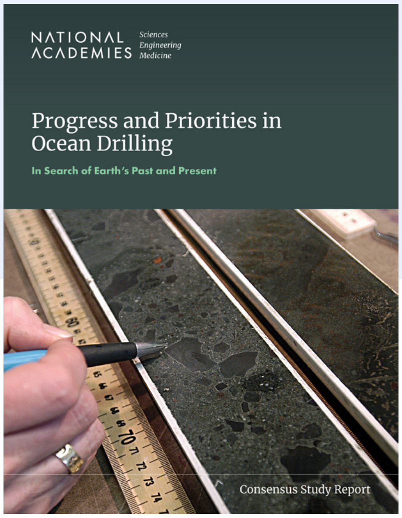
Progress and Priorities in Ocean Drilling: In Search of Earth's Past and Future



Research supported by scientific ocean drilling has fundamentally transformed our understanding of the planet, with key contributions to the discovery and theory of plate tectonics; the formation and destruction of ocean crust; the reconstruction of extreme greenhouse and icehouse climates during the past 100 million years; the identification of major extinctions; and the discovery of a diverse community of microbes in ocean sediments, rocks, and fluids. However, owing to rising costs that now far exceed the funding designated to operate the aging drilling vessel JOIDES Resolution, the NSF will terminate support in 2024. Without a dedicated drilling vessel, the capacity for future scientific ocean drilling for the United States and its international partners will be reduced to approximately 10% of its current capacity.

As the NSF evaluates alternative options for the future of ocean drilling, this report, which was produced at the request of NSF, provides a timely broad perspective of critical research and infrastructure needed to answer the most compelling research questions that can only be advanced with scientific ocean drilling.

FUTURE SCIENTIFIC OCEAN DRILLING PRIORITIES

The report's authoring committee identified five high-priority research areas that continue to require scientific ocean drilling to be understood. However, funding for scientific research is not unlimited and forward-looking prioritization is a must. To help guide NSF in setting priorities for investments in research, infrastructure, and workforce development, the committee evaluated each of these priority research areas in terms of two qualities: vital and urgent (see Box 1).

Ground Truthing Climate Change

Advancing understanding of climate and ocean change drivers, feedbacks, and past tipping points - coring the past, informing the future.
'Ground Truthing Climate Change' is deemed both vital and urgent because records recovered through scientific ocean drilling are important past analogues for modern and near future challenges of rapid global warming, sea level rise, and widespread ocean acidification and de-oxygenation. Data from these records are useful because they contain paleoclimate proxies of climate and ocean variables.

BOX 1. VITAL VS. URGENT

The committee defined two prioritization categories that NSF can use to prioritize investments in research, infrastructure, and workforce development:

- "Vital" science encompasses compelling, high-priority research that has the potential to transform scientific knowledge of the interconnected Earth system and the critical role of the ocean . Vital research can lead to paradigm shifts in understanding, potentially opening new doors to research and technology innovations that can benefit humanity with direct societal relevance.
- "Urgent" science is time-sensitive research that is relevant to emerging challenges from regional to global scales. Urgent research needs to be done now in order to understand changes that can inform predictive models and decision-making that may be related to tipping point vulnerabilities.

The proxy data collected serve as surrogates, or indirect indicators, of past changes in temperature, ice volume, and ocean chemistry, among others. One example of the urgency to move forward with this research is to answer questions regarding the potential shut-down of the Atlantic ocean circulation system which would have serious impacts on the habitability of Earth's land.

Future Research: Additional observations are required to assess the skill of climate models to replicate greenhouse gas-forced switches over geological time scales in temperatures, ice-sheet dynamics, sea level, and ocean circulation and constrain the role of feedbacks. To constrain Earth climate sensitivity to high greenhouse gas levels, additional scientific drilling is required to fill data gaps for extreme warm intervals in climatically sensitive regions.

Evaluating Past Marine Ecosystem Responses to Climate and Ocean Change

Using fossils to determine ecosystem responses to past environmental drivers (warming, ocean acidification, and deoxygenation) - a lens informing the future.

'Evaluating Past Marine Ecosystem Response to Climate and Ocean Change' is deemed vital and potentially urgent, especially given the importance of marine ecosystems as a source of food. Just as the past can help understand drivers of climate change, so too, can it provide insights into marine ecosystem responses across multiple timescales and geographies. Records that can only be recovered through scientific ocean drilling can provide insight into past ecosystem responses to accelerated changes in climate and ocean. Such records provide a framework and foundation to situate modern studies of changing climate and ocean conditions, and provide a necessary long-term context to assess impacts and feedbacks on ecosystem dynamics and food webs. Collectively these data inform predictive models of future change.

Future Research: Additional scientific ocean drilling that prioritizes locations with limited records will allow paleo-biologists to inform models of plankton ecosystem dynamics during past analog climate states. Existing long-term paleo-records can be further exploited for studies, capitalizing on the development of new databases and existing core samples to more fully assess global marine ecosystem responses to climatic and oceanic shifts.

Monitoring and Assessing Geohazards

Providing data to more accurately forecast and assess future risks of earthquakes, volcanic eruptions, submarine landslides, and tsunamis.

Deep, subseafloor observatories are used for both vital and urgent research under the theme of 'Monitoring and Assessing Geohazards.' These observatories allow smaller events to be detected and improve the potential for future earthquake forecasting. The results of this research could have direct societal benefits in terms of preparing for and better mitigating future geohazard risks.

Future Research: Future studies of subduction systems will allow scientists to more deeply understand different conditions that promote either seismogenic or stable fault motion.

Exploring the Subsea Biosphere

Advancing understanding, discovery, and characterization of the world of living microbes below the seafloor.

'Exploring the Subseafloor Biosphere' is characterized as vital although the research is more exploratory in nature. Building on pioneering research by ocean drilling, the exploration of sub-surface microbial life is on the cusp of discoveries that are expected to transform scientific understanding of microbial activity in extreme environments. Understanding the limits of life requires knowledge of the complex exchanges of fluids and nutrients that occur between the subseafloor biosphere, Earth's crust, the ocean, and the atmosphere.

Future Research: Scientific ocean drilling is necessary to address key unanswered questions in subseafloor biosphere research, which has direct implications for understanding the potential for life in other areas of the solar system, the origins of life on Earth, and the integral building blocks of ecosystems that nurture the biological world.

Characterizing the Tectonic Evolution of the Ocean Basins

Advancing understanding the dynamics of tectonic processes and the cycling of energy and matter between Earth's interior and the surface environments

'Characterizing the Tectonic Evolution of the Ocean Basins' is considered vital high-priority research. Sampling oceanic crust of different ages provides insight into processes that govern the occurrence of earthquakes, tsunamis, and volcanoes and the global cycling of energy and matter that produces economic resources of importance now and in the future.

Future Research: Only scientific ocean drilling can provide key constraints on the formation and evolution of oceanic crust and upper mantle. The cycling of fluids through the subseafloor and corresponding chemical exchanges have implications for processes with direct societal relevance, including the production of mineral resources, sequestration of atmospheric CO2, and origin of geohazards.

Though differing in detail and nuance, the five priority areas identified by the committee align with the initiatives identified throughout the years by the scientific ocean drilling community and directly connect to U.S. research priorities identified by the White House, the scientific ocean drilling community, and several previous National Academies' studies.

USING RESOURCES AND LEGACY ASSETS WISELY

While not all scientific objectives will be met without collection of new cores and installation of new observatories, opportunities exist to use available archived materials to accomplish essential ground-breaking scientific research. For example, the scientific ocean drilling community has proposed a new approach to collaborative research, with the first call for proposals for Legacy Asset Projects (LEAPs) issued in October 2023 by the IODP Science Support Office. If funded, LEAPs will provide opportunities to maximize the use of already acquired material and data to foster discovery and innovation.

As one example, scientific ocean drilling data can be used to help answer some of the fundamental questions surrounding marine carbon dioxide removal and sequestration approaches. Data can help characterize basement rock, understand rock alteration and mineralization, and evaluate potential for storage of carbon dioxide in the ocean crust.

However, many of the vital and urgent science priorities cannot be addressed with existing cores and data as the high demand core materials in critical locations and intervals have been depleted by use. An ideal scientific drilling program would include a robust LEAPs program combined with recovery of new subseafloor cores and installation of borehole observatories that address the five high priority research areas.

INFRASTRUCTURE NEEDS

Based on the five high-priority areas for future scientific ocean drilling, the committee identified criteria for successful achievement of the scientific goals. Rather than recommend

FIGURE 1: Example of a highly sampled core for an interval of high scientific interest. Styrofoam spacers (white) replace samples that have already been used. SOURCE: JRSO

any specific path forward in terms of drilling infrastructure, key parameters necessary for successful fulfillment of the "Urgent" and "Vital" scientific themes were identified. Theses drilling parameters include capabilities such as water depth, coring depth, the ability to collect cores continuously, and the ability to install and operate in situ observatories deep below the seafloor. It is clear that at a minimum, a drilling vessel that can operate in water depths greater than 3,000 meters and can penetrate sediment and rock deeper than 30 meters below the seafloor is a requirement for progressing all vital and urgent scientific ocean drilling priorities.

Additionally, the need for a diverse, equitable, and inclusive workforce in ocean science and engineering is identified as an infrastructure component fundamental to the advancement and future success of scientific ocean drilling. A trained workforce has been and will continue to be critical to the future of all ocean sciences, and ocean drilling contributes significantly to this goal. Some of the highly specialized positions in the drilling program will likely be lost with the closure, or even temporary cessation, of the U.S. scientific drilling program.

Another vital criteria is a nimble and focused management structure which is key to a sustainable and successful future U.S.-based scientific ocean drilling effort. Identifying the minimum required program capabilities to advance vital and urgent scientific goals would help to facilitate a stable, successful, dynamic, and sustainable U.S. scientific ocean drilling research program.

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