November 19-20, 2015

# NATIONAL OCEAN EXPLORATION FORUM

# REPORT

NATIONAL AQUARIUM®

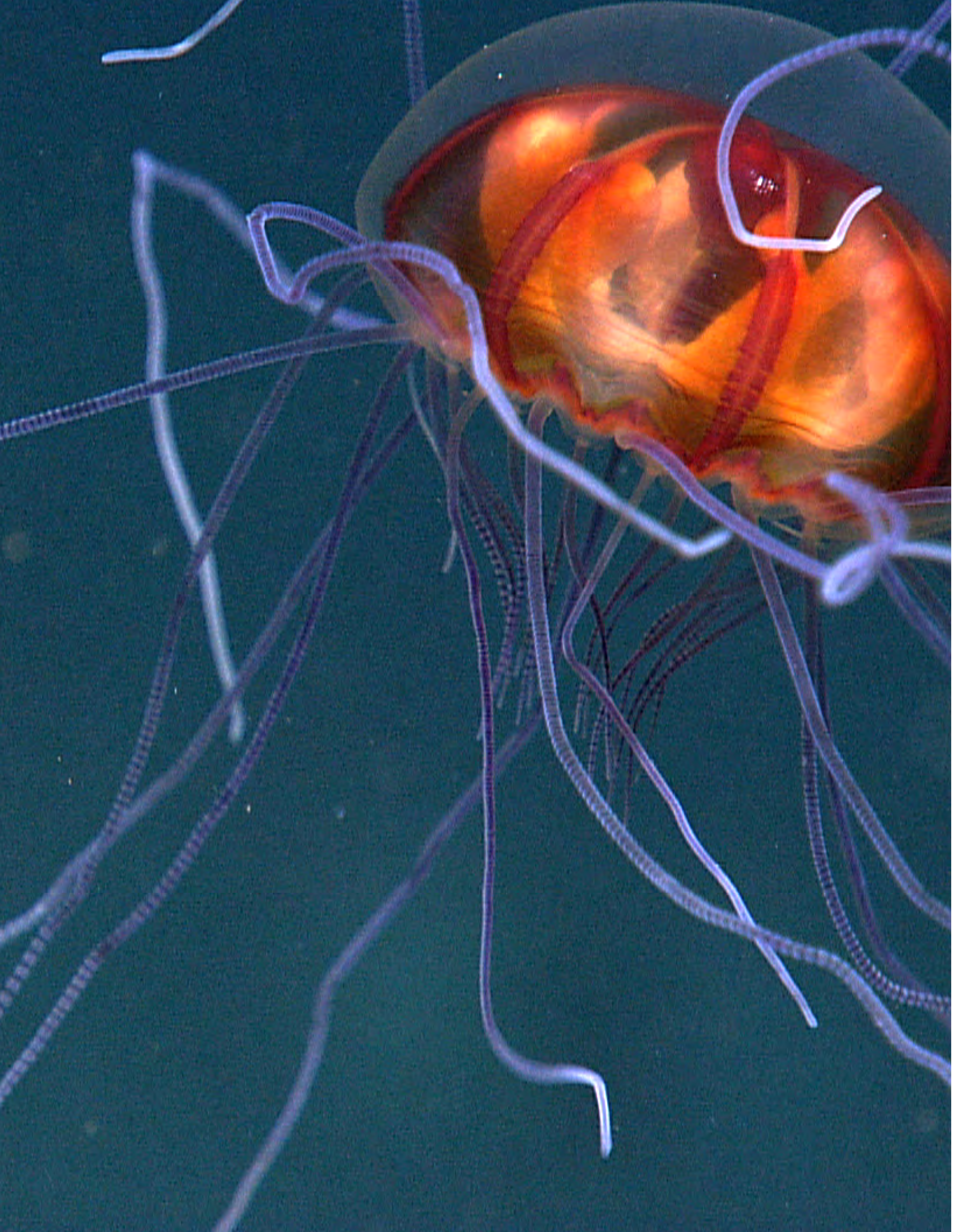
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

(Cover) Ctenophore. | *Credit: Harbor Branch Oceanographic Institute-Florida Atlantic University.*
(Right) *Montastraea cavernosa* from the Flower Garden Banks National Marine Sanctuary. | *Credit: Joshua Voss's group during their Sept 2016 CIOERT Mesophotic Reef Ecosystem expedition aboard the R/V* Manta*, Harbor Branch Oceanographic Institute-Florida Atlantic University.*



aqua.org/noef-report
oceanexplorer.noaa.gov/national-forum/welcome.html#2015

Printed February 2017
We choose recycled.



Hydromedusa, likely in the genus *Crossota*, seen at ~ 3,900 meters depth during exploration off Puerto Rico. | *Credit: NOAA Office of Ocean Exploration and Research, Océano Profundo 2015: Exploring Puerto Rico's Seamounts, Trenches, and Troughs.*

# TABLE OF CONTENTS

National Ocean Exploration Forum participants in the *Australia: Wild Extremes* exhibit at the National Aquarium. | *Credit: National Aquarium.*

# THANK YOU.

### THE 2015 NATIONAL OCEAN EXPLORATION FORUM WAS CO-HOSTED BY:

NOAA — National Oceanic and Atmospheric Administration, U.S. Department of Commerce

National Aquarium

This event wouldn't have been possible without our lead sponsor:

Schmidt Ocean Institute

Thanks to our sponsoring partners for their generous support:

Boeing

Sodexo — Quality of Life Services

### SPECIAL THANKS TO OUR COLLABORATING PARTNERS:

Aquarium of the Pacific at Long Beach

Autodesk

Bureau of Ocean Energy Management

Center for American Progress

Cooperative Institute for Ocean Exploration, Research and Technology

Global Foundation for Ocean Exploration

Khaled bin Sultan Living Oceans Foundation

Kickstarter

The National Academies

National Aeronautics and Space Administration

National Science Foundation

National Research Council

North Carolina Museum of Natural Sciences

Ocean Aero

Ocean Exploration Advisory Board

Ocean Exploration Trust

OpenROV

Southern Fried Science

United States Geological Survey

University of California, San Diego

University of Washington


Chimaera. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*

SECTION 1.0

# INTRODUCTION

National Ocean Exploration Forum 2015: Characterizing the Unknown (NOEF 2015) was the third in a series of annual forums focused on establishing a national strategy and program of ocean exploration as called for in the statute authorizing NOAA's ocean exploration program. Ocean Exploration 2020: A National Forum, held at the Aquarium of the Pacific in Long Beach, California, in July 2013, asked participants to describe elements a successful national ocean exploration program should exhibit by the year 2020. National Forum 2014 was a smaller forum held in September 2014 at the National Aquarium in Baltimore. It focused on how we can more comprehensively address national ocean exploration needs and connect ocean exploration results to NOAA mission priorities. National Forum 2014 participants also assessed the community's progress toward the ambitious targets set in OE 2020 to help identify topics for National Ocean Exploration Forum 2015.

NOEF 2015 challenged participants to describe the requirements for first-order exploration that meets multiple requirements and that could set a new standard for exploring unknown ocean areas and phenomena. Following the talks, panel discussion and the Marketplace of Ideas, participants broke into working groups with a charge to synthesize what they had heard so far with their own experiences and OE 2020 recommendations to designing expedition concepts based on ocean features of particular importance. A closing panel described and summarized key outcomes from NOEF 2015.

Welcome letter from John Racanelli to NOEF 2015 participants:

*John C. Racanelli*
*Chief Executive Officer,*
*National Aquarium*

While humans have mapped the surface of the Earth for millennia, and for the last several decades the surfaces of planets and moons, the opportunity to comprehensively explore and understand the ocean remains substantially unfulfilled.

The opportunity before us is to increase the pace, efficiency and general awareness of ocean exploration. Through a unique combination of factors, we have a chance to build this important foundation of knowledge through discoveries made by governmental and non-governmental experts, including academic institutions, private industry and entrepreneurs.

In 2000, the President's Panel for Ocean Exploration recommended that the United States develop a national program of ocean exploration, with discovery and the spirit of challenge as its cornerstones. That recommendation led to the establishment in 2009 of NOAA's Ocean Exploration Program, tasked with coordinating a national program promoting data management, sharing, public understanding and technology development. It also directed NOAA to bring the country's experts and stakeholders together to foster ideas and innovation.

In late 2015, the National Aquarium was honored to partner with NOAA to host the third in a series of annual symposia focused on establishing a formal, dedicated national strategy for ocean exploration. "Characterizing the Unknown: A National Ocean Exploration Forum" brought together some of the nation's most informed and experienced ocean exploration experts to compare notes on emerging technologies and attitudes, and to identify key characteristics of a national program of ocean exploration for 2020 and beyond.

This report summarizes the findings and recommendations that resulted from the Baltimore forum, all of which have incredible potential to move our country forward as an ocean exploration leader.

Welcome letter from Craig McLean to NOEF 2015 participants:

*Craig McLean*
*Assistant Administrator,*
*NOAA Office of Oceanic and Atmospheric Research*

This is an exciting time for the field of ocean exploration, as advances in observation platforms, technologies, and tools are quickly evolving to take us farther and deeper than ever before. But we still have a ways to go. This forum is a critical step in identifying the characteristics of the National Ocean Exploration Program needed to explore and understand our oceans.

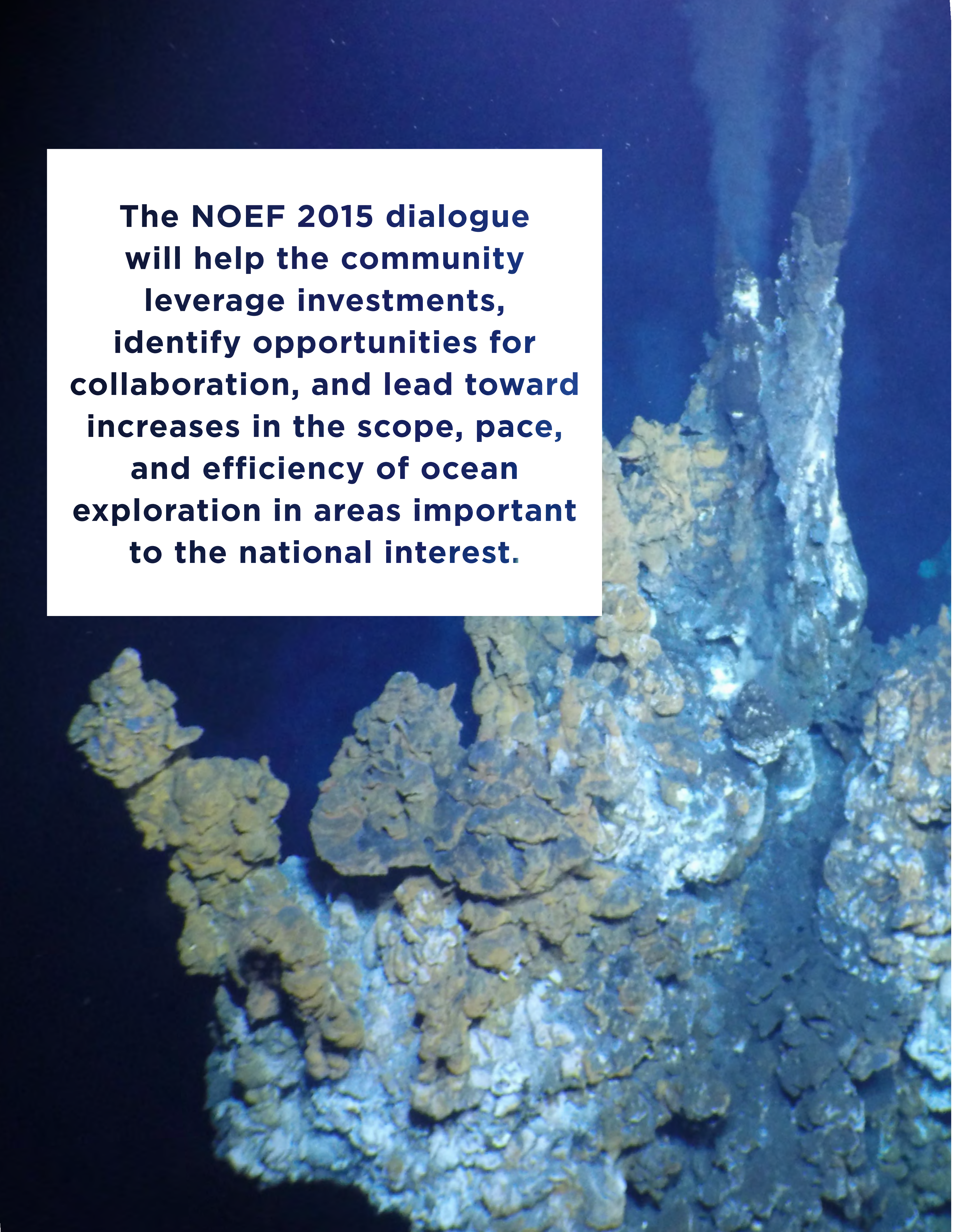
Public law requires the National Oceanic and Atmospheric Administration (NOAA) to host national ocean exploration forums; however, it is not the legal requirement that has brought any of us here. Rather, it is a passion for and recognition of the value and importance of ocean exploration as the foundation for managing and protecting our planet.

As the nation's ocean and atmospheric agency, ocean exploration is an important component of NOAA. While we have the only federal program dedicated to exploring our unknown ocean, no one organization can do it alone. That is why it is so exciting to have so many of you—our partners—joining us for this year's National Ocean Exploration Forum. I am hopeful that discussions over the next two days are just the beginning.

Building on progress made at the National Ocean Exploration Forum in 2013 and 2014, this year you will be challenged to push the boundaries of current possibilities, to define the requirements needed to set a new standard for exploring unknown ocean areas and phenomena. Be creative, forward thinking, and bold as you consider how we are exploring now versus where we want to be in next five years.

I would like to thank each of you for attending and bringing your expertise to this Forum. You, as ocean exploration leaders, have the vision, knowledge, passion, and experience to pave the way. We will not accomplish what is needed without you. Throughout the Forum, I ask you to stay engaged and proactive as we all work together to shape the future of a National Program of ocean exploration.

My respect and thanks goes out to all of you.



Hydrothermal vent. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*

**The NOEF 2015 dialogue will help the community leverage investments, identify opportunities for collaboration, and lead toward increases in the scope, pace, and efficiency of ocean exploration in areas important to the national interest.**

SECTION 2.0

# DESCRIPTION OF APPROACH: NATIONAL OCEAN EXPLORATION FORUM 2015

*—Characterizing the Unknown*

## KEYNOTE TALKS

Keynote talks from Jerry Schubel, president and CEO of the Aquarium of the Pacific at Long Beach, who hosted and chaired OE 2020, and from VADM Paul Gaffney II (ret.), chair of the NOAA Ocean Exploration Advisory Board, set the context for NOEF 2015 by reviewing the policy framework for a national ocean exploration program—which stretches back to the President's Panel Report of 2000—and the progress we have made to date in building the community that constitutes the national program envisioned in the law. VADM Gaffney summarized the national ocean exploration forum recommendations made in 2013 and 2014 and progress made to date in addressing those recommendations.

## PANELS

NOAA's primary federal partners in ocean exploration include the U.S. Geological Survey (USGS), the Bureau of Ocean Energy Management (BOEM), the National Aeronautics and Space Administration (NASA), the U.S. Navy, and the National Science Foundation (NSF). Academic, nongovernmental organization, and private sector stakeholders also play critical roles in almost all federal ocean exploration activities—and conduct their own expeditions of national significance. Many other observation tools and data can be integrated into federal and non-federal expeditions to help create a smarter, more comprehensive national ocean exploration program.

Along with NOAA, BOEM, USGS, NSF, NASA, and the Navy conduct or support ocean exploration for specific mission requirements. The National Academy's Jerry Miller chaired a panel of representatives from these agencies to discuss mission requirements, opportunities for collaboration, and participation in a national program.

The ocean exploration law may highlight the federal ocean exploration agencies and their needs, but it also recognizes that federal ocean exploration activities are only a part of the picture.

Mike Conathan from the Center for American Progress moderated a panel of representatives from non-governmental organizations that explore, including foundations, industry, and academia. Panelists representing the Ocean Exploration Trust, the Khaled bin Sultan Living Oceans Foundation, the Global Foundation for Ocean Exploration, the oil and gas industry, the marine biotechnology industry, and the Schmidt Ocean Institute discussed their missions, modes of operation, and ability to partner toward meeting common ocean exploration objectives.

These panels identified a broad set of drivers for ocean exploration—the "why" of exploration—that taken together form the basis for an inclusive and collaborative national ocean exploration program.

## MARKETPLACE OF IDEAS

The Marketplace of Ideas was a series of ten fast-paced talks on concepts, technologies, and ideas that could be relevant to ocean exploration in the future. Whether the potential of small, inexpensive, but increasingly capable sensors and platforms to disrupt conventional ways we explore, or new visualization techniques, or the importance of envisioning the future of data, Marketplace talks highlighted opportunities for the ocean exploration community to think differently about its activities and to leverage emerging technology and approaches to achieve national program objectives.

## WORKING GROUPS

NOEF 2015 used the Marketplace of Ideas, keynote talks, and panel discussions to set the context for working group consideration and design of conceptual expeditions that might take place in the year 2020. Rather than focus on ocean basins, participants were asked to think in terms of ocean features and themes of particular interest (and identified in OE 2020 and National Forum 2014). Working groups on the under ice environment, mid-ocean ridges and fracture zones, chemosynthetic communities, the continental shelf, the water column, canyons and seamounts, and submerged cultural resources met to discuss multiple requirements for understanding unexplored areas. Working group participants were asked to identify:

- priority questions about particular areas within these regions (areas that could be defined by a "cube" that extends from the upper atmosphere to below the seafloor);
- data and observations needed to establish baselines or to "characterize" these areas and set the stage for research to address the priority questions;
- new and emerging technologies and observation platforms that might inform, leverage or otherwise extend the value of ship based expeditions;
- new paradigms for exploration; and,
- other aspects of a hypothetical expedition that would take full advantage of stakeholder capabilities, multiple platforms and systems, technological developments, instrument design, data integration and synthesis techniques, and non-traditional paradigms to characterize the unexplored ocean environment.

Working group moderators and rapporteurs captured discussion results using a template organized by OE 2020 recommendations with the expectation that working group results would help define the desired characteristics of a national program to the next level of detail. Working group moderators reported their results in plenary *(see section 10)*.

## PARTICIPANTS

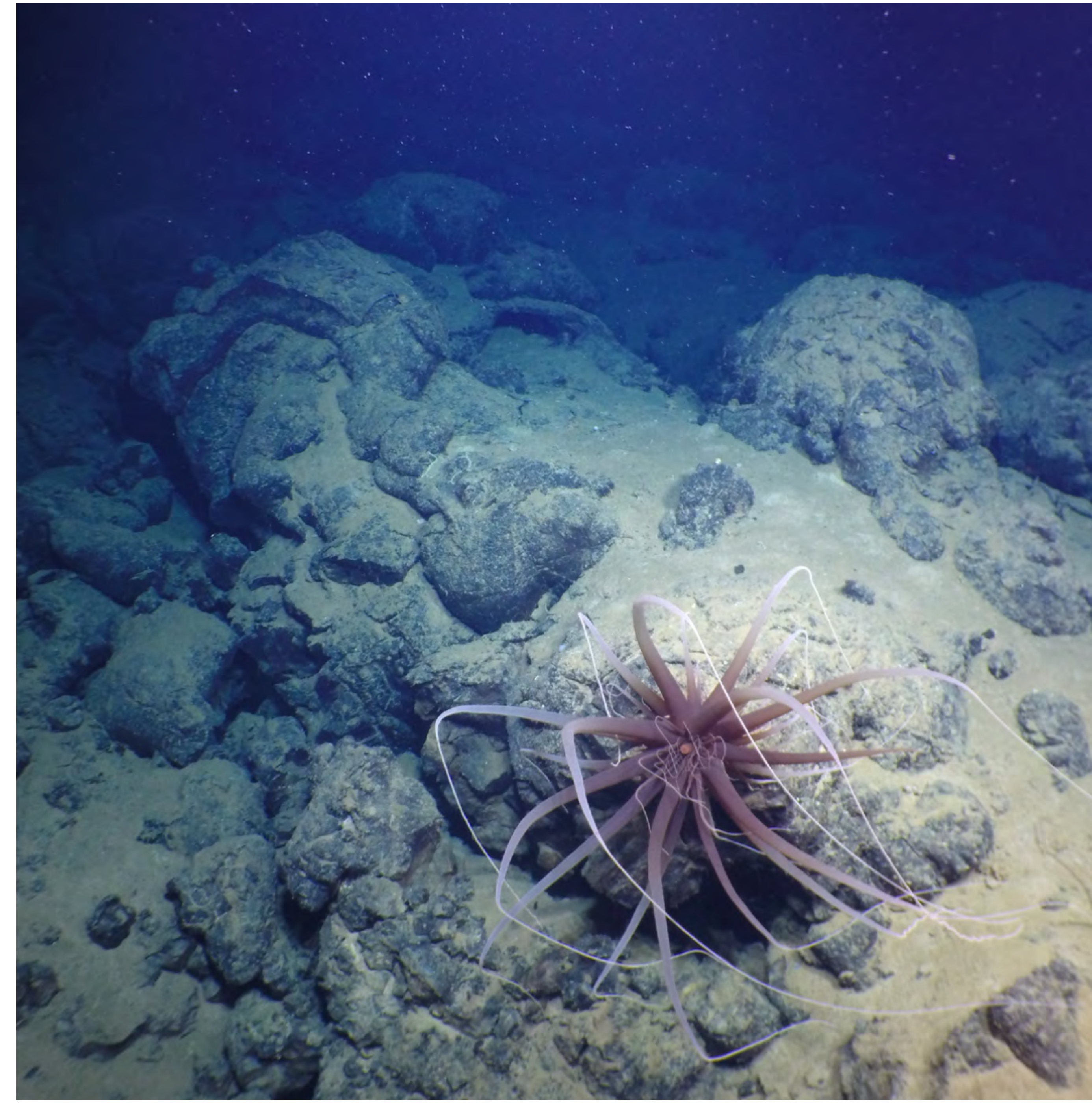
Practitioners, researchers, technology developers, educators, and others with a stake in a national program of ocean exploration were invited to participate in National Forum 2015. A total of 140 members of the nation's ocean exploration community registered to participate in the event; other participants joined NOEF 2015 through live streaming and a virtual working group meeting.

*See Appendix IV for a list of participants.*

## RESULTS

Before NOEF 2015, we said the form would be a success if it helped to build a national program of ocean exploration by:

- advancing recommendations from Ocean Exploration 2020 and the September 2014 mini National Forum;
- creating and reinforcing relationships among key stakeholders in a national ocean exploration program;
- identifying short-term (2-5 years) opportunities to explore priority areas, capitalize on emerging technologies, and exploit new exploration paradigms;
- continuing to build an inclusive community of ocean explorers from not-for-profits, academia, the private sector, and government; and,
- continuing to build support for ocean exploration among national and regional decision makers.



Sea anemone and lava flow. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*

The National Aquarium and NOAA believe the participants achieved these results and more. NOEF 2015 was an important step forward in building the national community of ocean explorers, building consensus about national priorities, and sharing information. The NOEF 2015 dialogue will help the community leverage investments, identify opportunities for collaboration, and lead toward increases in the scope, pace, and efficiency of ocean exploration in areas important to the national interest.

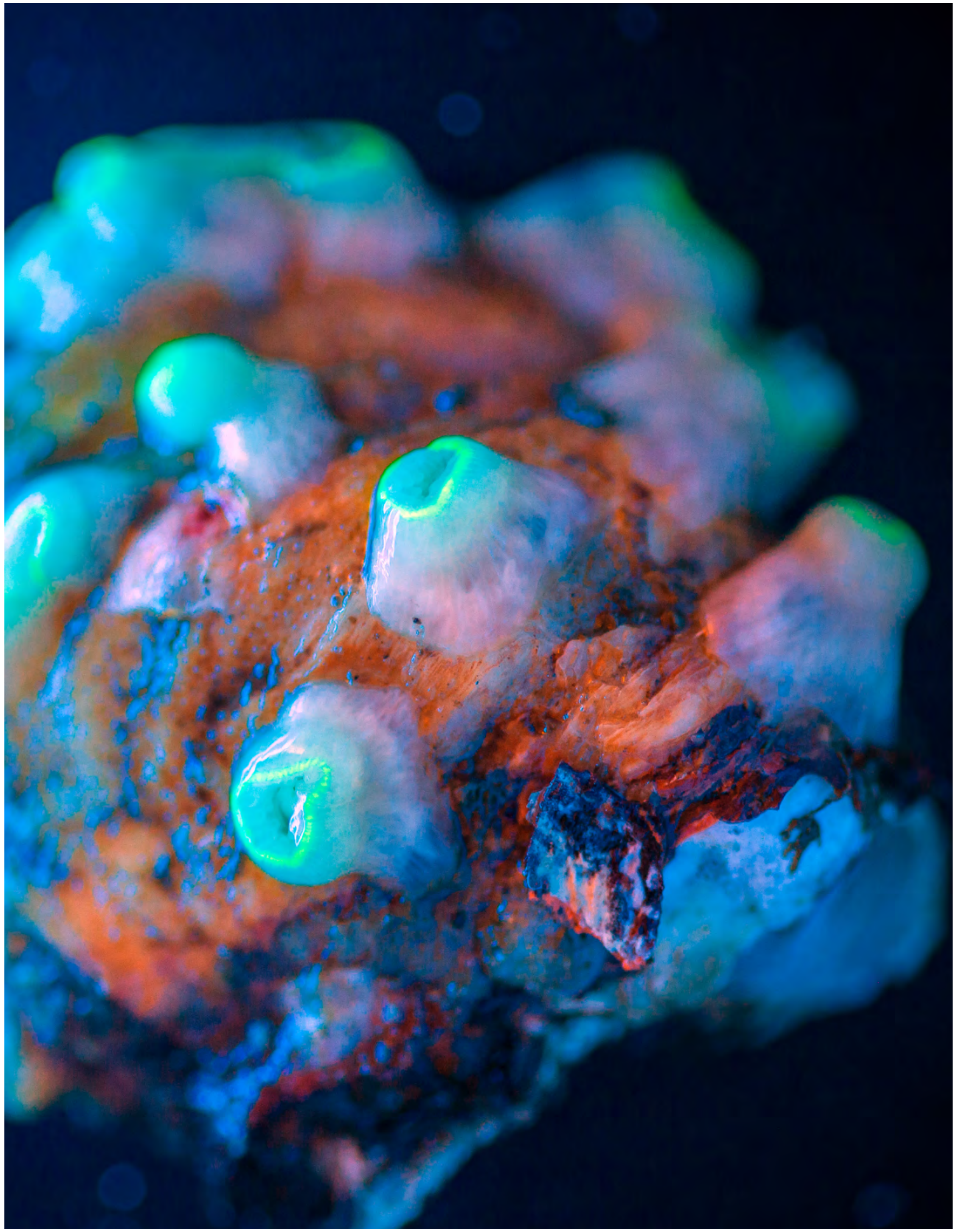


Coral imaged within the Wake Island Unit of the Pacific Remote Islands Marine National Monument. | *Credit: NOAA Office of Ocean Exploration and Research, Deepwater Wonders of Wake.*

SECTION 3.0

# OCEAN EXPLORATION ADVISORY BOARD LETTER

The OEAB congratulates NOAA, the National Aquarium and the Ocean Exploration community for coming together for its third time on a national scale to share information about science opportunities, federal exploration priorities and potential advances in technology. We are particularly buoyed by the collective endorsements for more partnerships among federal agencies and with private institutions and industry. Further, there was a loud cry to make more citizens and decision makers aware of the value of a robust national ocean exploration program. Opportunities abound in instruments and methods for discovery; geography and phenomena await curious examination; and our government is increasingly articulating its need to explore. We urge the community to speak out continually on the importance of ocean discovery and grasp the opportunities before it.



Sample of corallimorphs collected by ROV *Jason* photographed under a blacklight to demonstrate florescence. | *Credit: Art Howard, Deepwater Canyons 2013—Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

## Ocean Exploration Advisory Board

A Federal Advisory Committee Act Committee

The OEAB congratulates NOAA, the National Aquarium and the Ocean Exploration community for coming together for its third time on a national scale to share information about science opportunities, federal exploration priorities and potential advances in technology. We are particularly buoyed by the collective endorsements for more partnerships among federal agencies and with private institutions and industry. Further, there was a loud cry to make more citizens and decision makers aware of the value of a robust national ocean exploration program. Opportunities abound in instruments and methods for discovery; geography and phenomena await curious examination; and our government is increasingly articulating its need to explore. We urge the community to speak out continually on the importance of ocean discovery and grasp the opportunities before it.

**Vice Admiral Paul G. Gaffney II**
President Emeritus Monmouth University and Fellow, Monmouth University Urban Coast Institute

**James A. Austin, Jr., PhD**
Senior Research Scientist, University of Texas Institute for Geophysics

**Amanda W. J. Demopoulos, PhD**
Research Ecologist, U.S. Geological Survey

**Jacqueline Eaby Dixon, PhD**
Dean, College of Marine Science, University of South Florida

**Christopher R. German, PhD**
Walter A. & Hope Noyes Smith Chair, Department of Geology & Geophysics, Woods Hole Oceanographic Institution

**Ambassador Cameron Hume**
Business Consultant

**John R. Kreider**
Senior Vice President, Advanced Technology, Oceaneering International, Inc.

**David Lang**
Co-Founder, OpenROV

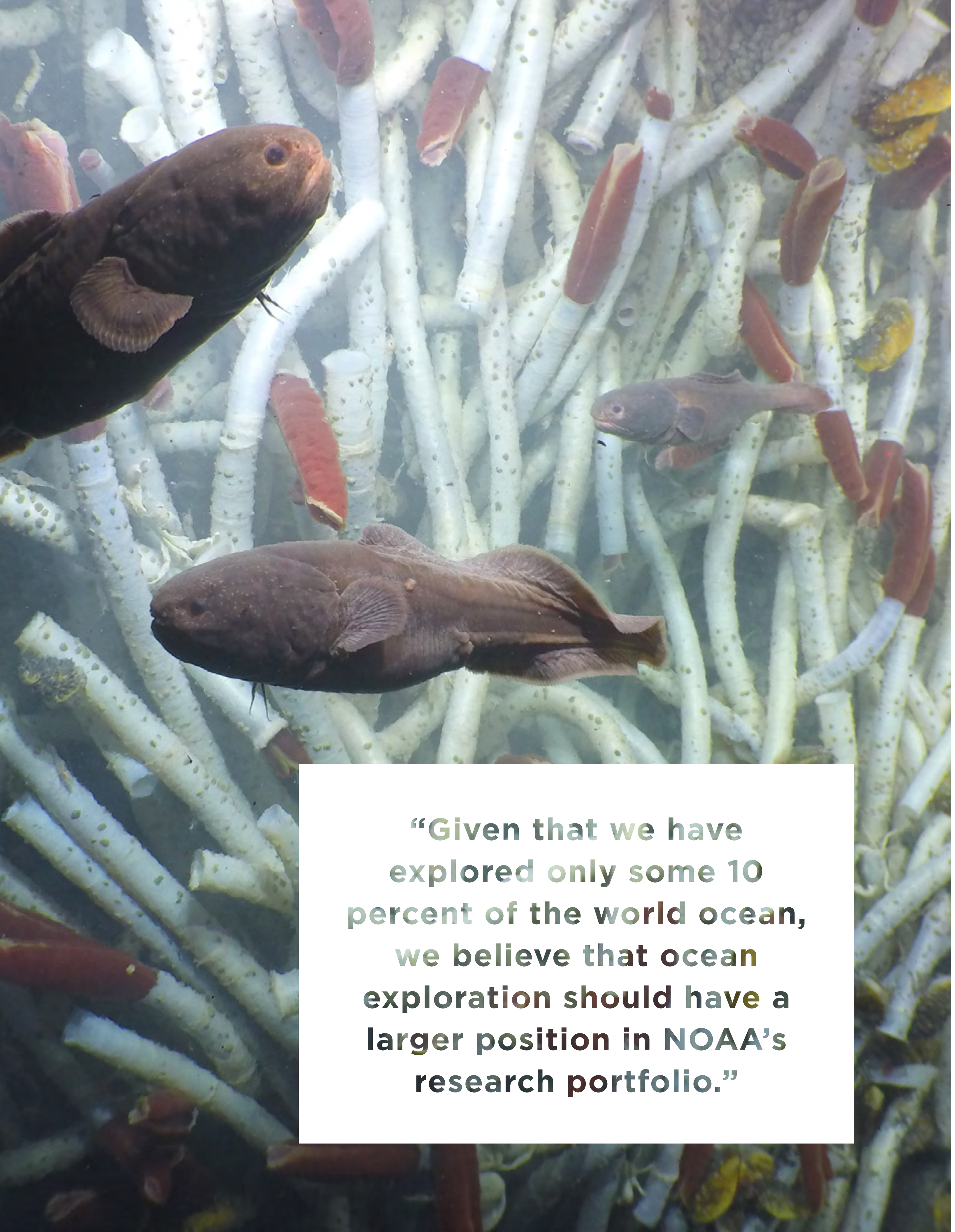
**Darlene Lim, PhD**
Research Scientist, NASA Ames Research Center

**Nicolette Nye**
Vice President for Communications and External Relations, National Ocean Industries Association

**Dominique Rissolo, PhD**
Special Projects Coordinator for CISA3, University of California, San Diego

**Richard J. Rikoski, PhD**
CEO/Chief Scientist, Hadal, Inc.

**Lance M. Towers**
Director, Advanced Technology Programs, The Boeing Company



Giant tube worms *(Riftia pachyptila)* and vent fish. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*

**"Given that we have explored only some 10 percent of the world ocean, we believe that ocean exploration should have a larger position in NOAA's research portfolio."**

SECTION 4.0

# KEYNOTE TALKS

Ocean Exploration 2020 convened the ocean exploration community—defined as practitioners from academia, institutions, non-for-profit organizations, foundations, advocacy groups, industry, and others—in 2013 to consider the question of a national ocean exploration program. A second, smaller forum the following year addressed a narrower question of ocean exploration's relevance to NOAA mission programs—an important step in institutionalizing ocean exploration and the national program coordination within NOAA. Because National Ocean Exploration Forum 2015 was designed as a logical next step in developing the foundation for a national program, a look back at policy drivers and recommendations from the past is important context. Jerry Schubel and VADM Paul Gaffney II (ret.) collaborated to prepare a summary of their talks that compared recommendations from earlier reports and highlighted the remarkable consistency of these recommendations and the challenges that remain. At the same time they noted important accomplishments and progress toward a national ocean exploration program that serves the national interest.

Craig McLean, National Oceanic and Atmospheric Administration. | *Credit: National Aquarium.*

## SOME THOUGHTS AS WE ENTER THE 2015 FORUM

*Jerry Schubel and VADM Paul Gaffney II (ret.)*

The ocean exploration forum convened by NOAA and the National Aquarium in Baltimore is the third in the series of ocean exploration forums called for by the Discovering Earth's Final Frontier: a U.S. Strategy for Ocean Exploration (2000), Public Law 111-11, which authorizes the NOAA ocean exploration program and establishes a collaborative national ocean exploration program, and by Ocean Exploration's Second Decade, a ten-year review of NOAA's Ocean Exploration program (2012).

The first national ocean exploration forum, Ocean Exploration 2020: A National Forum, held in Long Beach in 2013 at the Aquarium

Jerry Schubel, Aquarium of the Pacific. | *Credit: National Aquarium.*

VADM Paul Gaffney II (ret.), Monmouth University. | Ocean Exploration Advisory Board. | *Credit: National Aquarium.*

of the Pacific, identified seven elements that should characterize a national program of ocean exploration. A national ocean exploration program should:

- Be driven by priorities set by the community
- Be rooted in a dynamic network of partnerships
- Use and stimulate the development of new platforms
- Accelerate technology development
- Embrace an expanded role for citizen scientists
- Share data quickly and widely
- Facilitate a coordinated approach to public engagement

National Forum 2014, held in September 2014 at the National Aquarium in Baltimore, was by design a smaller forum focused on NOAA's mission requirements for ocean exploration. Its recommendations reinforced the primary recommendations from Ocean Exploration 2020, and added that the national community of ocean explorers should:

- Describe the value proposition for ocean exploration
- Exploit existing partnerships and mechanisms to build the national program
- Design ocean exploration expeditions using an "architecture of participation"

In 2015, VADM Paul Gaffney II (ret.), Chair of the Ocean Exploration Advisory Board, requested that NOAA's OER conduct an internal evaluation of how far it had come in achieving these goals. Their assessment and an independent assessment by Gaffney and Schubel are summarized below:

- Priorities: There has been a strong convergence on priorities—programmatic, geographic, and logistical—since the President's panel in 2000.
- Partnerships: Progress has been made, but significant potential remains. It may require a broader definition of exploration to include the kinds of exploratory research and operation survey done by the U.S. Navy and geological characterizations that are the responsibility of the U.S. Geological Survey.
- Platforms: The two primary vessels, *Okeanos Explorer* and *Nautilus*, are aging and need upgrades and eventual replacement. Use of UNOLS vessels should be embraced and a greater reliance on employing swarms of UAS and AUV vehicles from the mother ship. Where telepresence is required for scientific investigations or simply to increase the awareness of the general public and stimulate interest in science for students, it should be advanced to a state where it can be deployed on an increasing number of ships.
- Technology: Significant advances have been made in sensors and their use should be expanded on *Nautilus* and *Okeanos,* as well as on other platforms. A day-at-sea for exploration is every bit as dear as a day-at-sea for any ocean operation or research project that makes it imperative that as much data and as many samples as possible be collected incidental to traditional telepresence and bathymetric campaigns.
- Involvement of citizen scientists: Significant progress, but great unrealized potential.
- Data sharing: NOAA does a good job of releasing data quickly; other agencies should do the same. A time limit of two years seems reasonable.
- Public engagement: Telepresence and citizen exploration engage the public. More aquariums should be capturing these programs and bringing them to their visitors. Educators on board add value.

*This assessment may be found at Appendix V.*

## THE CASE FOR GREATER SUPPORT FOR OCEAN EXPLORATION NOW

It's clear that in the near future we will be turning to the ocean for more food, more energy—both renewable and non-renewable, more minerals, more pharmaceuticals, and more fresh water through desalination. All while more people turn to the ocean for recreation to escape overcrowded cities and increasing temperatures. Given that we have explored only some 10 percent of the world ocean, we believe that ocean exploration should have a larger position in NOAA's research portfolio. Ocean exploration is integral in realizing NOAA's priority on environmental intelligence. Ocean exploration of the U.S. Exclusive Economic Zone (EEZ) takes on added importance when one realizes that we have more of our nation underwater than above water, and much of the submerged portion has been only poorly explored.

The missing ingredients include:

- Leadership: The new director of OER and the recently established OEAB are reasons for hope.
- Money: The President's panel called for $75 million per year but OER's budget has never gotten to half this amount. It is buoying to note that this "environmental" issue is not polarizing and as a result, Congressional appropriators have been supportive of budget increases for NOAA Ocean Exploration for several years.
- More champions: We need more visible and more vocal champions within NOAA, in the Congress, and in other agencies of the executive branch of government. One may look back to the extraordinary U.S. Exploring Expedition of the mid-1800s. It was the persistent cry of champions of exploration, inside and out of government, which led to financial support for the expedition and White House pride in and ownership of it. Americans need to be vocal about the need for exploration of the oceans upon which this nation uniquely and increasingly depends.
- Greater public support: This would help generate more support by government and will come only through greater public awareness of the importance, challenges and excitement of ocean exploration. This will require the cultivation of young ocean explorers who can excite the public. It may take a campaign.

NOAA's OER continues to evolve and many important and exciting things are happening both by NOAA and by others supported by NOAA. The new director of NOAA OER has been able to gain new credibility for the program by aiming his program to meet the needs of other NOAA offices.


John Racanelli, National Aquarium. | *Credit: National Aquarium.*

The portfolio of projects has now reached the point that it would benefit from periodic syntheses to provide state-of-the-art summaries of what has been accomplished, what remains to be done, and what the challenges and opportunities are. Such syntheses are characteristic of mature programs and distinguish them from collections of projects. The long-term success of OER will depend upon it achieving the stature of a comprehensive internal-NOAA program, but also a program with the credibility to convince other agencies of government and private explorers to plan exploration campaigns together, leverage one another's talents, and share information and credit.

Ctenophore. | *Credit: Harbor Branch Oceanographic Institute-Florida Atlantic University.*

ESSAY

# AMERICA: AN EXPLORING NATION

BY **VADM PAUL GAFFNEY II (RET.)**

*Monmouth University | Ocean Exploration Advisory Board*

America, like no other nation, sits amidst the world's great ocean system. The ocean surrounds the United States, thereby insolating us from aggressors and serving as the conductor for the bulk of U.S. commerce. Increasingly, too, it brings us fresh water, pharmaceuticals, and energy. It promises access to rare but necessary minerals, and protein that is not hunted, but farmed and cultivated.

These features can add to the strength of a nation, ensure a certain quality of life, and will be more critical if Americans want to guarantee future security and continue to prosper as a society.

America is the world's greatest maritime nation, yet, ironically, it knows so little about the oceans that characterize its uniqueness. Here lies an opportunity to regain American leadership as an exploring nation; not just for prestige, but also for the good of an ever-growing nation.

A great nation pushes frontiers. It keeps its people looking forward, leading forward and moving forward. America has conquered and then developed its land frontiers. It has applied its fortunes to frontiers in deep space. Out of balance is investment in exploring, understanding and then responsibly using the ocean system in which America sits so strategically, and on which the nation will increasingly rely as the world population grows.

Remarkably the ocean remains unexplored, unmeasured, un-sampled and un-viewed. More than 90 percent of it is "dark" to all but our imagination. Yet, America, the world's greatest maritime nation and the one that depends most on the ocean, accepts this ignorance.

America must explore the frontiers that lead to the safety and well-being of its citizens. That means it must understand the oceans that encase the natural treasures it owns, but also those more distant and deeper realms that are so important to military security and in the global competition for resources.

Like most of the global population, Americans are relentlessly migrating to the edge of the ocean. Thousands do so each day. Most of the world lives within a few tens of kilometers from the coast today. As the total population heads toward nine billion, the competition for access to the ocean will be fierce.

America must be ready. It must be first to explore that unknown 90-plus percent. It must lead and be perceived as the global leader. America did so in the great western lands migration for sustenance, and it does so now to satisfy our curiosity about uninhabitable outer space. The murky, but promising, ocean regime must be next.

Before measuring, before understanding, before using, conserving or managing the ocean, the United States must start to explore that 90-plus percent of the ocean that it has yet to encounter. Start in America's own Exclusive Economic Zone—as big as the U.S. land mass. Then move boldly outward to unwrap the mysteries of the deep, for guaranteed national understanding of a global resource upon which the nation will surely depend.

> **“The federal panel was designed to clarify different agencies’ interest in ocean exploration and to help identify areas of convergence that help to reinforce the underpinnings of the national ocean exploration program.”**

The wreck of the USS YP-*389*, a United States Navy yard patrol boat sunk during World War II by a German U-boat off the coast of North Carolina. | *Credit: NOAA, Battle of the Atlantic expedition.*

SECTION 5.0

# THE FEDERAL PANEL

The federal panel was designed to clarify different agencies’ interest in ocean exploration and to help identify areas of convergence that help to reinforce the underpinnings of the national ocean exploration program. Representatives from the key ocean exploring agencies participated:

RDML Tim Gallaudet from the U.S. Navy, RADM Dave Score from the National Oceanic and Atmospheric Administration (NOAA), Dr. John Haines from U.S. Geological Survey, Bill Brown from the Bureau of Ocean Energy Management, Dr. Mary Voytek from the National Aeronautics and Space Administration (NASA), and Dr. Scott Borg from the National Science Foundation (NSF). The National Academy of Science’s Dr. Jerry Miller moderated the panel.

Organizers asked each participating agency to prepare a short description of its ocean exploration activities to help set the stage for the panel discussion. *These are included in Appendix VI.*

All of the agencies, except for NSF, are “mission” agencies—that is, they are charged with specific responsibilities under law. The missions they are mandated to pursue set the requirements that determine where they explore, who their partners are, how they explore, and how and when data and results are shared with the public. But clear themes relevant to all of the agencies emerged from the panel discussion. This section summarizes crosscutting issues and themes. This is followed by brief summary ocean exploration interests and statements of comments made by each of the federal agency representatives.

## CROSSCUTTING ISSUES

### *Partnerships*

All federal agencies partner with sister federal agencies in carrying out their missions. Those partnerships are strongest when they are formed to explore specific areas, features, or processes where each participating agency derives clear mission benefits from exploration results. National coordination mechanisms are important to identify opportunities to leverage other agency investments and opportunities to collaborate.

The panel discussion reinforced the Ocean Exploration 2020 report conclusion that partnerships of all kinds would be increasingly important. No federal agency, including the Navy, has the resources to conduct ocean exploration expeditions without partners that leverage resources, platforms and technologies, and expertise.

### *Data and Information*

How data and information are managed, archived, and disseminated is a function of agency mission, resources, and policy, but all federal agencies, except the Navy, are committed

*The Federal Panel:* (from left) Jerry Miller, National Research Council | RDML Tim Gallaudet, Naval Meteorology and Oceanography Command | Bill Brown, Bureau of Ocean Energy Management | Mary Voytek, National Aeronautics and Space Administration | RADM David Score, National Oceanic and Atmospheric Administration | Scott Borg, National Science Foundation | John Haines, United States Geological Survey. | *Credit: Tracey Brown Photography for the National Aquarium.*

to making the data available in a timely way. Some agencies target data availability within the customary two years—an objective that can be difficult to achieve when exploration activities are not complemented with a robust data management program. Others focus on real time or near-real time release of data.

USGS and BOEM produce analyses and reports to meet specific requirements as a primary product. NSF does not define a deadline for data release, but does encourage principal investigators (PIs) to make their data available according to the terms of the grant. They prefer to have their PIs responsible for the data, but are investing increasingly in data repositories in response to new requirements for public access to data. Much of the Navy data are classified for purposes of national security. Data from the high seas are subject to fewer restrictions than those from within the U.S. EEZ. NOAA is both a consumer of ocean exploration data and information and a provider. As such, the agency has invested heavily in providing timely access to data for decision makers who need it.

All federal agencies struggle with maintaining data repositories from which data can be readily identified and retrieved. This challenge will only increase as the volume of data increases dramatically. Data repositories are costly to develop and maintain and do not always have political, policy, and funding support. As NASA noted, the agency has "places where data go to die called 'data morgues'." The cost of recovering data from legacy systems and managing large archives of data for which management protocols were not established is simply too daunting. Every federal agency probably has data morgues.

All federal agencies acknowledge that while we need more data for scientific purposes, most of the stakeholders want information, not data; information tailored to their specific wants and needs. The panel discussion highlighted both the importance of making ocean exploration data and information available as quickly as possible—as recommended in the Ocean Exploration 2020 report—but also the complexity of doing so, particularly for legacy data sets.

### *The Need for Innovation*

All of the federal agencies acknowledged the need for innovation and for sharing new developments in ocean exploration technologies with federal and non-federal partners. Most agencies depend on partnerships with the academic community, foundations, and the private sector to develop new approaches, systems, and technologies. The panel discussed a number of areas where innovation is needed, including extending the range of autonomous vehicles (and other sensors and technologies that depend battery life), sensors that allow measurements in turbid and turbulent conditions, especially in coastal environments, and cyber security.

### *Acoustic Data*

The panel discussed the importance of acoustic data as an element of ocean exploration. Ocean Exploration 2020 highlighted the importance of exploring phenomena—including sound—in addition to the more traditional observations and sampling practices. Concurrently many in the public are increasingly concerned about anthropogenic noise being added to the ocean and the effects on marine life, particularly cetaceans. New instruments (and instrument networks) are needed to collect acoustic measurements from ships, buoys, and gliders and other autonomous vehicles.

### *The Need for More Support*

There was recognition of the need for more Congressional and public support for ocean exploration and a clear recognition that while all at the National Ocean Exploration Forum value exploration for exploration's sake, there is a requirement to ensure that ocean exploration data and results are relevant to societal needs. This requirement has implications for access to data for decision makers and means that everyone involved in ocean exploration must do a better job of communicating the importance of ocean exploration data and information to decision-makers and the general public.

(From left) Bill Brown, Bureau of Ocean Energy Management | Mary Voytek, National Aeronautics and Space Administration | RADM David Score, National Oceanic and Atmospheric Administration. | *Credit: Tracey Brown Photography for the National Aquarium.*

The panel agreed that the need for ocean exploration demands that we think more creatively about funding models with more diversified sources of support from both the public and private sectors.

## FEDERAL OCEAN EXPLORATION AGENCIES

### *U.S. Navy*

Historically, the U.S. Navy was the federal government's principal ocean exploration agency. The Naval Oceanographic Command maintains a fleet of survey ships dedicated to collecting data from the seafloor, through the water column, to the ocean surface. The Navy's activities focus in three major areas for national security purposes:

- Characterization of the physical environment;
- Identification of hazards to navigation; and,
- Characterization and impacts of human activity.

This includes exploration of the bottom to find sunken objects of interest, understanding the properties of the water column that affect the transmission of sound used in identifying large objects such as submarines in the water column, and seamounts that can be a hazard to navigation. The Navy is also interested in expanding the tools of exploration to make it more efficient and effective. Delivery of the USS MAURY in February 2016 will give the Navy the ability to launch entire fleets of underwater unmanned vehicles. The Navy is engaged in the development of new and better sensors to provide more and better data on the ocean realm. These innovations are shared with its federal partners. Most Navy data are classified and not available for dissemination, particularly in Exclusive Economic Zones. The restrictions on data from the high seas are less stringent.

## *Bureau of Ocean Energy Management*

BOEM is the federal agency responsible for managing the use of energy and mineral resources that are found on the Outer Continental Shelf beyond state waters. These resources include traditional oil and gas reserves, but also wind and energy from waves and currents. BOEM is charged with protecting the environment and managing environmental risk as energy development takes place. BOEM's interest in ocean exploration is primarily in understanding baseline conditions in areas where energy development could take place. Since BOEM's responsibilities are to assess the effects of its operations on the environment and on marine life, their interests extend from the seafloor to above the ocean surface.

Geographically BOEM is focused on Alaska and on the Gulf for oil and gas, and on the Pacific and Atlantic margins for wind. They are actively involved in leasing areas off the East Coast for wind power. BOEM conducts environmental studies several years in advance of potential development.

From BOEM's perspective, effective partnerships emerge because of shared interests. For example, on the East Coast, ocean exploration partnerships with NOAA have been particularly effective given a shared interested between NOAA and BOEM in the mid-Atlantic canyons. BOEM's partnership with the Navy emerged from a shared interest in the effects of sound on marine mammals. These illustrate that the best, most sustainable partnerships are built around shared interests where each partner has something to gain.

RDML Tim Gallaudet, Naval Meteorology and Oceanography Command

Mike Conathan, Center for American Progress

Mary Voytek, National Aeronautics and Space Administration

Jerry Miller, National Research Council

## *National Aeronautics and Space Administration*

NASA has made major contributions to our understanding of oceanic processes and phenomena, particularly from satellite-based sensors that provide synoptic coverage of large areas of the ocean, something not possible with ships. While the data are valuable primarily in understanding surface and near-surface phenomena, their data have also contributed significantly to understanding the shape of the sea floor. Many of these data have been incorporated into models to predict changes of regional and global regimes in response to climate change. These activities and others support NASA's mission to understand planet Earth.

NASA also has a growing interest in the search for oceans on other planets within our solar system, and even beyond. The agency sees the value of working with the ocean exploration community to refine its approach to interplanetary expeditions to ocean worlds. Because the costs of such expeditions are so high, the agency tests many of its ideas and instruments in extreme environments on Earth. Hydrothermal events and the Antarctic are examples of two such extreme environments. In this way they have made a significant contribution to the exploration of the Earth and Earth systems. NASA relies on other federal agencies such as NOAA and NSF since it does not operate ships.



## *National Oceanic and Atmospheric Administration*

NOAA is the only federal agency with an explicit ocean exploration mission. In addition to conducting its own ocean exploration expeditions in support of internal and external mission requirements, NOAA has a mandate to lead in the development of a national program of ocean exploration, one that involves a network of partnerships among other federal agencies and non-governmental ocean exploration stakeholders.

NOAA is the nation's "Environmental Intelligence Agency." In this regard, it not only has a responsibility to lead a coordinated national program, but also to ensure that the resulting data and information get into the hands of the people that use it. This goes beyond scientists to decision makers, teachers, students, and the general public. NOAA recognizes that for most these audiences, it is information, not data, that they want and need. This information must be timely, relevant, and actionable. NOAA's ocean exploration information must contribute to our understanding of the changes in the ocean, why these changes are happening, and what the implications are for managing fisheries, marine protected areas, safe navigation, and other areas for which NOAA has a major responsibility.

NOAA has multiple partnerships. An excellent example is the multi-year campaign to explore the Mid-Atlantic Canyon, an effort that included three federal agencies, two states, three museums, three international partners, and fifteen academic institutions. These collaborations resulted in 17 expeditions on five different ships with major discoveries that included: 570 cold seeps that had never been documented before, and large areas of deep sea coral. These findings led to the Mid-Atlantic Marine Fisheries Council to restrict fishing activity in these canyon areas.

## *National Science Foundation*

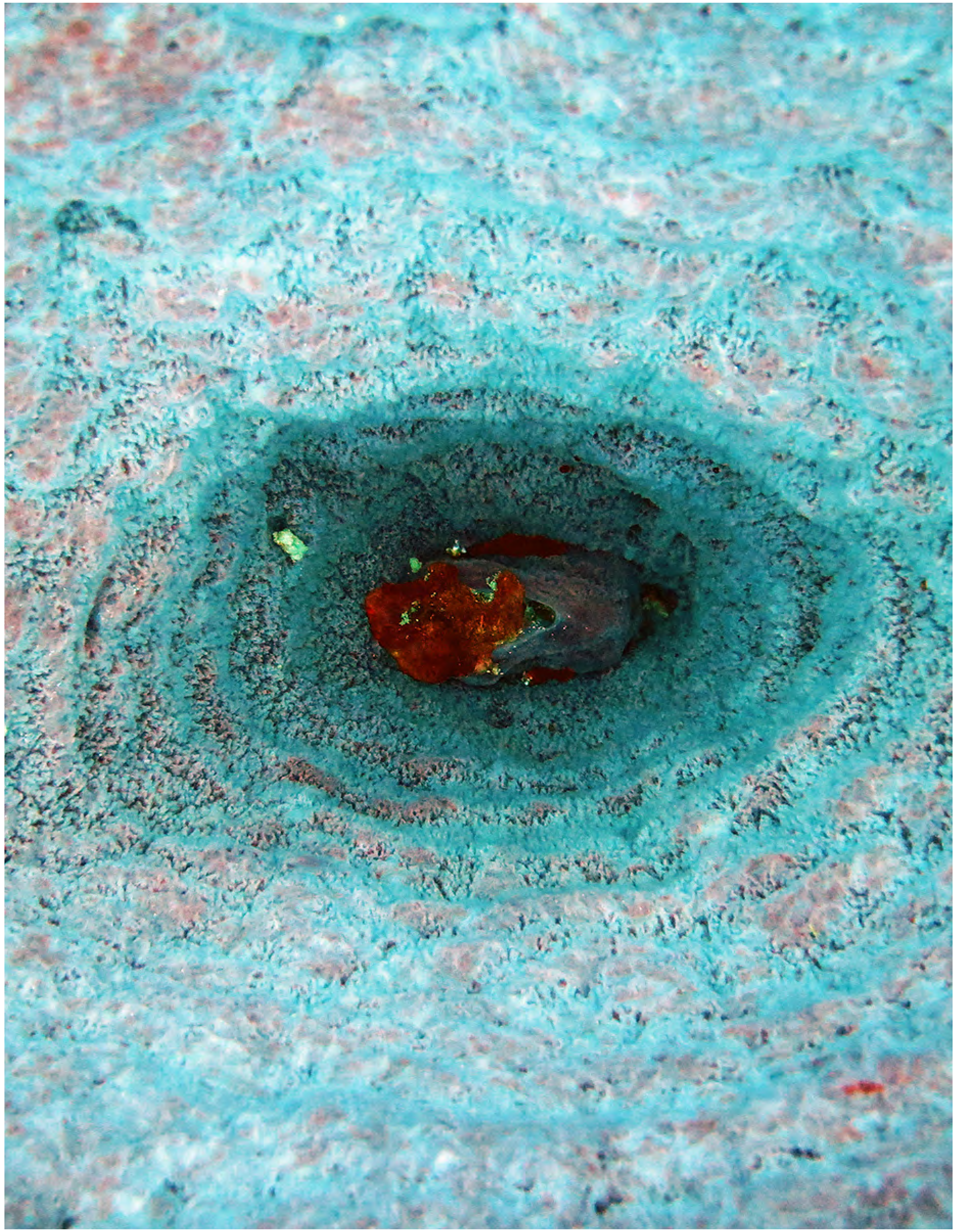
NSF is committed to hypothesis-driven research and so is responsive to research community priorities. But the agency recognizes the importance of a spectrum of activities that range from exploration to hypothesis-driven research. If exploration hypotheses are framed properly their chances of success in being funded by NSF increase. While NSF funds proposals in broad categories, it does not direct research. A proposal's success depends upon the external review process—another difference between NSF and the mission agencies.

In the past 10-15 years there has been increased interest by NSF in understanding the ocean, atmosphere, and land as the "Earth system." Large-scale endeavors such as the long-term international study CLIVAR (Climate and Ocean: Variability, Predictability, and Change) and GEOTRACES, an international study of marine biogeochemical cycles of trace elements, continue to have important implications for ocean exploration. NSF has flexibility in forming partnerships with other agencies and other nations to pursue hypothesis-driven research as a complement to discovery-based ocean exploration expeditions.

## *U.S. Geological Survey*

The USGS is a science agency and its mandate extends beyond geology to include all the other natural science disciplines. The USGS mission is to inventory and classify living and non-living resources—and then to understand processes that shape our environment. So USGS is concerned with mineral resources, biological distribution, natural hazards, and changing landscapes. This responsibility extends to deep-sea minerals.

But if USGS is a science agency, it is also an exploration agency. In the past, the lines of demarcation between a typically NOAA expedition and one that USGS might conduct was the seafloor. USGS interests were with the seafloor and below; NOAA's with the water column. But modern technologies such as multi-beam systems blur that line. As a result, USGS and NOAA often work closely together to leverage each other's comparative expertise. Examples include collaboration to discover methane hydrate seeps on the east coast of the United States recently, and the U.S. program to delineate the Extended Continental Shelf.



Barrel sponge (*Xestospongia muta*) with a moray eel in the sponge atrium. | *Credit: Harbor Branch Oceanographic Institute-Florida Atlantic University.*

ESSAY

# NASA'S EXPLORATION OF OCEANS ON EARTH ... AND BEYOND

BY **ELLEN R. STOFAN**

*Chief Scientist | National Aeronautics and Space Administration*

NASA uses the unique perspective of space to study Earth's oceans. The oceans play a central role in our planet's weather, climate, and biosphere, and therefore are essential to NASA's objectives to understand the Earth as an integrated system and to use that understanding to develop and test applications for societal benefit. Here on Earth, for example, oceans transport about half the heat from the tropics to the poles (atmospheric processes account for the other half of the observed meridional heat transport). Without the oceanic contribution, temperature differences between the equator and the pole would be significantly larger than we actually have.

Satellites are being used to measure a variety of important physical, dynamic, thermodynamic, and biological properties of the upper ocean, including ocean surface topography—the shape of the ocean surface as well as sea level, currents, waves, winds, precipitation, phytoplankton content and biological productivity, sea-ice extent and thickness, sunlight reaching the surface, and ocean surface temperature. On-orbit NASA ocean-observing satellites and space-borne instruments, many accomplished through domestic and international partnerships, include Aqua, Terra, GRACE, GPM, JASON-2, and RapidScat. In addition to measurements from space-borne instruments, NASA supports field programs that acquire detailed ocean measurements from airborne and ship-based instruments.

Upcoming NASA satellite research missions include ICESat-2, which will monitor sea-ice extent; PACE, which will measure ocean color to provide information on upper ocean ecosystems; and SWOT, which will provide first-ever, broad-swath, measurements of ocean topography and the first near-instantaneous, spatially extensive maps of the oceanic mesoscale eddy field.

NASA also studies evidence of oceans on planets beyond Earth. Mars, early in its history, had extensive bodies of water on its surface, raising the possibility that life could have evolved on Mars. Mars lost it oceans billions of years ago, in part due to the erosion of Mars' atmosphere by the solar wind. Rovers and orbiters at Mars continue to refine our understanding of the extent and duration of oceans on Mars, and future human missions to Mars could provide a definitive answer to the question of whether or not life evolved there, or is even possibly still present. It has also been hypothesized that Venus could have had oceans very early in its history, before being lost due to the runaway greenhouse conditions there.

Further out in the solar system, the Galileo mission to the Jupiter system and the Cassini mission to the Saturn system have demonstrated that oceans exist in the outer solar system. In the case of Jupiter's moon Europa (3,100 km diameter) and Saturn's moon Enceladus (500 km diameter), the oceans exist beneath an icy crust. The satellites are likely heated by the tidal pull of their giant planets as well as the decay of radioactive elements in their rocky centers, with that heat possibly melting the rocky cores and producing seafloor volcanism. At Enceladus and possibly Europa, the ocean at times erupts in geyser-like fashion from long cracks in the satellite's icy crust. The Cassini spacecraft has flown through Enceladus' plumes, measuring salty water, organic molecules, and silica. The


*Reception Keynote:* (from left) Craig McLean, National Oceanic and Atmospheric Administration | VADM Paul Gaffney II (ret.), Monmouth University, Ocean Exploration Advisory Board | Ellen Stofan, National Aeronautics and Space Administration | John Racanelli, National Aquarium. | *Credit: Tracey Brown Photography for the National Aquarium.*

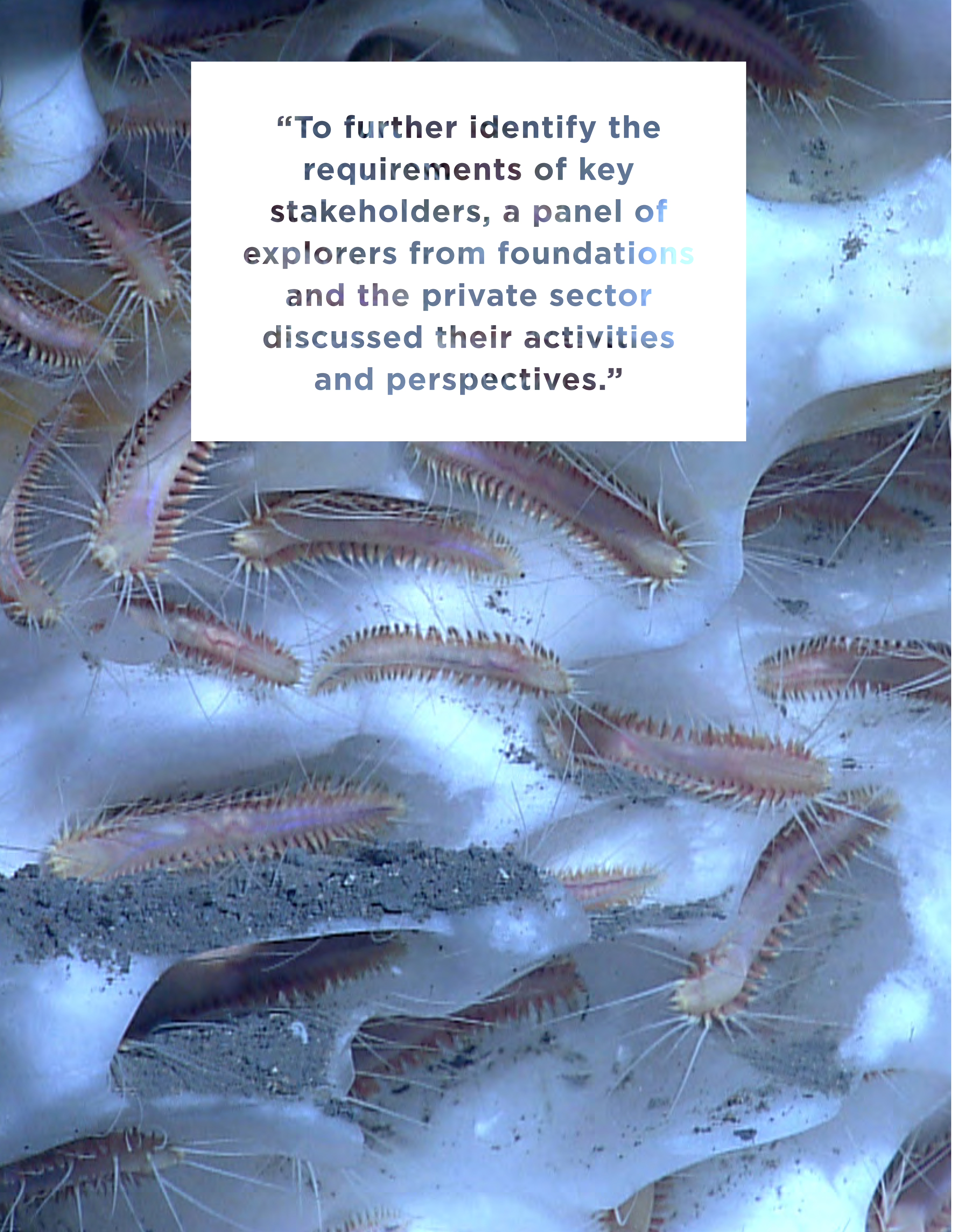
combination of seafloor volcanism and a stable ocean environment make Enceladus and Europa possible sites for extraterrestrial life.

In the 2020s, NASA will send a mission to Europa to measure the thickness of the icy crust, its surface composition, and determine the existence and composition of possible plume-like eruptions. NASA is also studying a possible lander for Europa, which may be able to make in situ measurements to try to measure the composition of material that may erupt from the subsurface oceans onto the surface. Future missions to Europa could include submarines that could melt their way through the icy crust to directly explore the Europan ocean.

Saturn's moon Titan is actually the only other body in the solar system besides Earth with surface bodies of liquid that exchange material with the atmosphere. However, the working fluid at Titan, where the surface temperature is about 90K, is liquid methane and ethane rather than water. However, Titan's seas, the largest of which is over 1,000 kilometers across, with depths of at least several hundred meters, are the only place where we can go to investigate coastal, air-sea interchange, and wave processes. Titan's seas are also an important astrobiological target, to determine how far chemical reactions might proceed towards life in the absence of water. The first sea lander on Titan might look a lot like one of NOAA's ocean buoys here on Earth. To explore oceans on other worlds, NASA will rely heavily on exploration technologies, instruments, and partnerships developed with NOAA.

From Earth to the outer reaches of the solar system, oceans can be a critical element in planet's evolution and current state, and may be an important indicator of the presence of life. The Kepler Space Telescope has identified about 5,000 candidate planets around other stars: exploring oceans on this planet and elsewhere in our solar system will help us better understand habitability in the universe. NASA and NOAA are already working closely in cooperation to understand the role of oceans in Earth system science; a national ocean exploration program brings together government, academia and private industry to expand this scientific endeavor and will lead to understanding oceans on this planet and beyond.

Skate. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*



"To further identify the requirements of key stakeholders, a panel of explorers from foundations and the private sector discussed their activities and perspectives."

An aggregation of methane ice worms inhabiting a white methane hydrate in the Gulf of Mexico. | *Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2012.*

SECTION 6.0

# THE COMMUNITY PANEL

To further identify the requirements of key stakeholders in a national ocean exploration program, a panel of explorers from foundations and the private sector parallel to the federal panel discussed their activities and their perspectives on a national ocean exploration program. Panelists were selected from organizations that typically fund or conduct ocean exploration and were asked to think about topics in advance that included geographic areas of interest, data and data sharing, public engagement, building support for ocean exploration, the role of exploration in identifying areas worthy of protection in need of management, and partnerships. Mike Conathan of the Center for American Progress was the moderator. The panelists were:

- Bob Ballard, *Ocean Exploration Trust*
- Missy Feeley, *ExxonMobil Exploration Company (ret.)*
- Eric King, *Schmidt Ocean Institute*
- Dave Lovalvo, *Global Foundation for Ocean Exploration*
- Shirley Pomponi, *NOAA Cooperative Institute for Ocean Exploration, Research and Technology/Harbor Branch Oceanographic Institution*
- Phillip Renaud, *Khaled Bin Sultan Living Oceans Foundation*

Again, organizers asked each panelist to prepare a short overview of their organization's ocean exploration activities to help set the stage for discussion. These summaries are included at Appendix VII. To open the session, Mr. Conathan asked each panelist to make a brief opening statement of what motivates them to explore, what approach they use in deciding where and how to explore, and what they look for. This was followed by several specific questions to spark discussion.

The panelists represented a diversity of interests and approaches to ocean exploration, but several important recurrent themes emerged that aligned well with the federal panel's conclusions and with Ocean Exploration 2020 report results. This section summarizes crosscutting issues and themes. Brief summary statements of panelists' ocean exploration interests and comments made in panel dialogue follow.

## CROSSCUTTING ISSUES

### *Partnerships*

The panelists communicated a strong desire for more, closer, and more diverse partnerships, and felt that partnerships among federal agencies and between federal agencies and private exploration institutions were easier to develop and sustain than partnerships between private exploration organizations. Private organizations sometimes compete for attention and funding, which can compromise effective partnerships. That said, there is room for increased part-


*The Community Panel:* (from left) Mike Conathan, Center for American Progress | Bob Ballard, Ocean Exploration Trust | Eric King, Schmidt Ocean Institute | Shirley Pomponi, Florida Atlantic University | Missy Feeley, ExxonMobil (ret.) | David Lovalvo, Global Foundation for Ocean Exploration | Philip Renaud, Khaled bin Sultan Living Oceans Foundation. | *Credit: Tracey Brown Photography for the National Aquarium.*

nership between federal agencies and private organizations. The panel recommended that a formal interagency coordinating committee for the national ocean exploration program be established to would serve as a clearinghouse for coordination and partner development. International partners are also important—collaboration among nations, principal investigators from other nations, and international organizations is key to exploring the global ocean. Partnerships among nations have great value not only to science but to international relations.

### *Data Sharing*

All panelists said that sharing data is desirable. But several pointed out that private sector interests can preclude the open data models favored by the federal government and by many in the academic and not-for-profit worlds. Ocean exploration conducted by the oil and gas industry is usually proprietary. In the case of ocean exploration focused on marine pharmaceuticals, data may be held until patents are filed. All others want the data available as quickly as possible, and in many cases, in real time or near-real time. Sharing data in many different ways is important because different stakeholders have different wants and needs. Sharing samples is also important and quite widely practiced among most of the groups represented. The point was made that data is not the only desired result of ocean exploration—some stakeholders want to share in the experience of exploration through live feeds of expeditions and stories.

### *Public Engagement*

Greater public engagement is key to securing, sustaining, and increasing the level of public support for a national program of ocean exploration. This will result in greater funding for the federal government and increase its ability to partner with and support non-government ocean explorers. To do this, we need to enhance the number and quality of "stories" about the excitement and importance of ocean exploration to science and society and develop and energize more expansive networks for distributing these stories. Our society needs heroes in these stories who convey the value of exploration in human terms. It is important that these heroes reflect the diversity of America to help reach groups across all segments of society. The suggestion was made to ensure greater diversity in the next National Ocean Exploration Forum.



### *Community Priorities*

The panelists agreed that the ocean exploration community should drive the priorities of a national program of ocean exploration. This is a message that came out of the first two forums and was repeated here. Workshops that bring experts together to explore and identify important geographic areas and themes with the greatest potential for discoveries have proven to be a good model for identifying priorities based on the best available science, community interest, and federal agency mission requirements. The panel noted that private philanthropic ocean exploration organizations could benefit by being more inclusive in the development of their programmatic and geographic priorities so as to leverage additional resources and partner and collaborator contributions.

## COMMUNITY OCEAN EXPLORATION ORGANIZATIONS

### *Khaled bin Sultan Living Oceans Foundation*

The Khaled bin Sultan Living Oceans Foundation's mission is to protect and restore ocean health through science-based solutions. The Foundation focuses on programs in science, education communication. The organization is driven by a concern for the rapid changes being seen, particularly in coral reefs, which many believe are the "canary in the mine" for the oceans. Science alone is insufficient to compel change. Ocean literacy and creative communications are fundamental to promoting changes that lead to improved ocean conservation and ocean health. The Foundation operates a research vessel that supports the Global Reef Expedition and conducts exploration and assessments using a Science Without Borders model.

### *Global Foundation for Ocean Exploration*

The mission of the Global Foundation for Ocean Exploration (GFOE) is to advance a national ocean exploration program with global reach and relevance. GFOE works with ocean exploration partners in government, academia, and private organizations to train the ocean exploration workforce of the future, supports NOAA and other ocean explorers with deep submergence engineering and operations capabilities, and develops new technologies for ocean exploration. GFOE is not hypothesis-driven. The Foundation's goal is to visit areas that are unknown or poorly known, collect data that helps to characterize these areas, and provide that data to any and all who wish it.

### *Oil and Gas Industry*

The ocean exploration drivers for the oil and gas industry are unique. Although some of the basic tools for exploration, such as multi-beam systems and seismic soundings, are the same

(From left) Mike Conathan, Center for American Progress | Bob Ballard, Ocean Exploration Trust. | *Credit: Tracey Brown Photography for the National Aquarium.*

Missy Feeley, ExxonMobil (ret.) | *Credit: Tracey Brown Photography for the National Aquarium.*

(From left) Eric King, Schmidt Ocean Institute | Shirley Pomponi, Florida Atlantic University. | *Credit: Tracey Brown Photography for the National Aquarium.*

(From left) Brian Midson, National Science Foundation | Brad Clement, Texas A&M University. | *Credit: Tracey Brown Photography for the National Aquarium.*

(From left) Missy Feeley, ExxonMobil (ret.) | David Lovalvo, Global Foundation for Ocean Exploration | Philip Renaud, Khaled bin Sultan Living Oceans Foundation. | *Credit: Tracey Brown Photography for the National Aquarium.*

as for exploration carried out by others, oil and gas companies gain competitive advantage by collecting and analyzing these data. The oil and gas industry has great expertise in remotely operative vehicles and other deep submergence assets, but again, the requirements are unique to oil field operations. Oil and gas provides the bulk of our energy. These energy sources will continue to be a major factor in the nation's energy consumption mix for a number of decades.

As the industry moves on to explore and develop these more and more "difficult" oil and gas deposits, the pace of technological progress will need to accelerate significantly if past production trends are to be maintained and future demand addressed. To achieve these technological advancements, investment in research and diverse partnerships are critical. Diverse skills, disparate viewpoints, access to unique data types, and, most importantly, creative ideas and applications are available through partnerships. Examples of types of the existing partnerships include industry-academic consortia, strategic alliances with service providers, and direct support for individual investigators.

## Marine Biotechnology and Pharmaceutical Industry

The marine biotechnology and pharmaceutical industry is dedicated to the discovery and development of products and services from marine organisms. Recent successes mean it is possible to talk about results, and not just potential. This is a rapidly growing and developing market sector. In addition to biologically active compounds, the surfaces of marine organisms may hold solutions to anti-fouling and drag reduction. Emerging areas include regenerative medicine and tissue engineering—many marine animals have quite remarkable powers of regeneration. The areas of the ocean that hold the greatest interest are hard bottom areas within the EEZ, because most of these animals are found on hard bottoms and because operating within the U.S. simplifies the process of commercial application and patents.

## Schmidt Ocean Institute

Schmidt Ocean Institute (SOI) was established



(From left) Eric King, Schmidt Ocean Institute | Shirley Pomponi, Florida Atlantic University | Missy Feeley, ExxonMobil (ret.) | David Lovalvo, Global Foundation for Ocean Exploration. | *Credit: Tracey Brown Photography for the National Aquarium.*

to advance the frontiers of ocean research and exploration through innovative technologies, intelligent observation and analysis, and open sharing of information. SOI operates the R/V *Falkor* as an advanced oceanographic research and exploration facility, which is available to the ocean exploration community at no cost through a competitive process. SOI programs are structured into five focus areas: advancement of oceanographic research; development of marine and exploration technology; collaborative, interdisciplinary science; communications, education, and outreach; and open sharing of data, research, and research outcomes.

SOI depends on collaborators to achieve its mission objectives. SOI's interest in this and previous National Ocean Exploration Forums stems from its desire to become an integral part of the exploration community.

## Ocean Exploration Trust

The Ocean Exploration Trust (OET) was founded in 2008 to engage in pure ocean exploration. The Trust operates the exploration vessel *Nautilus* to conduct exploration of the seafloor, including marine archeological sites. OET operates an array of science and education programs centered on engaging participants in hands-on ocean exploration expeditions on board the *Nautilus* and on shore via telepresence. OET goals include:

- To explore areas of the ocean seeking out new discoveries in the fields of geology, biology, maritime history, archaeology, and chemistry while advancing ocean engineering, technology, and engagement;
- To share our expeditions with explorers around the world via live telepresence; and,
- To serve as role models for the next generation of scientists, engineers, and educators and to turn everyday viewers into explorers.

OET believes that ocean exploration falls short because it doesn't have a compelling, unifying vision. Bob Ballard pointed out that we need a map of the submerged portion of the U.S. that captures the many uses we can make of it and to unify our interests as ocean explorers.

Hundreds of catsharks also called chainlink dogfish, rest on one of the *Billy Mitchell* Fleet shipwrecks, located in Norfolk Canyon, off the U.S. Atlantic coast. | *Credit: Deepwater Canyons 2013—Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

ESSAY

# THE FUTURE OF SUBMERGED AMERICA

BY **DR. ROBERT D. BALLARD**

*President of the Ocean Exploration Trust | Director of the Center for Ocean Exploration Graduate School of Oceanography | University of Rhode Island*

In 1803, President Thomas Jefferson agreed to pay the government of France $15 million to acquire the Louisiana Purchase so that Emperor Napoleon Bonaparte could pay off France's war debt with England.

In so doing, Jefferson doubled the size of America at that time, adding another 828,000 square miles to our country. This acquisition was followed by several more, both peaceful as well as at the end of a barrel that created the landmass we now call the United States of America.

Following the Louisiana Purchase, President Jefferson sponsored the Lewis and Clark Expedition to determine for the first time what our Nation had just acquired.

One hundred and eighty years later, in 1983, President Ronald Reagan picked up a pen—not to sign a checkbook—but to sign Proclamation 5030 that all but doubled again the size of America from 3.86 million square miles to its present 7.25 million square miles, with the potential for claiming even more.

It was not until 2010, more than 27 years later, however that the modern-day version of the Lewis and Clark Expedition could begin when NOAA's *Okeanos Explorer* and the Ocean Exploration Trust's E/V *Nautilus* began their long and ongoing quest to determine what we now own beneath the sea.

As this process continues and new living and non-living resources, beautiful marine landscapes, and cultural sites are being discovered, one has to wonder what will follow those discoveries, since exploration has always been followed by exploitation.

If the past is any predictor of the future, it is useful to see the complex tapestry of uses that has emerged across our above water landscape since the Lewis and Clark Expedition with the emergence of National Parks, oil and gas fields, non-federal grazing lands, coal mines, farms, ranches, and cities. One can only assume what we will see—and in some cases are already seeing—will be as complex a tapestry as the one above water.

ESSAY

# OCEAN EXPLORATION AND HUMAN HEALTH

BY **SHIRLEY POMPONI**

*Research Professor and Executive Director of the NOAA Cooperative Institute for Ocean Exploration, Research, and Technology | Harbor Branch Oceanographic Institute, Florida Atlantic University*

Consider that an estimated 1.7 million new cases of cancer will be diagnosed in the U.S. in 2016, and nearly 600,000 people will die from the disease. Direct medical costs for cancer are estimated at $75 billion annually. Some cancers remain extremely difficult to treat and new approaches are needed. Resistance to antibiotics is an emerging threat worldwide.

Or consider that up to 5 million Americans are suffering from Alzheimer's or related dementia with annual costs to Medicare/Medicaid estimated at more than $100 billion.

New pharmaceutical agents to treat cancer, dementia, and other diseases are constantly reaching the clinic. But with increasing death rates, emerging multi-drug resistant diseases, increasing cost of treatment, and the cost of lost productivity to the economy from disease, more effective drugs are still required.

Natural products have been an important source of new medicines; the majority of antibacterial and anticancer drugs approved for use in the U.S. over the past two decades have their origins in natural products, and marine natural products continue to provide unique sources for drug discovery and development.

The value of the oceans as a source of life-saving drugs has been well documented by the National Research Council, the U.S. Commission on Ocean Policy, and the NSTC Subcommittee on Ocean Science and Technology. Indeed, thousands of marine-derived chemicals with pharmaceutical relevance have been discovered. For the scientists engaged in exploration, discovery, and development of new marine-derived chemicals, the motivator isn't profit—it's the drive to discover cures or treatments for diseases that are fatal or debilitating.

Nevertheless, marine biotechnology has already demonstrated its value in developing products and processes for both human and ocean health. Examples include new drugs to treat cancer and manage pain, molecular sensors to detect contaminants in the environment, genetic fingerprinting techniques to conserve threatened species, and improved aquaculture methods for production of safe seafood for human consumption. There is a growing interest in marine biomaterials and how their properties can be exploited to develop biomimetic or bio-inspired materials. Unique structural designs in corals and deep-water sponge skeletons are being applied to innovation in fabrication chemistry and tissue engineering (e.g., development of structures for bone repair). Adaptation of deep-water organisms to extreme temperatures and pressures are the basis for development of novel composite biomaterials with applications in bio-sensing and medicine.

These are not hypothetical benefits. Marine biotechnology is a growing market sector. Net annual revenues for only two marine-derived drugs (Yondelis® and Prialt®) are greater than $100 million.

Despite these promising developments, there is almost no investment in efforts to discover new marine organisms and compounds of value. At a minimum, our national ocean exploration program should include the discovery of new marine-based pharmaceuticals and biotechnologies as an element of characterization and discovery.

There are two major challenges in the discovery and development of products from marine living resources:

1. **Program support.** While the National Institutes of Health and the pharmaceutical/biotech industry fund research and development of marine-derived chemicals with pharmaceutical potential, they no longer support the acquisition of these materials (i.e., expeditions to new areas and collection of unique samples). NOAA has been the primary source of support for discovery and collection of deep-water organisms (which has resulted in patented and licensed products), but the shift in exploration priorities away from sampling has effectively put an end to the discovery of novel biomedical resources from unexplored regions of the ocean (e.g., more remote geographic locations and deep-water habitats—both benthic and mid-water). This challenge is not simply one of funding; it's one of recognition that these unusual and diverse deep-water (and mid-water) organisms are novel sources for discovery of unique molecules for drug discovery, and are as important to document, sample, and protect as are deep-water fisheries and precious corals.

Researchers from the Cooperative Institute for Ocean Exploration, Research, and Technology at Florida Atlantic University and the University of North Carolina, Wilmington, have discovered, patented, and licensed marine-derived natural products for the treatment of cancer and metabolic disorders. These discoveries are the direct result of exploration and research activities funded by NOAA's Office of Exploration and Research. Research is leveraged with funding from NIH and from the States of North Carolina and Florida. One example is the deep-water sponge, *Aphrocallistes beatrix,* collected in deep water reefs 40 nautical miles off the southeast coast of Florida. A potent chemical, aphrocallistin, was isolated from this sponge; it is particularly effective against breast cancer that is resistant to cancer drugs. | *Credit: Harbor Branch Oceanographic Institute-Florida Atlantic University.*

2. **Technology transfer.** Unfortunately, the majority of discoveries with potential are languishing in publications and university technology transfer offices, trapped in the "valley of death"—the gap between discovery and commercialization. The issue is more than just the "transfer" of technology. Exploration and research need to be re-defined in terms of the broader context of societal benefit (on the university side of the "valley of death") and economic benefit (on the industry side of the "valley of death").

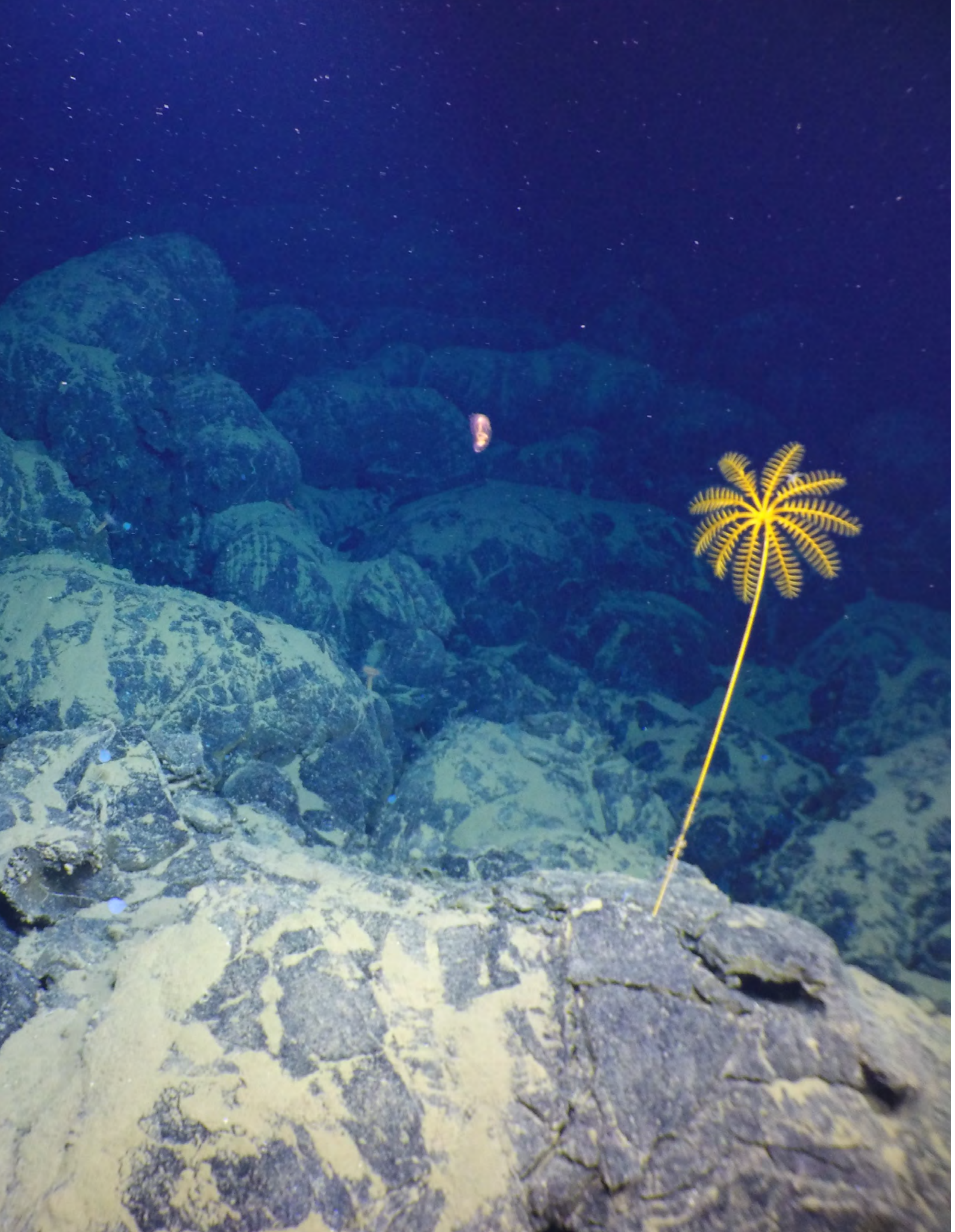
A national program to build support (and funding) for ocean exploration in general, and the discovery of novel resources with biomedical potential in particular, will require novel approaches to communication, cooperation, collaboration, and coordination in both discoveries and developments.

To quote Larry Mayer's comments about the progress we have made as a community since the first National Ocean Exploration Forum in 2013:

**"An area where we have seen little, if any progress, is in the formal and systematic coordination of ocean exploration activities amongst the various ocean exploration entities, and particularly amongst federal agencies. Given the mandate of PL-111-11 one would hope to see a formal interagency coordinating committee for national ocean exploration activities. More than a mandate is required for such an organization to be successful: a willingness on the part of all agencies involved to participate and contribute is essential. This may be the greatest challenge facing the future of U.S. ocean exploration activities."[1]**

The tangible benefits to society and the economy that marine pharmaceuticals and biotechnologies offer are yet another driver that requires us to re-emphasize and re-define the need and value of a national ocean exploration program—with partners from academia, government, industry, and the private sector.

[1]See Appendix V, page 96



Stalked crinoid. | *Credit: Ocean Exploration Trust, Galápagos, 2015.*

SECTION 7.0

# THE SYNTHESIS PANEL

## SYNTHESIS PANEL

The Synthesis Panel was asked to reflect on the first day's presentations and panel dialogue to identify common drivers, needs, and opportunities across the national ocean exploration community. John Racanelli moderated the session; Jerry Schubel, Jerry Miller, Mike Conathan, and Craig McLean served as panelists. Their commentary fell into several areas, which mirrored similar discussions at Ocean Exploration 2020.

## VISION

The Synthesis Panel concluded that there is a need for a compelling, unifying vision and story for why ocean exploration is important. We need to go much further in translating the vision and describing the tapestry to policy makers, decision makers, and funders—including Congress, philanthropic investors, the private sector—so that they understand the importance and value of ocean exploration in their terms. The vision must explain that ocean exploration leads to new discoveries that lead to a better future. And it must convey economic value, benefit to humanity, and great urgency.

## INSTITUTIONS

The Panel noted that we have come quite a long way since 2001 in the national ocean exploration endeavor. What used to be primarily a Navy function is now conducted not just by civilian and military agencies, but by private and not-for-profit organizations as well. These private philanthropic investments are significant, and increasingly important.

But still, the national ocean exploration program is somewhat less than the sum of its parts. The analogy is that our science enterprise does a good job of training scientists to make "bricks"—discrete blocks of knowledge, of information. But our science enterprise does not do a good job of assembling those bricks into coherent pictures and systems. We have an opportunity to create a tapestry of the ocean and learn how to describe that tapestry to the larger science community, to the public, and to decision makers.

The national framework should provide direction, but also allow for innovation and improvisation. It must remain open to new directions as discoveries lead to new knowledge and understanding. A national program should provide for both elements and hold them in tension.

## PARTNERSHIPS

Both the Federal and Community Panels focused on partnerships and how collaboration can allow organizations to work more efficiently and to leverage investments and capabilities across sectors. The Synthesis Panel acknowledged that

*The Synthesis Panel:* (from left) Mike Conathan, Center for American Progress | Jerry Miller, National Research Council | Jerry Schubel, Aquarium of the Pacific at Long Beach. | *Credit: Tracey Brown for the National Aquarium.*

federal funding will remain tight, and partnerships are essential to promoting development of new technologies, and to increasing the number, scope, and impact of ocean exploration expeditions.

Technology can promote and nurture partnerships as well. Innovative modes of exploration, sample sharing, other approaches both allow partnerships to function effectively and engage a much larger segment of the science community than used to be possible. Recent advances in platforms, vehicles, modes of operation, communications, and other technologies will only reinforce and expand partnership opportunities and effectiveness.

While noting considerable partnership successes, the panel noted that it's fair to ask whether the community has optimized collaboration. What would it take to create more synergy, more encouragement for partnerships? What catalytic investments would help? In the federal context, the panel identified the need to look across budgets and programs, but also to the structure of the national ocean exploration enterprise in the federal government to understand what changes are needed to optimize collaboration.

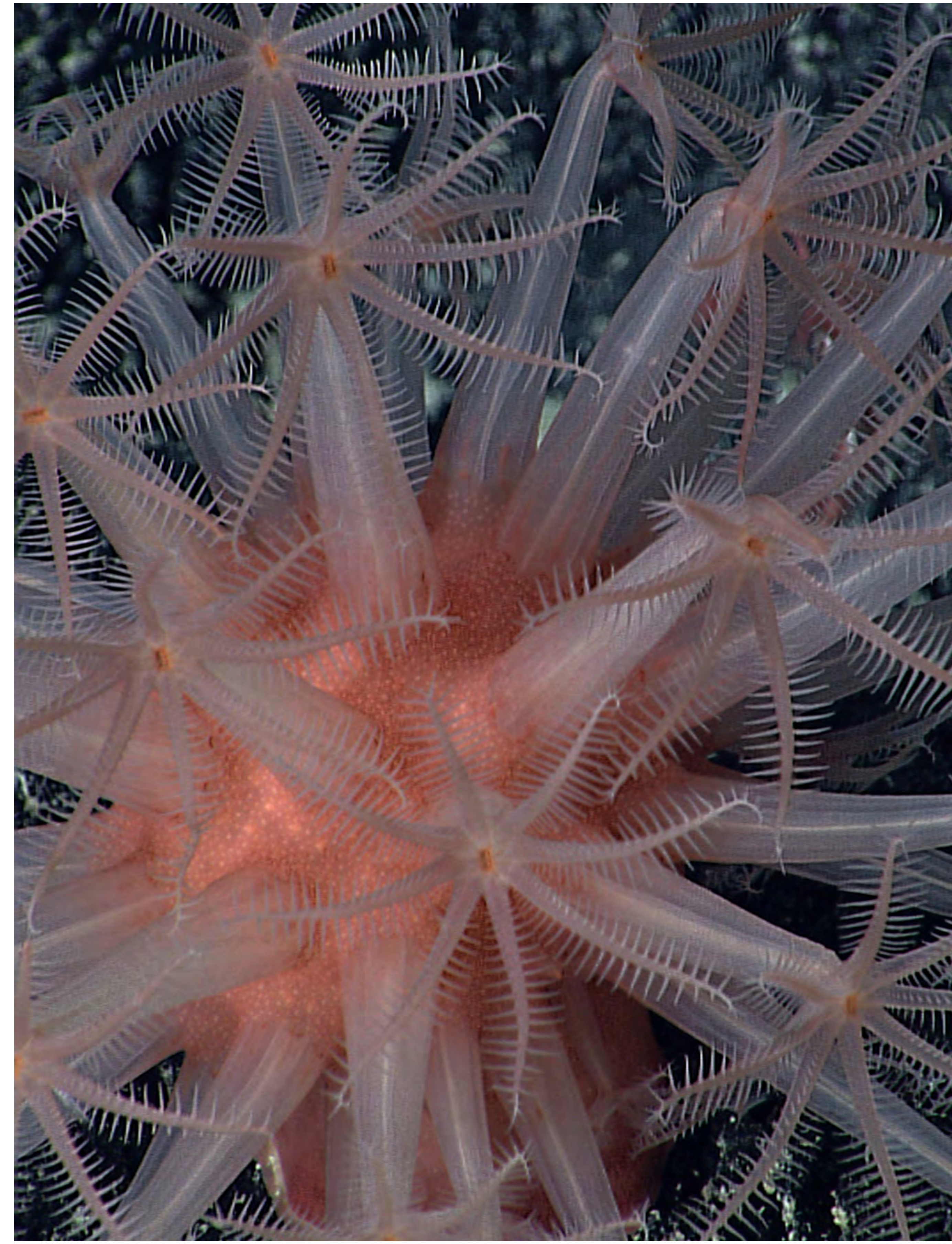
There is also a need to understand various drivers in organizations to create effective partnerships—then look for ways our organizations create impediments to collaboration and remove them.

## DATA

The Synthesis Panel identified data sharing and access to data as an important common theme as well. Open data encourages scientific discovery, which in turn promotes more exploration and more research. Even the private sector—which by definition collects proprietary data—understands the value of sharing data when possible.

## ENGAGEMENT

A national program must be relevant to the diverse America in which we live. And that requires a conscious effort to include communities that might not naturally gravitate toward science and ocean exploration. Public engagement is key—various demographics need to participate in ocean exploration. But we also need charismatic leaders who can work Congress, explain the value proposition for ocean exploration, and win support.



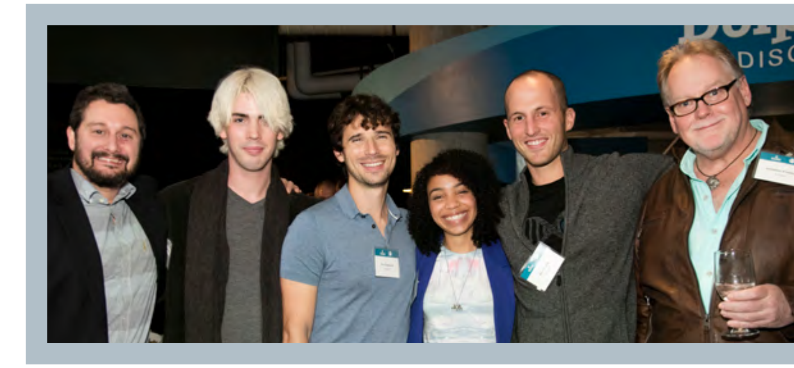
Close up of the octocoral, Anthosmastus; seen during NOAA's 2015 Hohonu Moana: Exploring Deep Waters off Hawaii expedition. | *Credit: NOAA Office of Ocean Exploration and Research, 2015 Hohonu Moana.*

(Left) Keynote speaker Ellen Stofan, National Aeronautics and Space Administration, speaking during the reception, hosted in the Harbor Market Cafe at the National Aquarium. (Below) Snapshots from the keynote reception. | *Credit: Tracey Brown for the National Aquarium.*

SECTION 8.0

# RECEPTION HIGHLIGHTS

Kevin Hand, National Aeronautics and Space Administration, Jet Propulsion Laboratory | Frank Pavia, Columbia University

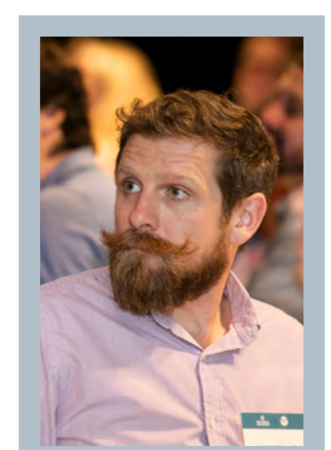


Andrew David Thaler, Southern Fried Science | Charles Cross, OpenROV | Eric Stackpole, OpenROV | Aurora Thornhill, Kickstarter | David Lang, OpenROV | Jonathan Knowles, Autodesk

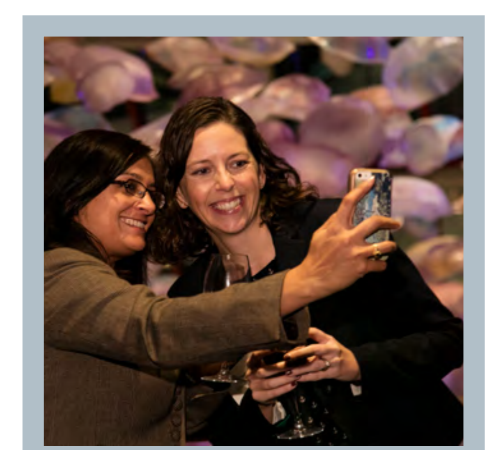
VADM Jon White, Consortium for Ocean Leadership | Bob Ballard, Ocean Exploration Trust


Caren and RDML Tim Gallaudet, Naval Meteorology and Oceanography Command | Thomas Curtin, MIT Sloan School of Management

Christopher Kelley, University of Hawaii

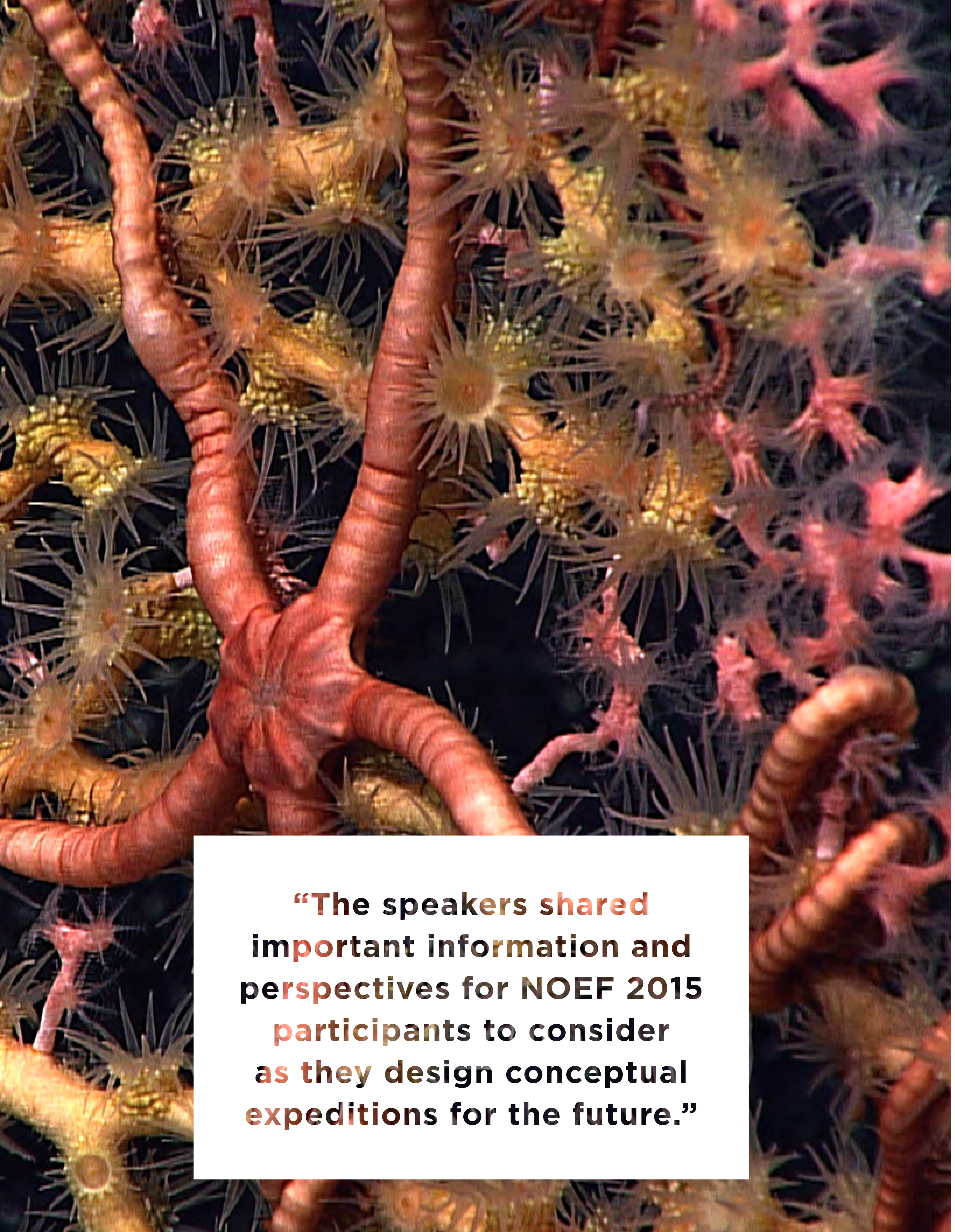


Jimmy O'Donnell, University of Washington



Jyotika Virmani, X-Prize Foundation | Allison Miller, Schmidt Ocean Institute

Shirley Pomponi, Florida Atlantic University | Jyotika Virmani, X-Prize Foundation | Leonard Pace, Schmidt Ocean Institute



A brittle star living on an octocoral (pink) that is being overgrown by a zoanthid (yellow). Seen while exploring deep waters off Hawaii. | *Credit: NOAA Office of Ocean Exploration and Research, 2015 Hohonu Moana.*

**"The speakers shared important information and perspectives for NOEF 2015 participants to consider as they design conceptual expeditions for the future."**

SECTION 9.0

# INTRODUCTION TO THE MARKETPLACE OF IDEAS

The Marketplace of Ideas was designed as a series of fast-paced talks from leaders in an array of fields to provoke discussions in the working groups that followed about what technologies, approaches, and paradigms might change the way we explore. Not all of these speakers represented disciplines traditionally associated with ocean exploration, yet all presented ideas and approaches that could be relevant to the National Ocean Exploration Program.

- **Eric Stackpole** described OpenROV's new, accessible exploration technologies and the OpenExplorer portal that allows citizen explorers to share results.
- **Aurora Thornhill** spoke about Kickstarter and important new ways crowdfunding is encouraging citizen exploration and science.
- **Andrew David Thaler** talked about the importance of using new communication tools and approaches for "transformative outreach."
- **Caren Cooper** reviewed the history of citizen science and emphasized that the value of engaging citizens in the enterprise extends well beyond education and outreach to scientific discovery.
- **Tim Kearns** envisioned a (near) future where ocean exploration data were organized and accessible to answer the questions we have when we have them.
- **Jonathan Knowles** described a world of "capture, compute, create" using tools available to almost everyone to transform how we design and build technologies and systems.
- **Dominique Rissolo** explained that immersive visualization environments can spur creativity and collaborative breakthroughs in understanding.
- **Jimmy O'Donnell** discussed recent developments in eDNA analysis that could lead to breakthroughs in how columns of ocean water and the life within them are characterized.
- **Darlene Lim** compared mission planning and control approaches in space and ocean exploration, concluding there is great benefit in the space and ocean exploration communities collaborating.
- **Kevin Hand** shared recent developments in technology focused on exploring interplanetary ocean worlds that may have relevance to terrestrial ocean exploration.

Moderated by David Lang, co-founder of OpenROV and a member of the Ocean Exploration Advisory Board, the ten speakers shared important information and perspectives for the NOEF 2015 participants to consider as they designed conceptual expeditions for the future.

*Short summaries of the Marketplace of Ideas discussion results follow.*

SUMMARY

# CONNECTED EXPLORATION

BY **ERIC STACKPOLE**

*OpenROV*

**“What if we can allow the true democratization of exploration discovery? That’s the future we want—that we want to provide. And it all starts with the camera.”**

I want to discuss technology, particularly sensors. There are very advanced sensors, such as pH sensors and dissolved oxygen sensors, but I want to talk about one that is extremely powerful, yet perhaps taken for granted: it’s the camera.

Cameras are an extremely positive tool, allowing you to see things that you may not otherwise see, while also telling a story. And that storytelling, combined with other collected data, can be really powerful, especially when we take cameras to places that we wouldn’t be able to see otherwise, and then share what those cameras see.

Camera technology is now becoming ubiquitous, as we carry smart phones that have amazing camera sensors on board. And that technology, which we can put in our pocket, is also connected to the internet, allowing us to capture and then share even the most random, rare encounters.

What if you could put cameras in the water everywhere, so those rare encounters can be captured by anyone? That’s the founding principle behind OpenROV—putting remotely operated vehicles (ROVs) in the hands of everyday people. And we’ve created a website, Open Explorer, where citizen scientists can share the stories of what they’re exploring, show the rest of the world what they’re doing, and hopefully get other people involved.

Open Explorer is just the beginning of not just democratization of the technology, but also democratization of storytelling. It’s not just Cousteau and National Geographic anymore. It’s all of us. And anyone can come up with the next big discovery.

There’s really cool stuff you can do with imagery from the camera. For example, you can create 3-D models, pull out data about the volume of things that you’re looking at, look at an object and see where it’s going, or tag what you see. Now add an internet connection. And imagine if, as you’re flying an ROV through the water, people from around the world can follow your dive online and tag what is being seen. Now you have a lot of really great data, and you’ve also got engagement.

You may have seen how drones have taken off—it’s estimated that a million aerial drones shipped this holiday season. So what if we can get just as many eyes in the water? What if we can allow the true democratization of exploration discovery? That’s the future we want—that we want to provide. And it all starts with the camera.



SUMMARY

# KICKSTARTER FOR SCIENCE

BY **AURORA THORNHILL**

*Kickstarter*

**“What story will you tell? What will you create, explore, discover, teach, inspire, learn from, and share with your community?”**

Kickstarter is a platform where people can raise funds for what we define as “creative projects,“ including not just art, film, and music projects, but also technology projects, scientific research projects, and more.

To date, 96,000 projects have been funded on Kickstarter, with $2.1 billion dollars pledged, and 87 percent of that funding going to successful projects. And while money is great, what really is important with Kickstarter is our community.

There are 9.9 million Kickstarter backers, 31 percent of whom are “repeat backers,” meaning they’ve backed more than one Kickstarter project. Those repeat backers have pledged 52 percent of all Kickstarter funds. This shows how strong our community is—people are coming back again and again and continuing to contribute to things that they find important, valuable.

At Kickstarter, we stress community so much because community anchors. Community anchors three types of engagement that are important, not just in running a Kickstarter project, but also in scientific outreach in general.

Community anchors validation, shows that something is important. By backing a project, it shows that people think the project is important and that they like that someone is trying to come up with something new and novel.

Community also anchors education. That’s a step above validation. People are saying not only do they think something is important, but that they want to learn more about it. Education is a critical piece of the puzzle, especially when we’re talking about science. You want to make sure that people are learning from what you’re doing.

Education can then turn into participation. That participation may be somebody that has been educated, who then goes out and teaches their community, their friends, their family. Or it could be more significant participation, such as with citizen scientists who are doing a lot of the scientific work themselves. Participation brings together validation and education into a much grander and more engaging type of interaction. It’s really important to build a strong community because you’re not going to get these types of engagement without that.

Community is your peers. Your fellow scientists, creators, the people you admire. But they may also be citizen scientists or amateurs who are excited about learning something new. They may be somebody who wants to help you develop your idea and make better. Community is vast and broad. But it is important to go beyond what you normally think community is, because not doing so can be detrimental; a lot more people are excited about, and willing to support, what you’re doing than you may think.So what story will you tell? What will you create, explore, discover, teach, inspire, learn from, and share with your community? Because that’s what Kickstarter enables you to do—to engage and share with your community in all of these exciting and different manners that are important. And this not only applies to Kickstarter projects, but to science outreach in general. You’ve got to think about community.

# SOCIAL MEDIA AND THE SEA

BY **ANDREW DAVID THALER**

*Southern Fried Science*

**"If you latch onto that perfect combination of new technology, science, and storytelling, you can really change everything and reach entirely new audiences."**

The deep sea still largely falls within the confines of out of sight, out of mind, making it hard to get people to care about the deep. This left me with a conundrum, because while deep-sea exploration is great for discovery, it is still really difficult to share those discoveries. We've made some progress, but we still have a long way to go.

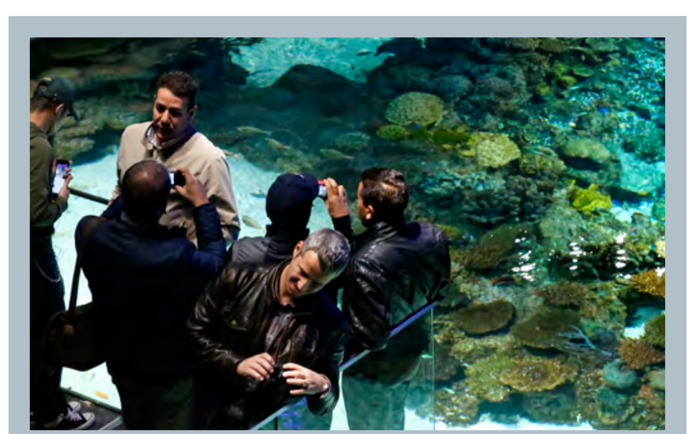
Ocean outreach needs to be able to adapt to rapid changes and harness existing momentum. Recently, social media has taken over as the dominant mode for science communication. Social media allows us to have conversations while being flexible and capitalizing on newsworthy moments. By taking advantage of the kind of momentum social media can bring, you can capitalize on events and use them to spread conservation messages. All of this is centered around the difference between subsistence outreach and transformative outreach.

Subsistence outreach is all the outreach we know and love. It is movies, books, photography. It is all the things we have to do to maintain a minimum baseline of awareness about any issue. We know the type of audience that subsistence outreach will reach.

Transformative outreach, on the other hand, is something new. It is when we take the established practices of subsistence outreach and adapt them to new audiences and new technologies. Really, all subsistence outreach starts as transformative outreach. At one point, even photographs were novel. For the last century or so, it has been submersible technologies that have driven the ocean outreach story, instilling a love for the ocean by taking a flat surface and giving it depth.

For the last century, we've made huge strides in getting humans into the deep sea, and the transformative story for this century is going to be about tearing down barriers and pushing for new models for outreach, particularly tools that turn your audience into active participants. Providing the resource and, most importantly, providing community networking, empowers the public to take an active role in the collection of ocean data.

We need to look at what technologies are out there and figure out how to use them for ocean outreach. And if you latch onto that perfect combination of new technology, science, and storytelling, you can really change everything and reach entirely new audiences.



Guests take photos of the *Blacktip Reef* exhibit at the National Aquarium. | *Credit: National Aquarium.*





# CITIZEN SCIENCE MOVEMENT

BY **CAREN COOPER**

*North Carolina Museum of Natural Sciences*

**"Citizen science is about more than just opening access to knowledge; it's about opening access to the very systems of knowledge production."**

I want to share my perspectives on citizen science, which is one method of scientific inquiry where we can make discoveries that would otherwise not be possible, and at the same time, build social capital so that those discoveries are valued and useful.

While the information and communication technologies we use to collect information may be new, the concept of gathering information from citizens is actually very, very old. For example, in the mid-1800s, Matthew Fontaine Maury and his team extracted information from old ship logbooks and used records of things such as winds and currents to create charts. What better way to inform a journey then basing it on the past journeys of others?

And Maury's charts were a success. Sailing became safer and faster. Within a few years, over a thousand ships were using special log books to record the data for Maury and sending data to him so that he could quickly update these charts. Every ship that navigated the high seas with his "crowd-sourced" charts and blank abstract logs was henceforth regarded as a floating observatory, a temple of science.

Maury didn't just make new discoveries; he also embedded science in the daily lives of sailors in a way that transformed superstitions into valuable scientific discoveries.

There are hundreds of citizen science projects today that deal with the oceans, from divers, sailors, people indexing phytoplankton, people tagging online where seals are on aerial photos. There are still drift bottle projects. Shark watchers. Whale watchers. And then the numerous sweeps where people are tallying garbage on beaches.

All of these projects, if they're designed well, have the potential to make new scientific discoveries. Some of these projects, if they're really well crafted, also have the potential to build social capital and to make that knowledge valued and useful the way Maury did.

Central to the success of these projects is the way scientists view their relationships with participants. It's about creating collaboration and valuing what people can do. Citizen science is about more than just opening access to knowledge; it's about opening access to the very systems of knowledge production.

That's my vision for the future of citizen science—where collaboration becomes so mainstream that there are systems in place so that making observations and sharing them systematically becomes part of what it means to be a responsible person living on this planet.

As one of the sailors wrote to Maury, "Until I took up your work, I had been traversing the ocean blindfolded." Citizen science is our best way to make new discoveries and build social capital so that we don't have to sail into the future blindfolded.

SUMMARY

# OCEAN EXPLORATION DATA AND THE NEXT GENERATION

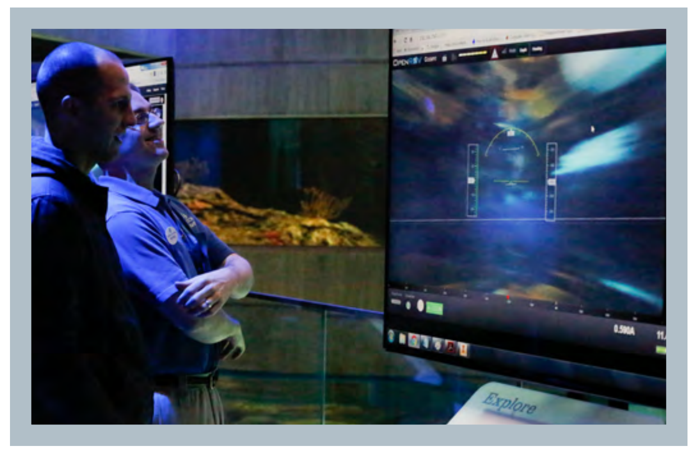
BY **TIMOTHY KEARNS**

*Ocean Aero*

**"The next generation won't want to be burdened by needing to be a data scientist. They're not going to want to be burdened by proprietary formats and information behind firewalls and limited distribution models. They're just going to want answers to their questions."**

We know that data come from a variety of platforms and vehicles: airplanes and satellites, ships and ROVs and open ROVs, and, of course, humans themselves. The direction these vehicles and platforms are going is largely autonomous. Look what's happening on land. We have driverless cars, autonomous package delivery systems, health and human services being delivered by drone, even autonomous home security systems, all part of a larger system called the internet of things. The same thing will happen in the ocean. The next generation of autonomous ocean vehicles will largely be fully autonomous: self-powered, self- propelled. Some will do double duty as submerged vehicles as well as surface vehicles, all the while collecting data. But autonomous vehicles are not really what will excite the next generation. What they will get excited about is being part of a larger system, a system that includes data collection, data processing, telecommunication analytics, and visual reporting—all part of an autonomous system. That's the direction that we need to be going.

The next generation of users will expect to live in an automated world. The fundamental difference between what we have today and what we will have tomorrow is automated systems. Humans will be increasing less involved in routine



Aquarium guests and staff watch live feed from an ROV provided by OpenROV in *Blacktip Reef* on Ocean Exploration Day. | *Credit: National Aquarium.*

operations. They will be less interested in data and more interested in information. This will be possible because we're moving into a new era of computing. One that is information driven. Cognitive computing, artificial intelligence, machine learning, are happening right now all over the world. It's going to change the way that we interact with machines. It was Ray Kurzweil who said, "In 2029, just 13 years from now, computers will declare themselves conscious, and we'll believe them, because we have to." Right now we have data confusion. Data that's difficult to collect, access, share. Often it's not available; often it's sometimes difficult to understand. We need to move to this new model where we have information that's available and accessible on demand. Imagine an information paradigm where we have oceanographic information delivered to us, not us having to go diving for it.



SUMMARY

# VISUALIZATION TOOLS

BY **JONATHAN KNOWLES**

*Autodesk*

**"Let's face it, science isn't just for scientists. The only way we're going to solve all the grand challenges that we face with regards to our oceans and other things is by getting all the minds in the world thinking about these issues."**

Autodesk is a 33-year-old software company. While most people are aware of our first product, AutoCAD, we now sell hundreds of products and we do all kinds of things in design. People using our software include designers, engineers, architects, scientists, and others.

Most people know us for the tools that are used to design airplanes, cities, buildings, and even tennis shoes. But we also have design tools that are used for things that you might not think about. For example, people can use computational fluid dynamics to determine airflow in operating room to help prevent the spread of disease. People use our tools to do amazing scientific visualizations, to bring to life things that may be too small to see or difficult to conceptualize. We've been thinking about how to use these tools to help people understand things like sea level rise and climate change, which are difficult for people to wrap their heads around because the time scale is just too different.

We are now in a realm of what we refer to as "infinite computing." Computing is almost free; the cloud gives us that capability. Things that used to cost a lot of money don't anymore. None of the things that I'm highlighting here cost any money; they are all free things that Autodesk has put out there to make things better.

Let's face it, science isn't just for scientists. The only way we're going to solve all the grand challenges that we face with regards to our oceans and other things is by getting all the minds in the world thinking about these issues. From using any kind of camera to create high-resolution models of coral reefs to monitor reef change to using technology to generate three-dimensional models of archaeological artifacts and fossils, people can now capture reality so that anyone can view it and better understand it.

We're moving into the world of generative design. We now have design tools that let us simply describe the engineering goals and challenges of something and the computer does the design. Computers are actually quite better at that in some cases. Think about where this is going to help us with things that we want to send to the deep ocean, where there are serious physics challenges.

We're definitely moving into a world of capture, compute, create. And the tools to do this are available to all of you.

These aren't just ideas. These are real things that are happening now and people are using these tools. And if you're not, you are behind the curve. So get on board, take a look at some of these things, and integrate them into what you're doing.

SUMMARY

# IN SITU 3-D VISUALIZATION

BY **DOMINIQUE RISSOLO**

*University of California, San Diego | Ocean Exploration Advisory Board*

**"Some of the most powerful things are the kinds of visualization and 3-D environments that allow you to have a conversation about your data. Get your colleagues around you, and the gears start turning differently in your head as you're immersed."**

How can technical divers exploring remote and hostile environments bring their discoveries to the surface without removing them? How do we create digital surrogates of important, yet delicate, sites for scientists to analyze?

Tools such as structure from motion (SFM) photogrammetry are allowing us to explore and analyze places like archaeological sites without disturbing them. It's the intrinsic value of recording things in situ and evaluating them in situ.

Because it's the relationship between objects and other natural and cultural features and their environment that will tell us the story of the natural and cultural processes that creates the archeological record. New techniques such as SFM photogrammetry now allow us to make the most out of these discoveries.

These tools can also be applied to any number of underwater sites, which are particularly challenging. SFM photogrammetry can bring an underwater place topside for scientists to work on.

One of the things that we're focusing on now is how to take this photogrammetric technique and have people in real time around the world be able to make measurements and work with extraordinarily dense point clouds.

We now have the kinds of techniques that allow us to manipulate the context of objects that we're interested in using SFM photogrammetry and additional software, both off-the-shelf and custom developed. We still need to create models that are visually photorealistic and geometrically accurate for measurements, but also allow us to look at the kinds of information that our eyes can provide.

We talk about individual experiences as far as virtual reality goes. Putting headsets on and looking around you is very powerful in terms of getting and controlling things in the water. But some of the most powerful tools are the kinds of visualization and 3-D environments that allow you to have a conversation about your data. Get your colleagues around you, and the gears start turning differently in your head as you're immersed.

It's not an individual experience. It's kind of a collaborative analysis that we can do with point clouds, with structure-from-motion models, using these environments. And now we're starting to take those environments on the road.

We can now take exploration sites—wherever they are, in seas, lakes, and rivers—to people at other locations to have conversations. And really that's where the ideas come from—when we work together as a group in front of these data and these visualization environments.



SUMMARY

# eDNA ANALYSIS IN EXPLORATION

BY **JIMMY O'DONNELL**

*University of Washington*

**"If we're going to address gaps where we have no data, we can't continue under our current paradigm. We need approaches that are both scalable and automatable."**

As the demand for marine resources grows, we're going to be faced with specific questions, such as how many fish are there in the sea and where are those fish?

We don't know the answers to those questions yet, because the ocean is gigantic and dark, and fish are hard to count there. Right now, if we want to know something about a place in the ocean, we drive there and drag a net around or put some cameras down. And then we have a taxonomic expert sort through the data.

Ocean expeditions are expensive and can be dangerous. We're also limited by the taxonomic expertise of the people we can bring with us or to whom we can get the data once we're home. This is reflected on a map of our knowledge of species in the ocean—it is sparse both spatially and with respect to taxonomy.

If we're going to address gaps where we have no data, we can't continue under our current paradigm. We need approaches that are both scalable and automatable. And a technique with exactly those properties is surveying a biological community by sequencing the DNA that it leaves behind in the environment.

Some colleagues and I tried this approach alongside counting fish in shallow water. Divers counted fish while we sequenced water samples the divers collected. While some of the results matched up, some did not. For example, there was no record of flat fish in the sand flats from divers, and yet flat fish DNA in was in the samples.

In a similar project, we surveyed eelgrass communities around Puget Sound by dragging a net along. In collected samples, we found the expected: crabs, shrimp, slow fish. But while the DNA results showed orders of magnitude greater taxonomic coverage, it was mostly from critters down below the sediment: all the clams, sea cucumbers, and worms that are no less important to maintaining a functional ecosystem, but are not things we're normally looking for.

I love that about eDNA. That forced broader perspective that says, you've been looking at this part of the community, but this is all the stuff that's really there. I'm excited about the role of eDNA in ocean research, because it is exactly that broad perspective you would want if you had one shot at surveying a biological community in a place that you had never explored before.

The technology to do this is already there. We're going to have more data than we know what to do with. One of the biggest challenges as sequencing technology gets cheaper, faster, and more portable is training the next generation of ocean explorers in the skills that we need to translate the data into information, and to move from, "There are plenty more fish in the sea," to "How many fish are there in the sea?"

SUMMARY

# EXPLORING EARTH AND SPACE

BY **DARLENE LIM**

*National Aeronautics and Space Administration | Ocean Exploration Advisory Board*

**"Moving ahead, a coordinated mission approach will not only change the way that ocean exploration is perhaps enabled, but it will also change the way that we sculpt our mission architectures for human exploration of space."**

Exploration on land, in the ocean, or in space all share the collective themes of science, science operations, and technology. At NASA, we often invoke the mission statement that "science enables exploration and exploration enables science." We can further draw on that and say that ocean exploration can enable space exploration and space exploration can enable ocean exploration.

Under the theme of science, there are questions that are relevant to astrobiology that we can ask in ways that require us to go into our oceans, so that the data we collect in our oceans can eventually be applied to understanding other water worlds.

In terms of science operations, the ocean exploration community is exemplary in their ability to execute complex research missions under extremely dynamic conditions. It is incredible to observe the discipline with which ocean exploration missions are planned and prepared, and the detailed decision-making protocols that permeate each outing. A treasure trove of scientific operational knowledge and experience exists in the ocean exploration community that is directly applicable to human space exploration, and it behooves us to share this know-how between the disciplines. Collaboration on this front will lead to innovations in how we conduct science and exploration, whether here on Earth or on other planets and beyond.

When it comes to technology requirements for ocean or planetary exploration, there are a number of similar mission characteristics that must be addressed. For example, these outings typically result in large mapping and imaging datasets, require precise in situ measurements and must contend with sample handling, return and contamination constraints that are equally challenging to address on Earth as they are during planetary exploration.

All of these themes are very much shared, and they can bind us as we move forward and start to look at how we manage the limited resources that we have in all spectrums of exploration science.

At the foundation of all of our field missions is science. We go in with real scientific questions, with graduate students that have to graduate, with post docs that are trying to build careers. And from there, we absorb the different exploration concepts and the different technologies that have been devised by engineering- and operations-focused analog missions, and we test these ideas in a real science environment. Through this testing, we drive out what works and what doesn't work, as well as what user design elements are required and which ones are not.

Moving ahead, a coordinated mission approach will not only change the way that ocean exploration is perhaps enabled, but it will also change the way that we sculpt our mission architectures for human exploration of space.

The Arctic Ocean is one of the most remote locations on Earth and a region where the impacts of climate change are strongly expressed, making its exploration now paramount to understanding future ecosystem change. | *Credit: Caitlin Bailey, GFOE, The Hidden Ocean 2016: Chukchi Borderlands.*

As a coordinated community, we need to share which knowledge gaps we have, whether they be in science, science operations, or technology. We should also be looking at how different issues have already been addressed, how they've been solved, and how they can suit specific custom requirements of different communities.

It is at these convergence points that we're going to have the "oohs" and the "aahs" and moments of inspiration. It already happens on a small scale during our missions and there is an exciting opportunity at hand to coordinate exploration between the ocean and the planetary science communities.

SUMMARY

# THE NEW AGE OF OCEAN EXPLORATION

BY **KEVIN HAND**

*National Aeronautics and Space Administration | Jet Propulsion Laboratory*

**"Our work creates a wonderful marriage, advancing our understanding of what's happening on our own planet while simultaneously feeding forward into our exploration of potentially habitable worlds beyond Earth."**

I want to talk about a bridge that exists already, and that I hope we can build in much greater capacity in the years to come with regard to robotic exploration of our ocean, and eventually, the robotic exploration of oceans beyond Earth.

It is my hope and my expectation that 100 years from now, when we look back at our century, we will see it as a new age of ocean exploration. This exploration will bring us to the deepest depths of our ocean and allow us to map the bottom of our ocean at necessary scales, and will be motivated by a desire to better understand our biosphere, to better understand our climate, and to better understand the resources in the depths of our ocean.

The next century will also be an age of ocean exploration that will bring us to ocean worlds beyond Earth. This exploration will be motivated by a desire to find signs of life in our solar system.

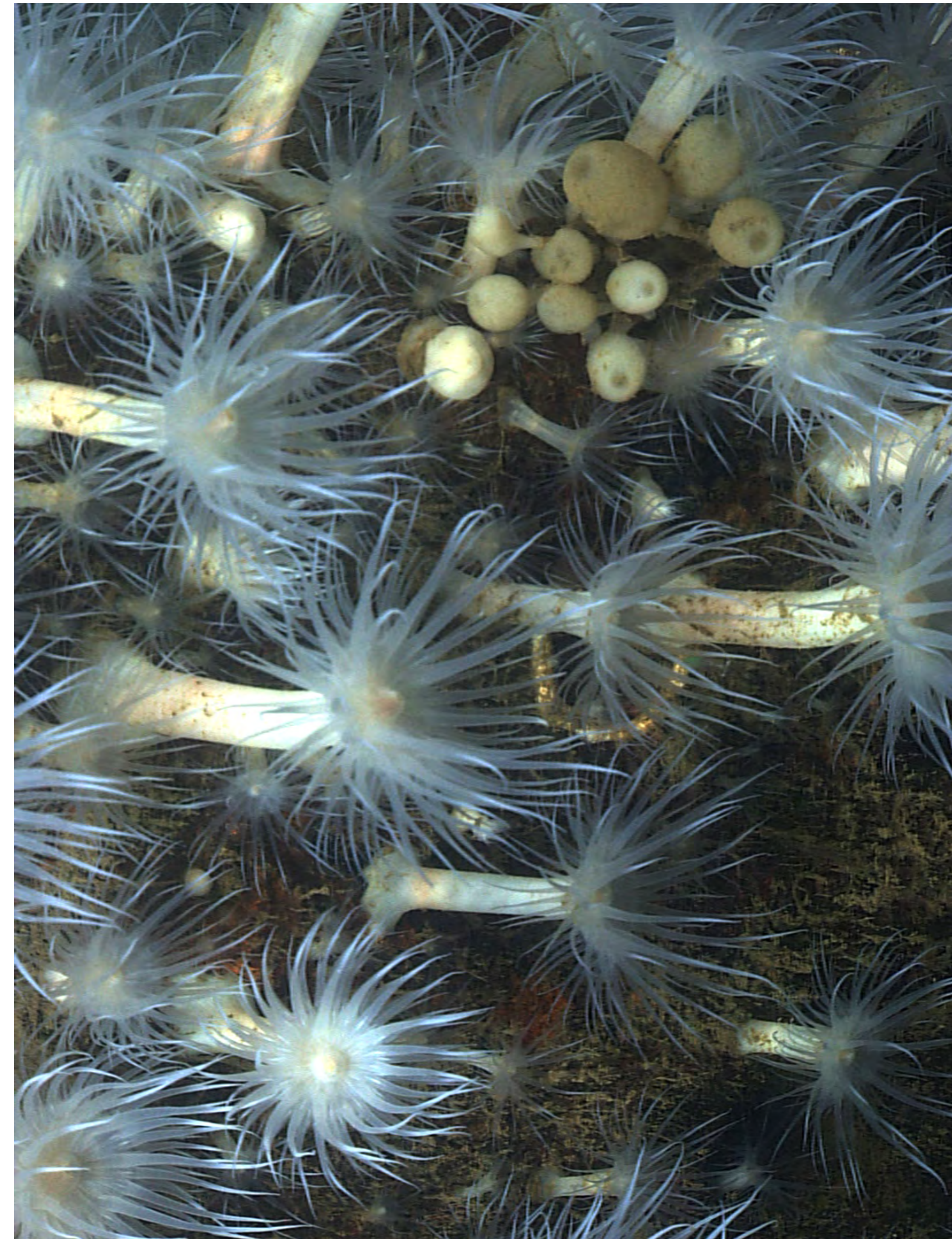
So what is the bridge? What is the opportunity here? NASA is engaged in a lot of Earth science, but most of the oceanic Earth science goes from the surface of our ocean upwards. The technological and scientific questions that we bring to bear on worlds like Europa and Enceladus offer a real opportunity for NASA to now dive deep, to use some of our technological capabilities to explore our ocean as a bridge to the exploration of these ocean worlds beyond Earth.

When it comes to Europa and Enceladus, the science is really about revolutionizing biology. But importantly, even in the absence of biology on these worlds, we will still be able to do comparative oceanography.

On the technological side, there are a lot of things converging at the NASA level that make some of these big missions possible, not the least of which are new launch vehicles and a need to start testing some of these robotic capabilities that would someday be used on the surface and in the subsurface of Europa and Enceladus.

For example, my team built a robotic vehicle that allows us to explore ice-covered lakes and sea ice in Alaska and map methane seeping from these lakes. This rover is an early precursor of something that we may someday fly to Europa. These frozen-lake ecosystems in Alaska are one example of environments that can help guide us in assessing whether or not a world like Europa could harbor life. And, in testing the rover in Alaska, we think it was the first time that an underwater, under-ice, untethered vehicle has been operated through satellite link.

Our work creates a wonderful marriage, advancing our understanding of what's happening on our own planet while simultaneously feeding forward into our exploration of potentially habitable worlds beyond Earth.



Anemone cover the remains of a shipwreck resting on seafloor in the Gulf of Mexico. | *Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2012.*

ESSAY

# OCEAN EXPLORATION DATA AND THE NEXT GENERATION

BY **TIMOTHY KEARNS**

*Vice President for Robotics and Data Services | Ocean Aero*

Let's talk about ocean exploration data and the next generation. Although my title suggests that I'm going to talk about data, I'm actually going to talk about the next generation—*of humans.*

Today, data comes from a variety of platforms including airplanes, satellites, ships, ROVs and, of course, humans themselves. The direction that this technology is headed is predominantly autonomous. To see where ocean exploration technology could go, we should take a quick look at what is happening in the terrestrial space.

On land, we're seeing the development of driverless cars, courier services, and even health services being delivered by autonomous drones. These, plus security systems, entertainment, transportation, and biometric monitoring are all a part of an emerging, overarching network called the Internet of Things. This same type of transformation will happen with ocean exploration technology.

The next generation of ocean exploration vehicles will be autonomous, self-powered, self-propelled and can collect data for days and weeks at a time. Some, such as the Ocean Aero Submaran, will do double duty as both a surface collection vehicle and a diving submersible as well. Tremendous advances in this industry will occur and will help pave the way for the next generation of ocean explorers.

Autonomous vehicles alone are not going to excite the next generation of ocean explorers. It is the promise that they will be part of a larger ecosystem. An ecosystem that is not just data collection, but data processing, telecommunication, analytics, and visual reporting as well.

The excitement will not rest with autonomous vehicles, but rather with autonomous systems. This is the direction that we need to be headed. These are the pillars that the current community needs to build for the next generation.

The root of autonomous is auto. It is not auto as in automobile; it is auto as in automatic, or automated. The next generation of humans will expect to live in an automated world. The fundamental difference between technology workflows that we employ today and those that we will use tomorrow is that it will be automated. Humans need to become increasingly less involved.

For ocean exploration, we currently have a paradigm that is dependent on mass human involvement. An ocean survey requires many people working on a ship and going out to sea. More people then need to process and analyze that data. And more people yet are involved in converting and serving that data so that it can be disseminated and consumed by humans.

We need to be the ones to transform current workflows into a different paradigm. We need to transition from a manual, data paradigm to an information paradigm that is based on an entirely autonomous system, with little human involvement. Whether data is from crowdsourced collection, autonomous vehicles, or even ships and planes, the goal should be automatic processing, modeling, visualization, reporting, and dissemination.

The future of ocean exploration should be a continuous system of information flow.

With a basis of understanding where the next generation of technology may be going, we can now shift to the other end of spectrum. The next generation of humans who will be consuming this technology will surely be different from ours. People today are Internet- and mobile-savvy, and are more comfortable sharing data, which is creating an information-on-demand economy.

They thrive in an app-driven ecosystem where their expectations and behaviors are different than the norms of yesteryear.

For ocean explorers of the next generation, this is already happening in other vectors of their life today. They will be less interested in ocean exploration data and more interested in ocean exploration information.

They are going to want answers to their questions. They will shy away from becoming a data scientist. They will avoid the burdens of proprietary formats, data behind firewalls, and limited distribution models. They are going to expect information at their fingertips.

And there is no reason why this can't happen. We are moving into a new era of computing. An era that is based on information access, not data demanded. It is based on answers to questions and information that is readily available. There's a reason that we call it the information age. We need to embrace that.

Cognitive computing, artificial intelligence, and machine learning are all happening right now. It is happening in many different verticals and it's happening all over the world. This evolution is going to change the way that we interact with machines. It was Ray Kurzweil who said that, in 2029, just 13 years from now, computers will declare themselves conscious, and we'll believe them, because we must.

Today, we have a paradigm of data confusion. Data is difficult to collect, access, and share. It is not readily accessible. It is often difficult to understand. We need to transition to a model where we have information that is available, accessible, and global. It must be on demand. This new paradigm needs to be based on autonomous systems that collect, process, and model data while we sleep. And they will do it for a fraction of the cost of how it's done today.

The goal is that, instead of searching our computers for content, computers will provide it to us, because it's what we're interested in. Imagine an information paradigm where we have oceanographic information automatically delivered to us based on our research, our geography, and our needs, not one where we have to go mining for it.

One thing is clear; it is our responsibility to build technology for the next generation of ocean scientists, knowledge workers, policy makers, students, and citizens alike. Ninety-five percent of the world's oceans remain unexplored; statements like this need to become a thing of the past.

ESSAY

# EXPLORATION WANTS TO BE SHARED

BY **ANDREW DAVID THALER**

*Southern Fried Science*

Though often constructed as a small team struggling alone against the wilderness, exploration has never been a solitary act. Beebe marked his descent into the Bermuda depths with the publication of "Half Mile Down." Darwin documented his long journey in "Voyage of the Beagle." More modern explorers share their expeditions through film, television, telepresence, livestreams, and social media. The greater challenge for explorers today is no longer "how will you get there?" but "how will you bring us with you?" Exploration wants to be shared.

Perhaps it is due to the long, colonial history of exploration; perhaps it is the demographics of privilege, but the audience for exploration outreach tends towards homogeneity. Exploration wants to be shared, but more often than not it is shared with those who are white, male, and affluent.

This apparent exclusivity can present, to underserved demographic groups, an insurmountable barrier to engagement. Removing that barrier requires a conscious, concerted effort on the part of the exploration team to engage with a diverse audience. When done without consideration for demographic barriers, exploration outreach may barely rise above the subsistence level, attracting a homogeneous audience that poorly reflects the American public. When done well, exploration outreach can be transformative, introducing a diverse and underrepresented cohort to the potential of exploration-based science and technology careers.

Successful, transformative initiatives can have generational impacts on ocean exploration. Examples of these kinds of projects include Dr. Cindy Lee Van Dover's Artist-at-Sea program, which brought a cohort of visual artists, including Jim Toomey of Sherman's Lagoon, out to sea, or Dr. Katie Croff Bell's *Nautilus* Exploration Program, or NOAA's program via the *Okeanos Explorer,* which provides access to real-time ROV feeds and, more importantly, a direct link to the scientists directing the ROVs.

Transformative outreach doesn't just happen. It needs to be deliberately structured and involve members of underserved communities early in the planning stage. Comprehensive outreach plans begin by recognizing that "the general public" is not an audience. Effective outreach is tailored towards a specific audience. Initiating an outreach plan with an explicit intended audience is the single most important step in building an effective outreach campaign.

Effective outreach goes where the conversation is. All the bandwidth in the world isn't going to engage communities with limited internet access. Designing a campaign using Google Hangouts and Twitter won't reach an audience that favors Instagram, Snapchat, and Ask.fm. This is one of many reasons why teams need to include members of that community, ideally as full participants, but at the very minimum as (paid) consultants. Empower potential mentors within those communities to take part, either in person or remotely, create lesson plans, and build outreach into your expedition plan. Everyone on your team should understand that outreach isn't an add-on, it is an essential component of exploration.

Collected by Oceaneering's *Global Explorer* ROV in the Arctic, this jelly (*Benthocodon hyalinus*) is found in the water column throughout the Pacific Ocean and from the Arctic Ocean to Antarctica. | *Credit: Caitlin Bailey, GFOE, The Hidden Ocean 2016: Chukchi Borderlands.*

Transformative outreach connects with audiences who may have previously never thought that exploration-based science could be a viable career path or a worthwhile endeavor. The technological infrastructure, educational components, and appropriate audience-engagement tools need to be in place, but the best outreach happens when your audience sees themselves reflected in the expedition. Program officers must seriously and honestly ask whether the composition of their team truly reflects the full breadth and diversity of the exploration community.

ESSAY

# ECOLOGICAL MARINE UNITS—ORGANIZING OCEAN EXPLORATION DATA INTO INFORMATION

BY **DAWN WRIGHT**

*Chief Scientist | Esri*

The Ecological Marine Units (EMU) project is a new undertaking of Esri in collaboration with Dr. Roger Sayre of the USGS, the Marine Conservation Institute, NatureServe, University of Auckland, GRID-Arendal, NOAA, and many others. The Group on Earth Observations (GEO) has officially commissioned the project as a means of developing a standardized, robust, and practical global ecosystems classification and map for the oceans. GEO, as many of you know, is a consortium of almost 100 nations collaborating to build the Global Earth Observation System of Systems (GEOSS). The EMU project is seen by GEO as a key outcome of the GEO Biodiversity Observation Network (GEO BON and MBON) and is now one of the four components of the new GI-14 GEO GEO Ecosystems Initiative (GEO ECO), as part of the GEO 2016 Transitional Work plan. The EMU is a follow-on to a comprehensive ecological LAND units project (ELU), also commissioned by GEO/GEOSS Task EC-01-C1.

The EMU project was initiated in February 2015, and has now moved into an exciting phase involving the presentation of some preliminary results at a series of back-to-back conferences including:

- **The Global Marine Protected Areas Partner Summit**, Redlands, California | November 2-3, 2015
- **The Esri Ocean GIS Forum,** Redlands, California | November 4-6, 2015
- **GEO-XII Plenary & Mexico City Ministerial Summit** Mexico City, Mexico | November 11-13, 2015

We are currently in the midst of developing a true 3-D data model (spatial resolution of 1/4 degree by 1/4 degree by varying depth to match the NOAA World Ocean Atlas, resulting in a mesh of over 50 million points) and 3-D data visualization tools. As part of this we are developing a k-means statistical clustering algorithm for identifying the physiographic structure of the water column based on temperature, salinity, nutrients, density, etc. the usual suspects that will drive ecosystem responses. Our clustering algorithm has been vetted by distinguished spatial statistics professor Noel Cressie of the U. of Wollongong, Australia. We have a working EMU prototype for the California coast but the ultimate goal is to have a global 3-D map by the end of 2016.

Additional collaborators include:

- **Rob Brumbaugh**
  Director of Ocean Mapping & Planning for The Nature Conservancy[1]s Global Oceans Team
- **Rodolphe Devillers**
  Director of the Marine Geomatics Research Lab, Memorial U. of Newfoundland
- **Maria Kavanaugh**
  WHOI Marine Chemistry and Geochemistry
- **Dick Feely | Simone Allen**
  and other colleagues of NOAA-PMEL
- **NOAA's Office of Habitat Conservation-Restoration**
- **The World Wildlife Fund | South Atlantic Fishery Management Council**

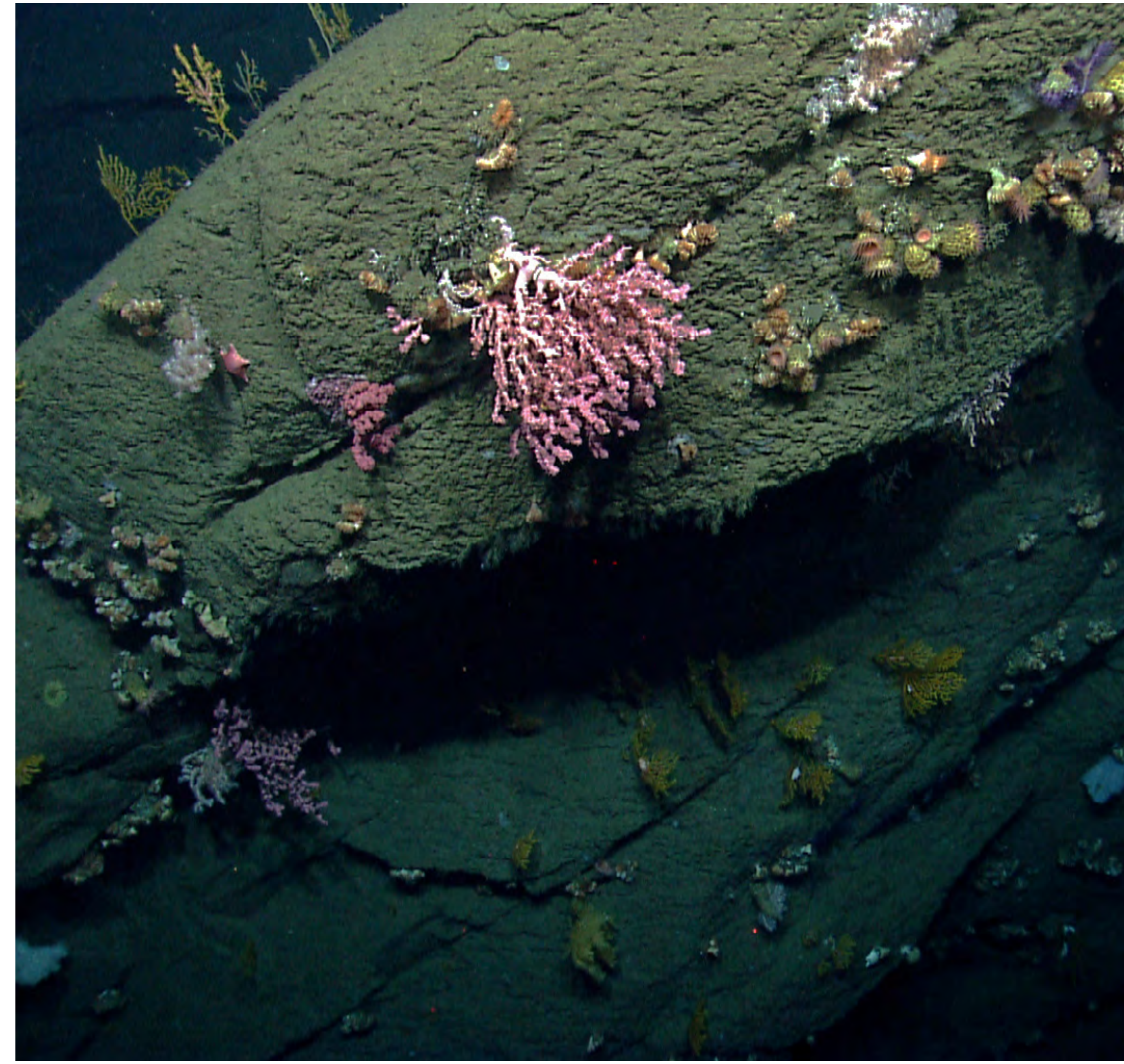
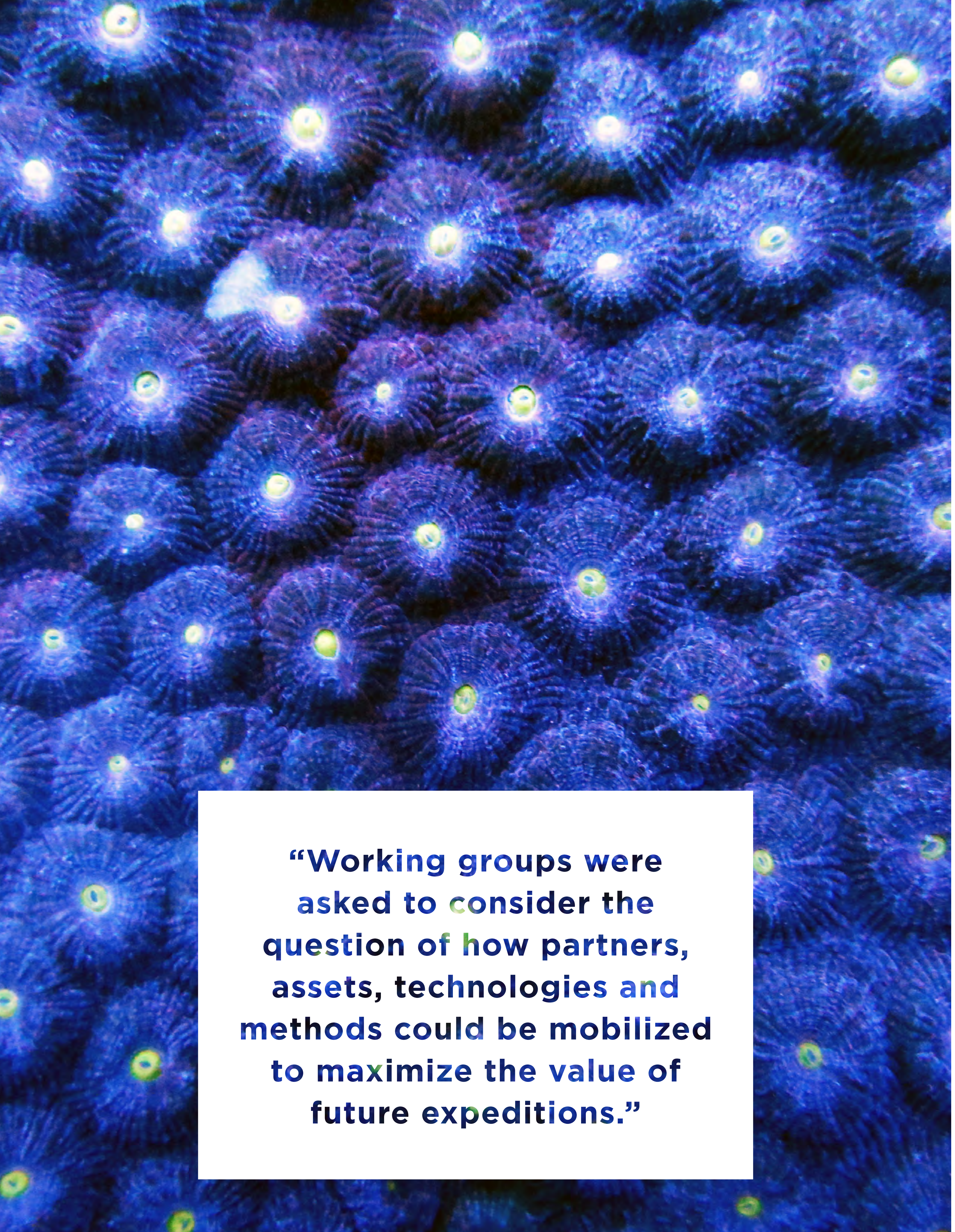


Image of a submarine canyon feature off the northeast U.S. coast that has been colonized by several different types of corals and other animals. | *Credit: NOAA Office of Ocean Exploration and Research.*

For more information:

- http://dusk.geo.orst.edu/Pickup/Esri/EMU-MPA-Summit.pdf
- *Roger's background of the GEOSS charge, technical data, and content background*
  http://video.esri.com/watch/4876/the-development-of-ecological-marine-units-part-1
- *Dawn's overview on the process and prototype results on the California West Coast.*
  http://video.esri.com/watch/4877/the-development-of-ecological-marine-units-part-2



“Working groups were asked to consider the question of how partners, assets, technologies and methods could be mobilized to maximize the value of future expeditions.”

*Montastraea cavernosa* from the Flower Garden Banks National Marine Sanctuary. | *Credit: Joshua Voss's group during their Sept 2016 CIOERT Mesophotic Reef Ecosystem expedition aboard the R/V Manta, Harbor Branch Oceanographic Institute-Florida Atlantic University.*

SECTION 10.0

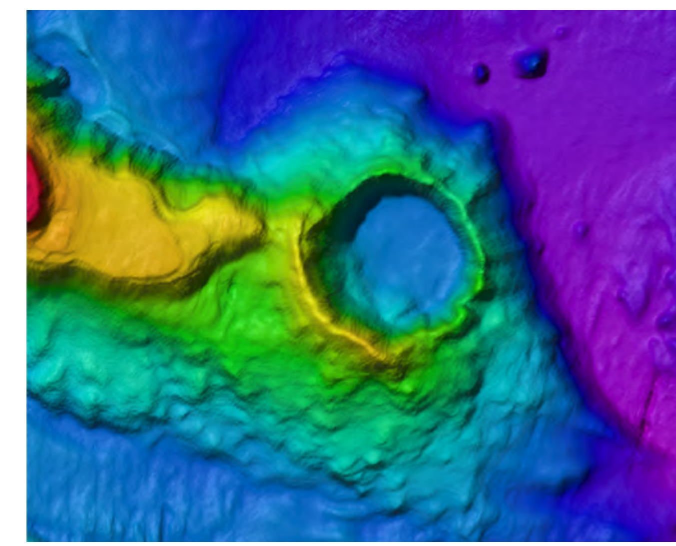
# CHARACTERIZING THE UNKNOWN: WORKING GROUP REPORTS

Participants broke into working groups, organized by ocean features and environments of interest, to design a conceptual future expedition that might take place in 2020 or 2025. As with any expedition planning process, working groups started with drivers and questions, identified resource and asset requirements (including tools and techniques expected to be available in the next five to 10 years) and addressed other relevant considerations. Forum participants were not required to be subject-matter experts to take part in a particular working group. The objective was to be creative, future-thinking and ultimately make progress on what best defines the initial characterization of the subject features and environments in the future.

Working groups were organized by ocean features and environments:

- Under ice
- Canyons and seamounts
- Continental shelf
- Mid-ocean ridges and fracture zones
- Chemosynthetic communities
- Water column and ocean chemistry
- Submerged cultural resources

Having heard about the information requirements from government and non-government explorers and about new ideas and developments, working groups were asked to consider the question of how partners, assets, technologies and methods could be mobilized to maximize the value of future expeditions toward establishing baseline characterizations of the greatest possible value. Moderators and rapporteurs helped to guide the discussions.



Bathymetric image of a crater located on the eastern ridge off Maro Reef. Sonar and sample data collected during the NOAA 2015 Hohonu Moana: Exploring Deep Waters off Hawaii expedition may provide insights into the previously unknown origin of the crater. | *Credit: NOAA Office of Ocean Exploration and Research, 2015 Hohonu Moana.*

Rapporteurs' notes were provided to the National Ocean Exploration Forum 2015 report authors, who used these working-group results to frame the report for the consideration of the national ocean exploration community.

## WORKING GROUPS

1. **Under Ice**
   **Moderated by Darlene Lim,** a research scientist in geobiology at NASA Ames and Ocean Exploration Advisory Board.
2. **Canyons and Seamounts**
   **Moderated by Emil Petruncio,** chair of the Oceanography Department at the U.S. Naval Academy.
3. **Continental Shelf**
   **Moderated by Larry Mayer,** director of the Center for Coastal and Ocean Mapping and director of the School of Marine Science and Engineering at the University of New Hampshire.
4. **Chemosynthetic Communities**
   **Moderated by Chris German,** senior scientist at the Woods Hole Oceanographic Institution and Ocean Exploration Advisory Board.
5. **Water Column and Ocean Chemistry**
   **Moderated by** Mike Ford, an expert in mid-ocean-depth ecosystems at NOAA Fisheries.
6. **Mid-Ocean Ridges and Fracture Zones**
   **Moderated by Jamie Austin,** a senior research scientist at University of Texas and Ocean Exploration Advisory Board.
7. **Submerged Cultural Resources**
   **Moderated by Dominique Rissolo** of the University of California, San Diego and Ocean Exploration Advisory Board.

*Short report summaries of working group discussion results follow.*

Despite reports of new minimums for sea ice in the Arctic, the USCGC HEALY encountered thick ice floe while navigating to the region's Chukchi Borderlands during a 2016 mission. | *Credit: Caitlin Bailey, GFOE, The Hidden Ocean 2016: Chukchi Borderlands.*



WORKING GROUP REPORT

# UNDER ICE

MODERATED BY **DARLENE LIM**

*Research scientist in geology | NASA Ames, Ocean Exploration Advisory Board*

Significant seasonal warming over the Arctic Ocean associated with reduced sea ice extent is the most recent manifestation of Arctic amplification. This phenomenon is expected to become stronger in coming decades, with predicted impacts both within the Arctic and around the world.

Sea ice is a ubiquitous feature in the Arctic that is heterogeneous and in a constant state of flux; however, its characterization remains largely unknown. A top priority of an expedition to the Arctic is to characterize the sea ice itself. The top characterization priorities identified by the working group include sea ice extent (coverage), depth, volume, and morphology. The expedition would aim to understand how chemical, physical, and biological aspects of the under ice environment respond to changes in the sea ice itself. Furthermore, the expedition would seek to understand, on a broad scale, how sea ice modulates the climate and the biosphere of the Earth.

An expedition to this difficult environment would rely on technology that improves large-scale mobility. For example, ships, which could carry personnel and various payloads, would ideally be able to get to, through, and move with the ice, and enable the deployment of other smaller payloads in remote locations within the ice and along the margins. The expedition would also rely upon technology improvements for autonomous platform power generation and longevity in the cold, overcoming challenges associated with deploying instrumentation in the Arctic waters.

For an expedition to this remote area to be successful, the working group agreed that there needs to be further discussion of the long-standing data isolationism that exists between various agencies, and academic and private entities conducting research and exploration in the Arctic. Additionally, system architecture associated with transmitting data from the sea ice environment will have to be developed to successfully transmit expedition data.

Microscopically small algae grow on the bottom of a piece of overturned Arctic sea ice. This algae would disappear if there is no longer any sea ice during the Arctic summer, impacting the entire Arctic food web. | *Credit: Katrin Iken, University of Alaska Fairbanks.*

The working group discussed the importance of a national ocean program to closely examine, understand and outline the regulatory implications of the impending International Maritime Organization Polar Code, which will come into effect in a few years. The group also noted that it will be important for a national ocean exploration program to examine how best to decrease the environmental impact of our assets, and to ensure that all new capabilities are in essence compliant with future standards.

# CANYONS AND SEAMOUNTS

MODERATED BY **EMIL PETRUNCIO**

*Chair | Oceanography Department at the U.S. Naval Academy*

With over 30,000 seamounts around the globe and over 9,000 submarine canyons, there is no shortage of targets for exploration.

Seamounts and canyons are hotspots for biodiversity due to the presence of energetic currents, steep bathymetry, hard substrates, hydrocarbon seeps, and, in the case of some seamounts, hydrothermal vents. These striking features should be high priority targets for exploration, as investigation will likely broaden scientific knowledge and inform natural resources management.

Technological advances in seafloor mapping over the next decade may result in large areas of the seafloor, in particular seamounts and canyons, being mapped to resolutions satisfactory for safe navigation. Therefore, the working group agreed that achieving high-resolution mapping, on the sub-meter scale, is of high priority. Future expeditions to explore canyons and seamounts could use a 'nested' exploration approach, using a range of technologies relying on various levels of automation. A marker of success would be the ability to translate data collected on the seafloor into freely accessible, actionable information in real time. This would improve the efficiency of ocean exploration and catalyze research across a range of disciplines.

The working group suggested collecting exploration data using a hypothesis-driven process to identify the most important geological feature or biological community to explore. Considerations include the time of day, lunar cycle, season, or year when various organisms are active, and the size and density of various features and organisms. The group also agreed that data obtained from a singular submarine feature and studied in isolation may not prove to be valuable. However, data used to compare communities, processes, and features across a region can be very valuable. For example, a high exploration priority would be to determine whether populations on different features are connected, and to characterize circulation patterns that could serve to transport larva and nutrients.

Lastly, there was a consensus among the working group members that data collection efforts should be prioritized and organized through a national ocean exploration program.

While exploring off the U.S. Atlantic coast, NOAA's ROV *Deep Discoverer* came upon a unique geological feature that scientists informally dubbed the "Octopus Grottoes." Densely packed stony corals surrounded these cave-like structures and almost each one had its own octopus. | *Credit: NOAA Office of Ocean Exploration and Research, Our Deepwater Backyard: Exploring Atlantic Canyons and Seamounts 2014.*





# CONTINENTAL SHELF

MODERATED BY **LARRY MAYER**

*Director | Center for Coastal and Ocean Mapping and of the School of Marine Science and Engineering at the University of New Hampshire*

The continental shelf represents our point of connection with the oceans. It's the part of the ocean that we have the most immediate access to, and in many ways, it's the part of the ocean we're most dependent on.

There is more temporal and spatial variability on the continental shelf than in the open ocean. The working group agreed that a singular expedition cannot provide the baseline required to understand changes in continental shelf, therefore adapting a temporal approach to exploration would be the most practical approach. The main priority of an exploration mission to the continental shelf would be to collect baseline data to support hydrography, safety of navigation, tsunami and storm inundation, habitat mapping, fisheries, resources, oil and gas, aggregates, sand resources, siting for alternate energy, gas seeps, fresh water seeps, maritime heritage, pollution, circulation and distribution of contaminants, algal plumes, recreation, and maritime cultural heritage.

Participants agreed that an expedition to the continental shelf would utilize technologies, including acoustics, satellite, optical, glider, and autonomous vehicles to collect data such as bathymetry, backscatter, imagery, chemical signatures, water quality measurements, and DNA. A successful expedition would adhere to a normalized data formats and classification schema so that observation from different groups could be combined and analyzed together.

A novel approach that the working group discussed was the formation of a powerful and well-funded integrated ocean and coastal mapping commission, coordinated through a national ocean exploration program. This commission would bring in state, local, tribal, and private-sector partners, and ensure that mapping efforts are both coordinated and represented.

There was consensus among the working group that the public represents a major potential partner in collecting and disseminating ocean exploration results from the continental shelf, due to the fact that the continental shelf is close to the general public. One example the group suggested was utilizing new emerging technologies, such as inexpensive black boxes that can be attached to opportunistic boats, to acquire crowd-sourced bottom bathymetry data. Another potential avenue to encourage the public to feel ownership of a particular ocean plan is through an "Adopt-a-Reef" model. Lastly, participants felt that to successfully engage the public in an ocean exploration mission, any data collected would have to be transformed into shareable information.

# CHEMOSYNTHETIC COMMUNITIES

MODERATED BY **CHRIS GERMAN**

*Senior scientist | Woods Hole Oceanographic Institution, Ocean Exploration Advisory Board*

There are several first-order, curiosity-driven scientific questions that could be addressed by exploring chemosynthetic communities, such as how did life on Earth originate? Additionally, an expedition to explore chemosynthetic communities would contribute to knowledge of rare earth mineral supplies, natural fluxes of greenhouse gases, and biomedical resources.

The working group came to the consensus that an expedition to explore chemosynthetic communities would focus on vents and seeps, both shallow and deep, along ridges and ocean margins, and seafloor fluid flow along tectonic plate boundaries and at isolated hot-spot volcanoes, for example in the midst of the vast Pacific Ocean. Due to the vastness of the oceans, the working group decided the best exploration approach would be to focus efforts on the Arctic and Southern Oceans first, because of the dearth of knowledge in these areas.

The working group envisioned an expedition that would utilize ship-free collaborative robotic systems to provide real-time engagement with platforms conducting exploration at the seabed and in the deep ocean interior from the convenience of a shore-based exploration station. Such platforms would have the ability to capture the size, shape, texture, and color of objects through advanced imaging capabilities, and also capture their composition in a method can be reported back to shore in digital forms. Examples include in situ laser ablation mass spectrometers for studying seafloor rock and sediment compositions and in situ DNA techniques used to complement digital imaging for taxonomic studies.

The expedition would benefit from collaborating with the U.S. Navy, NASA, and NSF. Key partnerships would include private philanthropic foundations and the private sector (oil and gas, marine mining, and pharmaceutical/biomedical sectors). The working group agreed that for the sake of both balance and transparency, interested and environmentally oriented NGOs should also be engaged as part of the expedition.

Thinking more broadly, the group envisioned an expedition where motivated citizen explorers could participate in deep ocean chemosynthetic animal tagging and tracking projects whether through live video feeds or by viewing archived video on a publically accessible system. Thinking outside of the box, the working group discussed the possibility of an expedition engaging with the public through outlets like prime-time telepresence game shows.

Lastly, the group discussed the importance of establishing a national ocean program, as deep ocean processes respect no national boundaries. A single coordinating program for ocean exploration would help engage with international partners. Secondly, identifying priorities through a single national program of ocean exploration would help various partners identify a coherent program of prioritization in the allocation of the national asset pool, which is distributed among many entities. A single and collective national program would consider all constituent priorities, rather than focusing exclusively on any single entity's narrow priorities.





# WATER COLUMN AND OCEAN CHEMISTRY

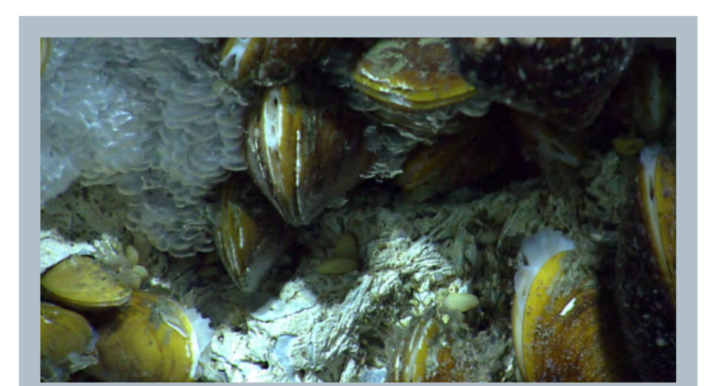
MODERATED BY **MIKE FORD**

*Expert in mid-ocean-depth ecosystems | NOAA Fisheries*

The ocean mid-waters represent the largest volume of living space on our planet, with 95-99 percent of biosphere found in this four-dimensional zone. Yet this is the part of biosphere about which we know the least, as it is the most unexplored part.

A top priority of an expedition to the oceans mid-waters would be to collect baseline data in the deep pelagic zone and identify and perfect a baseline of the organisms that live in this zone. What comes up from the seafloor versus what descends to the seafloor is not well understood, yet is important to tracing carbon fluxes' incorporation into the atmosphere. Understanding the carbon cycle is a priority, particularly due to the connection to climate change.

The working group suggested an approach that engages private partners, similar to that which enabled the in-depth study of Monterey Bay (Packard Foundation). Sample processing of water column and ocean chemistry data requires interdisciplinary teams to ensure that the value of the water sample is fully realized. Computer scientists are required to integrate these data types into user-friendly data discovery tools. Additional partners would include fishery scientists and climate scientists who understand the value of and the impact of this biome.



Carbonate outcrop inhabited with chemosynthetic mussels *(Bathymodiolus sp.)*, seen in the Gulf of Mexico. | *Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2014.*

The expedition would use ships as the foundation of exploration and as the backbone platform to launch all other smaller platforms. The working group discussed to possibility of using swarm technology, such as fleets of AUVs used in combination with ships, to obtain large scale, comprehensive water column/ocean chemistry datasets. An innovative approach that was suggested was using deep versions of ARGO floats that dive to full ocean depth beyond current 2,000-meter depth limitation. Such floats would stay out longer, collect a higher volume of data, provide more energy to onboard sensors, and draw less power. Alternatively to samples, the use of in-place eDNA technology could provide the necessary data.

As essential component of the expedition would be the maintenance of expedition data samples. The working group agreed that samples should be maintained in a well-supported cryorepositry as soon as they are captured. An easily accessible, comprehensive system to track images, samples, and associated data from other data streams would be required.

To engage future generations, the group suggested going beyond simply providing information to teachers by building the information into the school curricula, so that this ocean domain becomes a common part of every student's education.

# MID-OCEAN RIDGES AND FRACTURE ZONES


MODERATED BY **JAMIE AUSTIN**

*Senior research scientist | University of Texas, Ocean Exploration Advisory Board*


Mid-ocean ridges and fracture zone are globally important as the primary structural signatures of oceanic crust away from continental margins. The MOR system is about 60,000 kilometers long, and is punctuated by hundreds of FZs of diverse size.

The ultimate goal of exploring the mid-ocean ridges will be to map the entire 60,000-kilometer-long system in detail. To accomplish this goal, the working group came up with a novel approach in which the entire system is divided into unit cells, perhaps 500 kilometers long, based on differences in spreading rates and other factors. A global program might consist of 5-10 unit cells. Exploring each cell would take a multi-layered approach, including shipboard multi-beam seafloor mapping, dovetailed with multiple ROV focus sites, and AUV deployments some tens of meters above the ridge. In addition to mapping data, water chemistry measurements such as methane and pH measurements would be collected.

The working group discussed a more directed approach to exploring fracture zones by focusing an expedition on the Mendocino Triple Junction (MTJ), a portion of the Mendocino FZ that intersects with the Gorda MOR and trends eastward where it becomes buried along the U.S. west coast. An expedition so close to San Francisco, where everyone knows an ongoing seismic threat exists, would be socially relevant and interesting to the general public.

Participants agreed that such an expedition would provide opportunities for citizen science, everything from measurements from recreational boats to deployments of sensors from cheap ROVs. Concentrating an expedition at the MTJ would be a wonderful and visible way to focus national ocean exploration program activities proximal to a major metropolitan area and within the U.S. EEZ. Additionally, natural partnerships with federal agencies and private companies would develop, as the area is known for its productive fisheries and natural hazards.

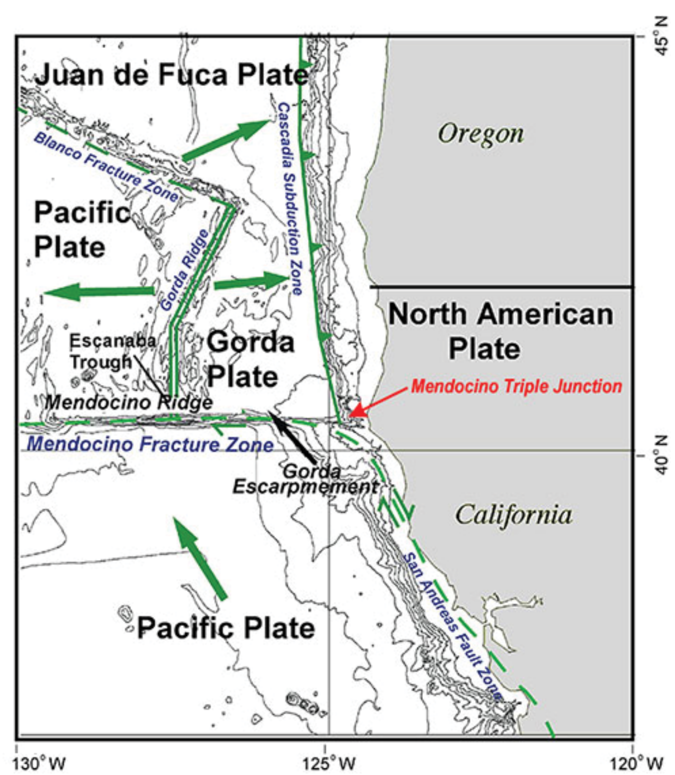



Figure 1. | *Attribution: Modified from Kela et al., 2007, GSA Bulletin, v. 119, p. 88-100.*

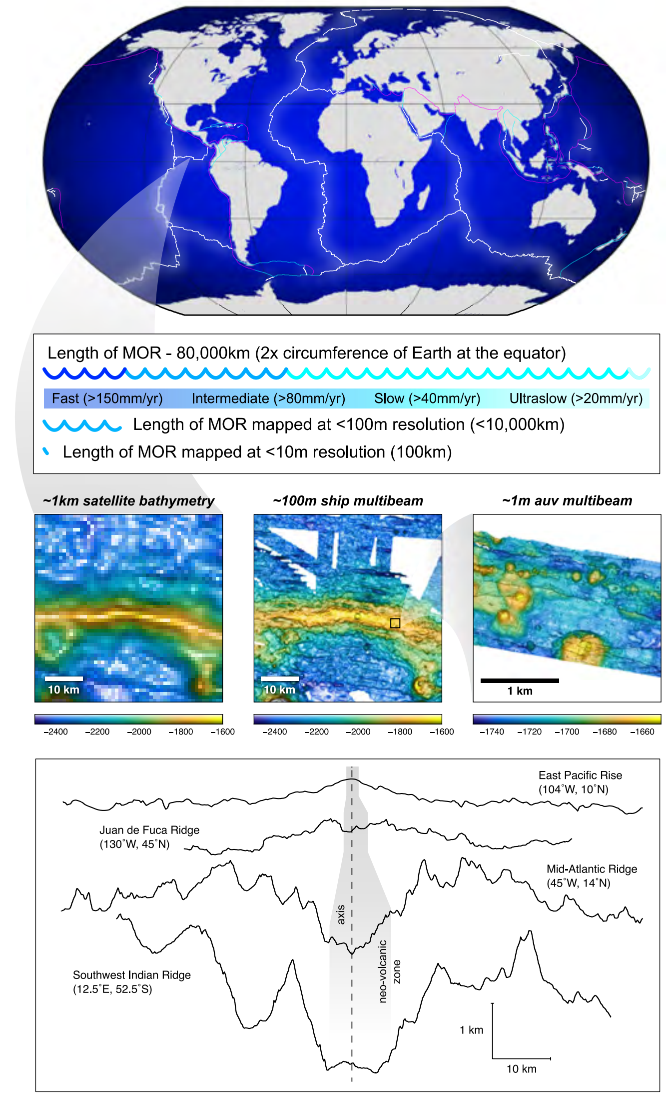
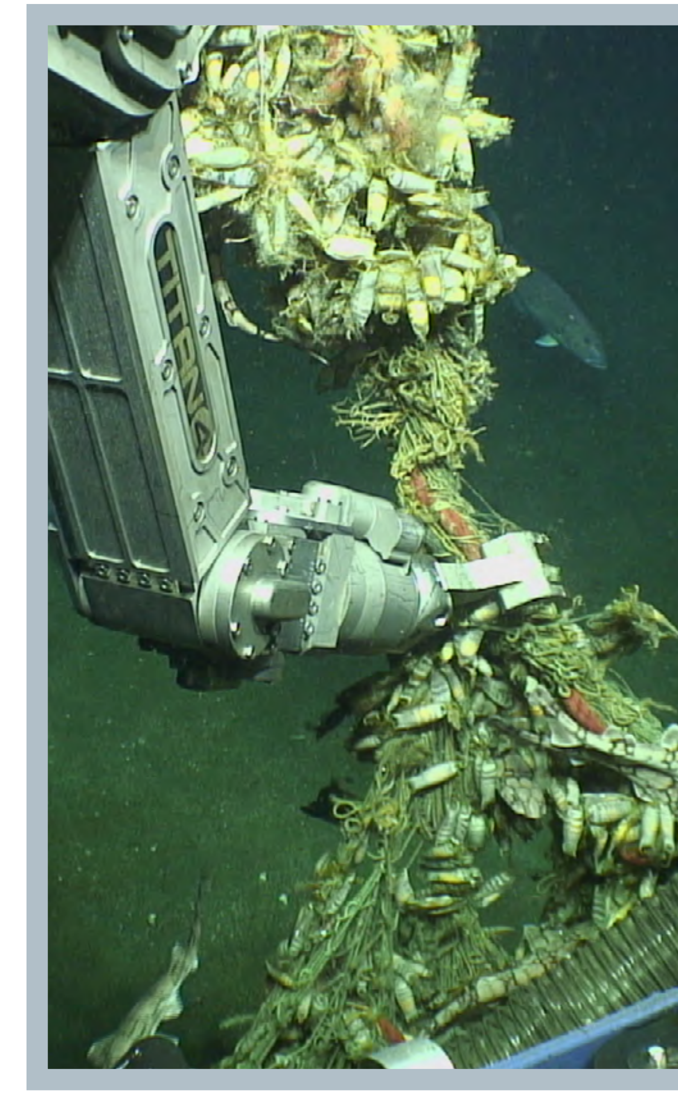



Figure 2. | *Attriubtion: Prepared by Adam Soule, Woods Hole Oceanographic Institution.*



ROV *Jason* cuts an abandoned fishing net suspended by floats from a shipwreck to allow for better image collection. | *Credit: Deepwater Canyons 2013 - Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

Snails, crabs, shrimp, and anemone compete for space at the Snail Vent hydrothermal site, located in the Mariana Back-arc. | *Credit: Submarine Ring of Fire 2014 - Ironman, NSF/NOAA, R/V* Roger Revelle, *ROV* Jason, *Copyright WHOI.*

WORKING GROUP REPORT

# SUBMERGED CULTURAL RESOURCES


MODERATED BY **DOMINIQUE RISSOLO**

*University of California, San Diego, Ocean Exploration Advisory Board*


One of the most enduring mysteries of American archeology is the peopling of the New World. When we talk about characterizing the unknown, we need to understand what North America looked like during this critical period in our hemisphere's history.

"Aquaterra," the submerged paleo-shoreline of the western continental United States holds the key to how humans, during the late Pleistocene, migrated to North and South America, populating the last of the world's great landmasses. Rather than plan an expedition on specific shipwrecks, the working group discussed exploring the aquaterra. While finding physical evidence of the migration poses a difficult challenge to explorers, the methods required for thorough exploration are likely to uncover traces of more modern human culture such as shipwrecks, aircraft, etc. The working group agreed that understanding the paleo-landscape terrain, as well as the location of food and other resources that would have been valuable to people, is critical in carrying out exploration activities.

Capturing all traces of human culture from prehistoric deposits to more modern shipwrecks, aircraft, and other cultural materials is important to archeologists. The expedition would utilize AUVs and ASVs to collect data for initial and focused characterization. Baseline characterization would include high resolution bathymetry, topo-bathy lidar, and sub-bottom profiler data. High resolution bathymetry would show the current seafloor and be used interpret previous landforms that may have eroded or been obstructed by sedimentation. Topo-bathy lidar could identify and map caves and rock shelters, which may have served as early occupation sites. Sub-bottom profiler data can reveal buried features as well as the depositional history of sediments.

Focused characterization would involve collecting data from cores to interpret the environment and paleoclimate, and proxy data for salinity to understand sea level transgression and when it occurred. The group agreed that developing methods for DNA analysis of archaeological materials would improve the ability to characterize cultural material.

Traditional knowledge and oral history provided by Native Americans are of great importance to archaeologists, so Native Americans would provide a critical partnership. Additional state and federal agency partnerships would be critical to preserving any discovered cultural resources and protecting them for long-term benefit. The group suggested utilizing citizen scientists to crowd-source images and video. Partnering with these explorers offers new opportunities for archaeologists and submerged cultural resources managers to make observations more rapidly and more often than ever before.

The snapped pintle on the sternpost of a shipwreck in the Gulf of Mexico provides habitat for a variety of animals. | *Credit: Sheli Smith, Lophelia II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks.*

NW Rota-1 seamount, located within the Marianas Trench Marine National Monument, is one of only two sites in the world where active volcanic activity has been observed underwater. | *Credit: Submarine Ring of Fire 2014 - Ironman, NSF/NOAA, R/V* Roger Revelle, *ROV* Jason, *Copyright WHOI.*

**"These forums help the ocean exploration community set national priorities, encourage new technology development, and identify opportunities for partnership as we seek to understand the undersea world on which we all depend."**

SECTION 11.0

# CONCLUDING OBSERVATIONS AND A WAY FORWARD

Most of the ocean remains unexplored, and current efforts by the U.S. and other nations are inadequate to produce the kinds of data, information and understanding needed to develop strategies to conserve the ocean for humankind in a timely way.

It's clear that, with a population of 7.3 billion on our way to 9 or 9.5 billion by 2050 and perhaps 10 billion or more by 2100, we will look to the ocean for more food, minerals, pharmaceuticals and even more water—more fresh water. The ways we grow and harvest our food on land, and the minerals we depend upon for our high-tech society can't be scaled up to meet the demands of a growing population without looking to the sea. For example, we devote about 50 percent of our ice-free land surface to growing crops, and appropriate 70 percent of Earth's freshwater to support agriculture. The United Nations (UN) estimates that by 2050, we will need 70 percent more food to feed people around the world. The ocean will play a critical role in meeting the needs of a growing population. One of those needs is for recreation, for re-creation. This becomes particularly important as more people move into cities, most of which are already over-crowded.

At present, we don't have the level of environmental intelligence about the ocean upon which to base decisions to protect the ocean ecosystems that we depend upon for our own survival. Exploration must be a part of the overall research portfolio. It offers the best chance for discovering surprises and for telling us where the most promising areas of the ocean are, which require more detailed and intensive research.

This means that we must invest more in not only the act of exploration, but also in the ways we explore. Current methods cover too little area and too little volume, and are too costly to scale up. But as we have heard in this conference, we are on the threshold of an entire suite of new ways to explore. One participant mentioned that we need "thousands of highly instrumented robotic Vasco de Gamas." Those need to be supplemented with the software and hardware to process the enormous volumes of data that would be produced and convert them into informational products to benefit society—the global society.

We need to employ the same tools, technologies and knowledge that we use to exploit the ocean to conserve it and the services it provides to humanity. In short, we need a partnership with the environment.

Regardless of the tools we develop, ocean exploration will remain a costly enterprise. We should look for new partners and more creative ways of funding it.

The summaries of the workshop results—including exploration to date of the under-ice environment and continental shelf, etc.—reveal what we don't know. And what we have learned gives urgency to further exploration so we can better understand everything from deep sea corals and fisheries habitats to methane seeps.

Ocean exploration needs to be a Program with a capital "P," not simply a series of projects, no matter how outstanding those projects are. And it should be an international program, one involving not only principal investigators from different nations, but also the governments of those nations. It could serve as a powerful diplomatic strategy in a troubled world, as we saw in the U.S.-Indonesia Ocean Exploration Partnership (INDEX-SATAL) in 2010.

Clearly we need more data, but to maximize their value, those data need to be distributed widely and rapidly. And they need to be synthesized into information; information that is tailored to the interests and needs of different communities ranging from decision-makers to school children to the general public. We need to do a better job of telling the story of ocean exploration and why it is so critically important. One dimension of that importance that is often overlooked is the relevance of ocean exploration to society. One of the forum participants suggested that we need to "capture, compute and create." We would add to that list the need to "communicate."

To communicate effectively with general audiences, we need the best scientists and engineers to partner with storytellers and communicators.

NOAA is widely recognized as a source of important and valuable data about the ocean. Public Law 111-11 mandates NOAA to take the lead in developing a national program that includes other federal agencies and forms partnerships with the private sector. Major progress has been made in achieving this mandate, but great opportunities remain.

## NATIONAL OCEAN EXPLORATION FORUM 2016 AND 2017

The next National Ocean Exploration Forum will be held October 20-21, 2016, and hosted by Rockefeller University and Monmouth University in New York. The theme is "Beyond the Ships: 2020-2025" and it will focus on innovative technologies that could expand the pace, scope and efficiency of traditional ocean exploration approaches.

Planning is already underway for the 2017 National Ocean Exploration Forum to be held in partnership with the Qualcomm Institute and the University of California at San Diego. "Ocean Exploration in a Sea of Data" will bring the ocean exploration and data science communities together to consider how big data analysis techniques might be used to "explore" the rich archive of historical data about the ocean and to develop new insight into integrated data from ships, autonomous vehicles, satellites, observational networks and other sources to help us understand the ocean environment.

The National Aquarium in Baltimore and NOAA thank the National Ocean Exploration Forum 2015 participants, contributors and sponsors. We believe this forum, and the forums planned for 2016, 2017 and beyond, will help the ocean exploration community set national priorities for the field, encourage new technology development, and identify opportunities for partnership as we seek to understand the undersea world on which we all depend.

# CONCLUDING PANEL

Alan Leonardi, National Oceanic and Atmospheric Administration

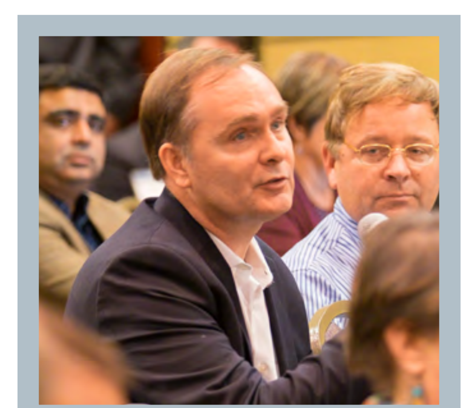
Chris German, Woods Hole Oceanographic Institution | Ocean Exploration Advisory Board

Emil Petruncio, U.S. Naval Academy

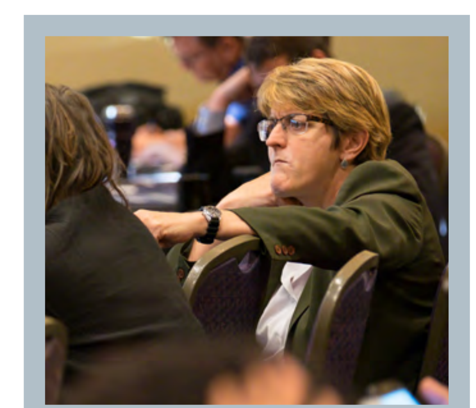
Eric Stackpole, OpenROV

Jamie Austin, University of Texas | Ocean Exploration Advisory Board

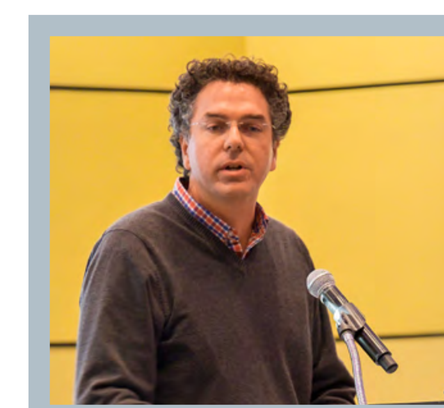
Jerry Miller, National Research Council



Jim Bellingham, Woods Hole Oceanographic Institution



Karen Kohanowich, National Oceanic and Atmospheric Administration



Mike Ford, National Oceanic and Atmospheric Administration

Close up of purple coral, imaged while exploring off of Puerto Rico. | *Credit: NOAA Office of Ocean Exploration and Research, Océano Profundo 2015: Exploring Puerto Rico's Seamounts, Trenches, and Troughs.*

# APPENDICES TABLE OF CONTENTS

A brittle star living in the branches of a pink coral; imaged while exploring a ridge within deep waters off Hawaii. | *Credit: NOAA Office of Ocean Exploration and Research, 2015 Hohonu Moana.*

APPENDIX I

# ACKNOWLEDGEMENTS

*David McKinnie*
*NOAA Office of Ocean Exploration and Research*

*Laura Bankey*
*National Aquarium*

National Ocean Exploration Forums are designed to build and reinforce the ocean exploration community. The priorities and directions participants identify are important to NOAA and, we believe, to other institutions, whether government, not-for-profit, academic, or private sector. The forums are intended to be of benefit to the community, but without the community's contributions, they would be impossible to organize. We'd like to extend our deep appreciation and thanks to everyone who played a role in NOEF 2015, from speakers to sponsors to participants.

Special thanks are due to Jerry Schubel. Jerry is the principal architect of the National Ocean Exploration Forum process and has played a vital role in each of the national forums to date. He consulted on the design of NOEF 2015, invested considerable time in the planning process, and drafted important parts of this report. We want to express our appreciation to John Racanelli for his leadership and the events team at the National Aquarium for their support.

We are also grateful for Jerry Miller's and Mike Conathan's advice and leadership as we prepared for NOEF 2015, and for their effective moderation of the federal and community panels. Similarly, we are grateful for David Lang's leadership of the Marketplace of Ideas and recruitment of speakers from a community of innovators, thinkers, and practitioners with much to offer ocean exploration. We want to thank VADM Paul Gaffney II (ret.), Ellen Stofan, the essayists, the working group moderators, Craig McLean, Alan Leonardi, and each of the panelists and Marketplace speakers for their contributions to NOEF 2015.

Finally, for their assistance with preparing this report, we would like to thank our editing and design team of Kate Schmelyun and Aimee Swartz (National Aquarium), and Emily Crum and Lindsay McKenna (NOAA-OER).

# DAY ONE

*November 19, 2015 | National Aquarium 4-D Immersion Theater*

**1 PM** **Forum Welcome**

*Forum Chair:* John C. Racanelli | *National Aquarium*

**1:15 PM** **Introduction**

Craig McLean | *NOAA Office of Oceanic and Atmospheric Research*

**1:30 PM** **Keynote: Toward a National Ocean Exploration Program**

Jerry R. Schubel | *Aquarium of the Pacific*

**2 PM** **Exploration Forums: Progress**

Vice Admiral Paul G. Gaffney | *USN (retired) President Emeritus Monmouth University and Chair | Ocean Exploration Advisory Board*

**2:15 PM** **Break**

**2:50 PM** **Federal Ocean Exploration Panel**

"If you could visit only once, what information MUST you have?"

*Moderator:* Jerry Miller | *National Research Council*

*Panelists:* Scott Borg | *National Science Foundation*

William Yancey Brown | *Bureau of Ocean Energy Management*

Rear Admiral Timothy C. Gallaudet | *USN Oceanographer and Navigator of the Navy and Commander | Naval Meteorology and Oceanography Command*

John Haines | *U.S. Geological Survey*

Rear Admiral David Score | *NOAA Commissioned Officer Corps, NOAA Office of Marine and Aviation Operations*

Mary Voytek | *NASA*

**4 PM** **Community Ocean Exploration Panel**

"Why do you do what you do? What must you achieve?

*Moderator:* Mike Conathan | *Center for American Progress*

*Panelists:* Bob Ballard | *Ocean Exploration Trust*

Mary "Missy" Feeley | *ExxonMobil Exploration Company*

Eric King | *Schmidt Ocean Institute*

Dave Lovalvo | *Global Foundation for Ocean Exploration*

Shirley Pomponi | *NOAA Cooperative Institute for Ocean Exploration, Research and Technology*

Philip Renaud | *Khaled bin Sultan Living Oceans Foundation*

**5:10 PM** **Synthesis Panel Remarks**

*Moderator:* John C. Racanelli | *National Aquarium*

*Panelists:* Mike Conathan | *Center for American Progress*

Craig McLean | *NOAA Office of Oceanic and Atmospheric Research*

Jerry Miller | *National Research Council*

Jerry R. Schubel | *Aquarium of the Pacific*

**5:45 PM** **Group Photo**

**6:30 PM** **Reception and Dinner**

*Keynote Speaker:* Ellen Stofan | *NASA*

# DAY TWO

*November 20, 2015 | Pier 5 Hotel*

**9 AM** **Welcome and Remarks**

Jerry R. Schubel | *Aquarium of the Pacific*

**9:15 AM** **Future Forward: A Marketplace of Ideas**

The Marketplace of Ideas highlights new and developing technologies and approaches that could change ocean exploration over the next five years. Speakers will give short presentations; the audience will have an opportunity to ask questions at the end of the session.

*Moderator:* David Lang | *OpenROV*

**Kickstarter for Science**
Aurora Thornhill
*Kickstarter*

**Ocean Exploration Data and the Next Generation**
Timothy Kearns
*Ocean Aero*

**Citizen Science Movement**
Caren Cooper
*North Carolina Museum of Natural Sciences*

**Exploring Earth and Space**
Darlene Lim
*NASA*

**Connected Exploration**
Eric Stackpole
*OpenROV*

**eDNA Analysis in Exploration**
Jimmy O'Donnell
*University of Washington*

**Visualization Tools**
Jonathon Knowles
*Autodesk*

**In Situ 3-D Visualization**
Dominique Rissolo
*University of California, San Diego*

**Undersea Exploration on Europa**
Kevin Hand
*NASA | Jet Propulsion Laboratory*

**Social Media and the Sea**
Andrew David Thaler
*Southern Fried Science*

**12 PM** **Lunch**

**1 PM** **Group Breakout Sessions**

*Speaker:* Alan P. Leonardi | *NOAA Office of Ocean Exploration and Research*

Participants will break into working groups, organized by ocean features, to design a conceptual expedition for the year 2020 starting with drivers and questions, and including tools and techniques expected to be available in the next five years. Having heard about requirements from government and non-government explorers and about new ideas and developments, consider the question of how we can mobilize partners, assets, technologies and methods to maximize the value of future expeditions toward establishing baseline characterizations of the greatest possible value.

Expedition concepts will be organized using themes developed in Ocean Exploration 2020:

- Exploration priorities
- Citizen science
- Key partnerships
- Data and data visualization
- Platforms
- Public engagement
- New technologies and methodologies

**5:10 PM** **Synthesis Panel Remarks**

*Moderator:* John C. Racanelli | *National Aquarium*

*Panelists:* Craig McLean | *NOAA Office of Oceanic and Atmospheric Research*

Jerry Miller | *National Research Council*

Jerry R. Schubel | *Aquarium of the Pacific*

**6:15 PM** **Closing Remarks**

*Forum Chair:* John C. Racanelli | *National Aquarium*

The tentacles of an anemone seen while exploring a submarine canyon on the north side of French Frigate Shoals. | *Credit: NOAA Office of Ocean Exploration and Research, 2016 Hohonu Moana: Exploring Deep Waters off Hawaii.*





# CHARACTERIZING THE UNKNOWN

*Working Group Descriptions*

Participants will break into working groups, organized by ocean features and environments of interest, to design a conceptual future expedition that might take place in 2020 or 2025. As with any expedition planning process, working groups will start with drivers and questions, identify resource and asset requirements (including tools and techniques expected to be available in the next five to 10 years) and address other relevant considerations. You don't need to be a subject-matter expert to participate in a particular working group. The objective is to be creative, future-thinking and ultimately make progress on what best defines the initial characterization of the subject features and environments in the future.

## OCEAN FEATURES AND ENVIRONMENTS

Working groups are organized by ocean features and environments:

- Under ice
- Canyons and seamounts
- Continental shelf
- Mid-ocean ridges and fracture zones
- Chemosynthetic communities
- Water column and ocean chemistry
- Submerged cultural resources

Having heard about the information requirements from government and non-government explorers and about new ideas and developments, working groups are asked to consider the question of how we can mobilize partners, assets, technologies and methods to maximize the value of future expeditions toward establishing **baseline characterizations** of the greatest possible value. Working-group output will form the primary content of the National Ocean Exploration Forum 2015 report. Moderators and rapporteurs will help guide discussion.

## EXPEDITION DESIGN TEMPLATE

The Ocean Exploration 2020 themes will serve as a template for the conceptual expeditions. Rapporteurs will use forms to capture working-group discussion, which should address these categories:

- What are the expedition **priorities**? What are the most critical information sets to gather with respect to the feature or environment? What requirements would be met?
- Who are the most critical **partners**? How will you leverage others' activities?
- Who are the most critical stakeholders/end users of the information? What user communities should be targeted? Why?
- What **platform** (ship, vehicle, other) capabilities will you need?
- What **technologies** would you like to be able to use?

- What are your priorities for **data collection** toward a baseline characterization?
- How will the **data** be managed and made accessible?
- How will you engage and leverage **citizen scientists and explorers**?
- How will you **engage the public**?
- How could a **national ocean exploration program** help make this expedition a success?

## EXPLORATION TO RESEARCH: LEVELS OF CHARACTERIZATION

It will be useful for working groups to distinguish among three aspects of baseline characterization:

- Initial characterization
- Focused characterization
- Investigations

*Initial Characterization:* This is the first stage of exploration whereby a diverse group of skilled and experienced participants observe and describe their surroundings as thoroughly as possible given the tools they have at hand. Like geographers, their job is to observe, record, assess and integrate information, in essence establishing a sense of place. One might think of a cube in geographic space that includes an ocean area, extends to and beneath the seafloor, and into the atmosphere.

Initial characterization is best served by following a systematic procedure and establishing a standard set of data and products. Initial characterization includes the use of relevant data from other sources—earlier expedition results, data from observational networks and satellites, and more to help complete the initial characterization assessment.

*Focused Characterization:* Focused characterization is best accomplished by building on the information obtained from initial characterization results and using those results to make strategic decisions about significant features, communities or phenomena that require more detailed assessment and description. Focused characterization can be interdisciplinary in nature (a more thorough, site- or phenomena-specific effort), or focused on a single discipline (e.g., biology or geology), depending on the characteristics of the feature itself.

Initial characterization "feeds" focused characterization, and the combination of the data and results can be captured as an "evolving baseline."

*Investigations:* This represents the realm of research, monitoring and marine resource assessment activities, and builds both on the results of initial and focused exploration. Typically, these efforts are very focused on a single discipline and are intended to provide a very in-depth understanding of a particular feature, community, or species. The results of these endeavors can also be incorporated into an evolving baseline.

The need for knowledge is what drives the initial characterization to begin with. It is equally important to note, however, that with exploration, the discoveries made and the results generated often unveil knowledge gaps we never understood we had.

## REPORTING OUT

Each working group will report out in plenary session, taking just a few minutes to highlight major elements of the conceptual expedition. Rapporteurs' notes will be provided to National Ocean Exploration Forum 2015 report authors, who will use working-group results to frame the report as guidance for the consideration of the national ocean exploration community.

## WORKING GROUP THEMES

| | Feature | Moderator |
|---|---|---|
| 1 | Under Ice | Darlene Lim |
| 2 | Canyons and Seamounts | Emil Petruncio |
| 3 | Continental Shelf | Larry Mayer |
| 4 | Chemosynthetic Communities | Chris German |
| 5 | Water Column and Ocean Chemistry | Mike Ford |
| 6 | Mid-Ocean Ridges and Fracture Zones | Jamie Austin |
| V | Submerged Cultural Resources | Dominique Rissolo |

*Darlene Lim is a research scientist (geobiology) at NASA Ames (and on the Ocean Exploration Advisory Board).*

*Emil Petruncio is chair of the Oceanography Department at the U.S. Naval Academy.*

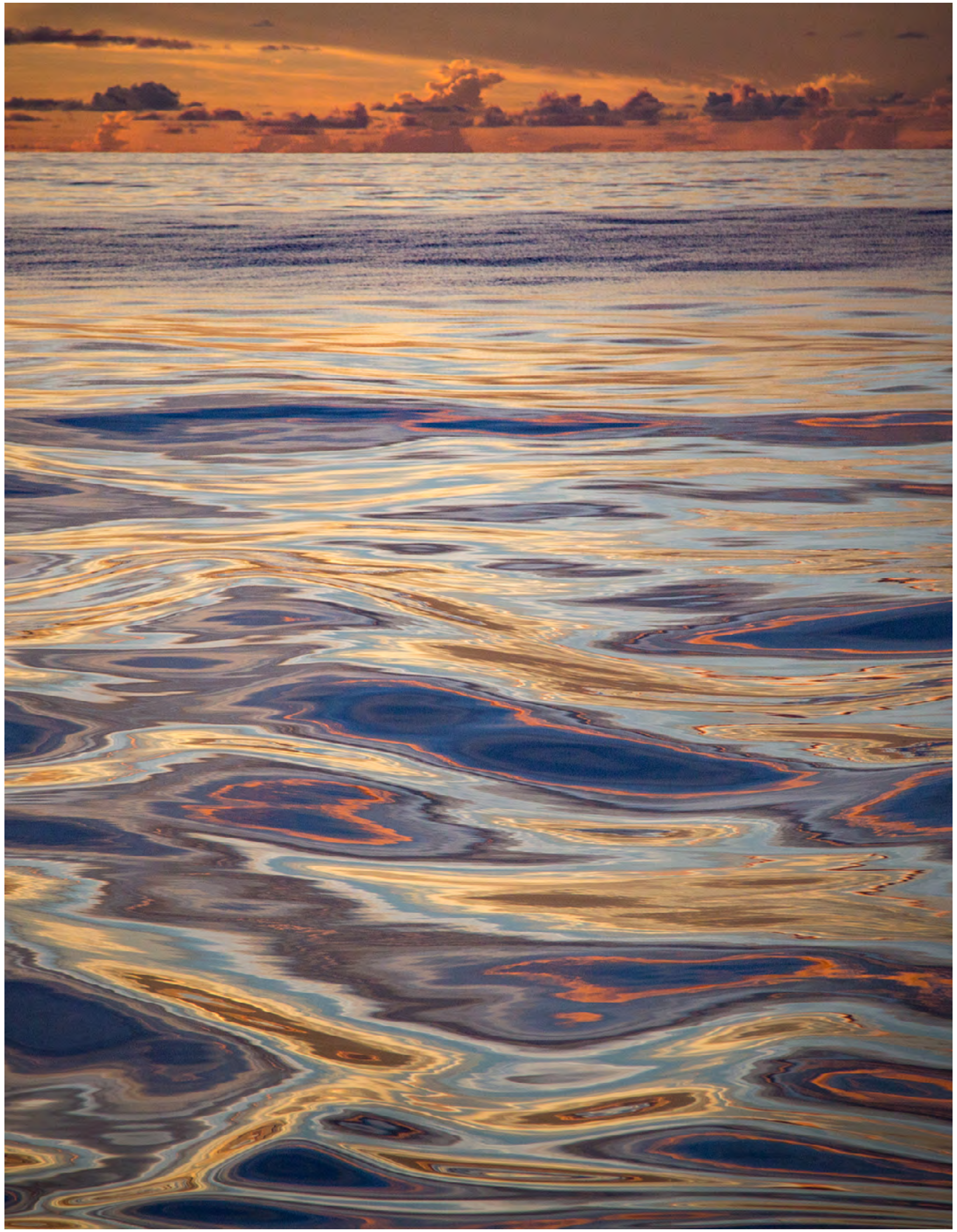
*Larry Mayer is director of the Center for Coastal and Ocean Mapping and director of the School of Marine Science and Engineering at the University of New Hampshire.*

*Chris German is senior scientist at the Woods Hole Oceanographic Institution (and on the Ocean Exploration Advisory Board).*

*Mike Ford is an expert in mid-ocean-depth ecosystems at NOAA Fisheries.*

*Jamie Austin is a senior research scientist at University of Texas (and on the Ocean Exploration Advisory Board).*

*Dominique Rissolo is at the University of California, San Diego (and on the Ocean Exploration Advisory Board).*



NOAA Ship *Okeanos Explorer* encountered incredibly calm waters while underway to the Pacific Remote Islands Marine National Monument. | *Credit: NOAA Office of Ocean Exploration and Research, Deepwater Wonders of Wake.*

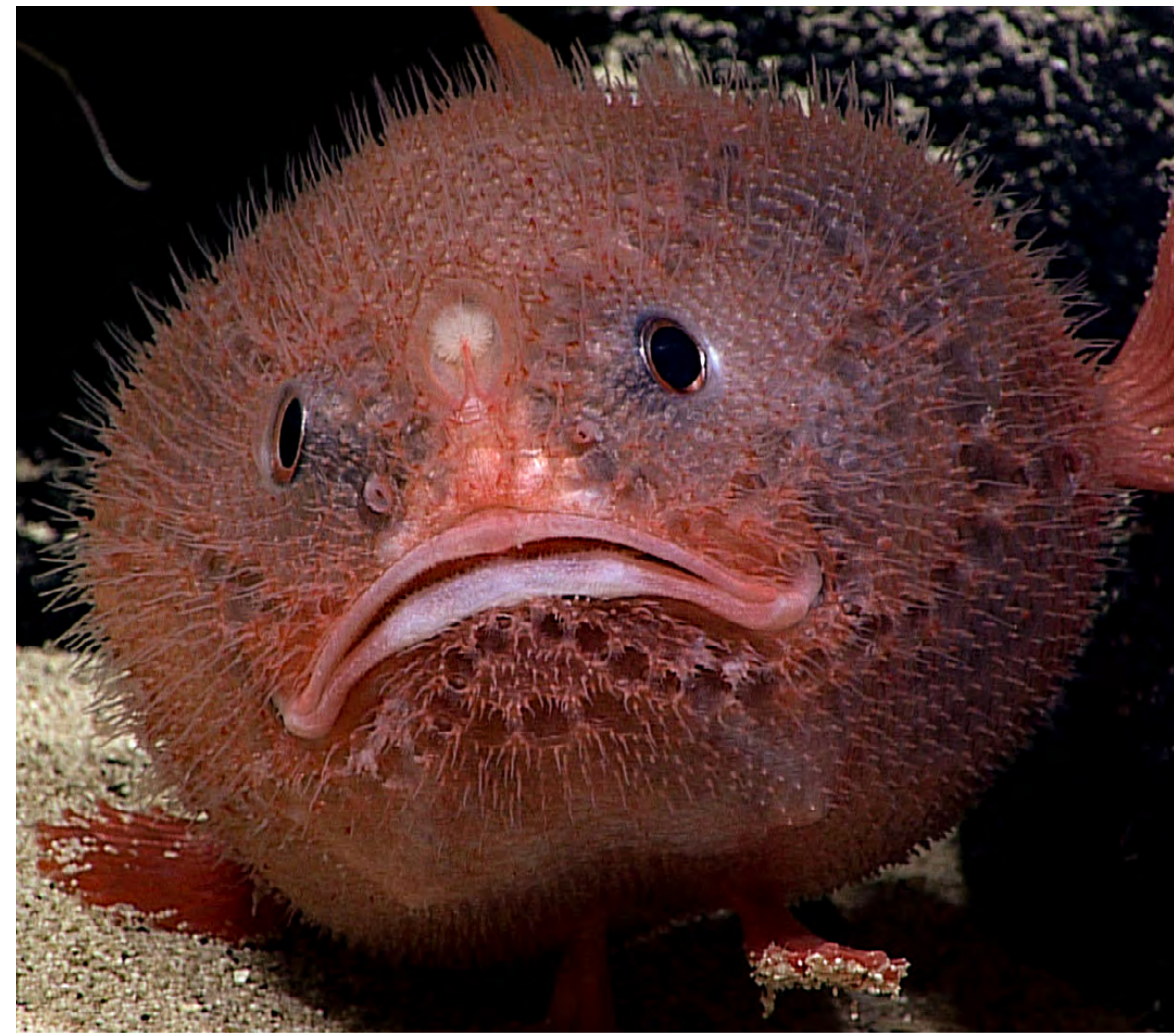
APPENDIX IV

# PARTICIPANT LIST

*2015 National Ocean Exploration Forum*

| | |
|---|---|
| Jamie Austin | University of Texas \| Ocean Exploration Advisory Board |
| Bob Ballard | Ocean Exploration Trust |
| Jason Baybutt | member of the public |
| Chris Beaverson | National Oceanic and Atmospheric Administration |
| Katy Croff Bell | Ocean Exploration Trust |
| Jim Bellingham | Woods Hole Oceanographic Institution |
| Erika Bergman | Open Explorer |
| Mark Blankenship | National Oceanic and Atmospheric Administration |
| Scott Borg | National Science Foundation |
| Andrew Bowen | Woods Hole Oceanographic Institution |
| Bill Brown | Bureau of Ocean Energy Management |
| Frank Cantelas | National Oceanic and Atmospheric Administration |
| Robert Carmichael | member of the public |
| Ashley Chappell | National Oceanic and Atmospheric Administration |
| Brad Clement | Texas A&M University |
| Dwight Coleman | University of Rhode Island |
| Allen Collins | Smithsonian Institution |
| Mike Conathan | Center for American Progress |
| Caren Cooper | North Carolina Museum of Natural Sciences |
| Valerie Craig | National Geographic Society |
| Emily Crum | National Oceanic and Atmospheric Administration |
| Thomas Curtin | MIT Sloan School of Management |
| Ned Cyr | National Oceanic and Atmospheric Administration |
| Gina Davenport | National Oceanic and Atmospheric Administration |
| Megan Davis | Florida Atlantic University |
| Samuel De Bow | National Oceanic and Atmospheric Administration |
| James P. Delgado | National Oceanic and Atmospheric Administration |
| Dante DelGrosso | Deep Ocean Discovery |
| Bob Dziak | National Oceanic and Atmospheric Administration |
| Kelley Elliott | National Oceanic and Atmospheric Administration |
| Robert Embley | National Oceanic and Atmospheric Administration |
| Jennifer Ewald | Bureau of Ocean Energy Management |
| Missy Feeley | ExxonMobil (ret.) |
| Mike Ford | National Oceanic and Atmospheric Administration |
| VADM Paul Gaffney II (ret.) | Monmouth University \| Ocean Exploration Advisory Board |
| RDML Tim Gallaudet | Naval Meteorology and Oceanography Command |
| Chris German | Woods Hole Oceanographic Institution \| Ocean Exploration Advisory Board |
| Deborah Glickson | Florida Atlantic University |
| Amy Gusick | California State University, San Bernardino |
| John Haines | United States Geological Survey |
| Stephen Hammond | National Oceanic and Atmospheric Administration |
| Kevin Hand | National Aeronautics and Space Administration \| Jet Propulsion Laboratory |
| Frederick Hanselmann | Texas State University |
| Susan Haynes | National Oceanic and Atmospheric Administration |

| | |
|---|---|
| Andy Hemmings | Gault School of Archeological Research |
| Joseph Hoyt | National Oceanic and Atmospheric Administration |
| Ambassador Cameron Hume | Consultant \| Ocean Exploration Advisory Board |
| Michael Ilteris | North Atlantic Treaty Organization |
| Renato Kane | University of Delaware |
| Timothy Kearns | Ocean Aero |
| Christopher Kelley | University of Hawaii |
| Brian Kennedy | National Oceanic and Atmospheric Administration |
| Todd Kincaid | Project Baseline |
| Matthew King | National Oceanic and Atmospheric Administration |
| Eric King | Schmidt Ocean Institute |
| Jonathan Knowles | Autodesk |
| Karen Kohanowich | National Oceanic and Atmospheric Administration |
| Gerhard Kuska | MARACOOS |
| David Lang | OpenROV \| Ocean Exploration Advisory Board |
| Alan Leonardi | National Oceanic and Atmospheric Administration |
| Doug Levin | Washington College |
| Darlene Lim | National Aeronautics and Space Administration \| Ocean Exploration Advisory Board |
| Meme Lobecker | National Oceanic and Atmospheric Administration |
| David Lovalvo | Global Foundation for Ocean Exploration |
| Tony MacDonald | Monmouth University |
| Stephen Maconi | Global Foundation for Ocean Exploration |
| Mashkoor Malik | National Oceanic and Atmospheric Administration |
| Larry Mayer | University of New Hampshire |
| John McDonough | National Oceanic and Atmospheric Administration |
| David McKinnie | National Oceanic and Atmospheric Administration |
| Craig McLean | National Oceanic and Atmospheric Administration |
| Kevin McMonagle | Video Ray |
| Sharon Mesick | National Oceanic and Atmospheric Administration |
| Brian Midson | National Science Foundation |
| Allison Miller | Schmidt Ocean Institute |
| Jerry Miller | National Research Council |
| Craig Mullen | Aurora Trust |
| Curt Niebur | National Aeronautics and Space Administration |
| Nicolette Nye | National Ocean Industries Association \| Ocean Exploration Advisory Board |
| Jimmy O'Donnell | University of Washington |
| Kevin O'Donovan | O'Donovan Strategies |
| Leonard Pace | Schmidt Ocean Institute |
| Frank Pavia | Columbia University |
| Emil Petruncio | U.S. Naval Academy |
| Rochelle Plutchak | National Oceanic and Atmospheric Administration |
| Shirley Pomponi | Florida Atlantic University |
| John Racanelli | National Aquarium |
| Nicole Raineault | Ocean Exploration Trust |
| Philip Renaud | Khaled bin Sultan Living Oceans Foundation |
| Rick Rikoski | Hadal, Inc \| Ocean Exploration Advisory Board |
| Dominique Rissolo | University of California, San Diego \| Ocean Exploration Advisory Board |
| Christopher Ritter | Global Foundation for Ocean Exploration |
| Tina Roberts | member of the public |
| Stockton Rush | Ocean Gate |
| Craig Russell | National Oceanic and Atmospheric Administration |
| Melissa Ryan | Global Foundation for Ocean Exploration |
| Ian Sage | North Atlantic Treaty Organization |
| Jerry Schubel | Aquarium of the Pacific at Long Beach |
| RADM David Score | National Oceanic and Atmospheric Administration |
| Katherine Segarra | Bureau of Ocean Energy Management |
| James Shambaugh | National Oceanic and Atmospheric Administration |
| Liz Shea | Delaware Museum of Natural History |
| Adam Soule | Woods Hole Oceanographic Institution |
| Eric Stackpole | OpenROV |
| Ellen Stofan | National Aeronautics and Space Administration |
| Andrew David Thaler | Southern Fried Science |
| Aurora Thornhill | Kickstarter |
| Michael Vecchione | National Oceanic and Atmospheric Administration |
| Jyotika Virmani | X-Prize Foundation |
| Mary Voytek | National Aeronautics and Space Administration |
| Katie Wagner | National Oceanic and Atmospheric Administration |
| Marjorie Weisskohl | Bureau of Ocean Energy Management |
| Chris Welsh | DeepSub LLC |
| Brent Whitaker | National Aquarium |
| Louis Whitcomb | Johns Hopkins University |
| VADM Jon White | Consortium for Ocean Leadership |
| Sandra Whitehouse | Ocean Policy Consultant |
| Dana Yoerger | Woods Hole Oceanographic Institution |



A sea toad, a type of angler fish, seen on an unnamed seamount located approximately 50 miles west of Wake Island. | *Credit: NOAA Office of Ocean Exploration and Research, Deepwater Wonders of Wake.*

APPENDIX V

# ADVANCING OCEAN EXPLORATION 2020 AND NATIONAL FORUM 2014 RECOMMENDATIONS

## *Perspectives from the Ocean Exploration Community and the Office of Ocean Exploration and Research*

During its second meeting in La Jolla, the Ocean Exploration Advisory Board (OEAB) asked for a summary of progress toward advancing Ocean Exploration 2020 report recommendations. The Office of Ocean Exploration and Research (OER) took a two-part approach to respond. First, we worked with Jerry Schubel, President and CEO of the Aquarium of the Pacific and co-host of Ocean Exploration 2020, to solicit external perspectives on progress toward a national ocean exploration program since OE 2020. We asked these experts to review a particular OE 2020 report recommendation, to reflect on progress made in that particular area since the first Forum, and to identify challenges that remain. Second, we have prepared a short summary of how the OE 2020 and National Forum 2014 report recommendations have shaped OER activities.

### BACKGROUND

The authorizing legislation for NOAA's ocean exploration program, Public Law 111-11, asks the agency to "establish an ocean exploration forum to encourage partnerships and promote communication" among stakeholders to "enhance the scientific and technical expertise and relevance of the national program."

With its partners at the Aquarium of the Pacific and the National Aquarium in Baltimore, OER organized a first National Ocean Exploration Forum, Ocean Exploration 2020, followed by a second, "mini-National Forum" in Baltimore at the National Aquarium in 2014. A third, Characterizing the Unknown—National Ocean Exploration Forum 2015, will take place in Baltimore in November. The design of the third National Ocean Exploration Forum is a conscious step forward: the event will focus on federal agency ocean exploration requirements and mission drivers for non-government ocean exploration entities as a framework for identifying how future expeditions will be able to take advantage of a successful national program. OER expects the National Ocean Exploration Forum concept to evolve with the national ocean exploration program and for other members of the community to host similar events in the future.

While OE 2020 resulted in rich guidance for a national program by defining key characteristics, the September 2014 mini-National Forum, held shortly before the OEAB convened for the first time, discussed on how ocean exploration supports NOAA programs that provide "actionable information" for decision makers based on environmental intelligence. Participants also discussed the evolution of the national program and provided recommendations for the next National Ocean Exploration Forum

While Forum report recommendations themselves are of great value to NOAA and the ocean exploration community, the events are important steps toward building and reinforcing a community that might identify itself as part of a national program.

### EXTERNAL PERSPECTIVES

In this section, experts external to OER share their informal thought about what progress we have made as a community toward developing the attributes OE 2020 participants identified as important to a successful national ocean exploration program.

### PRIORITIES

*Jerry Schubel, President and CEO*
*Aquarium of the Pacific at Long Beach*

Since the outset, there has been general agreement that the program should be global in scope, but have a focus, at least initially on U.S. waters, and that priorities should be set by the community while being responsive to national needs

Since the President's Panel on Ocean Exploration in 2000 there has been a convergence on geographic and ocean feature priorities. These sources include: the 2003 NRC report Exploration of the Seas, the 2012 review of NOAA's ocean exploration program, Ocean Exploration's Second Decade, the first national ocean exploration forum, Ocean Exploration 2020, and the second forum, National Forum 2014. These are summarized in the table below.

Setting of priorities by the community has been institutionalized through a series of forums starting with Ocean Exploration 2020 in July 2013, the smaller National Forum 2014 in September of that year, and occasional workshops that bring together ocean explorers and other research scientists together to focus on specific geographic areas, and how best to explore them. Two recent examples are the 2012 "Workshop on Telepresence-Enabled Exploration of the Caribbean Region," and the 2014 "Workshop on Telepresence-Enabled Exploration or the Eastern Pacific Ocean," both hosted by the Ocean Exploration Trust with support from NOAA and foundations.

An additional priority that has been called for since the President's Panel is the development of technologies, including platforms and sensors, to provide greater mobility to explore larger areas and volumes at lower cost, and sensors that provide physical, chemical, and biological data to characterize the environments which are being explored and observed. This is an area where great progress has been made in the past few years with the development of AUVs and UAS's (drones) which can covert any oceanographic research vessel into a ship of exploration, and the growing array of sensors have added a powerful diagnostic capability to visual exploration.

**A CONVERGENCE ON PRIORITIES: 2000 - 2014**

| GEOGRAPHIC AREAS | OCEAN FEATURES |
|---|---|
| Arctic | Water Columns |
| Antarctic | Trenches |
| Indo-Pacific | Coral Ecosystems |
| Central Pacific | Methane Seeps |
| U.S. EEZ | Marine Life |
| U.S. Extended Continental Shelf | Seamounts |
| | Under-Ice Communities |
| | Deep Water and Climate Change |
| | Oceans through Time |

## PARTNERSHIPS

*Larry Mayer, Director, Center for Coastal and Ocean Mapping, University of New Hampshire*

Under PL-111-11, NOAA has been charged with taking a leadership role in establishing a national program of ocean exploration and thus would be the logical agency to take the lead in establishing formal partnerships for ocean exploration. We have seen some progress along these lines. For example, NOAA has been working with the X-Prize Foundation to establish prizes in ocean-related areas, and we have seen collaborations established between NOAA, Bureau of Ocean Energy Management, and U.S. Geological Survey for exploration of methane seep-rich areas of the Atlantic margin.

Private foundations continue to support ocean exploration efforts (Schmidt Ocean Institute; Sloan Foundation; Moore Foundation, etc.) and there has been some level of coordination amongst these organizations. But they appear to be coordinating amongst themselves and not with federal agencies or the private sector.

We have also seen progress on the international front. For example, the National Science Foundation and the Swedish Polar Secretariat have formed a new agreement that supports sharing of ship-time in the Arctic, the highest regional priority for ocean exploration and an area where vessel resources are very scarce.

An area where we have seen little, if any progress, is in the formal and systematic coordination of ocean exploration activities amongst the various ocean exploration entities, and particularly amongst federal agencies. Given the mandate of PL-111-11 one would hope to see a formal interagency coordinating committee for national ocean exploration activities.

More than a mandate is required for such an organization to be successful: a willingness on the part of all agencies involved to participate and contribute is essential. This may be the greatest challenge facing the future of U.S. ocean exploration activities.

## PLATFORMS

*Peter Ortner, Research Professor and Director, Cooperative Institute for Marine and Atmospheric Studie*

Despite the OE 2020 report's call for an increased number of platforms, the size of the research vessel fleet continues to shrink. And yet if we use the term "ocean exploration" more broadly, to refer to the broad sense of acquiring data and information we previously did not have, there is progress. The idea is not to simply go to a particular bit of geography where we don't know what we will find, but to collect data over time and space scales impossible with old technology. We can "see" new geography through a different lens.

For example, ocean observatories may be part of this new ability to collect data over time and space (I think the jury still is out) but Autonomous Underwater Vehicles (AUVs) Unmanned Aircraft Systems (UAS, or "drones"), and ships of opportunity clearly must be included. Our conventional research fleet simply can't look across dynamic processes, time, and space in the way that these new technologies can, regardless of how large it is.

With AUVs and UAS' (particularly the latter) the challenge is improving weight/power requirements. We are doing better and better in that regard. A particularly exciting development that could radically improve the quality of optical data from UAS-based sensors is "fluid lens analysis"—a mathematical filtering and distortion correction process that allows us to see right through surface wave and light reflection distortion to the surface of coral reefs and other submerged features. **(See www.vedphoto.com/fluid-lensing)**. This is truly exciting stuff for many applications—enough so that NASA is investing millions.

New platforms are already proving their worth, but advances in instrumentation are even more impressive. Our ability to combine old and new platforms with smaller, low power, automated sensing systems—primarily optical and acoustic but also to a more limited extent chemical and biochemical sensors greatly expands the concept of "exploration." Much work remains to be done, but there are a number of promising technologies available or about to be available, including drop probes for an array of chemical parameters (like an XBT, but for much more than just temperature), including Oxygen, pH, Total Alkalinity, and Chlorophyll a. Another promising technology relating to drop probes is the ability to key fully automated launchers holding many probes based on real-time neural network analysis of continuous acoustic current data.

Platform integration is also gaining traction. Swarms of UAS and/or AUV vehicles that are "smart" and sample as a "team" could optimizing data collection and send it all to a "mother ship" for processing, analysis, and distribution. Some have even suggested this "mother" could be a helicopter based upon a research vessel. Integrating a series of platforms in this way dramatically increases the reach of any research vessel to sample a wider 3-D world around its position.

Because these new technologies are smaller and much lower cost than traditional research vessels (and some are even accessible to citizen explorers) the cost of access to areas of interest should go down, which helps create opportunities for a greater national ocean exploration "footprint"—new areas explored—despite tightening budgets.

## TECHNOLOGY

*Lance Towers, Director, Advanced Technology Programs, Boeing, Inc*

The ocean-based community focused on ocean exploration has continued to make technology progress toward the goals and objectives outlined in the Ocean Exploration 2020 report. However, the rate of progress has basically remained flat. The smaller technology firms and education-based communities have most likely grown the most.

The budget challenges at the federal level continue to dampen technology and program development that is needed to fully achieve the goals and objectives of the Ocean Exploration 2020 report.

Public awareness in areas such as weather predictions dominates investment allocations in technologies and products such as weather satellites.

The actual investment in deep ocean exploration has remained a small overall percentage of the federal budget. The federal budget focus has dampened the amount of participation by large industry in ocean exploration. To move the needle, so-to-speak, in ocean exploration technology development, a significant increase in federal spending is required in order to pull in the large industry community.

NOAA may benefit from engaging organizations such as DARPA and ONR on behalf of the national ocean exploration program. Both DARPA and ONR develop technologies that operate in the ocean environment. Many of these technologies are fully applicable to the missions needed for successful ocean exploration.

With today's tight budgets but expanding mission requirements, we need to establish new ways of conducting the same work for significantly lower cost. This will require a paradigm change in what we produce for ocean exploration. For example, most ocean exploration technologies currently require significant infrastructure for operation. For example, advanced remotely operated vehicles (ROV) or autonomous underwater vehicles (AUV) require a surface ship for launch, operation, and recovery. The cost of the surface or support ship typically dwarfs the cost of the ROV or AUV. To break the cost curve, new technologies and modes of operation are required that eliminate the need for a surface or support ship. This defines a set of technologies that can operate mainly autonomously for weeks or months at time, with the ability to collect vast amounts of data and carry a wide variety of sensors.

Another way to break the cost curve is investment in low-cost, lightweight systems that reduce required infrastructure while maintaining or improving data collection results.

## CITIZEN EXPLORATION

*David Lang, Co-Founder, OpenROV*

One of the most interesting trends in science is happening outside of science. The rapidly changing technology landscape is driving a new generation of tools that can be made more affordable and more connected. This explosion of new devices and sensors is driving involvement from a new genre of participant: the citizen scientists.

It isn't necessarily a new idea. Disciplines like astronomy and ornithology have been incorporating the research and perspective of non-professional scientists for decades. The concept is novel for ocean exploration because of the high costs associated with fieldwork and the relatively small amount of funding that supports the work. At OE 2020, we talked about the potential of this developing trend and how best to harness it. In the subsequent years, the discussion has continued with enthusiasm and the technology developed extensively.

The high cost of traditional ocean exploration infrastructure—ships, submersibles, remotely operated vehicles, and so on—and the limited federal investment in this expensive and often aging infrastructure, means that conventional ocean exploration assets are likely to remain limited. The dropping costs and rapid improvements in instrument capability of flexible, small platforms is creating an opportunity to expand the pace and scope of exploration in the near future. The challenge now is to move beyond dialogue and towards meaningful, systemic engagement.

## DATA SHARING

*Vicki Ferrini, Research Scientist, Lamont-Doherty Earth Observatory*

Community progress toward data sharing since 2013:

Over the past several years, there has been considerable progress with respect to making basic metadata and field data (unprocessed) acquired by ships openly accessible in a more timely fashion. This is in part due to the development and adoption of the "Rolling Deck-to-Repository" (R2R Program), which transformed the data submission paradigm and streamlined the transfer of data/metadata to the NOAA's National Centers for Environmental Information (NCEI) by working directly with vessel operators rather than individual scientists. While R2R was developed for the U.S. Academic Research Fleet, the model is highly efficient and NOAA has adopted many of its principles. Responsibilities for processing shipboard data vary by operator. In cases where data are processed by vessel operators, processed data are propagated fairly routinely to NCEI, but in cases where data processing lies with members of the science party the data are less routinely made available.

Multiple efforts have been developed over the past several years that focus on ensuring that high quality data are consistently acquired across the research fleet and that technical resources and best practice documentation are publicly available. These efforts typically provide expert oversight of the operation of a particular instrument suite, and include but are not limited to, the Multibeam Advisory Committee (MAC), Joint Archive for Shipboard ADCP (JASADCP), and Shipboard Automated Meteorological and Oceanographic System (SAMOS). Knowledge from these efforts is broadly shared across the Ocean Exploration Community. While this is proving to be a productive model, it has not yet been adopted for all data types.

Community input on metadata needs and data formats over the past several years is helping to improve the consistency and utility of data made available at NOAA's NCEI.

Collaborative efforts for developing standards for publishing and sharing metadata are helping with interoperability and discovery of related and complementary data in distributed systems. There is still work to be done to lower barriers to adoption of tools and interfaces for the science community and the public.

Over the past few years, more effort has been put into leveraging social media to disseminate highlight data (video, images, maps) with the public. This is an important and worthwhile aspect of public outreach and engagement that can significantly benefit our community.

### *Challenges and opportunities in this area over the next five years*

Final data products and interpretations generated by scientists are still falling through the cracks. We've made considerable progress with underway data and the culture is clearly changing, but documenting data and contributing final data products to appropriate repositories is still time-consuming for individual investigators and is not adequately rewarded. There are many opportunities for addressing this challenge including, but not limited to, software development/deployment, workflow development, and training.

It is still extremely challenging to comprehensively discover what data exist and how to access those data. We've done an excellent job with some data types, and have made little to no progress with others.

Video data management remains a growing challenge for our community, and includes topics such as video formats, data volumes, long-term storage, and access/accessibility. A small workshop will be held in 2016 that will include members of the Ocean Exploration Community and industry specialists to begin to develop community consensus on a way forward, but significant effort and cost will be associated with developing a robust solution for large volumes of video content (sourced from both submersibles and airborne drones).

The cost of managing scientific data is non-trivial and the mechanisms for supporting those costs remain unclear at best.

### *What can federal agencies, particularly NOAA, do to help?*

Foster partnerships among various data management efforts that are closely integrated with subsets of the Ocean Exploration Community to ensure that efforts augment one another, lessons learned are shared, and that distributed content can be accessed through common standards.

Ensure that data policies are consistently implemented across agencies and across data types (e.g. underway (raw) vs. processed data products; policies regarding open access to underwater photos/video acquired with federal research money is extremely variable at present).

Help to identify funding mechanisms/opportunities and possibly collaborations with the tech industry for developing/integrating the kinds of tools/techniques that will lessen the "burden of data management" on individual scientists and facilitate the flow of data/information. Tools that can be incorporated into the daily workflows of scientists are sorely needed.

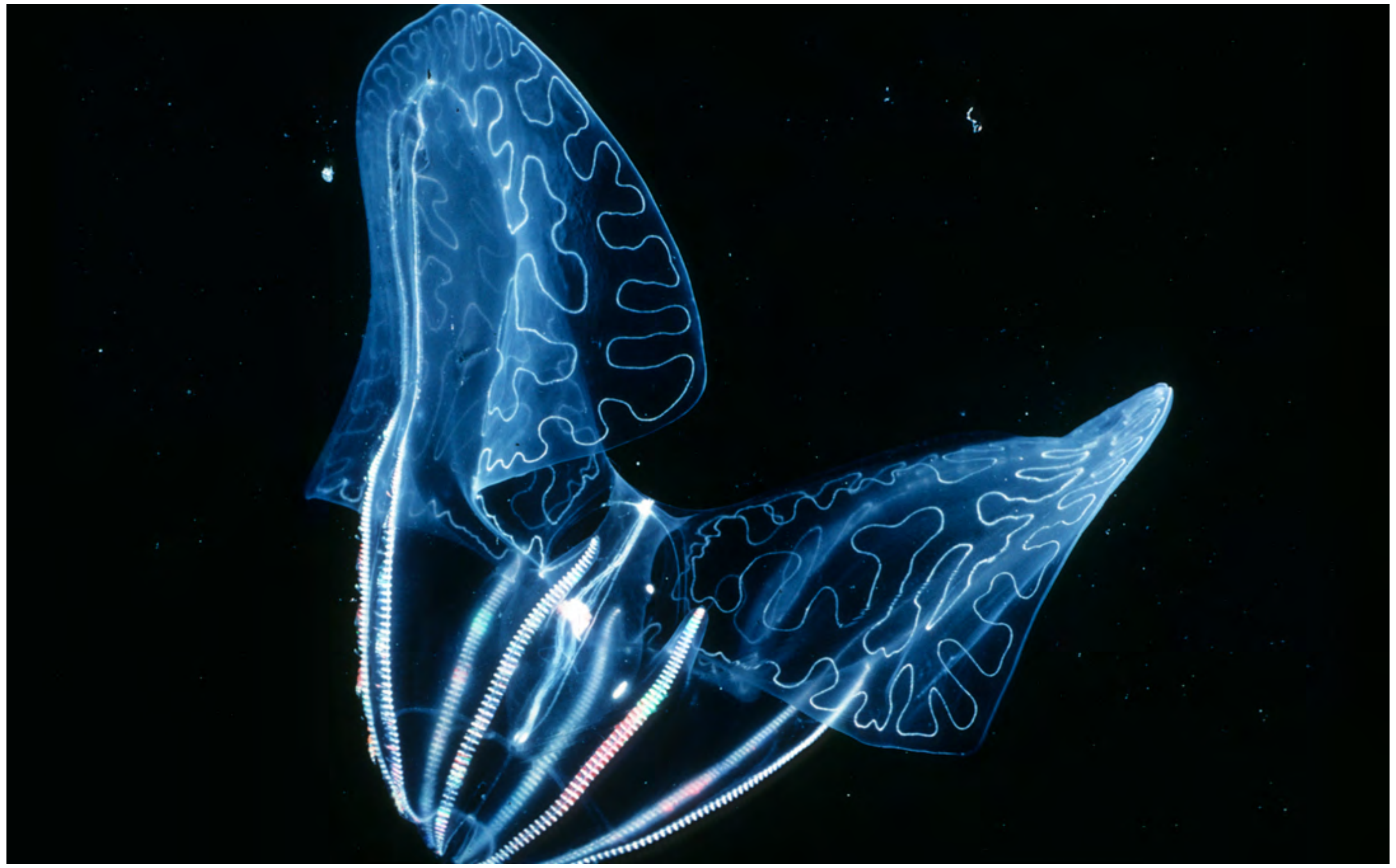
Continue to help shift the culture among the science community with respect to data sharing and data citation. Part of this entails clearly defining data sharing obligations/expectations and following up to ensure compliance. Software tools can and should be part of the solution along with professional credit for data contributions.

## PUBLIC ENGAGEMENT

*Louisa Koch, NOAA Director of Education*

Since Ocean Exploration 2020, the telepresence-enabled exploration model in place aboard the E/V *Nautilus* and the NOAA Ship *Okeanos Explorer* has been deployed on the Schmidt Ocean Institute's *Falkor*, and on some UNOLS research vessels. Anyone can now participate in ocean exploration via a standard Internet connection. The maturation of telepresence technology and its broader deployment have created important new opportunities to engage the public in ocean exploration.

Other efforts to engage citizen scientists in ocean exploration have made strides through projects such as the NOAA Phytoplankton Monitoring Network and the Marine Debris Tracker program. National and international initiatives like Ocean Sampling Day help build awareness of ocean issues and create context for public engagement in ocean exploration. These efforts should be expanded. As technology improves and is more widely available, the ability



Ctenophore. | *Credit: Harbor Branch Oceanographic Institute-Florida Atlantic University.*

of citizen explorers to contribute to the national program increases.

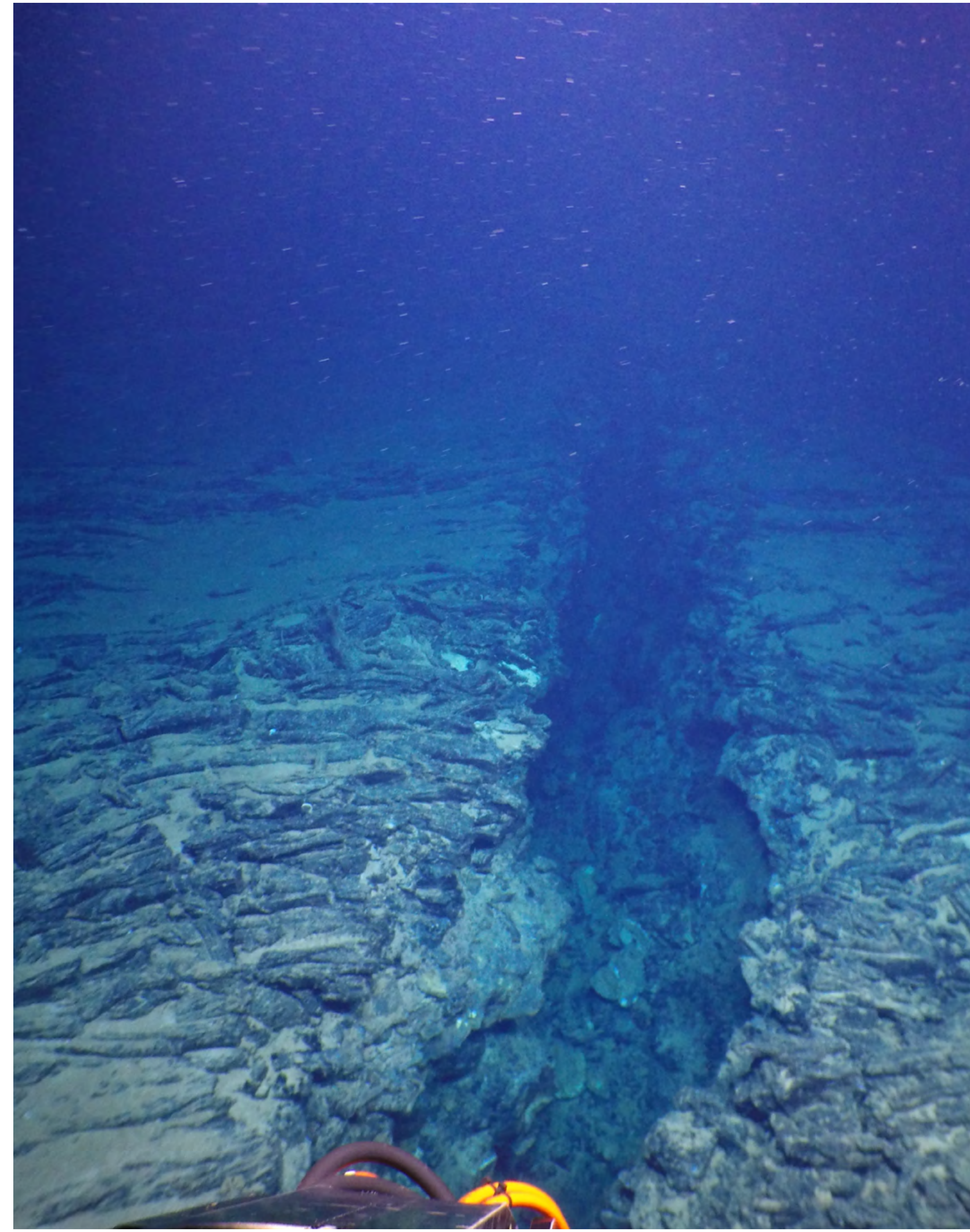
Increased coordination and leveraging of new develops in tools and methods among the three U.S. ships of exploration, the *Falkor*, *Nautilus*, and *Okeanos Explorer* could make it easier for education partners to connect with a broad array of ocean exploration expeditions. More coordination between the ships of exploration and formal and informal educational institutions could help educators use ocean exploration results in new and powerful ways to reach students, their parents, and the general public.

Closer working relationships between the ocean exploration programs (both government and non-government) and zoos and aquaria could help bring ocean exploration to a broader segment of the public.

While telepresence has proven to be an effective way of engaging the science community and providing access to the public, live expeditions can have greater educational impact with interpretation. The *Nautilus* has built an effective education program by having trained communicators aboard the ship. The Schmidt Ocean Institute's *Falkor* has also used this model.

Limited berth space might prevent the *Okeanos Explorer* from having on-board educators or communicators, but the ship could partner with a shore-based education institution that could provide the contextual interpretation of the live feeds as they're happening. NOAA could develop this model for interpretation with partners to help expand public engagement in any expedition.

The Next Generation Science Standards present new opportunities to incorporate ocean exploration themes. Ocean exploration through telepresence can bring authentic discovery right into the classroom.



Lava flow and fissure. | *Credit: Ocean Exploration Trust, Galapágos, 2015.*

# U.S. NAVY

## *Naval Oceanography Interest in Ocean Exploration*

### BACKGROUND

Up until the last century the U.S. Navy was the principal ocean explorer for the U.S. government. Today, Naval Oceanography operates a fleet of multipurpose oceanographic survey ships to collect information from the seafloor, through the water column to the ocean surface above. The United Nations Convention on Law of the Sea (UNCLOS) does not address military surveys, but the U.S. requires the ability to conduct military surveys without coastal state permission or notification within exclusive economic zones strictly for military use. Naval Oceanography shares some key ocean exploration themes such as the systematic mapping of the sea floor and related geologic and geophysical parameters, and the penetration of the sea floor by mechanical and acoustical means to comprehend geology, geophysics and geochemistry. However, those efforts meet specific military requirements and do not constitute traditional exploration. Naval Oceanography efforts are focused in the three following areas:

### *Characterization of the Physical Environment*

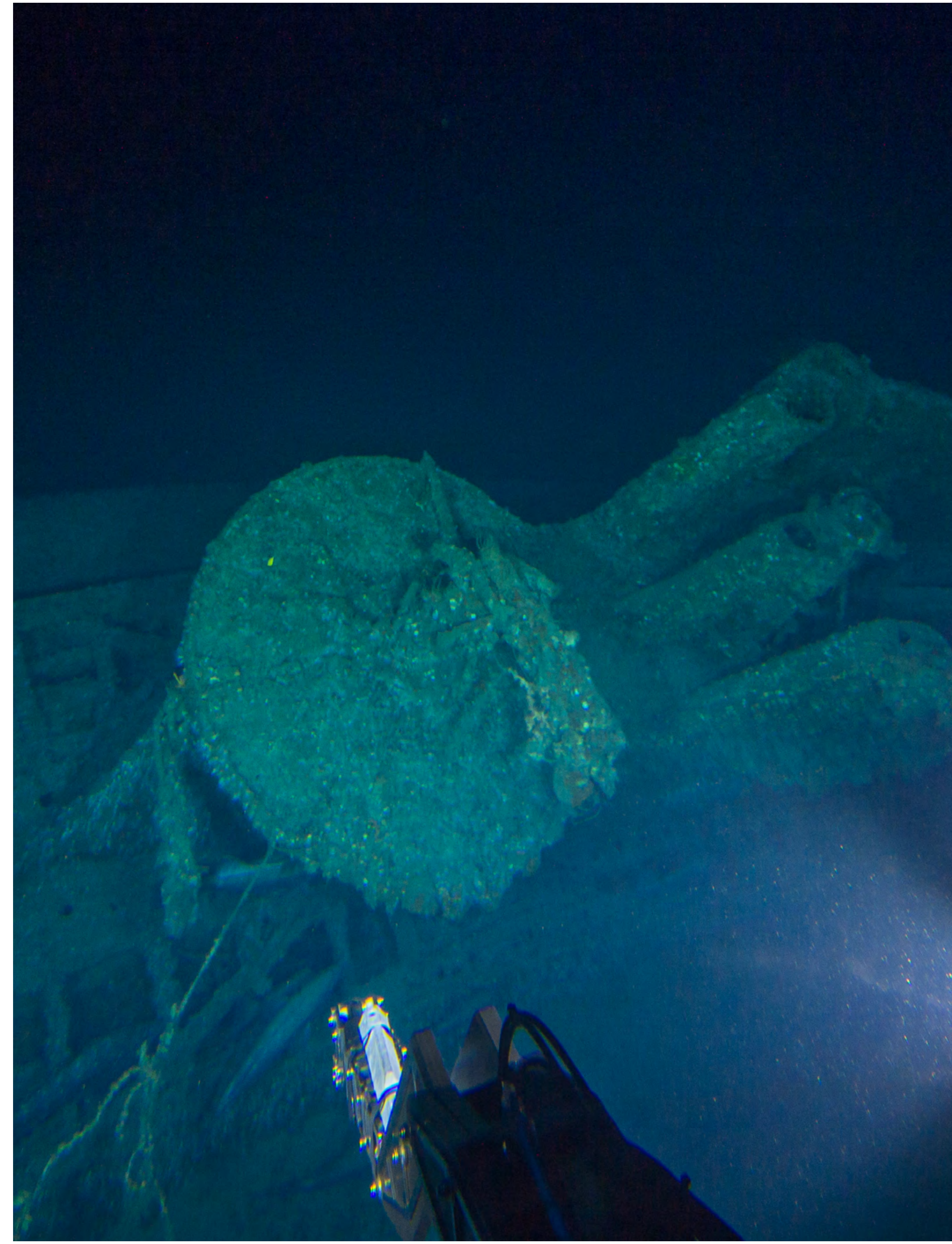
- Naval Oceanography is the primary ocean data collection organization for the Department of Defense.
- The Navy requires knowledge of the physical state of the ocean floor, the water column, the ocean surface and the marine atmosphere to effectively support naval operations.
- In addition to shipboard data collection, the Navy relies heavily on environmental satellites and unmanned systems to characterize the environment.
- To characterize the future physical environment up to 10 days in advance, the Navy uses robust, supercomputer-based coupled air-ocean-wave numerical models.

### *Identification of Hazards to Navigation*

- Naval Oceanography has global ocean bottom mapping responsibilities for the Department of Defense and collects data from the deepest part of the ocean to the shallowest of ports.
- Naval Oceanography works closely with National Geospatial Intelligence Agency (NGA) and NOAA to provide updated navigation chart information as well as information on wrecks, shoals and seamounts through the Notice to Mariners process.

### *Characterization and Impacts of Human Activity*

- **Maritime Domain Awareness**—The Navy is the lead DOD Executive Agent for maritime domain awareness in an effort to understand the impacts of human activities such as shipping, military activities, legal and illegal fishing, illicit trafficking, recreation, and resource extraction.
- **Task Force Climate Change—**As we deal with the impact of our changing climate and potential sea level rise, the Navy is working to shape proactive policies to mitigate risk to infrastructure and build an effective naval force to deal with the future's challenges.



The aft section of the *U-576's* conning tower, also known as the wintergarten, which served as a platform for the 20mm anti-aircraft flak gun. | *Credit: Joe Hoyt, NOAA - Battle of the Atlantic expedition.*

# BUREAU OF OCEAN ENERGY MANAGEMENT

The Bureau of Ocean Energy Management (BOEM) is the federal agency responsible for managing the use of energy and mineral resources that are found on the Outer Continental Shelf (OCS)—the 1.7 billion acres of our nation's continental shelf located beyond State waters. The resources covered include oil and gas; wind, waves, and current energy; and sand, gravel, and other minerals. About 18 percent of the oil produced in the United States currently comes from the OCS.

Energy and mineral development have environmental impacts, including oil spills, bottom disturbance, obstructions to migration, noise, air emissions, lighting, vessel traffic, and "viewscape" alterations. Diverse Federal laws task BOEM with protecting the environment as these activities go forward. Environmental protection requires science as well as policy, and since 1973 Congress has funded an Environmental Studies Program (ESP) for this purpose, mandated after 1978 by Section 20 of the Outer Continental Shelf Lands Act (OCSLA). Annual planned funding for the ESP is currently $35.7 million, although the expenditure level has varied over the years. Since its inception, the ESP has provided over $1 billion for research on environmental impacts from energy and mineral development. ESP develops, funds and manages rigorous scientific research specifically to inform policy decisions regarding development of Outer Continental Shelf (OCS) energy and mineral resources. Research covers physical oceanography, atmospheric sciences, biology, protected species, social sciences and economics, submerged cultural resources, and environmental fates and effects.

BOEM's Studies Development Plans (SDPs) are updated annually and cover two fiscal years. The information in the SDP is used to formulate annual National Studies Lists (NSLs) that describe ESP projects eligible for funding in a given fiscal year. Additional information on BOEM's ongoing studies can be found at our studies website: **https://www.boem.gov/current-research-ongoing-environmental-studies/**. Access to completed ESP products through BOEM's web is the Environmental Studies Program Information System (ESPIS) at **https://www.marinecadastre.gov/espis/#/** (enhanced ESPIS July 2015).

The ESP funds are currently dispersed for defined projects through three vehicles: interagency agreements with Federal agencies; cooperative agreements with State institutions; and competitive contracts. Irrespective of particular funding vehicles and recipients, BOEM aims to use funds in a way that will deliver the most needed and best research at the lowest cost consistent with those objectives.

Between 2010 and 2014:

- 41 percent of funds went to Federal agencies[1] (26 percent to NOAA alone);
- 28 percent to academic institutions;
- 26 percent to private research organizations;
- 3 percent to State government agencies; and
- 2 percent to other researchers.

Sponge and crinoids. | *Credit: Ocean Exploration Trust, Galapágos, 2015.*

The subject matter allocation of funds over the same time frame was:

- 29 percent marine mammals and other protected species;
- 28 percent habitat and ecology;
- 16 percent physical oceanography;
- 9 percent social sciences and economics;
- 9 percent fate and effects of oil spills;
- 5 percent information management; and
- 4 percent air quality.

ESP projects are developed by BOEM through internal and external review. Overall direction and coordination are provided by the Headquarters Office's Division of Environmental Sciences (DES) within the Office of Environmental Programs (OEP). Input is requested from BOEM's program and regional offices, and priorities are collaboratively developed. Prior to 2015, external review of project priorities was provided by the OCS Science Committee. This was a committee of independent experts established by the Secretary of the Interior under the Federal Advisory Committee Act. In 2015, BOEM entered into a contract with the National Research Council (NRC) to establish a standing Committee on Environmental Science and Assessment for Offshore Energy. The NRC will provide BOEM with advice on diverse issues, and BOEM has decided to secure advice on ESP project priorities from the NRC standing committee instead of the OCS Science Committee beginning with the 2016 SDP. In this transitional year, BOEM will determine priorities through internal subject matter experts. Most importantly for 2015, BOEM will ask the new NRC committee to help the ESP be the best research program in existence. BOEM wants to be second to none, and it recognizes that goal is ambitious and will take work. One approach might be for the NRC committee and the Bureau to identify the attributes of the most successful and respected research programs placed in contexts similar to the ESP; to benchmark the ESP against those programs; to identify steps, as needed, that will incorporate those attributes in the ESP; and then to take the steps identified. BOEM is eager and optimistic about this challenge.

[1] Combining and leveraging resources to satisfy common scientific needs is a central component of the Bureau of Ocean Energy Management's (BOEM) approach to gathering robust scientific information for its decisions and consultation processes. BOEM has federal partnership agreements with BSEE, USGS, USFWS, NOAA, DOE, ONR, FERD, USCGC, and the Smithsonian. Other partnership mechanisms include the NOPP and the Interagency Working Group on Ocean Partnerships; university partnerships through the Coastal Marine Institutes at Univ. of Alaska Fairbanks and LSU, the Cooperative Ecosystem Studies Units (CESUs), and the Texas A&M Offshore Technology Research Center.

*Bathypaleomanella*, a type of shrimp, in *Iridogorgia* coral. | *Credit: NOAA Bioluminescence and Vision on the Deep Seafloor 2015.*



# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION OCEANOGRAPHY

Looking at our Earth from space, it is obvious that we live on a water planet. Ocean covers over 70 percent of the Earth's surface and contains about 97 percent of the Earth's surface water. Life in the oceans can be found from the surface to the extreme environments at the bottom of the deepest submarine trench. It is not surprising that the oceans represent over 99 percent of the living space on Earth...we are indeed living on what is truly an ocean planet.

### OCEAN & EARTH SYSTEM

**https://science.nasa.gov/earth-science/oceanography/ocean-earth-system**

### PHYSICAL OCEAN

**https://science.nasa.gov/earth-science/oceanography/physical-ocean**

### LIVING OCEAN

**https://science.nasa.gov/earth-science/oceanography/living-ocean**

### BEYOND OUR PLANET

**https://science.nasa.gov/earth-science/oceanography/beyond-our-planet**

### LEARNING RESOURCES

**https://science.nasa.gov/earth-science/oceanography/learning-resources**

### OCEANS INTERACTIVE

**https://science.nasa.gov/earth-science/oceanography/oceans-interactive**

### DATA RESOURCES

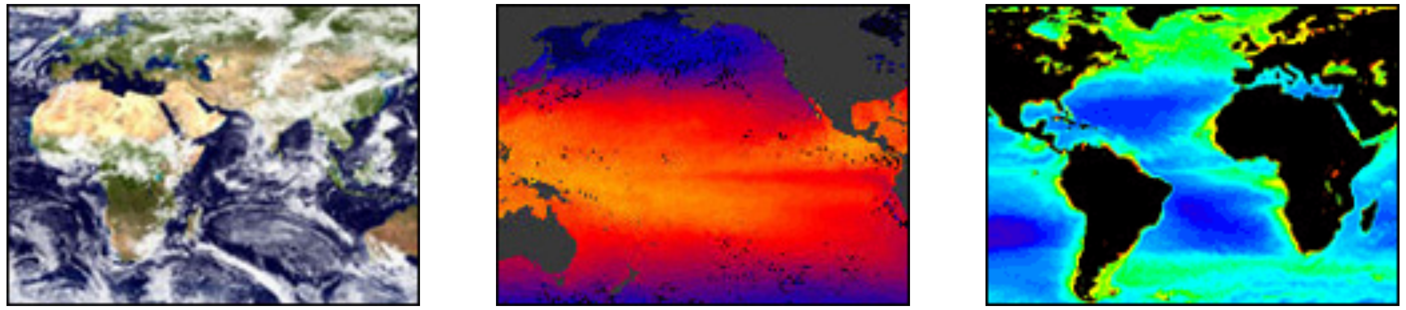
**https://earthdata.nasa.gov/about/daacs**

## WHY DOES NASA STUDY THE OCEAN?

Part of NASA's mission is to develop an understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Our oceans play a major role in influencing changes in the world's climate and weather. Collecting and analyzing long-term ocean data from satellites is a relatively new field of exploration. The analysis of remotely sensed ocean data makes it possible to understand the ocean in new and exciting ways.

Prior to satellite data, most of what we have learned about the oceans had come from infrequent measurements collected from ships, buoys, and drifters. Ship-based oceanographers are limited to sampling the ocean in a relatively small area with often a great deal of difficulty. Data from ships, buoys, and drifters are not sufficient to characterize the conditions of the spatially diverse of the ocean.

The advent of ocean-observing satellites has launched a new era of marine discovery. Remotely sensed satellite data and modeling techniques enable the global mapping of seasonal changes in ocean surface topography, currents, waves, winds, phytoplankton content, sea-ice extent, rainfall, sunlight reaching the sea, and sea surface temperature. Studying these patterns at a global scale help forecast and mitigate the disastrous effects of floods and drought. Images generated by ocean observing satellite missions tell us volumes about the most fundamental climate changes. During the last decade, forecasting models have benefited from satellite data as they have improved the ability to predict events such as El Niño and other global



*Credit: National Aeronautics and Space Administration.*

and regional climate cycles. These models will become more sophisticated as scientists and forecasters further develop the ability to simulate certain ocean phenomena and thus better predict when they will occur.

Using remote sensing data and computer models, scientists can now investigate how the oceans affect the evolution of weather, hurricanes, and climate. Oceans control the Earth's weather as they heat and cool, humidify and dry the air and control wind speed and direction. And the weather determines not just what you'll wear to work in the week ahead--but also whether the wheat crop in Nebraska will get enough rain to mature, whether the snow pack in the Sierras will be thick enough to water southern California, whether the hurricane season in the Atlantic will be mellow or brutal, whether eastern Pacific fisheries will be decimated by El Niño. Long-term weather patterns influence water supply, food supply, trade shipments, and property values. They can even foster the growth of civilizations, or kill them off. You can't escape the weather, or even change it--but being able to predict its caprice makes its impact manageable. And only by understanding the dynamics of the oceans can we begin to do this.

NASA has been observing the oceans from space for more than 20 years. NASA launched Seasat, the first civilian oceanographic satellite, on June 28, 1978. The satellite carried five complementary sensors designed to monitor the oceans from space. These sensors included:

- a radar altimeter to measure spacecraft height above the ocean surface
- a microwave scatterometer to measure wind speed and direction
- a scanning multichannel microwave radiometer to measure sea surface temperature
- a visible and infrared radiometer to identify cloud, land and water features
- a synthetic aperture radar to monitor the global surface wave field and polar sea ice conditions

Although a massive short-circuit in its power system ended all data-taking operations after only 105 days, the Seasat instruments provided as much oceanographic data as had been acquired by ships in the previous 100 years! The variables that Seasat measured in its short lifetime are some of the most important for understanding the ocean and its role in climate.

Another satellite, Tiros-N, was also launched in 1978. It carried the first AVHRR sensor that produced the first really useful maps of sea-surface temperature, and the Coastal Zone Color Scanner, that produced the first maps of chlorophyll and primary productivity in the ocean.

Today there are several ocean-observing satellite missions and an extensive scientific research community studying these data. Each mission provides its own unique contribution to our knowledge of the ocean, however our understanding is rapidly evolving such that we are coming to more fully understand the role that each parameter plays in the constantly changing conditions and cycles of the ocean and thus on climate and weather.

## OCEAN EXPLORATION

As defined by the President's Panel on Ocean Exploration (NOAA, 2000 | **http://oceanservice.noaa.gov/websites/retiredsites/supp_oceanpanel.html)**, exploration is discovery through disciplined, diverse observations and the recording of findings. Exploration is an early component of the research process; it focuses on new areas of inquiry and develops descriptions of phenomena that inform the direction of further study.

NASA is the exploration agency of the Federal Government. NASA Earth observing satellites often open up new vistas for earth science research. All are meant to explore the envelope of what is known and understood about the physical, chemical and biological processes of the planet.

No set of NASA Earth Science missions more exemplifies the spirit of exploration than the Earth System Science Pathfinder (ESSP) missions. These missions generally try to measure a geophysical parameter that has been poorly sampled or unattainable from in situ platforms and bring to bear new cutting-edge technology to address the problem.

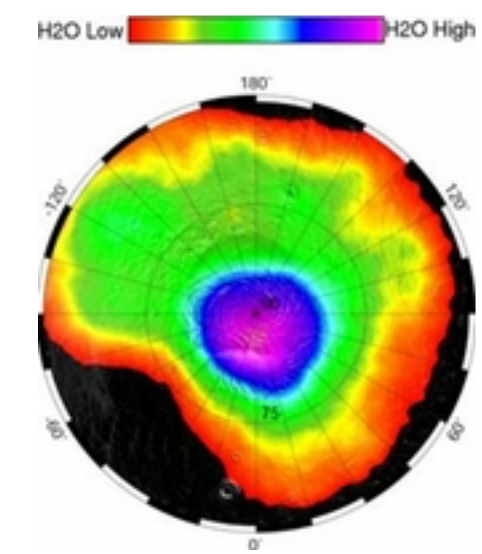
Two NASA ESSP missions address ocean exploration right now. First, the Gravity Recovery and Climate Experiment (GRACE) currently on orbit is exploring hitherto undetectable variations in the mass field of the ocean—important for climate and ocean circulation studies. Second, the Aquarius mission to be launched in 2008 will explore the salinity of the ocean from space. Historically, salinity measurements have been difficult to make in situ and so our knowledge of the spatial and temporal variability of ocean salinity is quite poor. Using microwave remote-sensing technology Aquarius will "reveal" for the first time the detailed patterns of salinity at the surface of the ocean. Ocean surface salinity is known to be an important, but poorly understood factor within the climate system.

NASA supports the research and preparation of explorers for all its missions. For the ocean, the basic research programs in physical and biological oceanography support the background developments needed to launch new explorations of the ocean (from space).

Previous NASA explorations of the ocean have lead to knowledge and technology that is now used widely in research and application (ocean surface topography as measured by precision altimeters, ocean vector winds as measured by scatterometers, and ocean color as measured by radiometers are three excellent examples where NASA initiated the field through is exploration initiative).

## BEYOND OUR PLANET

Since NASA studies both Earth and other planets, what we learn from Earth's oceans can help us make sense of clues to the watery pasts of other planets. Water is essential at the molecular level to moving life beyond its basic building blocks; thus, searches for extraterrestrial life usually involve a search for liquid water.

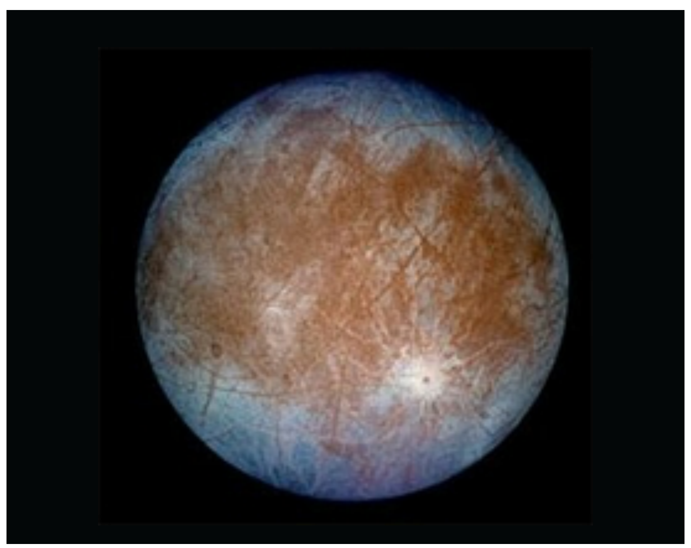



This map centered on the north pole of Mars is based on gamma rays from the element hydrogen—mainly in the form of water ice. Regions of high ice content are shown in violet and blue and those low in ice content are shown in red. The very ice-rich region at the North Pole is due to a permanent polar cap of water ice on the surface. | *Credit: University of Arizona.*

Mars is a cold desert planet that currently has no liquid water on its surface. Yet the terrain of Mars suggests that the red planet once had much more water on its surface than it does today. Some scientists wonder whether Mars may have had an ocean in its northern hemisphere long ago. While the word is still out on that, recent spacecraft findings have shown rocks that only could have formed in the presence of water, as well as evidence of lakebeds and other interesting features associated with water.

Discoveries made by the Mars Odyssey orbiter in 2002 show large amounts of subsurface water ice in the northern arctic plain. In 2008, the Phoenix Mars Lander will investigate this circumpolar region using a robotic arm to dig through the protective topsoil layer to the water ice below and ultimately, to bring both soil and water ice to the lander platform for sophisticated scientific analysis.

During the Galileo mission to Jupiter, its magnetometer observed the moon Europa. Strangely, it got a magnetic signal. Planetary scientists have deduced that Europa does not have enough mass to contain a metallic core, which would ordinarily be necessary for a body to produce its own magnetic field. So how could Europa have a magnetic field? The relatively weak field Galileo observed is consistent with what could be conducted by liquid salty water. Like an ocean.



False-color composite of Europa. Bright plains in the polar areas (top and bottom) are shown in tones of blue. Long, dark lines are fractures in the crust, some of which are more than 3,000 kilometers (1,850 miles) long. The bright feature containing a central dark spot in the lower third of the image is a young impact crater some 50 kilometers (31 miles) in diameter. | *Credit: NASA/JPL.*

But the surface of Europa is far too cold for liquid water to exist. Water may reside under the crust - the constant heaving of the moon as it's subjected to Jupiter's brutal gravity may produce enough heat to keep salt water in liquid state.

Europa is thought to be one of the most promising places to search for microscopic life in our solar system. The ice-covered world may have liquid water, energy, and organic compounds - all three of the ingredients necessary for life to survive.

Sometimes the search for extraterrestrial life takes place right here on Earth. Parts of the ocean are nearly as extreme as the environments we could find elsewhere in the solar system - and they contain life! Not puppies or kittens or even goldfish of course - they contain creatures called "extremophiles". These creatures live in harsh environmental conditions: hot, with a lot of extremely active volcanoes, and with little to no oxygen in the atmosphere. Today varieties of extremophiles are found thriving in circumstances once thought inhospitable to life, such as hot springs and deep ocean thermal vents. Studying extremophiles on Earth helps scientists design experiments to search for life on other planets.

The coral, *Chrysogorgia,* with the crab, *Uroptychus.* | *Credit: NOAA Bioluminescence and Vision on the Deep Seafloor 2015.*

# NOAA

## *National Oceanic and Atmospheric Administration and Ocean Exploration | National Ocean Exploration Forum*

### NOAA AND THE NATIONAL EXPLORATION PROGRAM

Established in 2001, NOAA's Office of Ocean Exploration and Research is the only federal organization dedicated to exploring our unknown ocean and is charged with coordinating a national exploration program. The support and investments from our partners, including federal agencies, foundations, private sector, and academia, help shape the way NOAA explores and contributes to national exploration efforts.

As part of the national exploration program, NOAA organizes exploration forums to promote collaboration among partners to enhance the expertise and relevancy of national exploration efforts. Through the National Forum and inclusive, strategic multi-year campaigns, we are fostering a collaborative network of ocean explorers to meet our critical need to understand the ocean environment.

### NOAA'S INVESTMENT IN OCEAN EXPLORATION

NOAA's mission is to understand and predict changes in climate, weather, oceans, and coasts. Through exploration, we work to fill the gaps in our understanding of the ocean. Despite all we have discovered to date, approximately 95 percent of the ocean has yet to be explored and an estimated 60-80 percent of marine species remain undiscovered.

We explore the ocean to discover new habitats and species but there is also a societal need to understand the ocean as it is vital to our existence on this planet. It provides half of the oxygen in the atmosphere, it regulates climate, and more than 2.6 billion people rely on seafood as a primary source of protein. Ocean exploration is not a luxury. It is not solely a hypothesis-driven endeavor. It is a critically important management tool.

### EXPLORING A CHANGING OCEAN TO INFORM MANAGEMENT DECISIONS

The ocean is changing. It is warming and acidifying, fisheries populations are shifting, and weather and climate patterns are increasingly fluctuating. We need to build our capabilities to predict, project, and respond to these changes, and we need to collect science-based information to sustainably manage resources. Below are two examples of how NOAA is using results from exploration to inform management decisions.

- Mid-Atlantic Coral Reefs and Fishery Management Council Decision: Over the course of three years, over 70 canyons and at least 40 species of coral (some new) were discovered between the US/Canada EEZ and North Carolina. These habitats are rich in biodiversity and serve as essential habitat for fisheries. This ocean exploration data helped managers to recognize the importance of these habitats to the region's fisheries, and the Mid-Atlantic Fishery Management Council voted to restrict fishing activity in 15 canyon areas spanning 38,000 square miles from Long Island, New York, to Virginia.
- Campaign to Address the Pacific Monument Science, Technology, and Ocean Needs (CAPSTONE): CAPSTONE is a major multiyear foundational science effort focused on deepwater areas of U.S. marine protected areas in the central and western Pacific. In 2015, NOAA explored the deep seafloor habitats off Johnston Atoll, part of the recently expanded Pacific Remote Islands Marine National Monument. Also in 2015, NOAA explored for the first time the habitats deeper than 2,000 meters in the Papahānaumokuākea Marine National Monument. These protected areas serve as relatively untouched living laboratories where we can study and understand change, and apply the best science to predict and project environmental change in the absence of pressures in non-protected areas. With this information, we can work to implement management plans to mitigate and adapt to change, and evaluate the impacts of these strategies.

CAPSTONE and the work in the Mid-Atlantic are the result of NOAA and its federal, state, foundation, and academic partners collaborating to set priorities and to plan expeditions. The result is a strategic framework for exploration that allows for multi-ship, multi-year campaigns that are efficient and effective. We think campaigns can be the basis for a national ocean exploration program, and we are eager to have that conversation here at National Ocean Exploration Forum 2015.

### OPPORTUNITIES TO ADVANCE TECHNOLOGY

A major advantage of having a dedicated program for ocean exploration is the focused investment in technology and the opportunity to advance technology. To date, the ocean exploration community has made major advancements with underwater vehicles, high-definition imagery (both acoustic and optical), defining how to integrate all of these new sensors and new platforms, and managing data so that it is available to all who need it.

The technological developments in telepresence allow large numbers of scientists around the world to participate in research without having to go to sea, and also allow the public to follow science in real-time and watch as discoveries happen miles away in the Pacific. Live video from the 2015 CAPSTONE expedition received approximately 575,000 views, with a total view time of 68,890 hours of live ocean exploration footage, and the expedition web pages received another 150,000 views.

Equally as important as telepresence technology is the ability to manage data. The pictures and video collected through telepresence are scientific data and NOAA ensures the collected data are available to anyone who needs it as soon as possible. Our multibeam data, for example, is typically available for download from NOAA's archives weeks after it is collected. Ready access to the data we collect is fundamental to our mission.

### CHALLENGES AND OPPORTUNITIES IN OCEAN EXPLORATION

Ocean exploration serves all humankind at a time when we are facing numerous daunting challenges of global change and great budget uncertainties. The ocean exploration community needs to think and act strategically. The size of the problems we're addressing, the limited budget, and the people on the planet demand it. Now is the time for smart exploration for a sustainable planet.

Those in the ocean exploration community cannot explore in isolation and without reference to others' requirements and needs. To collaborate effectively we need mechanisms that allow for cooperation around different drivers, capabilities, and modes of transportation.

Partnerships are necessary to raise the public profile of ocean exploration and citizen science is playing an increasingly important role in delivering data to communities. At the center of these partnerships is data. Open access to data provides a platform for open innovation and it can be a portal to a new blue economy that is service-based, information-dependent, and prediction critical.

We need to continue to work together to identify priorities, leverage effective partnerships, advance technology, provide access to platforms, make our data as accessible as possible to all, embrace the potential of citizen science and exploration, and engage the public to meet our nation's critical need for ocean exploration. This National Forum is an important starting point for collaborating strategically and prioritizing campaigns that are relevant to science and society.

A squat lobster resides on an octorcoral. | *Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2014.*





# NATIONAL SCIENCE FOUNDATION

## *The National Science Foundation and Ocean Exploration*

NSF, principally through the Divisions of Ocean Sciences (OCE) and Polar Programs (PLR), supports a wide array of research to understand the world's oceans and their role in the Earth as a system. While NSF-supported research is predominantly based on proposals designed to test hypotheses, many projects are intimately intertwined with opportunities for discovery. OCE and PLR have a long history of enabling ocean exploration as an outcome of investigating phenomena in remote regions.

OCE provides the broadest base of support for the field, including funding for research in physical, biological, and chemical oceanography and marine geology and geophysics, and the development, implementation, and operational support for ocean research infrastructure. OCE enables this research through support of facilities including the academic research fleet via the University National Oceanographic Laboratory System (UNOLS), scientific ocean drilling through the International Ocean Discovery Program, the National Deep Submergence Facility (NDSF), and the Ocean Observatories Initiative.

PLR provides support for oceanographic research in both the Arctic and the Antarctic, enabling research in ice-covered oceans. Research covers a broad range of scientific topics relevant to each region. In the Arctic, projects are supported in cooperation with UNOLS for access to the RV *Sikuliaq*, the USCG for access to the USCGC HEALY, and cooperation with other Arctic nations for access to foreign vessels. In the Antarctic, the U.S. Antarctic Program charters two ice-capable vessels to support a wide array of science projects.

Traditionally, NSF seeks community input on long-range research priorities and strategies to optimize scientific investments. Avenues for input include community-based workshops, discussions between NSF program officers and the community at scientific conferences, and sometimes via special emphasis studies conducted by the National Academy of Sciences.

NSF-supported research is focused on scientific discovery and hypothesis testing, and on the development of new ways to observe, sample, analyze, and simulate oceanic phenomena. NSF is a strong supporter of sea-going exploration through support of "voyages of discovery" that typically involve large multidisciplinary groups of scientists working collaboratively with international partners to understand how the ocean works and interacts with the solid Earth and atmosphere on local, regional, and planetary scales. Two high-profile examples currently underway are the international CLIVAR (Climate and Ocean: Variability, Predictability and Change) and GEOTRACES (an international study of marine biogeochemical cycles of trace elements and their isotopes), initiatives that, respectively, focus on the ocean as a planetary distributor of energy and of bioactive chemical substances. This summer, OCE and PLR jointly sponsored the Arctic GEOTRACES mission aboard the USCGC HEALY to perform a comprehensive study of the distribution and isotopic composition of the Arctic Ocean. OCE also recently partnered with NOAA's Ocean Exploration Program to investigate methane seeps using the NDSF AUV *Sentry* and telepresence from the *Okeanos Explorer*. In the south, the Southern Ocean Carbon and Climate Observations and Modeling project recently began a long-term observation program that will facilitate improved modeling of processes and ultimately advance understanding of the carbon cycle issues in the Southern Ocean.

International engagement and student training are additional hallmarks of NSF investments.

Recent documents relevant to potential NSF investments in ocean sciences research include:

1) **Sea Change: 2015-2025 Decadal Survey of Ocean Sciences** (NRC, 2015)

2) **A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research** (NRC, 2015)

3) **IODP Science Plan** (www.iodp.org/Science-Plan-for-2013-2023)

4) **Scientific Ocean Drilling: Accomplishments and Challenges** (NRC, 2011)

5) **Reports available via the NRC Ocean Studies Board and Polar Research Board**

6) **Dynamic Earth: GEO Imperatives and Frontiers 2015-2020** (NSF/GEO Advisory Committee, http://www.nsf.gov/geo/acgeo/geovision/nsf_ac-geo_dynamic-earth-2015-2020.pdf)

7) **The Arctic in the Anthropocene: Emerging Research Questions** (NRC, 2014)

Goosefish. | *Credit: NOAA Bioluminescence and Vision on the Deep Seafloor 2015.*

Seen in the Gulf of Mexico, this dumbo octopus displayed a body posture that had never before been observed in cirrate octopods. | *Credit: NOAA Office of Ocean Exploration and Research, Gulf of Mexico 2014.*

# KHALED BIN SULTAN LIVING OCEANS FOUNDATION

## *Why Do We Explore and How Do We Do It?*

BY **PHILIP G. RENAUD** | *Executive Director* | *livingoceansfoundation.org*

The Khaled bin Sultan Living Oceans Foundation is an American, public benefit, private operating foundation, created by His Royal Highness Prince Khaled bin Sultan of Saudi Arabia. The Living Oceans Foundation's mission is to protect and restore ocean health by providing science-based solutions. Our vision is that we have educated, inspired, and empowered people to preserve and improve ocean health. To fulfill our mission and achieve our vision, our organization has developed three core components: Science, Education, and Communications. We believe strongly that science alone is insufficient to compel people and decision-makers to implement substantial change. Ocean literacy is a fundamental building block and inspiring communication using creative media is essential. We harness these three capabilities to influence people in changing behaviors that will promote ocean conservation and lead to sustainability of ocean health and life.

Since 2011, the Foundation has been conducting an ambitious Global Reef Expedition to rapidly close gaps in the world's scientific knowledge of coral reef ecosystems worldwide. The operations of the Khaled bin Sultan Living Oceans Foundation have spanned the globe and have positively impacted many countries that lack the scientific capabilities to solve the coral crisis. The fieldwork component of this program has been an amazing series of exploration missions in remote parts of the world's oceans, facilitated by our capable research platform, M/Y Golden Shadow. When you think of a common definition for exploration such as "the action of traveling in or through an unfamiliar area in order to learn about it," the Global Reef Expedition is quintessential exploration. Nearly every terrestrial spot on earth has been explored by someone. That does not hold true for ocean exploration—much of it has never been explored. On many dives during the Global Reef Expedition, we commented that we were most likely the first humans to dive that spot.

We are nearly completed with the fieldwork component of the expedition but much hard work remains in data analyses. So far, we have engaged with 15 different countries; surveyed and mapped 110 different islands, atolls, and banks; and completed 521 days of research cataloging 242,640 corals and 10,046 fish surveys. We have mapped 33,325 square kilometers of reef. A total of 196 scientists have participated to date through our inclusive operational model of Science Without Borders®. This exploration phase represents only the tip of the iceberg—developing knowledge from the wealth of data we have collected represents the base of the iceberg. After that, we intend to inspire action from the knowledge gained. To us, ocean exploration is the exciting phase but stimulating positive change in the sustainability of our planet is the legacy we hope to achieve.

An octopus, sea star, bivalves, and dozens of cup corals share the same overhang in a deepwater canyon off the U.S. Atlantic coast. | *Credit: Deepwater Canyons 2013 - Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

# GLOBAL FOUNDATION FOR OCEAN EXPLORATION

*Why We Explore*

The mission of the Global Foundation for Ocean Exploration is to advance a National Ocean Exploration Program with global reach and relevance. We provide current and future generations with the training, opportunities, and motivation to explore and understand the world's oceans. GFOE is dedicated to the idea that to continue to advance our knowledge of the natural world, we must not only inspire the next generation but also provide meaningful opportunities to enable them to make lasting contributions.

We train the ocean exploration workforce, not only for the nation's ocean exploration program, but also for the community at large. Our team includes naval architects and highly skilled engineers of various disciplines, including: ocean, electrical, electronic, mechanical, aerospace, aeronautical, data, video, satellite and software. Some also have a background in science and education. We identify and develop career paths for students that allow them to experience an end-to-end process of design through application.

To achieve our mission, we:

- Work with public and private organizations, as well as academic institutions to identify, train, nurture and employ the engineers that will design and implement the ocean exploration technologies of tomorrow.
- Through partnerships and training opportunities, we develop the talent pool that will ensure that ocean exploration is performed to the highest standards in government and the private sector.
- Support NOAA and other ocean explorers with world-class deep submergence engineering and operations capabilities.
- Facilitate partnerships between NOAA and existing/new stakeholders to foster and support ocean exploration activities worldwide that expand the reach of national ocean exploration.
- Identify and support engineering innovation for deployment to the oceans wherever it may germinate—within industry, academia, or from public and private institutions.
- Interface with governments as necessary and appropriate to open the oceans everywhere to exploration, en route to their sensible, sustainable use.

## WHAT DO WE LOOK FOR WHEN WE EXPLORE?

Fortunately, from our perspective, we do not explore based on hypothesis. This means we approach our job with our "eyes wide open." We are not looking for anything specific. Our goal is to visit areas that are currently unknown or poorly known, collect data that helps to characterize these areas, and provide that data to any and all who wish to utilize it.

A Mola mola, or ocean sunfish, seen during the Deepwater Canyons 2013: Pathways to the Abyss expedition off the U.S. Atlantic coast. | *Credit: Deepwater Canyons 2013 - Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

# OIL AND GAS INDUSTRY

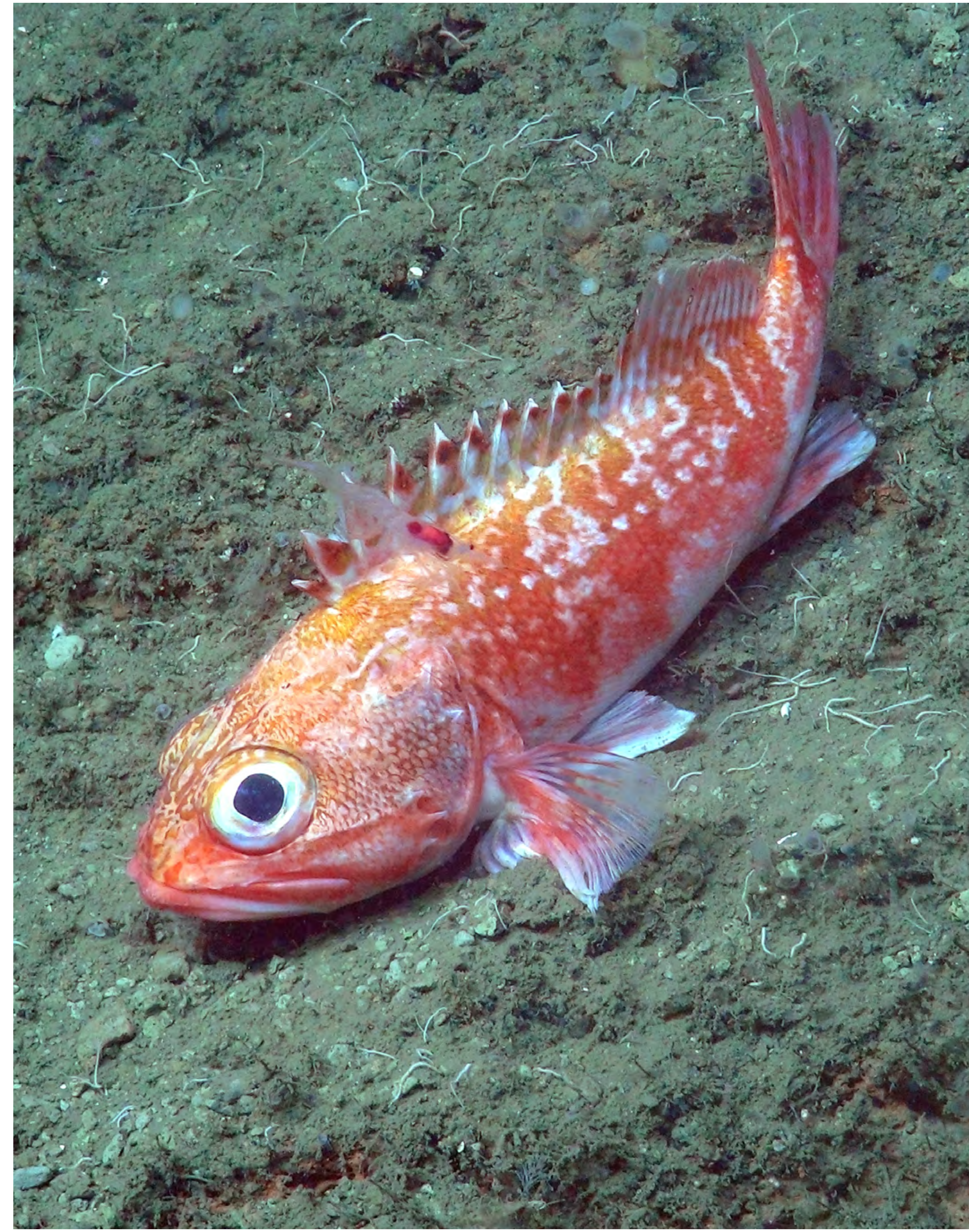
PREPARED BY **MISSY FEELEY** | *ExxonMobil (ret.)*

At the risk of stating the obvious, the human enterprise runs on energy and that demand for energy continues to grow. The global population is projected to rise by an estimated 30 percent to 9 billion in 2040, from about 7 billion in 2010. With this population rise, global GDP is expected to rise by about 140 percent. Key to this economic growth is energy and global energy consumption is expected to increase about 35 percent in that same period. Even with current energy demand at more than 250 million barrels per day oil equivalent (MBDOE), one out of every five people in the world still has no access to electricity. Population growth and increased economic development primarily in non-OECD countries will pressure suppliers with demand for electricity the single largest influence on global energy consumption. Over the coming decades, the world will continue to rely heavily on large-scale supplies of oil and gas as new alternative sources of energy evolve.

Advances in technology and significant investments continue to expand the availability of energy supplies to meet growing demand. In 1981, the USGS estimated there was less than 60 years' worth of recoverable crude and condensate. By year-end 2013, years-of-coverage had more than doubled, to over 150 years. However a greater number of these significant new oil and gas resources are in remote areas and challenging operating environments.

Hydrocarbon exploration is still an expensive, high-risk operation. The cost of discovering each new barrel of oil and gas has risen three-fold over the last decade as technology has pushed the frontiers of exploration into ever more remote areas. Exploration wells in the Arctic can require investments of billions of dollars with low chance of finding economic resources. Major projects are more capital intensive and operationally complex. In addition, access to new acreage is increasingly more competitive with National Oil Companies (NOCs) controlling over 80 percent of the world's remaining resource with the inherent political risk.

As the industry moves on to explore and develop these more and more "difficult" oil and gas deposits, the pace of technological progress will need to accelerate significantly if past production trends are to be maintained and future demand addressed. To achieve these technological advancements, investment in research and diverse partnerships are critical. Diverse skills, disparate viewpoints, access to unique data types, and, most importantly, creative ideas and applications are available through partnerships. Examples of types of the existing partnerships include industry-academic consortia, strategic alliances with service providers, and direct support for individual investigators. IOCs and NOCs will continue to invest in 'in-house' research efforts, but the diversity and complexity of the future challenges require the petroleum industry to expand and evolve its current models for partnering.



A blackbelly rosefish perches along the canyon wall. | *Credit: Deepwater Canyons 2013 - Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

# OCEAN EXPLORATION TRUST

## *Ocean Exploration Trust: Mission and Goals*

The Ocean Exploration Trust was founded in 2008 by Bob Ballard to engage in pure ocean exploration. Our international programs center on scientific exploration of the seafloor and many of our expeditions are launched from aboard Exploration Vessel (E/V) *Nautilus*, a 64-meter research vessel operated by the Ocean Exploration Trust. In addition to conducting scientific research, we offer our expeditions to explorers on shore via live video, audio, and data feeds from the field. We also bring educators and students of all ages aboard during E/V *Nautilus* expeditions, offering them hands-on experience in ocean exploration, research, and communications.

Ocean Exploration Trust goals:

- To explore areas of the ocean that have never been explored before, seeking out new discoveries in the fields of geology, biology, maritime history, archaeology, and chemistry
- To conduct all scientific research to the highest international academic standard
- To push the boundaries of ocean engineering, technology, education, and communications
- To share our expeditions with explorers around the world via live telepresence
- To serve as role models for the next generation of scientists, engineers, and educators
- To spread the excitement of ocean exploration and turn everyday viewers into explorers

A pair of mating deep-sea red crabs rests on a ledge of the canyon wall. | *Credit: Deepwater Canyons 2013 - Pathways to the Abyss, NOAA-OER/BOEM/USGS.*

Venus fly trap anemone. | *Credit: NOAA Bioluminescence and Vision on the Deep Seafloor 2015.*





# SCHMIDT OCEAN INSTITUTE

Schmidt Ocean Institute was established to advance the frontiers of ocean research and exploration through innovative technologies, intelligent observation and analysis, and open sharing of information.

We approach oceanographic research from the technological, operational, and informational perspectives: We maintain and operate R/V *Falkor* as a technologically advanced scientific platform suitable to support multidisciplinary oceanographic research and technology development. We provide our collaborators with free access to R/V *Falkor* with her on-board research facilities and expert technical support in exchange for a commitment to openly share and communicate the outcomes of their research, including the raw observations and data.

We combine advanced science with state-of-the-art technology to achieve lasting results in ocean research, to catalyze sharing of the information, and to communicate this knowledge to audiences around the world. We foster a deeper understanding of our environment.

## STRATEGIC FOCUS AREAS

Schmidt Ocean Institute works to advance the frontiers of global marine research by providing state of the art operational, technological, and informational support to the pioneering ocean science and technology development projects at sea. Our program is structured around the following key focus areas:

### *1. Commitment to Excellence in Oceanographic Research Operations*

Excellence in sea-going operations of scientific research vessels is critical to accelerating the pace of global marine science. Schmidt Ocean Institute is dedicated to supporting advanced marine science on R/V *Falkor*, including the following systems and activities:

- Technical and operational improvements of *Falkor* as a research platform
- Support of innovative shipboard embedded scientific instruments and systems
- Support of remote research via telepresence and satellite data streaming
- Shipboard high performance computing for at-sea modeling and data analysis

### *2. Infrastructure, Platform, and Technology Development for Marine Sciences*

Technology innovation drives scientific progress. Schmidt Ocean Institute supports at-sea testing and development of new scientific robotic vehicles, instruments, platforms, computational algorithms for data analysis and interpretation, and artificial intelligence systems, including the following technologies and activities:

- Robotic research vehicles (HROV, ROV, AUV, ASV, UAV, gliders, etc.)
- Deployable scientific platforms and analytical instruments (sensors, observatories, etc.)

An ROV provided by OpenROV explores *Blacktip Reef* during the 2015 Ocean Exploration Forum. | *Credit: National Aquarium.*

- At-sea R&D of new technologies and computational algorithms on SOI vessels and vehicles
- Technology focused R&D projects as part of *Falkor* cruise program

## 3. Collaborative Scientific Research aboard Falkor

Schmidt Ocean Institute provides researchers from around the world with access to *Falkor* to foster a deeper understanding of the global ocean through technological innovation. We support the following types of projects:

- Environmentally focused and societally relevant ocean research
- Projects with high intrinsic scientific value and meaningful impact potential
- Research effectively leveraging innovative technologies
- Oceanographic research encouraging student participation

## 4. Communications, Education, and Outreach Program

"The purpose of this ship, as she leaves on her various missions, is to communicate about the science of the oceans to people so that they can care about it. We can't take care of something that we don't understand and we can't care if we don't know."—*Wendy Schmidt, March 6, 2012.*

Our communications program includes the following activities:

- Telling the story about every project we support aboard *Falkor*
- Supporting continuous online presence and resources for our virtual visitors
- Holding workshops and symposia to discuss progress and future directions
- Encouraging partnerships, as well as student, and educator participation

## 5. Open Sharing of Information, Data, and Research Outcomes

Schmidt Ocean Institute supports open sharing of information about the ocean to stimulate the growth of its applications and user community, and amplify further exploration, discovery, and deeper understanding of our environment. These efforts are supported through partnerships with data management experts in the oceanographic community to enable standards-compliant sharing of scientific information and data collected during research cruises.