NEXT: Scientific Ocean Drilling Beyond 2023
WORKSHOP REPORT

May 6–7, 2019

Denver, Colorado

NEXT Workshop on

Scientific Ocean Drilling Beyond 2023

May 6-7, 2019

Denver, Colorado

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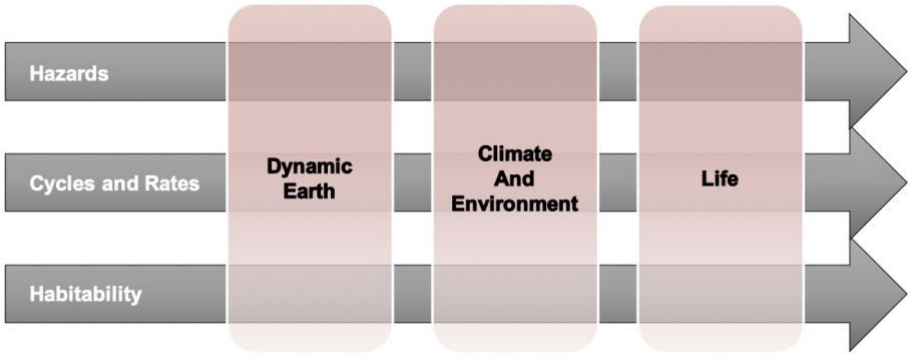
EXECUTIVE SUMMARY

Scientific ocean drilling is uniquely capable of providing essential data on the dynamics of the interconnected Earth system and is poised to generate new discoveries that will produce transformative scientific and societal benefits. Over the last five decades, results from the International Ocean Discovery Program (IODP) and its predecessor programs have provided the foundation for our understanding of Earth's climate, verified the theory of plate tectonics, revealed the presence of the subsurface biosphere, and probed the processes that drive natural hazards. While these discoveries have been revolutionary in both scope and impact, it is clear that future advancements and breakthroughs will require the successful integration of three components: **(i)** a novel, community-generated science plan; **(ii)** the deployment of a next-generation riserless drilling platform with modernized coring and logging technologies to increase scientific yield; and **(iii)** new collaborations with other Earth and planetary science programs.

On May 6-7, 2019, the United States IODP community convened a workshop in Denver, CO to consider the scientific and technological needs for the next phase of scientific ocean drilling. The workshop, entitled ***NEXT: Scientific Ocean Drilling Beyond 2023*** was attended by approximately 140 researchers and other stakeholders, both domestic and international. The primary outcomes of the NEXT workshop addressed each component of the integrated approach identified above.

First, the need for a newly structured science plan was identified as a critical priority. Because current and past science plans for ocean drilling have been designed around distinct themes and challenges that often led to "siloed" investigations, consensus was reached that future scientific ocean drilling should emphasize ***interconnected*** research. The proposed new science plan developed during NEXT focuses on understanding Earth's ***Hazards***, ***Cycles and Rates***, and ***Habitability***, each of which cuts across, or has natural pathways, among the general research topics of the ***Dynamic Earth***, ***Climate and Environment***, and ***Life.*** This new structure effectively takes on a "Whole Earth System" approach by exploring the linkages between Earth, life, and the oceans through time:



To explore this new structure the NEXT participants mapped out 22 overarching science questions under eight ***Strategic Objectives***. These ***Strategic Objectives*** are based on current knowledge and priorities but are crafted to be open-ended so as to accommodate and encourage new discoveries and innovations that will inevitably occur in the years to come. They are listed and discussed in ***Section III-C*** of this report.

Second, the community identified the requirements for updated technologies in the form of modern coring and logging systems that will dramatically increase the scientific return over current levels. Higher core recovery can be achieved through improved heave compensation, reduced weight on bit, and better drill bit rotational control. Faster pipe-tripping speed will gain more time for coring and logging operations. Increased transit speeds would result in more time on site, also enhancing scientific output. More than 93% of the NEXT participants indicated that the need for a modernized vessel to replace the *JOIDES Resolution* is critical to future scientific ocean drilling efforts in the coming decades. A next-generation globally ranging drillship operated by the U.S. with these technological improvements would provide the foundation for transformative, innovative science while continuing the track record of U.S. leadership in scientific ocean drilling.

Third, the community noted that scientific ocean drilling addresses Earth system concepts that dovetail with other Earth and planetary science research programs, and that collaborations with these entities could produce exciting synergies. IODP already collaborates with the International Continental Scientific Drilling Program (ICDP) on so-called “amphibious” expeditions, but these could be expanded to more ambitious projects in the future. The emergence of deep biosphere science in IODP naturally meshes with the objectives of the Center for Dark Energy Deep Biosphere Investigations (C-DEBI) and future joint endeavors could focus on the recovery and potential uses of subseafloor bacteria and viruses for environmental and pharmaceutical purposes. Future subseafloor observatories are critical to monitoring and understanding natural hazards such as earthquakes and volcanism and thus would benefit from collaboration with the Ocean Observatories Initiative (OOI). The National Aeronautics and Space Agency (NASA), like scientific ocean drilling, pursues studies in climate, extraterrestrial impacts, life in extreme environments, and volcanics. Results from NASA or scientific ocean drilling could inform mission planning by the other, and joint investigations would produce powerful synergies of science and technology.

The workshop also featured extensive discussion on broader impacts. It was agreed that a comprehensive communication, education, and public outreach strategy should be included and elevated in importance in the new science plan. This new strategy will require deeper engagement with scientists new to scientific ocean drilling, policy makers, and the public. In addition, the need for greater inclusiveness was stressed. While the U.S. has now attained gender parity in scientific ocean drilling, additional efforts will be required to enhance the involvement of underrepresented minorities. This will have the

benefit both of enhancing the scientific ocean drilling talent pool and of increasing the relevance of its discoveries to the public.

The NEXT workshop followed similar meetings by four of our international partners and consortia (India, Japan, the European Consortium for Ocean Drilling Research, and the Australian and the New Zealand International Ocean Discovery Program Consortium). Output from NEXT will be shared with representatives from the other post-2023 planning workshops at a meeting to be held in New York in late July 2019, with the goal of identifying a consensus science plan structure for scientific ocean drilling beyond 2023 and a roadmap for its production and implementation. The products from the July meeting will be presented to the IODP Forum in September 2019 in Osaka, Japan for endorsement.

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SECTION I: INTRODUCTION TO NEXT

I-A. MISSION AND GOALS

This is a year of optimism in the International Ocean Discovery Program (IODP) as we celebrate 50 years of scientific ocean drilling and the fact that the *JOIDES Resolution* is funded through Sept. 2024. At the same time, we have arrived at a turning point, with the IODP science plan expiring soon, and the *JOIDES Resolution* in need of replacement.

As we aspire to continue international scientific ocean drilling beyond 2023, it is ***our mission*** to put into place a next-generation, global-ranging U.S. riserless drilling platform and a new science program that will augment scientific ocean drilling results in the most challenging geological environments, both in U.S. territorial waters and around the globe.

To provide a strong impetus in this critical renewal process, a workshop called ***NEXT: Scientific Ocean Drilling Beyond 2023*** was convened in Denver on May 6-7, 2019. Approximately 110 U.S. and 30 non-U.S. IODP community members attended, with the overarching goal of developing a plan for continued scientific ocean drilling beyond 2023, and possibly as long as the next 20+ years. This group provided the widest possible scientific breadth and vision, and for two days they deliberated and delivered a proposal for an innovative, new science plan structure in support of future scientific ocean drilling.

During the workshop the following questions were addressed:

- What IODP 2013-2023 science plan challenges need to be modified/expanded, and what new scientific challenges should be addressed in the new post-2023 program?
- Why and how should these new challenges be implemented?
- What should be the framework or structure of the new science plan?
- What is needed in a new U.S. riserless drilling vessel (from coring to shipboard analysis) to answer the new or updated challenges?

The ultimate goals of NEXT were to provide a proposed ***strawman structure*** supported by the U.S. community for the post-2023 science plan and a list of ***strategic objectives*** to be addressed with future scientific ocean drilling. Both outcomes will be presented at the IODP Forum Meeting in Osaka, Japan in September 2019 with the hope that they will form the "core" of future international efforts in scientific ocean drilling.

I-B. NEXT WORKSHOP DEVELOPMENT

In its summer 2018 meeting, the United States Advisory Committee for Scientific Ocean Drilling (USAC) approved the formation of a steering committee to guide consideration of the future of scientific ocean drilling within the U.S. community. The steering committee was tasked with gathering from the U.S. community new ideas about future scientific directions and drafting a document representing the U.S. community's position

for the future of scientific ocean drilling. The NEXT workshop was the response to this directive.

USAC defined the steering committee structure to have two co-chairs, including one from USAC. USAC Chair Dr. Jim Wright was selected to fill this role. USAC also asked Dr. Anthony Koppers to be the second co-chair because of his extensive experience and knowledge of the program, including his experience as Chair of USAC in 2011-2013 and recently the *JOIDES Resolution* Facility Board (JRFB). The remaining members would be selected based on their track record of contributions to IODP and their expertise in different scientific disciplines. In addition, USAC strongly wished to see participation by the next generation of scientists in this process and preference was given to these scientists when possible, resulting in more than half of the steering committee being early- to mid-career scientists. USAC expected that some members would have broad past experience in positions of IODP leadership.

The steering committee met semi-monthly in virtual meetings from October 2018 until the NEXT workshop convened, and once in person at the 2018 fall meeting of the American Geophysical Union. Discussions among steering committee members determined that gathering input from the scientific ocean drilling community prior to NEXT and disseminating information to the participants prior to their arrival would be critical for the workshop goals to be achieved. To this end, each applicant was required to answer a set of survey questions (**Section II-A**). All answers to these questions were distilled and summarized in a single document by steering committee members and sent to every workshop attendee prior to their arrival at NEXT (**Appendix B: Reading Materials**).

Planning for the NEXT workshop benefited from following the J-DESC, PROCEED (ECORD), and Ocean Planet (ANZIC) workshops, with some steering committee members participating in those workshops. Importantly, while these workshops spent meeting time analyzing the current science plan, our steering committee, with input from NSF, determined that merely modifying the existing IODP science plan would not be sufficient to merit support for the next scientific ocean drilling program. A new science plan with a broader vision and innovative science was required, and therefore, during NEXT, only a one-hour breakout session in the morning of the first day was devoted to discussing the current science plan; the remainder of NEXT evolved around determining a novel structure for a future scientific ocean drilling science plan.

I-C. Transition to New Program Beyond 2023

Current IODP scientific themes have permeated the 50-year history of scientific ocean drilling and accordingly could remain the same. They provide continuity, but the challenges within each theme need updating/rewriting to reflect what has been accomplished, what remains to be done, and what new challenges and scientific frontiers have arisen based on what we have learned over the last 50 years.

The post-2023 science plan, therefore, needs to be both innovative and exciting, while addressing new scientific issues and testing current paradigms. The new science plan must support research with a strong focus on society; aim at emerging strategic objectives in the Earth, ocean, and life sciences; and be carried forward by the next generations of the scientific ocean drilling community.

This transition is a critical undertaking that is both complex and challenging. Planning for a new program, and for acquiring new facilities in support of future scientific ocean drilling, needs to start immediately. The NEXT workshop participants therefore adopted an expedited timeline with the goal of publishing a new science plan by June 2020.

SECTION II: SURVEY OF THE NEXT WORKSHOP PARTICIPANTS

II-A. OVERVIEW OF THE SURVEY

The goals of the NEXT workshop were (1) to provide a proposed strawman structure from the U.S. community for the 2023-2033 IODP science plan, and (2) to compile a prioritized list of science challenges to be tested with future scientific ocean drilling. To assist in achieving those goals, a pre-workshop survey was conducted as part of the application process. The NEXT application questions were:

- Looking beyond 2023, what current IODP science plan challenges need to be modified or expanded? How and why?
- What new scientific challenges should be formulated in the next IODP science plan?
- What is needed in a new U.S. riserless drilling vessel (from coring to shipboard analysis) to answer these new or updated challenges?

Responses to these survey questions helped shape the NEXT meeting program, provided the background to the generation of three strawmen science plan structures presented during Day 1 of the meeting, and provided a foundation to advance discussions at NEXT. In **Section II-B** we summarize the demographics of the respondents, followed in **Section II-C** by a short summary of all the survey results. A detailed summary of the survey results was provided in the reading materials before the NEXT meeting (**Appendix B**).

II-B. DEMOGRAPHICS OF THE RESPONDENTS

The ~110 U.S. workshop participants were well-distributed and represented 53 institutions in 28 U.S. states, with 43% being female and 39% being early- and mid-career scientists.

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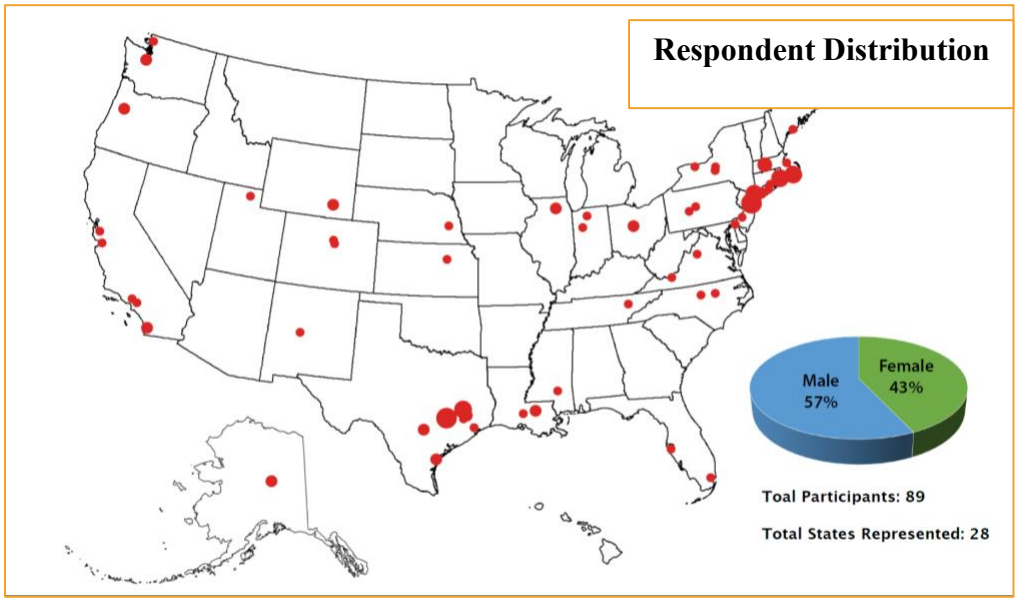
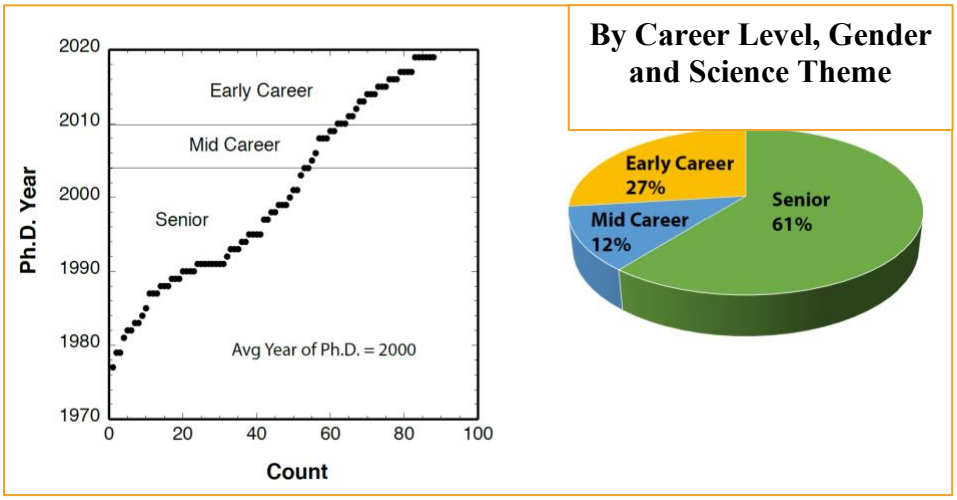


The demography was not skewed for the overall participant pool, yet there was a clear difference in the age distribution between males (average PhD year 1995) and females (average PhD year 2006). Deep Biosphere was the youngest discipline group (average PhD year 2007) while Earth Connections was the oldest (average PhD year 1997).



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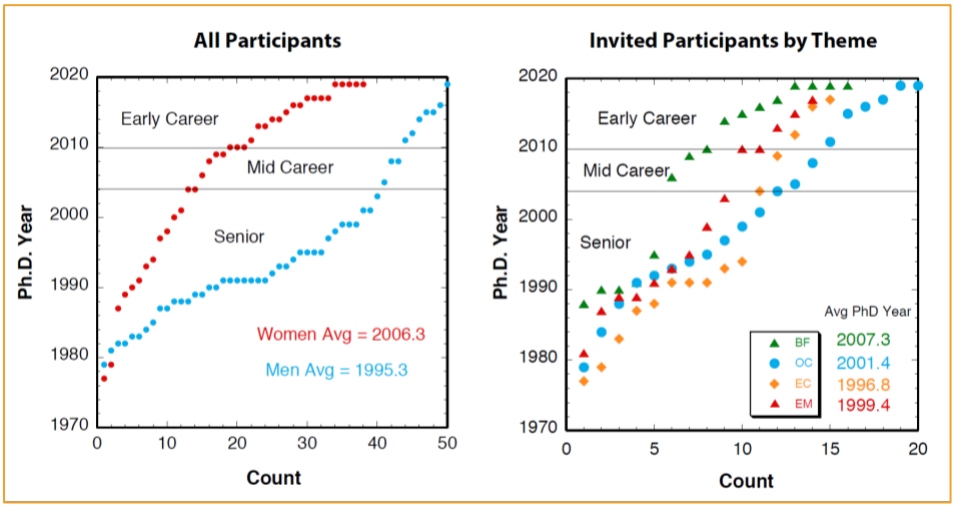


II-C. Summary of Survey Outcomes

Higher-Order Needs for the Next IODP Science Plan

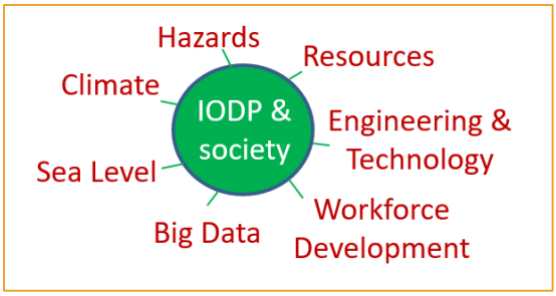
As designed, the application survey questions were largely "challenge" focused, thus supporting ***Goal 2*** of the NEXT workshop, to compile a prioritized list of *science challenges* to be tested with future scientific ocean drilling.

However, participants also used the survey response fields to provide feedback on higher-order needs for the future scientific ocean drilling. Such feedback supported ***Goal 1*** of the NEXT workshop, to provide a proposed strawman structure from the U.S. community for the post-2023 science plan, and clustered around two big ideas:

- The new science plan needs to communicate more effectively to our target audiences, with target audiences including the current IODP community, scientists new to IODP, funding agencies/policy makers, and the public.
- The new science plan needs greater emphasis on connections and synergies.

Connections and Synergies Recommended by Participants

(1) We need to highlight the societal relevance of scientific ocean drilling because it is strongly connected to society in many ways. These connections need to be explicit in the new science plan, and in future scientific ocean drilling communication, education, and public outreach strategies. Stronger societal engagement will depend on building a clear, a consistent, and an appealing "IODP brand."



(2) We need to better explore potential relationships between scientific ocean drilling and other Earth science reports and programs. First, IODP science could serve as model for several of the *NSF Big Ideas for Future Investment*, including growing convergent research, harnessing the data revolution, and navigating the Arctic. Making these connections explicit would highlight the relevance and importance of scientific ocean drilling to a broader community. Second, IODP science is described in the *National Academies' Sea Change 2015-2025 Decadal Survey* and thus the new science plan should demonstrate how IODP is addressing these national research priorities. Lastly, mutually beneficial connections should be explored between IODP and ICDP regarding land-to-sea drilling transects, and between IODP and NASA regarding scientific exploration especially in the fields of exobiology and habitability.

(3) We need to highlight linkages among science themes and/or challenges. The four current science plan themes (Climate and Ocean Change, Biosphere Frontiers, Earth Connections, and Earth in Motion) provide an organizational structure, but tend to "silo" the science. This creates artificial boundaries against needed cross-disciplinary research. Several cross-disciplinary linkages were proposed that span multiple current IODP science themes—for example, the cycling of water, carbon, nutrients, and the flow of energy; the relationships between ocean crust and biological communities; feedback mechanisms between tectonics, volcanism and climate; climate and sea-level change as geohazards on the human timescale; and using deep sea observational data for evaluating and testing models.

Scientific Challenges for the Future IODP Science Plan

Survey feedback on what science plan challenges need to be modified or expanded, and what new scientific challenges should be added to the future IODP Science Plan, are summarized in the table below. From the survey results it is clear that four major ideas span all four current science themes: (1) that there is much science still to do in order to comprehensively and systematically address the current challenges; (2) that the challenges should be broadened; (3) that there should be increased discussion of the relevance to society; and (4) that several key science directions exist within one or more of the current IODP science themes.

Future Scientific Challenges

		Ocean & Climate Change	Biosphere Frontiers	Earth Connections	Earth in Motion
1	Looking beyond 2023, what current IODP science plan challenges need to be modified or expanded? How and why?	*Much science still to do to comprehensively and systematically address current challenges* *Broaden the challenges* *Emphasis on societal relevance* • Focus on climate variability in regional to global high resolution records • Look at Earth system-wide responses to a warmer world, & times of transition	• Focus on distribution of deep biosphere as a function of lithology, microbial activity, and diagenesis; evolution • Deep-to-Surface biosphere connections	• Focus on drilling deeper and different oceanic environments • Upper mantle composition, structure, dynamics largely unanswered	• Focus on all forms of geohazards - earthquakes, tsunamis, slope failure, gas hydrate stability • "Monitoring the Earth" concept
2	What new scientific challenges should be formulated in the next IODP science plan?	• Add challenge on tipping points and recoveries • Explore record of episodic and rapid sediment delivery processes • New emphasis on the role of observational data/proxies in the development/testing of climate models	• Biosphere as an analog to type and discoverability of life on other planets • Focus on process-oriented science: role of biosphere in geochemical cycling and diagenesis • Investigation of carbon storage in the ocean	• New question on LIPs impact on environment and life • New questions on rifting, ocean basin formation, crustal evolution • Investigate a wider variety of tectonic settings • Better links to deep Earth geodynamics	• New cross-disciplinary challenge that builds on evidence that biologic assemblages vary with age/ composition of fluid seeps • Focus on spatial and temporal changes in fault systems • Focus on carbon cycling; resources

Scientific Capabilities Needed to Address New Science Challenges

Being already aware of the potential for a new riserless drilling ship to replace the current *JOIDES Resolution*, participants provided recommendations for improving core recovery and for improving data collection and analysis. Ideas primarily fell into categories of (1) expanding drilling and coring capabilities, and (2) expanding lab capabilities,

instrumentation and database optimization. The resulting "wish lists" in the table below aim to improve recovery of high-quality core material from a wider range of settings and substrates and analyze the material with shipboard analytical tools that optimize the ability to effectively describe and interpret the recovered records.

Drilling and Coring Capabilities "Wish List"	Lab Capabilities, Instrumentation, and Database Optimization "Wish List"

Improve the …
• Rate of drilling (faster pipe tripping)
• Recovery of more stratigraphically intact sequences that have variable degrees of consolidation/ strength (including at the sediment-water interface)
• Recovery of hard rock under all conditions (e.g., fractured, high temperature)
• In-situ sample/data collection capabilities (e.g., vertical seismic profiles)
• Ability to orient hard rock cores for structural, paleo-mag work
• Contamination control (esp. impacting collection of microbiological samples)
• Ability to access high-latitude sites
• Potential for drilling in shallower water
• Potential for drilling in deeper water
	Add …
	• More lab space and analytical equipment, for example:
	  • XRF
	  • X-radiograph imaging
	  • Particle size analyzer
	  • CT scanner
	  • EDS on the SEM
	  • Additional magnetometer
	• Clean room for microbiological sampling, curation, incubation, experiments
	• Ability to freeze microbiological samples
	Improve the …
	• Analytical software shipboard
	• Database with better connections among pre-expedition, expedition, and post-expedition data, and links to external databases

SECTION III: NEXT WORKSHOP

III-A. WORKSHOP PROGRAM AND ORGANIZATION

The NEXT workshop goals laid out in advance were ambitious and required a disciplined progression, given the breadth of topics to be covered in just two days. The structure of NEXT followed a familiar workshop formula: plenary sessions to introduce new information or topics to the full audience followed by smaller breakout group discussions, the results of which were reported back to the larger group. Sessions lasting ~2 hours reviewed the community survey results and technological needs in the new program, before focusing on the development of a strawman structure for the new science plan, and the scientific directions/questions to be included in this plan.

The first plenary session summarized the results from the application questionnaire, including demographic information of the workshop attendees. This was followed by a session that addressed the workshop goals regarding new technological requirements and

featured a presentation by Dr. Brad Clement (JRSO Director), who shared plans for a proposed new riserless ship, developed by Siem Offshore.

The subsequent plenary sessions focused on the development of the new science plan, beginning with a series of strawmen science plan structures based on attendees' responses to the application questions. International partners also reported the results of their meetings. The final plenary session was devoted to exploring linkages with allied geoscience organizations. Presentations by NASA and ICDP, as well as the case for handling "Big Data" culminated the plenary sessions.

The workshop benefitted significantly from investing in a real-time electronic discussion application, "Pigeonhole" (used previously at the PROCEED workshop). This allowed wider attendee participation in the discussion, especially during plenary sessions. Ultimately, more voices were heard than if a strictly oral meeting had been convened. On several topics, the electronic discussion board delved deeper into the themes than time would have allowed for oral contributions alone. Pigeonhole discussions were also archived for future reference. See **Appendix C** for a summary of Pigeonhole outcomes.

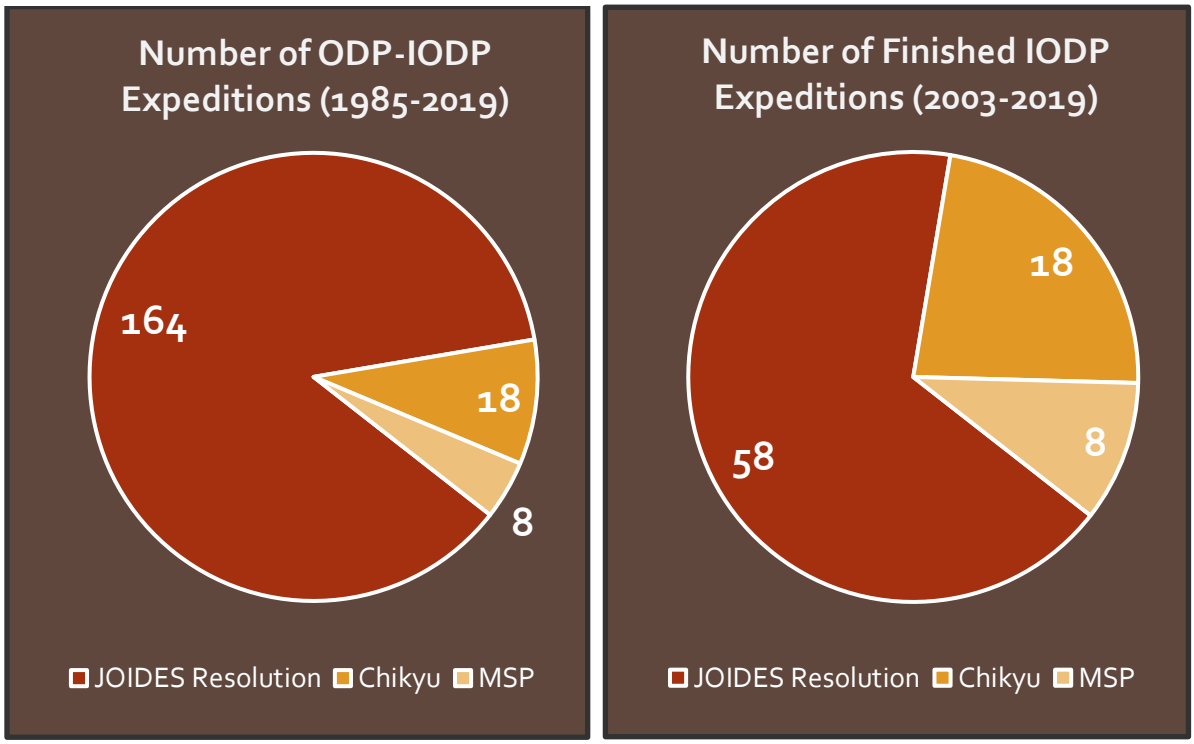
Members of the steering committee organized the breakout groups in various ways to meet different objectives during the meeting. At times, the steering committee members saw it as advantageous to have scientists with similar research interests meeting in specialized groups (following the four themes of the current science plan); for other sessions, attendees were assigned to randomized breakout groups to ensure diverse research interests, as well as career levels, in each group. This was intentional, to encourage discussion of cross-cutting ideas. On the second day, one breakout group was composed exclusively of early-career scientists (defined as either current students or those who earned their Ph.D. since 2009) to ensure that they were heard during the meeting. All breakout group reports were shared with the full NEXT audience.

The NEXT steering committee members worked a third day to distill the two days of discussions and identify common themes that emerged during the workshop. These results were presented by co-convener Dr. Anthony Koppers at the *JOIDES Resolution* Facility Board meeting that followed NEXT (**Section IV.C**).

III-B. Proposal for New Riserless Vessel in the U.S.

For more than 50 years, scientific ocean drilling has been exploring and studying the subsurface of the world's oceans, sending more than 5,000 researchers to sea and returning more than 490 km of core. Over those five decades, more than 95% of these missions have been carried out by the globally ranging drilling vessels *Glomar Challenger* and *JOIDES Resolution*, both funded by the U.S. National Science Foundation. The findings from half a century of scientific ocean drilling have been remarkable, yielding over 11,000 peer-reviewed publications, more than 500 of which have appeared in the leading scientific journals *Nature* and *Science*.

The current phase of IODP will end in 2024, by which time the *JOIDES Resolution* will be over 45 years old and in need of replacement by a modernized, next-generation riserless drilling platform. Thus far the *JOIDES Resolution* has carried out 111 Ocean Drilling Program (ODP) legs and 58 IODP expeditions. During ODP this accounted for 100% of all expeditions and all 342.1 km of drill core collected. Within the current IODP program the *JOIDES Resolution* has carried out 69% of the expeditions and recovered 91% of the 131.7 km of drill core obtained.



The availability of a riserless, globally ranging vessel to succeed the *JOIDES Resolution* is of paramount importance to the U.S. ocean drilling community. Results from the pre-meeting ***Pigeonhole*** polls (Appendix C) indicate that 93.8% of the NEXT participants feel that a *JOIDES Resolution*-type vessel is critical to the future of scientific ocean drilling. In addition, 91.3% of respondents agree that the U.S. platform should continue to follow a regional approach, in the context of circumnavigating the globe roughly once every decade.

Future requirements of the US scientific ocean drilling research community center around a significantly modernized riserless drilling vessel, specifically including capabilities that will improve core recovery, maximize scientific return, and allow operations in more challenging drilling environments for the next 10 years and beyond. The new riserless drilling vessel should be globally ranging, have 30+ berths per expedition to host

international science parties, and allow higher core recovery, faster tripping of pipe, and increased transit speeds.

Basic Requirements and Improvements

According to the NEXT workshop participants, the design of a replacement riserless drilling vessel for the *JOIDES Resolution* should include the following basic elements:

- The replacement vessel should be similar in size to the *JOIDES Resolution* but could be slightly longer and/or wider to improve stability.
- It should be operational throughout the global oceans for 11 months per year and have a hull design that allows porting in most of the world's harbors.
- The new vessel should house up to 120 personnel for 70 days at sea.
- Space onboard the vessel should have equivalent or larger laboratory and refrigeration requirements and the capacity to store equivalent amounts of drill pipe and casing when compared to the *JOIDES Resolution*.
- The new vessel should be able to pass beneath the *Bridge of the Americas* so that it can transit through the Panama Canal.
- The new vessel should have the ability to handle coring and wireline logging equipment and have an access beneath the rig floor for CORK installations.

The NEXT workshop participants highlighted the following needs for improvement in order to maximize science output:

- The replacement vessel should have improved fuel efficiency during transits and operations and require less time in port during mobilization and demobilization.
- The ship should have at least 30% more laboratory space.
- The ship should have at least 20% faster transit speed to gain more time on site.
- The ship should have at least 40% faster pipe-tripping speed to gain more time for coring and logging operations.
- The new vessel should have better core recovery through significant reduction in weight on bit, and improved heave compensation and drill bit rotational control.
- The design should result in a vessel that requires substantially less rig maintenance and reduces down-time resulting from mechanical breakdowns.

The above improvements will result in significant efficiencies at sea while maximizing coring time and increasing science output. For example, IODP Expedition 362: Sumatra Seismogenic Zone was characterized by deep water operations, drilling at 4,147-4,178 mbsl water depths. A new replacement vessel that transits at 13.5 kts, is capable of 1,000 m/hr tripping of pipe relative to current 600 m/hr on the *JOIDES Resolution*, has no need for moving the top drive in and out because of improved design, and has no need for extra bottom hole assembly (BHA) build time, would save about 2.9 days in transit time and 2.8 days in tripping days, for a total of 5.7 days saved. This would allow for enough extra time to drill into basement plus full logging of one site.

As a second example, IODP Expedition 363: Western Pacific Warm Pool was characterized by a large amount of between-site transit and relatively shallow water sites, at 874-3,424 mbsl water depths, and mainly APX and XCB soft sediment coring operations. Using the same assumptions as for Expedition 362, about 4.3 days in transit time and 2.6 days in tripping days would be saved, for a total of 6.9 days saved. Savings would provide enough extra time to occupy one more site and deeper penetration at another site, with an additional 1,000 m recovery possible and resulting in a record grand total of >8,000 m of sediment recovery during a nominal 2-month expedition.

The NEXT participants also agree the new ship's design need not:

- Have an ice-breaking hull.
- Drill in less than 70 m water depths.
- Be significantly larger than the *JOIDES Resolution.*
- Be able to produce wider and bigger core.
- Have routine logging-while-drilling (LWD) onboard capability.

A Globally Ranging Vessel to Enable Transformative Science Objectives

In summary, the NEXT workshop participants are seeking a new riserless drilling vessel that adds feasibility, reliability and sustainability to future scientific ocean drilling. This will be possible by designing a new vessel characterized by high operational flexibility and increased productivity. Many factors will contribute to this goal, including significant improvements in drilling, coring and logging capabilities; a high level of readiness across at least eleven months of any operational year; and globally ranging capabilities that enable operation from a large array of international ports and throughout all the world's oceans and seas.

As has been the case with the *JOIDES Resolution* for the last ~40 years, a new globally ranging, riserless vessel operated by the U.S. will provide the highest probability for transformative science within the Earth sciences along with profound, positive societal impact. It will also continue the track record of U.S. leadership in scientific ocean drilling, an endeavor which has been described by the journal *Nature* as "arguably the most successful international research collaboration ever." [25 September 2013]

III-C. Proposal for New Science Plan Structure

We primed NEXT workshop participants with three alternative science plan structures. These took the general form of: (1) "Mission Earth," with cross-cutting thematic areas of habitability, ecosystem sensitivity, resources, deep Earth dynamics and hazards; (2) NSF "Sea Change" thematic areas; and (3) a "Pathways" structure that emphasized cross-cutting themes of timescales, fluxes, transects, and events. A simplified variant of the "Pathways" architecture later emerged as the main outcome of the NEXT Workshop.

The conference was organized around five breakout groups over two days, followed by a third day of deliberation and synthesis by the NEXT Steering Committee. The workshop discussions were organized from the bottom up, starting with emerging science challenges and new developments contributed by individual scientists, and ending with discussions of connections to established programs and science initiatives, as well as education and outreach.

Breakout 1 focused on identifying themes or challenges for the future science plan, with participants grouped according to the four themes of the existing Science Plan: Climate and Ocean Change, Biosphere Frontiers, Earth Connections, and Earth in Motion. The charge was: **(1)** to identify emerging science, hot topics, and new concepts, building and expanding on the successes of the current science plan; and **(2)** to develop new and/or repackaged science objectives for the new science plan that might not necessarily fit the old themes but could emphasize their connections.

Breakout 2 focused largely on proposing a new science plan structure. Participants from all themes were randomized into four breakout groups. The charge was to evaluate and refine the provided "strawman" science plan structures or propose new ones. An overarching vision emerged from all of the group discussions that cross-links between themes are underdeveloped in the current science plan and should be emphasized in a new science plan structure. In these discussions, scientists favored an Earth systems approach, focusing on rates of change, cycles, tipping points, feedbacks, and sensitivities. Other convergent views in the group discussions were the need for more emphasis on the societal relevance in terms of hazards, resources, and planetary habitability.

Different types of infographics were proposed and discussed: **(1)** a matrix or heat map structure with 3 to 5 themes and 3 to 5 cross links; **(2)** Venn diagrams; **(3)** "star-burst" structures in which elements were arranged into a radial pattern; and **(4)** a series of thematically-defined "missions" that would unify processes and thematic questions around specific parts of the Earth system, such as "Monsoons," "Rifted Margins," "Ice Sheets," and "Extreme Events." Of these structures, the various breakout groups converged on a grid structure of "cross-cutting processes" in rows and "basic elements of the Earth system" in columns.

Proposed titles of the new Science Plan included "Exploring the Hidden Earth," "Expedition Ocean Planet," and "Mission Blue Planet" with the following structure:

Themes:

- Biosphere -Habitable Planet- Ecosystem Sensitivity - Life & Habitability – Ecosystems and Habitability
- Hazards – Geohazards - Planetary Hazards – Oceanic Geohazards

- Climate - Climate & Oceans - Changing Climate - Climate Variability - Climate & Ocean Evolution - Climate Forcings, Feedbacks, & Sensitivities – "Future From Past" – Climate History and Environmental Change
- Earth Dynamics - Deep Earth- Ocean Basin Evolution & Deep Earth Processes
- Resources - Transformation of Minerals and Rocks – Resources for Future
- Interactions
- Energetics and Activity
- Cycling of Carbon, Oxygen, and Water
- Catastrophic Events, Recovery, Thresholds
- Ocean Worlds and Habitability

Threads / Linkages / Networks / Convergences:

- Ground-Truthing Models
- Catastrophes - Catastrophic Events & Recovery - Disruptions thru Time
- Cycles (Carbon, Oxygen, Water) – Cycles and Rates
- Tipping Points
- Interactions - Land-Ocean Interactions - Life-Geo Interactions
- Societal Relevance
- Energetics & Activity
- Age Transects - Time slices
- Habitability
- Scales (Time and Space)

Missions:

- Monsoon
- Ice-Sheet Stability
- Earthquakes
- Sea Level
- Extreme Events
- Fault Zone
- Ocean Crust
- Carbon
- Moho
- Limits of Life
- Rules of Life
- Subduction
- 4D
- Rifting

Breakout 3 focused on identifying the "Theme" and "Crosslink" topic areas for a new Science Plan. The charge was to flesh out the proposed structure by identifying the

Theme and Crosslink topic areas. One group was comprised entirely of early- and mid-career scientists, with the remaining participants randomized into three additional groups. One new possible Science Plan title emerged from Breakout 3 ("Exploring our Blue Planet") and a Venn diagram was also produced showing the relationship among "Changing Planet: Climate & Ocean Through Time," "Active Planet: Hazards & Plates in Motion," and "Living Planet: Habitability & Limits of Life."

This breakout session produced the following refined structure:

Themes:

- Hazards – Natural Hazards – Geohazards
- Climate and Environment – Changing Planet (Climate and Oceans Through Time, Climate and Future Worlds) – Climate History and Environmental Change – Climate (Global Environmental Change, Climate and Ocean History)
- Life – Life Below the Seafloor – Biosphere and Life – Living Planet (Biosphere, Life and Habitability and Limits)
- Active Planet (Plates in Motion, Earth Dynamics or Dynamic Earth) – Earth Dynamics

Crosslinks:

- Fluxes (Life, Evolution)
- Feedbacks
- Cycles Interactions – Cycles and Rates – Cycles and Fluxes – Element and Energy Cycles – Cycling Energy and Matter
- Society
- Habitability – Habitability, Resilience, and Adaptation – Ecosystem, Evolution, and Habitability
- Scales (Time, Spatial)
- Land-Sea Atmosphere Interaction
- Extreme Events – Events and Thresholds – Changes, Disruptions – Geohazards – Hazards and Society
- Earth Evolution – Earth Spheres

Breakout 4 focused on specific science questions that the new program should be poised to address. Participants stayed in the groups defined during Breakout 3. The charge was to provide a prioritized list of new challenges, investigations or objectives, and a description of how they align with the science priorities in the Sea Change report. This exercise resulted in an aggregate list of 144 research questions.

Breakout 5 had self-identified thematic groups refine the research questions into overarching science priority groups that could be addressed by a new program. One alternative breakout group considered education and outreach needs of the new program,

with the goal of identifying emerging and crucial linkages with other community and science initiatives. This group developed the following statement:

> *"Beyond 2023, scientific ocean drilling will continue to implement our existing education and outreach initiatives, expanding the current programs to inclusively engage the community. Participants at the 2019 IODP NEXT meeting identified society as a key priority in future IODP programs and expressed an interest in developing a comprehensive communication and outreach strategy. This interest will lead to a workshop proposal focused on building a cross-platform scientific ocean drilling brand that maintains a consistent media presence, reaching a broader audience and capitalizing on our unique initiatives and skills. The IODP community is deeply dedicated to increasing public awareness and understanding of the Earth we all inhabit and making sure underrepresented groups and communities are included in scientific ocean drilling and offered opportunities to participate in the program."*

On **Day 3**, the NEXT Steering Committee distilled the list of 144 research questions to eight strategic objectives, each with two to four associated interdisciplinary questions. The Steering Committee also considered names and mission statements for the science plan. The following structure emerged from these discussions:

Proposed Structure (whereby the Themes and Crosslinks have equal weight)

- **Themes:**
  - Dynamic Earth
  - Climate and Environment
  - Life
- **Crosslinks:**
  - Hazards
  - Cycles and Rates
  - Habitability

Strategic Objectives for the Post-2023 Science Plan

- **Define the conditions for life and planetary habitability**
  - How do organisms live, interact, evolve, and die beneath the seafloor?
  - What are the interactions of microbes, lithology, and fluids?
  - What are the rules of life?
- **Constrain the feedbacks among earth, life and climate**
  - What are the feedbacks between life, the rock cycle and crustal properties?
  - How do active tectonic processes affect ocean and atmosphere circulation and chemistry?

  - What are the solar, climate, and tectonic factors that govern ocean productivity?
  - How does subseafloor life shape the cycling of energy and mass?
- **Examine the dynamics of the cryosphere and sea level under different climate states**
  - What are the mechanisms and rates of sea-level change through time?
  - When did polar ice sheets begin to grow and what are the feedbacks that lead to deglaciation?
- **Use the past to inform our understanding of a future Earth**
  - How productive was the greenhouse world of the past?
  - What were the climatic, biological and chemical characteristics of an ice-free planet?
  - What is the record and magnitude of human impacts in Earth systems?
- **Identify the causes, scales and consequences of climatic and environmental perturbations**
  - What are the timescales and patterns of ecosystem recovery to major disturbances?
  - How have catastrophic or major environmental perturbations shaped the history of life?
  - How do large igneous provinces (LIPs) and hot spots form and evolve, and what are their environmental and biosphere impacts?
- **Investigate the life cycle of a lithospheric plate and its impact on the earth system**
  - How does lithospheric architecture and evolution vary in response to spreading rate and tectonic setting?
  - How do lithospheric plate boundaries (subduction zones, transform faults, rift zones) form and evolve?
- **Characterize the transfer of water, energy, and matter in the Earth system**
  - What are the mechanisms and processes associated with geomagnetic reversals and secular variation as recorded in oceanic crust and sediments?
  - What processes influence the tempos of volcanism?
  - How is fluid flow affected by subsurface structure, how do fluid systems evolve, and how do these processes influence life, climate, and geochemical cycles?
- **Assess the conditions and processes that control the occurrence of natural hazards that affect society**
  - What are the rates, magnitudes and impacts of natural disasters?
  - What are the feedbacks between sea level and hazards such as tsunami, hydrate stability and storm surges?

New Science Plan Title

- "Exploring the record: Earth, oceans, climate, and life"

Mission Statement

- We explore Earth systems and processes that can only be uncovered through scientific ocean drilling.
- We are an international scientific community pioneering large-scale and interdisciplinary research throughout the world's oceans.
- We sample otherwise inaccessible places that constrain the mechanisms and feedbacks among Earth, life, climate, and society.

III-D. Linkages to Other Earth Science Programs and Big Data

Scientific ocean drilling covers a wide range of scientific topics and objectives that can be used to develop synergies with other programs. On **Day 2**, NEXT convened a plenary session to identify other Earth science organizations with scientific missions that intersect in part with those of scientific ocean drilling. The session led with presentations from NASA and ICDP and the subsequent breakout session identified several additional programs. Organizations most often discussed were the International Continental Scientific Drilling Program (ICDP), the Center for Dark Energy Deep Biosphere Investigations (C-DEBI), the Ocean Observatories Initiative (OOI), and NASA (and international space agencies).

International Continental Scientific Drilling Program

Geologic processes rarely stop at the shoreline and yet our current system of inquiry does not readily foster commonality in research between geologic archives below and above sea level. Synergies with ICDP have been explored in previous incarnations of scientific ocean drilling to link offshore and onshore geologic transects (for example, ODP Legs 150 and 150X: New Jersey Sea Level Transect and Coastal Plain). There have also been ICDP collaborations to facilitate and implement shallow water drilling through a combination of ICDP-IODP funding. Examples include IODP Expeditions 313 (New Jersey Shallow Shelf), 310 (Tahiti Seal Level), and 325 (Great Barrier Reef Environmental Changes), and 364 (Chicxulub K-Pg Impact Crater).

In the current scientific ocean drilling program, "Amphibious Drilling Proposals" are considered when full achievement of the scientific objectives requires scientific drilling at both onshore and offshore sites. However, while the current science plans of ICDP and IODP have similarities, there are challenges in trying to expand this collaboration that stem from the fact that ICDP and IODP are different in terms of organization, operations, and funding mechanisms. In addition, the review panels meet on different schedules and,

despite exchange of watchdogs for IODP/ICDP proposals, there is a lack of continuity in the feedback given to the proponents. Discussions between IODP and ICDP are continuing in order to better implement joint projects. For future scientific ocean drilling, NEXT participants endorsed having a stronger relationship with ICDP that includes a more integrated approach in implementing joint projects.

Center for Dark Energy Deep Biosphere Investigations

The youngest, fastest growing, and arguably most vibrant, area within IODP focuses on life below the seafloor. C-DEBI research focuses on the deep biosphere. Understanding the origin and evolution of microbial life below the ocean floor that makes up 70% of our planet's surface is critical in understanding where and how life can exist. Specifically, C-DEBI is interested in determining what organisms exist where, how long they've been there, how they might be related to other organisms found in continental areas or in the overlying ocean, and how subseafloor microbes help coordinate critical global biogeochemical cycles that keep Earth habitable. There is already considerable synergy between C-DEBI and scientific ocean drilling with regard to deep biosphere research. For example, much of the technology produced through protocols devised by the C-DEBI have important uses for IODP science.

Ocean Observatories Initiative

The Ocean Observatories Initiative (OOI) is designed to collect physical, chemical, geological, and biological data from the sea surface to the seafloor to monitor rapid events and long-term changes affecting the oceans. The interdisciplinary research supported by OOI includes themes similar to those in the current IODP science plan, such as climate variability, marine ecosystems, global-scale geodynamics, fluid-rock interactions, and the deep biosphere. Recently, direct collaboration has advanced with the advancement of IODP proposals to drill into and provide cabled monitoring within "zero-age" ocean crust. While technologically challenging, such a collaboration will yield important new data that will benefit both the OOI and IODP communities.

NASA (and potentially other space agencies)

Several NASA strategic objectives have potentially significant overlap with scientific ocean drilling, and both entities are interested in exploring synergies. Both programs are focused at the broadest scale on how the global Earth and climate systems are changing, what causes these changes, how future changes can be modeled, and how investigating these phenomena can benefit society.

In terms of climate, NASA's Earth Science Division records global temperatures, weather patterns, vegetation, and ice coverage through orbiting satellites that give a temporal year-by-year record for planet Earth. These data can be integrated with scientific ocean drilling results to enhance near-term climate modeling. NASA also shares an obvious interest with scientific ocean drilling in exploring and determining the

minimal conditions, evolution, and limits of life. Understanding the limits of life in the subseafloor through ocean drilling can aid NASA in determining where to seek life on other worlds. Another area of convergence is volcanics. Although Earth is the only terrestrial planet in the Solar System with active plate tectonics, scientific ocean drilling allows investigation of large igneous provinces and ocean island volcanoes on Earth, the findings from which can be extrapolated to studies of plume volcanics present on other terrestrial planetary bodies. NASA and IODP also share an interest in impact structures; here again, findings on Earth from drilling into, for example, the Chicxulub impact crater can inform NASA's extraterrestrial explorations.

Big Data

Automated machine-data analytics of large swaths of scientific ocean drilling data is a key advance that could dramatically enhance the utility of past, present, and future findings. In alignment with FAIR (Findable, Accessible, Interoperable, Reusable) data principles, shipboard and post-cruise revised data can be assembled in multiple ways and integrated with data available from other community platforms and agencies. For example, ground-truthing future climate change based on IPCC climate projections would require data aggregation from hundreds of globally distributed sites acquired over multiple scientific ocean drilling expeditions.

Scientific ocean drilling is unique in that it captures a global data set that goes back deep into geological time. Thus, the integration and deep analysis of ocean drilling could provide critical baseline data from periods under various global climate states. In addition, so-called big data efforts could be employed to build a subseafloor microbial databank to address critical questions of the range and limits of life in sediments and ocean crust. In theory, occasional future "expeditions" could be organized around information and statistics rather than a physical ship.

III-E. Outreach

Pre-workshop surveys of participants at the NEXT meeting identified connecting with society as a key priority in future scientific ocean drilling programs (see Section II.C.). This will require engaging with people beyond the scientists already involved in IODP, including scientists new to IODP, policy makers, and the public. Expectations are that engagement with these target audiences will both benefit society and have a positive feedback effect on ocean drilling itself (i.e., through increase support and recognized value of scientific ocean drilling, by contributing to workforce development, etc.). During breakout sessions and in plenary, there was intensive discussion on developing a comprehensive communication, education, and public outreach (herein, referred to as broader impact) strategy for the new science plan.

The community's interest and passion for expanding scientific ocean drilling's broader impact was clear from these discussions and from ongoing post-workshop conversations.

Notably, interest was particularly strong among early career researchers. Recommendations ranged from the nuts-and-bolts level (e.g., making use of specific social media platforms) to conceptualizing a common guiding framework for broader impact across the program. Among the many suggestions, three concepts stood out which are summarized below:

- **Increase funding and coordination of broader impact activities.** Budget constraints have limited past and current programs, keeping them relatively small in scope, although U.S. Science Support Program staff have been able to procure external NSF and other funds to expand ocean drilling outreach and products. If connecting with society is to be a key priority in future scientific ocean drilling, additional funding will be required to enhance the broader impact of scientific ocean drilling. Because of the decentralized organizational structure of the current IODP, increased coordination of broader impact activities will need to be creatively addressed. At a minimum, it will likely require regular meetings of the broader impact leadership from across the program components, as well as an input mechanism from the community to this leadership.
- **Define (and assess) measurable objectives and metrics for broader impact in the next science plan.** Just as science objectives should be measurable, so should broader impact objectives.
- **Establish a scientific ocean drilling brand**. Ocean drilling can strengthen connections to society by building a common brand that maintains a consistent media (including social media) presence, reaches a broader audience, and capitalizes on the excitement and results of scientific discovery, as well as the human element of IODP science. Communication and marketing expertise are especially needed to develop branding strategies that will successfully overcome the challenges of changes to the program name (from "IODP" to something new) and platform (new riserless drillship to replace the *JOIDES Resolution*).

A near-term recommendation was to hold a workshop on the future of broader impacts in scientific ocean drilling. This workshop could bring together experts in science communication, marketing, education, and outreach (including both those associated with current IODP Program Member Offices and from outside of IODP) to generate a broader impact strategy. The objectives of the meeting might include to determine what methods of communication, education, training, and public outreach are working; to develop stronger expedition-coordinated communication and public outreach; to leverage best practices to reach a broader audience on social media platforms (and how to measure their effectiveness); to establish approaches for strengthening the reach and impact of scientific ocean drilling; and finally to generate proposals to external funding agencies to support the broader impact strategy.

SECTION IV: CONCLUSIONS

IV-A. NEW SCIENTIFIC OCEAN DRILLING SCIENCE PLAN

Scientific ocean drilling has been sustained by a strong collaborative effort between the United States and its partner IODP member countries. The very core for such a continued long-term effort will be the formation of a novel, strongly forward-looking science plan. Following five decades of scientific ocean drilling, a clear rationale needs to be laid out by the international science community in support of our continued efforts and future programs. The results of the NEXT workshop as presented in this report are critical, as they highlight the strong need for future scientific ocean drilling both to address long-standing questions and to develop new research paradigms. This will be accomplished by pursuing new frontiers that only have evolved over the last decade, by viewing Earth as a complex interconnected system, and by focusing on research topics of significant concern and interest to society.

A consensus was reached at the NEXT workshop that future scientific ocean drilling should emphasize interconnected research questions and not "siloed" themes. The proposed new science plan structures developed during NEXT addresses this new approach by focusing on understanding Earth's ***Hazards***, ***Cycles and Rates***, and ***Habitability***, each of which cuts across, or has natural pathways, among the general research topics of the ***Dynamic Earth***, ***Climate and Environment***, and ***Life.*** This new structure effectively takes on a "Whole Earth System" approach by exploring the linkages between Earth, life, and the oceans through time.

To explore this new structure, NEXT participants mapped out eight ***Strategic Objectives***:

- Define the conditions for life and planetary habitability
- Constrain the feedbacks among Earth, oceans, life, and climate
- Examine the cryosphere and sea level under different climate states
- Use the past to inform our understanding of a future Earth
- Identify the causes, scales, and consequences of climatic and environmental perturbations
- Investigate the life cycle of a lithospheric plate and its impact on the earth system
- Characterize the transfer of water, energy and matter in the earth system
- Assess the conditions and processes that control the occurrence of natural hazards that affect society

These ***Strategic Objectives*** are based on current knowledge and priorities but are crafted to be open-ended so as to accommodate and encourage new discoveries and innovations that will inevitably occur in the years and decades to come. The objectives will also allow

scientific ocean drilling to explore connections with other geoscience organizations that share common scientific interests, such as NASA, ICDP, OOI, C-DEBI, and more. Some of these objectives include challenges that cannot be addressed currently because of technological constraints. However, new/improved technologies and advanced "big data" analytical approaches should make them attainable in the future. Furthermore, many of these objectives can only be addressed by implementing mission-oriented approaches that could extend multiple years, even decades.

IV-B. New U.S. Riserless Drilling Vessel

Overall, the U.S. community and NEXT workshop participants are extremely eager for the acquisition of a new and improved vessel to replace the *JOIDES Resolution*. Any future scientific ocean drilling implementation from the U.S. science perspective centers around a new, globally ranging, U.S.-operated riserless drilling vessel. From past experience and through leadership in the DSDP-ODP-IODP programs, we have learned that a similar riserless platform to *JOIDES Resolution* will provide the feasibility, reliability, and sustainability required to successfully address the science goals envisioned by the NEXT participants.

Scientific ocean drilling's bottom-up, peer-review proposal system, as well as the regional planning model of the *JOIDES Resolution* and the overall and functioning of the *JOIDES Resolution* Facility Board, are all highly transparent and endorsed by the NEXT participants. A continuation of this approach, coupled with increased participation and investment by *JOIDES Resolution* international partners, is needed if scientific ocean drilling is to continue beyond 2023 with a new U.S. riserless vessel as its centerpiece in the quest to increase understanding of the complex interconnected Earth system.

The new vessel should be based on similar design requirements as the current *JOIDES Resolution*, but improvements are required that will allow for increased science at sea through faster transit speeds, faster pipe tripping speeds, better heave control, enhanced fuel efficiencies, and larger onboard laboratory spaces.

IV-C. Timeline and Roadmap

The NEXT workshop was timed to occur just before and at the same venue as the *JOIDES Resolution* Facility Board (JRFB) meeting to allow international participants traveling to JRFB to also attend NEXT. More specifically, it allowed the IODP Forum Chair, Dr. Dick Kroon, and representatives of the international Program Member Offices (PMOs) and the *JOIDES Resolution* funding partners to be present to discuss and agree to the subsequent steps that would follow the spring workshops that cumulated with the NEXT meeting.

At the request of the Forum Chair, a July meeting was scheduled at Columbia University in New York City. Representatives from each of the partner countries and consortia will attend the meeting to discuss a range of issues prior to the annual IODP Forum meeting. Goals of this science plan working group meeting, to be chaired by Dr. Anthony Koppers, include the formulation of a consensus structure for the new science plan, its research priorities and duration, and guidelines for the makeup of the science writing team and its lead editors. The resulting proposal and roadmap will be open for commenting in the beginning of August via the IODP Science Support Office website, iodp.org, before a final proposal and roadmap will be presented at the IODP Forum in Osaka, Japan.

The IODP Forum will take place from 11-13 September 2019, where it is hoped that the new science plan structure will be ratified, the writing team established, and the roadmap determined toward a June 2020 completion date for the new science plan. Review procedures as well as mechanisms for community feedback will also need to be agreed upon. The next major gathering of the IODP community and presentation of the evolving science plan will occur at the IODP Town Hall meeting at AGU in December.

The process leading the international workshops culminating in NEXT was initiated in September 2018 at the IODP Forum meeting in India. At that time, an ambitious date of June 2020 was set for a new science plan. The last year for *JOIDES Resolution* operations in the current program is 2024, while the ship's environmental impact statement expires in 2028. The *JOIDES Resolution* will be 45 years old in 2024. Given the time it takes to present a new science plan and obtain new facility approval at NSF, and the length of time to build a new ship, the June 2020 completion date for a new science plan is a necessary and critical prerequisite in this process.

SECTION V: ACKNOWLEDGEMENTS

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NEXT: Scientific Ocean Drilling Beyond 2023

WORKSHOP REPORT

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Alexandra Witze
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Jim Wright (Co-Chair)
Rutgers University
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Danielle Wyrick
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APPENDIX B: READING MATERIALS

The majority of the 140 participants filled in a mini-survey during their application. The NEXT steering committee provided summaries of the mini-survey results for each IODP theme group to be read in advance of the meeting. These summaries were prepared by four different subcommittees (one for each theme), which resulted in some repetition when common issues were identified or when the observations were not specific to a theme or cross-linked. Each report started with a 1-2 page overview, before reporting on the survey question by question.

These reading materials were distributed via email to all participants before the meeting; they also were part of the NEXT agenda book. The full PDF of the reading materials can be downloaded from https://usoceandiscovery.org/next_workshop/.

APPENDIX C: PIGEONHOLE OUTCOMES

A. INTRODUCTION

Pigeonhole provided an interactive mechanism during the NEXT meeting to acquire polling data and to acquire real-time comments on presentations and discussions.

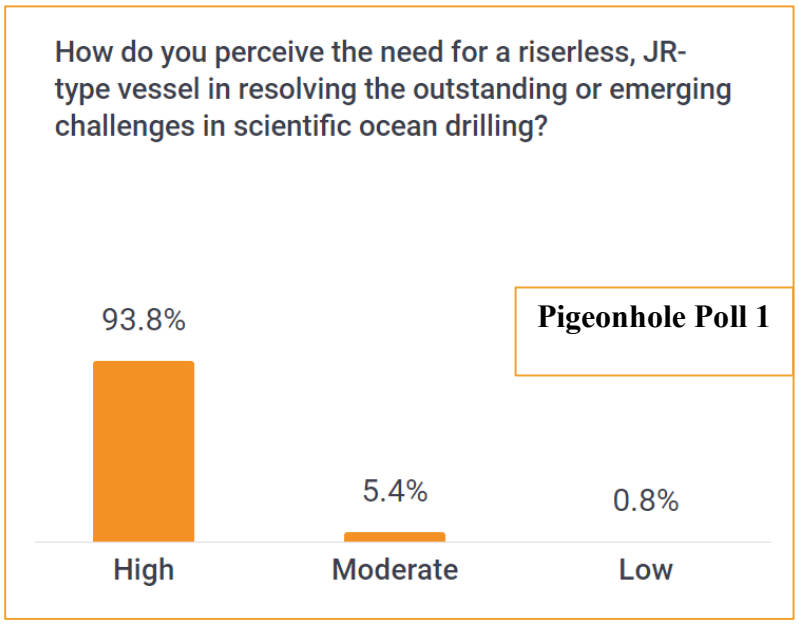
The *Pigeonhole* framework for the NEXT meeting included several surveys consisting of simple referenda, as well as text responses to specific questions. The real-time method provided for increased efficiency (focus) in discussions and helped to guide the direction of the meeting. It also allowed early-career researchers to have their voices heard in meetings where otherwise more senior community members might tend to dominate.

Pigeonhole was set up by two members of USSSP and one member of the NEXT steering committee and run by these three personnel throughout the meeting. For Day 1, polls and Q&A sessions were set up ahead of time and opened and closed as necessary; for Day 2, polls and Q&A sessions were created and opened as needed by the presenters. The "comment" function was enabled in *Pigeonhole* to allow participants to respond to previously posted comments and the "upvote" function was enabled to allow participants to register their approval of a comment or response by voting for it in the manner of "liking" or "favoriting" on social media platforms. *Pigeonhole* was run in "moderator" mode, requiring one of the three personnel running the software to approve comments before they were projected on screen.

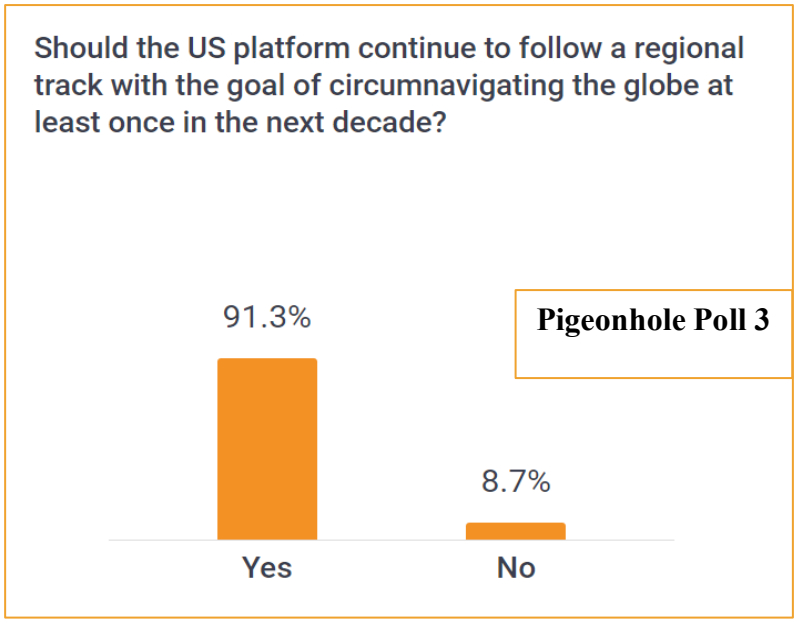
Overall, *Pigeonhole* was used for one pre-meeting poll, 10 polls during the meeting, and 11 Q&A sessions within the meeting. Select polls will be shown below and highlights from all polls and Q&A sessions will be given on the following pages.

B. Key Pigeonhole Polls

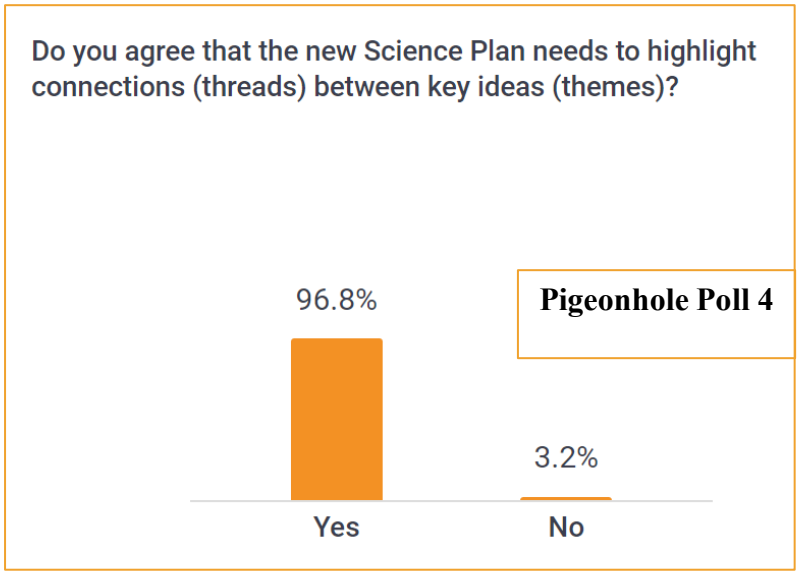
During the *Pigeonhole* introduction session led by co-chair Jim Wright on Day 1, results from the pre-meeting polls were shown on the screens. **Poll 1** indicates that **93.8%** of participants believe the *JOIDES Resolution* to be a highly important vessel in the future of the scientific ocean drilling program.



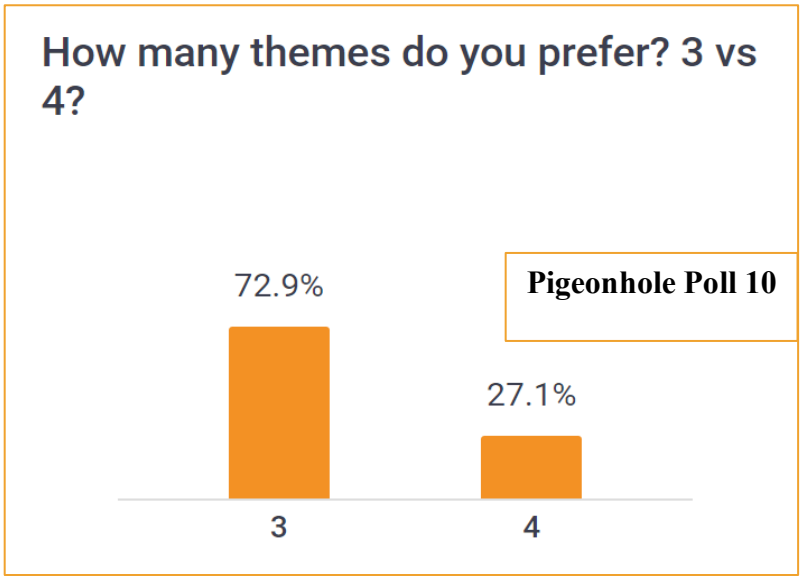
Poll 3 is drawn from the same introductory session and was carried out in real time. It indicates that the U.S. platform, whatever that looks like in the future, should continue to follow a regional track according to **91.3%** of the NEXT participants.



Poll 4 is drawn from the plenary session, at the end of Day 1. This question targeted the emerging concept of the themes and threads, testing the overall community response. Polling shows that **96.8%** of the NEXT participants liked the idea of connections and threads between more general theme or topic areas in the science plan. Follow up questions are shown in the highlights in **Section C**.



Poll 10 is drawn from the final plenary session, at the end of Day 2. This targeted the discussion of whether the proposed strawman structure for the science plan should have three or four themes as well as three cross-links. Polling shows that **72.9%** of the NEXT participants felt that three themes was preferable, resulting in a three by three structure of themes with interdisciplinary cross-links.



C. Highlights of Pigeonhole Polls and Q&A Sessions

Highlights from the polls and the open Q&A sessions will be listed in this report in the order that they were administered during the NEXT meeting.

Poll 1 – The Pre-Meeting Polls

This poll was to assess the participants' expectations regarding a new science plan and a new riserless vessel to replace the *JOIDES Resolution*:

- Participants were asked if they think the titles of current IODP science plan themes (Climate and Ocean Change, Biosphere Frontiers, Earth Connections, and Earth in Motion) effectively communicate the scientific priorities of IODP? To this question **59.5%** of the participants said no, indicating a major restructuring of the science plan is likely to be needed.
- A vast **93.8%** majority of the participants viewed as high the need for a riserless, *JOIDES Resolution*-type vessel in resolving the outstanding or emerging challenges in future scientific ocean drilling (with **5.4%** moderate; **0.8%** low).
- Participants were more divided on their perception for the need for a riser-equipped *Chikyu* in resolving the outstanding or emerging challenges in future scientific ocean drilling (with **54.2%** high; **46.8%** moderate; **8.1%** low).
- Participants had a slightly higher perception for the need for a Mission Specific Platform (MSP) program in resolving the outstanding or emerging challenges in future scientific ocean drilling (with **64.8%** high; **30.5%** moderate; **4.7%** low).

Poll 2 – The Pre-Meeting Open-Ended Question

The participants were asked before arriving at the NEXT meeting to describe, in no more than two or three sentences, what IODP provides to the scientific community that *cannot* be accomplished any other way. Highlights of the *Pigeonhole* discussion include:

- IODP provides a platform for large-scale international and interdisciplinary science that touches on all aspects of Earth science from the mantle to the Earth's fluid and biological envelope.
- IODP has provided the scientific community with continuous, long-term, and high-resolution records for which to understand Earth's past climatic events, plate tectonics, and marine evolutionary events.
- IODP is the Earth science version of the Hubble Telescope or the Large Hadron Collider. It samples otherwise inaccessible places to answer big questions (plate tectonics, climate history, etc.) and takes human exploration to places previously unimaginable, discovering entire new fields of science along the way.
- Through a multidisciplinary approach, IODP provides access to a treasure trove of information about geologic processes and Earth's structure, and helps reconstruct history and evolution of the Earth.
- IODP provides knowledge and understanding of the evolution of the Earth's oceans, climate, biosphere, and tectonic motions. It successfully brings the global science community together through geologic time.
- IODP wrote the book when it comes to past climate changes, older than the ice core data, and has provided an understanding of past climate changes that are analogous to aspects of present climate changes.

Poll 3 – Day 1 Demo Questions during Pigeonhole Introduction

This poll was setup to show participants how *Pigeonhole* works, but also to get a pulse on what the community is looking for regarding the future of IODP:

- A majority of the participants see a need for the current IODP Science Plan to be modified for the future, as **66.1%** voted to change it significantly; while **33.1%** voted to change it only marginally.
- A vast majority of **91.3%** of the participants agree that the U.S. platform should continue to follow a regional track with the goal of circumnavigating the globe at least once in the next decade.

Open Session 1 – Questions and Comments on 2017 JRAW Survey and the 2019 NEXT Mini-Survey Results

The participants were queried regarding the future of scientific ocean drilling following the presentation from Dr. Beth Christensen on the *JOIDES Resolution* Assessment Workshop (JRAW) and the results from the NEXT survey applicants had to fill out to participate to the workshop. Highlights of the discussion include the following:

- There is a strong consensus that the new science plan needs to be new and innovative and significantly different from the previous science plan. This will prevent segregation of the various specialties.
- IODP has been extremely successful in the past and should be confident in moving forward and focus on doing great science. While being confident and ambitious, IODP needs to convince others (funding agencies, the public, etc.) that more drill cores are necessary to answer the pertinent scientific questions.
- Thematic priorities should not be forgotten as the *JOIDES Resolution* scheduling is based on regional planning. However, these challenges could be overcome by a heavier use of the MSPs.
- JRAW was a useful and excellent summary of how science on the *JOIDES Resolution* has been accomplished relative to the four themes of the current IODP#2 science plan.

Open Session 2 – Questions and Comments on Newly Proposed U.S. Riserless Ship by JRSO and the Related Timeline

The participants were asked to comment on the presentation about the proposed new U.S. riserless research vessel and its timeline presented by Dr. Bradford Clement of the *JOIDES Resolution* Science Operator (JRSO). Overall, the community is extremely excited by the proposed option for the acquisition of a new and improved vessel to replace the *JOIDES Resolution*. The *Pigeonhole* discussion on this topic was limited, but the few comments included the following:

- Some improvements that scientists would like to see include a strengthened hull to break ice, a closed moon pool to reduce drag, directional drilling, larger recreational and living space, improved internet broadband capacity, and potential for diamond coring.
- The new vessel would benefit greatly by having a ROV capabilities (on the back deck using at sea containers) as they are an unprecedented opportunity to gain more spatial/temporal data to complement drilling data.
- Safety remains an important issue and a new vessel should be up to modern standards, like allowing for drilling in the U.S. Gulf of Mexico.
- It would be interesting to convert the current *JOIDES Resolution* into a museum for Earth sciences.

Open Session 3 – Results from Breakout #1 – New Themes, New Science Challenges, New Crosslinks

The charge for Breakout #1 was to identify emerging science, hot topics and new concepts, building and expanding on the successes of the current IOPD#2 science plan. The participants were divided in groups as per the previous IOPD#2 themes, and together they developed new and/or repackaged science objectives, which did not have to fit within the previous themes. Highlights of the discussion include the following:

- A common theme of scientific ocean drilling is the interdisciplinarity of the work and many challenges are relevant across many themes. An example of this interdisciplinarity is serpentinization, which is a recurring topic for fault rheology, slow slip, deep life, fluxes, and deep carbon capture.
- Many themes are of interest to the scientific ocean drilling community, including but not limited to Earth's dynamics, life and microbial activity, submarine volcanic eruptions, ocean health, the Miocene.

Open Session 4 – Questions and Comments on the Proposed Strawman Science Plan Structures in the Reading Materials and in Plenary Session

The participants were queried regarding the structure of the new science plan and the elements that compose it. Highlights of the discussion include the following.

- It was proposed that "themes" comprising the plan should be "more accessible and less academic" as an important audience will be funders and legislators.
- The "Mission Earth" title was discarded for a variety of reasons (too terrestrial, was a series of novels by L. Ron Hubbard, already used by NASA, etc.).
- It was recognized that the new science plan should "clearly articulate… how program execution over the next 10 years will likely result in compelling, transformative discoveries of broad societal interest/importance."

- Community engagement was proposed to be a central part of the plan. Substantial discussion ensued regarding community engagement, social media, and the potential contributions of different segments of the scientific community.
- It was proposed that students/postdocs and other early-career professionals take the lead in community engagement and social media outreach, with mixed comments on both sides.
- It was also proposed that "society or societal interest" (societal relevance) be integrated into all of the "themes" rather than standing on its own as a "society and hazards" theme.

Open Session 5 – Results from Breakout #2 – Strawman Science Plan Structures

Breakout #2 was tasked with formulating a strawman of the new science plan structure. Discussion centered on the composition and names of the science plan, and the "themes" comprising it. Highlights include the following.

- A 3 x 3 matrix consisting of "themes" and "cross-theme interactions" or "threads" was discussed as a good structure for the new science plan.
- Theme names should be easily understood by the general public and politicians.
- Infographics are important to present the structure to the public.
- Names considered for the plan included "Exploring Hidden Earth," "Changing Earth," "Exploring the Hidden Blue Planet," "Preserving Earth for the Future."
- Theme names included "Life and Habitability," "Mission Emerging Topics," "Hazards," "Ecosystem Services," "Geo-system Services," "Planetary Monitoring, Planetary Dynamics, Planetary Habitability, Planetary Climate," "Earth Dynamics."

Open Session 6 – Questions and Comments on New Science Plan Diagrams

This discussion focused on the need and components of diagrams to illustrate the structure and objectives of the new science plan. This included the creation and discussion of diagrams by breakout groups. Part of the purpose of this discussion and exercise was to help focus the structure of the plan.

- It was recommended that the focus should be on the science first, and not the diagrams. Professional designers can create the diagrams. The exercise was deemed premature by many.
- This open Q&A session also discussed a new acronym for the program. It was proposed that we stick with IODP or something similar to maintain the legacy, or at least have "Scientific," "Drilling," and "International" in the name.
- Name change would help to distinguish new endeavors from those that occurred under DSDP, ODP and IODP.

Poll 4 – End of Day 1 – Science Plan Structure

At the end of Day 1, which included two breakout sessions and many presentations, participants were asked if they agreed that the new science plan needs to highlight connections (threads) between key ideas (themes). Nearly all participants said yes with a majority of **96.8%**. Here are some of the comments:

- Science, not structure, should be the drivers of the next science plan. There should be specific questions to be addressed that are interdisciplinary in nature.
- The information on the themes and threads should be presented upfront and be associated with a good infographic.

Poll 5 – End of Day 1 – "If you said no"

This open-ended question followed the question in Poll 4 (above) and asked what participants thought the science plan should be like, if it did not follow the threads and themes structure presented in Poll 4. Comments included:

- The science needs to come first. If a 'thread' does not really touch more than one theme, that is fine as long as there is a strong scientific rationale. Many threads will cross through each theme and cross-link many themes.
- We have talked about form and not essence of the science – the latter which must come first.

Poll 6 – End of Day 1 – General Workshop Question 1

This open-ended question asked participants what had been most valuable to them in Day 1 of the workshop. Comments included:

- The idea that overarching themes should be simple, relevant and exciting enough to be shared with government officials, the public, as well as IODP scientists.
- Seeing similarities in potential science plan structures from different working groups and seeing the structure coalesce, also seeing coalescence with J-DESC and PROCEED.
- Seeing NEW ideas and knowing that we are not done with scientific ocean drilling.
- *Pigeonhole* providing a level playing field for anonymous comments to be evaluated without demographic information.
- Group discussions with diverse viewpoints, engaging large numbers of people in the process.
- Several votes for "Life and Time on Our Ocean Planet" as a title for the program.
- Information on the new ship and funding possibilities for the new vessel, although there were concerns about not going after an ice-capable vessel.
- The idea of themes and threads/pathways.

Poll 7 – End of Day 1 – General Workshop Question 2

Poll 7 provided a forum for addressing "concerns or suggestions for improvement" in the meeting design and implementation, although discussions veered away from this central topic. Highlights included:

- Bio-breakout group had excellent ideas but they were buried in the discussion, and life was treated as an add-on. Life in the context of environment is critical.
- The need was expressed to describe a list of the grand questions driving the science for the coming decade. Similarly, the scientific rationale and important questions that justify the program are paramount.
- It was expressed that the science should drive the communication strategy. Big questions need to be defined (analogues for the origin of life, habitability, etc.).
- The science plan should express a commitment to diversity, inclusion, accessibility, and equity in all aspects of the new program.

Open Session 7 – Results from Breakout Session #3 – Fleshing Out the New Science Plan Structure

This question requested feedback from Breakout #3, in which workshop participants, with the exception of early-career researchers, were assigned randomly to one of four groups, each of which was asked to propose an innovative science plan structure for the next phase of ocean drilling. For this Breakout #3 the early-career researchers met as a separate group. Highlights included:

- The responses that resonated most with attendees focused on equal weighting between what are currently referred to as "themes" and what in the future might be referred to as "threads" — that is, connections that run through each of the "themes." In this, avoiding "siloed" science themes was seen as a very high priority in order to emphasize the interconnectedness of various threads and concepts in IODP research.
- Attendees also noted that while this added some complexity to the design of a new science plan, keeping the number of themes no higher than 3 provided conceptual simplicity. The "power of three" was invoked as an important guide in communications.
- Regardless of the final science plan structure, specific overarching science questions will be needed to underpin this structure. Engineering and technology development will need to be highlighted in any new science plan structure.
- A professionally-designed and innovative diagram to represent the new structure will be critical in communicating its aims.

Open Session 8 – Comments Regarding the International Planning Workshops

This question invited general comments on all of the international post-2023 planning workshops that were held in 2019 (Japan, ECORD, ANZIC and U.S.).

- Concern was expressed that ECORD did not "seriously address" how to increase support for the IODP platform that their own scientists use most — the *JOIDES Resolution*. A respondent noted that ECORD's annual budget is ~$17M, $7M of which is allocated to the U.S. for *JOIDES Resolution* operations and $3M to Japan for the *Chikyu*. The remaining $7M covers MSPs and management costs. ECORD management is eager to increase core contributions, but it is complex to deal with 15 different funding agencies.
- The themes and science that emerged from the ANZIC workshop (Biosphere Frontiers; Earth Dynamics: Core to Crust; Global Climate; Natural Hazards; Ocean Health Through Time) received significant support.
- There were a significant number of comments related to diversity in this question, as the question was posted after a diversity-themed discussion in plenary. There was clear interest in increasing diversity in IODP and the geosciences in general; the lack of diversity in the community decreases our relevance to society.
- Investing in sustainable education programs that "widen the pipeline" of incoming scientists received strong support.

Open Session 9 – Comments on New Communities

This question explored establishing connections with other science programs and attracting participation of scientists who have not traditionally been involved with scientific ocean drilling.

- There was support for emphasizing the *exploratory* nature of scientific ocean drilling (as NASA does) in order to connect with the public and other programs, though it was also noted that NSF funding is oriented toward hypothesis testing so the scientific ocean drilling mission is fundamentally different from NASA's.
- Support for "big data" was strong, and "data expeditions" have a real potential for drawing more scientists into the community.

Poll 8 – Big Data as 4th Platform?

This poll put forward the question: "Do you think that a Big Data platform should be added to the Science Plan moving forward?" 70 participants voted **55.7%** "Yes" to the inclusion of Big Data. Comments included:

- This is an extremely important issue and there needs to be a data initiative to better integrate IODP data.
- Yes, to the importance of a big data initiative, but no to calling it the 4th platform.
- Not clear how the data initiative would be implemented.

Open Session 10 – Results from Final Breakout #5 Session

This question invited general feedback after the final breakout session, with participants again assigned randomly to one of four breakout groups and the early-career scientists meeting as the fifth group.

- The idea of an IODP "brand" for public outreach received strong support.
- It was emphasized that for research on faulting, all types of plate margins should be identified: transform, rifted and convergent. Having hazards as its own theme received mixed support.
- There was support for working more closely with the International Continental Drilling Program (ICDP).

Open Session 11 – Questions and Comments on the Presentation of the IODP Forum Chair

Dr. Dick Kroon, IODP Forum Chair, presented a concept and timeline for consolidation of results from the four workshops into a single roadmap, which involved convening a meeting of representatives from each of the workshop organizing committees, plus representatives from PMOs who did not hold workshops, in July 2019. A document would come out of this meeting and would be posted on iodp.org for community comment. The revised document, based on this community feedback, would be presented at the IODP Forum meeting in September 2019. The actual science plan writers would be selected shortly thereafter.

- Workshop attendees expressed support for this plan.
- There was again discussion of the need to avoid "siloed" science, with many agreeing that the idea of separate "themes" should be avoided or at least de-emphasized.
- The relative balance of the "themes" and their cross-cutting ideas was debated without strong consensus about which should receive more emphasis, though it was noted that the product (or at least its print version) will likely be presented linearly, so it will need to be resolved.

Poll 9 – Synthesizing the List of 144 Scientific Questions

This poll put forward the question: "Do you think that the NEXT steering committee should take the lead in boiling down the 144 science questions that came from the four groups in Breakout #4?" Only 24 participants voted: 18 voted "Yes" and 6 voted "No". Only two comments were made:

- With the condition of adding extra weight to comments of early career members of the steering committee.
- This is your chance to get excited about the suggestions that others have made.

Poll 10 – Questions about the New Science Plan

- Attendees were asked whether they preferred 3 or 4 science plan themes. There were 96 responses, with **72.9%** supporting 3 and **27.1%** preferring 4.
- Attendees were asked whether "hazards" should be a theme topic or crosslink topic. There was a slight preference at **57.3%** for hazards as a crosslink topic.
- The same question was asked regarding "Life," with a solid majority of **67.4%** responding that this should be a theme.

Poll 11 – Additional Poll on Diversity

This question asked about the ways that the U.S. scientific ocean drilling community can increase diversity. The following observations were made:

- It was clear that the community was united on the need for and benefits from this.
- The Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) was advanced as a mechanism to accomplish this. Members of the USSSP E&O staff have begun attending this conference to promote IODP.
- The University of South Florida College of Marine Science just started an HBI/HBCU REU program.
- The need to avoid "tokenism" and overtasking our underrepresented minority colleagues was noted.
- Increasing diversity is not only a pipeline issue, but a retention issue as well.
- The USSSP Ocean Discovery Lecture Series can target institutions with higher percentages of underrepresented populations.
- The possibility of re-instituting the undergraduate trainee program was discussed, with students "embedded" on each expedition.
- The diversity issue exists not only in IODP but in most STEM fields.
- Focusing on technology development and big data analysis would likely attract more members of underrepresented communities.