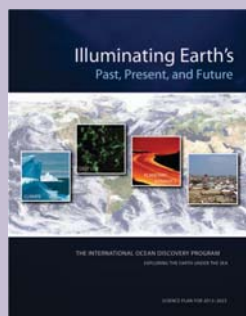


New Science Plan on Ocean Drilling Published



The science plan for the new ocean drilling program, the International Ocean Discovery Program 2013–2023, was published in June 2011. The title of the science plan is “Illuminating Earth’s Past, Present and Future”. The science plan (available on www.iodp.org) has been in preparation for more than two years with input from a broad scientific community representing Earth, ocean, climate and life sciences.

Numerous workshops were held, and white papers invited from across the community. The planning process culminated with the INVEST Conference in September 2009 at the University of Bremen, an event that was attended by approximately 600 scientists from 21 countries.

Based on the extensive report from the INVEST meeting, a select group of researchers prepared a draft science plan that underwent extensive community review in 2010 before being completed in spring of 2011. It was presented to the international press on 16 June (http://iodp.streamco.tv/IODP_-_Livestream_16th_of_June_2011.html).

The science plan includes four major themes (see below) and within these, 14 specific challenges.

- Climate and Ocean Change: Reading the Past, Informing the Future
- Biosphere Frontiers: Deep Life and Environmental Forcing of Evolution
- Earth Connections: Deep Processes and Their Impact on Earth’s Surface Environment
- Earth in Motion: Processes and Hazards on Human Time Scales

The New Web-Based Journal *Frontiers in Extreme Microbiology* Invites Manuscripts

*Abstract deadline: *15 July 2011*

*Manuscript deadline: *15 September 2011*

The new web-based journal “*Frontiers in Extreme Microbiology*” will mark its launch with a special topic, deep subsurface microbiology, and invites abstracts and manuscripts.

Deep subsurface microbiology focuses on the molecular detection and quantification, cultivation, biogeographic examination, and distribution of bacteria, archaea and eukaryotes that permeate the subsurface biosphere of deep marine sediments and the basaltic ocean crust. The deep subsurface biosphere abounds with uncultured, only recently discovered and (at best) incompletely understood microbial populations. In spatial extent and volume, the subsurface biosphere is only rivaled by the deep sea water column. So far, no deep subsurface sediment has been found that is entirely devoid of microbial life; microbial cells and DNA remain detectable at sediment depths of more than 1 km; microbial life permeates deeply buried hydrocarbon reservoirs, and it is also found several kilometers down in continental crust aquifers. Severe energy

limitation, either as electron acceptor or donor shortage, and scarcity of microbially degradable organic carbon sources are among the evolutionary pressures that have shaped the genomic and physiological repertoire of the deep subsurface biosphere. Its biogeochemical importance as a long-term organic carbon repository, inorganic electron and energy source, and subduction recycling engine is a major focus of current research at the interface of microbiology, geochemistry and biosphere/geosphere evolution. The *Frontiers in Extreme Microbiology* special topic will address some of the central research issues in deep subsurface microbiology and biogeochemistry: phylogenetic and physiological microbial diversity in the deep subsurface; microbial activity and survival strategies in severely energy-limited subsurface habitats; cell-specific microbial activity as reflected in process rates and gene expression patterns; biogeographic isolation and connectivity in deep subsurface microbial communities; and the ecological standing of subsurface biospheres in comparison to the surface biosphere. Is this region an independently flourishing biosphere, or merely a site of survivors that tolerate burial (along with organic carbon compounds), or a combination of both? Studying these issues on Earth’s

deep subsurface biosphere has far-ranging implications, not the least being in the field of astrobiology and the search for subsurface life beyond Earth.

*Abstracts and manuscripts will be considered with some flexibility (one or two months later than the posted deadlines).

Web Link: www.frontiersin.org/extrememicrobiology/specialtopics/deep_subsurface_microbiology.

Edited by Andreas Teske (UNC Chapel Hill), Axel Schippers (BGR), Peter Dunfield (Univ. of Calgary), Virginia Edgcomb (WHOI), and Jennifer Biddle (University of Delaware)

Call for IODP-Canada Graduate Student Research Awards

Application deadline: 18 November 2011



To enhance the experience of graduate students investigating marine geology questions related to the research themes of the Integrated Ocean Drilling Program, IODP-Canada offers merit-based awards of up to \$3000 to students enrolled in either an MSc or PhD program or employed as a post-doc at a Canadian institution. The research awards are

intended to support projects directed toward the objectives of upcoming or past DSDP/ODP/IODP expeditions, utilizing core material and/or shipboard data.

Please contact the IODP-Canada Coordinator (coordinator@mail.iodp-canada.ca) for more information.

The Netherlands Joins ICDP



Starting 2011, the Netherlands is a member country of ICDP. Dutch community, ICDP-NL, is an open platform that intends to bundle the expertise of (sometimes rather small) research groups and specialists and to support the ambitions of the Dutch scientists. The community consists of scientists of a broad variety of Earth science disciplines, ranging from archaeology to tectonics. It not only involves universities but also the Netherlands Organisation for Applied Scientific Research (TNO). The Board of ICDP-NL is chaired by Stefan Luthi (TU Delft) and advised by a representative of the drilling industry. The membership fee is financed by the Earth and Life Science division of the Netherlands Organization for Scientific Research (NWO).

A first symposium was held on 14 February 2011, during which also the agreement between NWO and ICDP was signed. ICDP-NL will cooperate closely with IODP-NL, for instance, by organizing joint meetings.

Dutch scientists already have a long track record in continental drilling. ICDP-NL will build on the expertise gained during these collaborative projects and is looking forward to now becoming fully involved in initiating and executing ICDP projects.

Contact details, the press release and the first newsletter can be found



on the ICDP website under National Programs.

Australia and New Zealand in Scientific Drilling



ANZIC IODP activities are proceeding smoothly. The 2010 ANZIC Annual Report is now available on www.iodp.org.au. The report not only covers Australian and New Zealand activities in IODP in 2010, but looks at the future and makes the point that we are fully committed to IODP, now and in the future. Australia now has funding until the end of the present phase of IODP, and New Zealand is actively pursuing such funding. Planning is underway for an IODP session at the International Geological Congress in Brisbane in mid-2012 (www.34igc.org), and a large number of international participants are expected to attend.

In the first six months of 2011, four ANZIC scientists participated in IODP expeditions: two aboard the Louisville Seamount Trail expedition (330), one aboard the CRISP expedition (334) and one aboard the Superfast Spreading expedition (335).

A New Zealand Scientific Drilling Workshop was held in Dunedin in March 2011, and a white paper is currently under development to sketch the concept and importance of the DrillNZ initiative to various stakeholders. A New Zealand-led IODP workshop “Conceptual framework for ocean drilling to unlock the secrets of slow slip events” was held at Gisborne, New Zealand in August 2011. Since beginning of August 2011, NIWA (the National Institute of Water and Atmosphere) has joined the consortium of New Zealand Universities and Crown research Institutes contributing to ANZIC, and has committed funds towards the New Zealand IODP membership fee up to 2013–2014.

An Indian Ocean IODP workshop will be held in Goa, India over the period 16–18 October 2011. The organizers are India and ANZIC. The aim of the workshop is to further develop

existing proposals and design new ones, in the hope that *JOIDES Resolution* will be in the Indian Ocean in 2014.

Australia and New Zealand are making important scientific contributions to IODP, and a number of major coring expeditions in our region have improved and will improve the understanding of global scientific questions. Although IODP is now working outside the region, these two countries remain keen supporters of global IODP science.

2nd Swiss ICDP Meeting (March 2011, Zürich)



About 40 scientists gathered in March 2011 in Zurich to exchange news about past, present and future ICDP projects with active Swiss involvement. Since Switzerland became an ICDP member through support from the Swiss National Science Foundation only three years ago, a series of projects with Swiss participation have been already drilled or are underway, and more are planned, reflecting an active contribution to the overall ICDP program. Scientists from Swiss institutions are acting as PIs and Co-PIs in several drilling projects targeting lake sediment records, the subsurface biosphere, volcanic domains, sedimentary basins and groundwater contamination.

One of the main goals of the meeting was to address new themes to take further advantage from the Swiss ICDP membership. For example, several ideas were raised in the context of research on geothermal energy, where large commercial projects are currently underway, and it was suggested that a geothermal component could complement any continental drilling project. In the same context, CO₂ sequestration gained wide attention and might be further explored in the near future. New ideas will address drilling targets also within Switzerland. For example, a drilling initiative involving scientists from perialpine countries aims to explore the timing and extent of alpine glacia-

tions and related erosion and sedimentation through drilling the sedimentary infill of overdeepened troughs all around the Alpine region. Kick-off meetings with international partners are planned to explore possibilities for an ICDP workshop proposal. In a similar fashion, the Alps themselves provide a series of drilling objectives that may serve as unique records of tectonic and petrologic processes. One example is the highly metamorphic Ivrea Zone (Southern Alps), where lower-crust rocks are outcropping at the surface and where a drill hole could reach upper mantle rocks (i.e., the Moho) in much shallower depth as in its original location.

Altogether, the Swiss scientific drilling community is very active, and the combined IODP and ICDP memberships will continue to provide the ideal platform to conduct and realize these fascinating drilling initiatives. Contact: flavio.anselmetti@eawag.ch.

D/V *Chikyu* Damaged by Tsunami, Repairs Planned



At 2:47 p.m. JST on 11 March, the Tohoku region in the northern Pacific coast of Japan suffered an M9 earthquake followed by a 7+ m tsunami strike and numerous aftershocks. At that time, D/V *Chikyu* was in port at Hachinohe preparing for IODP Exp. 337. The *Chikyu* immediately evacuated port; however, during the emergency evacuation the vessel suffered damage. All personnel and visitors aboard, including a visiting delegation of local elementary school students, were safely accounted for.

On 20 March, *Chikyu* arrived at the port of Muroran in southern Hokkaido where divers made a provisional assessment of the ship's damage. From 20 April until 18 June, the *Chikyu* was dry-docked for repair at the Yokohama Dockyard and Machinery, and returned to sea for testing on 18 June 2011.

One of DV/ *Chikyu*'s azimuth thrusters suffered damage as tsunami waves buffeted the vessel in the Hachinohe

port, and its replacement is currently being manufactured. The new thruster is expected to be installed by the end of March 2012.

IODP-Canada Summer School Scholarships



IODP-Canada is pleased to announce that five students received scholarships to attend one of the 2011 ECORD summer schools held in Bremen, Germany and Urbino, Italy.

Congratulations to Thi Hao Bui (PhD student, McGill University), Jon Furlong (MSc student, University of Victoria), Fritz Griffith (MSc student, University of Ottawa), Lucie Hubert-Théou (PhD student, McGill University), and Stefan Markovic (PhD student, University of Toronto).

IODP/ICDP-Canada Booth at GAC-MAC 2011



IODP-Canada and ICDP-Canada shared an exhibition booth at the joint annual meeting of the Geological Association of Canada and the Mineralogical Association of Canada, held at the University of Ottawa on 25–27 May 2011. Over 1050 Earth scientists (including 285 students) from Asia, Canada, Europe, and the U.S. attended the conference.

Anne de Vernal, Chair of IODP-Canada, and the Coordinators of IODP-Canada and ICDP-Canada staffed the booth and met with students, faculty and funding agency rep-

resentatives. Many ECORD, IODP and ICDP outreach materials were distributed, and subscribers to the Canadian mailing list increased by over 10%. The new IODP-Canada Website (www.iodp-canada.ca) was launched just prior to the start of the conference.

ICDP Dead Sea Core Opening Party, Part I



Within the framework of the ICDP Dead Sea Deep Drilling Project (DSDDP) a first core opening party took place at the GFZ German Research Centre for Geosciences, Potsdam, in June 2011. A group of 18 involved scientists and student helpers from Israel, Japan, Switzerland, and the U.S., together with the German team around Prof. Dr. Achim Brauer, opened and described around 470 meters of a total of 720 meters of sediment cores that had been obtained during the drilling campaign at the Dead Sea deep basin from November 2010 to March 2011. Additional assistance was given by the ICDP Operational Support Group. Furthermore, modern non-destructive scanning techniques, such as micro-XRF analyses, magnetic susceptibility measurements and photographic line-scanning, have been applied at the sediments, encouraging the scientists to work in a two-shift system seven days a week in order to cope with the enormous amount of Dead Sea sediments from one 450-m deep borehole and several short cores. First estimations based on the succession of salt, laminated sequences and detrital sediment flux point out that the sediments comprise at least two climatic cycles, hence covering the last ~200 thousand years. All scientists are looking forward to meeting again at the GFZ laboratories in October this year to perform the same procedure with the remaining 250 meters from the second deep borehole and to get new insights into this fascinating archive of natural climate dynamics and seismic activity.



ANDRILL Coulman High Project – Site Survey Outcomes and Future Plans



Field surveys were conducted from November 2010 through January 2011 on the Ross Ice Shelf (RIS), northeast of McMurdo Station and Scott Base, in Antarctica, in preparation for the proposed ANDRILL Coulman High (CH) Project. The survey work is chronicled in a well-illustrated blog provided by Dr. Frank Rack, which is online at <<http://www.andrill.org/science/ch/news>>.

The CH Project surveys, which involved integrated planning and execution by a combined international team from New Zealand and the United States, achieved all primary and secondary objectives. A transverse route from Ross Island to CH across the RIS was established using a tracked-vehicle-mounted ground-penetrating radar system supplemented by airborne radar. Four GPS stations and a weather station were established to measure lateral and vertical motions of the RIS and to monitor environmental conditions. A series of combined U.S.-NZ field camps on the RIS were occupied, and the ANDRILL hot water drill (HWD) system was used to melt numerous holes through 260–275 m of ice. Oceanographic moorings comprised of inductive oceanographic instruments were deployed through the RIS at two sites, and were recovered to the ice surface after two months; one mooring was then redeployed to accomplish multi-year observations at CH. Video camera observations of the interior and basal surface of the ice shelf were made at several sites and these observations were integrated with conductivity-temperature-depth (CTD) measurements through the ice shelf to the seafloor at each site. The Submersible Capable of under-Ice Navigation and Imaging (SCINI) underwater remotely operated vehicle (ROV) was deployed through the ice to explore the underside of the ice shelf while conducting operational tests. SCINI discovered an unusual biological community living in the ice and recovered bio-

logical samples using an improvised suction pump (Rack et al., 2011); these samples and extensive imagery are being further investigated.

ANDRILL is a multinational scientific program to investigate Antarctica's glacial and tectonic history. Of specific interest is Antarctica's past and future role in global environmental change as revealed through stratigraphic drilling along the Antarctic margin and related numerical modeling of climate and ice sheet behavior. ANDRILL is developing the CH Project to investigate Early Miocene and Paleogene paleoenvironmental and tectonic history by drilling at two sites on the Ross Ice Shelf, approximately 150 km east of McMurdo Station, over the subsea geologic structure known as the Coulman High. Further information about the project is available at <<http://www.andrill.org/science/ch>>.

The ANDRILL Science Committee (ASC) has issued an international call for submission of statements of interest in the CH Project from international scientists. This survey is available online at <<http://www.andrill.org/science/ch-survey>>. The scientific team for the project will only be selected from nations that belong to the ANDRILL consortium. If you would like to know more about how your nation might join the ANDRILL consortium as a participating member, please contact Dr. Tim Naish, Chair of the ASC, at <tim.naish@vuw.ac.nz> or contact Dr. Frank Rack, Secretary of the ASC and Executive Director, ANDRILL Science Management Office, University of Nebraska-Lincoln, at <frack2@unl.edu>.

Reference

- Rack, F., Levy, R., Falconer, T., Zook, R., Mahacek, P., Carroll, D., Williams, M., Stewart, C., Limeburner, R., and the ANDRILL Coulman High Site Survey Team, 2011. PS14.3: Interdisciplinary outcomes of the ANDRILL Coulman High Site surveys. [paper presented at 11th International Symposium on Antarctic Earth Sciences, Edinburgh, Scotland, 10–15 July 2011]

Bighorn Basin Coring Project (BBCP)

The Bighorn Basin Coring Project (BBCP) initiated drilling operations in the Bighorn Basin of Wyoming (U.S.) on 13 July 2011 and completed drilling on 4 August 2011. The main goal of the project is to recover complete, unweathered core samples from Paleogene continental strata that record rapid global warming events known as hyperthermals (e.g., Paleocene-Eocene Thermal Maximum [PETM] and Elmo). By applying various geochemical, geophysical, and paleontological methods on these

high-quality (HQ) cores, the project aims to better understand the causes of these climate events and their effects on continental systems. The project was highly successful in achieving all of its drilling goals with >95% core recovery in each hole. Three sites in the basin were targeted (Basin Substation, Polecat Bench, Gilmore Hill) with two holes drilled at each site to get overlapping cores. A total of 921 meters of HQ core was recovered in liners with all but one of the sites being drilled with municipal water only, thus reducing the potential for core contamination. In mid-August, the cores started their journey from

Powell, Wyoming to the IODP Bremen Core Repository at the University of Bremen, Germany, where they will be split, described, and sampled by the BBCP Science Team in early 2012. BBCP web page: <http://earth.unh.edu/clyde/BBCP.shtml>

Facebook page with real time updates: <http://www.facebook.com/pages/Bighorn-Basin-Coring-Project/120607821348013>.

ISAES-11 Antarctic Shallow Scientific Drilling Workshop

Following the 11th International Symposium on Antarctic Earth

The PASADO Core Processing Strategy: A Flexible Protocol for Sediment Subsampling in Multidisciplinary Drilling Projects

Subsampling of sediment cores is the important first step of almost every study. Sampling procedures were developed within IODP/ODP/DSDP to ensure the reproducibility of core treatment as well as its documentation. In contrast, procedures for lacustrine sediment cores are as manifold as the corresponding scientific questions and communities. A sampling assembly and a flexible sampling protocol are described in the version adapted to the PASADO project. This protocol introduces a core splitter and a sampling assembly consisting of a divider and a D-scoop for fast and efficient subsampling. Detailed information can be found in our recently published paper (Ohlendorf et al., 2011).

The core splitter cuts plastic core liners without contamination of the sediment by liner material. The core sampling assembly is used to sample one core half completely in contiguous steps. The core half is split into slices of similar thickness by inserting thin disks through a comb-like divider, and the D-scoop is used to sample these sediment disks (Fig. 1).

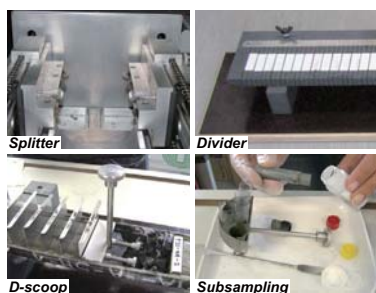


Figure 1. Photographs of core splitter and the sledges with the four blades, divider, and the D-scoop.

The utilization of the

sediment is optimized because all sediment is sampled in one step. Subsamples with known volume can then be taken from the exact same stratigraphic level in the core. Quality flags are defined to document the condition of every (sub)sample and to allow a first classification of the sediment character.

Reference

Ohlendorf, C., Gebhardt, C., Hahn, A., Kliem, P., Zolitschka, B., and the PASADO science team, 2011. The PASADO core processing strategy - A proposed new protocol for sediment core treatment in multidisciplinary lake drilling projects. *Sediment. Geol.*, 239:104–115, doi:10.1016/j.sedgeo.2011.06.007.

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and the PASADO science team

Related Web Link

http://www.icdp-online.org/front_content.php?idcatart=2794

Sciences (ISAES-11) in Edinburgh, Scotland, a one-day workshop on Antarctic Shallow Scientific Drilling was held in the John McIntyre Conference Centre of the University of Edinburgh (Scotland) on Sunday, 17 July 2011. The workshop, which attracted over thirty-six international attendees from six countries, was co-convened by Frank Rack (University of Nebraska-Lincoln) and Bruce Luyendyk (University of California, Santa Barbara). The presentations explored the use of numerical models and data-model integration strategies to answer important scientific questions, identified potential shallow drilling targets from specific sites around the Antarctic margin, including land-ocean transects, and reviewed the status of existing and emerging technology options that could be used to implement shallow (up to 200 mbsf)

scientific drilling/coring of glacial and glacial-marine sediment and rocks in ice-covered seas (e.g., mission specific platforms, including options for either ship-mounted rigs or seafloor drills). Further information about the outcomes of the workshop will be available online in the near future at <<http://www.shaldril.org>>.

International Workshop on Scientific Drilling in the Indian Ocean

17–18 October 2011, Goa, India



The Indian Ocean has experienced an extremely complicated tectonic history. From the disintegration of Gondwanaland to the collision of the

Indian plate with Asia and the subduction of the Indian plate in one of the most prominent subduction zones, the region has a diversity of key tectonic features. Much geo-scientific knowledge regarding the Indian Ocean was gained from the International Indian Ocean Expedition program (IIOE-1960–65). Since then, integrated geophysical and geological studies have considerably improved our understanding of geological evolution of this region. Results from previous studies in association with the ODP/DSDP boreholes in the Indian Ocean have further strengthened our knowledge.

Despite these remarkable efforts, several key questions related to the Indian Ocean with significant global relevance are still unanswered. Decades of geo-scientific work focused on this sector has produced compelling hypotheses on various fronts. Our

present understanding vis-a-vis these propositions requires corroboration from direct measurements such as deep ocean cores. The need for scientific drilling in the Indian Ocean sector is highly evident by several active IODP drilling proposals at various stages (e.g. proposal nos. 549, 552, 595, 667, 701, 702, 704, 717, 724, 727, 760, 776, 778, 780 and 783).

IODP-India in association with ANZIC is organizing an international workshop to discuss various scientific proposals for drilling in the Indian Ocean sector as well as to encourage discussions of new proposals in this sector for the new phase of the IODP. The Indian Ocean IODP Workshop will be held in Goa on 17–18 October with about 100 participants from all over the world. The workshop is planned back to back with the seventh Asian Marine Geology Meeting, also taking place in Goa during the previous week.

Because there has been no scientific ocean drilling in the Indian Ocean for nearly a decade, this workshop is vital to developing strong new drilling proposals. Also, India itself has only joined IODP recently, and such a workshop will provide wide exposure to the Indian science community of IODP science and IODP capability. The following four themes have been arranged for the workshop and with planning subcommittees largely formed:

1. Cenozoic oceanography, climate change, gateways and reef devel-

opment: broad questions related to the Indian Ocean, and narrow ones such as the Indonesian Throughflow, sea-level changes, and the origin of late Pleistocene reefs.

2. The history of the monsoons: tectonics, uplift, weathering and erosion, sediment deposition, climate and oceanography, and discussions/nurturing of proposals that have emerged since the 2008 Detailed Planning Group (DPG) workshop on monsoons.
3. Tectonics and volcanism: tectonism of the Indian Ocean, including plate tectonics, the evolution of the oceanic crust and mid-ocean ridge formation, the formation of large igneous provinces, continental rifting and related deposition, and subduction, arc volcanism and earthquakes.
4. The deep biosphere: studies of the “extremophiles” of the deep biosphere in sediments and basalts focusing on the nature of the oceanography and inputs of organic matter into the Indian Ocean.

More information on this workshop can be found at www.iodp.org/workshops/8/ or www.ncaor.gov.in/iodp/index.html.

Workshop conveners:

Dr. Dhananjai K. Pandey, Program Officer (IODP-India), e-mail: iodp.india@ncaor.org, and Professor

Neville Exon: ANZIC Program Scientist, e-mail: neville.exon@anu.edu.au.

International Review of the ICDP with Outstanding Results

icdp |



On behalf of the Assembly of Governors, (AOG)

and at the request of the main funding partners of the program, the International Continental Scientific Drilling Program was evaluated in May 2011 by an international review committee of independent experts with key expertise in major programs in the geosciences and funding organizations.

The committee concluded that ICDP is a highly successful program, achieving with very modest investments world-class science of global impact. The program has been highly effective in community-building and is driving integration in modern Earth system science. It has demonstrated strong scientific leadership and effective allocation of its limited financial resources. The program holds great promise to further attract new member states, organizations and industrial partners.

One important outcome of the assessment is to start developing a new ICDP Science Plan. The AOG has therefore initiated the planning for an International Symposium on Continental Scientific Drilling in 2013.

Drilling into the Fault Zone of the Giant Tohoku Earthquake?

Following the 11 March Tohoku earthquake, IODP mobilized a Detailed Planning Group (DPG) to investigate the feasibility of drilling into the seismogenic fault. Box 1 on page 61 is an excerpt from the report produced by the DPG.

A DPG meeting in May led to a full proposal for drilling within an area of 6–7 km water depth near the trench where the fault can be reached within 1 km subseafloor. Later plans are to measure ephemeral properties related to the rupturing of the fault as a baseline; repeat observations are a key target. Properties include an expected friction induced temperature anomaly providing a proxy for fault strength (friction) during rupture. Drilling is required within about 18 months after rupture before a

temperature anomaly has dissipated too much. This is a unique opportunity to sample a fault as close in time as possible to a major and large displacement earthquake event, but drilling and casing a hole in these water depths is a technological challenge. The study, if deemed feasible and implemented, will complement ongoing studies in the Nankai Trough, which targets a strong mega-fault expected to rupture within a few decades.

References for figures in Box 1 available in the full DPG Report, which is at <http://www.iodp.org/weblinks/Featured-Publications-HOME-PAGE/Tohoku-Rapid-Response-Drilling-DPG-Report/>.

Used by permission.

Box 1: The 2011 Off the Pacific Coast of Tohoku Earthquake (M_w 9.0)

The March 11, 2011 Tohoku earthquake came as a disheartening surprise to the geophysical community. With a historical record of nearly 500 years including 13 M_w 7 and 5 M_w 8 earthquakes, this region was thought to be relatively well understood in terms of the locations and sizes of expected subduction zone earthquakes. An M_w 9 event breaking through the entire region of many fault segments, with the associated huge tsunami, was not at all anticipated for this thoroughly studied area. This failure highlights the need for a more physically-based understanding of initiation and rupture.

The sequence started with an M_w 7.2 foreshock, which occurred 2 days before and about 40 km NE of the mainshock hypocenter. In the hour after the mainshock, there were large M_w 7.9 and M_w 7.7 aftershocks. In addition to the countless aftershocks in the immediate region, the seismic activity of small earthquakes increased across most of Japan with several M_w 5 and a few M_w 6 earthquakes over the following month. Small earthquakes were also triggered at 13 volcanoes according to the Coordinating Committee for Prediction of Volcanic Eruption.

Apart from the foreshocks, there were no clear precursory signs or large pre-slip. The foreshocks themselves were only identified as precursory with hindsight. Current models of earthquake clustering suggest that the probability of having an M_w 9.1 earthquake following an M_w 7.2 earthquake within 2 days is <0.001% and thus a societally useful prediction could not be provided based on the foreshocks alone.

Modeling of seismic, crustal deformation, and tsunami data shows very large slip on the fault plane, with values up to 30–50 meters (e.g. Simons et al., 2011, Sato, et al., 2011, Ammon et al., 2011, Ohta et al., 2011, Lay et al., 2011). The area of maximum slip is on the shallow portions of the fault trenchward of the hypocenter. The large and shallow slip near the trenchward limit of the megathrust caused large deformation of the seafloor, which generated the devastating tsunami. Because of the dense network of observations in the region prior to the earthquake, the extremely large slip has been verified by direct observations of displacement on the seafloor through repeat bathymetry and GPS.

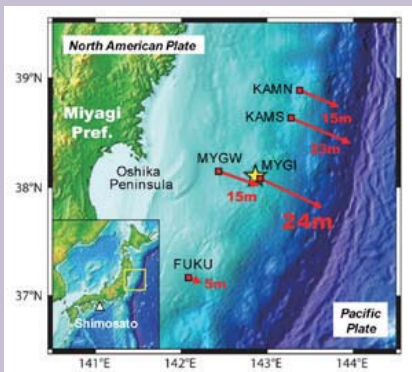


Figure 2. Horizontal coseismic displacements at seafloor benchmarks, associated with the Tohoku earthquake. Red squares are locations of GPS benchmarks and yellow star is the epicenter of the mainshock (Sato et al., 2011b)

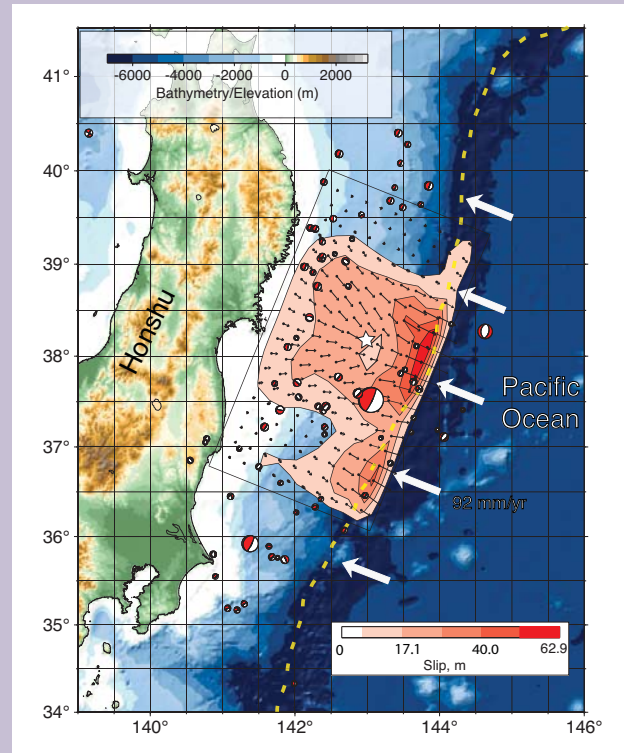


Figure 1. Teleseismic P-wave inversion for slip (Lay et al., 2011). Maximum slip ranges from 40–80 for a suite of inversion models with the majority of models placing large slip near the trench. Most models do not directly incorporate the ocean bottom observations in Figure 2 and 11 which require large slip towards the updip end of the rupture.

The earthquake produced severe strong ground motions with accelerations over 1 g and long durations of about 100 s. However, the large losses of lives and property were mainly due to the tsunami, and shaking damage was relatively limited, considering the size and intensity of the earthquake. Even the well-publicized problems at the Fukushima No. 1 nuclear power plant were caused by loss of power due to the tsunami inundation, and not by the shaking itself. The resilience of most structures throughout the region can be attributed to the high seismic standards of Japanese construction.

During the Tohoku earthquake, the regions of the fault that produced the dominant high-frequency energy are different from the areas of large slip. The large slip is on the shallow updip portion of the fault, while the high-frequency radiation originated from the deeper downdip portions of the fault (e.g. Ide et al., 2011, Wang and Mori, 2011, Koper et al., 2011). The difference in frequency of the radiated energy for different portions of the fault reflects variations in rupture dynamics. The deeper portion appears to have undergone a more brittle rupture with a higher proportion of radiated energy, while the large shallow slip probably absorbed more energy through dissipated processes. The greater dissipation may be characteristic of tsunami earthquakes and can be studied by sampling this portion of the fault with a borehole.