Technological Drivers for Future IODP Science

*Progressing from **application-specific** to **systematic** technological development*

Contributed by the IODP Engineering Development Panel

Abstract

Since its inception with the Deep Sea Drilling Project (DSDP) scientific ocean drilling has always had a technology development component. Technology development has been critical for advancing ocean drilling and scientific progress would not have occurred without it. Resolution of the simpler technical problems have progressed satisfactorily through an application-specific process, however the more difficult and complex problems that limit achieving many of the scientific objectives of the Initial Science Plan (ISP) and active IODP drilling proposals remain unresolved and will require a more comprehensive and systematic effort. This White Paper highlights key technological/scientific goals identified by the Engineering Development Panel (EDP)—Improving Core Recovery and Quality; Addressing Geohazards; Microbiology in the Marine Subsurface Environment; Drilling to the Moho and Other Complex Drilling Projects; and Virtual Staffing—that are derived from the EDP Technology Roadmap v. 3.0 (http://www.iodp.org/eng-dev), the ISP, and active drilling proposals; and reinforced by the Science and Technology Panel (STP) Roadmap (v. 0.93). They offer the greatest promise for transforming scientific ocean drilling. In order to accomplish some of these goals, large-scale engineering developments will be necessary to deliver the transformational science needed by any drilling program beyond 2013.

The Role of the EDP

The EDP lies within the Science Advisory Structure (SAS) of the IODP and is one of the key bodies charged with providing guidance on the development of engineering technologies for scientific ocean drilling. The EDP identifies long-term technological needs determined from active IODP proposals and the ISP, and recommends priorities for engineering developments to meet those needs, both for the annual IODP-MI engineering plan and on a longer term.

The EDP has been focusing on technological issues in support of scientific drilling objectives since its formation in September 2005, and has many recommendations to make to the scientific community in order to promote our understanding of the Earth. While much of the engineering development work in the past has been application-specific in nature, the EDP recognizes the need for a more systematic approach to engineering development, encouraging greater efficiency and improved methods, and delivering better quality of the science.

Key Technological Challenges for the Next Phase of Scientific Ocean Drilling

- **Improving Core Recovery and Quality** – improving borehole stability, core quality and quantity
- **Addressing Geohazards** – enabling the study of underlying geologic and geodynamic processes
- **Microbiology in the Marine Subsurface Environment** – advancing sampling and study of deep-dwelling microorganisms
- **Drilling to the Moho and Other Complex Drilling Projects** – reaching the Mohorovičic discontinuity and deep ocean-crust targets
- **Virtual Staffing** – developing shore-based operation centers to support complex drilling projects

Each of these technological challenges are examined below:

GOAL: Improving Core Recovery and Quality

CHALLENGES

Core recovery has been a significant problem in many drilling environments, including active fault zones, volcanic rubble in Mid-ocean ridge (MOR) settings, unconsolidated coarse material or zones of strong rheological contrast (e.g., chert-shale interbeds), igneous rocks (hard rock), gas hydrates, and gassy sediments (e.g., extruding cores on deck). Significantly higher core recovery of comparable lithologies typically occurs at land-based drill sites because the drill string is not subjected to the effects of ocean currents and vessel heave. These motions make accurate control of coring parameters almost impossible with the result that core recovery and quality are much worse that would normally be expected in an onshore context.

SOLUTIONS

Studies undertaken by IODP-MI suggest that core quality deteriorates with increasing rock hardness or brittleness. Industrial experience suggests that accurate control of the downhole drilling parameters, such as weight on bit and torsional stability of the drillstring, are critical determinants of core quality.

Isolating downhole conditions from the external environment by regulating feed and torsion through a seabed coring frame offers the prospect of dramatically improved core recovery and the ability to use a variety of new and "state of practice" sampling/coring tools as well as *in situ* testing devices (see the EDP and STP Technology Roadmaps for specific technologies and details). The addition of seabed frame technology is critical for aiding future scientific ocean drilling in achieving elusive science objectives and may create new scientific opportunities and targets. As early as 1998, the scientific community identified the need for a "seabed frame" to meet the IODP scientific goals with the new IODP non-riser vessel (CDC, 2000). The May 2004 Autonomous Downhole Tools Workshop participants re-affirmed this need (http://www.oceanleadership.org/programs-and-partnerships/usssp/workshops/past-workshops/usssp-past-workshops-2004/workshop-on-autonomous-downhole-tools-in-the-integrated-ocean-drilling/).

A recommended development pathway to deliver a step change in core recovery would be:

1. Review capabilities of existing deployment systems (vertical motion reduction systems such as vessel heave compensators) for utilizing seabed frames and installing/servicing borehole observatories;
2. Model and calibrate vertical motion reduction systems integrated with a seabed frame;
3. Specify a seabed frame for controlling bit feed, rotation, and ability for *in situ* testing experiments and stabilizing tools used for *in situ* measurements; and
4. Integrate coring and data acquisition systems for a common bottom-hole assembly (BHA).

A development of this nature will require a coordinated and focused effort. It will not happen as the result of application-specific developments by industry or academia. IODP-MI should create an engineering development organization charged with defining the options and producing a firm estimate of time and cost to implement these systems and then, if the Lead Agencies approve, oversee the resulting development program. This proposed engineering development organization would also be responsible for the long-term planning of complex drilling projects, such as a possible effort to reach the Moho, discussed further below.

STATE OF PRACTICE

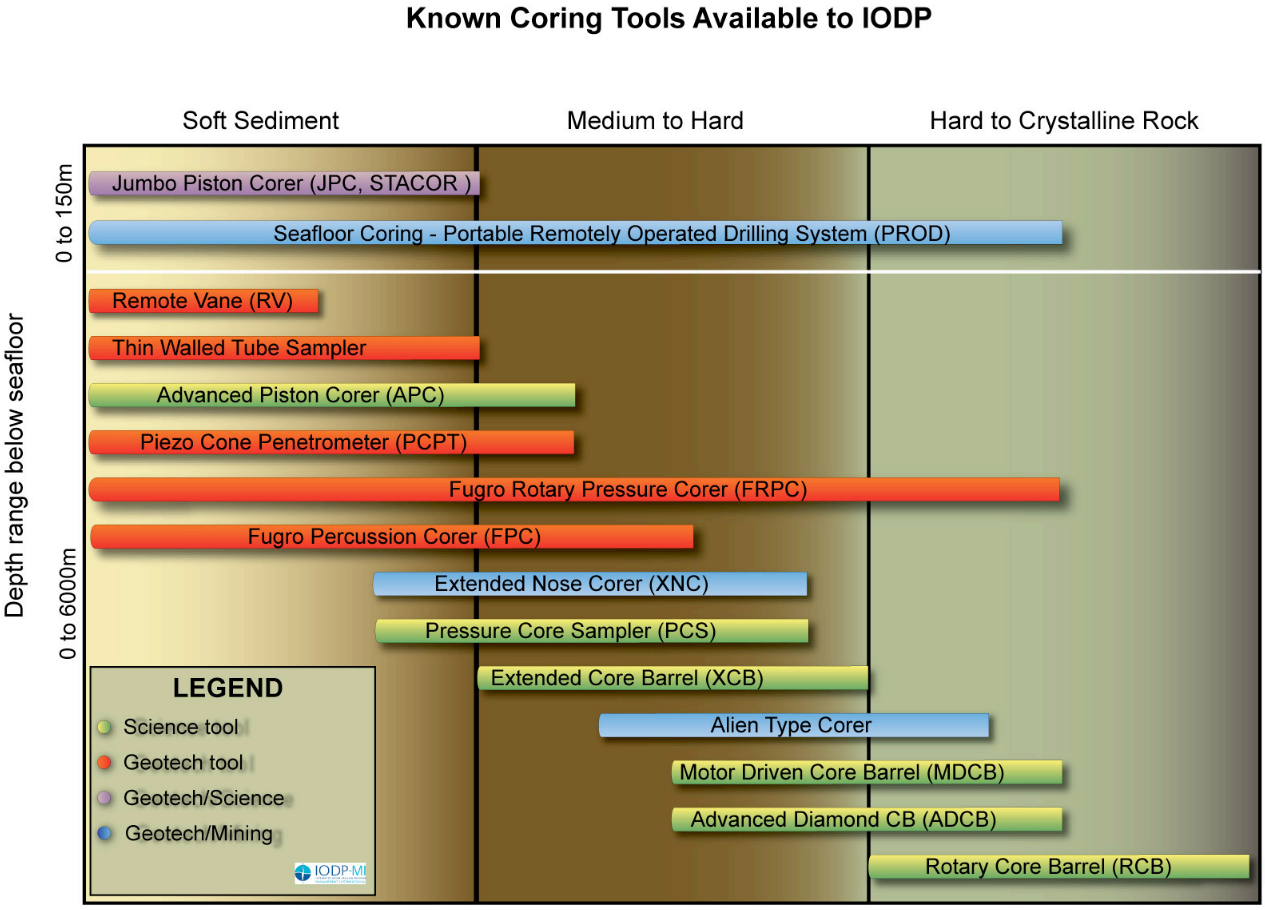
Seabed drilling systems are already being pioneered by the geotechnical community (e.g., RovDrill and DWACS), and by certain European (e.g., Marum MeBo and BGS Rockdrill) scientific activities. Current depth capabilities of these seabed corers are on the order of 100 to 150 meters. This type of technology in conjunction with new ‘state of practice’ ship heave compensation equipment should therefore be evaluated for application to the task of deep water and possibly 1-2 km deep borehole coring operations.

Seabed frame technology has been developed within the marine geotechnical industry over the past ~30 years. It provides stability to the drill bit for improved deployment of *in situ* tests, and hydraulics at the seafloor that may be used in conjunction with a seafloor-mounted swivel system to advance the borehole with a controlled feed rate to enable improved weight on bit control. This capability, possibly supported with a deep-water ROV or acoustically activated clamping and pull-down systems, would expand the non-riser drilling capability to meet scientific objectives that require the need for:

1. Recovery of sand on continental margins and deep-water fan systems;
2. Recovery of corals in shallow water environments;
3. Recovery of young or zero age crust;
4. Deployment of *in situ* tools for the measurement of pore pressure, resistivity, and temperature as well as gamma ray density, acoustic velocity and other “wireline” logging measurements in the upper 100 mbsf and in unstable borehole formations;
5. Deployment of specialty tools for the measurement of *in situ* stress (e.g., packers) pressure core samplers, and a variety of “off the shelf” geotechnical tools (e.g., penetrometers); and
6. Recovery of contacts between hard and soft layers (e.g., limestone/chert sequences, contacts between lava flows, soil horizons between lava flows).

Standard geotechnical seabed frames (i.e., without the more sophisticated swivel/hydraulic advancement control), use a set of hydraulic jaws to clamp the drill string eliminating motion at the bit. This operation provides more reaction for the passive heave compensator to work against and in a more efficient operating range to enhance recovery, and to allowing tools such as the motor driven core barrel (MDCB) to be used more effectively, to enable routine spudding of hard rock holes, as well as to improve core recovery using pressure core sampling (PCS) type tools (Figure 1). A further enhancement and one that will result in a step change in technology will be to utilize a more technically-advanced seabed frame that incorporates a hydraulic feed and swivel system to control weight on bit (WOB) from the seafloor, rather than from a heaving ship.

We also note that improving core recovery and core quality is a top priority of the Science Technology Panel (STP) Roadmap, which reinforces its critical importance to scientific ocean drilling. In addition, we emphasize the need for an integrated planning and development approach to acquire and implement drill bit stabilization technology. Ultimately, an integrated system, when coupled with high quality rig and drill string instrumentation, will enable the full suite of present and future downhole tools to work far more effectively in the full range of materials to be cored and tested (Figure 1).



Data provided by Leon Holloway (ConocoPhillips) and Gary Humphrey (Fugro)

Figure 1: Illustration of known coring technologies available to the IODP and their suitability for various sediment types.

GOAL: Addressing Geohazards

CHALLENGES

The governing processes and recurrence intervals of geohazards are still poorly understood. Data obtained through scientific drilling, coring, logging, *in situ* measurements, and post-drilling borehole observatories provide unique information on potentially geohazardous processes because oceanic sediments preserve evidence of past geohazards (e.g., earthquakes, landslides, volcanic eruptions/collapses, and bolide impacts). The *in situ* conditions of these sediments also provide key information on their state before, during and after a catastrophic event, which may help predict imminent (sub-) seafloor deformation.

SOLUTIONS

Incorporation and/or modification of existing technologies, and new innovations are needed for better data collection of oceanic geohazard processes. Improved drill bit stabilization is critical for increasing core recovery, improving core quality, and for conducting some types of *in situ* measurements. In addition, capability for directional drilling is needed. For shallow sub-bottom depths, thin-walled geotechnical samplers are needed to collect high-quality undisturbed cores for subsequent laboratory measurements. For greater sub-bottom depths, the drilling systems need to be upgraded and/or developed [e.g., rotary core barrel (RCB) and diamond coring systems (DCS, ADCB); Figure 1]. New developments for borehole measurements include characterization of the seafloor (e.g., cone penetrometers), pore pressure and *in situ* stress measurements [e.g., hydraulic fracturing (HF), hydraulic tests on pre-existing fractures (HTPF)], improved logging while drilling (LWD)/monitoring while drilling (MWD) capabilities and further development of logging while coring (LWC). A critical requirement of successful long-term monitoring systems is improved reliability and redundancy of components in systems for high temperature and pressure, and corrosive environments, including cables, connectors, data systems, telemetry, and power systems.

STATE OF PRACTICE

The IODP recently hosted a workshop addressing oceanic geohazards (Morgan et al., 2009). One of the tasks of this workshop was to evaluate, list, and document tools and technologies available for geohazards studies.

The Advanced Piston Corer (APC) is the standard tool for sampiong soft sediments. It penetrates 9.5 meters and is composed of thick-walled material incorporating a blunt nosed cutting shoe. The net result is that the core taken is highly deformed.

The passive heave compensation system on the *JOIDES Resolution* was recently refurbished while in dry dock during 2009. The state of practice for drill string stabilization is discussed above.

Current thin-walled geotechnical sampling tools exist in industry and could be implemented on IODP vessels if a standard type seabed frame were available to immobilize drill bit motion. Piezocone penetrometer (PCPT), remote vane (RV) tools, and a host of other industry available tools from the geotechnical community could be implemented on IODP vessels if a seabed frame were available.

Numerous methods for measurement of borehole stress exist which include geophysical logging, and *in situ* and core testing. Methods used routinely in the oil and gas industry include geophysical logging, leak-off tests and laboratory testing of intact cores. However, most methods only probe parts of the stress tensor. Multiple measurements thus provide the best characterization of the stress tensor and pressure.

GOAL: Microbiology in the Marine Subsurface Environment

CHALLENGES

The sub-surface biosphere has captured the curiosity and interest of the scientific community within the last decade, and what we are learning is revolutionizing how we view the seafloor and what is below it. There is a critical need to obtain uncontaminated sediment and microbial samples that preserve an intact microbial community at *in situ* pressure, temperature, and fluid chemistry. Integral to the sample recovery process is the capability of transferring the samples to laboratory apparatus without further compromising the integrity or contaminating the samples. There is a further need to better integrate the geochemical measurements of the core with microbiology (e.g., interstitial water sampling and analysis with microbiological sampling). This issue is also highlighted in the STP Technology Roadmap.

SOLUTIONS

A system is required to prevent core contamination by fluids (*in situ* formation fluids and circulated drilling fluids) during coring, as the core is advanced up into the inner core barrel. Systems are also needed for *in situ* incubation for properly identifying and describing community composition and function, and for understanding the physiology and nutrient requirements of these organisms. In most cases, recovery of microbiological samples at *in situ* conditions is desired, however some samples could be returned to the surface after completion of an incubation experiment. Long-term monitoring of microbial community composition and associated geochemical and thermal changes may be needed to meet some scientific objectives.

STATE OF THE PRACTICE

Land-based technologies should be thoroughly investigated to determine if there are concepts and approaches that can be used for offshore applications. The ODP and IODP have experimented with novel contamination tracers (fluorescent beads and perfluorocarbon - PFT) with some success. However, the IODP currently has no systems for preventing contamination of microbiological sample during coring, or for incubating them *in situ,* although there are independently-funded projects developing down-hole incubation systems.

The EDP has established a Microbiology Contamination Working Group that is addressing issues associated with minimizing or eliminating the physiological effects of drilling fluid contamination on *in situ* microbiological incubations and core sampling. Drilling fluids and muds used on all IODP vessels are complex mixtures of materials optimized to meet operational and engineering requirements for drilling. Determining the physiological effects of each specific component on microbes is a difficult bio-assay problem, primarily because most of the microbes found in deep-sea sediments cannot be cultured at the present time. What complicates assessment even more is that some formulations or components of drilling fluids and muds are proprietary. At this point, viewing mud components as classes of compounds is most expedient. For example, the use of chemically-reduced constituents that are bioactive, such as magnetite, should be replaced by a physiologically inert substance that meets the same performance requirements for the drilling mud. Investigating and reformulating drilling muds to minimize their effects on microbe physiology is a complex and potentially expensive endeavor. In the near-term, determining whether contamination has occurred would be more expedient.

GOAL: Drilling to the Moho and Other Complex Drilling Projects

CHALLENGES

Exploration of the oceanic crust down to the Mohorovičic discontinuity, as well as other complex deep ocean-crust drilling projects will require a higher level of engineering planning and development, including organization and planning/strategy (pilot hole, long-term project management, on-the-project technological developments) of the project, site characterization, vessel capacity, borehole management, as well as downhole equipment development than has hitherto not been the norm in the IODP.

SOLUTIONS

In comparison with the planning and lead-time for executing a typical 2-month ODP/IODP expedition and the experience gained with land-based ultra-deep drilling (e.g., the KTB and Kola Peninsula SG-3 boreholes), the planning process alone for initiating a Moho drilling project will be on the order of ten years. A dedicated project office will be required to manage such an ambitious goal. This project office should be set up under the auspices of IODP-MI to plan, coordinate and oversee the large-scale engineering developments necessary to execute ultra-deep drilling. It should be managed in the same manner as an industrial project of comparable scale, with all associated project management practices such as goal setting, organization structure, stage-gating, planning, scheduling, risk management and cost control. Global experts from other ultra-deep borehole projects should be consulted and retained as needed.

Time and resources must be allocated to conduct full site characterization of the nature of the ocean crust that will be drilled and the *in situ* state of effective stress, as well as the atmospheric and oceanographic environments to enable selection of an optimal site. Based on the experience gained during several deep-drilling projects (Kola SG-3 and the KTB) the exact knowledge of the stress field and borehole stability are of critical importance for the success of the project. Improved methods for measuring the state of stress must be developed. All equipment, tools and sensors must be adopted for high temperatures and pressures, and for highly corrosive environments. Required advances in drilling technology include developments in drillstring and casing handling [e.g., risers may be constructed from advanced materials, and/or "riserless mud recovery" (RMR™) systems may be implemented], next generation mud motors, cutting removal and high-temperature mud programs, and adequate safety considerations (e.g., blow-out preventer for hydrocarbon occurrence). Data collection should be as redundant as possible, by multiple data collection methods (e.g., LWD, MWD, LWC, cuttings analyses, logging and long-term monitoring) and robust data transfer from downhole sensors, and real-time transmissions to shore-based science and engineering collaborators, IODP-MI, and members of the SAS.

STATE OF PRACTICE

IODP-MI is currently executing a scoping study on ultra-deep boreholes at the request of the EDP to determine the present state of practice for ultra-deep drilling technologies.

Temperature and pressure ratings of all downhole tools are significant issues if the tools are to be deployed in a mud-filled borehole that exceeds 175 °C. The oil and gas and the geothermal industries have been drilling wells with borehole temperatures up to 250 °C and many downhole tools have been developed to work in these environments for short duration deployments. Limited tools are available for working at higher temperatures. Figure 1 lists coring tools known to be available to the IODP. Most of these would need to be modified for use at high temperatures and pressures, which would represent a significant engineering effort and cost.

There are two approaches to ultra-deep drilling: (1) riser drilling and a relatively new technology termed (2) "riserless mud recovery" (RMR™). Ongoing activities are increasing the depth capacity of the riser ship *Chikyu*, including systems for high-temperature and high-pressure conditions under deep sea floor, and development of carbon fiber reinforced plastic riser pipe. IODP-MI is working with the DeepStar Consortium to develop the ultra-deepwater RMR™ system in collaboration with its industry partner AGR Drilling Services. RMR™ can potentially be deployed on any IODP drilling platform.

ENGINEERING DEVELOPMENT AND OPERATIONS PLANNING

In the light of the future requirement for complex drilling projects and oversight of significant technological developments such as seabed frames, enabling technologies required for future scientific drilling programs will not be delivered through the existing informal arrangements that exist between EDP and IODP-MI. A drilling program of such scale will require a much more formal and structured approach to ensure success within the time-scales required.

It is recommended that a full-time engineering organization be set up under the auspices of IODP-MI to plan, coordinate and oversee the engineering developments necessary to deliver the transformational science associated with the scientific drilling beyond 2013. The organization should consist of two sections, technology development and operational planning.

The technology team, consisting of specialists in subsea engineering, drilling systems and downhole tools, would be responsible for solving the problems associated with drillstring stabilization, next generation coring systems, and ultra-deep water technologies.

The operations team, consisting of experienced well engineers and operations engineers, would be responsible for planning the introduction of the new technologies and also undertaking the long-range conceptual planning and budgeting for frontier exploration projects such as the 21st Century Mohole and other complex deep ocean-crust targets.

Based on current practice in the oil and gas industry, it is envisaged that such a organization would consist of approximately 12-20 people who would manage an annual external budget on the order of 4 to 5 million USD that supports meeting scientific drilling objectives requiring long lead-time planning and development. It should consist of established industry professionals and be located in close proximity to one of the major oil and gas industry centers in either the USA or Europe.

In addition to pursuing the long-term goals, recent experience with technology issues that have come before the EDP indicate that such a group would be well-placed to undertake technology scoping studies, reviews of specific technologies of value across all operators and provide specialist well engineering input to complex drilling projects. It is expected that with sufficient resources the complex problems associated with ultra-deep drilling (deep water, high temperatures and pressures) can be resolved and that drilling to the Moho will become possible.

GOAL: Virtual staffing

CHALLENGES

The anticipated increase in complexity of coring systems and the technological sophistication of instrumentation and analysis during the next phase of scientific drilling will require a larger ship-board crew comprising more professional engineers and technicians than in previous drilling programs. There is parallel need for sufficiently large science parties to take part in complex drilling projects, and to maximize the scientific output of the data collected. The challenge is to optimize the staffing of scientists, technicians and engineers considering the limited space available on the drilling vessels and mission specific platforms (MSPs).

SOLUTIONS

The rapid evolution of global communications and networking technologies offers a potential solution for integrating shore-based scientists and engineers with shipboard operations. Substantial operational benefits will be gained from the development and implementation of shore-based real time operations support centers. Such centers could allow more flexible staffing of scientist, technicians and engineers, and maintain a 24/7 presence on-shore for consultation and guidance. Each expedition should evaluate the Minimum Measurements Recommendation with their science plan to coordinate how to achieve the science with the appropriate ship-based crew supported by the virtual staff.

STATE OF PRACTICE

The practice of virtual science parties is well-established in the ESO MSP missions. Remote operations centers are well-established in the oil and gas industry and they have demonstrated benefits in cost-reduction and mission flexibility.

The EDP Technology Roadmap

Much of the above information has been extracted from the EDP Technology Roadmap, which is a long term vision (3-5 years) of priorities in engineering development that are vital to achieve the science goals of the IODP and future scientific ocean drilling programs. It is an evolving document that undergoes review annually at the summer meeting of the EDP. The roadmap is based primarily on the scientific goals of the IODP as enunciated in the Initial Science Plan and active IODP proposals, and outlines and examines the engineering development needs for achieving these initiatives.

More information

EDP and Roster of Members – http://www.iodp.org/edp

Technical Roadmap and Engineering Development Proposal Submission – http://www.iodp.org/eng-dev