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New Frontiers in Ocean Exploration

The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2017 Field Season

GUEST EDITORS | Nicole A. Raineault, Joanne Flanders, and Amy Bowman

FRONT COVER. A large *Deepstaria enigmatica* scyphozoan jellyfish is imaged up close at 974 m depth off of San Benedicto Island, Revillagigedo Archipelago, Mexico, on E/V *Nautilus* cruise NA092. This specimen, measuring approximately 55 cm across, was approached in almost complete darkness and remained undisturbed for several minutes, at which point it closed its umbrella and turned to present itself in high detail. An intricate network of anastomosing canals, assumed to be part of its digestive tract, is clearly visible. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

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Interior of a gas-rich pillow basalt off the west coast of Socorro island, Revillagigedo Archipelago, Mexico, from E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

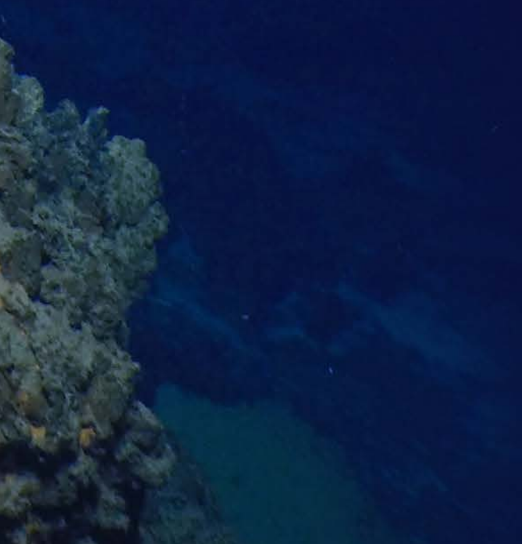
Contents

Introduction 1
2017 National Ocean Exploration Forum: Ocean Exploration in a Sea of Data 3
2017 Expedition Overview Map 4

PART 1. Ocean Exploration Trust – E/V *Nautilus* 6
Technology 8
2017 *Nautilus* Samples Program 14
Nautilus Education and Outreach Programs 16
Nautilus Field Season Overview 24
- E/V *Nautilus* Mapping Summary 2017: Cascadia Margin to the Revillagigedo Archipelago and Beyond 26
- Expedition 2017: Wiring the Abyss in the Northeast Pacific 28
- Submerged Sea Caves of Southern California's Continental Borderland 30
- Peering into the Abyss: Studying Our Own Ocean to Advance Astrobiology 32
- Discovering the Undersea Beauty of Cordell Bank National Marine Sanctuary 34
- Quinault Canyon and Olympic Coast National Marine Sanctuary 36
- Discovering Oregon's Lost Coast: Finding and Studying Submerged Archaeological Sites and Landscapes on the Pacific Continental Shelf 38
- Exploration of the Northern Guaymas Basin 39
- Biogeochemical Exploration of the Pescadero Basin Vents 42
- Exploring and Mapping the Revillagigedo Archipelago World Heritage Site in Mexico 44

PART 2. NOAA's Office of Ocean Exploration and Research 46
CAPSTONE: NOAA's Campaign to Address Pacific monument Science, Technology, and Ocean NEeds 48
CAPSTONE Operations 2015–2017 53
Exploring Pacific Maritime Heritage 54
NOAA Ship *Okeanos Explorer*: Exploring America's Deep Ocean 55
2017 NOAA Ship *Okeanos Explorer* Mapping Highlights 56
2017 Midwater Exploration on *Okeanos Explorer* 61
Working with Video to Improve Deep-Sea Habitat Characterization 64
Engagement: Exploring Global Opportunities in 2017 68
Diversity and Inclusion 71
2017 American Sāmoa Expedition: Suesuega o le Moana Amerika Sāmoa 72
Deepwater Exploration of the Pacific Remote Islands Marine National Monument and Central Pacific Basin 74
- Discovering the Deep: Exploring Remote Pacific Marine Protected Areas 76
- Mountains in the Deep: Exploration of the Seamounts of the Central Pacific Basin 78
- Laulima O Ka Moana: Exploring Deep Monument Waters Around Johnston Atoll 80

Deep-Sea Symphony: Exploration of the Musicians Seamounts 82
CAPSTONE Sampling Overview: Providing Insights in the Remote Pacific 84
Exploring the Pacific Through International Partnerships 86



Sponsored Projects: NOAA's Office of Ocean Exploration and Research 88

Cooperative Institute for Ocean Exploration, Research, and Technology 89

Pushing the Boundaries: Technology-Driven Exploration of Thunder Bay National Marine Sanctuary 90

Exploring the Sunken Heritage of Midway Atoll at the 75th Anniversary of the Battle of Midway 91

Cold Seeps of the Cascadia Margin 92

Exploring US Mid-Atlantic Margin Methane Seeps: IMMeRSS, May 2017 93

Innovative Observing Approaches to Better Understand the Big Picture 94

Northern Neighbors: Transboundary Exploration of Deepwater Communities 95

Innovative Nitrogen Sensor Maps the North Pacific Oxygen Minimum Zone 96

Realizing Capabilities Through Broad and Expanding Partnerships 97

DEEP SEARCH: Deep Sea Exploration to Advance Research on Coral/Canyon/Cold Seep Habitats 97

Southeast Deep Coral Initiative: Exploring Deep-Sea Coral Ecosystems off the Southeast United States 98

2018: A Shift in the Focus of Deep-Sea Exploration 100

PART 3. Schmidt Ocean Institute – R/V *Falkor* 102

Five Years of Research Aboard R/V *Falkor* 104

R/V *Falkor* in 2017 106

Epilogue 110

Authors 112

Acknowledgments 116

References 121

Acronyms 125

Dense aggregation of the tube worm *Oasisia aff. alvinae* with high abundance of small yellow dorvilleid polychaetes on the outer tubes. Red polynoid scale worms and anemones surround the bush of *Oasisia* on E/V *Nautilus* cruise NA091 in Pescadero Basin. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

Introduction

By Nicole A. Raineault, William Mowitt, and Victor Zykov

This annual ocean exploration supplement to *Oceanography* presents highlights of the latest field season for three vessels that investigate the world ocean: Ocean Exploration Trust's Exploration Vessel (E/V) *Nautilus*, NOAA Ship *Okeanos Explorer*, and Schmidt Ocean Institute's Research Vessel (R/V) *Falkor*. In 2017, work continued in the Pacific Ocean—with *Falkor* in the southern and western Pacific, *Okeanos Explorer* in the central Pacific, and *Nautilus* in the eastern Pacific, including Mexican waters for the first time. Late in 2017, after three years exploring the Pacific, *Okeanos Explorer* moved east into the Gulf of Mexico. Summaries of these expeditions describe new discoveries, advancements in ocean exploration technology, and outreach efforts aimed at all who are interested in the ocean's secrets.

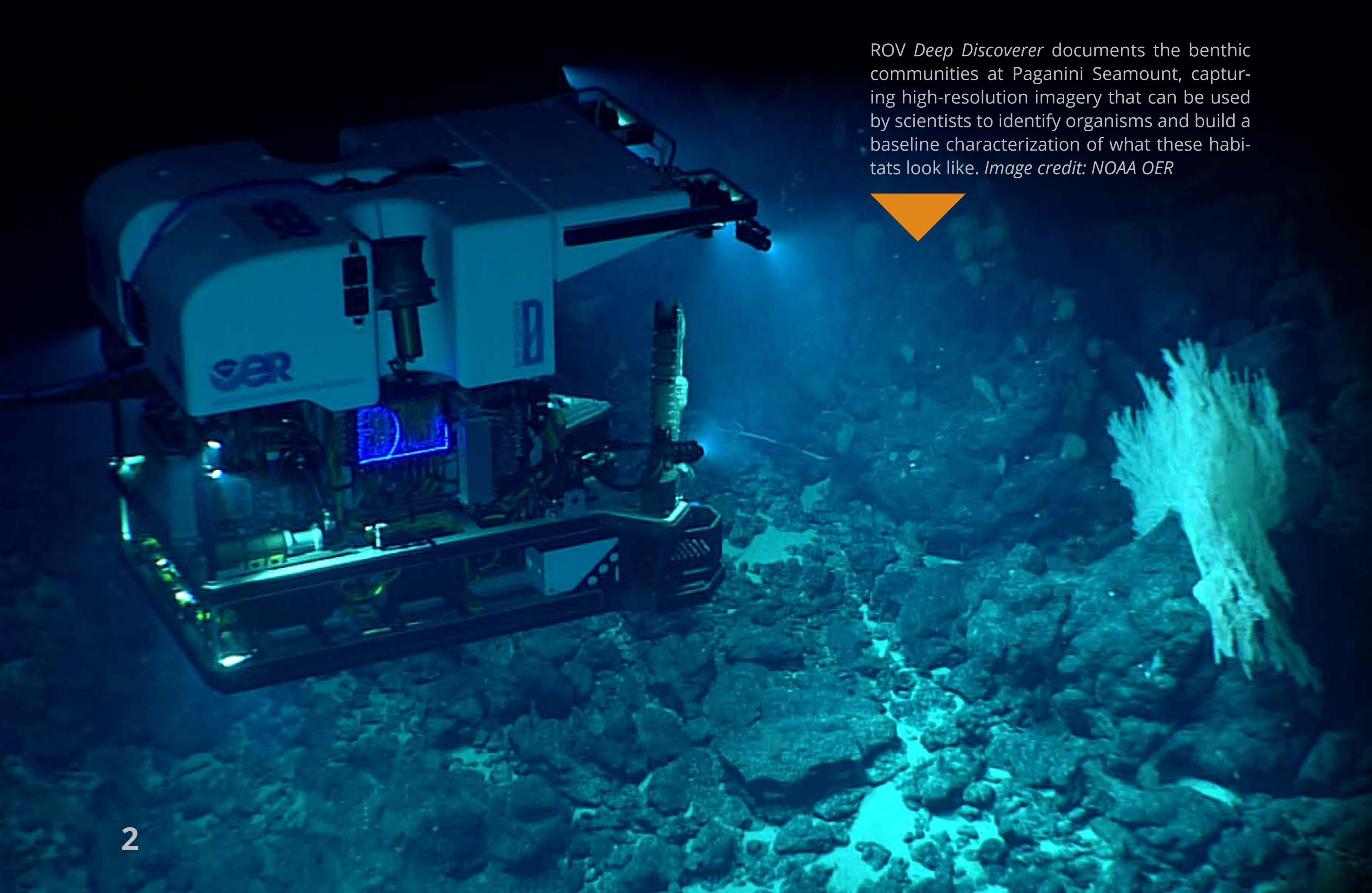
Continuing its mission of ocean exploration, innovation, and education, *Nautilus* embarked on its eighth field season in 2017. Part 1 of this supplement begins with a catalog of *Nautilus*'s technical capabilities (pages 8–13), as well as descriptions of new techniques and results of sample collection and analysis (pages 14–15). Next, we describe the global efforts of the Ocean Exploration Trust (OET) to increase interest and literacy in STEM fields through a variety of programs and development of educational materials (pages 16–23). Finally, we report on the early discoveries made during the 2017 field season, which explored geology, biology, and archaeology off the west coast of North America, from British Columbia to the Gulf of California and Revillagigedo Archipelago (pages 28–45). Four of the 14 cruises focused on mapping the seafloor—a critical first step in characterizing ocean regions and supplying baseline data needed for future, more detailed explorations (pages 26–27). In addition, several of the 14 cruises were undertaken in partnership with the NOAA Office of National Marine Sanctuaries; the results of these joint efforts support NOAA priorities in the region. The *Nautilus* team looks forward to expanding these and other relationships in 2018 and beyond.

Part 2 of this supplement focuses on the advances and accomplishments of NOAA Ship *Okeanos Explorer*, America's only federal ship dedicated to ocean exploration. The ship recently completed surveys that contribute to the Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE), as well as other exploratory efforts by NOAA's Office of Ocean Exploration and Research (OER). The OER section begins with the results of CAPSTONE (pages 48–53), including work in maritime archaeology (page 54), and introduces the capabilities of *Okeanos Explorer* (page 55). A description of innovations in ocean exploration follows, including ocean mapping, midwater column exploration, and the rich data source that video footage provides (pages 56–67). Next comes a review of OER's continuing commitment to encourage the next generation of ocean

explorers, scientists, and engineers through public engagement and education activities (pages 68–71). Then we take a deeper dive into *Okeanos Explorer* expeditions. Expeditions to several areas across the central Pacific included high seas surveys and exploration of the Musicians Seamounts and remote protected areas. We also report on how we manage our underwater biological and geological samples and leverage the intellectual capital of shoreside scientists by opening up sample collections for community input (pages 72–85), and we discuss the importance of international partnerships (pages 86–87) and their emergence during CAPSTONE. OER's sponsored projects include work with the Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT), and we present highlights of maritime archaeology and methane cold seeps exploration as well as showcase some new technology developments (pages 88–96). Finally, we discuss the power of partnerships to increase the potential for ocean exploration and highlight ones focused on deep-sea ecosystems in the Atlantic, including coral, and look at partnerships taking shape to enable the goals of the new Atlantic campaign to be met (pages 97–101).

The final part of this supplement highlights some significant accomplishments of R/V *Falkor*'s 2017 field season. Celebrating the ship's five years of research, Schmidt Ocean Institute (SOI) supported technology development as well as research that examined scalable approaches to the characterization of phytoplankton community dynamics, rates of past sea level change as recorded in the structure of ancient corals, diversity of geological processes surrounding some of the world's most active submarine volcanic provinces, and unique and novel biological ecosystems discovered within large and remote protected areas. Through its philanthropic efforts, SOI aims to demonstrate how scalable innovation can tackle important scientific and societal challenges (pages 102–109).

In 2018, cruise plans call for the three vessels to work in geographically distant parts of the globe. *Nautilus* will complete its first West Coast to Hawai'i circle, returning at the end of the season to San Pedro, California, and *Falkor* will continue to focus on the greater Pacific Ocean. *Okeanos Explorer* will venture into the Atlantic Ocean (including performing additional work in the Gulf of Mexico), initiating the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE). This is a large cross-Atlantic basin effort in support of the Galway Statement on Atlantic Ocean Cooperation, an initiative between the United States, Canada, and the European Union to advance knowledge of the Atlantic Ocean to improve stewardship and understanding. We invite you to follow along with our explorations online, and we look forward to sharing highlights of new discoveries with you next year.



ROV *Deep Discoverer* documents the benthic communities at Paganini Seamount, capturing high-resolution imagery that can be used by scientists to identify organisms and build a baseline characterization of what these habitats look like. *Image credit: NOAA OER*

2017 National Ocean Exploration Forum: Ocean Exploration in a Sea of Data

By David McKinnie and Adrienne Copeland

Ocean Exploration in a Sea of Data

From October 21 to 22, 2017, experts in ocean exploration and data science, as well as other fields, attended the fifth annual National Ocean Exploration Forum at the University of California, San Diego's, Qualcomm Institute, a division of the California Institute for Telecommunications and Information Technology. The goal of the 2017 interdisciplinary forum, Ocean Exploration in a Sea of Data, was to move the application of ocean exploration data into the future. Partners from the Qualcomm Institute, Lamont-Doherty Earth Observatory, NOAA, and others gave presentations, provided demonstrations on priority areas, and held discussion groups. Thinking of ocean exploration in broad terms, forum participants considered how relevant data—whether from satellites, ocean sensors, hydrophones, or deep ocean cores—can be integrated, analyzed, and visualized to understand the ocean in new ways.

Demonstrations of new technologies included those for exploring ocean data through audio spatialization and sonification, for applying near-360 degree immersive visualization of video and data, for exploring an active mid-ocean ridge volcano in real time through a fiber-optic cable connection to data, for visualizing Antarctic ice shelf structure and bathymetry from the air, and for allowing point-based visual analytics and habitat characterization using underwater photogrammetry. Participants shared impressions of these demonstrations and discussed how these tools could impact their work, areas of interest, and the ocean exploration community.

A Brief History of the Forum

Since 2013, leading ocean exploration experts have assembled at National Ocean Exploration Forums to discuss the priorities and aims of a national ocean exploration program. These forums have examined the future of ocean exploration through the lens of a coordinated NOAA-led, multi-agency federal collaboration with the private sector and academia.

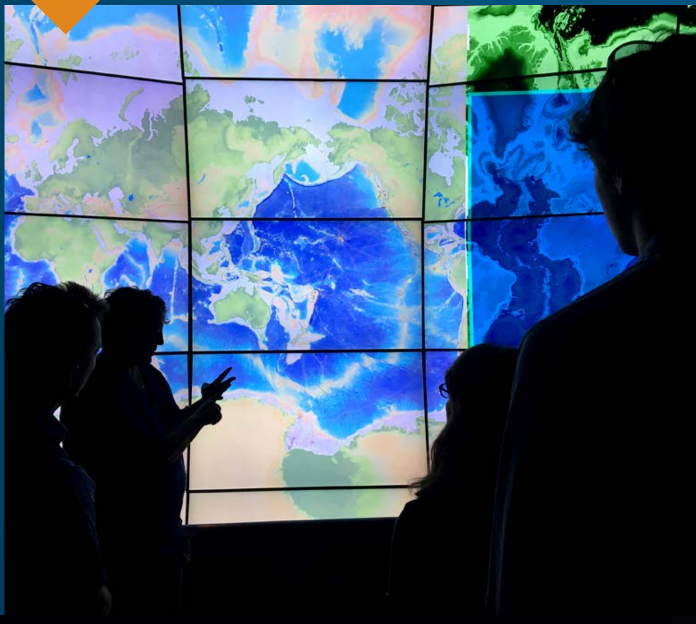
The inaugural 2013 Forum, called Ocean Exploration (OE) 2020, prioritized exploration in the polar, Indo-Pacific, and central Pacific regions and recommended expanding traditional ocean exploration to include ocean chemistry and the water column. OE 2020 recommendations emphasized the importance of using a variety of exploration platforms, developing new technologies, creating citizen science opportunities, increasing and fostering partnerships, improving low- to no-cost near-real-time data accessibility, and enhancing and expanding ways to communicate about ocean exploration. Subsequent forums have built upon these priorities and recommendations, helping to drive ocean exploration in both the public and private sectors in subsequent years.

Looking Ahead

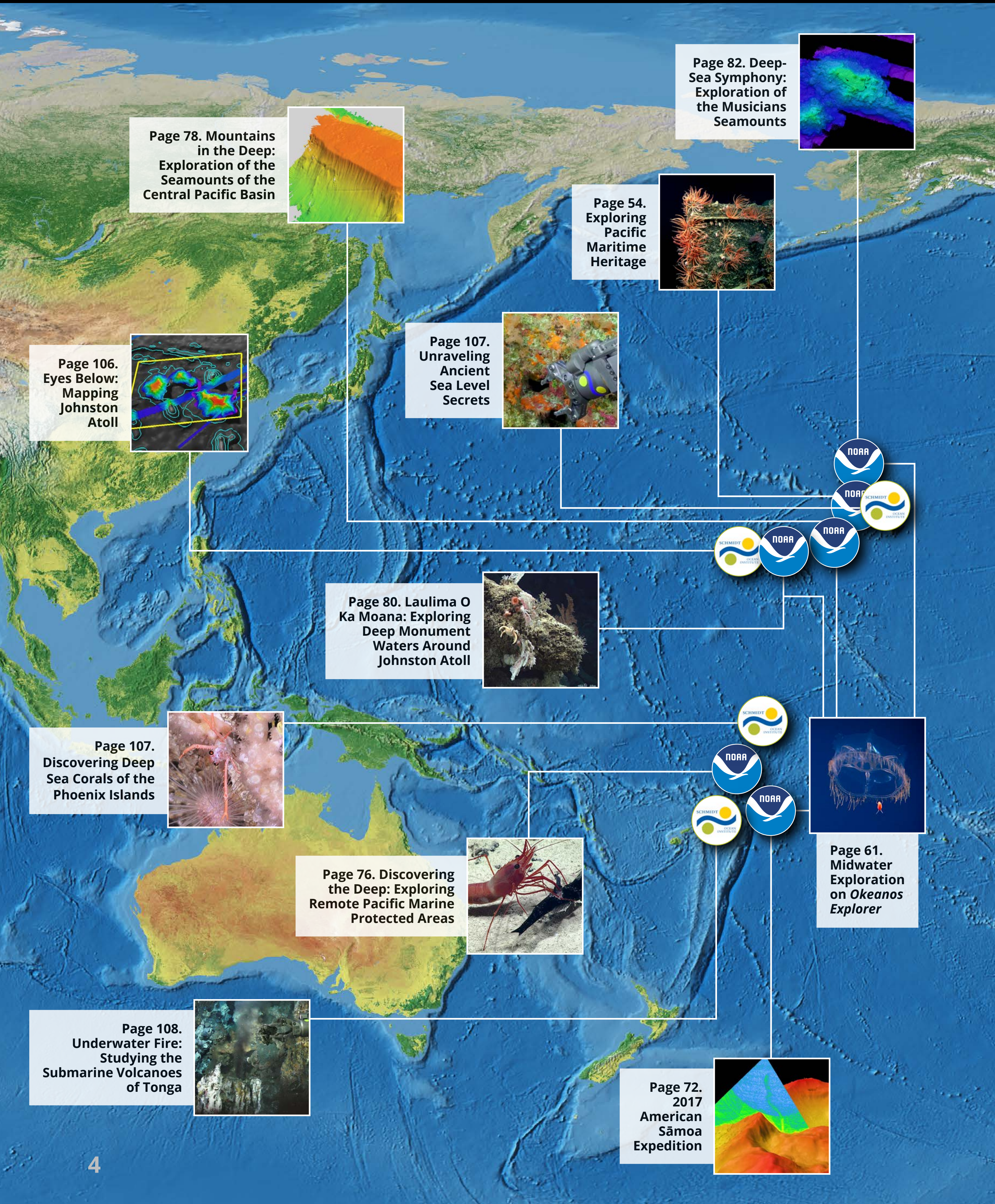
With these priority areas defined, further aims established, and additional ocean exploration conducted, the next step with the 2017 forum was to determine how the ocean exploration community can best manage large quantities of new and historical data and apply data science analysis and visualization techniques to them. The 2017 forum yielded community recommendations, described in a formal report to be released in 2018, for how data scientists, ocean explorers, and members of other disciplines can work together to expand traditional concepts of ocean exploration while driving toward new discoveries, increased access to contemporary and historical data, and improved public engagement.

The 2018 National Ocean Exploration Forum will continue to build upon previous recommendations and will review ways to better explain ocean exploration to students and the public with a goal of developing recommendations for more effective messaging and engagement strategies.

Vicki Ferrini of Lamont-Doherty Earth Observatory demonstrates the SunCAVE's near-360 degree capabilities at the 2017 National Ocean Exploration Forum. These immersive environment technologies allow experimentation with new ways to represent deep ocean bathymetry, seafloor features, and other attributes of the deep ocean. *Image credit: OER*



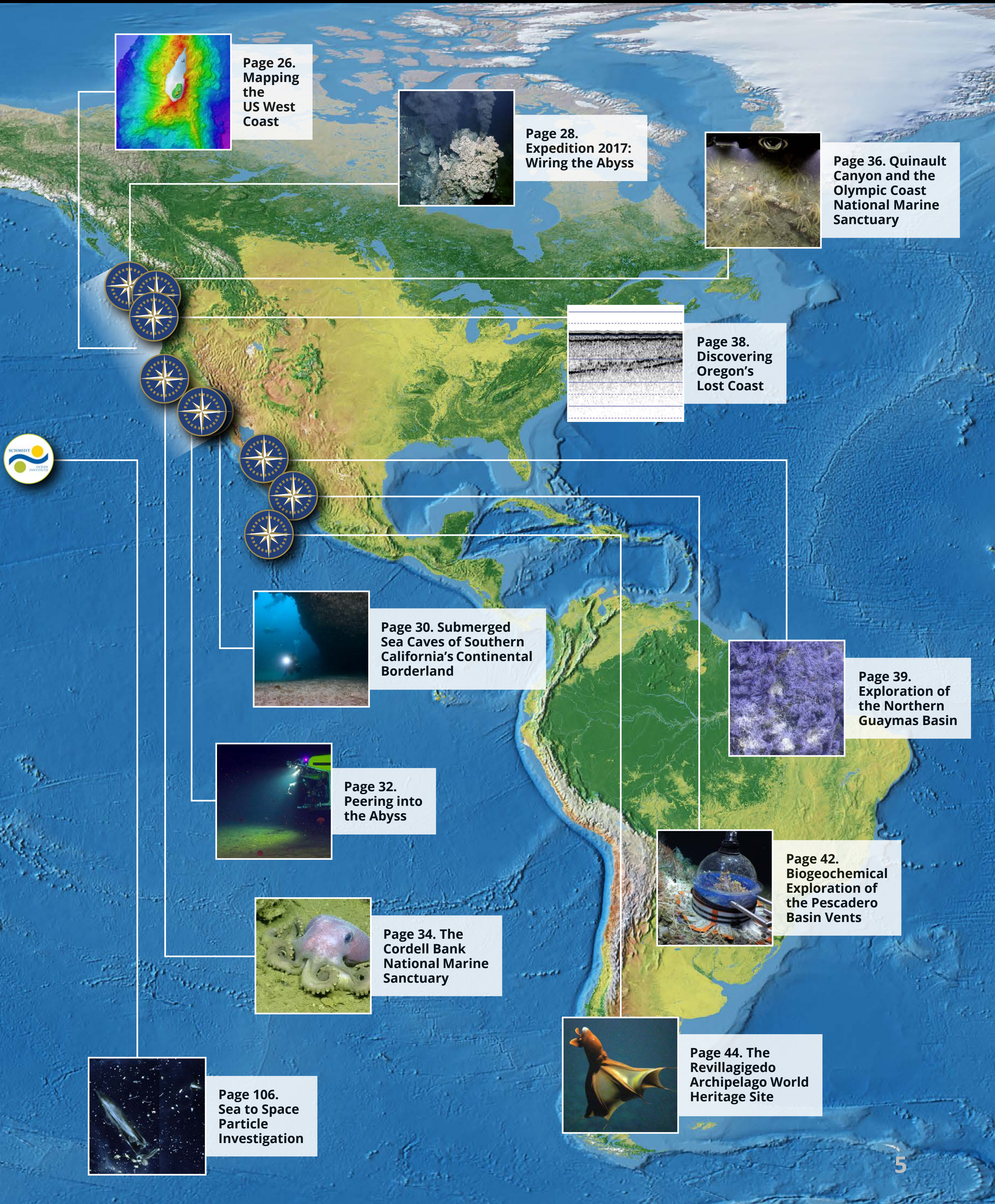
2017 Expedition Overview Map

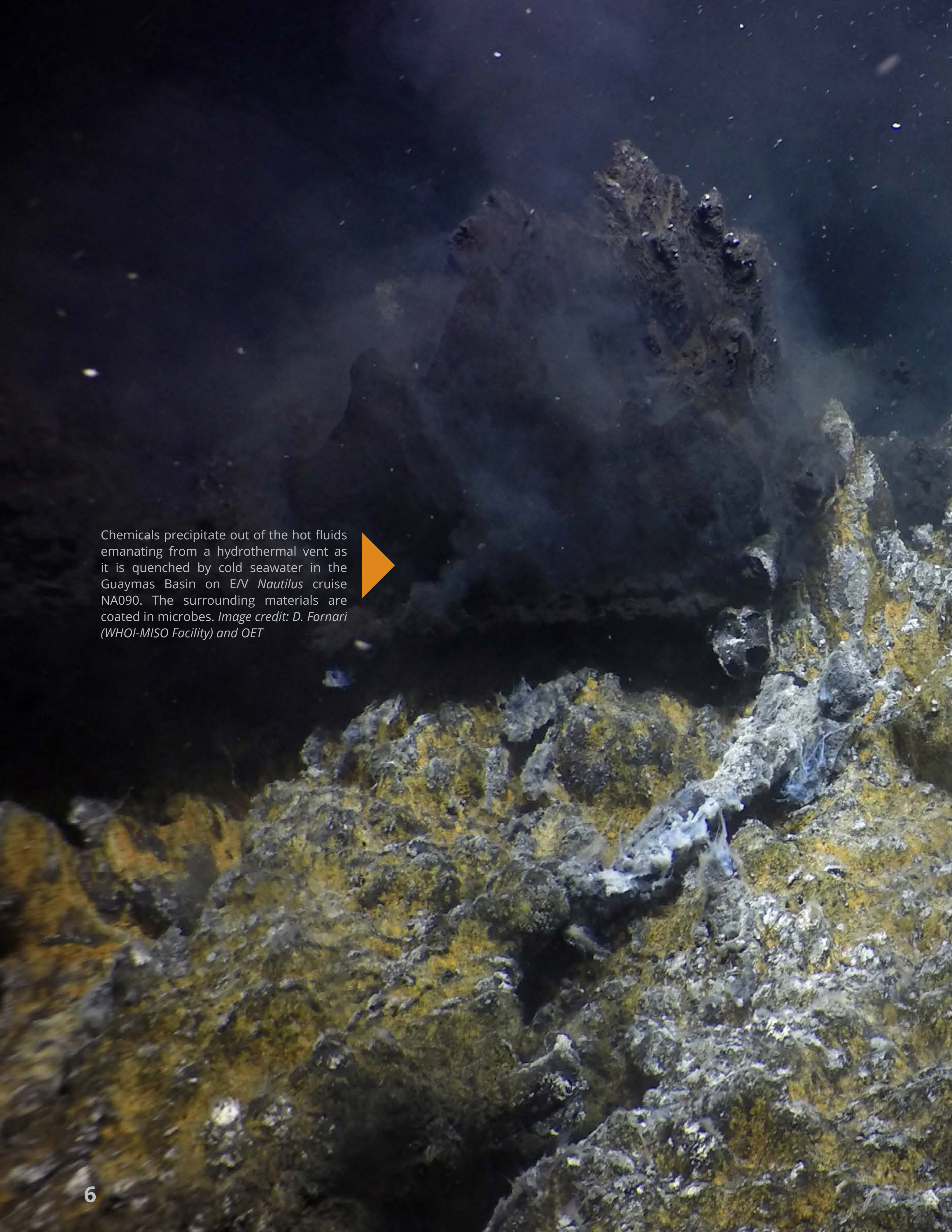


E/V *Nautilus* Expeditions

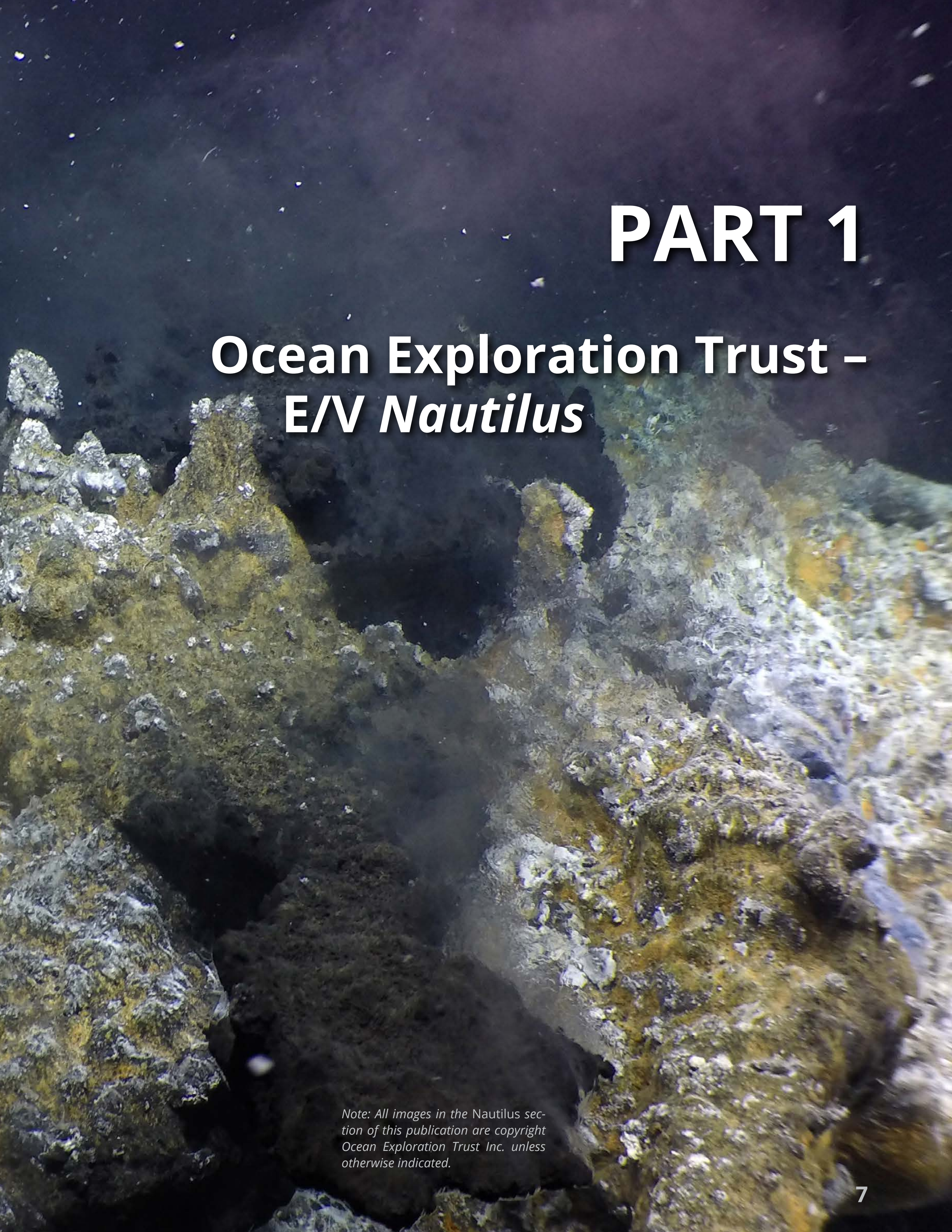
NOAA Ship *Okeanos Explorer* Expeditions

R/V *Falkor* Expeditions





Chemicals precipitate out of the hot fluids emanating from a hydrothermal vent as it is quenched by cold seawater in the Guaymas Basin on E/V *Nautilus* cruise NA090. The surrounding materials are coated in microbes. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*



PART 1

Ocean Exploration Trust – E/V *Nautilus*

Technology E/V *Nautilus*

Nautilus is an efficient 64-meter exploration vessel with 17 permanent crew and berthing for a 31-member rotating Corps of Exploration. The ship is equipped with a Kongsberg EM 302 multibeam echosounder and two ROVs named *Hercules* and *Argus* that explore the seafloor. The ship has a data lab and a wet lab, as well as other scientific facilities, for processing digital data and physical samples. As part of our effort to share our expeditions with students and colleagues, we use telepresence technology to stream live video from our ROVs and various locations on the ship in real time to our Nautilus Live website (https://nautiluslive.org).

GENERAL

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) at 10 knots

ENDURANCE | 40 days at sea

SPEED | 10 knots service, 12 knots maximum

FUEL CAPACITY | 330 cubic meters

PROPULSION | Single 1,285 kilowatt (1,700 hp) controllable pitch main thruster; 280 kW bow tunnel thruster; 300 kW jet pump stern thruster

SHIP SERVICE GENERATORS | Two 585 kVA generators, one 350 kVA generator

PORTABLE VAN SPACE | One 6.1-meter (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 A06063 1.73 centimeter (0.681 inch) diameter cable
- DT Marine 210 winch
- Bonfiglioli knuckle-boom crane, 2–6 ton capacity, two extensions
- Two airtuggers, SWL 900 lbs each
- A-frame, SWL 8 mtns
- Rescue boat davit with SWL 0.9 mtn
- Oceanscience UCTD 10-400 profiling system; max depth 1,000 meters

TELEPRESENCE TECHNOLOGY

VSAT | 2.4 meter axis stabilized Sea Tel 9711 uplink antenna capable of C- and Ku-band operation of up to 20 Mbps (C-band circular or linear)

REAL-TIME VIDEO STREAMING | Four Haivison X encoders designed for streaming live video via satellite to the Inner Space Center ashore

CAMERAS | Two Sony BZR-H700 high-definition pan/tilt/zoom cameras mounted to view the aft deck and port rail; one BZR-H700 in the control vans; Marshall VS-570 PTZ cameras in the wet lab and in the ROV hanger

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
- Telephone interface is available through a Rhode Island exchange for real-time collaboration between scientists ashore and on the ship
- Full Internet connectivity from shipboard LAN and wifi

DATA PROCESSING & VISUALIZATION LAB

AREA | 44.5 square meters (480 square feet)

WORKSTATIONS | Seven workstations for science manager, data loggers, navigators, educators, data engineers, satellite engineer, video engineer; seafloor mapping data processing; flexible bench space

RACK ROOM

AREA | 17.3 square meters (185 square feet)

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

EMERGENCY COMMUNICATIONS | Two Iridium phones

ELECTRONICS WORKBENCH | 2.3 cubic meters (80 cubic feet) of storage

PRODUCTION STUDIO

AREA | 12 square meters (130 square feet)

CAMERA | Remote controllable high-definition Sony BRC-H700, Canon FX-305 for live deck television broadcasts and interactions

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

HAZMAT |

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

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

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, educator

VIDEO STORAGE | Two Omneon Mediadecks (MDM-5321 and SMD-2200-BB) for video recording and storage, 2x LTO-6 archive media drives

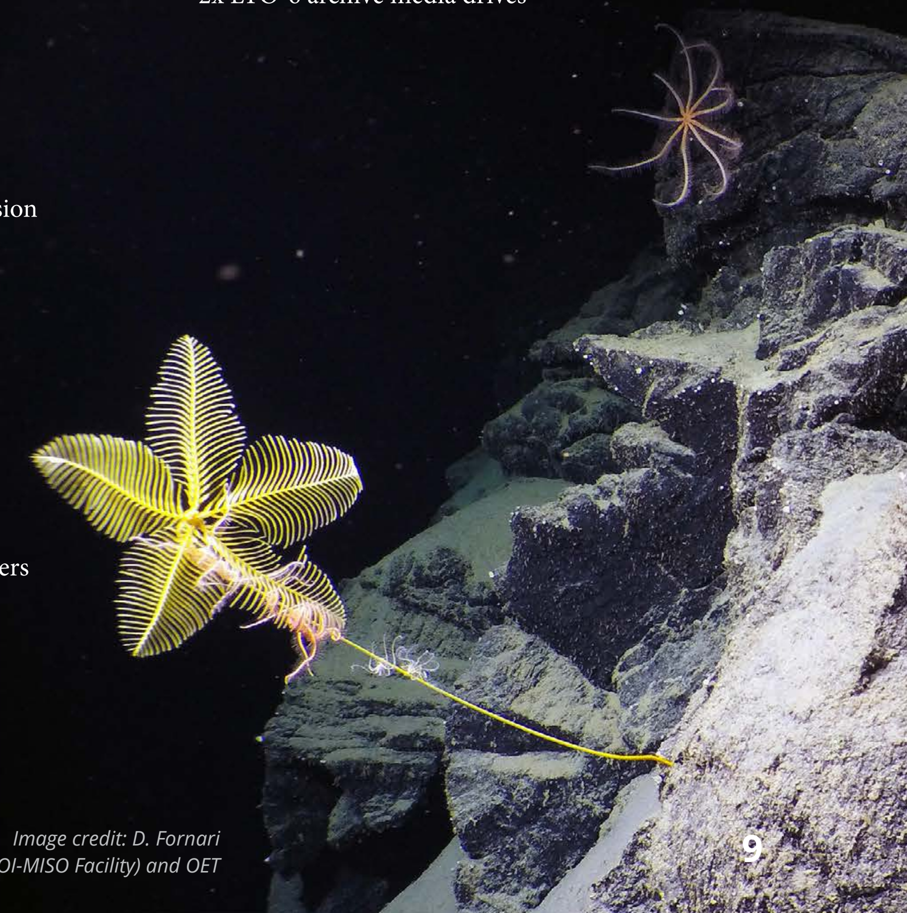


Image credit: D. Fornari (WHOI-MISO Facility) and OET

Acoustic Systems

KONGSBERG EM 302 MULTIBEAM ECHOSOUNDER

The EM 302 is a hull-mounted 30 kHz multibeam echosounder composed of two long transducer arrays mounted in a T-shape on the hull of *Nautilus*. It was installed on the ship between 2012 and 2013 to collect bathymetric, backscatter, and water column data. This information is useful for identifying areas or features of interest, creating bathymetric maps for ROV dive planning and situational awareness, and locating gas seeps. The EM 302 can efficiently map the seafloor in water depths from 10 m to 7,000 m (33 ft to 22,965 ft) at ship speeds of 8–10 knots.

FREQUENCY | 30 kHz

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

PULSE FORMS | CW and FM chirp

BEAMWIDTH | 1° × 1°

APPROXIMATE SWATH WIDTH | 3–5 times water depth, up to 8 km (5 miles)

APPROXIMATE GRID RESOLUTION | 10% water depth (e.g., 10 meters [33 feet] at 1,000 meters [3,281 feet] depth)

KNUDSEN SUB-BOTTOM PROFILER AND ECHOSOUNDER

The Knudsen 3260 is a sub-bottom echosounder mounted inside the hull of *Nautilus*. It operates at low frequencies (3.5–210 kHz) so that the sound it emits can penetrate layers of sediment to about 100 m below the surface. The sound that bounces back from each layer is captured by the system, creating a cross section of the seafloor. Scientists can use the data to identify subsurface geological structures such as faults and ancient channels and levees. The Knudsen 3260 can operate in full ocean depths. The Knudsen system also collects 15 kHz single beam sonar data.

PROFILER | Knudsen 3260 Chirp sub-bottom 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*

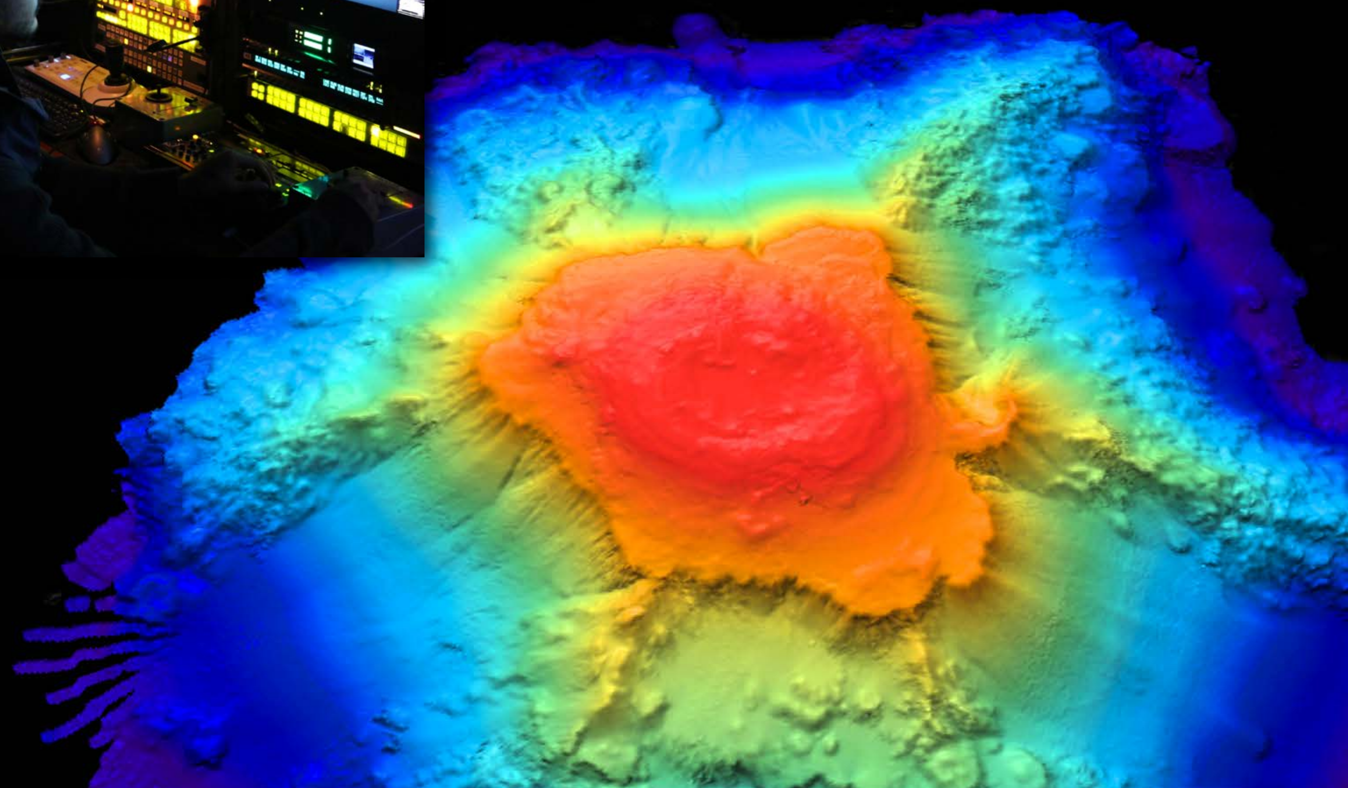
RANGE | Up to 5,000 meters (16,404 feet)

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

OPERATIONAL BEAMWIDTH | 120°

OPERATING FREQUENCY | 14.2 to 19.8 kHz

TARGETS TRACKED | *Hercules*, *Argus*, and two additional transponders are available. With more transponders, up to eight targets including the ROVs can be tracked



Remotely Operated Vehicle *Argus*

ROV *Argus* was first launched in 2000 as a deep-tow system capable of diving to 6,000 meters. More recently, *Argus* is used in tandem with ROV *Hercules*, where it hovers several meters above in order to provide a bird's-eye view of *Hercules* working on the seafloor. *Argus* is also capable of operating as a stand-alone system for large-scale deepwater survey missions.

GENERAL

DEPTH CAPABILITY | 6,000 meters (19,685 feet), currently limited to 4,000 meters (13,123 feet)

CABLE | 4,500 meters (14, 764 feet), 0.681 electro-optical, 3x #11 conductors, 3x SM fibers

SIZE | 3.8 meters long × 1.2 meters wide × 1.3 meters high (12.5 feet long × 3.9 feet wide × 4.3 feet tall)

WEIGHT | 2,100 kilograms (4,700 pounds) in air, 1,360 kilograms (3,000 pounds) in water

MAXIMUM TRANSIT SPEED | 2 knots

ASCENT/DESCENT RATE | 20–30 meters/minute (65–98 feet/minute) max

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
- Two Insite Pacific standard definition mini utility cameras (fixed mounted) 480 line NTSC format
- One Deep Sea Power & Light Wide-i SeaCam, downward-looking standard definition camera (fixed mounted)

LIGHTING |

- Four CathX Aphos 16 LED lampheads, 28,000 lumens each
- Two Deep Sea Power & Light 250 Watt incandescent lights

VEHICLE SENSORS & NAVIGATION

SYSTEM | NavEst integrated navigation system solution

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, 0.5–100 meter (1.6–328.1 foot) range typical

SUB-BOTTOM PROFILING SONAR | TriTech SeaKing Parametric Sub-bottom Profiler (10–30 kHz)

SCIENTIFIC INSTRUMENT SUPPORT

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

DIGITAL DATA CHANNELS | RS-232

Remotely Operated Vehicle *Hercules*

Since it was first launched in 2003, ROV *Hercules* has been working in tandem with ROV *Argus* to explore the geology, biology, archaeology, and chemistry of the deep sea. *Hercules* is equipped with a high-definition video camera, several LED lights, two manipulator arms, and a variety of oceanographic sensors and samplers, including a suite of high-resolution mapping tools that is available for use upon request. *Hercules* can deliver approximately 68–113 kg (150–250 lbs) of samples or tools to and from the seafloor.

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

PAYLOAD | Up to 113 kilograms (250 pounds)

MAXIMUM VEHICLE SPEED | 0.77 meters/second (1.5 knots) forward, 0.25 meters/second (0.5 knots) lateral, 0.5 meters/second (1 knot) 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)/15 meters/minute (49.2 feet/minute), or 20–22 meters/minute (65.6–7.2 feet/minute) average

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

SYSTEM | NavEst integrated navigation system solution

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 | Sea-Bird FastCAT 49

OXYGEN OPTODE | Aanderaa 3830

TEMPERATURE PROBE | WHOI high-temperature probe (0°–450°C, 0.1°C resolution)

USBL NAVIGATION | 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 scanning sonar, 300 kHz, 1–200 meter (3–656 feet) range typical
- TriTech Super SeaPrince 675 kHz, 50 meter (164 feet) range

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, port rail, and aft region 480 line NTSC format
- One Insite Pacific Aurora utility camera to view the eight-jar suction sampler, NTSC format
- One Deep Sea Power & Light Wide-i-SeaCam to view starboard side sample box, NTSC format

LIGHTING |
- 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 green 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; forward-looking configuration possible
- Two stereo Prosilica still cameras, one black & white, one color; 2,750 × 2,200 pixels; 29° × 39° field of view; 2–4 meter (6.5–13 feet) range; 200 watt-second strobe lighting at one image every three seconds
- Structured light laser system with a dedicated Prosilica GC 1380 still camera; runs concurrently with stereo imaging; 532 nanometer, 100 mW coherent laser; 45° line generating head
- System also supports Kongsberg M3 sonar

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, eight 3-liter discrete samples
- Venturi dredge 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 and sensors can be integrated

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 113 kilograms (250 pounds) depending on sensor package
- Custom configuration of boxes, crates, and containers

ELEVATORS | Mission configurable; free ascent; maximum standard payload 68 kg (150 lb)

SCIENTIFIC INSTRUMENT SUPPORT

SWITCHED POWER |
- 110 V, 60 Hz AC
- 24 VDC
- 12 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 5 GPM
- 1,850 psi at 5 GPM
- 3,000 psi at 5 GPM (advance notice needed)

EXAMPLES OF USER-INSTALLED TECHNOLOGY |
Advance notice is required for custom solutions to engineering integration of user provided sensors and equipment
- In situ mass and laser spectrometers
- Fluorometer
- pH sensor
- eH sensor
- Kongsberg M3 multibeam sonar
- 18 MP Ethernet connected digital still camera
- Low-light camera (Canon ME20F-SH HD, 1080p at up to 4 million ISO, 24 mm f1.4 prime lens)
- Modular soft grippers powered by an independent seawater-based hydraulic drive system

2017 *Nautilus* Samples Program

By Nicole A. Raineault, Meredith Everett, Dean Pentcheff, Elva Escobar Briones,
Adriana Gaytán-Caballero, and Esmeralda Morales Domínguez

Physical samples are critical for organism identification and for understanding the geological and geochemical history of an area. In 2017, the Ocean Exploration Trust collected 768 unique biological, rock, sediment, gas, and water specimens. These samples were split into 1,721 subsamples to be archived at partnering institutions or provided directly to scientists. For the 2017 field season, Harvard University's Museum of Comparative Zoology (MCZ) received 442 biological vouchers and DNA subsamples, which can be requested for research via their museum's website (http://mczbase.mcz.harvard.edu/SpecimenSearch.cfm). The University of Rhode Island Graduate School of Oceanography's Marine Geological Samples Lab (MGSL) is archiving the 142 rock samples and short sediment cores, and they are also available by request (https://doi.org/10.7289/V5JQ0Z0W). Below we provide some of the highlights of our 2017 sample program.

eDNA & Genetic Barcoding

Environmental DNA (eDNA) is genetic material obtained from an environmental sample rather than directly from an organism (Thomsen and Willerslev, 2015; Valentini et al., 2016). Because all marine organisms shed DNA into the water, we are developing the ability to inventory biodiversity by sampling and sequencing seawater—which is far easier than exhaustive specimen sampling and identification. Another advancement, use of genetic barcodes, allows scientists to determine the species of an organism based on specific short gene sequences. An eDNA inventory can only be effective if there is at least one reference barcode sequence for each species of interest. Although marine invertebrates are not yet well represented in genetic barcode reference databases, the Diversity Initiative for the Southern California Ocean (DISCO) program at the Natural History Museum of Los Angeles County (NHMLA) is generating genetic barcode references for the marine invertebrates of Southern California.

During 2017 dives, ROV *Hercules* pilots gathered numerous specimens, including many species that would otherwise be difficult or impossible to obtain. Some, such as the lithodid crab (Figure 1), were selected based on real-time requests from shore-based scientists. These full specimen or tissue samples were shipped to the NHMLA for identification and reference sequencing (Figure 2). In addition, the ROV pilots collected geologically interesting rocks that were covered with hundreds of invertebrates. These were preserved in ethanol on E/V *Nautilus* and then cleaned of organisms at the NHMLA. The rocks were subsequently sent to the MGSL for

Figure 1. Capture of a lithodid crab by ROV *Hercules* on request by a shore researcher.

Figure 2. Undergraduate Makenzie Hajek taking a tissue sample from the crab at the Natural History Museum of Los Angeles County to generate a genetic barcode reference sample.

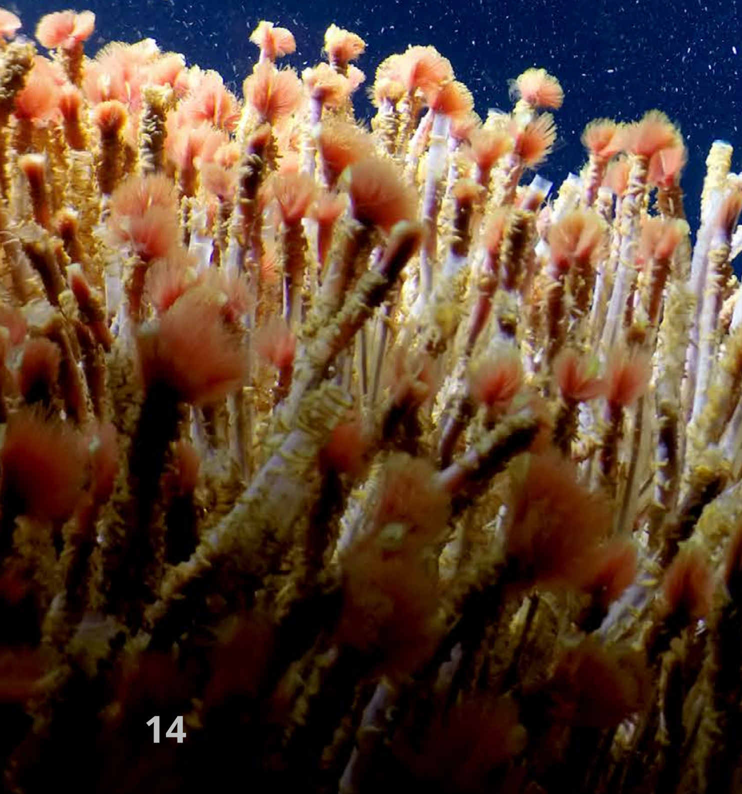


Figure 3. ROV *Hercules* captures a water sample for eDNA analysis in an onboard Niskin bottle along a canyon wall covered in *Lophelia* coral.

Figure 4. Short sediment push cores were taken at and adjacent to chemosynthetically active areas to study infaunal and microbiological communities, pore-water chemistry, and sediment geology.

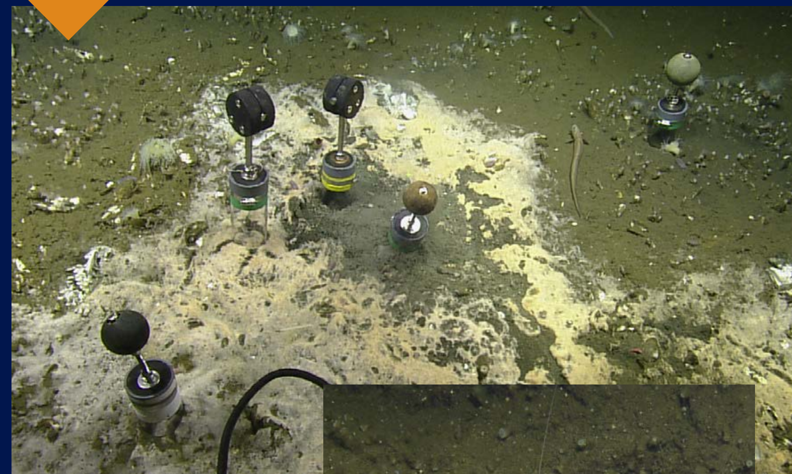


Figure 5. *Munidopsis* squat lobsters suggests the presence of at least two new records (cf. *Munidopsis producta* and *Munidopsis* sp.) at the Pescadero Basin site.

use by geologists. The 2017 collections will fill in key missing taxa as genetic barcode references, contributing significantly to our ability to detect and monitor marine biodiversity.

Deep-sea coral communities observed along the US west coast during the 2017 *Nautilus* season were profiled using eDNA sequencing (Everett and Park, 2017). There is growing interest in understanding the possible associations of fish communities with deep-sea corals (Milligan et al. 2016), which occur in patchy and difficult-to-access environments, can be delicate and slow growing, and are difficult to identify from images or video alone (Cairns et al., 2017). During 2017, 60 eDNA samples were collected from both stony and soft coral habitats (Figure 3) and from sites where no corals were observed. Each sample will be amplified and sequenced using primers specific to both octocorals and fish. Coral and fish species will be identified using phylogenetic methods, and video footage will be examined for secondary confirmation. This will allow us to look for associations between deep-sea coral and fish communities as well as to further profile deep-sea coral communities found in the marine sanctuaries along the US west coast.

Mexico Biological Samples

Guaymas Basin sites are poorly known, difficult to access, and require special sampling tools. In 2017, OET partnered with researchers from the Universidad Nacional Autónoma de México (UNAM) on three ROV expeditions within Mexican waters. One cruise continues studies of Guaymas Basin vent fields, including the distribution of mega-, macro-, and meiofauna. While HD video and images allow researchers to characterize habitat diversity and the complexity and taxonomy of megafauna, samples collected with the suction sampler, scoop, ROV manipulator, and a baited trap (Pescadero Basin) offer a rare opportunity to identify small or cryptic species. Sediment push cores collected at representative habitats allow cross-disciplinary study of sediment-hosted infaunal and microbiological communities at chemosynthetically active areas (Figure 4). Qualitative samples obtained from water and sediment materials remaining in the biobox containers complement the taxonomic records for the explored sites.

UNAM's main objective in Guaymas Basin is the descriptive ecology and zonation of the benthic components at chemosynthetic locations (vent fields) and nearby background habitats in order to understand compositional differences using visual information obtained from video transects and HD images. Representative samples of anemones (Actinaria) were obtained to analyze their molecular identity and symbiotic relationships. Studies of specimens of the area's abundant snails (Gastropoda) and amphipods (Gammaridae) will provide a diversity description and a complete population analysis for these organisms. Our field observations and general analysis of the specimens of *Munidopsis* squat lobsters suggest the presence of at least two new records (cf. *Munidopsis producta* and *Munidopsis sp.*; Figure 5). The group was abundant at the "zoanthid colonies mound" habitat and inside the crevices of carbonate layers, where behavior was also observed.

Collaborative scientific research in Guaymas Basin began in the late 1980s and early 1990s with the EDUMAR cruise with Robert Ballard, followed by the GUAYNAUT cruise with IFREMER. UNAM collaborated on other cruises as well, allowing UNAM scientists to monitor long-term vent-associated communities in the Guaymas Basin and to explore new sites. This collaborative effort has provided support for nomination of Guaymas Basin as the first deep-sea hydrothermal Natural Protected Area worldwide.

Nautilus Education and Outreach Programs

Sparking Interest in Ocean Exploration and Providing Experiential STEM Programs for Students and Educators

By Allison Fundis, Samantha Wishnak, Megan Cook, Kathy Sutton, Kelly Moran, Scott Munro, and Tim Burbank

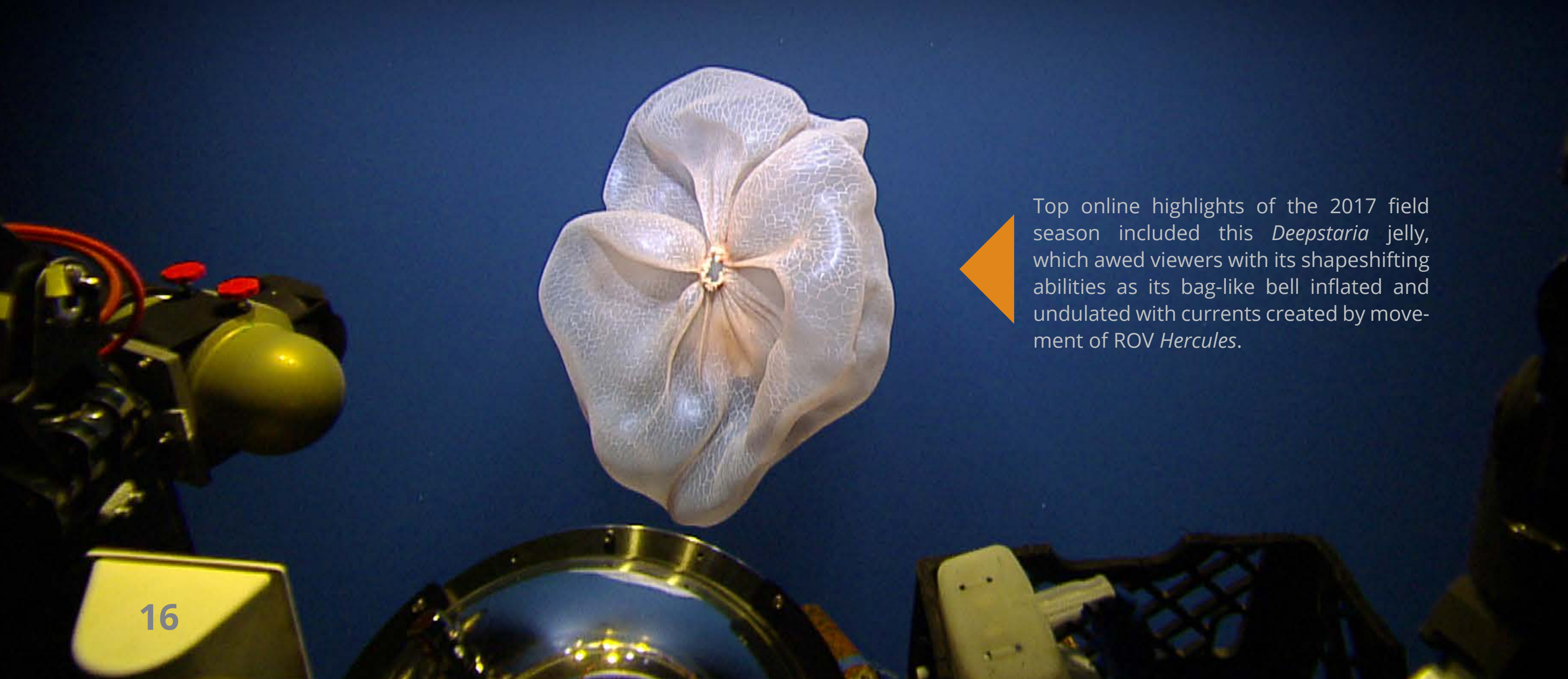
The Ocean Exploration Trust uses E/V *Nautilus* and the research it supports as platforms for providing innovative and educational programs that will generate enthusiasm for and exposure to the breadth of STEM disciplines associated with ocean exploration as well as the diverse career paths and vocations that make it possible. Through a series of programs and resources, OET connects students and the public in a variety of settings—classrooms, science centers, universities, aquariums, and living rooms—to seagoing STEM professionals, their fields, and their tools of exploration.

OET uses research conducted aboard E/V *Nautilus*, the ship's associated technologies, and shore-based facilities at the University of Rhode Island's Inner Space Center to take a multifaceted approach to education and outreach. Programming includes: (1) outreach to inspire the online public through 24/7 connectivity to explorers at sea; (2) ocean exploration-themed STEM curricular materials; (3) professional development opportunities for educators on shore; (4) infusion of *Nautilus* content into science centers, aquariums, museums, and other informal education institutions; and (5) immersive, hands-on opportunities for students, educators, and artists to participate in *Nautilus* expeditions. Through these efforts, we have reached tens of millions of people worldwide since 2009 as we strive to better equip the next generation with the skills and role models they need to be our future explorers, innovators, policymakers, and members of a productive workforce.

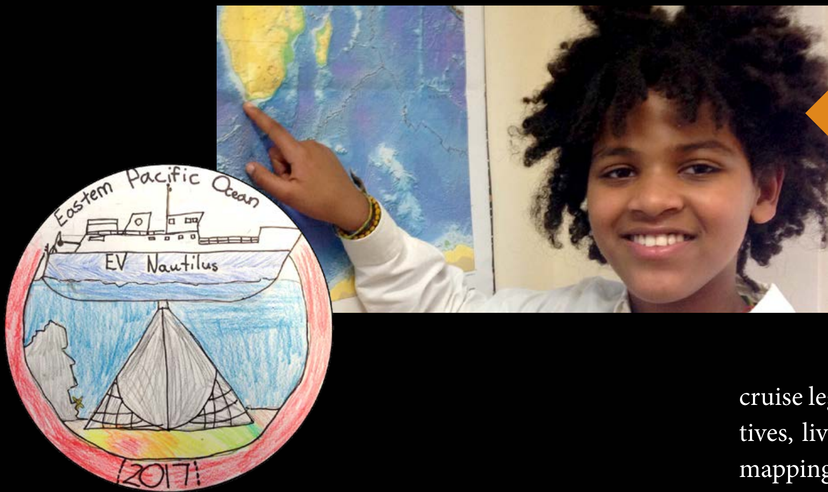
Major sponsors of OET's 2017 education programs included the Office of Naval Research, CITGO, University of New Hampshire, University California–Santa Barbara, AltaSea at the Port of Los Angeles with support from the Goldhirsh Foundation, Connecticut Science Museum, Perot Museum of Nature and Science with support from the Lyda Hill Foundation, and private donors.

Public Outreach

OET's outreach goals include introducing a broad and diverse global audience to the process of exploration and the excitement of discovery while continually adjusting to the rapidly changing landscape of social and mass media. During the 2017 *Nautilus* field season, we continued to focus efforts on streaming 24-hour live video of expedition operations and deep-sea exploration, social media, and news media in addition to experimenting with new ways to reach the public through evolving social platforms.



Top online highlights of the 2017 field season included this *Deepstaria* jelly, which awed viewers with its shapeshifting abilities as its bag-like bell inflated and undulated with currents created by movement of ROV *Hercules*.



Winning entry of the Nautilus Patch Design Contest submitted by Sintayehu Shannon of Washington. The annual contest is open to young artists ages 6 to 14.

NAUTILUS LIVE

Featuring live streaming video of expedition operations from shipboard and ROV cameras, as well as audio commentary from scientists, engineers, educators, and students, the Nautilus Live website drew more than 1.9 million views during the six-month 2017 field season. Approximately 40% of those viewers were new visitors to the website. An important element of the baseline engagement in OET's programming is the opportunity for students and audience members to interact directly with our Corps of Explorers through the "Send a Question" feature of the Nautilus Live website. In 2017, our scientists, engineers, and educators received over 32,800 questions that were answered over the audio stream accompanying the live video feed.

Enhancements to the website allowed basic oceanographic data—vehicle depth and water temperature—to stream alongside the video feed during ROV operations, boosting educational context for the viewing experience. Regular publishing of new photo albums, expedition overview blogs, and highlight videos showcased our research partners, innovative technologies, and the exploration goals of each expedition during the season. The interactive element of the web experience enables audiences around the world to play a role in identifying archaeological, biological, and geological discoveries made throughout the expedition season, creating a crowd-sourced participatory experience that encourages the public to dive deeper into the content and research being conducted on board.

SOCIAL MEDIA

One of the primary goals of the Ocean Exploration Trust is to share the excitement of ocean exploration with viewers around the world. To help achieve this goal, we use telepresence to populate social media platforms with real-time video and photo highlights of our expeditions. Positioning each expedition as a social media campaign within the larger 2017 field season, social media posts focus on the launch of various cruise legs, background information about exploration objectives, live ROV dive alerts and updates of ROV science and mapping operations; and expedition wrap-up and follow-up content. We engage with our frequent viewers and capture new viewers on social media platforms such as Facebook, Twitter, Instagram, and YouTube where they are already active. Offering a real-time, behind-the-scenes glimpse of *Nautilus* operations, Facebook Live events and Instagram story takeovers by *Nautilus* team members help us reach younger audiences and inspire a new generation of students and ocean explorers.

Popular social media hits concentrated on cephalopod sightings, including vampire squid and transparent cockatoo squid in addition to close encounters with large broadnose sixgill sharks and a shiver of over 30 prickly sharks in Channel Islands National Marine Sanctuary. While charismatic megafauna dominated the deep-sea spotlight, we also saw high levels of engagement with seafloor mapping content developed to complement the 50% of our field season dedicated to mapping operations. In addition to biology- and geology-focused stories, one of our top social media hits of the 2017 season brought together partners from NOAA's Office of National Marine Sanctuaries, Olympic Coast National Marine Sanctuary, US Navy, Naval Historical Foundation, veterans, and more during a multiple hour exploration of the wreck of World War II submarine USS *Bugara* that was broadcast on Nautilus Live, Facebook Live, and in museum venues across the country.

Our Instagram story takeovers gave participating interns, educators, scientists, engineers, and crew the chance to share aspects of their lives onboard as role models and performing the various tasks required for ocean exploration.

Nautilus Live's Facebook audience steadily increased in 2017 to over 86,000 followers, with an extended reach of more than 4.2 million. Testing our capabilities to deliver unique behind-the-scenes glimpses into *Nautilus* operations, Facebook Live broadcasts yielded some of the highest levels of engagement we've seen on this page. Answering questions from highly engaged fans at pivotal moments in an expedition, like the first moments of exploring the USS *Bugara* wreck, on deck before an ROV launch, or a Q&A from the control van during mapping expeditions, offers an interactive experience to complement the Nautilus Live underwater streams.

As Twitter has led the way as an efficient mechanism for delivering content in real time to followers, it has become our primary platform for live dive alerts and expedition updates. With frequent tweets and cultivating an active community of followers who share our tweets as well as their own screenshots and observations of Nautilus Live exploration, our extended reach doubled since 2016 with approximately 5 million impressions this year.

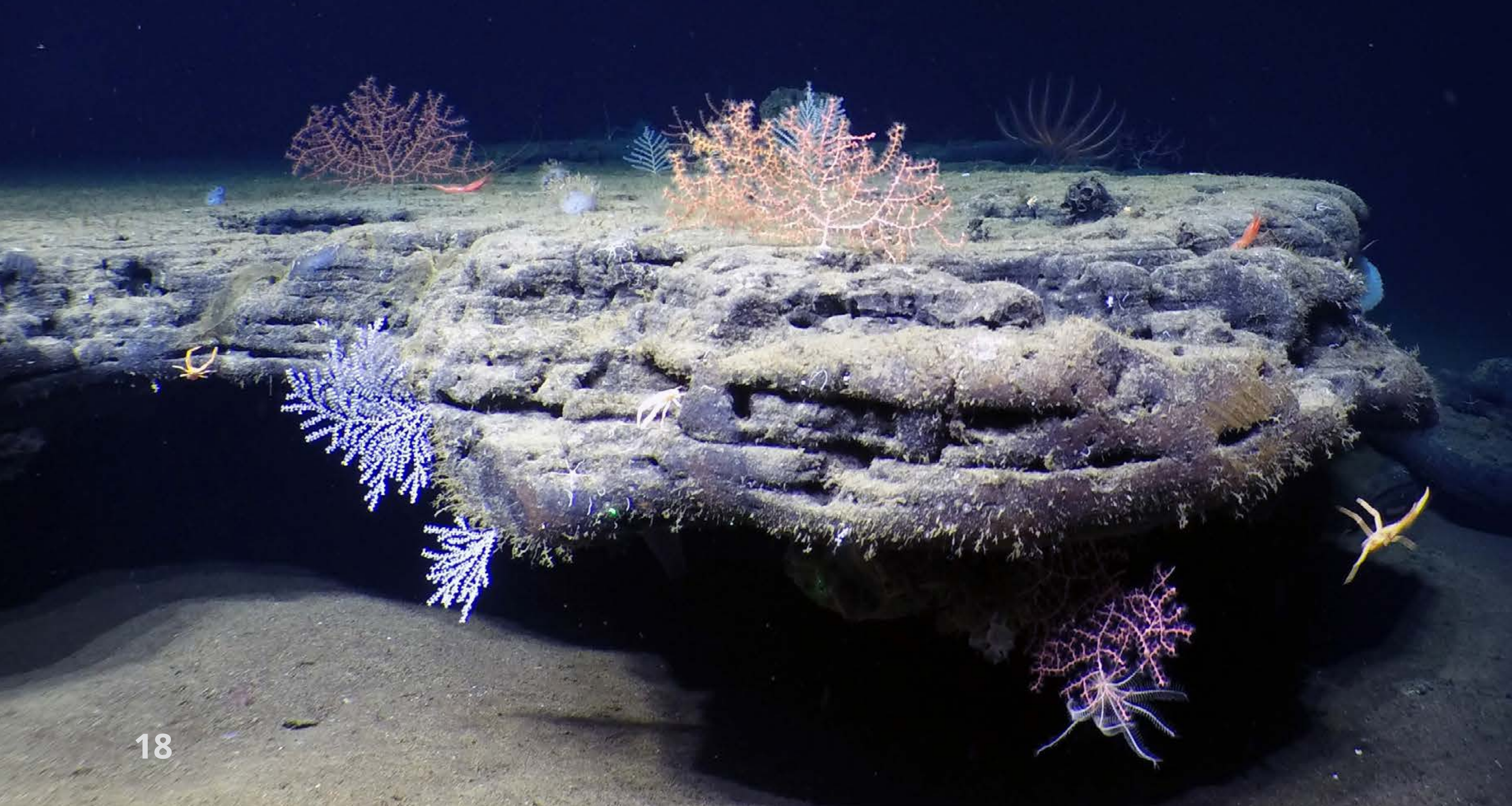
Regularly publishing new video highlights of interesting sightings on YouTube and embedding these videos into Nautilus Live led to a 50% increase in views, with over 30 million views during the expedition season. Increased views also allowed us to more than double our YouTube audience to 103,000 actively engaged subscribers, with over 26 million minutes watched by this community and first-time viewers.

Regularly scheduled Instagram posts grew our followers by 70% over the expedition season, and introducing the platform's new Instagram Story at the beginning of the season allowed us to engage a younger generation of explorers who actively connected with this spontaneous and temporary feature. During the expedition season, Instagram Story takeovers by members of the Corps of Exploration offered opportunities for the diverse experiences and perspectives of our students, educators, and science team members to shine.

Press and Media

The work of the scientists and explorers aboard E/V *Nautilus* was featured in over 500 news reports in print, television, radio, and online with an estimated reach of more than 40 million people. Top media outlets that featured stories include CNN, Fox News, NBC, National Geographic, Discovery, Business Insider, and many others. Top stories picked up by media included close-ups with sharks in Channel Islands National Marine Sanctuary, the "deep sea lava lamp" *Deepstaria* jelly, cephalopods including cockatoo squid, vampire squid, and last year's "googly eyed" squid that appeared in a commercial with Taylor Swift, and the exploration of USS *Bugara*. Additionally, the scientists, students, and educators participating in the 2017 *Nautilus* expedition were often featured in local and national media stories.

In addition to extensive media coverage, OET directly shared Nautilus Exploration Program updates with over 12,600 subscribers who opted to receive our newsletter, opening and engaging with the content at higher rates than standard nonprofit industry rates. Our monthly email newsletters feature expedition overviews, favorite exploration highlights, and opportunities to participate in our at-sea programs and citizen explorer community.



Students at the Jaffrey Public Library in New Hampshire interact with a Science Communication Fellow and mapping expert aboard *Nautilus* through a live ship-to-shore broadcast.

Video Engineering Intern Erin Ranney controls the camera for a live ship-to-shore interaction with OET's STEM Education Specialist, Katherine Sutton (left), and Science Communication Fellow, Fleur Ferro (right).

LIVE SHIP-TO-SHORE BROADCASTS

In addition to supporting the live video of *Nautilus* operations on the Nautilus Live website, onboard telepresence technology allows audiences to engage in a unique and intimate two-way dialogue with at-sea team members by connecting them directly with onshore audiences at venues such as universities, museums, science centers, out-of-school programs, and classrooms. Through these live ship-to-shore interactions, the team aboard *Nautilus* connects with tens of thousands annually at these venues.

Throughout the 2017 field season, OET expanded the number of broadcasts conducted and the number of sites reached with 353 live interactions into 163 venues across 26 states and in four countries. Major venue partners during the 2017 field season included: The Perot Museum of Nature and Science in Dallas, Texas; Connecticut Science Center in Hartford, Connecticut; Submarine Force Library & Museum in Groton, Connecticut; Port Royal Museum in Okatie, South Carolina; and the Exploratorium in San Francisco, California. Additionally, OET offered these live ship-to-shore interactions in Spanish for students at Universidad Nacional Autónoma de México while the ship was exploring in Mexican waters during the Pescadero Basin and Revillagigedo cruises. OET also continued outreach programs with a variety of schools, universities, research conferences, professional development workshops, and out-of-school programs including robotics clubs and Boys and Girls Clubs.

K–12 Education

STEM CURRICULA

OET's STEM Learning Modules are inquiry- and project-based lessons that supplement educators' curricula and foster student engagement in STEM disciplines found in oceanographic research and exploration. Lessons lead students through fundamental concepts involved in deep-sea exploration such as pressure, density, seafloor mapping techniques, plate tectonic dynamics, animal adaptations and ecosystems, and engineering design. Each module is standards-aligned and guided by the performance expectations of the Next Generations Science Standards, Common Core State Standards, and Ocean Literacy Principles.

Five new lessons were added to the STEM Learning Modules in 2017, which now include 24 inquiry-based lessons with educator and student versions as well as connections to *Nautilus* digital resources and role models. These new modules emphasize engineering and technology topics, including a design challenge module where students engineer and race rubber band-propelled thrusters and an introductory circuit module where participants build series and parallel circuits with household supplies. Another new element this year is a three-part sensor technology lesson series that introduces students to microcontrollers and coding using Arduino-based platforms. Using an inexpensive coding platform, students can collect data about their own habitat and monitor changes in environmental factors. The modules were made accessible through the OET website this year, allowing a centralized site for participating educators to access materials through a registered user system.

Louis Mora, a 2017 Science Communication Fellow from Los Angeles, sits watch in the ROV control room while exploring within Channel Islands National Marine Sanctuary. *Image credit: Ed McNichol*

DIGITAL RESOURCE LIBRARY

In a new effort to make more resources available online, we developed a Digital Resource Library (DRL) to diversify the resource types available to educators as they work to inspire curiosity about the deep sea and STEM. This collection of resources was designed to provide educators with supplemental material and compact activities appropriate for all ages. These resources also include downloadable features to ensure reliable access to OET materials as educators navigate information technology barriers that can often burden live-streaming connections in schools. The DRL has grown throughout the year, offering education program alumni opportunities to contribute to the library to showcase material they create in three categories: graphics & photos, expedition video playlists, and activities & resources. The graphics & photos section offers explainer animations and graphics, including illustrations of global oceanographic and geological processes often investigated by the Nautilus Exploration Program and the technology required to explore the deep sea. Expedition videos simplify the massive highlight library of the Nautilus Exploration Program into themed YouTube playlists such as "Hydrothermal Vents," "Fish, Sharks, & Skates," "Geologic Formations," and "Shipwrecks." The DRL activities contain a variety of material, such as downloadable data sets, for further exploration and fun, attention-grabbing resources, such as Nautilus Live Bingo and coloring pages. OET's first bilingual resource, a Spanish-language ocean exploration glossary, was also published in the DRL this year.

EDUCATOR PROFESSIONAL DEVELOPMENT WORKSHOPS

In 2017, OET created high-energy workshops in sponsored communities in California, Louisiana, and New Hampshire to introduce teachers to the myriad STEM connections to ocean research and exploration. These professional development training workshops differentiated attendees by the grade level they taught and were customized based on the attendees' prior knowledge of oceanographic research and tools for exploration. These introductory workshops show teachers how they can become active explorers, along with their students, through the use of OET's telepresence capabilities. The DRL and STEM Learning Modules—which educators gain access to through their participation in OET workshops—equip these educators with the tools to bring ocean exploration into their teaching with the support of standards-aligned content and OET staff coaching.

OET provided training for 149 educators with a reach of over 8,800 students in 2017. Educators active with the OET program teach at all levels, from early childhood to college prep, and at nonprofit organizations and community institutions such as libraries. In Louisiana, at one of OET's longest-running STEM partner communities, a professional development workshop included a panel featuring four local at-sea program alumni who shared how OET resources have improved their teaching. Mentorship across OET's programs underscores a commitment to coaching and highlighting program participants as inspiration for the next generation of explorers and for an entire community. In post-workshop evaluations, all surveyed attendees agreed or strongly agreed that attending the OET workshop introduced them to new real-world STEM applications that will benefit their teaching.

At-Sea Programs for Students, Educators, and Artists

SCIENCE & ENGINEERING INTERNSHIP PROGRAM

Since 2009, OET's Science & Engineering Internship Program has provided hundreds of talented undergraduates, graduate students, and early career professionals with on-the-job vocational training in the fields of ROV and video engineering, navigation, ocean science, and seafloor mapping while being mentored by professionals in each field. Interns, who are selected through a competitive application process, sail on *Nautilus* for three to five weeks as part of the expedition team. ROV engineering interns learn about vehicle systems, maintenance, and operations in addition to filling the copilot role during ROV dives. Video engineering interns operate all video equipment during ROV dives and learn about the complexities that allow shipboard broadcast systems to stream live video and data to shore. Navigation interns focus on the logistics and operational skills required to work with ROVs and their support vessels as well as multibeam data acquisition and processing. Ocean science and seafloor mapping interns work in key science-team roles, including ROV dive annotation, data processing, sample management, and multibeam mapping surveying. All participating interns also serve as role models to their peers ashore and to learners around the world through the Nautilus Live website and live broadcasts from sea.

In 2017, 19 students from 13 US states, British Columbia, and Nova Scotia participated in this program that included representatives from OET's partnering agencies and institutions, including NOAA's Educational Partnership Program, US Naval Academy, and US Coast Guard Academy.

SCIENCE COMMUNICATION FELLOWSHIP

The Science Communication Fellowship provides formal classroom and informal educators with tools and training in the fields of science communication and digital storytelling in addition to introducing each participant to ocean exploration and STEM professionals working in the field. During the yearlong fellowship, participants attend OET's annual Science Communication Workshop in Rhode Island 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 fundamental science and engineering knowledge to underscore the mission and objectives of the upcoming E/V *Nautilus* field season, (3) learn best practices for incorporating the Nautilus Exploration Program into formal and informal education spaces, and (4) bring personal experience to network with other fellows and develop local outreach and education plans for the program.

While at sea, Science Communication Fellows moderate the control room broadcast during live exploration, translating exploration science for a global audience and engaging active online participants by weaving shore-based questions submitted through the website into the operational conversation. Fellows also lead the live ship-to-shore broadcast interactions with public venues and classrooms worldwide. The deliverable of the fellowship is a body of outreach or original STEM-focused lessons that translate the fellows' experiences to a broad audience of learners. These deliverables contribute to the growth and expansion of the STEM Learning Modules and resources that are made available to OET's expanding network of educators, partners, and program participants.

The 2017 Science Communication Fellowship, selected through a competitive application process, included 19 educators from 14 US states and British Columbia. Fellows represented formal educational institutions from middle schools to community colleges to four-year universities, and encompassed public, private, and charter institutions. Informal educators came from backgrounds in aquariums, museums, science centers, and scientific writing.

ARTIST-AT-SEA PROGRAM

The Artist-at-Sea program invites artists aboard *Nautilus* to foster creative conversation and collaboration around curiosity-based exploration with Science Communication Fellows and the entire Corps of Exploration. Drawing inspiration from their time at sea, artists share their experiences with new audiences and support OET in integrating arts into outreach programs and shaping STEM education into STE[A]M education. Since this program was launched in 2014, artists who have sailed aboard *Nautilus* have been 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 in addition to engaging existing followers and participants in science and engineering from an alternative perspective.

Ocean Science Intern Bryce Corbett from Illinois, processes geological and biological samples collected during an ROV dive.

Science Communication Fellow Megan Chen, from the Smithsonian National Museum of Natural History, lends a hand processing samples in the ship's lab.

Daniel Kohn, a New York-based painter, joined the 2017 expedition and used a variety of media—including sound, still photography, video, drawing, and watercolor—to observe and document ocean exploration through the lens of an artist. His experience, interviews with scientists aboard the ship, and the work he produced while aboard will contribute to his ongoing project exploring ocean memory.

Community STEM Program

The Community STEM Program (CSP) works closely with education partners to bring the portfolio of OET education programs to action within a community. CSP partners and stakeholders include school districts, nonprofits, STEM professionals, public venues, universities, community colleges, museums, and aquariums.

In 2017, participating communities included Corpus Christi, Dallas, and Houston, Texas; Lake Charles, Louisiana; Lemont, Illinois; Los Angeles and Santa Barbara, California; and the state of New Hampshire. Programs and program participants in each of these locations were funded with the support of our CSP sponsors—CITGO, University of New Hampshire, the Perot Museum of Nature and Science with support from the Lyda Hill Foundation, University of California–Santa Barbara, and AltaSea at the Port of Los Angeles. CSP communities were represented in all of OET's at-sea programs this season by three undergraduate and graduate students who received workforce development training in the Science & Engineering Internship Program, five educators who participated in the Science Communication Fellowship, and six educators who joined the team at sea through the Nautilus Ambassador Program.

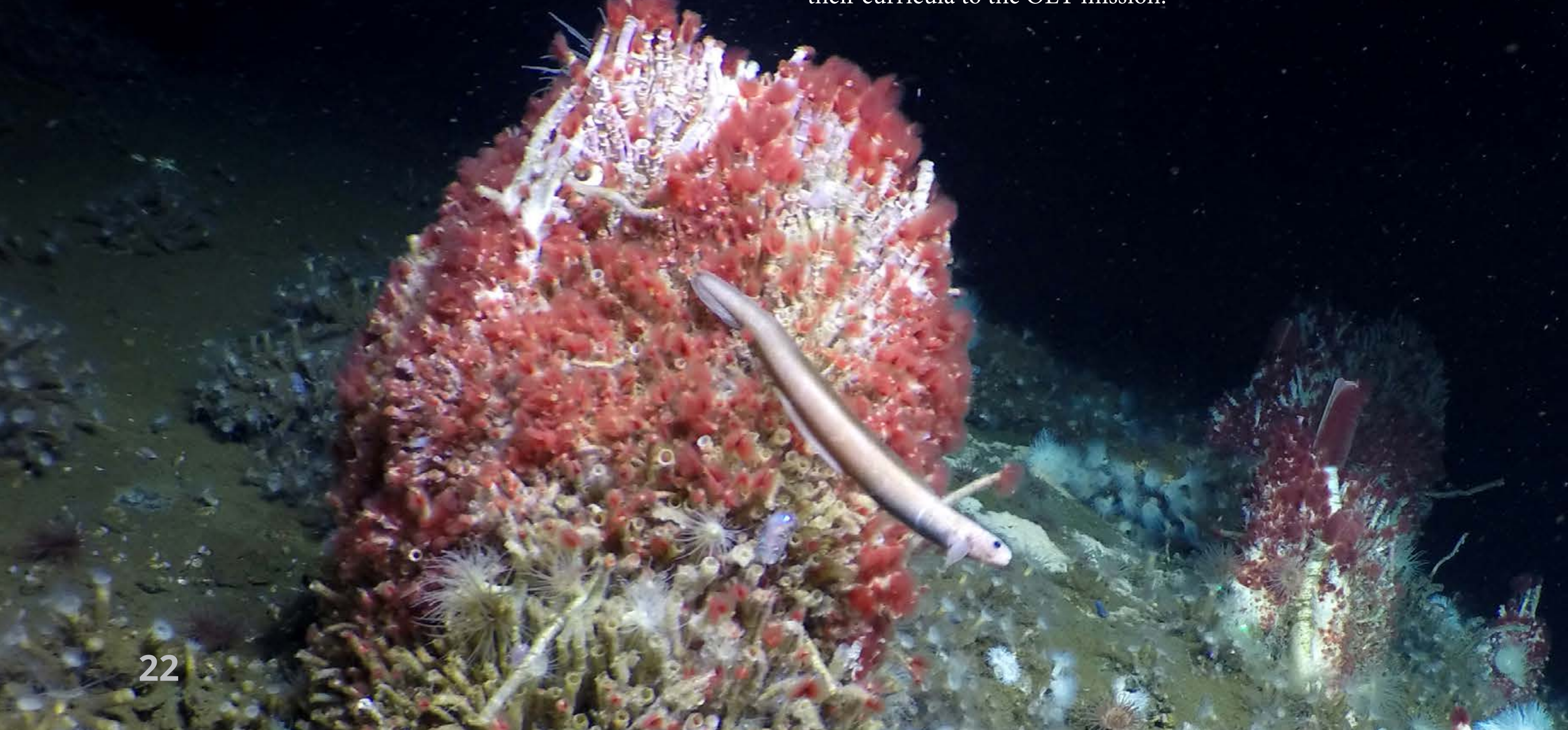
COMMUNITY SITE VISITS

With the goal of introducing explorer role models to learners in their home settings, OET designed a series of local experiences to highlight the Corps of Exploration in collaboration with and support from CITGO. OET staff visited our CITGO community sites throughout the year, building events with alumni from each CSP locale. Local experiences ranged from drop-in classroom teaching and delivering keynote addresses at local events to hosting first-of-their kind community STEM events.

In Illinois, OET joined a high school program as the keynote for a STEM event with more than 150 students attending. Here, students designed rubber band-powered machines—an activity offered through the STEM Learning Modules—to illustrate the forces generated by robotic thrusters. During a site visit in Houston, the Corps of Exploration took over high school classes with STEM challenges for a day, working alongside students on their designs. In Los Angeles, middle school students joined the Corps for explorer-led ship tours the morning *Nautilus* departed for the 2017 expedition season. In Corpus Christi, more than 400 students and members of the community came out to the school's first-ever STEM Night.

EDUCATOR MINI-GRANTS

OET launched the Nautilus Exploration Mini-Grant Program—new in 2017 and supported by CITGO—for educators and local CSP organizations to receive funding that leverages OET resources and programs to motivate, energize, and engage students in STEM and to highlight careers in these fields. This program drew strength from tapping workshop and at-sea program alumni to identify local, highly relevant opportunities to bring ocean exploration into curricula or students' lives. The program also provided local educators assistance in nominating and proposing projects that bridged their curricula to the OET mission.



Nautilus Ambassador Samuel Freeman Jr. from Texas works with OET STEM Education Specialist Katherine Sutton on an OET lesson about coding and microcontrollers.

Through a competitive application process, four projects were selected to receive over $7,500 in grant funding reaching 582 students. In Lemont, a grant-funded project in an advanced research high school course provided ROV design kits for students to supplement their technology and engineering skills by developing their own exploration tools. After successfully constructing their own ROVs, these high school students wrote their own curricula to teach middle school and special needs students in their district concepts of buoyancy and engineering design learned through the projects.

In Houston, a mini-grant supported the Girls Influencing Real Lives in STEM conference for intermediate and middle school girls in Alief Independent School District. More than 150 young women and STEM educators had the chance to work hands-on in breakouts on the diversity of STEM careers as well as attend a motivational keynote and an ocean exploration keynote in this day-long event.

Also in Houston, OET funded a summer camp program to provide access to STEM activities not typically available to students in underserved communities that generate and motivate interest in ocean exploration fields of study and careers. The project took an established robotics summer program and blended the Nautilus Exploration Program into design challenges for a deep ocean robotics program. Providing an eight-day experience for 112 students, this program received strong student and parent reviews, with several parents reporting they were previously unaware of their child's interest in or ability to create robots that operate in water.

In Lake Charles, the mini-grant program supported an ocean and STEM-themed back-to-school unit for all fourth and fifth grade students at E.K. Key Elementary School, bringing hands-on and inquiry-driven challenges and activities to their classrooms. With support from this grant, more than 200 students and parents also attended a community Science Night where activities engaged the community in fun and interactive exploration with an ocean theme.

NAUTILUS AMBASSADOR PROGRAM

The Nautilus Ambassador Program is an at-sea program aboard *Nautilus* only available through CSP partnerships. The program brings educators selected for their leadership in STEM teaching onto *Nautilus* for a short expedition to introduce them to the field of ocean exploration. Six ambassadors representing elementary and middle schools, public science institutions, and higher-education professional training joined *Nautilus* in August 2017 for the Central California expedition. Educators worked alongside scientists and engineers in testing a new in situ sampling platform on a methane seep community. Four ambassadors represented our CITGO STEM Communities from the states of Texas, Illinois, and Louisiana, and two ambassadors from California were selected to represent OET's partnership with the Goldhirsh Foundation's MyLA2050 award with AltaSea at the Port of Los Angeles.

Ambassadors were involved in all aspects of the Nautilus Exploration Program while on board. They received training in science communication and professional development using the STEM Learning Modules and the Digital Resource Library, gained experience making scientific observations by standing watch in the ROV control room, and assisted in the ship's lab with processing of samples after ROV dives. New in 2017, ambassadors received Arduino-based microcontroller kits and were trained in using this technology, which accompanies OET's new three-part Sensor Technology Series in the STEM Learning Modules. This technical coaching—conducted by OET's education team and the engineers on board—was a highly lauded program addition that exposed interdisciplinary educators to new STEM skills and subject matter.

By igniting interest in ocean exploration and STEM careers through all of our programs and outreach, we hope to motivate more students and the public to be lifelong learners and to provide exposure to careers and opportunities that they may not otherwise encounter. We strive to use our educational programming and outreach efforts to inspire future explorers, innovators, policymakers, and the future STEM workforce, while ensuring that anyone can find a role model within the Nautilus Corps of Exploration.

Nautilus Field Season Overview

By Nicole A. Raineault and Robert D. Ballard

The year 2017 marks our longest expedition season since E/V *Nautilus* began exploring the ocean basins in the summer of 2009. During 204 days at sea between May and November, *Nautilus* operations included a total of 98 ROV dives—more time exploring the seafloor than any other year. We also mapped large portions of the US exclusive economic zone: four of our 14 expeditions were mapping-only cruises that surveyed critical areas within national marine sanctuaries off the west coast of the United States and also a newly created national park and UNESCO World Heritage Site in Mexico around the Revillagigedo Archipelago.

From May through November 2017, *Nautilus* continued its mission of exploration, innovation, and education in the eastern Pacific Ocean, ranging from waters off the west coasts of southern Canada and the United States to Mexican waters both within the Gulf of California and offshore of the Revillagigedo Archipelago. More than 240 people participated on board *Nautilus*, and over 50 researchers shared their expertise from shore.

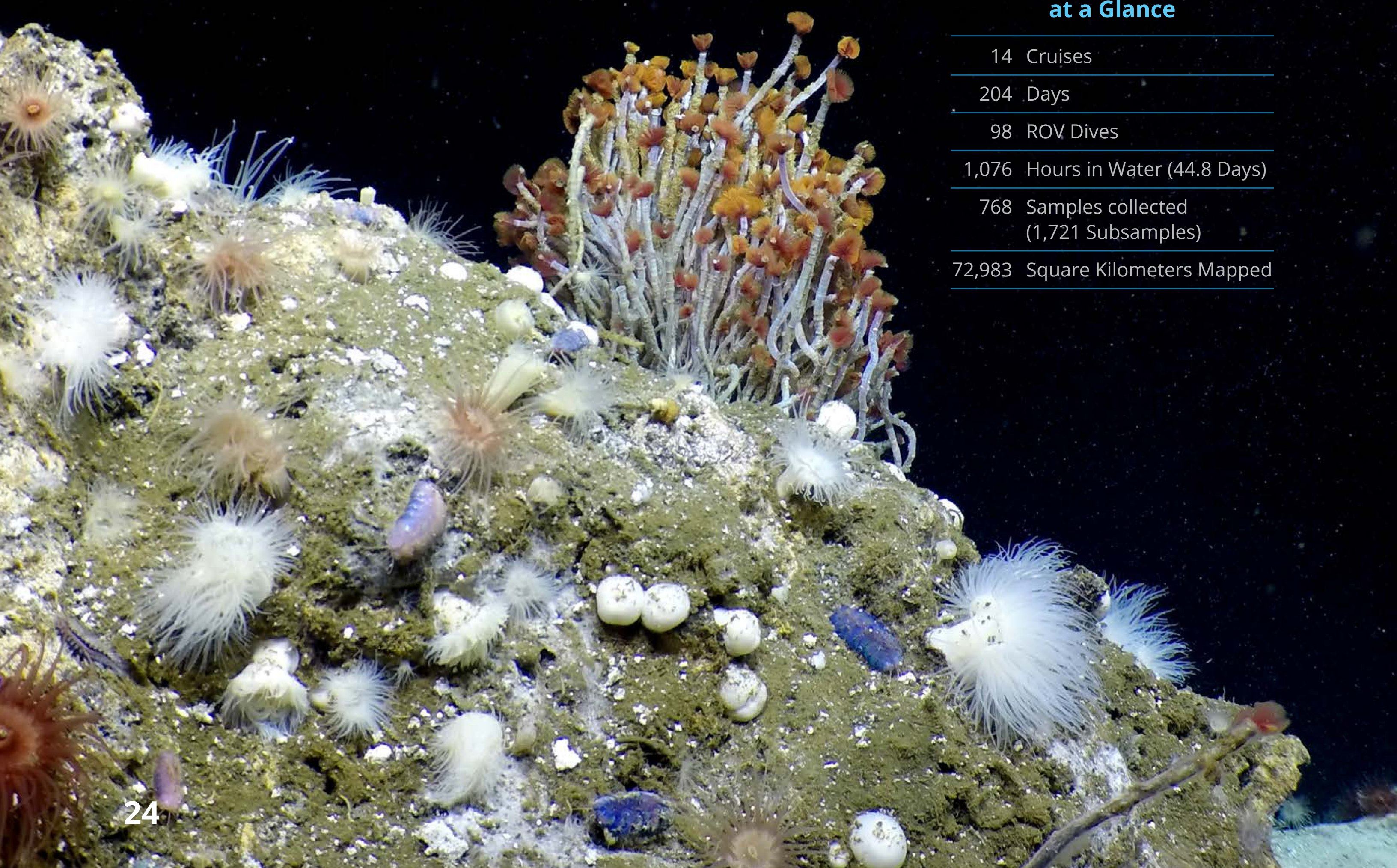
After mobilization and a shakedown cruise off the coast of San Pedro, California, *Nautilus* mapped off the west coast of the United States to prepare for national marine sanctuary explorations (pages 28–29, 30–31, 34–35). During a three-week cruise from San Pedro to Victoria, Canada, *Nautilus* mapped some portion of every West Coast sanctuary and also along the Cascadia margin to locate methane seeps. In Victoria, we mobilized personnel and gear for a three-week Ocean Networks Canada (ONC) cruise (pages 28–28). *Nautilus* aided in laying fiber-optic cable for British Columbia's earthquake early warning system, which was particularly timely, as a magnitude 4.8 earthquake occurred on the Juan de Fuca Ridge to the north during this expedition.

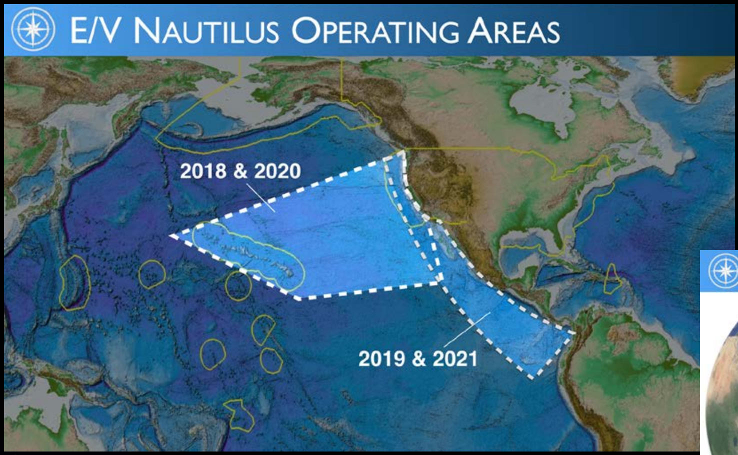
Following a successful ONC cruise, *Nautilus* mapped the Olympic Coast National Marine Sanctuary in preparation for an August expedition there (pages 36–37). Two additional mapping-only cruises in September and October charted areas in advance of upcoming expeditions and for next year's operations (pages 26–27).

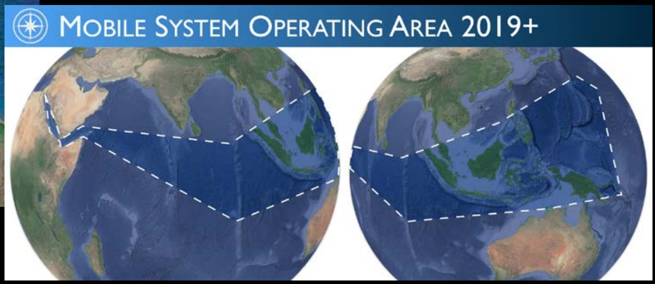
In July, we collaborated with the Channel Islands National Marine Sanctuary, University of New Hampshire's Center for Coastal Ocean Mapping, and a scuba diving team led by Kenny Broad of the University of Miami to test mapping

2017 *Nautilus* Field Season at a Glance

14	Cruises
204	Days
98	ROV Dives
1,076	Hours in Water (44.8 Days)
768	Samples collected (1,721 Subsamples)
72,983	Square Kilometers Mapped







technologies for locating submerged shorelines and identifying cave features (pages 30–31). This multiplatform operation involved working with a new autonomous surface vehicle (ASV) equipped with a high-resolution mapping system; a pole-mounted mapping system from the National Marine Sanctuary's vessel *Shearwater* for initial reconnaissance; ROV, shipboard echosounder, and ASV surveying from E/V *Nautilus*; and scuba investigation of targets from the dive boat *Conception*. The successful month-long field campaign yielded discovery of multiple caves at the four shallowest submerged marine terraces between 8 m and 100 m depth. Next season we will continue this multiyear project, focusing on locating caves on deeper offshore banks in the Southern California Continental Borderland and testing new diver-aided mapping technologies.

We also tested new optical communications and sensor technologies being developed by researchers at Harvard for future space missions in a brief cruise at Point Dume (pages 32–33). While deployed, the microbiological and geochemical lab incorporated into a lander was able to communicate with scientists on the ship and also quickly transmit data, including images and video. Following the Ocean Exploration Trust's open-access policy, the software and hardware designs will be made available to the public.

The next two cruises were in collaboration with the national marine sanctuaries at Cordell Bank (pages 34–35) and off the Olympic Coast (pages 36–37). Exploration of the deep areas of Cordell Bank National Marine Sanctuary utilized maps made by *Nautilus* on earlier cruises to target hard grounds, particularly Bodega and Box Canyons, where deepwater coral and sponge communities were surveyed. Research in Olympic Coast National Marine Sanctuary also involved characterization of several canyon systems. An autonomous underwater vehicle was used to survey the canyon rims and complemented the work the ROVs completed in steeper parts of the canyons. This is an ocean acidification sentinel site, and water sampling, plankton tows, and oceanographic measurements were made at a critical time of year for understanding the impacts of ocean acidification on the region. During a final, short cruise in the Pacific Northwest on Heceta Bank, sub-bottom profiling surveys located a buried paleo river channel that may be useful for identifying sites of ancient humans settlements (page 38).

Nautilus conducted three ROV expeditions in Mexican waters with partnering researchers from the Universidad Nacional Autónoma de México, Woods Hole Oceanographic Institution, and the University of Rhode Island, along with other shore-based scientists (pages 39–45). The Guaymas Basin expedition explored a diverse range of vents located over a seafloor spreading center covered with a thick blanket of terrigenous sediment. Both high-temperature black smokers and cold methane seeps were observed, along with the unique ecosystems they feed. The Pescadero Basin cruise investigated the deepest high-temperature vents known in the Pacific Ocean. Geochemical and biological sampling followed up on a 2015 cruise where unusual carbon-rich vents were first discovered. Finally, *Nautilus* explored the new national park and UNESCO World Heritage site at the Revillagigedo Archipelago. After completing the first maps of the region since the 1993 submarine eruption west of Socorro, Mexico, the ROVs targeted several sites around the Revillagigedo islands to gain a better understanding of the nature of the volcanism. Although the volcanic terrain was stunning, some of the biological images taken with a low-light camera, including those of the *Deepstaria* jelly (pictured on the cover) and the vampire squid, mesmerized scientists and the public alike.

Next year, *Nautilus* will undertake its first westward loop to the Hawaiian Islands in an approximately seven-month season. At the end of the 2018 season, we plan to test the new mobile deep ROV system that will be jointly owned and operated by the Ocean Exploration Trust and the National Deep Submergence Facility, with funding from NOAA's Office of Exploration and Research and the National Science Foundation. We are excited to start working with researchers to build field programs starting in 2019 in the far western Pacific, Indian Ocean, and Red Sea—unexplored but vital areas for understanding our Earth and ocean.

E/V *Nautilus* Mapping Summary 2017: Cascadia Margin to the Revillagigedo Archipelago and Beyond

By Nicole A. Raineault, Lindsay Gee, Renato Kane, Miles Saunders, Erin Heffron, and Steven Carey

Seafloor mapping is critical to ocean exploration. Maps are the foundation of any expedition, providing information about seafloor features, sediment drape, and signs of gas seepage. Accurate maps allow us to choose the areas with the highest potential for discoveries to target with remotely operated vehicle dives and to safely navigate the vehicles over the sometimes treacherous terrain. E/V *Nautilus* mapped nearly 73,000 km^2 of seafloor in 2017, collecting bathymetric data on all but one of its 14 cruises. *Nautilus* drove over 25,000 km of tracklines—more than any other year, in part due to four mapping-only cruises. Mapping between Canada and Mexico focused on areas within US west coast national marine sanctuaries (Channel Islands, Monterey Bay, Cordell Bank, Olympic Coast) and around the Revillagigedo Archipelago and the northern Guaymas Basin in Mexico. The last three years of mapping effort covered large areas within the US exclusive economic zone between Washington state and southern California (Figure 1). A few highlights from our 2017 mapping efforts are described here.

US West Coast Seeps

Seafloor mapping of the US west coast continental margin was a major focus of the first half of the 2017 *Nautilus* field season. A significant portion was conducted in areas of potential methane seepage, and multibeam operations were optimized for bubble stream detection in the water column. The water column data were combined with the bathymetry and backscatter data to provide an indication of the seabed substrate to support ongoing and future exploration of seep locations. *Nautilus* always maps the seafloor on transits between different exploration locations and ports. Unfavorable weather restricted some seep mapping on the West Coast transits in 2017; however, nearly 100 seeps were still detected on transits mostly adjacent to the 500 m bathymetric contour (Figure 1).

The northern *Nautilus* cruises, NA080, NA082, and NA088, continued mapping on the US–Cascadia continental margin and covered areas from Cape Mendocino to Cape Flattery. Operations on cruise NA080 off southern Oregon extended the area mapped by *Nautilus* in 2016 northward, and covered approximately 3,700 km^2 of the seafloor in depths from 100 m to 3,000 m. Over 150 bubble streams were detected in the water column on these cruises, ranging from individual anomalies to areas of multiple diffuse seeps. Further mapping on NA088 south of Astoria Canyon completed coverage of an area explored in 2016 and added over 50 seep detections.

Mapping in 2017 added over 300 methane seep locations to the number detected by *Nautilus* in the last three years, for a total of over 1,000 seep sites. The new data enhance the baseline information on the abundance and distribution of seeps on the US continental margin.

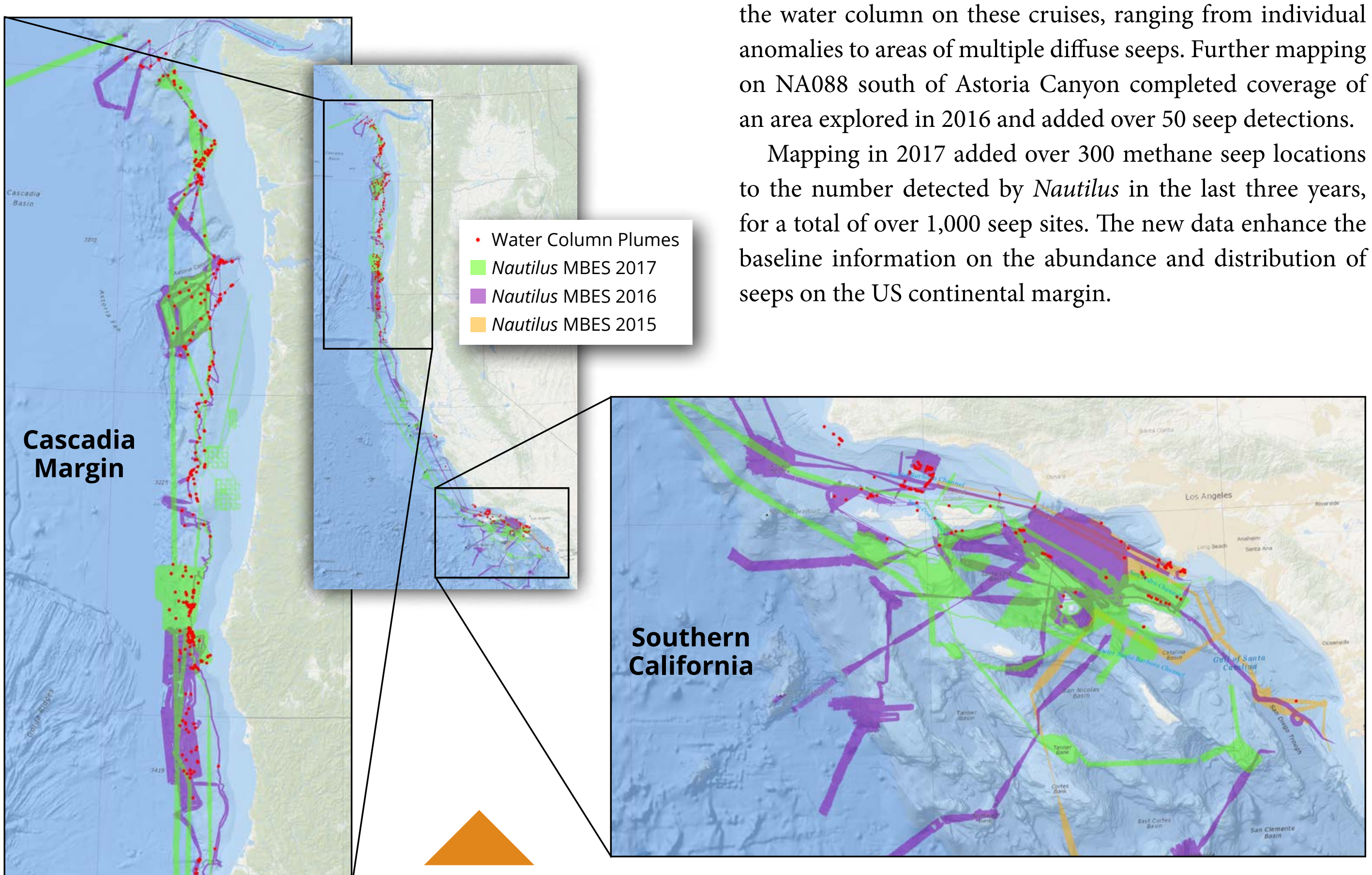


Figure 1. Multibeam echosounder (MBES) mapping to date by *Nautilus* along the western United States colored by year. The Cascadia margin and Southern California Borderland have been focus areas for mapping. Red dots indicate locations where seeps were detected by the multibeam sonar.

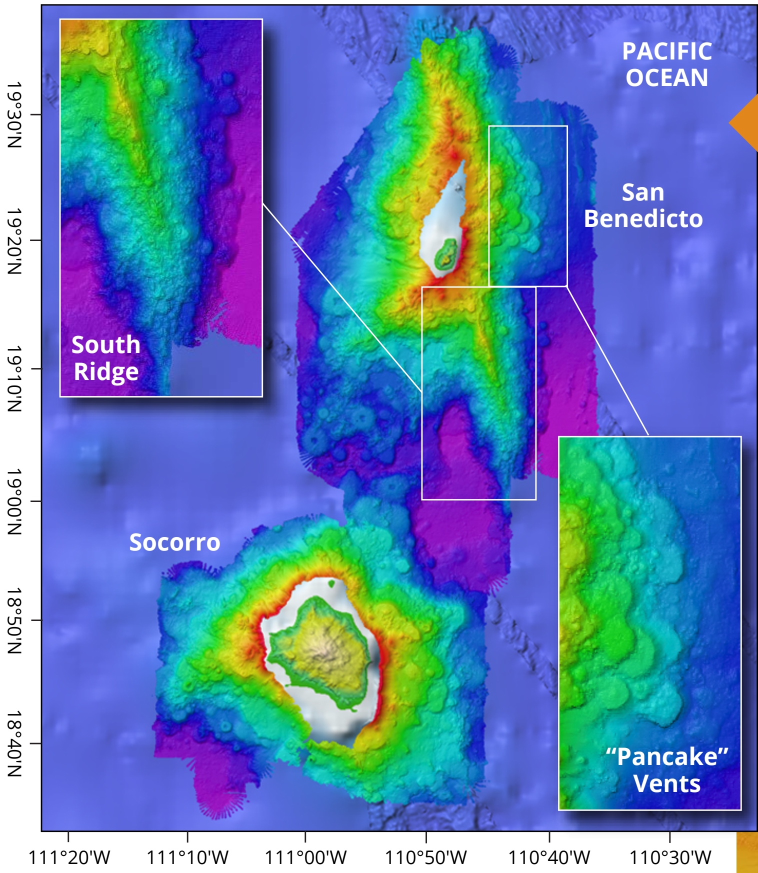
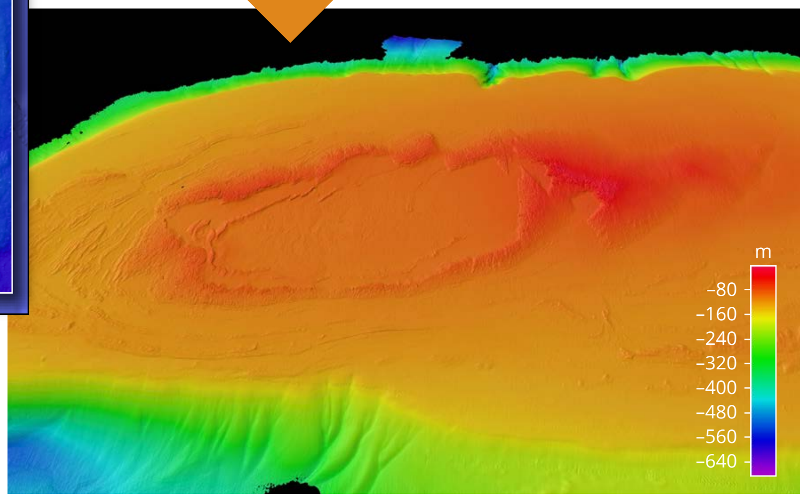


Figure 2. Multibeam bathymetry surrounding the islands of Socorro and San Benedicto in the Revillagigedo Archipelago, Mexico. The upper left inset shows a prominent south-southeasterly trending volcanic ridge that roughly parallels the structure of remnant faults from the nearby Mathematician spreading center. The lower right inset shows the flat-topped "pancake" volcanic centers that are common around both of the islands. (30 m grid, 2x vertical exaggeration)

Figure 3. Tanner Bank bathymetry reveals areas of high relief and long, sinuous ridges that may host submerged caves (7 m grid, 6x vertical exaggeration)



Revillagigedo Archipelago

New multibeam mapping around the islands of Socorro and San Benedicto in the Revillagigedo Archipelago provides important insights into the formation and structure of these volcanic islands. Located at the northern end of the abandoned Mathematician spreading center, ~800 km from Mexico's west coast, the islands remain volcanically active and host the only peralkaline magmas in the Pacific basin. Socorro is the largest of the two islands, with a peak (Mt. Evermann) that rises 1,050 m above the seafloor; its last eruption was a submarine event in 1993 (Siebe et al., 1995). San Benedicto is slightly smaller and elongated, with a relatively new volcano, Barcena, that formed at the southern part of the island in 1952.

A distinctive feature of the submarine portions of Socorro and San Benedicto is the abundance of circular, flat-topped volcanic craters with very steep sides. At least 100 can be identified around the two islands. In many areas, such as the eastern side of San Benedicto, they are stacked like pancakes and appear to form the deep foundation of the islands (Figure 2). These craters likely represent monogenetic volcanic activity, and their unique flat-topped morphology has been linked to the existence of a ponded submarine lava lake during their construction (Clague et al., 2000).

Another interesting feature of San Benedicto is the existence of two major submarine ridges that extend to the north and south of the island (Figure 2). These ridges trend parallel to north-south normal faults that appear in deep water to the east-northeast of the island. These faults appear to be remnant structures associated with the Mathematician spreading ridge that was abandoned about 3.5 million years ago (Mammerickx et al., 1988). It is likely that north-south structural features created in the oceanic crust during plate spreading at Mathematician Ridge still control the distribution of magma that is currently feeding volcanism on San Benedicto.

Southern California Borderland Mapping

In September 2017, as a continuation of our efforts to map the submerged shorelines of the Southern California Borderland region, *Nautilus* mapped several offshore banks. Nidever, Tanner, and Fortymile Banks were previously incompletely or poorly mapped or data were unavailable to the public. We mapped Nidever and Tanner Banks at three submerged shoreline depths between 100 m and 120 m where no caves were located this year. Nidever Bank has highly rugose features on an otherwise flat oval-shaped summit. Tanner Bank has long, sinuous, hard ridge features that stand above sediment rippled by waves and currents on its broad, more rectangular summit (Figure 3). The northwestern end of the summit has a series of concentric ridges that are about 5 m tall and 250–500 m apart. These new multibeam maps provide a rich data set for planning 2018 exploration with remotely operated vehicles aboard *Nautilus*.

Expedition 2017: Wiring the Abyss in the Northeast Pacific

By Adrian Round, Richard Dewey, Steve Mihály, Fabio De Leo, Martin Heeseman,
Martin Scherwath, and Akash Sastri

During Expedition 2017: Wiring the Abyss, Ocean Networks Canada (ONC) serviced, expanded, and upgraded its coastal and offshore cabled observing networks off the west coast of Canada (Figure 1). Major goals of the two-leg expedition (April 28–May 7 and June 6–26) included maintenance at observatory node sites, cycling autonomous moorings, cable repair using two ships, multibeam mapping, and biological and geological surveys and sampling. Telepresence technology connected scientists and the public around the world to live ROV dives and onboard science and engineering teams.

Leg 1, a joint expedition with Natural Resources Canada onboard Canadian Coast Guard Vessel *John P. Tully*, used ROV *Odysseus* to complete routine observatory maintenance at coastal and offshore sites. In addition, a new monitoring experiment that combines imaging sonar, video, and hydrophones was deployed in the Strait of Georgia to record fish vocalizations and identify their sources. This study will support future use of passive acoustic monitoring for studying fish abundance, diversity, and interactions. While working on the continental slope offshore Vancouver Island, *Odysseus* captured video imagery of a swarm of pyrosomes, small filter-feeding animals usually found in tropical waters. The video went viral, generating questions about warming of Northeast Pacific waters.

During the first week of Leg 2, teams aboard E/V *Nautilus* and the cable ship *Cable Innovator*, collaborated in a 3 km cable repair at Clayoquot Slope, connecting eight new instruments at this 1,200 m deep site in the Cascadia subduction zone. During this delicate, stern-to-stern, dual-ship installation, ROV *Hercules* monitored the descending cable assemblies (mud mats) to ensure accurate placement for connecting to the observatory node and instrument platforms. At the same time, a magnitude 4.8 earthquake occurred 350 km from the site and was recorded by the new sensors—highlighting the importance of Clayoquot Slope as a site for studying seismicity related to subduction processes.

A multibeam survey of nearby Clayoquot Canyon (Figure 2) conducted by the team on *Nautilus* provided the first high-resolution map of this unique geological feature. The map will be used to study slope stability and inform ocean glider routes for an ongoing study of connections between plankton productivity and gray whale migration.

During the second week of Leg 2, *Nautilus* went to the Endeavour hydrothermal vents on the Juan de Fuca Ridge to reposition and connect a broadband seismometer (installed in 2016 on the Pacific Plate; Figure 3). ROV *Hercules* also collected water and biological samples that are contributing to the long-term monitoring of the Endeavour vent fields, which are in Canada's first marine protected area (MPA), established in 2003.

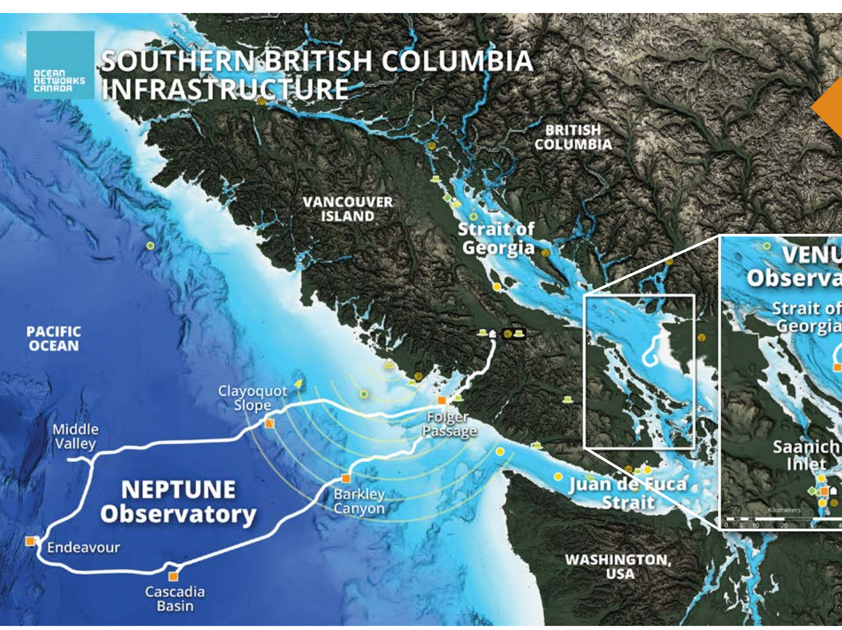
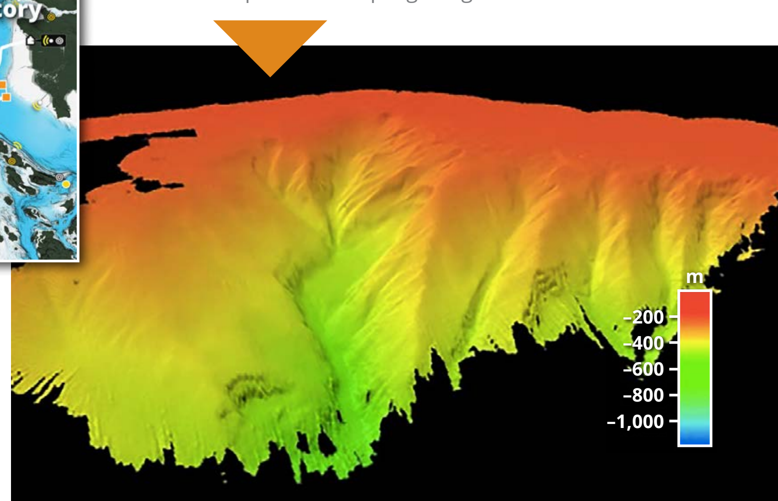


Figure 1. During Expedition 2017: Wiring the Abyss, ONC serviced, expanded, and upgraded its coastal and offshore cabled observing networks off the west coast of Canada.

Figure 2. A multibeam survey of Clayoquot Canyon provided the first high-resolution map of this unique geological feature.



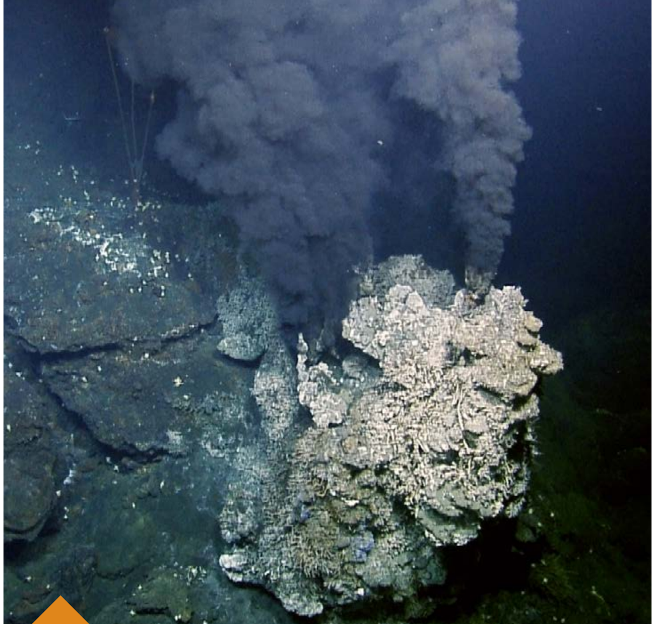


Figure 4. After a decade-long mission on the methane gas hydrate fields at Barkley Canyon, Wally was retrieved for refurbishment and redeployment in 2018.

Figure 3. Black smoker at Endeavour hydrothermal vent field.

Figure 5. Glass sponge reefs off Galiano Island in the southern Gulf Islands between Vancouver and Vancouver Island.

Nautilus also visited ONC's Barkley Canyon site. There, eight science platforms are positioned from the continental shelf edge at 400 m depth, down into the depths of the canyon at 985 m, supporting studies of methane gas hydrates, sediment dynamics, upwelling, plankton productivity, water column physical processes, benthic biodiversity, and ecosystem dynamics. One of the dives in Barkley Canyon was dedicated to recovering Wally (Figure 4), an Internet-connected vehicle modeled after a space rover and designed to study extreme environments. This marked the culmination of a decade-long mission on the seafloor where Wally explored methane gas hydrate fields for a team of scientists in Bremen, Germany. Wally will be refurbished and redeployed in 2018 for a newly determined mission.

At ONC's deepest site, the Cascadia Basin, located at 2,660 m depth on the abyssal plain, the team retrieved data from International Ocean Discovery Program CORK 1027, a sealed, instrumented borehole that allows researchers to monitor subsurface stresses and fluid movements to better understand ocean crustal hydrogeology.

Throughout the expedition, ONC celebrated Canada's 150th birthday of confederation by placing the #Canada150 logo on many of the underwater instruments, including ROV *Hercules*, a float in Wallyland, and a new dual hydrophone array at Cascadia Basin.

On the penultimate day, the team aboard *Nautilus* spent a few hours exploring the spectacular ancient glass sponge reefs (Figure 5) off Galiano Island in the southern Gulf Islands between the city of Vancouver and Vancouver Island. Early in 2017, similar 9,000-year-old glass sponge reefs in Hecate Strait and Queen Charlotte Sound, a few hundred kilometers to the north, were designated as an MPA by Canada's Minister of Fisheries and Oceans.

With 95% of the planned maintenance work complete, marine biologist and postdoctoral fellow Jackson Chu came aboard *Nautilus* to complete his fourteenth seafloor video transect in Saanich Inlet, a natural low-oxygen habitat and one of the best-studied fjords in the world. Jackson maps species in relation to changing average oxygen levels in Saanich Inlet to better understand how growing oxygen stress in coastal waters will impact biodiversity and fisheries.

ONC's Expedition 2017: Wiring the Abyss brought together an international team of partners and collaborators—working on board and from shore—from Canada (Fisheries and Oceans Canada and Natural Resources Canada), the UK (Global Marine Systems), Germany (Bremen University), France (IFREMER), and the United States (Pelagic Research Services, Ocean Exploration Trust, Woods Hole Oceanographic Institution, University of Washington).

Ocean Networks Canada is proud to have collaborated so successfully on this year's expedition in its efforts to monitor the west and east coasts of Canada and the Arctic. Thanks to Oceans 2.0, ONC continuously delivers data in real time for scientific research that helps communities, governments, and industry make informed decisions about our future. Using cabled observatories, remote control systems and interactive sensors, land-based oceanographic radar, and big data management, ONC continues to enable evidence-based decision-making on ocean management, disaster mitigation, and environmental protection.

Submerged Sea Caves of Southern California's Continental Borderland

By Robert D. Ballard, Nicole A. Raineault, Jason Fahy, Larry Mayer, Erin Heffron, Kenneth Broad, Julie Bursek, Christopher Roman, and Kristopher Krasnosky

In 2016, funding from NOAA OER supported systematic mapping of portions of Channel Islands National Marine Sanctuary (CINMS) by E/V *Nautilus* (Figure 1). One focus of that effort was to locate and explore submerged paleo-shorelines formed over the last 22,000 years when sea level stopped rising for 2,000 to 3,000 years at a time (Figure 2). These lulls in sea level rise permitted pounding waves, typical of the high-energy coast of today's Southern California shoreline, to excavate caves, as they continue to now.

Figure 1. Channel Islands areas chosen for investigation of paleo-shorelines in 2017 are highlighted. *Basemap credit: D.L. Divins and D. Metzger, NGDC Coastal Relief Model, http://www.ngdc.noaa.gov/mgg/coastal/coastal.html. Download provided by the Southern California Coastal Ocean Observing System http://sccoos.org/data/bathy*

The goal of our 2017 expedition in the Channel Islands area of the Southern California Continental Borderland was to search for submerged sea caves. Areas initially selected for investigation were the islands of Santa Cruz, Catalina, and Santa Barbara (Figure 1), where numerous sea caves are known to exist above present sea level (Bunnell, 1988, 1993), as well as where divers have already located them at the base of rock scarps resting at the 8 m to 10 m and 33 m paleo-shorelines (Figure 2).

The first phase of this effort used a team of divers led by author Kenny Broad of the University of Miami to investigate caves known by the local diving community off Santa Cruz, Anacapa, and Santa Barbara Islands and to begin mapping and documenting their interiors (Figure 2).

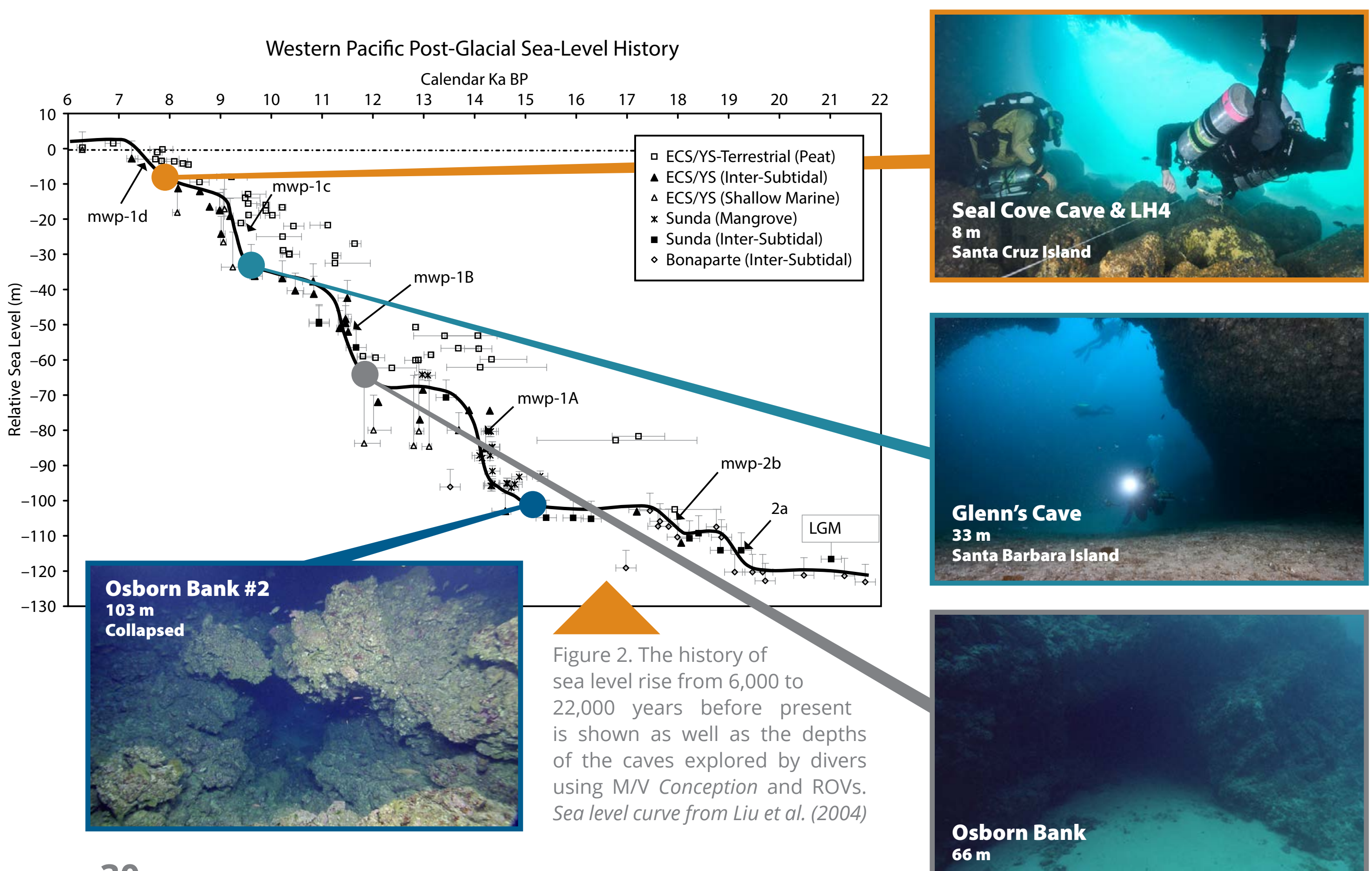


Figure 2. The history of sea level rise from 6,000 to 22,000 years before present is shown as well as the depths of the caves explored by divers using M/V *Conception* and ROVs. *Sea level curve from Liu et al. (2004)*

Figure 3. An autonomous surface vehicle (ASV) mapped the shallow submerged shorelines adjacent to the islands.

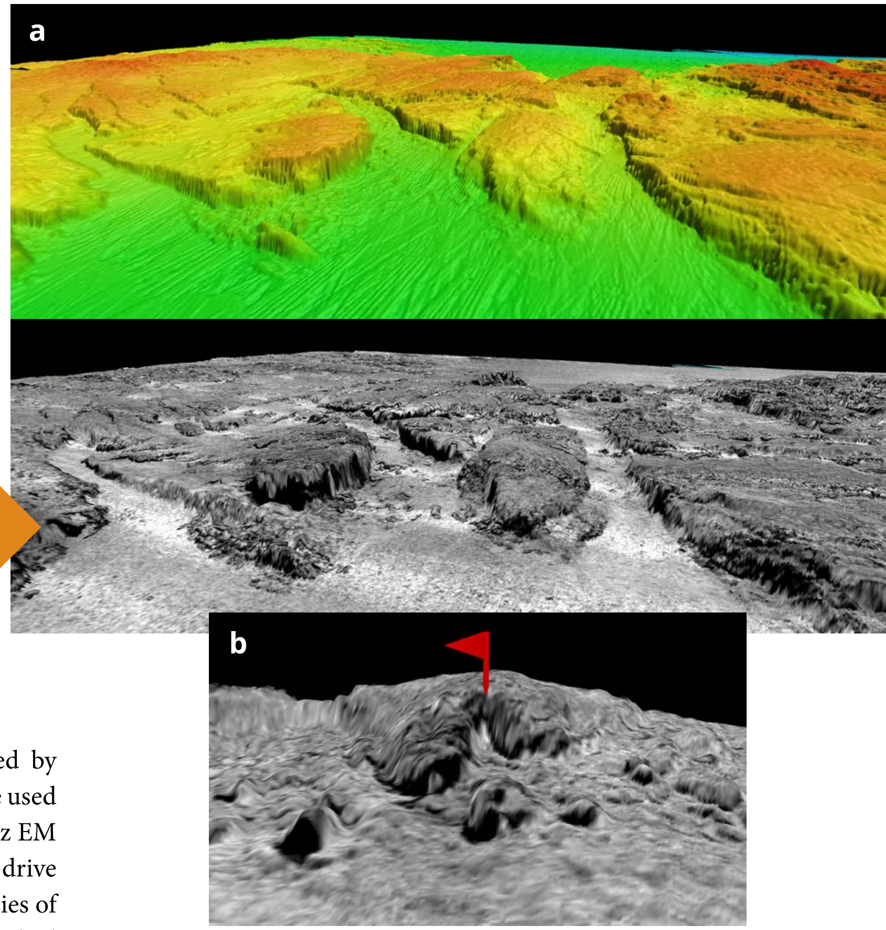


Figure 4. (a) (top) Bathymetry (8–80 m depth, 25 cm grid, 1.5x vertical exaggeration) and (bottom) backscatter (50 cm grid, 1.5x vertical exaggeration) draped over bathymetry data from the ASV provided targets for divers to investigate. (b) The feature identified by the red flag is a cave (40 cm grid, 1x vertical exaggeration).

While that effort was underway, a second team led by author Larry Mayer of the University of New Hampshire used an autonomous surface vehicle equipped with a 200 kHz EM 2040 Kongsberg multibeam echosounder (Figure 3) to drive along the paleo-shoreline depth contours, locating a series of sonar targets that the dive team then investigated. The dual ASV-scuba operations proved the ability of the mapping technology to locate subsurface caves, which appear as dark spots in the sonar backscatter data (Figure 4).

A third team led by authors Robert Ballard and Nicole Raineault of the Ocean Exploration Trust and CDR Jason Fahy of the US Naval War College used the Kongsberg EM 302 mounted on the hull of *Nautilus* to map deeper paleo-shorelines located on Osborn Bank (Figures 1 and 2) at depths of 66 m and 103 m.

ROVs *Hercules* and *Argus* were then used to explore the more complex and rougher terrain of the western and eastern segments of Osborn Bank. Five caves were located along the 66 m to 70 m paleo-shoreline, and one cave was located along the 103 m paleo-shoreline (Figure 2). Altogether, the unexpected discovery of caves at Osborn Bank led to a breakthrough in our understanding of where to find submerged caves in the region and the orientation of caves entrances.

This region of the California Continental Borderland contains numerous northwest to southeast trending faults that cut across the hard rock terrain (Astiz and Shearer, 2000). Our search for submerged sea caves was most successful not along the northeast or southwest facing fault scarps but along the ends of the fault blocks where wave action had attacked the brecciated ends of the faulted bedrock surfaces and "hollowed out" caves.

We were also more successful finding sea caves on submerged banks such as Osborn Bank as opposed to off the Channel Islands because those islands continue to erode, with sediments pouring into the sea where paleo-shorelines are located. Once sea level rose above the top of Osborn Bank, for example, major erosion ended and subsequent burial of submerged features tapered off dramatically.

Authors Christopher Roman and Kristopher Krasnosky of the University of Rhode Island are conducting post-cruise analysis of their detailed mapping effort using various optical and acoustical imaging systems described in past issues of this *Oceanography* supplement (Roman et al., 2012, 2013). In this particular application, the sensor suite was mounted on the front of ROV *Hercules*, looking forward to enable mapping of vertical walls and cave entrances.

Our 2017 team will continue their efforts in 2018 and will focus on: (1) locating sea caves at the 103 m, 110 m, and 120 m paleo-shorelines on other submerged banks in the Borderland where *Nautilus* has subsequently collected bathymetric and backscatter maps since this cruise (see pages 26–27); (2) mapping the interior of several of the caves using a diver guided three-dimensional imaging system; (3) using the ASV to locate possible cave entrances along deeper paleo-shorelines; (4) following that effort with a visual inspection of any new caves using the ROVs; and (5) collecting water and sediment samples within selected caves to better understand their resident fish populations through eDNA analysis. We may also deploy long-term environmental monitoring systems within selected caves to determine their seasonal variations.

Peering into the Abyss: Studying Our Own Ocean to Advance Astrobiology

By Peter R. Girguis and Allison Fundis

The upper 1 km of ocean harbors the overwhelming majority of familiar sea creatures. Notably, sunlight is absent below a kilometer, and in this "twilight zone" there are myriad bizarre and other-worldly creatures. Even nearshore environs, such as the Southern California Borderland (Weaver, 1969), foster little-known organisms and habitats. For example, during E/V *Nautilus* cruise NA066 in 2015, the exploration team discovered a new hydrocarbon seep system off Point Dume, California, that appears to be a feeding ground for spotted sole and other commercial species (Levin et al., 2016).

Such missions of exploration often lead to the discovery of new sites, demonstrating that despite decades of effort, there is still much to be learned about the deep sea. Water is a formidable barrier to visible light and other electromagnetic energy, making it a challenge to study and map. Seawater's other great strengths—corrosivity and heat capacity—make ocean chemical measurements a challenge.

For decades, ocean scientists and engineers have worked together to develop new sensor systems that help illuminate—literally and metaphorically—the deep, dark sea. At the same time, space scientists and engineers have sought to see further into our solar system and beyond. In recent years, they've discovered that some of the moons of Jupiter and Saturn may be harboring enormous oceans, in some cases deeper than our own. These scientists, who have developed a variety of tools to study a planet's surface from a satellite, lander, or rover, are in the dark about how to explore an ocean on another world.

With support from NASA, we are developing an autonomous deep-sea system that combines the latest in sensor and communication technologies to advance our knowledge of the deep sea, and to provide the broader space science community an opportunity to participate in—and ultimately improve upon—these efforts for future missions to explore the ocean of other worlds. This system, called ABISS (Autonomous Biogeochemical Instrument for In Situ Studies), is a computer-controlled geochemical and microbiological laboratory built onto an autonomous vehicle lander (Figure 1). ABISS is designed to autonomously collect still-frame and video images of a sampling site, analyze geochemical composition, and then collect fluid and sediment samples for in situ experiments and laboratory analyses. The system consists of underwater mass spectrometers (ISMS; Wankel et al., 2011; Meier et al., 2016, 2017; Olins et al., 2017) and isotope analyzers (or laser spectrometer; Wankel et al., 2013), along with an "optical modem" that allows scientists to communicate with deep-sea instruments at unprecedented speeds (Farr et al., 2005). Thus, scientists will be able to reprogram this remote laboratory by talking to the computer with a laser. They can also recover the data, including high-definition video, at broadband speeds. This is a tremendous advance over existing technologies, which limit scientists to acoustically transmitting data at speeds similar to dial-up modems. When complete, ABISS will be the most technologically advanced autonomous seafloor observatory to date. It will also be an "open design" platform that allows any and all scientists to access its designs, software, and hardware.

During our first *Nautilus* expedition (NA084) with ABISS, our primary goal was to test subcomponents of the geochemical analyzers onboard ROV *Hercules*, and to test the optical

Figure 1. The Autonomous Biogeochemical Instrument for In Situ Studies (ABISS) prototype shown here is equipped with a suite of cameras as well as an optical modem for transmitting HD video and still frames in real time to ROV *Hercules*.

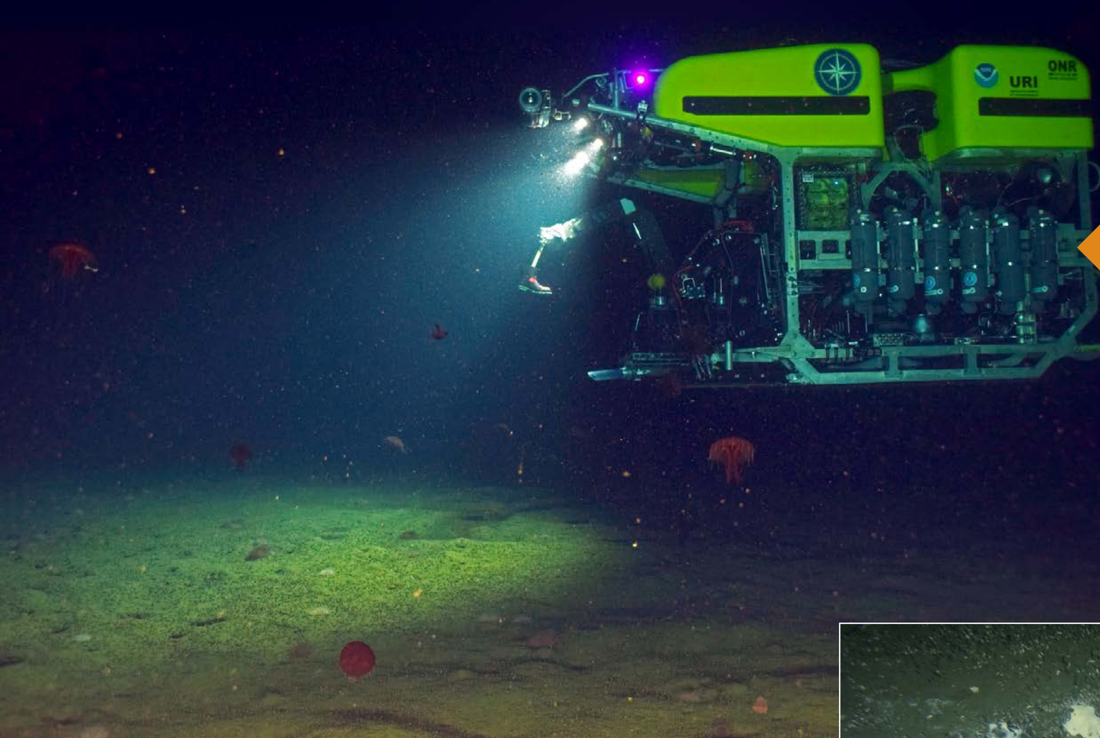
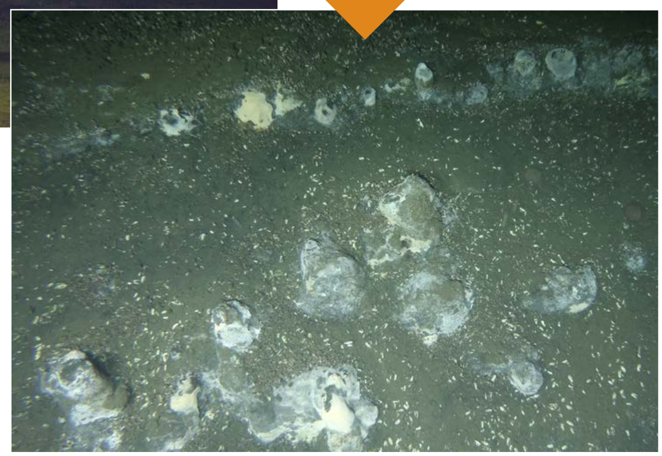


Figure 2. A view of ROV *Hercules* taken from the ABISS lander, 723 m depth off Point Dume, southern California.

Figure 3. ROV *Hercules* positions itself to sample these unusual "chimlets"—mounds produced by microbes that eat the methane gas emitted from the seafloor.



modem and camera systems onboard the autonomous lander. On July 31, 2017, the prototype ABISS lander system was deployed in 723 m of water at the Point Dume seep (Figure 2). One hour later, ROV *Hercules*—equipped with the ISMS, the laser spectrometer, a pH sensor, a temperature logger, and a prototype water sampling system—caught up to ABISS. The ABISS cameras and optical modem were tested by having the ABISS camera take a picture of *Hercules* (Figure 2) and send that image to *Hercules* via optical modem, and then those data were sent to the surface in real time, allowing the shipboard exploration team to watch themselves (i.e., *Hercules*) at work from the vantage of ABISS. These tests were a resounding success, as they showed that the optical modem can "wirelessly" communicate 40 m or more in the particle-rich deep water and in full sunlight.

For the next dive, we equipped *Hercules* with an array of sampling devices, and began a thorough assessment of the carbonate mounds (or "chimlets") found along the seep (Figure 3). These chimlets largely result from extremely active microbial communities that harness energy via the conversion of methane to carbonate (Marlow et al., 2014). During this dive, we used the ISMS and the laser spectrometer to measure the composition and the isotope ratios of the methane-rich fluids, and collected carbonate and sediment samples for determining the rate of methane utilization. The data so far suggest that Point Dume seep methane oxidation rates are among the highest measured to date. Our current efforts are aimed at further lab-based sediment composition analyses and genomic/proteomic sequencing.

Equally important was the opportunity to engage with teachers, students, and others who were a part of the Nautilus Ambassador Program. While on board, the six Ambassadors took part in ROV dive operations, contributed to sample processing in the ship's wet lab, conducted ship-to-shore broadcasts with audiences in their hometowns and around the world, and collaborated on plans to bring the experience back to their students through lesson plans and outreach opportunities. Through their efforts, our science finds its way into classrooms and museums, and through their enthusiasm and intellect we inspire a new generation of scientists, engineers, navigators, pilots, ship's crew, and more.

It should also be noted the data collected on NA084 will be used to further our capacity to search for and identify life on other worlds. To that end, we are aiming to develop an algorithm that will incorporate these data to make predictions about the presence and extent of biological methane cycling in the environment, without needing any sample recovery or in situ biological analyses. Ultimately, the ABISS system and the resulting data will serve as a model of how astrobiologists might explore the ocean worlds at the far reaches of our solar system. While payload limitations may restrict space scientists to far smaller observatories, the lessons learned from ABISS may help astrobiologists design the best tools to explore these outer ocean worlds. With a lot of hard work and a bit of luck, we might peer into abysses of outer ocean worlds and find that life thrives beyond our own.

Discovering the Undersea Beauty of Cordell Bank National Marine Sanctuary

By Danielle Lipski, Gary Williams, Dan Howard, Jennifer Stock, Jan Roletto, Guy Cochrane, Carina Fish, and Kaitlin Graiff

Cordell Bank National Marine Sanctuary (CBNMS) is one of 13 national marine sanctuaries and two marine national monuments in the United States managed by NOAA. National marine sanctuaries are areas of national significance designated to provide conservation, management, and enhanced public awareness of the ocean. CBNMS encompasses 3,300 km^2 offshore of Point Reyes, north central California. The centerpiece of the sanctuary is Cordell Bank, a rocky feature that rises to within 35 m of the surface and is surrounded by continental shelf to the east and deep slope and canyon habitat to the west. In 2015, NOAA doubled the size of CBNMS to increase protection of this special place in the ocean. The expansion added seafloor habitat in Bodega Canyon and on the deep slope that had never been surveyed. Without an understanding of habitats and species in this area, our ability to effectively manage it is limited.

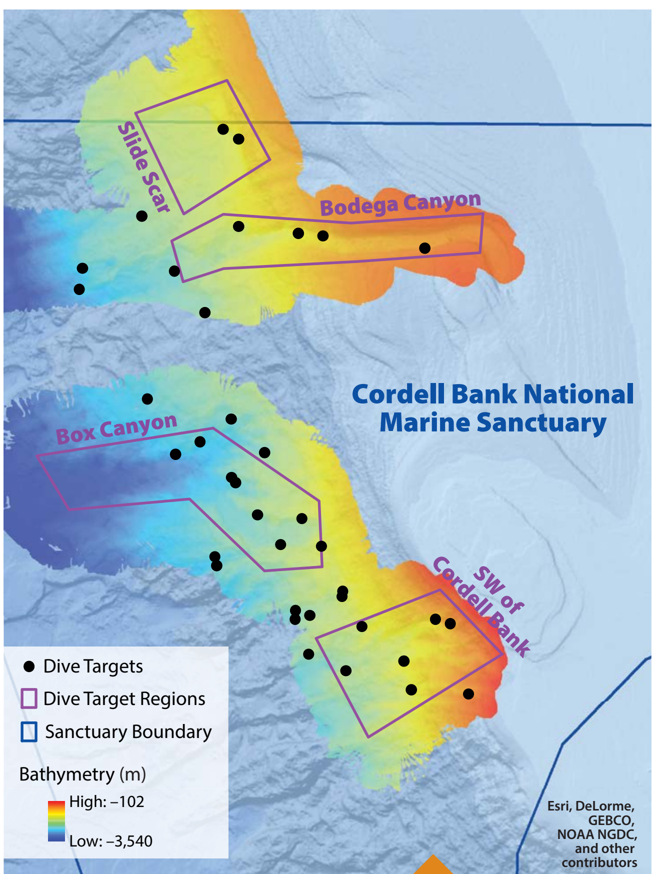


Figure 1. Overview of study area and dive targets.

The primary objectives of cruise NA085 were to: (1) conduct visual surveys of canyons and slope areas, focusing on hard substrates that might harbor deep-sea corals, sponges, and fish; (2) collect biological samples of deep-sea corals and sponges and associated species for identification, age, and growth rates, and water samples for eDNA analysis; and (3) collect environmental and physical data to enable evaluation of climate conditions and impacts.

Using maps created from data collected during cruise NA080 in May 2017, dive targets were identified in areas with hard substrate and high slope, which are indicators of potentially suitable substrate for corals and sponges (Figure 1). We selected sites across a north-south gradient in the sanctuary, as well as a depth gradient thought to be suitable for corals and sponges. All targets were in previously unexplored areas.

From August 6 to 12, 2017, we completed six ROV dives at depths ranging from 740 m to 2,700 m, and spent 76 hours collecting seafloor data.

Bodega Canyon

Our first dives were in Bodega Canyon, a prominent feature in the sanctuary that extends from the continental shelf to over 3,000 m depth. We completed three dives here, surveying the deep canyon east to west from 2,200 m to 740 m depth. Hard substrate and vertical walls provided habitat for corals, including black and bamboo corals (Figure 2), which had never been recorded in CBNMS before, as well as primnoid (*Callogorgia kinoshitae*) and bubblegum (*Paragorgia* sp.) corals. We collected live and dead bamboo coral specimens to determine their ages and to conduct chemical analysis of the skeletons to assess environmental conditions the corals experienced over time. Brittle stars, anemones, and California Tanner crabs were abundant at times. Other observations included sponges, sea cucumbers, many octopuses (*Graneledone pacifica*; Figure 3), and grenadiers.

Box Canyon

Our deepest dive, 2,700 m to 1,975 m, was on the deep slope to the south of Bodega Canyon nicknamed "Box Canyon." We observed and collected several types of black corals, including *Umbellapathes* sp., *Lillipathes* sp., and *Bathypathes* sp.; a spiral sea whip coral (*Radicipes* sp.); and bamboo corals. Several hours into this dive, we came across a tall, overhanging cliff

Figure 3. Many octopuses were observed.

Figure 2. Large bamboo corals grow horizontally from cliff walls into the water column.

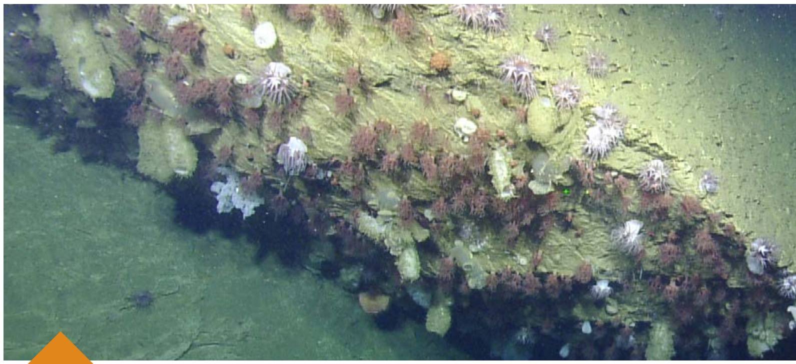


Figure 4. An overhanging cliff face was covered with sponges and corals.

face that was densely covered with many large sponges and some coral (Figure 4). We spent time sampling and comprehensively documenting this feature.

Southwest of Cordell Bank

We completed two dives on the slope to the southwest of Cordell Bank at depths from 1,125 m to 870 m. We observed thornyhead rockfish and a high abundance of sponges, including bright yellow Picasso sponges belonging to the genus Staurocalyptus, and we sampled several corals, including *Paragorgia* sp. and red sea fans (*Swiftia* sp.). Lost trawling gear was detected in this area, which is open to fishing, illustrating one of the threats to deep-sea communities.

Observations, Collections, and Analysis

Throughout the surveys, marine snow was abundant and some coral specimens were quite large, over a meter tall and wide, indicating that food delivery is plentiful and the corals are long-lived. Overall, there was high diversity of corals and sponges, as well as other macroinvertebrates.

Although the last two days of diving were canceled because of deteriorating sea state, we were nevertheless able to survey most of our priority areas and to collect imagery and samples from the deep sea in CBNMS. Over 230 biological specimens, sediment, and water samples were collected. The California Academy of Science scientists and other collaborators will identify the biological specimens. Many specimens cannot be confidently identified until they are studied in the lab using a scanning electron microscope, so the identifications mentioned here are conditional until confirmed. At least 16 of the 21 coral specimens are likely new coral records for CBNMS. This cruise also provided new species observations for the sanctuary of sponges, sea cucumbers, anemones, and fish, along with information about habitats and environmental conditions. Species abundance and distribution will be quantified from visual imagery by CBNMS staff. University of California, Davis, scientists will analyze water samples for carbonate chemistry, sediment samples for benthic microorganisms and geochemistry, and coral skeletons for age and chemical composition. NOAA National Marine Fisheries Service scientists will analyze water samples for eDNA.

Outreach

Education and public engagement is a priority for both the Ocean Exploration Trust and CBNMS, and together through live streaming we reached at least 16,000 viewers from around the world. We also spoke with nearly 900 people during 30 live interactions, including 170 people on August 12 for "Get Into Your Sanctuary Day," coordinated by the NOAA Office of National Marine Sanctuaries to connect communities to their local sanctuary.

Conclusion

Cruise NA085 significantly expanded the information about deep habitat in CBNMS, and opened up new topics for future research and outreach. However, we had only a glimpse of this vast habitat and hope to complete surveys in other areas and to revisit some sites for more comprehensive examination.

Quinault Canyon and Olympic Coast National Marine Sanctuary

By Jenny Waddell, M. Elizabeth Clarke, Ervin Schumacker, and Nathalie Valette-Silver

Returning to the Pacific Northwest, E/V *Nautilus* embarked on a 16-day expedition to the Olympic coast in August 2017 to explore and characterize shelf break and submarine canyon habitats and communities using an ROV and an autonomous underwater vehicle (AUV; Figure 1). Many habitats in Juan de Fuca, Quinault, and Quileute Canyons had not been visited or explored with these technologies previously, despite being prominent features of Washington's continental shelf.

The team completed 16 ROV dives, primarily to explore high-slope habitats likely to harbor long-lived species such as deep-sea corals and sponges (Figure 2), but also to visit known methane seep locations and explore the wreck of the WWII-era submarine USS *Bugara*. Twelve AUV dives complemented the ROV characterization work by focusing on lower slope areas around canyon rims. AUV surveys provide quantitative information on benthic biota (including fish, corals, and sponges) and their fine-scale spatial relationships. ROV and AUV dives revealed that much of the area surveyed was covered by sediment. However, some areas, especially

Figure 1. Scientists deploy plankton nets at the stern of E/V *Nautilus* near ROVs *Argus* and *Hercules*, while in the foreground scientists download data from the National Marine Fisheries Service AUV *Popoki*. *Image credit: NOAA/OCNMS and Ocean Exploration Trust*

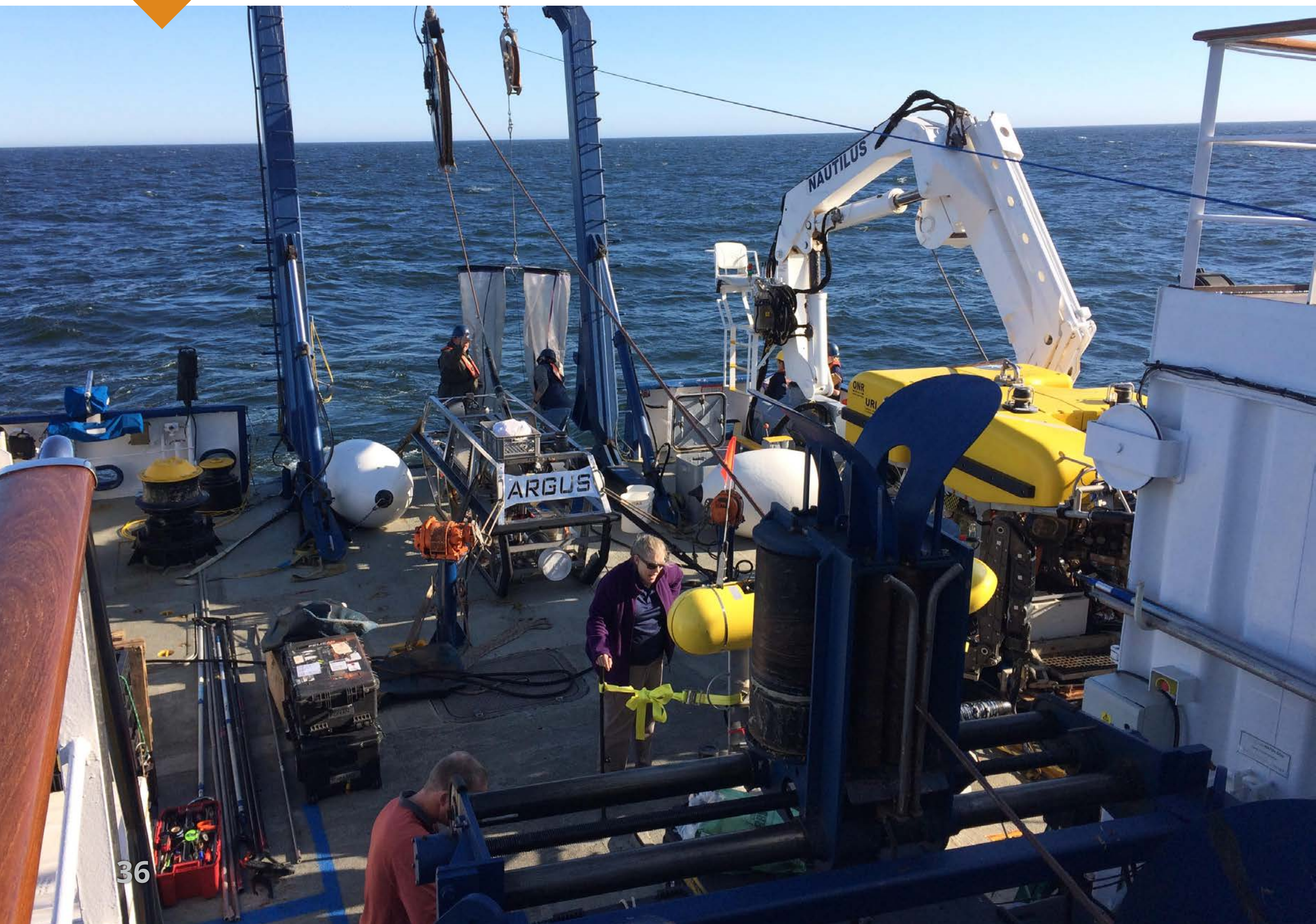


Figure 2. ROV *Hercules* completed 16 dives in Olympic Coast National Marine Sanctuary to explore and characterize high-relief areas—persistent habitats known to support long-lived species such as the deep-sea community pictured here in Juan de Fuca Canyon.

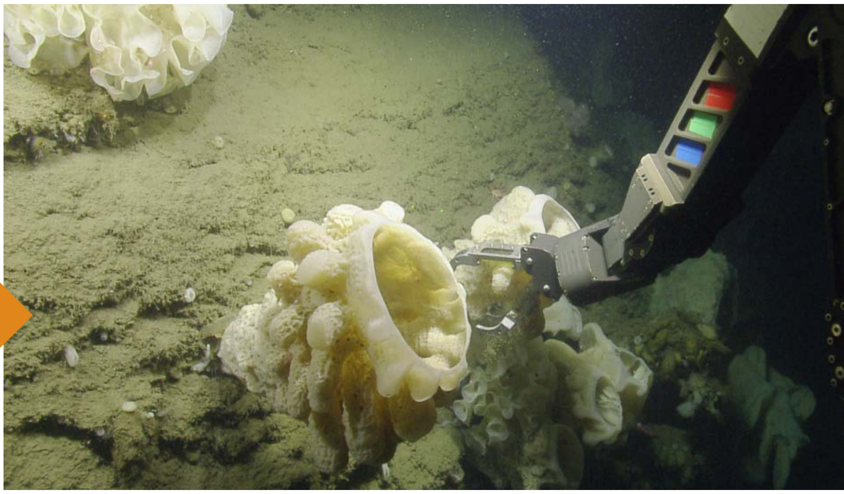


Figure 3. ROV *Hercules* collects a piece of sponge from a sediment-covered Quinault Canyon wall.

canyon walls, had high densities of corals and sponges, several of which were collected with the ROV (Figure 3). Initial review of collected samples indicates range extensions for some corals and sponges, and there is the possibility that several new species were collected.

In addition, samples were collected to contribute to the designation of the Olympic coast as a sentinel site for ocean acidification (OA). In fact, the expedition was scheduled for late summer specifically to coincide with seasonal processes related to OA in order to capture the period of maximum expression for the region. OA-related research activities included ROV collection of whole water samples for carbon chemistry, ROV and AUV water column measurements for oxygen concentrations, collection of push cores from the seafloor to establish a record of benthic organism exposure to OA over time, and plankton tows in the top 100 m of ocean waters to capture pteropods and other organisms that serve as indicators of OA exposure in the water column.

The ship's multibeam sonar was used during the expedition to refine dive planning in a section of Juan de Fuca Canyon (24 km^2) as well as to map deeper areas of Juan de Fuca Canyon (485 km^2) and Quileute and Quinault Canyons (788 km^2). Much of this work also contributes to fulfillment of offshore mapping priorities identified through a multi-agency spatial prioritization process conducted in May 2015 (Battista et al., 2017).

A unique aspect of the Olympic Coast expedition was incorporation of the perspectives of the four Coastal Treaty Tribes that co-manage marine resources in the region: the Makah, Hoh, and Quileute tribes and the Quinault Indian Nation (a collaborator on the original proposal). At the request of the tribes, two social scientists with experience working in tribal communities joined the expedition to share information about the tribes and underscore the importance of marine resources to tribal community well-being, primarily through the narration of ROV dives.

Discovering Oregon's Lost Coast: Finding and Studying Submerged Archaeological Sites and Landscapes on the Pacific Continental Shelf

By Loren Davis, Frank Cantelas, and Nathalie Valette-Silver

How and when humans entered the New World remain open questions. Anthropologists hypothesize that humans migrated from northeastern Asia into North America some time during the last glacial period, skirting the edge of the Cordilleran ice sheet by using watercraft, by walking along unglaciated coastal refugia, or by a combination of both methods. From this perspective, evidence of the earliest human habitation in the New World should be found along the northeastern Pacific Ocean's coastal margin, now buried in submerged terrestrial landforms that were once part of ancient coastal landscapes before sea level rose.

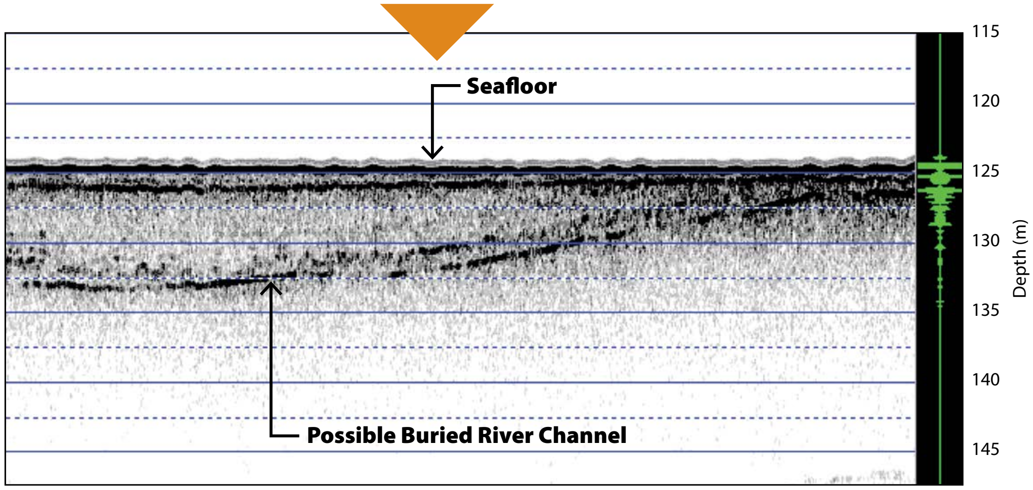
Figure 1. Members of the scientific party stand watch as E/V *Nautilus* collects multibeam and subbottom profiler data along the Oregon's coast. *Image credit: Loren Davis*

From September 5 to 10, 2017, author Davis led a scientific expedition aboard E/V *Nautilus* (Figure 1), collecting more than 1,500 km of new acoustic survey data in 120 m to 100 m water depth along central Oregon's Pacific outer continental shelf. This region was predicted to be the location of coastlines from about 21,000 to 15,000 years before present.

Preliminary examination of the acoustic data reveals buried traces of what appear to be river channel features incised in an ancient exposed coastal plain (Figure 2). Because coastal rivers and estuaries provided abundant resources for ancient coastal peoples, it is anticipated that submerged archaeological sites may be found close by. Using the knowledge of where these key environments were located on the continental shelf, Davis's team will choose targets to collect cores of stratified deposits of ancient landforms and any archaeological materials they may hold. Subsequent physical, geochemical, and radiocarbon analysis of these sediment cores will provide key insights into Oregon's past coastal environments and relative sea level history.

If these cores yield evidence of early coastal settlements on late Pleistocene-aged shorelines along Oregon's coast, this work could enhance understanding of North America's earliest archaeological record.

Figure 2. Subbottom profiler data from a survey transect that crossed what appears to be a buried river channel. *Image credit: Loren Davis/OET*



Exploration of the Northern Guaymas Basin

By S. Adam Soule, Jeff Seewald, Scott Wankel, Anna Michel, Roxanne Beinart, Elva Escobar Briones, Esmerelda Morales Domínguez, Peter Girguis, Dwight Coleman, Nicole A. Raineault, Jamie Wagner, Aubrey Foulk, Anshika Bagla, and Jeffrey Karson

The Gulf of California, a marginal sea that lies between the Baja California peninsula and mainland Mexico, began forming ~14 million years ago as the North American continent tore apart. As rifting proceeded, small oceanic spreading centers separated by long transform faults developed within the Gulf. Today, those spreading centers remain active and form the western boundary of the North American Plate between the East Pacific Rise to the south and the San Andreas fault to the north. In the central Gulf of California, some signs of seafloor spreading are evident, including a central rift valley that marks the axis of spreading. However, other typical signs of seafloor spreading, including lava flows on the seafloor, are masked by a 0.5–1.5 km thick sediment blanket that results from river delivery of large volumes of sediment to the Gulf as well as high biological productivity fed by upwelling of nutrient-rich bottom waters in the narrow sea.

The thick sediment blanket inhibits magma rising to the seafloor. Instead, the magma is injected into the sediment as sills. Such sills have been sampled by scientific ocean drilling in the well-studied southern Guaymas Basin and interpreted to have been injected at the spreading axis and then subsided as the plate rafted away (Einsele et al., 1980). In the northern Guaymas Basin, seismic studies suggest that sills are injected not only at the rift axis, but also on the rift flanks up to 40 km away (Lizarralde et al., 2011). The goal of this expedition was to visit a number of potential sill injection sites identified from seafloor mapping and determine the nature of local fluid circulation. Little was known about the temperature, fluid composition, biological communities, and geology at most of these sites.

Over the course of seven days, we visited five sites and found a remarkable range of vent types, from black smokers to cold seeps (Figure 1). The diversity of venting styles within a fairly restricted area solidifies the northern Guaymas Basin as an amazing natural laboratory to study an array of seafloor and Earth system processes. With ROV *Hercules* we were able to characterize the sites and collect geological, biological, and fluid samples for analysis on board E/V *Nautilus* and ashore.

Just outside of the ~3 km wide and ~200 m deep axial graben, *Hercules* visited a ridge of high-temperature black smoker vents (H1650). These vents were discovered serendipitously in 2015 by a German-led multichannel seismic cruise (Berndt et al., 2016), but had not been explored by ROV. The 400 m long ridge is made up of four mounds, each of which has a black smoker at its peak. The highly complex vent structures rise 10 m to 30 m from the tops of the mounds and often widen at their tops, with flange structures forming where clogged vertical conduits shunt hydrothermal fluid out the sides of the structures (Figure 2a). Fluid temperatures at the sites reached 331°C as measured by isobaric gas-tight samplers. The vents and surrounding areas were heavily colonized by *Riftia pachyptila* tubeworms, associated scaleworms, squat lobsters, and white microbial mats. Nearby, extinct sulfide mounds displayed dense mats of blue folliculinid ciliates in

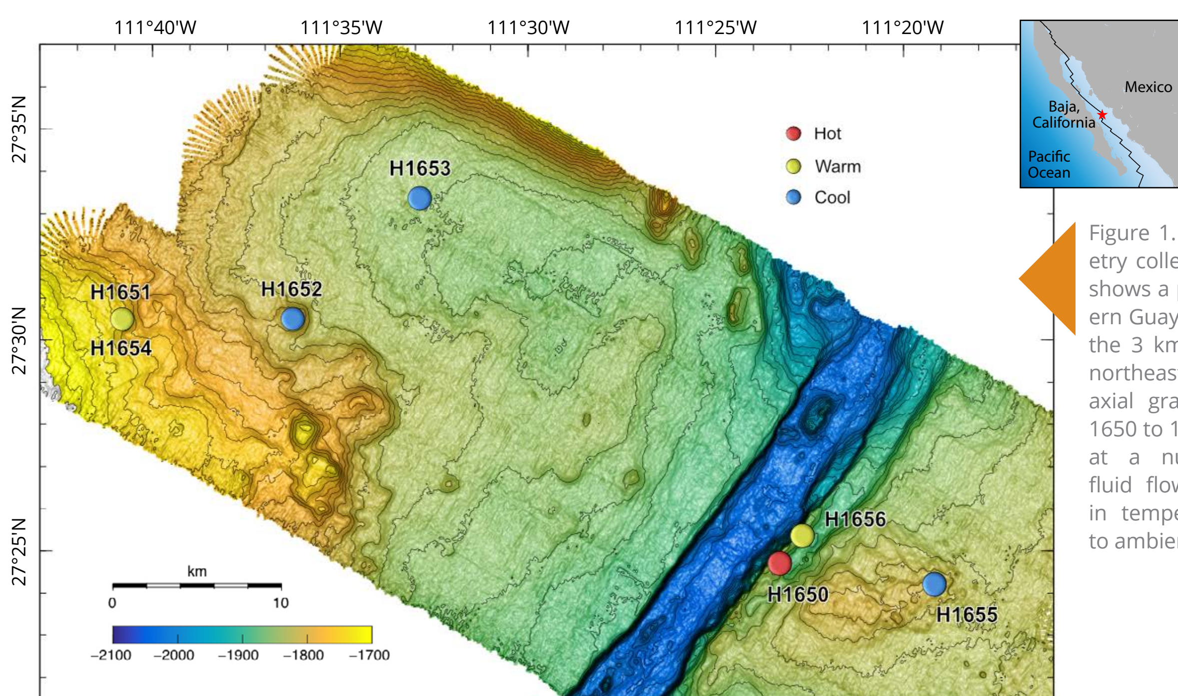


Figure 1. Multibeam bathymetry collected by E/V *Nautilus* shows a portion of the northern Guaymas Basin, including the 3 km wide, 200 m deep northeast-southwest trending axial graben. *Hercules* dives 1650 to 1656 were conducted at a number of seafloor fluid flow sites that ranged in temperature from 322°C to ambient.

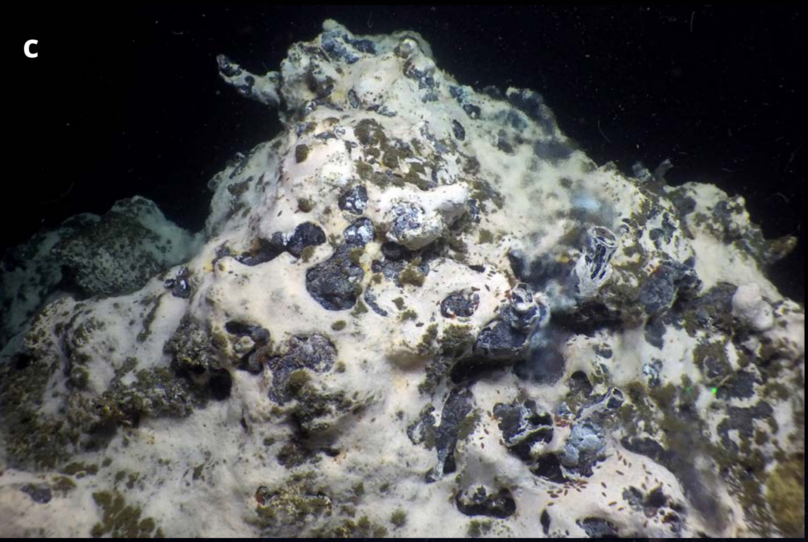
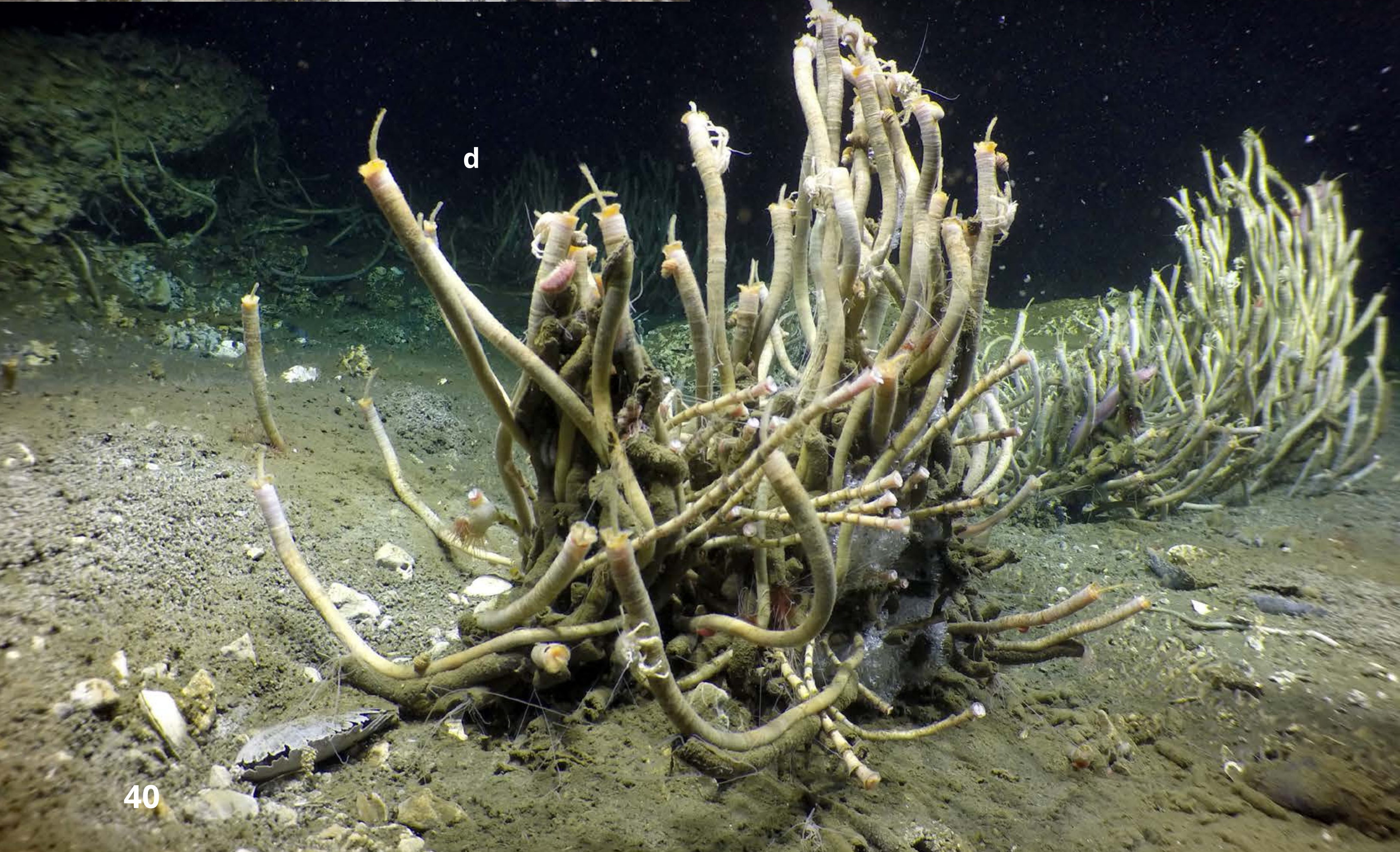


Figure 2. Selected images from dives in the northern Guaymas Basin. (a) Flanges on a black smoker chimney. (b) Blue folliculinid ciliates in association with gastropods, scaleworms, some sessile polychaetes, deep-sea sponges, a few *Escarpia* tubeworms, and a third unidentified tubeworm species. (c) Meter-high mound covered by a thick bacterial mat. Images are from a GoPro Hero4 camera in a deepwater housing with water-corrected optics provided by the WHOI MISO facility. (d) A clump of *Lamellibrachia* and *Escarpia* tubeworms with associated galatheid crabs and snails.



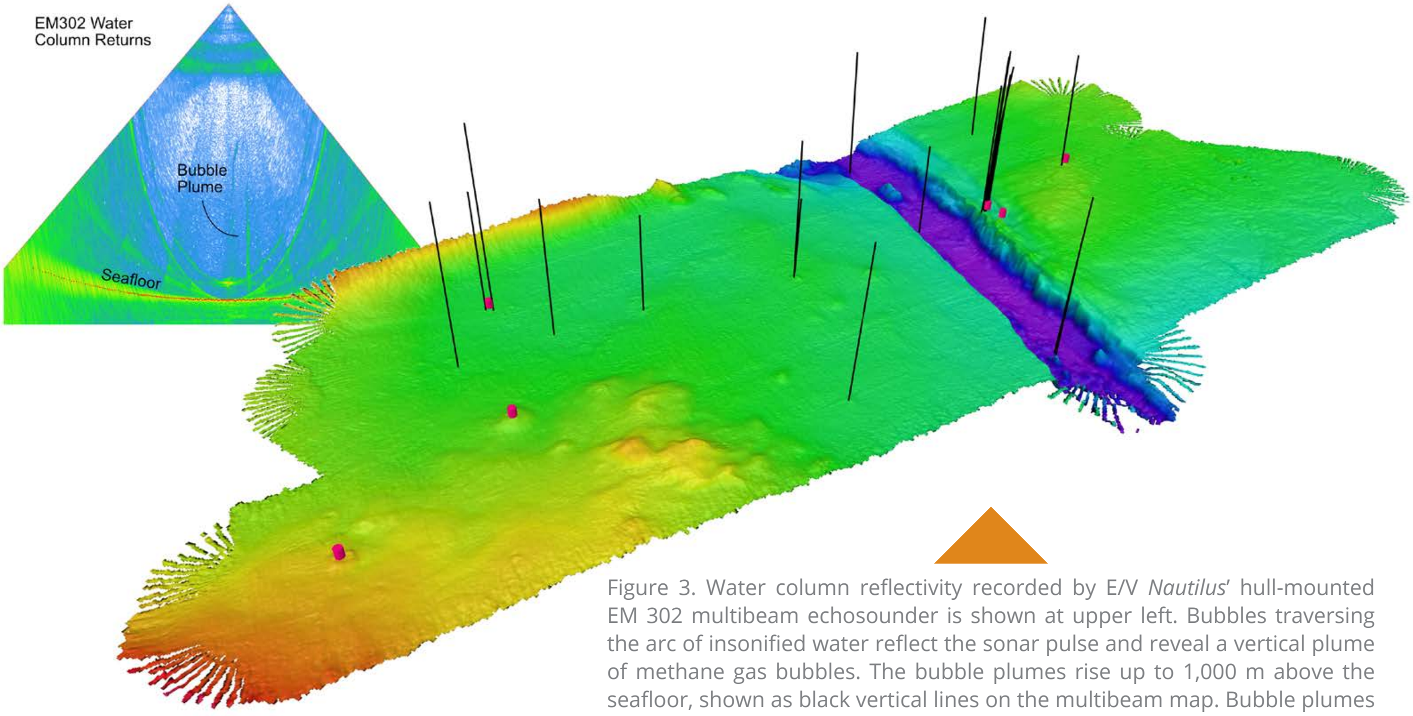


Figure 3. Water column reflectivity recorded by E/V *Nautilus*' hull-mounted EM 302 multibeam echosounder is shown at upper left. Bubbles traversing the arc of insonified water reflect the sonar pulse and reveal a vertical plume of methane gas bubbles. The bubble plumes rise up to 1,000 m above the seafloor, shown as black vertical lines on the multibeam map. Bubble plumes directly under the vessel are more clearly imaged, so it is not known how many more bubble plumes may be present than the 12 identified on this cruise.

association with gastropods, scaleworms, some sessile polychaetes, deep-sea sponges, a few *Escarpia* tubeworms, and a third unidentified tubeworm species (Figure 2b).

Over 30 km from the axial graben, on two million year old crust, we visited a site called Ringvent (H1651, H1654), which seismic data suggest is underlain by a shallow (young) sill that an *Alvin* submersible dive in 2015 showed to vent warm fluids (A. Teske, University of North Carolina, Chapel Hill, *pers. comm*., 2017). This site is defined by a circular ridge dotted with depressions. We found a small, meter-high mound emitting clear fluids at 70°C at a location identified during the 2015 *Alvin* dive. The mound appeared to be constructed of thin sheets of carbonate covered with thick bacterial mat (Figure 2c). Around the site, small chimlets and bacterial mats were common. The focused vents were not colonized beyond the microbial mat, but in areas of more diffuse flow, dense clumps of *Lamellibrachia* and *Escarpia* tubeworms were common as were sea stars, ophiuroids, vesicomyid clams, gastropods, squat lobsters, scaleworms, and anemones.

A similar vent system was found just outside the axial graben, only 1 km north of the black smoker site (H1656). This site also displayed focused venting at 70°C, with vent structures and animal communities (Figure 2d) comparable to those at the Ringvent site. In addition, this site hosted isolated *R. pachyptil*a tubeworms that were common at the black smoker site.

We visited three sites where fluid flow was less vigorous and at temperatures near ambient bottom water. Two sites were located ~20 km northwest of the axial graben (H1652, H1653), and the third site was located ~8 km southeast of the axial graben (H1655). The northwestern sites were previously identified from seafloor mapping, but the southeastern site was identified on this cruise from multibeam echosounder data that showed a plume of bubbles in the water column (Figure 3). Each of the cold sites was characterized by areas of thick microbial mats, clumps of *Lamellibrachia* and *Escarpia* tubeworms, ophiuroids, vesicomyid clams, solemyid bivalves (though we did not see any live individuals, only empty shells), crabs, squat lobsters, and anemones. At two of the sites, we located the source of bubble plumes and attempted to measure gases with the isobaric gas-tight samplers.

This expedition established the presence of a dramatic diversity of venting and seepage in previously unexplored areas, and characterized the geological and geochemical diversity of these sites. Moreover, the expedition documented the associated animal and microbial communities, and collected representative samples that were sent to repositories for access by the broader community. Exploration led to a number of compelling questions. Is off-axis warm venting driven by injection of magma up to 30 km from the ridge axis? By what mechanism do magmas reach this location and is it common to mid-ocean ridges or specific to sedimented ridges (e.g., Han et al., 2014)? To what degree are organic and inorganic carbon released from the sediments by magma injections and how much of that carbon reaches the water column? This latter question is of particular importance, as similar mechanisms (magma-sediment interaction during large igneous events) are implicated in punctuated global-scale climate shifts, mass extinctions, and ocean anoxic events in Earth's history (e.g., Svensen et al., 2007). The groundwork was laid here for future expeditions that could be tailored to address these questions, and many others that resulted from this mission of exploration.

Biogeochemical Exploration of the Pescadero Basin Vents

By Anna Michel, Scott Wankel, Stace Beaulieu, S. Adam Soule, Lauren Mullineaux, Dwight Coleman, Elva Escobar Briones, Adriana Gaytán-Caballero, Jill McDermott, Susan Mills, Daan Speth, and Robert Zierenberg

Overview

In 2015, the deepest high-temperature hydrothermal vents in the Pacific Ocean (3,700 m) were discovered in a sediment-covered pull-apart basin along the Pescadero Transform Fault in the Gulf of California. Biological communities were observed thriving among the carbonate chimney structures (Figure 1; Goffredi et al., 2017). As a result of their striking contrast to other hydrothermal systems, the high-temperature, high-carbon Pescadero Basin vents provided the opportunity to examine the influence of tectonic setting on the nature of seafloor vent sites, the fundamental geochemical controls on biological colonization in the deep ocean, and the role of fluid venting on global-scale ocean chemistry and climate. In November 2017, with support from the Dalio Ocean Initiative, a multidisciplinary science team led by Woods Hole Oceanographic Institution scientists set out on E/V *Nautilus* to investigate this area of active venting.

Vent Exploration

We explored the primary known Pescadero Basin venting sites, including Z vent, C Vent, P Vent, Diane's Vent, and the Matterhorn. In addition to these prominent vertical mounds, numerous small areas of focused and diffuse venting were observed. Although located in close proximity (within ~500 m) and sharing many characteristics (microbial mats, fauna, structure, fluid chemistry), distinct features of each type of venting provided context for comparison. Diane's Vent is a short (~1 m high) carbonate chimney exhibiting exceptionally vigorous flow of hot fluids (~288°C) from an orifice ~30 cm across. The Matterhorn is a hydrothermal mound that rises ~12 m above the seafloor. Its central vent emits energy-rich fluids supporting dense *Oasisia* tubeworm colonies. Z vent is a large carbonate mound that rises ~20 m above the seafloor and exhibits a more variable structure, with large flange features along the outside of the mound and small chimneys venting fluids as hot as 299°C (Figure 2).

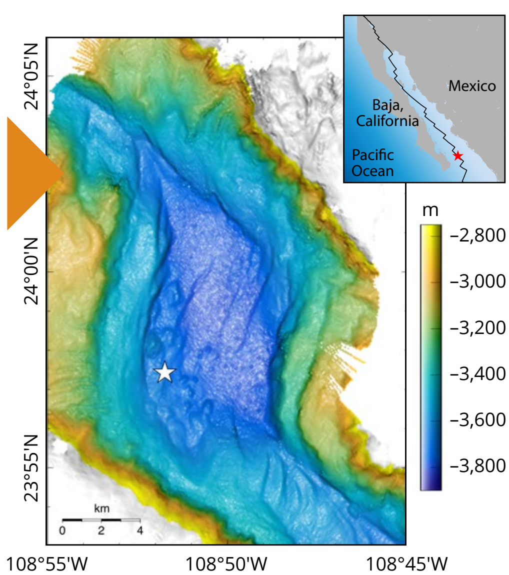


Figure 1. Location of Pescadero Basin (red star in inset) and vents (white star in bathymetric map) in the Gulf of California, which were discovered in 2015.

Biological Communities

Megafaunal epibenthic communities appeared to be distinctly zoned in relation to proximity of active fluid venting. On the outskirts of the larger carbonate mounds, more sparsely inhabited benthic communities included anemones, *Munidopsis* squat lobsters, and holothurians. Around the base of the mounds, clams and zoanthids were frequently quite dense on soft and hard substrata, respectively. Other types of fauna clustered more directly around venting fluid orifices in communities typically dominated by the tubeworm *Oasisia* (Figure 3), with occasional lone *Riftia*. Some areas near venting orifices exhibited a distinctly separate community structure, typified by microbial mats. An apparent zonation in microbial mat morphology and extent within these communities may indicate fluid venting governing both temperature and delivery of energy-rich fluids. Sediment push cores

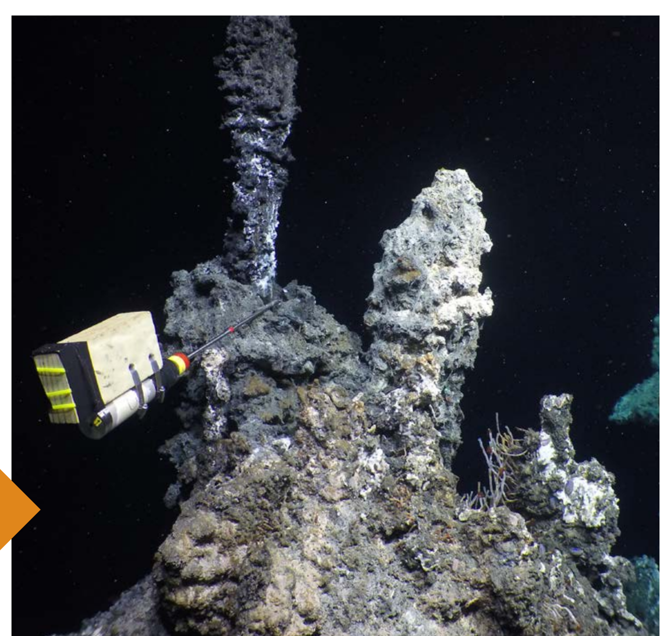


Figure 2. The Z vent was characterized by tall carbonate spires. An in situ temperature probe (left part of image) was installed to capture temperature variability of the fluids emanating from the chimneys.

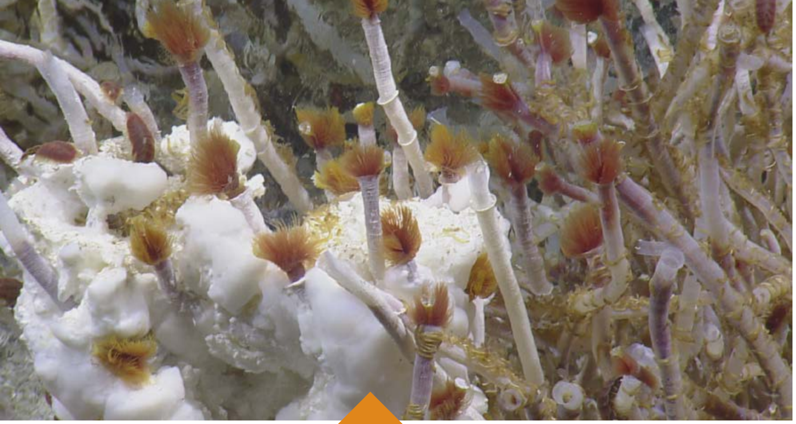


Figure 3. *Oasisia* tubeworms were a prominent species observed near sites of active fluid venting. Some of these areas also contained microbial mats enshrouding tubeworms as shown above.

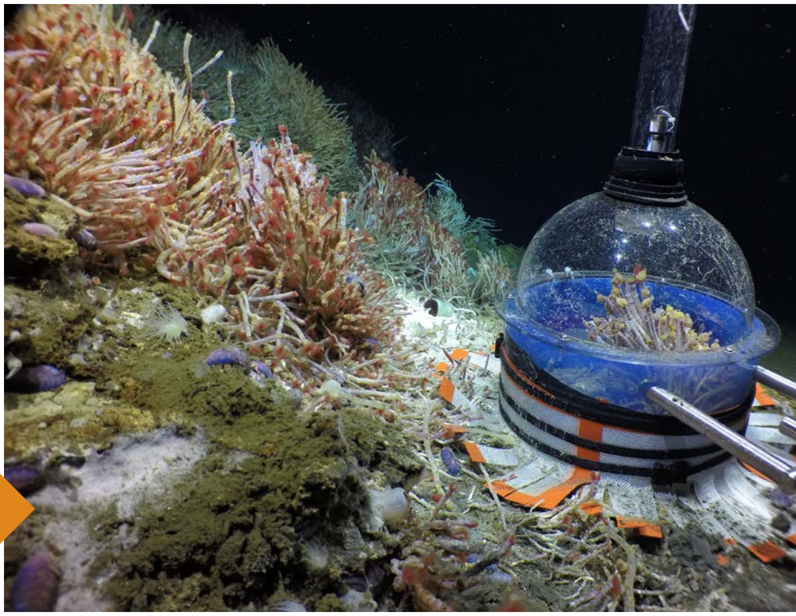


Figure 4. A flux integrator coupled to both an in situ laser spectrometer and a mass spectrometer allowed chemical fluxes and temperature fluxes to be measured.

were collected to study infaunal and microbial community structures, pore water chemistry, and chemical and mineralogical composition of sedimentary particles. Representative rock specimens were also collected for analysis of rock-hosted megafaunal and microbial communities.

To understand vent biological community compositional differences and zonation, we collected fauna from distinct positions within the communities and from the water column at seven locations. Water column samples will be examined to compare the taxonomic composition of larvae with that of the benthic communities. We collected megafauna and sediment push cores for the Universidad Nacional Autónoma de México. To complement the biological sampling, we made in situ chemical measurements at these same locations.

In Situ Chemical Analyses Using Advanced Technologies

A range of novel deep-sea tools and advanced technologies were employed for chemical analyses. An in situ mass spectrometer was used for real-time measurement of dissolved volatiles, including hydrogen, methane, carbon dioxide, hydrogen sulfide, and higher-order hydrocarbons. A deep-sea laser spectrometer facilitated in situ measurement of the stable carbon isotopic composition of methane. To enable chemical and temperature measurements of diffuse flows in and around tubeworm clusters, a flux integrator (Figure 4) was coupled to these instruments. The combined instrument deployment for chemical concentration and isotope measurements was a scientific first for deep-sea vent exploration, and will prove essential for quantifying the origins and fluxes of carbon and other chemical species from these types of hydrothermal vent systems. Preliminary analyses indicated an abundance of hydrogen, methane, carbon dioxide, and higher-order hydrocarbons in the vent fluids, likely influenced by the organic-rich sediment overburden.

Isobaric gas-tight samplers were used to collect high-temperature fluid samples for determining their inorganic, organic, and volatile chemistry. In combination with in situ chemical data, these discrete measurements will constrain sources of dissolved carbon dioxide, hydrocarbons, organic acids, lipids, and other organic species to the seafloor at the Pescadero Basin vent field. The nitrogen and sulfur systems and fluid metal contents will be examined to comprehensively describe the Pescadero Basin geochemical framework.

Geological Studies

Geological sampling and analyses focused on the mineralogical and geochemical characterization of rock samples, particularly hydrothermal precipitates, to constrain past and ongoing hydrothermal conditions. Collection of representative rock samples, including carbonates, from the vents will permit detailed mineralogical studies. A few geologic samples contained obvious hydrothermal/petroleum-like hydrocarbon, which had not been observed previously at Pescadero Basin. Rock slabs and chimneys associated with lower temperature biological communities contained more abundant barite relative to previously collected material. Further examination of these samples promises to shed light on the unique nature of this hydrothermal system. To measure vent fluid temperature changes, a temperature logger was deployed in the Z vent (Figure 2). Upon returning three days later, we discovered a new chimney had grown ~1 m high above the logger and samples were collected to examine this growth.

Funding was provided by the Dalio Ocean Initiative and ICML UNAM. Images courtesy of Ocean Exploration Trust, Woods Hole Oceanographic Institution, Dalio Foundation, Alucia Productions, Adam Soule, and the MISO Facility. We thank our MBARI colleagues for providing vent field maps and for multibeam data processing, and our shore based team, especially P. Girguis and D. Hoer.

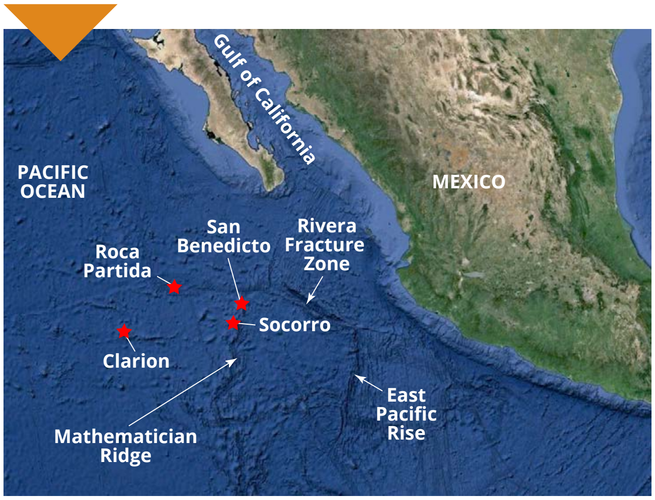
Exploring and Mapping the Revillagigedo Archipelago World Heritage Site in Mexico

By Steven Carey, Karen Wishner, Claus Siebe, Katherine Kelley, Brennan Phillips, Christopher Roman, Megan Lubetkin, and Esmerelda Morales Domínguez

The Revillagigedo Archipelago consists of four volcanic islands located 450 km south of Baja California (Figure 1). The islands are situated at a major convergence of two marine biogeographical regions, the Northeastern and the Eastern Pacific. In particular, this area is where the California and Equatorial Currents mix, creating a complex and highly productive marine environment. Often referred to as "Mexico's Galápagos," the islands are isolated from the mainland and are home to a significant number of endemic species both on land and in the marine environment. The shallow waters around the islands are remarkable for the abundance of large marine predators and pelagic species. Large populations of sharks (hammerhead, silky, and whale), rays, tunas, and turtles attract recreational scuba divers from around the world. In particular, the archipelago hosts the largest aggregations of giant manta rays (*Manta birostris*).

The unique biological, geological, and oceanographic features of the Revillagigedo Islands has led to their designation as a World Heritage Site by UNESCO in 2016. E/V *Nautilus* cruise NA092 was the first to deploy an ROV to explore the deep marine environment surrounding two major islands of the archipelago, Socorro and San Benedicto. Primary focus themes of the cruise included processes of submarine volcanism, characterization of benthic and pelagic fauna, and impacts of the oxygen minimum zone (OMZ) on marine ecosystems occupying the island flanks.

Figure 1. Location of the Revillagigedo Islands (Socorro, Clarion, San Benedicto, and Roca Partida) in the eastern Pacific Ocean. *Basemap from Google Earth, GEBCO*



Submarine Volcanism

The most recent submarine volcanic eruption in the archipelago was in 1993 about 4 km off the west shore of Socorro (Siebe et al., 1995). It is one of only five known submarine eruptions that have produced large floating lava blocks, known as scoria. The scoria eventually broke into pieces, and often were propelled laterally by vigorous steam jets. Despite its surface manifestations, the location of the underwater vent was unknown. With the aid of new multibeam maps of the area, ROV dives explored nine potential target sites. The vent site was located at 275 m water depth on the summit of a small volcanic cone that exhibited an extensive field of white, filamentous bacteria surrounding meter-size scoria blocks (Figure 2). The dives revealed that the amount of large scoria was likely relatively minor and that most eruptive products consisted of glassy volcanic sand. Construction of submarine cones from such material produces structures that are potentially unstable and susceptible to mass wasting, as shown by the presence of collapse scars on many of the slopes.

In deeper water (>1,000 m), the sides of both Socorro and San Benedicto Islands consist of overlapping, flat-topped satellite vents, often with a central depression likely monogenetic in origin. The sides of these structures are quite steep

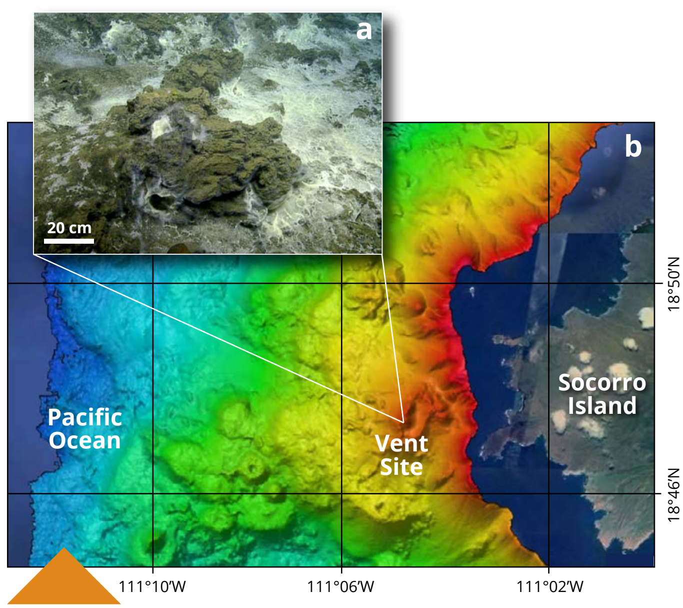


Figure 2. (a) Photo of a scoria block surrounded by white bacterial mats at the summit of the 1993 submarine vent site west of Socorro Island. (b) Map showing the seafloor morphology in the vicinity of the 1993 vent site and the abundance of other circular vents and cones. Multibeam bathymetry from cruise NA089.

Figure 3. Near-vertical pillow lava tubes on the side of a flat-topped volcanic center to the southeast of San Benedicto Island.

Figure 5. Using a low-light camera equipped with extremely dim lights, a vampire squid (*Vampyroteuthis infernalis*) was observed up close at 1,225 m depth in an apparent relaxed state.

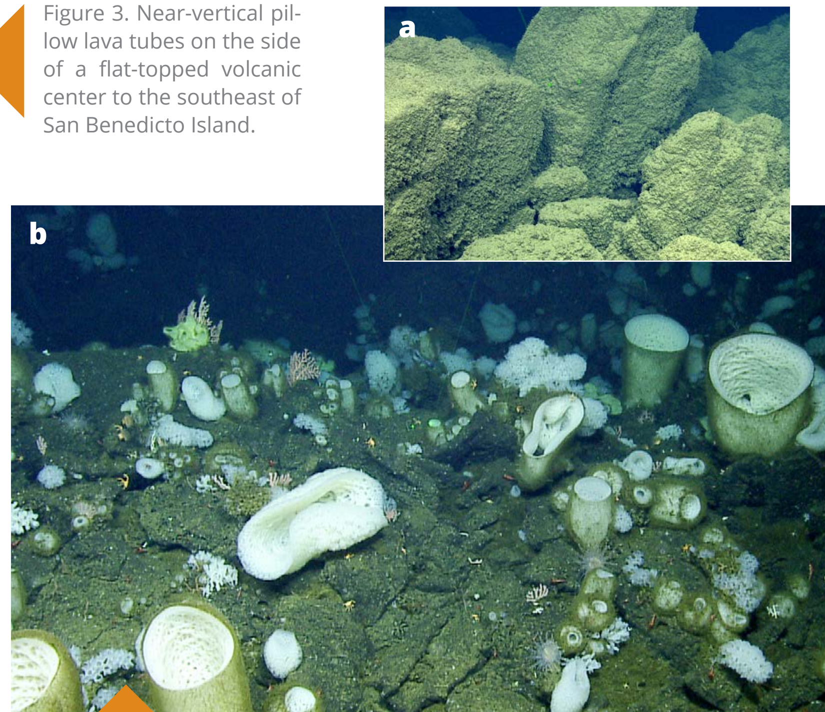


Figure 4. Biological zonation through the oxygen minimum zone. (a) Rocks at 345 m depth in low-oxygen water are covered with a fuzzy biological mat but no larger animals. (b) Abundant diverse sponges and other large epifauna in the Sponge Garden at 851 m depth where oxygen levels are higher.

and consist dominantly of pillow lavas and elongated pillow tubes (Figure 3). Fresh basaltic glass was recovered from some of these vents, suggesting that the frequency of submarine eruptions may be underestimated in the region. Geochemical analyses of the samples will be used to evaluate the origin of the magmas and investigate how volcanism has sustained these active oceanic islands on the Mathematician spreading ridge after abandonment approximately 3.5 million years ago.

Marine Ecosystems and the OMZ

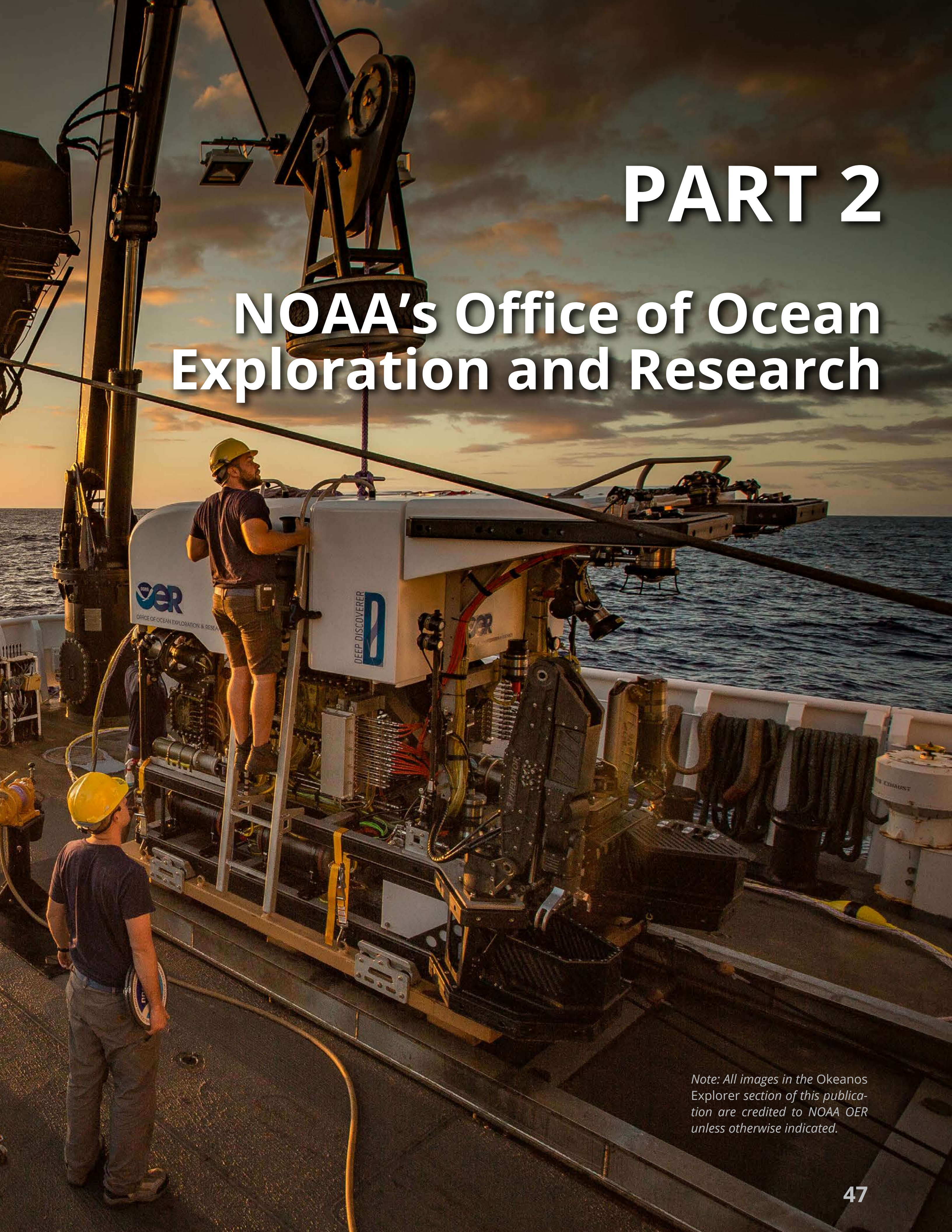
This oceanographic region of the world is characterized by extremely low oxygen at mid-water depths from about 200 m to 800 m. Previous work in 1988 at a nearby seamount (Volcano 7) that penetrated into the OMZ showed benthic faunal zonation along the seamount slope into the low-oxygen water, with the summit devoid of large animals (Wishner et al., 1990, 1995). Our *Nautilus* dives confirmed this basic pattern and provided detailed high-resolution photographic imaging, comprehensive associated physical data, broader depth coverage, and sample collection of key benthic taxa.

ROV transects revealed strong zonation of benthic fauna associated with depth, geological features, and oxygen concentration. On the flanks of Socorro Island, deep regions were characterized by high abundances of colorful corals, crinoids, and big sponges. A spectacular "sponge garden" was observed in a narrow depth zone, where diverse sponges and corals occupied almost every bit of open space (Figure 4b). There were virtually no macrofauna higher up the slope in low-oxygen water, except for occasional sightings of squat lobsters, brittle stars, and fish. At the lowest oxygen level, a fuzzy mat completely covered all surfaces of the substrate (Figure 4a). The extensive white bacterial mat at the 1993 vent site was in this lowest oxygen environment. This may account for the lack of any larger typical vent and seep fauna, such as tubeworms or clams. Even though nutrition for these communities is derived from chemoautotrophic endosymbionts, the larger animals require oxygen to support their metabolism. Vertical zonation on San Benedicto Island was not as dramatic, possibly a reflection of the shorter time for settlement and growth since the creation of this peak in the 1952 eruption of Barcena Volcano. This effect may be compounded by the lack of hard substrate available, as widespread layers of ash were observed on these slopes.

A special low-light camera, designed to image bioluminescence in color and to allow stealthy, less intrusive observation of animals, obtained some dramatic footage. Bioluminescent responses of several planktonic animals were imaged, but none of the deep-sea corals in this region appeared to be bioluminescent. Dimmable lights were used to approach a vampire squid, which appeared initially relaxed with closed arms and then transitioned to a predator-avoidance posture with its arms and glossy webbing expanded (Figure 5).

The results of cruise NA092 have dramatically increased the characterization of the geology and the ecosystems of the deep-sea environment within this newly created World Heritage Site.

ROVs *Deep Discoverer* and *Seirios* on the deck of NOAA Ship *Okeanos Explorer* at sunset.



PART 2

NOAA's Office of Ocean Exploration and Research

Note: All images in the Okeanos Explorer *section of this publication are credited to NOAA OER unless otherwise indicated.*

CAPSTONE

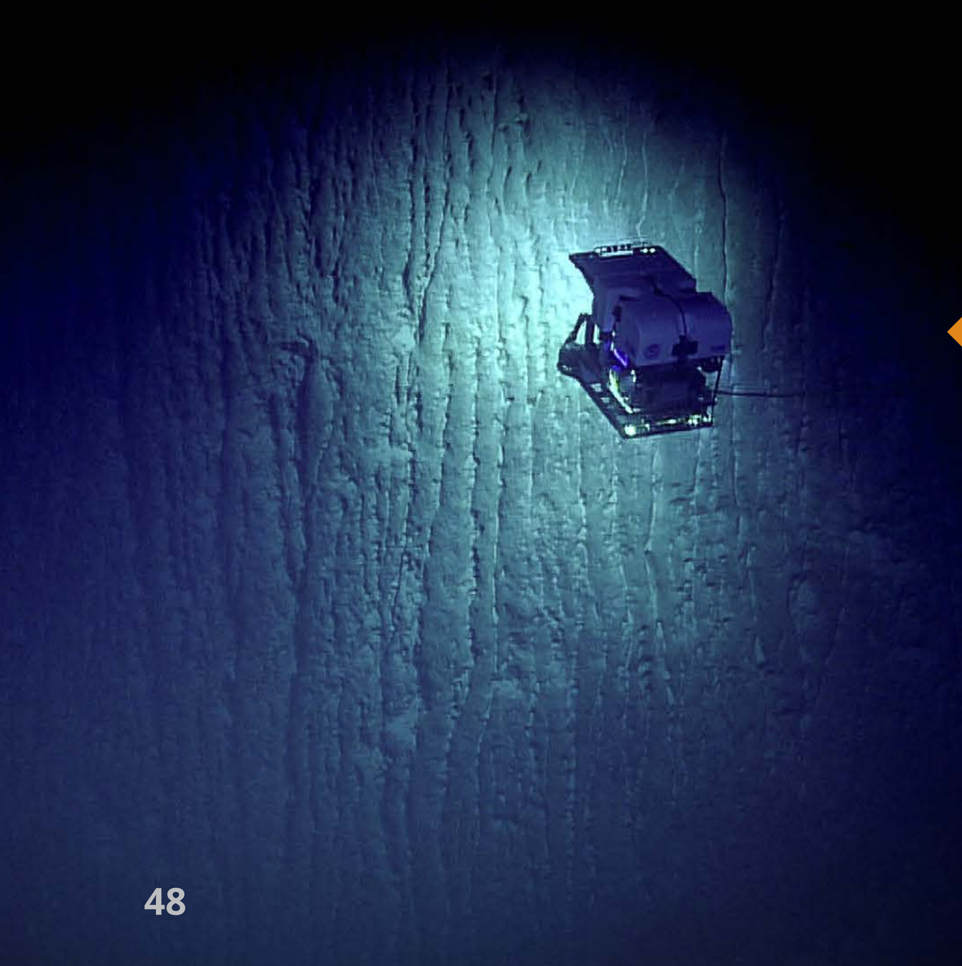
NOAA's Campaign to Address Pacific monument Science, Technology, and Ocean NEeds

By Alan Leonardi, John Armor, Pat Montanio, and Cisco Werner

Completed in 2017, CAPSTONE was a multiyear foundational science initiative to collect deepwater baseline information to support science and management decisions in and around US marine protected areas in the central and western Pacific. During the campaign, scientists identified and mapped marine habitats, investigated the geological history of and biological communities on Pacific seamounts, and discovered and characterized significant archaeological and cultural heritage resources. Extensive cross-NOAA and interagency support and collaboration, as well as international and academic partnerships, were crucial to setting priorities and conducting exploration activities.

Okeanos Explorer 2017 Expeditions

10	Cruises
8	Vessel CTD Casts
167	Submersible CTD Casts
453	XBT Casts
85	ROV Dives
52,026	Kilometers Distance Mapped
250,000+	Square Kilometers Area Mapped
Over 3.7 M	Views of Live Video Feeds



ROV *Deep Discoverer* observes a cliff that marks the edge of a coral platform in American Sāmoa. Fine sediments derived from the coral platform above accent the grooved channels down the steep slope face.

This shrimp in the family Aristeidae, possibly in the genus *Cerataspis*, was imaged on a potentially new species of yellow bamboo coral at approximately 1,700 m depth on the seamount informally named Kahalewai during the Mountains in the Deep: Exploring the Central Pacific Basin expedition, one of the five ROV expeditions completed in 2017 as part of CAPSTONE.

CAPSTONE's success depended on all parts of NOAA, including the National Environmental Satellite, Data, and Information Service; National Marine Fisheries Service; National Ocean Service; Office of Oceanic and Atmospheric Research; and Office of Marine and Aviation Operations. External key partners included the Global Foundation for Ocean Exploration, the US Geological Survey, US Fish and Wildlife Service, University of Hawai'i, Hawai'i state government agencies, insular government agencies in Guam, and the Commonwealth of the Northern Mariana Islands. The Secretariat of the Pacific Regional Environment Programme provided coordination with Pacific Island nations and continues to be a regional steward of CAPSTONE data and information products. Other organizations, such as the Schmidt Ocean Institute, are continuing to contribute critical baseline information about the deep ocean in CAPSTONE priority areas. CAPSTONE operations and activities summarized below are also covered in depth later in this publication.

CAPSTONE Summary

NOAA and its partners initiated CAPSTONE using NOAA Ship *Okeanos Explorer* in July 2015, and NOAA's Office of Ocean Exploration and Research (OER) coordinated campaign activities on behalf of NOAA. During this multiyear project, nearly 270 scientists, student researchers, and managers participated in CAPSTONE expeditions, most through the use of telepresence technology. Expeditions ran 24-hour operations that included ROV dives, mapping, and limited biological and geological sample collection. Operations in US waters were conducted in the deepwater areas of the Papahānaumokuākea Marine National Monument, Pacific Remote Islands Marine National Monument, Marianas Trench Marine National Monument, Rose Atoll Marine National Monument, and National Marine Sanctuary of American Sāmoa. Additionally, deepwater operations were conducted on the high seas.

In 2017, NOAA partnered with five Pacific Island jurisdictions in support of the Pacific Oceanscape Framework and Big Ocean, a network of the world's large-scale marine managed areas. Partners included American Sāmoa, the Republic of Kiribati's Phoenix Islands Protected Area, the Independent State of Sāmoa, New Zealand's Territory of Tokelau, and the Cook Islands. The data NOAA collected and provided to partners will help Pacific Island officials and managers govern their ocean resources wisely. New educational materials and special training programs for educators created in partnership with Pacific Island collaborators helped bolster local STEM (science, technology, engineering, and mathematics) programs and connect traditional cultures to their ocean heritage.

In addition to providing valuable information on the habitats and species in and around marine protected areas in the Pacific, CAPSTONE also contributed publicly accessible data and information that are needed to respond to emerging regional issues such as deep-sea mineral locations, sustainable deep-sea fisheries, and potential US Extended Continental Shelf designations.

CAPSTONE's deep ocean exploration of the US Pacific islands is unprecedented in its geographic scope and level of engagement among the scientific community, stakeholders, and the public. Through NOAA's telepresence technology, thousands of viewers experienced the wonder and beauty of previously unknown deep-sea coral and sponge communities. The new discoveries are already being used to inform our understanding and management of these unique ecosystems. NOAA's National Marine Fisheries Service and the Deep Sea Coral Research and Technology Program are proud to have been founding partners in this campaign.

– Pat Montanio, Director, NOAA Fisheries Office of Habitat Conservation

Biology

In 2017, nearly every ROV dive yielded a new discovery. During the Discovering the Deep expedition on a dive within the Tokelau Seamount Chain, scientists were surprised to witness a caridean shrimp capture and consume a midwater dragonfish, as deep-sea shrimp have typically been observed as scavengers, not hunters. In 2017, the *Okeanos Explorer* team conducted midwater transects and dedicated midwater dives to increase our knowledge about the water column—the largest, yet one of the least understood, biomes on Earth.

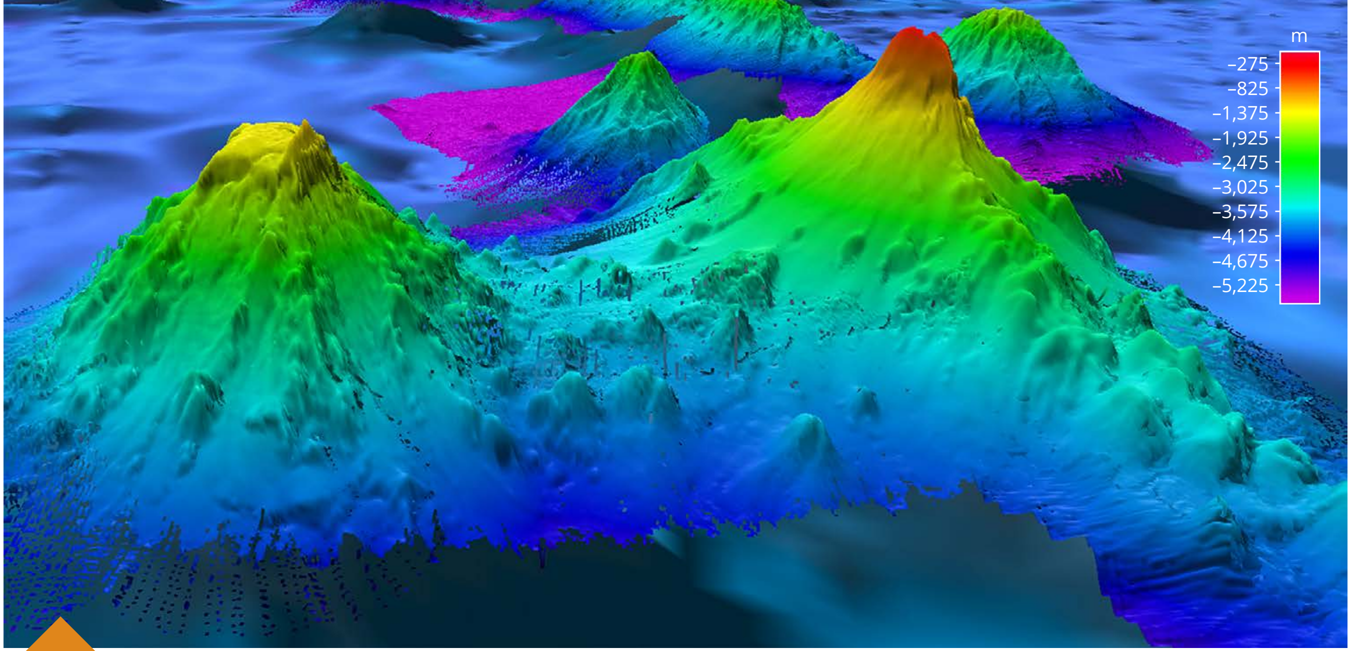
Since CAPSTONE's inception, hundreds of different types of animals have been identified and multiple high-density coral and sponge communities surveyed. Overall, 767 biological samples (including associates) were collected, and many could be undescribed species. Samples will undergo further analysis to increase understanding of biogeographic patterns across the central and western Pacific.

Geology

In 2017, scientists examined seamounts, volcanoes, manganese-encrusted seafloor, an active hydrothermal vent, atolls, a deep trough, ridges, plateaus, and other seafloor features of the Pacific. While exploring Vailuluʻu Seamount within the National Marine Sanctuary of American Sāmoa, an active volcano lying in the eastern region of the Samoan hotspot, the team discovered that the volcanic cone in the crater—called Nafanua—had grown extensively since 2012. Mapping data also revealed that many seamounts differ greatly in height from what satellite altimetry data suggests. Since CAPSTONE began in 2015, expedition teams have collected rock samples for use in geochemical composition analysis and age dating to increase understanding of how underwater geological features are formed. In total, 278 geological samples were collected during this campaign and sent to the Marine Geology Repository at Oregon State University for archiving.

CAPSTONE Science Themes

- Acquire data to support priority monument and sanctuary science and management needs
- Identify and map vulnerable marine habitats—particularly high-density, deep-sea coral and sponge communities
- Characterize seamounts in and around the Prime Crust Zone—the area of the Pacific with the highest concentration of commercially valuable deep-sea minerals
- Investigate the geologic history of Pacific seamounts, including potential relevance to plate tectonics and subduction zone biology and geology
- Increase understanding of deep-sea biogeographic patterns across the central and western Pacific



Mapping marine habitats was a CAPSTONE priority. Multibeam bathymetry of Pao Pao Seamount (right) and an unnamed guyot (left) shows one example of neighboring seamounts with very different geomorphology. Pao Pao Seamount comes to a very sharp peak at around 300 m depth and has steep flanks, while the unnamed feature has a distinct flat top. Biological communities found on these features may differ greatly at similar depth intervals, despite being only 25 km apart.

Mission Control aboard NOAA Ship *Okeanos Explorer*.

Maritime and Cultural Heritage

In 2017, archaeologists searched the waters near O'ahu for a Japanese submarine, *I-23*, and examined USS *Baltimore,* a late nineteenth century warship, discovered in 2016. After the *Baltimore* served with distinction in the Spanish American War followed by a long naval career, parts of the old warship were salvaged and the hull scuttled during World War II. This final dive of CAPSTONE ended a comprehensive look at a range of World War II-era sites across the Pacific that mark major events in US history.

Engagement: Social Media, Education, and Outreach

Engaging and communicating with the public was an important objective of the campaign. Online coverage of CAPSTONE expeditions allowed members of the public to join ROV dives and explore the ocean virtually, along with the scientists participating in expeditions. Throughout CAPSTONE, live video from the expeditions received approximately 8.4 million views through OER's YouTube channel and over eight million additional views through sharing via other channels such as Facebook Live. Expedition content posted on the NOAA Ocean Explorer website received over 2.1 million views. Expedition information and observations reached millions via social media. To date, CAPSTONE has provided opportunities for 25 mapping students through NOAA's Explorer-in-Training program, which helps to provide real-world expedition experience for the next generation of ocean explorers.

What's Next?

It will be some time before we understand the full impact of what CAPSTONE has achieved. In many ways, the campaign has only just begun. The University of Hawaiʻi and NOAA's Deep Sea Coral Research and Technology Program, a partner in CAPSTONE, will be analyzing data on the deep-sea coral communities to inform future resource management. Both the Schmidt Ocean Institute's R/V *Falkor* and the Ocean Exploration Trust's E/V *Nautilus* will continue to explore the Pacific region, adding to this foundation of knowledge. OER, OET, and SOI share data for efficiency and to leverage exploration successes. NOAA helped fund the science party aboard R/V *Falkor* on its return to the Phoenix Islands Protected Area, where the ship added to recently collected data from *Okeanos Explorer* operations. Soon, OET will begin to explore in this region, contributing to the collective knowledge of the deep waters of the Pacific. This work will continue to supplement the information needed for science-based management decisions. NOAA is proud to be part of a network of explorers and scientists unlocking the secrets of the deep ocean for the benefit of all.

Ocean Exploration Celebration

By Katie Wagner

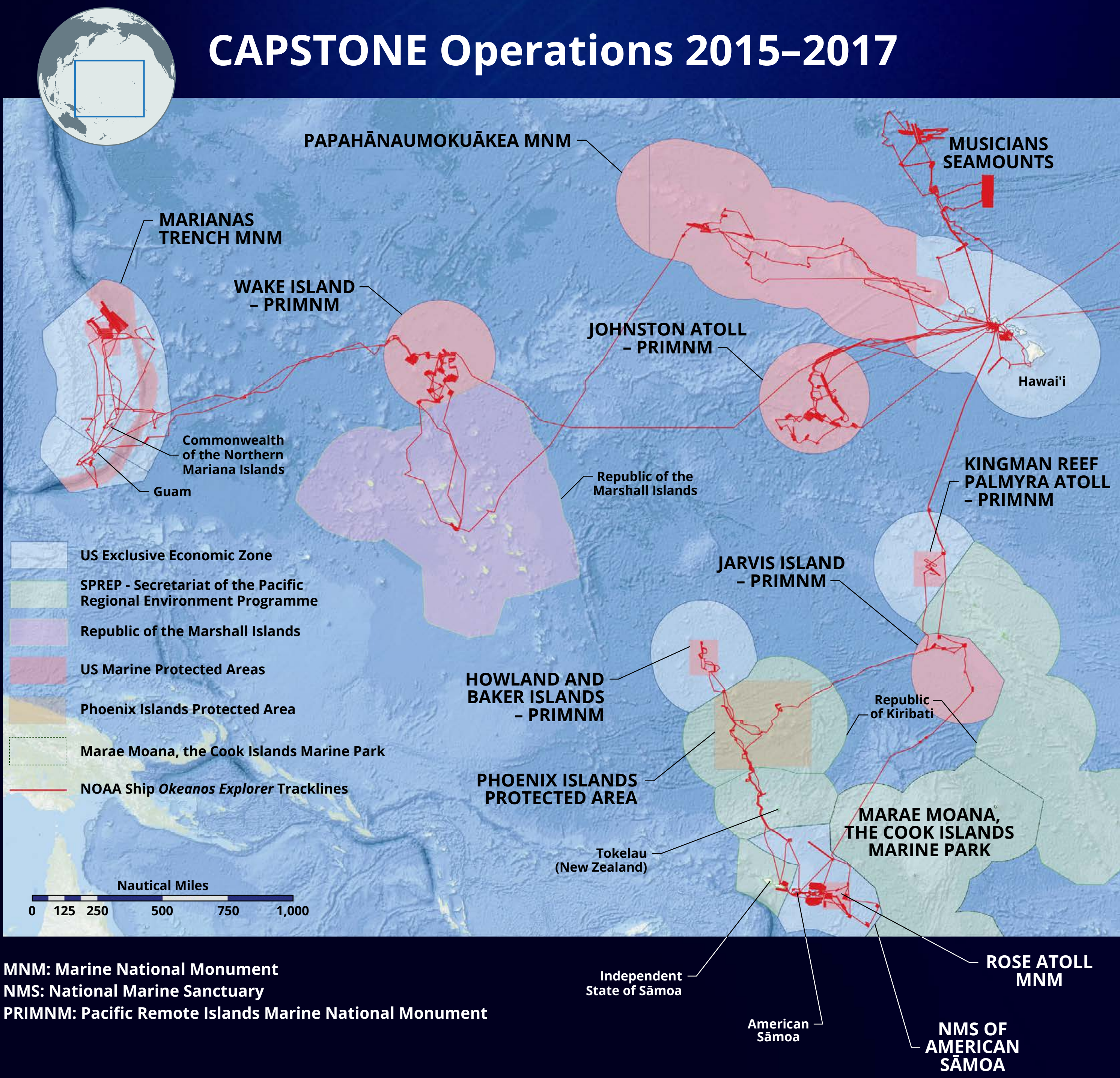
On Sunday, October 1, 2017, NOAA, the Schmidt Ocean Institute, and the University of Hawai'i (UH) cohosted the Ocean Exploration Celebration at the UH Marine Center – Pier 35, in Honolulu, Hawai'i. The daylong celebration consisted of a media event, VIP and public ship tours of both NOAA Ship *Okeanos Explorer* and R/V *Falkor*, and a dockside education pavilion.

The event began with opening remarks from Wendy Schmidt, Founder of Schmidt Ocean Institute; Craig McLean, Assistant Administrator for NOAA Research and Acting Chief Scientist; and Brian Taylor, Dean of the UH School of Ocean and Earth Science and Technology. A media crew from KITV Island News was on site for the remarks and to conduct dockside interviews with representatives from each host organization.

More than 600 people attended the event and toured the ships, including Senator Brian Schatz (D-HI) as well as his deputy chief of staff and congressional staffers for Senator Mazie Hirono and Representative Colleen Hanabusa. Members of the public disembarked from the ships with smiles and thank yous for sharing the ocean exploration activities and discoveries.

The dockside education pavilion included exhibits from NOAA, the Polynesian Voyaging Society, the Waikīkī Aquarium, the Hawai'i Institute of Marine Biology, and the University of Hawai'i. The public enjoyed the exhibits and had excellent questions about the various displays.

CAPSTONE Operations 2015–2017



MNM: Marine National Monument
NMS: National Marine Sanctuary
PRIMNM: Pacific Remote Islands Marine National Monument

Exploring Pacific Maritime Heritage

By Hans Van Tilburg, Frank Cantelas, James P. Delgado, and Amy Bowman

In 2017, NOAA's Office of Ocean Exploration and Research conducted several cultural heritage dives with NOAA Ship *Okeanos Explorer* to help fill in gaps in our knowledge and understanding of human history. Sometimes the target is known. Other times, there are surprises.

In 2016, NOAA explored the wrecks of two Japanese mini submarines that were involved in the December 7, 1941, attack on Hawaiʻi. USS *Ward* sank one of them prior to the aerial attack at Pearl Harbor, and it was last explored in 2014. The science team documented the condition of the wreck sites, recorded imagery, and live streamed video of the exploration. This first-time live viewing of these submarines received over 1.5 million views in just a few hours. Examination of the previously visited sub revealed deterioration of hull plating and propeller blades, separation of the forward section from the midsection, exposure of the interior of the submarine's bow, and significant biological growth on the submarine's surface (Figure 1). The dive provided additional information about the importance of structures and deep ocean reefs to biodiversity.

On September 28, 2017, ROV *Deep Discoverer* investigated a previously located sonar anomaly. The objective for this dive was to completely characterize the anomaly and—if it was a cultural heritage target—confirm its identity, record its condition, and document damage from its disposal or sinking. Five targets selected from multibeam sonar images were examined and determined to be rock formations. However, an unexpected target was identified: the remains of a World War II-period floating causeway, known as a "rhino barge" (Figure 2). These barges were part of the loading and transfer of supplies for many amphibious operations in the Pacific.

The following day, the ROV dove on USS *Baltimore*, a late nineteenth century cruiser that served both in the Spanish-American War of 1898 and in World War I, when its crew was responsible for laying mines in European waters to block German U-boats. Later decommissioned at Pearl Harbor, the ship was eventually scuttled at sea in 1944. The dive conducted a noninvasive video survey of *Baltimore*'s remains, collected imagery to be compiled for a three-dimensional model, assessed scuttling damage and the general state of preservation, and inventoried the organisms residing on the shipwreck (Figure 3).

Data collected from these dives will provide insights into the maritime heritage sites, contribute to a better understanding of American history, and supply information about the habitat that shipwrecks provide for marine animals.

Figure 1. The Japanese mini submarine sank when USS *Ward* fired a four-inch shell that smashed through the conning tower (hole at base), sinking the mini submarine and two-person crew before its deadly mission could be carried out.

Figure 2. At 785 m depth, ROV *Deep Discoverer* encountered a World War II-period "rhino barge," a floating pontoon section that allowed easy access to beaches for offloading of vehicles and supplies following initial amphibious assault landings in the Pacific.

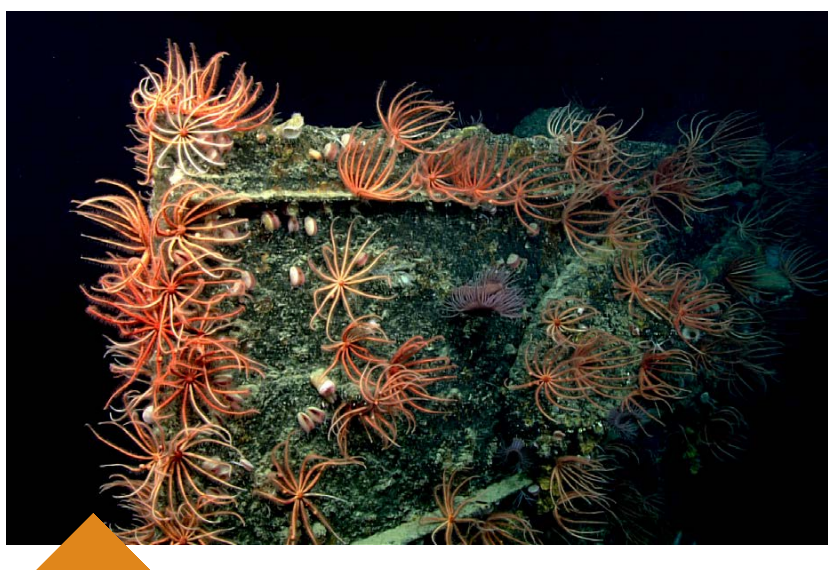


Figure 3. The knife-edge bow stem of USS *Baltimore* was covered in brisingids and other deepwater fauna.

NOAA Ship *Okeanos Explorer:* Exploring America's Deep Ocean

By Craig Russell

NOAA Ship *Okeanos Explorer* is the only US federal vessel dedicated to exploring our largely unknown ocean for the purpose of discovery and the advancement of knowledge. Exploration supports NOAA mission priorities and national objectives by providing high-quality scientific information about the deep ocean to anyone who needs it.

In close collaboration with government agencies, academic institutions, and other partners, NOAA's Office of Ocean Exploration and Research is responsible for coordinating the nation's federal ocean exploration program, working with the ocean exploration community to address national priorities. OER conducts deep ocean expeditions from *Okeanos Explorer* using advanced technologies. From mapping and characterizing previously unseen seafloor to collecting and disseminating information about ocean habitats and organisms, the data collected by *Okeanos Explorer* provide baseline information about the ocean and fill in data gaps. Federal open access standards apply to these data, which are made publicly available within 60 to 90 days after the end of a mission. This ensures the delivery of reliable scientific data needed to identify, understand, and manage key elements of the ocean environment.

Okeanos Explorer is equipped with four types of mapping sonars, a dual-bodied ROV that can dive to 6,000 m, and a rosette equipped with a conductivity-temperature-depth (CTD) sensor. The ship helped pioneer telepresence technology, which uses satellite communications to connect the ship to shore in real time. This technology permits the ship to operate with the majority of its participating scientists on shore, expanding the breadth of available expertise and increasing the pace and efficiency of exploration. It is also used to live-stream video from ROVs *Deep Discover* and *Seirios* over the Internet to millions of people around the world, allowing viewers to share in the excitement of observing unusual animals and rock formations in the ocean depths.

Under advisement from the Ocean Exploration Advisory Board, OER is advancing the multiyear, multiplatform campaign model for ocean exploration. *Okeanos Explorer* has just completed the successful three-year CAPSTONE (pages 48–53). The new Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE) has recently begun. Its purpose is to align existing deepwater efforts supporting the Galway Statement on Atlantic Ocean Cooperation to capitalize on near-term opportunities across the North Atlantic, while building interest in and momentum toward funding and organizing a major international field campaign targeting the Mid-Atlantic Ridge in 2019 and 2020 (pages 100–101).

NOAA Ship *Okeanos Explorer*

LENGTH | 68 meters (224 feet)

BEAM | 13 meters (43 feet)

DRAFT | 5.1 meters (16 feet, 10 inches)

DISPLACEMENT | 2,312 long tons

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

SPEED | 10 knots

ENDURANCE | 40 days at sea

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

DYNAMIC POSITIONING (DP-1) | 550 HP retractable azimuth bow thruster and two 250 HP stern thrusters

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

BERTHING | 49 persons (26 crew, 23 mission/science)

FLAG | United States of America

HOME PORT | North Kingstown, RI, USA

NOAA Ship *Okeanos Explorer* at port in Pago Pago, American Sāmoa.

2017 NOAA Ship *Okeanos Explorer* Mapping Highlights

By Elizabeth Lobecker, Derek Sowers, Michael White, and Mashkoor Malik

NOAA's Office of Ocean Exploration and Research and NOAA Ship *Okeanos Explorer* collected mapping data almost daily during all 2017 expeditions. Highlights of this work are discussed in several articles in this supplement to *Oceanography*. In total, over 250,000 km^2 of seafloor were mapped using the ship's multibeam sonar, and more than 46,000 linear kilometers of EK60 water column sonar and subbottom profiler 3.5 kHz chirp sonar data were collected. Acoustic Doppler current profiler (for estimating currents at various depths) and EK60 data were gathered during nearly all ROV dives, including those under the new operational mode that is entirely devoted to water column exploration (pages 61–63). Half of the eight 2017 expeditions were 24-hour per day mapping cruises.

All images were created using QPS Fledermaus, with vertical exaggeration set to 3. Depth scale bar units are meters.

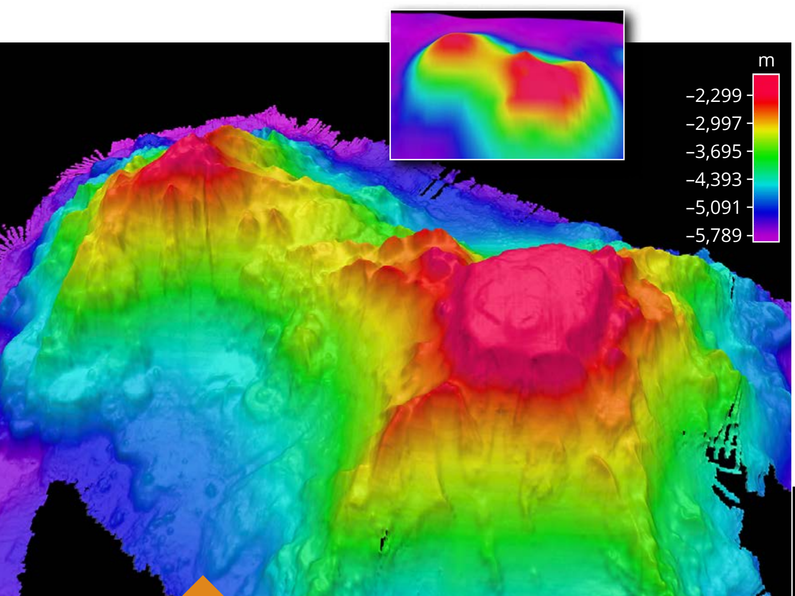
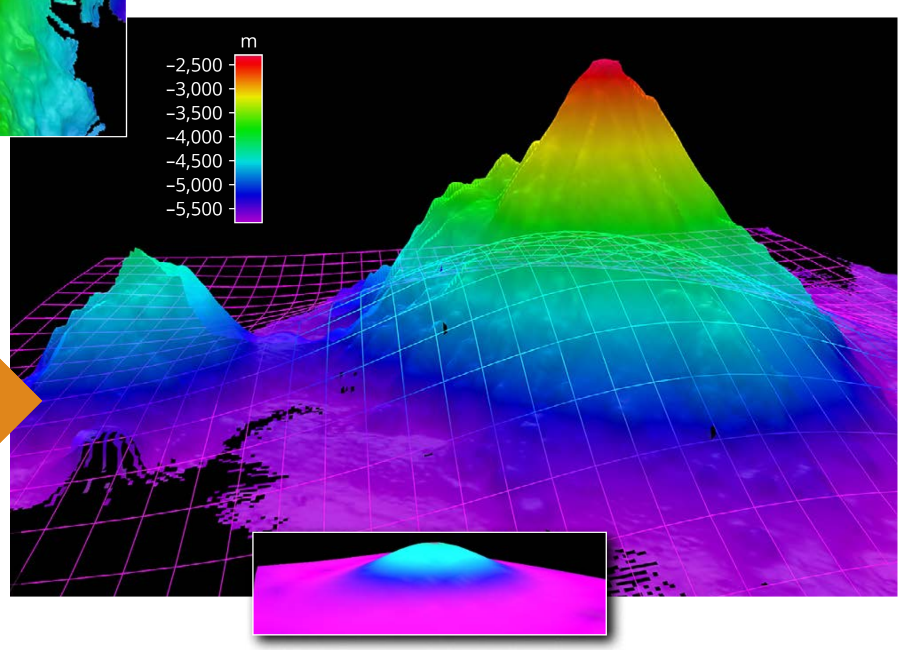


Figure 1. At Debussy Seamount, a difference of 300 m minimum depth means the difference between a conical peak (left) and a flat guyot top (right). Inset: Satellite-derived bathymetry.

Major Seabed Features

For the third consecutive year, *Okeanos Explorer* focused on exploring US marine national monuments and other marine protected areas established around remote small island chains, atolls, and reefs in the Pacific Ocean as part of CAPSTONE. Mapping operations supported CAPSTONE goals of identifying possible deep-sea coral and sponge community habitats in these areas. Therefore, much of our 2017 effort was spent on mapping seamounts. In all, over 220 seamounts and ridges were totally or partially mapped. Due to their remote nature and distance from well-traveled great circle routes, there was little to no modern sonar data for the majority of these features, many of which are not yet named in the IHO-IOC GEBCO Gazetteer of Undersea Feature Names (https://www.gebco.net). Steep slopes along these seamounts were frequently identified by scientific mission personnel as high-probability sites for coral and sponge habitat, and were consequently the focus of the majority of ROV dives. Ship-mounted multibeam images revealed many of the seamounts to be guyots (flat-topped seamounts; Figure 1)—a morphology that typically cannot be identified with the resolution currently available from satellite-derived bathymetry maps. The global distribution of flat-topped versus cone-shaped seamounts (Figure 2) is not yet well documented because most seamounts have not been mapped in detail, nor yet discovered in the cases of smaller seamounts. Based on satellite altimetry, it is estimated that there are over 100,000 seamounts greater than 1,000 m in height in the global ocean (Wessel et al., 2010).

Figure 2. Multibeam sonar mapping reveals what appeared in satellite-derived bathymetry to be a single 1,000 m high unnamed seamount in American Sāmoa to actually be two distinct seamounts over 3,000 m high. The inset image shows satellite bathymetry, while the larger image is multibeam sonar with satellite bathymetry underlain as wireframe.



Smart Transit—Always Exploring

As the ship steams between ROV and mapping operational areas, *Okeanos Explorer's* mapping department chooses precise transit lines that will add valuable data to unique features in rarely visited, remote areas, where even a single swath of data can result in new geological insights. During the 2017 expeditions, while transiting between the Line Islands and the Phoenix Islands Protected Area, a single swath of data was collected along a 1,300 km section of the Nova-Canton Trough and ridge (Figure 3), the western extension of the Clipperton Fracture Zone. Later, a single swath was collected in transit over 3,700 km of the Clarion-Clipperton Fracture Zone (CCFZ), including a continuous 740 km long section paralleling the Clarion Fracture Zone. The CCFZ is under the jurisdiction of the International Seabed Authority, which oversees permitting for deep-sea mining of polymetallic nodules.

During the 2017 *Okeanos Explorer* mapping expedition to the Musicians Seamounts north of the Hawaiian Islands, a 13,500 km^2 section of the Murray Fracture Zone was mapped in detail, revealing new information about this poorly understood seafloor feature. A discussion of the initial results of this survey appears on page 60.

Using smart transit lines, over 10,000 km^2 of Horizon Tablemount were surveyed during a total of four separate expeditions in the years 2009, 2015, 2016, and 2017 (Figure 4).

Telepresence Mapping

Telepresence technology uses modern computer networks and a high-bandwidth satellite connection to enable remote users to participate virtually in ocean research and exploration cruises. Through telepresence, remote users have provided support for operations planning and execution, troubleshooting for both hardware and software, and data interpretation during exploratory ocean mapping and ROV missions led by OER. Two of eight total cruises in 2017 were conducted as telepresence mapping expeditions, with the mapping team split between *Okeanos Explorer* and the Exploration Command Center (ECC) at the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center (UNH CCOM/JHC). The onboard team executed complex seamount survey plans designed in advance by OER mapping leads and had the power to determine in the field how best to obtain full bottom coverage based on actual sonar performance.

The application of telepresence technology to mapping expeditions to date has enabled (1) expanded shore-based data processing of multiple sonar data streams leading to enhanced, rapid, initial site characterization; (2) remote access control of shipboard sonar data acquisition, processing computers, and data storage; and (3) enhanced training opportunities.

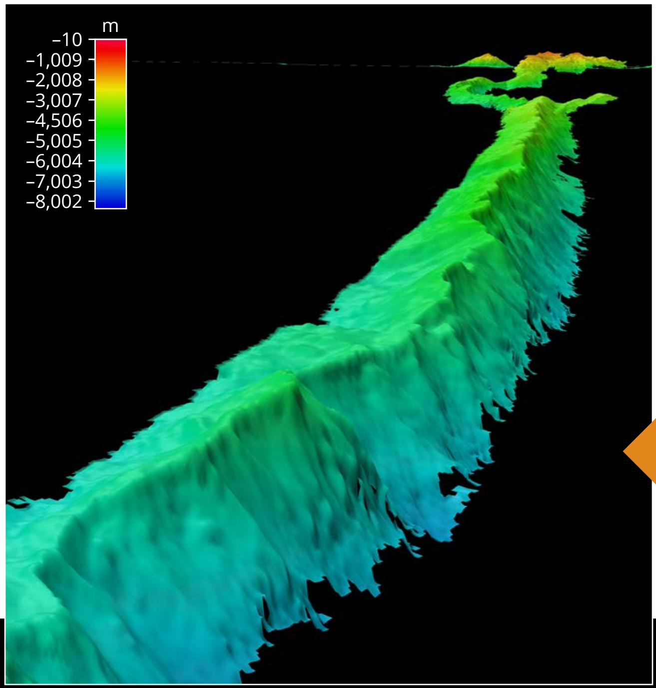
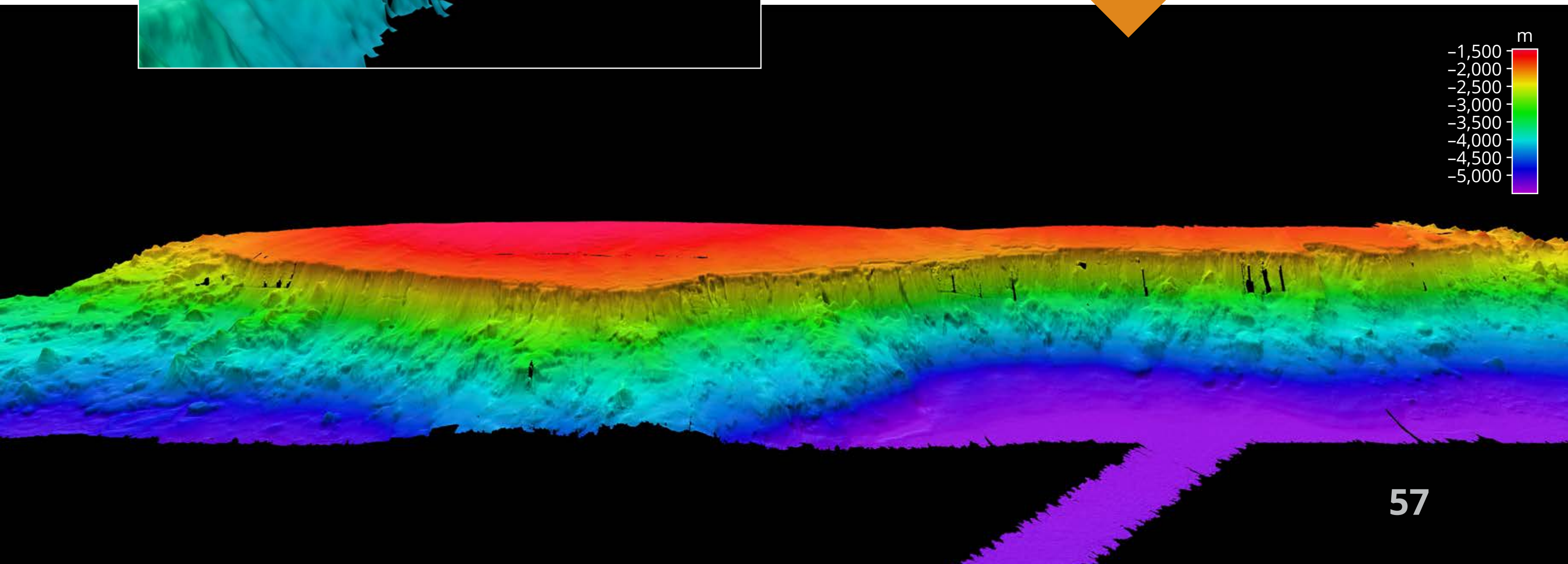
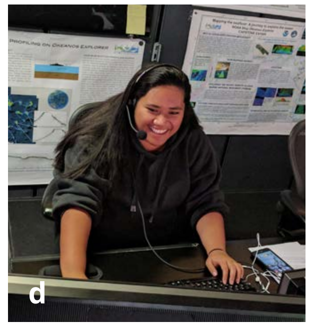


Figure 3. A steeply sloped ridge along the Nova-Canton Trough.

Figure 4. A 245 km long section of Horizon Tablemount mapped during strategic transits of four cruises.





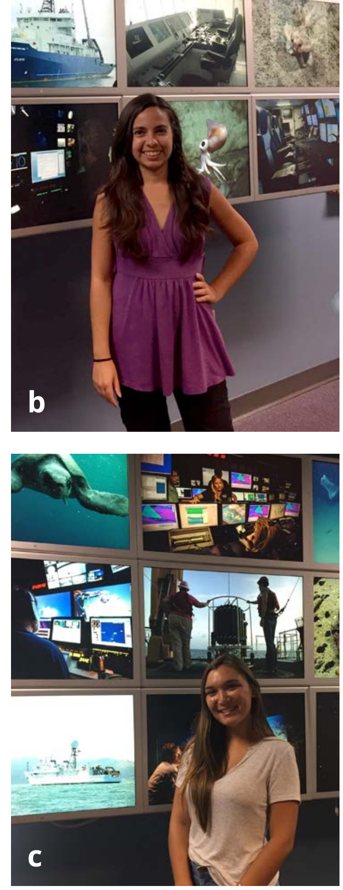


Figure 5. (a) Explorers-in-Training Laura Almodovar, Victoria Dickey, and Kelsey Lane standing mapping watch at UNH CCOM/JHC. (b) EiT Laura Almodovar. (c) EiT Victoria Dickey. (d) EiT Claudia Thompson. *Image credits: (a) CCOM. (b–d) Anna Hallingstad, NOAA OMAO*

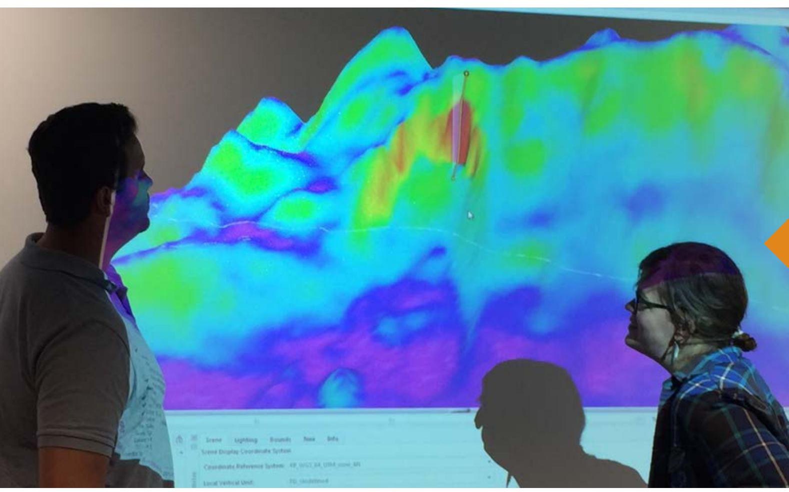


Figure 6. OER Physical Scientist Michael White and EiT Kelsey Lane discuss a potential ROV dive site on a steep slope (shown in red) of a seamount mapped during the Musicians Seamounts expedition.

Enhanced Explorer-in-Training (EiT) Program

In 10 years (2008–2017) of *Okeanos Explorer* operations, 145 seafloor mapping training opportunities have been provided to 108 early career scientists and Explorer-in-Training (EiT) students, with many returning for second and third cruise experiences to further develop their skills. The mapping team hosted seven EiTs during 2017. A two-part experience was implemented: EiTs first participated in a 24-hour mapping cruise while onshore at the UNH CCOM/JHC, standing independent sonar data processing watches and observing sonar operations through live feeds streaming sonar data acquisition screens (Figure 5); later, they participated at sea on a round-the-clock mapping cruise, aboard either *Okeanos Explorer* or Ocean Exploration Trust's E/V *Nautilus*.

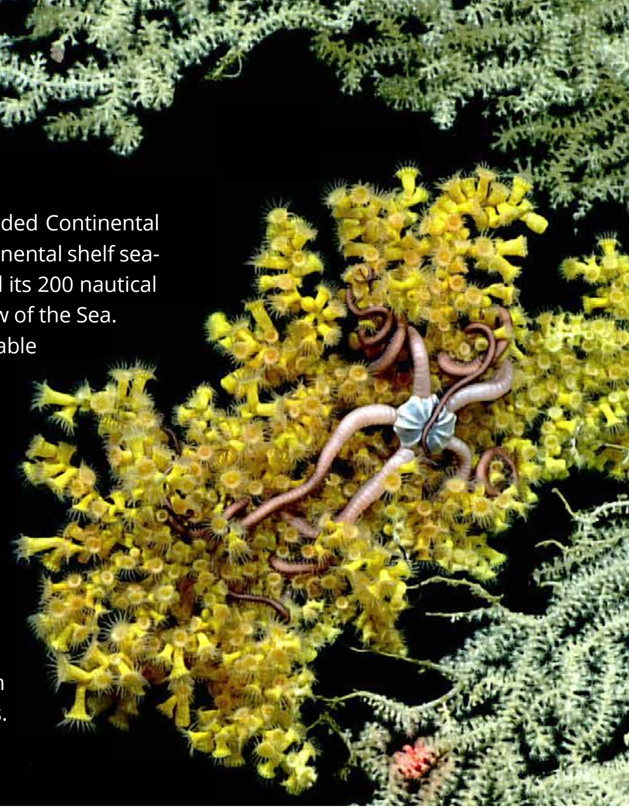
EiTs found the onshore experience educationally rich as they learned how to perform first-order sonar data processing, such as multibeam ping editing, and how to create advanced data products, such as multilayer three-dimensional scenes showing bathymetry, seabed slope, and seabed backscatter used by OER for ROV dive planning (Figure 6). They also learned the basic principles of collecting water column backscatter data, along with several methods for detecting such features as gaseous seeps or aggregations of water column biology in the data.

Onshore EiTs were directly exposed to the UNH CCOM/JHC community for one month. They toured the new UNH research vessel *Gulf Surveyor*; participated in a guest lecture on an introduction to at-sea surveying methods, decision-making requirements, situational awareness, and equipment troubleshooting by UNH CCOM/JHC academics; and were given software training on water column backscatter data processing by industry experts.

The EiT program provides a pragmatic pathway for supporting advancement of the next generation of marine science academics and explorers. Many EiTs have converted their new mapping skills into careers as hydrographers for NOAA or private survey companies, marine spatial planners, marine archaeologists, and marine resource managers. Other EiTs have used their new skills to pursue or enhance their graduate school research in marine science, geography, and ocean engineering. The competitive EiT program provides participating students with support for travel and a daily stipend.

US Extended Continental Shelf Project: Taking the Longer View

By Margot Bohan



NOAA's Office of Ocean Exploration and Research is a critical partner on the US Extended Continental Shelf (ECS) Project, a multi-agency effort focused on identifying the extent of the US continental shelf seabed and subseafloor over which the United States can exercise sovereign rights beyond its 200 nautical mile exclusive economic zone, consistent with the United Nations Convention on the Law of the Sea.

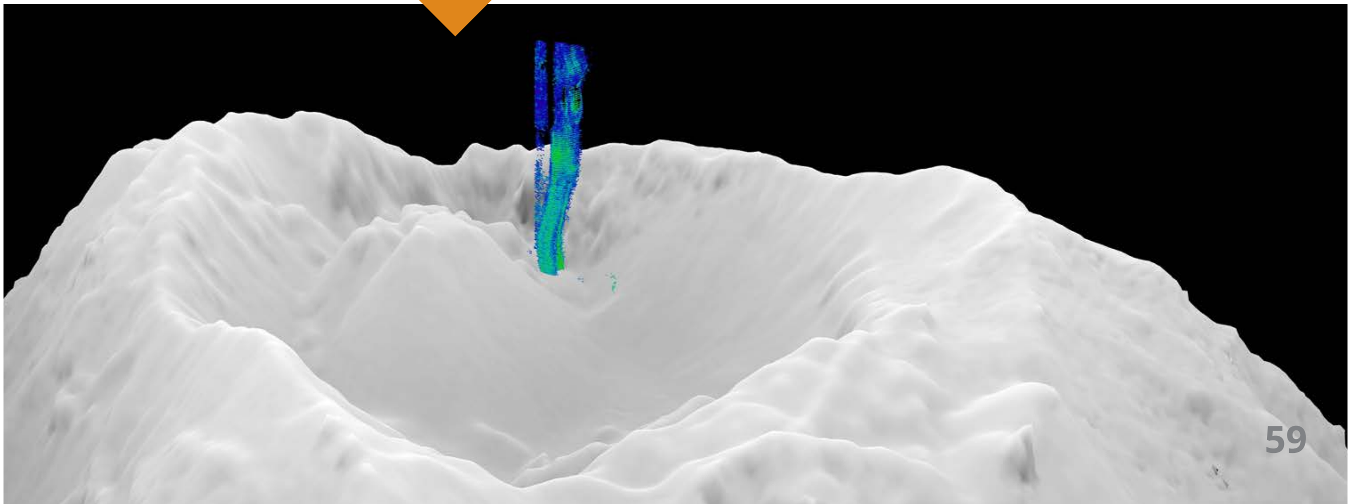
The US continental shelf is considered a significant maritime zone and includes valuable petroleum, mineral, and "sedentary living marine resources." Determining the actual shelf limits requires the collection and analysis of data that describe the depth, shape, and geophysical characteristics of the seabed and subseafloor. While the demand to harvest deep ocean resources is still relatively low, a window of opportunity exists to have these ECS data serve as a foundation for collecting additional physical, biological, and chemical measurements that, in turn, will improve our insights about the extent and value of the marine resources in these frontier ocean regions.

It is time to stimulate new partnerships, target these mapped areas in new ways, employ innovative technologies, model processes where feasible, and leverage existing data to conduct more detailed deep-sea (ocean floor and water column) investigations. In turn, these undertakings will bring clarity to key marine science questions and inform emerging stewardship obligations in these poorly known, yet likely resource-rich realms.

Vailulu'u Scanning

A strong gaseous plume observed at Vailulu'u Seamount, an active submarine volcano in American Sāmoa (see pages 72–73), offered an excellent opportunity to test the three-dimensional scanning mode capability of *Okeanos Explorer's* EM 302 multibeam sonar. As the ship held station for several minutes over the plume, continuous multibeam water column data were collected at different tilt angles to obtain an extremely dense, temporally continuous data set over this unique feature. The gaseous plume was observed to be emitting from the volcanic crater at 905 m depth, and was detected in the water column as high up as approximately 628 m above the seafloor, or approximately 278 m below the sea surface (Figure 7).

Figure 7. A dense point cloud of multibeam water column sonar data collected over the gaseous plume in the crater of Vailulu'u Seamount in American Sāmoa. Data processed in QPS FM Midwater.



Open Data Access

During every cruise, the *Okeanos Explorer* Atlas is updated daily with new gridded bathymetry data (available at https://service.ncddc.noaa.gov/website/EXAtlas/viewer.htm). These grids, as well as raw sonar data, can be downloaded from an FTP site managed by the Global Foundation for Ocean Exploration. Pursuant to the OER strategic goal of rapid public access to all data, all mapping data collected by *Okeanos Explorer* continue to be available in raw and processed formats approximately 60 to 90 days after the end of each cruise. This quick public data dissemination enables easy access for other explorers, researchers, resource managers, and citizens to leverage maximum scientific value from *Okeanos Explorer* data. With telepresence mapping, more advanced data products are produced by trainees for review by mapping leads before they are archived. All data are paired with metadata and are available from NOAA's National Centers for Environmental Information at https://www.ncei.noaa.gov.

The Murray Fracture Zone By Thomas Morrow

The Murray Fracture Zone is the remnant of a right-stepping transform fault (TF) along the now extinct Pacific-Farallon spreading center. Magnetic surveys indicate the TF was ~700 km long 83 million years ago (Granot et al., 2009), and lithosphere on the southern side of the fracture zone (FZ) in the field area is ~5 million years younger than that on the northern side. The mapped region of the Murray FZ (Figure 1) contains a complex array of structures similar to those formed at parallel FZs and intra-transform spreading centers (ITSCs), consequences of changing plate motions during the late Cretaceous (Atwater et al., 1993). ITSCs are short (<50 km) spreading segments bounded on either side by a TF. Within the region mapped by NOAA Ship *Okeanos Explorer* in 2017 there are two ITSC-generated sections of lithosphere bounded by three FZs (Figure 1). These new maps permit identification of characteristics of the Murray FZ that differ from those of other FZs.

Observations at the Murray FZ suggest that fractures in the lithosphere were weak enough to accommodate tectonic motions that overprinted expected age-depth relationships. Older, cooler lithosphere lies deeper than younger, warmer lithosphere and thus is bent downward where it contacts younger material. Likewise, because younger lithosphere is warmer and cools and subsides faster than older lithosphere, the young side of a FZ typically has a characteristic upward bend approaching the FZ. These age-depth relationships are not always apparent at Murray FZ and, in some cases, they are reversed (Figure 1). FZ 2 is characterized by a bathymetric low, and the older (northern) side of FZ 2 is anomalously shallower than the adjacent, younger lithosphere to the south. To reverse the predicted young-side high and old-side low, the intervening FZs must have been weak and able to slip vertically for some time after formation. The bathymetric low in the field area punctuated by small (<4 km) ridges may be interpreted as a region of weak material (Fox and Gallo, 1984; Tucholke and Schouten, 1988; Pockalny, 1997), and the additional complexity introduced by the closely spaced fractures at Murray may have promoted weakness in the FZ, though these effects are poorly understood.

Further to the west, near the Musicians Seamounts, there is also evidence for plume-FZ interaction (see pages 82–83). Previous work (e.g., Small, 1995; Sleep, 2002) suggests that the age discontinuity across a FZ may influence the flow of plume material along the base of the lithosphere, resulting in volcanic activity concentrated at the FZ. Sitting astride one of the main FZ traces, Liszt Seamount (Figure 2) has a small ridge that extends eastward along the FZ, evidence of melts exploiting the FZ to ascend and erupt on the seafloor. Although not conclusive, these features suggest that the Murray FZ was close enough to the Musicians hotspot to influence the distribution of volcanism during the seamounts' emplacement.

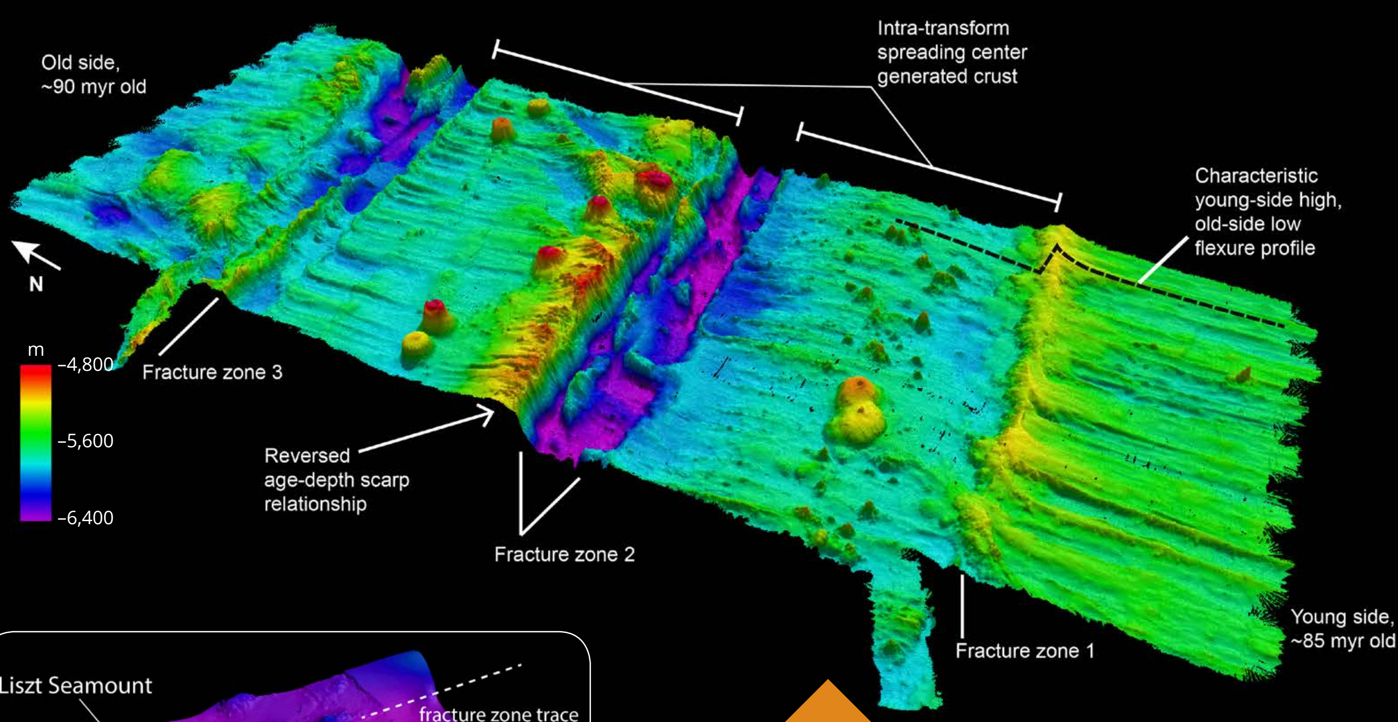


Figure 1. Swath bathymetry over the Murray Fracture Zone. FZ 1 displays a characteristic age-depth relationship with a young-side high. The broad bathymetric low at FZ 2 may indicate a large zone of weakness adjacent to an anomalously high old-side scarp. FZ 3 age-depth relationships are ambiguous.

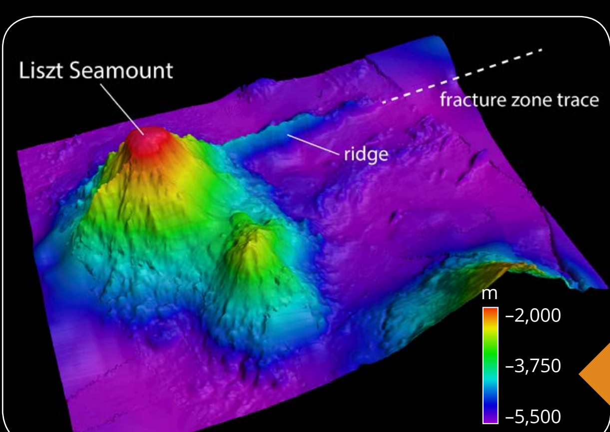


Figure 2. Liszt Seamount sits astride one of the fractures in the Murray Fracture Zone. A small ridge is observed extending along the trace of the FZ, suggesting a relationship between the location of the FZ and where melts are able to penetrate the lithosphere and erupt on the seafloor.

2017 Midwater Exploration on *Okeanos Explorer*

By Amanda N. Netburn, Michael Ford, and Dhugal Lindsay

Background

The water column—from the ocean's surface to just above the seafloor—comprises 95% of the available habitat for multicellular life-forms. Though essential to many critical ecosystem processes such as trophic energy transfer, carbon sequestration, nutrient cycles, and sedimentation (Robinson et al., 2010), the water column remains vastly underexplored throughout the globe (Robison, 2009). The biodiversity of the deep midwater environment throughout the CAPSTONE region is poorly documented (Sutton et al., 2017), and many new and undescribed species likely reside there. Gelatinous organisms, in particular, are poorly sampled by trawl nets, and their biogeography is not well known.

In response to community input and a new NOAA Office of Ocean Exploration and Research effort to expand capabilities and support for water column exploration (Netburn and Cantwell, 2017), there was a drastic increase in time and effort allocated for midwater operations in 2017, culminating in a total of 15 ROV dives over four expeditions during which midwater work was conducted: 2017 American Sāmoa Expedition: Suesuega o le Moana o Amerika Sāmoa; Mountains in the Deep: Exploring the Central Pacific Basin; 2017 Laulima O Ka Moana: Exploring Deep Monument Waters Around Johnston Atoll; and Deep-Sea Symphony: Exploring the Musicians Seamounts (Figure 1). The work consisted of 13 benthic dives augmented with several hours of midwater transects, and two full days of midwater dives—a first for ROV *Deep Discoverer*—that occurred on the Musicians Seamounts expedition. Surveyed depths ranged from 250 m to 1,500 m, generally focusing on acoustically detected deep scattering layers from 300 m to 800 m.

A team of nearly 20 midwater scientists participated in these expeditions, providing expertise in gelatinous animals, fishes, micronekton, cephalopods, engineering, acoustics, and optics. Data from the ROV's CTD and acoustic backscatter from the shipboard EK60 echosounder became routine elements of dive planning, execution, and post-dive analysis. The breadth of midwater exploration conducted throughout the final year of CAPSTONE led to a remarkable number of discoveries.

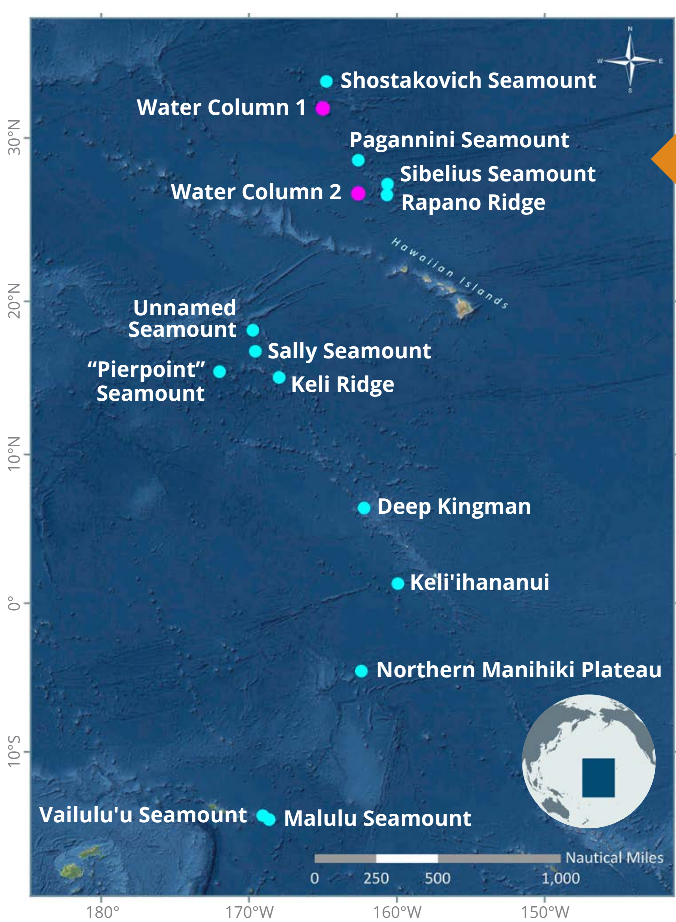


Figure 1. Map showing the locations of all midwater ROV dives conducted throughout the 2017 CAPSTONE expeditions. Cyan points represent seafloor sites with extended time for midwater transects. The two fuchsia points indicate where the two full-day midwater surveys occurred.

Undescribed Taxa

Many undescribed species of ctenophores ("comb jellies") and hydrozoan jellyfish were observed throughout 2017. Some examples include several different lobate ctenophores, such as one with bright glands that are likely bioluminescent, a cydippid ctenophore that is probably in a new family, and several "pseudo-cryptic" species of *Solmissus* sp. ("dinner plate jellies," Figure 2). Narcomedusae in the genus *Bathykorus*

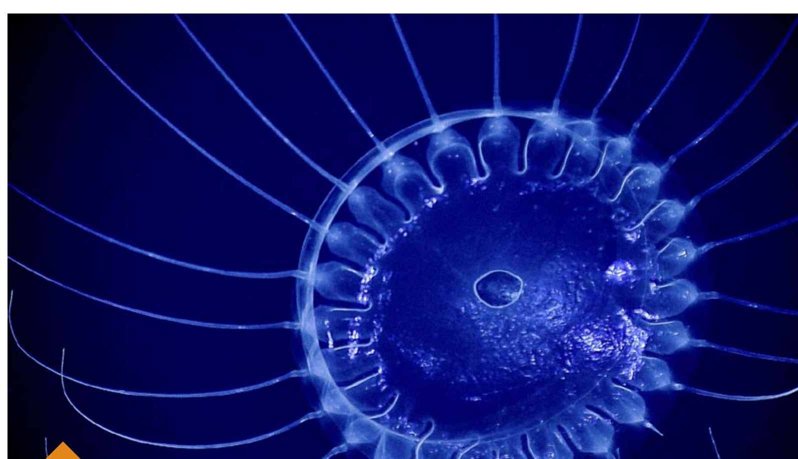


Figure 2. *Solmissus incisa* sensu lato jellyfish. Multiple cryptic species within this genus were encountered throughout 2017, many of which remain undescribed.

Figure 3. *Crossota alba*, dubbed the "cosmic" jellyfish, imaged near the seafloor.

were seen on several midwater dives during CAPSTONE. Using tentacles held above their bells, they are avid predators of gelatinous animals in the midwater. Though they are typically transparent, a pigmented *Bathykorus* was observed at Keliʻihanuanui and appears to be an undescribed species. This new central Pacific observation represents a significant expansion in the known range of this genus.

Range Expansions of Rare Taxa

Throughout 2017, numerous species were observed far beyond their known ranges. The first sighting of the doliolid *Doliolula equus* (Robison et al., 2005a) outside of Monterey Bay, California, occurred at 400 m depth at Pierpoint Seamount. Another doliolid, *Pseudusa bostigrinus* (Robison et al., 2005b), was similarly observed for the first time outside of Monterey at Malalu Seamount. The trachymedusa *Crossota alba* (Figure 3), never before observed in the Southern Hemisphere (Larson and Harbison, 1990), was seen just above the seafloor at the south Manihiki Plateau site at a depth of 3,020 m. The recently redescribed narcomedusa *Aegina rosea* (Lindsay et al., 2017) was seen just above the seafloor at the Howland Island shallow site. This represents only the third unequivocal record for the species and the first away from its type locality off the east coast of Japan.

Observations of Animals Never Before Seen Alive

At Sibelius Seamount, a fish in the family Howellidae was observed with a very unusual color pattern that has never been seen before—a pigmented body with bright white coloration at the tips of the caudal (tail) fin and the tip of the snout. While this individual could not be positively identified to species level, no fish experts recognized this coloration, indicating this fish either loses its unique patterning when collected in trawl nets or this is an entirely new species.

Unexpected Abundance of Unusual Organisms

Throughout the 2017 expeditions, high abundances were encountered of several animals that were thought to be rare or that have been generally poorly observed. As examples, pelagic holothurians (*Pelagothuria* sp., or sea cucumbers) were seen in the hundreds at some sites in the Southern Hemisphere on the Mountains in the Deep expedition, and high densities of protists, such as radiolarians and phaeodarians, were encountered at many locations throughout the 2017 operational area (Figure 4).

Behaviors and Species Associations

These expeditions offered unusual opportunities to observe natural behaviors and interactions of midwater organisms. Lancetfish (*Alepisaurus ferox*, Figure 5) are commonly collected in fisheries surveys (Portner et al., 2017), but they are rarely observed alive. Though they are thought to be active predators, the individual observed at Sally Seamount was motionless and oriented vertically, behavior more typical of a "lay and wait" predator. Cranchiid squid were seen throughout the Musicians Seamounts expedition assuming different postures and inking (Figure 6). Some novel species interactions included *Pelagothuria* sp. (Figure 7a), a salp (pelagic tunicate, Figure 7b), and the jellyfish *Halicreas minimum* (Figure 7c) hosting amphipods, and a crustacean larva that appeared to be clinging to a phaeodarian protist (Figure 7d). Many such associations could not possibly be observed by collecting animals with a trawl net because the organisms would separate.

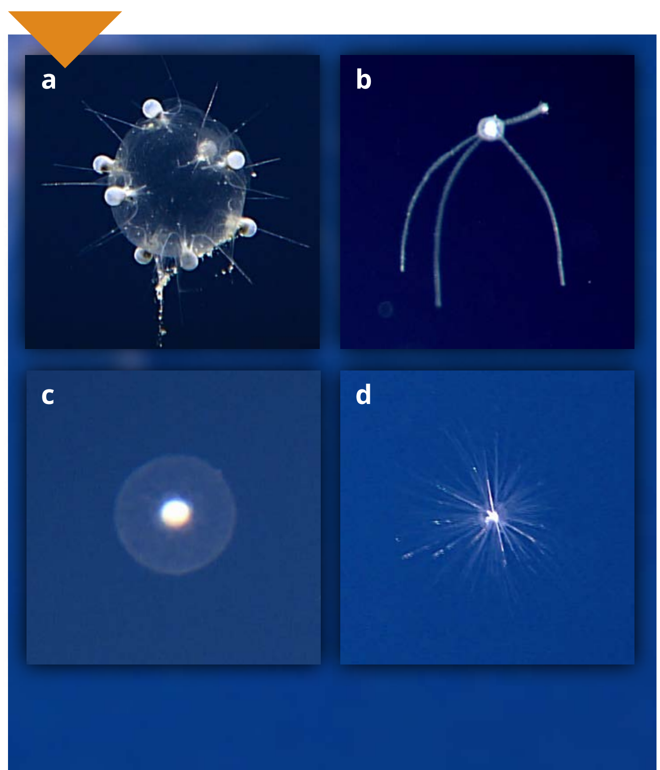


Figure 4. A high abundance and diversity of large protists were seen throughout 2017. Some examples include (a) a tuscarorid phaeodarian, (b) coelodendrid phaeodarian, (c) collodarian radiolarian, and (d) a pelagic foraminiferan.

Bentho-Pelagic Interactions

Throughout 2017, several novel interactions were observed near the seafloor. A caridean shrimp, *Heterocarpus* sp., was observed attacking and then feeding on a midwater dragonfish (possibly a stareater, *Astronesthes* sp.) at around 1,000 m depth at Ufiata Seamount in the Tokelau Seamount Chain during the Discovering the Deep: Exploring Remote Pacific Marine Protected Areas expedition. Near Jarvis Island, a highly active squid was surprisingly captured and eaten by two ophiuroids ("brittle stars"), which are not known to be active predators. One of the highlights of the 2017 expeditions was NOAA Ship *Okeanos Explorer*'s first targeted collection of a jellyfish, which was located associated with a deep-sea coral. By observing the specimen under the microscope, it was found that this organism likely belongs to a new genus.

Looking Ahead

The 2017 expeditions marked a period of rapid advancement for water column exploration with *Okeanos Explorer*, using ROV *Deep Discoverer*, and incorporating various ancillary water column data sources. This progress represents a significant step in implementing the recommendations of the March 2017 workshop From Surface to Seafloor: Exploration of the Water Column. In addition to the many discoveries facilitated by the increased time spent conducting midwater ROV exploration, some accomplishments include: (1) expansion of the team of participating midwater experts; (2) development of methods to streamline collection, analysis, and reporting of ancillary water column data, such as water column acoustics (EK60) and CTD data; and (3) successful operations with a shore-based science team communicating in real time with the shipboard ROV team to direct ROV requests. As *Okeanos Explorer* moves into the Gulf of Mexico and Atlantic Ocean basins, the midwater team will continue to grow expertise, refine methods, and work toward characterizing the full volume of the ocean.

Figure 5. Lancetfish, *Alepisaurus ferox*, seen vertically oriented in the water column.

Figure 6. Transparent cranchiid squid were seen throughout the Musicians Seamounts in various postures—sometimes oriented vertically, sometimes horizontally with tentacles raised, and occasionally inking.

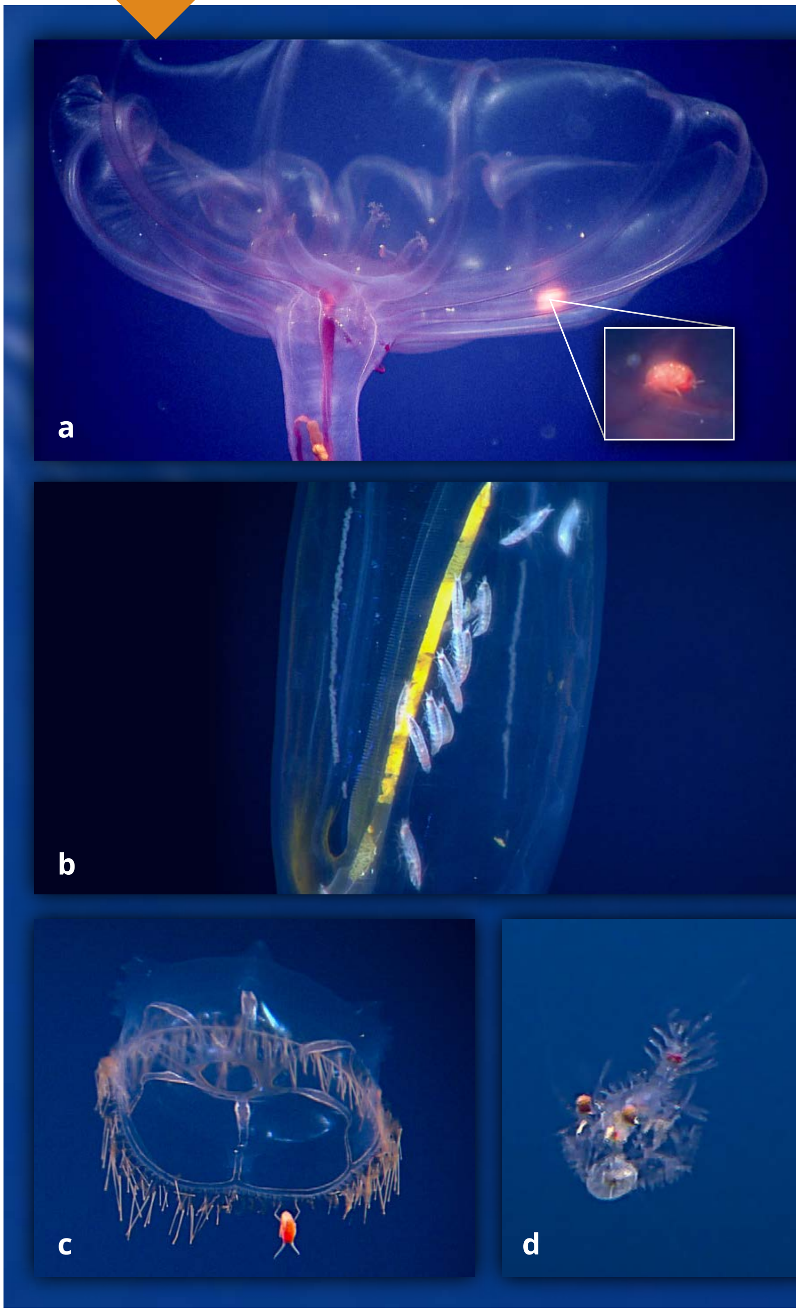


Figure 7. Several novel species associations were observed in 2017. Different species of amphipods were seen on hosts: (a) *Pelagothuria* sp. (pelagic sea cucumber), (b) salp, (c) and *Halicreas minimum*. (d) A crustacean larva was imaged grasping a phaeodarian.

Working with Video to Improve Deep-Sea Habitat Characterization

By Peter J. Etnoyer, Mashkoor Malik, Derek Sowers, Caitlin Ruby, Rachel Bassett, Jennifer Dijkstra, Nikolai Pawlenko, Susan Gottfried, Kristen Mello, Mark Finkbeiner, and Angela Sallis

Introduction

Videos collected from ROVs empower people to explore the ocean from any location. Beyond the immediate value of revealing the mysteries of the deep ocean, video footage provides a rich data source that contributes to our fundamental understanding of the physical, biological, and chemical properties of explored ocean areas. NOAA's Office of Exploration and Research and its partners are improving video data management to extract the highest scientific value from these hard-to-obtain surveys of the deep. In addition to making video data publicly available through the OER Video Portal (https://www.nodc.noaa.gov/oer/video), OER and its partner organizations are adding substantial scientific value to video data through development of species identification guides, improved scientific annotations, application of a standard classification scheme, citizen scientist engagement, and improved marine habitat assessment and characterization (Figure 1).

Identifying Deepwater Species

One of the most exciting things about an ROV dive is the potential to capture a rare or even previously unknown marine animal on video. During CAPSTONE, OER science advisor Christopher Kelley worked closely with the OER Data Management Team, led by NOAA's National Centers for Environmental Information, to develop a way to share images and information about the deepwater animals encountered by NOAA's ROV *Deep Discoverer*. This collaboration led to the development of the Benthic Deepwater Animal Identification Guide, an online collection of in situ images of deepwater animals taken from video frame grabs that have been identified by a team of taxonomic experts. The guide, organized according to taxonomic groupings and displaying multiple images of the different genera and species, is available at http://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html.

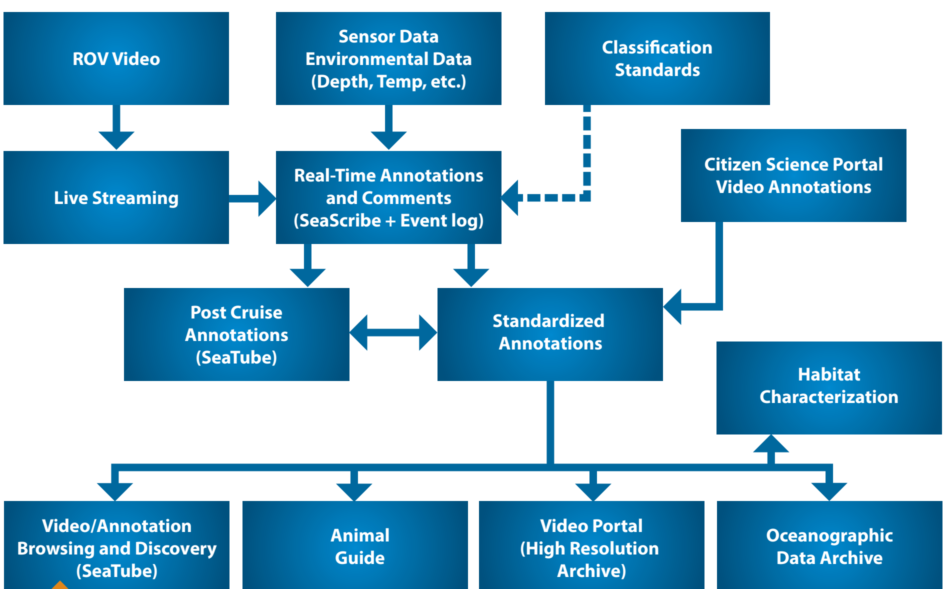


Figure 1. Conceptual diagram of connections between video data collection, annotation, and management.

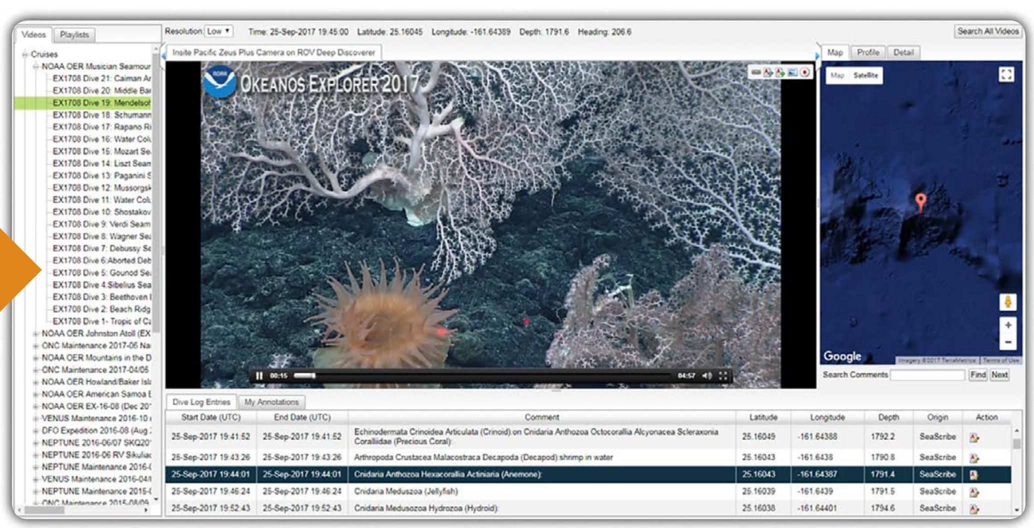


Figure 2. Example screen from the annotation software SeaTube showing the user interface that enables video playback, position, and time-stamped observations. *Image credit: NOAA OER and ONC*

Improving Video Annotation

When scientists want to focus on certain organisms or features within a video such as deep-sea corals, they need tools to efficiently locate relevant video segments. Searching through video requires textual descriptions known as video annotations. Since 2010, OER has been inviting experts to participate remotely in the ROV dives to provide these video annotations. In 2017, OER partnered with Ocean Networks Canada to implement annotation software tools that provide an end-to-end annotation workflow for the scientists to create, review, and validate video observations. SeaScribe is an online annotation tool that both shore-based and shipboard participants can access concurrently during an ROV dive. SeaTube is a cloud-based video archive and browsing interface that enables playback of previously recorded videos and entry of new annotations (Figure 2). These tools reduce post-cruise annotation time and improve the utility of OER video for enhanced insight into explored areas. Annotations are thus providing a rich data set that can be "mined" by many different scientists for different purposes.

Applying Standard Classification to Video

Scientifically relevant annotations enhance the value of video data. NOAA scientists have been researching the application of the Coastal and Marine Ecological Classification Standard (CMECS; Box 1) for classification of deep-sea environments through video annotations. Annotating video with CMECS vocabulary improves the data's compatibility with other coastal and marine data sets and has the potential to unify the current, varied methods used among the deep-sea exploration community for habitat and substrate classification. Three different, but complementary, research efforts explored the application of CMECS to OER video data from the Pacific Ocean, the Gulf of Mexico, and the US Atlantic continental margin.

1. Pacific Ocean. NOAA's Deep Coral Ecology Laboratory processed 32 ROV dives and more than 6,400 ROV video still images to classify dive transects using a simple CMECS annotation scheme in order to understand the application of CMECS to deep-sea coral research (Bassett et al., 2017). To test this scheme, the study classified substrate, geoform, and water column CMECS components from three deep-sea benthic surveys in the Pacific Ocean in 2015, including telepresence-enabled cruises with NOAA Ship *Okeanos Explorer* in Hawai'i and E/V *Nautilus* off southern California. The primary outcome of the study was the discovery that CMECS geoform and water column components can be captured by field-based exploration teams with little modification to standard procedures. The ROV routinely collects parameters such as depth, temperature, salinity, and oxygen that can be employed to characterize water column attributes using standard CMECS classes.

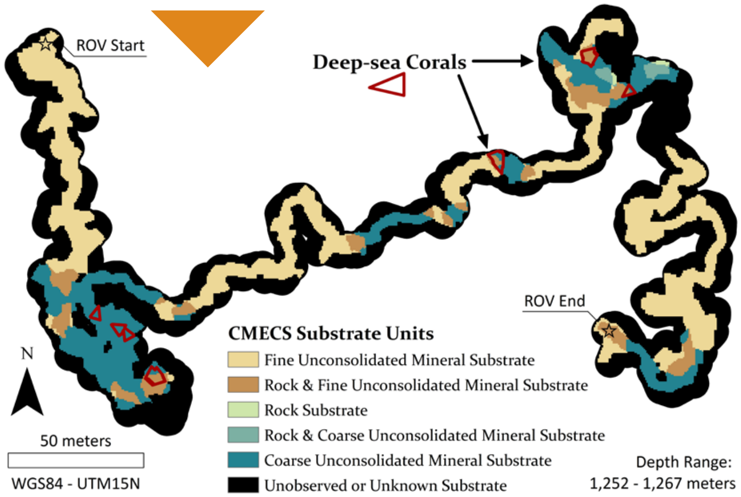
BOX 1. THE COASTAL AND MARINE ECOLOGICAL CLASSIFICATION STANDARD (CMECS)

Compilation of disparate data collected by various government, academic, and collaborative institutions contributes significantly to knowledge of the world ocean. But how can such diverse data be organized into something that can be easily discovered, analyzed, compared, and used to support additional research, management, or exploration efforts? One strategy for effective data management is to implement a standardized method for classifying observed environmental features. For this reason, in 2012, the Federal Geographic Data Committee endorsed the Coastal and Marine Ecological Classification Standard (CMECS), which created a comprehensive framework of common terminology for classifying biological species, water column properties, and seafloor morphology and composition. CMECS provides a common language to describe estuarine, lacustrine, coastal, and offshore environments, enabling scientists and managers to integrate and use data from a variety of sources.

Many federal and state governments, nongovernmental organizations, and partnerships around the United States and internationally have adopted CMECS. In particular, CMECS is the required benthic classification for Renewable Energy and Marine Minerals programs at the Bureau of Ocean Energy Management. CMECS incorporates the use of provisional units, which allow researchers to add proposed new units to the standard as they are discovered. This flexibility is especially valuable in the deep ocean environment, where knowledge is increasing rapidly and new discoveries abound. Eventually, a peer review process will examine these units to inform future versions of the classification. For more information on CMECS go to: https://iocm.noaa.gov/cmecs.

The CMECS structure allows scientists to classify environments to varying levels of detail, which is especially useful in deep-sea environments where data coverage is low and access is limited. *Image credit: Federal Geographic Data Committee*

Figure 3. CMECS-compliant map layers allow scientists to spatially analyze ROV video content. Individual viewsheds (colored triangles) show the substrate type. Red polygons show deep-sea corals. The presence of deep-sea corals coincides with rocky and coarse unconsolidated mineral substrate for this particular dive. *Image credit: Caitlin Ruby, NOAA*



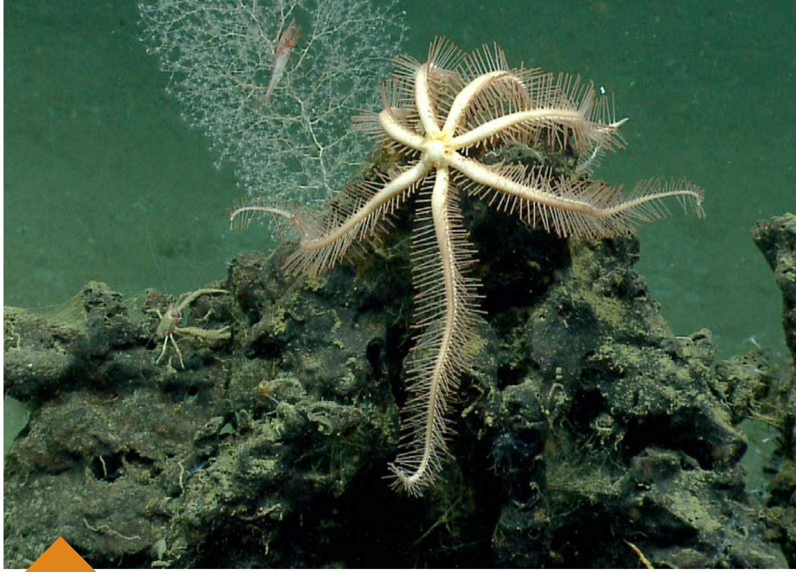
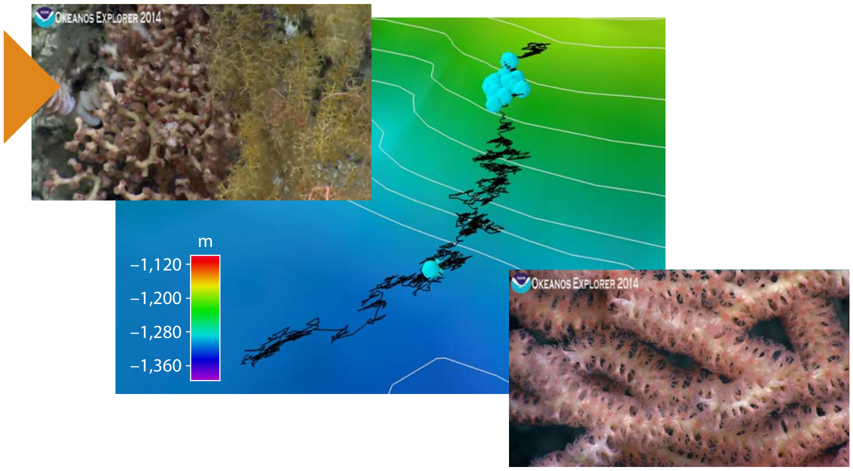


Figure 4. This photo exemplifies a deep-sea coral community near 1,260 m depth with a brittle star (center), two octocorals, a shrimp, and crab. The source video for this image, which was taken by ROV *Deep Discoverer* in the northern Gulf of Mexico during 2014, was used to produce Figure 3.

Figure 5. Researchers mapped the distribution of corals (blue spheres) along ROV tracks (black lines) in McMaster Canyon, which incises the continental slope off of Delaware. Some of the coral species observed included a cup coral (top left image), as well as many bamboo corals (bottom right image). *Image credit: Kristen Mello and Jennifer Dijkstra, UNH CCOM/JHC*



2. Gulf of Mexico. The OER Data Management Team collaborated with the Northern Gulf Institute and Mississippi State University to develop techniques for mapping deep-sea environments using video collected by ROV *Deep Discoverer* during OER's 2014 Exploration of the Gulf of Mexico expedition (Ruby, 2017). Videos from 10 ROV dives were examined and annotated using biological, geological, and substrate descriptors found within CMECS. Researchers then combined CMECS annotations with ROV coordinates and the surrounding water column information in order to map the recorded environments (Figure 3). Considering that the viewable distance within a video is limited to the ROV's light source and camera angle, maps were constrained to areas viewed by *Deep Discoverer*'s main, forward-facing camera. The research team determined that map layers are an efficient toolset for spatially viewing ROV video content and quickly assessing complex environmental relationships that stimulate scientific inquiry. For example, Figure 4 shows deep-sea corals associated with rock and coarse substrates.

3. Atlantic Ocean. In collaboration with OER, researchers at the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center examined community structure among ROV dive sites, and classified the substrate encountered during the dives using CMECS. The researchers analyzed full underwater video footage collected by ROV *Deep Discoverer* during three cruise legs of the 2013 and 2014 *Okeanos Explorer* expeditions along the Atlantic continental margin. During these cruises, the ROV sampled seamounts, seeps, and canyons spanning a depth range of 580 m to 1,875 m. UNH CCOM/JHC researchers mapped the distribution, abundance, and assemblage of taxa along ROV tracks (Figure 5). Results of this study are being used to help ground truth high-resolution multibeam sonar bathymetry and backscatter data collected by NOAA and UNH CCOM/JHC in order to inform improved CMECS classification of large areas off the US east coast between the shelf break and 5,000 m depth.

Harnessing Citizen Scientists for Video Exploration

Citizen science is the collection and analysis of data by the general public. Citizen science engages the public in research collaborations and is particularly effective when labor-intensive tasks can be completed by volunteers. Video analysis involves time-consuming review and annotation, and thus is often a major bottleneck in extracting useful scientific information from raw video footage. Using a new portal being developed as part of Ocean Video Lab (http://www.oceanvideolab.org), citizen scientists will gain access to thousands of hours of video from ROVs and other platforms (Figure 6). By creating "bookmarks," these volunteers will identify observations of interest that will then be routed to an expert for more detailed annotations. For example, instead of watching a full dive, a coral specialist can focus on video footage where corals have been bookmarked. With the help of citizen scientists around the globe, Ocean Video Lab hopes to make major contributions to ocean exploration by filling in knowledge gaps within valuable legacy video. The Schmidt Ocean Institute provides funding for Ocean Video Lab, and a NOAA Big Earth Data Initiative grant funded integration of the OER citizen science video interface into the Ocean Video Lab portal.

Habitat Suitability Modeling for Deep-Sea Corals and Sponges

Accompanying advances in video data management, exciting new analyses are enabling researchers to more thoroughly characterize explored areas and predict unexplored areas. The high-resolution images collected by ROV *Deep Discoverer* provide important data such as species identity, number, and size. NOAA's Deep Coral Ecology Laboratory is using these images to assess the abundance and health of deep-sea corals, and then making these images publicly available through NOAA's growing National Database of Deep Sea Corals and Sponges (Hourigan et al., 2015). The public can access the database through a web portal at https://deepseacoraldata.noaa.gov. The portal debuted in 2015, and has since grown to house more than 575,000 observations of corals or sponges around the world. By pooling these records, the database provides the resources to answer questions such as: Has this species been observed in this region or at this depth before? How common or rare is that type of sponge? (Figure 7)

Among the most powerful applications of deep-sea coral data are habitat suitability models that predict where a species is likely to be observed, and where it is not. NOAA scientists construct the models by combining image observations from *Okeanos Explorer* with environmental data and records from museums and other research expeditions, and then overlaying this information with additional environmental data (depth, temperature, bottom type) in a geographic information system. The models provide exploration teams with new targets to examine that will in turn help verify these models.

When growth rates are known, as in the case of some fish and corals, the size of an organism can then be correlated to age. Noninvasive, image-based sampling techniques that employ scaled lasers may one day replace destructive sampling of long-lived organisms (Etnoyer et al., 2017). Age class structure is important information for coastal managers who seek to conserve and protect deep-sea corals that can be hundreds or thousands of years old. The use of video data to assess and predict marine habitats enables well-informed ocean management decisions, providing a tangible return on investments made in ocean exploration.

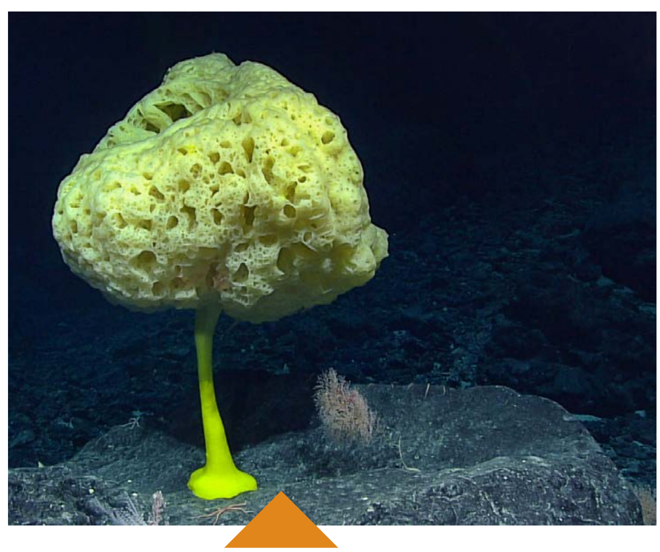


Figure 7. ROV *Deep Discoverer* observed this vibrant yellow glass sponge (*Bolosoma* sp.) at 2,479 m depth on Sibelius Seamount.

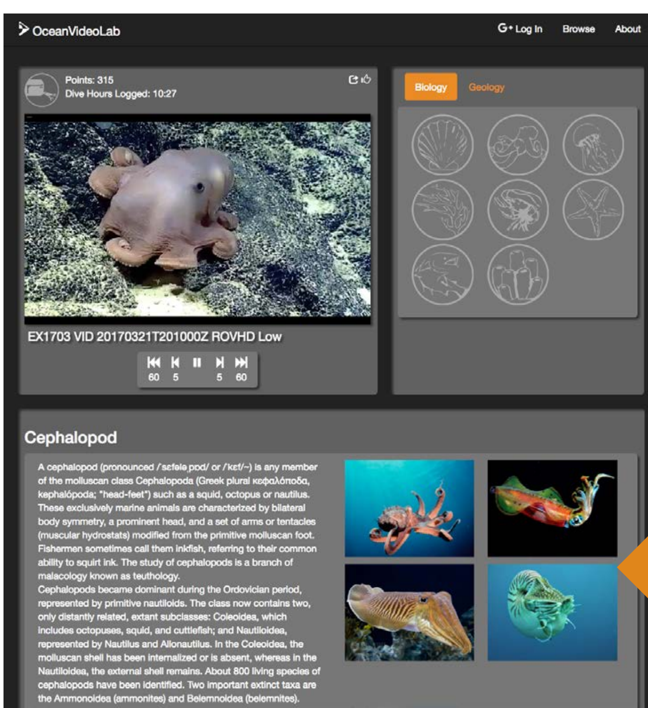


Figure 6. Ocean Video Lab's citizen science interface is being developed in partnership with NOAA's Office of Exploration and Research, Lamont-Doherty Earth Observatory, and the Inner Space Center located at the University of Rhode Island. *Image credit: Vicki Ferrini, LDEO*

Engagement

Exploring Global Opportunities in 2017

By David McKinnie, Emily Crum, Susan Haynes, Katie Wagner, and Debi Blaney

NOAA's Office of Ocean Exploration and Research endeavors to creatively engage stakeholders and the public in ocean exploration and to deliver information about deep ocean exploration to the scientific community, decision-makers, educators, students, and the general public. These efforts enhance ocean literacy, inspire the next generation of ocean explorers, and help educate key stakeholders about the value of and need for ocean mapping, sampling, and observing to inform science-based decision-making.

In 2017, the engagement program's online communications, educational opportunities, and outreach and media interactions made meaningful impacts on communities and classrooms spanning the ocean, continents, and cultures. Taking advantage of port calls, the program shared some of the exciting results of ocean exploration with educators and the public in remote areas. OER presentations made an effort to connect residents' traditional ocean knowledge and practices with the tools and results of modern ocean exploration.

Online Communications

In 2017, 18 deep ocean expeditions extending from the Pacific and South Atlantic to the Great Lakes were featured on the OER website (http://oceanexplorer.noaa.gov). Overall, the site received more than 12.7 million visits. Images, videos, and onboard participants' logs helped members of the general public follow along as scientists uncovered the mysteries of the deep.

Live video from NOAA Ship *Okeanos Explorer* continued to be a favorite for armchair explorers around the world, as they tuned in to watch scientists direct ROV *Deep Discoverer* in the Pacific (Figure 1). The live video streams received more than 3.7 million views through the OER YouTube channel and millions of additional views as others streamed *Okeanos Explorer* live video to outlets such as Facebook.

Social media remained a key tool for engaging members of the general public in deep ocean exploration activities, with OER reaching millions through these platforms. In addition to daily posts about missions that reached growing numbers on Facebook, Twitter, and Instagram, OER used social media tools to conduct active dialogues with interested audiences. A Reddit Ask Me Anything (AMA) session held during the Mountains in the Deep: Exploring the Central Pacific Basin expedition was the most popular Reddit AMA ever hosted by NOAA as it reached millions of Reddit users (Figure 2). During the same expedition, OER also hosted its first-ever Facebook Live event, inviting Facebook users to ask questions of the expedition science leads. OER went on to host multiple similar live interactions on Facebook, reaching more than 235,000 people and adding a new tool to the repertoire used to reach the public. Again in 2017, OER joined exploration partners Schmidt Ocean Institute and Ocean Exploration Trust to celebrate World Oceans Day in June with a Google+ Hangout On Air to share upcoming exploration plans with a worldwide audience.

Figure 1. A group of children visiting the Charleston Marine Life Center in Oregon watch the live-streaming video as NOAA Ship *Okeanos Explorer* surveys Malulu Seamount near American Sāmoa. *Image credit: Trish Mace, CMLC*

Figure 2. The Science Team aboard NOAA Ship *Okeanos Explorer.* From the left, DelWayne Bohnenstiehl, Kasey Cantwell, Scott France, and Mike White prepare for the Reddit "Ask Me Anything" session.

Education

PROFESSIONAL DEVELOPMENT

Since 2003, OER has maintained a large group of education Alliance Partnerships comprised of aquariums, informal science centers, and museums across the country, offering daylong ocean science and exploration professional development opportunities to educators at these venues. In 2017, through the 15 current Alliance Partners, OER held 34 Exploring the Deep Ocean with NOAA workshops across the country and introduced 770 educators to the NOAA Ship *Okeanos Explorer* Education Materials Collection: *Why Do We Explore?* and *How Do We Explore?* Workshops were also offered at non-Alliance Partner sites in central Texas, Utah, and New Mexico to reach educators in inland locations where ocean science educational opportunities are scarce. All eight lessons associated with the Exploring the Deep Ocean with NOAA workshop were translated into Spanish and provided online to broaden access to these materials.

In Hawaiʻi, two professional development workshops held in partnership with the Hawaiʻi Institute of Marine Biology and the Waikīkī Aquarium offered teachers opportunities to participate in discussions about the science behind *Okeanos Explorer* expeditions. In addition, a Family Night that was also held at the aquarium, an Alliance Partner, was attended by 143 educators. One of the professional development workshops was held on Oʻahu and the other on the Island of Hawaiʻi at the Mokupāpapa Discovery Center for Hawaiʻi's Remote Coral Reefs, an outreach center for the Papahānaumokuākea Marine National Monument. These workshops and events brought ocean science education resources and recent discoveries from CAPSTONE to educators throughout the Hawaiian Islands (pages 48–53).

In American Sāmoa, a professional development workshop was held with the National Marine Sanctuary of American Sāmoa at the Tauese P.F. Sunia Ocean Center in Pago Pago (Figure 3). OER provided new lessons based on recent exploration results and other teaching resources tailored to American Samoan educators to convey new findings in the context of Pacific Islanders' rich traditional relationship with the ocean. Through workshop activities, participants learned about discoveries made during the 2017 American Sāmoa Expedition: Suesuega o le Moana o Amerika Sāmoa, and discussed the importance of communicating Samoans' unique relationship with the sea based on the living tradition of Faʻa Sāmoa (The Samoan Way). Opportunities such as these expose educators in remote locations to NOAA's mission and the value of ocean exploration, increase their understanding of the deepwater ecosystems of their region, and help them share authentic, current ocean science with their students, creating a bridge between island culture, sacred traditions, and modern ocean exploration.

WEBINARS AND NEWSLETTER

Pre-expedition webinars were offered throughout the year, providing an opportunity for educators to learn about the science behind the expeditions, as well as the associated educational materials available for classroom use. OER executed five pre-expedition webinars this year, which were joined by over 170 participants and registrants from the United States, American Sāmoa, Australia, Canada, the Cook Islands, Ecuador, India, Germany, Peru, Portugal, Puerto Rico, and the United Arab Emirates. OER also reached educators through an education-focused monthly newsletter initiated in January 2016. It is designed to provide quick access to ocean exploration-focused, standards-based tips and tools to bring the excitement and science of ocean exploration into the classroom. The newsletter currently reaches a listserv of over 5,700 educators.

2017 Engagement Activities by the Numbers

WEB

Website Visits: ~12,740,000

Live Video Views: ~3,700,000

Expeditions Covered:
- 9 *Okeanos Explorer* cruises
- 9 non-*Okeanos Explorer* cruises

Expedition Content Added:
- ~200 content essays
- ~1,030 images
- ~105 videos

SOCIAL MEDIA

- Facebook Likes: ~123,000 25% ↑
- Instagram Likes: ~9,600 1,352% ↑
- Twitter Followers: ~186,000 136% ↑
- YouTube Subscribers: ~65,000 87% ↑

EDUCATION

Educator Professional Development Workshops: 34

Educators Trained: 770

Estimated Number of Students Reached: ~90,000

Listserv/Newsletter Subscribers: 5,700+

PUBLIC OUTREACH

Ship Tour Attendees: ~1,400

In-Person Event Attendees: ~1,800

Live Interaction Attendees: ~810

Media Mentions: 300+

Figure 3. Educators participate in a communications lesson during a 2017 professional development workshop at the Tauese P.F. Sunia Ocean Center in American Sāmoa. *Image credit: Emily Narrow, Global Foundation for Ocean Exploration*

Figure 4. Live telepresence interactions were conducted with dozens of groups and institutions throughout the year. Nearly 200 students attended this session at the Tauese P.F. Sunia Ocean Center in American Sāmoa. *Image credit: Iosefa Siatu'u, NOAA ONMS NMSAS*

Figure 5. A public tour group visits the control room aboard NOAA Ship *Okeanos Explorer* during the October 2017 Ocean Exploration Celebration held at the University of Hawai'i Marine Center in Honolulu. *Image credit: Art Howard, Global Foundation for Ocean Exploration*

Outreach and Media

In 2017, OER engaged nearly 4,000 people through in-person and telepresence-enabled events associated with *Okeanos Explorer* expeditions (Figure 4). Nearly 1,400 people toured the ship during port calls in American Sāmoa, the Independent State of Sāmoa, and Hawai'i (Figures 5). Live telepresence interactions were conducted with dozens of groups and institutions, including the Smithsonian Institution's National Museum of Natural History, the Exploratorium, Marian Koshland Science Museum of the US National Academy of Sciences, the Big Ocean network, National Transportation Safety Board, US Navy and Coast Guard, and Office of Samoan Affairs. Among notable in-person events were presentations on Polynesian celestial navigation and ocean exploration in Apia, Sāmoa, and Pago Pago, American Sāmoa, and the Festival of Sites hosted by the National Marine Sanctuary of American Sāmoa.

OER also interacted with local communities, agency partners, and schools around NOAA Headquarters and regional offices through events such as a NOAA Open House and NOAA Kid's Day, and by hosting special events and seminars in Exploration Command Centers across the country.

Media continued to play a critical role in OER's public engagement efforts. Press releases and "Exploration Alert" emails kept media representatives, social media managers, and public affairs contacts informed of expedition activities and discoveries, helping to drive audiences to live video online. Stories were generated by hundreds of outlets ranging from CNN, ABC, and CBS, to the Associated Press, *The Washington Post*, *The New York Times*, *National Geographic*, *Scientific American*, and local media outlets in American Sāmoa, the Independent State of Sāmoa, and New Zealand.

A Look Ahead

In 2018, *Okeanos Explorer* will investigate the Gulf of Mexico, the Caribbean Sea, and the North Atlantic Ocean. OER has prepared an ambitious engagement schedule, with plans to implement new ways to share the excitement of deep ocean exploration with people around the world.

Diversity and Inclusion

By Catalina Martinez

In support of NOAA's Diversity and Inclusion Strategic Plan (Figure 1), NOAA's Office of Ocean Exploration and Research develops opportunities to help train and recruit a more diverse and skilled NOAA workforce through cross-NOAA partnerships and participation in agency-wide working groups.

Partnering with NOAA's Office of Education, OER continues to help identify and remove barriers to entry for underrepresented minorities in gateway scholarship and fellowship programs, developing best practices that can ultimately translate to the NOAA-wide diversity and inclusion strategy.

To achieve a more visible and coordinated presence at key minority-serving conferences focused on STEM fields, OER works with individuals across NOAA to include student-centered networking, engagement, career development opportunities, recruitment efforts, and a more deliberate approach overall to staffing and participation (Figure 2).

Internships on board NOAA Ship *Okeanos Explorer* and Ocean Exploration Trust's E/V *Nautilus* provide outstanding training and experiences for undergraduates and graduate students each year. Many are made possible through long-standing partnerships with NOAA's Educational Partnership Program and with the University Corporation for Atmospheric Research. Professional and technical skills developed through these unique opportunities have translated to further graduate studies and jobs for students fortunate enough to participate (Figure 3).

As part of a "campaign" exploration model, the *Okeanos Explorer* team also engages local communities in regions where the ship operates and works with local scientists and educators to host a variety of events that provide access and opportunity to local residents. OER also works on a variety of efforts to help expose students from groups underrepresented in NOAA's workforce to the breadth of NOAA careers (Figure 4).

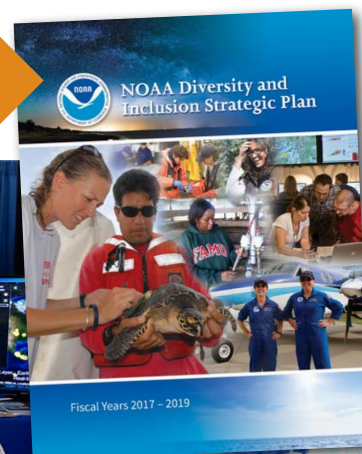


Figure 1. NOAA's Diversity and Inclusion Strategic Plan. Available at: http://www.eeo.noaa.gov/d&i/NOAA Diversity and Inclusion Strategic Plan.pdf

Figure 2. NOAA personnel participating in the annual conference of the Society for Advancement of Chicanos/Hispanics and Native Americans in Science in Salt Lake City, Utah. *Image credit: Corey Garza, California State University, Monterey Bay*

Figure 4. LTJG Nick Pawlenko, NOAA OER Expedition Operations, participates in the Hope High School Futures Forum in Providence, Rhode Island. *Image credit: Stephen Cronin, Hope High School Life Skills Program Coordinator*

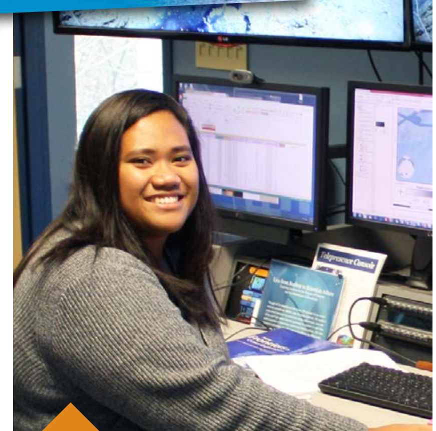


Figure 3. American Sāmoa Community College student Claudia Thompson was trained as a hydrographer through NOAA's Explorer-in-Training program. As part of the science team, Claudia brought a unique perspective to the expedition while building a bridge to her local community. *Image credit: ENS Anna Hallingstad, NOAA*

2017 American Sāmoa Expedition: Suesuega o le Moana Amerika Sāmoa

By Santiago Herrera, Matthew Jackson, Jasper Konter, Elizabeth Lobecker, and Kelley Elliott

Expedition Overview

Five 2017 cruises conducted with NOAA Ship *Okeanos Explorer* investigated unknown and poorly known areas in American Sāmoa and the Independent State of Sāmoa, including Rose Atoll Marine National Monument and the National Marine Sanctuary of American Sāmoa. The 2017 American Sāmoa Expedition mapped the seafloor at priority locations, including prominent features and seamounts in and around the monument and sanctuary, six previously unmapped seamounts, submarine landslides, changes to the crater of volcanically active Vailulu'u Seamount, and unmapped areas offshore of Upolu. Thirteen ROV dives investigated deep-sea coral and sponge communities, bottomfish habitats, seamounts, an active undersea volcano, and the water column.

Benthic Communities

Knowledge of the fauna populating the deep waters of the central Pacific, including American Sāmoa, is extremely scarce. Obtaining a baseline characterization of the species, communities, and ecosystems that inhabit this area is important for understanding their place in global marine biogeography (Watling et al., 2013). ROV dives during the expedition explored the distribution of benthic habitats, with an emphasis on areas with the highest probability of hosting deep-sea coral communities, particularly on the steep slopes and ridges of seamounts within American Sāmoa. Seamount communities were visually structured by depth.

Figure 1. This stony coral with associated squat lobster was observed in the upper bathyal level at ~286 m depth on Dive 13 of the 2017 American Sāmoa expedition.

UPPER BATHYAL

Four ROV dives targeted bottom fish and precious coral habitats at depths between 250 m and 700 m; however, no precious corals (octocoral family Coralliidae) were observed. Other common deep-sea coral groups—bubblegum corals (octocoral family Paragorgiidae) and sea pens (octocoral order Pennatulacea)—were conspicuously absent from the American Sāmoa region. In general, these dives revealed a greater abundance of organisms and apparent higher diversity of megafaunal species than deeper dives (Figure 1). At this depth range, structuring of biological communities associated with depth was observed, likely a result of the rapid temperature changes in the main thermocline.

LOWER BATHYAL

Two dives at Swain's Atoll and Vailulu'u Seamount targeted depths between 700 m and 1,150 m. A high diversity and abundance of sponges and high densities of scleractinian coral colonies (*Enallopsammia* sp. and *Madrepora* sp.) were observed. Five dives between 2,000 m and 3,000 m revealed different communities compared to other depth ranges. Golden octocorals (family Chrysogorgiidae), bamboo octocorals (family Isididae), and glass sponges were the dominant sessile fauna. Coral colonies at this depth were the largest observed during the expedition, particularly *Iridogorgia* and bamboo corals (family Isididae).

ABYSSAL

Similar to organisms found at lower bathyal depths, golden octocorals (family Chrysogorgiidae), bamboo octocorals, and glass sponges (Figure 2) were the dominant sessile fauna observed during the dives conducted between 3,700 m and 4,000 m; however, the species appeared to be different

Figure 2. Potential new species of *Bolosoma* glass sponge found at ~2,420 m depth at Malulu Seamount.

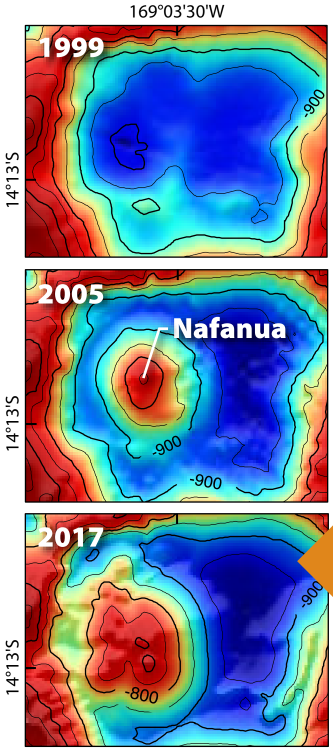


Figure 3. Multibeam bathymetry of the crater at Vailulu'u Seamount (in meters), showing growth of the central cone over time. The map combines data from three different bathymetric surveys. *Graphic credit: Jasper Konter, University of Hawai'i at Mānoa*

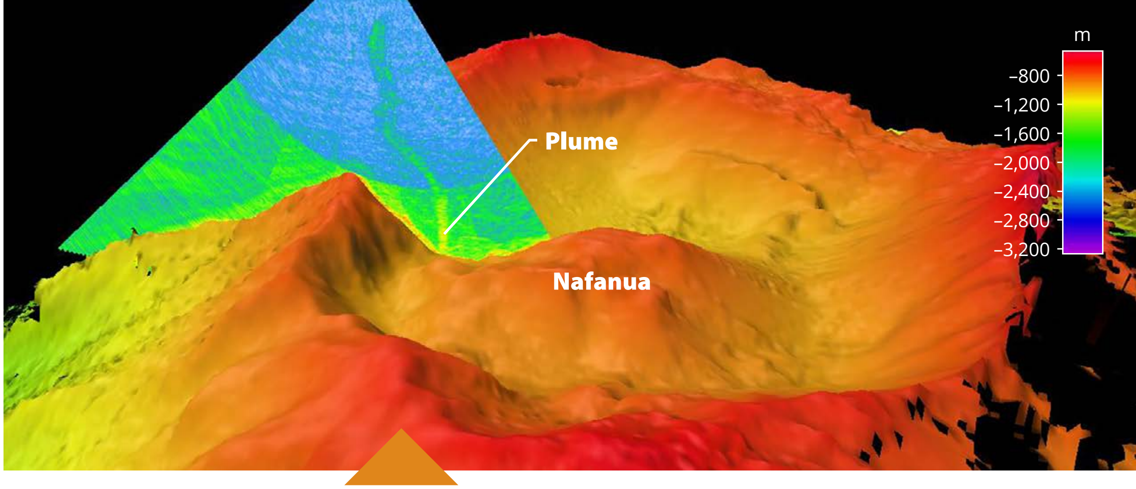


Figure 4. Bathymetric map of Vailulu'u Seamount showing the summit crater. Sonar detected a plume (likely composed of CO_2 gas bubbles) emanating from the crater, near where hydrothermal venting was observed in 2005 (Staudigel et al., 2006).

and their sizes were generally smaller. Further analyses are required to test the significance of the observed general patterns of depth structuring, and to characterize the deep-sea fauna in the American Sāmoa region and its biogeographical connections with surrounding areas in the Pacific.

Geologic History and Active Volcanism

The 2017 American Sāmoa Expedition provided an opportunity to explore the geologic history of the region. Eleven ROV dives recovered 30 rock samples from nine different volcanoes within the American Sāmoa EEZ, including basaltic material from previously unsampled volcanoes.

Four successful dives were made on the flanks of three volcanoes—Rose Atoll, Malulu Seamount, and the informally called Seamount D—located to the east and east-southeast of Vailuluʻu Seamount, the current location of the Samoan hotspot. Four dives were made on three previously unexplored volcanoes located approximately 150 km to the north of the Samoan chain, informally called Leoso, Utu, and Moki. Due to their locations east and east-southeast (Rose Atoll, Malulu Seamount, and Seamount D) or north (Leoso, Utu, and Moki) of the Samoan hotspot, they are unlikely to be volcanically linked to it.

Dives on the flanks of three volcanoes previously shown to be related to the Samoan hotspot—Taʻu Island, Tutuila Island, and Vailuluʻu Seamount—yielded a spectacular surprise. While dives on Taʻu and Tutuila Islands revealed no evidence for active submarine volcanism, consistent with subaerial observations, new bathymetric mapping revealed that the central volcanic cone in Vailuluʻu crater, called Nafanua, has grown substantially since 2005 (Figure 3). Backscatter imaging revealed a plume extending hundreds of meters into the water column, coming to within 100 m or less of the sea surface (Figure 4). The plume is likely related to hydrothermal venting and volcanic degassing from the crater floor, and is near a location where prior hydrothermal venting was observed (Staudigel et al., 2006). High turbidity in the volcanic crater prevented the ROV from directly observing venting sources and biological communities. Reduced turbidity at shallower portions of Nafanua revealed diverse biology, and observations suggest changes in the composition of biological communities are related to the age of the lava flows (all flows on Nafanua are <17 years old). This observation indicates a possible succession order of colonization in a young benthic ecosystem.

Submarine Landslides

Submarine landslides are significant hazards associated with actively forming seamounts. Observations of seafloor lava flows suggest that Vailuluʻu and Malumalu Seamounts were active from a few thousand to a few years ago. Vailuluʻu is part of a chain of similarly shaped volcanoes (Ofu and Taʻu Islands) whose island morphologies show evidence of large-scale collapses. High-resolution bathymetry was collected to assess potential landslide risk around the youngest Samoan volcanoes. The most striking result is the lack of any identifiable fragments of the volcanic edifice, in contrast to some of the seamount-sized fragments found off Oʻahu, Hawaiʻi (e.g., Moore and Clague, 2002). Instead, the southern breached side of Taʻu Island shows a chute that splays into an approximately 80 km long submarine fan beyond Malumalu and Vailuluʻu Seamounts characterized by large hummocks. The lack of large fragments suggests that recent activity has only included debris and/or turbidity flows, not infrequent massive avalanches (Watt et al., 2014), although the fan thickness (~1 km) at the base of the island may hide evidence of early, larger events. These observations contrast with those from the western more mature volcanoes, where both flow and avalanche deposits are present (Hill and Tiffin, 1993).

All work in the NMSAS was conducted under permit NMSAS 2017-001.

Deepwater Exploration of the Pacific Remote Islands Marine National Monument and Central Pacific Basin

By Kasey Cantwell, Kelley Elliott, and Brian R.C. Kennedy

When CAPSTONE began in 2015, NOAA set out to collect baseline information about the deepwater habitats of US marine national monuments and marine protected areas in the Pacific. Since then, nine CAPSTONE cruises have focused on the Pacific Remote Islands Marine National Monument (PRIMNM), one of the largest US marine monuments (Figure 1). Designated in 2009 by President George W. Bush and expanded in 2014 by President Barack Obama, the monument covers over 1,269,000 km². The five regions that make up PRIMNM are the Wake Island Unit, Howland and Baker Islands Unit, Kingman Reef and Palmyra Atoll Unit, Jarvis Island Unit, and Johnston Atoll Unit. These islands, atolls, and their surrounding waters constitute the most widespread collection of marine and terrestrial protected areas on the planet

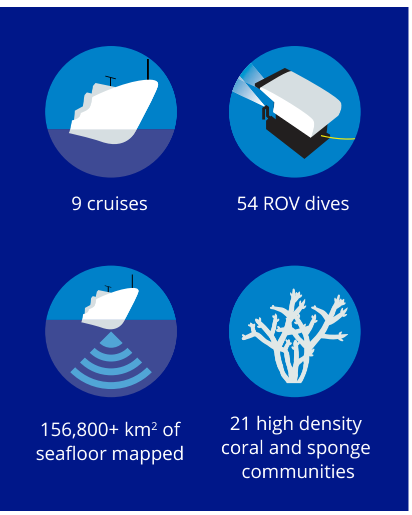


Figure 1. Summary of CAPSTONE work completed from 2015 to 2017 by NOAA Ship *Okeanos Explorer* within the Pacific Remote Islands Marine National Monument and Central Pacific Basin.

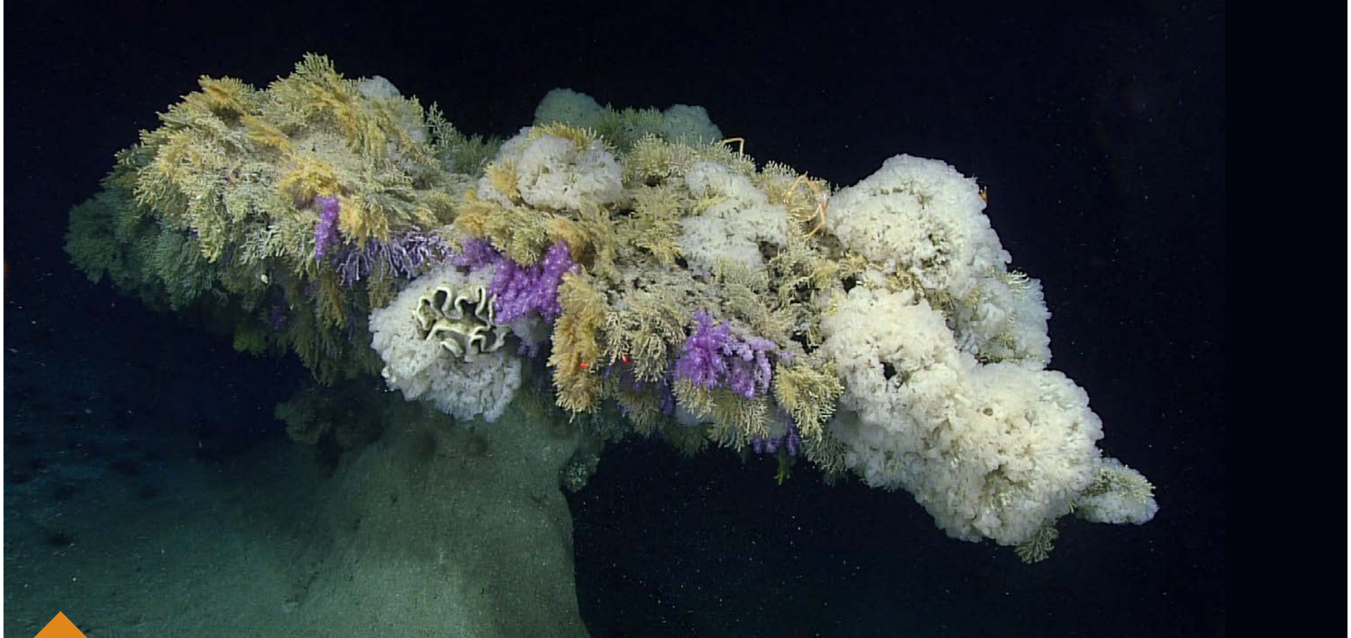


Figure 2. One of the priorities for each of the five ROV expeditions in PRIMNM was to locate deep-sea coral and sponge habitats. A highlight of the exploration of the Jarvis Island Unit was this unusual umbrella-shaped pillar feature covered in deep-sea corals and sponges.

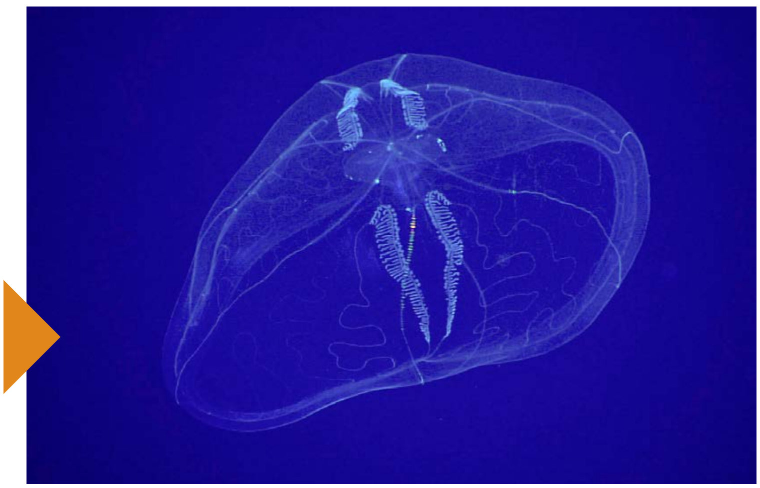


Figure 3. As part of CAPSTONE, NOAA and partners conducted the first water column exploration in the Kingman Reef and Palmyra Atoll, Jarvis Island, and Johnston Atoll units. This ctenophore was imaged during a midwater transect at Johnston Atoll in 2017.

under a single country's jurisdiction. Prior to the start of CAPSTONE, the vast majority of PRIMNM was unexplored, and its deepwater habitats were largely a mystery.

During the three years of CAPSTONE expeditions, NOAA has visited every unit of PRIMNM, greatly expanding our knowledge about what exists within the boundaries and making critical data publicly available for managers and scientists. These expeditions brought the first opportunity to evaluate deepwater biological communities via ROV exploration in the vicinity of the Howland and Baker, Jarvis Island, Johnston Atoll, and Wake Island Units, and they conducted the deepest surveys in every unit. Hundreds of observations were made of new or yet to be described species, new records, and novel behaviors and associations (Figures 2 and 3). Mapping data acquired over the last three years by NOAA Ship *Okeanos Explorer* and partners, including the Schmidt Ocean Institute, the University of Hawaiʻi, and the US Extended Continental Shelf Project, have significantly advanced knowledge of the seafloor within the monument. CAPSTONE efforts mapped over 156,800 km^2 of seafloor in PRIMNM, revealing the morphology of features, including flat top guyots and canyons, and past events such as seamount mass wasting. Rock samples collected will provide new insights into the geologic history of seamount groups in the central Pacific.

As NOAA prepared to explore the Howland and Baker and the Jarvis Island Units, the 2017 expeditions offered the opportunity to partner with neighboring countries to investigate the deepwater habitats in their waters. During transits to and from PRIMNM, the expedition teams collected preliminary data on how these ecosystems might be connected to those within monument boundaries. Working in partnership with the marine resource managers of the Republic of Kiribati's Phoenix Islands Protected Area; Marae Moana, the Cook Islands Marine Park; New Zealand's Territory of Tokelau; the Independent State of Sāmoa; the Secretariat of the Pacific Regional Environment Programme; and the Big Ocean network, regional exploration priorities were established to complement overarching CAPSTONE themes.

The next three articles in this collection will provide an overview of the 2017 expeditions to PRIMNM and highlight some of the discoveries and new insights.

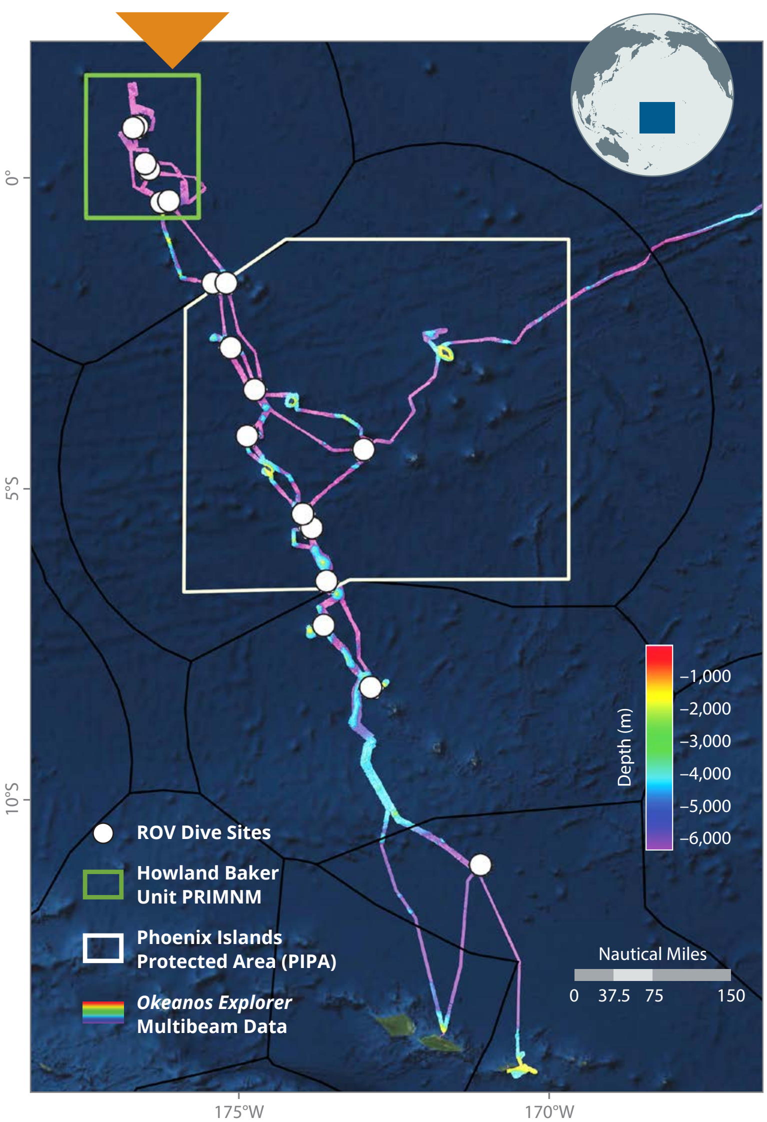
Discovering the Deep: Exploring Remote Pacific Marine Protected Areas

By Amanda W.J. Demopoulos, Steven Auscavitch, Derek Sowers, Nikolai Pawlenko, and Brian R.C. Kennedy

The 2017 Discovering the Deep expedition provided the first glimpse of the deep-sea geology and ecology of the deepwater regions of Swains Island, the Howland and Baker Islands Unit of PRIMNM, Phoenix Islands Protected Areas (PIPA), and the Tokelau Region (Figure 1). Prior to this expedition, virtually no visual reconnaissance had been conducted in any of these areas below scuba diving depths.

ROV dives during this expedition focused on deep-sea corals, sponges, and fish assemblages, with particular interest in locating high-density and high-diversity biological communities. Indeed, nine high-density biological communities were documented out of the 19 dive sites explored. Many of these observations were new records for these regions, and several likely yielded species new to science. Acoustic mapping operations covered more than 47,000 km^2 of seafloor. The collected imagery and specimens will improve our understanding of the distribution of deep-sea corals and sponges, the ages of the seafloor features, and overall geological context of these different environments.

Figure 1. Expedition summary map showing the multibeam sonar data collected as well as the ROV dive sites.



Howland and Baker Islands

The Howland and Baker Islands Unit of PRIMNM was formed as fringing reef around small volcanic islands. On this expedition, seven dives were conducted inside the monument boundaries and one dive in the US EEZ outside of the monument. Three major features were visited within the monument: the deep slopes of Howland and Baker Islands as well as Titov Seamount, a large crescent-shaped guyot. Outside the monument, a seamount of the Winslow Reef complex was mapped and subsequently explored with ROV *Deep Discoverer*.

The steep slopes at both Howland and Baker Islands were characterized by dramatic karstic formations with cathedral-like arches and overhangs. This morphology creates a complex environment for fishes and provides an excellent substrate for attachment of deepwater corals and other fauna.

A shallow dive at Howland Island (357–584 m) observed species-rich fish communities with at least 30 records reported. Precious corals (Coralliidae) were found throughout this depth range in addition to framework-forming scleractinians (*Madrepora* sp. and *Enallopsammia* sp.). A deep ridge dive at Howland Island (2,000-2,200 m) yielded both highly diverse and dense deep-sea coral communities, and there was a rare sighting of an octopus egg case (possibly *Grimpoteuthis* sp., adults of which were spotted in the area) attached to a colony of bubblegum coral (*Paragorgia* sp.). This observation underscores the importance of corals not only as habitat but also as potential nursery grounds.

South of Howland and Baker Islands, two dives were conducted on Titov Seamount and one west of Winslow Reef on the edge of the US EEZ. Diverse and high-density biological communities were observed at Titov Seamount on both its western ridge (1,895–1,740 m depth) and its crest (1,227–1,145 m depth), with the greatest diversity and density near the guyot's summit (Figure 2). On the shallower dive, precious corals (Coralliidae), along with at least 25 other coral taxa, were observed. The highest coral densities occurred on local topographic highs associated with iron-manganese hydroxide-encrusted boulders.

The southernmost site visited in the US EEZ was an unnamed seamount west of Winslow Reef, where one dive (1,561–1,361 m depth) revealed one of the highest densities of

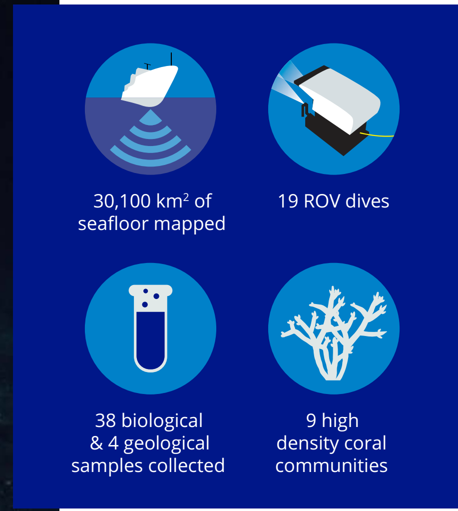


Figure 2. A dense stand of corals on the crest of Titov Seamount (~1,200 m depth) within the Howland and Baker Islands Unit of PRIMNM.

large branched bamboo corals (Family Isididae: Keratoisidinae S1 clade, *Eknomisis* sp. D2 clade, *Lepidisis* sp. D1 clade) observed on this expedition. High densities of bamboo corals were observed along nearly the entire length of the dive track.

PIPA

PIPA is one of largest marine protected areas and UNESCO World Heritage Sites in the world, with over 400,000 km^2 of protected waters. First created in 2008, it includes a chain of islands, seamounts, and atolls that are largely uninhabited. Much like the environments around PRIMNM, PIPA also has rich shallow-water coral reef environments. In 2015, PIPA became a fully no-take MPA, with no commercial or recreational fishing of any type permitted inside its boundaries.

A total of eight dives across eight deep-sea features were made within PIPA boundaries. Seven of these dives were on seamounts and one was in a deep portion of a hadal trough that descends to nearly 6,500 m. This dive traversed a small topographic rise of exposed rocky substrate containing a surprising high diversity of attached fauna. Six of the eight dive targets were characterized as high-density biological sites (Carondelet Reef, Polo Seamount, and unnamed seamounts), and the other two dives observed high-diversity sites (Carondelet Reef and unnamed seamount).

Tokelau

The Tokelau region is characterized by several seamounts along with linear ridges that connect seamounts across the central Pacific. There are also multiple islands and atolls that rise hundreds to thousands of meters from the seafloor.

Two dives were conducted in the Tokelau EEZ region, one at Pao Pao Seamount (226–544 m depth) and one at Ufiata Seamount (745–998 m depth; Figure 3). Of the two sites, Pao Pao Seamount had a higher diversity of corals and commercially important fishes. As the ROV crossed the seamount summit, large groupers, amberjacks, snappers, and sharks were commonly observed darting in and through ROV *Deep Discoverer*'s field of view.

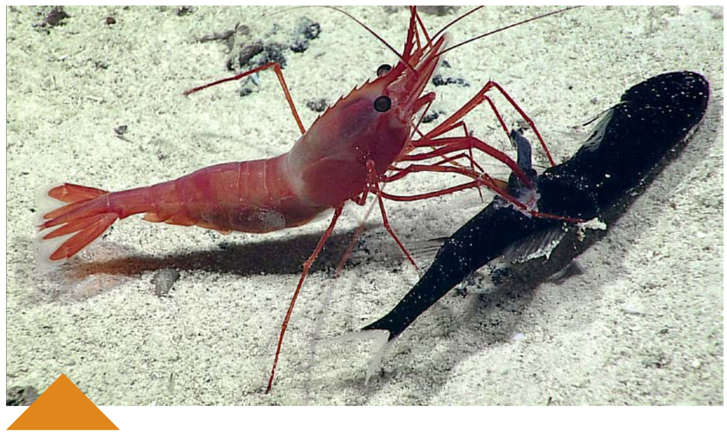


Figure 3. A gravid caridean shrimp, *Heterocarpus* sp., was observed feeding on a type of midwater fish, possibly a stareater (*Astronesthes* sp.), at around 998 m depth on Ufiata Seamount.

Summary

This expedition provided the first extensive look into an almost completely unexplored region. The publicly available data collected will help spark new ideas and interest about the area that will foster follow-on research and exploratory projects. Rock collections will help refine age estimates for the features explored in the region. These data will also establish baseline assessments of deep-sea coral and sponge biodiversity and distribution across these MPAs and remote Pacific territories and nations. The video collected will be used to estimate the diversity, frequency, and fidelity of coral-associated communities, knowledge critical to evaluating the impact of the MPAs on deep-sea ecosystems over time.

Mountains in the Deep: Exploration of the Seamounts of the Central Pacific Basin

By DelWayne R. Bohnenstiehl, Scott C. France, Kasey Cantwell, and Michael White

In 2017, using NOAA Ship *Okeanos Explorer*, NOAA and partners collected baseline geological and ecological data in and around two units of PRIMNM—the Jarvis Island Unit and the Kingman Reef and Palmyra Atoll Unit—and Marae Moana, the Cook Islands Marine Park (Figure 1). These are some of the most remote areas on Earth, with large swaths that had never been mapped or seen by human eyes. Of the many thousand seamounts within this area of the Central Pacific Basin (Wessel and Lyons, 1997; Yesson et al., 2011), fewer than 40 had been previously explored or scientifically sampled.

Marae Moana and the High Seas

Marae Moana covers much of the Manihiki Plateau, a submarine large igneous province that formed prior to 120 million years ago in association with a hotspot. It was once part of a much bigger volcanic province that included the Ontong Java and Hikurangi Plateaus, which rifted apart shortly after formation (Taylor, 2006). While transiting through Marae Moana, the expedition mapped approximately 4,300 km^2 of previously unmapped seafloor.

Two ROV dives were conducted north of the Marae Moana and Cook Islands EEZ. The first dive surveyed a large plateau of unknown origin at about 2,500 m depth. Ferromanganese-crusted lava flows covered the landscape, with small patches of biogenic sediments between outcrops. Throughout the dive, higher densities of suspension-feeding fauna were observed on the tops of taller rock outcrops and boulders. Overall, fauna were sparse. The most abundant megafaunal taxa were brisingid asteroids and stalked tunicates (?*Culeolus*).

The second dive in this region discovered a large-scale, high-density coral community atop an elongate ridge at about 2,200 m depth. The forest included at least 14 species of coral. The dominant species was an open bushy bamboo coral, possibly related to *Cladarisis* (Figure 2). Many of the colonies were taller than the ROV. Fish were uncommon, with only three species observed. Additionally, new bathymetric data revealed a number of previously unknown small cones and lava flow terraces as well as a significantly different depth of the ridge crest (approximately 1,000 m shallower) than was predicted by satellite altimetry (Figure 3).

Jarvis Island Unit

Five ROV dives surveyed a range of ecosystems in the Jarvis Island Unit of PRIMNM, including shallow bottomfish habitats, abyssal communities deep in a fracture zone, and three previously unexplored seamounts. Seamounts within the Jarvis Island Unit are part of the Line Islands linear volcanic chain formed on mid-Cretaceous age seafloor (Davis et al., 2002). Recent work shows that the ages of volcanoes are nearly the same along major segments of the chain (90–70 million years old). Such coeval volcanism, over distances of several thousand kilometers, cannot be easily reconciled with a

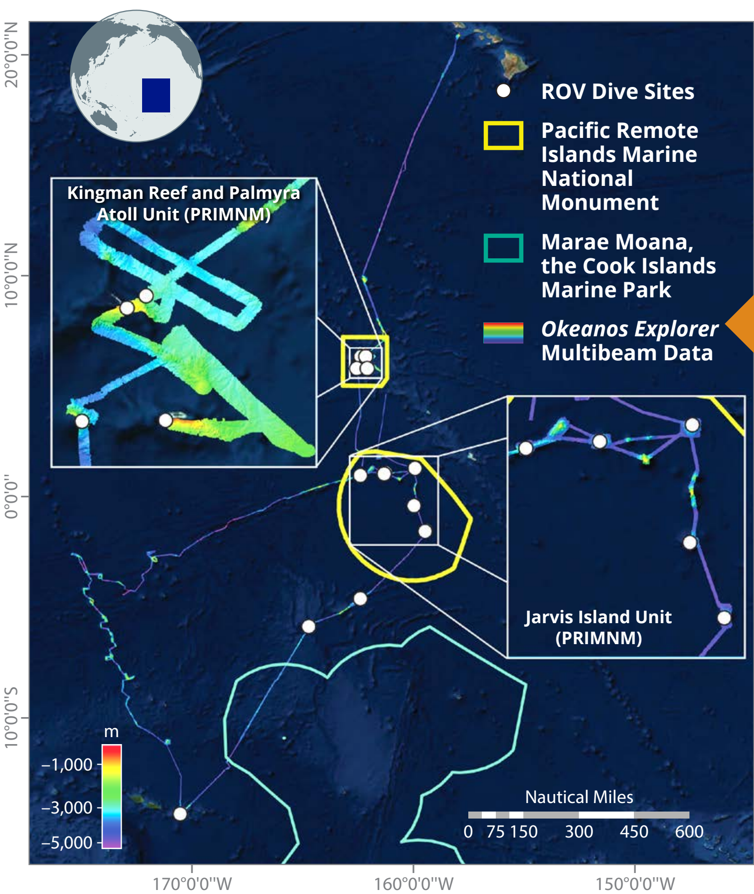


Figure 1. During the 23-day Mountains in the Deep expedition, 12 ROV dives (white dots) were conducted, from 230 m to 4,570 m depth, and over 36,800 km^2 of seafloor were mapped using shipboard sonars. Insets show work conducted within PRIMNM.

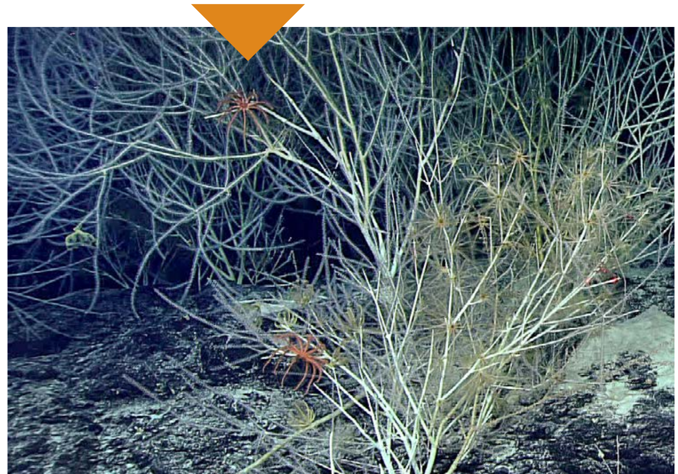
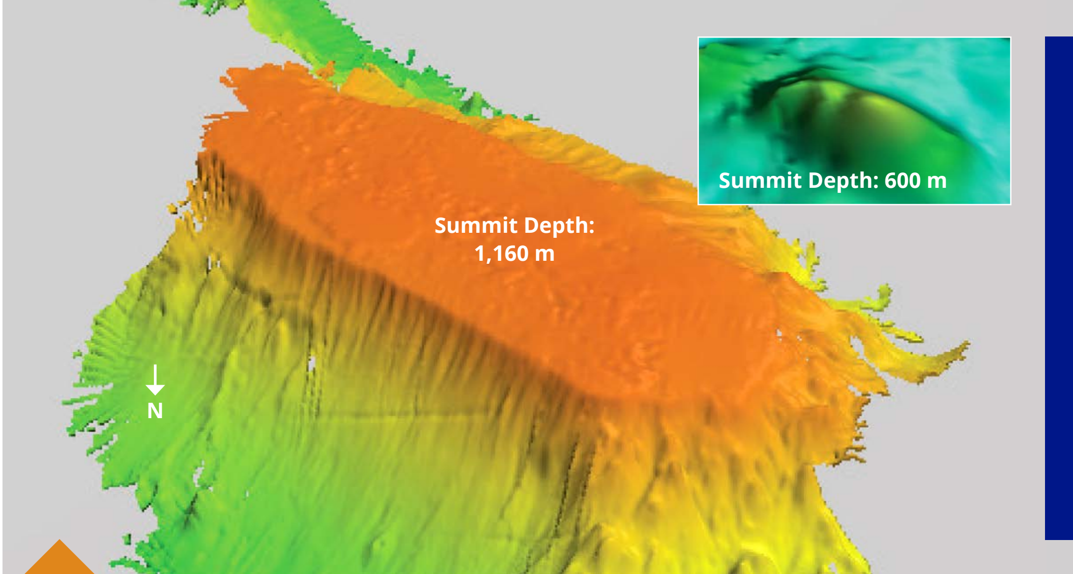


Figure 2. High-density community north of Marae Moana that is dominated by bamboo corals.



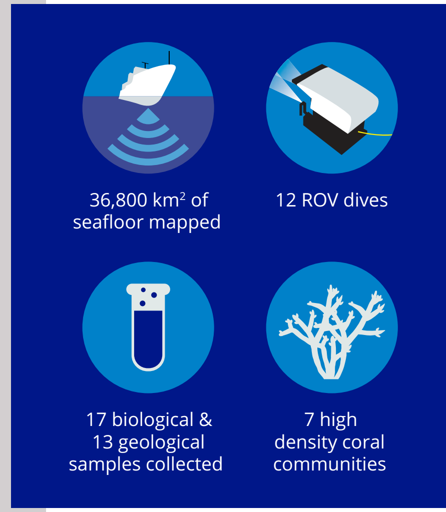


Figure 3. In several instances, mapping operations found significant differences in both form and depth of the seafloor when compared to satellite altimetry data. Here, a ridge-like feature is revealed to be a guyot when mapped with high-resolution multibeam sonar. Inset: Same formation derived from satellite altimetry.

hotspot model; forthcoming radiometric age dates and chemical analyses obtained from the rock samples collected may shed new light on the origin of these seamounts. When data from this expedition are paired with those from an earlier *Okeanos Explorer* expedition, all or part of every major seamount in the Jarvis Island Unit has been mapped, totaling over 16,100 km^2 of seafloor.

During the dive at Jarvis Island, we documented six small- to medium-sized high-density communities dominated by different fauna in different depth ranges, including *Madrepora* stony corals, psolid holothurians, polychaete tube thickets, extensive carpets of small anemones or zoanthids, primnoid octocorals, and urchins. Bands of large carbonate blocks provided habitat for sessile organisms looking to be elevated into currents. This dive also had the richest diversity of fishes seen on the expedition.

Corals and sponges were seen on all three seamounts explored in the Unit, but the communities were typically sparsely populated. Coral diversity ranged from about nine to 16 species. Fish observations were few, except on the shallowest dive where more than 14 species were recorded, including the rarely seen Pacific sleeper shark (*Somniosus pacificus*)—possibly only the fourth time this species has ever been recorded alive—and four morphotypes of batfish and goosefish.

The deepest dive of the expedition (~4,500 m) explored the western end of the Clipperton Fracture Zone. This feature is among the longest tectonic structures on Earth, extending more than 7,000 km from the Line Islands across the modern East Pacific Rise and into the Middle America Trench beneath Central America. The ROV transited up a south-facing scarp within the oldest portion of the fracture zone, sampling rocks from a section of the upper oceanic crust that is thought to have been emplaced more than 120 million years ago. The biological communities reflected the abyssal depths, with the fauna dominated by black corals (Schizopathidae, *Bathypathes*) and at least eight species of sea cucumbers (Holothuria). The second deepest known collection of a bamboo coral (*Bathygorgia*) was observed at 4,523 m depth, and a tube-dwelling anemone (Galatheanthemidae), known mostly from deeper trenches, was collected at 4,514 m depth. Fish from four families were seen, including typical abyssal fauna such as tripod fishes (Ipnopidae), cusk eels (Ophidiidae), deep lizardfishes (Bathysauridae, *Bathysaurus mollis*), and rattails (Macrouridae, *Coryphaenoides yaquinae*).

Kingman Reef and Palmyra Atoll Unit

Kingman Reef and Palmyra Atoll are the exposed summits of two seamounts within the Line Islands volcanic chain. The islands are the last subaerial remnants of a horseshoe-shaped volcanic platform spanning roughly 200 km in diameter. The elevated platform from which the seamounts arise comprises about a dozen individual volcanic centers whose heights exceed 3,000 m above the nearby abyssal plains. Carbonate material is moved from the islands into deep water via a complex network of submarine canyons (Lyle et al., 2016).

Four ROV dives were conducted in this Unit, two at approximately 2,000 m depth, one on a cone emerging from a flat-topped platform at about 1,000 m depth, and on the margin of Palmyra Atoll (490–300 m depth). Surveyed areas were mostly sparse for sessile fauna, but nonetheless diverse in corals, echinoderms, sponges, and fishes. A higher-density coral community was observed on the cone feature at approximately 1,000 m depth despite relatively low dissolved oxygen concentrations (~1.7 mg L^{-1}). Highlights from these dives included documenting a snail preying upon a crinoid, an interaction known previously only from Paleozoic fossils (e.g., Gahn and Baumiller, 2003), the first observation for the central Pacific of a benthic jellyfish (*Ptychogastria*) known from polar oceans, and a rare observation of a sea star preying on a crinoid.

Laulima O Ka Moana: Exploring Deep Monument Waters Around Johnston Atoll

By Christopher Kelley, Christopher Mah, Mashkoor Malik, and Kelley Elliott

Expedition Overview

The 2017 Laulima O Ka Moana expedition focused on collecting critical baseline information about unknown and poorly known deepwater areas in the Johnston Atoll Unit (JAU) of PRIMNM to support science and management needs. Fourteen ROV dives from 250 m to 2,600 m depth investigated seamounts, manganese-encrusted seafloor habitats, and both benthic and water column communities (Figure 1). Five of these dives were conducted on seamounts mapped in January 2017 by the Schmidt Ocean Institute's R/V *Falkor* in the unexplored western part of the JAU.

Mapping operations focused on adding coverage to existing mapping data, conducting surveys to support ROV dive site planning, and underway transit mapping of uncharted areas. A total of approximately 38,331 km^2 of seafloor were mapped, including about 23,161 km^2 inside of the JAU (Figure 1). This effort yielded complete or near complete high-resolution bathymetry and backscatter coverage of eight previously unmapped seamounts. Two other seamounts were partially mapped for the first time, and coverage was added to fill gaps in the data on four additional seamounts.

Diverse Deep-Sea Habitats

More than 99% of the JAU seafloor is in deep water and most has not been previously explored. A key expedition objective was to examine the diversity and distribution of benthic communities, including precious as well as non-precious corals and sponges. Of particular interest was the presence of two large-scale environmental phenomena within the JAU that may cause geographic and depth differences in communities: (1) currents moving east to west in opposite directions that potentially divide the northern and southern halves of the monument, and (2) shoaling of the oxygen minimum zone from north to south in this region. The CTD data showed the lowest oxygen levels at approximately 500 m depth at the northernmost seamounts, and at approximately 350 m depth at the southernmost. Thus, dives were conducted on the previously unexplored southern seamounts for comparison to northern seamounts where data already existed. Shallower surveys around Johnston Atoll and in the water column examined potential impacts of oxygen levels on community composition. Video annotation and data analysis are already underway to determine possible impacts from these phenomena.

Deep-Sea Coral and Sponge Communities

One dive was designed to determine if commercially valuable precious corals were present in the JAU. The only location shallow enough for these corals is Johnston Atoll. During our dive, a spectacular bed of the precious coral *Hemicorallium* sp. (Figure 2) was found at 400–550 m depth in very low oxygen conditions, suggesting commercially harvested shallower coralliid species can tolerate a wide range of oxygen levels and potentially colonize a relatively wide latitudinal range in the central Pacific.

Documenting communities on manganese-encrusted seafloor was a CAPSTONE priority, and consequently, 13 dives were conducted within the manganese crust mining depth range of 1,000 m to 2,500 m (Hein et al., 2009). During the surveys, corals, sponges, many other invertebrates, and fishes were encountered on crust substrate. These data will be combined with those from other CAPSTONE cruises to provide a detailed compilation of benthic communities living in the Prime Crust Zone, so designated for its mining potential.

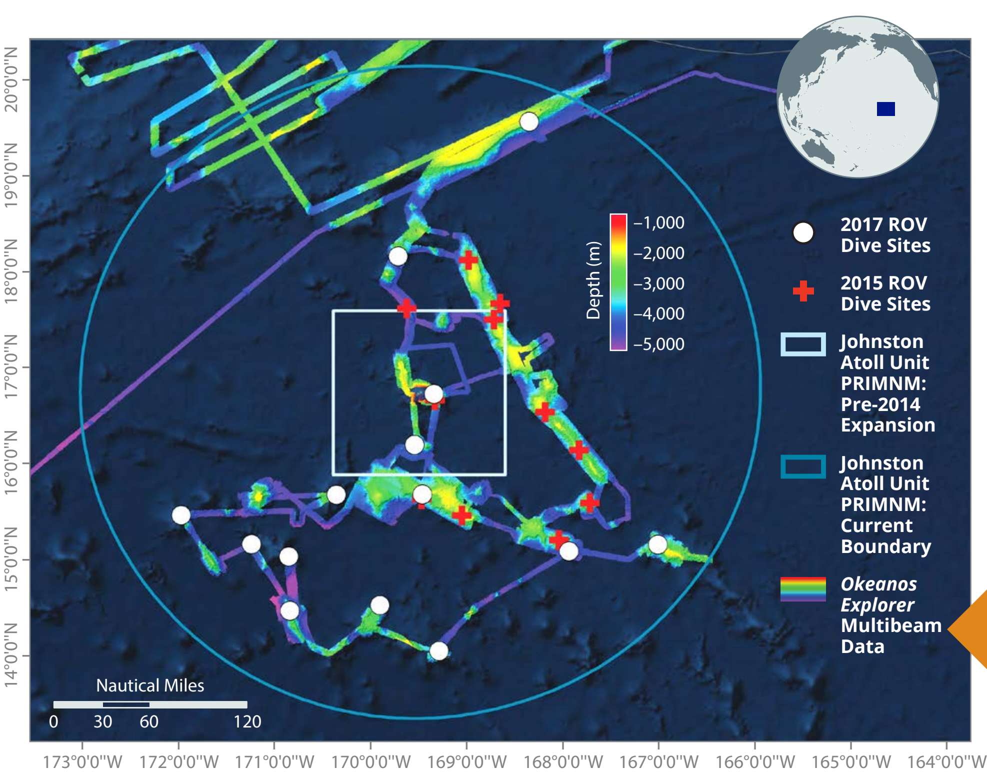


Figure 1. Map showing bathymetry data and ROV dive locations from the NOAA Ship *Okeanos Explorer* expeditions to the Johnston Atoll Unit of PRIMNM. *Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GISUserCommunity*

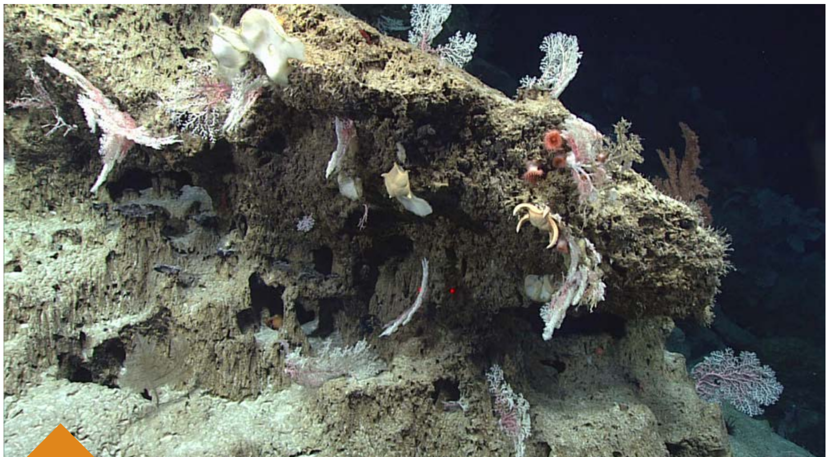


Figure 2. Numerous colonies of the precious red coral *Hemicorallium* sp. were discovered offshore of Johnston Atoll in karstic carbonate formations.

Figure 4. A new species of sea star in the genus *Hippasteria* was observed feeding on this deep-sea octocoral in the genus *Narella*.

Figure 3. A high-density community dominated by sponges in the families Euplectellidae and Farreidae was encountered on "Ridge" Seamount. Many of the observed sponges had their concave sides directed toward the current.

An important related objective was to determine if high-density coral and sponge communities exist on manganese crusts in the JAU because only one "patchy high-density" *Chrysogorgia* sp. community was found in 2015. During the 2017 cruise, high-density communities were found consistently on four of the 13 dive sites, each with a unique species composition and different dominant taxa: two with bamboo corals (family Isididae), another with a deep species of coralliid *(Hemicorallium)*, and the fourth with sponges in the families Euplectellidae and Farreidae (Figure 3). Three other patchy high–density communities were found at sites with large blocks and/or other elevated topography. Dominant taxa in these communities included corals in the family Plexauridae, needle-like carnivorous sponges (?Cladorhizidae), and yet another with a mix of corals and glass sponges. The shallower Johnston Atoll dive also documented high-density patches on large blocks; in one case, glass sponges in the genus *Farrea* covered one side of the block while another side was covered by acanthogorgiid corals.

Ecological Observations and Undescribed Species

Noteworthy observations included over a dozen new observations of sea star predation on corals, including at least three attributed to new, undescribed species (Figure 4). Sea stars represent ecologically important predators in shallow-water ecosystems, and those in deep-sea systems likely show parallel relevance. Other significant ecological observations include a large sea spider (Pycnogonida) feeding on the spiral coral *Iridigorgia* and multiple observations of a small narcomedusae feeding on octocorals.

A large diversity of undescribed animal species were observed, including a new species of snailfish and abyssal nudibranch (genus *Bathydoris*), multiple new species of sea stars, and many undescribed octocorals and glass sponges. Collection was often critical for identification. One sponge, identified from photographs for years as being in the calcarean genus *Clathrina,* was collected and found to be a hexactinellid, a completely different class. It was further discovered to have a commensal hexacoral (a sea anemone or a zoanthid) growing in association with the skeleton of the glass sponge.

Geological History

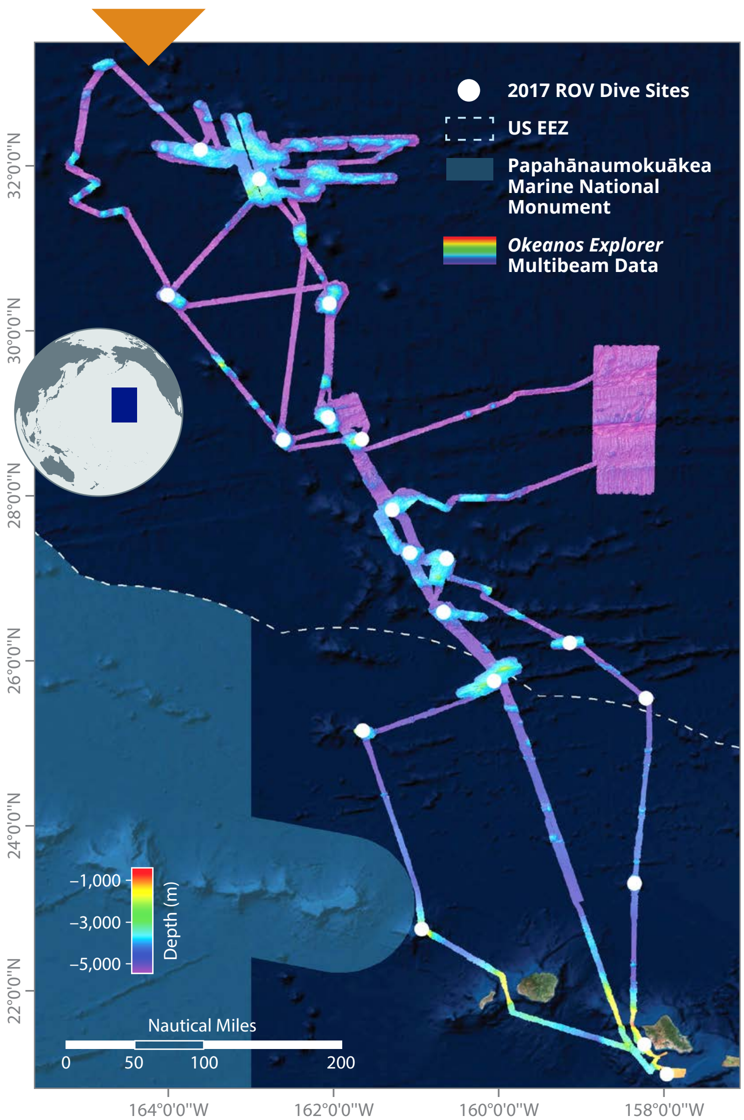
The geologic age of a seamount can only be determined by geochemical analyses and basalt dating techniques of collected samples. Therefore, rocks were collected at every dive site except Johnston Atoll (with carbonate substrate) and Horizon Guyot (limited time and no suitable rocks) for a total of 24 rock samples. Dive video from 13 sites clearly showed thick manganese crusts on exposed rocks, which is indicative of great age (i.e., 60–80 million years). Mapping data also provided clues to the ages of some of the previously unmapped seamounts. Five of the newly mapped seamounts were guyots whose summits below 1,000 m depth make them characteristic of Cretaceous volcanoes that were once at the surface.

Deep-Sea Symphony: Exploration of the Musicians Seamounts

By John R. Smith, Meagan R. Putts, Eric Mittelstaedt, Kasey Cantwell, Elizabeth Lobecker, and Michael White

The high seas are some of the least-studied areas on the planet, yet they connect to the EEZs of countries across the globe. In 2017, NOAA and partners conducted two expeditions on NOAA Ship *Okeanos Explorer* to collect critical baseline information about unknown and poorly understood deepwater areas around the Musicians Seamounts, located northwest of the Main Hawaiian Islands (Figure 1). Previous research along this 1,200 km long seamount chain consisted of only low-resolution single-beam echosounding, opportunistic multibeam mapping during transits, and rock dredges to establish ages of some of the seamounts in the region (Clague and Dalrymple, 1975). As the final CAPSTONE expedition, the Deep-Sea Symphony expedition aimed to characterize the biological diversity and the geologic setting of this fascinating region that lies just outside the US EEZ. Insights gained from this expedition about the potential connectivity between the Main Hawaiian Islands and the Papahānaumokuākea Marine National Monument (PMNM) and the communities that live there will inform decision-making regarding fisheries and monument management plans. Additionally, the Musicians Seamounts offer a unique opportunity to expand our geological knowledge of fracture zones, hotspot volcanism, and the interactions between mantle plumes and mid-ocean ridges.

Figure 1. Map of the 2017 Deep-Sea Symphony expedition in the Musicians Seamounts.



Geological Insights

The Musicians Seamounts were likely built from eruptions fed by partial melting of an upwelling mantle plume. The portions of the Musicians chain explored during this expedition formed near a mid-ocean ridge, in contrast to other linear, plume-fed seamount chains, such as Hawaiʻi. As a result of its proximity to the mid-ocean ridge, the mantle plume fed not only a chain of seamounts but also two sets of volcanic ridges, or lineaments, that extend from the main seamounts eastward toward the former location of the mid-ocean ridge axis.

New mapping data reveal that the Musicians' lineaments are constructed of large volumes of volcanic material, much greater than erupted at similar times along the main Musicians Seamounts. For example, within the northern set of lineaments, several volcanoes sit atop an extensive plateau constructed approximately 100 km east of the main seamount chain. Along the lineaments, new maps reveal many guyots (flat-topped seamounts) that likely were previously above sea level and subjected to wave and wind erosion (Figure 2). Furthermore, video observations of extensive sheet flows with little to no pillow basalt construction suggest that high-effusion-rate eruptions fed by voluminous magma supplies were the norm. Magma supply to the seamounts of the Musicians lineaments contrasts with that of seamounts along other hotspot lineaments. For example, the volume of erupted material making up the young (<2 million years old) Galápagos lineaments is a fraction of that erupted to construct the main Galápagos Archipelago (Mittelstaedt et al., 2014). Furthermore, limited photographic imagery from the Galápagos lineaments reveals significant pillow basalt eruptions, suggesting lower effusion rates. Such differences imply that the dynamics of plume-ridge interaction at the Musicians may have differed greatly from that of other near-ridge mantle plumes.

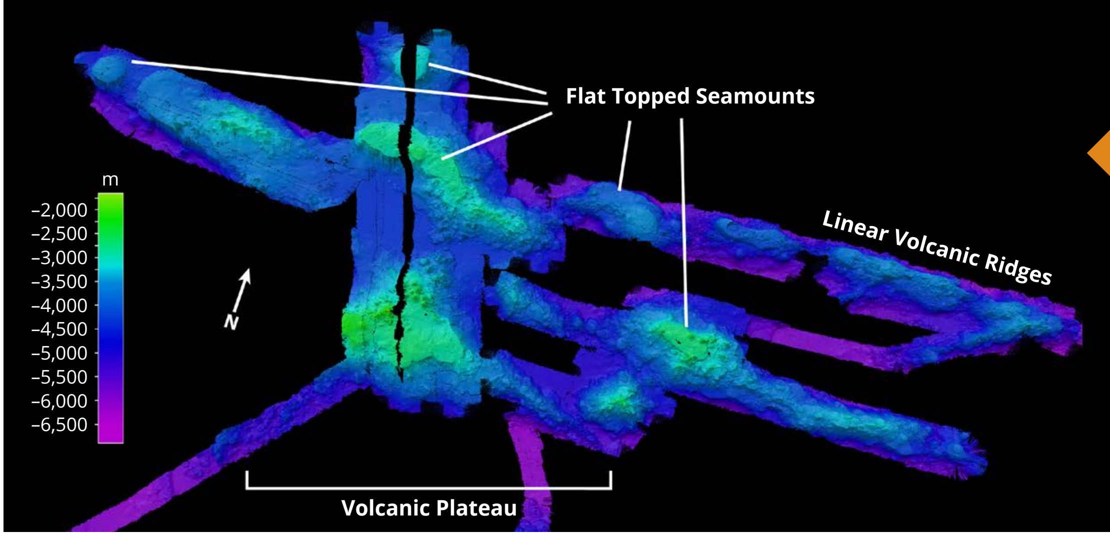
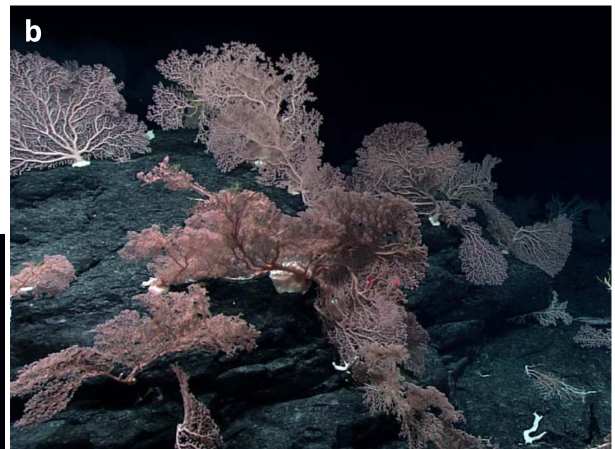
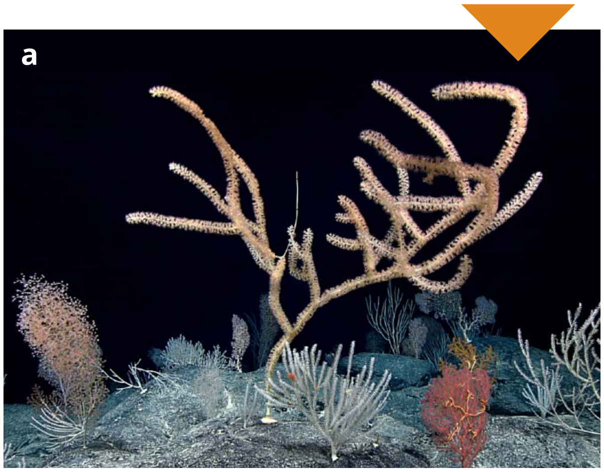


Figure 2. New mapping data along the northern extent of the expedition operating area revealed an elevated volcanic plateau with several guyots and linear volcanic ridges. *Image credit: Eric Mittelstaedt, University of Idaho*

Figure 3. Coral communities throughout the Musicians Seamounts were diverse. Shown here is: (a) a diverse community at Debussy Seamount with several large colonies indicating a stable environment, as well as several relatively young colonies, and (b) a dense *Hemicorallium* community at Mendelssohn Seamount, one of two high-density communities found during this dive.





High-Density Communities

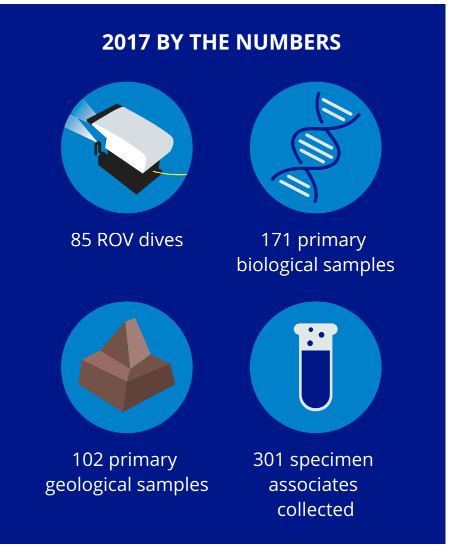
High-density deep-sea coral and sponge communities provide habitat for other organisms, foster biodiversity throughout the ocean, contribute to important commercial fisheries, and are a potential source of biomedical compounds (Hourigan et al., 2017). Of regions explored during CAPSTONE, the greatest number of high-density coral and sponge communities was discovered in the Musicians Seamounts, and each site exhibited a unique composition (Figure 3). This finding was completely unexpected and a marvel to behold. Some communities consisted of primarily one major taxa such as at Shostakovich Seamount, where bamboo corals 3 m tall and 2 m wide were the predominant fauna. Paganini Seamount supported a diversity of Chrysogogiidae coral with low concentrations of other coral and sponge taxa. Mendelssohn Seamount hosted two patches of precious coral. Upon ROV touchdown, there was a dense *Hemicorallium* (pink coral) community composed of large colonies (>1 m wide). Upslope, a dense community of massive (2–3 m tall) bamboo colonies was discovered, one of the densest communities surveyed during CAPSTONE. Other locations exhibited mixed groups of high densities of precious coral (bamboo, pink, and black corals). At least one occurrence of a precious coral was recorded on each dive, marking the first observation of precious corals in the Musicians region.

At Schumann Seamount, a rare glass sponge in the subfamily Lanuginellinae, also known as the "minivan" sponge, was observed. This species was first discovered in, and is only known from, the PMNM (Wagner and Kelley, 2017). Its presence in the Musicians Seamounts may be an indication of connectivity between the two regions and the importance of the Musicians as refugia and a source of larval dispersal and genetic diversity.

Data from this expedition will be used to better understand regional biodiversity, interpret novel observations, inform habitat suitability models for deep-sea corals and sponges, and help unravel the complex geologic story of this region. We also anticipate future studies to evaluate the numerous high-density deep-sea coral and sponge communities discovered and to conduct further research into regional biogeographic patterning.

CAPSTONE Sampling Overview: Providing Insights in the Remote Pacific

By Kasey Cantwell, Kelley Elliott, Christopher Kelley, and Susan Gottfried



In 2015, NOAA's Office of Ocean Exploration and Research commenced the three-year CAPSTONE effort to collect critical baseline information about the deepwater (>250 m) habitats of marine protected areas of the Pacific. The campaign targeted unexplored and rarely explored areas to provide a foundation of publicly accessible information to inform management and spur follow-on research. During CAPSTONE, 767 biological specimens were collected that include new species, new records, and range extensions, as well as morphological variations and diversity assessments. The 278 rocks collected during the multiyear campaign are available to the community to provide information on the geologic history of Pacific seamounts and characterize ferromanganese content on seamounts in and around the Prime Crust Zone, an area of the Pacific with the highest levels of commercially valuable deep-sea mineral deposits.

The philosophy that guided sampling during CAPSTONE was deliberately different than that for traditional research cruises. Here, the science teams sought to acquire the minimum number of specimens that would provide a general representation of the biological and geological setting of each dive site. Biological collections were generally limited to dominant fauna or morphotype in a habitat, undescribed organisms or those that appeared to be outside their known habitats, or other samples' significant discovery potential. Priorities for geological sampling included obtaining rocks for geochemical analysis and age-dating, analysis of ferromanganese content, or meeting other expedition-specific objectives.

OER is committed to making its data publicly available and adheres to the federal government's equal and open data policy (Beaujardiere and Kaske, 2015). Telepresence-enabled operations facilitate initial sample evaluation by giving the shoreside team immediate access to digital sampling data. Throughout CAPSTONE sampling operations, collection methods and processing steps were fully documented and published to permit easy data discovery and access as well as to facilitate long-term data stewardship. Digital information collected aboard NOAA Ship *Okeanos Explorer* is made publicly available within 60 to 90 days after the end of a mission. The designated sample repositories provide access to samples as quickly as possible.

Acquisition, Processing, and Documentation

As with expedition planning and execution, sampling operations on *Okeanos Explorer* are community-driven. Leveraging the vast intellectual capital of the onshore team participating via telepresence (Kennedy et al., 2015), the onboard team opened up sample collections for community input, collaboratively determining the highest needs for sampling, depending on the specific site and dive objectives, expedition goals, and CAPSTONE themes.

Once on board, biological samples were processed as quickly as possible to minimize tissue deterioration (Figure 1). Prior to preservation, each specimen was carefully examined to identify and remove associated fauna. All animals, whether primary specimens or associates, were preserved in either formalin or ethanol depending on which preservative was more desirable for the particular taxa and based on consultation with the shoreside science team. Specimens were preserved for taxonomic analysis (ethanol), genetic analysis

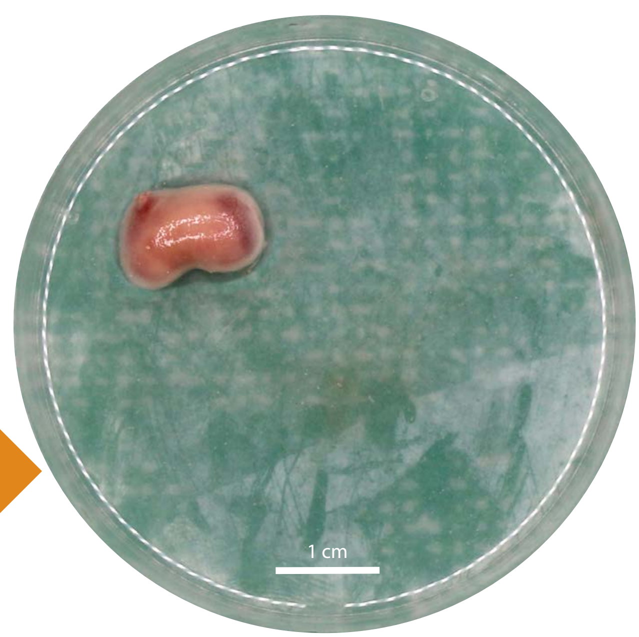


Figure 1. This neomeniomorph aplacophoran (*Helicoradomenia* sp.) was collected as an associate with a hexactinellid specimen. The shipboard team was unable to identify it, so the images were circulated to the shoreside science team. By the following morning, positive identification came from an expert on shore.

Figure 2. A digital microscope capable of recording high-resolution video and imagery of specimens at a macro scale brought new capabilities in 2017. Its imagery was shared with the shore-based team in near-real time to facilitate taxonomic expert consultations and specimen identification. *Image credit: Chris Kelley, HURL*

Figure 3. Geology Science Team Lead Matthew Jackson retrieves a sample from the ROV *Deep Discoverer* rock box.

(CHAOS buffer or OGL fix), and in some cases, histological examination (10% buffered formalin). Geological samples were also examined for biological associates, then weighed, photographed, and dried.

To facilitate post-cruise data discovery, all samples collected by *Okeanos Explorer* were documented in the Sampling Operations Database Application (SODA) created specifically for CAPSTONE. SODA was designed to efficiently create metadata records, catalog associated images and video, and create daily sampling reports. Following the completion of each cruise and quality control of database entries, collection data were provided to the sample repositories, incorporated into a specimen data layer in the *Okeanos Explorer* Digital Atlas (a GIS application), and then archived at NOAA's National Centers for Environmental Information.

One of the benefits of telepresence-enabled operations is the ability to rapidly share information not only with the expedition science team on shore but also with the broader science community. Throughout CAPSTONE, widespread distribution of imagery (Figure 2) led to discussions about fauna, quick engagement of taxa experts to ensure optimal preservation, rapid identification of unknown specimens, and the drafting of journal articles while expeditions were still underway. Beyond the formal communications among colleagues, CAPSTONE expeditions continued to expand their reach to additional experts and citizen scientists through social media.

Post-Cruise Sample Processing and Curating

At the conclusion of each cruise, samples were catalogued and provided to appropriate facilities for curation. All biological samples are accessible through the Invertebrate Zoology collection, National Museum of Natural History, Smithsonian Institution. When possible, selected coral and sponge specimens were split, with subsamples provided to the Bernice Pauahi Bishop Museum's Invertebrate Zoology collection to facilitate additional access by scientists located in the Pacific Islands region. Prior to preservation, a small aliquot of tissue was also removed and preserved for genetic analysis when doing so did not effectively destroy the specimen. These tissue samples were provided to the Ocean Genome Legacy Center at Northeastern University.

Geological specimens collected during CAPSTONE (Figure 3) were shipped to the Marine Geology Repository at Oregon State University, where the rocks are curated and described from a petrology perspective (e.g., mineral content, texture, alteration, rock name). Thin and polished sections are cut, microphotographed, and entered into the repository's sample library. The repository provides online metadata and images of the samples as well as images of thin and polished sections.

Looking Ahead

OER routinely evaluates its collection activities, including the types of samples to be collected, the characterizations desired for each sample type, and the appropriate repositories for the samples. Sampling operations will continue to focus on specimen collections that contribute to an interdisciplinary baseline characterization of poorly understood habitats in high-priority target areas identified by the science community. Samples will continue to be made publicly available within six to eight months of expedition completion. Future operations may include incorporation of new sampling tools that permit better characterization of the water column, facilitate enhanced benthic collections, and improve real-time access to sample data and digital characterization data via telepresence.

Exploring the Pacific Through International Partnerships

By David McKinnie, Randi Rotjan, and Atuatasi Lelei Peau

Science helps us to understand our natural world and provides the data and information needed to manage its resources. In Pacific Island nations, it is critical to connect science not only with decision-makers but also with traditional leadership and the people. In meeting US needs, opportunities to partner with Pacific Island nations and the Secretariat of the Pacific Regional Environment Programme (SPREP) emerged, and three-year CAPSTONE effort was initiated. Through partner discussions, exploration priorities were identified, operating areas were refined, and mapping and dive targets were selected. NOAA relied on SPREP to provide guidance on how best to engage local partners and communities, and Pacific Island nations helped to identify requirements, provide operational permits, and facilitate other support. This led to the exploration of unknown or poorly known deep waters of American Sāmoa, Sāmoa, the Republic of Kiribati, the Cook Islands, and New Zealand's Territory of Tokelau.

Using NOAA Ship *Okeanos Explorer*, NOAA worked in and near the exclusive economic zones of these regions to map the deep ocean, collect high-resolution video, and take limited samples (where permitted) to give better insight into the biology and geology of these largely unknown ecosystems. NOAA also provided professional development seminars for teachers, live interactions, and public access to live exploration for its Pacific Islands partners. NOAA operates on an open-science, open-data model—anyone can participate in *Okeanos Explorer* expeditions via live video streams on the Internet, and the data are publicly available.

Figure 1. Deputy Superintendent Atuatasi Lelei Peau of the National Marine Sanctuary of American Sāmoa introduces Dan Rogers of the Global Foundation for Ocean Exploration, who gave a presentation on modern and traditional ocean exploration at the Tauese P.F. Sunia Ocean Center in Pago Pago, American Sāmoa.

American Sāmoa

NOAA and the American Sāmoa Government Office of Samoan Affairs collaborated to set priorities for exploration that would meet National Marine Sanctuary System needs while being culturally relevant to American Samoans. All work performed at the National Marine Sanctuary of American Sāmoa (NMSAS) must be approached with sensitivity to place and the culture of American Samoan people. Three themes emerged: the connection between deepwater and shallow water ecosystems, connections between communities at different seamounts, and potential geohazards such as undersea landslides. Working closely with partners at the NMSAS, NOAA conducted seven dives in American Samoan waters and mapped over 40,879 km^2 in high resolution. In addition, the *Okeanos Explorer* team hosted tours for more than 500 people, conducted interviews with local television and radio stations, shared the excitement of ocean exploration in American Samoan waters to over 1,000 cruise ship passengers at the National Marine Sanctuaries Festival of Sites, and cohosted a presentation on Polynesian celestial navigation and ocean exploration in partnership with the Global Foundation for Ocean Exploration and the NMSAS (Figure 1).

Sāmoa

NOAA worked with the Government of Sāmoa's Ministry of Natural Resources and Environment, the National University of Sāmoa, SPREP, Sāmoa's Ministry of Agriculture and Fisheries, and others to set priorities. While exploring within the Samoan EEZ, expedition teams mapped approximately 5,600 km^2 of seafloor, including extensive uncharted areas around the entire eastern half of Upolu. Tour groups visiting *Okeanos Explorer* included nearly 220 people from local colleges, the National University of Sāmoa, the Sāmoa Voyaging Society, the Sāmoa Conservation Society, environmental ministries, the US Embassy in Apia, and SPREP (Figure 2). NOAA cohosted a presentation on Polynesian celestial navigation and ocean exploration, in partnership with the Global Foundation for Ocean Exploration, the Sāmoa Voyaging Society, and SPREP.

Republic of Kiribati

While exploring in and around Kiribati's EEZ and Phoenix Islands Protected Area (PIPA), NOAA mapped approximately 25,200 km^2 of seafloor in PIPA and an additional 1,200 km^2 in the Line Islands. This work provided new high-resolution bathymetric maps of portions of 10 seamounts,

Figure 2. While in port at Apia, Sāmoa, the mission team on board NOAA Ship *Okeanos Explorer* led tours for nearly 220 people. Here, some of the visitors learn about the ROV *Deep Discoverer* and the camera sled ROV *Seirios*. *Image credit: US Embassy, Apia, Sāmoa*

Figure 3. On June 8, 2017, NOAA Assistant Administrator for Oceanic and Atmospheric Research, Craig McLean, second from left, met with the Cook Islands Prime Minister, Henry Puna, left, at the United Nations Ocean Conference in New York. Attendees discussed the high value of the collaborative work in the region and anticipate future NOAA or partner exploration opportunities in the Cook Islands and with other Small Island Developing States.

three prominent ridge and island flank features, and PIPA's deepest feature, the 6,350 m deep "Hadal Trough." Eight ROV dives were conducted in PIPA, revealing high-density coral communities, areas of high biodiversity, and large octocoral fans. According to the PIPA Science Advisory Committee, this opportunity was important for comparison across neighboring marine protected areas as part of PIPA's collaborative arrangement with the Pacific Remote Islands Marine National Monument.

Tokelau

While exploring New Zealand's Territory of Tokelau, NOAA mapped approximately 13,300 km^2 of seafloor, including portions of nine seamounts and five highly prominent ridge features. During two ROV dives conducted in Tokelau's territorial waters, scientists surveyed a high diversity of coral and commercial fish at Pao Pao Seamount and observed precious corals at Ufiata Seamount. A delegation of 30 individuals from Tokelau toured *Okeanos Explorer* during a port call in Apia, Sāmoa.

The Cook Islands

While exploring priority areas north of the Cook Islands' EEZ and within Marae Moana, the Cook Islands Marine Park, NOAA mapped more than 4,300 km^2 of seafloor and conducted two dives that revealed a previously unknown large-scale, high-density deep-sea coral community. The expedition team participated in a telepresence interaction with a number of Cook Islands schools, as well as a live telepresence interaction with media and participating scientists at New Zealand's National Institute of Water and Atmospheric Research. On June 8, 2017, NOAA's Assistant Administrator for Oceanic and Atmospheric Research, Craig McLean, met with the Cook Islands Prime Minister, Henry Puna, at the United Nations Ocean Conference in New York (Figure 3). Attendees who discussed the high value of the collaborative work in the region anticipate future NOAA or partner exploration opportunities in the Cook Islands and with other Small Island Developing States.

NOAA and SPREP reconvened in September 2017 to share expedition results and maps of deepwater areas for Pacific Island nations. Multibeam data files, water column sonar files, track and position data, environmental information, video, still images, maps, and more were provided to each international partner at this meeting. Currently, biological and geological samples are available through NOAA partner repositories at the Bernice Pauahi Bishop Museum, the Smithsonian Institution's National Museum of Natural History, and the Marine Geology Repository at Oregon State University. Results of genetic analysis (and any remaining tissue samples) are available from the Ocean Genome Legacy Center at Northeastern University (see pages 84–85). In addition to sharing the live dives and the data, NOAA encouraged follow-on expeditions and research. This also provided the opportunity to discuss how future work in the regions can leverage alliances between NOAA and partner organizations, such as the Schmidt Ocean Institute and the Ocean Exploration Trust. NOAA is grateful for the opportunity to explore these regions and provide data to SPREP members, and looks forward to continuing and strengthening these partnerships.

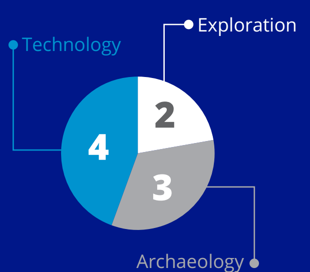
Sponsored Projects:
NOAA's Office of Ocean Exploration and Research

FY2017 BY THE NUMBERS

NUMBER OF PROPOSALS AND AWARDS

86 Pre-Proposal Requests
27 Full Proposal Requests
9 Awarded

NUMBER OF AWARDS BY THEME



FUNDING SUMMARY

$37,250,000 Pre-Proposal Requests
$12,240,000 Full Proposal Requests
$3,600,000 Awarded

Introduction

By Nathalie Valette-Silver, Frank Cantelas, Chris Beaverson, Amanda Netburn, Yvette Jefferson, Joyce Woodford, and Stephen Hammond

To help accomplish its mission to explore and characterize the deep ocean, NOAA's Office of Ocean Exploration and Research sponsors projects through grants and cooperative agreements, as well as intra- and interagency agreements. These projects complement systematic ocean exploration conducted by NOAA Ship *Okeanos Explorer*.

On an annual basis, OER publishes a Federal Funding Opportunity (FFO) that invites the submission of proposals focused on ocean exploration (including maritime exploration for, and of, culturally important submarine sites) and on technological innovations with the potential for increasing the pace and scope of ocean exploration.

For the past several years, dependent on OER's year-to-year budget, the funding allocation for the FFO has ranged from $3 million to $4 million. Projects are selected based on a community-standard process of peer review, coupled with published programmatic selection factors.

Funded projects benefit from proactive OER support, including assistance with cruise planning, federal administrative reporting requirements, and communication of project discoveries and results by means of OER's website.

This section highlights a few of OER's 2017 sponsored projects in archaeology, technology, and exploration that demonstrate the breadth of work supported by OER. In addition to those presented here, two other archaeology projects were supported by OER and conducted using the Ocean Exploration Trust's E/V *Nautilus* (see pages 36–38).

Under the supervision of its pilots, an unmanned aircraft system takes off over Lake Huron in Thunder Bay National Marine Sanctuary. See details on page 90. *Image credit: TBNMS, NOAA*

A new sensor for detecting nitrogen gas was tested on *Okeanos Explorer* in October 2017. See details on page 96. *Image credit: Charles Wilkins, Okeanos Explorer*

Calcified green algae are important to the biogeochemical cycles of coral reefs. In this garden of algae, the science team observed three species of *Halimeda*, as well as *Udotea* and *Rhipocephalus*. See details on page 89. *Image credit: Cuba's Twilight Zone Reefs and Their Regional Connectivity*

Cooperative Institute for Ocean Exploration, Research, and Technology

By Shirley Pomponi, John Reed, Joshua Voss, Dennis Hanisak, M. Cristina Diaz, Andrew David, Felicia Drummond, Patricia González-Díaz, Linnet Busutil López, Beatriz Martínez-Daranas, Dorka Cobián Rojas, and Nathalie Valette-Silver

NOAA's Cooperative Institute for Ocean Exploration, Research, and Technology (CIOERT) is a partnership of Florida Atlantic University-Harbor Branch Oceanographic Institute, University of North Carolina Wilmington, University of Miami (UM), SRI International, and NOAA's Office of Ocean Exploration and Research. Activities focus on three themes: exploration of continental shelf edge frontiers, research on vulnerable coral and sponge ecosystems, and development of advanced underwater technologies.

From May 15 to June 13, 2017, CIOERT conducted an expedition to discover and characterize the extent of mesophotic reefs around Cuba and to compare the health and connectivity of mesophotic and shallow coral reef ecosystems in Cuba and the United States. This collaborative effort involved six Cuban institutions and agencies (Centro de Investigaciónes Marinas at University of Havana, Centro Nacional de Áreas Protegidas, Instituto de Ciencias del Mar, Geocuba Estudios Marinos, Guanahacabibes National Park-Sistema Nacional de Areas Protegidas, and Acuario Nacional de Cuba), and NOAA's Office of National Marine Sanctuaries, National Marine Fisheries Service, and OER. The team explored never-before-studied mesophotic coral reefs from 30 m to 150 m depth around the entire island. Details, mission blogs, and photos are available at http://oceanexplorer.noaa.gov.

Figure 1. Vertical, rugged rock walls were common at most study sites in Cuban waters from 50 m to 125 m depth. Black whip corals (*Stichopathes* sp.) and whip gorgonians (*Elisella* sp.) are ubiquitous here, feeding on plankton carried along by deep currents. *Image credit: Cuba's Twilight Zone Reefs and Their Regional Connectivity*

Through daily ROV dives from the UM R/V *F.G. Walton Smith*, scientists focused on characterization of deep coral reefs, documenting the geomorphology, biological zonation, and diversity of marine biota (Figures 1 and 2). Many dives were conducted in or adjacent to Cuba's extensive network of marine protected areas to explore locations for possible creation of new MPAs or expansion of existing boundaries. Data analyses are in progress to document density and cover of corals, sponges, algae, and fishes, as well as to determine genetic connectivity among corals from Cuba, Central America, the Gulf of Mexico, and the Florida Keys.

CIOERT also supports NOAA's Deep Sea Coral Research and Technology Program priorities to identify and understand deepwater sponge ecosystems, with active participation in a partner project funded by the European Union Horizon 2020 Program (SponGES). In 2017, several expeditions to the North Atlantic were conducted in support of this project aboard US, Norwegian, Spanish, Swedish, and Canadian research vessels.

CIOERT scientists participated in NOAA Ship *Okeanos Explorer* missions, both as ship-based science leads during two legs of the Marianas Trench Marine National Monument expedition in 2016 and as shore-based science teams supporting the CAPSTONE effort in 2016 and 2017.

Figure 2. Cuba's mesophotic reefs support an incredible diversity of beautiful organisms. *Image credit: Cuba's Twilight Zone Reefs and Their Regional Connectivity*

Pushing the Boundaries: Technology-Driven Exploration of Thunder Bay National Marine Sanctuary

By John Bright, Russell Green, Frank Cantelas, and Nathalie Valette-Silver

Since the expansion of Thunder Bay National Marine Sanctuary in 2014, the priority of sanctuary researchers has been to search new sanctuary waters to discover shipwrecks.

In 2017, Thunder Bay National Marine Sanctuary assembled a collaborative, interdisciplinary team to bring together several different remote-sensing technologies to survey both in shallow water and in some of the deepest offshore areas of Lake Huron.

Although 94 historical shipwrecks are already known throughout this area, archival research indicates that as many as 100 more are yet to be found within the expanded sanctuary. Funded by a grant from NOAA's Office of Ocean Exploration and Research to locate new wrecks, researchers conducted a four-part expedition to test new applications of tools for archaeologically focused remote sensing during the spring and summer of 2017. In particular, innovative approaches to bottom mapping were of great value to maritime archaeologists.

Figure 1. NOAA archaeologist Stephanie Gandulla reviews sonar data with Michigan Tech PI Guy Meadows. *Photo credit: TBNMS, NOAA*

The team took advantage of the exceptional early spring clarity of Lake Huron's water to test new approaches for using unmanned aircraft systems (UASs) as marine archaeological survey tools. Camera-equipped UASs operating over the water in April to image the shallow lake floor produced imagery so detailed that individual timbers from shipwreck sites were easily visible. Partners from NOAA's National Geodetic Survey's Remote Sensing Division, Oceans Unmanned, and Trumbull Unmanned supplied the UAS platforms and pilots.

In May, the team transitioned to deepwater surveying within the sanctuary's new northern boundary. Partnering with the University of Delaware, they used an Edgetech 6205 sonar integrated onto NOAA research vessel R8001. Operating 24 hours a day, the team conducted a wide-area acoustic survey, mapping 243.5 km^2 of lake bottom and revealing two new targets that appeared to be historic shipwrecks.

Target investigations took place throughout June and August, starting with an assessment conducted with an AUV provided and operated by Michigan Technological University. Equipped with an EdgeTech 2205 sonar, the AUV imaged important details such as the size, shape, design, and integrity of each target (Figure 1). Comparing the sonar images to historical records provided the first tentative identities of each vessel. Follow-on investigations using a small ROV provided by Northwestern Michigan College confirmed the sites to be the wooden bulk carrier *Ohio* (lost in 1894) and the steel bulk carrier *Choctaw* (lost in 1915; Figure 2).

Executing the research phases sequentially reduced the amount of time between discovering a historical shipwreck and completing a detailed baseline archaeological understanding of its remains. Likewise, the shallow-water survey completed with UAS technologies provided new insights into their broader application as valuable marine survey tools, especially within the clear waters of the Great Lakes.

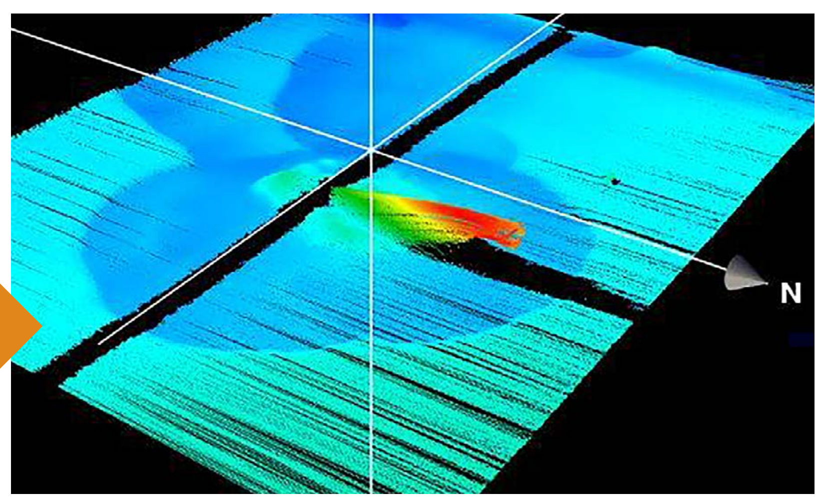


Figure 2. Rendered three-dimensional bathymetric data product from the archaeological site identified as the remains of steel bulk carrier *Choctaw*. *Image credit: Michigan Technological University*

Exploring the Sunken Heritage of Midway Atoll at the 75th Anniversary of the Battle of Midway

By Kelly Keogh, Bert Ho, Nathalie Valette-Silver, and Frank Cantelas

The legacy of World War II is perhaps nowhere more evident than at Midway Atoll, a World Heritage Site located within the Papahānaumokuākea Marine National Monument (Figure 1). One of the most decisive US victories of World War II, the Battle of Midway is considered the turning point of the war in the Pacific, and material remains on the seafloor at Midway are considered war graves. Archival research reveals that at least 31 planes (22 American and 9 Japanese) crashed within 5 km of Midway Atoll (Linville, 2010), and dozens more are probably resting further away from it. June 2017 marked the 75th anniversary of this battle, and our project aimed to raise awareness and honor the legacy of the brave men who perished during the battle.

In May 2017, using small boats provided by the US Fish and Wildlife Service, a team of archaeologists and biologists conducted an exploratory search for sunken aircraft associated with the Battle of Midway and assessed their potential as habitat for invasive species in the Northwestern Hawaiian Islands.

To document and analyze known sunken aircraft remains as well as new discoveries, the team of scientists used a technique called photogrammetry, which makes measurements from photographs. This tool is extremely useful in that the imagery can be collected in a short amount of time, providing scientists with a great deal of information. Photogrammetry was used at Midway to produce detailed three-dimensional images of sunken aircraft.

One of the best tools for locating cultural or man-made material underwater is a marine magnetometer, which detects variations in Earth's magnetic field caused by ferrous material. Employing a magnetometer, the team identified 137 magnetic anomalies or "targets" for further visual investigations by divers. Using scuba equipment and freediving to explore some of the shallower anomalies, the team investigated 102 anomalies, 86 of which had positive findings for cultural material (Figure 2). Findings included nineteenth century anchors, Navy anchors, building debris, and possibly part of a radial aircraft engine.

We believe some remarkable discoveries will emerge from this survey (Figure 3), but at this point, the specific identities of the artifacts are inconclusive. Archaeologists are continuing to analyze data and consult records in order to produce more conclusive identification to be shared with the public.

Figure 1. Aerial view of Midway Atoll. *Image credit: Papahānaumokuākea Marine National Monument/NOAA*

Figure 2. A diver documents a structure discovered by magnetometer survey for any invasive species. *Image credit: Brett Seymour, Exploring the Sunken Heritage of Midway Atoll expedition*

Figure 3. Jason Leonard photographs the remains of the radial engine from the Brewster Buffalo fighter plane. *Image credit: Brett Seymour, Exploring the Sunken Heritage of Midway Atoll expedition*

Cold Seeps of the Cascadia Margin

By Robert Embley, Susan Merle, Nicole A. Raineault, Lindsay Gee, Nathalie Valette-Silver, and Stephen Hammond

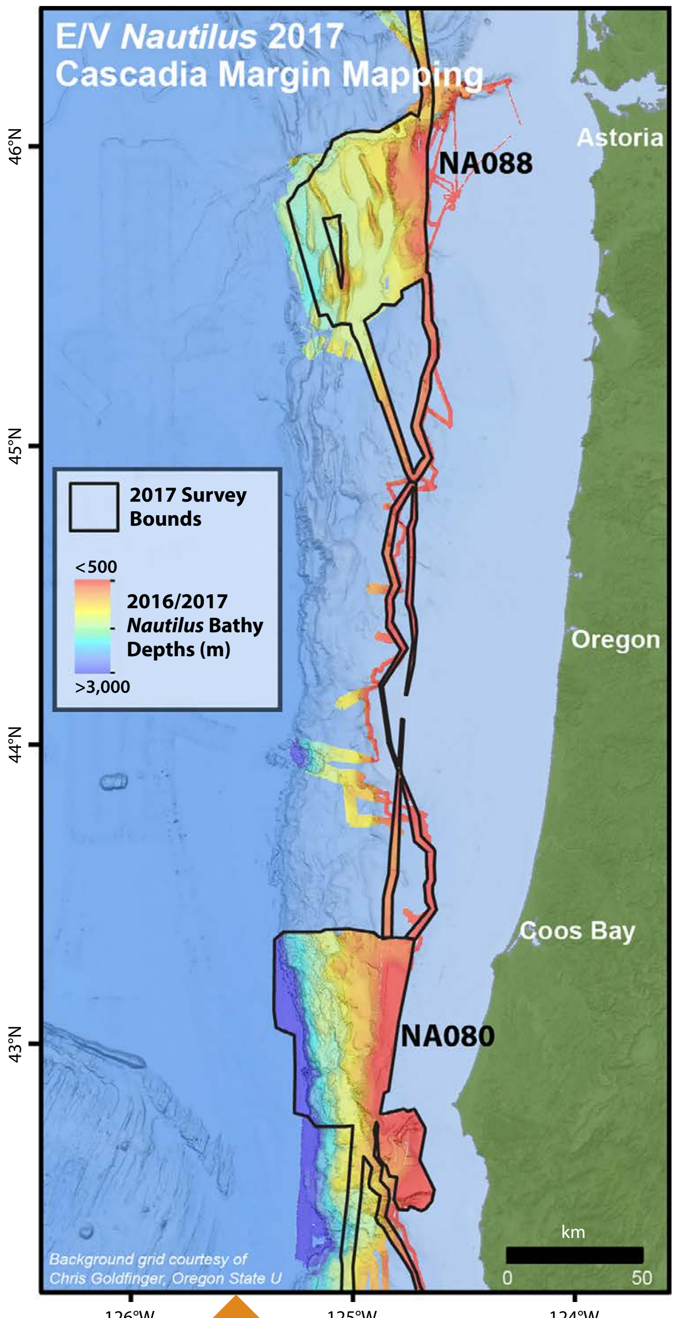


Figure 1. Black polygons enclose the main areas surveyed on the Cascadia margin in 2017 by E/V *Nautilus*. *Image credit: Susan Merle, NOAA PMEL*

In June and September 2016, Ocean Exploration Trust cruises explored cold seeps along the continental margins of Washington, Oregon, and northern California. Work aboard E/V *Nautilus* included bathymetric and water column mapping surveys that identified hundreds of new methane bubble stream sites, which were subsequently explored with ROV *Hercules* (Embley et al., 2017).

In 2017, *Nautilus* cruises NA080 and NA088 conducted seafloor and water column surveys using the EM 302 multibeam echosounder, adding substantially to the database of methane bubble stream sites off the Cascadia continental margin (Figure 1). Subsequent initial processing of the 2017 data aided in the identification of many additional sites in water depths ranging from 83 m to 1,972 m. The NA080 survey added data to an area extending 68 km north of the 2016 surveys, inclusive of the western edge of Coquille Bank and extending west to the base of the continental slope. Cruise NA088, on the northern Oregon continental slope, added considerably to the 2016 survey of this area. During the 2017 field season, *Nautilus* also collected multibeam data on transits along the Cascadia margin in addition to the two planned surveys.

Data from the 2016 and 2017 *Nautilus* surveys are being collated, along with new data from other sources, into an expanded database of methane bubble sites along the entire Cascadia margin. Applying a spatial filter with a 300 m radius, the 2016 and 2017 *Nautilus* surveys located 380 new methane bubble stream sites, about three and a half times the number of sites known prior to 2016. These new data, in addition to new sites identified on 2016 and 2017 multibeam surveys from the Olympic Coast National Marine Sanctuary conducted by NOAA Ship *Rainier*, as well as survey lines made by academic research vessels, provide a significantly expanded baseline for research on potential effects of climate change and tectonics on the ocean carbon cycle. These data sets will also be important for assessing the distribution and extent of methane vent-associated chemosynthetic communities and hard-ground habitat on the Cascadia continental margin.

Exploring US Mid-Atlantic Margin Methane Seeps: IMMeRSS, May 2017

By Carolyn Ruppel, Amanda W.J. Demopoulos, and Nancy Prouty

The May 2017 Interagency Mission for Methane Research at Seafloor Seeps (IMMeRSS) expedition studied the geology, ecology, chemistry, and physics of methane seeps between Baltimore and Norfolk Canyons on the US Mid-Atlantic margin (Figure 1). IMMeRSS was led by US Geological Survey (USGS) scientists in collaboration with the British Geological Survey (BGS) and with support from NOAA's Office of Ocean Exploration and Research and the US Department of Energy.

The IMMeRSS team used Deep Sea Systems ROV *Global Explorer,* managed by Oceaneering International Inc., to complete five dives from May 3 to May 11, 2017, at water depths of 425 m to 1,450 m (Figure 1). The cruise marked the first time that the University of Delaware's R/V *Hugh R. Sharp* was used for ROV operations in water depths greater than 500 m.

Since 2012, over 600 methane seeps have been discovered between Cape Hatteras and Georges Bank on the US Atlantic margin. The seeps occur from the outer continental shelf (~100 m depth) to the middle of the continental slope (~1,500 m depth), with many located on the uppermost slope (150–450 m depth), just shallower than the landward limit of gas hydrate stability. Only a handful of these cold seep sites have been visited by ROVs or the submersible *Alvin*. During the 2017 IMMeRSS cruise, researchers carried out detailed surveys at seeps where chemosynthetic communities had previously been identified, and conducted discovery dives at recently detected seeps (Figure 2).

A key focus of IMMeRSS was acquiring samples of methane-derived authigenic carbonates, unique seafloor rocks that form in their present locations as a result of microbial processes. BGS scientists are analyzing the carbonates using uranium-thorium radioisotopic methods to constrain the age of methane emissions responsible for the formation of these rocks. To characterize benthic community ecology, researchers sampled chemosynthetic organisms such as mussels and surveyed the distribution of benthic biota along video transects that crossed seep fields. Biogeochemical data acquired from the organisms, surrounding sediment, and deep ocean waters are being analyzed to determine how environmental factors affect seep ecology. Researchers also collected samples that can be used to infer whether microbial processes or processes like those responsible for petroleum formation produce the methane that is leaking at the seeps.

Outreach activities included real-time video streaming of the ROV dives to onshore web portals managed by OER and Oceaneering International Inc. The video stream received more than 22,000 individual views, with the highest number accessing the portal when an intact baleen whale skeleton was found on the seafloor. The image-only video stream was supplemented with real-time social media updates coordinated by the USGS. The Facebook posts increased likes, reach, and engagement for the USGS Coastal and Marine Geology page by more than 2,000% according to detailed analytics compiled during the IMMeRSS cruise.

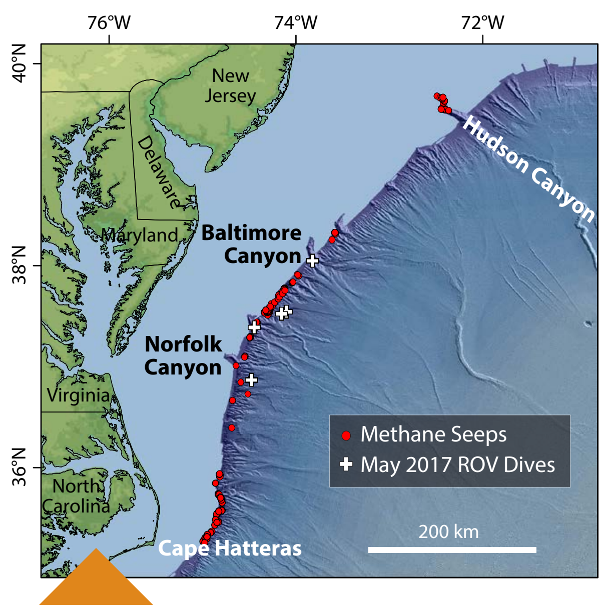


Figure 1. Map showing location of methane seeps (red circles) and dives led by the USGS using ROV *Global Explorer* from R/V *Hugh R. Sharp* in May 2017.

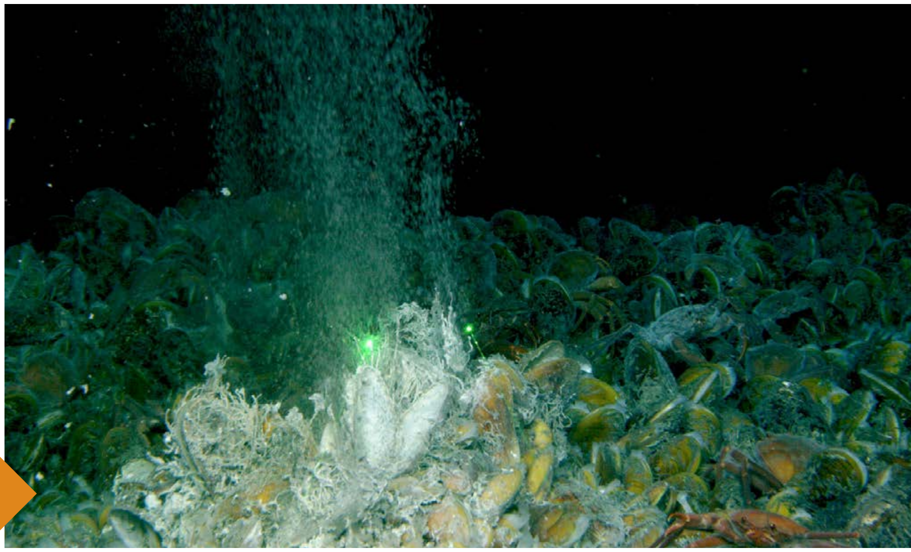


Figure 2. A newly discovered methane seep at approximately 1,000 m water depth offshore Virginia. The bubbles are emanating from a densely populated field of *Bathymodiolus* mussels. Lasers (green dots) are separated by 10 cm. *Image credit: USGS*

Innovative Observing Approaches to Better Understand the Big Picture

By Gabrielle Canonico and Margot Bohan

NOAA's Office of Ocean Exploration and Research provides funds for and advocates on behalf of two independent, complementary ventures that are tapping into new methods for observing the marine environment. The NOAA California Cooperative Oceanic Fisheries Investigations (CalCOFI) Genomics Project (NCOG) and the US Marine Biodiversity Observation Network (MBON) place high value on biological observing to increase our understanding of the Great Lakes, coasts, and ocean, and to augment existing ecosystem assessment and monitoring efforts.

Since 2014, as a component of CalCOFI, NCOG scientists have sequenced marine rDNA and mRNA and conducted associated bioinformatics to identify and quantify microbial organisms and their functions within the context of physical and chemical conditions in the southern California Current ecosystem. Understanding the sensitivity of marine microbial populations to natural and anthropogenic stressors will expand our current insights into ecosystem resiliency, enabling us to better predict environmental tipping points.

MBON scientists working on three demonstration projects (Arctic, Santa Barbara Channel, and National Marine Sanctuaries MBON) are also collaborating to define and develop common biological observing methods and standards to be used as model practices for a national biodiversity observing network. They are making progress on molecular eDNA techniques to evaluate habitat and multi-trophic-level diversity. This novel approach will aid in the detection of significant change in biodiversity (Figure 1) over time, and help identify invasive species. MBON teams are also focused on multivariate remote-sensing techniques to evaluate dynamic seascapes from regional to global scales, enhancing the spatial footprint of in situ observations.

To maximize sustainable use of ocean resources for economic growth and to improve livelihoods and jobs, we need refined tools such as those stemming from NCOG and MBON to provide a fuller, more integrated picture of how our ecosystems function.

Figure 1. Marine biodiversity is key to ocean health and human well-being. *Image credit: Gustav Paulay and Steve Haddock*

Northern Neighbors: Transboundary Exploration of Deepwater Communities

By Martha Nizinski and Caitlin Adams

In June 2017, a team of scientists aboard NOAA Ship *Henry B. Bigelow* spent 14 days at sea exploring canyon and slope habitats off the coast of the northeast United States and Atlantic Canada. Using the Canadian Scientific Submersible Facility's (CSSF) ROV ROPOS, the team targeted minor canyons between Nygren and Heezen Canyons (United States; Figure 1), Georges and Corsair Canyons and Fiddler's Cove (Canada), and sites in western and central Jordan Basin in the northern Gulf of Maine (United States, Canada; Figure 2).

The research team completed 11 ROV dives between 152 m and 1,200 m depth for a total of 180 hours of bottom time. Over 125 physical samples were collected for studies on taxonomy, population connectivity, coral reproduction, age, and growth.

This expedition was the second transboundary US–Canada collaboration; the first was completed in 2014. Through this partnership and sharing of resources, an international team of scientists has gained a better understanding of deep-sea communities on both sides of the border. The data collected both support science and provide resource managers with information to better inform management and conservation actions. In fact, the majority of sampling locations were selected based on the data needs of the New England Fishery Management Council and the Department of Fisheries and Oceans Canada. This collaboration also supports NOAA interests in the Galway Statement on Atlantic Ocean Cooperation and the newly formed ASPIRE campaign (pages 97–101).

Figure 1. A diverse assemblage of deep-sea corals found on a ledge in an unnamed canyon between Heezen and Nygren Canyons (United States). *Image credit: Northern Neighbors: Transboundary Exploration of Deepwater Communities*

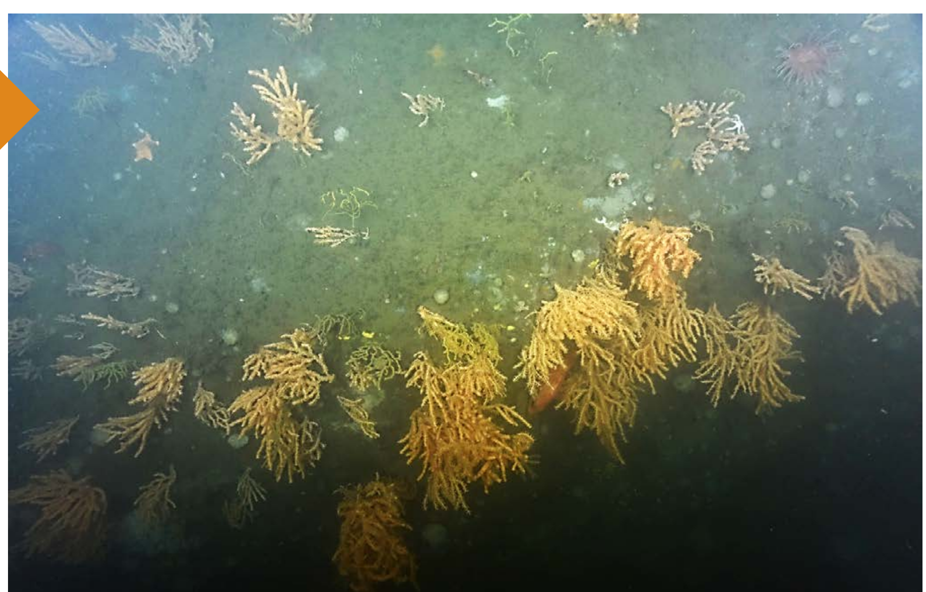


Figure 2. A coral garden found on a large outcrop in western Jordan Basin, northern Gulf of Maine (United States). *Image credit: Northern Neighbors: Transboundary Exploration of Deepwater Communities*

Innovative Nitrogen Sensor Maps the North Pacific Oxygen Minimum Zone

By Craig McNeil, Eric D'Asaro, Andrew Reed, Mark A. Altabet, Annie Bourbonnais, and Chris Beaverson

Oxygen minimum zones (OMZs) play important roles in regulating the ocean's global carbon and nitrogen cycles. In these functionally anoxic waters, denitrifying and anammox (short for anaerobic ammonium oxidation) microbes remove nitrogenous nutrients from the biosphere by transformation to biologically unavailable nitrogen gas (N_2). A newly developed sensor can detect this "excess" N_2 in OMZ regions in order to quantify these nitrogen-loss processes. The near-term goal is to explore OMZs and collect high-quality excess N_2 data to document their baseline inventories. The long-term objective is to determine if excess N_2 inventories in OMZs are increasing as a result of ocean deoxygenation (Stramma et al., 2008; Schmidtko et al., 2017).

N_2 Sensor. Although this new gas tension device (GTD; McNeil et al., 2006) was designed as a low cost, fast response profiling sensor for NOAA Ship *Okeanos Explorer*'s CTD, it could easily be deployed on AUVs, wire crawlers, and gliders. Concentration of N_2 in anoxic waters is derived from gas tension using Henry's Law and expressed as excess N_2, or ΔN_2, relative to atmospheric equilibrium. A standard dissolved oxygen probe compensates the GTD signal for O_2 in hypoxic waters. Biogenic production of N_2 is evidenced by $\Delta N_2 > 0$.

Sensor tests were performed on *Okeanos Explorer* in October 2017 while the ship transited the eastern tropical North Pacific OMZ during a multibeam bathymetry survey (Figure 1). This is the first instance of an OER Federal Funding Opportunity project that leverages *Okeanos Explorer's* capabilities.

Preliminary Results. With the ship on station and the new sensor mounted, the CTD was lowered to a depth of 600 m to soak for 10 minutes to equilibrate heat and gases with the surrounding seawater. After Niskin bottles were triggered, the CTD was raised to the next sampling depth. Repeating this procedure approximately 10 times during the same cast created accurate vertical profiles of dissolved O_2 and N_2. Ten casts during the cruise provided approximately 100 samples.

The measurements (Figure 2) show strong vertical and longitudinal variability. Several layers of waters with different properties are indicated, including: (1) a warmer, fresher, aerated and well-mixed near surface layer; (2) a subsurface layer at 80–200 m depth with minimum salinity; and (3) a weakly stratified deeper layer at 300–600 m depth with low O_2. High ΔN_2 was found in the upper layer of the low O_2 waters, consistent with organic matter export from the sea surface fueling microbial denitrification there. Strong longitudinal variability in O_2 was observed with generally lower O_2 and shallower oxycline toward the east, and minimum O_2 in the OMZ core region. Peak ΔN_2 was found in the OMZ core region at 60–300 dbar. Further analysis will consider mixing effects and the source water supply of ΔN_2 to the region.

The new sensor appears to have worked well and allowed real-time measurement of ΔN_2 on the ship. During post-cruise analysis, these ΔN_2 measurements will be compared to independent estimates derived from N_2/Ar ratios by mass spectrometry and biogenic N_2 using nutrient data.

Figure 1. Map showing 10 CTD stations (red markers) along the cruise track of NOAA Ship *Okeanos Explorer* between Hawai'i and Panama that crosses the eastern tropical North Pacific oxygen minimum zone where loss of nitrogen-based nutrients to N_2 gas occurs (approximate location of high N_2 regions indicated by the shaded gray region. *Image credit: Google Earth overlay with high N_2 regions taken from Figure 1 in Deutsch et al. (2014)*

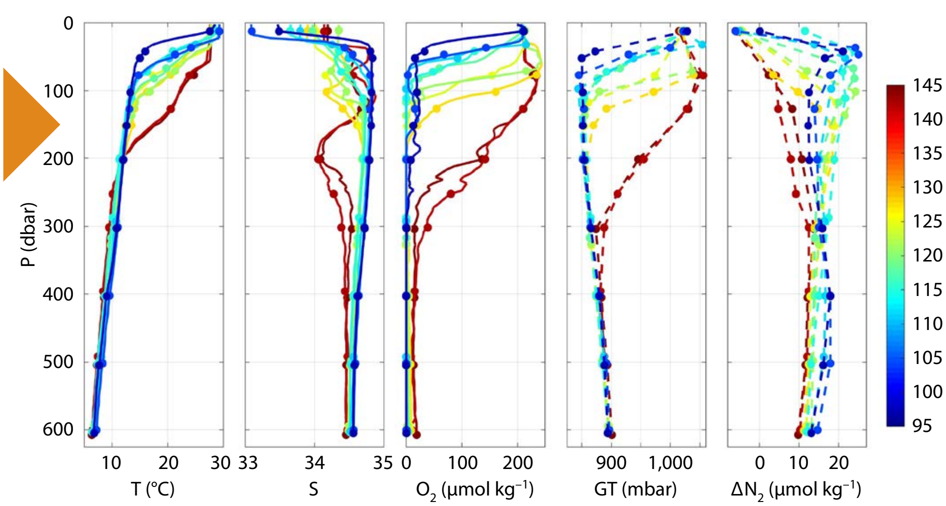


Figure 2. Preliminary data collected at 10 CTD stations (refer to map in Figure 1) showing vertical profiles (plotted to hydrostatic pressure P) of seawater temperature (T), salinity (S), and dissolved oxygen concentration (O_2) collected by an SBE 43 electrochemical sensor; gas tension (GT) measured by the new sensor described here; and derived excess nitrogen concentration (ΔN_2). Data are color coded by longitude (see color bar). Solid lines indicate depth binned (5 m) CTD data and dashed lines linear interpolation between equilibrated data points (colored dots). Intercalibrations and data quality control will be performed during post-cruise analysis.

Realizing Capabilities Through Broad and Expanding Partnerships

Without partnerships, NOAA could not fully realize its potential for ocean exploration. The partnerships featured in this section, DEEP SEARCH and SEDCI, are representative of the broad, integrative coalitions that help the national ocean exploration community meet its goals. In 2018, these partners will work in close communication with the NOAA Ship *Okeanos Explorer* team to align cruise planning and exploration opportunities in the Gulf of Mexico and Atlantic Ocean. These efforts are components of the ASPIRE campaign, a large cross-Atlantic basin effort in support of the 2013 Galway Statement on Atlantic Ocean Cooperation, an initiative between the United States, Canada, and the European Union to advance knowledge of the Atlantic Ocean to improve stewardship and understanding.

DEEP SEARCH: Deep Sea Exploration to Advance Research on Coral/Canyon/Cold Seep Habitats

By Erik Cordes, Amanda W.J. Demopoulos, Gregory Boland, and Caitlin Adams

Launched in August 2017, Deep Sea Exploration to Advance Research on Coral/Canyon/Cold seep Habitats (DEEP SEARCH) is a multiyear, multi-agency study to characterize the deep-sea ecosystems of the US Mid- and South Atlantic (Figure 1). The study is funded through an interagency partnership between NOAA, the Bureau of Ocean Energy Management (BOEM), and the US Geological Survey, and it is sponsored by the National Oceanographic Partnership Program. DEEP SEARCH will spend four and a half years (from 2017 to 2021) researching the habitats of the US Atlantic to better understand the distribution of sensitive seafloor communities to inform potential offshore energy development and other deep-sea management needs.

With DEEP SEARCH, each agency is contributing in a distinct way. BOEM initiated the work with its studies development plan and contracted TDI-Brooks International Inc. through a competitive award process to conduct the research. The USGS identified five complementary research areas integrated into the study and is supporting the participation of collaborating investigators. NOAA's Office of Ocean Exploration and Research is providing the assets (ship and submersible), as well as expedition coordination, data management, and engagement support, for all research cruises.

TDI-Brooks has assembled an interdisciplinary team, led by author Erik Cordes, with scientists from six US institutions: Temple University, University of New Hampshire, Nova Southeastern University, University of Georgia, Florida State University, and Harvey Mudd College.

From September 12 to 22, 2017, Chief Scientist Amanda Demopoulos, the lead of the USGS component of DEEP SEARCH, completed the first expedition aboard NOAA Ship *Pisces*, using AUV *Sentry* to survey the seafloor and collect baseline imagery of gas seep habitats and deep-sea coral

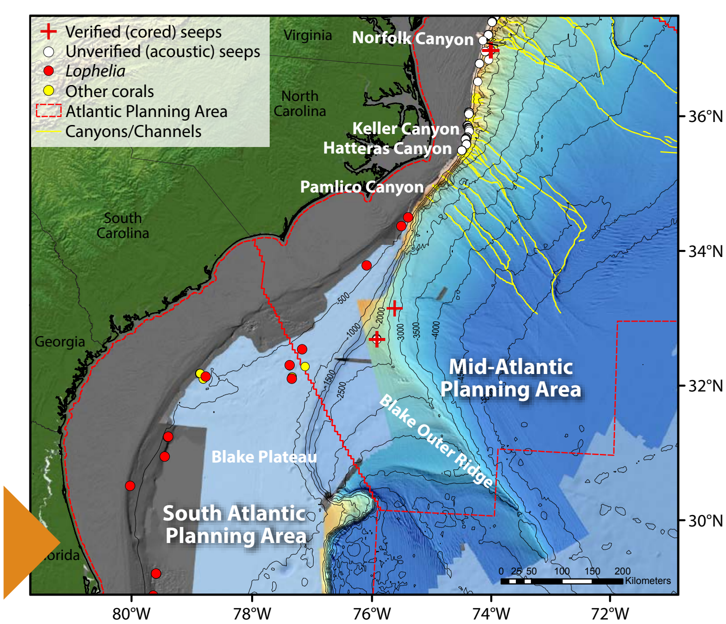


Figure 1. Map showing the full extent of the DEEP SEARCH study area. *Image credit: NOAA OER/BOEM/USGS*

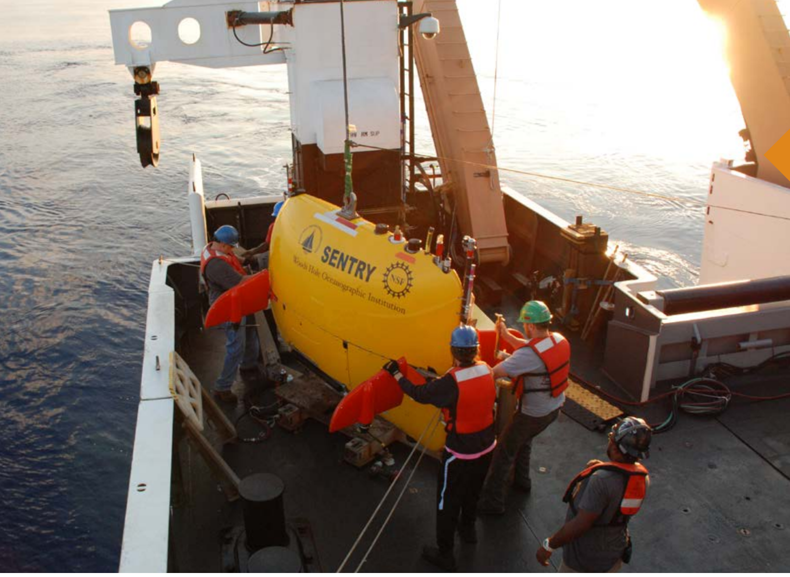
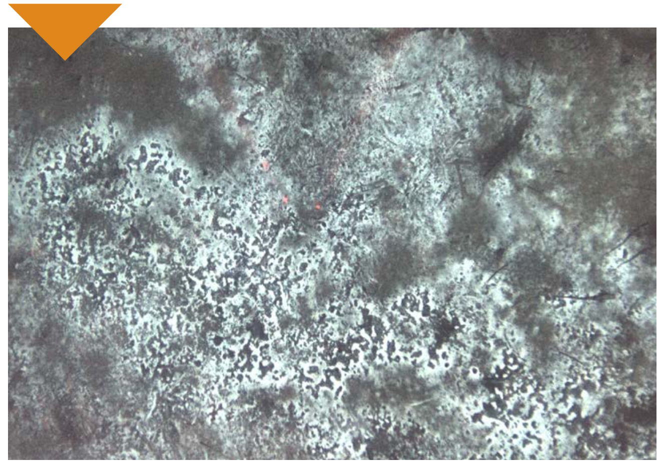


Figure 2. AUV *Sentry* is secured into its cradle following completion of the DEEP SEARCH 2017 expedition aboard NOAA Ship *Pisces*. *Image credit: NOAA OER/BOEM/USGS*

Figure 3. AUV *Sentry* captured this image of an extensive bacterial mat (white areas) at an unverified seep target off the coast of North Carolina. *Image credit: NOAA OER/BOEM/USGS*



features (Figure 2). During this expedition, *Pisces* mapped 44.7 km (linear distance) of seafloor, and *Sentry* mapped an additional 145 km (linear distance) of seafloor. Despite three hurricanes, three *Sentry* dives were completed; two surveyed previously unverified seeps located offshore of North Carolina (Figure 3), and one investigated a potential coral habitat located off South Carolina. The team ground truthed several unverified seeps, imaged multiple seep habitats, and collected corresponding acoustic sub-bottom and backscatter data. The deep-sea coral habitat data will inform future dives in this area and determine the siting of benthic landers that will provide continuous environmental data around these features. Lastly, water column and sediment samples were collected using the ship's CTD rosette and monocore to help better understand the explored environment.

In 2018 and 2019, there will be additional DEEP SEARCH expeditions to the US Mid- and South Atlantic to expand the study area and further investigate these sensitive habitats using a submersible to capture video of the seafloor and collect samples. Each year of the study, scientists will collect data to better understand the functional roles of these hardbottom habitats where environmental complexity influences the distribution and abundance of deep-sea organisms, including many commercially important species. The knowledge generated by this work will improve our ability to predict sensitive areas of the deep sea and inform future management decisions in the region.

Southeast Deep Coral Initiative: Exploring Deep-Sea Coral Ecosystems off the Southeast United States

By Daniel Wagner, Peter J. Etnoyer, Martha Nizinski, George P. Schmahl, Emma Hickerson, Travis Sterne, and Marissa Nuttall

In 2016, NOAA launched a four-year initiative to study deep-sea coral ecosystems in waters off the southeast United States (Figure 1). This multidisciplinary effort, known as the Southeast Deep Coral Initiative (SEDCI), is led by a NOAA team from multiple offices and works in collaboration with partners from federal and academic institutions. Funding for SEDCI is provided primarily through NOAA's Deep Sea Coral Research and Technology Program.

SEDCI builds on previous multi-agency collaborations aimed at increasing our understanding of the deep sea. Most recently, CAPSTONE completed a successful study of deep-sea habitats across the Pacific. Modeled after CAPSTONE in many ways, SEDCI's goals are to collect and provide data to support science-based decision-making and to ensure public access to this information.

SEDCI's priorities were developed in consultation with fishery management councils and national marine sanctuaries, as well as partners from the Bureau of Ocean Energy Management, US Geological Survey, and academic institutions (Schull et al., 2016; Wagner et al., 2017). Through this collaborative approach, SEDCI strives to collect information needed by agencies that manage deep-sea coral ecosystems.

SEDCI fieldwork started in 2016 with expeditions to the northwestern Gulf of Mexico and submarine canyons off North Carolina. Fieldwork continued in 2017, with expeditions that returned to these areas and to additional habitats on the West Florida Slope (Figure 2).

North Carolina Canyons

During 2016–2017, NOAA's Office of Ocean Exploration and Research and SEDCI provided support for two expeditions aboard NOAA Ship *Pisces* that explored five submarine canyons off North Carolina. Using AUV *Sentry*, 10 dives to depths between 700 m and 2,000 m were conducted, totaling 150 hours of bottom time and covering a distance of over 200 km. In addition to AUV surveys, monocore sample collections, multibeam mapping, and CTD casts were performed in order to further characterize canyon habitats. Preliminary analyses revealed the presence of deep-sea corals in each surveyed canyon. However, coral diversity and abundance varied widely, with each canyon appearing to have its own signature.

Gulf of Mexico Northwestern Banks

Flower Garden Banks National Marine Sanctuary's (FGBNMS) R/V *Manta* supported 2016–2017 surveys of mesophotic and deepwater banks in the northwestern Gulf of Mexico. Using ROV *Mohawk*, these expeditions surveyed depths between 50 m and 200 m on 12 banks, all of which are under consideration for expansion of FGBNMS. Seventy-seven dives yielded over 75 hours of bottom time, and included visual surveys as well as biological specimen collections to support taxonomic and phylogenetic studies. A total of 119 biological specimens were collected, including several black corals that represent new species based on preliminary observations. Furthermore, many, but not all, banks hosted dense communities of corals and other invertebrates, highlighting the importance of these surveys to support management decisions.

West Florida Slope

In August 2017, NOAA Ship *Nancy Foster* supported deep-sea surveys on the West Florida Slope using ROV *Odysseus* that focused primarily on four areas that are under consideration for new habitat areas of particular concern (HAPC). A total of 13 ROV dives collectively surveyed 13 km of seafloor during 51 hours of bottom time. Large aggregations of corals were documented within all proposed HAPCs (Figure 2). Additionally, 53 biological samples were collected for studies on population connectivity, taxonomy, age, and reproduction. In addition to ROV dives, the expeditions included CTD casts and multibeam mapping of over 2,750 km^2 of seafloor.

Conclusion

While the 2016–2017 SEDCI expeditions provided a great amount of information, much remains to be done. In late 2017, NOAA Ship *Okeanos Explorer* returned to the Atlantic to support exploration in the Gulf of Mexico and North Atlantic. These expeditions will support not only SEDCI, but also other multi-agency collaborations such as DEEP SEARCH and ASPIRE. Given the vast expanses of seafloor that remain to be explored, collaborations among numerous partners will continue to be essential for advancing our understanding of the deep sea.

Figure 2. A thorny tinselfish, *Grammicolepis brachiusculus*, swims above a dense aggregation of *Lophelia pertusa* and the squat lobster *Eumunida picta* at 496 m depth on the West Florida Slope. *Image credit: NOAA SEDCI-Pelagic Research Services*

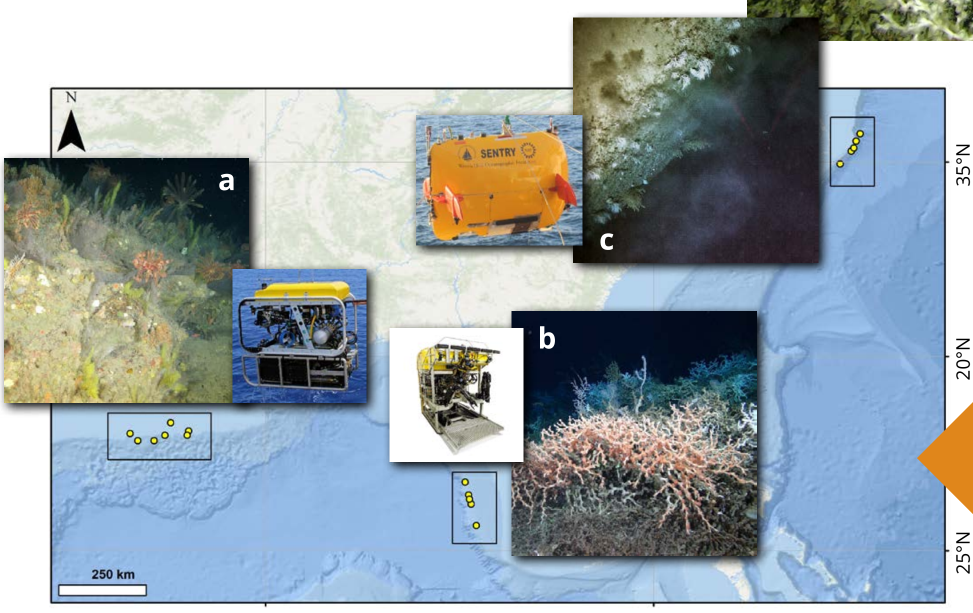


Figure 1. Map showing areas surveyed using deep-sea submersibles during SEDCI-funded expeditions in 2016–2017. These areas include (a) deepwater banks in the northwestern Gulf of Mexico surveyed using ROV *Mohawk*, (b) West Florida Slope habitats surveyed by ROV *Odysseus*, and (c) submarine canyons off North Carolina surveyed using AUV *Sentry*. *Map credit: NOAA*

2018: A Shift in the Focus of Deep-Sea Exploration

Daniel Wagner, Scott C. France, and Caitlin Adams

In 2017, CAPSTONE completed its successful three-year effort to explore deep-sea habitats across the central and western Pacific Ocean. As the deepest part of Earth's ocean, this region has few landmasses and a remoteness that has presented logistical challenges for studying its vast resources. Through CAPSTONE, NOAA and numerous partners from federal and academic institutions mapped, surveyed, and sampled deep-sea habitats, the vast majority of which had never before been explored. The telepresence exploration aboard NOAA Ship *Okeanos Explorer* focused on areas in and around national marine sanctuaries and monuments, providing a great wealth of publicly available data to support decision-making.

In addition to collecting the first high-resolution maps, images, and video footage of numerous deep-sea areas in US waters of the Pacific, CAPSTONE also marked the first-ever collection of geological and biological specimens in this region by *Okeanos Explorer*. Rock samples will support studies of the geologic history of Pacific seamounts. Biological specimens were collected if they were suspected to be species new to science, or represented significant range expansions of known species. These specimens, along with the great amount of publicly available video and mapping data collected during CAPSTONE, will support scientific studies for years to come.

Many exciting outcomes from CAPSTONE expeditions have already been published, such as high-resolution maps of submarine features that had never before been mapped, discovery of high-density communities of deepwater corals and sponges (Figure 1) including the largest known sponge on the planet (Figure 2), and the first in situ observations of several deepwater species. Ongoing and future analyses of these data will undoubtedly lead to many more discoveries.

In 2018, *Okeanos Explorer* will shift its geographic focus and support deepwater investigations in the Gulf of Mexico and the North Atlantic (Figures 3 and 4). Major fisheries and substantial oil and gas reserves drive the need for exploration and management in this region. These deep waters are far less remote and better known than the vast expanse of the Pacific Ocean explored during CAPSTONE. While the

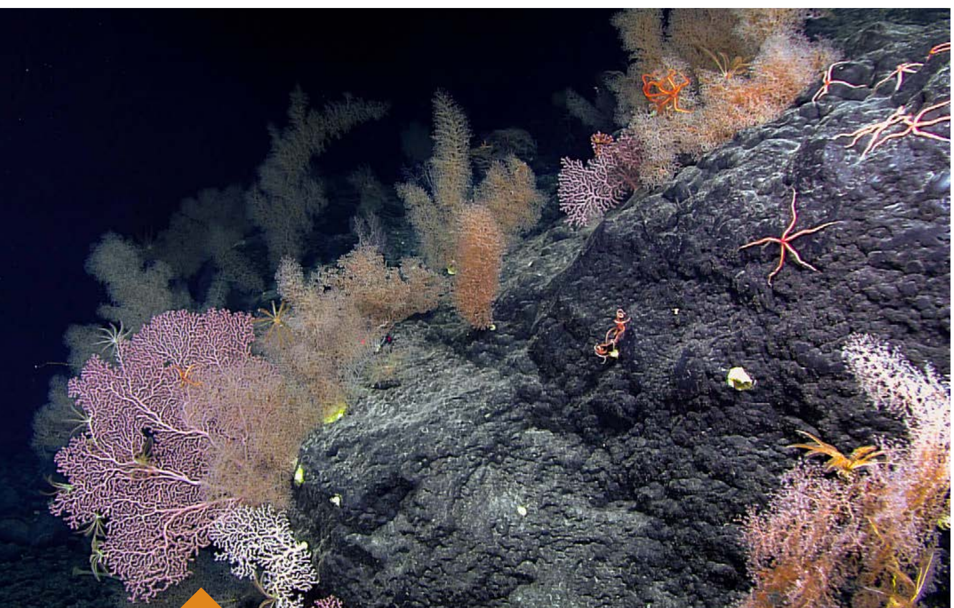


Figure 1. The coral community at Sibelius Seamount was one of several high-density communities discovered during CAPSTONE in the central Pacific.

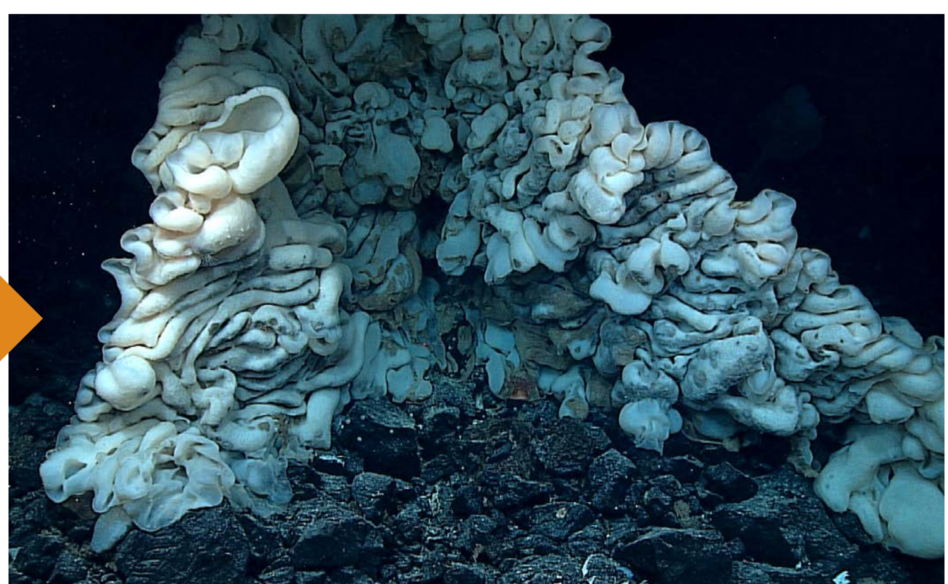


Figure 2. Massive sponge photographed at 2,117 m depth during the 2015 CAPSTONE expedition to the Northwestern Hawaiian Islands.

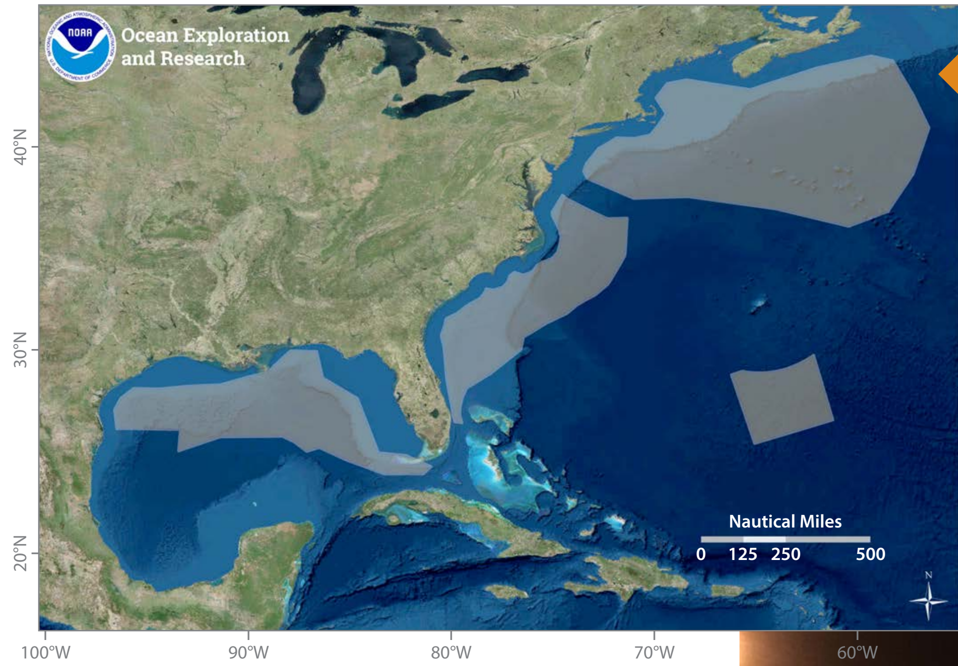
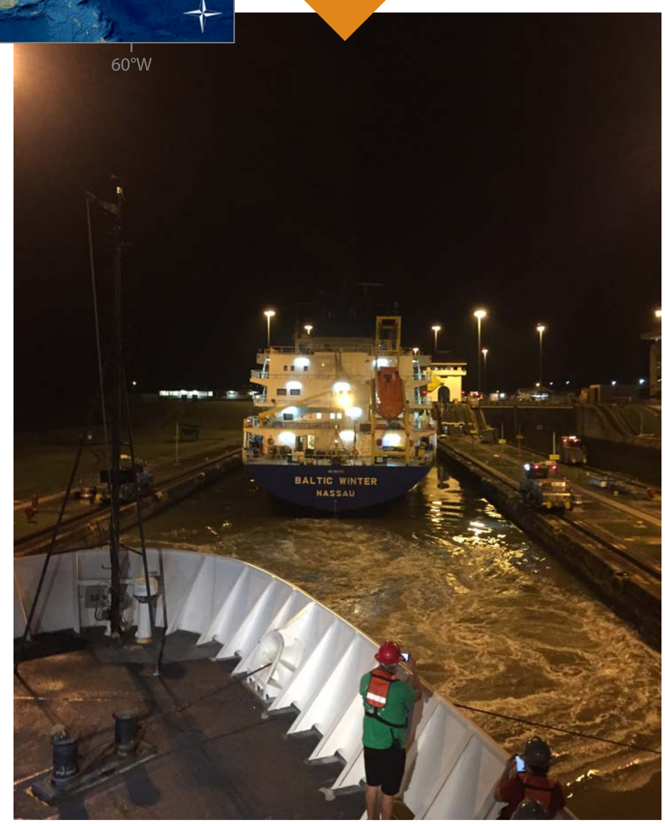


Figure 3. Map showing the region that will be targeted for deep-sea exploration by NOAA Ship *Okeanos Explorer* in 2018. This region includes areas that are the focus of several multi-agency collaborations such as DEEP SEARCH, SEDCI, and ASPIRE. Upcoming fieldwork by *Okeanos Explorer* will support all of these efforts and thereby advance our knowledge of the deep sea.

Figure 4. NOAA Ship *Okeanos Explorer* officially returned to the Atlantic basin on November 15, 2017, when the ship made an overnight transit through the Panama Canal. *Image credit: Commander Eric Johnson*



Atlantic Ocean has been more extensively studied than the Pacific Ocean, much remains to be explored. For instance, the majority of the US EEZ in the Atlantic Ocean has never been mapped at high resolution, and only a tiny fraction of that area has been surveyed by deepwater submersibles.

In contrast to the CAPSTONE expeditions where vast expanses of seafloor were completely unexplored, the planning and selection of targets for future Atlantic expeditions will benefit from, and be guided by, rich existing data sets. Over the years, many programs, institutions, and investigators have explored the deep sea in the Gulf of Mexico and the North Atlantic. Using *Okeanos Explorer,* NOAA's Office of Ocean Exploration and Research conducted a series of successful expeditions in these regions from 2011 through 2015. Collectively, these past explorations will allow us to refine our future exploratory efforts. Furthermore, these past explorations have informed proposals for new management areas, including expansions of the Flower Garden Banks National Marine Sanctuary, potential new habitat areas of particular concern in the Gulf of Mexico, and potential new special management zones in the US South Atlantic. *Okeanos Explorer* will be able to survey many of these proposed managed areas, thereby providing information that is needed to evaluate these proposals.

Much like the successful CAPSTONE effort, future exploration of the North Atlantic and the Gulf of Mexico will continue to require collaborations among myriad partners. With both the DEEP SEARCH study (pages 97–98) and SEDCI (pages 98–99) already working in the region, *Okeanos Explorer* has the opportunity to align field efforts with many existing US federal and academic partners. These efforts, as well as previous expeditions, such as the US-Canadian Northern Neighbors: Transboundary Exploration of Deepwater Communities expedition (page 95), are all part of the ASPIRE campaign, a multiyear, multinational collaborative field program focused on raising our collective knowledge and understanding of the North Atlantic. NOAA is partnering with Canada and the European Union to conduct work in support of the Galway Statement on Atlantic Ocean Cooperation, an initiative to advance knowledge of the Atlantic Ocean leading to improved stewardship and understanding. Only by working together, will we be able to advance our understanding of the deep sea.

R/V *Falkor*, pictured here recovering ROV *SuBastian* near Palmyra Atoll during the Unraveling Ancient Sea Level Secrets research cruise, has been conducting scientific expeditions for five years.

PART 3

Schmidt Ocean Institute – R/V *Falkor*

Five Years of Research Aboard R/V *Falkor*

By Carlie Wiener, Victor Zykov, and Victoria Sindorf

In 2017, Schmidt Ocean Institute (SOI) celebrated five years of research aboard its research vessel *Falkor* after a series of science shakedown cruises in 2012. To date, 42 expeditions have been conducted in all parts of the ocean, logging more than 416,820 km—the equivalent to seven trips around the globe. Schmidt Ocean Institute remains committed to fostering innovation and using the best platforms and tools, as well as increasing access to data from remote and hard to reach places, to accelerate scientific understanding of our ocean. Through strategic partnerships, SOI leverages expertise and encourages broader community involvement to help marry science and technology. The development of Squidle+, a software platform for annotation of seafloor imagery, is one example of such a collaboration. The program was demonstrated onboard *Falkor* in 2015, and was further developed this year, allowing researchers on the ship to explore, manage, and annotate images collected by the cameras on the Institute's ROV *SuBastian*. Future development of Squidle+ includes looking to sync the local annotations with an online version so that scientists can continue annotating after the cruise or involve collaborators from shore in real time. Open sharing of information and broad collaborations encourage global adoption of effective marine survey and data analysis methods that can lead to more effective ecosystem management practices, risk mitigation strategies, educational materials, and globally relevant conservation policies.

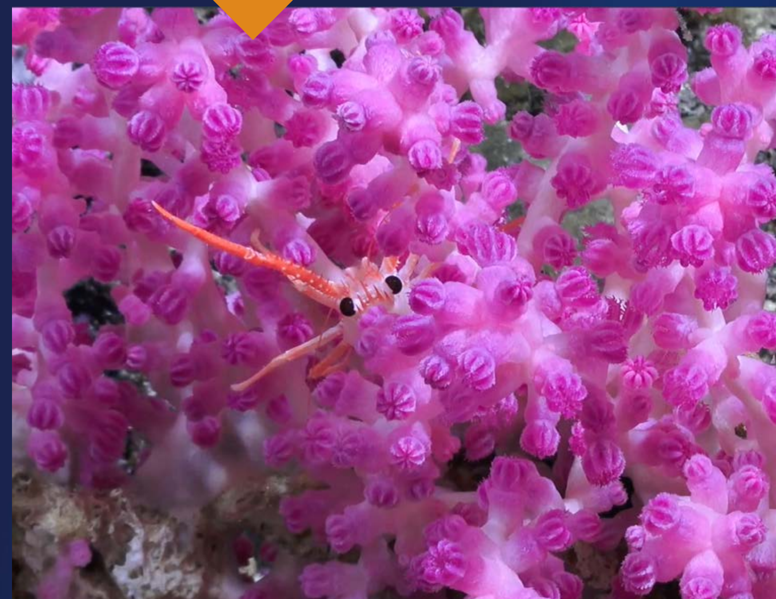
Falkor has been used to support many high-impact research projects that continue to make a difference. The year 2017 was the first full research year for the 4,500 m depth capable ROV *SuBastian*. In the South Pacific, the ROV successfully sampled ancient corals, deep-sea biological samples, and geological treasures, from pillow lavas to active hydrothermal vents. The unique open design of ROV *SuBastian* allows scientists to incorporate many instruments and collection systems based on the needs of each expedition. For example, the newly developed "squishy fingers" or soft robotics actuators were tested and redesigned this year during ROV dives in the Phoenix Islands Protected Area within the Republic of Kiribati. This tool development allowed the research team to expand their

ROV *SuBastian* is launched from R/V *Falkor*'s aft deck (from the same cruise as background image). *Image credit: SOI*

R/V *Falkor* at sea during the Unraveling Ancient Sea Level Secrets expedition, which took place off the Hawaiian Island of Moloka'i, as well as Palmyra Atoll and Kingman Reef. *Image credit: SOI*

ROV pilots holding position and operating the hydraulic arms to gather samples of ancient, drowned corals. *Image credit: SOI*

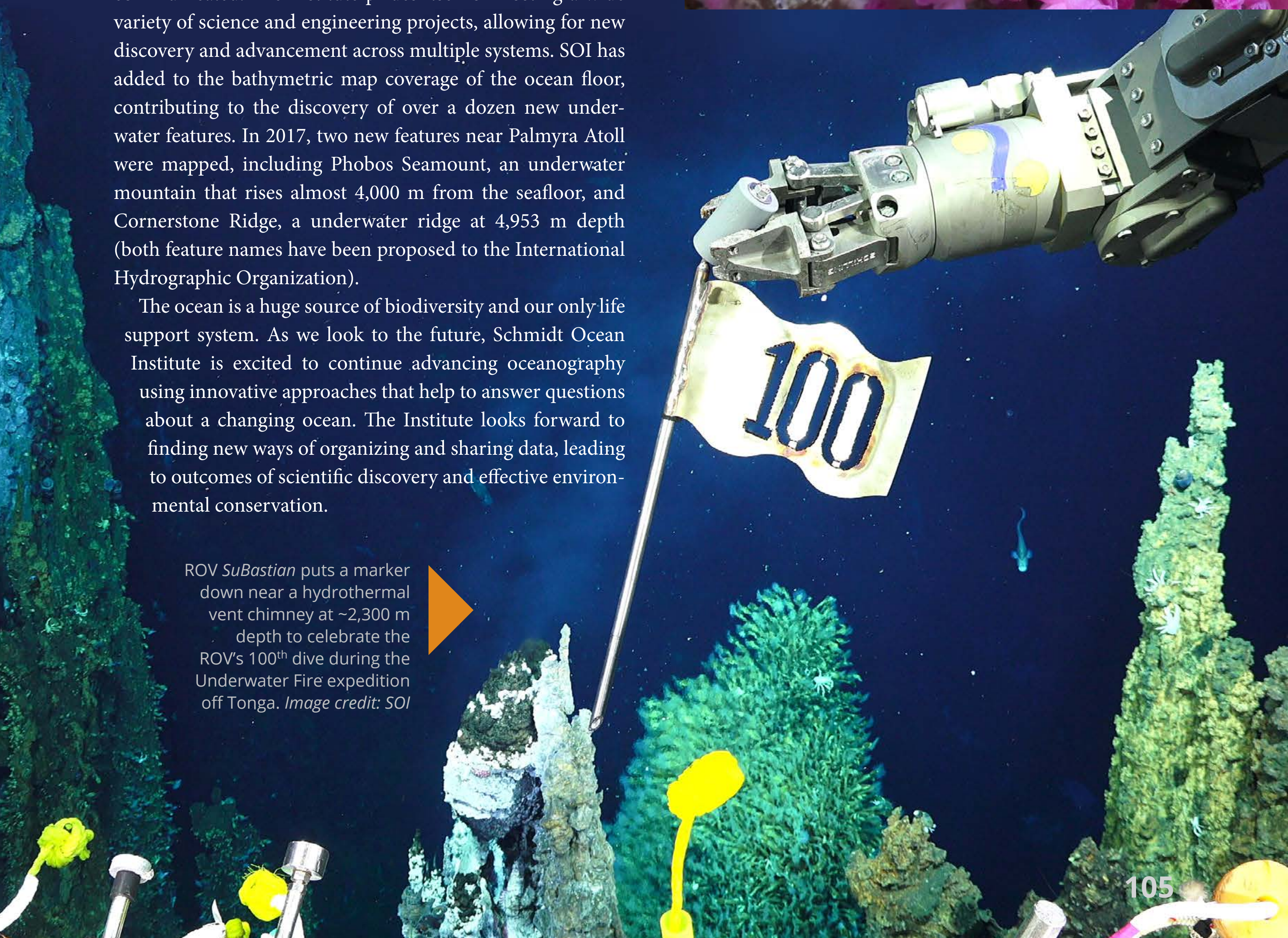
Victorgorgia soft coral with a chirostylid squat lobster associate in the Phoenix Islands, in Kiribati during the Discovering Deep Sea Corals in the Phoenix Islands research cruise. *Image credit: SOI*



collection capabilities to fragile, soft-bodied organisms that could not otherwise be collected intact. ROV *SuBastian* also completed its first 100 dives in 2017, a significant milestone since field testing in 2016. All of the dives have been shared through the Institute's website, YouTube, and (new this year) our Facebook Live page, allowing million of viewers to watch and listen to the expeditions in real time.

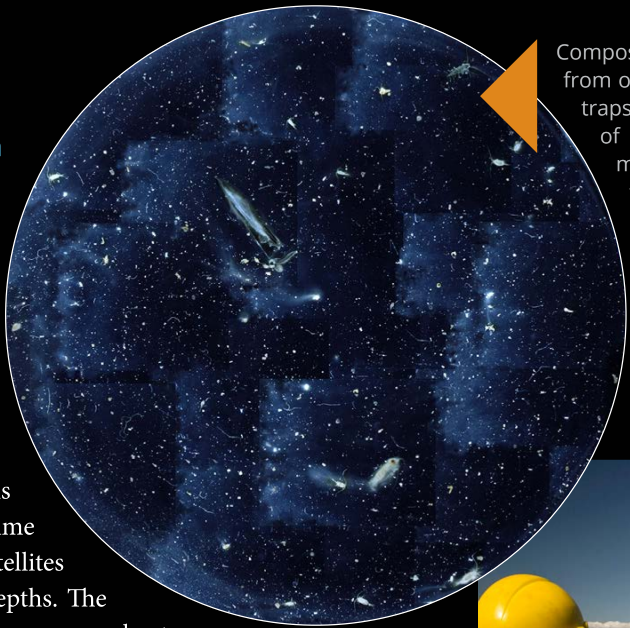
For the past five years, SOI has helped challenge the prevailing paradigm of how ocean research is conducted and communicated. The Institute prides itself on hosting a wide variety of science and engineering projects, allowing for new discovery and advancement across multiple systems. SOI has added to the bathymetric map coverage of the ocean floor, contributing to the discovery of over a dozen new underwater features. In 2017, two new features near Palmyra Atoll were mapped, including Phobos Seamount, an underwater mountain that rises almost 4,000 m from the seafloor, and Cornerstone Ridge, a underwater ridge at 4,953 m depth (both feature names have been proposed to the International Hydrographic Organization).

The ocean is a huge source of biodiversity and our only life support system. As we look to the future, Schmidt Ocean Institute is excited to continue advancing oceanography using innovative approaches that help to answer questions about a changing ocean. The Institute looks forward to finding new ways of organizing and sharing data, leading to outcomes of scientific discovery and effective environmental conservation.



ROV *SuBastian* puts a marker down near a hydrothermal vent chimney at ~2,300 m depth to celebrate the ROV's 100th dive during the Underwater Fire expedition off Tonga. *Image credit: SOI*

R/V *Falkor* in 2017



Composite image of findings from one of the gel sediment traps, created from a series of photos taken with a microscope. Aggregates, fecal pellets, phytoplankton, zooplankton, and other particles can be identified. *Image credit: Melissa Omand, University of Rhode Island*

Sea to Space Particle Investigation

– Chief Scientist Ivona Cetinić, NASA Goddard Space Flight Center

Technological advancement and innovation abounded on a 25-day expedition across the Pacific, where a multidisciplinary team of oceanographers, engineers, biologists, and computer scientists debuted numerous new instruments aimed at measuring phytoplankton community dynamics. This expedition allowed scientists for the first time to follow particles identified with NASA satellites through the surface of the ocean to ocean depths. The ground-truthing analysis is aimed at developing more robust methods of studying phytoplankton and nutrient cycles through remote sensing, but early results also reveal some unexpected players in oceanic carbon export. Time-lapse sediment trap and holographic cameras provided new imagery and data about particle size distribution, collecting over one million images and over two billion continuous hyperspectral data points. Used in connection with the NASA-funded Flow Extended Range Particle Sensor, these data will allow the development of mathematical models to differentiate types of phytoplankton observed with next-generation satellites. Never-before-used, near-real-time virtual reality allowed scientists to immerse themselves in the data, and it continues to be an effective investigative and educational tool.

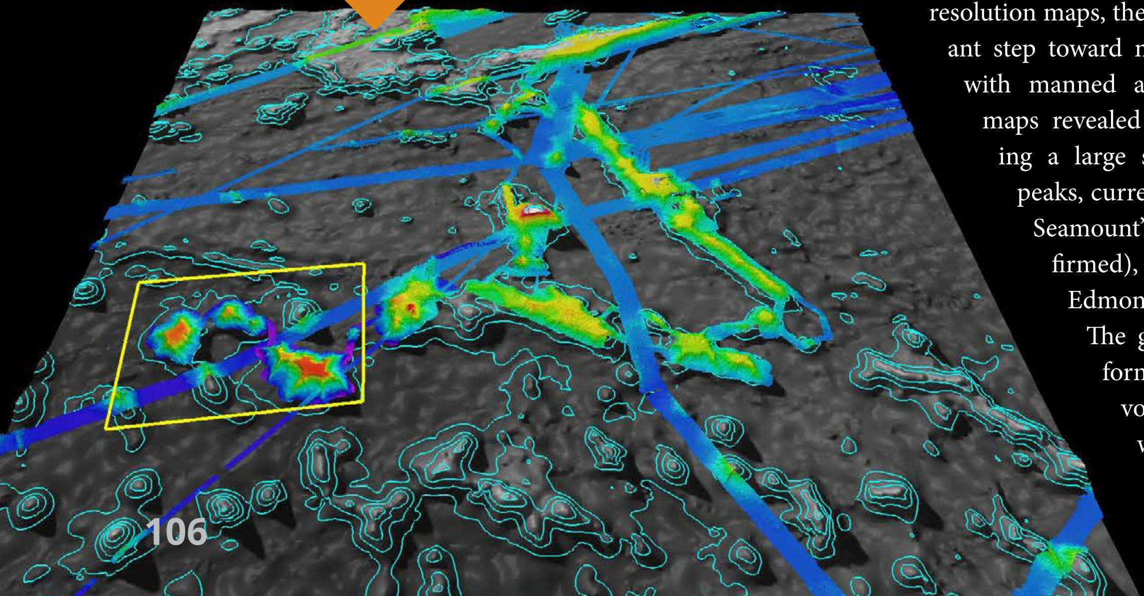
Melissa Omand deploys a sediment trap during the Sea2Space research cruise, which aimed to improve the accuracy of particle size distribution products gathered from satellite and remote-sensing data. *Image credit: SOI*

Eyes Below: Mapping Johnston Atoll

– Chief Scientist John R. Smith, University of Hawai'i at Mānoa

R/V *Falkor's* first expedition of 2017 was conducted around Johnston Atoll in the Pacific Remote Islands Marine National Monument. This region is known to be populated with a high density of deep-sea corals and sponges, and is of particular interest to researchers because it may serve as a stepping-stone between distinct marine ecosystems in the Northwestern Hawaiian Islands and the central and South Pacific. Over 11,000 km^2 of seafloor were mapped using *Falkor's* multibeam sonar system. These high-resolution maps, the first of this area, are an important step toward more focused follow-up studies with manned and robotic submersibles. The maps revealed fascinating structures, including a large seamount dotted with smaller peaks, currently referred to as "Edmondson Seamount" (name to be officially confirmed), after marine biologist Charles Edmondson of the Tanager Expedition. The geologic implications of such a formation suggest that four distinct volcanoes, rising from 5,000 m water depth, merged through eruption and erosion into one large, subsurface mountain.

High-resolution map of seamounts around Johnston Atoll, created from data collected by R/V *Falkor*, January 2017. *Image credit: SOI*



Unraveling Ancient Sea Level Secrets

– Chief Scientist Ken Rubin, University of Hawai'i at Mānoa

Ancient changes in sea level were investigated through their geologic record in fossilized coral reefs around Hawaiʻi using a combination of mapping, observations, and sample collections. As an isolated volcanic island free from major influences of continental plates and glacial dynamics, the "drowned reefs" of Hawaiʻi and the Line Islands offer an ideal geological record for relative sea level reconstruction. The study was designed to look at the impact of sea level change on coral reef structure, morphology, and ecology at the two study sites. The last deglaciation (end of the ice age) represents the last time in Earth history when sea level changed at rates similar to those predicted for the future, so researchers aim to use reefs from this time to help make predictions about future sea level change impacts. The first leg of the expedition focused on mapping with R/V *Falkor's* multibeam system and Woods Hole Oceanographic Institution's AUV REMUS 600. Detailed mapping and imaging of the Penguin Bank region will help to form the basis of an innovative remote-sensing reconstruction of the ice age reef structure. During the second leg of this expedition, ROV *SuBastian* was used to ground truth the mapping data. Nearly 200 coral samples were collected, and they will lead to a vastly improved quantitative understanding of sea level change. The discoveries made regarding the impacts of past sea level change as read through coral reef deposits will improve predictions of future sea level change in Hawaiʻi and elsewhere in the central Pacific Ocean.

ROV *SuBastian* collecting samples of ancient drowned coral around Kingman Reef and Palmyra Atoll. *Image credit: SOI*

Discovering Deep Sea Corals of the Phoenix Islands

– Chief Scientist Erik Cordes, Temple University

Daniel Vogt displays the "squishy fingers" sampling device. *Image credit: SOI*

In 2017, *Falkor* transited to the Phoenix Islands Protected Area (PIPA) in the Republic of Kiribati, one of the largest and deepest UNESCO World Heritage Sites. The team aboard the ship completed 178 hours of diving using ROV *SuBastian*, revealing eight previously unexplored eastern seamounts and atolls, adding knowledge to the initial exploration of the western seamounts by NOAA Ship *Okeanos Explorer.* The live footage from the ROV was streamed from *Falkor* in high definition to the public, revealing new observations of octopus behavior, capturing one of the deepest records of mantis shrimp, and defining seamount habitat zones from the deep sea to the surface for the first time. More than 400 samples of deep-sea coral and a range of coral-associated fauna, sediments, and water were collected using new and existing technology. Daniel Vogt from the Wyss Institute at Harvard University developed new soft robotic actuators, affectionately named "squishy fingers," for the collection of fragile and soft-bodied organisms. Further refined in situ using three-dimensional printing on board *Falkor*, the "squishy fingers" tools successfully collected several specimens whose intact collection would not have been possible otherwise. These samples have contributed to the possible discovery of at least two new species of coral and crab, and have vastly expanded our understanding of deep-sea corals and their associates.

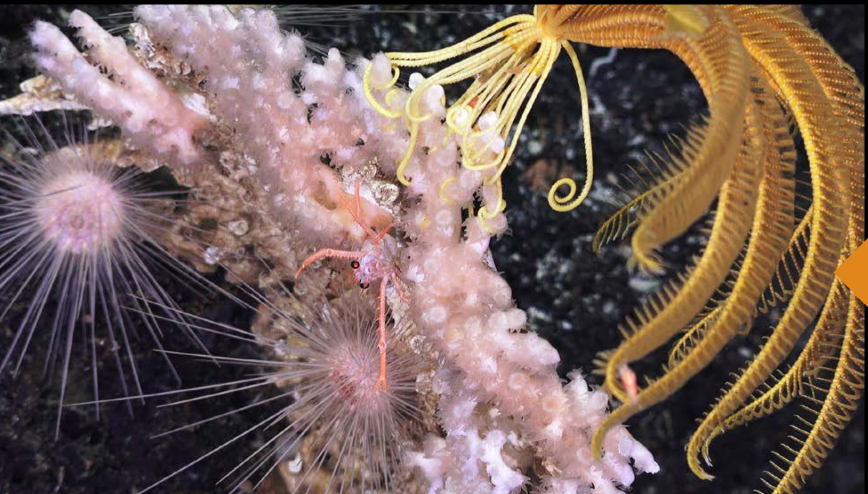


Image of *Enallopsammia*, a scleractinian coral (similar to those that build large coral reefs in shallow water) with associates, including a crinoid, two urchins, and squat lobster. Image collected by ROV *SuBastian* while performing some of the first ROV dives in the Phoenix Islands Protected Area. *Image credit: SOI*

ROV *SuBastian* takes a geological sample from a hydrothermal vent chimney at 2,300 m depth during the Underwater Fire expedition off Tonga. *Image credit: SOI*

Underwater Fire: Studying the Submarine Volcanoes of Tonga

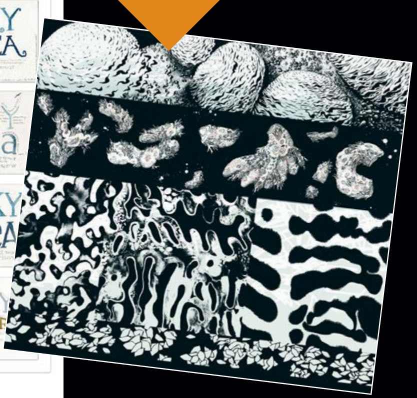
– Chief Scientist Ken Rubin, University of Hawai'i at Mānoa

The Mata Volcano group and neighboring volcanoes in the northern area of the Kingdom of Tonga represents the densest collection of undersea volcanoes in the world. Following recent changes in seafloor depth observed through ongoing mapping efforts by NOAA's Office of Ocean Exploration and Research and R/V *Falkor,* a multidisciplinary team took a two-leg expedition to investigate the region. Prior studies lacked a geologic focus for understanding the diversity of the area's rock types (some among the rarest on the planet), volcanic landforms, and how and why eruptions occurred here. The science team aboard *Falkor* was able to develop a stronger geological underpinning for the history of these volcano sites and their levels of activity. Geological observation; mapping of structures and eruption deposit types; rock, sediment, biological, and hydrothermal fluid sampling; and analysis of rocks and minerals were completed during the 21 dives with ROV *SuBastian*. Sonar mapping with Woods Hole Oceanographic Institution's autonomous underwater vehicle *Sentry* during the expedition's leg one took stock of recent changes on previously mapped volcanoes, producing the first high-resolution maps of six new eruption deposits. This expedition was the first to survey across a suite of 11 volcanoes, permitting investigation into the role of magma generation across a wide array of volcanic sites, ecosystem history, and connectivity between individual volcanoes.

Artists-at-Sea

Our Artist-at-Sea program flourished in 2017. Eleven artists sailed on *Falkor* and displayed their work at a unique traveling exhibit throughout the United States. The exhibit, featuring over 50 pieces inspired by the artists' time at sea, was showcased at several special venues, including America's Cup in Bermuda, the International Ocean Film Festival, Bishop Museum, and Sail Newport. The artists worked with SOI's expedition scientists and *Falkor* crew to create pieces that highlight the science and data collected at sea, bringing ocean-based research to different audiences in new and engaging ways.

Artist-at-Sea Kirsten Carlson documented the various blue shades of the sky and the ocean's surface on the Sea2Space expedition. Watercolor, pencil, and ink.



Sonar backscatter study by Artist-at-Sea Natasha Russell. Gouache and ink on paper.

Young and curious, several children on board R/V *Falkor* for a public tour in Honolulu, Hawai'i, put ROV *SuBastian*'s manipulators to a special quality control test. *Image credit: SOI*

On January 12, 2017, *Falkor* held a ship-to-shore video call with the Mariposa Foundation in the Dominican Republic. Ten-year-old girls learned about the ocean, and met some of the women making the Mapping The Floor expedition possible. *Image credit: SOI*

Gateways to Science – Collaborations and Outreach

Schmidt Ocean Institute fosters partnerships in ocean research, education, and marine operations to leverage expertise, facilities, and programs. Open Vessel Data Management (OpenVDM) software is one example of this partnership. Development of this shipboard sensor data management software was supported by the Institute for several years, and is now being used on many research vessels, including R/V *Helmer Hanssen*, R/V *Atlantic Explorer*, R/V *Endeavor*, and R/V *Annie*/ROV *Yogi*. In 2017, SOI continued to work with its developer, expanding the base version to additionally manage data from deployable platforms such as AUVs and ROVs, including SOI's ROV *SuBastian*.

Other thriving collaborations allowed for broader sharing of information and outreach to the public. SOI worked closely with the teams operating NOAA Ship *Okeanos Explorer* to distribute high-resolution maps of the monuments in the Pacific region along with a map that illustrates joint mapping efforts. These maps were debuted at a day of joint public ship tours in Honolulu, Hawai'i, at the University of Hawai'i Marine Center where over 700 guests toured *Falkor* and *Okeanos Explorer* and learned about the research efforts conducted in 2017, as well as the importance of private and public entity collaborations.

Schmidt Ocean Institute was excited to be able to share some of its high-resolution imagery from the ROV dives with numerous organizations and institutions to create content-rich education videos and live interactive experiences. Footage was showcased in several NASA education videos, BBC's *Oceans 2*, and a documentary about the deep sea from Japan's public broadcaster NHK. In addition to live-streaming ROV dives on the Institute's YouTube channel, SOI also extended live broadcasts to its Facebook page this year. More than three million viewers tuned in to watch real-time science and listen to live commentary from the shipboard scientists. Through our partnerships with aquariums, universities, and school classrooms, we were able to connect science teams aboard *Falkor* to over 90,500 students, allowing them to share their science and answer questions. These interactions created meaningful connections that capture the imagination and inspire continued learning.

Ken Rubin of the University of Hawai'i shows genuine excitement at first viewing of samples of ancient drowned coral collected by ROV *SuBastian* off Penguin Bank, near the island of Moloka'i, Hawai'i. *Image credit: SOI*

Epilogue

By Robert D. Ballard and Alan Leonardi

Exploring our largely unknown ocean is one of the great challenges of our time—and great challenges breed mighty endeavors. NOAA's Office of Ocean Exploration and Research, the Ocean Exploration Trust, and the Schmidt Ocean Institute are meeting this challenge. The accomplishments shared in this supplement to *Oceanography* represent the combined efforts and contributions of many talented individuals and key partnerships, including the financial support of numerous individuals and public and private institutions.

At first glance, ocean exploration is a simple task: determine a place in the ocean no human has ever been to or seen, go to that place, and observe what is there. Yet, as the ocean exploration and ocean science communities know, executing at-sea missions is no simple task. Months, if not years, of planning are required to make sure all of the people, ships and vehicles, instruments, and shore-side capabilities are available at the same time, in the same place, and in top operating condition. Even then, expeditionary teams must remain both agile and flexible as they encounter dynamically changing conditions, such as weather delays and engine or instrument issues, or important new discoveries that require participation of experts ashore.

Given the many challenges at hand, we continually look to strengthen the footprint of our exploration capabilities and expand the reach and impact of our partnerships. In the past few years, we have focused primarily on exploring the vast Pacific Ocean and have deployed new sensors and systems, including enhancements to the existing OER and OET ROVs and bringing a new SOI ROV online.

Moving into 2018 and beyond, we will continue to expand our geographic horizons with NOAA Ship *Okeanos Explorer* migrating east and focusing on the Gulf of Mexico, Caribbean, and Atlantic Ocean and the OET Exploration Vessel *Nautilus* maintaining a presence along the west coast of North America and increasingly operating in the central Pacific Ocean, particularly in and around the Hawaiian Islands. We have also begun working with the US National Science Foundation-funded National Deep Submergence Facility and the Woods Hole Oceanographic Institution to develop expanded ship-independent capabilities for use by the broader oceanographic community, including mobile satellite communications and fly-away 6,000 m ROV capabilities that should be available for community use in the 2019 timeframe. When coupled with capable vessels of opportunity such as the University-National Oceanographic Laboratory System fleet, these soon-to-be-online mobile capabilities will complement our existing dedicated exploration vessels and assets and allow us to access 98% of the world ocean floor.

Given our many accomplishments and our plans for the future, the only questions that remain are: where will we choose to go, and who will join us in these pursuits? Are you ready for the challenge?


Deep-sea corals provide essential habitat for many associated fauna. Here we see a small community of brittle stars, family Ophiacanthidae, and squat lobster, *Munidopsis* sp., at home on a large white coral, *Paracalytrophora* sp. This image was captured on the Musicians Seamounts expedition. *Image credit NOAA OER*

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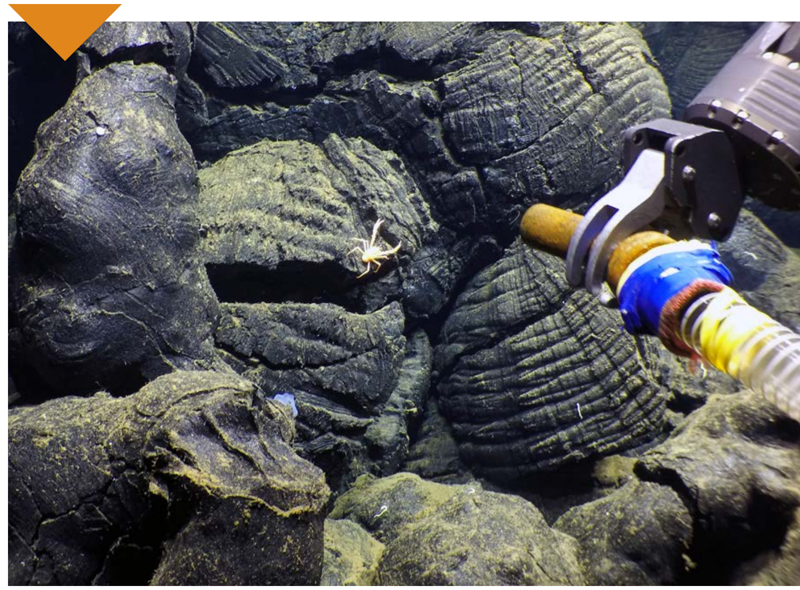
A scorpionfish was observed at 460 m depth next to a mushroom coral during the Musicians Seamounts expedition. Due to its extremely large pectoral fins, the fish was identified as *Setarches guentheri*. Unlike most scorpionfish, which are ambush predators, *Setarches guentheri* swims up into the water column at night to feed. *Image credit: NOAA OER*

ROV *Hercules* prepares to take a suction sample of a galatheid crab on a pillow basalt outcrop on the slope of Socorro Island, Revillagigedo Archipelago, Mexico, from E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*



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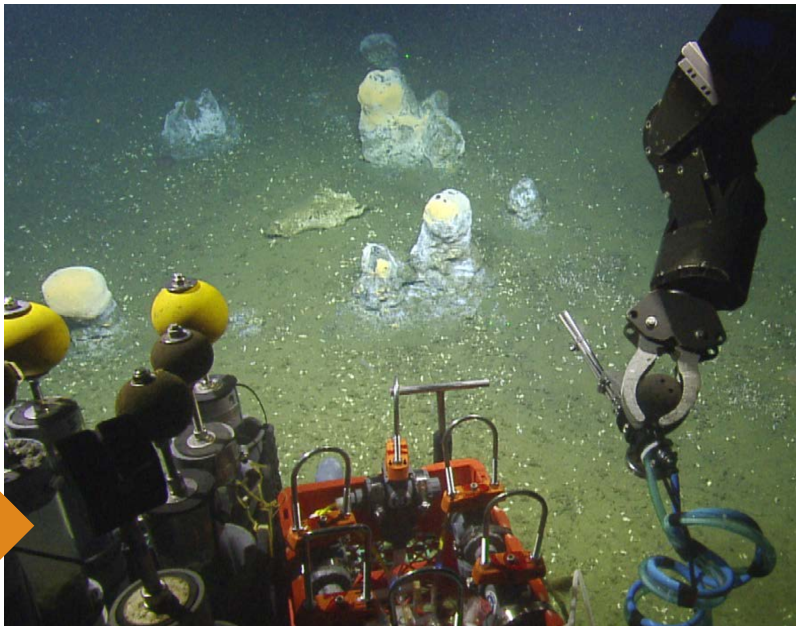
The water column, which consists of all the water in the ocean between the surface and the seafloor, makes up 95%–99% of the total livable volume on Earth, yet it remains one of the most poorly explored environments. This graceful jellyfish, *Poralia rufescens*, was spotted during a dive by ROV *Deep Discoverer* (Musicians Seamounts expedition) that was fully dedicated to exploring the water column. *Image credit: NOAA OER*



ROV *Hercules* manipulator is poised to take geochemical measurements at the Point Dume chimlets off southern California on E/V *Nautilus* cruise NA084. *Photo credit: OET*

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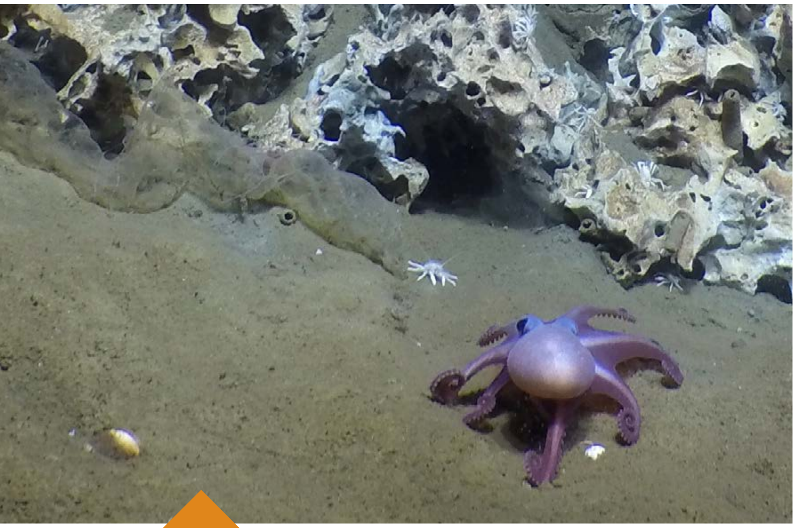
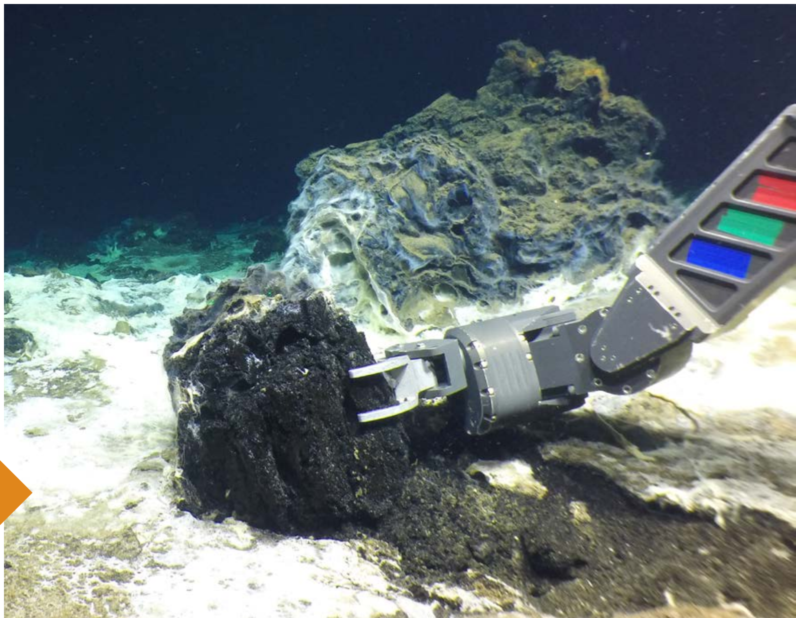


An octopus moves toward a carbonate outcrop in the northern Guaymas Basin, Mexico, vent "El Faro" on E/V *Nautilus* cruise NA090. *Image credit OET*



Sampling of basaltic scoria surrounded by bacterial mat off the coast of Socorro Island, Revillagigedo Archipelago, Mexico, during E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

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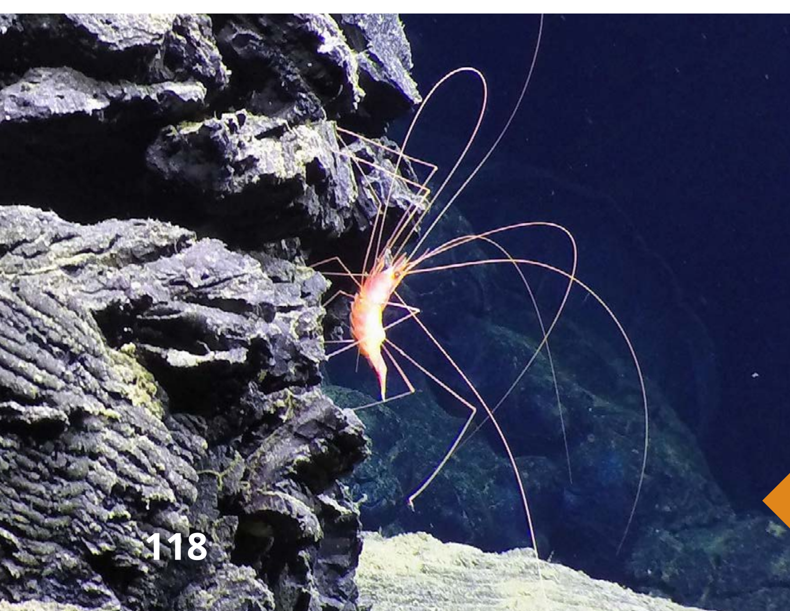

Shrimp on the surface of a pillow lava on the slopes of Socorro Island, Revillagigedo Archipelago, Mexico, from E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

NOAA's Office of Ocean Exploration and Research

In 2017, NOAA's Office of Ocean Exploration and Research mapped over 250,000 km^2 of seafloor using NOAA Ship *Okeanos Explorer*, which ran 24-hour operations that included ROV dives and biological and geological sample collection. Partnerships spanned Pacific Island jurisdictions and included pan-Pacific nations and resource management programs at the international, federal, and state levels, as well as the industry, research, and academic sectors, and education community. CAPSTONE, the unprecedented three-year campaign to map and explore US waters in remote areas of the central and western Pacific, collected critical baseline information, providing insights into US marine resources, including fisheries, energy, minerals, and conservation. The program's accomplishments are a testament to a distinctive network of people with expertise in at-sea and shoreside operations, mapping, science and technology, data management, education, outreach and media, and administrative requirements. In 2017, existing partnerships were strengthened and new ones formed, questions answered and new ones raised, and technologies tested and new ones proposed. The business of ocean exploration improves US technical capability; provides data that helps quantify US ocean resources; and bolsters STEM education, which creates critical thinkers, increases science literacy, and enables the next generation of innovators that leads to new products and processes that sustain our economy. It is with great respect that we acknowledge the collaborative network of people responsible for a productive and successful 2017 ocean exploration season.

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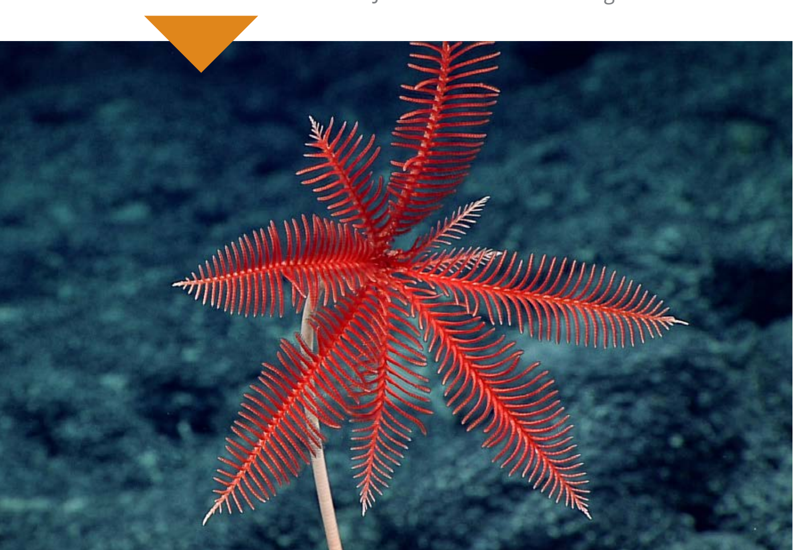
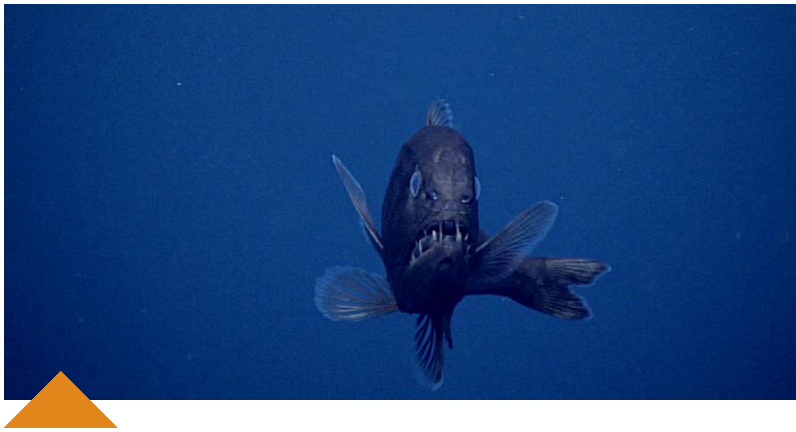
  - » Department of Education, Pago Pago, American Sāmoa
  - » Department of Marine and Wildlife Resources
  - » Department of Port Administration
  - » Office of Samoan Affairs, Tafuna, American Sāmoa
- Government of Sāmoa, Apia, Sāmoa
  - » Department of Port Administration, Apia, Sāmoa
  - » Ministry of Agriculture and Fisheries, Apia, Sāmoa
  - » Ministry of Natural Resources and Environment, Apia, Sāmoa
  - » National University of Sāmoa, Apia, Sāmoa
- Aquarium of the Pacific, Long Beach, CA
- Audubon Aquarium of the Americas, New Orleans, LA
- Birch Aquarium at Scripps Institution of Oceanography, La Jolla, CA
- Bureau of Ocean Energy Management, Sterling, VA
- Canadian Scientific Submersible Facility, North Saanich, British Columbia, Canada
- CollabraLink Technologies Inc., McLean, VA
- Cooperative Institute for Marine and Atmospheric Studies/CIMAS, Miami, FL
- Cooperative Institute of the North Atlantic Region/CINAR, Woods Hole, MA
- Cooperative Institute for Ocean Exploration, Research & Technology/CIOERT, Fort Pierce, FL
- Dalhousie University, Halifax, Nova Scotia, Canada
- Dauphin Island Sea Lab, Dauphin Island, AL
- ERT/Earth Resources Technology Inc., Laurel, MD
- ECOVIDA - National System of Protected Areas, Guanahacabibes National Park, Guanahacabibes, Cuba
- Georgia Aquarium, Atlanta, GA
- Global Foundation for Ocean Exploration, Mystic, CT
- Government of Canada, Fisheries and Oceans, Ottawa, Ontario, Canada
- Government of the Cook Islands, Office of the Prime Minister, Rarotonga, Cook Islands
- Marae Moana, the Cook Islands Marine Park, Rarotonga, Cook Islands
- Great Lakes Foundation, Port Huron, MI
- Harbor Branch Oceanographic Institute - Florida Atlantic University, Fort Pierce, FL
- Hawai'i Institute of Marine Biology, University of Hawai'i, Kaneohe, HI
- IFREMER, Paris, France
- Inner Space Center, Narragansett, RI
- Instituto de la Ciencias del Mar, Havana, Cuba
- Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Kanagawa, Japan
- John G. Shedd Aquarium, Chicago, IL
- Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY
- Lehigh University, Bethlehem, PA
- National Aquarium, Baltimore, MD
- National Institute of Water and Atmospheric Research, Auckland, New Zealand
- New England Aquarium, Boston, MA
- North Carolina State University, Raleigh, NC
- Northeastern University, The Ocean Genome Legacy of New England BioLabs, Boston, MA

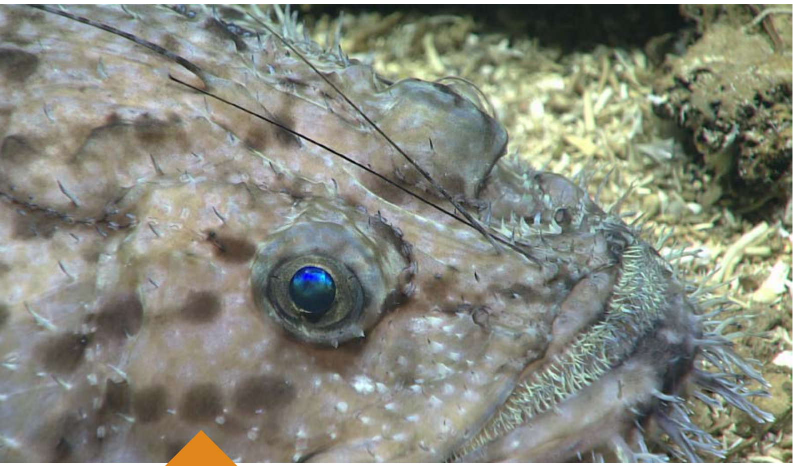
A crinoid (Echonodermata Crinoidea Articulata) observed at water depth of 1,600 m during a dive an on unnamed guyot located in the south center of the Johnston Atoll Unit. *Image credit: NOAA OER*





This fangtooth fish was an exciting observation at 800 m depth during a midwater transect on the Musicians Seamounts expedition. *Image credit: NOAA OER*

- NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, MD
  - » National Centers for Environmental Information, John C. Stennis Space Center, MS
- NOAA National Marine Fisheries Service, Silver Spring, MD
  - » Marine National Monument Program, Honolulu, HI
  - » National Systematics Laboratory, Washington, DC
  - » Northwest Fisheries Science Center, Seattle, WA
  - » Office of Habitat Conservation, Deep Sea Coral Research and Technology Program, Silver Spring, MD
  - » Pacific Islands Fisheries Science Center, Honolulu, HI
  - » Pacific Islands Regional Office, Honolulu, HI
  - » Southeast Fisheries Science Center, Miami and Panama City, FL
- NOAA National Ocean Service, Silver Spring, MD
  - » National Centers for Coastal Ocean Science, Silver Spring, MD
  - » Office for Coastal Management, Coastal Services Center, Charleston, SC
  - » Office of National Marine Sanctuaries, Silver Spring, MD
    - – Flower Garden Banks National Marine Sanctuary, Galveston, TX
    - – Maritime Heritage Program, Silver Spring, MD
    - – National Marine Sanctuary of American Sāmoa, Pago Pago, American Sāmoa
    - – Olympic Coast National Marine Sanctuary, Port Angeles, WA
    - – Thunder Bay National Marine Sanctuary, Alpena, MI
  - » US Integrated Ocean Observing System, Silver Spring, MD
- NOAA Office of Education, Educational Partnership Program, Silver Spring, MD
- NOAA Office of Marine and Aviation Operations, Silver Spring, MD
- NOAA Office of Oceanic and Atmospheric Research, Silver Spring, MD
  - » Atlantic Oceanographic and Meteorological Laboratory, Miami, FL
  - » Pacific Marine Environmental Laboratory, Seattle, WA
- Ocean Exploration Trust, New London, CT
  - » E/V *Nautilus*, AltaSea at the Port of Los Angeles
- Ocean Networks Canada, Victoria, British Columbia, Canada
- Oregon Museum of Science and Industry, Portland, OR
- Oregon State University, Corvallis, OR
  - » Department of Anthropology
  - » Marine Geology Repository
- Oceaneering International Inc., Houston, TX
- Papahānaumokuākea Marine National Monument, Honolulu, HI
- Phoenix Islands Protected Area Conservation Trust, Bikenibeu, Tarawa, Republic of Kiribati
- Phoenix Islands Protected Area Implementation Office, Tarawa, Republic of Kiribati
- Quality Positioning Services Inc., Portsmouth, NH
- Republic of Kiribati
- Schmidt Ocean Institute, Palo Alto, CA
- Secretariat of the Pacific Regional Environment Programme, Apia, Sāmoa
- Smithsonian Institution, National Museum of Natural History, Washington, DC
- South Carolina Aquarium, Charleston, SC
- State of Hawai'i, Department of Land and Natural Resources, Honolulu, HI
- SEARCH, Jacksonville, FL
- SRI International, St. Petersburg, FL
- Temple University, Philadelphia, PA
- Texas State Aquarium, Corpus Christi, TX
- The Nature Conservancy, Palmyra Program, Honolulu, HI
- TDI-Brooks International, College Station, TX
- University of California, Santa Barbara, Santa Barbara, CA
- University Corporation for Atmospheric Research, Boulder, CO
- University of Delaware, Lewes, DE
- University of Havana, Marine Research Center, Havana, Cuba
- University of Hawai'i at Mānoa, Joint Institute for Marine and Atmospheric Research in the School of Ocean and Earth Science and Technology, Honolulu, HI
- University of Idaho, Moscow, ID
- University of Louisiana at Lafayette, Lafayette, LA
- University of Massachusetts Dartmouth, Dartmouth, MA
- University of New Hampshire, Center for Coastal & Ocean Mapping, Durham, NH
- University of North Carolina Wilmington, Wilmington, NC
- University of Rhode Island, Graduate School of Oceanography, Narragansett, RI
- University of South Florida, College of Marine Science, St. Petersburg, FL
- University of Washington, Applied Physics Laboratory, Seattle, WA
- US National Park Service, Submerged Resources Center, Lakewood, CO
- US Fish and Wildlife Service, Washington, DC
  - » Rose Atoll Marine National Monument, Pago Pago, American Sāmoa
- US Geological Survey
  - » Reston, VA
  - » Woods Hole, MA
  - » Pacific Coastal and Marine Science Center, Santa Cruz, CA
  - » Wetland and Aquatic Research Center, Gainesville, FL
- US Naval Academy, Annapolis, MD
- Waikīkī Aquarium, Waikīkī, HI
- Woods Hole Oceanographic Institution, Woods Hole, MA



This monkfish, *Lophiodes miacanthus*, was found squatting in a bed of Hawaiian gold coral, *Kulamanamana haumeaae*, at Middle Bank, a seamount located on the border of the Papahānaumokuākea Marine National Monument. *Image credit: NOAA OER*

This image shows the rounded stern of USS *Baltimore*, which was modified to include doors and deployment rails for laying sea mines during World War I. The wreck is located about 37 km south of the island of O'ahu. *Image credit: NOAA OER*

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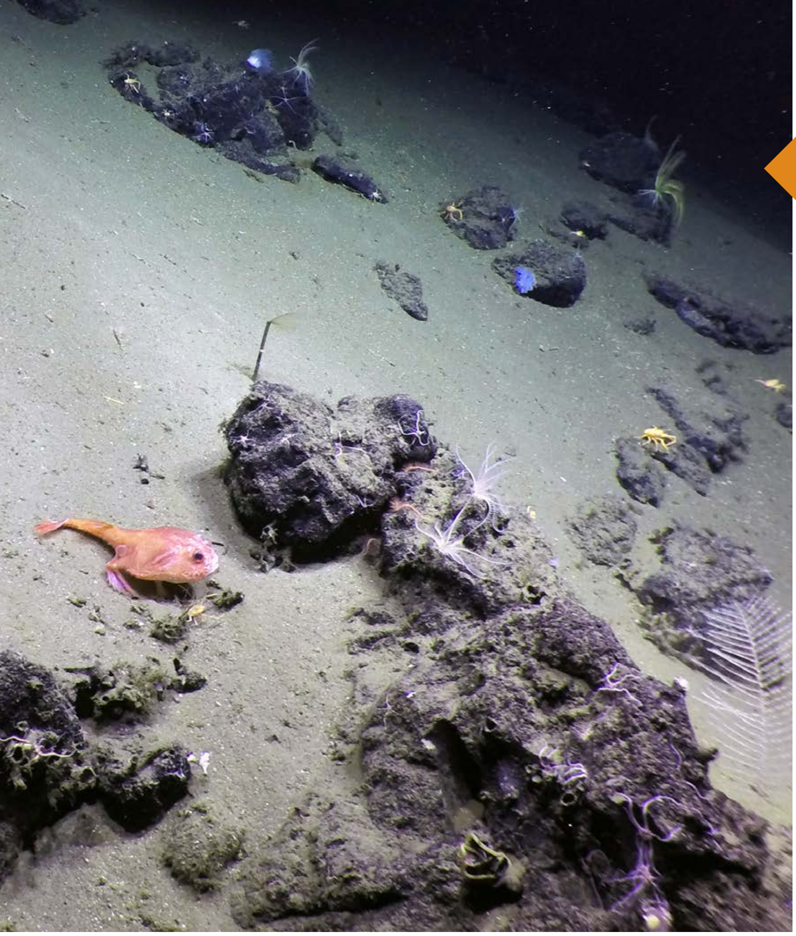

Benthic community, with a goosefish in the foreground, on the slopes of Socorro Island, Revillagigedo Archipelago, Mexico, from E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

During exploration of the Musicians Seamounts, mushroom corals like these *Anthomastus* were common and seen at sites such as Liszt Seamount and Beethoven Ridge. *Image credit: NOAA OER*

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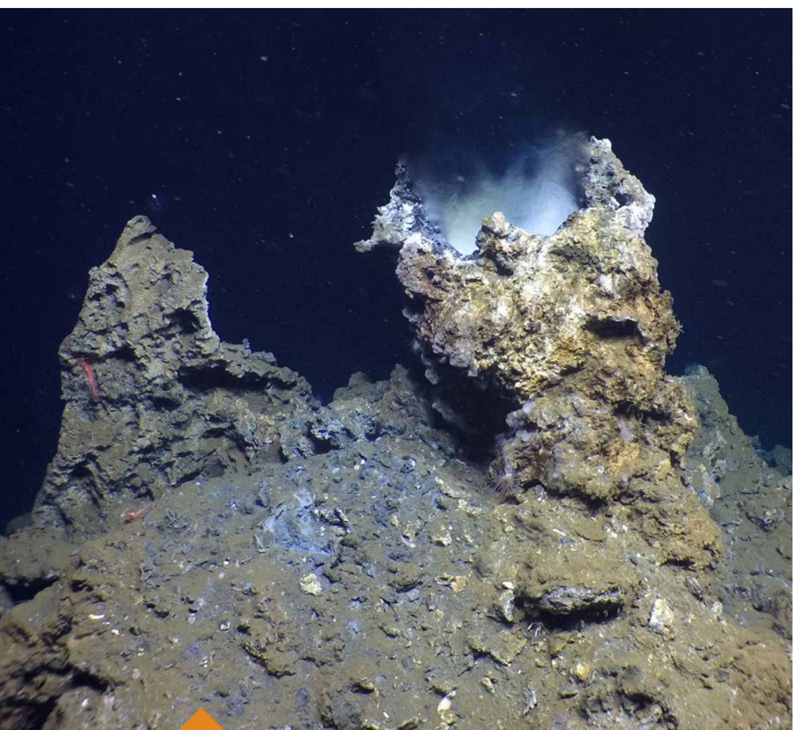
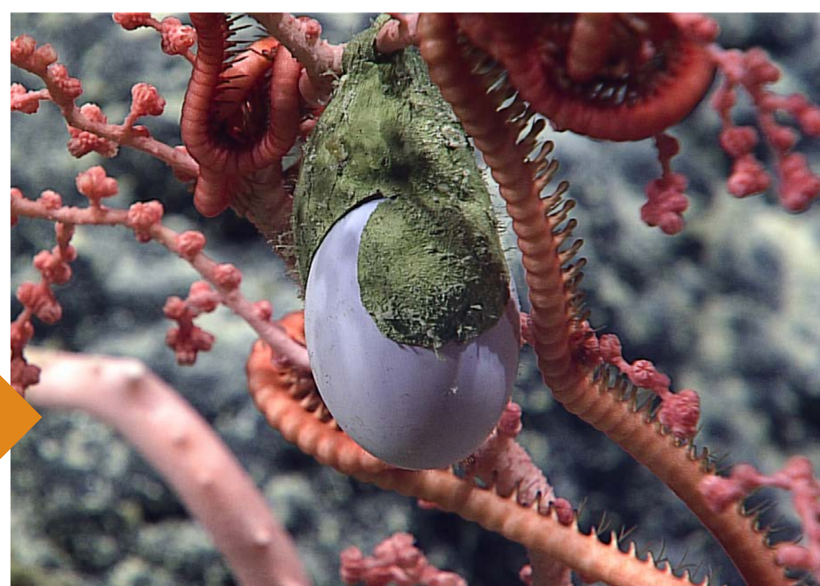
This *Chaunux*, a type of anglerfish, was observed at approximately 3,148 m depth. The bright red color and ciri on the fish's body made it an unusual find. This ROV dive was the first in a series that investigated the similarities and differences in community composition between different features across the Musicians Seamounts. *Image credit: NOAA OER*



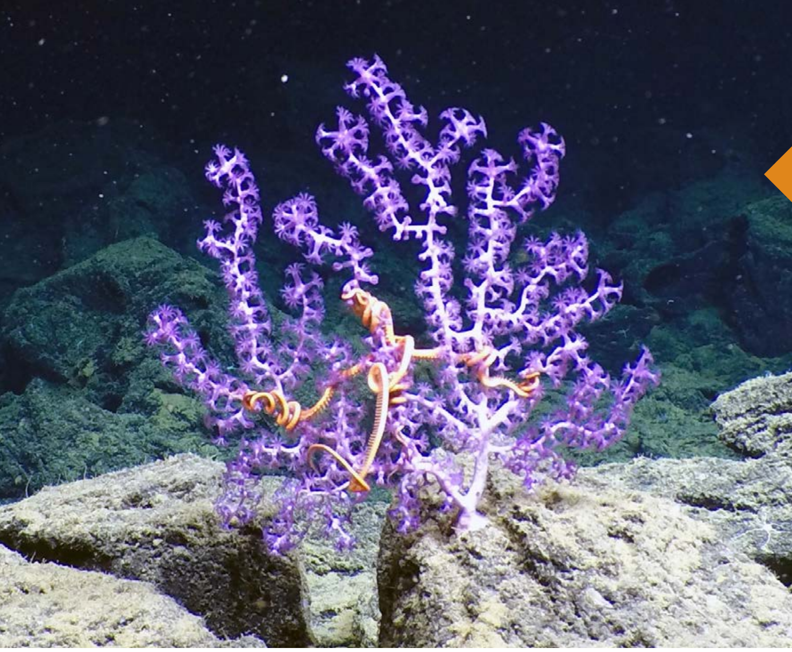
Diane's Vent had the most vigorous fluid flow of the sites that were visited in Pescadero Basin, Gulf of California, E/V *Nautilus* cruise NA091. The fluid temperature was measured to be ~290°C. *Image credit: OET*



Close-up of a cirrate octopod egg case (brown) and inner chorion (purple) attached to an octocoral (*Paragorgia* sp.). The octopus embryo will develop within the chorion until it is ready to hatch. This image was captured on the Discovering the Deep: Exploring Remote Pacific MPAs expedition. *Image credit: NOAA OER*

Acronyms

ABISS............................ Autonomous Biogeochemical Instrument for In Situ Studies
AMA .... Reddit Ask Me Anything
ASPIRE .... Atlantic Seafloor Partnership for Integrated Research and Exploration
AUV .... Autonomous underwater vehicle
BGS .... British Geological Survey
BOEM............................ Bureau of Ocean Energy Management
CalCOFI......................... California Cooperative Oceanic Fisheries Investigations
Calit2............................ California Institute for Telecommunications and Information Technology
CAPSTONE................... Campaign to Address Pacific monument Science, Technology, and Ocean NEeds
CBNMS .... Cordell Bank National Marine Sanctuary
CIMAS .... Cooperative Institute for Marine and Atmospheric Studies
CINAR........................... Cooperative Institute of the North Atlantic Region
CINMS........................... Channel Islands National Marine Sanctuary
CIOERT.......................... Cooperative Institute for Ocean Exploration, Research & Technology
CNMI .... Commonwealth of the Northern Mariana Islands
CMECS .... Coastal and Marine Ecological Classification Standard
CSP............................... Community STEM Program
CSSF .... Canadian Scientific Submersible Facility
CTD .... Conductivity, temperature, depth sensor
DEEP SEARCH .... Deep Sea Exploration to Advance Research on Coral/Canyon/Cold seep Habitats
ECC............................... Exploration Command Center
ECS............................... Extended Continental Shelf
EEZ .... Exclusive economic zone
EiT .... Explorer-in-Training Program
EPP............................... Educational Partnership Program
E/V............................... Exploration Vessel
FFO............................... Federal Funding Opportunity
FGBNMS .... Flower Garden Banks National Marine Sanctuary
GEBCO .... General Bathymetric Chart of the Oceans
GFNMS .... Greater Farallones National Marine Sanctuary
GTD .... Gas Tension Device
HAPC............................ Habitat Areas of Particular Concern
IHO-IOC .... International Hydrographic Organization – Intergovernmental Oceanographic Commission
IMMeRSS .... Interagency Mission for Methane Research at Seafloor Seeps
ISMS .... In situ mass spectrometer
JAMSTEC .... Japan Agency for Marine-Earth Science and Technology
JAU .... Johnston Atoll Unit
MBNMS .... Monterey Bay National Marine Sanctuary
MBON .... Marine Biodiversity Observation Network
Mbps............................. Megabits per second
MPA.............................. Marine protected area
MTMNM .... Marianas Trench Marine National Monument
NCOG........................... NOAA CalCOFI Genomics Project
NMFS .... NOAA's National Marine Fisheries Service
NMSAS......................... National Marine Sanctuary of American Sāmoa
NOAA .... National Oceanic and Atmospheric Administration



A brittlestar associate on an octocoral (Family Anthothelidae, *Victorgorgia* sp.) east of Socorro Island, Mexico, from E/V *Nautilus* cruise NA092. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

On a dive at an unverified seep site off the shore of North Carolina, AUV *Sentry* caught a glimpse of a scalloped hammerhead shark (*Sphyrna lewini*) swimming along the seafloor. *Image credit: NOAA OER/BOEM/USGS*

OA .... Ocean Acidification
OER .... NOAA's Office of Ocean Exploration and Research
OET .... Ocean Exploration Trust
OMZ .... Oxygen Minimum Zone
ONC .... Ocean Networks Canada
PIPA.............................. Phoenix Islands Protected Area
PMNM.......................... Papahānaumokuākea Marine National Monument
PRIMNM .... Pacific Remote Islands Marine National Monument
RAMNM .... Rose Atoll Marine National Monument
ROPOS .... Remotely Operated Platform for Ocean Sciences
ROV .... Remotely operated vehicle
R/V................................ Research Vessel
SACNAS .... Society for the Advancement for Chicanos and Native Americans in Science
SEDCI .... Southeast Deep Coral Initiative
SODA .... Sampling Operations Database Application
SOI................................ Schmidt Ocean Institute
SPREP........................... Secretariat of the Pacific Regional Environment Programme
STEM .... Science, technology, engineering, and mathematics
UAS .... Unmanned aircraft system
UC .... University of California
UNCLOS....................... United Nations Convention on the Law of the Sea
UNESCO....................... United Nations Educational, Scientific, and Cultural Organization
UNH CCOM/JHC........... University of New Hampshire Center for Coastal and Ocean Mapping/Joint Hydrographic Center
USGS .... United States Geological Survey
USS............................... United States Ship
WHOI .... Woods Hole Oceanographic Institution
WHOI MISO .... WHOI Multidisciplinary Instrumentation in Support of Oceanography Facility

Paralomis sp. lithodid crabs feast on a *Deepstaria* sp. deep-sea scyphozoan jellyfish carcass at 899 m depth east of Socorro Island, Revillagigedo Archipelago, Mexico, during E/V *Nautilus* cruise NA092. These “jelly falls” are recognized as major contributors of organic flux to the deep ocean, but are rarely witnessed as they are rapidly consumed by benthic scavengers. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

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This hydromedusan jellyfish, *Crossota* sp., was observed just south of O'ahu while searching for an underwater cultural heritage site. *Image credit: NOAA OER*

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