CHIKYU 地球 HAKKEN 発見

EARTH DISCOVERY

Special Topic

NanTroSEIZE: Towards Stage 2

Chikyu **Goes for the First Riser Drilling in the History of Scientific Drilling**

IODP Challenges of the Mysteries of Earth Science

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Special Topic 1

NanTroSEIZE: Towards Stage 2

Chikyu Goes for the First Riser Drilling in the History of Scientific Drilling

In 2007 – 2008, Deep Sea Drilling Vessel *Chikyu* conducted the Stage 1 Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) expeditions under the Integrated Ocean Drilling Program (IODP). This Spring (2009), *Chikyu* will proceed to Stage 2 and start deep sea drilling anew at the Kumano Basin off the Kii Peninsula.

Stage 1 produced tremendous results. Geological data collected from Logging While Drilling (LWD), a technology to measure the distribution, condition and properties of rocks and geological layers while drilling, and from core samples were successfully extracted from eight sites exposed to the strong Kuroshio ocean current. Drilling operations reached a maximum depth of approximately 1,400 meters under the sea bed. For the first time in the world, a core sample was directly extracted from the Megasplay fault at the central section of the Nankai Trough accretionary prism. In Stage 2, riser drilling will be carried out for the first time in the history of scientific drilling. With the aim of better understanding of the mechanisms that govern the development of major ocean-trench type earthquakes and tsunamis, preparations will start in 2009 for the future installation of a borehole observation system that will provide realtime data from the Nankai Trough plate subduction zone.

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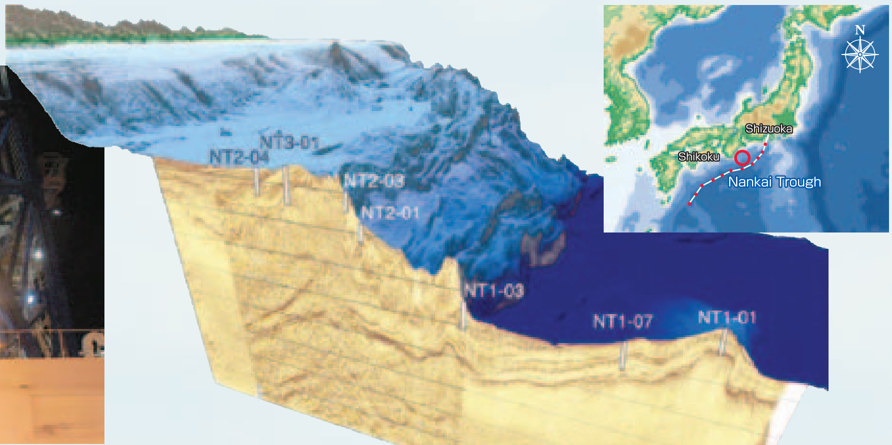
Lowering the riser pipe (center) into the sea. *Chikyu* has already successfully drilled to more than 3,000 meters below the seafloor with riser drilling during the shakedown cruise.



Topographic features of the seafloor in the Kumanonada Nankai Trough off the coast of the Kii Peninsula, with subterranean structure obtained from 3-dimensional reflective seismic wave analysis.

Drilling directly above Seismogenic Zone using Riser Technology

At the Port of Kobe on 15 February 2009, the Deep Sea Drilling Vessel *Chikyu* was opened to the public, where it generated great interest in large crowds of the general public. *Chikyu*, a vessel equipped with the cutting edge scientific technologies, was built by Japan to pioneer new advances in deep sea drilling and Earth Sciences, began a new phase of activity for 2009 on this day.

After completing trial operations and training expeditions off the coasts of Suruga and the Kii Peninsula, *Chikyu* prepares to continue operations on the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) IODP mission that began the year before last. NanTroSEIZE is a massive long term project off the coast of Kumanonada, which comprises four Stages. The second Stage is scheduled to start with Expedition 319 (Riser/Riserless Observatory 1) in May 2009, immediately followed by Expedition 322 (Subduction Inputs).

Stage 2 Expedition 319, will conduct the first scientific riser drilling (see page 4) in the history of ocean drilling. Riser drilling is a drilling system where *Chikyu* and the seafloor borehole are joined by a riser pipe inside which the drill pipe passes through and drills into the seabed. Drilling fluid is circulated inside the riser pipe through the drill pipe. This special drilling fluid balances the pressure inside the borehole, protecting the walls of the borehole and preventing the borehole from collapsing, thus allowing stable drilling to much greater depths than was previously possible.

Expedition 319 will conduct drilling at two sites. The riser drilling site (Site NT2-11) is located directly above the seismogenic zone at the central region of the Kumano Basin. Drilling will be conducted from the sedimentary layer towards the accretionary prism up to a depth of 1,600 meters beneath the seafloor. The other site (NT2-01) is located directly above the megasplay fault extending from the seismogenic zone at the southern margin of the Kumano Basin. At this site riserless drilling is scheduled to pierce through the megasplay fault and up to a depth of 525 meters beneath the seafloor. Further, pipes to protect the borehole wall, called casing, will be inserted in place at both boreholes. This will preserve the boreholes over the long term as the system for long term borehole monitoring is intended to be installed within these boreholes (see pages 9-10).

Expedition 322 will conduct drilling at Site NT1-07, right above the sea plate located further to the sea side from the plate interface. Here, a thick accumulation of turbidites, material carried from land by river systems, and sediments deposited over time on the seafloor can be found lying on top of the oceanic crust. As a result of plate subduction, these sedimentary materials are most likely the raw materials for the formation of accretionary prisms, long recognized as possible crucial factors in the origin of faults and their movements that lead to earthquakes. These drilling plans form an important part of the overall exploration aimed at clarifying the formation of seismogenic zone systems by understanding the initial conditions of subducted materials. This is why drilling and sampling the sedimentary layers before they subduct is so important to science. Riserless drilling (up to a depth of 1,200 meters beneath the seafloor) intends to collect core samples over the entire stratum that spanning the sedimentary layer to the oceanic crust (basalt).

Leading Edge Technologies Shed Light on the Structure and Conditions of Mega-Seismogenic Zone

Core sampling during Expedition 319 at Site NT2-11 will focus on the deepest sections of the borehole. However, a significant feature of the riser drilling is the fact that all the drilling fluid together with the drilling cuttings are flushed back onboard the vessel. Recovered cuttings are samples that are equally important as cores and will be put to good use by putting the cuttings under various geological and biological analyses. On one hand, other than on core samples, importance is given to measurements and analyses like Logging While Drilling (LWD), Measurement While Drilling (MWD), and wireline logging. In LWD and MWD, sensors are mounted on the drill pipe above the drill bit to collect

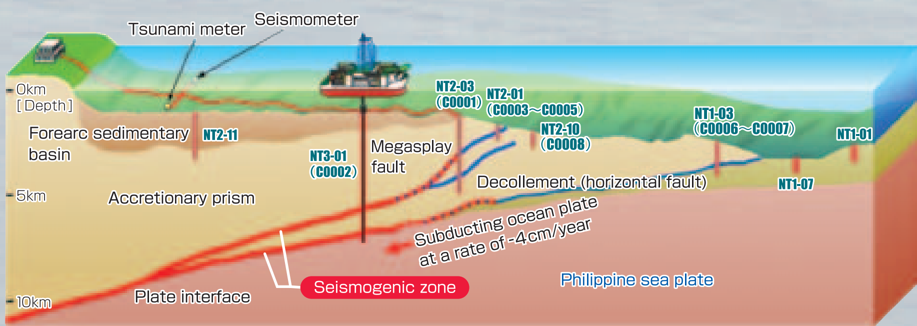


Chart showing all NanTroSEIZE drill sites. Riser drilling in 2009 is planned at Site NT2-11 .

measurements simultaneously while drilling. In wireline well logging, sensors are mounted on a wire and lowered down the borehole after drilling has stopped. Combining these measurements aims at gaining important data on temperature, density, porosity as well fracture conditions of geological layers in more detail and at greater depths.

Dr. Masataka Kinoshita, Co-Chief Project Scientist of NanTroSEIZE and geophysicist at the Japan Agency for Marine-Earth Science and Technology, Institute for Research on Earth Evolution, says "The site where riser drilling is to be conducted this time is directly above an asperity (locked area) and is predicted to have large accumulated strain. One of the important themes of this drilling is to gain a detailed understanding of the 'strain distribution,' that is how much and where are these strains accumulated. For that reason, borehole logging is given significant importance. Even at the other site, NT2-01, borehole logging is naturally given importance in gaining an understanding how wide the asperity is and, further, to understand what is happening in places outside the asperity through its relation with slow slips that causes slow earthquake."

Furthermore, as described earlier, a long term borehole monitoring system will be set up in these boreholes as part of the plan to continuously monitor temperature, pressure, and seismic waves inside the borehole. Furthermore, in order to utilize this long term monitoring system effectively, the plan is to connect the entire system to the seafloor cable network of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET), the preparations for which will start in 2009. This will enable real-time transmission of measured data above ground and thereby help establish a system for the early detection of major earthquakes and tsunamis.

Co-Chief Scientists conduct preliminary discussions prior to the Stage 2 of expeditions in preparation for drilling.

Dr. Eiichiro Araki, a Co-Chief Scientist of Expedition 319 from the Marine Technology Center in JAMSTEC, who also happens to be a DONET researcher, has this to say regarding the expected drilling results: "The drilling to be conducted this time will further clarify how the accretionary prisms grow in subduction zones located above seismogenic zones. Moreover, the site where we are to conduct riser drilling is directly above the seismic fault that causes a major catastrophe once in 100 to 150 years. Indeed, it is located above the place where strain has accumulated. Drilling here and taking detailed measurements make it possible for us to have a glimpse at the detailed structure and impact of seismogenic zones, something that we have not understood until now, for the first time."

The new "NanTroSEIZE" challenge starts now.

Voices from the Co-Chief Scientists for Expedition 319 and 322

There are four Co-Chief Scientists for Expedition 319, Araki Eiichiro (Japan Agency for Marine-Earth Science and Technology), Timothy Byrne (University of Connecticut), Lisa McNeill (University of Southampton) and Demian Saffer (Pennsylvania State University), and there are two Co-Chief Scientists for Expedition 322, Michael Underwood (University of Missouri) and Saneatsu Saito (Japan Agency for Marine-Earth Science and Technology). We asked three of these scientists for their thoughts right before their expeditions start.

■Araki Eiichiro

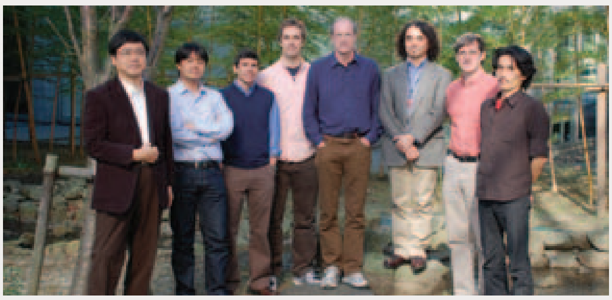
I think that the riser drilling to be conducted this time is one important step for the future of deep sea drilling and also towards clarifying the seismogenic system at the Nankai Trough. Participating scientists with many varied viewpoints collaborate so sometimes the sharing of such ideas with the whole group leads to clashes, with everyone passionately supporting their positions. Looking for ways to resolve these contentions, and coming up with consensual resolutions, is difficult sometimes but gives much enjoyment. I think that actively fostering such interactions is part of the role of the Co-Chief Scientists.

■Demian Saffer

I am honored that I have been asked to contribute to the NanTroSEIZE science program. I am also excited that we will be attempting so many new measurements and new operations for IODP. If we succeed, I hope that the data we collect will provide new insight into how subduction zone earthquakes and faulting occur. I believe that there are two key pieces. The first is that we must have good communication and collaboration between the scientists, CDEX staff technicians, drillers, and engineers to achieve our goals. Many of our objectives combine scientific and technical challenges, so we are going to have to work together toward a shared success. Second, we will need a little bit of luck! Ocean drilling is always an adventure, and there are going to be some unexpected challenges.

■Michael Underwood

After planning for nearly 10 years, I am very excited about finally getting the opportunity to study the inputs to the Nankai subduction system. The expedition has been postponed and rescheduled several times. Good core recovery and high-quality cores will be keys to success. It will be especially important to recover material from within the lower Shikoku Basin facies. Those deposits probably control the lithologic character of the plate boundary at seismogenic depths, so we must be able to establish their initial conditions prior to subduction. My biggest worry is running out of time before we reach our highest-priority coring objective; however, I also look forward to working with a fantastic team of shipboard scientists. I think everyone is eager to get the job done.



Riser Drilling Technology:
Stable Drilling Down to Greater Depths

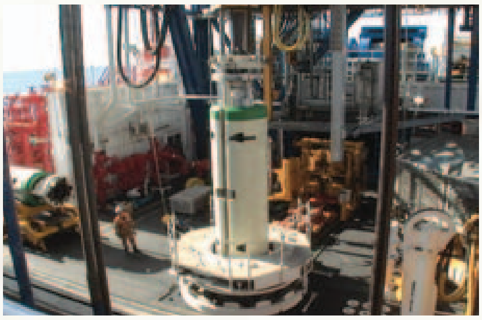
Scientific riserless drilling, as shown in figure ❷ below, is a drilling method whereby sea water is pumped continuously through the drill pipe and out from the drill bit into the borehole and out onto the seafloor which carries the drilling cuttings out of the borehole. However, it is extremely difficult to drill deeply with this method because the borehole walls collapse easily, trapping the drill pipe. In fact, this same problem plagued riserless drilling during NanTroSEIZE's Stage 1.

The riser drilling system installed in *Chikyu* overcomes this problem and makes it possible to drill a deep and stable well hole. Riser drilling, as shown in Figure ❹ below, connects *Chikyu* and the borehole (well head atop the seafloor surface) in the seafloor with the riser pipe (mounted on the Blow Out Preventer (BOP) at the surface of the seafloor). To drill, the drill pipe is lowered down inside the riser pipe (Figure ❺ below). Furthermore, the "drilling fluid," a special fluid for drilling, circulates through the drill pipe to carry cuttings upwards through the riser pipe and back onto the boat. Drilling fluid, whose specific gravity and viscosity have been adjusted to optimize conditions within the borehole, balances the pressure inside the borehole, thus stabilizing and protecting the walls of the hole, and preventing the collapse of the borehole thereby allowing drilling up to a deeper depths than before possible.

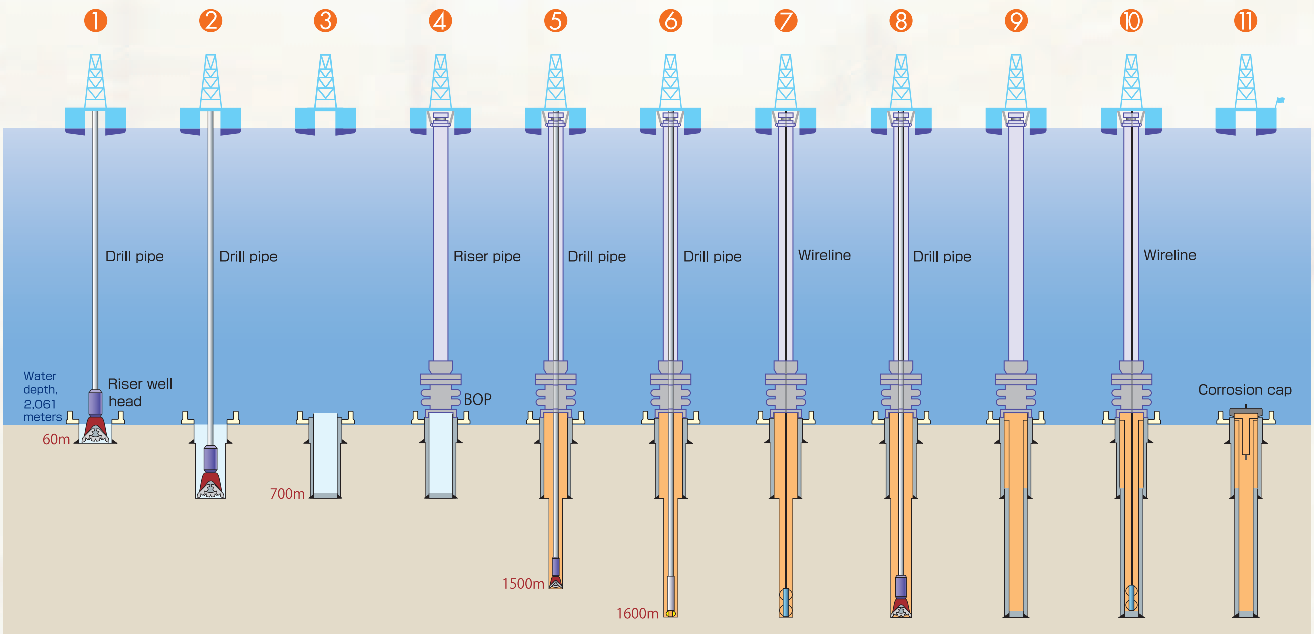
During NanTroSEIZE's Stage 2 Expedition 319, *Chikyu* will perform the first ever riser drilling to be conducted in the history of scientific drilling. During shakedown drilling operations in 2006, *Chikyu* successfully drilled up to a depth of approximately 2,700 meters underneath the seafloor in water depths close to 2,200 meters. While technical issues have already been resolved, drilling will now be conducted in Kumanonada under the influence of the strong Kuroshio current, and under complicated geological conditions; this will not be a time to let one's guard down. All possible preparations are ongoing; a vibration-deterrent fairing is being installed on the riser pipe to counter drag from the current. To address the complex geological structure, a detailed three dimensional seismic analysis on a scale never before heard of is being conducted to predict geologic layer conditions at the proposed drill sites. Teruaki Kobayashi, Leader of Drilling Operation Group at CDEX explains, "Plans will be nothing more than plans. We will never know what will happen unless we drill. This time's scientific riser drilling is expected to pose difficult operations that are clearly beyond those met in industry off-shore drilling in deep waters. Definitely, it is a challenging drilling."

Riser pipe being lowered from the drill floor into the sea.

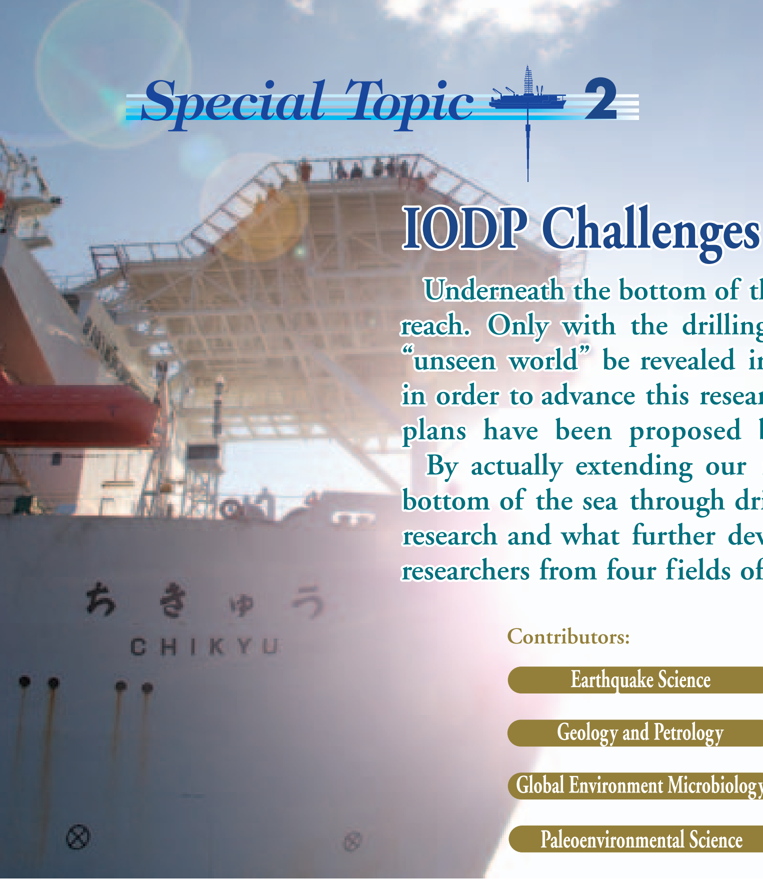
Use of drilling fluid plays a crucial role in riser drilling. The picture shows the mud pump used to increase pressure and pump the drilling fluid inside the drill pipe and hole.



One riser pipe is 27 meters long. Since Site NT2-11 is approximately 2,000 meters deep, more than 70 pieces will be needed to connect to the well head sitting on the surface of the seafloor.



Planned riser drilling sequence for Site NT2-11. Drill to a depth of 700 meters below seafloor using the same method as riserless drilling ❷, insert casing ❸. This will serve as the foundation for installing the Blow Out Preventer (BOP). *Chikyu* and BOP are connected by the riser pipe ❹, drilling up to approximately 1,500 meters employing riser drilling starts ❺, about 100 meters of core is sampled ❻. After conducting wireline logging measurements ❼, the borehole diameter is increased ❽, and casing is mounted inside the hole ❾. After wireline logging is conducted again inside the casing ❿, hole opening is sealed for future installation of the long term borehole monitoring system ⓫.



Special Topic 2

IODP Challenges of the Mysteries of Earth Science

Underneath the bottom of the sea, a vast unknown world extends beyond our direct reach. Only with the drilling made possible through IODP, can a portion of this "unseen world" be revealed in its entirety and made accessible for research. Hence, in order to advance this research, where and how should drilling be done? Scientific plans have been proposed by international researchers from many fields.

By actually extending our reach into the geologic layers and rocks beneath the bottom of the sea through drilling, what effects will this have on previous scientific research and what further developments can be expected? We asked representative researchers from four fields of studies regarding what they expect from IODP.

Contributors:

Earthquake Science — **Professor Emeritus Akira Hasegawa** (Tohoku University)

Geology and Petrology — **Professor Susumu Umino** (Kanazawa University)

Global Environment Microbiology — **Professor Kenji Kato** (Shizuoka University)

Paleoenvironmental Science — **Professor Yasufumi Iryu** (Nagoya University)

The Mechanisms of Large Earthquakes

Allowing heat to escape from the Earth's interior to outer space via the surface helps cool the interior. For that reason, convection current flows from the interior's mantle towards the Earth's surface in the much the same manner as water boiling inside a kettle. Plate movements correspond to that convective flow, so that the Pacific Plate in Eastern Japan and the Philippine Sea Plate in Western Japan subducts under the continental plate. The sudden movements that occur in the contact area between the continental plate and oceanic plate are "Plate Boundary Earthquakes." As Prof. Emeritus Akira Hasegawa of Tohoku University says, "If the oceanic plates subducted continuously without resistance, ocean-trench type large earthquakes would not develop. Large earthquakes occur shallower than a depth of approximately 50 km in the case of the Pacific Plate and at a depth approximately 30 km for the Philippine Sea Plate. Plates getting caught at the plate boundary are the source of earthquakes. At depths greater than those mentioned above, temperature rises and 'sticking' does not occur: therefore, earthquakes do not develop."

These areas of "sticking" are called "asperities" and form in patches along the plate boundaries. When friction between the plates increases enough to cause sticking, the plates get stuck. Eventually, since the subduction force of the plates is very powerful, the parts that are frictionally locked will no longer be able to resist and will slide at once. These events are the ocean-trench type large earthquakes, technically known as plate boundary earthquakes. After the earthquake, the plate can get stuck in the same asperity. Since this is repeated, large earthquakes occur repeatedly at definite intervals. The larger the asperity, the larger the earthquake develops. This seismogenic mechanism is called "asperity model." The asperity model of plate boundary earthquakes was developed at the beginning of this century and research on this type of earthquake is clearly more advanced compared with other types.

The final objective of earthquake research is to predict the occurrence of large earthquakes. Towards that end, it is necessary to understand the mechanisms of earthquake genesis, construct a seismogenesis model, transform the model into a numerical model and reproduce it as a computer model. At present, earthquake phenomena can be reproduced in the lab through repeated adherence and slip and research introducing the formula of friction proceeding onwards so that it can be said that seismogenesis models are being developed.

"Numeric modeling requires that the spatial distribution of friction parameters be known. Besides the plate boundary, we also want to know the material characteristics of the upper plate. Hence, for these purposes, core samples need to be obtained and measured. One more thing of importance is the detailed monitoring of the regions underneath the Earth where events occur. A cable network, the Dense Oceanfloor Network System for Earthquakes and Tsunamis

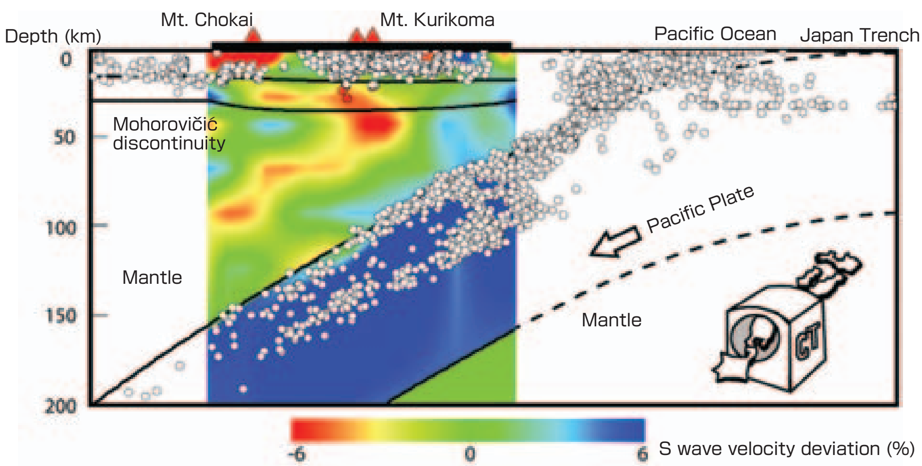
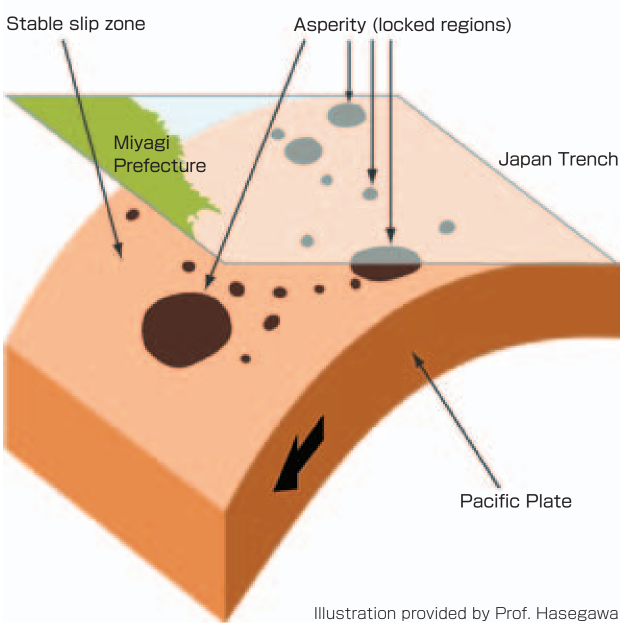
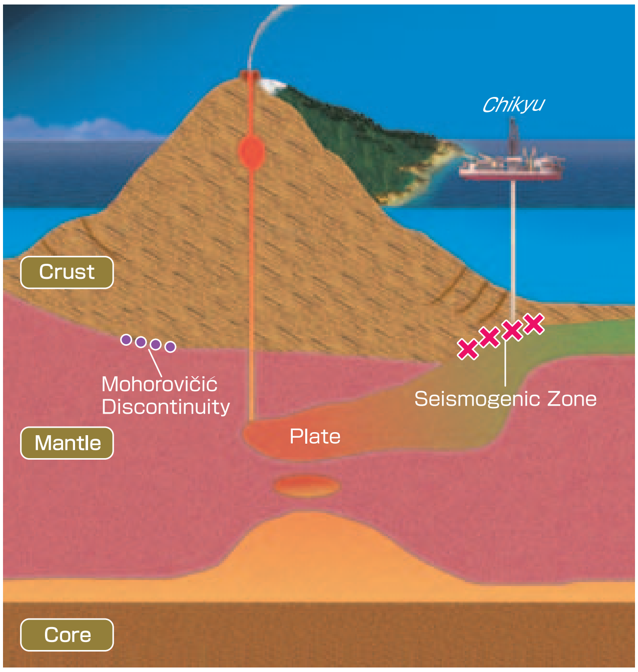


Illustration provided by Prof. Hasegawa

Image of geologic structure underneath North-Eastern Japan taken through seismic wave tomography
Image generated from seismic waves of the Pacific Plate subducting beneath north-eastern Japan. The blue areas indicate seismic waves traveling at high speeds (high density, low temperature) while the red areas indicate seismic waves traveling at slow speed (low density, high temperature). ○ refers to seismic center ▲ active volcano.



Modality of asperity and Earthquake development at the plate
Asperities (locked regions) exist like patches, large and small. Giant earthquakes occur more readily as patches grow bigger or when several patches slip together.



Schematic of the Earth's interior.

(DONET) is being developed for deployment off the shores of Kumanonada by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Placing monitoring devices in the borehole after cores are extracted, and connecting these devices to undersea cables to the network makes it possible to transmit data in realtime. There are plans to drill up to the splay faults or to the plate interfaces; hence, it might be possible to gather data in places where adherence and slip occurs, or close to those places."

Although using seismic waves to study events occurring underground is a basic tenet in earthquake engineering, it is also important to know what materials make up the fault surfaces where earthquake occurs in order to gain an understanding of the mechanism of seismogenesis. Prof. Emeritus Hasegawa stresses the significance saying that "Integrating these two would certainly provide a fuller understanding. I think that IODP drilling is one step towards that direction."

What is Going on in the Earth's Interior?

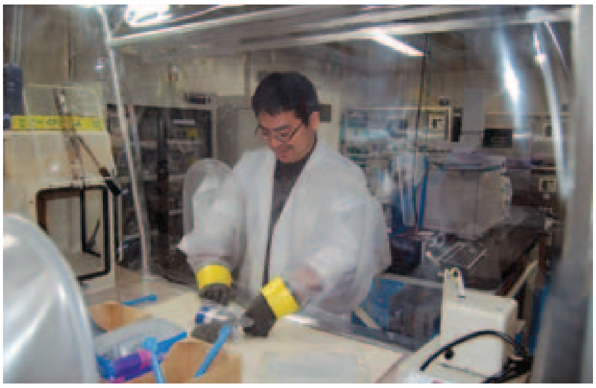
Prof. Susumu Umino of Kanazawa University is studying the interior of the Earth and surface plate movements from the vantage point of petrology. The structure of the Earth's interior is surmised from how seismic waves are propagated and the strength of gravity. Starting from the surface, the Earth is divided into the Earth's crust, mantle and core in that order. It is thought that continental plates are made of granite, oceanic plates of basalt, mantle of peridotite and the core of metallic iron. The reflection of seismic waves shows that a Mohorovičić discontinuity (Moho) exists at the boundary of the mantle under the Earth's crust. However, this knowledge is gained indirectly from seismic waves and gravitational surveys. No one has ever seen what the actual conditions are.

Prof. Umino says, "Although in the main our research is aimed at the structure of oceanic plates, I do not know what rocks of what structure and chemical composition actually exists in the deeper parts of the plates. It is possible to extract the rocks in the deeper parts of oceanic plates from fault cliffs in the seafloor. Further, in geological layers called ophiolites, oceanic plate rocks from geological ages have cropped out on the Earth's surface. I have studied these rocks and I have been now suspecting that the same kinds of things are formed now at the ocean floor and mid-ocean ridges."

Since ocean drilling started in the 1960's, most of the drilling has reached only up to the sedimentary rocks under the bottom of the sea. Further, this has happened in only two boreholes: one reaching approximately 2 kilometers below the seafloor off the coast of Costa Rica in Central America, and the other off the coast of Guatemala in Central America which reached up to the magma pool Gabbros. Prof. Umino, who participated in the latter Expedition, explained, "The lower crust of a continental plate is made of these Gabbros. Below it lays the mantle with a Moho at the boundary. Lately, it has been realized that there are different variations in Moho. In order to know why these variations came into being, it is necessary to drill and obtain rocks directly."

The mantle under the Moho is an important layer that consists a large part of the volume of the Earth. Although old sections of the mantle may jut out from the surface of the Earth in some locations, the exposure process must have altered its characteristics from their original state when it was still in the interior of the Earth. Consequently, we want to dig as deep as possible and to extract fresh

Prof. Umino examining layered gabbros 'ophiolite' in Wadi Hilti (Oman), which was at one time part of the lower section of the ocean crust.
Photograph provided by: Prof. Umino



Core samples are subjected to microbiological analysis in the laboratories on board *Chikyu*. The experiment is held in a nitrogen atmosphere tent, sealed to avoid to exposure to oxygen.

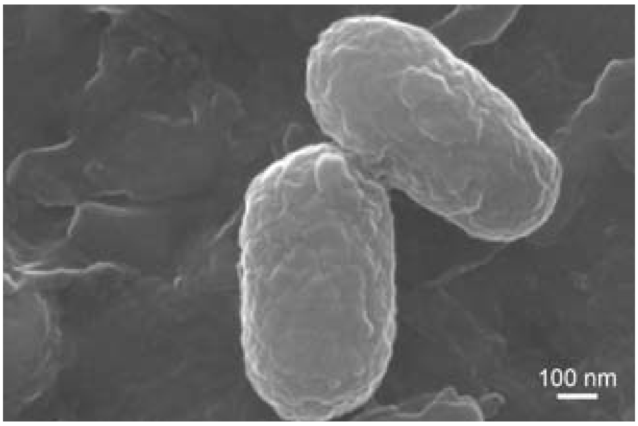


Image of a microorganism found inside the core as seen through a scanning electron microscope. Many microorganisms of the group Archaea live underneath the seafloor. Provided by Geomicrobiology Group, Kochi Institute for Core Sample Research

mantle samples to study its properties. Further, if a hole into the Moho (Mohole) is drilled, it means that the entire oceanic crust above the discontinuity will have been pierced and the characteristics of the oceanic crust can be examined in detail. "Even with the drillings done up to now, there were instances when we have thought 'It must probably be like this' which turned out to be entirely different after drilling. I expect that daring to drill up to the mantle will result to new discoveries without fail."

However, it is difficult to drill to the Moho, especially with riser drilling with *Chikyu* being limited to a depth of 2,500 meters at present. Prof. Umino says that "We are proposing that riser drilling to a water depth shallower than 2,500 meters, such as in the Ogasawara Ridge, where seismic wave speed studies show that the Moho rises relatively close to seafloor surface, while at the same time developing riser drilling technology to reach water depths of 4,000 meters where the typical Moho structures are found."

For the record, there are many researchers like Prof. Umino whose research interests expanded from above ground ophiolites to ocean drilling. The world's largest ophiolite is in the Middle East, where there is a large exposed "fossil" Moho in Oman. Rocks like this, exposed on the Earth's surface are precious sample that gives us indications of what happened inside the Earth's interior in the past.

Microorganism Biosphere Lying Under the Bottom of the Sea

Computation of the amount of carbon reveals that there are about several thousand to several ten thousand times of microorganism living on (and in) the Earth compared to humans. Many of these live underneath the Earth; the truth being that there is a vast microorganism biosphere inside the Earth.

In the middle of the 1990's, the British researcher John Parkes revealed the existence of a vast subsurface biosphere from Ocean Drilling Program (ODP) data. At that time, the maximum drilling depth was approximately 830 meters beneath the seafloor. Currently, research has extended to a depth of 1,600 meters under the seafloor. The existence of unique microorganisms inhabiting lodes of gold at depths of 3,000 meters under the Earth's surface had been confirmed, extending the reach of the subsurface biosphere beyond what we previously imagined.

Microorganisms can be simply divided into two groups: Archaea and Bacteria. Although Archaea are found under extreme environmental conditions of superheat, extreme salinity or oxygen-free environments, they comprise about one tenth of the microorganisms found in seawater. Even with Archaea, there are groups that inhabit extremely hot water whose numbers increase at depths closer to the seafloor, indicating that microorganisms from hydrothermal vents and underground are increasing. Prof. Kenji Kato of Shizuoka University says that "Drs. Fumio Inagaki and Yuki Morono, researchers at the Kochi Institute for Core Sample Research and Bremen researchers analyzing ocean drilling data obtained by drillships such as *Chikyu* published their results in *Nature* showing that the number of Archaea in subsurface biospheres is mind-boggling. The tenacity of research in this field has earned global attention."

Archaea living under the ocean floor metabolize energy underground, where there is no light nor oxygen, using reductive substances like hydrogen, hydrogen sulfide or methane, forming an ecosystem different from the world we live in. Evolution of life forms completely different from the ecosystem at the Earth's surface, where energy from the sun is used, is a continuous process.

"Humans evolved from microorganisms. However, microorganisms whose forms have not changed with time still exist. This is because their strategy for survival is to stop evolving once a place fit for living has been acquired," Prof. Kato said.

"Typical examples are microorganisms that manufacture methane in oxygen-free environments and microorganisms that use that methane and convert it back to carbon dioxide. Metabolic processes in the subsurface biosphere must be related to the biosphere above ground, on a time scale of 100 or 1,000 years, the activities of these microorganisms are extremely powerful and have the capacity to drive the global environment. That is why understanding the metabolism of subsurface biospheres is indispensable to understanding the entire material cycle in the world."

Expectations are also high that the subsurface microorganisms could become new biological resources. "It is possible that new microorganisms with unknown forms of metabolism can be discovered. Although methane hydrates, produced by microorganisms, are important resources, discovery of new forms of metabolism might be of even greater help to next generation energy systems."

"Moreover, of deeper interest to us humans, is researching the demands of the so-called ' Limits of Life.' The deep drilling plan of the Okinawa Trough proposed by Dr. Ken Takai in JAMSTEC was given a highly-ranked evaluation and preparations are now ongoing for its implementation. I would like to know how microorganisms behave under high temperatures greater than 100℃." Prof. Kato expects that if boreholes become laboratories in the future and cul-

Drillship *DP Hunter* of IODP Expedition 310 (Tahiti Sea Level) © ECORD/IODP

ture experiments of microorganisms are realized, it would provide knowledge of a different magnitude than what is obtained from inside test tubes in laboratories aboveground.

Record of Global Environmental Changes Sleeping Beneath the Seafloor

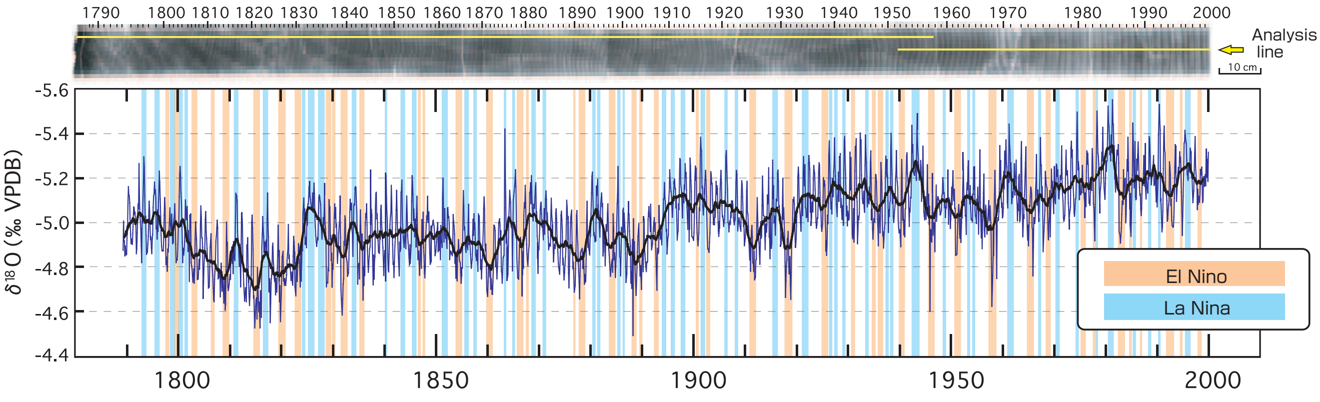
Biospheres exist and fossils of ancient life exist underneath the seafloor at the same time. One of these is corals. Corals live in shallow waters of the tropics, forming coral reefs that teem with a high diversity of life. The type of corals to be found depends precisely on various environmental factors such as water temperature, water depth, salinity, nutrients and the amount of materials supplied from the land. In other words, if one sees corals and "fossil" coral reefs, it is possible to reproduce the climate of the time in great detail.

It is possible to determine climate changes spanning several thousands to several ten thousands as well as the changes in coral reefs resulting from such climate changes from coral reefs. For that reason, Prof. Yasufumi Iryu of Nagoya University says that it is necessary to accurately determine when coral reefs were formed. "We can determine past eras from the degree of decomposition of radioactive elements: up to fifty thousand years back with radioactive carbon elements, and up to an era 300,000 years ago with uranium. To identify ages older than these, using strontium isotope will enable the measurement up several hundreds of millions of years ago theoretically. However, since the sample from old generations change, effective fossils are investigated in order to determine the age of calcareous plankton fossils. The Kochi Institute for Core Sample Research has the technological capability to measure strontium to the highest degree of precision, eliciting excitement over getting the epochal dating of coral reefs."

Furthermore, corals contain records of global environmental changes spanning various time scales. Since it is possible to analyze the temperature and salinity of the time concerned using the ratio of strontium/calcium and ratio of oxygen isotope inside coral bone structure, changes in temperature and salinity can be determined with a precision of within two weeks to one month for a period of several hundred years into the past. Furthermore, analyzing the bone structure in more detail, it is possible to determine the temperature in the past to a precision of one day or less. That is why it is possible to reconstruct climate changes in the past from corals. Prof. Iryu says that "The east-west movement of masses of warm water in the Western Pacific causes El Nino and La Nina. Drilling and analyzing coral reefs in the Pacific along the Ryukyu Islands and Island of Tahiti, we can know behavior of masses of warm water in the past and, therefore, know these climate phenomena of the time. Data on climate monitoring of the Pacific Islands starts only from the 20th century. Hence, in order to know the climate mode prior to that, it is imperative that corals that have lived continuously for 200 years and more and coral fossils be analyzed."

From the fossils contained in coral reefs of the past, it is possible to determine the age and the depth of water that the coral reef lived in. Using this, it is possible to determine where the water level was at a certain point in time in the past. Since the extent of ice sheet formation is related with the rise and fall of global sea levels, it is possible to estimate the climate at that time. "In the IODP coral reef drilling conducted in Tahiti in 2005, the path of the rise of sea level for the past 20,000 years became clear. Further, it also became known that during the time after the last glacial age when it was getting warm, there was a period of a backward swing (a period of cooling).

Prof. Iryu, et al., has proposed drilling in the Ryukyu Islands aboveground and in a transect across the seafloor to IODP and International Continental Scientific Drilling Program (ICDP). He said "The Ryukyu Islands are an excellent field to probe the history of coral reefs. At present, the northern limit of the coral reef distribution lies near the Hirota coast in Tanegashima. However, 20,000 years ago, this was way down to the south. As the glacial age transitioned to the interglacial age, the northern limits of the coral reefs must have moved northwards. Moreover, because coral reef sediments differ during warm periods from those during cold periods, I would like to accurately identify the changes that occurred with time."



Cycles of El Nino and La Nina for the past 210 years, determined from oxygen isotope ratio records in the coral bone structure of coral from Guam (Asami et al., 2005). It can be seen that cycles of El Nino, unlike in the present, changed over a period of from three to eight years. The gray zone above the graph shows an x-ray image of corals.

Provided by Prof. Iryu and Asami

Long Term Borehole Monitoring System

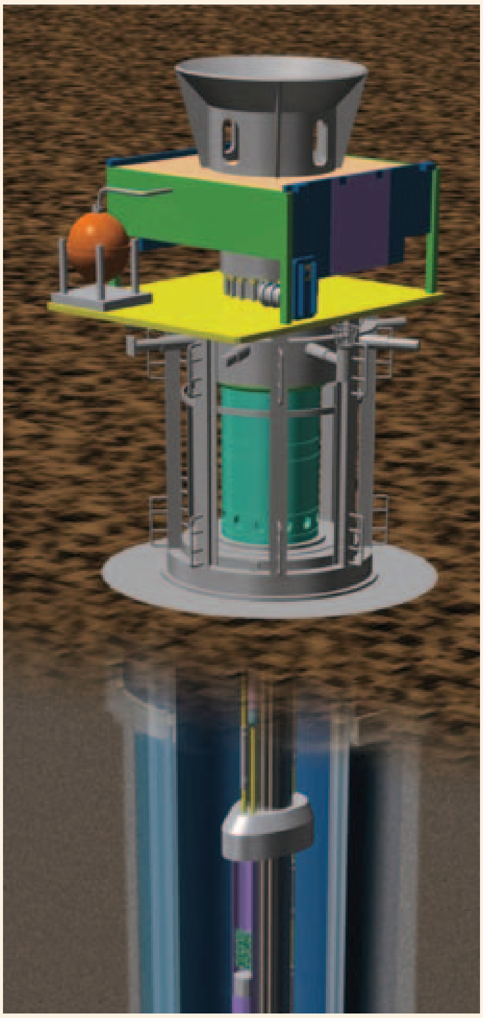
Observing Nankai Trough Seismogenic Zone Behavior using Boreholes

Long Term Monitoring - using Boreholes

To clearly explain the mechanisms behind giant ocean-trench earthquakes in the Nankai Trough, describe the conditions underneath the seafloor, and understand what might happen in the future, core samples and logging data have been collected to obtain a better understanding of the conditions inside the boreholes. However, by themselves, these data will not provide an understanding of the dynamic processes occurring in seismogenic zones. Therefore, NanTroSEIZE long-range plans include the installation of a long-term borehole monitoring system, to continuously monitor earthquakes, the Earth's crustal movement, and hydrogeological parameters with such sensors as temperature, seismometers, tiltmeters, and strainmeters.

During the ODP period, researchers placed seismometers inside boreholes in the Western Pacific Ocean and accumulated over a year of long-term borehole monitoring experience. NanTroSEIZE is planning a high-level monitoring system that is more advanced than this, which will span more than five years, observing many variables at much greater depths, higher temperatures and more intense pressures. Further, the monitoring system will be linked to the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) ocean floor cable network in the Kumanonada region which will start deployment from this year, 2009, to make it possible to transmit the data gathered in real time above ground. This development of a vertical observation network is an epoch-making effort never before attempted anywhere in the world.

The monitoring system concept is shown in the figure on the right. The borehole is lined with casing and a piping system called "tubing" runs up and down the hole. A module carrying various sensors is placed at a scientifically interesting depth and position and then connected to a telemetry cable. Data are transmitted to the subsea module sitting at the top of the borehole opening through a cable, which then connects to a shore monitoring station via the ocean floor cable. The deepest part of the borehole is provided with a plug called "packer" that prevents fluids from infiltrating into the borehole. A sensor is also mounted at the bottom of the hole.



The "Christmas Tree" – a wellhead section of the Long Term Borehole Monitoring System.

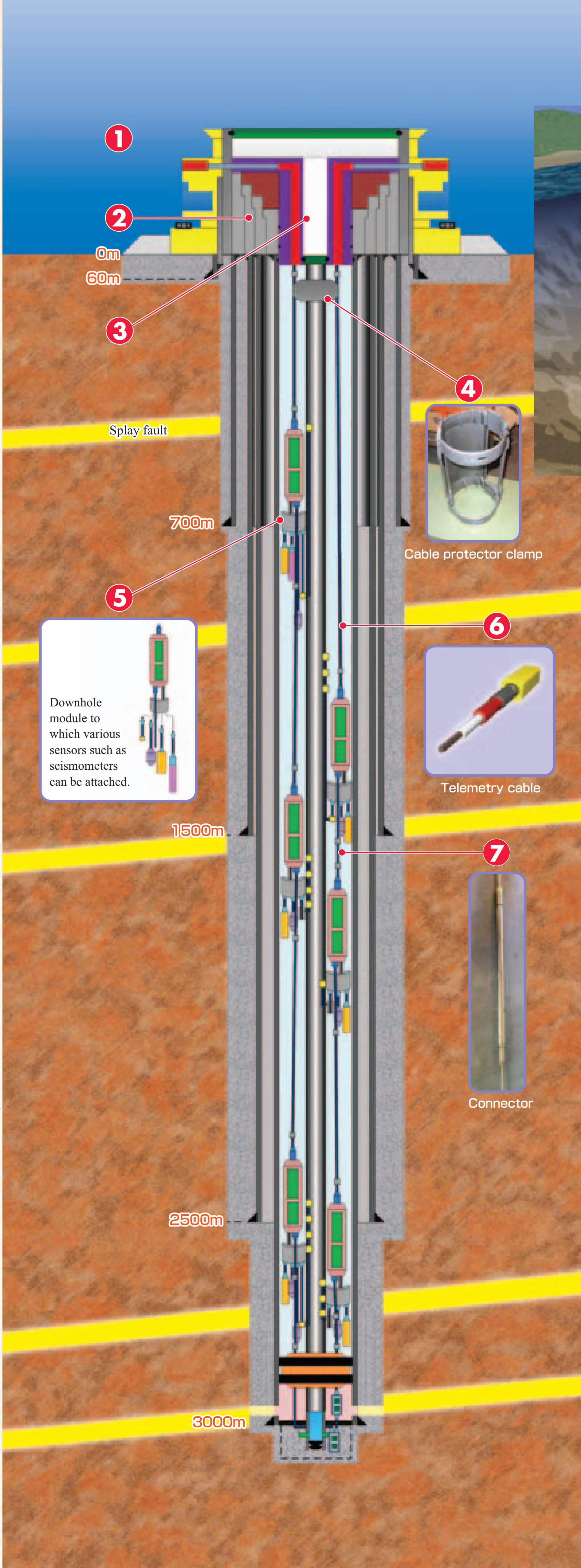
Overcoming Difficulties to Make the System a Reality

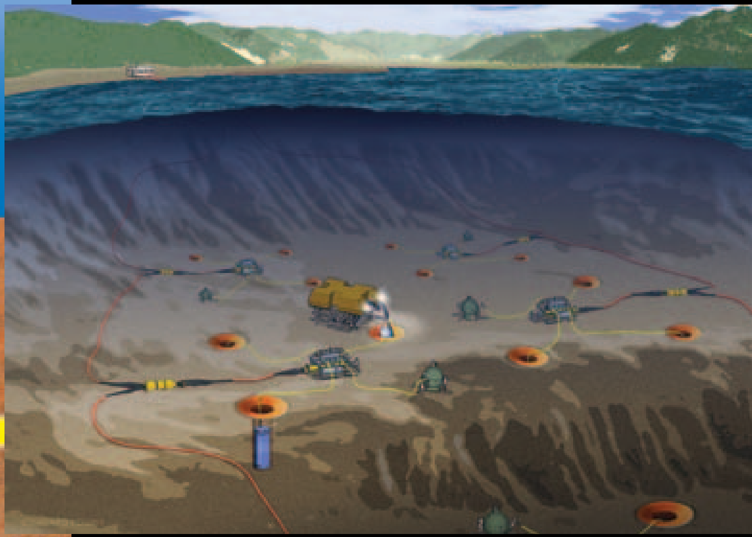
There are many technical challenges to be resolved to make a system a reality, including establishing monitoring system installation technology and safety facilities, developing long lasting, robust, equipment (lifespan > 5 yrs), able to resist 250 G impact, and developing a data transmission system that would neatly organize and synthesize the varied data obtained. The list of problems goes on. For example, let us consider only the seismometers: they must be able to cover a wide area and must have a wide dynamic range in order to detect earthquakes ranging from slight tremors to giant earthquakes. Furthermore, these seismometers will be placed in many zones, requiring that seismometers be synchronized with high precision.

One especially difficult problem is high temperatures, since seismic faults are locked in regions where the temperature rises above 200ºC. At present, the initial engineering target objectives for the monitoring system are 125ºC at a depth of 3,500 meters. In general, commercially available electronics have guaranteed operational temperature limits up to about 85ºC, beyond which, troubles may easily arise. Although high-temperature resistant parts have been developed in the automotive, rocketry and nuclear power fields, and are therefore technically possible, setting up a long-life monitoring system is not easy. Many other problems need to be overcome, such as measures against high pressure and corrosion. On top of this is the problem of how to create low-power consumption equipment to connect to the system since the power is supplied via ocean floor cables. Technical development efforts to overcome these problems are now underway, and efforts to turn the monitoring system into reality are now ongoing at a feverish pitch.

The Long Term Borehole Monitoring System is scheduled for deployment in Kumanonada around 2011. Connecting this with the ocean floor monitoring system will ensure the establishment of a 3-dimensional advanced monitoring network, expected to advance our understanding of the mechanism of the genesis of earthquakes and contribute to more precise earthquake prediction and disaster prevention and damage minimization.

Contributor: Masanori Kyo, Principal Research Scientist, CDEX Engineering Department

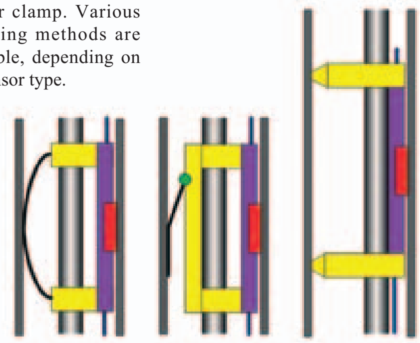


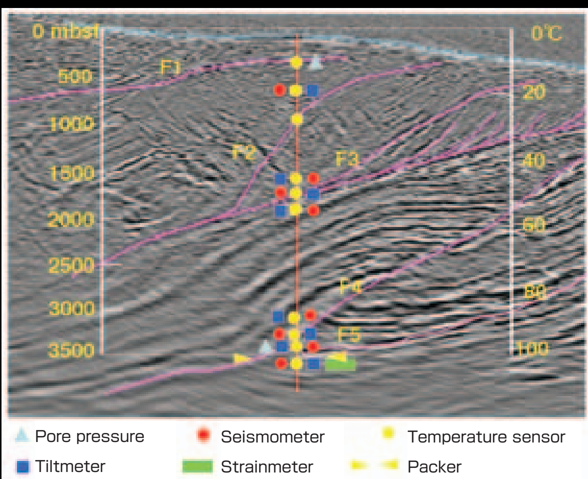


Graphical illustration of ongoing development of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) at Kumanonada. This ocean floor cable network will be connected to the Long Term Borehole Monitoring System for power supply and data transmission. With this, long term monitoring and real time data transmission will become reality.

Illustration provided by DONET

Sensor clamp. Various clamping methods are available, depending on the sensor type.





Example of sensor installation. The configuration may change depending on geological structures such as the depth of the splay fault.

JOIDES Resolution (US)
(IODP scientific drilling vessels)

IODP: Promoting earth science by drilling the seas of the earth

Science Team will Reveal Past Climate Changes via Drilling in the Bering Sea

Interview with
Professor Kozo Takahashi
IODP Expedition 323 Bering Sea Co-Chief Scientist
Professor, Science Research Institute, Graduate School of Science, Kyushu University

In 2009, the three scientific drilling vessels of the Integrated Ocean Drilling Program (IODP), *Chikyu* of Japan, the US *JOIDES Resolution*, and the European Mission-Specific Platform (MSP), together embark on scientific drilling expeditions around the world. This is the first time these three scientific drilling vessels embark on drilling expeditions since the inception of IODP.

Nine research expeditions are planned this year, including expeditions to the Nankai Trough off the coast of the Kii Peninsula, the equatorial Pacific Ocean off Hawaii, and off the eastern coast of the US, off New Jersey. One of these expeditions is in the Bering Sea headed by Prof. Takahashi at the Kyushu University.

From July to September of 2009, the US scientific drilling vessel, *JOIDES Resolution*, will drill in the Bering Sea (IODP Expedition 323). Prof. Takahashi of Kyushu University is one of the Co-Chief Scientists of this research expedition.

Several aspects of past climate change still remain unclear. Prof. Takahashi says that the Bering Sea at the rim of the Pacific Ocean, in particular, remains a blank zone with almost no drilling done ever to collect sediments.

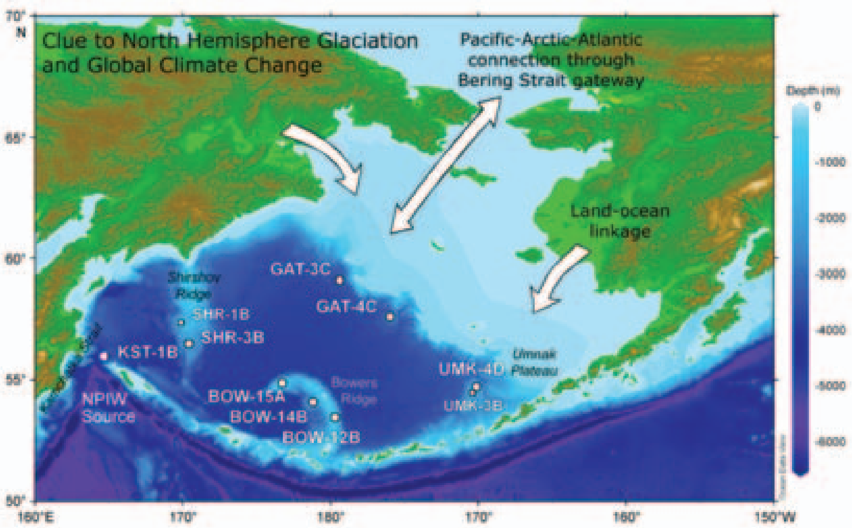
"The primary purpose of the drilling is to investigate the history of the connection between the Pacific Ocean and the Atlantic Ocean in the Northern Hemisphere. Sea water movements in the Pacific and Atlantic Oceans are critical in any attempt to clearly understand climate changes since these movements transport heat and salt. It is said that ice sheets started to develop in the Northern Hemisphere about 2.7 million years ago. Although it is possible that the Bering Sea separated from the Arctic Ocean when the sea level dropped, there is very little understanding on the history of the connection between and closure of the Pacific and Atlantic Oceans.

The second purpose is to trace the beginnings of the North Pacific Intermediate Water (NPIW). At present, NPIW is still formed in the northern seas, one of which is the Bering Sea. NPIW forms a large mass of water and contributes to climate change to a great extent.

The third is to investigate how interactions changed between the land and sea. The Bering Sea is a marginal basin surrounded by land and is strongly connected to land and sea changes. "This can be tied to the formation of ice-sheets in the Northern Hemisphere and to the connection between the Pacific and Atlantic Oceans. Sea level rises and drops depending on the difference between glacial and interglacial stages. At the time of the largest drop in sea level, about 130 m lower than the current sea level, the Northern Bering Strait completely dried up and the continents were connected. The cycle of glacial and interglacial stages acts as a mediator that establishes and breaks down this connection."

Drilling the sea bed to extract a sedimentary core would clarify water depth and salinity from the fossilized relics in the core, and whether or not the land masses were connected at that time. Prof. Takahashi also participated in the 2004 Arctic Coring Expedition (ACEX) (IODP Expedition 302) which purpose was also to investigate the connection between the Atlantic and Pacific Oceans. "There were many excellent fossils recovered from samples that corresponding to 56 million up to 44 million years ago. During that age, the Arctic Ocean and the Atlantic Ocean were not yet connected. It is surmised that the conditions then were the same as those currently existing in the present-day Black Sea. However, samples from years younger than 44 million years ago are almost free of fossils, so there is presently no understanding of the relationship between the Pacific Ocean and the Bering Sea meeting at the Arctic Ocean. Naturally, the Bering Sea must be drilled.

In 1999, a preliminary survey of the sea area to be drilled was carried out using the scientific research vessel *Hakuho-maru*. Samples taken from 100 to 300 thousand years ago, spanning both the glacial and interglacial stages of that era contained a neat array of fossils. Prof. Takahashi summarized the significance of the coming drilling expedition as follows:"5 to 10 million years ago, fossils rich in calcium carbonates must have been left since that era was much warmer than the present day. The conditions being such, I believe that drilling would be a work worth undertaking with results applicable to a global scale."



The relationship between the research target and the Bering Sea drilling site Figure provided by Kozo Takahashi

IODP Curator: responsible for effective use and management of core samples

Management of precious core samples obtained from scientific ocean drilling

Members of the IODP Curatorial Team posing in a reefer at Kochi Core Center. In the back row, from left are Yohei Arakawa (Curatorial Specialist), Lallan P. Gupta (IODP Curator), Toshio Hisamitsu (Curatorial Superintendent). Middle row, from left, Shigako Nigi (Curatorial Assistant), Satoshi Hirano (Curatorial Specialist). Front row, Masaru Yasunaga (Curatorial Specialist).

Proper storage of core samples

The precious core samples extracted from below the seafloor by the scientific drilling vessels, such as the Deep Sea Drilling Vessel "*Chikyu*", during the IODP (Integrated Ocean Drilling Program) research expeditions are transported to the Kochi Core Center (KCC) located in the Kochi Prefecture, Japan and stored under appropriate ambient conditions for research and education purposes. Responsibility of storage and curation of these samples lies with the IODP Core Curatorial Team of the Kochi Institute for Core Sample Research.

The KCC is a research facility jointly operated by the Kochi University and JAMSTEC. The KCC is equipped with many leading edge analytical instruments and has a large core repository that occupies half of the first floor area of the KCC building. The huge freezer (keeping samples at about –20˚C) and reefers (keeping samples at about 4˚C) of the core repository can house approximately 180,000 halved core sections that are 1.0 to 1.5 m long. Moreover, many cryogenic storage tanks using liquid nitrogen to keep samples around –160˚C for microbiological research are also installed separately.

In addition to the core repositories in the Texas A&M University, USA and in the University of Bremen, Germany, the KCC is one of the three world-class core repositories of the IODP that stores the core samples obtained during IODP research expeditions in the Western Pacific Ocean and Indian Ocean regions. Further, the core samples taken from the same oceanic regions by the former Deep Sea Drilling Program (DSDP) and Ocean Drilling Program (ODP) have been relocated from the USA and Germany, and are now stored and curated in the KCC.

Judging how to distribute the precious samples

The Core Curatorial Team does not only store and manage the core samples but also distributes the samples after receiving and evaluating requests for core samples for research purposes from researchers around the world. The person who is responsible for discharging this role is the IODP curator, Lallan P. Gupta.

"Core samples extracted through drilling below the seafloor are cut into 1.0 to 1.5 m long sections, which are further split vertically into 2 halves on board the drilling vessel. One half of these is for non-destructive measurements and 'permanent' storage (archive half) while the other half is used for sub-sampling for various research purposes (working half). Researchers who participate in a research expedition are given priority to use the samples and data for a period of one year after the samples are extracted (moratorium period). After the moratorium period elapses, researchers all over the world may submit a request for the use of core samples, also educators and museums may submit a request for use of core samples in education and special display. My work is evaluating and judging these requests and their contents, approving the use of the samples, drafting sampling plans and implementing them," tells Gupta.

The curator says, "Evaluating requests for samples is an intricate process." Questions like, 'what kind of research will the sample be used in?', 'will clear results be obtainable from such research?' need to be asked. The nature of the request has to be examined from various standpoints and, if necessary, questions are sent to the requester. Evaluation is carefully conducted in order to come up with a sound judgment. "Evaluating requests in the light of IODP policies and making sure that communications with requester are proceeding smoothly at the same time is a difficult task and is very important because the core samples that have been collected from oceans are quite precious," says Gupta. Eleven years have passed since he came to Japan, and has spent long time in continuing research on global climate changes. However, his job as a curator requires knowledge that goes beyond his specialization. He goes on to say that there are also many things one can learn from sample request evaluation. "I often discover that one can do 'such kind' of research using the core samples. Moreover, I am filled with expectation upon sending the samples, wondering what kind of results will come out," reveals Gupta.

According to the curator, although requests for samples come from all over the world, much of these requests come from researchers in Europe and the USA. He further says, "Perhaps, information regarding IODP is not yet widely known in Asia and Oceania. I wish that information on what research is being done using scientific ocean drilling program and what results are obtained would become more widely known and that research from the regions of Asia and Oceania would use the samples we have here at the KCC."

Core sampling activity

Core handling activity in a reefer

Meeting to discuss core curation on D/V *Chikyu*.

Experiencing the world of a new Earth Science

A wide variety of events are progressing, heightening interest in Scientific Drilling and *Chikyu*. This report introduces some of these events.

A two-day heartfelt experience aboard *Chikyu*

Joining the "Real-Laboratory@the *Chikyu*
・The Earth as seen on board a 'Floating Research Vessel'

Practical training on looking for microfossils contained in seabed sediments (above). Participants enjoyed personally experiencing life aboard and deepening relations with the crew (below).

The event "Real-Laboratory@the *Chikyu*" was blessed with beautiful, clear weather. Members of the 'Friends of the National Museum of Emerging Science and Innovation' and students from Keio Senior High School participated together in the event and spent a meaningful time aboard the vessel, enjoying a more detailed educational tour than is offered for the usual general public tours. All participants experienced actual research conditions by observing microfossils and participating in a joint science cafe with young researchers aboard *Chikyu* for the Core School that was being held at the same time. They had the following to say about their experience: "I learned that, more than being just a 'vessel for drilling samples,' *Chikyu* is a 'research vessel' that is able to gather extremely beautiful data," and "All the researchers had a sense of humor and were easy to get along with." They reflected on how they came to understand the technologies of a scientific drilling vessel and the different aspects of being a researcher.

I too have come to a closer personal understanding of what *Chikyu* is in the two days that I spent with the researchers and getting in touch with the real thing. Up to now, I have known only from books and lecture presentations about the status of the project and the superiority of its drilling technology, as well as the researchers' passion. The talks that I heard while on board *Chikyu* gave me greater satisfaction than I have ever felt before.

I think this event, chock-filled with numerous precious personal experiences, turned into a time that tickled the intellectual curiosity of adults. One of these was the surprise last demonstration of *Nankin Tamasudare* (bamboo screen used for street performance) on the theme *Chikyu* made by the participants on the second day. The applause and the song started, and eventually I noticed that the assembly hall came together!! Indeed, I was thrilled to have witnessed a moment when science became culture. This idea largely came to her talking with the researchers during discussions lasting until midnight. I wish that such situations where adults share new knowledge, where scientific topics bring enthusiasm to daily life, would increasingly become a part of daily life more and more in the future. Furthermore, I wish that many people would pay attention to this international project from now on.

(Tomoko Yuzuriha, Science Communicator, National Museum of Emerging Science and Innovation)

Cooperation with study program "Occupational Workshop"

In cooperation with the Tokyo Metropolitan Hakuo Junior High School

The Center for Deep Earth Exploration (CDEX) worked in cooperation with the Tokyo Metropolitan Hakuo Junior High School in their course study program "Occupational Workshop" utilizing integrated learning hours allotted to first-year students. The staff acted as teachers giving lessons to all students on the research that comprises the Integrated Ocean Drilling Program (IODP). They also implemented a program whereby the students were made to think about what research might make good use of the *Chikyu*.

First, the workshop started by providing the students with a good understanding of the activities of CDEX, and were asked to study the website materials on their own and ask questions on what they wanted to know better, as well on topics they had no understanding of. The students were also asked to think about "what can be done, assuming they can do anything at all using *Chikyu*."

On the last day of the month-long workshop, the students were divided into four groups, as the staff of the CDEX watches, each gave a presentation that synthesized their findings and thoughts on the themes "The Possibilities of Microorganisms," "Food from the Depths of the Ocean," "Discovery of New Energy," and "Our Planet" through posters, dramatizations and other creative presentations. All were filled with many wonderful original ideas on how to solve the various problems facing society today, formulated from actual research and detailed investigations of *Chikyu's* capabilities. I think that through the workshop we were able to appreciate the fun of studying an Earth that even until now still remains largely mysterious and unknown.

(Yukari Kido, IODP Department, CDEX/JAMSTEC)

On the last day, discussions with the CDEX staff and presentations by each group were held (above). Students brainstorming on what possibilities can be achieved with the scientific drilling vessel, *Chikyu* (below).

This is the year when Integrated Ocean Drilling Program (IODP) breaks through I'm looking forward to wide-ranging research results

After the hardships, a year to start anew

Last year was a very unfortunate year. No cruises were performed due to azimuth thruster gear damage (thrusters used to hold ship position) and other adversities. However, with the establishment of a new and an entirely operational management structure for *Chikyu* during this period, progress has been made to stabilize and strengthen operations. With the completion of repair work this February and trial drilling and function verification testing, preparations for research at the Nankai Trough starting in May have been steadily moving onward.

For me, I think that 2009 is the year when IODP starts in earnest. The refurbishing and modifications for *JOIDES Resolution* have also been completed so that this is the first year when all three IODP scientific drilling vessels, *Chikyu*, *JOIDES Resolution*, and the Mission-Specific Platform (MSP), will all go to sea on research expeditions. Until now, there was real anxiety and fear whether IODP would really be able to continue. However, having overcome hardship, I feel in my bones that this year would turn out to be a good year filled with much encouraging news. In September, an international conference, "IODP New Ventures in Exploring Scientific Targets (INVEST)", to discuss IODP scientific plans for beyond 2013 will be held in Bremen, Germany. Through this discussion, if the scientific community as a whole is built up and active drilling using the three scientific drilling vessels bears much fruit, then research will, without fail, enter into "full steam ahead" mode at once and proceed to the future.

First Scientific Riser Drilling

This year, *Chikyu* will be faced with the challenges of the first scientific riser drilling in its drilling program. Barring unforeseen failures, no technical problems are expected since it has already undergone shakedown drilling. The sea area where drilling will be done is comparatively minimally affected by the strong Kuroshio current. Furthermore, a fairing (a mechanism for alleviating water resistance) for the riser pipe has been installed and other measures to reduce the impact of strong sea currents have been put in place. What is left is "the struggle with time" to determine whether drilling activities would run as smoothly as planned. And, of course, "weather." This expedition will be at sea in a time when typhoons are expected to develop so that measures to respond to weather conditions are extremely important.

With regards to the research per se, drilling will occur exactly at the boundary between the Kumano Basin (sedimentary basin) and the Accretionary Prism. This was once thought of as a geologic layer of sedimentation that settled on top of the accretion. The layer folded, disappeared and accumulated in the Kumano Basin. Drilling through and analyzing these three layers will generate important data that could clearly point to how the Kumano Basin came into being and clarify its relationship with seismogenic zones. On the one hand, although it has been established from previous drilling that the stress fields change at the boundaries of spray faults, it is expected that data will be obtained that will contribute to the understanding of the overall picture of stress fields as subduction proceeds towards the landward side. It is also expected to generate fresh views on the deep earth biosphere.

One more thing of significance is that the riser drill hole will be used as a well for a long-term monitoring system. The data from the borehole, when linked to the planned Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) scheduled for deployment in 2009, would provide a three-dimensional real-time observation picture of the sea floor and below. To be sure, this network is unprecedented and will provide much valuable scientific knowledge. The first step towards this is the drilling that *Chikyu* performs this year.

IODP should Take the Lead in this much Wider Field of Scholarship

Although this is also related to INVEST, I think that it is important for IODP to change how science goes forward from this time on. I think that we should open our eyes to the fact that we should pave the way to a much wider academic field by connecting with related research undertakings and not be limited to a "science exclusive" viewpoint of drilling research. The DONET linkage with is just such an example. I hope that we may be allowed to pursue developments within the large framework of a much wider environmental science that links the drillings done in the Bearing Sea, research on climate changes and oceanographic observations in the North Arctic Sea, and climate modeling researches by such facilities as the Earth Simulator.

I therefore wish that many IODP researchers think of what broader possibilities might open with drilling research as a pivotal element. I hope that this year is a year of wonderful IODP scientific results and a year where these results are proclaimed to the world.

IODP scientific drilling vessels together