Exploring and Understanding Earth's History, Processes, and Structure





THROUGH SCIENTIFIC OCEAN DRILLING

Scientific ocean drilling addresses fundamental questions about Earth's history, processes, and structure by collecting samples of sediments, rocks, biota, and fluids from beneath the seafloor, often at great depths, and deploying state-of-the-art downhole measurement devices and long-term borehole observatories. Drilling data provide insight into the Earth system at a range of time scales. Ocean sediments and rocks record the history of mountain building, and ocean basin formation and recycling, and along with fluid samples and in situ measurements, enable scientists to understand how these long-term tectonic processes affect short- and long-term climate, biological processes, and biogeochemical cycles. On time scales of tens to hundreds of thousands of years, the continuous sedimentary record recovered by drilling reveals variations in Earth's orbital parameters, which scientists can link to periodic changes in global climate. Within this signal of long-term climate variability can be found details of abrupt changes that occurred over decades to centuries. On the shortest time scales, scientific ocean drilling provides access to fault systems that cause earthquakes, landslides, tsunami, and other geologic hazards.

MORE PEOPLE, BETTER TECHNOLOGY

The scope of scientific ocean drilling has expanded considerably since the initial efforts in 1968, pushing the limits of technology, developing new tools, and asking more difficult questions. An enthusiastic and growing international community devotes ever-increasing intellectual capacity to investigating Earth processes, including those that control climate, geologic hazards such as earthquakes and tsunami, the movement of fluids within Earth's crust, the nature and origins of life, and the dynamics of lithospheric formation and recycling. Over time, technological advances and the ingenuity of scientists and engineers have broadened the range of studies associated with the drilling program. Today, scientific ocean drilling enables researchers to recover sediment, rock, fluid, and biological samples from enormous depths, make downhole measurements, and install subseafloor observatories to continuously record processes throughout Earth's oceans.

SCIENTIFIC OCEAN DRILLING

In an early and fundamental contribution to the Earth sciences, scientific ocean drilling tested and confirmed the seafloor spreading hypothesis by collecting samples that demonstrated the progression in seafloor age away from mid-ocean ridge spreading centers. The first drilling expeditions also began the decades-long development and refinement of the geomagnetic polarity time scale back to 45 million years ago, an essential tool for determining rates of processes operating across many aspects of the terrestrial and marine geosciences. The study of changes in ocean life, chemistry, and circulation through time—known as the field of paleoceanography—originated with scientific ocean drilling and provides the reference frame for nearly all investigations of global environmental change. Among other important studies related to climate, drilling scientists demonstrated the role of orbital variability in driving climate change, including the expansion and contraction of global ice volume over the last 35 million years. Direct sampling of the upper oceanic crust through ocean drilling has led to development of new complex models of crustal accretion and evolution. By providing access to the subseafloor environment, scientific ocean drilling demonstrated the active flow of fluids through crust of many ages, which ultimately influences crustal and ocean chemistry, alternation, and fate. Drilling at convergent margins has begun to illuminate fault zone behavior and processes at these plate boundaries where Earth's largest earthquakes and tsunami are generated, and has provided a quantitative understanding of subduction recycling of rocks and fluids. Drilling has also demonstrated the presence of active microbial life up to 1.6 km deep within marine sediments, and has shown that uncontaminated microbial samples can be recovered successfully for laboratory study. Scientific ocean drilling continues to be a critical community resource for understanding our dynamic Earth.

SEA LEVEL

Recovery of sediment and coral samples through scientific ocean drilling from margins and reefs around the globe provides insight into the rates, driving forces, and magnitude of past sea level changes. Analysis of these samples permits reconstruction of a 100-million-year history of global sea level fluctuations. Knowledge of these past sea level changes helps us better understand how quickly ice sheets melt under warmer conditions, and how the related sea level rise will be distributed around the globe. This information also can be used to test models of future sea level change, and has direct application toward planning for current and future climate change impacts.

Analyses of corals recovered by mission-specific platforms offshore of Tahiti and the Great Barrier Reef provide detailed information on the rates of sea level change following the last glacial maximum, roughly 20,000 years ago, when sea levels were about 130 m lower than they are today. Drilling data show that sea level rose remarkably rapidly (> 4 m in a century) about 14,000 years ago. "Fingerprinting" indicates that the sources of meltwater were from Northern Hemisphere *and* Antarctic sources.

By correlating data from two projects—shallow-water drilling using a jack-up rig on the New Jersey margin and deep-water drilling by *JOIDES Resolution* in the Canterbury Basin, New Zealand—as well as data from previous scientific ocean drilling expeditions along the world's continental margins—researchers are teasing apart the relative contributions to sea level made by tectonics, ice sheet fluctuations, and sediment supply.

Evaluating the response of ice sheets during past warm periods in Earth's history (Pliocene ca. 3 million years ago, early Miocene ca. 20 million years ago, and early Eocene ca. 50 million years ago) allows scientists to evaluate the sensitivity of sea level to higher atmospheric CO_2 in the twenty-first century. Only by drilling ancient strata can we obtain a full understanding of sea level change and its interactions with global temperature and CO_2.

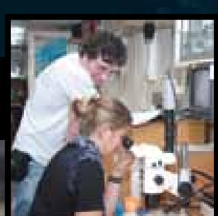
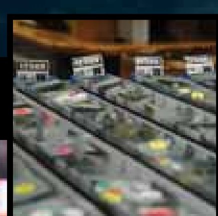
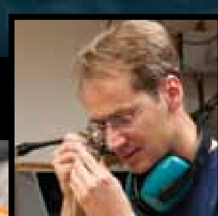
EARTH'S CLIMATE HISTORY

As an essential component of climate studies, scientific ocean drilling is needed to assess future changes resulting from fossil-fuel burning. Drilling provides the only practical way to access continuous marine geologic records of ocean temperature, chemistry, and circulation for at least the last 65 million years. Earth's climate has not been constant. Drilling studies show that Earth temperatures were much warmer than at present for millions of years, despite similar levels of heating by the sun. Chemical information in the cores is also being used to evaluate the past levels of atmospheric CO_2 and to understand the sensitivity of global temperatures to greenhouse gases. Other drilling studies have identified time intervals when natural transient releases of greenhouse gases were of the magnitude of expected anthropogenic CO_2 releases, permitting scientists to track the length of time and magnitude of environmental disruption. Because archived cores continue to provide samples long after drilling has concluded, researchers can study additional ocean systems during important time intervals. Slowly, a grid of information about Earth's past climates is being assembled.

More recently, ocean drilling expeditions have included both poles and the equator. Using these data, scientists can reconstruct Earth's environmental changes in detail and study the processes that maintained global warmth and caused rapid climate change. Drilling in the Arctic, the Bering Sea, and near Greenland has targeted the development of northern ice and the rates at which ice sheets grow and decay. Arctic drilling recovered the first sediment sections from near the North Pole to identify how the Arctic cooled and became covered with ice. Drilling in the equatorial Pacific is providing new insights into the evolution of tropical temperatures, ocean acidification, and the stability of the carbon cycle over the last 50 million years. Drilling off of Antarctica is being used to study Southern Ocean cooling and the development of large ice sheets from about 35 million years ago onward. Future drilling is targeting other important environmental systems in which both variability of the system and processes that affect the system must be explored, such as the effect of climate on the Asian monsoon cycle. Earth scientists do not have a crystal ball for predicting the future, but we do have a deep-sea record that is rich with information about how Earth's climate system has worked in the past, and is working in the present. Scientific ocean drilling is the key for unlocking and decoding the history stored below the seafloor.

OCEANIC CRUST FORMATION AND EVOLUTION

Formation of oceanic crust is the principal magmatic process on the planet, generating the ocean basins that cover most of Earth's surface, and enabling heat and chemical transfer from the deep interior to the crust, ocean, and atmosphere. This process is also a significant component of the planetary carbon cycle. Scientific drilling is crucial for testing models of how magmatic and tectonic processes interact within oceanic rift zones, and for determining the implications for crustal structure and hydrothermal circulation. Early models of crustal formation, derived mainly from on-land exposures and marine seismic studies, suggested a simple layered structure with erupted volcanics overlying intruded crustal rock, and a basal mantle layer whose composition is parental to the magmatic crust. Drilling in the Pacific has generally confirmed this model where oceanic crust is created at moderate to fast rates. However, drilling in the Atlantic and Indian oceans, where oceanic crust is formed much more slowly, has shown that this model is overly simple. Large areas of the ocean are directly underlain by thick sections of intrusive rock and/or altered mantle rock. Together with recent seafloor mapping and geophysical imaging, scientific ocean drilling is demonstrating that when oceanic plates rift apart slowly, long-lived faults can control the distribution of magmatism and alteration. Major factors in forming oceanic crust are now understood to include direct intrusion of small magma bodies, an absence of large magma chambers, the flow of melt through permeable crust, and significant melt-host rock reaction. A long-standing goal of scientific ocean drilling—full penetration and recovery of intact Pacific oceanic crust, including the underlying mantle—is more important than ever for testing new models of tectonic plate formation and evolution. Complete penetration of the oceanic crust will be complemented by drilling in "tectonic windows," where faulting exposes deep crustal layers, extending our understanding across a range of plate spreading rates and across the globe.

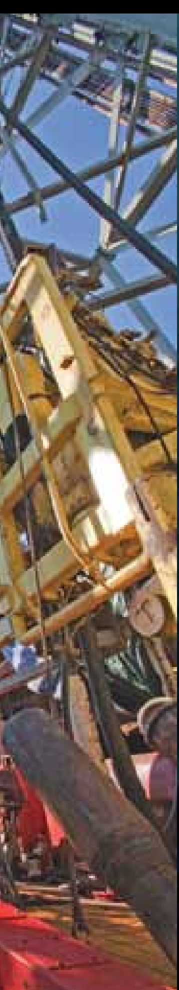

STETHOSCOPE ON SUBDUCTION

The world's largest and most destructive earthquakes and tsunami occur at subduction zones, where earthquake-generating, or seismogenic, plate boundary faults are active deep beneath the seafloor. Earth scientists are learning how, when, and why great earthquakes, such as the 2004 event off Sumatra, are triggered and can propagate along these fault systems. Understanding the behavior of these plate boundary fault systems, and the underlying conditions, processes, and mechanisms, requires sampling, downhole measurements, and establishing an experimental presence along the deep interior of active seismogenic zones.

The Nankai subduction zone off the eastern coast of Japan has a 1400-year-long recorded history of magnitude 8+ earthquakes and large tsunami recurring about every 120 years. Drilling of several holes into the upper end of the seismogenic zone is elucidating the changes that occur in the sediments, rocks, and fluids as they subduct. Data from two key faults sampled by drilling that lie just a few hundred meters below the surface show that faulting is well developed and that tsunami-generating slip has likely occurred even at these shallow depths.

In the next few years, drilling at Nankai will cross faults of the main plate boundary to depths never before accessed—5000 to 7000 m below the seabed—to sample these seismogenic rocks, and to measure stress, pore fluid pressure, and chemical and temperature conditions deep within the fault system. Scientists will place long-term sensor packages into sealed deep and shallow drillholes to understand the role of fluids in earthquake and faulting processes, determine how the faults accumulate strain between earthquakes, and assess whether changes can be detected when an earthquake is imminent. Borehole observatories will be connected to a cabled network, providing real-time access to data and experimental control in response to tectonic and volcanic events.

BOREHOLE OBSERVATORIES USED FOR FLUID FLOW EXPERIMENTS IN THE CRUST



Scientific ocean drilling is allowing scientists to conduct sophisticated experiments below the bottom of the ocean, deep within the Earth's crust, to find out how fluids, heat, chemicals, and microbes move from place to place and influence each other. Drilling studies have determined that hydrothermal fluids can travel tens of kilometers within the crust, but much is unknown about the rates of transport, the shapes of pathways, and the influence of these flows on the evolution of Earth's lithosphere, ocean, and biosphere. Borehole observatories are being used to monitor conditions far below the seafloor, to measure the temperature and pressure of crustal fluids, and to collect samples of these fluids for analysis in shore-based laboratories. As part of recent ocean drilling expeditions, researchers used a long-term borehole observatory to inject chemical tracers into the crust, and will use other observatories to determine when these tracers appear in surrounding boreholes placed in different directions and depths from the injection site. In addition, pumping into one hole causes pressure changes in surrounding holes. The timing and magnitude of these changes tell scientists about the crust's fluid transport properties at multiple spatial scales. Incubation experiments deployed within the observatories allow scientists to learn which microbes are best adapted to extreme conditions within the crust, and what rocks and minerals are most favorable to their growth. By running all of these experiments in the same network of boreholes, at the same time, teams of scientists are learning about how these different properties and processes are related. This work helps us to understand how life on the early Earth (and on other planetary bodies that have volcanic rock, heat, and liquid water) may have developed. These studies also have implications for the use of Earth's crust as a reservoir for the sequestration and storage of excess carbon dioxide that is building up in our atmosphere.

WORKFORCE DEVELOPMENT

Tackling the challenges of global climate change, energy and water resources, and geohazards requires a workforce able to function in highly technical, fast-paced, interdisciplinary, and international settings. Scientific ocean drilling brings together scientists and engineers from around the world who collaborate to select important research projects, organize and implement expeditions, and conduct research. Drilling expeditions and shore-based analyses change the lives of participating early-career scientists, graduate students, and undergraduates. Scientists with whom they collaborate through the drilling program become mentors, colleagues, and employers. In this way, scientific ocean drilling is an important training ground for a diverse community of technically literate citizens who work in the private sector, academia, and government.

EDUCATION AND OUTREACH

Working together, ocean drilling researchers, educators, and communicators coordinate a broad range of initiatives to engage students, teachers, policymakers, and the general public in Earth science learning and research. Specific outreach programs and tools offered include lesson plans and activities that are based on real scientific ocean drilling expeditions and are designed for K–12, university, and informal educators and their students; slide presentations and tips for scientists doing public outreach; and opportunities for educators and communicators to participate in research at sea.

PHOTO CREDITS

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