Technology Developments for IODP Phase 2

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Abstract

Japanese planning for technology developments started by listening to what Japanese scientists wish to achieve during the IODP Phase 2, and extracted technical problems, which are of essential importance to achieve the following science targets: (1) Geohazard, (2) Earth's Interior, (3) Paleoenvironment and (4) Deep Biosphere and Sub-seafloor Aquifer.

1. **Ultra deep drilling (Earth's Interior and Geohazard)**
2. **Coring (For all the themes)**
3. **Monitoring and Observatory for the next generation (Geohazard, Geochemistry and Microbiology)**
4. **Site Surveys**

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Introduction

1. **Ultra deep drilling (Earth's Interior and Geohazard)**

1-1 Earth's Interior: Mohole

As one of the important themes of Earth's Interior, Japanese scientists propose to reach to Moho as The "21st Century Mohole". It needs important technological breakthroughs:

(1) Great water-depth (<4500 m)

Records/plans of drill ship building and drilling in oil industry are designated in the Table below.

Year	Wataer depth (m)	Drilling depth (m)	Drilling site	Oil company	Drilling ship	Remarks
1999	3048	10668			Transocean Discoverer Enterprise	Drill ship: constructed
2003	3051	3866	GOM	ChevronTexaco		Drill hole: drilled
2009	3658	12192		Chevron	Transocean Discoverer Clear Leader	Drill ship: constructed

Riser and BOP technologies are most important elements for ultra deep water drilling.

Regarding the riser, the axial resonance of the riser with the heaving of the drill ship should be avoided in case of ultra deep water drilling. The steel riser has been used for "Transocean Discoverer Clear Leader" for 3658 m deep water drilling. However, composite risers such as CFRP (Carbon Fiber Reinforced Plastic) riser are indispensable for 4000 m and over 4000 m deep water drilling. In case of CFRP riser, the axial period decreases and the resonance can be avoided.

Electro Hydraulic Multiplex Control System (EH-MUX) for BOP reduces response time normally encountered with hydraulic control system, which is now used for drilling vessel "Chikyu" for 2500 m deep water drilling. EH-MUX was used for "Transocean Discoverer Clear Leader" for 3658 m deep water drilling. Upgraded EH-MUX for 4000 m and over 4000 m deep water drilling will be developed without much difficulty.

(2) Deep subbasement drilling using riser technology (drilling depth below rig floor <12000 m)

"Transocean Discoverer Clear Leader" has a drilling capability of 12,192 m, which means that the deep subbasement drilling using riser technology almost exists. In case deeper drilling than 12,192 m is required, technologies such as "Riserless Mud Recovery" for upper hole and "Expandable Casing" for lower holes will be utilized in order to reduce the casing strings.

(3) Improvement of core recovery (quality and quantity) at the target depth interval

It is not easy to accomplish both the deep drilling under hostile conditions and coring for the entire depth interval. The drilling and coring strategy should be determined with careful evaluation of geology and petrophysical properties, cost and risk evaluation.

(4) Drilling, coring and logging at high temperature (250-300°C)

One of the key technologies for high temperature drilling is cool technologies of the borehole. There is already a drilling/coring results in extremely high temperature of 540°C by TDS (Top-drive Drilling System) cooling method. Because high temperature drilling/coring strongly depends on petrological conditions, it is highly necessary to drill a pilot hole to obtain necessary information prior to drilling of the main hole, and decide drilling strategy including the technology development time schedule. LWD has more advantages in terms of temperature if we can use TDS cooling method.

(5) Possible deep gas

It is important to reduce drilling risk to obtain information on possible gas and gas pressure beforehand.

(6) Technology development under combined hostile conditions

These have to been done in multi-stage: As the 1st stage, each element technology have to be developed, then as the 2nd stage, technology has to be developed under combined hostile conditions (Figure 1).

1-2 Deep drilling to asperity/non-asperity

To reach and drill into the asperity/non-asperity areas, it is necessary to drill deeper than the current capability of "Chikyu" (water depth:<4000 m and drill depth <10000 m).

To achieve ultra deep drilling, we need to solve the following problems:

(a) Drilling under great water-depth (>4000 m)

(b) Improved riser system (riser material etc), BOP system etc under great water depth.

(c) Deep subbasement drilling using riser technology

We have to solve the Wild Cat problem, high temperature problem etc.

(d) Wild Cat problem

In practical drilling of IODP boreholes, unexpected technological problems, such as borehole stability, abnormal high/low pressure (=lost circulation, kick etc), high shear/fault activation, cavity, toxic gas/fluid, have appeared under complex/coupled harsh environments. It is common in IODP that no a prior information from neighboring borehole is available for determination of drilling program. One of the solutions to this problem is a drill of pilot hole to collect geological information.

(e) Deep Seismic Imaging

Integrated analysis of 3D seismic, wide angle seismic survey, VSP and logging can be effectively used to image deep structure. Passive (microseismic) mapping/reflection can also provide deep seismic image. Development of repeatable downhole seismic sources, which has capability to radiate sufficient energy to the formation under high temperature/pressure environment, would be of importance to realize reverse VSP or cross-hole seismic measurement. Downhole multi-component seismic array is one of the few methods to collect full information on the seismic wave. Progress in operation temperature/pressure, sensitivity, frequency range, coupling to the borehole, detectability of 3D motion of the seismic signals, deployment/retrievement techniques in IODP boreholes are required for downhole seismic passive/active imaging in IODP projects.

2. Core Recovery and Core Quality (For all the themes)

Core recovery and core quality are fundamental needs to maximize IODP sciences. Although core recovery rate has been improved since DSDP/ODP era, there are still significant problems for the specific science targets and specific lithologies.

Degree of core recovery strongly depends on variable conditions such as depth, lithology, physical properties as well as coring tools. Even if average core recovery is good, science could not be achieved without enough core recovery from the critical intervals or specific rock-type. Examples of problems due to low/none core recovery are; a) chert or alternating beds of chert/shale, b) carbonates, c) poorly consolidated sand intercalated with mud, d) sand/gravel in high latitude ocean, e) hydrothermal deposits, f) basaltic lava and sheeted dyke complex, and g) fault zones. Investigations are required for coring technologies, including but not limited to, update of ADCB, MDCB, APC, XCB, and RCB. Prioritization of those coring technologies should be linked to the specific scientific demands.

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Core recovery is a complicated issue as there are many variables that interface and affect it (e.g., rpm, circulation rate, weight on bit [which is in turn affected by heave], torque, type of cutting shoe [for XCB coring system], any notable problems with the coring system [i.e., core catchers stuck open or check valves plugged, etc.], hole stability, and offset of the ship from where the hole was spudded [which changes the length of the drill string],amount of heave to name a few).

Extensive use of cuttings, side-wall cores, and logging is also important to complement the cores in case of low/no core recovery.

Core quality issues are also significant problems and are divided in to four categories: (1) core disturbance, (2) contaminations, (3) magnetic properties, and (4) core orientation. Enhanced core recovery and coring without disturbance should be considered for IODP phase 2.

3. **Monitoring and Observatory (Geohazard, Geochemistry and Microbiology)**

3-1 Monitoring while drilling

As is shown in the Geohazard WS report (Morgan et al., 2009), development and application of certain *in situ* tools could greatly expand understanding of *in situ* pressures and stress state. Pore pressure can be measured with downhole tools (DVTPP, T2P) or with instrumented boreholes such as Circulation Obviation Retrofit Kits (CORKs) in rather soft formation. For the hard formation, we have to develop new technologies, such as packer injection/fracturing test.

Vertical stress can be evaluated from density data. Meanwhile, horizontal stress has not been measured within DSDP/ODP/IODP projects. We already have several new ideas for the stress tensor determination, which do not rely on unreliable rock strength estimates.

Large-scale hydrologic tests can also help to up-scale the core measurements and small interval packer tests. These tests include injection tests, slug tests, and cross-borehole pressure tracer studies.

In situ geotechnical tools are used routinely in the geotechnical community and should become an integral part of IODP Geohazards investigations (Morgan et al., 2009). These tools have been applied mainly for soft formations. Incorporating these types of measurements into IODP operations in hard formations would increase the quality of petrophysical data of near-surface sections prone to failure.

3-2 Long term monitoring and borehole observatory

In the ODP period, mainly hydrological monitoring (Kastner et al., 2006) and ocean seismic observatories (Suyehiro et al., 2006) have been developed. In the IODP period, the LTBMS (Long Term Borehole Monitoring system), which enable us monitoring in deep riser boreholes, was developed by IODP SOC budget as the first attempt of ED proposal.

In the Phase 2 of IODP, several new ideas are proposed:

(1) Geochemical/microbiological monitoring
(2) Real time monitoring during active experiments for Geohazard
(3) Real time monitoring in/around the asperity and non asperity region of great earthquakes
(4) Construct seismic network for deep Earth structure
(5)

For the Earth structure studies, the following ideas are presented.

1) Seismic tomography with ambient noise to reveal the crust and upper-mantle structure beneath the Pacific Ocean around Japan.
2) Imaging of seismic discontinuities beneath an oceanic area (Moho, lithosphere-asthenosphere boundary, 410- and 660-km discontinuities, and the other unknown boundaries).
3) New seismic observations of core phases in oceanic areas.

For these purposes, the followings are necessary

(a) Deployment of the multi-boreholes or observatory array rather than an isolated borehole that is a representative for a global-scale configuration as proposed by the International Ocean Network (ION).

(b) Broadband and high sensitivity seismometer should be installed in a hard basement, not a sediment layer.

Innovation in the data recovery must be considered.

Distribution and mobility of water along and across faults in broad time scale (e.g. interseismic, coseismic and postseismic) must play a significant role to control the fault properties, especially coefficient of friction. In order to answer why asperity and non asperity are sometimes adjacent to each other (i.e. almost the same PT conditions), also why rupture occurs over several asperities, we need to collect spatial variation in the physical properties from core samples and logging data at different locations and different slip types. The mechanism of low frequency earthquakes in accretionary prisms may also be revealed by deformation analysis of core samples and geophysical monitoring. It is fundamental for revealing spatial variation of frictional parameters along the seismogenic zone to locate all of diverse kinds of slip events as precisely as possible. This requires development of stable, sensitive and long-term monitoring network of broad-band seismic and geodetic sensors. Sub-bottom sensor installation techniques developed by the ODP-IODP and long term borehole monitoring system (LTBMS) developed by IODP pphase1 provide us with great opportunity to realize the network. The monitoring system for this sake should be composed of instruments distributed over wide area and those installed deep into the seismogenic zone.

Durability of the system under high temperature and high pressure must be realized for the monitoring. Because number of monitoring stations may be limited, multicomponent seismic monitoring can provide maximum information on the seismic wave. Reliable fixing mechanism of the seismometers to borehole is of importance. Distributed fiber-optical sensors, where fiber itself detects the seismic signals, have potential to realize widely distributed seismic monitoring network.

In situ monitoring system of 3D tectonic stress is of importance to interpret behavior of sesimogenic zones. Development of downhole tools for estimation of magnitude of 3D stress field will be highly appreciated. Downhole clinometers and strain meters can also provide information on dynamic behavior of the seismogenic zones.

<u>Integration with on land/ seafloor data and collaboration with other community</u>

To conduct these proposals, collaboration with the technical working group is crucial. Data integration, sharing the technical and scientific experiences with other community will help IODP borehole monitoring and observatory.

<u>Data management</u>

Open data policy and quick data distribution is inevitable to ensure the integration the IODP borehole observatory with other observatory system such as on land/ seafloor/global observatory system. The data format should be compatible with the standard, the system description/evaluation and calibration must be disclosed and the requests from the scientists must be appreciated to improve the system.

4. Core/cuttings-log-seismic-monitoring integration (CCLMM)

CCLMM is important for several reasons:

(1)Extensive use of cuttings, side-wall cores, and logging is also important to complement the cores in case of low/no core recovery.

(2) Because physical properties are scale dependent, we need to construct physical model from the

analysis of core/cuttings-log-seismic-monitoring results.

5. Site Surveys

According to the Geohazard WS Report (Morgan et al., 2009), standard site surveys for geohazard objectives can provide two types of information:

(1) Definition of the geophysical, stratigraphic, and structural framework of the area capable of generating the Geohazard. Swath bathymetry and acoustic backscatter imagery are necessary to identify morphological features associated surficial depositsor subsurface structure (i.e., for placement of boreholes or observatories). Seismic reflection profiling, particularly in 3D, serves to constrain the internal structural and stratigraphic architecture of the region with which to interpret past events and their temporal and spatial distribution.

(2) Pinpointing the exact locations for future drilling and assessing what knowledge would be gained at each site. Information can be gleaned from high-resolution seafloor acoustic images coupled with 3D seismic reflection images to identify reflections and impedance contrasts that might indicate target horizons, fault traces, or fluid pathways. Submersible dives can provide detailed information at the proposed point of entry, including local fluid or heat flow data.

Pre-drilling monitoring of microearthquake, seafloor gradient/displacement, and temperature anomaly in near seafloor sediment would be also effective to pinpoint the target in Geohazard drilling. Related technologies for site surveys need higher resolution/reliability than currently existing ones to collect information on hazardous structure, such as extension and homogeneity of asperities, microscopic distribution and orientation of existing water saturated fractures, for successful Geohazard drilling.

In addition to these, we need to establish a strategy for deep imaging as described in 1. Ultra deep drilling (e) Deep Imaging section.

6. New strategy for technology developments

Technology developments will play more important role in the IODP Phase2. The technology developments, especially those for “Chikyu” will be key to accomplish IODP science, such as deep drilling under deep water depth and high temperature, and deep borehole observatory.

These technology developments should be accomplished by close collaboration between IOs, IODP SAS and scientists from the early stage.

References

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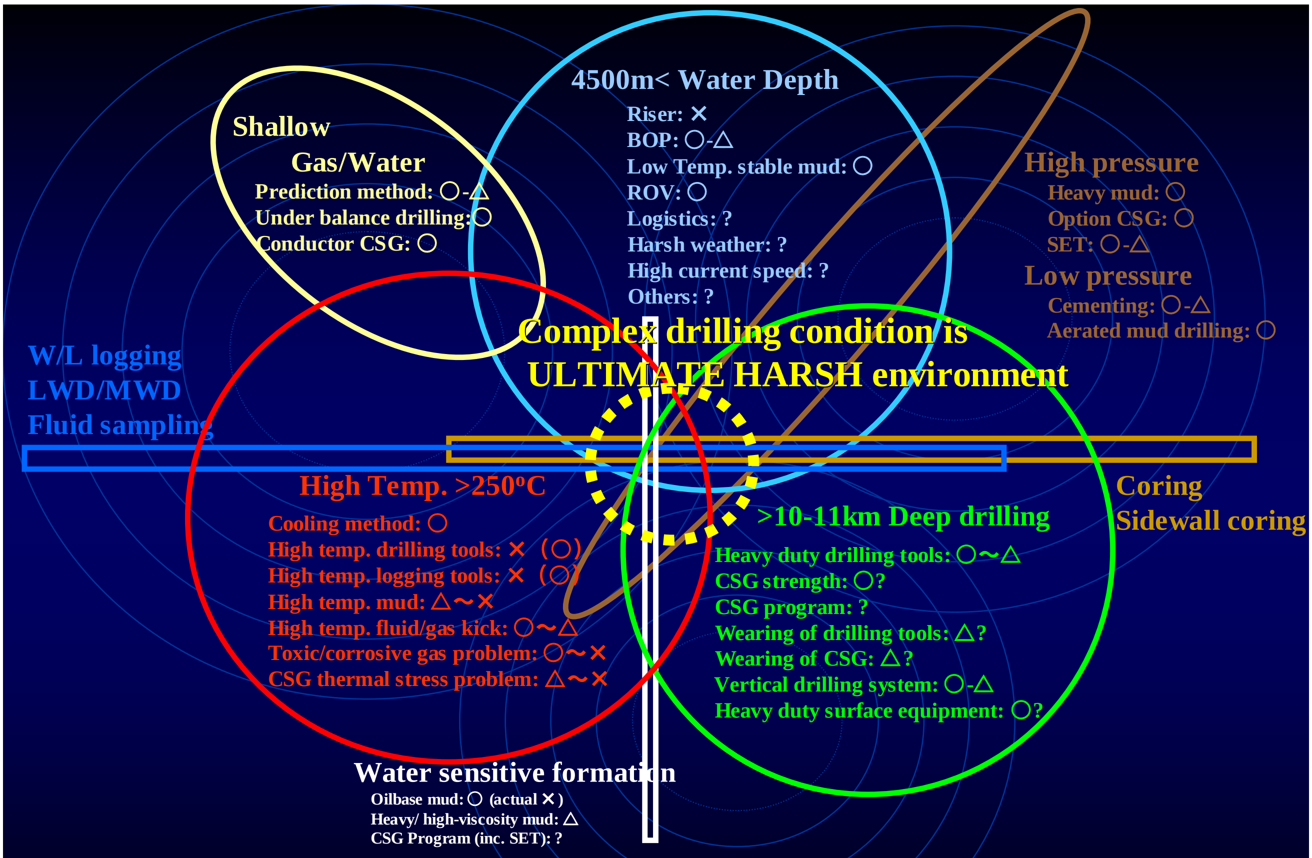

Fig-1. Drilling difficulty at complex harsh condition

Each element technology has been developed/evaluated independently.
Under complex harsh environment, performance will be reduced and unexpected problem may arise.