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Mission Moho: Formation and evolution of oceanic lithosphere

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In Brief

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Arctic continues warming trend The Arctic continued to show signs of warming in 2001–2005, according to a report authored by a group of international scientists and released on 16 November by the U.S. National Oceanic and Atmospheric Administration. These signs include a continued reduction in the extent of sea ice, which reached a record minimum in 2005. An increase in the northward transport of ocean heat through the Bering Strait in 2001–2004 is believed to be a factor in the loss of sea ice. The State of the Arctic Report also documented increasing permafrost temperatures

and increasing greenness of tundra vegetation. The report is available online at <http://www.arctic.noaa.gov/>

—SARAH ZIELINSKI, Staff Writer

Twin satellites to study Sun Twin satellites of the Solar Terrestrial Relations Observatory (STEREO) mission, launched by NASA on 25 October, promise to provide scientists with three-dimensional views of the Sun and solar wind. The satellites also will help with exploring the origin, evolution, and effects of coronal mass ejections (CMEs). CMEs can hurtle billions of tons of solar plasma into interplanetary space, which can disrupt satellite systems, radio communications, and

power grids. CMEs also can pose hazards to space-faring astronauts. STEREO's satellites will monitor CMEs in three dimensions, with one spacecraft flying behind the Earth at a slightly wider orbit and another flying ahead at a slightly narrower orbit, allowing for depth perception. Instrument packages mounted on each satellite also will observe properties of solar particles and track radio disturbances that move from the Sun to the Earth. Data will be used to help predict adverse space weather events. For more information, see http://www.nasa.gov/mission_pages/sterEO/main/index.html

—MOHI KUMAR, Staff Writer

MEETINGS

Mission Moho: Formation and Evolution of Oceanic Lithosphere

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The formation and evolution of the oceanic lithosphere is the dominant process in the chemical differentiation and physical evolution of our planet. Plate tectonic processes completely repave the ocean basins every 100–200 million years. Lithosphere formation encompasses the transfer and transformation of material and energy from Earth's mantle to the crust and from the crust to the ocean and atmosphere. Independent of sunlight, the evolving ocean crust supports life in unique seafloor and subsurface habitats that may resemble Earth's earliest ecosystems. From its formation until its return to the mantle by subduction, the evolving oceanic lithosphere interacts with seawater, sequesters water and other materials, and ultimately recycles them back into the mantle.

Mission Moho is the culmination of a four-decade quest by the Integrated Ocean Drilling Program (IODP; <http://www.iodp.org>) and its predecessors (Ocean Drilling Program, Deep Sea Drilling Project) to increase our understanding of the oceanic lithosphere through deep scientific drilling. The Moho (Mohorovičić discontinuity) is a seismically imaged interface assumed to represent the transition between the Earth's crust and its pristine mantle. To date, this elusive frontier has been a symbolic goal for many geologists but beyond the reach of available technology. With the recent commissioning of IODP's new riser-drilling vessel, *D/V Chikyu*, the technically challenging goal of drilling to and through the Moho has become feasible.

The Mission Moho workshop was convened to provide guidance on the scientific and operational framework of a 'Mission

Moho' for IODP, by redefining scientific objectives and proposing elements of a global strategy to understand processes that drive the formation and evolution of the oceanic lithosphere. The Mission Moho project will provide the scientific framework and encourage the technical development that will ultimately allow scientists to drill to and beyond this 'last frontier.'

The journey to the Moho will involve a huge technological and logistical effort, but the rewards will be manifold. As progressively deeper and more technically challenging drill holes probe and sample the ocean crust, scientists will be able to examine the primal architecture of the ocean crust and ultimately sample Earth's uppermost mantle, the driver of plate tectonics.

Mission Goals

Current understanding of the deep structure and composition of ocean crust, although

limited, has been increasingly influenced by data and samples from a relatively small number of boreholes in areas where deep crustal rocks have been exposed at the seafloor by faults. Since the early 1970s, the standard model of a uniformly layered ocean crust has evolved. Continuous investigations using ocean drilling and other marine geological tools have led to a more detailed and spatially variable picture of crustal architecture.

Ocean crust created at fast-spreading ridges appears to be uniformly layered and relatively homogeneous, reflecting a relatively uniform mode of accretion. In contrast, ocean crust created at slow- and ultraslow-spreading ridges is spatially heterogeneous over distances as small as a few hundred meters.

For example, at some ridge segment centers in the northern Atlantic, magmatic processes dominate, and accretionary processes resemble those of fast-spreading ridges. Toward segment ends, however, accretion is much more heterogeneous, and even discontinuous. In such areas, the ocean crust consists of a mixture of serpentinized peridotite and gabbroic intrusions, locally capped by lavas with or without sheeted dikes. Because of this heterogeneity, workshop participants recognized that the primary Mission Moho objective of full crustal penetration must be supplemented by studies of spatial and

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Online moderated discussions of topics introduced in Eos are being initiated with this week's issue. The three initial topics for discussion are:

- Eos's publication of comments on the award to Michael Crichton
- Scientific journals staying strictly with science or broadening their perspectives
- Ways the journal review process might be improved, especially as related to the anonymity of reviewers

Anyone can read the discussions and related Eos items. Only individuals who register may post a comment. The author of a comment will be identified in the posting. All comments will be reviewed for adherence to the discussion rules, which can be found online at the discussion site.

If you have an opinion on one or more of the topics listed above, go to www.agu.org/fora/eos

temporal variability if a comprehensive understanding of the origin and evolution of the ocean lithosphere is to be achieved.

Despite the heterogeneity of oceanic lithosphere, a clear consensus emerged among workshop participants: that drilling a deep, full crustal penetration hole through the Moho and into the uppermost mantle at a single site is the first priority and that Mission Moho planning should focus on achieving this goal as soon as it is feasible.

Drilling and sampling a complete crustal section will enable scientists to accurately estimate the bulk composition of the crust; understand the extent and intensity of hydrothermal exchange between the ocean crust and seawater; establish the chemical connections between the lavas that erupt at the seafloor and the melts that leave the mantle; more accurately estimate the chemical flux returned to the mantle by subduction; test competing models of lower crustal magmatic accretion; calibrate regional seismic measurements and the layered-crust models derived from them; better understand the origin of magnetic anomalies; and determine cooling rates of the lithosphere. Only by sampling across the crust-mantle boundary will we be able to define, at least in one place, the geological meaning of the Mohorovičić discontinuity; determine the *in situ* composition of the uppermost mantle and its deformation; and address details of the physics and chemistry of mantle melt migration.

There was also a clear consensus that the first full-penetration hole should be in fast-spread ocean crust. Although only 20% of the modern mid-ocean ridge system is fast-spreading (> 80 millimeters per year), more than 50% of present-day ocean crust (representing 30% of the Earth's surface) was created at fast-spreading ridges. Well-developed theoretical models encompassing several possible styles of magmatic accretion at fast-spreading ridges already are available. Hence, an understanding of accretion processes based on one site might reasonably be extrapolated to describe a significant portion of the Earth's surface.

Workshop participants also agreed that complementary studies of slow-spread lithosphere will be essential to fully understand the architecture of the ocean crust. Studies that explore crustal structure and the nature of the Moho in slow-spread lithosphere will supplement the vision gained from fast-spread crust. Wherever studied, slow-spread crust is laterally heterogeneous. Crustal sec-

tions often are complicated by fault-emplaced, serpentinized peridotites of mantle origin.

Despite this complexity, the (seismically defined) Moho usually is well defined. Current hypotheses are that the Moho in slow-spreading environments is (1) the boundary between residual (after melting) upper mantle rocks and an intrusive igneous crust, (2) a broader zone of interlayered ultramafic and mafic rocks, (3) an alteration front caused by deep penetration of water (serpentinization), or (4) any combination of these three. Carefully targeted deep drilling is needed to assess these hypotheses and related questions, including the role of serpentinization in modifying seismic signatures, and especially in the transition from 'crustal' to the higher 'mantle' seismic velocities of around eight kilometers per second.

The extent to which existing or planned drilling projects in slow-spread crust should be included in a Mission Moho was not resolved at the workshop. Criteria for inclusion of such projects will have to be defined by a mission proponent team.

Mission Strategy

It is imperative that any site chosen for a deep penetration hole be thoroughly investigated and characterized geophysically, geologically, geochemically, and petrologically, meeting participants agreed. Boreholes are spatially limited, and they need to be understood in their broader context. Spatial context for IODP holes is provided by appropriate site surveys, which can occur before or after drilling. Essential complementary knowledge can be gained by field studies in dismembered pieces of oceanic lithosphere found on land (ophiolites), in particular the Oman ophiolite, and by IODP drilling in tectonically exposed lower crustal and upper mantle rocks.

Drill holes in such windows of opportunity provide important 'shortcut' access to environments otherwise difficult to access. Studies of accretion processes, hydrothermal alteration, and physical properties in these areas will lead to improved models and better experimental designs as we progress to deeper and deeper holes.

Penetrating the entire ocean crust will require the enhanced well control provided by riser-drilling technology. The world's only scientific riser D/V (drilling vessel) *Chikyu* ('Earth' in Japanese; <http://www.jamstec.go.jp/chikyu>) currently is undergoing system integration tests. *Chikyu*'s first multiple plat-

form IODP project involving both riser and riserless drilling is scheduled in the Nankai Trough beginning in September 2007. For eventual penetration of the oceanic fast-spread crust, a technically challenging modification of the riser from the current 2500-meter maximum depth to 4000–4500 meters will be required.

The construction of such deep-water riser capability recently was included as one of five domestic science and technology high priorities by the Japanese government. Even with this depth capability being available sometime after 2010, the journey to the Moho will be long and the number of potential sites—on seafloor that is old enough (>15 million years) and therefore cold enough for deep drilling in fast-spread crust is limited.

IODP recently has established deep holes at two complementary sites. Hole U1309D (1415 meters below seafloor) has recovered a complex series of gabbroic rocks from slow-spread Atlantic Ocean crust. Hole 1256D (1507 meters below seafloor) has, for the first time, penetrated the entire pillow basalt and sheeted dike sequence in superfast-spread crust of the eastern Pacific Ocean, terminating in the transition between sheeted dikes and underlying gabbros. Both holes remain open and very likely will be deepened in coming years.

Site 1256 is a potential location for a deep penetration crustal hole and much can be learned from continued drilling at this site. At the same time, potential alternative sites need to be identified and evaluated before a final full crustal penetration site is selected.

The Mission Moho Workshop, cosponsored by IODP Management International, the Joint Oceanographic Institutions, Ridge 2000, and InterRidge, was held 7–9 September 2006 in Portland, Ore. A full report of the meeting will be available online at <http://www.iodp.org> in early December.

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