreds of thousands of students to the breadth of STEM disciplines used in ocean exploration and research since 2009. OET's educational resources and programs—including K12 STEM Learning Modules, the Honors Research Program (HRP), the Science & Engineering Internship Program (SEIP), and the Science Communication Fellowship (SCF)—are structured in a way that a young child could begin using the resources and continue through the program as they mature.

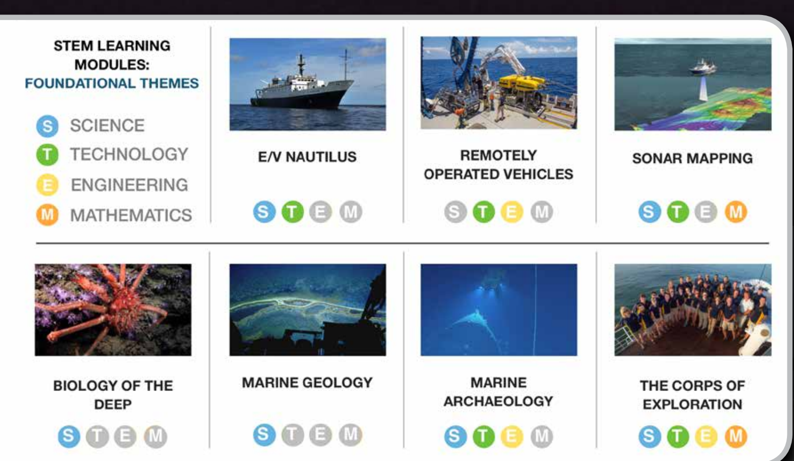
K12 STEM Learning Modules

The Nautilus Exploration Program K12 STEM Learning Modules, set to launch in spring 2015, are a series of lessons that use the research and operations conducted on board *Nautilus* to engage learners with the STEM disciplines and help them develop scientific inquiry skills. Development of these modules is being guided by performance expectations of the Next Generation Science Standards, Common Core State Standards, and Ocean Literacy Principles. Each lesson will explore a facet of the Nautilus Exploration Program and guide students through the myriad STEM components involved in deep-sea exploration, including real-world challenges that the Corps of Exploration face every day and the concepts used to solve them. Lessons will come with guiding questions, themes, standards addressed, and educator and learner instructions, as well as extensions and differentiation. This structure means that each lesson can be adapted for use with a variety of audiences and at many levels. Educators within each of OET's Community STEM Program locations will have the opportunity to attend training workshops to explore these resources and integrate the lessons into their own educational practices.

Honors Research Program

Since 2010, HRP has provided the opportunity for a small cohort of rising high school seniors to participate in a five-week summer program at URI GSO followed by a culminating experience onboard *Nautilus.* While at GSO, students are exposed to the interdisciplinary nature of oceanography by experts in geology, biology, archaeology, engineering, and computer science. Students collaborate on research projects aimed at preparing them for their time at sea and providing them with the opportunity to contribute to the scientific objectives of their expeditions.

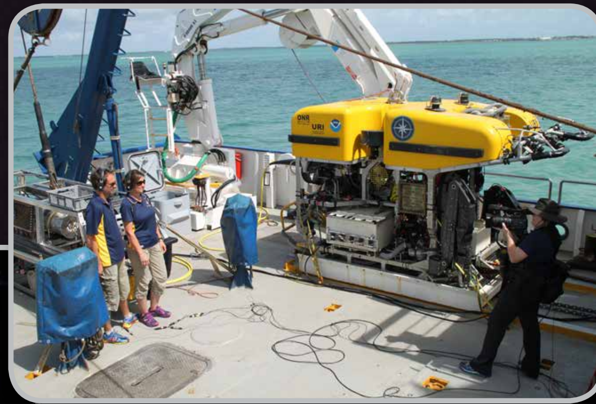
In its fifth year, eight students participated in HRP from public and private high schools in California, Connecticut, Florida, Georgia, New Jersey, South Carolina, Texas, and Virginia. While at GSO, the students collaborated on two projects: (1) an extensive analysis of the distribution of invasive lionfish seen during *Nautilus* expeditions in 2013 and 2014 in the Gulf of Mexico and Caribbean Sea, and (2) the design, building, and deployment of four ocean drifters—two surface drifters and two deep drifters, or drogues—to study complexities of global ocean currents. Through both of these projects, students were able to make direct and significant contributions to data sets being curated by researchers at the US Geological Survey, NOAA, and the Reef Environmental Education Foundation.



(above) K12 STEM Learning Modules will enable formal and informal educators to explore the many aspects of STEM used in ocean exploration with their students.

(below) The 2014 HRP cohort with the four ocean drifters they designed, built, and deployed at sea.

(right) SCFs Nell Herrmann and Lloyd Godson connect live from the back deck of *Nautilus* to a shoreside audience at a science center.



(above) Katarina Bujnoch, an ROV Engineering Intern, pilots ROV *Argus* while on watch.

Science & Engineering Internship Program

The SEIP has enabled hundreds of undergraduate, graduate, and community college students studying all ocean science disciplines, ROV engineering, seafloor mapping, or video engineering to have real-world experiences aboard *Nautilus*. Interns are selected through a competitive application process. They are embedded directly in the ship's professional teams for three to five weeks, allowing intensive learning and training experiences. Ocean Science Interns play a critical role as members of the science team during ROV dives and seafloor mapping surveys. ROV Engineering Interns learn about the vehicle systems, maintenance, and operations in addition to co-piloting *Argus* during ROV dives. Video Engineering Interns operate video equipment during ROV dives and learn about the complexities of the shipboard broadcast system that allows *Nautilus* to stream live footage to shore.

Sixteen interns from 10 US states and Puerto Rico participated in the 2014 SEIP, including students representing the National Eagle Scout Association, US Naval Academy, US Coast Guard Academy, and NOAA's Educational Partnership Program.

Science Communication Fellowship

The SCF program trains formal and informal educators to communicate the science and operations of each *Nautilus* expedition to onshore audiences. At the beginning of the 2014 SCF program, Fellows attended an annual Science Communication Workshop at GSO to (1) learn effective science communication strategies and hands-on technical skills to enable them to translate their at-sea experiences to shoreside audiences, (2) gain a solid foundation for understanding the scientific and engineering objectives of the 2014 expedition, and (3) understand how to incorporate the Nautilus Exploration Program in both formal and informal educational settings.

While at sea, Fellows serve as key expedition communicators. They relay information and stories to shore-side audiences who are following the expedition via the Nautilus Live website and through live ship-to-shore interactions. Fellows are also responsible for translating their experiences into STEM-focused lesson plans or activities to be used in classrooms and/or out-of-classroom programs. Working through the spring of 2015, the 2014 Fellows are implementing these lessons and activities, many of which will be incorporated into the K12 STEM Learning Modules, shared with the growing network of Fellows, and made available online so that educators around the world can incorporate them into their classroom activities.

The 2014 SCF cohort included 21 educators from 12 US states—Arizona, California, Connecticut, Florida, Hawaii, Maine, Massachusetts, Missouri, North Carolina, Rhode Island, Texas, and Virginia—as well as the countries of Australia, Jamaica, New Zealand, Northern Ireland, and Wales. The 12 Fellows within the cohort who represented formal classroom instruction came from backgrounds in elementary to university education, special needs education, and homeschool education. The nine informal educators who participated in the 2014 program included a children's book author, a painter, aquarium educators, educators from non-profit organizations, and a marine edutainer.

TIER 4. COLLABORATE

Students who have risen through OET's programs are now scientists at universities or research institutions, engineers who have started their own businesses, and staffers for congressional committees, all continuing to contribute in their own ways to the exploration of our planet. We continue to work with many of these young scientists and engineers on oceanographic research, the development of new technologies, and maintaining ocean exploration as a high national priority.

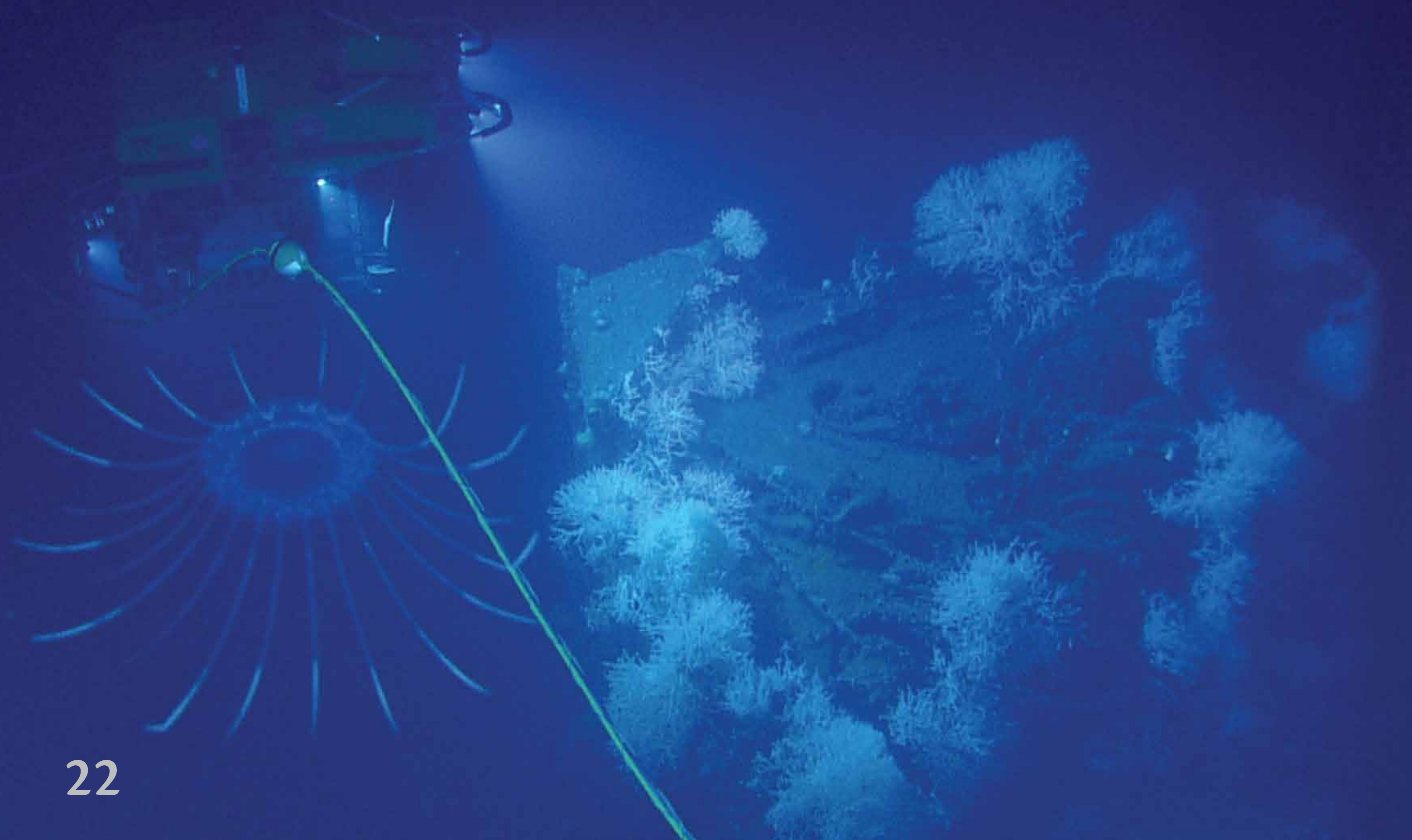
Engineering Design Challenge

The Engineering Design Challenge (EDC) was piloted in 2014, offering annual opportunities for undergraduate engineering students to creatively design solutions to current ocean engineering problems. In its first year, the EDC challenged students from Texas A&M Corpus Christi, McNeese State University, and Virginia Tech to design a new rock sampling tool for ROV *Hercules.* The winning EDC team from McNeese State University will work with professional OET engineers to build their instrument for deployment during the 2015 *Nautilus* field season. Future opportunities for the EDC could include expanding the program to high school and graduate students as well as broadening the disciplines involved, such as offering a software engineering challenge.

Scientist Ashore Program

A significant strength of *Nautilus* expeditions is the Scientist Ashore Program, which uses telepresence to allow shipboard scientists to collaborate with researchers on shore. Due to the uncertainty of what any exploratory expedition may discover, a team of experts can be called upon at any moment to contribute their expertise to the expedition from the comfort of their homes, offices, or laboratories. In addition to strengthening the scientific capability of the shipboard team, this program enhances the experience for the students on board and on shore participating in OET programs. The students actively participate in the collaboration and also gain access to a significantly larger pool of mentors. During the 2014 field season, over 25% of the science team was not physically onboard *Nautilus,* but instead connected to the ship via telepresence.

Working at the intersection of education and seagoing research, OET inspires lifelong learning and encourages students to pursue STEM educational and career pathways through creative educational programs and outreach efforts that expose students to the wonder of ocean exploration and technological innovation. Our goal is to nurture the next generation of explorers, scientists, and engineers and to ensure that any child can find a role model within the Corps of Exploration.



BOX 2. Artists at Sea: Offering Additional Perspectives

By Karen Romano Young, Lily Simonson, and Allison Fundis

A gorgeous photo with a well-crafted caption or an exciting video with an informative voice-over capture exciting and moving moments during our expeditions. So what do we need additional art media—paintings, sketches, comics, music—for?

Art draws us in. As shipboard communicators and artists, *Nautilus* 2014 Artists at Sea had the opportunity to show aspects of their adventures through their own eyes, offering an added perspective to communicating the complex scientific and engineering stories being told during the five-month 2014 expedition. The differences between them illuminate why having artists aboard is an important contribution for storytelling and education.

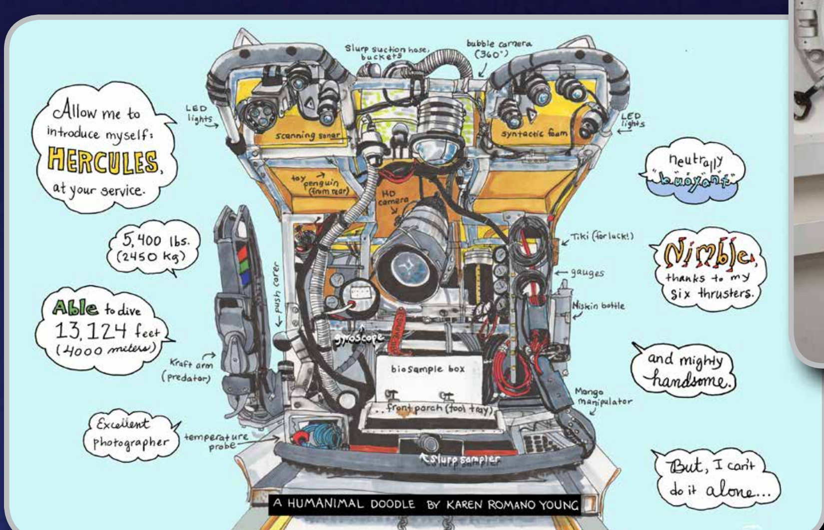
Lily Simonson captured the beauty of unique undersea life in splendid acrylic paintings, on canvases set up amid the buzz of the ROV hangar, and throughout the ship. Lily's work is displayed in galleries and on the Internet, and it travels along with Lily as she explores Antarctica and participates in art shows.

Karen Romano Young drew quirky pen-and-ink comics showing details of *Nautilus* and the ship's technologies and people, focusing on processes and personal perspectives. Karen's creations are linked with her work as a children's author and illustrator, and they will become part of magazines and a book.

Jim Salestrom, an award-winning musician and member of Dolly Parton's band, joined the 2014 *Nautilus* expedition for his second year with his guitar in tow. Jim has been able to capture the excitement of ocean exploration and the various personalities aboard *Nautilus* by writing songs while at sea and producing a full album about *Nautilus* and the Corps of Exploration (available at http://www.jimsalestrom.com/tracks.html).

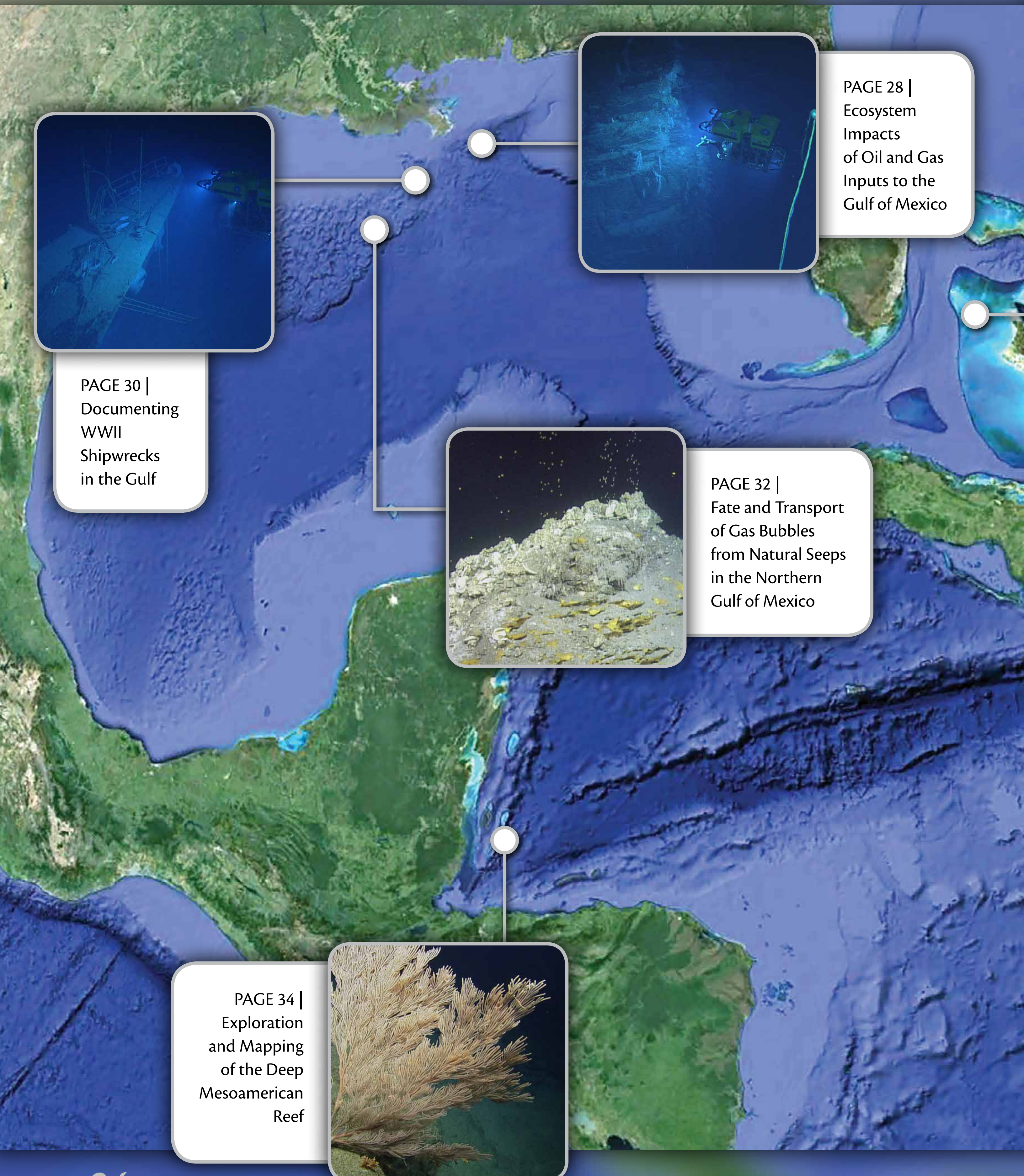
Having artists on board during the 2014 expedition allowed us to integrate the Arts into our programs to effectively transform our focus on STEM into STE[A]M education. They were powerful role models for young followers of the expedition who through these creative outlets may have seen themselves in a scientific endeavor for the first time. Or perhaps a follower already engaged in science and engineering saw it as a new way to tell stories. The Corps of Exploration and followers of the *Nautilus* expeditions were enthusiastic about having artists at sea. The seagoing experiences endure through the artwork—as well as the outreach made possible by it—long after our Artists at Sea come back ashore.

Lily Simonson paints on board using freshly collected shrimp specimens collected at hydrothermal vents as models. Acrylic painting on canvas, 48 x 30"



Karen Romano Young's detailed drawing of the front of ROV *Hercules*, with parts and functions detailed in comic-book style.

2014 FIELD SEASON SUMMARY



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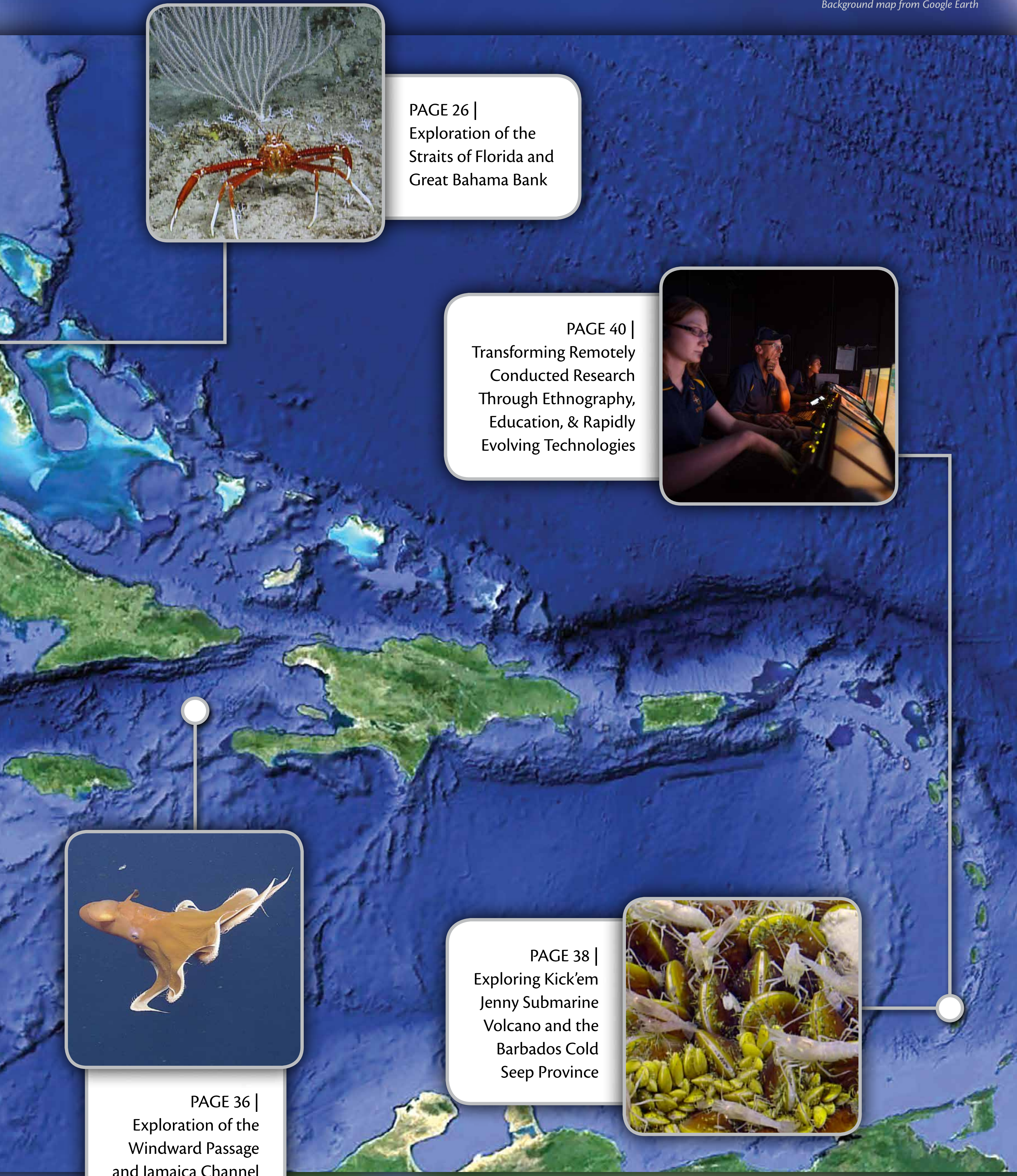

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PAGE 40 | Transforming Remotely Conducted Research Through Ethnography, Education, & Rapidly Evolving Technologies

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Exploration of the Straits of Florida and Great Bahama Bank

By Nicole Raineault, Larry Mayer, Gregor Eberli, Renato Kane, and Sarah Fuller

The Straits of Florida is a trough that separates the Florida Peninsula from Cuba and the Great Bahama Bank (Figure 1). It acts as both a conduit and a barrier for ecosystem exchange and is an important biodiversity hotspot. Strong, persistent currents create a contiguous environment for many benthic organisms, extending their habitat ranges from northern South America to southern Florida (http://www.nova.edu/ocean/messing/strait-of-florida). At the same time, these strong currents act as a biological barrier by creating strong differences in water mass properties from one side of the Straits to the other. The deep regions of the Straits of Florida contain an underexplored cold-water coral province that appears to be more diverse than known cold-water areas (Eberli et al., 2012).

The main objective of cruise NA041 was to explore the different seafloor geomorphological domains and associated benthic communities along the western edge of the Great Bahama Bank and area north of Cay Sal Bank. Three sites were selected for ROV study (Figure 1) because of their potential for discovery of new cold-water ecosystems and for improving understanding of geological hazards and processes. The first site was a large erosive sediment bypass located north of Bimini that is composed of a complex network of furrows and ridges. The mechanism of genesis is still speculative, but it was possibly formed by material avalanching from the edge of Cay Sal Bank (Mulder et al., 2012). Second, we explored large ridges that lie perpendicular to Cay Sal Bank. They are largest along the western slope of Great Bahama Bank and potentially host cold-water communities. Finally, we investigated a mysterious hole in the seafloor that was evident in multibeam data. The geological origins of this hole remain uncertain.

In addition to ROV operations, we used the hull-mounted EM302 multibeam between dives to map areas that complement the existing data sets. These surveys revealed numerous karst features, particularly along the Florida Shelf in the Straits of Florida. A final mapping survey was conducted in an area south of the Dry Tortugas, in advance of the next cruise (NA042).

North of Bimini

Hercules and *Argus* dove at the erosive ridge site north of Bimini. We took five short sediment cores in the trough and ridge environments and one crinoid sample (Figure 2). We observed spectacular large mounds populated by coral, sponge, and crinoid communities (Figure 3). Of particular interest was a large mound with step-like ridges, predominantly covered in crinoids.

Shimmering water observed at the top of a large vertical ridge was likely caused by a density flow due to water temperature variability. There was a 1.5°C difference in water temperature from the top of the ridge to the bottom (9.0°–10.4°C over 20 m relief). The crinoids were most dense along the ridge, where the water mass density gradient was visible.

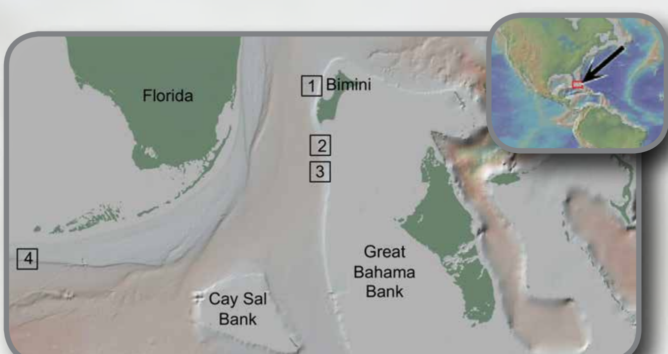


FIGURE 1. Locations of the ROV dives (1, 2, 3, and 4) along the Great Bahama Bank and mapping surveys (3, 4).


FIGURE 2. Collecting crinoid (top) and push core (bottom) samples at the erosive area north of Bimini.

Ridge, West Bahama Bank

The Ridge dive started just south of the base of the large (southernmost) ridge. The total relief of the explored ridge was 210 m (540–750 m water depth). We observed abundant dead standing coral covering the ridges and mounds, with about 10% new growth or colonization (Figure 4).

Bedforms were observed in the sediment between these low ridges (Figure 5). When the ROVs reached the top of the first large mound, we found increased recolonization by diverse species, including many varieties of coral, squat lobster, and sponge. We explored the first large ridge and took several samples, including a clump of dead coral, a push core in a rippled area between mounds, and a grab sample of a flaky crust.

Live *Lophelia* coral colonizes the tops of both ridges most abundantly, as well as some *Paramuricea* coral. There are also many varieties of octocorals present on these ridges.

Mysterious Hole

Using the hull-mounted multibeam, we mapped a hole in the ocean floor that looked out of place in the otherwise flat area west of the Great Bahama Bank (Figure 6). The feature was just over 100 m deep (824–930 m water depth) and had interesting concretions (possibly phosphorite?) at the bottom and also a hexagonal pattern similar to desiccation cracks. There were what appeared to be abundant manganese-coated coral along the inner margins of the crater. The center of the hole had bedforms and many cutthroat eel living among accumulated garbage (Figure 7). We observed a possible former seep community in cobbly terrain that hosted bivalves as well as live ophioroids, corals, and cnidarians. The origin of the hole remains unknown.

Future Work

Two future projects are planned for these data. University of Miami scientists will analyze the video footage with two goals: (1) calibrate the geophysical (backscatter) data to delineate seafloor composition and then expand this calibration to areas where the ROV did not go (i.e., characterize the seafloor), and (2) identify the deepwater fauna and determine their distribution with regard to depth, seafloor type, and morphology.

FIGURE 3. Example of ridge seascapes and biological communities observed north of Bimini.

FIGURE 4. Standing coral masses with some new growth (white) at the Ridge site on West Bahama Bank.

FIGURE 5. *Hercules* explores sediment bedforms between ridges.

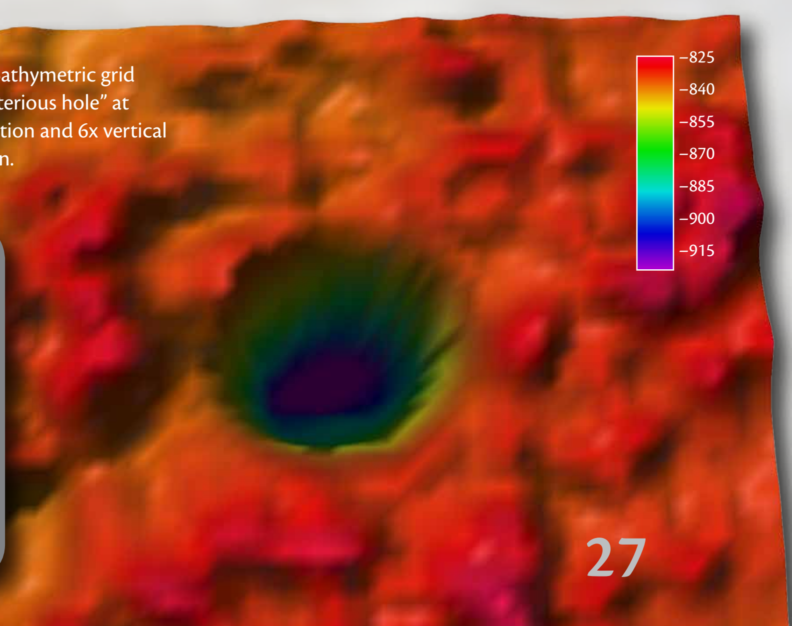


FIGURE 6. Bathymetric grid of the "mysterious hole" at 20 m resolution and 6x vertical exaggeration.

FIGURE 7. Sediment ridges and an abundance of eels were present on the seafloor at the bottom of the hole.

Ecosystem Impacts of Oil and Gas Inputs to the Gulf of Mexico (ECOGIG)

By Charles R. Fisher, Iliana B. Baums, Amanda W.J. Demopoulos, Nicole Dubilier, Fanny Girard, Kaitlin Kovacs, Melissa Kurman, Jeff Mentch, Jillian M. Petersen, Miles Saunders, Lizbeth Sayavedra, Ryan J. Sibert, and Sam Vohsen

There are thousands of deepwater sites in the Gulf of Mexico where persistent natural hydrocarbon seepage contributes to the formation of authigenic carbonate hardgrounds on a seafloor dominated by soft sediment and animals specialized for that habitat (Roberts et al., 2010). In these areas, rocks are formed by carbonate precipitation, which is an indirect result of the metabolic activities of free-living bacteria oxidizing hydrocarbons. Hardground sites with active seepage are often colonized by mussels that harbor methane and/or sulfur oxidizing bacteria (Fisher et al., 2007; Dubilier et al., 2008). As the carbonate development proceeds, tubeworms colonize actively seeping sites (Bergquist et al., 2002), and these tubeworm aggregations may persist for centuries (Bergquist et al., 2000, 2003). Continual seepage at some sites contributes to the production of carbonate boulders and exposed carbonate shelves that can persist long after seepage wanes. If the oceanographic conditions are appropriate, these sites may be colonized by colonial corals, which also provide habitat for numerous other animals (Fisher et al., 2007; Cordes et al., 2008).

In June and July of 2014, with support from the Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) Consortium, we spent 18 days at sea on multidisciplinary expeditions to explore new sites and revisit others to study the deep-sea corals, the infauna living in the sediment around the corals, and symbiont-containing mussels associated with active and historically active hydrocarbon seep sites. Our primary foci were studies of corals and coral communities impacted by the 2010 Deepwater Horizon spill from the Macondo well. Additionally, we collaborated with scientists from the Max Planck Institute for Marine Microbiology to collect several species of mussels from a variety of more active seep sites for both shipboard and laboratory-based analyses and experiments.

A primary focus of the Penn State team was to re-image corals at sites we have been studying for several years (Figure 1; Hsing et al., 2013; Cordes et al., 2014; Fisher et al., 2014b). This included four sites within 25 km of the Macondo well and two other control sites farther away. We used our new BFC6000 digital still camera, which produced stunning images at a resolution that allows detailed analysis of changes in the corals since our last visit (Figure 2). In order to allow more precise calculation of the sizes of all coral colonies, we also employed a new high-tech device specially fabricated by the *Hercules* team for this year's expedition: the WhAM (Whiffle Assisted Measuring) device (Figure 3). Over the course of the expedition, we re-imaged over 350 corals at the six sites we had previously visited and also discovered and imaged 100 new corals at those sites. In addition, we explored a new site in Mississippi Canyon lease block 258 and discovered a small coral community (of 11 colonies) 25 km to the east of the Macondo well. Preliminary analysis of the images confirms the stability and persistent good health of corals at our control sites and indicates that while some of the originally impacted corals are showing signs of recovery, others are losing branches and not recovering. It may be many years until we know the final fate of many of the impacted corals. Understanding the role of bacteria closely associated with deep-sea corals is another of our goals, and we collected small pieces from select coral colonies to better characterize the microbiomes associated with corals.

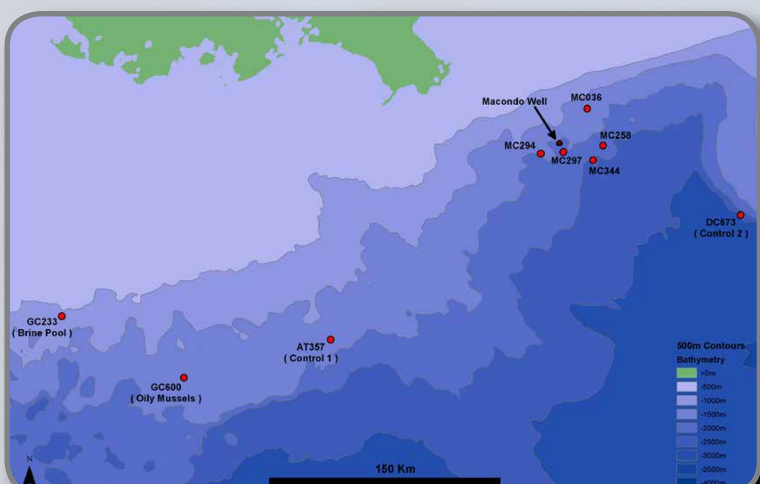


FIGURE 1. *Hercules* dive sites for the spring 2014 ECOGIG expedition

FIGURE 2. A portion of a colony of *Paramuricea biscaya* from lease block MC297 with healthy orange polyps expanded and other portions covered by encrusting hydroids.

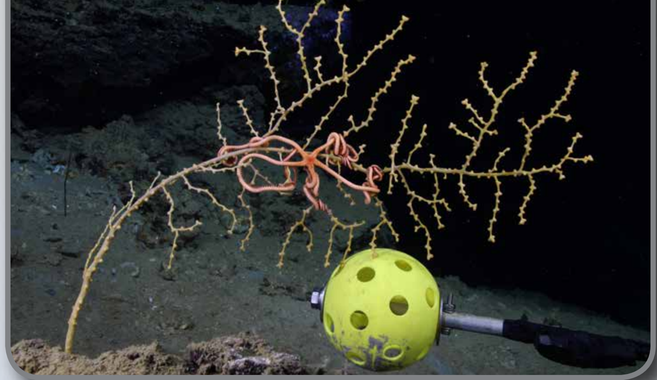


FIGURE 3. *Paramuricea biscaya* from lease block MC344 with attached commensal brittle star, and 8.9 cm diameter WhAM (Whiffle Assisted Measuring device) in frame for scale.

Although we know that the corals at our study sites are slow growing and very long lived (Prouty et al., in press), we do not understand the growth patterns within a colony or over a colony's long life. The team from Temple University used a custom-built device and calcein dye to begin to address these questions. The open-bottom chamber was placed over corals on the seafloor, then filled with fluorescent dye and left in place for 14 hrs to stain the coral (Figure 4). When the coral is collected in 2015, the new (unstained) growth areas will be quantified.

At each of our sites, we also collected push cores from the sediment near corals to continue our time series study of the effects of the spill on sediment communities. Previous studies have documented changes in infauna composition, diversity, and abundance in response to environmental contamination (Peterson et al., 1996; Gage, 2001). Montagna et al. (2013) used the composition of the infauna community to help determine the footprint of the spill's impact on the deep Gulf of Mexico. Analysis of infaunal abundance, diversity, and composition is very labor intensive and still underway for our 2014 samples. However, results from samples collected during previous cruises demonstrated shifts in community dominance at one site impacted by the spill as well as changes in the composition of the community at that site in the early years after the spill (Fisher et al., 2014a). Analysis of the samples taken during this cruise will be used by the US Geological Survey team to assess the resilience of the communities and monitor the time scale necessary to return to a community structure comparable to control sites.

Collections of three species of symbiont-containing deep-sea mussels from four sites complemented these studies. The ability to use a variety of substrates for energy and growth is a hallmark of many microbial species, and the University of Georgia team is conducting experiments to document novel metabolic processes in mussel-bacteria symbiosis. We anticipate exciting results from at least one of the sites where the mussels were collected from sediments that were literally bubbling oil. The team from the Max Planck Institute for Marine Microbiology (MPI) in Bremen is using a different species of mussel collected from Brine Pool NR1 (MacDonald et al., 1990) in experiments designed to help unravel the details of the "molecular conversation" between the host mussels and their symbionts that must occur for successful colonization. Understanding molecular host-microbe interactions, which also underpin non-symbiotic (pathogenic) bacterial infections, has been a long-standing goal in symbiosis research. These mussels can be maintained alive in the lab, and follow-up experiments to those conducted at sea were made with live mussels at Penn State when the MPI team visited in October 2014. Successful colonization of gill cells by labeled bacteria was confirmed.

All in all, we had a very successful cruise (Figure 5). We obtained critical data for our time series studies of the coral communities impacted by the oil spill, discovered a new community of corals near the Macondo well, collected samples that will be used to better understand the relations between corals and symbiotic microbes, and conducted experiments that will provide new insights into the molecular bases of interactions between bacteria and animal hosts.

ACKNOWLEDGMENTS. Funding for the cruise and associated studies was provided by the Gulf of Mexico Research Initiative (GoMRI) to the ECOGIG Consortium, the Max Planck Society, and the Gordon and Betty Moore Foundation. Support for A. Demopoulos is from the USGS Terrestrial, Freshwater, and Marine Environments Program. The cruise metadata are accessible through the GoMRI Information and Data Cooperative projects no. R1.x132.136:0021. This is ECOGIG contribution #306.

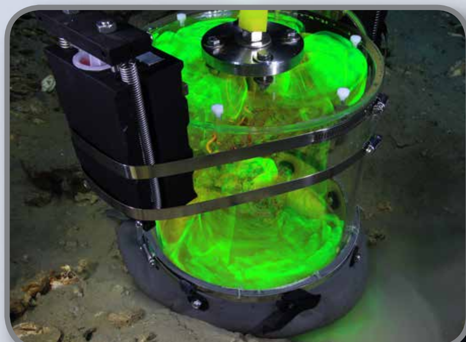


FIGURE 4. Coral staining device filling with the fluorescent dye calcein in situ over a small Paramuricid coral and commensal brittle star in lease block AT357.

FIGURE 5. *Hercules* at work imaging corals at 2,200 m depth on an escarpment in lease block DC673.

Documenting WWII Shipwrecks in the Gulf

By Michael L. Brennan, Katherine L.C. Bell, Clara Smart, J. Ian Vaughn, and Robert D. Ballard

In 1942, during World War II, Germany brought the war to America's waters. U-boats were sent to the East Coast as well as the Gulf of Mexico to disrupt the shipping routes for oil and other commodities, lying in wait mere miles from Louisiana's shore. Over the course of a year, 17 U-boats sank 56 merchant vessels along the shipping lanes at the Mississippi River delta offshore New Orleans (Blair, 2000; Warren et al., 2004). Sister ships *U-506* and *U-507* were among the first submarines to enter the Gulf in May 1942. On May 6, *U-507* sank the freighter *Alcoa Puritan*, which was carrying a cargo of bauxite, in waters east of the Mississippi Delta. The submarine stopped the freighter with gunfire into its side, and then sank the ship with a torpedo after letting the crew abandon ship (Blair, 2000). Over the next two weeks, these two submarines were responsible for sinking seven vessels off Louisiana, including the oil tankers *Gulfpenn* and *Gulfoil* by *U-506*.

Then in July, *U-166* entered the Gulf of Mexico to lay mines off the Mississippi Delta. After attacking ships in the Caribbean on its way to the Gulf, on July 30, the submarine torpedoed and sank the passenger ship *Robert E. Lee*, which was on its way into the Gulf from Trinidad (Blair, 2000). Although the ship sank quickly, only 25 people were killed, as most of the 407 on board were rescued by the anti-submarine escort *PC-566*. While *Robert E. Lee* was sinking, *PC-566* sailed over the suspected position of the U-boat and dropped depth charges, but only an oil slick appeared on the surface (Church et al., 2007). Two days later, a patrolling aircraft bombed a U-boat on the surface with a single depth charge, sinking what was assumed to be *U-166*. Only the location of the U-boat near the wreck of *Robert E. Lee*, discovered in 2001 during a survey by C&C Technologies, proves *PC-566* actually succeeded in sinking the submarine (Church et al., 2007). H.G. Claudius, the commanding officer of the escort ship, passed away in 1981 without recognition of the kill. A ceremony was held on December 18, 2014, to recognize his success and officially credit *PC-566* for sinking *U-166*. The honor was received by his son.

The *U-166* wreck lies at 1,450 m depth with the bow and stern sections approximately 140 m apart and a scattered debris field in between (Warren et al., 2004; Church et al., 2007). The U-boat was broken in half by the depth charge explosion, probably in close proximity to the deck of the submarine. With the exception of this damaged area, the remainder of the shipwreck is in good condition, with intact guns, railings, and conning tower, which has significant anemone and rusticle growth and evidence of deteriorated wood planking (Figure 1). The wreck of *U-166* was buried into the sediment, as sediment mounds were pushed up by the impact of the stern section into the seabed. Just over 2 km away is the wreck of *U-166*'s victim, *Robert E. Lee*. The shipwreck is largely intact and lies upright on the seabed. The stern of the ship had anemones growing on the deck gun and railings. We also investigated two lifeboats that now lie 700 m off the port bow of the wreck, and conducted a photomosaic survey (Figure 2).

FIGURE 1. *Hercules* investigating the wreck of German U-boat, *U-166*.

FIGURE 2. Photomosaic of the lifeboats sunk next to the *Robert E. Lee* wreck.

FIGURE 3. *Gulfoil* wreck overgrown by *Lophelia pertusa* and acting as an artificial reef for fish and other organisms.

During the expedition to investigate these sites, we also dove on the *Gulfpenn* and *Gulfoil* tanker wrecks. These wrecks are in shallower water, at 550 m depth, and are thereby colonized by different organisms. The deck of *Gulfoil* is overgrown with *Lophelia pertusa*, a deepwater coral, and inhabited by many species of fish that use the structure of the wreck as an artificial reef habitat (Figure 3). The wreck of *Alcoa Puritan*, however, is deeper, at nearly 2,000 m, and is largely clear of biological growth with the exception of rusticles formed from bacterial activity during the oxidation of steel (Figure 4a; Cullimore and Johnston, 2008). We also observed holes in the side of the ship from the shells fired by *U-507* during its attack (Figure 4b). A microbathymetry survey of the bow section conducted with *Hercules* illustrates the intact state of the shipwreck standing proud on the seabed (Figure 4c). This type of mapping of larger shipwrecks can only be done with the multibeam sonar at a higher altitude, but it provides a high resolution, three-dimensional map of the wreck site that illustrates features of the wreck sometimes not visible with cameras due to limited lighting (Brennan, 2013).

During the *Nautilus* expedition, we investigated one shipwreck that was not part of the U-boat war in the Gulf. Working with the Bureau of Ocean Energy Management, *Hercules* dove on a large, unidentified target from a side-scan sonar survey. The target turned out to be the wreck of the *Spruance*-class destroyer *USS Peterson*, sunk in 2004 as part of a training exercise (Figure 5). While we were exploring the wreck, veterans who once sailed on *Peterson* began writing into the Nautilus Live website, identifying *Spruance*-class features before we had come across the name of the vessel at the stern. Real-time identification of modern shipwrecks through Nautilus Live also occurred for the wreck of M/S *Dodekanisos* that we found in 2012 off Turkey (Brennan, 2013). In the current case, *Peterson* is a recent enough wreck that crew who had sailed on her were able to engage with the discovery. The investigation of this destroyer, alongside wrecks from World War II, speaks to the Gulf's long naval history.

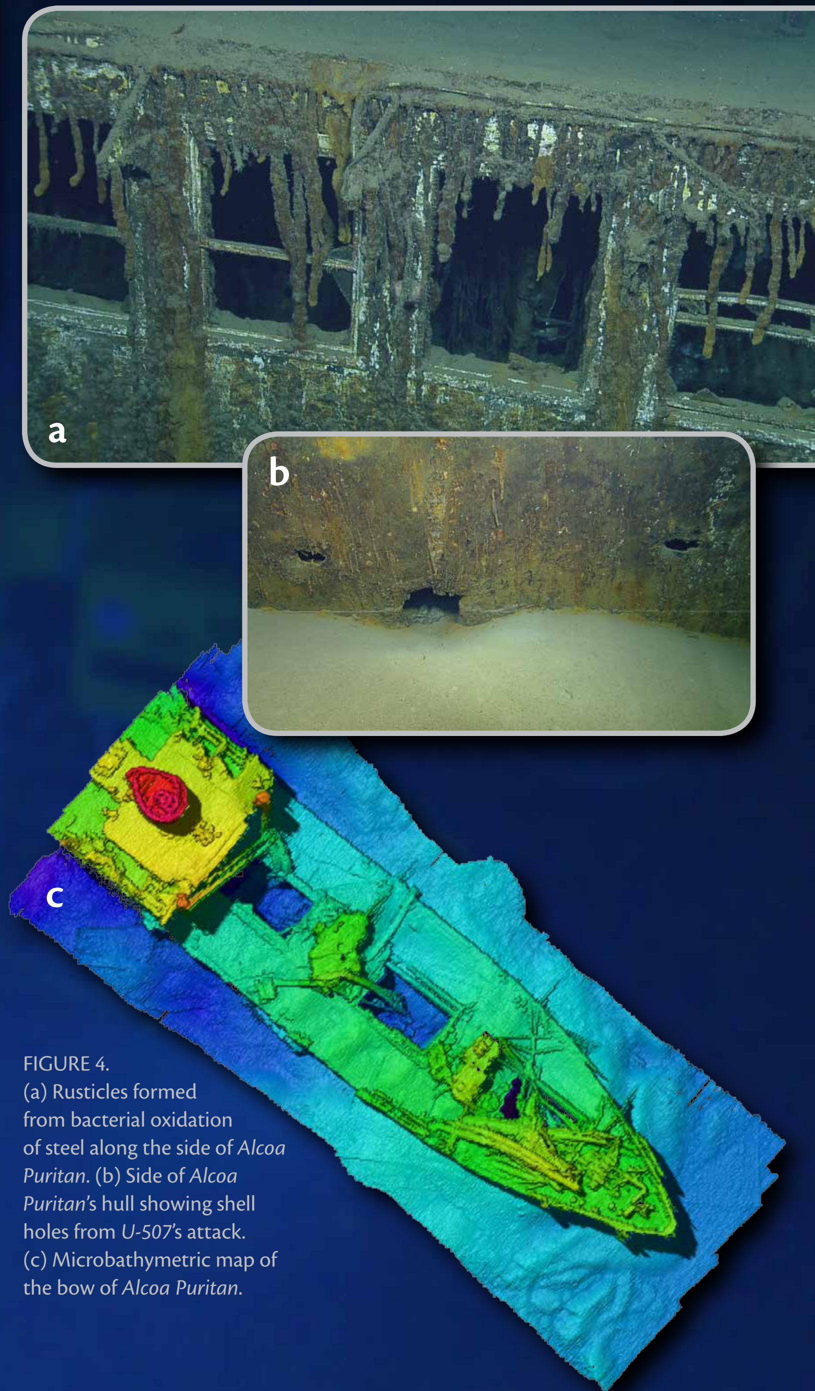


FIGURE 4.
(a) Rusticles formed from bacterial oxidation of steel along the side of *Alcoa Puritan*. (b) Side of *Alcoa Puritan*'s hull showing shell holes from *U-507*'s attack. (c) Microbathymetric map of the bow of *Alcoa Puritan*.

FIGURE 5. *Hercules* investigating the bow of the Spruance-class destroyer *USS Peterson*.

Fate and Transport of Gas Bubbles from Natural Seeps in the Northern Gulf of Mexico

By Scott A. Socolofsky, John A. Breier, Jeffrey S. Seewald, Binbin Wang, Samantha Maness, Christian Nygren, and Nicole Raineault

The fate of oil and gas emitted from natural seeps is an important component in the global hydrocarbon cycle. Cruise NA046/G07 on E/V *Nautilus* was conducted as part of the Gulf Integrated Spill Response (GISR) Consortium, funded by the BP/Gulf of Mexico Research Initiative (GoMRI). The GISR Consortium's goal is to understand and predict the fundamental behavior of petroleum fluids in the ocean environment. This capability is critical to inform decisions during response to oil spills and for development of mitigation plans, ultimately yielding significant environmental and financial savings. The mission of currently funded activities is to develop a multiscale modeling system validated by field and laboratory experiments to track the pathways of transforming hydrocarbons released from deep oil spills in the ocean.

The purpose of this cruise was to collect new field measurements needed to validate numerical models of oil and gas dissolution in the water column. To achieve this goal, the cruise visited two natural hydrocarbon seeps in the Gulf of Mexico and the scientists aboard used in situ and remote-sensing methods to gather information on seep plumes and the fate and transport of oil and gas released from the seafloor. The specific cruise objectives were to:

- Observe the evolution of bubble and droplet size distribution, analyze the gas composition, and measure dissolved hydrocarbon concentrations in and around the natural seep flares as a function of height above the seep source using in situ data collected by ROV *Hercules*.
- Characterize background ocean currents and chemistry using a moored current profiler, a conductivity-temperature-density (CTD) instrument to collect hydrographic profiles, and an array of Niskin bottles to take water samples.
- Conduct multibeam surveys between ROV dives to map the acoustic returns of the seep plumes over several days, thus, capturing some of their variability as a function of changes in the background currents.

The two seep sites visited on this cruise were near 1,000 m water depth, below the hydrate stability zone for methane. The first site had one main seep source (the Sleeping Dragon seep; Table 1 and Figure 1), which emitted a range of clean and lightly oiled gas bubbles. The second site, located in the GC600 megaplume region (Table 1 and Figure 2), was in a field of seep sources. The main seep investigated, known as the Confetti plume, was in a field of three similar seep sources and consisted of more heavily oiled gas bubbles. The background currents and the source fluid flow rates and composition were different at these two sites, so they provided a diverse data set for analysis and model validation.

The in situ measurements were made using ROV *Hercules*' base instrument packages, including depth sounder, ultra-short baseline navigation system, high-definition camera, 5–10 L Niskin bottles, an on-board CTD, and a Doppler velocity log system for auto positioning that was configured for this cruise to function to an altitude of approximately

FIGURE 1. Bubbles rise from the seafloor at the Sleeping Dragon seep at site MC 118.

Table 1. Target coordinates for each of the main seafloor vents investigated during the GISR cruise.

Region	Vent Name	Depth (m)	Latitude	Longitude
MC 118	Sleeping Dragon	888.3	28°51.1421'N	88°29.5109'W
GC 600	Confetti Plume	1185.4	27°22.1954'N	90°34.2624'W

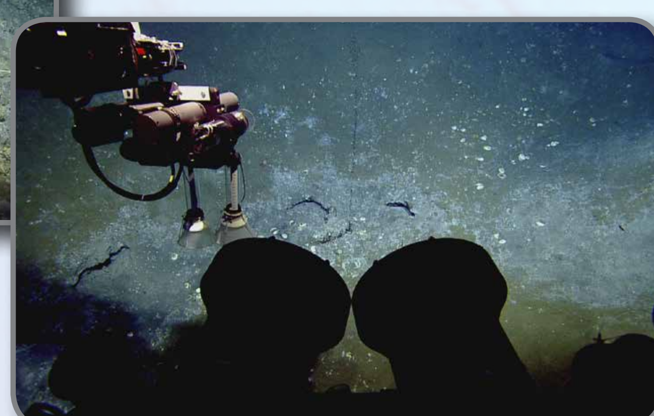


FIGURE 2. Confetti plume seafloor seep at GC 600 had three seep sources that resulted in heavily oiled gas bubbles.

FIGURE 3. SUPR sampler inlet with the rubber deflector plate (tube inlet in center of field of view) on the starboard manipulator arm of the ROV during sampling at Confetti plume.

120 m above the bottom. We added the following dedicated measurement platforms to the *Hercules* instrument payload:

- SUPR sampler. This sampler used 14 two-liter bottles to make precision, high throughput samples of discrete geochemical features in the water column. It was used to obtain end member samples exiting the seafloor, water column samples of plume water, and background samples in and around the seep plumes. The sampler was originally designed for suspended sediment sampling via recirculation (SUPR), and has since evolved to a wide range of sample types, for example, the collection of a sample at the Confetti plume source site (Figure 3).
- IGT samplers. Two isobaric gas tight (IGT) samplers were carried by the ROV on each dive. They were outfitted with cylindrical sample collectors to allow recovery of gas bubbles with hydrate shells at the source. The samples were then carried to a lesser depth where they dissolved and where the free gas could be drawn into the samplers. IGT samples of end member gas bubbles and of gas bubbles at various elevations (over 100 m) above the seafloor were collected, such as hydrate-coated bubbles at Sleeping Dragon (Figure 4).
- TAMU high-speed cameras. Two Phantom Miro cameras from Vision Research were placed in a stereoscopic configuration to make high-speed, high-resolution image sequences of bubbles and droplets within the seep plumes. Camera images were transmitted to the ship in real time over the ROV cable, allowing quantification of bubble and droplet size and shape and seep flow rate of free oil and gas, and evaluation of the presence of hydrate shells on the gas bubbles (Figure 5).
- Forward-looking Kongsberg M3 sonar. This system successfully followed the weak bubble plumes over 700 m of altitude above the seep sources, allowing the ROV to find the plume at any height. The system also measured plume cross-sectional dimensions as a function of height above the bottom.
- Down-looking acoustic profiler. Mounted on the front bumper bar of the ROV, this instrument measured the distance to the bottom when the ROV was close to the seep source (less than 5 m above the seafloor), allowing precise measurement of the altitude of the various sampling tools.

FIGURE 4. Isobaric gas tight collection tubes are filled with gas bubbles at Sleeping Dragon.

FIGURE 5. A raw image of bubbles at the Confetti plume site taken by one of the TAMU stereo cameras.

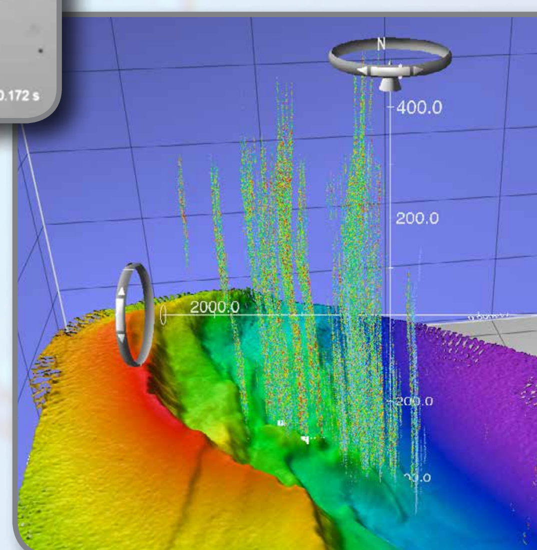


FIGURE 6. Fledermaus scene of the water column data for the multibeam surveys at GC600. Colored bathymetry shows bottom return; colored pixels in water column show locations of bubble plumes visible to the multibeam. Data processing and scene creation conducted by Nicole Raineault, member OET Science Party.

In situ chemistry samples recovered by the SUPR sampler and the IGTs were analyzed at sea for methane, hydrogen, and radon-222. On shore, samples will be analyzed for concentrations of higher molecular weight hydrocarbons and other gases and for radium isotopes. Niskin water samples will be analyzed for dissolved nutrients, salinity, dissolved inorganic carbon, and dissolved oxygen. Multibeam acoustic surveys were conducted along repeated ship tracks between ROV dives. These surveys were used to measure the acoustic backscatter from the bubble plumes in the water column, showing the evolution of plume trajectories with time as the currents changed (Figure 6).

The data collected during this cruise provide a clear characterization of the seep plumes and their fate in the water column. This information is being used with the Texas A&M Oilspill Calculator to develop models of hydrocarbon fate from natural seeps and accidental spills in the ocean. All data collected during this cruise will be made publicly available through the GoMRI GRIIDC database in July 2015.

Exploration and Mapping of the Deep Mesoamerican Reef

By Peter J. Etnoyer, Michael L. Brennan, Daniel Finamore, Stephen Hammond, Marsha Vargas, Xavier Janson, Suna Tüzün, Jamie Wagner, Danielle Ferraro, and Will Snyder

The Mesoamerican Reef (MAR) extends from the Yucatán Peninsula to the Gulf of Honduras, a distance of nearly 250 km along a rimmed carbonate shelf in the western Caribbean Sea. The MAR is considered the second longest fringing barrier reef in the world, after the Great Barrier Reef in Australia. It was explored to a depth of 300 m with R/V *Seamark* and the *Nekton* submersible in the 1970s (James and Ginsburg, 1979), but deeper parts had never been mapped or explored.

In August 2014, E/V *Nautilus* explored the Mesoamerican Reef's offshore slopes, atolls, and outer cayes. The expedition's objectives included mapping areas ranging from 50 m to 3,000 m water depth, exploring ecosystem habitats, ground truthing of multibeam and backscatter data using ROV *Hercules*, and collecting deep-sea corals and sponges for study.

The continental margin seaward of the barrier reef off Belize consists of a series of three shallow, northeast-trending continental ridges and two deeper outer basement ridges further to the east. Before this expedition, only sparse depth soundings of the study area were available. Thus, the first objective of the expedition was to map areas along the continental slope east of Lighthouse Reef, Glover Reef, and the Turneffe Atoll at high-resolution using the ship's hull-mounted EM302 multibeam sonar (Figure 1).

With maps in hand, the *Nautilus* team conducted seven ROV dives over six days. The dives confirmed indurated seafloor consistent with sonar backscatter returns, and small rocky outcrops were also occasionally observed. Many areas, especially those deeper than 500 m and the areas around Turneffe Atoll, were heavily sedimented with few outcrops or rocky surfaces suitable for coral colonization.

Carbonate submarine morphology was observed along exposed surfaces and slopes of the shelf break between 100 m and 300 m water depth. Dissolution features were evident along the exposures, and are commonly observed in subaerial bedrock in Belize (Brennan et al., 2013b; Figure 2). Outcrops were often composed of heavily sedimented, stepped carbonate blocks that had been transported downslope. *Halimeda* sands and *Strombus* conch shells were seen down to 600 m depth. Very little of the block surfaces appeared to be colonized, presumably due to frequent slumping and other mass wasting events.

The deepwater fore-reef and slope off Belize may represent important stepping-stones for dispersal of deepwater corals from the Caribbean Sea to the Gulf of Mexico. Deep-sea coral colonies grow very slowly over hundreds to thousands of years, making them vulnerable to bottom-contact fisheries, and valuable to climate science. Large soft coral colonies have growth rings, allowing scientists to study oceanographic conditions decades and centuries ago. Therefore, biological sampling of corals was a high priority for this expedition.

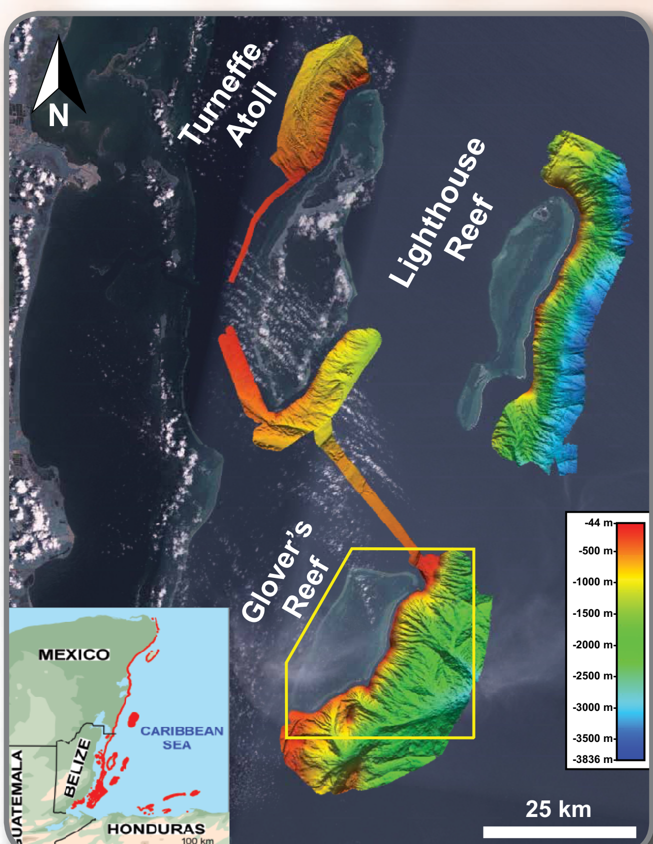


FIGURE 1. Overview of the bathymetric mapping off Belize. The inset at lower left shows the larger map as a light gray box and the Mesoamerican Reef in red.

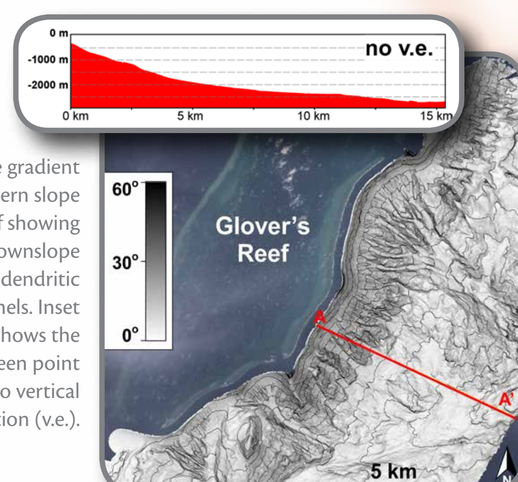


FIGURE 2. Slope gradient map of the eastern slope of Glover's Reef showing numerous downslope convergent dendritic submarine channels. Inset at upper left shows the slope profile between point A and A' with no vertical exaggeration (v.e.).

The science team collected corals and sponges for species identification and age and growth determination, and also to learn whether these corals may be preyed upon by sea stars, gastropods, or urchins. During four sampling dives, the research team collected 13 corals, five sponges, nine echinoderms, six crustaceans, and two worms. Several species were collected for the first time off Belize. At least 28 species are represented by the collection. These samples were archived at Museum of Comparative Zoology and made available to taxonomic experts around the world.

The largest and most abundant coral fauna we observed was off Lighthouse Reef. Rocky habitats near 500 m water depth were colonized by the octocorals *Chrysogorgia fewkesii* and *Iridogorgia* and the large sea fan *Paracalyptrophora carinata*. The stony corals included *Enallopsammia rostrata* and *Madrepora oculata*. A small colony of *Madrepora carolina* was also observed. The epifauna in shallower water (100–250 m) were hexactinellid sponges and *Nicella* sea fans (Figure 3). This is the first report of these species from Belize.

The samples and observations of the recently described *Paracalyptrophora carinata* (Figure 4) were particularly important because they add context to similar observations in Honduras (Etnoyer et al., 2011). The colonies off Lighthouse Reef were large (> 1 m) with a thick holdfast (6 cm) useful for age and growth estimates using radioisotope techniques. One stolon of a dead colony was collected for this purpose. It had dense, concentric rings, and a golden color (Figure 5a). The species identity was confirmed using NOAA's scanning electron microscope (Figure 5b; see also Cairns and Bayer, 2004).

Overall, their were few coral colonies, likely due to high sedimentation and a paucity of exposed hard bottom habitat. When hard bottom was available, colonies were small and infrequent. Stalked crinoids and feather stars were also scarce, and fish and echinoderm densities were low. However, diversity and habitat heterogeneity were high, thus making it very likely that new species and new habitats will be found as the region is further explored.

Given the short timeframe of the cruise, the extent of the area mapped by *Nautilus* in 2014 is remarkable, but it represents only 15% of the seafloor habitat off Belize between 50 m and 3000 m water depth. The ROV surveys pushed the limits of observation from 300 m to 1,000 m, but important bathymetric features lie deeper, for example, along a mid-slope collapse scar near 1,500 m water depth. Mapping and observing hard bottom habitats at these depths holds promise for new discoveries. Given the geology and biology revealed by this expedition and others, mapping the entire Mesoamerican Reef, from the Bay Islands to the Yucatán Channel, should remain a high priority for future expeditions. The region provides a unique opportunity to link investigations of shallow, mesophotic, and deep reef habitats in the western Caribbean Sea and the adjacent Gulf of Mexico.

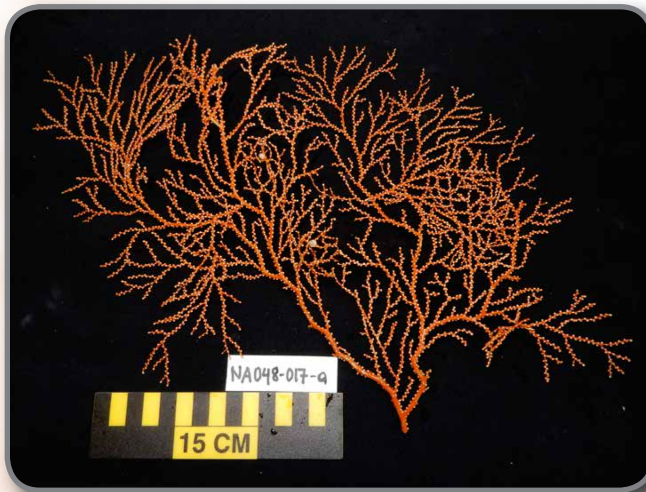


FIGURE 3. A *Nicella* sea fan from the mesophotic zone, where surface light is diminished.

FIGURE 4. The deep-sea fan *Paracalyptrophora carinata* off Lighthouse Reef in Belize.

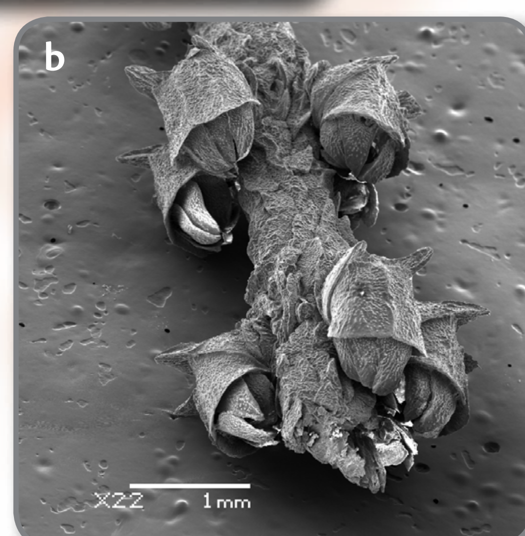


FIGURE 5. (a) This fossil coral holdfast is climate science gold. (b) SEM image of the *Paracalyptrophora carinata* polyps.

Exploration of the Windward Passage and Jamaica Channel: Tectonic Gateways to the Caribbean Sea

By Marie-Helene Cormier, Ruth Blake, Dwight Coleman, Kelly Guerrier, Nixon Saintilus, Jamie Wagner, and Steven Auscavitch

In August 2014, E/V *Nautilus* explored the region delimited by two deep straits of the northern Caribbean: the Windward Passage, which separates Cuba and Haiti, and the Jamaica Channel, which separates Jamaica and Haiti (Figure 1). Tectonically, the depth of each strait is controlled by a left-lateral transform fault: the Septentrional Fault and the Enriquillo-Plantain-Garden Fault (EPGF). Both faults slip at approximately 1 cm/yr and have produced large historical earthquakes. The Septentrional Fault last ruptured offshore Haiti in 1842, destroying the town of Cap Haitien. A previously unrecognized fault that abuts the EPGF system (now known as the Léogâne Fault) ruptured catastrophically in 2010 near Port-au-Prince, with devastating consequences, including a death toll of greater than 100,000. Tsunamis were associated with both earthquakes. Hydrographically, the Windward Passage is a major Caribbean "gateway," accommodating two-way water exchange between the North Atlantic Ocean and the Caribbean Sea. Thus, it is likely to be of key importance for deep-sea ecosystems.

The specific objectives of expedition NA050 were to follow the traces of the Septentrional Fault and the EPGF and detect signs of recent tectonic activity and landslides, characterize the water column, observe the benthic ecosystems, and inventory potential cold seeps. We also set out to explore the slopes surrounding Navassa Island, a small, uninhabited island managed by the US Fish and Wildlife Service as a National Wildlife Refuge. Because of the protected status of this island, a unique and pristine mesophotic ecosystem was expected in its vicinity. Navassa is located only 20 km north of the EPGF, but its structural and tectonic relation to that plate boundary is unclear.

Altogether, eight *Hercules* ROV dives were carried out in water depths ranging from 2,300 m to 200 m. The Septentrional Fault is clearly visible in the *Hercules* video imagery as impressively steep escarpments, or in places, as a series of thin slivers of rocks aligned subparallel to plate motion (Figure 2). South of Navassa Island, we explored the headscarp and a 4 km wide landslide debris field. Its age remains unclear, making it difficult to correlate it to a particular earthquake event. At the base of the steep northern slope of Navassa Island, we observed lava flows draping over sediment (Figure 3), which may have been emplaced as part of the Caribbean Plateau or as part of the volcanic arc that migrated eastward through the area—suggesting that Navassa likely grew as a coral atoll over a volcanic substrate. We also explored the length of a small canyon that had been folded and whose walls were colonized by a diversity of corals and other benthic animals. While we anticipated discovering some fluid seeps along the transform fault, as has been reported elsewhere in similar tectonic settings, we did not. This is not surprising because seeps typically affect only small areas of the seafloor, can be ephemeral, and are often discovered serendipitously.

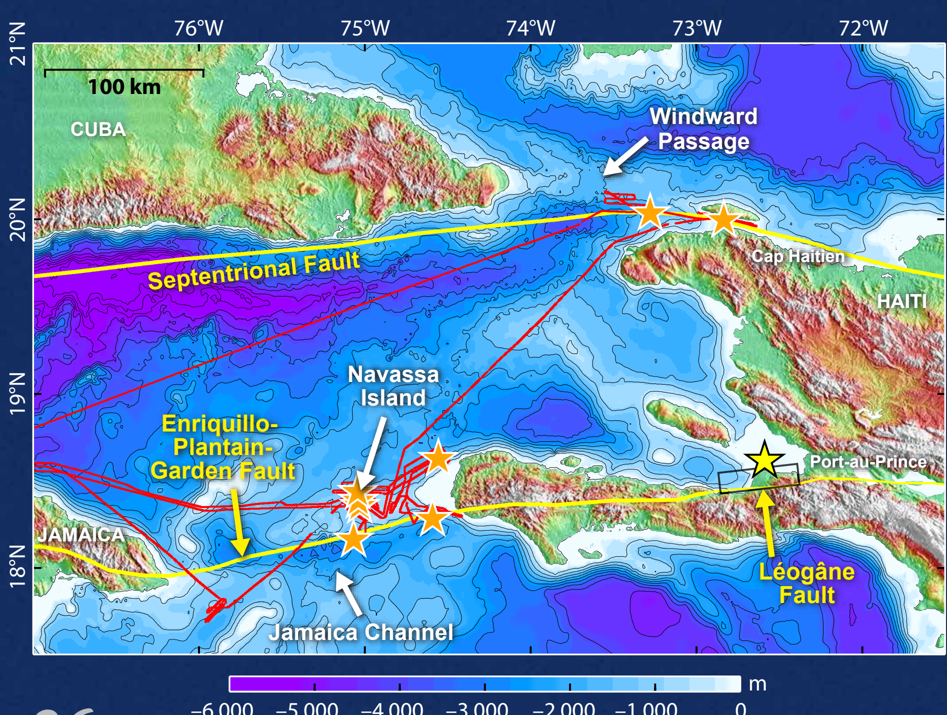


FIGURE 1. Map of the Windward Passage and Jamaica Channel regions, showing the location of the islands of Cuba, Jamaica, and Haiti, along with the two major strike-slip fault systems, the Septentrional Fault to the north and the Enriquillo Plantain-Garden-Fault to the south (yellow lines). The location of the 2010 Port-au-Prince earthquake is indicated by a yellow star, and the black box approximately outlines the associated rupture area on the Léogâne Fault. The red lines indicate the ship tracks and the orange stars the dive locations.

FIGURE 5. An unidentified cirrate octopod swimming above the seafloor along the Septentrional Fault Zone.

FIGURE 2. Highly tectonized seafloor within the damage zone of the Septentrional Fault.

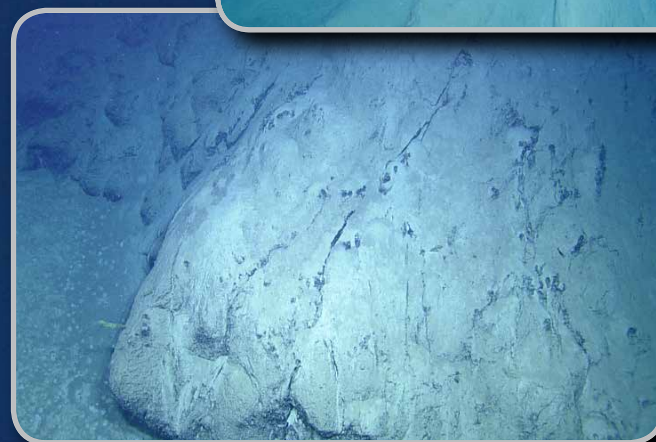


FIGURE 3. A lava flow covered with a thin veneer of sediment exposed at the base of the steep northern slope of Navassa Island.

We took water column measurements during the ROV dives, particularly along the deepest parts of the Windward Passage and Jamaica Channel. We used the CTD and Niskin bottles mounted on the ROV to obtain information on water column properties and to sample different water masses within the Windward Passage proper, along the convergence zone between Atlantic and Caribbean waters, and within and outside of Jamaica Channel. We also obtained vertical profile samples of the water column to study regeneration of dissolved phosphate from sinking organic matter ("marine snow") using PO_4 stable oxygen isotope compositions. Two mini-autonomous plume recorders (MAPRs) clamped onto the ROV cable measured and logged the presence of suspended particulate matter, oxidation-reduction potential, pressure, and temperature. The data did not reveal anomalous measurements that might have indicated hydrothermal plume activity or fluid seeps along the fault systems.

Some physical properties of water circulation through the Windward Passage and Jamaica Channel were examined during the cruise. Two drifters developed and deployed by the students involved in the Ocean Exploration Trust's Honors Research Program (see page 22 for details) floated with the ocean currents, and their positions were tracked with a GPS receiver. The information collected was regularly transmitted to a shore-based server, allowing the students to record drifter speed and location over time. Both drifters recorded data for several months and revealed an interesting pattern of eddy activity and an overall surface flow through both channels directed westward toward the Yucatán.

This *Nautilus* expedition provided the first observations of animal life on the deep seafloor of the Windward Passage and Jamaica Channel, as well as the deep slopes of Navassa Island and Hispaniola. During our exploration of the region, we encountered diverse seafloor communities. Hard-bottom slopes of Navassa Island and Hispaniola, below ~200 m, were frequently covered in clusters of sponges and cold-water corals. Rocky walls and escarpments in this area hosted a diverse assemblage of corals, including solitary and colonial stony corals, primnoid and bamboo octocorals, and black corals, as well as their numerous invertebrate and fish associates. Fauna were notably sparser on soft sediment patches at the bases of slopes and escarpments, and consisted primarily of sea cucumbers, crinoids, asteroid sea stars, and occasional sea pens (Figure 4). In addition, there were a few observations of pelagic fauna, particularly the cirrate or "dumbo" octopods (Figure 5) and large chains of siphonophores. Biogeographic questions remained to be answered as to the relationship of these faunas with those of adjacent ocean basins in the Caribbean Sea, Gulf of Mexico, and western Atlantic Ocean.

FIGURE 4. An unidentified red-orange brisingid sea star observed in a submarine canyon northwest of the Tiburon Peninsula.

Exploring Kick'em Jenny Submarine Volcano and the Barbados Cold Seep Province, Southern Lesser Antilles

By Steven Carey, Katherine L.C. Bell, Chris Roman, Frederic Dondin, Richard Roberston, Judith Gobin, Scott Wankel, Anna P.M. Michel, Diva Amon, Leigh Marsh, Clara Smart, Ian Vaughn, Bernard Ball, Katherine Rodrigue, Morgan Haldeman, Adrienne George, and Robert D. Ballard

The seafloor in the southern Lesser Antilles island arc is an area of active volcanism, cold seeps, and mud volcanoes (Figure 1). The Caribbean's most active submarine volcano, Kick'em Jenny (KEJ), lying only 190 m below the surface, last erupted in 2001. The seafloor near Trinidad and Tobago hosts an extensive province of mud volcanoes and colds seeps that are generated by compression of fluid-rich marine sediments as the Atlantic plate subducts beneath the Caribbean plate in the forearc of the Lesser Antilles (Westbrook et al., 1983; Olu et al., 1996). During exploration with *Nautilus* in 2013, cold seeps were also discovered to the west of KEJ on a large debris avalanche deposit that extends to depths of more than 2,000 m (Carey et al., 2014). Their origin in this unusual geologic setting was attributed to overpressuring of subsurface fluids caused by the catastrophic collapse of the volcano and subsequent fluid movement downslope. In addition to exploration of these areas, we also used this cruise to conduct a study on the best use of telepresence for science and education (see pages 40–43).

During the 2014 field season, the KEJ debris avalanche area was further investigated using ROV *Hercules*. Eight new cold seep sites were discovered at depths ranging from 1,800–2,100 m. The sites typically occur on relatively steep slopes and appear as dark and white intertwining streams flowing downslope (Figure 2). Chemosynthetic communities of mussels, clams, gastropods, shrimps, holothurians, and tubeworms occupy the stream areas along with a significant number of white bacterial mats. At one site, a mussel shell of the species *Bathymodiolus boomerang* measured 36.6 cm in length and is believed to be the largest mussel ever sampled (Figure 3). One of the newly discovered seep sites was about four times the area of the largest site found last year, and it appears that these seeps are quite common along the front margin of the KEJ avalanche deposits. The discovery suggests that there may be a much greater abundance of chemosynthetic biological communities than previously thought in areas of marine sediment avalanches such as along lower continental margins.

ROV exploration of the KEJ debris avalanche surface upslope from the seep area revealed large blocks of volcanic rock that likely constituted the ancestral KEJ volcano. The blocks consisted of gas-rich dome lava, volcanic breccias, and pyroclastic deposits from explosive eruptions. All of these rock types suggest formation in relatively shallow water (< 300 m), with subsequent transport downslope to depths of

FIGURE 1. Map showing the southern Lesser Antilles region, the location of Kick'em Jenny submarine volcano, and the cold seep/mud volcano province south of Barbados.

FIGURE 2. Cold seep on the distal end of the Kick'em Jenny debris avalanche deposit. Downslope direction is from top to bottom of photo. Water depth is 2,230 m. Clam shells in lower right hand corner of photo are approximately 10 cm long.

FIGURE 3. Shell from a *Bathymodiolus boomerang* mussel recovered from a cold seep on the debris avalanche deposit of Kick'em Jenny. Water depth at the recovery site was 2,043 m.

~ 2,000 m when the volcano collapsed. A unique section was discovered that exposed the contact between overlying carbonate sediment and the debris avalanche deposit (Figure 4). Carbon-14 radiometric dating of samples collected from the contact between the two units will be used to determine the age of the debris avalanche deposit.

During this leg, the water column reflection trace collected by the shipboard EM302 multibeam mapping system was used to detect gas bubbles rising through the water column and to locate their sources on the seafloor. These data enabled us to map the spatial distribution of gas vents in the crater of KEJ and assess their relative strengths (Figure 5). Rising gas streams were generally restricted to the smaller inner crater of the volcano at a maximum depth of 265 m. ROV dives to the source of the gas vents revealed steady streams of carbon dioxide discharging from both the sides and floor of the inner crater. Gas-flux and carbon isotope measurements were collected at the top of Champagne vent in the same place where measurements were made in 2013. No changes were detected in the flow rates between these dates. Such measurements are important for assessing the volcano's current condition and for evaluating potential volcanic hazards. New measurements of fluid flow from the same vents using high-resolution imagery will provide important information about the flux of chemical components and heat loss from the active hydrothermal system in the crater.

In the area of the cold seep/mud volcano province east of Trinidad and Tobago, water column multibeam data detected numerous bubble plumes coming from circular dome-like structures and ridges. This area was known to have cold seeps, but had not been previously explored by ROVs (Olu et al., 1996). At Dome 1 of the El Pilar site (Olu et al., 1996), large beds of *Bathymodiolus* mussels, Alvinocaridae shrimps, *Lamellibrachia* tubeworms, amphipods, and eelpout (*Pachycara*) fishes were discovered around an area of active methane venting (Figure 6). Numerous sponges were also noted in peripheral areas of the seeps, as well as squat lobsters, ophioroids, and crabs. An accumulation of white methane hydrate was found beneath a ledge where methane was venting from the seafloor and trapped on the underside of the ledge (Figure 7). Parts of the methane hydrate were then leaking through the top of the ledge, forming a diffuse bubble plume that had been picked up by the ship's multibeam.

We also detected bubble plumes in previously unexplored areas in the El Pilar region. Dive targets were selected based on the locations of these bubble discharges. An area of strong bubble venting was found to host enormous mussels beds, shrimp, gastropods, eelpout fish, and two types of tubeworms. This site had fewer *Lamellibrachia* tubeworms than the Dome 1 location. At all seep sites, most of the *Bathymodiolus* mussels were juveniles, indicating ongoing recruitment. The abundance of bubble plume targets detected by the relatively limited multibeam survey suggests it is likely that a large number of chemosynthetic communities populate this area of active sediment deformation in front of the Lesser Antilles.

FIGURE 4. Light-colored bedded carbonate sediment directly overlying a dark debris avalanche deposit on the western flank of Kick'em Jenny at 1,651 m water depth.

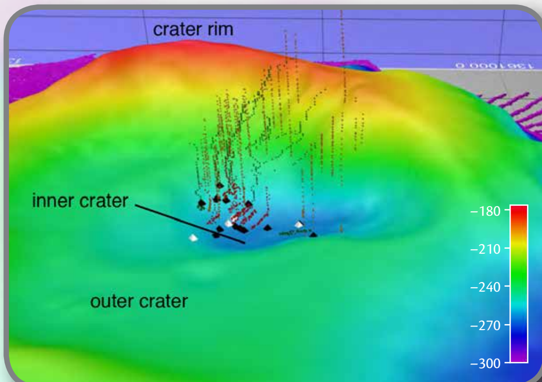


FIGURE 5. Three-dimensional bathymetric map of Kick'em Jenny's crater showing the location of gas vents (vertical dotted lines). The scale at bottom right indicates water depth in meters.

FIGURE 6. Chemosynthetic community consisting of *Bathymodiolus* mussels, Alvinocaridae shrimp, limpit gastropods, and amphipods at a large cold seep east of Tobago. Water depth is 1,586 m.

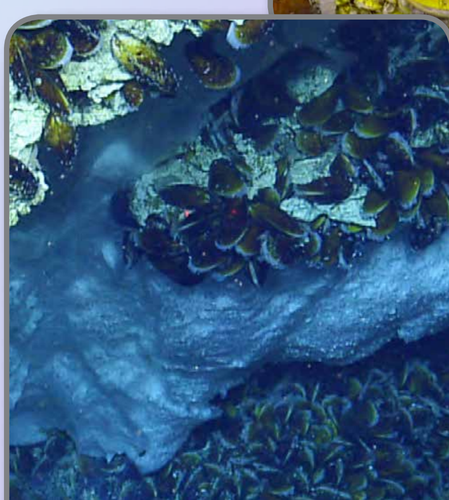


FIGURE 7. Accumulation of methane hydrate (bluish white material) beneath a carbonate rock ledge at a cold seep east of Tobago. Two red laser dots near center of photo are 10 cm apart. Water depth is 1,043 m.

Transforming Remotely Conducted Research Through Ethnography, Education & Rapidly Evolving Technologies (TREET)

By Katherine L.C. Bell, Christopher R. German, Zara Mirmalek, and Amy Pallant

The TREET project brings together a combination of oceanographic, ethnographic, and educational researchers to investigate how to best use telepresence to direct research remotely from shore and to bring authentic participation in research into undergraduate classrooms worldwide. This pilot project engaged four principal investigators, six early career scientists, eight undergraduates, and two senior scientist mentors from seven institutions across the United States.

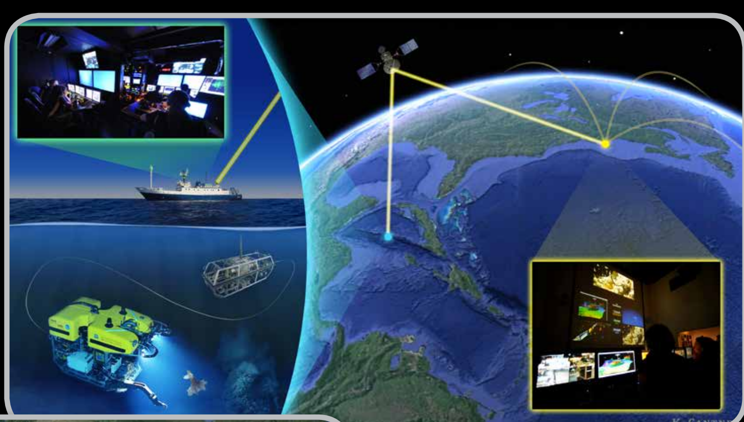
In the spring of 2014, a weekly synchronous, online seminar series was held to introduce early career scientists and undergraduates who had never before used telepresence to the locations that would be explored and the technologies used for their research. They developed a cruise plan that would be executed at sea, together with core protocols for communication between the science team ashore and the operations team at sea. This seminar series provided important preliminary training for the team on the capabilities and limitations of telepresence. Another critical outcome was the building of a team of researchers and students who had never before met each other and would not do so in person until the cruise commenced. Convening the seminars synchronously allowed team members to gain some familiarity with each other by communicating in real time and face to face via video conferencing technology.

During the expedition, a typical complement of 31 scientists, engineers, and educators sailed aboard *Nautilus*, while 20 scientists, students, and educational, and ethnographic researchers stood watches at the Inner Space Center at the University of Rhode Island, and a smaller Exploration Command Center (ECC) at the Woods Hole Oceanographic Institution (WHOI). The shore-based team drove the majority of the scientific decision making, in consultation with the at-sea team via 18- to 24-hour per day communication between the watch teams, as well as by daily conference calls, Situation Reports, and other means of regular communication, such as talking directly with watchstanders at sea. Over the course of three weeks and 17 ROV dives, the team investigated a range of interrelated biological, geochemical, and geophysical phenomena at two sites of seafloor fluid flow: the Kick'em Jenny submarine volcano off the coast of Grenada and the Barbados mud volcano cold seeps off Trinidad and Tobago (see pages 38–39).

Highlights from the cruise include:

- First ethnographic study of oceanographic telepresence
- First time deployment of in situ isotope analyzer for combined carbon isotopes of CO_2 and CH_4
- First time utilization of in situ laser spectroscopy for chemically analyzing bubbles
- Discovery of new methane hydrates, cold seeps, extensive mussel beds, and associated fauna at the Barbados cold seeps
- First bubble flow imaging and high-resolution seafloor mapping at the Barbados cold seeps
- Discovery of new cold seep sites at the distal end of the Kick'em Jenny debris avalanche
- Detailed seafloor magnetic survey of an active submarine volcano

Telepresence technology connects ROVs and an at-sea science and operations team on board E/V *Nautilus* with teams of scientists on shore at the Inner Space Center at the University of Rhode Island and Exploration Command Center at the Woods Hole Oceanographic Institution (WHOI).



Scientists and students from seven organizations across the country participated in the TREET project, including the University of Idaho, Michigan State University, Harvard University, and Duke University (red), as well as the Woods Hole Oceanographic Institution, University of Rhode Island, and Ocean Exploration Trust (yellow) where the shore-based teams stood watches to take part in the expedition. E/V *Nautilus* was conducting dives on Kick'em Jenny volcano and the Barbados mud volcanoes, located off the coasts of Grenada and Trinidad and Tobago, respectively.

Oceanographic Research

The initial goals of the oceanographic aspects of the project were primarily focused on the impact caused by the release of the greenhouse gases methane (CH_4) and carbon dioxide (CO_2) from the seafloor. This work was pursued through a combination of (1) understanding the geological processes that underpin the hydrothermal and seep systems at each of the study sites, (2) quantifying the gas compositions and fluxes at each of the sites, and (3) studying the extent to which biological communities are coupled to these biogeochemical inputs from the seabed.

Over the course of the project, each of these objectives were investigated, and expounded upon by various members of the science party. The scientific questions that are currently being addressed through post-cruise data analysis include:

- Using multibeam bathymetry and high-resolution photomosaics, does the Kick'em Jenny crater exhibit geomorphological and/or biological changes between 2013 and 2014? *— L. Hart, C. Normington, C. Scott*
- What are the extents and structures of hydrothermal fields and subsurface volcanic systems of the Kick'em Jenny crater, as revealed by high-resolution magnetometry? *— M. Tominaga*
- What are the mass-wasting processes around Kick'em Jenny? *— S. Whitley*
- What is the age of the Kick'em Jenny debris avalanche, and is it composed of different lithologies and facies? *— T. Ruchala, S. Carey*
- What is the distribution of cold seeps at the distal end of the Kick'em Jenny debris avalanche, and how does the biodiversity associated with cold seeps vary from site to site? *— S. Carey, A. Stote, P. Girguis*
- Have there been changes in the gas flux inside the Kick'em Jenny crater over a one-year period? Do the fluids at the Kick'em Jenny vents show evidence of phase separation? What are the in situ concentrations of CH_4 and CO_2 carbon isotopes in the fluids and bubbles of Kick'em Jenny vents? *— S. Carey, A. Michel, S. Wankel, E. Mittelstaedt, P. Girguis*
- What are the composition, rate, and distribution of the fluid and bubble flows at the Barbados cold seeps? *— T. Westlund, E. Mittelstaedt, A. Michel, S. Wankel, P. Girguis*
- How are Kick'em Jenny and Barbados seep invertebrate populations genetically related to populations at Cayman, Gulf of Mexico, and Atlantic margin seeps and vents? *— C. Van Dover*
- How can we best utilize laser-based technology for improved understanding of deep-sea carbon biogeochemistry? Can this technology be used to chemically and isotopically explore deep sea environments? *— A. Michel, S. Wankel*
- How can high-resolution mapping using structured light, high-resolution multibeam, and stereo imaging, best be used to support time-series investigation, low-temperature vent flux measurements, and gas flux measurements? *— C. Roman, C. Smart, I. Vaughn*

Data from the cruise are now being analyzed and will be reported back to the group via a second seminar series in the spring of 2015, followed by submission for peer-reviewed publication and conference presentations.

ABOVE. Masako Tominaga (center), an early career scientist at Michigan State University, with her team of undergraduate students, Carly Scott, Laney Hart, Cody Normington, and Tyler Ruchala. *Photo credit: Masako Tominaga*

BACKGROUND. At-sea Lead Scientist and project mentor Steve Carey (center) works with data loggers Morgan Haldemann (left) and Diva Amon (right) on board *Nautilus*, while communicating with watchstanders on shore at the Inner Space Center and the Exploration Command Center at WHOI to direct ROV dives.

(RIGHT PHOTO) Undergraduate Taylor Westlund directs an ROV dive on the Barbados mud volcanoes from the Exploration Command Center at WHOI, while (LEFT PHOTO) fellow undergrads Silas Whitley, Alex Stote, and Tyler Ruchala look on from the Inner Space Center. *Photo credits: Zara Mirmalek and Alex DeCiccio/Inner Space Center*

Ethnographic Research

The TREET project's ethnographic research will offer insight into new ways of conducting telepresence-based research and new computational tool requirements. This research is being undertaken to study and share analysis on social interaction, information flow, and access to and analysis of scientific data brought about through the use of remote telepresence.

Data are currently being analyzed to address the following ethnographic research goals:

- Characterize work practices, communication, and social relationships among scientists using remote telepresence
- Provide insights into the cultural processes shaping human-machine relationships
- Support early career scientists and their undergraduates to elucidate effective approaches for using remote telepresence to conduct research, both in terms of scientific and educational research goals
- Recommend how to improve interactions on multiple levels

Learning best practices for the use of telepresence to direct deep-sea research from shore will be particularly important in the context of UNOLS' new Ocean Class vessels where scientific berths will be at a premium. The collaborative tools and work practices that we develop in this project will prove invaluable for UNOLS and other NSF-sponsored research as the paradigm of using real-time and near-real-time data to make decisions during the course of experimentation is evolving rapidly through the combination of deep-sea robotic systems and telepresence technology. In addition to E/V *Nautilus*, other proponents of this new paradigm include the NOAA Ship *Okeanos Explorer*, NSF's Ocean Observatories Initiative, and the NSF-funded Monterey Accelerated Research System.

The development of robotic assets for oceanographic and other applications continues to change the scientific process in various ways, for example:

- Decision making now occurs within and during the experimental process rather than subsequent to it
- Data gathering and analysis occurs at a substantially faster rate than before, leading to increased reliance on sophisticated computational methods
- Robotic assets are and have been re-tasked to deal with rapidly changing experimental goals, which has, in turn, resulted in increased opportunistic science
- Rising volumes and rates of data gathering have increased the pace of experimentation and data return

As a consequence, scientists whose working community did not previously use remote telepresence methods are now interested in developing the use of such tools, both for their own research and, increasingly, to achieve the longer-term goal of sustaining their fields by attracting and retaining the next generation of researchers through K12 STEM programs. In addition, the impacts of this project will extend far beyond the ocean. Telepresence enables scientific discovery from afar, resulting in new methods of data gathering and analysis. These protocols will necessarily involve development of new methods to deal with the large amounts of data collected, with widespread benefits to the research community.

Education Research

The educational component of the TREET project immerses a small group of undergraduates in research activities related to the project over two academic years, mentored by three early career research scientists from the University of Idaho, Michigan State University, and Harvard University.

The educational research goals focus our investigation on whether remote participation for students appears to be a good design for engaging undergraduates in an authentic research experience. The following research questions guide our work:

- What did the students learn about science and scientific research?
- To what extent do students gain in understanding research methodology?
- Did students experience authentic research?
- When student involvement in scientific research is made possible by remote access, what are key factors that appear to support the educational objectives of the students and their professors?
- Did student participation help advance the research goals of the cruise?
- Were students able to make important observations or significant findings?
- How can our approach be improved for future projects?

The educational research methods employed during the course of the project included surveys, interviews, and observations, analysis of online interactions during the seminar, and of student presentations. All students were enrolled in a semester-long, for-credit online seminar series between January and May 2014. The seminar was designed to introduce the project and provide students with background they needed to participate in the oceanographic research cruise to Kick'em Jenny and the Barbados cold seeps. The seminars, led by participating scientists, provided students with the background needed to undertake their research, covering Earth and life science research pertinent to the sites to be studied, more detailed case studies of the unique features of the research sites, the advanced robotic vehicles, and the analysis tools to be employed.

During the cruise, a trained observer was present at both the ISC and ECC. Observers used a protocol that focused on the nature of the scientific activities of the students, the quality of the engagement of researchers with the students, and the topics that the students studied. To provide additional narrative data, all project participants—principal investigators, expert mentors, and early career scientists—were interviewed at the beginning and end of the project.

The educational research component of the TREET project will result in a better understanding of how telepresence can be leveraged in such a way that ensures that students remain invested in all phases of planning and execution of the research, including the challenges of directing that research remotely. With the shrinking of the US oceanographic research fleet, and the resulting decrease of seagoing opportunities for students, it will be critical to be able to engage students in remote research experiences so that they remain interested in the field and pursuing careers in oceanographic science and engineering.

Co-PI Katy Croff Bell and At-Sea Lead Scientist Steve Carey give a remote briefing to the Inner Space Center team from E/V *Nautilus* to demonstrate the capabilities and limitations of telepresence. *Photo credit: Alex DeCiccio, Inner Space Center*

The science team on shore at the Inner Space Center watches the ROV dive in progress on the big screen while taking part in a daily conference call with the science leads on board *Nautilus* to discuss the day's progress and plans for the following day.

A Symposium on Archaeological Oceanography in the Mediterranean and Black Sea

By Michael L. Brennan and Dan Davis

Nautilus began its exploration of the world ocean in the Mediterranean, Aegean, and Black Seas, predominantly in the coastal waters of Turkey. Our work there covered important unexplored areas while remaining in relatively shallow waters and within easy access to ports and shipyards for the renovations the ship required before its transit across the Atlantic. The investigations spanned all three coastlines of Turkey, from documenting the oxic/anoxic boundary in the Black Sea, to mapping damage to the benthos in the Aegean resulting from trawl fishing, to exploring the Anaximander seamounts and mud volcanoes in the eastern Mediterranean (Brennan et al., 2012, 2013a; Raineault et al., 2013).

Between 2009 and 2012, we discovered 53 shipwrecks ranging in date from the sixth century BCE to modern times. These expeditions turned Robert Ballard's vision of a synergistic relationship between archaeology and oceanography into a reality as a multidisciplinary and interdisciplinary field of archaeological oceanography (Brennan and Ballard, 2014). We documented these sites using high-resolution, deepwater mapping and imaging systems to identify artifacts and ship elements to understand the sites in the broader submarine environment. While shipwrecks provide volumes of data on maritime history and archaeology, they also serve as platforms for observing and studying the interaction of cultural materials—such as cargos and the ships themselves—with the marine environment. These site formation processes include both oceanographic effects, such as bioturbation and sedimentation, and anthropogenic damage, such as that wrought by bottom trawl fishing (Brennan et al., 2012).

In October 2014, in Bodrum, Turkey, we held a two-day symposium, "Archaeological Oceanography in the Mediterranean and Black Sea." The symposium, co-sponsored by the Ocean Exploration Trust and Turkish Ministry of Culture and Tourism, provided a venue to present our work to both the Turkish public and the wider academic community. Bodrum was chosen because the field of nautical archaeology began here in earnest in the 1960s with the founding of the Bodrum Museum of Underwater Archaeology, largely through the efforts of George Bass, founder of the Institute of Nautical Archaeology. In preparation for the symposium, data from the *Nautilus* expeditions were disseminated to scholars for review and study. Of the 53 shipwrecks discovered, 21 were presented by 16 scholars from both Turkey and the United States. We are now working on distributing the rest of the sites to scholars who specialize in their respective time periods.

Photomosaic of Ereğli E shipwreck in the Black Sea.

Stereo image of amphoras on Knidos C shipwreck.

As a group, we presented our preliminary findings on one of the largest sets of shipwrecks found in the ancient world. This collection of sites exceeds that at Yenikapı in Istanbul, where archaeologists discovered 36 shipwrecks ranging between the fifth and tenth centuries CE. The large volume of shipwreck discoveries is exceeded only by the work of French and Egyptian teams in Egypt's Heracleion-Thonis, where to date they have found over 60 ancient shipwrecks ranging from the sixth to second centuries BCE. However, while the wrecks of Yenikapı and Heracleion-Thonis are concentrated in harbor areas, those presented here were found along maritime highways and spread over large geographic areas, giving us snapshots of maritime activity occurring in midstream, rather than at end points of the voyages. Our discoveries allow us to speak of sea routes, maritime connectivity, and trajectories of seaborne trade through various historical periods.

At the same time, the data also allow us to gain insights into deepwater oceanographic processes around shipwreck sites rather than in harbors. The wide-ranging topics covered at the symposium include damage to shipwreck sites by bottom trawl fishing, the high-resolution mapping technology on *Hercules*, the microbiological community structure of the oxic, suboxic, and anoxic sediments of the Black Sea, and sonar imaging of the World War I shipwrecks off Gallipoli.

The two-day symposium also offered ample time for discussion, allowing both oceanographers and archaeologists to engage with representatives from both fields and with the topics presented. One common frustration raised by many archaeologists was the lack of physical artifacts in the *Nautilus* data set, as we never touched any of the shipwrecks. It was also noted that the very high level of ROV mapping and imaging capability is adequate to study form and stylistic details of the artifacts for identification, although more physical studies such as volumetric measurements and ceramic mineralogy of amphoras are not possible. However, the wrecks we discovered remain intact on the seabed for the day when funding, permits, and technology are available for their excavation.

The symposium was a first step in sharing these discoveries and their significance with the public and the academic community. The next step will be to continue to identify scholars of the historical periods represented by the set of wrecks discovered so that each can be analyzed comprehensively while ideas generated by the symposium are developed further. Finally, with permission from the Turkish Ministry of Culture and Tourism, we plan to publish these discoveries in one scholarly volume, which will present the shipwrecks and oceanographic data, along with our synthesis of both, to piece together a broad picture of the maritime cultural landscape in Turkey's deep waters.

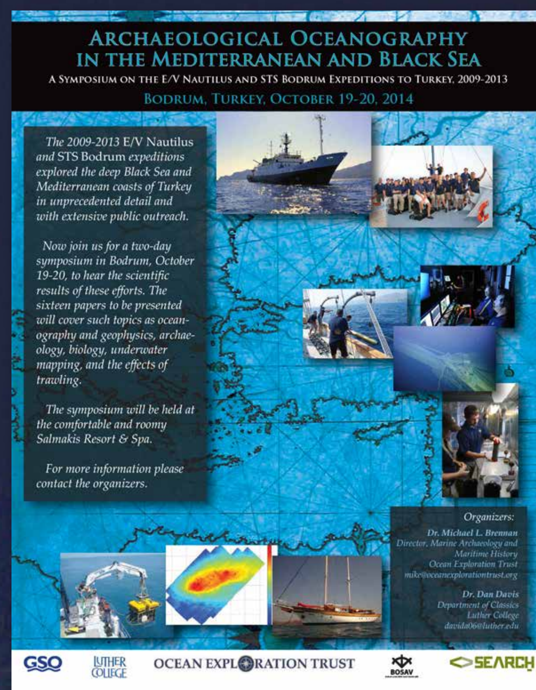


Photo credit: Jeff Emerson

Workshop on Telepresence-Enabled Exploration of the Eastern Pacific Ocean

By Katherine L.C. Bell, Michael L. Brennan, Nicole A. Raineault, Christopher German, James P. Delgado, Emil Petruncio, Stephen Hammond, Dwight Coleman, Steven Carey, Larry Mayer, and Robert D. Ballard

BACKGROUND

The Workshop on Telepresence-Enabled Exploration of the Eastern Pacific Ocean is the fifth in a series of workshops held in response to recommendations by four executive and congressional panels:

- *Discovering Earth's Final Frontier: A US Strategy for Ocean Exploration*, Ocean Exploration Panel, 2000
- *Exploration of the Seas: Voyage into the Unknown*, National Academy of Sciences, 2003
- *An Ocean Blueprint for the 21st Century*, US Commission on Ocean Policy, 2004
- *Final Recommendations Of The Interagency Ocean Policy Task Force*, Interagency Ocean Policy Task Force, 2004

A common recommendation throughout these reports is that the United States should be a leader in ocean exploration, striving to increase scientific understanding of the ocean, and including public outreach and education as an integral component of a national ocean exploration program.

In response to these recommendations, the NOAA Ship *Okeanos Explorer* and E/V *Nautilus* emerged as two national platforms dedicated to ocean exploration. Since 2007, community input has been solicited to assist in shaping these budding programs through a series of workshops hosted by the Ocean Exploration Trust and NOAA Office of Ocean Exploration and Research:

- Technological Requirements for *Okeanos Explorer*, Monterey Bay Aquarium Research Institute, 2007
- Priority Areas for Exploration in the Pacific Ocean, National Geographic Society Headquarters, 2007
- Priority Areas for Exploration in the Atlantic Ocean, University of Rhode Island Graduate School of Oceanography, 2011
- Telepresence-Enabled Exploration of the Caribbean Region, Miami, 2012
- Telepresence-Enabled Exploration of the Eastern Pacific Ocean, San Francisco, 2014

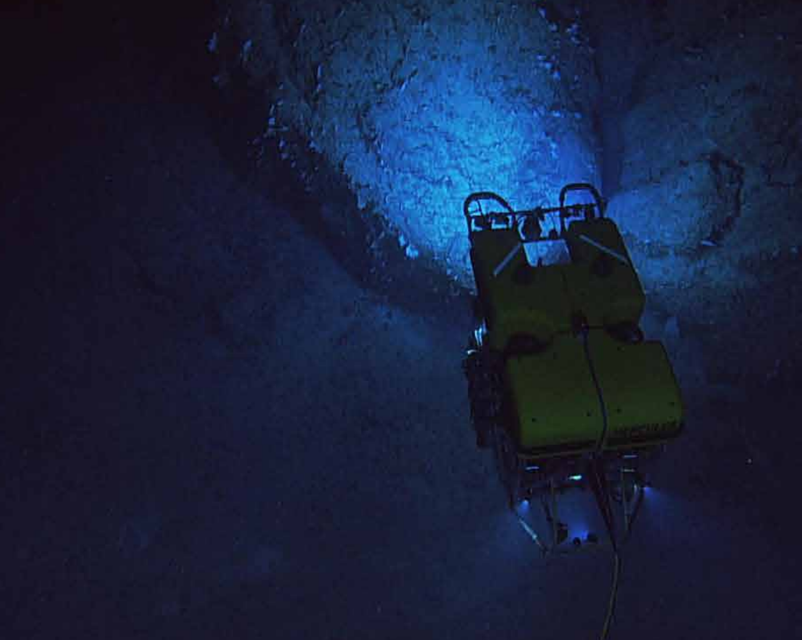
The results of the 2012 Caribbean Workshop were used by OET to plan the *Nautilus* schedules for the 2013 and 2014 field seasons. Many of the scientists who participated in the workshop also participated in the 2013 and 2014 expeditions, either as Lead Scientists at sea or Scientists Ashore. Based on the success of this model, the Lounsbery Foundation funded OET to hold a fifth workshop in 2014 on Telepresence-Enabled Exploration of the Eastern Pacific Ocean.

Seventy-seven white papers were submitted to the 2014 Eastern Pacific workshop, and 67 scientists representing 13 countries participated in it, nearly double the number who attended the Caribbean workshop. Through a series of Breakout Group discussions, the participants' primary goals were to:

1. Identify key archaeological, biological, geological, physical, and chemical questions that face the eastern Pacific Ocean
2. Identify high priority target areas for exploration by *Nautilus* and *Okeanos Explorer*

A Google Unhangout webinar, hosted by the MIT Media Lab, was held after the workshop to inform the community about workshop results and solicit input from those who could not attend. This report documents the results of both events.

The Eastern Pacific Workshop was funded by the Richard Lounsbery Foundation and in-kind support from the NOAA Office of Ocean Exploration & Research, the Exploratorium, and the MIT Media Lab.



IDENTIFYING HIGH PRIORITY TARGET AREAS

During the workshop, there were two rounds of discussions. The first round consisted of four breakout groups divided by discipline—biology, geology, archaeology, and physical/chemical oceanography. The disciplinary groups identified several major eastern Pacific-wide questions that can be answered through telepresence-enabled exploration and 50 areas/transects that can be explored to address those key questions (Figure 1). These areas/transects were then overlain on a map of the eastern Pacific, resulting in identification of seven overlapping Priority Areas, three in the northern Pacific, two in the South/Central Pacific, and two in the eastern Pacific (Figure 2).

On the second day, participants were broken up according to geography—northern Pacific, South/Central Pacific, and eastern Pacific. The groups were asked to identify six to 10 high priority areas in their regions that: (1) address multiple key questions from the first day's breakout sessions, (2) have high potential for discovery, (3) apply available technologies appropriately, (4) lend themselves to multidisciplinary exploration, (4) have high potential for education and outreach activities, and (5) are politically feasible with respect to permitting. The result of these deliberations was a list of 33 High Priority Target Areas that will be considered for exploration in the Pacific over the coming years (Figure 3).

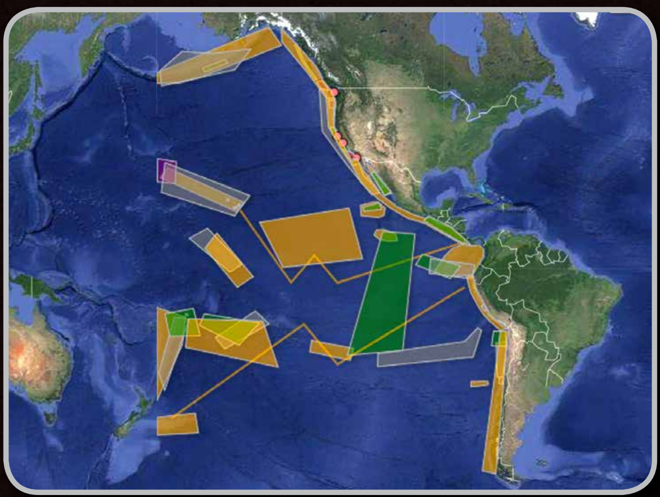


Figure 1. Composite map of the eastern Pacific Ocean, showing the 50 areas/transects of interest identified by the archaeology (purple), biology (orange), geology (green), and physical/chemical oceanography (gray) breakout groups.

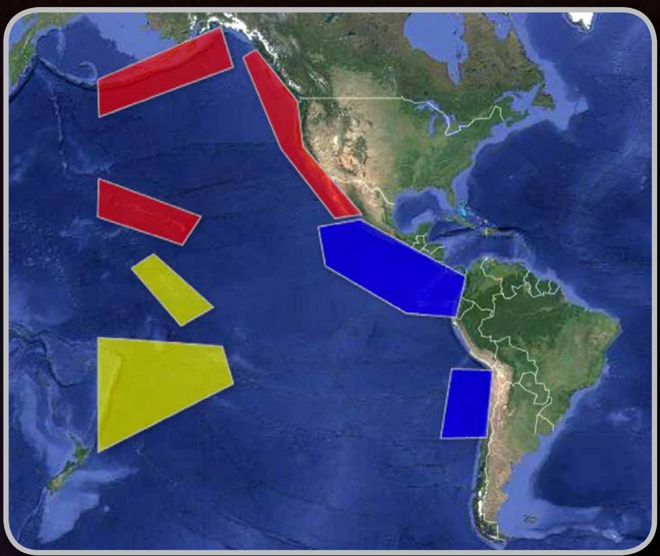


Figure 2. Priority areas identified by the regional breakout groups. The northern Pacific group (red) focused on Hawaii, the Aleutians, and North American margin; the South/Central Pacific group (yellow) on the Line Islands and Samoa and Tonga to French Polynesia; and the eastern Pacific group (blue) on the eastern tropical Pacific and South American margin.

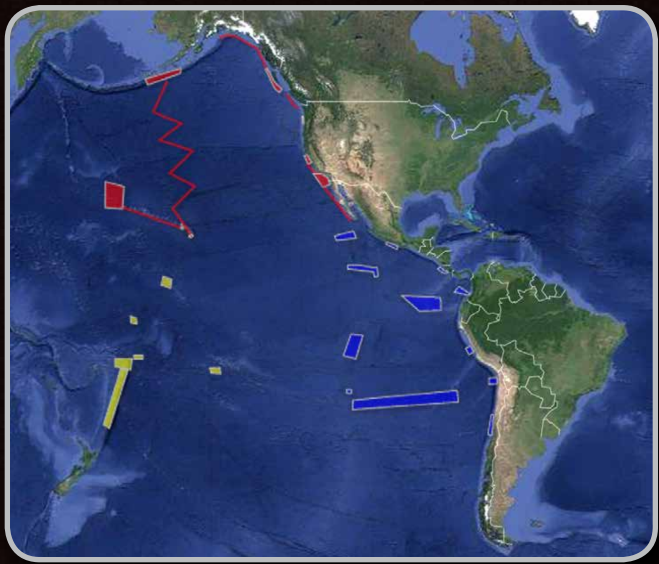


Figure 3. Map of all 33 high priority target areas.

Full Workshop Report

http://nautiluslive.org/2014pacificworkshop

ARCHAEOLOGICAL OCEANOGRAPHY

The Archaeology Breakout Group focused on hubs of historic maritime activity, known naval battle sites, and known or suspected deepwater wreck sites. Due to the expanse of the Pacific Ocean, trade routes were not considered. The group also considered the development of Pacific maritime economies, intercultural exchange, and the movement of people within a marine landscape. The breakout group came up with five key questions and key areas or sites to target.

- AQ-01: What does the patterning of wrecks around key ports tell us about the development of Pacific economies and intercultural exchange?
- AQ-02: Can potential submerged prehistoric settlement sites be discerned in the post-glacial maximum coastline?
- AQ-03: How can we apply a detailed landscape view to an underwater battlefield and deepwater archaeological site to reinterpret historical events using forensic evidence?
- AQ-04: Can we identify key sites in the Pacific that speak to the archaeology of discard, and what are the environmental impacts of these sites?
- AQ-05: Can we find archaeological evidence of pre-European Asian contact at eastern Pacific sites?

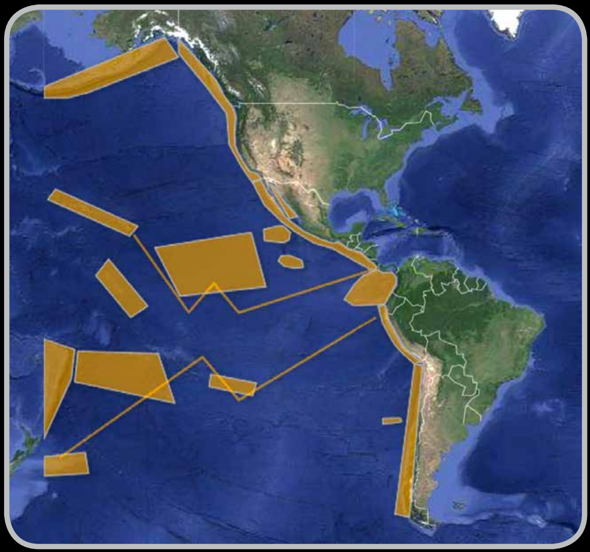
GEOLOGICAL OCEANOGRAPHY

The Geology Breakout Group identified 10 key questions that could be addressed in the eastern Pacific. Some questions had fairly strict geographic requirements, lending themselves to small boxes. Others lent themselves to broader geographical areas. There was vibrant discussion surrounding volcanic processes and coastal/shelf hazards, as well as opportunities for interdisciplinary science. The questions identified reflect an effort to generalize many of the specific topics discussed.

- GQ-01: What are the tectonic, volcanic, and/or sedimentary controls on submarine groundwater flow and discharge?
- GQ-02: What are the characteristics of submarine geohazards in the eastern Pacific and how do they relate to the tectonic setting?
- GQ-03: What factors control the origin, distribution, evolution and eruptive behavior of submarine volcanoes?
- GQ-04: What are the patterns of marine mineral resources of the eastern Pacific and how do they relate to tectonic and oceanographic processes?
- GQ-05: What are the magmatic, tectonic, and morphological characteristics of plate boundary intersections?
- GQ-06: What are the possible climate impacts of submarine geological processes?
- GQ-07: What are the geomorphic provinces of the Pacific basin and how would they be defined and characterized?
- GQ-08: How would you create a geological map of the entire eastern Pacific at a scale similar to the DNAG North America map (1:5,000,000)?
- GQ-09: Are there large undiscovered cosmic impact structures in the eastern Pacific Ocean?
- GQ-10: What are the relationships between ecosystems and geological processes in the eastern Pacific?

BIOLOGY

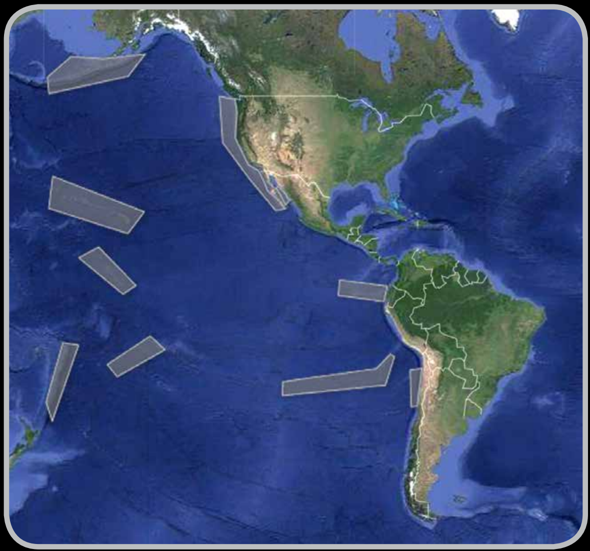
With such a large area to consider, the Biology Breakout Group crafted broad questions in order to cover a diversity of habitats. The group made sure to include protected and non-protected areas, pristine sites and those that are stressed by anthropogenic sources. The group also suggested transects through unexplored regions with varied bathymetry. Discussions focused on connectivity, adaptive capacity, and management challenges associated with potential impacts of global climate change. The results are six key questions that can be addressed in virtually any location.



- BQ-01: What is the distribution of biodiversity in the water column and on the seafloor?
- BQ-02: What biological baseline information is required to facilitate effective environmental management?
- BQ-03: What are the large-scale biogeographic boundaries of the deep Pacific?
- BQ-04: What are the successional patterns of deep sea communities following perturbation?
- BQ-05: How are biological systems interconnected in the eastern Pacific?
- BQ-06: How can natural environmental gradients in the eastern Pacific help inform organism and ecosystem adaptations to global change?

PHYSICAL AND CHEMICAL OCEANOGRAPHY

The Physical and Chemical Oceanography Breakout Group focused on seawater chemistry, marine pollution, and the physical forcing that interacts with seafloor topography and affects water mass characteristics and the distribution of nutrients, minerals, and dissolved oxygen. Participants considered basin-scale and mesoscale circulation, abyssal flows, waves and tides, the variability of pH and alkalinity, the oxygen minimum zone, and plumes from cold seeps and hydrothermal vents. These discussions resulted in the identification of geographic areas that would be suitable for addressing 14 key questions through mapping and exploration.



- PCQ-01: How do large-scale currents in the upper ocean interact with islands and seamounts, and how do they affect marine archaeology, nutrient and mineral distribution, and O_2 variability?
- PCQ-02: How do mesoscale features such as eddies and upwelling jets interact with seamounts, islands, and the abyss, and what is their impact on O_2 and nutrient distribution?
- PCQ-03: How do tides, wind-driven waves, and internal waves interact with islands, seamounts, and the continental shelf, and how do they contribute to ocean mixing?
- PCQ-04: What is the direction and magnitude of abyssal flow, and is it impacted by mesoscale eddies and/or internal waves?
- PCQ-05: What are the sources, fluxes, and sinks of nutrients required for primary production? Are they retained along the coast, or are there significant losses due to mixing and exchanges offshore? What are the causes and extent of ocean desertification?
- PCQ-06: What is the depth of the O_2 minimum zone, and how does that depth vary in the vicinity of the continental shelf break, islands, and seamounts? What is the impact of the O_2 minimum zone on biology and geology?
- PCQ-07: How do pH and alkalinity vary spatially and temporally, and what is the impact on carbonate saturation levels? Where is the transition to unsaturated water, and how unsaturated is the water below the transition zone?
- PCQ-08: Why are vertical-walled coral atolls present in the Pacific? What is the impact of pH and O_2 levels on their existence?
- PCQ-09: How are cold seeps distributed in a given region, and how far can they be detected in the water column? Are the chemicals from these seeps transported by currents, and if so, how far?
- PCQ-10: How does ocean chemistry vary in the vicinity of hydrothermal vents? How far do mineral and nutrient-rich plumes extend from their source, and what is their fate?
- PCQ-11: How does ambient noise in the ocean vary spatially and temporally?
- PCQ-12: What is the lateral and vertical extent of plastics in the water column? Is ingestion of plastics concentrating toxins in the food chain?
- PCQ-13: How are sediments transported in submarine canyons?
- PCQ-14: What is the fate of Fukushima radionuclides, and can they be used to trace abyssal circulation?

REGIONAL BREAKOUT DISCUSSIONS AND HIGH PRIORITY TARGET AREAS

EASTERN PACIFIC

EPA-01: REVILLAGIGEDO ARCHIPELAGO is a volcanically active group of seamounts with very interesting magma chemistry and little anthropogenic impacts, thus making it a compelling target for biological and geological exploration.

EPA-02: MEXICO TRENCH is a tectonically active region with compelling questions related to subduction, particularly with regard to geohazards, fluid flow, and their impacts on the distribution and successional patterns of deep biological communities.

EPA-03: CLIPPERTON ISLAND & EAST PACIFIC RISE provide the opportunity to investigate off-axis magma bodies and their associated impacts on ocean chemistry and biological communities as well as a pristine oceanographic region that should be explored as a baseline for anthropogenically impacted areas around the globe.

EPA-04: COSTA RICA MARGIN has extensive areas of hydrothermal vents and cold seeps in the same locations, resulting in fascinating biogeography. There may also be serpentinization along normal faults in this area with potential for the discovery of Lost City-like hydrothermal sites never before found in the Pacific.

EPA-05: COLOMBIA MARGIN is considered one of the most biodiverse countries in the world, both on land and in the shallow ocean. However, its importance in terms of its contribution to the biodiversity and resources in the deep sea remains unknown.

EPA-06: GALÁPAGOS exploration will address many unanswered questions that cut across geology, biology, chemistry, and physics disciplines, from the understanding of submarine lava flows, to mid-water biology, to equatorial undercurrent and upwelling.

EPA-07: EAST PACIFIC RISE: WILKES TO GARRETT has the potential for discovery of new venting, hydrothermal circulation, off-axis volcanic eruptions, and associated biological communities.

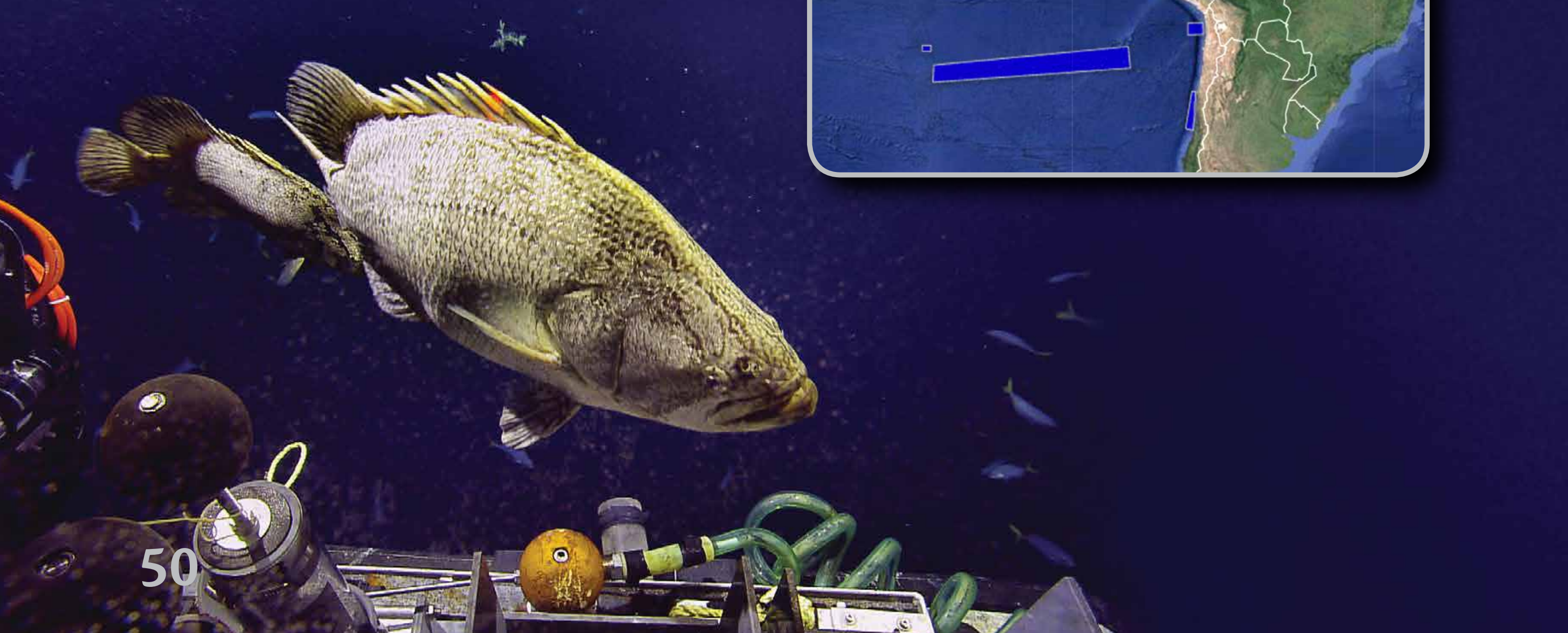
EPA-08: PITO DEEP is a deep canyon connecting two limbs of the East Pacific Rise, providing access to a crustal cross section and a poorly explored deep smoker site that has abundant hydrothermal vent fauna.

EPA-09: SALA Y GOMEZ RIDGE TO EASTER ISLAND is a chain of over 400 seamounts, most of which have never been explored. This chain passes through several different productivity zones, potentially giving way to varying communities on seamounts in each zone.

EPA-10: PERU MARGIN offers cold seep areas within offshore canyons, including diverse biological communities living on poorly explored chemical systems. There is also an archaeological site off Lima, Peru, with potential for more, offering another dimension to exploration in this region.

EPA-11: CHILE MARGIN holds Petit Spots, an underexplored type of volcanism found in very few locations around the world. There are also potential vent sites that have been located by water column surveys, but never before explored.

EPA-12: CHILEAN CANYONS have never been explored biologically nor geologically, but have the potential for an abundance of cold methane seeps and a high degree of biodiversity, including seep communities and deepwater coral assemblages. The area off Valparaiso, Chile, may hold shipwrecks that used this historic port for hundreds of years.



NORTHERN PACIFIC

NPA-01: LOIHI SEAMOUNT is interesting primarily for biological and geological reasons, in particular hotspot volcanism and the succession of biological communities on lava flows of different ages.

NPA-02: PEARL HARBOR & S-28 are focused on historical sites, some of which have known locations, but have yet to be explored. There are also opportunities for investigating coral habitats, hotspot volcanism, and the biological colonization of wreck sites of known dates.

NPA-03: MIDWAY is focused primarily on the historic World War II battle. There are also opportunities for biological colonization studies as well as exploration of the Papahānaumokuākea Marine National Monument.

NPA-04: ALEUTIAN ARC, a volcanic island chain, was selected for studies of geohazard and tsunami potential, active vents and seeps, and deepwater habitat characterization. It is an area especially in need of mapping.

NPA-05: QUEEN CHARLOTTE FAULT is part of a dynamic triple junction that has not been well studied. This area was selected for mapping and geohazard assessments, upwelling and seep biology, and potential paleoshorelines for glacial and habitation evaluation.

NPA-06: COASTAL OREGON is an area where effects of the Kuroshio current and Alaska current present an opportunity to locate evidence of prehistoric migration. The coastline offers an opportunity for mapping and geohazard assessment.

NPA-07: CENTRAL CALIFORNIA is an area where exploration of the Gulf of the Farallones and Monterey Bay Sanctuaries can be expanded to study San Andreas Fault-governed geohazards, deep-sea ecology, and numerous archaeological targets.

NPA-08: SOUTHERN CALIFORNIA MARGIN is an area where a plate boundary and upwelling environment are in close proximity to the largest US cities on the West Coast. This region provides abundant opportunities to study a variety of subjects, including deep-sea corals, vent communities, and paleolandscapes.

NPA-09: GULF OF CALIFORNIA includes a sedimented ridge situated between the East Pacific Rise and the San Andreas Fault that offers an opportunity to study hydrothermal vents and unusual seafloor morphology. This environment allows for an overlap between vent and seep communities due to sedimentation on the ridge.

SOUTH/CENTRAL PACIFIC

SCPA-01: KINGMAN REEF & PALMYRA ATOLL are part of the Pacific Remote Islands Marine National Monument, making it an important target for the shark-dominated ecosystem, as well as seamount formation and potential geohazard exploration.

SCPA-02: PHOENIX ISLANDS & LINE ISLANDS are part of the largest world heritage site, but we know almost nothing about it. There is very little multibeam data and no deepwater exploration, so there is little idea what is being protected. This area was selected because exploration is needed to create a baseline for sampling.

SCPA-03: AMERICAN SAMOA contains the Vailulu'u hotspot, which has been active within the past decade, but is tectonically understudied. Part of the American Samoa National Marine Sanctuary, this area may be central in understanding the deepwater biodiversity. This is also the area where the Samoan Clipper, a Pan-American airliner, was lost in 1938.

SCPA-04: NORTHEAST LAU BASIN is one of the fastest subduction zones in the world, with multiple unexplored submarine volcanoes and calderas. It is an important target for characterization of volcanic and hydrothermal processes and their effects on the biological communities.

SCPA-05: TONGA-KERMADEC ARC contains many hydrothermal vent areas and submarine volcanoes, as well as a variety of deep-sea habitats, including abyssal plain, ridge, seamount, deep-basin, trench, and active hydrothermal venting.

SCPA-06: FRENCH POLYNESIA is an area with potential to explore the biology of seamounts at a series of depths and to conduct diversity studies. In addition, the area has many hydrothermal vents that needs to be explored to determine if and where they are active.

EPILOGUE

By Robert D. Ballard

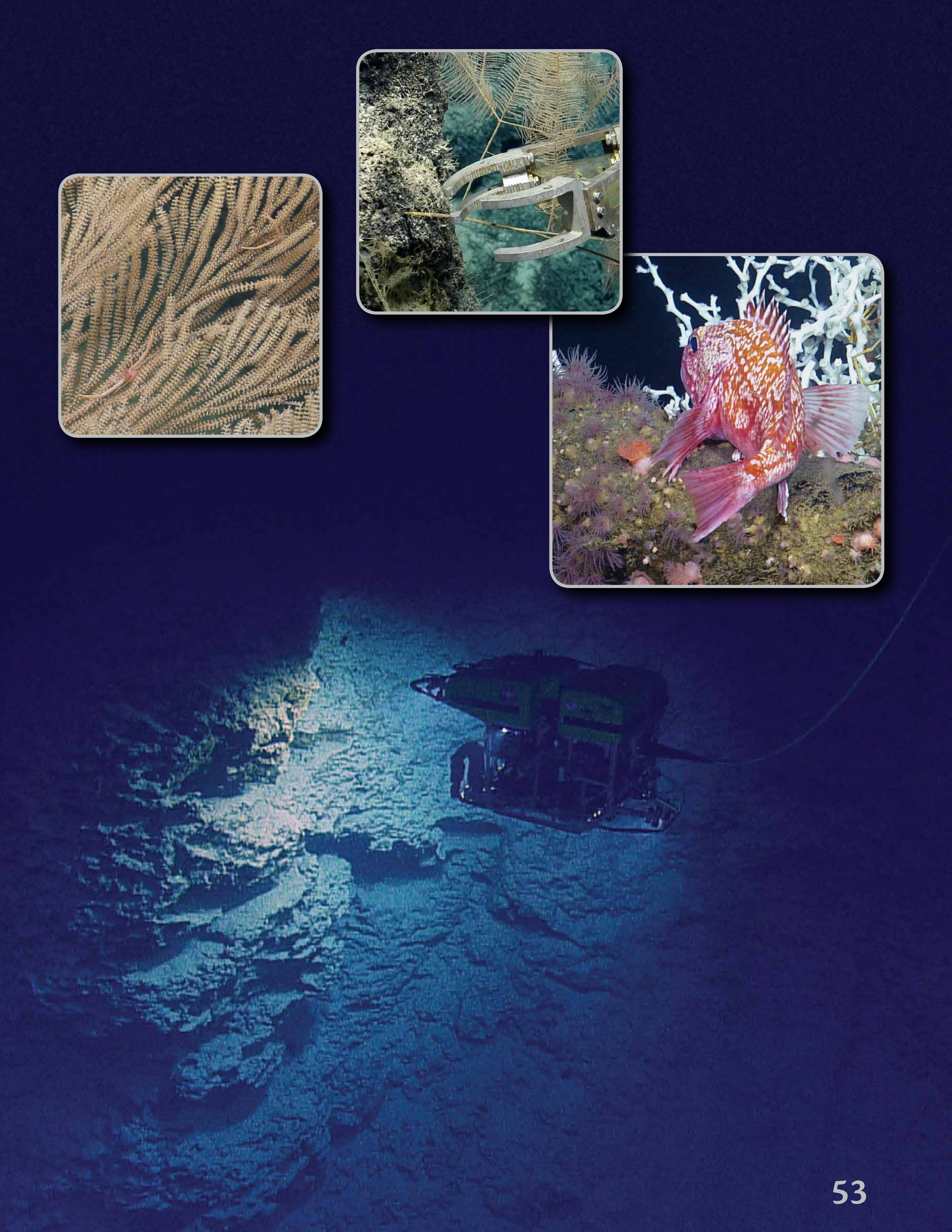
Within two months of completing our 2014 field season in the Gulf of Mexico and the Caribbean Sea, the Trust conducted the Workshop on Telepresence-Enabled Exploration of the Eastern Pacific Ocean at the Exploratorium in San Francisco, sponsored by the Lounsbery Foundation (pages 46–51). Prior to the workshop, 77 groups of scientists from the United States and 12 other countries submitted white papers that outlined a series of exploratory missions in the eastern Pacific Ocean from the 180th Meridian to the Americas. The results of the workshop identified 35 key questions related to the archaeology, biology, geology, physics, and chemistry of the eastern Pacific, as well as 33 High Priority Target Areas that are poorly understood or completely unexplored. The workshop report is currently being used to plan the 2015 *Nautilus* field season, and it will continue to be used for the coming years, until *Nautilus* reaches the western Pacific Ocean.

Nautilus spent the winter of 2014–2015 in St. Petersburg, Florida, for installation of a new fiber-optic cable, a satellite antenna, and a fire suppression system in preparation for 2015 work in the Pacific Ocean. We plan to complete a number of efforts in the Gulf of Mexico during April and May before heading to the Galápagos Islands, where the ship will spend the month of June.

During July, our work will be devoted to seafloor mapping from the Galápagos to San Diego, and in August, *Nautilus* will conduct a series of exploratory programs off the coast of California, based on missions proposed at the 2014 Eastern Pacific Workshop. In September, we will work with Ocean Networks Canada off the coast of British Columbia on their seafloor observatory.

Throughout the entire expedition, we will, as always, have a very large focus on STEM education, through our global presence on Nautilus Live and our Community STEM Program. This new program has grown rapidly in the last nine months and is a large area of potential growth for the Trust in the future. We hope by 2017 to integrate all of our educational efforts by combining our education and outreach programs into 20 STEM Communities that will provide one unified series of learning experiences to better serve the students in each community.

We are planning for *Nautilus* and the Corps of Exploration to spend 2015, 2016, and possibly a portion of 2017 working close to the Americas in the Pacific Ocean where we will explore High Priority Target Areas identified by the Eastern Pacific Workshop before heading west to Hawaii and beyond.



AUTHORS

Diva Amon is a post-doctoral fellow, University of Hawaii, Manoa, HI

Steven Auscavitch is a graduate student, School of Marine Sciences, University of Maine, Orono, ME

Bernard Ball is Associate in Research, Duke University, Durham, NC

Robert D. Ballard is President, Ocean Exploration Trust; Director, Center for Ocean Exploration, Graduate School of Oceanography, University of Rhode Island

Iliana B. Baums is Associate Professor of Biology, Pennsylvania State University, University Park, PA

Katherine L.C. Bell is Executive Vice President and Chief Scientist, Ocean Exploration Trust, Old Lyme, CT

Ruth Blake is Professor, Department of Geology and Geophysics, Yale University, New Haven, CT

John A. Breier is Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA

Michael L. Brennan is Director of Marine Archaeology and Maritime History, Ocean Exploration Trust, Old Lyme, CT

Steven Carey is Professor, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI

Jason Chaytor is Research Geologist, Woods Hole Science Center, US Geological Survey, Woods Hole, MA

Mike Cheadle is Associate Professor, Department of Geology and Geophysics, University of Wyoming, Laramie, WY

Dwight Coleman is Director, Inner Space Center, University of Rhode Island, Narragansett, RI

Marie-Helene Cormier is Research Scientist, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI

Dan Davis is Assistant Professor, Classical Archaeology, Luther College, Decorah, IA

James P. Delgado is Director, Maritime Heritage Program, Office of National Marine Sanctuaries, National Oceanic and Atmospheric Administration, Silver Spring, MD

Amanda W.J. Demopoulos is Research Benthic Ecologist, Southeast Ecological Science Center, US Geological Survey, Gainesville, FL

Frederic Dondin is Research Fellow Volcanologist, Seismic Research Centre, University of the West Indies, St. Augustine, Trinidad and Tobago

Nicole Dubilier is Professor and Director of the Symbiosis Department, Max Planck Institute for Marine Microbiology, Bremen, Germany

Gregor Eberli is Professor, Department of Marine Geosciences, University of Miami, Miami, FL

Peter Etnoyer is Marine Biologist, National Center for Coastal Ocean Science, National Oceanic and Atmospheric Administration, Charleston, SC

Danielle Ferraro is a graduate student, University of Delaware, Newark, DE

Daniel Finamore is Russell W. Knight Curator of Maritime Art and History, Peabody Essex Museum, Salem, MA

Charles R. Fisher is Professor of Biology and Associate Dean for Graduate Education, Pennsylvania State University, University Park, PA

Sarah Fuller is a graduate student, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI

Allison Fundis is Director of Education, Ocean Exploration Trust, Old Lyme, CT

Samuel Garson is Education Programs Coordinator, Ocean Exploration Trust, Old Lyme, CT

Adrienne George is a graduate student, University of South Florida, Tampa, FL

Christopher R. German is Senior Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA

Fanny Girard is a graduate student, Pennsylvania State University, University Park, PA

Judith Gobin is Lecturer, Department of Life Sciences, University of the West Indies, St. Augustine, Trinidad and Tobago

Ethan Gold is Director of Software & Data Engineering, Ocean Exploration Trust, Old Lyme, CT

Kelly Guerrier is Professor, Université d'État d'Haïti, Port-au-Prince, Haiti

Morgan Haldeman is an undergraduate student, University of Rhode Island, Kingston, RI

Stephen R. Hammond is Senior Scientist, National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory, Newport, OR

Xavier Janson is Research Scientist, Jackson School of Geosciences, University of Texas at Austin, Austin, TX

Barbara John is Professor, Department of Geology and Geophysics, University of Wyoming, Laramie, WY

Renato Kane is a graduate student, University of Delaware, Newark, DE

Kaitlin Kovacs is Research Biologist, Southeast Ecological Science Center, US Geological Survey, Gainesville, FL

Melissa Kurman is an undergraduate student, Temple University, Philadelphia, PA

Samantha Maness is a graduate student, Coastal Carolina University, Conway, SC

Connor Marr is a graduate student, University of Wyoming, Laramie, WY

Leigh Marsh is a recent PhD recipient, National Oceanography Centre, University of Southampton, Southampton, UK

Larry Mayer is Director, Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH

Jeff Mentch is an undergraduate student, Pennsylvania State University, University Park, PA

Anna Michel is Assistant Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA

Zara Mirmalek is a postdoctoral fellow, Harvard University, Cambridge, MA

Scott Munro is Executive Producer, Ocean Exploration Trust, Old Lyme, CT

Christian Nygren is a graduate student, Texas A&M University, College Station, TX

Amy Pallant is Senior Research Scientist, The Concord Consortium, Concord, MA

Jillian M. Petersen is a postdoctoral fellow, Max Planck Institute for Marine Microbiology, Bremen, Germany

Emil Petruncio is Professor, United States Naval Academy, Annapolis, MD

Susan Poulton is Digital Media Consultant, Ocean Exploration Trust, Old Lyme, CT

Nicole A. Raineault is Director of Science Operations, Ocean Exploration Trust, Old Lyme, CT

Richard Robertson is Director, Seismic Research Centre, University of the West Indies, St. Augustine, Trinidad and Tobago

Katherine Rodrigue is a recent recipient of a B.S. at the University of Rhode Island, Narragansett, RI

Christopher Roman is Associate Professor, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI

Karen Romano Young is a self-employed writer and artist, Bethel, CT

Nixon Saintilus is Marine Biologist, Service Maritime et de Navigation d'Haiti, Port-au-Prince, Haiti

Miles Saunders is a graduate student, Pennsylvania State University, University Park, PA

Lizbeth Sayavedra is a graduate student, Max Planck Institute for Marine Microbiology, Bremen, Germany

Jeffrey S. Seewald is Senior Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA

Ryan J. Sibert is a graduate student, University of Georgia, Athens, GA

Lily Simonson is a lecturer, California State Polytechnic University, Pomona, CA

Clara Smart is a graduate student, Department of Ocean Engineering, University of Rhode Island, Kingstown, RI

Will Snyder is a graduate student, Department of Ocean Engineering, University of Rhode Island, Kingstown, RI

Scott A. Socolofsky is Associate Professor, Texas A&M University, College Station, TX

Suna Tüzün is a graduate student, Istanbul University, Istanbul, Turkey

Marsha Vargas is Assistant Fisheries Officer, Belize Fisheries Department, Belize City, Belize

J. Ian Vaughn is a graduate student, Department of Ocean Engineering, University of Rhode Island, Kingstown, RI

Todd Viola is Digital Media Consultant, Ocean Exploration Trust, Old Lyme, CT

Sam Vohsen is a graduate student, Pennsylvania State University, University Park, PA

Jamie Wagner is a graduate student, Duke Marine Lab, Duke University, Durham, NC

Binbin Wang is a postdoctoral fellow, Texas A&M University, College Station, TX

Scott Wankel is Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA

ACKNOWLEDGEMENTS

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EASTERN PACIFIC WORKSHOP PARTICIPANTS

• Diva Amon[114] • Jesse Ausubel[84] • Amy Baco-Taylor[30] • Robert Ballard[73, 33]
• Katherine L.C. Bell[73] • Amaris Blackmore[26] • Ruth Blake[136] • Jose Blanco[37]
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• Stephen Hammond[72, 78] • Gretchen Hofmann[108] • Matthew Jackson[108]
• Hiroaki Katayama[61] • Katie Kelley[33] • Christina Kellogg[129]
• Brian Kennedy[72] • Eric King[90] • Rie Koko[61] • Jasper Konter[114]
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• Robert McGuinn[65] • Lindsay McKenna[72] • Anna Michel[135] • Mary Miller[26]
• Eric Mittelstaedt[115] • Angela Murphy[73] • Craig Nicholson[108]
• Kate O'Donnell[26] • Su Oh[62] • Leonard Pace[90] • Grif Peterson[51]
• Emil Petruncio[130] • Rob Pockalny[33] • Andrea Polanco[38] • Nicole Raineault[73]
• Brendan Roark[100] • Paul Rose[59] • Pablo Rosenblatt[37] • Kenneth Rubin[114]
• Srishti Sethi[51] • Tim Shank[135] • Clara Smart[124] • Adam Soule[135]
• Derek Sowers[72] • Liz Spencer[26] • Lisa Strong[26] • Alison Swaddling[91]
• Mitchell Tartt[75] • Uri ten Brink[129] • John Toner[52] • V. Dorsey Wanless[8]
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AFFILIATIONS

1 Acton-Boxborough Regional High School, Boston, MA
2 Australian Centre for Field Robotics, Sydney, Australia
3 Belize Fisheries Department, Belize City, Belize
4 Blue Hill Consolidated School, Blue Hill, ME
5 Bishop O'Dowd, San Leandro, CA
6 Bureau of Ocean Energy Management, New Orleans, LA
7 Bureau of Safety and Environmental Enforcement, New Orleans, LA
8 Boise State University, Boise, ID
9 CBS, New York, NY
10 Claremont Colleges, Claremont, CA
11 Center for Coastal & Ocean Mapping, University of New Hampshire, Durham, NH
12 C&C Technologies, Houston, TX
13 Coastal Carolina University, Conway, SC
14 Cape Eleuthera Institute, Eleuthera, Bahamas
15 Cape Henry Collegiate School, Norfolk, VA
16 Christ the King Catholic School, Hampton, VA
17 Concord Consortium, Concord, MA
18 Connecticut College, New London, CT
19 Colorado School of Mines, Golden, CO
20 California State Polytechnic University, Los Angeles, CA
21 City University of New York, New York, NY
22 David Heil & Associates, Portland, OR
23 Duke University, Durham, NC
24 Ecole Normale Superieure, Paris, France
25 Eagle Pass High School, Eagle Pass, TX
26 Exploratorium, San Francisco, CA
27 The Florida Aquarium, Tampa, FL
28 Florida Atlantic University, Fort Pierce, FL
29 Fox Chapel Area High School, Pittsburgh, PA
30 Foga Road High School, Clarendon, Jamaica
31 Gates Acoustic Services, Gaithersburg, MD
32 Government of the British Virgin Islands, Tortola, British Virgin Islands

33 Graduate School of Oceanography, University of Rhode Island, Narragansett, RI
34 Harvard University, Cambridge, MA
35 Hickory Hills Middle School, Rogersville, MO
36 Innovation Academy at Foy H. Moody High School, Corpus Christi, TX
37 Instituto Milenio de Oceanografia, Concepción, Chile
38 INVEMAR, Sta Marta, Colombia
39 Inner Space Center, University of Rhode Island, Narragansett, RI
40 Istanbul University, Istanbul, Turkey
41 Indiana University Bloomington, Bloomington, IN
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52 Maritime Management, Wicklow, Ireland
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55 Max Planck Institute for Marine Microbiology, Bremen, Germany
56 Michigan State University, East Lansing, MI
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58 National Center for Coastal Ocean Science, National Oceanic and Atmospheric Administration, Charleston, SC
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60 Naval History and Heritage Command, Washington, DC
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62 Natural History Museum of Los Angeles, Los Angeles, CA
63 National Institute of Water and Atmospheric Research, Victoria University of Wellington, Wellington, New Zealand
64 North Kingstown High School, North Kingstown, RI
65 National Oceanic and Atmospheric Administration, Silver Spring, MD
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89 Service Maritime et du Navigation d'Haiti, Port-au-Prince, Haiti
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92 University of Southampton, Southampton, United Kingdom
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134 University of Western Sydney, New South Wales, Australia
135 Woods Hole Oceanographic Institution, Woods Hole, MA
136 Yale University, New Haven, CT
137 Bethel, CT

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Layout and Design: Johanna Adams

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THE OCEANOGRAPHY SOCIETY

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