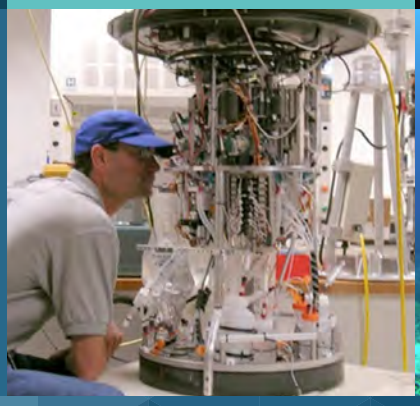
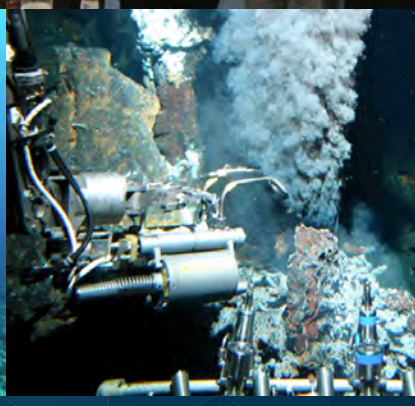
NATIONAL OCEAN EXPLORATION FORUM

Beyond the Ships 2020-2025

October 20-21

2016





Final Report
February 2017

The Marine Science & Policy Series

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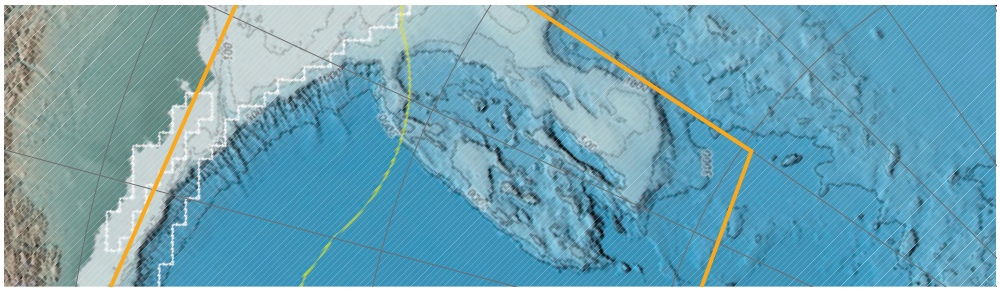

Acknowledgments

Many people and organizations contributed to the success of the 2016 National Ocean Exploration Forum. First, thanks to the 107 participants. Second, thanks to the sponsors — NOAA (Office of Ocean Exploration and Research, Dr. Alan Leonardi), the Schmidt Ocean Institute (Mrs. Wendy Schmidt), and Dr. Jamie Austin. Our own Monmouth University-Rockefeller University Marine Science and Policy Initiative also contributed. Third, thanks to the members of the Forum's Advisory Committee, who gave much wise and practical advice: Jamie Austin, John Kreider, Lance Towers, Rick Rikoski, Shirley Pomponi, Frank Herr, Alan Leonardi, Victoria Tschinkel, and Jerry Schubel.

Fundamentally, we thank the explorers whose expeditions and achievements during the past year the Forum highlighted, including Shirley Pomponi, Pete Girguis, Jim Delgado, Eric King, Nicole Raineault, Jamie Austin, Ruth Blake, Dwight Coleman, Jim Thomson, Amanda Demopoulos, Larry Mayer, Brian Kennedy, Emil Petruncio, Tim Shank, and Yogish Girdhar. Thanks to Terry Collins for leading the Forum's public engagement efforts, which celebrated these achievements. Thanks to Amélie Walker-Yung and Castle Builder Design for our presence on the web and to H. Dale Langford for editorial assistance.

We also thank the people who have done the daily work that makes a meeting a success. From Monmouth, Tony MacDonald, leader of the Urban Coast Institute, a timely well-designed effort of growing importance to the Mid-Atlantic region, and Tony's associates Karl Vilacoba and Danica Simmons, and also Monmouth University students, future explorers.

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We thank Dr. Robert Ballard for the creativity, energy, and charisma of his dazzling career and for the capstone he provided to the Forum.

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Download the report and Forum presentations and papers at phe.rockefeller.edu/noef.

Final Report

2016 National Ocean Exploration Forum
Beyond the Ships 2020–2025

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Preface: Background and Setting

In 2009 Public Law 111-11 (33 USC 3400 *et al.*) formally established a U.S. national ocean exploration program. The law assigns the federal lead for ocean exploration to the National Oceanic and Atmospheric Administration (NOAA) but urges participation of other agencies with oceanographic capabilities. Recognizing the value of the collective experience, wisdom, and capability of persons and organizations in and outside of government, the statute calls for a Forum to "encourage partnerships and communicate among experts and other stakeholders in order to enhance the scientific and technical expertise and relevance of the national program."

The first Forum, in July 2013, resulted from discussions in the Ocean Exploration Advisory Working Group to the NOAA Science Advisory Board. Board member Dr. Jerry Schubel, Chief Executive Officer of the Aquarium of the Pacific (AOP), Long Beach, California, led planning of the Forum and executed it in cooperation with NOAA professional staff members and in partnership with several other organizations, including the Global Foundation for Ocean Exploration, Schmidt Ocean Institute, and Google, Inc. Held at the AOP, the Forum brought together a cross section of the community, included an opinion survey on exploration priorities and tools, and issued an attractive, wide-ranging report: *Ocean Exploration 2020 – A National Forum.* (link) The 2013 Forum also included a day of activities for the general public to celebrate exploration, and resulted in an 18-minute video "Perspectives on Ocean Exploration" (link) featuring leading American explorers. Subsequently, NOAA organized Forums in 2014 and 2015 at The National Aquarium, Baltimore.

At the 2015 Forum the Monmouth University–Rockefeller University (MU-RU) Marine Science and Policy Initiative, offered to organize the 2016 Forum on the campus of The Rockefeller University in New York City. We thank the exploration community for embracing the offer, which differed from earlier Forums in the extent to which members of the community rather than a federal agency accepted responsibility for the Forum, and in a narrower focus, namely, imminent exploration technologies and styles.

The MU-RU Initiative committed its own funds and resources as the largest source of support for the Forum. To achieve the desired level of funding and to represent the community in a balanced way, MU-RU then successfully submitted proposals for partial support to NOAA and to the Schmidt Ocean Institute and Jamie Austin (philanthropies involved in ocean exploration). To operate as a truly community-driven Forum, we formed an Advisory Committee comprising explorers and technologists, state and federal interests, public, for-profit and not-for-profit sectors, and diverse ocean domains.

To achieve the goals set for the Forum within the time available, the Advisory Committee agreed on a target of about 100 participants. The Forum attracted a diverse set of participants including scientists, engineers, managers, educators, lawyers, regulators, diplomats, and students; seasoned hands and new faces; and employees of the exploration and research arms of federal government, large and small firms providing maritime goods and services, nongovernmental organizations fostering education and conservation, academia, and enterprises involved in media and communications.

To celebrate ocean exploration discoveries of the preceding year and to share news of the Forum widely, we developed an engagement plan including a press release and a public website. To lift knowledge, identify issues, and stimulate debate on key scientific, educational, and managerial topics, top experts prepared five discussion papers (the "Austin papers") posted about a month before the Forum.

Summary and Recommendations

Jesse H. Ausubel and Paul G. Gaffney II

The Forum Advisory Committee and we as co-convenors established "Beyond the Ships" as the theme and title of the 2016 Forum and chose to focus on the time interval of 2020–2025.

Fundamentally, the vision of ocean exploration during the time period of interest encompasses expanded exploration vehicle and technology options rather than a program built out largely from the availability of mother ships.

Moreover, the vision relies on development of "campaigns" rather than efforts happening only once or not as part of a regular sequence. A campaign of exploration is a strategically planned set of activities to characterize a yet-to-be-explored or underexplored geographic area, selected to meet sponsor requirements and maximize potential scientific opportunity, and often spanning several years and involving multiple sponsors and performers. Rather than limiting observation to a single subject or sense, campaigns can characterize an area or volume of ocean in terms of marine life, chemistry, geology and geophysics, history and archaeology, and bathymetry (mapping), include dynamic measurements and sample collection, and record observations using a broad range of methods of perception, including hearing, smell, touch, taste, and sight, as extended by advanced technologies.

Necessity as well as opportunity favors movement to campaigns beyond the ships. Current, dedicated U.S. ocean exploration ships (NOAA Ship *Okeanos Explorer,* E/V *Nautilus*, E/V *Falkor*, and E/V *Alucia*[1]) may not be regularly available in 2020–2025, at all, or for

1 Before the Forum in October 2016, most participants were unaware of the acquisition of the *Alucia 2* by the Dalio Ocean Initiative as a new research and survey vessel capable of operations in most marine environments.

some areas of interest. Even with good availability, regions such as the Arctic would be inaccessible by these core ships. Fortunately other private, UNOLS-operated[2], NOAA, U.S. Coast Guard, and U.S. Navy ocean research, survey, and exploration ships will be available for a variety of exploration tasks.

In any case, the U.S. can undertake more numerous and ambitious ocean exploration campaigns by making more platforms[3] capable of measuring, sampling, and imaging yet-to-be-explored areas. Opportunities range from at-sea DNA sequencing to autonomous vehicles that learn as they navigate to find the most interesting features to virtual reality devices that display data collected in ways that help remote operators best optimize "bottom time."

Realizing this vision of ocean exploration requires identification, adaptation, and adoption of new or yet-to-be-employed technologies by the greater ocean exploration community and integration into upcoming plans and proposals.

To develop the vision "Beyond the Ships" we commissioned five discussion papers:

- **Discussion Paper on Marine Minerals (link)**
  Mark Hannington (University of Ottawa, and GEOMAR Helmholtz Center for Ocean Research Kiel) and Sven Petersen (GEOMAR Helmholtz Center for Ocean Research Kiel)

- **Exploring the Ocean Through Sound (link)**
  Jennifer L. Miksis-Olds (University of New Hampshire) and Bruce Martin (Dalhousie University)

- **Emerging Technologies for Biological Sampling in the Ocean (link)**
  Shirley A. Pomponi (Cooperative Institute for Ocean Exploration, Research & Technology [CIOERT], Harbor Branch Oceanographic Institute, Florida Atlantic University), with contributions from Jesse Ausubel (Rockefeller University),
  Peter Girguis (Harvard University), and Mark Stoeckle (Rockefeller University)

2 University-National Oceanographic Laboratory System (UNOLS) is an organization of 58 academic institutions and National Laboratories involved in oceanographic research and joined for the purpose of coordinating oceanographic ships' schedules and research facilities.

3 other ships, ROVs, AUV/ASVs, and other vehicles, platforms, sensors, or installations

- **Positioning Ocean Exploration in a Chaotic Sea of Changing Media (link)**
  Jerry R. Schubel (Aquarium of the Pacific)
- **New National Leadership for Ocean Exploration (link)**
  U.S. Ambassador Cameron Hume (retired) (Georgetown University)

Forum Program

Jesse Ausubel opened the Forum with a keynote titled "SuBastian and the Roboats." (page 28)

> SuBastian is not the lead singer of an indie rock band but a superbly capable autonomous undersea vehicle (AUV) developed by the Schmidt Ocean Institute. The Roboats are not back-up singers and musicians but robotic floats, autonomous surface vessels (ASVs), which navigate the canals of Amsterdam. SuBastian and the Roboats exemplify the theme of the Forum, Beyond the Ships.
>
> We must consider the new vocabulary overtaking many domains of our life…autonomy, sensors, precision, miniaturization, and machine learning and artificial intelligence. Bandwidth. Drones. Telepresence. Cyberspace and meatspace. They associate with better forms of energy storage and, increasingly, with sharing to boost asset utilization. The adjectives modifying the concepts tend to be words like smaller, lighter, faster, denser, cheaper, and virtual. At the same time they benefit from economies of scale and can form huge integrated systems, eased by better information handling.
>
> The new vocabulary signals that we are entering a world of farming without farmers, flying without pilots, and sailing without sailors. This will be the world of the 2020s, and ocean exploration must adapt and adopt, and should innovate too. It will be the world of SuBastian and the Roboats.

Speakers then provided seven short briefings weaving discussion of four technologies with three geographies. Government experts spoke on future demands for exploration in three geographic areas in the U.S. Exclusive Economic Zone (EEZ) likely to gain some measure of federal exploration funding over the next decade:

- **Arctic** (Dr. Jeremy Mathis, NOAA Arctic Program): Shallow and deep waters, some ice-free, some continually ice-covered, some with a seasonal and permanent marginal ice zone, in the Canadian Basin and East Chukchi Sea generally north of Alaska to 80 degrees north latitude. (link)
- **Gulf of Mexico** (Dr. Russell Callender, NOAA National Ocean Service): Deep central Gulf, outside of any EEZ, the so-called Doughnut Holes; shallow areas of the Flower Garden Banks

Marine Sanctuary off Texas and Louisiana as well as waters from the Florida Keys Marine Sanctuary to the north and west coasts of Cuba. These scenarios involved possible international cooperation. (link)

- **Southeast U.S. Atlantic Bight** (Dr. Amanda Demopoulos, U.S. Geological Survey [USGS]): Within the U.S. EEZ, off the U.S. East Coast from the Baltimore Canyon in the north through the Blake Plateau region in the south. While the scenario area includes shallow continental shelf areas and the deep foot of the slope areas, the main interest was characterizing canyons on the continental slope outward from the Mid-Atlantic region though Georgia. (link)

Note: Because the *Nautilus*, *Okeanos Explorer,* and *Falkor* are all currently exploring in the Pacific and expect to be there for the near term, we did not develop a Pacific scenario.

Looking forward to 2020–2025, university researchers then offered views of technologies for exploration in acoustics/bathymetry, biology, geology, and information technology and communications:

- Acoustics/Bathymetry: Dr. Larry Mayer, University of New Hampshire (link)
- Biology: Dr. Shirley Pomponi, Florida Atlantic University (link)
  Geology: Dr. Ruth Blake, Yale University (link)
- Telepresence: Dr. Dwight Coleman, University of Rhode Island (link)

The Forum participants then split into six Breakout Groups of 15 to 20 persons, with two groups assigned to each of the geographies (Arctic, Gulf of Mexico, and the Southeast U.S. Atlantic Bight). Cochairs of the six groups (link) managed the discussion and later summarized the views of each group. Guidance to the groups included assumption of modest growth in funding available for exploration by the 2020–2025 timeframe.

Summaries of Breakout Groups

The following three sections offer highlights of Breakout Group discussions consolidated by campaign area. Links to the full report (text and/or slides) of each Breakout Group are provided in the text below.

Arctic

The Arctic groups (link) discussed potential future ocean exploration campaigns in the (mostly) American Arctic from the North Slope littoral to approximately 80 degrees north latitude. An area of shallow and deep water mostly ice-covered in winter with a marginal ice zone (MIZ) and ice edge year-round, it is tectonically and geologically not well understood, and its changing physical oceanography demands characterization. The Arctic, with its harsh weather, persistent ice (even in recent years), unavailability of ship support except for short periods in summer, and long distance from robust shore support redefines ocean exploration. Ocean exploration here must be characterized by "duration" not "one-stop shopping." Autonomous sensors must be deployed when the weather and ice allow. Retrieval of the same sensors also depends on environmental friendliness. A ship is not readily available to hover nearby in case of trouble, nor is technical support available from a nearby laboratory. Explorers must plan for campaigns with duration of 8 to 12 months or longer. Hence, exploration in the Arctic verges on observation and can offer a transition to it.

Arctic exploration is currently and will continue to be enabled by autonomous underwater vehicles, mobile ice-implanted buoy networks, bottom-mounted instruments, and ASVs in the open water and the MIZ. Conveniently, autonomous vehicles and sensors developed for Arctic exploration will be useful elsewhere: "if it will work in the Arctic it will work anywhere." Such an exploration/observation network of autonomous devices will have to be supported by a previously installed and complementary network of navigation (since GPS will not be available), refueling/repowering, and communications nodes. Surface ships simply cannot carry out these functions throughout most of the year. Such a support infrastructure may be (a) mobile and ice-based with instruments hanging into the water column; (b)

mobile and surface ocean buoys-based; (c) bottom-mounted with or without tendrils rising through the water column; or (d), likely, combinations of all of the above.

Future exploration vehicles and instruments will need to employ adaptive sampling software wherein an instrumented drone can learn as it goes, find or change its way and sample where it finds the water column or bottom most interesting. Simply "mowing the grass," gaining full sensor coverage, then identifying new or changing features is not practical in the Arctic.

It will always be expensive and hazardous to explore in the Arctic because of weather, ice, and distance, and also the environmental sensitivities of polar ecosystems. Moreover, much Arctic exploration is carried out in darkness. These factors heighten the importance of partnerships in general and in particular with industry and international friends (e.g., Canada, First Nation peoples, Denmark, NATO). For the technical, safety, and environmental reasons already stated, and because the area has potential for international competition, is home to several endangered species, and is commonly used for traditional purposes by First Nation peoples, exploration campaigns will require extensive planning.

Technologies of note in the next decade:

- Long-duration autonomous vehicles smart enough to devise exploration plans on the fly
- Smaller, autonomous devices that need less power even assuming high-capacity batteries and recharging capability
- Pre-deployed, cheap (perhaps nonrecoverable) network(s) to support navigation, communications/data dumps and refueling or recharging
- Ice-hardened vehicles and instruments that do not get crushed by moving ice in any season

Southeast U.S. Atlantic Bight

The Southeast U.S. Atlantic (SEUS) Bight groups separately discussed an ocean exploration campaign in the SEUS (link). Unlike the other regional campaigns in the 2016 Forum, the federal government is already planning a SEUS campaign, for the period 2016–2020, with funding commitments under consideration and ship time in negotiation among Bureau of Ocean Energy Management (BOEM), USGS, and NOAA, and thus the groups considered the near term as well as 2020–2025. The area to be explored stretches south from the Baltimore Canyon to the Blake Plateau. This plan, while covering a very large

area, focuses on discrete areas for high-resolution exploration. To generalize, the SEUS planners are most interested in identifying seeps and deep coral and sponge habitats; canyon areas are expected targets.

In accordance with the joint-agency plan, BOEM may issue a request for proposals (RFP) in early 2017. The discussants noted that, so far, the RFP is not asking for proposals that include archeological exploration activities. In view of the commitment of ship time, this seems a lost opportunity in an area that was a major seaway for early settlement of the Americas.

While the SEUS area has been "home base" for ocean research and survey activities for decades, it highlights several issues:

- Although the area has been widely surveyed bathymetrically, present high-resolution bathymetry and acoustic imagery and information do not suffice to discern seeps, sponge, and coral communities and archeological artifacts. Greater attention could be given to high-resolution bathymetry, at least in high-interest areas, by launching swarms of AUV/ASVs equipped with multibeam sonars. Here the ship not only collects bathymetric data, but can also serve as a launch platform and mother ship for autonomous vehicles that can significantly increase bathymetric coverage at lower cost. Increasingly, too, these autonomous vehicles could be launched from shore on long-endurance missions. In areas like SEUS, where the shore is within reasonable range, shore-launched autonomous vehicles could frugally serve to decrease reliance on ships.
- As one thinks about using emerging autonomous vehicles or present-day remotely operated underwater vehicles (ROVs) in areas of suspected seeps and deep sponge/coral habitats, one needs either higher-resolution bathymetry to help prevent costly AUV/ROV collisions with craggy canyon features and direct the vehicles toward suspected or hypothesized targets, or the deployment of adaptive, deep-diving autonomous vehicles that can make decisions on fly to avoid danger, search for the most interesting features, and find recharging, communication, and navigation nodes.

- Assuming an unusually rich general baseline of information in this particular campaign area, the campaigners have an opportunity to compare archived data with newly collected higher-resolution data. Determining how much we really did or didn't know and what has changed could help better design future campaigns. To complete such comparative analysis, campaign sponsors need to establish a "dedicated fund" for a pre-campaign effort to gather archival oceanographic/bathymetric data in the areas of highest interest, at all resolutions and wavelengths, and make that data available to explorers for operational planning and post-campaign comparative analysis. One group suggested establishing a campaign "joint information center" to marshal archival and new data, and communicate with those ashore. Both groups stressed the need to invest in campaign data management and visualization.
- This campaign would be less about exploring for the first time, and more about trying new tools, bringing new technologists to the cruise, looking at exploration in different ways, and comparing past observations with new findings at higher resolution. In short, one might design it as a scientific control for exploration.

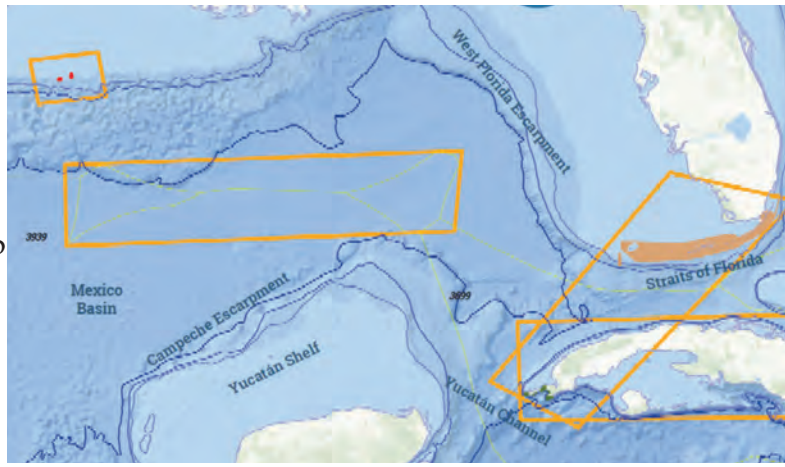
The notion of a campaign designed with multiple platforms and multiple sensors in mind, even in the 2016–2020 timeframe, should be an incentive for greater OE collaboration. The SEUS campaign already brings three federal agencies together. The opportunity now exists to attract partners and cosponsors from the private sector. Moreover, the already planned campaign follows current exploration practices and is an area with some general, baseline data. What better opportunity to involve individuals with new ideas or specific talents to witness an expedition or try out a technology? Such guest riders may not be from the usual oceanographic community. They might be medical technology developers or citizen scientists, for example.

Campaigns such as SEUS can bring more platforms and players together. It offers good opportunity to integrate telepresence on more platforms and with more participants ashore and incentivize cross-communication and data/imagery sharing among platforms when two are in the campaign area at the same time. To the present, telepresence for ocean exploration has centered on one vessel of discovery but in the 2020s working synchronously from multiple platforms will surely become normal.

Technologies of note over the next decade:

- Exploration ships and ships of opportunity as "deployers" of autonomous vehicles
- Long duration autonomous vehicles smart enough to adapt exploration plans on the fly
- Swarms of autonomous vehicles equipped with multibeam sonars
  - Take advantage of geography and use shore-launched autonomous vehicles when possible.
- Pre-campaign dedicated funding to assemble data already collected
  - Establish a campaign "joint information center."
- Develop (little development is required) and invest in mobile telepresence units available to vessels when engaged in the campaign and in integration of telepresence teams.
- Find ways to connect an exploration campaign with other exploration or science projects in the same general area in the same time frame. For example, a SEUS exploration campaign might integrate with the National Ocean Partnership Program's ADEON project, which aims to develop passive acoustic sensing in the same region.

Gulf of Mexico



The Gulf of Mexico plenary presentation had offered two target areas for the possible campaign, deep and shallow. The two Gulf groups (link) chose to divide their efforts.

- One group focused on the deep central Gulf in two sub-areas outside of any nation's EEZ, the so-called Doughnut Holes. EEZs from the United States, Mexico, and Cuba nearly converge, but leave two largely unexplored gaps that are roughly 3000 meters deep. Not only is the pristine ocean bottom in these sub-areas interesting, so too is the prevalence of the Gulf's important Loop Current and the eddies it sheds westward into U.S. and Mexican oil and gas drilling zones.

- The other group discussed shallower Gulf marine sanctuaries. Out for public comment is a NOAA proposal to extend the Flower Garden Banks Marine Sanctuary, located in the Northern Gulf, eastward from Texas toward Louisiana. At the same time, better understanding similarities and linkages between the shallow Florida Keys Marine Sanctuary and the largely unexplored national marine park on Cuba's western tip attracted great interest. This discussion unexpectedly extended west along a traverse to include characterizing the Yucatan Channel as a conduit between the Caribbean and the Atlantic through which water enters and exits the Gulf.

Both groups stressed the international opportunity that presents itself when exploring "America's Sea," the Gulf of Mexico. In every scenario the discussants see benefit in partnering with Mexico and Cuba in campaign planning and actual expedition excursions. Advanced technology brought to the Gulf for demonstration during an exploration expedition would need to comply with international technology-transfer restrictions. A second common point was the potential for rich submerged archeological and historical discoveries.

Like the groups discussing the other geographies, the Gulf discussants urged higher-resolution bathymetry and backscatter information to characterize biological colonies and define bottom geology. They see this need being gradually addressed over time by undersea and surface autonomous vehicles. The shallower waters closer to shore offer an attractive opportunity for citizen science in the next decade. Borrowing from the SEUS discussion, shore-launched autonomous vehicles can be a bonus.

One technology not discussed by the other groups can fit nicely in the Gulf's geography if politics allow; namely, the dual use of undersea communication cables to host oceanographic sensors in key Gulf straits.

In deeper waters — for example when addressing the Doughnut Holes — one Gulf group called for fitting more marine mammals and other large animals with instruments as a way of supplementing gliders and other autonomous and remotely operated mechanical vehicles.

The Forum presentation delivered by Dr. Shirley Pomponi featured several ideas for biological sampling that explorers could apply in the Gulf, including needle biopsy technologies, samplers that avoid damaging soft biological material, and eDNA extraction from water

samples. Further, the use of passive acoustics to sense biodiversity levels in "first time" exploration and over longer periods discussed in the Forum paper by Dr. Jennifer Miksis-Olds (link) would also apply. These approaches could be particularly exciting in shallow water campaigns in the Gulf over the next decade.

The group that chose to focus on the shallower area moved away from the classic exploration model where an explorer goes to a fixed spot and attempts full characterization and imaging of bottom biology and geology and the surrounding water column. The group seized on the unknowns of water flow in and out of the Gulf and chose a less standard exploration model where the exploration "follows the water" through the Yucatan Channel. Ideas that emerged included using the rich collection of potential vessels of opportunity (commercial shipping, cruise ships, fishing vessels, and oil/gas industry vessels) as platforms to launch autonomous vehicles — moving over time toward "swarms" of cheaper/smaller/enduring/disposable sensors. Both Gulf groups want and foresee better battery life on smaller vehicles and free-floating sensors.

Technologies of note over the next decade:

- Cross-strait cable systems hosting oceanographic sensors
- Autonomous vehicles with advanced multibeam sonars
- Cheaper, smaller, enduring, disposable sensors that can be deployed in swarms
- Vehicles and sensors easily deployable by untrained crews on ships of opportunity as an extension of the expendable bathythermograph (XBT) concept
- Mobilization of citizen scientists with instruments that employ a wider variety of sensors: imagers, chemical sensors, eDNA samplers and sequencers, etc.
- Sensors fitted to large marine mammals and other large animals
- Continued development of biosampling and collection devices that consider the fragility of the samples and ambient environment in which they live
- Passive acoustic monitoring (PAM) to determine biodiversity levels

Recommendations

The following synthesizes the Forum papers, plenary session lectures and discussions, group discussions and reports, general discussion, and closing lecture by Dr. Robert Ballard.

On the Exploration "Campaign" Concept

1. Embrace the "campaign" concept. Forum participants agreed that when characterizing any previously uncharacterized, unexplored area of ocean, campaigns should be as comprehensive as possible, benefiting from multiple emerging exploration technologies, covering as many scientific disciplines as possible. **A larger fraction of U.S. national ocean exploration should be conducted as campaigns.**

The casual observer may see or understand "ocean exploration" as simply bottom mapping and capturing images of wrecks and new species of marine life. Of course, such a view is incomplete. Because it is costly to go to sea, whether by dedicated ship or by new autonomous vehicles, when one goes to sea, one should collect information about the whole cube of ocean in an exploration campaign area, satisfying as many demands and disciplines as possible, as suggested in the definition of campaign above.

To solidify campaign planning, the Forum identified several actions:

2. Avoid "stovepipes" within organizational and scientific disciplines.

3. Appreciate and benefit from the diversity of motivations for exploration among federal agencies. The potential sponsoring agencies engage in exploration for many reasons. For example,

- For NOAA, exploration is a pure and assigned mission.
- For the Office of Naval Research and the National Science Foundation, discovery and exploration are typically precursors of, or incidental to, pursuing hypothesis-driven research. They also develop technologies that can be tested in campaigns

and are likely tools of future exploration (and science and monitoring).
- For USGS and BOEM, their missions require characterizing ocean areas for responsible natural resource management.
- For the Naval Oceanographic Office (NAVOCEANO), Navy Fleets offer the charge to characterize important national security areas, globally; called "ocean survey," not research or exploration, but the results may often be categorized as new discovery.

Every federal ocean agency explores and discovers, mostly by chance and incidental to mission operations. These distinctions can be benefits to U.S. national ocean exploration, not barriers.

4. Gain multiyear commitments from the lead sponsor and its cosponsors. Budgets should be developed and funding commitments sought to cover the costs of a full campaign even if some cosponsors do not provide resources for every year or every facet of the campaign. This is a major challenge because candidate sponsors have different views on, and different processes for, resource commitments beyond an initial execution year. With federal funding, agencies are subject to will of the Administration, must negotiate funding levels by line item with the Office of Management and Budget and ultimately gain line-item appropriations from the Congress. Nonetheless, when sponsors agree to a campaign, they must be prepared to protect campaign resources from within the core of their budget line items. Some have cited the relative stability of multiagency/multiyear resource commitments under the National Ocean Partnership Program (NOPP) model.

5. Make sure the lead sponsor "owns the campaign." While campaigns are envisioned to attract and integrate cosponsors, one (or two) sponsors inevitably must serve as champion, leading spokesperson, mediator, overall planner, problem solver.

6. Participate in processes (such as the NOEF) that help prioritize candidate campaign areas. Less than 10 percent of the global ocean is explored in a modern way, and the same can be said for the U.S. EEZ and, astonishingly, its marine protected areas. Therefore, one can envision many areas that would be ideal exploration campaign candidates, too many to address adequately with available resources. A

self-selected lead sponsor that then sells its campaign ideas to other potential cosponsors could initiate a priority-setting process. Another option is for key public and private funding organizations to come together regularly to share information, discuss campaign values and goals and availability of funding and other resources. NOAA, as the designated lead federal ocean exploration agency, could facilitate such regularly scheduled discussions. Variations on this theme could delegate the coordinating role to a neutral third party or a federally designated Cooperative Institute.

7. Understand better the "demand" for exploration. Recent designations expanding marine protected areas within the U.S. EEZ indicate a growing federal demand to explore within its own EEZ.

8. Develop some measures or indicators for whether an ocean area is explored and characterized. For marine life, an example might be the number of reliable observations of species in a polygon in the Ocean Biogeographical Information System. As campaigns characterize previously unexplored areas, they will gather a great deal of oceanographic information for the discrete campaign area. The previously underexplored area will become a characterized area, so that by the end of a campaign the area may be considered a reference area available for test and evaluation (T&E) of emerging instruments. It should be possible not only to map the seafloor but gradually to represent areas or volumes of the ocean in terms of the level of exploration and characterization, including geology, history, and other dimensions.

9. Convene key potential sponsors again soon to agree on a prioritization process to propel forward campaigns for the 2020–2025 interval.

10. Facilitate processes for advice from the science community about campaign priorities and then get further advice from scientific workshops and additional guidance once a campaign area is identified. While funding sponsors have specific agency and organization requirements to fulfill as they design and coordinate campaigns, the scientific community (exploration performers) have their own views on opportunities for new discovery. These are important views formed by experience and hypotheses. As campaign sponsors gather to design future campaigns, they should be informed by

scientific opportunity. In the recent past such workshops have been supported by various organizations (e.g., The Lounsbery Foundation, NOAA, etc.). Such input is essential to good campaign planning and should be enabled and regularly scheduled by NOAA, perhaps by a subcommittee of experts under the Ocean Exploration Advisory Board (OEAB). Groups such as the Ocean Studies Board of the National Research Council could also help.

11. Ensure that NOAA's Ocean Exploration Program commits to campaigns in general and to particular high-priority campaigns as they earn a leading position. For campaigns and the campaign concept to flourish and endure, most if not all U.S. campaigns will need core campaign funding (or in-kind resources) from NOAA's Ocean Exploration Program. While campaign funding can be gathered from multiple organizations (and a variety of sources within an organization), NOAA should anchor most major campaigns. As Boeing said "Let no advance in flying pass you by," so NOAA's OE program should aim to provide stable assistance to major advances in U.S. ocean exploration.

12. Use campaigns as systematic "proving grounds" for emerging ocean exploration technologies. While in campaign areas, leverage assets to test emerging technologies.

13. Include use of emerging technologies as a request in campaign RFPs. Once sponsors decide to conduct a campaign, the lead sponsor will likely publish some kind of RFP. These can be written to provide incentives for new technologies and styles of exploration.

14. Once a campaign is awarded to a performer or set of performers, require that one or more technology developers join campaign expeditions, as guest riders or as additional legs of an expedition, to better understand the opportunities for and barriers to adoption/application of new exploration devices.

15. After a campaign's area and goals are established among its sponsors but before the campaign starts, **direct all oceanographic data previously collected and archived (however spotty or incomplete) in the largely unexplored area (and its boundary areas) be assembled** and synthesized to inform final campaign planning. Support the work of persons who synthesize previously collected information.

16. Use prizes and other nontraditional competitive approaches to incentivize and reward explorers. Prize competitions for new technologies (including telepresence) can be included in campaign planning. This will also interest citizen scientists, the general public, and the press.

17. Design pre-campaign press coverage and actively solicit support of citizens and organizations most likely to have an interest in the campaign. This includes local and regional press, businesses, STEM programs, local political leaders, and native peoples.

18. Distinguish more consistently between first time and one time. Ocean exploration is a "first time" endeavor: imaging, measuring, and collecting within an area for the first time. Sometimes the public perceives this to mean "one time": Stop, dive, capture an image, then move on. This is not always the case and shouldn't be. For example, exploration in the Arctic necessarily means deploying instruments in one season and then waiting to retrieve them months later when conditions allow. When that happens one does not get just the "first image." One gets time-series data. Full characterization of a cube of unexplored ocean requires that some measurements be made over an appropriate time period. Another example is using passive acoustics to gain a background characterization of biodiversity near a reef (see paper by Drs. Jennifer Miksis-Olds and Bruce Martin (link)). The distinction between exploration and observing is often blurry and perhaps unimportant except for budget tidiness. (Ambassador Hume discusses in his Forum paper (link) the need to review the distinction between exploring and observing, especially when speaking to the public.)

19. Deepen and rank the identification of U.S. diplomatic opportunities associated with ocean exploration. Potential abounds to design campaigns extending beyond the U.S. EEZ to include the EEZs of international partners: Mexico and Cuba in the Gulf and Canada, NATO and Russia in the Arctic.

20. Leverage opportunities to partner in exploration campaigns of the high seas. While the U.S. has the world's largest EEZ, the greatest unexplored volume in the global ocean is in international waters. An important goal for NOAA is to fulfill its North Atlantic exploration obligations (still being defined) under the Galway Agreement.

21. Speed "the baseline" exploration activity to map the U.S. EEZ comprehensively with multibeam bathymetry at appropriate resolution.

22. Embrace an international goal to map the entire ocean: a long-term goal publicly described and endorsed by a group of experts operating under the concept of the General Bathymetric Chart of the Oceans (GEBCO).

23. Beyond a bathymetric map, consider in detail the ambitious, exciting idea of conducting a Global Geological Survey of the Oceans. Such a project might begin a number of achievable transects that focus on specific geodynamic settings of significance for global ocean resources. (See the Forum discussion paper (link) by Drs. Mark Hannington and Sven Petersen.)

On Emerging Technologies in Support of Ocean Exploration Campaigns in 2020–2025

24. Continue to use ships, including the four exploration-dedicated vessels: E/Vs *Okeanos Explorer, Nautilus, Falkor,* and *Alucia* (plus the upcoming *Alucia 2*). Their range, operating area or season, and finally life span depend on material condition. The experienced oceanographers and crew on these vessels make them valuable as platforms to test emerging technologies alongside current operations. As new technologies emerge, the community should be able to shrink the time such expensive ships spend "hovering" above a discrete ROV dive site. They can expand their exploration reach and widen their exploration aperture by husbanding a multitude of autonomous surface and underwater vehicles. On a sober note, a new fully capable, global-ranging oceanographic or exploration vessel will cost in excess of $100 million to procure and cost $30,000 to $90,000 per day to operate.

25. Think and plan Beyond the Ships, both because it is unrealistic that federal budgets or generous philanthropy will keep the fleet of four dedicated exploration ships operating for decades and because new styles of operation with more features can substitute for old.

26. Leverage other U.S. oceanographic ships, including the UNOLS fleet, the Navy T-AGS- 60- class ocean survey fleet operated by and for NAVOCEANO, U.S. Coast Guard Ice Breakers, and other fully capable NOAA ships (e.g., *Ron Brown*). Operational and research assignments for these vessels send them around the world, in and outside of the U.S. EEZ. They are capable of conducting a wide range of bathymetric and oceanographic activities. They generally are not permanently outfitted with deepwater ocean exploration equipment (deep ROV systems) or telepresence capabilities, but can be with fly-away systems (see next under).

27. Allow many more oceanographic vessels to become vessels of ocean exploration by two technology-related actions that can be taken almost immediately:

- **Outfit vessels with telepresence communications capabilities.** This allows connectivity to scientists and the public ashore for deep exploration imaging operations and to scientists and laboratory/data centers ashore for all other oceanographic or exploration activities both for data transfer and shoreside involvement in expedition command and control.
- **Modularize deep ROV and other systems in air/ship moveable containers** (ROVs, command control vans, winches, maintenance and repair equipment, etc.). This is not investment in new research, but investment in known engineering tasks. A containerized deep ROV system can be transported to a convenient port where a ship waits, available for a deep exploration mission. For some ships a team of deep ROV system operators may need to come with the module. A federal investment in at least one such "fly away" system could immediately triple the capability to conduct global deep exploration missions globally. This concept fits with the "share economy" that now lifts the use of capital in many sectors.

28. Leverage other "ships of opportunity" to expand the U.S. exploration capability or meet unique or immediate requirements. These could be vessels of international partners or one of many classes of

industry owned and operated ships (viz., offshore drilling support vessels, which at this time are readily available and affordable).

29. Increase use of commercial freight, cruise, and fishing vessels to drop-deploy exploration devices such as buoys and swarms of small vehicles when crossing a campaign area.

30. Develop a scalable telepresence procurement plan that involves some standardization of packages so that usage becomes familiar and routine to many more operators. Telepresence has earned its stripes in deep ROV expeditions. It connects the expedition to an interested public and allows key scientists to observe, participate in, and control dive operations. As bunk space becomes dearer and deployment becomes harder for safety, personal, health, or business reasons, telepresence becomes even more attractive. Telepresence command, control, and communications technologies evolve quickly and could become less expensive if standardized. Federal exploration investors should consider a procurement plan to outfit the most capable U.S. oceanographic ships as well as purchase one or more "fly-away" telepresence systems, while keeping in mind that system components will mature. Procurement plans must ensure that system designs allow affordable upgrades of modules (e.g., new antennas to handle different frequency bands) during the life of the system.

31. Invest in support infrastructure to enable the employment of the new technologies. For example: autonomous underwater vehicles need a subsea navigation reference system when GPS is unavailable; recharging and refueling stations; a way to communicate their findings to the surface or ashore if live connection to scientists and the public is a requirement. In some areas of extreme distance, weather, or ice, special logistics are needed just to get the technology into the vicinity of the campaign area.

32. Recognize the emerging data burden and increase resources carrying it. Data output from exploration continues to grow, and the interested public and decision makers will demand more sophisticated manipulation and presentation of data collected.

This Forum recognized the emerging data burden, and endorsed the exploration data challenge as the focus of the 2017 National Ocean Exploration Forum at the University of California at San Diego's Qualcomm Institute.

33. Support development of environmentally responsible disposable exploration sensors, and devices, including vehicles. In a departure from focused interest in spot exploration of the deep bottom, participants keenly support exploration of wider areas: vertically, horizontally, and over time. To that end, they supported further development of small sensors, and the small packages that carry them (tiny vehicles, floating devices, "rubber ducks," buoys that drift in the MIZ, etc.). The goals are sensors that require little power, are able to communicate and navigate, are cheap enough to be deployed in swarms or showers of sensors, and are disposable. If small, inexpensive, and degradable or environmentally harmless, retrieval would not be an issue. This concept resembles developing and adopting the first XBT, AXBT, and various ship- and aircraft-deployed sonobuoys.

34. Further support autonomous vehicles technology development. Autonomous surface vehicles (ASVs) already exist, but have not been used in classic stationary-location deep exploration. They do have a place in bathymetric baseline exploration and as a reconnaissance tool to identify promising areas in which to follow on with more detailed classic deep exploration. They can be ideal in many shallow water exploration scenarios and can be easily deployed and recovered from all kinds of support vessels, or from a nearby shoreline. Those participants who looked at the Arctic exploration scenario mentioned a hovercraft as a form of ASV that would be useful in the marginal ice zone. Communication and navigation are less challenging for ASVs. Moreover, ASVs will themselves be able to deploy ROVs and AUVs. ASVs exemplify emerging technology that forces the community to think more expansively about what defines an ocean exploration campaign.

The autonomous underwater vehicle (AUV) is a mature technology, but not one that has been harnessed for classic ocean exploration campaigns. New adaptive sensing, machine learning, and artificial intelligence developments can help AUVs seek and find unexpected, new, or different bottom features, find recharging stations, and avoid

collision -- a few examples among many novel capabilities. The AUV can be paired with more robust ROVs or with docking stations installed on the ocean floor. Like ASVs, their capabilities enable the community to think about ocean exploration more expansively in vertical, horizontal, and time domains. When the participants discussed AUVs, inevitably the conversation settled on the challenges of data communication (especially if a real time connection to the surface or shore is desirable), navigation, and recharging or refueling. Those with an under-ice interest stressed the need to consider establishing bottom navigation and recharging infrastructure prior to a wider area and longer exploration.

One typically thinks of deployment of an AUV by a sophisticated oceanographic vessel. Several in the Forum noted that current development of the AUV will make it easy to drop-deploy from a wide variety of ships-of-opportunity that may be crossing near an ocean exploration campaign area, or to deploy from shore.

In keeping with a more expansive vision of ocean exploration, several groups reminded the Forum that instrumenting marine mammals and other large animals could help with ocean exploration reconnaissance and water volume baseline ocean chemistry, biology, and dynamics characterization. The marine animals may, for example, know better how to explore for prey than humans do.

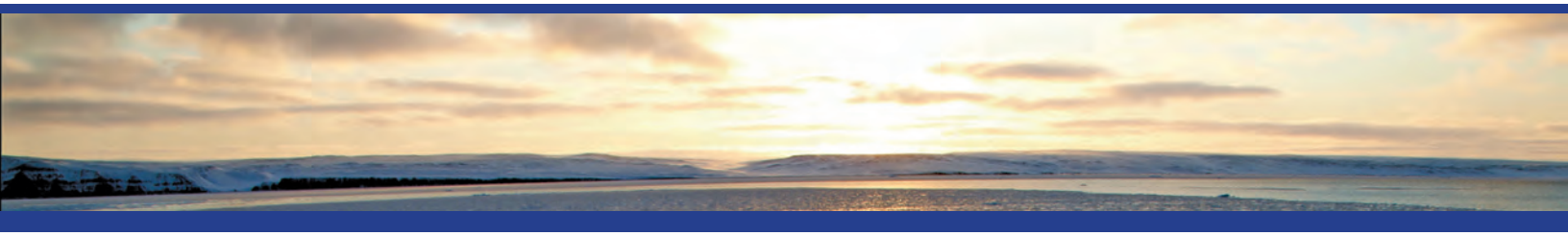
Already our most renowned explorers are gathering more measurements, thinking more about the water column between ship and deep ROV dive site, and using bathymetric survey techniques to queue follow-on imaging near the bottom. The next step is to explore this dynamic, ever-changing environment over broader areas for longer periods of time so that boundaries are understood and normal variability can be chronicled. This is not a recommendation to merge "first time" exploration with long time series (LTS) observations, but definitions are rightfully blurring.

35. Continue R&D on broadband multibeam bathymetric sonar with the aim to lower mapping costs under $10 per square kilometer. The Forum unanimously agreed that multibeam bathymetric surveying at the appropriate resolution is now the sine qua non of every exploration campaign.

36. Promote new, nondestructive means of collecting biosamples, especially sampling techniques that do not destroy a marine species when it is brought to the surface, or techniques that

nondestructively collect a sample of biomaterial from the organism in situ, or the water. "Soft gloves" mated with articulating arms on ROVs/HOVs demonstrate the maturity of technology development and enable the explorer to collect the whole animal and bring it to the surface. Alternatively, the goal is not to capture the whole animal, but rather to sample tissue for DNA or other analyses, in which case "needle biopsy" techniques can be employed by remote or autonomous vehicles to sample an organism nondestructively. Techniques have also been developed to bring a sample from depth in "bottles" that preserve the surrounding seawater, including maintaining its temperature and pressure until aboard, where the organism is ready for processing in a ship-based lab.

A corollary is to gain knowledge of the marine life in the exploration cube without either capturing the sample or invading it with needles or other biosamplers. One can collect free-floating DNA from seawater – environmental or extracellular DNA (eDNA). Investigators in places like New York harbor and coastal New Jersey are proving this technique by collecting a few tens of milliliters of real seawater and then isolating and sequencing the DNA floating therein. The NOAA Ocean Exploration program is also investing in this new technique. Within the Forum 2020–2025 time frame, this technique will mature, allowing in situ collection and rapid at-sea analysis, most useful when a DNA sequence reference library ensures accurate and faithful identification.



Conclusion

Paul Gaffney concluded the Forum by calling attention to the fundamental need to better match U.S. demand and supply for ocean exploration (page 32). Increasing interest in the Arctic, discoveries of fountains of methane bubbling from the seafloor, designation of vast marine protected areas, and popular fascination with newly observed forms of life and long-lost shipwrecks evidence demand. Meanwhile, the Forum showed that the American ocean exploration

enterprise could explore the ocean in more ways, covering more territory, more comprehensively, and affordably. Supply can then increase and better match demand. But that likely does not mean just building new-dedicated exploration vessels. We have other, better ways to augment traditional exploration, beyond the ships. Through technology America can lift its exploration supply to match the demand and discover America's submerged territory. The national commitment to align supply and demand has lagged. Small investments can help the market to clear and thrill Americans and the world.

SuBastian and the Roboats

Jesse H. Ausubel

After I was hired at The Rockefeller University, I was sent to talk with the President Emeritus. After I babbled for a while about environment, he turned to me and said, "Just remember, there is no reason to do anything trivial here." That is the basic guidance for the 2016 National Ocean Exploration Forum: do not do anything trivial.

Our point of departure is respect for the achievements of the engineers among us, and their peers. They present SuBastian and the Roboats. SuBastian is not the lead singer of an indie rock band but a superbly capable autonomous undersea vehicle (AUV) developed by the Schmidt Ocean Institute. The Roboats are not back-up singers and musicians but robotic floats, autonomous surface vessels (ASVs), which navigate the canals of Amsterdam. SuBastian and the Roboats exemplify the theme of the Forum, Beyond the Ships.

Of course we love ships, and I personally have had marvelous experiences aboard the E/V *Nautilus* and the E/V *Okeanos Explorer* and heard many direct reports of excitement on the *Falkor, Alucia,* and other vessels as well.

SuBastian

Nevertheless, to fulfil our charge to envision ocean exploration during the interval of 2020–2025, we must consider the new vocabulary overtaking many domains of our life. Think of Uber, GPS, and self-driving cars. Think of satellite farming, precision agriculture, and pervasive distributed sensors that allow a farmer to know the moisture needs of each square meter of his fields. Think of IBM's Watson computer now doing medical diagnostics. Think of the so-called Revolution in Military Affairs emphasizing reconnaissance, robotics, and precision force. Think of Siri and Echo and voice-activated devices diffusing in our homes, offices, and mobile devices. Think of binge-watching, clickbaiting, and netiquette.

All of these associate with autonomy, sensors, precision, miniaturization, and machine learning and artificial intelligence. Bandwidth. Drones. Telepresence. Cyberspace and meatspace. They associate with better forms of energy storage and, increasingly, with sharing to boost asset utilization. The adjectives modifying the concepts tend to be words like smaller, lighter, faster, denser, cheaper, and virtual. At the same time they benefit from economies of scale and can form huge integrated systems, eased by better information handling.

The new vocabulary signals that we are entering a world of farming without farmers, flying without pilots, and sailing without sailors. This will be the world of the 2020s, and ocean exploration must adapt and adopt, and should innovate too. It will be the world of SuBastian and the Roboats.

Early in October 2016 I attended Japan's biennial marine technology expo, Techno-Ocean, in Kobe. I asked our Japanese counterparts what differs from a generation or two ago. One answer was simple and consistent. During the 1950s and 1960s Japan built ships to help rebuild its industrial structure. A generation ago Japan still competed aggressively to

A Roboat

build ships. Much of a comparable earlier expo would have related to ship technology and competition with Korea, China, and other shipbuilders. Now Japanese firms see potential growth and profit in other kinds of marine technology. The markets for these span offshore exploration and production of oil and gas, possibly exploitation of other seafloor minerals and ocean energy, tourism, environmental protection, science, and national security.

In Kobe the firms, not only Japanese, showcased autonomous surface vehicles, like the Roboats; autonomous undersea vehicles, including those that can hover and can follow complex mid-water routes, of many sizes, capacities, and endurance, like SuBastian; autonomous and remotely operated cameras, from small to large; passive acoustic devices to listen to marine life (the discussion paper by Jennifer Miksis-Olds and Bruce Martin offers a far-sighted look at this field); active acoustic devices and 3D acoustic video cameras to sound out marine life, shipwrecks, and other objects; new devices of several kinds, some autonomous, to swath map the seafloor; devices for depth profiling operable with little deck space and without electric power sources; and gliders that use small changes in buoyancy to convert vertical motion to horizontal and thereby propel themselves while consuming minimal power.

Inevitably, future marine technology exhibitions will also showcase more life technologies and biological sensing, the subject of Shirley Pomponi's discussion paper. As host, I take the prerogative to share the success of my colleague Mark Stoeckle with naked DNA in seawater, eDNA, shed by resident or passing organisms. In the East River right next to where we meet on The Rockefeller campus, Mark collects small bottles of seawater and filters it for eDNA. The results are astonishing. Without capturing or photographing the animals, we know the fish species that live nearby. When Mark measures eDNA month by month, we get dynamic results superbly consistent with data obtained by traditional surveys at great cost. The levels of DNA present even seem to index abundance.

The power of eDNA makes us wonder what the future of biodiversity surveys might look like. Will it be a traditional vessel with nets and fish-finding sonars? Or, will it be a small drone, an autonomous aerial ecologist, that can lower empty vials into the ocean to catch a little water with DNA?

To scout smartly underwater, Forum participant Yogesh Girdhar of the Woods Hole Oceanographic Institution already builds small curious swimming robots, the size of an attaché case, that learn as they

swim and can efficiently explore a coral reef like an experienced scuba diver but without the needs of a human diver.

Let's also think during the next two days about what we could do collectively, how we might mount campaigns together, for example, in the Arctic, Gulf of Mexico, and South East Atlantic Bight. Let's advance ways we might share data, whether from geology or maritime history, to create eye-opening resources that might engage many millions of people. In each campaign we plan, let's think critically about public engagement, as Jerry Schubel's hard-hitting discussion paper emphasizes.

The technical change will force or stimulate change in the organizations, institutions, and programs in which ocean explorers operate. Cameron Hume's discussion paper reminds us that a necessary part of our task during the Forum is also to stimulate an update of the vision of our institutions and how we operate.

Former Assistant Secretary of the Navy, Robert Frosch, who also served as Administrator of NASA, used to object to the so-called Precautionary Principle, promulgated by some regulators, as tantamount to "Don't do anything for the first time." Bob rightly emphasized the importance for evolution and learning of the antithesis, doing things for the first time. For me, that is the essence of Exploration. It is precisely about the thrill and value of doing things for the first time.

During the Forum, let's think imaginatively about doing a bunch of things for the first time. Let's not do anything trivial. Take seriously the ambitious aim of mapper Larry Mayer for a high-resolution General Bathymetric Chart of the Oceans (GEBCO) to guide and ease the work of all explorers and many others at sea. Take seriously the exhortation of Mark Hannington and Sven Petersen in their informative and inspiring discussion paper on marine minerals to initiate a Global Geological Survey of the Oceans and transects or traverses that can demonstrate its feasibility.

I hope by now it is clear that the 2020s will not be a world of exploring without explorers. On the contrary, there will be many more explorers, but we and our diverse prostheses will play new roles. Let's adventure with SuBastian and the Roboats.

Thank you.

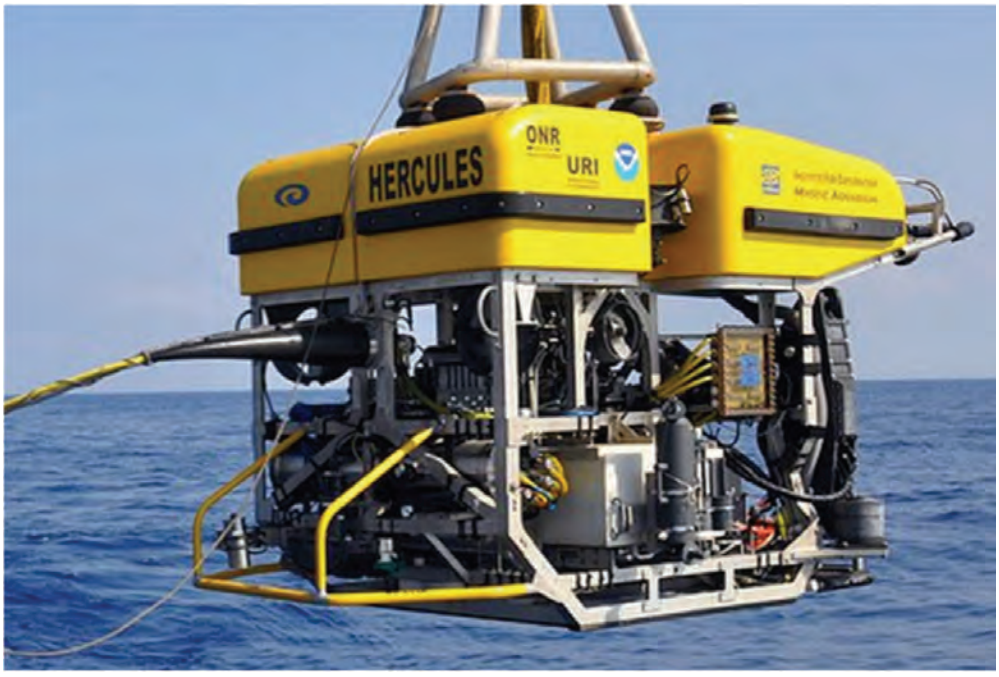
A shorter version of this essay appeared as the editorial "SuBastian and the Roboats: Ocean Exploration's Future" in *Sea Technology* v58 No 1 p. 7, January 2017. (link)

Ocean Exploration: A Supply–Demand Mismatch

Paul G. Gaffney II

Demand is up; supply is down. We are talking about Ocean Exploration; the simple characterization of a cube of ocean for the first time. In recent months the President rocketed the size of the marine sanctuary that heads out northwest of the main Hawaiian Islands. A few weeks later he designated a new marine sanctuary off New England. Both will now demand some sort of comprehensive characterization; ocean exploration campaigns.

Meanwhile, NOAA, in issuing a draft Environmental Impact Statement, has asked for public comment on options to expand, eastward, the Flower Garden Banks marine sanctuary in the northern Gulf of Mexico. New demand.



Logically, exploring an ocean area precedes designating it for protection. Such has rarely been the case, but the nation should take the area seriously once designated and characterize it better.

It just makes sense to learn about the living and mineral resources that make our sanctuaries their home. And for the appetite of the public and for the further edification of American historians and archeologists, America might make a few excursions to investigate wrecks and evidence of submerged human cultures in these areas, as well.

In one week in October, leading up to the National Ocean Exploration Forum, nearly 300 news stories about recent American ocean exploration discoveries earned time and space in the media in 36 countries. Some reporters seized on strange new " purple" creatures discovered for the first time, but nearly all wrote about the 500 new methane seeps fizzing from seafloor along the US West Coast. Those discoveries inspired renewed interest in natural oceanic methane releases into the atmosphere — oh no, another greenhouse gas! And, the speculation that if these gigantic pools of gas in the ocean sediments could be accurately located and then safely captured there would be an energy source for America for centuries; cleaner than coal or oil.

Where exactly does the methane seep, how do we best find seeps, how deep are they and what happens to the methane as it bubbles up toward the surface? Exploration demands — demands likely to increase as the USGS and NOAA start a campaign to explore the continental slope and its canyons off the US Southeast coast over the next few years.

Then there is the Arctic. Scientists and politicians are currently focused on the great variability of ice cover and the changing ocean below it. It makes sense to measure the change. But picking the right spot to make long-term measurements is crucial, because, conditions in the Arctic are harsh thereby requiring that the few measurement sites that we can afford are the right spots. Priority exploration campaigns in the Arctic will help us identify the best places for longer-term measurements.

A compelling paper[1] written for the Forum pointed out how little we know about the minerals in the sea — e.g., seafloor massive sulfide (SMS) deposits. Is there a national demand to explore for these resources? Other nations have recognized the demand.

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1 A Discussion Paper on Marine Minerals by Mark Hannington and Sven Petersen, October 20, 2016, for the National Ocean Exploration Forum 2016.

At the end of October, The Rockefeller University and Monmouth University convened the fourth National Ocean Exploration Forum, in New York City, on the venerable Upper East Side Rockefeller campus. 100 top explorers, scientists, industrialists, public and private funders, NGO representatives and diplomats came together to talk about emerging technologies for exploration in the next 5–10 years. They foresee a fast-evolving cluster of technologies including: autonomous surface vehicles that deploy sensors, AUVs and even ROVs; to swarms of disposable "rubber ducks" and drifting buoys; to passive acoustic methods to sense biodiversity; to better connectivity between all oceanographic ships and scientists and the public ashore and to modular fly-away sets of exploration tools to be used on "mudboats" and other atypical ships. There was much more.

The point: we can explore the ocean in more ways, covering more territory, more comprehensively, affordably. Supply can then increase and better match demand. That likely does not mean just building new dedicated exploration vessels. We have other, better ways to augment traditional exploration.

Through technology America can lift its exploration supply to match the demand and discover America's submerged territory. Much of it for the first time: the dry 50% of America is largely explored; the 50% that we own below sea level is largely unexplored.

The supply to meet the demand is technologically within reach. The national commitment to align supply with a demand has lagged. A new Administration may want to know what natural resources America owns and which of those it wants to use, sustain or manage. The demand is high. The supply is low. Small investments can help the market to clear and thrill Americans and the world.

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