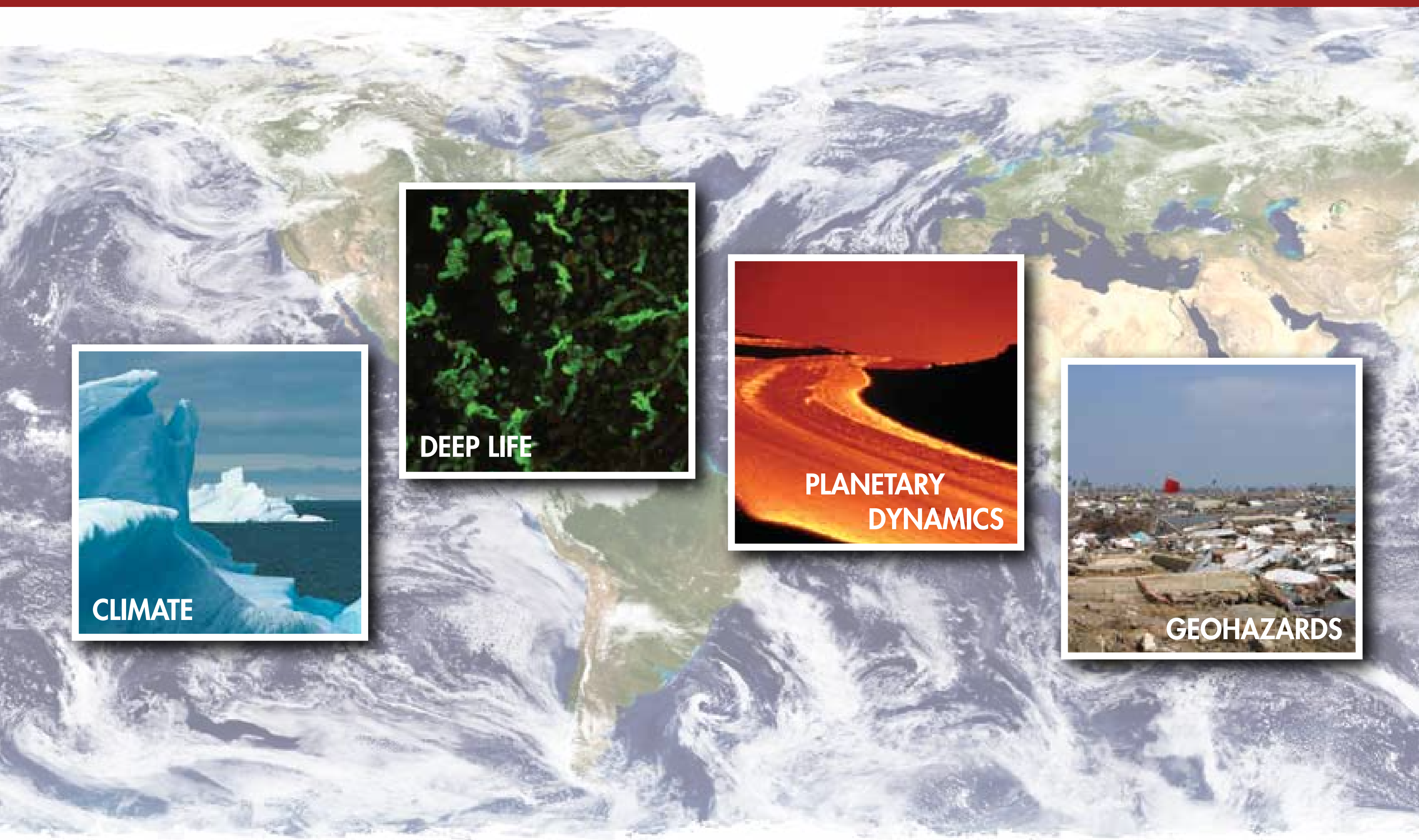
Illuminating Earth's
Past, Present, and Future



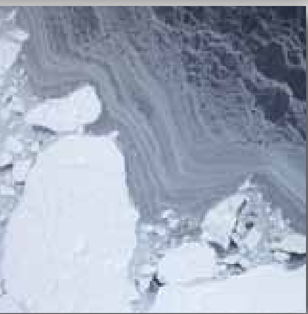
THE INTERNATIONAL OCEAN DISCOVERY PROGRAM

EXPLORING THE EARTH UNDER THE SEA

Summary

OF THE SCIENCE PLAN FOR 2013–2023








The International

GLOBAL PARTICIPATION

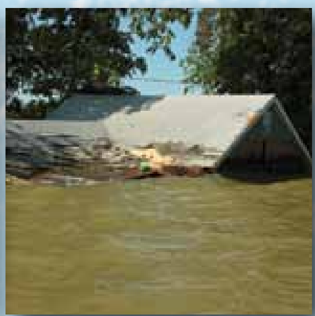
Scientific ocean drilling is an international, multidisciplinary collaboration among scientists, students, engineers, marine technicians, and educators. Every year, thousands of people around the world develop drilling proposals, collect data in support of drill site planning, sail on drilling expeditions, operate the drilling rigs, analyze post-cruise samples and data, and disseminate results to the scientific community, in the classroom, and to the public.

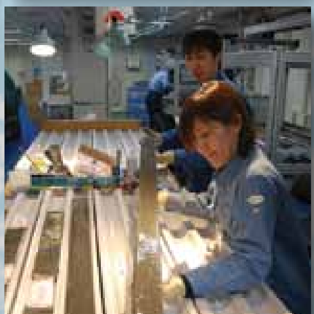
EXPLORING THE EARTH UNDER THE SEA

Ocean Discovery Program

As Earth's population expands, changing climate conditions, increasing demand for resources, and the risks of geohazards such as earthquakes and tsunami demonstrate the need for better understanding of the close connection between the Earth system and daily human life. Millions of years of Earth system change—devoid of human influence—are recorded in the sediments and rocks located beneath the seafloor, providing a baseline record against which we can compare current and future planetary change. The seafloor itself contains potentially valuable new resources and hosts novel microbial communities that live at the limits of habitability. The flows of mass and energy from Earth's deep interior to the surface create new crust, build volcanoes and islands, and generate earthquakes and landslides. Scientific ocean drilling provides the only means to access valuable historical information, collect samples and data, conduct experiments, and monitor conditions and active processes as they occur in remote marine environments. The 10-year International Ocean Discovery Program's four research themes, addressing fundamental questions about Earth's climate, deep life, geodynamics, and geohazards, will facilitate a long-term, global perspective on some of today's most pressing environmental issues.







RESEARCH

Climate and Ocean Change: Reading the Past, Informing the Future

Photos courtesy of (from top):
(1) IODP/ECORD
(2) US Geological Survey
(3) IODP/USIO
(4) Ted Scambos and Rob Bauer, NSIDC

CHALLENGES

1 | How does Earth's climate system respond to elevated levels of atmospheric CO_2?

2 | How do ice sheets and sea level respond to a warming climate?

3 | What controls regional patterns of precipitation, such as those associated with monsoons or El Niño?

4 | How resilient is the ocean to chemical perturbations?

How will climate, the ocean, and ice sheets respond to ongoing increases in greenhouse gases? Deep-ocean sediment cores are the most important, widespread, and continuous archives of Earth's climate history. Information extracted from these cores provides the majority of what we know about global changes to the Earth system prior to the last ice ages, and is used to reduce the uncertainty in models that predict future climate changes. For example, decline of summer sea ice cover in the Arctic Ocean and polar ice covering Greenland and western Antarctica is occurring more rapidly than predicted by climate models. To better understand Earth's response to rapid climate changes, and how different parts of Earth's climate system interact to amplify or diminish the effects of increasing global temperatures, scientists must collect and analyze environmental information from deep-ocean sediments that were deposited millions to tens of millions of years ago when atmospheric carbon dioxide levels and global temperatures were much higher than today. These records of the ocean's physical, chemical, and biological responses to past changes in greenhouse gases will enable us to:

- Assess the sensitivity of global climate and ocean ecosystems to sustained higher levels of greenhouse gases
- Better predict the amplitude and timing of future sea level changes that may result from the disintegration of large ice sheets
- Address how changes in ocean and atmospheric temperatures may influence regional precipitation patterns, and hurricane distribution and frequency
- Resolve how the ocean responds to increased acidity, elevated levels of nutrients, and other chemical changes

THEMES

Biosphere Frontiers: Deep Life and Environmental Forcing of Evolution

CHALLENGES

5 | What are the origin, composition, and global significance of deep subseafloor communities?

6 | What are the limits of life in the subseafloor realm?

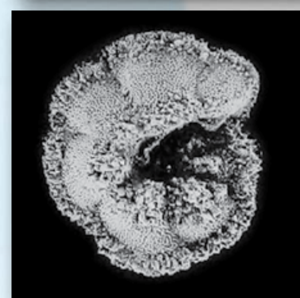
7 | How sensitive are ecosystems and biodiversity to environmental change?

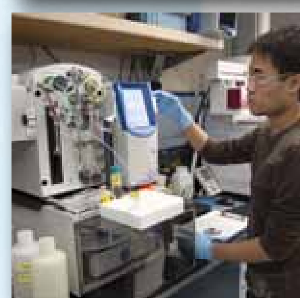
Earth's biosphere includes regions far below our planet's surface, extending deep into ocean sediments and rocks. Understanding the origins and evolutionary history of the deep biosphere, the mechanisms that fuel microbial growth, and what characteristics of subseafloor environments make microbial life abundant will provide insight into the evolution of ancient life on Earth and perhaps inform ideas on life elsewhere in our solar system. The activities of these pervasive buried microbial communities may influence global biogeochemical cycles, mineral alteration, and the production and destruction of hydrocarbons.

Above the seafloor, many ocean ecosystems are being stressed by rising temperatures, hypoxia, and acidification. Seafloor sediments preserve the history of biodiversity in the ocean, including the origin and extinction of species, and can be used to better understand how current environmental change is affecting marine biodiversity. In addition, land-derived material within deep-sea cores can provide a record of climate shifts and related changes in terrestrial ecosystems that may have affected evolution, including that of hominids in Africa.

Samples and data provided by the International Ocean Discovery Program will help to:

- Understand the physical and chemical limits to life in the subseafloor, including mechanisms that microbes use to generate energy and fix carbon far from the influence of Earth's surface (photosynthetic) environments
- Elucidate the composition and diversity of subseafloor communities, the processes by which they are established, and the ease by which they disperse and find new resources
- Determine the timing of extinction and speciation events, rates of oceanic migration, and the speed of threshold shifts within ecosystems in response to rapid environmental change





Photos courtesy of (from top):
(1) IODP/USIO
(2) Olsson et al. (1999), Atlas of Paleocene Planktonic Foraminifera, *Smithsonian Institution Press*
(3) IODP/USIO
(4) Imachi et al. (2011), The ISME Journal, doi:10.1038/ismej.2011.64

Earth Connections: Deep Processes and Their Impact on Earth's Surface Environment

Photos courtesy of (from top):
(1) IODP/USIO
(2) Commonwealth Scientific and Industrial Research Organisation
(3) D. Buchs, Université de Lausanne
(4) R. Hadian, US Geological Survey

CHALLENGES

8 | What are the composition, structure, and dynamics of Earth's upper mantle?

9 | How are seafloor spreading and mantle melting linked to ocean crustal architecture?

10 | What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?

11 | How do subduction zones initiate, cycle volatiles, and generate continental crust?

The primary transfer of energy and material from the deep Earth to the surface environment occurs when seafloor volcanism creates oceanic crust, including mid-ocean ridges, seamounts, volcanic islands, massive oceanic plateaus, and island arcs. Melting processes that generate these features leave nuanced records in seafloor rock of the mantle's thermal state and composition. Over millions of years, oceanic crust exchanges chemicals with seawater, forming mineral deposits near mid-ocean ridges and leaving an imprint of past ocean chemistry in the altered rocks. At subduction zones, recycling of material back into Earth's interior releases volatiles and results in some of the most explosive volcanic eruptions on Earth. Studies of the oceanic crust and upper mantle are essential for understanding the influence of deep processes on Earth's surface environment and for linking conditions and processes active today with those that have shaped our planet for billions of years.

Scientific ocean drilling will:

- Pursue the challenge of penetrating the 5–6 km thick oceanic crust and directly sampling for the first time the underlying mantle from which all oceanic crust, and much of the continental crust, is derived
- Test three-dimensional models for the formation of oceanic crust—a process that has created two-thirds of Earth's surface in less than five percent of Earth's history
- Decipher the record of seawater-rock exchange and quantify its role in global geochemical cycles of important elements such as carbon
- Probe how subduction initiates and how ocean island arc formation may provide the initial building blocks of continental crust

Earth in Motion: Processes and Hazards on Human Time Scales

CHALLENGES

12 | What mechanisms control the occurrence of destructive earthquakes, landslides, and tsunami?

13 | What properties and processes govern the flow and storage of carbon in the subseafloor?

14 | How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?

Many dynamic Earth processes occur on a human time scale. Strain accumulates and releases, causing earthquakes, landslides, and tsunami. Carbon is cycled and stored in subseafloor sediments and the igneous oceanic crust. Heat, solutes, and microbial materials flow between the ocean and subseafloor. These active processes and interactions are directly observable through scientific ocean drilling and associated borehole experiments.

Recent advances in downhole measurement tools and the establishment of long-term borehole observatories now enable continuous monitoring of subseafloor processes. Long-term data collection allows quantification of system response to natural and induced perturbations. Interactive, real-time observations of Earth in situ provide unique opportunities for engaging students and the public.

Scientific ocean drilling tools and experiments will:

- Measure and monitor rock properties and conditions that might be associated with very large earthquakes and tsunami at subduction zones
- Explore the formation, distribution, dissolution, and impacts of gas hydrate deposits within marine sediments on Earth's carbon cycle, biogeochemical systems, and climate
- Facilitate pilot studies of subseafloor carbon sequestration within the marine environment in collaboration with national and international programs
- Quantify the extent, rate, and influence of large-scale fluid flow below the seafloor that affects microbial systems, stress-strain behavior, and heat and solute transport

Photos courtesy of (from top):
(1) IODP/USIO
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(3) IODP/JAMSTEC
(4) US Geological Survey

GLOBAL SCIENTIFIC

DRILLING PLATFORMS

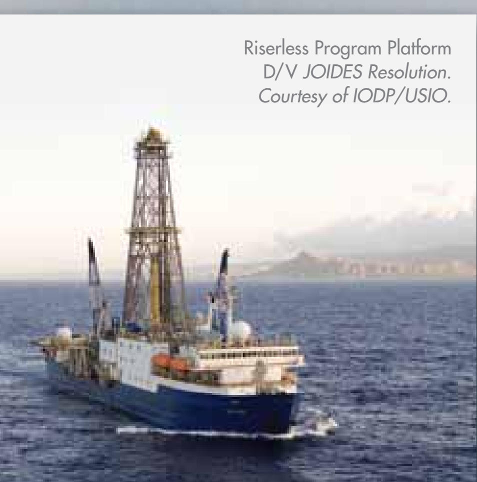
Three complementary drilling platforms will be used to address the scientific challenges of the International Ocean Discovery Program.

The US-supplied riserless drillship *JOIDES Resolution* is the workhorse of the international community. Operating with as close to a full annual schedule as possible, this vessel will provide the most flexible and multifunctional "tool." It can drill, core, and collect downhole logs in water as shallow as 75 m, and as deep as 6000 m, and has a "lab stack" that houses numerous state-of-the art laboratories.

Chikyu, a state-of-the-art, deepwater riser drilling platform supplied by Japan, is expected to be made available for scientific drilling for about five months per year. This vessel will provide access to the deep oceanic crust, the underlying mantle, and seismogenic zones, and to geological and biological systems in hydrocarbon-prone regions. *Chikyu* is equipped with a suite of state-of-the-art laboratories similar to *JOIDES Resolution*.

Mission-specific platforms, supported by the European Consortium for Ocean Research Drilling and chartered from industry according to specific needs, are expected to involve one major operation per year. These diverse platforms will continue to operate at the frontier of challenging drilling environments, including the high Arctic and shallow-water reefs.

Example of Mission-Specific Platforms. *Courtesy of IODP/ECORD.*

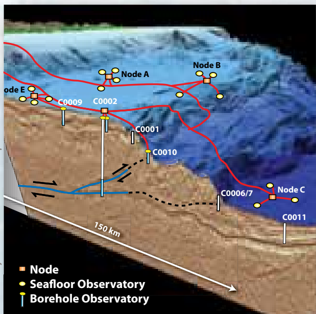


Riserless Program Platform D/V *JOIDES Resolution*. *Courtesy of IODP/USIO.*

Riser Program Platform D/V *Chikyu*. *Courtesy of IODP/JAMSTEC.*

CAPABILITY

SUBSEAFLOOR OBSERVATORIES



Courtesy of the IODP Exp. 319 Scientists

The technology and scientific communities engaged in subseafloor observatory science have developed from within the ocean drilling community. Researchers are pushing toward greater depths and higher temperatures and pressures, making measurements of conditions in situ, recovering samples of fluids and microbial material, and conducting active experiments to investigate fluid flow, deformation, and seismicity. International teams are linking subseafloor observatories through cabled networks for real-time monitoring off the shores of Japan and western North America. Europe and China are developing plans for similar networks. The development and operation of subseafloor observatories will be coordinated with seabed and water-column studies.

GLOBAL DEEP-SEA CORE REPOSITORIES

Courtesy of IODP/USIO

Scientific ocean drilling cores collected from the start of the Deep Sea Drilling Project (1968) are kept in three regional core repositories: The US Gulf Coast Repository in College Station, Texas, the Bremen Core Repository at the University of Bremen, Germany, and the Kochi Core Center at Kochi University, Japan. Curators oversee the cores and their sampling during operations at sea and at the core repositories. These cores are available for sampling by scientists from all over the world.

DATA MANAGEMENT AND INFORMATION SERVICES

The International Ocean Discovery Program will use a common data and information portal to provide a single point of access to expedition-generated core descriptions, core measurements, logging data, publications, and post-expedition data. This portal is built on open-source components and uses international standards and protocols for metadata and data.

Continuing with the successful practices of the previous drilling program, the International Ocean Discovery Program will publish its initial drilling results and core descriptions on the program's website. Short, peer-reviewed summaries of initial scientific results will appear in the journal *Scientific Drilling,* published jointly with the International Continental Scientific Drilling Program. All post-drilling research will be published in the open, peer-reviewed literature.

BENEFITS AND


Courtesy of IODP/JAMSTEC

EDUCATION AND OUTREACH

The International Ocean Discovery Program's global array of assets—research vessels with state-of-the-art laboratories, core repositories on three continents, openly accessible data, continuous in situ experimental and monitoring sites, and thousands of professionals worldwide who actively participate in the program—will contribute to a variety of activities, with special emphasis on three outreach initiatives.


Courtesy of IODP/ECORD

Training the Next Generation of Scientists

By providing opportunities for early-career scientists, graduate students, and undergraduates to work alongside international teams of scientists and engineers, the International Ocean Discovery Program will serve as a technical and scientific training ground.

Courtesy of IODP/USIO

Fostering Stewards of the Planet

The International Ocean Discovery Program will give educators access to resources and help them develop materials for teaching geoscience, bioscience, and related disciplines. It will also offer opportunities for educators to participate in hands-on activities at sea and at core repositories, where they can work with scientists on real samples and data.

Informing and Inspiring the Public

The International Ocean Discovery Program will build and maintain a vibrant public communication program, using print, audio, and video media, public institutions, and social networking to inform, influence, and inspire citizens about Earth system and life science.

APPLICATIONS

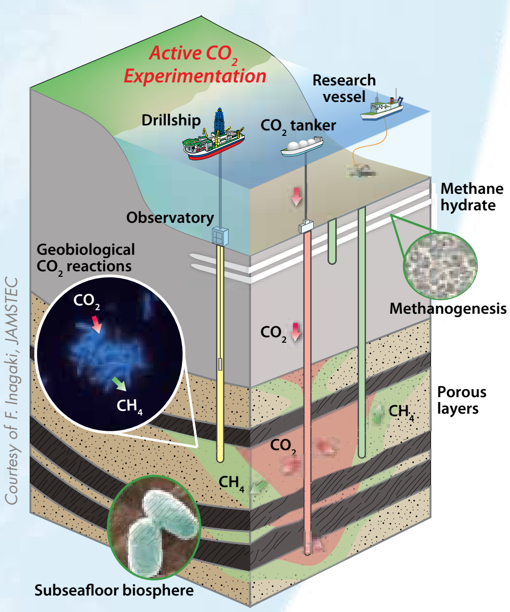
Courtesy of K. Takai, JAMSTEC

COMMON GOALS

The International Ocean Discovery Program research themes incorporate shared interests with other national and international research programs. Some are marine-based (e.g., various ocean observing initiatives, InterRidge, GeoPRISMS). Others focus on land (e.g., International Continental Scientific Drilling Program), ice (Antarctic Geological Drilling), climate (e.g., International Geosphere-Biosphere Programme, Past Global Changes project, European Project on Ocean Acidification), or the deep biosphere (e.g., Deep Carbon Observatory). Among other benefits of collaboration, scientific ocean drilling provides critical geological and biological samples, ground truth of geophysical data, and boreholes for emplacement of long-term instruments offshore.

RESOURCE EXPLORATION AND MANAGEMENT

The research conducted by International Ocean Discovery Program scientists will play a valuable role in establishing the research framework and geological understanding that is necessary for the development of resource opportunities. Scientific ocean drilling contributes to the understanding of gas hydrate formation, extent, and stability; seafloor metal deposit formation; the nature and role of microbial communities in generating and biodegrading hydrocarbons; and potential storage environments for CO_2. The program will also provide access to environments and samples in extreme subseafloor environments where highly adapted microbial communities have the potential to yield novel compounds of medical and commercial value.



Courtesy of F. Inagaki, JAMSTEC

FRONT COVER PHOTO CREDITS

BACKGROUND EARTH. Using a collection of satellite-based observations, scientists and visualizers stitched together months of observations of the land surface, oceans, sea ice, and clouds into a seamless, true-color mosaic of every square kilometer (.386 square mile) of our planet. Credit: NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights). Image from http://visibleearth.nasa.gov/view_rec.php?id=2431

GEOHAZARDS. Debris and standing water left from tsunami, northwestern Sumatra, January 21, 2005. Image from http://walrus.wr.usgs.gov/tsunami/sumatra05/Banda_Aceh/0708.html

BIOSPHERE. Microbes in crust. Credit: Orcutt, B.N., W. Bach, K. Becker, A.T. Fisher, M. Hentscher, B.M. Toner, C.G. Wheat, and K. Edwards. 2010. Colonization of subsurface microbial observatories deployed in young ocean crust. *The ISME Journal*, doi:10.1038/ismej.2010.1157.

FIRST SPREAD PHOTO CREDITS

(1) IODP/USIO. (2) NASA/Digital Mapping System team and Operation IceBridge Arctic 2011. (3) IODP/USIO. (4) Gary McManus, Oklahoma Climatological Survey. (5) IODP/USIO. (6) R. Hadian, US Geological Survey. (7) IODP/JAMSTEC. (8) NASA/Jeff Schmaltz, MODIS Rapid Response Team. (9) IODP/USIO. (10) FEMA/Dane Golden. (11) IODP/USIO. (12) IODP/USIO. (13) Harry Yeh, University of Washington. (14) IODP/ECORD. (15) FEMA/Steven Zumwalt. (16) IODP/USIO. (17) iStock photo. (18) IODP/JAMSTEC. (19) NOAA. (20) IODP/USIO. (21) iStock photo. (22) IODP/USIO.

MEMBER COUNTRIES OF THE INTEGRATED OCEAN DRILLING PROGRAM, 2003–2013

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This publication is a summary of the science plan for the International Ocean Discovery Program (2013–2023), *Illuminating Earth's Past, Present, and Future*, available at http://www.iodp.org.

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