

Blue Earth

海と地球の情報誌

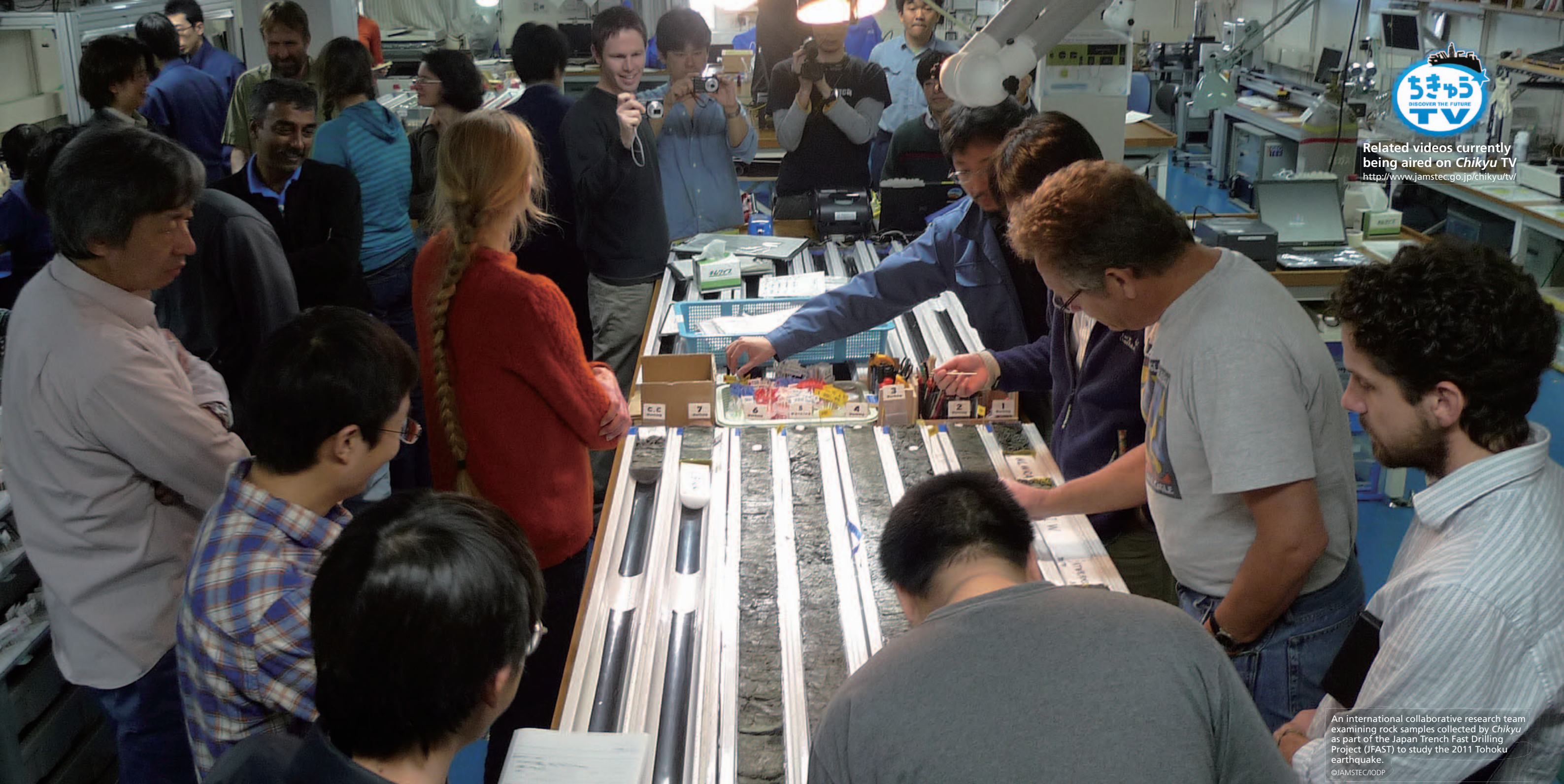
Japan Agency for Marine-Earth Science and Technology

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2011 Tohoku Earthquake

What we now know:
**mysteries of the
massive earthquake
and tsunami**





Related videos currently
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An international collaborative research team
examining rock samples collected by *Chikyū*
as part of the Japan Trench Fast Drilling
Project (JFAST) to study the 2011 Tohoku
earthquake.

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Job titles and positions were current as of the time of reporting

What we now know: mysteries of the massive earthquake and tsunami

Inspector general

Shin'ichi Kuramoto

Deputy Director-General,
Center for Deep Earth Exploration (CDEX),
Japan Agency for Marine-Earth Science and Technology

The 9.0 M Tohoku earthquake struck on March 11, 2011,
accompanied by a tsunami that reached heights of 40 m and caused enormous damage.
In 2012, Deep Sea Drilling Vessel (D/V) *Chikyū* conducted an ocean floor scientific drilling study
at the point of origin of the tsunami. Four papers presenting the results of research based on
this study were published in journal of *Science*.^{*} To what extent have we understand the
mechanism of mega earthquakes and tsunamis?

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Chikyu successfully collects core samples and measures temperature at plate boundary fault.

Interview: **Nobu Eguchi** JAMSTEC Center for Deep Earth Exploration, Manager for Science Operations

"Actually I don't really remember those days, because we had too many things to do just after Tohoku earthquake," recalls Nobu Eguchi, the manager for science operations at the Center for Deep Earth Exploration (CDEX). As Japan's Integrated Ocean Drilling Program (current name as International Ocean Discovery Program (IODP)) implementing organization, CDEX is responsible for operating Deep Sea Drilling Vessel (D/V) *Chikyu*.

In May of 2011, IODP community put together the plan to drill 1,000 m below the seafloor at the fault zone, where the fault had slipped 50 m at a water depth of 7,000 m, to reach the plate boundary. The goal of this project was finding slipped fault, collecting rock samples (cores) from the fault zone, and most importantly installing temperature sensors at the slipped fault zone. Just one year later, from April to May and in July of 2012, *Chikyu* carried out the Japan Trench Fast Drilling Project (JFAST) as the IODP Expedition 343 and 343T.

JFAST needed to be carried out as soon as possible. Frictional heat is generated when a fault slips during the earthquake. The easier the fault slips, the lower the frictional heat generated. Thus, by measuring the residual frictional heat, we can estimate the ease with which the fault slipped. "But, in order to measure this residual heat, which was continuously cooling, we needed to install temperature sensors at the fault as early as possible within 2 years after the earthquake."

Nobu explains that "the greatest difficulty was making sure that the drill pipe, whose total length was 8,000 m, was strong enough." Up to that point, the record for drill pipe length was 7,049.5 m, set by the D/V *Glomar Challenger* in 1978 during the Deep Sea Drilling Project (DSDP). In that case, however, the drill only bored 15.5 m below seafloor at water depth of 7,034 m. The deepest *Chikyu* had drilled until then was approximately 4,000 m below sea level.

"A 7,000-m drill pipe weighs approximately 350 tons. We had to dangle a pipe of this weight, rotate the drill bit (blade) attached to its tip, and drill 1,000 m below seafloor. If there were no waves, wind, or currents, and the ship could be kept perfectly still, the strength of a conventional pipe would have been sufficient. But there was no guarantee that the pipe wouldn't break if the ship were to move. We considered the forces on the pipe that would be expected when the ship moved in three dimensions, built a new pipe, and conducted strength tests as quickly as we could.

Another challenge was to develop a method for deploying instruments. "The drill pipe is the only tool that can be used for tasks performed at the seafloor. We had to insert the drill pipe into the borehole with temperature sensors attached to its tip. When we did this, we needed to be able to somehow detach the temperature sensors, but we weren't able to use the conventional method. In shallow sea areas, we could have simply rotated the drill pipe, which is the conventional method for deploying observational

instruments. However, at a depth of 7,000 m, removing a screw at the tip of the pipe is impossible. The technical staff at CDEX came up with a deployment device that, by applying water pressure to the inside of the pipe, would cause a valve to release and thereby detach the instrument."

With these issues resolved, *Chikyu* left Shimizu Port, Shizuoka Prefecture on April 1, 2012 with 32 researchers from 10 countries on board and headed for the Japan Trench.

"Although we reached the drilling site three days after leaving port, the weather was bad and we couldn't work for a while." Finally, on day 12, work began on installing the wellhead to set the temperature sensors. "However, we ran into trouble when the newly developed deployment device wouldn't work properly. We were able to resolve this problem by repairing and improving the device on board the ship."

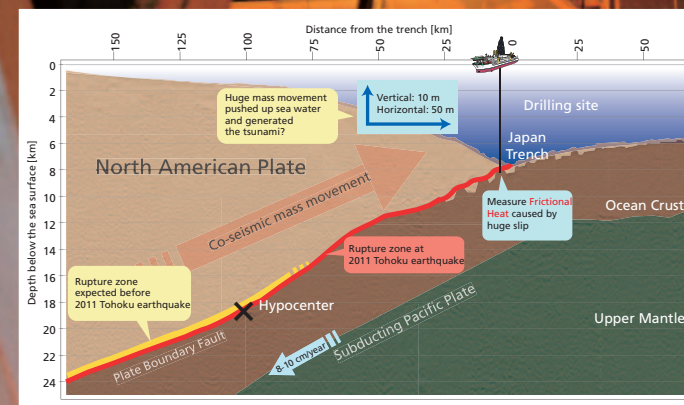
To identify the depth of the fault inside the borehole, logging while drilling (LWD) was performed. The position of the fault was determined by measuring the natural gamma radiation and resistivity of the borehole wall with various sensors equipped with a special pipe, which is set just above the drill bit at the tip. *Chikyu* set a new record of 7,740 m for total drill pipe length with drilling 850.5 m below the seafloor at water depth of 6,889.5 m. As a result of LWD, data suggestive of a fault was identified at the depth of 720 m and 820 m below the seafloor.

Thereafter, various problems, including rupture of the drill pipe and trouble with the underwater camera system, occurred in rapid succession. Without images from the underwater cameras, performing the work needed to install the temperature sensors would be impossible. With the expedition's end date of May 24 rapidly approaching, it was decided that priority should be given to collecting core samples from the fault over measuring residual heat at the faults.

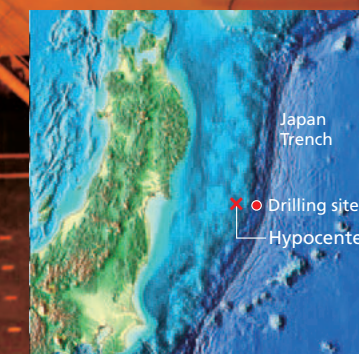
"Under normal circumstances, collecting a series of cores from the seafloor down to the fault is ideal. However, it would require huge amount of time. So, we focused on collecting samples from the vicinities of 720 m and 820 m below the seafloor where the potential fault zones suggested by LWD data."

The core samples were numbered 1R, 2R,... starting from the top to the bottom. On May 21, 2012, a core sample with characteristics clearly different from those collected at shallower depth was retrieved. This was sample 17R, collected from the vicinity of 820 m below seafloor. Dr. Kohtaro Ujiie of Tsukuba University confirmed, "This is exactly the plate boundary fault." Among researchers, core sample 17R is known as "the Miracle Core." (see page 8-9.)

Subsequently, after re-adjusting *Chikyu's* schedule, *Chikyu* headed out to the same area a second time in July in accord with the fervent wishes of numerous stakeholders. In the end, 55 temperature sensors in total were installed in the borehole near the fault zone, magnificently fulfilling the objectives of JFAST.



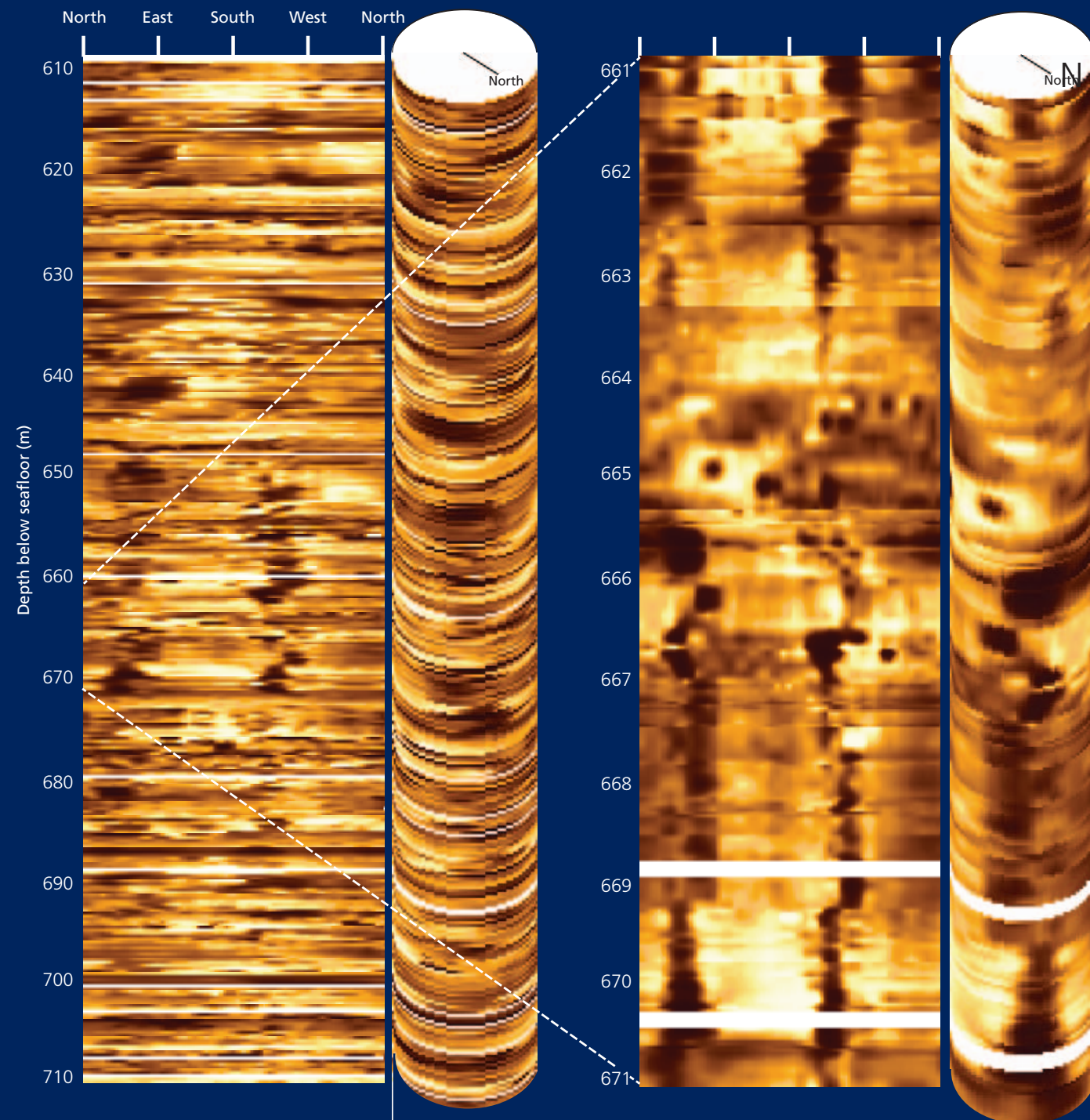
Conceptual image of sub-seafloor structure at the drill site



Drill pipe being lowered to the seafloor from *Chikyu*
©JAMSTEC/IODP

Plate boundary fault near trench had also accumulated stress

Interview: **Weiren Lin** JAMSTEC Kochi Institute for Core Sample Research, Group Leader



Adapted from Lin et al. (2013)

Resistivity images taken by logging while drilling (LWD)
Dark vertical bands indicate electrically conductive borehole breakouts

After the JFAST expedition, research was advanced to clarify the actual conditions of the plate boundary fault that caused the massive tsunami. In February 2013, the results of research led by GL Weiren Lin at the Kochi Institute for Core Sample Research was published in Science. As GL Lin explains, "the findings overturned conventional thinking about earthquakes at frontal thrust in subduction system."

At the locked plate boundary 10 to 20 km below the seafloor, strain accumulates as the overriding North American plate is pushed in along with the subducting Pacific Plate. This causes stress to accumulate at the fault and in the surrounding strata. Stress is the compression or tension that occurs within an object when it is subjected by external force. When the stress accumulated at the fault exceeds the ability of the fault to resist failure, the fault ruptures and instantaneously undergoes massive slip, causing an earthquake.

However, the plate boundary was not considered to be locked in shallow regions near trench axes. For this reason, the conventional wisdom was that the North American plate is hardly pushed in at all by the subducting Pacific plate. "So the belief was that stress did not accumulate at and around the fault, and that fault rupturing propagated during an earthquake from a hypocenter located deep in the crust would not be amplified."

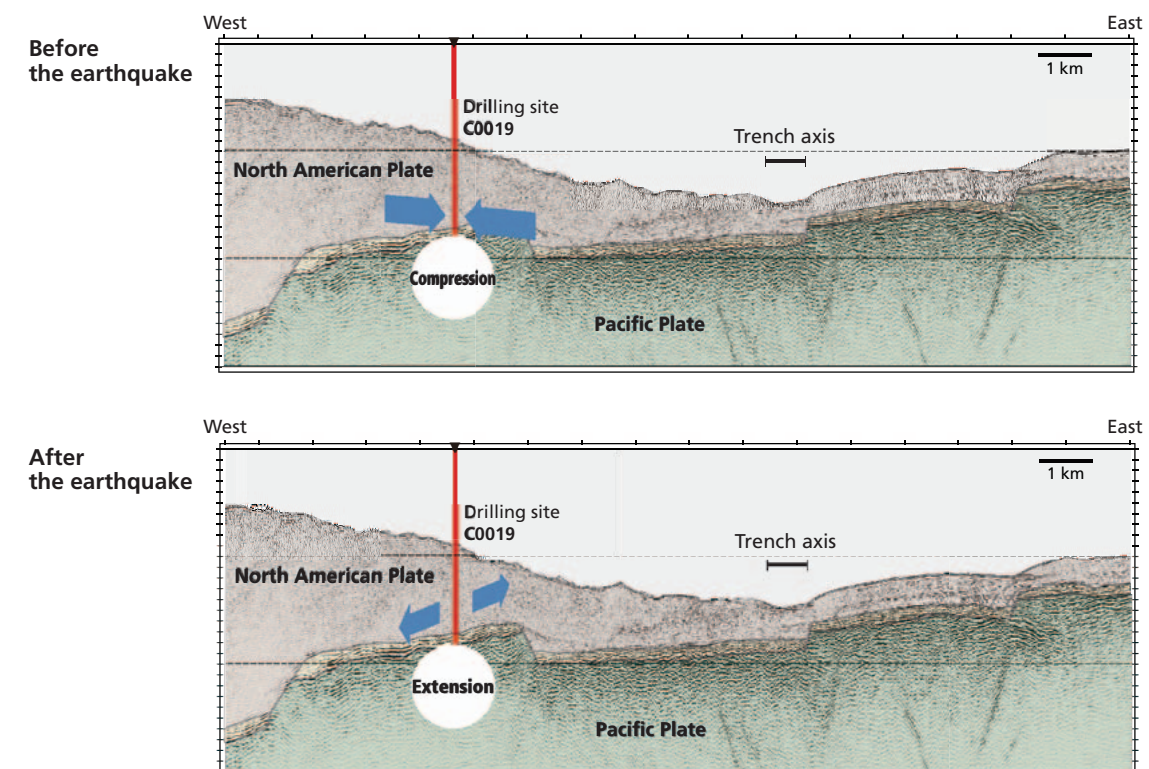
What then, was the stress state of the plate boundary fault that slipped 50 m during the 2011 Tohoku earthquake? To answer this question, GL Lin and collaborators analyzed the logging while drilling (LWD) resistivity data collected at the borehole of

JFAST.

"Based on our analysis, we found breakouts along the borehole wall. Breakouts are a kind of compressive failures that develop by stress concentration on the borehole wall. Fluid in the borehole fills these failure parts, increasing electrical conductivity and appearing as dark bands in the images. From the direction and width of these breakouts, we found that the stratum above the fault (North American plate) is being subjected to stress that causes strata to elongate (i.e. an extensional stress state). Meanwhile, geological structure analysis by JFAST and previous surveys suggest that a compressive stress state associated with subduction of the Pacific plate had developed before the Tohoku earthquake."

What is the significance of the reversal in the stress state from compressive to extensional as a result of the Tohoku earthquake? "We can interpret this as meaning that nearly all of the accumulated stress was released by the earthquake and that the plate boundary near the trench axis had also accumulated substantial stress. The accumulation of substantial stress before the earthquake, and the release of this stress during the earthquake, explains why the coseismic fault slip displacement increased associated with rupturing from deep to shallow and then reached the order of 50 m near to trench axis."

What type of material is the plate boundary fault made of? The true nature of the fault was revealed by the "Miracle Core" collected as part of JFAST—



The stress state of the North American plate above the fault changed from a compressive stress state before the earthquake to an extensional stress state after the earthquake.

Adapted from Lin et al. (2013)

The true nature of the fault revealed: a clay layer of volcanic origin

Interview: **Kohtaro Ujiie** Faculty of Life and Environmental Sciences University of Tsukuba, Assoc. Prof.

The “Miracle Core” 17R was recovered as a part of JFAST. Assoc. Prof. Kohtaro Ujiie (University of Tsukuba), who confirmed aboard the ship that 17R comprised the plate boundary fault, describes the characteristics of the core as follows. “The rocks comprising 17R have the appearance of fish scales. This is a characteristic of clay that has failed. Subsequent analysis revealed that 78% of 17R was made up of a type of clay mineral known as smectite.”

Smectite consists of extremely small grains that are a few μm or smaller in size. A large amount of water is retained within and between these grains. This water is held tightly and is highly immobile.

Chikyu has also conducted drilling expeditions in the plate subduction zone of the Nankai Trough that extends in a southerly direction off the coast of southwest Japan. The Nankai Trough marks the zone where the Philippine Sea plate is subducted beneath Japan. The smectite content of cores recovered from the Nankai Trough plate boundary fault is on the order of 30%.

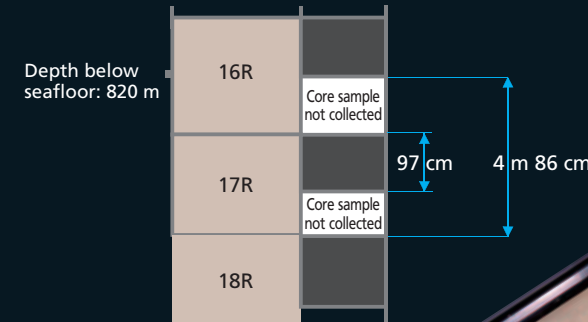
The total length of 17R is 97 cm. The composition of 17R has been confirmed to differ from that of core 16R or 18R, which respectively lie above or below 17R. There are gaps between 17R and 16R or 18R, from which core samples could not be collected. Assuming that these gaps also have the same composition as 17R, the maximum thickness of the smectite-dense layer is still 4.86 m. “Normally, clay layers are 20 m or more in thickness. The plate boundary near the trench axis off the coast of Miyagi Prefecture had a very thin layer of highly concentrated smectite.”

Why does such a smectite layer exist in the Japan Trench? “To begin with, smectite is a clay formed through the transformation of extremely small particles of volcanic ash origin that have been carried by wind (several thousand km on occasion) and deposited on the seafloor. The smectite found in 17R was derived from volcanic ash generated by volcanic activity several tens of millions of years ago and deposited on the floor of the Pacific Ocean. This seafloor has moved along with the Pacific plate and is now being subducted at the Japan Trench. Meanwhile, the Nankai Trough is supplied with large amounts of terrigenous sediments because of its proximity to on land. Therefore, its smectite content is low relative to that of the Japan Trench.”

The concentration of smectite in such a thin layer indicates that there was volcanic activity during a certain time period several tens of millions of years ago. This thin smectite-rich layer may have been the underlying cause of the tsunami that occurred on March 11.

How then, did this thin smectite layer cause large slippage? —

Chester et al. (2013) and Ujiie et al. (2013)



Overall image of Miracle Core as 17R. Detailed analyses including microscopic observations are being performed by Assoc. Prof. Ujiie and colleagues to determine if the core contains material that slipped during the earthquake.

Close-up image of 17R. A fish scale-like morphology is observed.
©JAMSTEC/IODP

Frictional heat increased water pressure and caused rapid fault slippage

Interview: **Kohtaro Ujiie** Faculty of Life and Environmental Sciences University of Tsukuba, Assoc. Prof.

The fault rupture that occurred on March 11 began 24 km below the seafloor off the coast of Miyagi Prefecture. What happened when this slip reached the fault zone near the trench axis?

To reconstruct the conditions of the earthquake faulting on March 11, Assoc. Prof. Ujiie and colleagues carried out friction tests of the rock from 17R. "The tests triggered a phenomenon known as thermal pressurization, in which water pressure increases owing to the generation of frictional heat."

As the fault slippage is transmitted, the resulting friction heats the large amount of water held in the

smectite layer, causing it to expand. "As a result, the water pressure increases. When this happens, the water in the smectite layer is maintained under high pressure because it tends to be immobile. Normally, the fault does not slip easily because it is pushed downward by the weight of the overlying rocks and ocean water. When the water pressure in the smectite layer pushes back against this downward force, the fault becomes more likely to slip instantaneously."

Confinement of water in the thin smectite layer likely enabled the water pressure to rise to extremely

high levels. The extremely low permeability of the smectite layer in 17R was confirmed by Wataru Tanikawa and fellow researchers at JAMSTEC's Kochi Institute for Core Sample Research.

"First of all, smectite has the lowest friction coefficient of all minerals. So in a plate boundary fault containing 78% smectite, the opposing plates are unlikely to be locked together. The conventional wisdom was that the part of the plate that slips during an earthquake is the part that becomes strained when it is locked to and pulled under by the subducting plate. I believe that one of the major contributions of the JFAST project is that it demonstrated that even faults that have not experienced substantial locking before an earthquake can undergo substantial slippage when failure originating elsewhere is transmitted."

The analysis of LWD data by GL Weiren Lin and colleagues at the Kochi Institute for Core Sample Research demonstrated that the stress state changed drastically from a compressive stress field before the earthquake to an extensional stress field after the earthquake. This observation is consistent with the results of the friction test, which indicated the fault weakening during the earthquake.

Regarding his outlook on future research, Assoc. Prof. Ujiie explains, "I would like to continue conducting research focusing on the behavior of faults during earthquakes."

The fault rupture that occurred on March 11

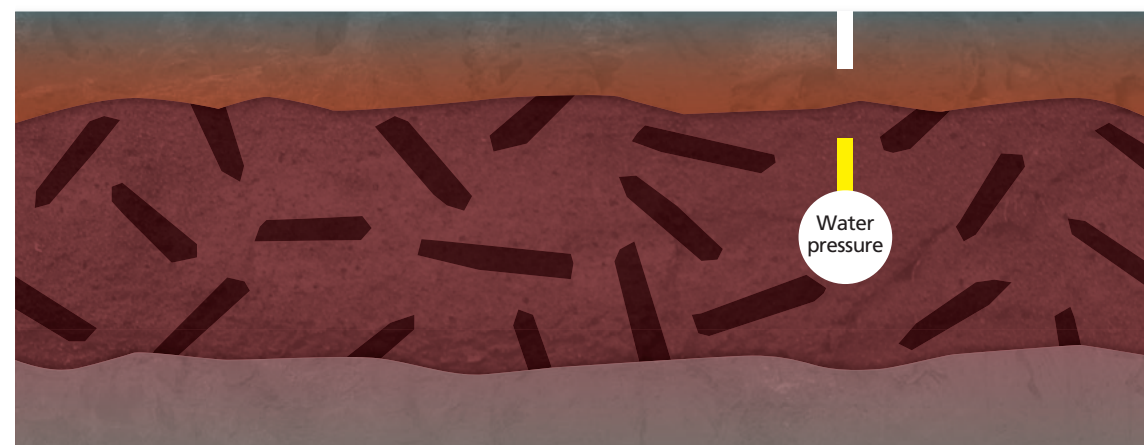
began at a deep plate boundary, 24 km below the seafloor. The plates are thought to have been continuously locked at this location and accumulating stress. What kind of rock does this fault comprise and how did it behave during the earthquake? "The current technology doesn't allow us to recover core samples from the locked zone deep under the Japan Trench. So I decided to study ancient plate boundaries that are exposed on land."

In January of 2014, Assoc. Prof. Ujiie and students from his laboratory set out to study and collect fault samples from a 250 million-year-old geological formation exposed along the Kiso River in Gifu Prefecture. "Around that time, there was a mass extinction in which the majority of organisms living in the oceans died off. This resulted in the deposition of mud containing large amounts of organic matter on the seafloor. It appears that the plate boundary fault developed alongside this organic mudstone. In addition, the chert layer (formed from the remains of radiolarians) is turned completely black and is apparently being affected by violent fault movements. In the future, we plan to analyze the collected fault samples to find traces of past slippage and to clarify the movement of deep plate boundaries during earthquakes."

Fault formed along the 250 million-year-old strata next to the Kiso River (The black layer near the hammer is the organic mudstone and chert layer)



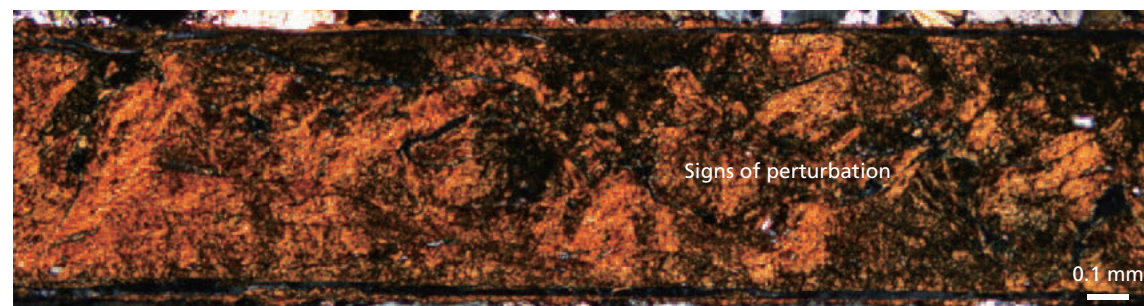
Before the earthquake



During the earthquake

Mechanism of thermal pressurization

The water trapped in the fault is heated as a result of the frictional heat generated by the earthquake faulting and increases in pressure. The increased water pressure pushes back against the pressure from above, creating conditions conducive to fault slippage. At this point, the fault material behaves like a fluid and is fluidized. Signs of this fluidization can be seen in the rock samples from 17R after the friction tests (below).



Signs of perturbation

0.1 mm

Sample following a friction test

Adapted from Ujiie et al. (2013)



Borehole temperature measurements also verify that fault was very slippery

Interviews: **James J. Mori** Disaster Prevention Research Institute Kyoto University, Prof. and **Yasuyuki Kano** Asst. Prof.

"When the Tohoku earthquake occurred, I felt that as an earthquake researcher, I had to do something and that I needed to clarify the cause of the large slip that characterized this earthquake," recalls Prof. James J. Mori of Kyoto University. "So, I consulted with Weiren Lin at JAMSTEC's Kochi Institute for Core Sample Research and others, and presented a proposal at the IODP meeting held in late March to measure the residual frictional heat from the earthquake directly at the fault."

Prof. Mori, together with Asst. Prof. Yasuyuki Kano and colleagues, have experience conducting temperature measurements of the land fault that slipped during the M7.7 Taiwan Chi-Chi Earthquake of 1999. "I believe we were the first to directly measure the temperature of an earthquake fault. However, because 5 years had already passed since the earthquake, the difference in temperature between the fault and the surrounding rock was on the order of 1/100 °C. It was questionable whether this was really residual frictional heat from the earthquake. So we were thinking that, whenever the next great earthquake occurred somewhere, the temperature should be measured within 2 years."

The temperature sensors installed in July of 2012 as part of JFAST were recovered in April of 2013 by JAMSTEC's remotely operated vehicle *Kaiko 7000II*. A team of international scientists including Prof. Mori and Asst. Prof. Kano analyzed the continuous temperature data taken over a 9-month period.

"The drilling itself perturbs the temperature in the borehole and that of the surrounding rocks. It took approximately 2 months for temperatures to equilibrate. We looked for places where temperatures were higher than in the surrounding rock and where they gradually cooled. The cooling is proof that the heat reflects residual frictional heat from the earthquake," explains Asst. Prof. Kano. "We found a site that was up to 0.31°C warmer than the surrounding rock while cooling. This was near 820 m below the seafloor."

The result of these temperature measurements also supported the conclusion that the area near 820 m below the seafloor corresponds to the plate boundary that slipped during the Tohoku earthquake. "0.31°C is a very small increase in temperature, which means that the frictional heat generated wasn't very high. We estimated that the friction coefficient, which indicates easily the fault slips, was 0.08," adds Prof. Mori.

Smaller friction coefficients indicate slippage slippery fault. Prof. Mori explains, "the friction coefficient for a typical rocks and another typical rock ranges between 0.5 and 0.7. In other words, we found that the fault had become highly susceptible to slippage during the earthquake. The friction coefficient of 0.08 is also consistent with the results of the friction tests performed by Prof. Ujiie and colleagues on rock from core 17R. So the same conclusion was derived from two different methods: temperature measurements and friction tests."

Asst. Prof. Kano describes his outlook for future research as follows: "In the study in Taiwan, we used fairly large temperature sensors. We learned, however, that if the temperature sensor itself is large, the sensitivity decreases. So, in JFAST, we used 55 small temperature sensors that were connected together. I would like to continue to tackle the mysteries of earthquakes from temperature and other parameters obtained by borehole measurements."

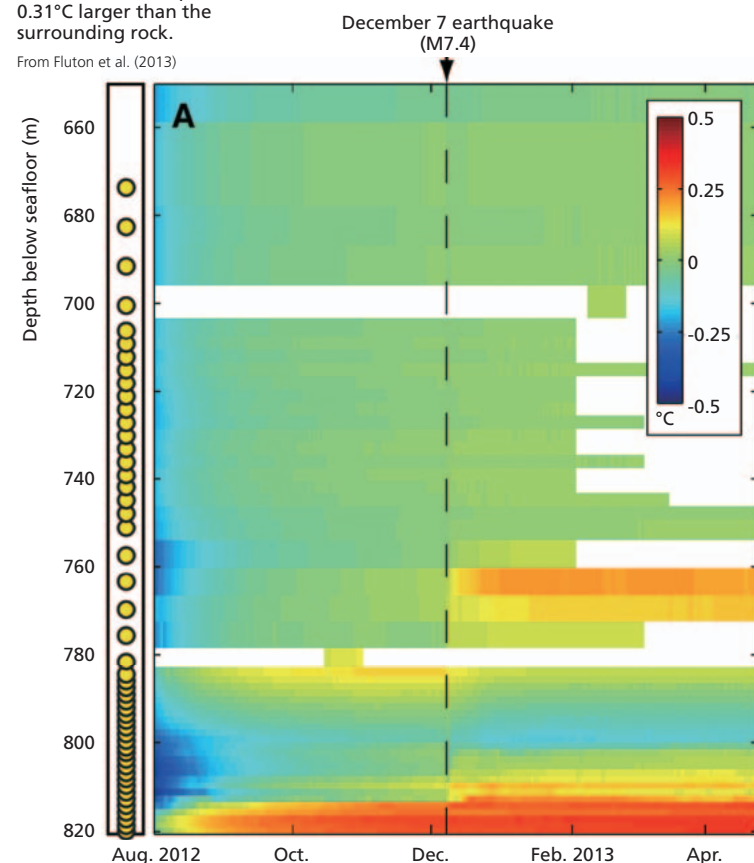
Meanwhile, Prof. Mori states his outlook: "I want to explore the relationship between water and earthquakes. When water flows into a fault, the fault becomes more likely to slip. So when water infiltrates and permeates a fault, such as dam construction, induced earthquakes may occur. Natural earthquakes may also occur as a result of water flowing into a fault. We may expect that when water infiltrates a fault, the friction is lowered and earthquakes occur more easily."

What would happen if water were injected into a plate boundary fault zone? Prof. Mori is proposing to conduct just such an experiment using *Chikyu*. "Plate boundaries slide laterally against each other at relatively shallow depths. I want to deepen our understanding of earthquakes by drilling down to the fault zone, injecting water into the fault, and observing its behavior, in a sea area where no damage would be caused even if an earthquake occurs."

Fault temperature measurement data

The temperature of rocks near 820 m below the seafloor was up to 0.31°C larger than the surrounding rock.

From Fluton et al. (2013)

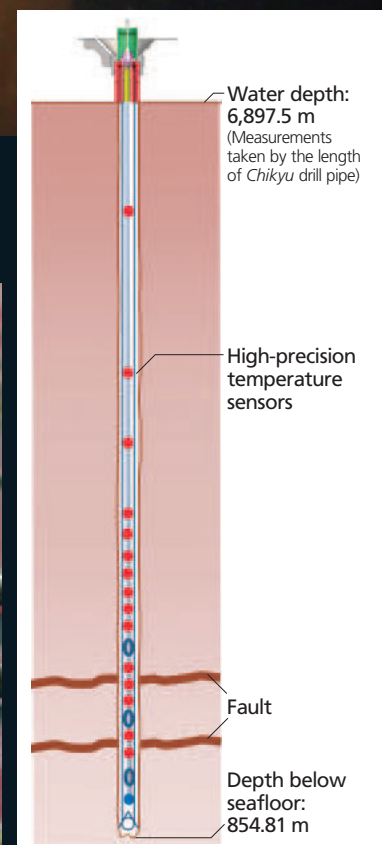


verify that fault was very slippery

Kaiko 7000II at work recovering temperature sensors. The pole-like object sticking out of the wellhead is the top of the long-term borehole temperature observatory.



Overview of high-precision temperature sensors and long-term borehole temperature observatory. The 55 high-precision temperature sensors are connected with rope, and positioned at particularly high density in the vicinity of the fault.





Deepwater drilling of plate boundary earthquake faults to elucidate massive ocean trench earthquakes and tsunamis

Deep Sea Drilling Vessel (D/V) *Chikyu* carried out the Japan Trench Fast Drilling Project (JFAST) as expedition 343 of the Integrated Ocean Drilling Program (IODP) in April to May and July of 2012, only a little over a year after the Tohoku Earthquake (magnitude 9.0). *Chikyu* set a new world record for scientific drilling, achieving a total drill-pipe length of 7752.31 m from the ocean surface to the borehole bottom (water depth, 6897.5 m; depth below sea floor, 854.8 m; borehole C0019D). As a result of this drilling, in addition to successfully recovering rock samples directly from the plate boundary fault in the vicinity of the hypocenter, researchers were able to install a long-term temperature sensor array in the borehole for measuring the friction

temperature near the fault plane and succeeded in directly measuring the residual friction heat generated by the fault slip.

JFAST yielded scientific proof that a seismic slip had occurred in a shallow region of the plate boundary fault in subduction zone where seismic slips were previously believed not to occur and made significant strides towards elucidating the fault-slip and tsunami-generating mechanisms. These results have already led to the start of a new project to investigate the plate boundary fault in even greater detail, namely the Tracking of Tsunamigenic Slips Across and Along the Japan Trench (JTRACK) drilling project proposed to the International Ocean Discovery Program (New IODP). "In the previous drilling expedition, although we were able to recover core samples, including that of the plate boundary fault, the recovery rate was low and we still don't understand the structure and state of the entire borehole. Furthermore, because we recovered fault core sample only from a single borehole, it is unclear what the surrounding area is like.

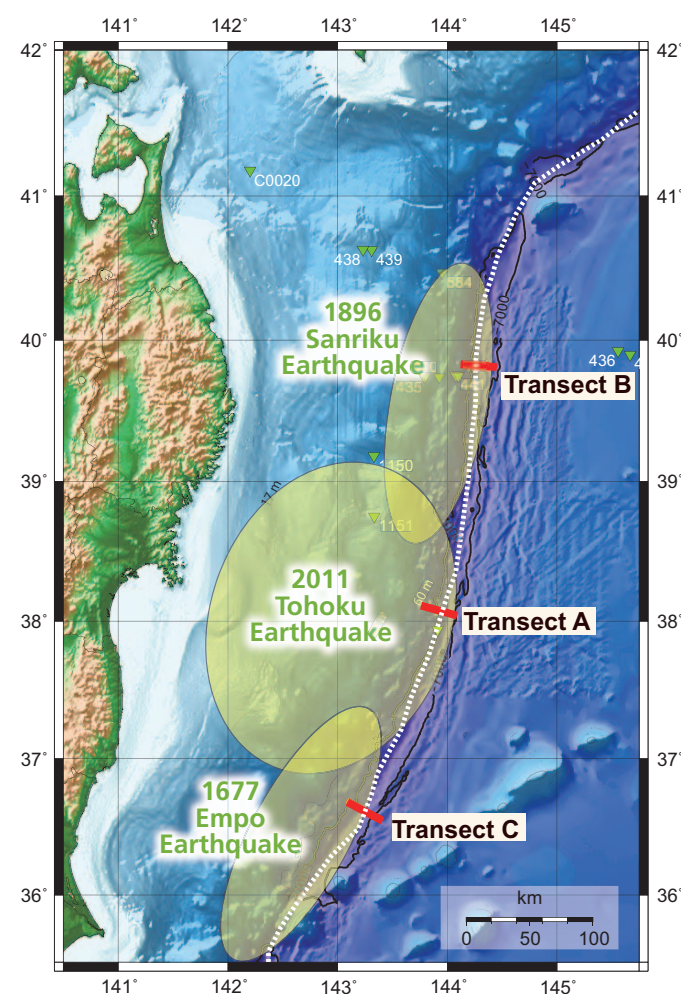
So, in addition to recovering cores from the entire borehole including the fault, our goal this time around is to methodically gather data by collecting numerous core samples along the axis of the Japan Trench, both in locations where substantial slip occurred and in locations where only minimal slip occurred, and by drilling a series of boreholes (i.e., transects) perpendicular to the Trench axis on the oceanic plate before it is subducted," explains Kodaira, director of the R&D Center for Earthquake and Tsunami (CEAT). The plan is to install sensors in the boreholes to enable long-term monitoring of temperature and water pressure for an even longer period than the previous project.

Also as part of JTRACK, drilling surveys will be conducted in the hypocentral regions of the Meiji Sanriku Earthquake that occurred in 1896 and the tsunamigenic earthquake that is said to have occurred off the coast of the Boso Peninsula (Empo Earthquake) in 1677 with the goal of elucidating differences between faults and the history of tsunamigenic earthquakes. "However, we received a recommendation from the IODP Science Evaluation Panel that we should first narrow our focus to the 2011 Tohoku earthquake, so we are planning to initially focus on the area that was drilled in the JFAST project and to conduct a more detailed and comprehensive drilling investigation," explains Director Kodaira. "That said, the 2011 earthquake and tsunami made us amply aware that, for all of our previous work, we don't know much about the long history of massive earthquakes and tsunamis. Our feeling now is that we need to change our attitude which has been established looking

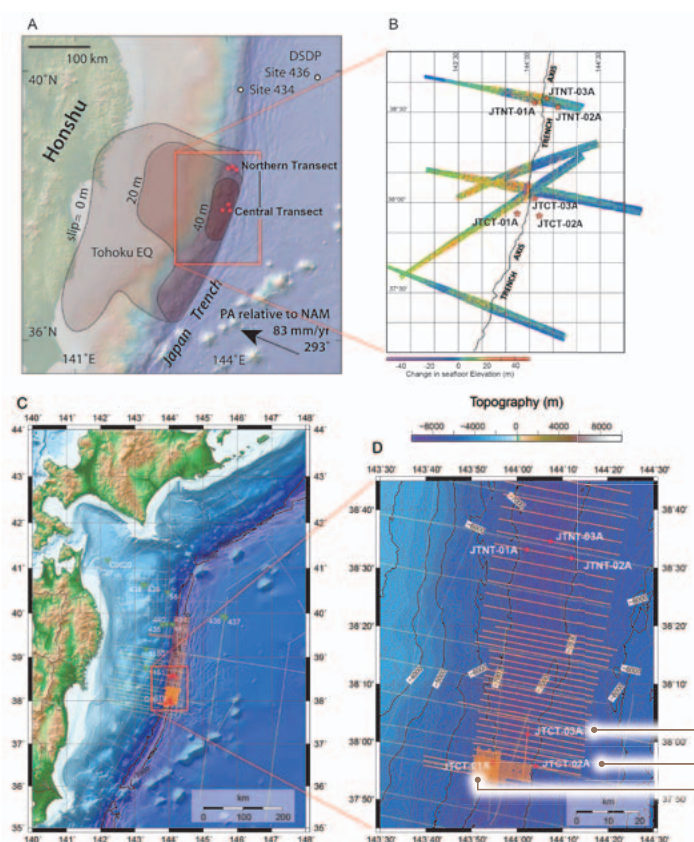
just over a few hundred years of long history of earthquake and tsunami. The current proposal is infused with our aspirations for tracing back the history of earthquakes on a geologic time scale in the future."

It was from this perspective that our research group made an earlier-stage proposal to the IODP for a JTRACK Paleoseismology project separate from, but with close linkage to, the JTRACK using *Chikyu*. Although previous studies have examined tsunami deposits on land to identify massive tsunamis that occurred in the past, the objective of the proposed project is to find traces of past tsunamis not on land but, rather, in marine sediments deposited near the axes of ocean trenches. Specifically, the proposal is to collect marine sediment cores to a depth of 50 m below seafloor, using an equipment known as a giant piston corer (an instrument that pushes a pipe-shaped cylinder into the seafloor to collect core samples) at 20 to 30 locations near the axis of the Japan Trench between regions offshore of the Sanriku coast and the Boso Peninsula to study the history of tsunamis. Director Kodaira clarifies, "The sediment should contain traces of massive earthquakes and tsunamis that caused substantial slippage near the ocean trench axes. We feel that if we can get 50 m below sea floor, we will be able to trace back 50,000 years of history."

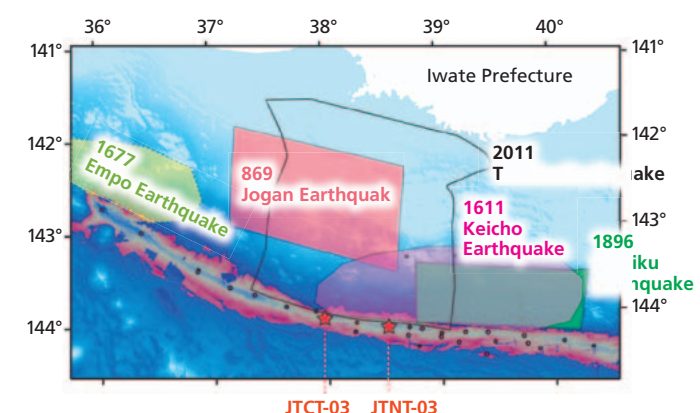
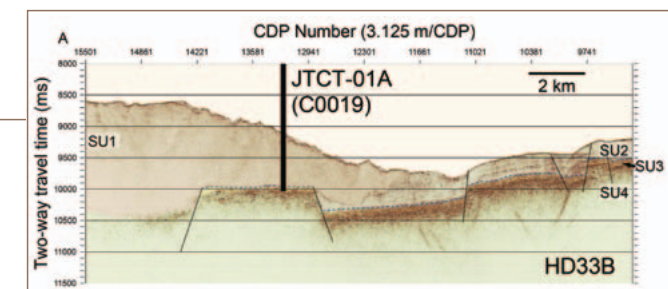
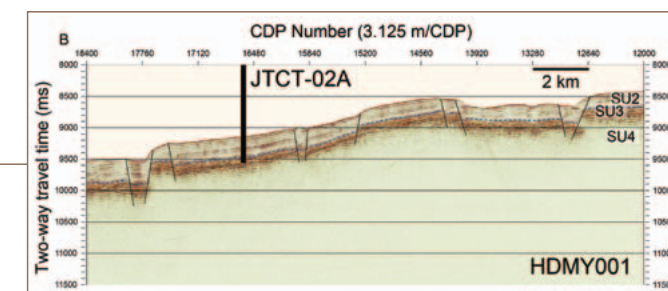
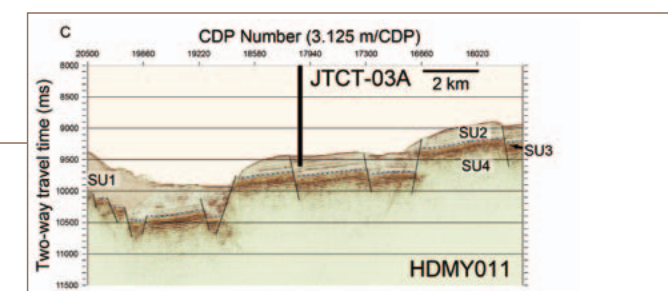
Regarding the implementation of JTRACK, Director Kodaira enthusiastically explains, "Projects that utilize *Chikyu* inevitably tend to expand in terms of both scale and time frame. However, in the case of this JTRACK, because it does not take a lot of time to drill each borehole, we think the project can be carried out little by little between other drilling projects. In the case of JFAST, we prioritized immediacy so that scientists could reveal the mechanism of the devastating earthquake and tsunami and could report the scientific results to the public as quickly as possible before the motivation of the researchers changed. In the new JTRACK project, we want to achieve even greater success by bringing the highly-aware and highly-motivated young researchers who participated in the JFAST project to the forefront."



Overview of the JTRACK project. In addition to drilling near the plate boundary fault in the vicinity of the hypocenter of the 2011 Tohoku earthquake, the plan is to drill and compare the hypocentral regions of massive earthquakes and tsunamis that occurred in the past.

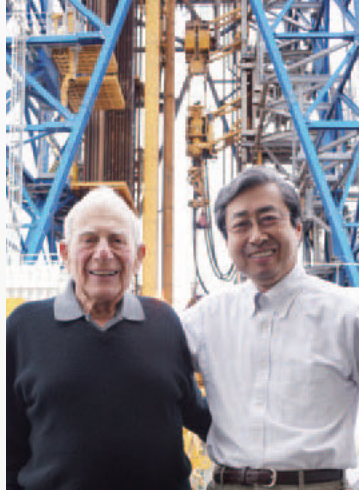


Planned JTRACK drilling sites. Based on recommendations received from the IODP Science Evaluation Panel, the decision was made to narrow the project focus and drill near the plate boundary fault in the vicinity of the hypocenter of the 2011 Tohoku earthquake. As shown in (A), drilling will be carried out in locations that underwent different magnitudes of slip.



Core sampling locations (black circles) for the JTRACK Paleoseismology Project. The plan is to collect marine sediment cores to a depth of 50 m below sea floor, using a giant piston corer.

Planned JTRACK drilling sites. The plan is to drill and sample the shallow fault regions near the ocean trench axis of the plate boundary fault in the vicinity of the hypocenter of the 2011 Tohoku earthquake, as well as two locations with different conditions lying perpendicular to the trench axis.



Drs. Munk and Taira
onboard *Chikyu*

Scientific Ocean Drilling: 50 years of legacy and me

Asahiko Taira

President,
Japan Agency for
Marine-Earth Science
and Technology

In the spring of 1957, Walter Munk and Harry Hess considered necessity of a large-scale project that would do the most to open up new avenues of thought and research in the earth science. They thought that the taking of a sample of the earth's mantle would be most significant (Bascom, 1961). This was the beginning of one of the most successful scientific projects of all the time. The Mohole Project and later successor, Deep Sea Drilling Project (DSDP, ODP and IODP) brought a completely new world of earth science including the proof of seafloor spreading hypothesis.

When I learned about the DSDP and D/V *Glomar Challenger*, I was a student at Tohoku University of Sendai, Japan. At that time, I was interested in physical processes of sedimentation and this was my main motivation to study sedimentary rocks at the University of Texas at Dallas for Ph.D. under the supervision of Peter Scholle. Then, at Kochi University, Japan, I started a mapping project of the Shimanto Belt, known as an enigmatic geological terrain because of its highly deformed structure and paucity of mega-fossils. Eight years of fieldwork allowed me to interpret that this belt is an accretionary prism and I gradually realized the importance of marine geology to better understand the geological process at the subduction plate boundary. Naturally, the Nankai Trough, the off-shore of counterpart of the Shimanto Belt, draw my keen attention.

After I moved to the Ocean Research Institute of University of Tokyo in 1985, the study of the Nankai plate boundary became one of my main objectives as well as management of the Japan ODP office

succeeded from Kazuo Kobayashi. ODP Leg 131 first penetrated a complete section of an accretionary prism through decollement down to the top of oceanic crust. The drilling in the Nankai Trough however was extremely difficult. The rocks are fragile and sticky and the ocean environment is full of hazard including the strong Kuroshio current and frequent typhoon attack. By 1990, I started to dream constructing a riser-equipped scientific drilling vessel that can drill deeper and withstand harsh climatic conditions. The main sales-point was that as Japan locates in the area of most active earth dynamics, it would our main responsibility to study such phenomena as earthquake and volcanic activities. The idea was shared by government officials and finally realized as a large-scale facility project led by the Japan Marine Science and Technology Center (JAMSTEC). The project was called OD21 (Ocean Drilling in the 21st Century) and was promoted by many leaders such as Noriyuki Nasu, Hajimu Kinoshita and Kiyoshi Suyehiro. It was such wonderful moment that I also have been involved with this phase of preparation including participation to IODP planning subcommittee (IPSC).

When D/V *Chikyu* was launched, I have never experienced such emotional moment, but also never imagined that later we would encounter many difficulties. On March 11, 2011, a M9 earthquake attacked NE Japan accompanied by huge tsunami, the scale nobody have ever seen before. *Chikyu* was at the port of Hachinohe and badly damaged and lost one of thrusters. But the recovery was swift due to collaborative work of international team. One year later, *Chikyu* drilled 850 mbsf at the water depth almost 7km in the Japan Trench. The results were truly impressive: discovery of weak and thin fault zone and temperature anomaly indicating very low friction coefficient.

In 2012, Walter Munk visited *Chikyu*. It was such an honor for us to have him on board. Commemorating this historic event, we name the library of *Chikyu* as "Walter Munk Library and Research Room". In 2014, news which was great honor to me arrived from AGU: the establishment of the Asahiko Taira International Ocean Drilling Research Prize. The amount of my contribution to the development of ocean drilling science and technology has been only fractional but all I can say is that ocean drilling is still full of excitement. I strongly encourage younger generation continues to challenge this frontier as was started in 50 years ago.



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