Scientific Ocean Drilling Beyond 2023

Science Plan Working Group

Columbia University, New York, U.S.A.

July 23-24, 2019

Delegates (18)

Anthony Koppers **(Chair)**	Oregon State University	U.S.
Cristiano Chiessi	University of São Paulo	Brazil
Gail Christeson	University of Texas at Austin	U.S.
Mike Coffin	University of Tasmania	Australia (ANZIC)
Rosalind Coggon	University of Southampton	U.K. (ECORD)
Stuart Henrys	GNS Science	N.Z. (ANZIC)
Yoon-Mi Kim (*in absentia*)	KIGAM	Korea
Iona McIntosh	JAMSTEC	Japan
Katsuyoshi Michibayashi	Nagoya University	Japan
Yuki Morono	KCC, JAMSTEC	Japan
Antony Morris	University of Plymouth	U.K. (ECORD)
Richard Norris	Scripps Inst. of Oceanography	U.S.
Matt O'Regan	Stockholm University	Sweden (ECORD)
Anais Pages	CSIRO	Australia (ANZIC)
Dhananjai Pandey	NCPOR	India
Sandra Passchier	Montclair State University	U.S.
Zhen Sun	S. China Sea Inst. of Oceanology	China
Huaiyang Zhou	Tongji University	China

Others (7)

Jamie Allan	National Science Foundation	NSF IODP
Carl Brenner	Lamont-Doherty Earth Obs.	USSSP
Beth Christensen	Rowan University	U.S.
Dick Kroon	University of Edinburgh	IODP Forum Chair
Maureen Raymo	Lamont-Doherty Earth Obs.	USSSP
Sanny Saito	$MarE^3$, JAMSTEC	J-DESC
Angela Slagle	Lamont-Doherty Earth Obs.	USSSP

PREAMBLE ON PLANNING PROCESS

Six international planning workshops were organized in September 2018, and April-May and August 2019 by IODP-India, J-DESC, ECORD, ANZIC, USSSP, and IODP-China. More than 650 scientific ocean drilling scientists participated, including 32% female and 36% early- to mid-career scientists. The results from those workshops were presented and discussed on July 23-24 during the first meeting of the *Science Plan Working Group* at Columbia University. In this document, the 18 scientist delegates, representing all IODP member countries and consortia, including IODP-Brazil and IODP-Korea (*in absentia*), are providing a consensus proposal for a new science plan structure in support of future *Scientific Ocean Drilling Beyond 2023*. This proposal, also including a roadmap toward publication of the new science plan by June 2020, will be presented to the IODP Forum during its September 2019 meeting in Osaka, Japan.

PROPOSED PLAN FOR SCIENTIFIC OCEAN DRILLING BEYOND 2023

The new science plan for scientific ocean drilling beyond 2023 is structured around **Eight Strategic Objectives** that are based on current knowledge and priorities, and are crafted to be open-ended in order to accommodate and encourage new discoveries and innovations. These strategic objectives emphasize interconnected research questions by focusing on understanding Earth's ***Natural Hazards***, ***Cycles and Rates***, and ***Health and Habitability***, each of which cuts across, or has natural pathways, among the general research topics related to ***Dynamic Earth***, ***Climate and Environment***, and ***Life***.

The new plan has a long-term, greater than 25-year outlook, ending in 2050. This allows the scientific community to apply exciting new foundational approaches that range our research efforts far into the mid-21st century, via the implementation of **Five Long-term Flagship Initiatives** that reflect community priorities expressed through the international planning meetings. These flagship initiatives are based on interdisciplinary research that may reach across several strategic objectives, span multiple expeditions over potentially multi-decadal time periods, and include collaborations with external partner organizations. These initiatives address the eight strategic objectives that form the core of the science plan and are expected to evolve through bottom-up proposal submission and periodic community review between now and 2050.

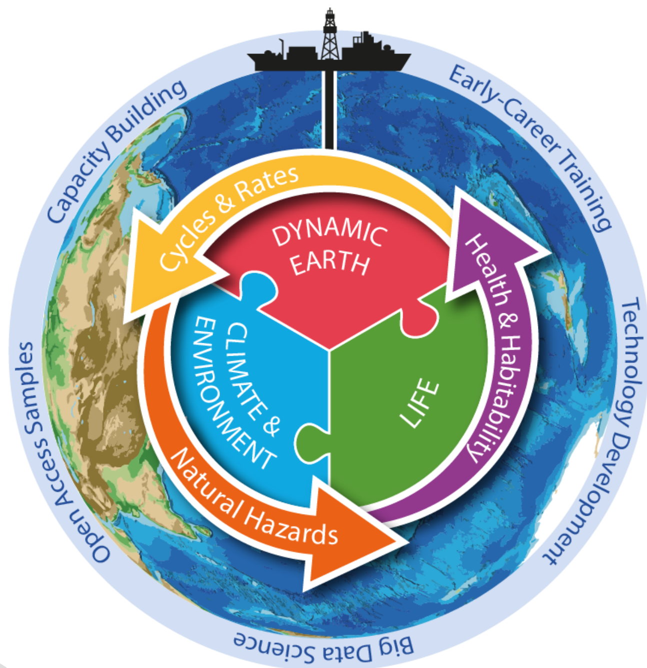
Progress toward the new science plan will be assessed with a five-year programmatic review cycle. This allows for intermediate adjustments or additions to the strategic objectives and flagship initiatives.

A. SCIENCE PLAN TITLE AND VISION STATEMENT

EXPLORING EARTH BY SCIENTIFIC OCEAN DRILLING

To explore Earth system processes and feedbacks through geological time with scientific ocean drilling.

B. Who We Are and What We Do



- We are an international scientific community pioneering large-scale, interdisciplinary research in the subseafloor of the world's oceans.
- We explore Earth systems in places that can only be accessed and understood through scientific ocean drilling.
- We probe past time to reveal the interactions among the oceans, Earth, life, climate, and society.

C. Overall Structure

Scientific ocean drilling through 2050 centers around eight ***Strategic Objectives*** that aim to advance our understanding of Earth as an interconnected system. In this structure five ***Flagship Initiatives*** provide longer-term endeavors to attain fundamental progress in those strategic objective areas that require a sustained, multi-faceted, and global effort. Successes in future scientific ocean drilling are strongly intertwined with communicating our results to the public and policy makers, capacity building within the international scientific community, training the next generation, access to big data science, open access to samples and data, and new developments in technology. This new structure will demand an even stronger interdisciplinarity in scientific ocean drilling. It also shows how our science informs society, while addressing foundational Earth system research questions.

D. Strategic Objectives

A strategic objective emphasizes interconnected research linking science disciplines to address societally critical paradigms. These strategic objectives will apply scientific ocean drilling to make new discoveries and deepen our understanding of Earth's ***Natural Hazards***, ***Cycles and Rates***, and ***Health and Habitability***, each of which can only be addressed by researching the cross-cutting pathways among the broad research areas of the ***Dynamic Earth***, ***Climate and Environment***, and ***Life***.

The eight strategic objectives thus form the core of scientific ocean drilling through 2050. Each objective is described below with example research topics that resonated across all six international planning meetings. Each objective has been designed to be open-ended, to encourage new discoveries and innovations, and allow new Earth system science to emerge through the proposal writing and review process.

- **Define the conditions for life and Earth habitability**
  - How organisms live, interact, and die beneath the seafloor
  - How microbes interact with lithology and fluids
  - Rules of life and how these both govern and are affected by Earth processes
- **Constrain the feedbacks among oceans, Earth, life, and climate**
  - Feedbacks among life, the rock cycle, crustal properties, and mantle dynamics
  - Active tectonics and their impact on oceanic and atmospheric circulation and chemistry
  - Solar, climate, and tectonic factors that govern ocean productivity
  - How subseafloor life and Earth's environment shape the cycling of energy and mass
- **Examine the cryosphere and sea level under different climate states**
  - How mechanisms and rates of sea level change vary through time
  - Feedbacks that lead to ice sheet growth and deglaciation
  - Evolution of polar land and ocean systems under different climate states
  - How the overall cryosphere, including sea ice, permafrost and marine gas hydrates, responded to climate change in the past
- **Use the past to inform our understanding of Earth's projected future**
  - Ocean productivity and ecosystem dynamics in the greenhouse worlds
  - The climatic, biological, and chemical characteristics of an ice-free planet
  - Record and magnitude of human impacts in Earth systems
  - Evolution of ocean health over geologic time in the lead up to the Anthropocene
- **Identify the causes, scales, and consequences of climatic and environmental perturbations**
  - Timescales and patterns of ecosystem recovery after major disturbances
  - Effects of catastrophic environmental perturbations that shaped the history of life
  - Formation of large igneous provinces and their environmental and biosphere impacts
  - Evolution of rainfall and aridity patterns as a function of tectonics
  - Climate teleconnections between the poles and tropics
  - Consequences of reaching different tipping points in the climate system
- **Investigate the life cycle of a lithospheric plate and its impact on the Earth system**
  - Causes and processes of plate boundary formation (including rift zones, ridge systems, transform faults, subduction zones, passive margins) and implications for geohazards
  - Impact of spreading rate, tectonic setting, and geologic aging on lithosphere architecture
  - Hydrothermal and microbiological interactions among plates and the mantle, oceans, and atmosphere, with impacts on geochemical cycles, resources, and life
  - Controls on the biogeography of microbial communities within the oceanic crust
  - Mechanisms of back-arc formation, ophiolite emplacement, and continental growth

- **Characterize the transfer of water, energy and matter in the Earth system**
  - Processes that influence the occurrence and magnitude of volcanism
  - Impacts of geomagnetic reversals and secular variations on the Earth system
  - Evolution of subsurface fluids and influences on life, climate, and geochemical cycles
  - Deep carbon storage in the subseafloor and mantle
- **Assess the conditions and processes that control the occurrence of natural hazards that affect society**
  - Rates and amplitudes of natural disasters in the past
  - Impacts of natural hazards on the climate and environment, including tsunami, hydrate destabilization, and storm surges
  - Feedbacks among sea level, climate, volcanism, and tectonics
  - Physical processes controlling slip behavior at the subduction interface
  - Improving hazard assessment guided by monitoring

E. Flagship Initiatives

The next scientific ocean drilling science plan will have a distant time horizon in the mid-21st century to allow for the implementation of flagship initiatives requiring sustained, long-term research efforts. These flagship initiatives are expected to comprise multi-expedition foundational scientific ocean drilling endeavors that cross-cut multiple strategic objectives and require interdisciplinary efforts over 10-20-year time periods. These flagship initiatives may in particular help address societal challenges.

- **Ground-truthing Future Climate Change**

Climate change is one of the greatest challenges confronting modern society. State-of-the art computer models allow future climate projection, but these models are imperfect and require independent validation. Climate records from across the globe, capturing recent and deep geological time, are essential to understand the feedbacks that operate in both warmer and colder climate states than present. This information is needed to test, train, and improve global climate models, the outputs of which guide international agreements on tackling climate change. Scientific ocean drilling is uniquely positioned to provide these critical ground-truthing data sets over the next decades. A sustained coordinated approach aimed at collecting high-resolution, complete-recovery cores along transects and grids will be required. North-south transects across the ocean basins, from the poles to the tropics, and high-density grids in the polar regions, will provide a fundamental contribution in positioning society for future climate change.

- **Probing the Deep Earth**

The quest to achieve a complete penetration of Earth's oceanic crust has been a long-term aspiration and compelling motivation for scientific ocean drilling, but has been challenging and elusive due to technological limitations and long-range scheduling constraints. Deep drilling is required to understand the formation and evolution of twothirds of our planet's surface, the fundamental nature of Earth's deep interior and its geodynamic behaviour, and the interrelationships between geological, biogeochemical and climate cycles in the wider Earth system. The greater than 25-year outlook of the new science plan will allow the scientific ocean drilling community to adopt a staged approach to reaching the Earth's upper mantle, via a series of interconnected, ambitious expeditions that will take full advantage of emerging 21st century drilling technologies.

- **Diagnosing Ocean Health**

Through scientific ocean drilling, we can explore past interactions between life and Earth's environment leading up to the Anthropocene. The health of our oceans is currently seeing growing impacts of long-lasting human-made materials, gases, and industrial pollutants that contribute to anthropogenic climate change, global ocean acidification, and the expansion of oxygen minimum and dead zones. Still, very little is known about the impact of these contaminants on our oceans and its ecosystem. Geologically-induced perturbations, such as past global warming and cooling, increased global volcanism, oceanic anoxic events, meteorite impacts, and mass extinction events, provide vital instances in the history of our planet when the entire interconnected system of the oceans, Earth, and life underwent a significant readjustment. A concerted effort in future scientific ocean drilling should provide access to comprehensive marine records that contain the pre-Anthropocene baselines and analogs to ocean acidification, deoxygenation, nutrient inputs, and rapid temperature change that could be used to inform the impact of today's ongoing environmental changes and perturbations.

- **Exploring Life and Its Origin**

Scientific ocean drilling has revealed that microbial organisms are present and metabolically-active at kilometers depths in both sediment and ocean crust. Deep biosphere research on these newly discovered lines of Archaea, Bacteria, Eukarya, and viruses remains in its infancy, and most of the deep, hot biosphere is yet to be explored and understood. Scientific ocean drilling through 2050 will allow us to capitalize on new and emerging techniques in this rapidly developing field to explore the fundamentals of life, and its persistence, resilience, interactions and diversity through time. A systematic study of life in the subseafloor throughout the world's ocean basins can provide a powerful approach to unraveling species origin, evolution and extinction, to understanding life on the early Earth, and to characterizing and searching for habitable environments in the universe.

- **Assessing Earthquake Hazards to Society**

The most catastrophic event in recent history was the magnitude 9.1 Sumatra 2004 Boxing Day earthquake and tsunami that killed more than 230,000 people. Natural hazards, including such mega-scale earthquakes, are prominent targets for scientific ocean drilling, because it remains the only tool capable of directly accessing the source regions of these devastating sub-seafloor events. Revolutions in instrument development are enabling us to detect and monitor such natural hazards in novel ways and ever-greater detail. The time is ripe for ambitious, long-term drilling strategies to investigate seismic slip in a range of global fault environments, and through complete earthquake cycles, in order to aid future earthquake and tsunami risk assessments and projections.

F. Relation to Allied Programs

The strategic objectives and flagship initiatives that underpin scientific ocean drilling through 2050 aim to study Earth as an integrated and interconnected system of processes and feedbacks. The science priorities laid out in this new science plan strongly align and complement research initiatives in allied research programs, such as the International Continental Scientific Drilling Program (ICDP) and the National Aeronautics and Space Administration (NASA) and other space agencies around the world (ESA, JAXA, CNSA, ISRO, ASA). The strong alignment is evident in the five science themes of the ICDP science plan that includes ***Active Faults and Earthquakes***, ***Heat and Mass Transfer***, ***Global Cycles and Environmental Change***, the ***Hidden Biosphere***, and ***Cataclysmic Events***, and, for example, is expressed under NASA's Strategic Objective 1.1 ***Understand the Sun, Earth, Solar System, and Universe*** that includes the goal of ***Searching for Life Elsewhere***. Within the new era of scientific ocean drilling we will capitalize on new opportunities afforded by parallel coordinated research efforts within ICDP and the various national space agencies. This will allow for critical new science growth in those overlapping research areas.

G. Big Data Science

Progress toward addressing the eight strategic objectives and the five flagship initiatives increasingly and critically depends on the integration of data sciences using so-called ***Big Data*** in scientific ocean drilling. For example, ground-truthing future climate change based on IPCC climate projections will require data aggregation from hundreds of globally-distributed sites acquired over many scientific ocean drilling expeditions. These analyses are unique, as only scientific ocean drilling is able to acquire data covering large-scale geographic areas with information going back deep into geological time, providing comprehensive baseline data from time intervals under various global climate states. In a similar fashion, exploring life and its origin on Earth would require the building of a subseafloor microbial databank to allow for methodical progress in this flagship initiative. By focusing on FAIR (Findable, Accessible, Interoperable, Reusable) data practices, scientific ocean drilling will allow scientists to focus on the linkages among data types that are critical for meeting our future strategic objectives.

H. Technology, Monitoring and Observatories

Future developments in technology, monitoring, and observatory science will underpin our ability to achieve the core strategic objectives and implementing the flagship initiatives. For example, downhole instrumentation enables studies and monitoring of the earthquake cycle in locations only accessible through ocean drilling. In addition, deep biosphere exploration, and the discovery of life and its diversity, is only made possible by ongoing technological developments. Over the next decades, progress in scientific ocean drilling will continue to be uniquely driven by new technology developments.

I. Societal Relevance and Outreach

Societal relevance is integral to all scientific ocean drilling. This is strongly apparent in the five flagship initiatives that are built upon the eight strategic objectives in the new science plan. Natural hazards, and the health and habitability of Earth and its oceans, are cross-cutting themes central to the well-being of global society. For example, ground-truthing future climate change will provide critical information to all coastal communities threatened by a projected average sea level rise of one or more meters over the next few decades. Studies in aridity, rain, and storm patterns; the hazards resulting from tsunamis, landslides, and earthquakes; and the origin and sustainability of life on our planet, all contribute to prediction and risk assessment of future impacts on society, as well as a more profound basic understanding of the Earth system.

It will be critical to convey the wealth of information gained through scientific ocean drilling to the public across the globe. Outreach and public engagement through consistent media presence, reaching and engaging a broader audience, will need to capitalize on the extraordinary scientific ocean drilling expeditions and initiatives. The scientific ocean drilling community must remain deeply dedicated to increasing public awareness and understanding of the Earth we all inhabit.

Proposed Roadmap Until June 2020

The new science plan in support of scientific ocean drilling through 2050 is proposed to be published by ***June 2020*** based on agreement amongst the 18 international delegates of this Science Planning Working Group. This early publication date will allow IODP partners to start planning for future platform replacements.

A. Products

- **Full Version of International Science Plan:** ~60-70-page document, including an executive summary, written for the overall scientific ocean drilling community.
- **Summary of International Science Plan:** ~12-page document, written in layman's language for society at large.
- **Pamphlet of International Science Plan:** 2-page document, written in language appropriate for funding agencies.
- **National Science Plan Versions, Executive Summaries and Pamphlets:** depending on needs, individual Program Member Offices (PMOs) may opt to produce translated versions of the international science plan, executive summary, and pamphlet, and create derived variations tailored to demands in their countries and consortia.

B. Timeline and Deadlines

DEADLINE	ACTION	DETAILS
11 Sept 2019	IODP Forum discusses new science plan proposal	• Forum endorses new science plan structure and roadmap • Forum selects science plan writing team lead editor(s), number of writers, writer profiles, charge • Forum endorses print/online versions to be produced
16 Sept 2019	Invitations go out to writing team	• Science plan writers accept by 26 Sept 2019
30 Sept 2019	First Zoom meeting with science plan writing team	• Laying out charge to science plan writing team • Assignments for writing chapters
1 Nov 2019	First ***internal*** draft due for review by science plan working group	
1 Dec 2019	Second ***internal*** draft due for review by science plan working group	
8 Dec 2019	Pre-AGU meeting for science plan working group and writing team	
11 Dec 2019	AGU Townhall	• Presentation of new science plan structure and roadmap • Introduction science plan working group and writing team • Q&A session on scientific ocean drilling beyond 2023
15 Jan 2020	Final ***internal*** draft due	
22 Jan 2020	Posting ***public*** draft ***version 1*** online at IODP.org	• Community gets 3 weeks for commenting • Science plan writing team gets 3 weeks for updating the science plan documents
4 Mar 2020	Posting ***public*** draft ***version 2*** online at IODP.org	• Community gets 2 weeks for commenting • A group of external reviewers gets 2 weeks for reviewing • Science plan writing team gets 3 weeks for updating the science plan documents
15 Apr 2020	Final version presented to science plan working group and Forum for endorsement	
30 Apr 2020	Final version to be sent to printer	
June 2020	Publication of new science plan	

C. Science Plan Writing Team

- **11 Writers:** we will invite in total eight writers, who will together work in teams of two on two related strategic objectives, and on one or more flagship initiatives; we will invite three additional writers who will focus on the remaining chapters; each writer will get assigned a primary chapter and will act as a secondary author on one or more other chapters.
- **2 Lead Editors:** the science plan writing team will be led and coordinated by a lead editor and a deputy lead editor.

Charge: the science plan writing team will fill in the science plan structure, but leave the intent of the strategic objectives and flagship initiatives intact. They will write toward a broad audience resulting in mostly jargon-free chapters that will elevate the excitement in our new approaches. They also will emphasize where we have excelled in the past by addressing key science successes and the advances that can be made by new science priorities. They will work together with professional science writers and illustrators.

D. Science Plan Working Group

- **18 Delegates:** these delegates represent all IODP member countries and consortia.

Charge: the science plan working group has four tasks: providing guidance to the writers as guardians of the science plan vision; reviewing the science plan (drafts); endorsing in conjunction with the IODP Forum the final science plan draft; and acting as liaisons with the IODP science community in their PMO countries and consortia.

Note: there will be some overlap in the working and writing groups. The chair of the working group also functions as the lead editor of the writing group; the deputy lead editor also is a delegate of the working group; and some of the other delegates may be invited as science plan writers. This provides efficiencies in communication between both groups, required because of the contracted time line ending in June 2020.

E. Review and Commenting

- **Community Review:** as shown in the timeline table, the overall scientific ocean drilling community will have two opportunities for commenting in January and March 2020; earlier drafts will be reviewed by the science plan working group delegates.
- **External Review:** in addition, draft ***version 2*** of the new science plan will be sent to a group of external reviewers, including researchers outside the IODP community.