Scientific Technology Roadmap

Scientific Technology Panel
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EXCECUTIVE SUMMARY

The Scientific Technology Panel (STP) has developed over the last 2.5 years a technology roadmap that is designed to improve the science that can be conducted using IODP cores and boreholes. This roadmap has been coordinated with that of the Engineering Development Panel (EDP). The STP is beginning to work with the IOs and the funding agencies to devise an implementation plan. The roadmap is composed of 4 major categories, 8 subcategories, and 62 items. In essence, the STP Top Ten are shown as following items:

Deep hole/water penetration technologies [B1-1]

Deep hole/water penetration technologies are essential to achieve one of the biggest IODP mission, understanding origin and nature of the in situ oceanic Moho. This requires riser drilling in water deeper than 2500 m. Riser drilling in water depths >4,000 m or Riserless Mud Recovery Systems should be required.

Enhanced core recovery and quality [B2-1, B2-2, B2-3]

Enhanced recovery of sequences that are difficult to recover, recovery of minimally disturbed and contaminated core material, and oriented core are extremely important for many disciplines in IODP sciences. New coring systems must be developed in order to be able to recover such core material.

Evaluation of core contamination [A1-6, A1-7]

Monitoring and assessment of the potential drilling mud contamination of cores obtained are essential technologies and strategies for geochemical and microbiological purposes. Novel tracers would be used as indicators of seawater and circulation water contamination of cores.

Stress and pressure measurements [C2-2, C2-3]

To obtain a reliable 3D picture of stress magnitude and orientation will immediately impact science in solid earth area. *In situ* pore fluid pressures are a major influence on the fluid chemistry and on geotechnical/tectonic formation stability; and being able to measure such pressures routinely is important.

Large diameter pipe [B1-2]

Use of a larger diameter drill string provides many advantages including the ability to drill deeper, to obtain larger volumes of quality core material, to reduce contamination for geochemical and microbiological purposes, and a greater variety of logging technologies.

X-ray CT system on JR [A1-15]

3D visualizations of the full core obtained by X-ray CT provide assessment of fabric, structural and flow pathway develpment and core disturbances. It can affect sampling strategy and estimation of original core orientation, and thus has value to IODP science.

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DESCRIPTION OF ROADMAP ITEMS

A: Shipboard/Laboratory

A1: Shipboard/laboratory measurements

A1-1. Automated system for cell counts (e.g., microscopic imaging system, flow cytometry).

Such a system will enable accurate enumeration of microbial populations in geological materials. Although "eye-independent" recognition of fluorescently labeled microbial cells will require QA/QC to assure that is remains accurate through a range of sample types this approach has the potential to speed evaluations of cores for "hot spots" of biomass. The technology is expensive but could be adapted to shipboard analyses.

A1-2. Laser optical mass spectrometer for oxygen isotopic ratio of H_2O

This tool advances the ability to characterize interstitial water in the cores. The technology already exists and has been tested and recognized the valuable on *Chikyu*.

A1-3. Membrane-inlet mass spectrometry (MIMS) technology.

This technology allows the determination of in situ dissolved gas concentrations for various gas species such as hydrocarbons (methane, ethane, etc.) and permanent gases (N_2, CO_2, He, Ar, H_2, etc.) according on scientific aim after void gas recovery from cores. The technology already exists for this instrument so the priority for development may drop from 1 to 2 or 3.

A1-4. Cathodoluminescence X-ray spectrometer

This analytical capability which analyzes trace mineral geochemistry, is not currently available aboard ship; however, such a system was utilized as third-party tool during Leg 304/305.

A1-5. Laser optical mass spectrometer for carbon isotopic ratio of CH_4 and CO_2

This method would allow on-board determination of carbon isotopic ratio of CH_4 and CO_2 which is critical for assessing biological activities in sediments and developing models for organic carbon turnover in geological systems. A1-5 is strongly related to B3-1 (real-time mud gas monitoring) and it is possible that the technology described here (A1-5) can be included in B3-1.

A1-6. Real time, on board evaluation of core contamination

Assessment of the deep biosphere depends upon collection of high quality cores for microbiological analysis. Drilling is inherently dirty so it is essential to monitor potential contaminants from the drilling fluids. The development of rapid evaluation of core quality by studying drilling mud constituents (chemicals and microbes) will enable rapid decision-making for cores that are of high value and for when coring strategies must be changed to improve core quality. This item is strongly linked though not dependent upon progress on A1-7 and linked to EDP road map items ED A-21 (Anti-Contamination System), C-7 (Identifying, tracking and minimizing drilling contamination).

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A1-7. Novel contamination tracer.

Novel tracers would be used as indicators of seawater and circulation water contamination of cores. A1-6 and A1-7 are similarly aimed at improving the way in which drilling fluid tracers are used but they are distinct. These two items should be developed in connection with each other and tied to developments in A1-1 which will focus on real time measurement of cells in samples using cell fluorescence. Priority: 1

A1-8. Semi-automatic sample treatment equipment for microfossils

Automatic sample processing (analog to that for chemical analysis) would free up time so that shipboard scientists can provide more detailed data, which will be important for development of the age-depth model for example. Sample preparation techniques used for micropaleontology are chemical and physical reaction processes, and it should be possible to automate this process, using existing industrial equipment. This technology could be useful also for safety issue because chemical treatments by shipboard party will be minimized.

A1-9. Sediment grain size- and shape analysis

Quantitative characterization of sediment particles is essential for sedimentology, geochemistry, micropaleontology and microbiology. Novel analyzers use high-speed digital cameras with a pulsed laser system to automatically capture numerous particles in a flow-cell, so that we can analyze not only grain-size but also grain-shape and optical properties of each grain. Such a system has potential to eventually replace in the future smear slide analysis by the shipboard party.

A1-10. Formation Factor

Chemical fluxes are fundamental data for estimation of flow rates of nutrients for microbiological work and pore water inter-connectivity. Formation factor provides data related to the flow rates of fluids through geological media as well as pore water inter-connectivity. Evidence of flow indicates the degree to which microbes can receive nutrients, electron donors and electron acceptors that are necessary for survival. The measurement of formation factor is likely to become routine for IODP and this will assist our understanding of the degree of fluid flux that occurs in strata where life can be supported. Formation factor is defined as the resistivity ρ_{rock} of the l00% water-saturated rock framework to the resistivity ρ_{water} of the water solution contained in the rock. Archie (1942) also proposed a relation $F = 1/\phi^m$ where ϕ is porosity and m is an empirically constrained cementation factor. We currently measure ρ_{rock} and ϕ in ODP/IODP. But to measure ρ_{water} is difficult for such cases as lower porosity sediments are hard to squeeze for pore water. Thus, in the cases, ρ_{water} should be definable from temperature and water chemistry data.

Formation factor is a traditional concept suggested in 1940s (Archie, 1942), and has a simple measurement method in principal. For the formation factor routine measurement, however, soft sediment resistivity measurements by a proper device such as Impedance Analyzer needs to be further evaluated and tested. QA/QC might be difficult.

A1-11. Anelastic strain recovery (ASR)

The principle idea behind the ASR technique is that stress induced strain is released first instantaneously (i.e., as time independent elastic strain), followed by a more gradual or time dependent (or anelastic) release. Thus, anelastic strain can be measured after a time lag from the core was drilled. It is possible to determine three

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dimensional stress orientation by measuring ASR because principal orientations of stress and anelastic strain tensors are same each other for isotropy and viscoelastic materials. In addition, if two anelastic strain compliances which illustrate the relations between stress and anelastic strain can be examined by calibration tests in shore-based laboratory after expedition, stress magnitude will be estimated from the anelastic strain values.

A1-12. Thermal Conductivity Meter

Knowledge of the geological structure in terms of its thermal conductivity is necessary to properly determine heat flow from the geothermal gradients observed in boreholes. Thermal conductivity 'logging' is currently difficult or impossible as the measurements must occur on individual samples. New laser-based systems allow for more rapid scanning along the core and could possibly be implemented as part of the existing MSCL core scanning procedures.

A1-13. Small-bore Cryomag

A detailed geomagnetic record along core is an important tool in the determination of a depth-age model at a given site. Such information is obtained by logging of the core through a cryomagnetometer that is sensitive to remnant magnetization/'polarization. The current cryomagnetometer is sufficiently sensitive to detect remanent magnetization to 10^{-10} Am^2 and as such can make measurements on smaller samples. Having access to a smaller sized bore sample using a small sample holder (e.g. 1cm-diameter/1cm-height cylinder) would be useful as it requires less material. Sample deformation is reduced relative to conventional cubes (2cm x 2 cm x 2 cm) or u-channel (2cm x 2 cm x 150 cm). Further, corresponding u-channel materials should be taken to one side of the split core in order to allow space to obtain appropriate mini-core or cube samples.

A1-14. Thermal Demagnetizer

Thermal demagnetic treatment is used to demagnetize highly coercive magnetic minerals (e.g. hematite, goethite) that occur in highly oxidized sediments. AF (alternating field) demagnetization treatment is more commonly used but it is not appropriate to such minerals. The thermal treatment should be used in on-board paleomagnetic measurement on both the JR and Chikyu in order to avoid sample degradation (because of time constraint and thermo-chemical destruction of samples).

A1-15. Volume imaging

Volume imaging refers to methods to nondestructively obtain 3D visualizations of the full core to provide assessment of fabric and structural development. Because such techniques may be important in influencing sampling, they should be a shipboard measurement. X-ray computed assisted tomography (CAT), which is primarily sensitive to x-ray attenuation (mass density), is known best with applications well developed in the analysis of core and in addition to its own interpretive capabilities (e.g. texture, fracturing) allows for more informed detail sample selection. Such imaging is part of the core handling flow on the Chikyu. Less used and developed forms of volume imaging include ultrasonic and resistivity tomography. Standard CT 3D scanning imaging provides voxels resolved to ~ 1 mm^3 with microCT techniques as low as 1μm^3 available. Linear 2D x-ray scanning during initial core handling may be useful in guiding early sampling.

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A1-16. Non-destructive core logger

Onboard non-destructive measurements are important because they record ephemeral parameters, such as identification of manganese compounds and sulfides, which are rapidly oxidized in split cores. We would like to see development of (1) a spectroscopic core-logger in the ultraviolet and near-infrared ranges, and (2) a two-dimensional moisture content logger.

A1-17. Improvement of whole-round surface core Logger

In this logging, whole core pieces of sufficiently indurated rock or transparently-sleeved unconsolidated sediments are rotated during image scanning to produce an unwrapped image of the core surface. These images can then be used much like split core images during geological core descriptions and for later comparative analyses with wellbore image logs. Indeed, combinations of such core and borehole images can be used for core orientation. Such technology is already readily available and is carried out routinely as part of most ICDP and ANDRILL projects.

A1-18. Shipboard science on pressure cores

This refers to having the ability to maintain confining/pore pressures on and to work with cores specially obtained under pressure. This would be done to maintain in situ conditions as much as possible in order to greatly reduce or eliminate depressurization effects on chemistry, physical properties, and microbiology. Some commercial options may already exist for such operation but this would likely require some technical developments.

A1-19. New sample preservation strategies: Cell alive system (CAS) freezing

The focus of this effort would be to explore new methods such as those used in the food industry for maintaining cell integrity or as used by geochemists or physical property experts for preservation of samples. CAS freezing preserves cell integrity (as currently being studied at the KCC). This would possibly involve new equipment for shipboard/laboratory measurements. New methods to preserve samples for microbiological and chemical analysis need to be explored.

A1-20. New sample preservation strategies: Vacuum preservation

The focus of this effort would be to explore new methods such as those used in the food industry for maintaining cell integrity or as used by geochemists or physical property experts for preservation of samples. Examples include the vacuum preservation of samples. This would possibly involve new equipment for shipboard/laboratory measurements. New methods to preserve samples for microbiological and chemical analysis need to be explored.

A1-21. SQUID Magnetometer on Chikyu

Provides remanent magnetization measurements on weak natural samples. Has been developed for continuous measurements of split or whole core samples. Coupled with alternating field (AF) demagnetization to allow for demagnetization experiments that can in most cases remove week drill string and natural magnetic overprints. Recent development of liquid He free design allows cryogenic temperatures to be reached using a He gas compressor.

Shipboard magnetic measurements are a stated IODP Standard Measurement. They are used to determine magnetic polarity and polarity zonations that establish shipboard chronologies, help assess core orientation, assist in making drilling decisions,

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capture ephemeral properties and are used to assess magnetic potential and reliability for additional post cruise research.
Weakness: System may be susceptibility to radio frequency interference (RFI) that can induce flux jumps and other measurement issues. New designs to further separate the AF coils for the SQUID pickup coils should reduce this issue. Without the liquid He the system is not thermally buffered and therefore relies on compressor for being in a cryogenic state, therefore a continuous electrical and electrical and water supply are required.

A2: Software/Databases

A2-1. Digital Taxonomic Dictionaries

Digital Taxonomic Dictionaries are lists of taxa but also contain information on morphology (including images), and stratigraphic and geographic distribution. They are of prime importance for QA/QC of paleontological data, and for data compilation for studies of paleoenvironmental analysis and evolutionary studies of biota. We need to collect information and high quality images (3-D where appropriate) to capture into database.

A2-2. Automatic age- depth models

Age models are of prime importance for the full shipboard party as well as post - cruise research which relies on sediment accumulation rate estimates. Automatic age- depth models need to be iterative and integrative: as the age models change, so must the age- depth plots. They need to be able to handle uncertainty and conflicting evidence. Shipboard paleontologists and paleomagnetists must be able to input data easily, to be combined with stored information on time scales (GPTS) in order to generate an age depth plot.

A2-3. Integrated Visual Core Description (VCD) system with multi-data browsing system.

VCD is the basic information on cores, and the VCD database is significant for all on-board and post-cruise research, as well as decisions on sampling. We should evaluate the existing systems (J-CORES and DESKInfo), and develop a next generation VCD system integrated with multi-data browsing software.

A2-4. Digital catalog of smear slides and thin sections

This is a self-instructive module on smear-slide preparation, description, and interpretation for use by shipboard sedimentologists without previous training.
One of most common methods of core description by sedimentologists is the microscopic observation of sediment components in smear slides or thin sections. Many cores recovered IODP are non-lithified, and therefore the smear slide technique is especially critical for the characterization of sediments and the determination of lithological names assigned to cored materials. However, shipboard sedimentologists often have little or no experience in the semi-quantitative description of smear slides, so that shipboard tutorial material is necessary for QA/QC of sedimentological descriptions.

A2-5. Unified Ocean Drilling Database with tracking system of literature

Scientists (including those from outside the traditional drilling community) would greatly benefit from easy (on-line) access to a relational database which would help to

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optimize sample requests for specific analyses (e.g. new geochemical proxies need to be done on samples from a specific age/ocean basin/water depth/lithology). However, data are present in many different formats, many only in published literature. Thus, an unified ocean drilling database linked with the tracking system of literature is needed. This would require integration and expansion of existing database work (e.g., Neptune, Chronos, SEDIS, J-CORES, LIMS).

B: Drilling/Coring

B1: Drilling technologies

B1-1. Deep hole penetration technologies (deep water, deep drilling).

To determine the architecture and composition of the ocean crust which hosts life (and its limit) and holds the history of Earth origin and evolution, geologic origin and nature of the seismic reflector that defines the in situ oceanic Moho, and extent of hydrothermal activity, deep hole penetration technologies are necessary. In addition, deep-hole drilling is necessary on passive margins, in thick fans (e.g., Indus Fan), and in basins where we can recover Jurassic sediments (Somali basin). This requires riser drilling in water deeper than 2500 m. However, this development may be expensive in terms of instrument development, longer drilling time and even for getting riser for this capability, thus it is a long-term objective. This technology development is important target of ED roadmap.

B1-2. Large diameter pipe

Use of a larger diameter drill string provides many advantages including the ability to drill deeper, to obtain larger volumes of quality core material, to reduce contamination for geochemical and microbiological purposes, and a greater variety of logging technologies (such as electrical resistivity image logging and sidewall coring). It must be noted, however, that larger core has substantial implications for the handling of core and would require that many of the existing core logging and handling equipment would need to be revamped. In addition, the volumes of material handled, shipped, and stored would also be increased. This item has strong link to items in EDP road map of ED A-7 and B-1.

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B1-3. Directional Drilling

Directional drilling refers to the ability, now commonly used within the petroleum industry and recently applied to the SAFOD San Andreas fault scientific drilling, to control the direction of the drill bit by the use of special drilling assemblies and MWD logging and surveying technologies. This allows researchers to target laterally discontinuous horizons, to follow dipping or horizontal geological structures, or to drill multiple dog-legs from a given drill location. This item strongly linked to item in EDP road map of ED B-15.

B1-4. Real time mud gas monitoring

The aim of this capability is the measurement of dissolved gas species and their isotopic analyses in a riser drilling system without pressurized coring. This is one of the true advantages of riser drilling as it allows acquisition of real time dissolved gas data. This will also contribute to safety drilling as it would report the values of hazardous gases coming the surface. The availability of such real time data would contribute to decisions made on board with respect to sampling. The technology already exists as a combination of some commercial tools.

B2: Coring technologies

B2-1. Enhanced core recovery

For many disciplines enhanced recovery of sequences that are difficult to recover are of prime importance. These include hard-soft sequences (e.g., chert-limestone), hard rocks (e.g., young oceanic crust), non-lithified sands, fault zones, and poorly consolidated sediments. Techniques to be explored include thin-walled, short-stroke Shelby tube samplers (which exist in the geotechnical community). Sea bed frames might be a major advance in increasing core recovery. This item has overlap with many items in EDP roadmap of ED A-1, A-3, A-4, A-5, A-9, A-13, A-14, A-16, A-24, and B-30.

B2-2, Coring without disturbance of soft sediments and/or heterolithic sediments (replace XCB system).

Recovery of minimally disturbed and contaminated core material is extremely important for high resolution paleoclimate studies, development of high-resolution time scales, structures, paleomagnetic and deep biospheric studies, and measurement of reliable physical property data. New coring systems must be developed in order to be able to recover such core material, including some systems in development by CDEX (e.g., Extended Punching Coring System and the Extended Vibration Coring System), and ultrasonic (ultrasound) methods.

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B2-3. Oriented cores

Oriented core is important to many disciplines (e.g. magnetics, paleomagnetism, structural geology, stress orientations, sedimentary structures). Several technologies can be employed to orient core. Examples of these techniques include use of the secondary magnetization, the characteristic remnant magnetization (ChRM), a tensor Tool, matching of the patterns of bore hole and core surface images, combining core scribing with the Tensor tool, and impressing marks at the top of the core top in conjunction with the tensor tool.

B2-4. Non-magnetic core barrel

Induced magnetization is acquired by core samples due to the adjacent rotation of the highly magnetic steel drilling tools of the borehole assembly (BHA) and the core-barrel (Faraday Law). Nonmagnetic core barrels constructed from Monel metal have not been completely successful due to their lack of strength. Consequently, the development of new nonmagnetic, high-strength, low cost core barrels would assist the recovery of more core safe from induced demagnetization.

B2-5. Motor driven core barrel

To take hard rock core without drilling fluid contamination in riserless drilling, a technology of motor driven core barrel is needed. This may enhance geochemistry as well as microbiology on hard rock environments. This coring system is also needed to obtain better core quality for brittle sediments such as porous carbonates. This item strongly linked to EDP road map item of ED A-10.

B2-6. Pressurized coring with temperature control

Pressurized coring is already done in the frame of IODP (e.g. gas hydrate sampling) but temperature control is not achieved. Temperature control of pressurized cores is important for some scientific objectives (e.g., gas hydrates, carbon capture, and marine microbiology) but it is not achieved so far. Temperature might be difficult to control but should be at least monitored and recorded. This tool would be used in systems where recovery of hydrates or super-critical CO_2 was targeted or where active piezophilic or psychrophilic microbes were anticipated. The native recovery of gases and subsequent determination of in situ gas concentration would be possible. This item has strong link to EDP road map item of ED A-16.

B2-7. Sidewall coring

Sidewall coring refers to existing technologies, often employed in the petroleum industry, to obtain small core plugs from the open borehole wall. Coring of missed intervals or enhanced sampling of critical sections would be possible using this approach. Also, if conventional coring is deemed to be too expensive or time consuming then sidewall coring would be a more economical alternative although the size of the cores is quite limited. Sidewall coring requires large diameter pipes. This item strongly linked to EDP road map items of ED A-11 and B-15.

B2-8. Cuttings analysis for riser drilling.

Cutting analysis is the only way to provide information on drilled sequences which are not cored during riser drilling, and provide additional information on cored intervals, especially when recovery is poor. Cuttings are used for standard lithological and micropaleontological characterization, and may be used to sample piezophilic and psychophilic microbes, and determine their activity. It may be possible to recover clathrate in situ and certainly determine in situ gas concentration.

C: Downhole measurements

C1: Logging technologies

C1-1. Logging while coring (LWC)

Logging while coring (LWC) refers to the ability to passively log the borehole (e.g., gamma ray and resistivity) during coring with data downloaded once the coring barrel has been returned to the surface. LWC is a very useful method to obtain both Logging While Drilling (LWD) data and core in the same hole, which is important for core-log integration under unstable borehole conditions (e.g., unconsolidated sand/clay, fault zone). This is essentially the same as now commercially available LWD technologies but is more limited because the coring string metal is usually not as thick as drill string pipe and, hence, will not accommodate as wide a variety of measurement sensors. Some technologies have been developed particularly with regards to the logging of various coring parameters (e.g. weight on coring string). This is a technology that needs to be monitored in the future. It may be worth noting that new instruments that will allow for logging while pulling of the coring/drilling string are now under development and may soon be available for use.

C1-2. Multi-arm caliper

This refers to existing logging tools consisting of many small arms that allow for the caliper measurement of the borehole cross-sectional shape. Such information is

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useful for correction of other logging tools as well as on its own as an indicator of borehole breakout directions for stress direction interpretation.

C1-3. Downhole magnetometer (GHMT) and C1-4, Vector (3 axis) magnetometer

There is a need for downhole magnetometry for studying the magnetization of igneous crust and for downhole magnetostratigraphy in sediments. At present, the old GHMT total field tool is unavailable to IODP, and the GPIT 3-axis fluxgate magnetometer is designed only for tool orientation. A new magnetometer tool is under development at Lamont-Doherty Earth Observatory that incorporates the latest total field and 3-axis fluxgate sensors, for use in IODP holes.

C1-5. Advance borehole imaging

Advanced borehole imaging primarily refers to imaging techniques that produce unwrapped images of the borehole wall rock using visual optics, ultrasonic reflection amplitudes/travel-times, and electrical resistivity. Such logging technologies exist and are often used in scientific drilling, the latest example being use on the IODP Expedition 313 New Jersey. The images so provided are usually oriented and hence can provide important structural information as well as providing a reference against which the surface whole-round core logging can employ in core orientation.

C1-6. Slim-line logging tools from other vendors

Logging tools are widely used and available in IODP. Slim-line logging tools would minimize necessary hole diameters for logging. These tools are available (e.g. at ICDP) but usually not used at IODP so far except for MSPs

C1-7. Seismic while drilling

Seismic while drilling ties seismic sections to cores and can potentially be used to update the scientific plan ahead of the bit. Commercial tools exist but are usually not used for IODP.

C1-8. Open-Water Re-Entry Logging

Technology to expand logging capability and measurements using ROV to put standard logging tools in an open borehole without going through the drill pipe. This approach can expand the available tool suite without requiring larger diameter pipe.

C1-9. Logging while pulling pipe

Innovative, developmental procedure to put memory logging tools down the drill pipe, which then latches into the bottom hole assembly and provides log measurements while tripping pipe.

C2: In situ measurements / fluid sampling

C2-1. Compressive and strength of sediments

Compressive and strength measurements on sediments collected during scientific ocean drilling are necessary to understand scientific problems related to deformation and failure of sediments. In addition these data can be used to develop safe drilling strategies.

Tools for in situ testing are available for shallow soft sediments (e.g., penetrometers, mini-vane) and for deep, strong sediments (e.g., mini-frac, hydro-frac). These in situ

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measurements would augment and strengthen lab-based measurements made shipboard and shorebased and may provide crucial constraints on empirical strength relations.

C2-2. Stress measurements

Understanding stress state including both magnitude and orientation will immediately impact science in solid earth area especially in tectonics, geodynamics, seismology, structural geology etc. In addition, stress data is also needed for designing of riser drilling operation and of long term borehole observatories. Therefore stress measurements are necessary and important for numerous scientific drilling campaigns such as seismogenic zone drilling etc.

Stress measurement as a traditional topic has been carried out in continental drillings and industry. Several measurement methods are available, but there is no foolproof method by which the magnitudes and orientations of three-dimensional stresses can be reliably measured at large depths. For scientific deep-drilling, the combined application of borehole methods and core-based methods is necessary to obtain a complete, three-dimensional picture of stress and to enhance the reliability of the measurement results.

For stress orientation, analyses of drilling induced borehole compressive failures (breakouts) and tensile fracture, core-based method(s) such as anelastic strain recovery measurement, structure analyses of core and borehole image are possible techniques. For stress magnitude, leak-off test (LOT) or extended leak-off test (XLOT), and hydraulic fracturing which have been conducted in continental drillings and industry should be attempted although they are not operated in ODP and IODP deep drillings. To constrain the stress magnitude, moreover, it is valuable to link borehole breakouts, core-based method, theoretical analyses (Anderson's fault law) etc.

C2-3. Formation pore pressure

In situ pore fluid pressures are a major influence on the fluid chemistry (gas saturations, total dissolved solids, etc.) and on geotechnical/tectonic formation stability; and being able to measure such pressures routinely is important. Various techniques are already used in industry (straddle packer assemblies, DST logging tools) to obtain this and related information.

C2-4. Collection of formation fluids at in situ pressure and temperature

This approach is routinely done in industry to understand in situ conditions of reservoir fluids. This should not become a routine sampling technique but it would be useful (e.g. hydrate decomposition). Fluids collected in this manner would yield data that are more useful for the interpretation of the conditions under which microbes in the subsurface exist. This item strongly linked to EDP road map item of A-23.

C3: Long-term downhole sensors

C3-1. Downhole borehole sensors for long-term monitoring in high-T environment

To monitor the nature in the near field of seimogenic zone and other deep scientific targets, downhole borehole sensors for long-term monitoring in high-temperature environment are necessary. This technology may become a key issue to catch anomalies prior t0 earthquakes. This technology exists but is limited to less than 100 degree C but needs to be extended to higher temperatures and pressures.

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D: Underway geophysics

D1. Sea-surface magnetometer

Sea-surface magnetometers can be used to gather valuable information of the Earth's magnetic field while being in transit, especially in poorly surveyed area. Such data has been acquired during past DSDP, ODP, and IODP expeditions by using a towed sea-surface magnetometer but the old sea-surface magnetometer was retired without being replaced. Existing magnetometers (e.g. Cesium magnetometers) are easy to deploy and would allow collecting high-quality magnetic field data.

D2. 3-Axis Magnetometer

As for D1, such a magnetometer would be used to gather information of the Earth's magnetic field. The system is not towed behind the vessel but usually installed in the vessel stern and corrected by the gyro-system of the vessel. It provides additional data (3 components) compared to a towed magnetometer (D1) but needs more processing compared to a towed magnetometer. Systems are available.

D3. Echo sounders

Echo sounders including sediment echo sounders and multibeam bathymetric sounders are widely used during pre-site surveys. Hence data are usually available before going to site but it would be useful to update existing data during transit and around the site. Technology is existing and widely used in science and industry.

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