Engineering Development Panel Technology Roadmap
Version 4.0
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History:

Engineering Development Panel Technology Roadmap Version 1.0 was prepared between January 2006 and July 2006. There was no previous document. It was formally ratified by the EDP at the June 2006 meeting in Germany pending editorial revisions.

Engineering Development Panel Technology Roadmap Version 2.0 was prepared between January 2007 and November 2007. It is a modified version of the EDP Technology Roadmap Version 1.0 based on comments made by the EDP at their January 2007 and July 2007 meetings. At the July 2007 meeting in Salt Lake City the technology roadmap was formally ratified by the EDP pending editorial revisions.

Engineering Development Panel Technology Roadmap Version 3.0 was prepared between January 2008 and July 2009. It is a modified version of the EDP Technology Roadmap Version 2.0 based on comments and discussion made by the EDP at its meetings between January 2008 and July 2009. Version 3.0 was formally ratified by the EDP at its July 2009 meeting in Sweden.

Engineering Development Panel Technology Roadmap Version 4.0 was prepared between April 2010 and July 2010. It is a modified and reorganized version of the EDP Technology Roadmap Version 3.0 based on comments and discussion made by the EDP at its meeting between January 2010 and July 2010, the EDP contribution to the INVEST meeting, and by the work by a small EDP work group that was active from April-June 2010. Version 4.0 was formally ratified by the EDP at its July 2010 meeting in Santa Fe (USA). This version is partly reorganized and expanded in comparison to previous versions of the roadmap to also include a new section of achievements. Because of the transition of the Science Advisory Structure into the new science drilling program, this is the final version of the Engineering Development Panel Technology Roadmap.

EDP Technology Roadmap
Version 4.0

1 Executive Summary

The Engineering Development Panel (EDP) of the Integrated Ocean Drilling Program (IODP) has developed the Technology Roadmap. The Technology Roadmap summarizes EDP roles and responsibilities. It describes technology challenges that face the IODP as it attempts to achieve its science goals and details a range of developments that could contribute to achieving these science goals. In addition, the Technology Roadmap describes the IODP-MI Engineering Development proposal process, which is the first formalized plan that departs from ad hoc engineering development. The impact of this procedure is mirrored in the final chapters of the Technology Roadmap, where achievements of engineering development are highlighted and a path forward to the next phase of ocean scientific drilling program is offered.

The EDP recognizes that engineering advancements have the potential of providing improved abilities to achieve the science goals of IODP, for example to investigate the deep biosphere, obtain higher recovery and better-quality drill cores for improved estimates of past climate, and reach seismogenic zones. Major infrastructure improvements will undoubtedly also inspire totally new avenues of investigation as well as lead to more cost- and time-effective, safer, and environmentally-friendlier operations. New science proposals have always followed the introduction of new capabilities.

In order to achieve some of the critical scientific breakthroughs that require advances in engineering and technology, a long-term commitment by the program for sustained funding and management of engineering development projects is required. This can be enhanced by establishing external partnerships with other science programs, governmental agencies, and industry.

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2 Introduction and EDP Roles and Responsibilities

The Integrated Ocean Drilling Program (IODP) builds from the successes of the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP), yet it is a fundamentally more extensive and challenging multi-national endeavor. The IODP involves simultaneous use of riser, riserless, and mission-specific drilling platforms, and it will explore environments and problems that could not be addressed previously. These characteristics influence virtually all facets of planning, funding, at-sea operations, and technical development. It is particularly important to examine the role of Engineering Development (ED) because advances in these efforts are critical to IODP science, because the development and application of engineering solutions are the responsibility of the three implementing organizations (IO´s) and third-party developers, and because technology advances are driving new measurement capabilities and scientific demands.

The Engineering Development Panel (EDP), a panel within the Science Advisory Structure (SAS) of IODP, is one of the key bodies charged with providing guidance on ED in the IODP. The following is extracted from the EDP mandate (http://www.iodp.org/edp/). "*The panel shall provide advice on matters related to the technological needs and engineering developments necessary to meet the scientific objectives of active IODP proposals and the IODP Initial Science Plan (ISP) to the Science Planning Committee (SPC); through the SPC, to the Science Planning and Policy Oversight Committee (SPPOC) and IODP-MI; and, through IODP-MI, to the implementing organizations (IO´s) …The EDP shall identify long-term (two to five year lead time) technological needs determined from active IODP proposals and the ISP, and recommend priorities for engineering developments to meet those needs, both for the annual IODP engineering plan and on a longer term*."

At its bi-annual meetings, the EDP will provide SPC with a prioritized plan for FY+2 engineering developments for the Program Plan that is based on reviewing and ranking of engineering development proposals submitted to IODP-MI. Through this technology roadmap, EDP will examine and define long-term ED needs (FY>2). EDP will provide guidance to IODP-MI and the Implementing Organizations (IO's) by reviewing the engineering development plan within the Program Plan (FY+1).

The SPC will use the guidance provided by EDP's spring meeting to prioritize the annual engineering development plan along with the annual science plan. At their summer meeting, SPC must make specific recommendations to SASEC (Science Advisory Structure Executive Comm.) for the FY+2 engineering development plans. Thus, the SPC must recommend the 2010 engineering development plan at its summer 2008 meeting. EDP is charged with providing as much detail as possible on their FY+2 engineering development recommendations. However, it will not be at the level of detail required for the formal Annual Program Plan. That level of detail is developed by IODP-MI in the formal Annual Program Plan. SPC must be able to map specific FY+2 developments against the long-term technology roadmap developed by EDP.

3 The Technology Roadmap

The Technology Roadmap provides a long-term vision (> 2 years) of priorities in ED that are vital to achieve the science goals of the IODP. It was an evolving document from 2006 to 2010 that received major review at EDP's July meeting each year. The roadmap is founded on the scientific goals of the IODP as enunciated in the ISP (IODP, 2003) and active IODP Proposals. The Technology Roadmap assesses the ED needs for achieving these initiatives.

The ISP has three major scientific themes: 1) The Deep Biosphere and Subseafloor Ocean, 2) Environmental Change, Processes and Effects, and 3) Solid Earth Cycles and Geodynamics. Within each theme there are a number of new program initiatives (Table 1). These initiatives incorporate novel scientific approaches and require major advances in drilling platforms and technologies.

Table 1. Major Themes, Scientific Opportunities and Initiatives for the IODP

Scientific Themes	**Initiatives**
Theme 1: The Deep Biosphere and the Subseafloor Ocean	
The Subseafloor Ocean in Various Geological Settings	
The Deep Biosphere	Deep Biosphere (1a)
Gas Hydrates	Gas Hydrates (1b)
Theme 2: Environmental Change, Processes and Effects	
Internal Forcing of Environmental Change (2a)	Extreme Climates (2b)
External Forcing of Environmental Change (2c)	
Environmental Change Induced by Internal and External Processes (2d)	Rapid Climate Change (2e)
Theme 3: Solid Earth Cycles and Geodynamics	
Formation of Rifted Continental Margins, Oceanic LIPs and Oceanic Lithosphere (3a)	Continental Breakup and Sedimentary Basin Formation (3b) Large Igneous Provinces (LIPs) (3c) 21st Century Mohole (3d)
Recycling of Oceanic Lithosphere Into the Deeper Mantle and Formation of Continental Crust (3e)	Seismogenic Zone (3f)

Keys: Numbers within parentheses (1a, 1b, 2a-e, 3a-f) refer to the column "ISP Science Goals" in Tables A-1, B-1, and C-1 of Appendices A, B, and C.

3.1 Technology Challenges Facing the IODP

To achieve the scientific goals identified in the ISP, there is a range of technology challenges that requires engineering development (Table 2).

Table 2. Technology Challenges for the IODP

1	Expand temperature and pressure tolerance
2	Drill/Instrument unstable lithologies and over pressured zones
3	Improve core recovery and quality
4	Improve depth control and cross-instrument depth correlations
5	Develop long-term borehole monitoring systems
6	Develop ability to perform in situ experiments
7	Improve well directional control

8	Make measurements under in-situ conditions
9	Sample at in situ conditions and transfer samples at in situ conditions shipboard
10	Improve hard-rock drilling capabilities
11	Improve remote and post-deployment capabilities
12	Improve reliability
13	Extend depth capabilities
14	Improve operability under strong currents and severe sea state
15	Magnetic orientation

1. Expand temperature and pressure tolerance

We need to expand the temperature limits of drilling and measurement technology. Drilling targets are deeper than those of the ODP, and the more extreme sites that have been avoided in the past are of great interest. Long-term monitoring in hot boreholes will require ED that address sensor reliability, robustness, and drift in hostile thermal and chemical environments.

During the ODP, the LDEO/BRG wireline Hi-T probe and the University of Miami GRC Ultra Hi-T Memory Tool were available. The LDEO/BRG Hi-T tool can be deployed in situations where temperatures do not exceed 235°C, whereas the GRC tool was used in situations where the temperatures exceed the upper limit of wireline capabilities.

Long term monitoring is a challenge because exposure to both high temperature and corrosive fluids occurs over a long time-frame. Significant technological developments must be made to use muds, cements, and drilling technologies for high temperature settings. Drilling muds used at high temperature cannot include standard clays, such as bentonite or sepiolite, without modifications. Additives can extend the temperature range for these materials to some degree, but investigation of more exotic materials will be essential. It will be important to use experience and knowledge of drilling high temperature wells in the geothermal and the oil and gas industry.

Material aging at high temperatures in corrosive environments is not well understood or investigated. Aging will affect the reliability and life-time of in situ experiments and long-term monitoring systems in hostile environments.

2. Drill/Instrument unstable lithologies and over pressured zones

Three lithologies have proven to be difficult to complete drilling:

- Fault zones
- Volcanic rocks in mid-ocean ridge (MOR) settings
- Unconsolidated sands and other coarse-grained materials

The IODP faces drilling in the Nankai accretionary prism to considerable depths across the décollement. In this environment, the stress state is complicated and the pore pressures poorly known. Borehole instability may result from large differences in maximum and minimum stresses along the wellbore, which can cause breakout leading to excessive borehole enlargement. Possible approaches that could be used to drill more successfully include: 1) sophisticated mud programs, 2) casing the borehole while advancing, and 3) wells oriented and mud density controlled to take into account the stress condition in the borehole.

3. *Improve core recovery and quality*

Core recovery has been a significant problem in at least 6 environments in DSDP/ODP/IODP history:

- Fault zones. A major goal of the IODP, see Science Theme 3 and the Seismogenic Zone Initiative (ISP, 2003). Fault zones and surrounding rocks are often highly deformed and core recovery is low.
- Volcanic rocks in MOR settings. In intensely fractured, young lava flows, the core is often so broken up so that intact pieces of core are not recovered.
- Unconsolidated coarse material or zones of strong rheological layering (e.g., chert-shale interbeds). In shallow poorly indurated deposits such as unconsolidated sands and/or layered hard-soft lithologies (e.g., chert-shale interbeds), core recovery is often frustratingly low.
- Igneous rocks (Hard Rock). Initiation of coring on bare and sloping seafloors and improvement of core recovery in hard rock have been long-term issues that will need to be solved.
- Gas hydrates. Gas Hydrates quickly "melts" once removed from the high pressure and cold temperatures of its natural environment, making it very challenging to recover and analyze.
- Gassy environments. Coring of gassy unconsolidated fine-grained sediments often result in extruding cores on deck as the result of de-gassing of the cores. This process decreases the core recovery and degrades the core quality.

IODP needs to improve quality of cores for geotechnical testing. Geotechnical cores may be collected to determine formation rheology, strength, permeability, and maximum past effective stress; currently, the only IODP platform they may be collected from is Mission-Specific Platforms (MSP). Deformation caused by the Advanced Piston Corer (APC) onboard *JOIDES Resolution* and the Hydraulic Piston Coring System (HPCS) onboard *Chikyu* compromises the core quality. In general, deformation caused by the existing coring systems, particularly the Extended Core Barrel (XCB) systems, compromises the quality of many sediment cores.

It is important to preserve the magnetic orientation of core samples. Operational procedures for coring with mud should be developed for *Chikyu*.

4. Improve depth registration and cross-instrument depth correlations

The primary reference for all coring operations is the cumulative length of the drill string below the rig floor. The actual uncertainty in drill pipe measurement and, hence, depth of an interval of core is significantly higher, on the order of 0.2–4 m or more mainly owing to the variations of ship motion at sea. Precise estimation of error in drill pipe depth is difficult. The magnitude of the error is demonstrated by the difference between precision depth recording devices and drill pipe measured depths. In addition, multiple adjacent drill pipe measurements often disagree by as much as a few meters. An additional obstacle to high-resolution depth estimation in piston coring is the requirement to lock out heave compensation before firing the advanced piston corer (APC). Accurate depth registration is fundamental to sedimentation rate calculations and any modeling based on the relationship between age and depth.

Depth-estimation errors are now well-understood and investigated by industry (e.g., Wilson et al., 2004; Chia et al., 2006; Dashevskiy et al., 2006; Brooks et al., 2006). There are now numerous ways to address the additional depth-precision needs of the paleo-oceanographic community, methods have improved on precision depth recording devices and tools for correlating core and log data (e.g., Magnetic Susceptibility Sonde, shipboard Natural Gamma Ray Scanner).

5. Develop long-term borehole monitoring systems

A fundamental goal of the IODP is to apply long term monitoring and perform active experiments in boreholes in remote locations. These endeavors will require technological developments, robust operational/deployment plans, and post-deployment management.

Efforts to study the subsea biosphere and to perform hydrogeological and geochemical experiments rely on the ability to isolate zones within a borehole and perform experiments only within these zones. Sealing technologies that need further development include packers, multilevel seals, cementing strategies and materials, and borehole hanger sealing systems. Understanding the source of contamination and tracking potential contamination of fluids, gases, and in situ microbiological communities is essential to performing successful experiments.

Geophysical experiments and observing systems will require improvements in physical coupling to the borehole, identification and reduction of noise, and strategies for deployment of the sensors, and the conditioning/data logging electronics.

A challenge in developing thermal measurements in boreholes is the development of thermally-neutral borehole completions that do not significantly alter the thermal properties of the borehole environment. For example, steel pipe has a significantly different thermal conductivity from sediments, thus the long-term monitoring of the thermal structure of a sedimentary section may give stable, equilibrated values, but they will be biased by the presence of the borehole infrastructure.

Reduced power consumption and optimization of seafloor and downhole instrument packages is a necessity. New low power technologies for sensor (e.g., optical sensing systems) need to be investigated and developed. If submarine cable connections become a reality for some drilling sites, this problem will be diminished to some extent, but will remain a problem for deep boreholes because of limitations in copper conductor sizes and power losses in hot and chemically-hostile environments.

A critical requirement of successful long-term monitoring systems is improved reliability and redundancy of components in the system, including cables, connectors, data systems, telemetry, and power systems. Installing long-term monitoring devices is costly. It is critical to design these systems with redundancy so that they perform over long time scales. Reliability includes not only the components and system design, it is also critical at the manufacturing level that qualified individuals assemble and test the electronics boards, fluid connection system, connector and cable mating, etc.

6. *Develop ability to perform in situ experiments*

We should pursue the ability to perform in situ experiments. Examples have included hydrologic experiments. However, others might include microbiologic culturing and gas hydrate manipulative experiments.

7. *Improve well directional control*

IODP needs to implement technology to allow the well to follow the design plan (vertical or deviated). Often wells do not follow the design plan due to dipping beds and stress anisotropy which results in borehole deviation from vertical. In the IODP, much deeper boreholes are envisioned than previously drilled and it will be important to be able to control the well direction. Vertically accurate boreholes are required for successful installation of tiltmeters, borehole seismometers, casing, and strain-meters.

Directional control while drilling can be done, but the challenge is to have directional control while coring. New scientific problems could be addressed and more stable well paths could be found if deviated well bores could be cored.

8. *Make measurements under in-situ conditions*

Making measurements in the borehole includes a wide range of logging, geochemical and geotechnical tools. Successful measurements often depend on adequate stability of the drillstring and/or effective decoupling. The stability of long-term measurements is limited by in situ temperatures; the higher the temperature, the shorter the stable observation period.

9. *Sample at in-situ conditions and transfer samples at in-situ conditions shipboard*

There is a need to obtain samples that preserve the in-situ pressure, temperature, chemistry and biology. Integral to this process is the capability of transferring the samplers to laboratory apparatus without further compromise of integrity. This effort is critical to the Science Theme ‘The Deep Biosphere and the Subseafloor Ocean’ and it is also a crucial component to the Hydrate Initiative.

10. Improve hard-rock drilling capabilities

Challenges in drilling hard rock include:

- Borehole initiation on sloping sea floors or in terrains with little or no sediment cover over a hard-rock base,
- Advancing the drill bit through unstable formations, and
- Development of technologies that allow more rapid rate of penetration in homogeneous lithologies (i.e., even in the event of reduced recovery such as in sheeted dike sequences) is required for total crust penetration.

Borehole advance through unstable formation continues to be a problem. A key issue is that the formation material collapses on the bottom hole assembly (BHA). This prevents drilling advancement, occasionally resulting in the BHA becoming stuck and consequently lost. Expandable casing technology might offer solutions that can be deployed in stages. ODP Leg 193 and Hole 1256D (ODP Leg 206 and IODP Expeditions 309 and 312) are examples of drilling operations in hard rock that would have benefited from a technology that optimized rate of penetration even at the expense of reduced recovery. Industry has pioneered rapid penetration techniques and protocols (e.g., Exxon/Mobil’s Fast Drill process) that might be adapted to achieving IODP ISP science objectives. New advances in bit technology without coring are being developed by the petroleum industry for faster drilling applications.

HRRS was developed for spudding and casing at the same time on hard rock, but reduced budgets have prevented this technology from being deployed with proven components (i.e., old prototype hardware and that shown to not be as successful have been used since the original hardware was built resulting in disappointing failures and wasted time at sea.

11. Improve remote and post-deployment capabilities

There is a need for remote manipulation of borehole infrastructure and seafloor instrument packages while the drillship is on station and afterwards. In many cases, the complexity of subsea completions requires the use of an ROV as an adjunct to the drillship deployment capabilities. The visualization capability of ROV´s and their ability to manipulate equipment on the seafloor has revolutionized how science is conducted on the seafloor. Extension of this capability to boreholes has been envisioned, but not enabled for scientific ocean drilling primarily due to lack of sufficient funding and space requirements on the *JOIDES Resolution (JR)*.

Post-drilling deployment of instruments and borehole monitoring systems and their maintenance can be achieved in some cases using an ROV, but ships of opportunity and other borehole re-entry systems (e.g., the Scripps wireline re-entry vehicle) may be necessary approaches. Developing designs for wellhead completions, seafloor frames and templates that are compatible with ROV operations and non-IODP vessels is essential for enabling implementation of non-IODP platforms and re-entry tools.

There is also an emerging interest in connecting long-term borehole monitoring systems to existing or future submarine cable networks. Developing compatible ROV-serviceable, cable-connected wellheads will enable maximum use of seafloor networks. Long-term monitoring systems will require periodic visits by ROV´s or other platforms for servicing and modifications to existing experiments.

12. Improve Reliability

The Engineering Development Panel recommends that IODP institute a surveillance and reliability program for both drilling and borehole monitoring operations. This program would be focused across all activities in a given type of operation, rather than attempting to increase reliability on a single project basis. Tasks would include maintaining databases on operating parameters and failure modes, root cause failure analysis on breakdowns, quality control and assurance on system components, and recommendations on operating procedures and limits. Most large offshore installations in the petroleum industry employ surveillance and reliability engineers as a dedicated job role. This is a different engineering discipline than project engineering, which has more of a focus on cost, schedule, and functionality, with reliability as one of many other priorities.

13. Extend depth capabilities

Fulfilling the ISP requires access to deep biosphere, the lower oceanic crust and upper mantle, and the seismogenic zone. For accomplishing these objectives, further developments will be important. The scheduled and future Seismogenic Zone drilling needs technology development to achieve deeper drilling, coring, borehole experiments etc. To achieve the goal of sampling the deep ocean crust and the upper mantle, drilling technology will need to be developed for hostile environments (high temperature and pressure, high deviatoric stress), deepwater operations and deep drilling. In all cases, improved borehole stability is required.

The following list is an example of engineering developments needed to achieve this goal.

- AHC (Active Heave Compensation)
- Vertical drilling system (VDS) and rotary steerable technology to control hole trajectory
- LWD/MWD for high temperature applications
- Remote drilling

14. Improve operability under strong currents and severe sea state

To conduct riser drilling in strong current areas such as the Nankai trough while maintaining good operability, some modifications of existing systems on the *Chikyu* are required.

The stronger current force might result in larger angles of both flex joints beyond their tolerable range. Also, VIV (vortex induced vibration) on the riser under strong current is recently indicated to cause severe and rapid fatigue damage. To prevent these problems, it is necessary to reduce the drag coefficient of the riser pipe and the vortex around the pipe. Installing fairings onto the riser is effective for reduction of the current force. Optimal shape and arrangement of fairings needs to be studied as well as the logistical issues associated with this hardware.

Also, in order to increase operability of *Chikyu* under the severe sea conditions, more precise and efficient control for position keeping is required. Based on investigating the present abilities of *Chikyu*, the control method of DPS, RACS (Riser Angle Control System), and PMS (Power Management System) should be improved.

3.2 Pathways in Engineering Development

The EDP has identified three major categories of platform-independent ocean drilling activities that impact the types and quality of science that can be achieved: (A) Sampling, Coring and Logging; (B) Drilling Vessel Infrastructure; and (C) Borehole Infrastructure. Engineering development challenges within these three categories are listed in Tables 3-5 and described in Appendices A-C, respectively. Also included in each appendix is a table in which each engineering development task is summarized with respect to requirements (What needs to be accomplished?), Science Goal (How does it fit with ISP?, see Table 1), ISP Technology Challenges (see Table 2) and Availability (Is there any existing technology?)

There are several instances where the same technology is described under the three categories of platform-independent ocean drilling activities. Therefore, references to related challenges generally are included under respective item

3.2.A <u>Engineering Developments A: Sampling, Logging, and Coring</u>

Table 3 lists the engineering development challenges for Sampling, Logging and Coring. Further details are provided in Appendix A.

Table 3. List of Engineering Developments A: Sampling, Logging Coring

ED ID	Engineering Development	Technology Challenge (see Table 2)
A-1	Thin-walled Geotechnical Sampler	3
A-2	Cone Penetrometer/remote Vane	8,1
A-3	Upgrade to RCB System	3,10
A-4	Hard Rock Re-entry System (HRRS)	11,10,2
A-5	Coring Guidelines/Operations Manuals	
A-6	Diamond Coring System (Piggyback coring system)	3,10,2

A-7	Large diameter Diamond Coring Systems (ADCB)	3,10,2
A-8	Retractable Bit Technology	3,2
A-9	Vibracore/percussion Sampler	3,2
A-10	Motor Driven Core Barrel (MDCB)	3,10,2
A-11	Rotary Sidewall Coring	3,10
A-12	Provide Core Orientation on Standard Coring Tools	8
A-13	Seabed Coring Devices	3,10,2
A-14	Jumbo Piston Corer (JPC)	3
A-15	Downhole Tools Calibration and Testing Facility	
A-16	Pressure Coring Systems (PTCS, PCS, FPC, HRC, etc.)	3,8,9,6
A-17	Pressurized Sample Transfer	8,9,6
A-18	Common Bottom Hole assembly (BHA)	3,
A-19	New RCB Bits	3,10
A-20	Upgrades to XCB System	3
A-21	Anti-contamination Systems	3
A-22	New In-situ Sensors	8
A-23	Fluid Samplers, Temperature and Pressure Measurement Tools	1,8,6,9
A-24	Transition Corers/XCB	3,2,10

3.2.B Engineering Developments B: Drilling/Vessel Infrastructure

Table 4 lists the engineering development challenges for Drilling/Vessel Infrastructure. Further details are provided in Appendix B.

Table 4. List of Engineering Developments B: Drilling/Vessel Infrastructure

ED ID	Engineering Development	Technology Challenge (see Table 2)
B-1	Large Diameter Pipe	1, 7, 8, 9, 11
B-2	ROV-guided Logging Tools	1, 7, 8, 10,12
B-3	Heave Compensation	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12
B-4	Heave Compensation During Advanced Piston Coring	3, 4
B-5	Seabed Frame (SBF)	6, 7, 8, 10, 13,
B-6	Pressure Compensated Bumper/Thruster Sub	2, 3, 4, 9
B-7	Rig Instrumentation System (RIS)	2, 3, 4, 5, 7, 8, 9, 11, 12,
B-8	Improved Automatic Driller	3, 4, 9, 11
B-9	Drilling Parameter Acquisition While Coring	2, 3, 4, 7, 8, 9, 10,
B-10	Real-time Drilling Parameter Acquisition While Coring	2, 3, 4, 7, 8, 9, 10, 11
B-11	Real-time Logging While Coring (RT-LWC)	2, 3, 4, 7, 8, 9, 10, 11
B-12	Radio Frequency ID Chip Implant in Drill Pipe	1, 4, 7, 8, 11
B-13	Intellipipe	2, 4, 7, 8, 9, 10, 11
B-14	Electric/optical Wireline	1, 2, 4, 5, 7, 8, 10, 11
B-15	Directional Coring	2, 3, 6, 7, 8, 9, 11, 12
B-16	Non-magnetic Drill Collars	3, 4, 11
B-17	Non-magnetic Core Barrel	3, 4, 11
B-18	Magnetic Shield for Core Barrels	3, 4, 11
B-19	Protocol for Proper Mud Design	1,2,3,6,7,9,12,
B-20	Borehole Cameras and Imaging Devices	5,8
B-21	4,000-meter Class Riser System	12
B-22	4,000-meter Class Blowout Preventers	12

B-23	Reduce Current Force on Chikyu Riser	13
B-24	Improve Dynamic Positioning Systems	13
B-25	Improve expandable casing system	12
B-26	Cementing protocol for deep drilling	1, 5, 11, 12
B-27	Drill Pipe for Total Depth Ocean Drilling	1, 11, 12
B-28	High temperature, high pressure drilling system	2,7,10,13
B-29	Mud Circulation in Drilling Systems over 2,500-m Water Depth	1, 11, 12
B-30	Freestanding, Remotely-Operated Deepwater Shallow Hole Coring System	3, 10, 12
B-31	Drill Pipe Conveyed Deep Water, Shallow Hole Coring Tools	3, 12
B-32	Temperature Tolerant Muds and Drilling Bits	1
B-33	Protocol for Proper Design to Minimize Borehole Stability Problems	2,7,10,13
B-34	Virtual Shipboard Party	2, 4, 6, 7, 8, 9, 11
B-35	Seafloor Drilling Systems	2, 3, 4, 7, 8, 10, 11, 12, 14

3.2.C Engineering Developments C: Borehole Infrastructure

Table 5 lists the engineering development challenges for Borehole Infrastructure. Further details are provided in Appendix C.

Table 5. List of Engineering Developments C: Borehole Infrastructure

ED ID	Engineering Development	Technology Challenge (see Table 2)
C-1	High Temperature Electronics, Sensors, and Sensor Systems	1
C-2	Improved Cementing Techniques (high temperature and hydrologic isolation)	1
C-3	Corrosion Tolerance	1
C-4	Hydrologic Isolation	1, 5
C-5	Reliable Wellhead Hanger Seals	5
C-6	Electric, Optical Fiber and Fluid Feed-throughs at Wellheads and in Subsurface Casing Completions	5
C-7	Identifying, Tracking, and Minimizing Drilling Contamination	1,5
C-8	Casing Boreholes Through Active Fault Zones	5
C-9	Physical Coupling of Acoustic Instruments to Formations and Decoupling from Noise Sources	5
C-10	Accurate Estimates of Downhole Temperatures	5
C-11	Techniques for Borehole Microbiology Incubation Systems	5
C-12	Development of Low Power Sensors – Temperature, Pressure, Electromagnetic, Seismic, and Chemical Measurements	5
C-13	Cross-hole Hydrologic Experiments	5
C-14	Systems Reliability for Long Term Monitoring System (LTMS)*	5
C-15	ROV-serviceable Wellheads and Submarine Cable Connections	5, 10

C-16	Efficient Power Systems, Including Distribution	5
C-17	Design Standards for Electrical, Communications, Mechanical, and Fluid Systems	5, 10
C-18	Deployment Procedures for Borehole Infrastructure and Instruments	1, 5, 10
C-19	Managing Borehole Experiments	5, 10
C-20	Data Systems and Telemetry in Boreholes and on the Seabed	5
C-21	Borehole Instrument Deployment, Re-entry and Servicing Systems	5, 10
C-22	Stress Measurements	6,8

3.3 Priorities in Engineering Development

EDP has constructed a hierarchal chart to illustrate dependencies of engineering developments of Tables 3-5 (Figure 1). Appendix D presents the chart in more detail. Figure 1 supersedes the previous prioritization scheme utilized by the EDP. Each year at the EDP summer meeting, the EDP would choose from these ED tasks in the top ten high priority developments and list them as an unranked list in a table by category. The last time a table of this form was created was at the July 2007 EDP meeting and it is retained in this document for reference purposes only (Table 6). This prioritization was established by an expertise-weighted algorithm described in the minutes for the July 2007 meeting.

Figure 1. Internal dependencies of engineering development challenges.

See Appendix D

Table 6. Unranked List of Engineering Developments (EDP, July 2007)

Group A: Sampling/Logging/Coring	**Group B: Drilling/Vessel Infrastructure**	**Group C: Borehole Infrastructure**
A-1: Thin-Walled Geotechnical Sampler	B-3: Heave Compensation	C-1: High temperature electronics, sensors, and sensor systems
A-2: Cone Penetrometer /Remote Vane	B-5: Seabed Frame	C-4: Hydrologic Isolation
A-4: Hard rock re-entry system (HRRS)	B-8: Improved Automatic Driller	C-5: Reliable wellhead hanger seals
A-11: Rotary sidewall coring	B-9: Drilling Parameter Acquisition while coring	C-6: Electric, optical fiber and fluid feed-throughs
A-12: Provide core orientation on standard coring tools - Structural Orientation of Hard Rock Cores	B-10: Real Time Drilling Parameter Acquisition while coring	C-9: Physical coupling of acoustic instruments to formations and decoupling from noise sources
A-13: Seabed coring devices	B-14: Electric/Optical Wireline	C-14: Systems reliability for LTMS
A-16: Pressure coring systems (PTCS, PCS, FPC, HRC, etc.)	B-19: Protocol for Proper Mud Design	C-15: ROV-serviceable wellheads and submarine cable connections
A-17: Pressurized Sample Transfer (autoclave)	B-21: 4000 m class riser system	C-17: Design standards for electrical, communications, mechanical, and fluid systems
A-21: Anti-contamination system (gel core barrel)	B-22: 4000 m class BOP	C-18: Deployment procedures/soft-landing for borehole infrastructure and instruments
A-23: Fluid samplers, temperature, and pressure measurement tools	B-27: Drill pipe for ultra deep ocean drilling	C-19: Managing borehole experiments
A-24: Transition corers		

3.4 Engineering Development Proposal Process

EDP has put a great deal of effort into developing a process to nurture, evaluate, and advance technology developments within IODP. We summarize several of the significant processes we have adopted.

3.4.A Five Stage Development Process

Any proposed technology development should follow a 5-stage process that includes the following stages: Concept, Design, Fabrication, and Testing Implementation. Every project should pass through each of these stages. Many projects many enter the Concept phase, but only a few may make the Fabrication phase.

EDP recommends that a review be performed at the end of each of the 5 stages. EDP is not the reviewer, but would like to see a summary of the review. EDP would give advice at the Concept stage, and by exception give advice later in project life.

3.4.B Open Proposal Process

Three avenues for submission of EDP proposals to allow effective implementation of the ED goals of the IODP include:

- IO's may submit proposals to IODP-MI based on internal needs assessment.
- Interested parties submit proposals to IODP-MI in response to RFP´s issued by IODP-MI.
- Third Parties submit unsolicited proposals to IODP-MI.

Proposals submitted to IODP-MI must satisfy the requirements of Stage 1 (Concept). Proposals will be identified as addressing one or more of the remaining 4 stages of engineering development: Design, Fabrication, Testing, and Implementation.

3.4.C EDP Review

EDP will review proposals after the Concept Phase. EDP will evaluate the proposal relative to the EDP Technology Roadmap or relative to achieving the goals of the ISP if the proposed development is not yet addressed in the Roadmap. The evaluation will assess how well the proposal meets established ED needs and provide a recommended course of action to SPC. In the event an ED Proposal does not address an established need, it will be evaluated with regards to its benefit to overall IODP-MI needs.

EDP has developed a five-star ranking system that is related to the factors above:

5 stars: Extraordinary Proposal. ED impacts multiple aspects of the ISP and/or Tech Roadmap. Exceptional cost/benefit ratio: very high probability of success.

4 stars: Very Good Proposal. Impacts the ISP and/or Tech Roadmap: good cost/benefit, high probability of success

3 stars: Good Proposal. Impacts the ISP and/or Tech Roadmap: acceptable cost/benefit, acceptable probability of success.

2 stars: Proposal Could be Strengthened. Can impact ISP: contains deficiencies in organization, and/or poor cost/benefit, and/or poor probability of success.

1 star: Not Acceptable Proposal. It does not impact the ISP or contains deficiencies in organization, and/or poor cost/benefit, and/or poor probability of success.

4 Achievements

4.1 Role of roadmap in IODP ED process

The TR is the central document in the ED process.

Resolution of the simpler technical problems has progressed in the past through an *ad-hoc* process, with focus on specific applications rather than the overall technological development. A more comprehensive and systematic effort will resolve 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. The EDP TR is the first effort to improve procedure.

The TR coupled with IODP-MI's proposal composed the Engineering Development Proposal Process [ref]. This provides a mechanism for receiving, reviewing and potentially executing ED proposals from the IOs and 3rd parties. The main source of funding is SOC money but the process has also helped supporting the POC and 3rd party development.

Scoping studies help identify the big investment that need to be done to achieve overarching issues. Two scoping studies have been initiated (core quality and ultradeep water and -drilling).

4.2 Implementation status of scoping objectives.

This table documents the achievements made on the highlighted unranked needs defined by EDP in 2007 [Table 6], on SOC and non-SOC projects.

Group A: Sampling/Logging/Coring	
A-1: Thin-Walled Geotechnical Sampler	
A-2: Cone Penetrometer /Remote Vane	Commercially available (major geotechnical logging companies)
A-4: Hard rock re-entry system (HRRS)	
A-11: Rotary sidewall coring	Commercially available (major logging companies)
A-12: Provide core orientation on standard coring tools - Structural Orientation of Hard Rock Cores	Directional measurement tools are being tested by CDEX DSS development by USIO will resume in 2011.
A-13: Seabed coring devices	IODP-MI received proposal – Williamson proposal
A-16: Pressure coring systems (PTCS, PCS, FPC, HRC, etc.)	
A-17: Pressurized Sample Transfer (autoclave)	
A-21: Anti-contamination system (gel core barrel)	Fundamental test on gel performance done by CDEX
A-23: Fluid samplers, temperature, and pressure measurement tools	MDHDS (Motion Decoupled Hydraulic Delivery System) for in-situ temperature and pressure devices soon to be tested.
A-24: Transition corers	

Group B: Drilling/Vessel Infrastructure	
B-3: Heave Compensation	
B-5: Seabed Frame	IODP-MI received proposal – Fugro seabed frame
B-8: Improved Automatic Driller	
B-9: Drilling Parameter Acquisition while coring	USIO is working to finalize the Drilling Sensor Sub development. Directional measurements tool are being tested by CDEX
B-10: Real Time Drilling Parameter Acquisition while coring	IODP-MI received proposal. Directional measurements tool are being tested by CDEX
B-14: Electric/Optical Wireline	
B-19: Protocol for Proper Mud Design	
B-21: 4000 m class riser system	- Riser fairings built by CDEX - Riser motion analysis ongoing by CDEX - IODP-MI received proposal for CFRP (Carbon Fiber Reinforced Plastic) feasibility
B-22: 4000 m class BOP	
B-27: Drill pipe for ultra deep ocean drilling	CDEX acquiring S160 12km long drill pipe

Group C: Borehole Infrastructure	
C-1: High temperature electronics, sensors, and sensor systems	Telemetry system development currently done by CDEX High Temperature sensors are developed by commercial logging companies.
C-4: Hydrologic Isolation	To be implemented in next LTBMS (Long-Term Borehole Monitoring System) by CDEX
C-5: Reliable wellhead hanger seals	
C-6: Electric, optical fiber and fluid feed-throughs	
C-9: Physical coupling of acoustic instruments to formations and decoupling from noise sources	
C-14: Systems reliability for LTMS	Telemetry system development currently done by CDEX Endurance test done on electronics of LTBMS by CDEX
C-15: ROV-serviceable wellheads and submarine cable connections	Telemetry system development currently done by CDEX "To be implemented in next LTBMS (Long-Term Borehole Monitoring System) by CDEX"
C-17: Design standards for electrical, communications, mechanical, and fluid systems	
C-18: Deployment procedures/soft-landing for borehole infrastructure and instruments	Iodp-mi received proposals (scimpi/common deployment system) – common deployment system To be implemented in next LTBMS (Long-Term Borehole Monitoring System) by CDEX (details?)
C-19: Managing borehole experiments	

Out of the 31 items highlighted by the roadmap, 16 were tackled by IODP-MI, IOs and 3rd parties. Four were partly solved.

5 Next phase of scientific ocean drilling

IODP will end on 30 September 2013, and planning for the next phase of scientific ocean drilling has started. In September 2009, the scientific/technological community gathered at the IODP New Ventures in Exploring Scientific Targets (INVEST) meeting in Bremen (Germany) to provide input for the new science plan. The contribution by EDP is included in Appendix E. EDP members have also identified the following enabling technologies[1] based on the white papers submitted by other groups of scientists at the meeting[2]:

- Ultra-deepwater, deep penetration technologies [B-21,B-22,(B-25, B-26), B-B-27, B-29, C-2]
- Top drive drilling system (TDS) for HT drilling [B-(26), B-28]
- HP/HT logging/coring tools [C-1]
- Borehole control technologies [B-19, B-29, B-33, C-8]
- Turbine-driven core barrel
- Oriented coring tool [A-12a,A-12b]
- Further advances in slim hole logging tools

(The alpha-numeric codes shown in the bracket after each item indicates corresponding ED challenges.)

Members of the EDP believe that many goals in the new science plan can only be achieved with new technologies, and that consultation with engineering professionals is critical. A strategy for continuing communication among scientists, engineers, and drilling operators to achieve a common understanding of ocean drilling technologies and their limitations is required. In order to achieve some of the critical scientific break-throughs that require advances in engineering and technology, a long-term commitment by the program for sustained funding and management of engineering development projects is required. This can be enhanced by establishing external partnerships with science programs such as the International Continental Drilling Program (ICDP), other governmental agencies (e.g. European Commission, the US Department of Energy, and the Japanese Ministry of Economy, Trade and Industry), and industry(e.g. hydrocarbon-, mining, - geothermal, -geotechnical, and nuclear water disposal industry)..

6 References

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[1] The order of the items in the list is arbitrary.

[2] IODP INVEST Report, 2010

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8 Appendix

8.1 Appendix A – Summary of Group A Engineering Developments

8.2 Appendix B – Summary of Group B Engineering Developments

8.3 Appendix C – Summary of Group C Engineering Developments

8.4 Appendix D – Hierarchal Dependency of Engineering Developments

8.5 Appendix E – EDP contribution to the INVEST meeting in Bremen (2009)

<u>Engineering Developments A: Sampling, Logging, and Coring</u>

1.1 Challenges

ED A-1: Thin-walled Geotechnical Sampler

Develop a short length (~ 1 to 2m) geotechnical-type sampler utilizing thin-walled stainless steel tubing (0.083" or 0.092"). There is considerable deformation in long stroke, thick kerf cut cores as seen with the current version of the APC. Interpretation of pre-consolidation stress, determination of permeability, and analysis of sediment properties is dependent on obtaining high quality undeformed core. If a piston type sampler is used it should isolate the piston upon withdrawal of the tool to eliminate any suck-in from the formation upon withdrawing from the formation.

The standard tool used on the *JOIDES Resolution (JR)* and the *Chikyu* is the Advanced Piston Corer. This device penetrates 9.5 meters and is composed of thick-walled material incorporating a blunt nosed cutting shoe. The net result is that the core that is taken is highly deformed.

Current thin-walled samplers tools exist in industry and could be implemented on IODP vessels if a seabed frame were available. Modifications to a hybrid type nose cone on the APC have lead to less disturbance but it is difficult to get the CT's to run them since more care must be used to not damage the sharp cutting edge on the extended nose section

ED A-2: Cone Penetrometer/remote Vane

Develop the ability to deploy a piezocone penetrometer (PCPT) or remote vane (RV) through the drill string. If adopted, this current hardware would need to be deployed with a seabed frame (SBF), which will isolate drill string movement. These industry standard tools offer in-situ measurements of shear strength as well as a means to accurately define micro strata in sediment sequences. Sediment density, pore pressure and material type can also be interpreted/measured from PCPT data. Current tools exist in industry and could be implemented on IODP vessels if a seabed frame were available and a means to activate a clamping system to transfer the weight of the SBF onto the drill string to compensative against.

A new umbilical-less deep-water CPT (>2000ft water depth) has been developed and is undergoing testing that does not require a seabed frame. It is called the Stinger –CPT and is deployed inside a Jumbo Piston Corer. It can be configured in a number of lengths and collects both dynamic CPT data through the column of soil that it is inserted as well as static CPT data beneath the length of the reaction sleeve. A similar tool is being developed to be used within a drill string but would still require a seabed reaction frame to decouple the vessels motion.

ED A-3: Upgrade to RCB System

Review status of hard-rock coring technology using Rotary Core Barrel (RCB). The RCB has been the work horse of the ODP. New strategies might include moving the landing shoulder in the RCB away from the bit so as to decouple vibration from the bit into the inner core barrel (a CDEX improvement), improved bit hydraulics, incorporation of a core anti-jam device, and improvements in cutting structure of the bit design.

An alternative, new coring system should also be studied which might offer advantages in certain formation types. This system might utilize an internal triple tube coring system run in tandem with the larger outer bit so that the existing long core guides on the RCB are eliminated and the inner tube is placed closer to the incoming core. This core barrel might resemble a type of coring system that is used within DOSECC named the Alien.

ED A-4: Hard Rock Re-entry System (HRRS)

Improve the HRRS. The HRRS is a combination re-entry/drilling system that allows a borehole to be started and cased on a sloping hard rock seafloor with limited or no initial rotation of the drill string until the hole can be started. Successful deployment results in a cased hole and re-entry funnel at the seafloor so that the hole can be re-entered for coring to be initiated. The system utilizes a downhole fluid hammer which uses high pressure fluid to drive the hammer. While the re-entry/casing systems appear to be proven technology, additional work is need on bit design and hammer components to increase durability.

The current design of the HRRS installs a single string of 16" casing to shallow sub seafloor depths (<30 m). This depth limitation is likely insufficient to isolate the unstable upper crust of morphologically young basalt flows, thus limiting the ability to attack scientific objectives focused on zero age crust. The penetration limitation is partly due to frictional drag along the casing as it follows behind the hammer bit. An improved theoretical design of the hammer-in-casing system uses dual hammers: one hammer at the bit creates the hole and is coupled to a second hammer at the top of the casing, which overcomes the frictional drag and drives the casing assembly into the bedrock. This development is still completely theoretical at this time. The two bit styles that have been developed with a ring style offer the most promising option.

ED A-5: Coring Guidelines/Operations Manuals

Develop coring guidelines. In order to promote an understanding of the dynamics of the coring operations, a series of guidelines/manuals needs to be prepared. This would document each type of tool and the intricacies they require in their operations as well as the cost associated with their deployment. Operating parameters, ancillary equipment requirements, and typical dimensions should also be provided so that there is a clearer understanding of what is needed to run these tools. Guidelines would be a resource for operators to use in training for drilling programs or new techniques.

ED A-6: Diamond Coring System (Piggyback coring system)

A piggyback diamond system has been routinely used in the offshore geotechnical industry to simulate onshore diamond coring techniques. This system uses thin kerf high-speed diamond bit technology. It is limited to water depths less than 1,500 m with current mining strings on geotechnical vessels. This concept uses a secondary coring rig located in the rooster box above the top drive. A smaller slim hole coring string is then lowered through the API string. The API string is basically serving as a riser to support the coring string. The API string is held in tension by attaching it to a seabed frame.

There may be other ways to provide this technology without the development of a piggyback coring system for the *JR*. Development of such hardware is considered a long-range objective and not technology to be presently pursued before the end of Phase I in 2013. Existing hardware is currently being used in the geotechnical community [Note A-1]. It should be noted that the petroleum industry is backing away from this kind of operation due to safety issues.

ED A-7: Large diameter Diamond Coring Systems (ADCB)

During ODP Leg 193, the ADCB was the coring tool of choice in intensely fractured, young lava flows. Whole round intervals, with insufficient integrity to hold together after removal from the core liner, were recovered intact using the ADCB. This tool is similar to PQ core barrels used exclusively on many onshore applications. Based on thin-kerf diamond technology, drilling with this system requires minimal weight-on-bit (WOB) variation, and is therefore highly dependent on adequate heave compensation. Capturing shallow subsurface cores that reveal the tectonic history recorded in the uppermost section of exposed oceanic basement is likely to be one of the important contributions of this type of tool to the goals of the ISP. Further engineering developments might include operating this tool with a seabed frame for initial stabilization when spudding and/or with the HRRS to bring this system to maturity for potential applications in hydrothermal systems and zero-age crust. However, before this toll or any other IODP coring toll makes dramatic improvements in core recovery, heave compensation and weight on bit variations need to be improved.

ED A-8: Retractable Bit Technology

Develop a retractable bit technology. This technology allows the cutting structure of the bit to be removed via a wireline or wireline tool. This device can save time by preventing the need to trip the string and save money by removing hardware expenses associated with re-entry schemes and mechanical bit release. By inspecting the bit each time the inner core barrel is pulled or when the performance is lacking, different cutting structures or completely new bits can be replaced to optimize drilling advancement or core recovery. While current bit longevity has improved, there still might be a

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[Note A-1] **Heave Compensation**

Poor heave compensation limits core recovery and lowers core quality. A robust, durable, drill string heave compensation system is critical for improved core recovery and quality of samples for the IODP. This technology was successfully used on Expedition 310 with piggyback coring. The improved core recovery and core quality that was achieved during Expedition 310 should provide an impetus to advance this technology across IODP platforms. It should be noted that the size of the passive heave compensator used on Expedition 310 with a Seacore rig was ~ 10 x smaller than that of the JR.

Improvements have already been made in the hydrocarbon industry with the use of heave-compensated drilling systems. However, industry is going away from Piggy Back coring due to the safety issues associated with placing men and equipment in the rooster box.

requirement in the not so distant future where development of this concept might be very beneficial especially in deepwater or deep borehole applications. Development of such hardware is considered a long-range objective and not technology to be presently pursued within Phase I of the IODP.

Retractable bit technology was pursued at ODP for several years while the Diamond Coring System (DCS) was being developed as a piggyback coring system. Several versions were developed and tested. These include diamond bits from Russia, Australia and the USA as well as retractable tri-cone type bits based on the Russian technology that was developed during the ultra-deep Kola drilling project. Development of such hardware is considered a long-range objective and is not presently being pursued.

ED A-9: Vibracore/Percussion Sampler

This technology was originally developed for shallow water granular sediment coring projects where lithologies are friable or weakly consolidated non-cohesive materials (i.e., sands). A vibrating mechanism, operating under hydraulic, pneumatic, mechanical or electrical power, drives a coring tube into the sediment via gravity enhanced by vibration. Vibracoring has proven effective in coring unconsolidated, heterogeneous sized or shaped sediment particles; however, it is not effective in coring clays, packed sand, cemented or indurated materials.

Adaptation of the new fluid hammers coupled with an APC type of deployment may offer new opportunities in recovering granular sediments without the need to rotate and/or pump fluids for advancement. "Off the shelf" industry hammers and tools (FPC) should be investigated to see which might offer the best solution and whether different frequencies might allow the tool to be tunable via fluid flow and pressure to optimize performance [Note A-2].

Sonic coring is a subset of vibracoring technology that uses ultrasonic vibration. This technology has been shown to enhance penetration rates in shallow environments. A sonic drill rig uses an oscillator or head with eccentric weights driven by hydraulic motors to generate high sinusoidal force in a rotating pipe drill. The frequency of vibration (generally between 50 and 120 cycles per second) of the drill bit or core barrel can be varied to allow optimum penetration. Issues that must also be resolved include creating a drill pipe design that will withstand the dynamic stresses caused by the high frequency vibrations in open water applications.

ED A-10: Motor Driven Core Barrel (MDCB)

The MDCB was initially developed to be compatible with the APC/XCB BHA in order to allow a single hard rock or basement core to be taken at the conclusion of sediment sampling or at the interface between two such materials. This technology used a

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[Note A-2] **History of the VPC**

A vibro-percussion corer (VPC) was developed in the early 1990's. The tool had limited testing and consequently was never developed to an operational state. The tool uses a similar technology as the fluid hammer in the HRRS. Since initial development, great strides have been made in down hole fluid hammer performance and longevity as demonstrated by the Fugro Percussion Corer.

wireline retrievable mud motor and thruster system to advance a high-speed diamond bit/core barrel into the formation without rotating the main drill string. There were three main drawbacks to this system [Notes A-3, A-4].

Developments in the mid to late 1990's saw extension rods made to allow several cores to be cut before the hole had to be reamed with the larger main bit. Improvements in the thruster also provide more reliability to the tool. Issues with getting the bit back to the bottom of the hole on the next deployment and continuing problems with reaming the core hole still persisted [Note A-4].

With the introduction of a seabed frame (see B-5) to isolate all drill string motion and an outer bit (possibly coupled with a center bit combination) capable of reaming out the core hole, the MDCB should be re-examined as another means to obtain shallow surface core before casing is set or for deeper penetrations where high speed diamond technology has proven to be superior to roller cone technology in collecting core. Operation of such a system in corals might also provide high and superior core recovery than other systems currently available at IODP. Corals may not provide the resistance needed for reaming out the hole with existing roller cone bits. The possibility of interfacing with a powered sand line also offers some advantages in monitoring the status of the operation.

ED A-11: Rotary Sidewall Coring

Develop the ability to take rotary sidewall cores. This sampling will be done after primary drilling and logging operations are completed. The ability to take rock/sediment samples that are precisely located from logging after primary drilling will allow sampling of missed or absent cores. If larger drill pipe is available (i.e., 6 5/8") then existing industry tools can be used. If only existing 5.5" pipe is available then a rotary side wall corer would have to be specifically developed and may not be cost effective at this time. It is likely that rotary sidewall technology for 5.5" pipe will not be developed in the near

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[Note A-3] **Drawbacks to the MDCB**

The first issue is that the borehole has to be reamed after the MDCB core is cut if more than one MDCB core is required. The second issue is that the bit normally associated with the APC/XCB is larger in diameter and is usually not as robust as that of the RCB. Thus, very limited advancement can be made in reaming out the diamond-cored hole with the larger bit before it becomes incapable of advancement. The third issue is that configuring the thruster to produce the proper thrust/WOB is tricky. This, coupled with poor heave compensation of the main drill string often results in core jams and lack of recovery. Due to the nature of the mining-style diamond core barrel core catchers, any small vertical upward movement imposed on the system when the diamond core barrel is operated usually results in a core jam or stall-out of the mud motor.

[Note A-4] **MDCB Operation**

While offering much promise for the future, the current MDCB has been infrequently used. Although it uses a similar BHA as the APC and XCB, additional subs are required in the string and must be planned for in advance of starting the borehole. Because the MDCB coring assembly advances by a thruster, the outer BHA is stationary. Thus, the driller cannot monitor the weight on bit (WOB) of the MDCB cutting shoe. This WOB must be pre-selected before the tool is deployed by a means of opening and closing valves in the thruster tool body. MDCB WOB is controlled by pump pressure, but because the flow is relatively low, auxiliary pressure readouts are needed on the surface to better indicate the variations in pump pressure so that the driller knows when the motor has stalled out and/or when the end of stroke is reached. Solution to this problem may include instrumentation that can track the stroke of the MDCB and transmit it up hole if other solutions such as better string isolation are not successful.

future (i.e., before the end of the IODP) unless funding can be obtained and it is unclear whether large diameter pipe will be available on IODP platforms in the future. (See B-1). Additional crew is required to operate the hardware if large diameter pipe is obtained. This reduce the bed space available for scientific staff.

ED A-12: Provide Core Orientation on Standard Coring Tools

Develop a long-term ED pathway to enable core orientation.

a. Sediment core orientation: Current tensor tools (sediment core orientation apparatus) are no longer supported by the manufacturer. These have performed reliably for the last decade; however, maintenance and repair are problematic. Investigations into potential developments, performance enhancements, and internal support of the entire system are required. There are other systems available for diamond coring systems used in the mining industry which should be investigated to see whether they can be made compatible with existing tools.

b. Structural orientation of hard rock cores: The various components of a hard rock core orientation system (scribe, sonar target, sonic monitor, transducer, and rig instrumentation) are all necessary components of an overall system. Equipment used in the mining industry should be investigated to see if these units might be integrated before initiating independent development.

ED A-13: Seabed Coring Devices

Explore the application of seabed coring devices to capture the uppermost 100 to 200 m of the seafloor. Several shallow seabed-coring devices have been developed, utilizing high-speed diamond coring techniques employed by the mining/mineral exploration field. Developments in the mid- to late-1990's saw the advent of several new seabed corers with extended reach capabilities that are capable of obtaining deeper cores with the addition of rods behind the core barrel.

Continued development of these types of tools into the 2000's has seen these devices become a routine tool for geotechnical operations for collecting not only hard rock cores but CPT data and piston samples as well. Newer seafloor corers have wireline retrieval capabilities and reverse circulation modes for capturing 100 percent of the material drilled and capable of operating in water depth s to 4000 m.

It is envisioned that if used in tandem with other IODP tools (HRRS/ADCB/ MDCB/RCB), but on separate expeditions to collect core from 100 to 200 mbsf, then IODP might not have to focus engineering development efforts on attempts to collect shallow core and more precise heave compensation for the shallower depths. Instead, the IODP could concentrate on using more robust tools inside boreholes established by the HRRS or to start coring below 100 to 200 mbsf. It is envisioned that this technology would not be developed or acquired, but existing systems would be used to complement existing IODP capabilities through MSP's. Another possibility would be to deploy such corers with an IODP drill string so that cores could be recovered via wireline operations versus stored in the carrousel on the corer and only recovered after the boring termination depth is reached. This technology also allows for an IODP drilling site to be selected that would have a higher success rate be drilled and cored by using the seafloor corer to locate stable locations to initiate a deeper borehole from. (See B-30 & B-35)

ED A-14: Jumbo Piston Corer (JPC)

Develop the ability to take long piston cores from IODP drillships. This will provide an effective means to sample the upper 30-50 m of sediment. This concept would limit or eliminate the number of triple APC cores because continuous core could be collected. Deployment could be concurrent with lowering the drill string and would be off axis, from the side of the vessel. A number of other science programs now own and operate this hardware and if coordinated with other operators this might result in IODP being able to focus on deeper cores and techniques than surface sampling. With the modifications presently being made to the *JR* it is doubtful whether there will be sufficient space available to handle and deploy a JPC. Another tool recently developed by industry uses the JPC body to deploy a CPT the same length as the JPC. The CPT is push out beneath the depth of the JPC insertion. (See ED A-2)

ED A-15: Downhole Tools Calibration and Testing Facility

Create a downhole tool calibration facility, primarily on land and secondarily on vessels, as required. Calibration of IODP downhole tools has not been a routine practice owing to the unique engineering requirements for each tool and lack of a commercial venture capable of providing routine calibration of these tools. The implementation of routine verification of tool performance will increase the tool reliability and data quality. A quality control program also needs to be incorporated into overall program. Environmental stress testing should also be a prerequisite for all tools used in IODP either through IODP facilities or other avenues.

ED A-16: Pressure Coring Systems (PTCS, PCS, FPC, HRC, etc.)

Most of the recent industry pressure coring work has been performed with a seabed frame that isolates the drill string motion and enhances the opportunity for these types of samplers to effectively work. The addition of a seabed frame to the IODP may be needed to increase the recovery percentages with both current IODP and third party tools. In addition, placement of the tool with respect to the outer bit, flow paths, cutting shoe design, size, and sealing mechanism, are still some of the items that need to be re-examined with regards to the IODP tools. Further enhancements might include additional temperature and pressure measurements while coring and de-gassing. Some of the new industry supported tools and associated equipment are only pressure rated to 250 bar and hence will need upgrading to achieve all the objectives associated with samples deeper in the sediment column and in deeper water. A considerable amount of work and deployments have been made with industry tools, which has resulted in a better understanding of operating parameters and increased recovery percentages.

ED A-17: Pressurized Sample Transfer

Sub-seafloor microbiological investigations have been enhanced now that it is possible to maintain in situ pressures when transferring cores to laboratory apparatus. A few samples have been recovered at in situ conditions, held at those conditions, and manipulated in the laboratory without significantly altering the pressure. This recent development has allowed experiments to take place investigating the barophilic nature of microorganisms. These third-party transfer systems are currently pressure limited to 250 bar. Consequently, further development is needed to upgrade these systems to operate at higher pressures so that similar objectives can be achieved deeper in the sediment column and at greater water depths. IODP presently does not have such a system to transfer a pressurized core. Industry currently has a working autoclave system.

ED A-18: Common Bottom Hole assembly (BHA)

Current IODP practice uses the rotary core barrel (RCB) BHA for recovering core samples in medium to hard formations and the APC/(XCB) BHA for soft to medium formations. The APC/XCB BHA can also be configured to run the motor-driven core barrel (MDCB) for use in hard, fractured rock, although it is seldom used and is typically limited to only a few cores due to the inability of drilling the APC/XCB roller cone bit into harder formations. The four coring systems each have different core sizes (APC = 66 mm, XCB = 60 mm, MDCB = 57 mm, RCB = 59 mm) despite all three except the MDCB using the same size core liner.

Operational time required to round trip pipe when formations become too hard for APC/XCB coring can take as long as a day in deep water. A common BHA will save operational time as well as long-term costs and reduce inventory. The practicality of combining all coring systems into one BHA makes sense but may be rather difficult to physically achieve and would require a redesign of all tools. This would be a major undertaking and likely to require several years work and testing before the new system could be released for routine work.

The downside to this plan lies in the fact that one bit design is not suitable for all formation types. Possibly a better approach may be to investigate whether some additional transitional coring tools such as those developed by DOSECC, which already are designed around the same size liner might be applicable in the existing APC/XCB BHA. These transitional core barrels may offer better core recovery between APC/XCB intervals and XCB/RCB cores. Another possibility might be to investigate retractable bit technology versus redesign of all existing coring tools to be compatible with the same BHA. Based on current engineering development and the limited funds and staff, any major redesign to accommodate a single BHA most likely should be viewed as a long range project and would not be attempted within the remainder of Phase I of the IODP.

ED A-19: New RCB Bits

RCB bits have been improved over the years. A number of different designs are available depending upon the formation and abrasiveness of the material being cored. It is doubtful that any redesign would result in a rate of penetration (ROP) improvement. Another issue that IODP faces is that very few suppliers are interested in building a specialty bit with only small orders being placed. Presently IODP has only one roller cone bit supplier. For intermediate or softer formations materials a bit with an increased number of smaller cones should be investigated. This bit design would reduce the height of the core guides. This improvement may increase core recovery in the transition between XCB and RCB.

ED A-20: Upgrades to XCB System

The XCB coring assembly operates very well in most cases, but improvements are needed. When coring through hard, dry clay, the face discharge waterways tend to plug, preventing circulation on the cutting face. The plugged waterways result in overheating which in turn destroys the cutting structure of these bits. This problem might be reduced by redesigning the coring shoe and providing automatic valves to maintain face discharge velocity, and/or powering the XCB shoe with a positive displacement motor independent of the XCB bit. At the very least, improvements to this system that CDEX has made to their extended core barrel should be investigated. A similar coring system developed by DOSECC should also be reviewed to see if these changes might also be incorporated to enhance the XCB or pursued independently.

ED A-21: Anti-contamination Systems

A system is required to prevent contamination of the core from circulated fluids as the core is advanced up into the inner core barrel. Land-based technologies should be thoroughly researched to determine if there are concepts that can be used for offshore applications.

ED A-22: New In-situ Sensors

Understanding in-situ chemical conditions will require the development of new devices. The possibility of implementation of new technologies such as Ion Sensitive Field Effect Transistor (ISFET), ion specific probes, and pH sensors should be investigated. These sensors while important for research and obtaining a better understanding of in-situ conditions, may be more applicable as long range projects as staff and funds become more difficult for developing new tools. (See C-1 & C-22)

ED A-23: Fluid Samplers, Temperature and Pressure Measurement Tools

High temperature water samplers deployed during ODP had a poor history of performance. These were all third-party tools, rarely deployed, and commonly poorly maintained between deployments. Tools deployed for measuring high borehole/formation temperatures/pressures returned useful data, but owing to design were not rugged and provided little real time feed back so that the driller could not determine if the tool was properly deployed, which in some instances leading to eventual tool failure or damage. Industry has developed hostile environment (max 200 °C) temperature/pressure measurement and water sampling tools, but most have a minimum diameter too large to fit through the current IODP drill string. Thus, a new a slim line equivalent, with elevated temperature (~350 °C) is required for sampling fluids at high temperature environments, unless large diameter pipe (6 5/8”) can be used on IODP platforms.

ED A-24: Transition Corers/XCB

Additional corers should be investigated to enhance the core recovery through formation transition zones where recovery has been poor. These new samplers should be compatible with the existing APC/XCB BHA. Tools envisioned include an extended non-rotating sampler for sediments between where the APC and XCB produce good results and a triple tube diamond core barrel similar to DOSECC's Alien corer that would be deployed between the XCB and RCB initiation. Both of these tools already exist and use the existing IODP liner. Either of the tools allows the inner coring portion to be fet flush with the main bit or extended out in front of the main bit to prevent disturbance to the incoming core. These new transition corers might eventually phase out the XCB.

1.2 Requirements, Science Goal, ISP Technology Challenges and Availability

ED Cat	ED #	Engineering Development	Requirements	Science Goal	ISP Technology Challenges	Availability
		Description of develoment	**What needs to be accomplished?**	**How does it fit with ISP?** Refer to Table 1	Refer to Table 2	Existing Technology (E), Modification (M), Innovation (I)
A	1	Thin Walled Geotechnical Sampler	Acquire minimally disturbed geotechnical cores	all	3	ME
A	2	Cone Penetrometer/Remote Vane	Better characterization of in-situ strength and material properties	all	8,1	ME
A	3	Upgrade to RCB system	Better core recovery through modifications to RCB	all	3,10	M
A	4	Hard rock re-entry system (HRRS)	Hard rock spudding - review bit and hammer performance	all	11,10,2	M
A	5	Coring guidelines/operations manuals	Reliable description and operation manuals of tools	all		M
A	6	Diamond Coring System (Piggyback Coring System)	Improved core quality and core percentage recovery through PBCS	all	3,10,2	MI
A	7	Large Diameter Diamond Coring Systems (ADCB)	Improved core quality and core percentage for specific formations through bit design and lighter WOB control	all	3,10,2	M
A	8	Retractable Bit Technology	Improve coring efficiency and ROP in hardrock and unstabe formations	all	3,2	I
A	9	Vibracore/Percussion Sampler	Improve percentage of core recovery in unconsolidate sand/silt formations	all	3,2	M
A	10	Motor Driven Core Barrel (MDCB)	Develop hardware to operate in a broader range of application for mediyn to hard rock/coral coring formations	all	3,10,2	M
A	11	Rotary sidewall coring	Review industry hardware to determine if it can be used in larger diameter drillpipe or whether hardware should be developed for existing IODP ID drill pipe	all	3,10	EI
A	12a	Provide core orientation on standard coring tools - Sediment Core Orientation	Core orientation	all	8	I
A	12b	Provide core orientation on standard coring tools - Structural Orientation of Hard Rock	Core orientation	all	8	I
A	13	Seabed coring devices	Shallow sampling (unconsolidate sands/ corals) or high quality hard rock cores <100 to 150mbsf using existing industry hardware	all	3,10,2	E
A	14	Jumbo Piston corer	Long continuous sediment cores <40mbsf	all	3	E
A	15	Downhole tools calibration and testing facility	Improve reliability of coring and drilling hardware through inhouse QA/QC program	all		M
A	16	Pressure coring systems (PTCS, PCS, FPC, HRC, etc.)	Maintain in situ sample conditions and tool relability (pressure & chemistry)	all	3,8,9,6	M
A	17	Pressurized Sample Transfer (autoclave)	Maintain in situ sample conditions (pressure & chemistry) to transfer cores into autoclave device	all	8,9,6	MI
A	18	Common Bottom Hole Assembly (BHA)	Operate all coring systems in common BHA	all	3,	I
A	19	New RCB Bits	Improve recovery in some formations through development of new bit with shorter core guides and different con configurations	all	3,10	M
A	20	Upgrades to XCB system	Improved core quality and core recovery percentage	all	3	M
A	21	Anti-contamination systems	Provide sterile and higher percentage core recovery	all	3	IM
A	22	New In situ sensors	Measure selected chemicals, pH and field effect	all	8	I
A	23	Fluid samplers, temperature, and pressure measurement tools	improve reliability of high temperature fluid sampling, and pressure measuring tools	all	1,8,6,9	M
A	24	Transition corers	Improve core recovery in transition zones between existing coring systems (i.e. add additional coring/sampling tools to better capture formations between APC/XCB and XCB/RCB)	all	3,2,10	EM

Engineering Developments B: Drilling/Vessel Infrastructure

1.1 Challenges

ED B-1: Large Diameter Pipe

Standard and specialty large-diameter logging tools can be conveyed through a conduit pipe with an outside diameter of 6-5/8-inches. The purchase or rental of pipe should be considered. This would enable development and use of coring tools for obtaining large-diameter cores. Justification for acquisition of large-diameter pipe is logging and coring operations, not drilling. (See A-11)

ED B-2: ROV-guided Logging Tools

A feasibility study should be completed to evaluate the possibility of using an ROV to guide logging tools into an open borehole if large diameter is not a cost-effective option for this purpose. This system is often used in industry today and there is need for an investigation as to how this operation is carried out. (See B-15, C-15 & C-18)

ED B-3: Heave Compensation

It should be determined whether procurement of a new or modified Active and/or Active/Passive Heave Compensation system for the *JOIDES Resolution (JR)* and, if appropriate, the *Chikyu*, will significantly improve weight on bit control. Approaches to improve passive heave compensation performance might include modifications to cylinders, pistons, and seals; or whether a new, more modern system might be required. Improved active heave compensation hardware may also be required in terms of increasing the range of operable sea states and improving system reliability.

We emphasize the need for an integrated planning and development approach. Ultimately, an integrated system (including active and/or passive heave, a pressure compensated bumper/thruster sub, and a sea bed frame utilizing a clamping system and/or hydraulic pull-down system) when coupled with high quality rig and drill string instrumentation will enable the full suite of present and future down hole tools to work far more effectively in the full range of materials to be cored and tested. The first step might be to model the heave compensation system with various components (i.e., passive heave system, low friction seals, valve arrangements, APV size & configuration) and then add other items such as a automatic driller feed system, seabed frame with and without a seafloor feed system, thruster sub, etc.) to determine what items and the order they might be added to the physical hardware to achieve the most significant improvements in Weight-on-bit (WOB) control. Computer-simulated drilling software should be investigated/utilized to enhance/configure the BHA design to reduce/eliminate vibrations when coring/drilling in different formations and water depths. As of 7/01/10, both IODP vessel continue to utilize passive heave compensation only. Data needs to be acquired to evaluate this and other alternatives and whether this should be the focus of the next program. (See B-4, B-5 and B-6)

ED B-4: Heave Compensation during Advanced Piston Coring

This will reduce bit motion during APC coring. The current system requires shutting down heave compensation as the hydraulic piston core is charged and fired. During this process, the bit will respond to vertical ship motion, and ascertaining bit depth at the moment the piston fires has an error roughly equivalent to that of the bit travel. The result is poor absolute depth resolution and repeated or missing sediment sequences. A possible introduction of a seafloor frame to clamp onto BHA to isolate the heave may help elevate some of the problem described above. Thus, further efforts should be investigated if this concept alone can solve the problem or whether design changes in the tool itself are required. (See B-3, B-5 and B-6)

ED B-5: Seabed Frame (SBF)

A feasibility study should be initiated to determine the ability to deploy a seabed frame on IODP platforms. A seabed frame is considered part of the drill bit weight on bit control system. The immediate requirement to eliminate bit motion during a specific test could adopt existing technology from the geotechnical community. The second phase and which may be more technological challenge would be to couple the seabed frame with a swivel and hydraulic pull-down system to accurately control weight on bit and feed rate simultaneously from the seafloor.

Seabed frame technology, developed within the marine geotechnical industry over the past ~30 years, has two major capabilities: (a) a seafloor mass that provides stability to the drillstring for improved deployment of tools; and (b) hydraulics at the seafloor that can be used for controlled in-situ testing and some coring applications where mud motor technology is utilized. This capability, possibly supported with a deep-water ROV or acoustically activated clamping system, would expand the non-riser capability to meet scientific objectives [Note B-1]

A further enhancement to free the vessel motion from the bit might be to utilize a seabed frame that incorporates a hydraulic feed and swivel system to control WOB from the seafloor. Development of such hardware utilizing a hydraulic feed is considered a long range objective and not technology to be presently pursued within the time

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[Note B-1] **SBF Technology**

Seabed frame technology, possibly supported with a deep-water ROV or acoustically activated clamping system, would expand the non-riser capability to meet scientific objectives:

(a) Recovery of sand on continental margins and deep-water fan systems;
(b) Recovery of corals in shallow water environments;
(c) 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; and
(d) Deployment of specialty tools for the measurement of in situ stress (e.g., packers).

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 Downhole Tool Workshop participants re-affirmed this need (http://www.usssp-iodp.org/PDFs/DHT_Workshop_Final.pdf). Implementation of such seafloor devices may enhance recovery, allow the MDCB to initialize spudding on hard rock holes, and improve core recovery. Being able to immobilize the drill string may also improve the recovery of certain PCS-type tools.

remaining in Phase I of the IODP. However, including this option in modeling the heave compensation system should be investigated. (See B-3, B-4, and B-6)

ED B-6: Pressure Compensated Bumper/Thruster Sub

A feasibility study should be pursued on the development of a pressure-compensated Bumper/Thruster Sub to remove residual amounts of drill string motion as a means to improve core quality and quantity if passive and/or active heave compensation systems are incapable of producing constant weight on bit control themselves and whether this tool could be used in combination with several other means to regulate WOB control.

Bumper subs were used in the early days of offshore drilling to help keep the bit on the bottom of the hole due to the vertical movement of the pipe from ship motion. A bumper sub is nothing more than a drill collar sized tool that incorporates a sliding sleeve and can transmit axial torque.

Due to the length and consequently the weight of the drill string typically deployed on the *JR*, even with the most advanced heave compensation system, it is doubtful that all vertical movement can be eliminated by a single device whether it is an active or passive heave compensator due to the weight of the hardware involved. Thus, there is a need to investigate whether a mechanical and/or pressure activated sub can be developed to complement whatever primary heave compensation system is selected. This particular type tool might be 3rd or 4th line of defense in acquiring constant weight on bit control [*Note B-2*].

A possible first step in any further development of such tools would be to test the existing tool in a side-by-side comparison while using the ADCB and the bit motion accelerometer tool developed by Lamont. Knowledge learned from such a test program would be invaluable before approaching a vendor to develop a larger version that would be of the same size as the current IODP BHA design. The reduction in the micro WOB fluctuations that can be provided by such a tool may be a giant step for better understanding existing tools as well as improved core recovery. This tool may be considered secondary in the overall scheme of motion compensation but may be a final piece of the puzzle in accomplishing better WOB control.

ED B-7: Rig Instrumentation System (RIS)

The RIS is an important tool to achieve drill string compensation. It is essential for effective drilling operations and in many situations a key component for achieving scientific objectives by providing drilling operations measurements. Rig instrumentation data should be preserved as a part of the scientific data.

[*Note B-2*] **Shock Sub**

A first-generation shock sub was developed for the ADCB in the late 1990's during the ODP. The system was developed to reduce costs by extending bit life, increasing ROP and reducing drill string failures. The tool extends bit life by reducing impact loading on the bit. ROP is increased by reducing BHA vibration allowing optimum rotary speeds to be used. The tool was designed to operate effectively under a combination of WOB, bit pressure drop, mud weight, or borehole depth. While this tool was not designed to specifically maintain a constant WOB, it does provide some damping before the load eventually finds it way to the bit.

The primary technology advancements in a rig instrumentation system will be increased sampling rate, integration of measurement while drilling applications, and integration of operational data into the arsenal of tools used to interpret formation characteristics. Potential improvements include accurate, continuous position recording and measuring tidal influences as they apply to true depth estimates.

ED B-8: Improved Automatic Driller

A recent development in industry is to use data from rig instrumentation systems to automate some of the drilling process. The simplest systems attempt to modulate weight on bit variations and thus improve coring efficiency. This system removes the variability between different human drillers.

ED B-9: Drilling Parameter Acquisition While Coring

Complete the technology development and routinely deploy the down-hole sensor sub (DSS) and remote memory module (RMM). These tools have been or are scheduled for bench testing. DSS is incorporated as part of the BHA and the DSS and RMM both store data and the RMM returns incremental data sets via coring line after each core barrel run. These instruments are designed to record weight on bit, torque on bit, annular pressure, and temperature. Down-hole pressure can be used to estimate whether there is gas or sand flow within the annulus. Knowledge of weight on bit, and torque on bit can be used to modify drilling procedures to optimize coring conditions. (See ED B-10)

ED B-10 Real-time Drilling Parameter Acquisition While Coring

Transmit from down-hole sensor sub (DSS) in real time the drilling dynamics data to the surface like weight on bit, torque on bit, annular pressure and temperature. Most probable technique will be mud-pulsed telemetry to the surface. A subset of the same data acquired by the logging-while-coring system can be continuously transmitted to the rig floor. The real-time knowledge of weight on bit, and torque on bit can be used to modify drilling procedures to further optimize coring conditions.

Mud pulse telemetry is a method widely used in industry to transmit drilling data from the bit to the rig floor. This type of system is commercially available and historically reliable, with data transmission rates on the order of 12 bits per second. The digital data stream from the sensors is compressed and transmitted to the surface via pressure pulses, where each pulse is one bit of a data stream. The pressure wave travels through the pipe and is detected by sensors at the rig floor. The sensor data is decoded and displayed as downhole diagnostic parameters. If displayed in real time, the driller can make active adjustments to drilling parameters and optimize drilling stability, thus potentially improving core recovery and quality. This system is contingent on the successful completion of the DSS. (See ED B-9)

ED B-11: Real-time Logging While Coring (RT-LWC)

Once real-time logging data acquisition systems have been developed and qualified in field tests, the next logical step is to include formation evaluation logging sensor data (i.e., natural gamma-ray radioactivity, resistivity, bulk density) in the data transmission stream to the drill ship.

ED B-12: Radio Frequency ID Chip Implant in Drill Pipe

Current practice for measuring the depth of the bit below rig floor is to physically measure (strap) the length of each joint of pipe and to tally these individual lengths as each joint or stand of pipe is added. This process can be automated via the use of Radio Frequency Identification Devices (RFIDs) embedded in the tool joint of each length of pipe, pre-coded with several types of information including length. As the tool joint passes a sensor on the rig floor, the length is uploaded to an automated accounting system, thus eliminating potential operator error in pipe length determination. Additional data stored on RFID tags can potentially be used to prolong pipe utility through preventative maintenance programs.

ED B-13: Intellipipe

Several engineering developments can be applied to advancements with in-situ formation characterization. These range from direct application or adaptation of off the shelf industry technology, to complete developments for unique operational environments. Intellipipe is a real-time, high-speed data transmission system that allows deployment of multiple sensors at or near the bit to provide drilling and formation parameter measurements (the pipe is essentially wired). In current designs the data transmission system runs inside the pipe and compatibility with coring operations is not well-developed. In addition, current pipe acquisition is on a lease only basis from the sole source vendor, thus cost could be a significant issue.

ED B-14: Electric/optical Wireline

A technology development that could provide enhanced data acquisition functionality while saving operational time is development of a powered fiber-optic augmented coring line (essentially combining the logging and coring lines). While it is not likely this line could be used on a routine basis (owing to excessive wear of an expensive cable), for specific applications power could be delivered to down-hole coring or measurement tools without special rigging. This could also potentially directly communicate with observatories via wet connectors and/or active overshot connectors.

ED B-15: Directional Coring

There are multiple applications of the industry-proven directional drilling technology to scientific ocean coring. Successive hole deviations in deep penetrations can save operational time and provide a three-dimensional perspective to the more routine single-dimensional view developed from a single core. Horizontal drilling may be required to develop an understanding of seafloor hydrothermal systems, and controlled directional drilling is directly applicable to characterizing three-dimensional structure and investigating tectonic problems. This technological development requires application and adaptation of proven industry tools and practices that incorporate continuous coring.

ED B-16: Non-magnetic Drill Collars

Non-magnetic drill collar material is today an accepted partial solution to address the drilling related overprinting phenomenon. Their application however is limited due to their generally weak mechanical properties and investment cost. Suggested developments should include more robust tool joint designs and alternate "low magnetic" materials [Note B-3]. (See ED B-17 & -18)

ED B-17: Non-magnetic Core Barrel

The suggested development is including the replacement of today's normal steel core barrel with either high strength non-magnetic material or composite compound materials [Note B-3]. (See ED B-16 & -18)

ED B-18: Magnetic Shield for Core Barrels

Similar to the effect of dynamic noise cancellation in acoustic, the feasibility of such an active electro-magnetic shield for normal steel core barrel shall be investigated. Such a system would continuously measure the magnitude and duration of a magnetic field from the surrounding steel on each section of the drilled core section and apply a reverse magnetic field to restore the virgin magnetic properties over the entire core length. (See ED B-16 & -17)

ED B-19: Protocol for Proper Mud Design

The *JR* has historically not continuously drilled with mud, but has spotted mud occasionally. The Mission Specific Platform approach generally uses some type of mud at all times. The *Chikyu* will have a full mud program. A protocol should be developed to document the basis for decisions regarding mud deployment. The protocol should take into account cost and drilling efficiency. A well designed and executed mud program is critical to drilling, logging, and coring operations with a riser, so this item is relevant to all of the ISP objectives.

ED B-20: Borehole Cameras and Imaging Devices

a. Borehole camera looking downward. This borehole camera is for looking down the borehole. The justification for looking down the borehole is primarily operational, to aid decisions in drilling and coring.

b. Borehole camera looking at the borehole wall. This borehole camera is for imaging the borehole wall. The justification for imaging the borehole wall is primarily to obtain data about the section being drilled.

[Note B-3] **Magnetic Overprint**

Table. Magnetic permeability and yield strength of some materials

Material	Magnetic permeability	Approximate yield strength (MPa)	Cost/cost of iron
Titanium	1.00005	950 MPa	2500
Monel	1.002	100-150 MPa	4000
Stainless steel	1.008	500-600 MPa	700
Iron	150	300-500 MPa	1
Silicon iron (4% Si)	500	no data	no data

These cameras may be acoustic rather than light devices to overcome the restrictions of a non clear fluid is present in the borehole; however the development does not exclude optical devices.

ED B-21: 4,000-meter Class Riser System

The existing *Chikyu* riser system cannot extend beyond 2,500 m water depths with current technology. A riser system capable of drilling in 4,000 m water depths should be investigated as to whether this system or a riserless type system makes more sense both economically and including the physical limits attributed to the deployment and operation of such a long and cumbersome systems. Several of the ISP objectives will require wells in water depths exceeding 2,500 m. Carbon fiber should be considered as an alternative material to alleviate axial vibration. See B-29)

ED B-22: 4,000-meter Class Blowout Preventers

The current subsea blowout preventers on the *Chikyu* are driven by hydraulic force powered by the surface vessel and subsea nitrogen accumulators. In water depths of 4,000 meters, these accumulators will no longer work well due to changed characteristics of the extremely compressed nitrogen, and the hydraulic pressure supplied from the surface accumulator greatly decreases due to pressure loss through longer hydraulic lines between surface accumulators and blowout preventers. To drill in water depths between 2,500 and 4,000 m, a new blowout preventer based on a different technology will be required to accompany the new riser system described above. Whatever is developed, reliability will need to be an integral part of the design and testing program.

ED B-23: Reduce Current Force on *Chikyu* Riser

While drilling under normal conditions, mean angles at both of upper flex riser joint and lower one have to be maintained within 2 degrees. Stronger current force might cause the larger angles of both flex joints beyond its tolerable range. Also, larger VIV (vortex induced vibration) on the riser under strong current is recently indicated to cause fatigue damage. In order to prevent these problems, it is necessary to reduce the drag coefficient of the riser pipe and the vortex around the pipe. Installing fairings onto a riser has been shown to effectively reduce the current force. Optimal shape and arrangement of fairings needs to be studied as well as the logistics aspects for their deployment including the long-term operation. Adding additional hardware to the outside of a deep ocean riser needs to be included in any study for longer risers as to whether these devised actually reduce the external forces to a level that can be effectively managed. (See B-35)

ED B-24: Improve Dynamic Positioning Systems

In order to increase operability of *Chikyu* and other DP vessels under severe sea and current conditions, more precise and efficient control for position keeping will be required. Based on investigating the present abilities of the *Chikyu*, the control method of DPS, the Riser Angle Control and Power Management Systems should be improved. The justification will come from item 13 in the Technology Plan, and an investigation of expected sea states and currents in anticipated drilling locations is needed.

ED B-27: Drill Pipe for Total Depth Ocean Drilling

Chikyu is currently equipped with drill pipe that is designed to drill 10,000 m below sea level. To drill into the lower ocean crust and upper mantle, a 12,000 m length drill string is required. The practical maximum drilling depth is primarily constrained by the strength-weight ratio of the drill string. In order to reach 12,000 m depth below sea level, it is necessary to develop a high strength and light-weight drill pipe that is not degraded by high temperature and H_2S.

ED B-29: Mud Circulation in Drilling Systems over 2,500-m Water Depth

The limit of water depth for the current riser drilling system is approximately 2,500 m. Parallel to efforts to develop deeper water riser drilling technology and a BOP, it is important to consider alternative drilling systems such as flexible risers and dual-gradient drilling systems that utilize a seafloor pump to return drilling mud to the ship (e.g., riserless mud recovery). Comparison advantages and disadvantages between deeper water riser technology and alternative systems should be initiated. (See ED B-32)

ED B-30: Freestanding, Remotely-Operated Deepwater Shallow Hole Coring System

There is a gap in core recovery for science objectives while coring in deepwater conditions with riser and non riser vessels. In some settings, core recovery is low to nonexistent from the first 50-100 meters below seafloor. Recently new remote drills have been brought onto the market that can recover this type of core and operate in water depths up to 4,000 m. A feasibility study should be made into the existing remote drills to determine what equipment is available as well as the limitations on the current generation of seafloors corers (See A-13 and B-35)

ED B-31: Drill Pipe Conveyed Deep Water, Shallow Hole Coring Tools

Prototypes of coring tools that are designed to recover shallow cores from lithified sediment or basement exposures at the seafloor have proved promising but require engineering development. Mud motor operated systems require new bit designs to improve core recovery and internal component development to reduce maintenance and improve performance. In addition, the driller cannot monitor the weight on bit (WOB) of the MDCB cutting shoe. MDCB WOB is controlled by pump pressure, but because the flow is relatively low, variations in pump pressure do not clearly indicate WOB or even motor stalling. The solution to this problem may require instrumentation that can track the stroke of the MDBC and transmit the information uphole. (See A-10)

In its current design, the ADCB BHA precludes initiating a borehole with this system. Capturing shallow subsurface cores that reveal the tectonic history recorded in the uppermost section of exposed oceanic basement is likely to be one of the greatest contributions of a tool of this theme of the ISP. Further engineering developments in drill collar design and deployment protocols are required to bring this system to maturity for potential applications in hydrothermal systems and zero-age crust (see A-7).

ED B-32: Temperature Tolerant Muds and Drilling Bits

The geothermal drilling industry has developed methods and materials appropriate for drilling hot dry rock and hot geothermal fluids. Collaboration with this industry and development of joint development partnerships would be the most beneficial approaches to identifying the technological solutions to drilling into hot, wet rocks.

In current technology, maximum temperature limits of water-based mud are 240-260 °C. In holes drilled by *Chikyu*, the bottom hole temperature are expected to reach ~300 °C. Development of the drilling mud systems that can be applied to these drilling targets is clearly necessary. Operations in other high temperature environments will also require modified mud systems and drilling bits to achieve depth targets. (See ED B-29)

ED B-33: Protocol for Proper Design to Minimize Borehole Stability Problems

Many drilling problems such as formation collapse and sticking of drilling tools have been caused by borehole stability problems. Boreholes have been abandoned because of these problems. In the case of deep scientific drilling, possible solutions to minimize borehole stability problems should be seriously considered and applied in both the planning stage and during drilling. Factors that contribute to borehole stability problems are inadequate design and operation of drilling mud system, unstable lithologies (soft formations, lithologic changes, fault zones, etc.), and the state-of-stress and thermal stress.

ED B-34: Virtual Shipboard Party

The rapid evolution of electronic communications and networking technologies, currently in vogue in the education community, has potential for great operational benefits from the development and implementation of shore-based real time operations and scientific support. Such support could allow more flexible staffing of seagoing scientists, technicians and engineers. A few examples are (1) the potential need for more technicians and engineers experienced in operational activities, while shore-based scientific communities assist the ship-based scientific party, (2) experienced technologists providing shore-based real time advice, and (3) additional participation of inexperienced junior scientists.

ED B-35: Seafloor Drilling Systems

One of the primary goals of the IODP is the acquisition of quality cores from a diverse range of deep ocean environments. Coring objectives range from very soft sediments to hard crystalline rock. Studies undertaken by IODP-MI suggest that core quality deteriorates with increasing rock hardness. Industrial experience suggests that accurate control of the downhole drilling parameters, including weight on the core head and torsional stability of the drillstring, is the critical determinant of core quality.

In riserless coring operations, the entire drillstring is subject to the effects of ocean currents and vessel heave. These motions make accurate control of coring parameters almost impossible with the result that core recoveries are much worse that would normally be expected in an industrial context. Isolating the downhole conditions from the external environment by regulating feed and torsion through a seabed coring frame offers the prospect of dramatically improved core recovery.

Seabed drills are already being pioneered by the geotechnical community and certain

European scientific activities. This technology should therefore be evaluated for application to the task of deep ocean and 1 to 2 km deep borehole coring operations (see A13 & B30).

1.2 Requirements, Science Goal, ISP Technology Challenges and Availability

ED Cat	ED #	Engineering Development	Requirements	Science Goal	ISP Technology Challenges	Availability
		Description of develoment	What needs to be accomplished?	How does it fit with ISP? Refer to Table 1	Refer to Table 2	Existing Technology (E), Modification (M), Innovation (I)
B	1	Larger Diameter Pipe	Deploy wide diameter tools logging and sampling	all	1, 7, 8, 9, 11	E
B	2	ROV Guided Logging Tools	Run large diameter tools without large diameter drillpipe	all	1, 7, 8, 10,12	E
B	3	Heave Compensation	Improve Heave Compensation	all	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12	M
B	4	Heave Compensation during Advanced Piston Coring	Improve depth resolution	1a, 1b, 2a, 2b, 2c, 2d, 2e,	3, 4	I
B	5	Seabed Frame	Stabilize Drill String at sea floor	1a, 1b, 2a, 2b, 2c, 2d, 2e, 3f	6, 7, 8, 10, 13,	M
B	6	Pressure Compensated Bumper/Thruster Sub	Improve core quality and quantity	all	2, 3, 4, 9	M
B	7	Rig Instrumentation System	Record/communcate/store rig instrumentation data	all	2, 3, 4, 5, 7, 8, 9, 11, 12,	M
B	8	Improved Automatic Driller	Better Weight On Bit Control	all	3, 4, 9, 11	E
B	9	Drilling Parameter Acquisition while coring	Record pressure, weight on bit	all	2, 3, 4, 7, 8, 9, 10,	M
B	10	Real-Time Drilling Paramater Acquisition while coring	pressure, weight on bit	all	2, 3, 4, 7, 8, 9, 10, 11	M
B	11	Real-time Logging While Coring (RT-LWC)	Monitor at bit driling parameters and formation data	all	2,3, 4, 7, 8, 9, 10, 11	I
B	12	Radio Frequency ID Chip Implant in Drill Pipe	Reliable Depth Measurement	all	1, 4, 7, 8, 11	I
B	13	Intellipipe		1b,3a,3b, 3c,3d,3e,3f	2, 4, 7, 8, 9, 10, 11	E
B	14	Electric/Optical Wireline	Monitor and Control Observatories	1a, 1b, 3a,3b, 3c,3d,3e,3f	1, 2, 4, 5, 7, 8, 10, 11	E
B	15	Directional coring	Enable Directional Drilling while Coring	1b, 3a,3b, 3c,3d,3e,3f	2, 3, 6, 7, 8, 9, 11, 12	M
B	16	Non-magnetic collars	Reduce drilling induced Magnetic overprint	all	3, 4, 11	M
B	17	Non-magnetic core barrel	Reduce drilling induced Magnetic overprint	all	3, 4, 11	M
B	18	Magnetic shield for core barrels / anti-contamination core barrel	Reduce drilling induced Magnetic overprint	all	3, 4, 11	I
B	19	Protocol for Proper Mud Design	Better Hole Cleaning, and hole stability	all	1,2,3,6,7,9,12,	E
B	20a	Borehole camera looking downward	Looking ahead borehole visualization	all	5,8	E
B	20b	Borehole camera looking borehole wall	Borehole wall visualization		5	E
B	21	4000 m class riser system	Deeper water riser targets	3d,3e,3f	12	M
B	22	4000 m class BOP	Deeper water riser targets	3d,3e,3f	12	M
B	23	Reduce current force on Chikyu riser	Increase operatability in currents	all	13	M
B	24	Improve dynamic positioning systems	Incrase operatability in severe sea states	all	13	E
B	25	Improve expandable casing system	Casing in deep penetration, high temperature, high pressure, hostile environments	3d,3e,3f	12	M
B	26	Cementing protocol for deep drilling	Casing in deep penetration, high t emperature, high pressure, hostile environments	1b, 3a,3b, 3c,3d,3e,3f	1, 5, 11, 12	M
B	27	Drill pipe for total depth ocean drilling	Drilling for deep water and deep penetration targets	3a,3b, 3c,3d,3e,3f	1, 11, 12	M
B	28	High temperature, high pressure drilling system	need high temperature and high pressure directional drilling system for deep well drilling in case the temperature and presure capabilities of exitsting technology is not sufficient	all	2,7,10,13	M
B	29	Mud Circulation Drilling System at over 3000m water depth.	Current drilling riser system water depth limit is approx. 3000m due to static + dynamic load caused by heaving..	3a,3b, 3c,3d,3e,3f	1, 11, 12	M
B	30	Freestanding remotely operated deep water shallow hole coring system	Deep water shallow hole coring	1a, 1b, 2a, 2b, 2c, 2d, 2e,	3, 10, 12	M
B	31	Drill pipe conveyed deep water, shallow hole coring tools	Deep water shallow hole coring	1a, 1b, 2a, 2b, 2c, 2d, 2e,	3, 12	M
B	32	Temperature tolerant muds/drilling bits etc.	higher temperature tolerance for longer peiods of time; market survey and state-of-the-art; establish qualification procedures	1b, 3a, 3d, 3e, 3f	1	EMI
B	33	Protocol for proper design to minimize borehole stability problem	need the protocal for proper design to avoid and/or minimize bore hole stability problem by considering not only proper mud/hydraulic design but also lithological conditions and influenced by the stress (field stress and thermal stress)	all	2,7,10,13	I
B	34	The Virtual Shipboard Party	accommodating need for more technical personnel shipboard for operating more complex engineered drilling/coring/sampling systems	all	2, 4, 6, 7, 8, 9, 11	I
B	35	Seafloor Drilling Systems	high quality core from diverse and difficult drilling environments	all	2, 3, 4, 7, 8, 10, 11, 12, 14	EM

Engineering Developments C: Borehole Infrastructure

1.1 Challenges

ED C-1: High Temperature Electronics, Sensors, and Sensor Systems

Deep drilling targets, such as the Nankai Trough, and shallow, high temperature hydrothermal systems at spreading ridges have a critical need for the development of high temperature electronics, sensors, and sensor systems. Issues include not only use of high temperature semiconductor and discrete components (>85°C, industrial grade), but the design and performance of printed-circuit boards, potting and sealing of electronics, longevity of downhole connectors, and the aging of materials in high-temperature and chemically hostile environments. Future drilling targets are above existing temperature-time curves. Identifying appropriate sensors compatible with long-term deployment (5-10 years+) is challenging because each sensor technology has different temperature-time performance and aging characteristics. Basic types of sensors envisioned for borehole observatory use include temperature, pressure, strain, tilt, seismometers, resistivity, and specialized chemical sensors. Longer-term science objectives for drilling deep crustal targets will require even higher temperature tolerance and reliability not presently available commercially or from academic laboratories.

Substantial efforts are underway commercially and in academic labs for creating new types of high temperature-tolerant sensors and signal conditioning electronics for high temperature borehole applications. Collaboration with these groups on specific scientific applications on IODP drilling legs would be the most beneficial approach for obtaining access to these emerging technologies. Joint development partnerships funded specifically for drilling targets would also be a suitable approach. (See A-22)

ED C-2: Improved Cementing Techniques (high temperature and hydrologic isolation)

The installation of long-term borehole monitoring systems and isolation of hydrologic zones in boreholes located in high temperature environments will require improvements to cement composition and emplacement techniques. Understanding the physical properties of cement and its temperature dependence are critical for identifying appropriate compositions that will cure and age in an acceptable manner. Cements with values of Young's Modulus higher than currently available are needed for some of the deeper observatory targets (>3,000 mbsf). Heat released during cement curing can be substantial and will affect sensors embedded in the cement. If water is used to control temperature, micro fractures will develop, changing the physical properties of the cement in potentially unacceptable ways. New techniques and technologies will be required for some sensor deployment scenarios.

Improved casing-to-formation cementing techniques are required to provide hydrologic isolation (hydrology experiments and fluid sampling) and mechanical coupling with formations (strain meters, seismology experiments). Improved cementing techniques may obviate the need for packers in some instances.

Much can be learned from the geothermal industry, and the hydrocarbon industry regarding existing technologies. (See B-26)

ED C-3: Corrosion Tolerance

Long-term deployments and deployments in chemically hostile environments will require use of more exotic materials for pressure cases, sensor probes, etc. Investigation of the effects of strain on metal corrosion is needed for selecting appropriate materials for long-term deployments in active tectonic environments. Existing geothermal/hydrocarbon industry practices and technologies should be explored.

ED C-4: Hydrologic Isolation

Reliable hydraulic isolation of multiple horizons in open and cased boreholes, especially across a décollement, is critical for achieving IODP science goals. The reliability, temperature tolerance, and long-term integrity of existing approaches to borehole sealing (e.g., packers or cement) are inadequate. There is no established method for monitoring the integrity of borehole seals and no protocol for what to do if a seal is lost. Retrievable packers are a science requirement for some proposed drilling legs. Given the high demand for CORK technology in the drilling proposals under consideration or scheduled, an assessment of packer technology is dictated.

ED C-5: Reliable Wellhead Hanger Seals

Although this appears to be an incremental improvement, successful long-term deployment of any borehole experiment (not just CORK deployments) relies on creating and maintaining the integrity of seals between each casing string run into a borehole. At present reliable wellhead seals have not been designed or installed for non-riser boreholes. A Feasibility/Design Study is needed to assess present sealing techniques, and to investigate design improvements. The design improvements may radically change the topside configuration of the borehole hangers, thus this study has the potential to expand beyond its initial focus in order to achieve the desired technological outcome. (See ED C-6, C-15, C-17, C-18)

ED C-6: Electric, Optical Fiber and Fluid Feed-throughs at Wellheads and in Subsurface Casing Completions

The desire to install long-term borehole monitoring systems and to conduct in situ borehole experiments requires that electrical cables, optical fibers, and fluid tubing pass through the wellheads of boreholes. The feed-through strategy must be compatible with existing shipboard deployment procedures and casing hanger geometries. The topside connections at the wellhead must be ROV-compatible and easily accessed for making and breaking connections. One challenge is accommodating the increasing number of desired feed-through connections and their types. For example, the Christmas tree used for riser-drilled boreholes presently is limited to a maximum of 8 feed-throughs, but each feed-through could accommodate multiple conductor bundles. This limitation will constrain the topology of downhole monitoring systems. Feed-through methods need to be developed for all 3 IODP platforms. The need for developing suitable feed-throughs also extends to packer zones; in most cases electrical cables cannot be spliced (for long-term reliability), thus these cables have to be passed through packers in operationally practical ways. (See ED C-5, C-15, C-17, C-18)

ED C-7: Identifying, Tracking, and Minimizing Drilling Contamination

Advances in geochemical and microbiological measurements depend on obtaining pristine samples, uncontaminated by drilling fluids and materials from selected horizons in a borehole. Some tracer methods have already been employed during the ODP (e.g., fluorescent beads in a bag), however there is need for further development of tracer techniques and better means for identifying and minimizing chemical or microbiological contamination. In particular, before starting a long-term hydrologic or microbiological borehole experiment, the presence of chemical or microbiological contamination will have to be determined. Studies of fluid movement within and between boreholes may be enhanced by the development and use of inert tracers. In the case of coupled hydrologic/microbiological pump/chase experiments, novel approaches for tracing fluid movement may be required.

Commercial products, such as the gel coating system or cleaning the well offer potential solutions to minimizing drilling fluid contamination of retrieved samples or the sidewalls. Tracer techniques suitable for identifying and tracking drilling contamination of sediment around the borehole and the return of the borehole to pre-drilling conditions need further development.

ED C-8: Casing Boreholes Through Active Fault Zones

A major drilling target for the *Chikyu* is the Nankai Trough. Drilling through and successfully casing an active thrust fault for long-term monitoring has not been accomplished and is integral to the scientific objectives of this major effort. Lessons from the ICDP SAFOD project indicate both the difficulty of accomplishing this task and guidance for potential solutions. We need good strategies for drilling the hole, clearing cuttings, managing breakouts, casing, and cementing. Success with these operations requires knowing in real-time an accurate state of stress and fluid pressure conditions in the zone spanning active deformation. Adaptation of methods from academic research and industry practice to measure stress and pressure will help to achieve this goal. (See ED B-25)

ED C-9: Physical Coupling of Acoustic Instruments to Formations and Dcoupling from Noise Sources

Further development of techniques for coupling seismic and other geophysical sensor to formations is needed to conduct both active and passive acoustic experiments. The measurement of mechanical noise in boreholes to identify its source, strength, and frequency range is needed to help mitigate its effects on subsequent sensor installations in other boreholes. Techniques are needed for reducing noise, such as isolation of sensors from casing strings and other noise sources (e.g., pumps, borehole convection, and seafloor infrastructure), and for emplacing sensors in the borehole (e.g., mechanical arms, multiple clamping, motors, springs, sand/glass beads, or cementing permanently into place).

ED C-10: Accurate Estimates of Downhole Temperatures

Accurate estimates of downhole temperatures are necessary for designing a borehole observatory, including specifications for downhole instruments, mud selection, and well completion design and cementing. Both the static formation temperature and recovery temperature are desired. Because most IODP drill sites will be located in new areas, methods for using existing drilling data, geophysical and geologic data, and site survey data are needed to predict formation temperatures.

ED C-11: Techniques for Borehole Microbiology Incubation Systems

In some cases, the return of microbiological samples to the surface is not suitable, and in situ incubation may be the best means for properly identifying and describing the community composition and understanding the physiology of these organisms. Some samples (enrichment cultures, stained samples, or archived materials) could be returned to the surface after completion of the incubation experiments. In other cases, recovery of microbiological samples at in situ conditions will be desired. Requires low contamination of borehole and surrounding sediments.

ED C-12: Development of Low Power Sensors – Temperature, Pressure, Electromagnetic, Seismic, and Chemical Measurements

Each type of sensor (temperature, pressure, electromagnetic, seismic, and chemical measurements) needs development that matches science requirements. Low power consumption is an essential technological development for any long-term borehole monitoring system. The development of novel optical-based sensing systems (DTS, or optical-seismic sensors) that do not require downhole electric circuits is one approach to achieving substantial reduction in overall power requirements.

ED C-13: Cross-hole Hydrologic Experiments

Methods need to be developed for conducting cross-hole hydrologic experiments to determine geohydrologic properties (e.g., permeability, storativity), similar to those that are routinely conducted on land by commercial consulting companies. Monitoring techniques, sensors, inert tracers, continuous chemical measurements and sensor deployment strategies in the observation borehole are needed to optimize the outcome of these experiments. The development of borehole pumping systems or means of propagating a pressure disturbance in a borehole is also needed.

ED C-14: Systems Reliability for Long Term Monitoring System (LTMS)

High reliability systems are required for successful deployment and operation of long-term monitoring systems. Manufacturing and test procedures, strategies for redundancy and fault tolerance, maintenance procedures and strategies are critical elements of maintaining high-level systems reliability. Much of these requirements are mature methods in major industries, such as the telecommunications industry (including submarine telecom cabling), and are readily available and can be easily adapted for engineered systems on and below the seafloor.

ED C-15: ROV-serviceable Wellheads and Submarine Cable Connections

With the establishment of long-term monitoring programs for boreholes, periodic maintenance will be required to change batteries, collect samples, download data, change experimental gear, make submarine cable connections, and to repair the monitoring systems. The wellheads initially deployed by the drillships will need to be designed to accommodate ROV servicing. The ROV manipulators will have to reach the interior portion of the wellheads, be able to lift and exchange instrument packages, and to plug and unplug electrical and telemetry cables, and fluid lines at the wellhead. A test borehole facility could be used for training ROV-pilots and testing procedures. This would minimize operational costs and improve efficiency and reliability of actual deployments. There is also a need for standardization of interfaces between wellheads and ROVs. (See ED B-2, B-5, ED C-5, C-6, C-17, C-18)

ED C-16: Efficient Power Systems, Including Distribution

Depending on the sophistication and planned lifetime for long-term monitoring systems in boreholes, efficient power systems, including power supplies, cables, connectors, and control/monitoring systems will be required to support these monitoring systems. Fault tolerance, ground fault sensing, resettable thermal breakers for isolating faulty equipment, development of observatory control systems for power load management and engineering data subsystems are necessary components of an efficient and effective power system.

ED C-17: Design Standards for Electrical, Communications, Mechanical, and Fluid Systems

Uniform standards need to be established for electrical, communications, mechanical, and fluid systems in borehole observatories, in coordination with observatory initiatives in the US, Japan, and Europe. Standards will enable compatibility, integration, and inter-operability between different subsystems developed independently by a variety of investigators on a more cost-effective basis. This will also reduces errors and increase reliability.

An understanding of non-IODP platform capabilities and how to interface these systems with borehole experiments and long-term borehole monitoring systems will be necessary to optimize maintenance and recovery/re-installation of borehole observatory instruments. Thus, these standards cover not only efforts by the three IODP partners, but any 3rd party engineering development or operations. (See ED C-5, C-6, C-15, C-18)

ED C-18: Deployment Procedures for Borehole Infrastructure and Instruments

Placement of instrument strings, CORKs, casing, seismometers, and complex borehole instrument systems into boreholes will require improved precision in depth placement, tolerance for ship heave, and possibly common deployment systems. Reduction in ship heave would be the most beneficial technological development, however, other strategies to dampen or de-couple ship motion could be developed and employed. The use of ROV-like devices can also provide solutions for placement of instrument strings and other devices into boreholes.

ED C-19: Managing Borehole Experiments

Effective management of long-term borehole experiments is essential for continued success of these systems and for the provision of opportunities for multiple investigators to participate in the scientific experiments. Data policies need to be established. Procedures for instrumented systems qualification need to be established and enforced before deployment. One way to qualify instrumented systems is to test them at a borehole test facility (systems integration lab).

ED C-20: Data Systems and Telemetry in Boreholes and on the Seabed

Reliable data systems and telemetry are required for the operation of long-term borehole monitoring systems. These systems need to meet the distance/cable length and power requirements of the experiments. Metadata for the suite of borehole instruments is necessary for proper borehole management and data archiving. The telemetry system will need a system status and reporting system to monitor the engineered parts of the system.

ED C-21: Borehole Instrument Deployment, Re-entry and Servicing Systems

Techniques and infrastructure will be required to allow deployment, recovery, and possible re-installation of borehole instruments (e.g., seismometers or osmosamplers) in order to perform short-duration borehole experiments, maintain long-term borehole observatories (repair and replace) and re-use existing ODP/DSDP boreholes. This may include re-designing wellhead templates and modifying operational procedures shipboard.

Successful long-term borehole observatories will require an integrated deployment plan, methods for replacing sensors and components when required, and a built-in-test (BIT) plan to monitor the status of sensors and system infrastructure over the life cycle of the experiment.

ED C-22: Stress Measurements

Knowledge of the state of stress is important for engineering and scientific purposes, for example borehole stability, and fault/fracture and earthquake dynamics. The state of stress is often non-linear and discontinuous, especially in complex geologic settings such as accretionary prism complexes, and cause hard drilling conditions.

Many stress measuring methods for boreholes exist using geophysical logging, and in situ- and core testing. Methods that routinely are used in petroleum industry include geophysical logging, leak-off tests and laboratory testing. However, most methods only probe parts of the stress tensor, and in situ testing methods are both challenging and time consuming to perform. Therefore, technology and operation developments are needed.

1.2 Requirements, Science Goal, ISP Technology Challenges and Availability

ED Cat	ED #	Engineering Development	Requirements	Science Goal	ISP Technology Challenges	Availability
		Description of develoment	**What needs to be accomplished?**	**How does it fit with ISP?** Refer to Table 1	Refer to Table 2	Existing Technology (E), Modification (M), Innovation (I)
C	1	High temperature electronics, sensors, and sensor systems	higher temperature tolerance for longer peiods of time; low drift; market survey and state-of-the-art; establish qualification procedures	1a, 3a, 3d, 3e, 3f	1	EMI
C	2	Improved cementing techniques (high temperature and hydrologic isolation)	higher temperature tolerance for longer peiods of time; market survey and state-of-the-art; establish qualification procedures	1a, 3a, 3d, 3e, 3f	1	EMI
C	3	Corrosion tolerance	higher temperature tolerance for longer peiods of time; market survey and state-of-the-art; establish qualification procedures	1a, 3a, 3d, 3e, 3f	1	EI
C	4	Hydrologic Isolation	need for higher reliability; means for deploying multiple levels of pakcers; development of alternative systems, packer-like techniques	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	1, 5	EMI
C	5	Realiable wellhead hanger seals	need to develop sealing mechanism for existing borehole hangers used by IODP; redesign hanger sealing system for future borehole completions	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EM
C	6	Electric, optical fiber and fluid feed-throughs at wellheads and in subsurface casing completions	need to develop techniques for accomplishing this for all platforms	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EMI
C	7	Identifying, tracking, and minimizing drilling contamination	further develop contamination tracking techniques and analytical methods; identify and develop techniques for contamination control	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	1,5	EMI
C	8	Casing boreholes through active fault zones	drilling and casing strategies need to be developed for actively deforming lithologies; measure pore pressures and stress field before casing; need local monitoring sensors and telemetry;	1a, 3a, 3d, 3e, 3f	5	MI
C	9	Physical coupling of acoustic instruments to formations and decoupling from noise sources	need to develop techniques for coupling sensors to casing or formation; need noise measurements in borehole to identify sources and strength/frequency band; need to develop techniques for reducing noise	1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EMI
C	10	Accurate estimates of downhole temperatures	Accurate estimates of downhole temperatures are necessary for designing a borehole observatory	1a, 2d, 3a, 3b, 3c, 3d, 3e, 3f	5	EM
C	11	Techniques for borehole microbiology incubation systems	develop more versatile sampling techniques for microbiological samples; (get beyond contamination halo); develop downhole systems for incubation experiments, some could return samples to the surface after completion of incubation; minimize contamination; shipboard culture system comparable to borehole system	1a	5	EMI
C	12	Development of low power sensors - temperature, pressure, electromagnetic, seismic, chemical measurements	this is a broad spectrum of needs; each type of sensor needs development that matches science needs; low power consumption is an essential develop for LTMS; development of optical-based sensing systems that do not require downhole electrical circuits	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EMI
C	13	Cross-hole hydrologic experiments	need methods for conducting cross-hole hydrologic experiments; monitoring techniques and sensors; sensor deployment strategy to optimize data; develop borehole pumping systems or means of propagating a pressure disturbance	1a, 1b, 3a, 3b, 3e, 3f	5	EM
C	14	Systems reliablity for LTMS	high reliability systems are required for successful LTMS; methods, testing procedures; redundancy strategies; maintenance procedures and strategies	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EM
C	15	ROV-serviceable wellheads and submarine cable connections	re-design seafloor templates, re-entry cones, etc for ROV compatibility; provide means for making submarine cable network connections by ROV; need standardization of interfaces	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5, 10	EM
C	16	Efficient power systems, including distribution	need well-designed power systems (batteries and submarine cables) that have fault tolerance, ground fault sensing, resettable thermal breakers; need an observatory control system for power and data subsystem control	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EMI
C	17	Design standards for electrical, communications, mechanical, and fluid systems	standards need to be established so that uniformity, compatibility, and inter-opererability is straightforward and cost effective	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5, 10	E
C	18	Deployment procedures for borehole infrastructure and instruments	need techniques to ensure that borehole instrumentation is not damaged during deployment, can be recovered in specific instances;	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	1, 5, 10	EM

ED Cat	ED #	Engineering Development	Requirements	Science Goal	ISP Technology Challenges	Availability
C	19	Managing borehole experiments	essential for LTMS and cable-connected systems that permit multiple investigators to participate in the sciencific experiments; need to establish data policies; instruement qualification procedures before deployment;	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5, 10	E
C	20	Data systems and telemetry in hole and on the seabed	reliable data systems and telemetry are required for LTMS; need to meet distance/cable length and power requirements of the experiments; include metadata; and system status reporting	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5	EM
C	21	Borehole instrument deployment, re-entry and servicing systems	techniques and infrastructure need to be developed to allow re-entry of boreholes and the removal and re-installation of borehole instruments packages and systems	1a, 1b, 3a, 3b, 3c, 3d, 3e, 3f	5, 10	EMI
C	22	Stress Measurements	Technology and operational methods for in situ measurements of stress states	1a, 3a, 3b,3f	6,8	EMI

IODP Technology Roadmap Hierarchy and Dependencies – rough draft 10-07-09

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).

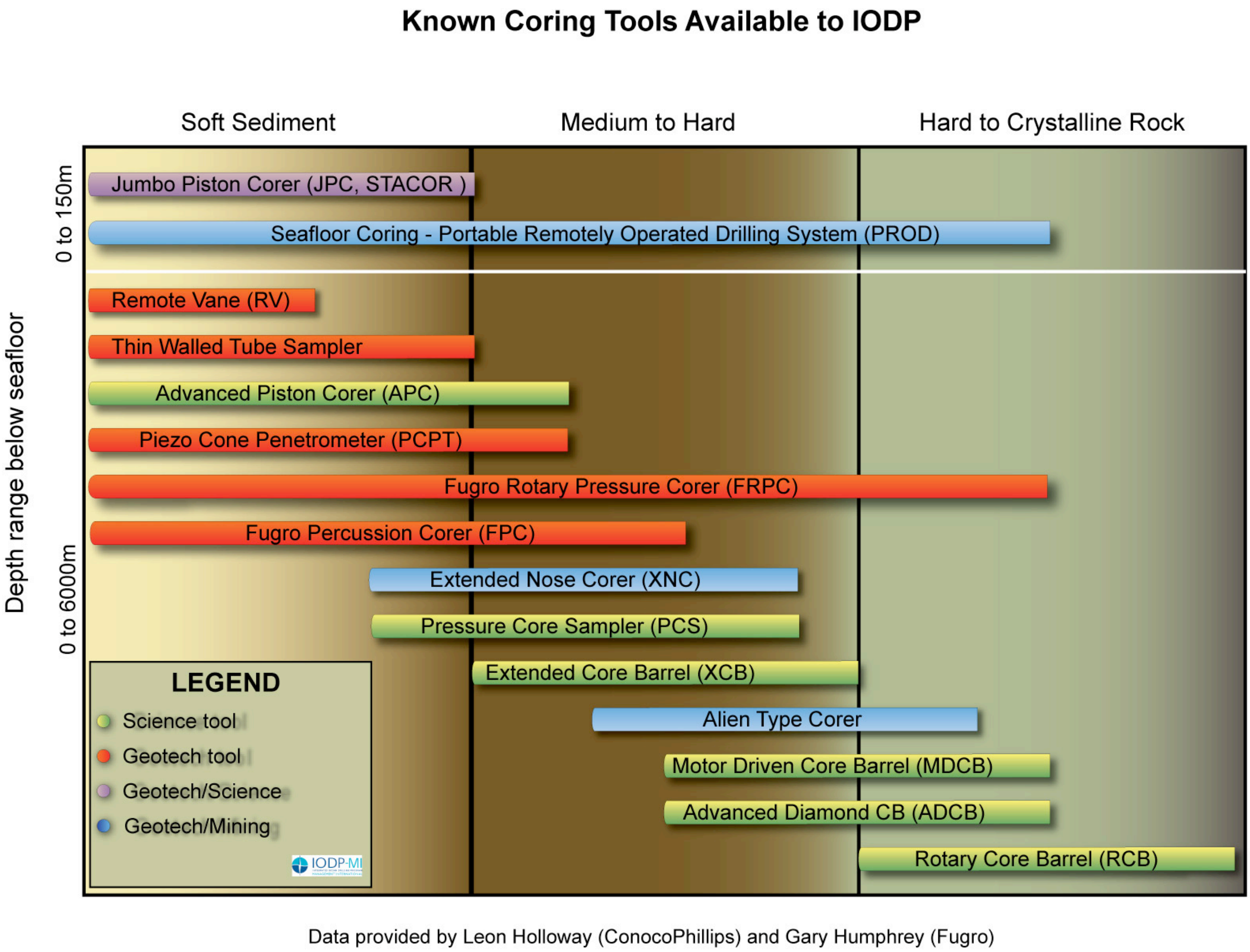

Figure 1: Illustration of known coring technologies available to the IODP and their suitability for various sediment types.

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 ^{o}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