Workshop Report

Downhole Tools in the IODP: Achieving Critical Goals of Scientific Ocean Drilling

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Photo of participants of the USSSP supported workshop "Downhole Tools in the IODP: Achieving Critical Goals of Scientific Ocean Drilling", held May 24-25, 2004, Washington, DC

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1.0 <u>Executive Summary</u>

Fifty-one scientists, engineers and program managers met in Washington, DC in May, 2004 to discuss the state of the art in Downhole Tools (DHTs) and to identify priorities for tool development. This USSSP-supported workshop was the first community-wide effort to assess DHTs within the context of IODP. For the workshop, the definition of downhole tools was limited to "instruments that are lowered into a borehole and are intended to collect samples, or make measurements of formation or fluid properties during a short period of time over a limited depth interval." To focus discussions, the topics of wireline logging and logging-while-drilling technologies were avoided.

Three working groups—reflecting IODP's primary research themes—determined what DHT measurements were necessary. Next, the groups identified the gaps between essential measurements/sampling and current capabilities. Table 1 shows a subset of operations important to meeting a broad range of the IODP's scientific goals. The workshop participants discussed tool development, examining case histories and identifying both successes and failures in how tools progress from "concept" to "implementation." Two technical working groups (measuring physical state and sampling) suggested an appropriate development process to accomplish DHT measurements.

Table 1*: *High-Priority Downhole Tool Operations for Meeting IODP Initial Science Plan Goals

Deep Biosphere and Subseafloor Ocean	Environmental Change Processes and Effects	Solid Earth Cycles and Geodynamics
• Recover samples (solid, fluid, gas, bio) at *in-situ* conditions, over a broad range of temp. and pressure	• Detect mm-scale lithologic variability *in-situ* from 0-200 mbsf	• Formation/fluid pressure
• Formation/fluid pressure	• Core in difficult regime s(e.g. sand, carbonate, chert/shale)	• Formation/fluid temperature
• Formation/fluid temperature	• Recover continuous core at the millimeter scale	• Compressional and shear velocity, anisotropy and absorption
• In-situ aqueous chemistry	• Detect ash layers	• Rheology (shear and compressive strength)
• High-return, high-quality core	• Formation/fluid temperature	

Participants ranked high-priority technical needs that crosscut ISP science issues and are of a scale best championed by individual investigators. Table 2 outlines these “bottom-up” developments. Table 3 shows five critical needs that are best addressed with a “top-down” approach. These developments have broad application, often emphasize engineering, and are not likely to be funded at a grassroots level.

Table 2: Top 5, Bottom-up, Investigator-Driven, Development Needs	***Table 3: Top 5, Top-Down, Program Development Needs***
1. Solid/fluid/gas/microbiological samples at *in-situ* conditions	1. Facilities for testing, calibration, and inter-comparison of tools
2. In-situ permeability and stress	2. Rapidly deployable, live, weight-bearing, umbilical
3. Pore pressure and temperature in sediments, indurated sediments, and hard rock with high precision to high temperature limits	3. Seabed or re-entry cone frame with camera
4. Analyte-specific *in-situ* sensors	4. Consider larger pipe diameter (or other approach) to allow use of more commercial tools
5. Side wall sampling (sampling after primary drilling)	5. Improve drilling/coring/sampling highly fractured and/or high temperature rock

Successful DHTs are developed in five steps: 1) idea, 2) design, 3) construction, 4) testing, and 5) implementation/institutionalization. IODP excels at generating ideas, conceptual designs, and initial fabrication. Yet, the process for testing and implementing DHTs can be strengthened. Ideal DHT development requires scientists and engineers to collaborate throughout extensive and repeated testing, during which tools should be progressively optimized, ‘ruggedized,’ and simplified. Although early testing should be independent, tools must be tested on IODP platforms to be effective when deployed on scientific expeditions.

Although some DHTs have limited applicability, tools addressing a range of objectives should be institutionalized for widespread and consistent IODP use. We recommend that the IODP take these steps:

1) Devote a modest number of days (~ten) each year per platform for engineering tests. Develop a competitive proposal process for allocation of testing time. Support investigators to conduct these tests (time could revert to scientific use if justified.)
2) Develop a competitive process to support top-down tool development. Solicit the best individuals and/or institutions to meet specific technical needs.
3) Develop a process to institutionalize bottom-up developments critical to multiple ISP goals. Support investigators and contractors to transfer from “third party” to “standard” tool status.

2.0 <u>Introduction</u>

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 endeavor. The IODP involves simultaneous use of riser, riserless, and mission-specific drilling platforms, and it explores 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 downhole tools (DHTs) in the IODP because they are critical to IODP science. Their development and use are the responsibility of numerous implementing organizations and third-party developers, and their technology advances are driving new measurement capabilities and scientific demands.

Fifty-one scientists, engineers and program managers met in Washington for two days in late May, 2004 to discuss Downhole Tools (DHTs). For the purposes of this workshop, we limited our definition of downhole tools to "instruments that are lowered into a borehole and are intended to collect samples, or make measurements of formation or fluid properties during a short period of time over a limited depth interval." We specifically avoided discussion of conventional and developmental wireline logging and logging-while-drilling technologies in the interests of time and to help focus our discussions.

The workshop participants were asked to concentrate on these questions.

1) What downhole measurements and sampling are essential to address fundamental goals described in the Initial Science Plan (ISP) for IODP?
2) What capabilities exist for use of these tools on the various IODP platforms, and what technologies are needed for future success?
3) How can IODP and its scientific and technical partners nurture development of new tools, and facilitate the transfer of technology from the development stage to become part of standard operations?

This was the first community-wide meeting to assess DHT development and use within the context of the new program. It begins a discussion among scientists, engineers, and administrators of how to strengthen our ability to use DHTs to address the scientific goals of IODP. We examined the state of the art in DHTs, and identified priorities for the next generation of tool developments. Just as importantly, we explored the process of tool development and proposed steps to strengthen our ability to develop and deploy downhole tools successfully.

3.0 <u>Background and Motivation</u>

The ODP community has realized a long series of notable achievements with respect to DHTs, including development of hydrogeologic testing instruments, a pressure core sampler, pore-fluid samplers, and tools for measurement of *in-situ* temperatures. These tools have been deployed in a broad range of environments, to address questions related to hydrogeology, hydrates, diagenesis, climate change, active margins, crustal evolution, and other topics. However, the road to success with these projects has been rough in some cases, and several important developments have proven less successful or been abandoned after expenditure of considerable funding and effort. Should DHT operation and development within IODP be fundamentally different from that practiced during DSDP and ODP? There is often misunderstanding within the scientific drilling community as to what is broadly possible, what developments have been attempted during ODP, and what deployments comprise "standard" drilling operations. The Downhole Measurements and Shipboard Measurements Panels of ODP have at various times reviewed earlier developments, made recommendations as to what tools are needed, and helped to develop guidelines for investigators wanting to create new tools for use at sea ("third-party" developments). However, there has never been a community-wide meeting to assess DHT development and use within the context of the new program.

DHTs are critical to achieving IODP science and there is growing momentum behind improving present tools and developing new ones. The Hydrogeology PPG Report stressed the importance of developing, improving, and maintaining tools, the importance of the routine collection of hydrogeologic data, and described a series of hydrogeological science problems where understanding hydrologic properties and *in-situ* pressures are critical (Ge et al., 2002). An industry-academic workshop cited the need to develop geotechnical tools for measurements in the shallow sedimentary section (Flemings et al., 2000). The geochemical community recommended to "Increase the Use, Development, and Quality of *In Situ* and Other Instrumentation" (Murray et al., 2001, 2002). DHTs, and how to improve their capabilities and integration with other aspects of platform based measurements, is under discussion by both the Scientific Measurements Panel and Technical Advisory Panel within the iSAS/IODP Advisory Structure. Other communities are also working towards improved *in situ* sensors and instrumentation.

This workshop was the first community-wide meeting to assess DHT development and use within the context of the new program. It begins a discussion among scientists, engineers, and administrators of how to strengthen our ability to use DHTs to address the scientific goals of IODP. We described the state of the art in DHTs, and identified priorities for the next generation of tool developments. Just as importantly, we examined the process of tool development and proposed steps to strengthen our ability to develop and deploy successful downhole tools.

4.0 <u>Workshop Overview</u>

Fifty-one scientists, engineers and program managers met on May 24 and May 25, 2004 in Washington D.C. (Appendix A). During the first day, participants split into three working groups that reflected the three primary IODP research themes identified in the Initial Science Plan (ISP). Working groups focused on what measurements must by made with DHTs to achieve the goals of the ISP. Next, working groups identified current capabilities and existing gaps between these capabilities and critical measurements and sampling.

During the second day, we focused on the process of tool development. We examined case histories of tool development and identified successes and failures in the processes by which tools progress from "concept" to "implementation". We subsequently broke into two technical working groups focused on (a) measuring physical state and (b) sampling. Groups worked on identifying an appropriate development process to achieve DHT measurements. We closed the day by recognizing top technical needs and identifying approaches to improve the process to achieve those needs. The full agenda is in Appendix B.

5.0 <u>The IODP Initial Science Plan and Downhole Tools (DHTs)</u>

5.1a What DHT measurements are important to The Deep Biosphere and the Subseafloor Ocean theme of the ISP?

This working group prepared Table 1 to list DHT measurements that are critical to achieve the science goals of the ISP related to the deep biosphere and the sub-seafloor ocean. This research theme has two components (Deep Biosphere and Sub-seafloor Ocean) and two Initiatives (Hydrates and the Deep Biosphere), as defined in the Initial Science Plan. Comments related to desired measurements are listed after the table.

Table 4: Critical DHT measurements for study of the research theme 'Deep Biosphere and the Sub-seafloor Ocean.' Each category was ranked as critical (C), important (I) or not applicable (N/A)

Category	**Measurement Description**	**Deep Biosphere**	**Hydrates**	**Inorganic sub-seafloor ocean**
Fluid sampling	Incubation, spiking, preservation	C	I	N/A
Fluid Sampling	Recover samples at *in-situ* conditions from high temperature and pressure regimes	C	C	C
Fluid Sampling	Gas – exsolved (e.g. CH_4)	C	C	I
Fluid Sampling	Gas – dissolved (e.g. CH_4)	C	C	I
Fluid: *in-situ*	Microbial activity, Metabolites, activity rates, biomass, biodiversity,	C	C	N/A

Category	Measurement Description	Deep Biosphere	Hydrates	Inorganic sub-seafloor ocean
	DNA/RNA, microscopy, kinetics?			
Fluid: *in-situ*	Pressure	C	C	C
Fluid: *in-situ*	Temperature	C	C	C
Fluid: *in-situ*	P_h, Pe	C	I	I
Fluid: *in-situ*	Flow rates	C	C	C
Fluid: *in-situ*	Aqueous chemistry – for specific analytes	C	C	C
Fluid: *in-situ*	Gas chemistry	C	C	I
Formation properties	Porosity	C	C	C
Formation property	Permeability	I	C	C
Formation property	Shear Strength	-	C	I
Formation property	Resistivity	I	C	C
Formation Property	Magnetic	I	C	C
Formation property	Thermal Conductivity	C	C	C
Sampling: Formation In-situ	Sediment, rock sample return	C	C	I
Sampling: Formation	High return, high quality core recovery – "quality" specific to particular applications	C	C	C
Sampling: Formation	Geochemistry – in situ	I	I	I
Formation state	Stress (in-situ)	N/A	C	C in specific environment
Formation: *State*	Pressure (in-situ)	C	C	C
Formation: *State*	Temperature (in-situ)	C	C	C

Hydrates. DHTs are critical for achieving the ISP's scientific goals related to gas hydrates and microbes. Quantifying the amount of methane in sediments is important and there have been major successes in this. However, it is now also critically important to measure properties and parameters that illuminate the processes governing gas hydrate occurrence.

Microbial community. The effects of occurrence, temperature, and time were the main themes covered in discussions related to microbes. How do time and temperature affect the microbial community? What is the linkage between lithology and microbial diagenesis? What are the groups of microbes? How is microbial distribution correlated with millimeter scale lithologic changes? Are there microbe-specific bio molecules, lipids, and/or surfactants?

Discrete samples at in situ pressure and temperature. The ability to recover discrete samples at *in situ* pressure and temperature is required for geotechnical, geochemical, and microbial studies. Maintenance of *in situ* conditions will provide more pristine samples. Equipment such as the PCS and HYACE to recover samples while maintaining *in situ* temperatures are not yet functional. Developing the capability to maintain core at *in situ* pressure and temperature would allow laboratory studies of fluid, gas, and sediment at in situ conditions without pressure/temperature cycling.

Discrete samples. At sites with low-core-recovery (especially in mixed lithology sequences, e.g. chert-chalk, clays-sands) it is highly desirable to have discrete *in situ* samples to fulfill a number of scientific objectives. Discrete samples can: 1) provide physical properties data (e.g. porosity, density, gamma-radiation) that can be used to "ground truth" interpretation of standard wireline logging data; 2) provide lithological information; 3) provide biostratigraphic information.

Increased quality sample return: Sample "quality" holds different meaning for different specific scientific objectives. Primary considerations are: recovery, preservation of chemistry and biology, and mechanical disturbance. Some tools exist to maximize recovery in hard rock (RCT). Tools also exist to assess chemical and biological sampling disturbance (e.g., tracer tests). In general, APC provides high recovery with little chemical/biological disturbance in soft sediments – but samples are allowed to expand in the core liner, making them of low quality for geotechnical testing. Sidewall coring (SWS) has the potential to provide chemically/biologically undisturbed samples in some cases. Recovery of chemically or biologically undisturbed samples in indurated sediments and hard rock remains a challenge.

Discrete fluid samples at in situ pressure and temperature. It is desirable to measure and collect discrete fluid samples at *in situ* P, T conditions. The collection of fluid samples negates the need to take whole core rounds for pore water sampling for palaeoclimate studies (e.g. $\delta18O$ in pore waters can be used to reconstruct $\delta18O$ of palaeo-seawater).

Lateral variations in physical properties. Lateral variations in physical properties are an important parameter that has hardly been investigated at single-hole DSDP and ODP sites. Obvious ways to obtain lateral variability include: multiple hole measurements at appropriate lateral separation, cross-hole, and deviated borehole measurements. The most useful techniques are seismic, electrical, and hydrological. Lateral scales ranging between a few meters to several kilometers should be possible.

Microbiology. A possible DHT approach is to perform an initial exploratory survey of microbial signals with a fluorescence logger and then collect samples from specific depths, taking precautions to avoid contamination and to maintain ambient temperature, pressure, and fluid/gas composition.

In-situ distribution of microbial types. Use laser- or LED-induced auto fluorescence to map total microbial concentration (tryptophan signal) and methanogen concentration (F420 signal) as a function of depth, and relate maximum temperature (depth) for existence of mesophiles, thermopiles, and hyperthermophiles. A major goal would be to search for maximum temperature at which any microorganisms can survive. Several months after the initial drilling and logging, a follow-up log should be obtained, in order to look for growth of microbial mats on the borehole wall. Fluorescence logger exists but needs to be modified for high pressure.

In-situ distribution of biomolecules – Use laser- or LED-induced auto fluorescence to map biomarkers of former microbial life: porphyrins and other degradation products of microbial decomposition. Fluorescence logger exists but needs to be modified for high pressure.

Chemistry. Chemical measurements encompass a wide-range of dissolved specifies, including inorganic ions (major cations and anions), the dissolved carbonate system (pH, alkalinity, and total CO_2), gases, and trace amounts of organic molecules (e.g., dissolved organic matter, biopolymers, and fluorescent compounds). There is an enormous variety of laboratory-based analytical methods that are capable of quantifying small sub-classes of these compounds at concentrations typical of those in sedimentary pore fluids. Adapting these techniques to high pressure and temperature borehole applications is possible; however selectivity, sensitivity, and specificity of the method will be significant analytical issues. In some cases creating an instrument that can fit down a borehole and be powered from batteries or a conducting wireline will be challenging. The effects of corrosive downhole chemical environments and fouling of sensors (especially optical) will present operational and reliability challenges. Because of these analytical and technical difficulties, we consider *in situ* chemical analysis to be technically difficult. The most promising methods for *in situ* analysis include those that have selectivity for a suite of compounds. Various scanning spectroscopy techniques (e.g., ultra-violet, vibrational, and fluorescence) with variable frequency sources (perhaps laser-based) and in situ mass spectrometry appear to be the most promising techniques. There is at least one commercial product coming onto the market that uses ultra-violet scanning spectroscopy (e.g., ISUS) for in situ measurements of dissolved bromide and bisulfide in ocean water. The biggest challenge for borehole mass spectrometry development is the construction of an inlet system suitable for the high-pressure difference that will exist across the inlet.

5.1b What DHT measurements are important to <u>Environmental Change, Process and Effects</u>?

Table 5: Critical DHT Measurements for study of the research theme 'Environmental Change, Process and Effects.'

Scientific Goal	**Measurement**
Millenial and longer scale records	Detecting mm-scale lithologic variability in-situ, from 0-200 mbsf
	Coring in difficult environments: Sand, carbonate, chert/shale
	Recover continuous records from extreme climate records at the millimeter scale
	Detect ash layers
Reconstructing Bottom Water temperatures	High spatial resolution of temperature in the shallow section

The Environmental Change, Process and Effects group focused on the need to collect records of environmental change with improved resolution. In addition, it was felt that DHTs might be used to acquire better high resolution temperature records that would allow reconstruction of the evolution of bottom water temperatures through time and also allow monitoring of marine permafrost on continental margins.

Detection of mm-scale lithological changes. In certain palaeoenvironmental settings extremely high-resolution marine sedimentary records may be preserved (e.g. varves, coral banding, and millennial scale records). APC coring can cause disturbance in extremely soft sediments and conventional logging tools cannot be used in the uppermost part of the sedimentary section.

Detection of ash layers. Explosive volcanic events may have a significant short-term effect on global climate. High-resolution records of ash layers may be important for understanding rapid climate change. Ash layers are generally easily recognized in APC cores using the MST and visual core description. In the absence of core, FMS logs, in conjunction with other data, can be used to identify ash layers.

Reconstructing bottom water temperature. One method to help lengthen our understanding of environmental change on the ocean floor is through reconstructions of bottom water temperature. One method for doing this is to monitor the vertical distribution of temperature within boreholes over time. Perturbations to the background thermal regime can be used to reconstruct bottom water temperatures.

Marine Permafrost. In polar regions an important and sensitive indicator of climate change is the state of marine permafrost associated with continental shelves. Temperature measurements are an effective way to assess the health of permafrost. Equally important is monitoring the position of the phase change between water and ice at the top of the permafrost. The depth extent of permafrost may also be important to monitor.

5.1c What DHT measurements are important to Solid Earth Cycles and Geodynamics?

Table 6: What DHT measurements are important to Solid Earth Cycles and Geodynamics (SECGD)? These are measurements of Material Properties/State/Fluxes. Each category was ranked Essential (E) or Would-be-nice/Important (I). "I" includes things that are essential but can be obtained in other ways than DHTs. E1 is items that apply across all SECGD projects

Justification	
1) Material State: Pore Pressure	E1
Temperature	E1
Stress tensor (σ_1, σ_2, σ_3, S_{Hmin}, S_{Hmax})	E
2) Fluid and Gas Chemistry (both concentration and samples)	E
3) Seismic structure velocity (compressional and shear) Velocity anisotropy Absorption (Q)	E1
Seismicity (active micro-earthquakes, hydro fracture experiments, passive micro-earthquakes)	I
4) Permeability	E
5) Porosity (heterogeneity, scale dependence)	
6) Compressibility (elastic properties)	E
7) Electrical Structure	I
8) Thermal Conductivity	I
8) Fluid Flux	I
9) Gas Flux	I
10) Heat Flux	I
11) Momentum Flux	I
12) Rheology shear, compressive strength	E1
Seismic waveform (frequency, amplitude)	E
13) Strain transients—tilt, strain tensor	I
14) Rock/Sediment samples (precisely located "special" cores—e.g. sidewall, cuttings, sampling, mechanically undisturbed samples	I
Rock Fabric—wall structure	I

In situ stresses: In situ stresses may be recovered from stress relief (over coring), core recovery, borehole failure, and hydraulic fracturing methods. Stress relief methods are not applied in deep boreholes in hostile environments, but have the advantage that they yield the full stress tensor. Core recovery methods involve restressing an oriented core to ambient in situ conditions, with arrival at these conditions indexed by elevated acoustic emissions, or by marked changes in deformation modulus. Borehole breakouts may be used to define orientations of the minimum principal stress (Bell and Gough, 1981), and magnitude of the breakouts may be used to define the magnitude of components of borehole-normal stress or the differential stress (e.g., $Sh_{max} - Sh_{min}$).

Hydraulic fracturing is routinely used in deep environments to define minimum principal stress magnitude and orientation (e.g. Haimson and Fairhurst, 1968). Extended leak-off tests are performed by isolating a short section of open hole with a drill string packer, then pumping into this interval until flow into the formation increases. With several cycles of active pumping and shut-in, the initial hydraulic fracture stress ($Co + \sigma_3$) and the least principal stress can be determined (extended leak-off test: XLOT). This is commonly done in industry and geothermal applications. HTPF (hydraulic testing of pre-existing fractures) testing may be used to determine the oriented state of stress on pre-existing fractures (Cornet and Julien, 1989). The zone is packed and inflated to breakdown and the known fluid pressure and observed (borehole camera or impression packer) orientation of the fracture used to determine the stress normal to the pre-existing fracture. Stimulation of multiple variably inclined fractures enables the full stress tensor to be determined. Injection tests to steady-state may be used to measure fracture permeability with stress (Rutqvist and Stephansson, 1996).

Advanced downhole rheologic experiments. There is a need to go beyond standard geotechnical measurements as well. For many problems of interest to the IOPD community (fault mechanics, limits of the seismogenic zone, aseismic transients), there is a need to move beyond simple failure laws defined by only a few elastic parameters or static strength measurements. These problems require measurements of inelastic strength, determination of the strain rate dependence of strength, and flow properties of candidate materials. Ideally, these measurements would be made in-situ, in soft sediments, indurated sediments, and hard rock, to augment detailed laboratory experiments on core. New experiments will be developed for which existing downhole technology is yet to be identified, though it may encompass adaptations of dilatometers, borehole jacks, packers, and fluid pressure perturbation capabilities.

5.2 What are the current DHT capabilities?

Working groups identified current capabilities and existing gaps between these capabilities and critical measurements and sampling. Comments follow Table 7.

Table 7: DHT measurements that are important to the ISP, current methods to achieve the measurements, and the status of these measurements. All of the measurements are deemed important to the ISP. 'Difficulty' is a qualitative measure of how difficult it will be to make the measurement. A minor improvement of an existing tool would be 'low' whereas a new tool with new technology would be 'high.'

Category	*Measurement Description*	*Method*	*Difficulty*	*IODP Status*	*Quality/ Success Rate*
Fluid sampling	Incubation, Spiking, preservation	Manifold sampling system	High	In development (3rd Party)	?
	From soft sediments	WSTP	Low	Standard	Low
	From soft sediments	Fissler (IWS)	Moderate	3rd Party	Low
	From soft sediments	Bat-probe	High?	Commercial?	?
	From Soft Sediments	PCS	Low	ODP	Good
	From indurated sediments	RFT	High	Commercial. Does not fit in Joides Resolution drill pipe	High in permeable formations
	From permeable sediments	Pack-off and let flow or pump	can't pump out	ODP	High
	From fractured rock	RFT WSTP	Low	3rd Party—easily contaminated.	Low unless in permeable formation
	Gas – exsolved & dissolved	PCS RFT HYACE	Low Low Low	Exists. Commercial Exists	Moderate Variable Unknown
Rock sampling	High return, high quality core – "quality" specific to particular applications	RCT SWS GEL coring	Moderate -diameter -operator High - diameter	3rd Party	Good Variable ?

Category	***Measurement Description***	***Method***	***Difficulty***	***IODP Status***	***Quality/ Success Rate***
	Sediment, rock sample return at *in situ* conditions	PCS	moderate	3rd Party? on hold	variable, soft seds only
State	Pressure in soft sediments	A. DVTP-P B. Piezoprobe C. MDT	Low Low Low	A. IODP B. 3rd party C. 3rd party	Highly variable Good Good in permeable sediment
	Pressure in rock & indurated sediments	Wireline Packer Drill String Packer MDT (Modular Dynamics Tester)	High Low Low	3rd Party (industry) 3rd Party. Do-able but non routine Standard in industry, available if pipe diameter is large. May be limit in rock induration and permeability to get result	Fair/ Low Good/High Good/High
	Stress	Drillstring Packer, (Extended leak-off test) LAST & LAST-II Industry (Fugro) tools: stressmeters?	Routine in industry, not done in ODP, should be do-able difficult Should be investigated Unsucc.	ODP plus 3rd party gauges Developed >10 years ago, deployed once or twice commercial	High low

Category	*Measurement Description*	*Method*	*Difficulty*	*IODP Status*	*Quality/ Success Rate*
		Geoprops probe	3rd party	Dormant/dead	
	Temperature in soft sediments	DVTP APCT	Low Low	Routine Existing and under development?	Excellent High
	Temperature in rock	DVTP Spiess Logging Probe Wireline logging tool	Low	Routine/ can only be deployed in borehole.	Limited to temperature of borehole, which may not be equilibrated to formation
	Microbial activity in fluids	Fluorescence PCR devices	High	Non-existent	?
	PH, pE	Probes	Low	Non-existent	?
	In-situ aqueous chemistry – for specific analytes	Probes Raman scatter Optrodes	High	In development for *seafloor* applications	?/?
	In situ gas chemistry	GC's Mass Specs	High	In development for *seafloor* applications	?
	Fluid and Gas Chemistry	PCS other pressurized samplers MDT IWS Pack-off and let flow or pump	Low Low high high low	A. ODP B. 3rd party commercial ODP, not ready ODP	High for soft sediments ? high Low Done in overpressure d settings; can't pump out
Material Property		VSP, other Vane Shear Penetrometer	Low Low Low	Exists 3rd Party 3rd Party	High/variabl e High/variabl e Moderate
	Rheology/ geotechnical properties	Cone Penetrometer Piezoprobe		commercial commercial	Good Good

Category	*Measurement Description*	*Method*	*Difficulty*	*IODP Status*	*Quality/ Success Rate*
		Seimic shear wave measurement Undisturbed whole core Borhole jacks/dilatometers Sacks-Everdon strainmeter.		commercial (Routine logging measurement) exists non-ODP; routine in geotechnical use An observatory element, has been deployed in ODP	Poor data in low velocity sediments/Hig APC samples cause disturbance
	Hydrologic properties	DVTP-P piezoprobe packer expts -pumps -realtime P RFT	Low Low Low Low	Existing 3rd Party existing commercial	variable variable Variable (need better pumps, real time p data) Variable
	Electrical, magnetic	DLL, DIL	High	In development (3rd Party)	
	Thermal conductivity	Probe	High	Existing	Variable, soft sed. Only
	Seismic Velocity and Attenuation	Broadband Borehole seismometers 3-comp VLF seismometers Multi-node strings Mems and fiber sensors	Low Low Low High	3rd party 3rd party 3rd party requires emerging technology	Good Good ? ?

Fluid Sampling

Many of the scientific problems posed in the ISP are critically dependant on fluid (gas) chemistry. While there are some available tools, none adequately provides pristine samples of the formation fluids. Most samples of pore fluids have been extracted from solid samples recovered in the cores. However the properties of these samples change during core recovery and processing. Some tools exist to sample *in-situ*, but need improvements. All of the tools listed below compromise the samples.

At present there are essentially no techniques to make meaningful chemical measurements of most key components within the formation. The uncertainty in the data provided by the existing tools and approaches compromises the interpretation of the data, and thus hinders scientific progress. New tools need to be developed. It is critical to be able to make measurements of the pore fluid within the formation, both within the bore hole, and in samples that are recovered in a pristine state from within hard and soft rocks.

The existing tools that need improvements include:

WSTP – The water sampling temperature probe has existed, in various forms, since DSDP. However, this tool is known to fracture hard and semi-lithified formations, leading to contamination in some cases.
Fissler (IWS) - The Fissler Intersitial Water Sampler was a modification of the WSTP, with a superior shape and sampling design. However, this development was never completed and it could be worthwhile to pursue it.
PCS (Pressure Core Sampler) - This tool was originally developed during DSDP (under the name Pressure Core Barrel). However, it was not until Leg 164 that it recovered pressurized cores routinely. This device has generally been used solely to determine the amount of gas contained in the sediments, and not used as a pore fluid sampling tool. Its use requires extensive engineering and technical support, and there are no standard ways for working with recovered solids and fluids under in-situ conditions.
HYACE (HYACINTH-project) - The HYACE, developed by a European consortium, was first used successfully on leg 204. The HYACE tool was designed to measure *in situ* core properties on samples collected under pressure and to transfer these samples to other pressurized containers for other measurement. It is still in the development stage and is not primarily for pore water sampling.
Bat-probe - The group was not very aware of this DHT. However we understand it to be a commercially available sampler.
MDT-RFT- These tools were originally designed by Schlumberger but are also available through other wireline logging companies. They both measure in situ pressure and hydraulic conductivity and can be used to take fluid samples. They do not fit within the borehole diameter of the drill pipe on the JOIDES Resolution.

Rock Sampling

Solid sample return at *in situ* conditions:

PCS (Pressure Core Sampler): - This tool was originally developed during DSDP (under the name Pressure Core Barrel). However, it was not until Leg 164 that it did recover pressurized cores routinely. Its use requires extensive engineering and technical support, and there are no standard ways for working with recovered solids and fluids under in-situ conditions.

HYACE (HYACINTH-project): - The HYACE, developed by a European consortium was first used successfully on leg 204. The HYACE tool has been designed to allow in situ core properties to be measured on samples collected under pressure and ultimately to be transferred to other pressurized containers for other measurement. It is still in its developmental stage.

State

Temperature, Pressure, Conductivity. The TPC tool, which is under development, measures temperature, pressure and conductivity changes within the headspace of an APC core during core recovery. Historical shipboard observations of cold core temperatures, frozen pore water, and catwalk core temperature measurements of gas-rich cores suggest that gas expansion cools the core during its ascent to the surface. The TPC is designed to measurement these temperature changes during core recovery. It is a completely autonomous downhole tool that is contained completely within the interior of the APC piston sub-assembly. The major components of the TPC include the sensors (P, T, and C), a signal conditioning board, a 32-bit 16 MHz computer with 48 Mbyte RAM, and 2 double "D" lithium batteries. This tool has been run on ODP Legs 195 for engineering tests, and on Legs 201 and 204 for scientific measurements. The goal is to use the T, P, and C data to provide constraints on the relative gas content of continental margin sediments and to learn more about the effects of coring on sediments.

Pressure. DVTP-P – After several deployments in ODP, it is still in development stage and has been moderately successful. Its wide diameter requires significant time to interpret in-situ pressure. It runs on a separate run on the coring line and its range of operations is limited to the upper range of XCB coring. An absolute pressure sensor was added to the DVTP tool to measure in situ formation pressure with DVTP-P. More deployments in different sediment types are needed to gain more experience and allow a full assessment of the tool's capabilities and limitations.

Pressure. Piezoprobe – Deployed routinely by Fugro and was run successfully on ODP Leg 204. Available commercially and a similar tool is now under development as a third party tool. The Piezoprobe, a Fugro-developed pore pressure probe, was deployed twice during ODP Leg 204, and one successful measurement was made. The tool is currently being optimized through a NSF-funded proposal.

*Pressure**.*** Modular Formation Dynamics Tester (MDT) - Commercial and fully operational wireline deployed tool. This tool takes several pressure measurements in a single run. It requires the use of a large diameter pipe (6"5/8). It was run successfully on the JOIDES Resolution during the JNOC gas hydrate experiment.

*Pressure***.** Packer measurements. Extrapolation to *in situ* pore pressure can be made through isolation with drill string or wireline packers. Primary issues include the effects of drilling perturbations on fluid pressures. Previous tests in ODP have generally not been run long enough to confidently extrapolate to in situ pressures.

Temperature. In low permeability and soft sediments, penetrometer tools, if equipped with a thermistor, (e.g. the DVTP-P, Piezoprobe, cone penetrometer) can be used to measure formation temperature and pressure. Temperature measurement is a fairly routine technique. The DVTP is a routine tool used since ODP Leg 164. It has been consistently reliable at provided good quality temperature data. It runs on a coring line. Its range of operation is limited to moderately hard sediments, in the upper range of the XCB coring.

Temperature. APCT (formerly known as Adara). The existing APCT has been very successful and reliable for temperature measurements in soft sediments. The thermistor is located in the APC cutting shoe, and its operation range limited to soft sediments. The old tool electronics are currently being updated by a German-funded project (H. Villinger, U. Bremen). At the same time, a sub is being developed (A. Fisher, UCSC) which will host a second set of electronics and which will potentially allow determination of *in situ* temperature gradient. This requires frequent and careful calibrations to guarantee high quality absolute temperature data. This is important for consistency of data between legs and instruments.

Temperature. The DVTP is routinely run in semi-consolidated sediments and has a proven record of providing reliable temperature data. Both the APCT and DVTP instruments require periodic, careful calibration to guarantee high quality absolute temperature data. This is important for consistency of data between legs and instruments. In addition, processing of recovered data to extrapolate to in-situ temperature requires experience and sound scientific judgment - it can not be automated.

Temperature. Borehole temperature logging. No technique exists for measuring *in situ* temperatures within hard formations that cannot be penetrated. Downhole tools can be used to log borehole temperatures shortly after drilling operations, with established methods for extrapolating to estimate formation temperatures. In addition, holes can be revisited long after drilling by wireline reentry for logging of temperatures after dissipation of any drilling disturbances. Among the existing tools available for logging borehole temperatures are the following:

1) DVTP and APCT tools, while normally used in penetration mode in sediments, can also be deployed to log open-hole borehole temperatures.
2) LDEO Borehole Research Group operates a memory temperature-logging tool that can be added to the bottom of a wireline logging string.

3) The MPL Control Vehicle wireline reentry system includes a logging sonde that can continuously log borehole temperatures on wireline reentry.
4) In the 1990's, NSF supported acquisition of a dewared, memory, temperature logging tool that can be run on the coring ling to log temperatures in hot holes. It has been used successfully in ODP to log borehole temperatures up to 318°C, and, although still a third-party tool, it remains available for IODP use.

Temperature. Install a high precision thermistor string in a borehole and logging temperatures as a function of time. One potential shortcoming of this technique is that data loggers limit the number of thermistors on the string, and thus limiting the spatial density of measurements. One way to overcome this obstacle would be to log the borehole through a borehole seal.

Comment: Hi-temperature (>150 to 300 C) issues are critical for some applications. Most existing tools are not capable to temperatures above ~125 C.

Comment: Many of the temperature and pressure tools listed above generate a transient disturbance of the parameter to be measured. The extrapolation of the decay in temperature or pressure to undisturbed formation state needs further standardization to allow comparison of data sets.

Stress: LAST tool: The LAST tool was developed in ODP to measure lateral stress in soft sediments. It was deployed with limited success and its development abandoned.

Microbial activity: A suite of downhole instruments need to be developed to measure microbial activity in situ (i.e. at the bit).

Gas concentrations. The PCS is a proven tool to estimate the *in situ* concentration of subsurface gasses. It has been successfully used on legs 164, 201, and 204. However the sampling is time and effort intensive. Approximately 60 PCS samples of methane concentration exist to date including Blake Ridge, Hydrate Ridge, and the Peru margin). The major shortcoming of the PCS is the inability to keep samples at in situ temperature. The best way forward is to start using PCS routinely and measure gas concentrations in different geological environments and depths. Also, the logging of PCS before and during degassing would provide valuable information on the distribution of gas phases and properties of sediment.

pH, pE, and in situ aqueous geochemistry. Electrodes need to be developed or modified to penetrate the formation at or ahead of the bit. The measurements can be transmitted via cable in real time, allowing drilling strategy to be adapted. The electrodes could be designed at the bit or in a probe-type of instrument inserted ahead of the bit. Analytes of interest (mainly for deep biosphere objectives) include Fe, H2S, pH, and pE. This is critical for some analytes (pH, pE) because they change during sample retrieval and cannot be measured shipboard.

Gas Chemistry, in situ. A suite of downhole tools will require development – including GC and Mass Spec. These tools are being developed for seafloor applications, but do not currently exist for use in boreholes.

Material Properties

Rheology. Borehole (Menard, 1957) and self-boring dilatometers (Hughes and Wroth, 1970) are routinely used in soils, and borehole jacks (Goodman, 1976) in rocks, in shallow terrestrial environments. All measure deformation of borehole walls displaced by a pressure applied through a packer or opposing platens. If stressed to failure, dilatometers will measure cohesive and frictional characteristics of soils.

uCPT are routinely applied in soils at shallow depths to measure end-bearing, sleeve friction, and drivage-induced excess pore pressures – these data define magnitudes of undrained cohesion and frictional resistance.

Piezoprobes may be used in a similar manner if outfitted with a load cell behind the penetrometer tip. Field vane shear apparatus are used to measure in situ cohesive strengths in soft clays.

Mechanical: A suite of elastic and geotechnical properties can be measured in the borehole. Acoustic properties can be measured through a vertical seismic profile. Shear strength can be directly measured with a vane shear, and other geotechnical properties can be measured with a penetrometer. In most cases, elastic/acoustic properties can also be measured using existing logging while drilling (LWD) and/or wireline logging tools.

The Cone Penetrometer Tool (CPT). The CPT is a commercial tool, providing good quality data. It is a passive tool, limited to soft sediments and needs some adaptation for latching problems.

Hydraulic Conductivity. Piezoprobe and DVTP-P (inferred)*:* Hydraulic conductivity can be estimated from dissipation records (pressure vs. time) of penetrometer devices in soft sediments. The method relies on matching the observed pressure dissipation with predictions from theoretical models. Permeability can be derived from the hydraulic conductivity if the formation stiffness is known. The utility of this technique is limited to formations in which the probes can penetrate without cracking (soft to moderately stiff sediments). Penetrometers (e.g. piezocones/piezoprobes) are used to determine hydraulic properties. Dissipation of excess pore pressures around penetrometers is used to determine transport properties. Pressure dissipation recovers hydraulic diffusivity (consolidation coefficient) and if coupled with independently measured compressibility enables permeability to be determined.

Permeability. Packer Test. Measured by steady state injection tests in rock and sediment. Injection within a packed-off zone enable steady flow rates to be linked to observed pressure drop via injection geometry and permeability. Shipboard packer tests for determination of permeability using drill string packers have been conducted successfully (but are not routine) within ODP in stable formations and within the bottom of casing in unstable formations. Currently, downhole pressure gauges are third party. For improved hydrologic testing, better resolution shipboard pressure gauges and pump control have been recommended. Feasibility of wireline packers should be investigated, because of the saving in deployment time over drill string packers. Primary issues in packer tests are the limited scale of measurement, especially within low permeability formations.

Compressibility. Packer Test: Single-well tests cannot provide storage parameters, so cross-hole tests are necessary (e.g., instrumenting and sealing one or more borehole, and pumping at a nearby borehole). Cross-hole tests are currently planned for early IODP operations, but have not yet been conducted.

Electromagnetics. These measurements, in general, can already be obtained via standard (or available) logging tools.

Thermal Conductivity. Tools to measure downhole thermal conductivity do not currently exist. A probe-type tool could be used in soft sediments, but this requires development.

Fluxes

Flow Rates. Fluid flow rates can be measured "directly" using mechanical, thermal, or chemical flowmeters. For high flow rates, third party borehole flow meter tools exist. For low-flow environments (e.g., mm's to cm's yr^{-1}), a collector-type of flowmeter using a chemical or thermal tracer would need to be developed. This type of tool would amplify formation flow rate through a measurement device by reducing the area of flow from the formation to the measuring point, as is done in "benthic barrel" instruments used at the seafloor. The use of such tools is possible in packed open-hole intervals or screened, cased intervals. Flow rate in many formations can also be calculated using independent measurements of fluid pressure and permeability (both discussed above).

Borehole Seismology

Performing vertical seismic profiles (VSPs) walk away and offset VSPs, and crosswell seismic experiments will be desirable in many IODP operations in crust and sediment sections. Such studies require a wireline-deployed single seismometer or array of seismometers. Crosswell experiments will require a wireline-deployed seismic source. Single component, short period seismometers such as the WST (well seismic tool) are established for routine ODP operations. 3-component clamped seismometers, including very low frequency (VLF: 5-100 Hz) instruments are available as commercial third party tools, as are broadband borehole instruments. High-resolution recording of active source experiments will require deployment of arrays of sensors along the borehole, which has been rarely done in ODP. Quality of VSPs is expected to increase in IODP versus ODP through use of appropriate tools for lithologies and depths of a drill site, cumulative experience, and standardized procedures.

Emerging promising technologies that have not yet been adapted for scientific ocean drilling include MEMS (micro-electronic machined sensor) and fiber-optic acceleration or displacement sensors, now being used in industry downhole applications.

Both of these technologies offer potential advantages in high-temperature applications, low power requirements, cost, and physical sensor size.

6.0 Overview: Present and Future Processes of Tool Development

We address the process of how to achieve the DHT measurements. We begin with a discussion of the historical process of tool deployment in ODP through a limited number of case studies.

6.1 Past Process of Tool Deployment

Tool development has been pursued in two manners. First, some tools are developed and maintained by the primary contractors. These 'Standard' DHTs are available on all ODP scientific legs. Second, ODP some DHTs have been developed outside the framework of its primary contractors. These "third-party" tools are developed by individual investigators. A successful "third party" tool may evolve to be an ODP "standard" tool that is supported/maintained by the operator.

In the U.S., third party tool development support has often come from the ODP division of NSF Ocean Sciences. Alternatively, tool development has been pursued by the primary contractors under the direction of the Science Advisory panel structure. There are also examples where tool modifications have been supported by other U.S. government agencies. Finally, there are examples of independent tool developments pursued in the international arena that have ultimately been assimilated into ODP.

6.2 Future Structure of Tool Support

At present, within the United States, tool development largely follows the legacy approach described above. There are a number of third party tool developments that are proceeding in addition to tools that continue to be developed and refined by the operators. However, we are at the onset of the IODP and it is appropriate to consider the form of the future DHT Program.

1) What are the responsibilities of individual scientists in generating these tools? What are the responsibilities of the operator(s)? What is the role of the central management organization (IODP-MI)?
2) How will input from the science community be translated into the development and support of specific tools?
3) What is the role the operator should play in tool development/maintenance? How can we create an environment where tools are well maintained?
4) How do we create an environment where individual champions can be encouraged to develop needed tools? How should these tools make the transition from experimental to mainstream, operational status?
5) Role of NSF ODP in tool development

6.3 Brainstorming How to Achieve Tool Development

One large obstacle in obtaining new downhole tools (DHTs) is constructing a streamlined, timely, and cost-efficient methodology for taking the idea for a specific sample or measurement and developing and implementing the tool that can meet the scientific objectives. We propose a simple, straw-man system with five steps: (1) development of the scientific idea; (2) develop a proposal to build the DHT; (3) engineer and construct the DHT; (4) test tool; and (5) routinely use DHT for reliable measurements. A further breakdown of each step was suggested to provide an informal mechanism for taking a measurement idea through reliable and routine deployment.

(1) Development of the Scientific Measurement Idea
The first phase is to establish the measurement or sample that is necessary. This will require a champion scientist to take a measurement of interest to the greater ocean drilling community and goals of the ISP and start pushing it forward. The next step is to assemble a small working group of scientists, engineers, and operators to assess the feasibility of designing the tool. This is a critical step before moving forward to a full proposal but will require seed-funding. Seed money could be provided by USSSP. Seed money would allow for the working group to assemble for a mini-workshop and to allow for detailed definition of the tool for a full proposal. This definition would include the engineer and scientist working to develop tool drawings that not only define the key technology and design specifications but also how the tool will integrate with existing drilling infrastructure.

(2) Develop a Proposal to Build the DHT
After the working team has assembled and formulated a plan for tool development that includes detailed diagrams and insights on the implementation with operations, specific drilling legs, and the ISP, the champion must lead the charge on developing a fundable research proposal. Funding might fall into two separate categories: (a) NSF funding and (b) IMI funding.

(a) NSF funding would be pursed for tool development that involved modest funds for development (a few $100k or less). The champion would take the lead for developing the full proposal with close contact between engineers and operators. Key inputs for the proposal include necessity of the tool to the goals of specific drilling and larger goals of the ISP, technical specifications for the tool including design specifications, and how its deployment fits into the operations. One other suggestion was that tool ideas be run through the appropriate IODP panel (e.g., SciMP).

(b) IMI funding would include a multiple stage procedure that needs to be defined. One possible pathway is for the team or team leader to notify the appropriate IODP panel (e.g., SciMP, TAP), which would be followed by a presentation of the tool and its capability within the program to the IODP panel. If the panel deemed the concept valuable and feasible, the panel would then suggest to IMI that the tool would be a value to the program and that an RFP should be issued. The IMI would then issue the RFP and the tool would be developed by the winning awardee. One concern with this path forward is separation from the idea originator (the working group and team leader) and the developer. Without open communication, the scientific goals may be compromised in the full tool development.

Discussion also focused on the time-frame for soliciting outside funding for assisting in tool development. It was decided that outside agencies (e.g., DOE, MMS) should be contacted early in the proposal stage to see if additional funds are available.

(3) Engineer and Construct the Tool
With successful funding through NSF or IMI funds, tool development would be initiated. The design and development of the tool must proceed with constant communication between scientists, engineers, and operators. Communication between the science party and the engineer will promote the development of an efficient tool that will take the desired scientific measurements. Interaction with operators or operators experienced with ODP/IODP drilling operations will allow for streamlined development that can be integrated with the operational procedures and techniques of the IODP drillships and MSPs. Development should proceed with prototype stages in mind so progress of tool development can be assessed and tested during development. This suggestion is intended to prevent excess time being lost in development.

(4) Test Tool at Multiple Levels
The testing of new tools during development and prior to deployment on a scientific drilling leg is necessary for creating tools that are reliable and going to be considered as routine within the IODP. It is recommended that a formal protocol for pre-cruise testing of all new tools be established. This protocol should allow for demonstration that the tool produces reliable and reproducible results and that the tool will be compatible with operations. The protocol would include, but not be limited to, (a) testing on land-based holes and test facilities, (b) testing on ocean trials in existing holes, and (c) testing on IODP engineering legs that are designed for tool development. A secondary part of tool testing is calibrating it with other tools that make similar measurements such that tool performance can be compared.

(5) Routinely use DHT for Reliable Measurements
The final stage in tool development is routine and reliable use within the IODP. One new aspect to deployment is that a legacy program should be developed for tracking of tool performance from design through all deployments. This legacy database not only will track all measurements made by a specific tool, but will keep a history that will be useful in developing new tools and obtaining measurements as it will be a historical record of what works, what works well, and what still needs improvement.

It is also critical that tool guides and instruction manuals be provided and updated on a regular basis, and that shipboard engineering and technical personnel be trained in proper use and maintenance of DHTs. Some former and currents DHTs have essentially been "orphaned" in the sense that existing support personnel are unfamiliar with their history, design, theoretical basis, and use.

A few other topics related to DHTs were discussed. One aspect of this discussion was setting up a borehole management system. This would not only give a record of what measurements have been made (e.g., wireline, core, DHT) but also what measurements are ongoing or planned. This is instrumental for planning and initiating successful research in the future. A secondary DHT-related discussion revolved around obtaining the technology to enhance cable-to-borehole observatories. With increased desire for long-term monitoring stations, protocols for quickly and easily connecting to boreholes warrants research and development similar to DHT development.

7.0 Technical Recommendations

We identified 11 critical technical needs that cut across the ISP and are of a scale that are best championed by individual investigators. We termed these 'Bottom Up' developments.

	Bottom-up, Investigator-Driven, Development Needs
1	Solid/fluid/gas/microbiological samples at *in-situ* conditions
2	*In-situ* permeability and stress
3	Pore pressure and temperature in sediments, indurated sediments, and hard rock with high precision to high temperature limits
4	Analyte-specific *in-situ* sensors
5	Side wall sampling (sampling after primary drilling)
6	Hole completion methodology – e.g., case then perforate. How does completion affect what tools can be used
7	Soil samples for high quality geomechanical testing. Improved coring technology to get less disturbed samples.
8	Borehole stress measurement (e.g. lateral stress) in sediments and rock
9	Way to cap holes such that removing cap is easy for returning. Highly simplified, un-instrumented CORK
10	High resolution sampling of seismic wave field
11	Complicated measurements of rheologic parameters. Things that can be cast in constitutive laws

We also identified five critical technical needs that are best addressed with a 'Top-Down' approach. These developments have broad application and serve an array of scientific objectives. They are less likely to be championed by a single investigator or funded by a single grant to a sole PI or small groups of PI's.

	Top-Down, Program Development Needs
1	Facilities for testing, calibration, and inter-comparison of tools
2	Rapidly deployable, weight-bearing, conductor cable
3	Seabed or re-entry cone frame with seabed camera

4	Consider larger pipe diameter (or other approach) to allow more commercial tool deployment
5	Improve drilling/coring/sampling highly fractured and/or high temperature rock
6	Extending riser capability to 4 km
7	Fulltime deepwater ROV or seafloor camera capability.
8	Maintaining a hole status database.

<u>Live weigh-bearing umbilical</u>

A high-speed conductor cable is routinely used on geotechnical ships and would be low cost yet potentially dramatically advance downhole tool deployment. Temperature limits of these cables should be explored

<u>Seabed frame and/or seabed camera</u>

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). Workshop participants re-affirmed this need.

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. The current phase I non-riser vessel and the proposed phase II vessel could readily be equipped with a seabed frame. This capability, supported with a deep-water ROV or some form of seafloor camera, would expand the non-riser capability to meet scientific objectives that require the need for:

(a) Recovery of sand on continental margins and deep water fan systems;
(b) Recovery of corals in shallow water environments (the current phase I vessel's DP can be used in ~30 m water depth);
(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).

8.0 <u>Process Recommendations</u>

We envision five critical steps to the development of a successful DHT:

1) idea

2) design
3) construction
4) testing
5) implementation/institutionalization

As a science-driven program, IODP and its members are very good at generating ideas and conceptual designs and initial fabrication. However, we can strengthen the process by which we test and implement downhole tools. DHT development, to be successful, must have an extensive testing phase. During repeated testing, tools should be progressively optimized, 'ruggedized', and simplified. In this process, scientists and engineers must be encouraged to work together to make incremental improvements in tool development to achieve science goals. Early testing should be accomplished independently from the IODP platforms. Ultimately, the tools must be tested on the platforms so that they will be effective when deployed on a scientific expedition.

Some DHTs have never entered the mainstream of application in ocean drilling. In some cases this is appropriate: the tools might address a very narrow scientific objective that will be addressed by only a few scientists on a limited number of drilling expeditions. However, some DHTs are necessary to meet a broad range of the goals of the ISP. There must be a process to institutionalize these tools into the IODP so that they can consistently used by a range of investigators with success. The process might include bridge grants that take the DHT from 'third party' to 'standard tool' where investigators and operators are supported for the specific task of implementing a particular tool.
We recommend:

1) Devote a model number of days (perhaps 10) per year on each platform for engineering testing. Develop a competitive proposal process by which investigators apply for testing time. Support the investigators to achieve platform testing. This time could revert to scientific use if justified;
2) Develop a competitive process to support 'top-down tool' development. Pursue a philosophical approach of soliciting the best individuals and/or institutions to meet the specific technical need;
3) Develop a formalized process to institutionalize 'bottom-up' developments that are deemed critical to multiple ISP components. Support investigators and contractors for transfer from 3rd party to standard tool status.

9.0 <u>Other Comments from the Afternoon of Day 2</u>

1. A facility for borehole testing is very important. It doesn't have to be a place. It could/should include a shiptime request for testing.

2. Wherever possible, it is important to keep industry involved because they often have standardization procedures in place that would make our standards in place
3. One need to get a working tool and then standardize it is a model. Don't let standardization force you to lose site of your goals
4. A high-speed conductor cable is routinely used on geotechnical ships and would be low cost yet potentially dramatically advance downhole tool deployment. Temperature limits of these cables should be explored.
5. How to streamline tool development from IDEA – PROPOSAL – DEVELOPMENT – TESTING - IMPLIMENTATION
    - a) Leader scientist
    - b) Assemble a working team
        - i) expertise in engr, science, and operation
        - ii) mini-workshop to flush out idea/ feasibility (USSSP ?)
    - c) Develop full proposal for 'small' tool development
        - or work with IMI/TAP/SAS to develop RFP for larger tools/improving assets (sea bed frame, hotwire) to serve the wider community
    - d) Funded proposals – work with open and constant communication between scientists and engineers – make sure the scientific objectives are not compromised
    - e) Integration of project engineers and scientists with engineers experienced with ODP/IODP
    - f) Testing of tools
        - i) land-based studies and ocean trials in existing holes
        - ii) prototype testing
        - iii) Tested on the drillship or MSP
        - iv) Develop a protocol for pre-cruise testing of all new tools
    - g) Implementation
        - i) Tracking of tool performance
        - ii) Develop means for keeping a tool legacy
6. Borehole management
7. Develop technology to conduct cable-to-borehole observatories
8. Seabed frame needs to be investigated – feasibility of facilitating many tools with one new piece of equipment; compatibility with drillship
9. Need to contact appropriate IODP groups early for endorsement. Not a requirement but might help to get SciMP, TAP insights and saying needed technology.
10. Important for linking tool development to a specific drilling objective or target and to the ISP.
11. Make your proposals drilling objective/target specific. How does your tool fit into the overall science goals or program? Gives motivation for building and for timeframe.
12. How do we push an idea up to IMI for funding bigger projects? Potential problem of smearing the science or losing focus.

13. Where are you going to get the engineering support and insights to write to the initial proposal?
14. Need slush funds to get initial designs? NSF supplement? USSSP proposal to get money to write a larger proposal?
15. Tool development: 2/3 is for the design, 1/3 is for getting it to work with the platform
16. Do we create a separate entity for engineering? Overhead, costs, keeping them busy and up to date with the equipment.
17. Bring in experts on a necessity basis. Find the best people for the measurement at hand vs. a single entity.
18. Now we have a list of desired needs that are prioritized. How does a leader emerge to take a specific measurement and get it made? Who argues to IMI/SAS to get it going?
19. How do you differentiate between going from top-down (IMI) and from person-up (NSF)? RFPs from IMI on larger tools?
20. IMI – top down contract: still need scientist/engineering champion to get the right person to get RFP; SAS insights are used to determine priority structure for RFPs
21. Need a leader in all tools so the designers/engineers/operators can go back to somebody with routine questions so tools are continually re-modified.
22. Problems with RFP; there is some flexibility within the RFP. Scientists/engineers who will be using the tool need to be in constant communication with the design.
23. What about when you spec everything out and the clever engineers design exactly what you spec out but doesn't accomplish any of your goals.
24. Need a hero that can assemble a team that is capable of completing all of the desired goals for the specific measurement.
25. Need open communication between engineers and users to make sure that approximations used in design to hinder the desired measurement.
26. Are we trying to implement a matrix management onto top-down management structures? Is this possible?
27. It would be worthwhile to have some clearinghouse of engineering insights for getting the original information/sketch for proposal so PI can demonstrate they understand/have thought about the technical details.
28. How do we create a system that will lead to more success in tool development? Historically we have had more failures than successes.
29. At some point in the IODP structure, we now need to pay for engineering time (shipboard, development, etc). How do we make sure to incorporate this?
30. How do you get individual champion efforts to be linked so each tool is not completely different from others? Ease of use on multiple platforms, ease of swapping in and out, etc. Standardized systems to connect in and out need to be developed. Larger effort through IMI?
31. Need be careful about uniform interfaces; not to exclude tools. Maybe employ a building block approach that is interchangeable. Stress common interchangeable interfaces.

32. Champion -> seed money before going to RFP or full proposal -> then bring team together to get a full proposal…how do you get the team -> then you can develop
33. USSSP money to have pilot meetings to get things rolling (scoping groups) -> get operators to come because they may end up with the contract that evolves on the full proposal
34. Scope groups – have outside expertise to make sure you are not missing things…scientists have what they want to measure, operators and engineers may know things that exist or need to be developed
35. IMI, re-fit funds for development of infrastructure to make new tools available (e.g., seabed frame)…definitely need to push forward improved devices that will allow us to deploy new tools and measurements that we can't get today (0-200 mbsf).
36. At what point on expensive tool development do you look for outside funding (e.g., DOE, MMS) that might be used to continue the charge? Do it early in the process to make sure that the appropriate planning can be made.
37. Seabed frame might be a solution to a lot of tools that have failed in the past. Should explore the capability to use it for expanding our horizons, deploying new tools, making failed tools work.
38. Testing: pressure testing, pre-sea trial requirements for tools, protocols for testing on land and at sea.
39. Develop the technology to connect between fiber optic cables and boreholes. Need to come up with means to test that.
40. iTAP recommended to iSAS that about a week of ship time per year to do engineering tests on separate short legs with the real people who will operate the tool in the real world. Get real sea-test on every tool before it is deployed in a science leg. Plan for this in the schedule.
41. How do you know that two different tools are giving the same measurement? Quality control during testing phases.
42. Hotwire umbilical cord during coring to improve assets…something that doesn't interrupt coring to swap in/out cable for running downhole tools.
43. How do we assess tool performance? Tool legacy. Keep a detailed track record for each tool deployment and it success. Who is in charge of keeping this record, IMI?
44. Borehole management is critical. We need a structure that is easy to access and understand what is going on in what locations. Keep a cradle to grave record.

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Attachment 1 - Workshop Agenda on Downhole Tools in the IODP

Day One - May 24, 2004

Opening: (08:00-08:30) Conveners welcome and introduce participants, and summarize workshop goals.

Session IA: (08:30-10:15) DHTs and the IODP Science Plan (All)
Each theme of the Science Plan will have two leaders. Speakers (*) will describe their component of the Science Plan and what downhole measurements are critical to meeting the plan.
a. 08:30-08:50: The Deep Biosphere and the Subseafloor Ocean (D. Saffer*, M. Lilley)
b. 09:00-09:20: Env. Change Processes and Effects (R. Harris*, B. Price)
c. 09:30-9:50: Solid Earth Cycles and Geodynamics (H. Tobin*, R. Stephen)

(Break)

Session IB: (10:30-12:15): What DHT Measurements are Needed (Working Groups). Summary of session goals by Fisher.
Overview: Thematic working groups (a.,b., and c., above) will meet separately and define DHT measurements and importance to IODP. They will elucidate why DHTs are critical to Science Plan.

Photo: (12:15-12:20): Group Photo

(Lunch, downstairs in cafeteria or nearby) Thematic leaders will merge results of each thematic working group over lunch break

Session IIA: (13:15-14:00) Summary of important DHT measurements (All)
Thematic leaders will present merged results to all.

Session IIB: (14:00-15:30) Current Capabilities and Future Goals (Working Groups)
Thematic working groups will analyze current state of DHT measurements, determine the gaps between our current capability and what is needed to achieve the IODP Science Plan, propose appropriate technologies to achieve particular measurements and establish a matrix of priorities vs. difficulties

(Break).

Session IIC: (15:30-17:30) Identification and Summary of Current Capabilities and Goals: (ALL)
Thematic leaders will present results from working groups. 10 minutes for each thematic leader, and one hour for discussion.
(Evening) Group Leaders/Reporters/and workshop leaders will merge results of thematic working groups.

6:30-7:30 Refreshments

7:30-9:30 Dinner

(Refreshments & Dinner will be at the Franklin Square City Club in their Park View Annex Room and will include a cash bar. The cost for non USSSP-supported participants will be $20.00.)

Day Two - May 25, 2004

Session IIIA: (08:00-09:45) ODP Tool Development and Future Technological Requirements (All)
a. Overview: Case studies of tool development in ODP, Development Issues, Reentry, & Funding:
i. 08:00-08:20: K. Becker* - The Drill String Packer Tool Development and Deployment
ii. 08:20-08:40: K. Moran*, G. Humphrey - Cross Platform, Extreme Borehole Conditions, Common Data Interfaces, and suggestions for improving DHT measurement capability on the riserless vessel.
iii. 08:40-09:00: B. Ussler* - TCP Tool: Development, Deployment, Results
iv. 09:00-09:20: F. Spiess*, D. Foster - Wireline and HOV/ROV reentry DSDP/ODP/IODP holes: technical developments, capabilities, and needs.
v. 09:20-09:40: C. Ruppel* - NSF Perspective on DHT Development and P.I. Responsibilities

(Break)

Session IIIB: (10:00-11:45) How to Achieve Tool Development (Working Groups)
a. Overview: Break two Technical Working Groups: focus on how to achieve desired measurements in a technical sense. What does it take to get where we want to go?
1) Measuring Physical State (e.g. temp, press, chemistry) (Group Leaders: A. Schultz, H. Villinger)
2) Collecting Discrete Samples (e.g. fluid, solids, gasses). (Group Leaders: B. Dugan, M. Kastner)

(Lunch, downstairs in cafeteria)

Session IVA: (12:30-13:30) Recommendations for Technical Process of Future Tool Development (All).
Overview: Presentations by Group Leaders and discussion.

(Break)

Session IVB: (13:30-16:30) Tool Development Process: Recommendations

Overview: Workshop Leaders will lead group discussion to focus on larger scale issues of tool development process. What key steps can we recommend to achieve technology development in an efficient manner that achieves the ISP? Address possible mechanisms for funding and for interaction between individual P.I.'s, contractors, funding organizations.

(End of workshop for participants)

Attachment 2

Table 8: ODP and 3rd Party Tools /Developmental Tools in the ODP

Tool Acronym	Status	Description.
DVTP	ODP	The Davis-Villinger Temperature Probe (DVTP) is designed to take heat-flow measurements in semiconsolidated sediments that are too stiff for the Advanced Piston Corer Temperature (APCT) tool. Coring must be interrupted to take a temperature measurement. The DVTP can also be run on wireline and hung below the bit (when the bit is off bottom) as a temperature logging tool for borehole fluids. http://www-odp.tamu.edu/publications/tnotes/tn31/cork/cork.htm
PCS	ODP	The Pressure Core Sampler (PCS) is capable of retrieving core samples from the ocean floor while maintaining in situ pressures up to 689.7 bar (10,000 psi). The primary application of the PCS is to recover in situ hydrates. The PCS is free-fall deployable and wireline retrievable. http://www-odp.tamu.edu/publications/tnotes/tn31/pcs/pcs.htm
APCT	ODP	The Advanced Piston Corer Temperature (APCT) tool is an instrumented version of the coring shoe that is run on the Advanced Piston Corer (APC). It is deployed in soft sediments to obtain formation temperatures to determine the heat flow gradient and is essential in determining hydrocarbon maturity for pollution prevention purposes. http://www-odp.tamu.edu/publications/tnotes/tn31/apct/apct.htm
APC	ODP	The APC is a hydraulically actuated piston corer designed to recover relatively undisturbed continuous 9.5 m long oriented core samples from very soft to firm sediments that cannot be recovered well by rotary coring. http://www-odp.tamu.edu/publications/tnotes/tn31/apc/apc.htm http://www-odp.tamu.edu/publications/tnotes/tn10/10toc.html
BIH	ODP	Borehole Instrument Hanger http://www-odp.tamu.edu/publications/tnotes/tn31/bih/bih.htm
CORK	ODP	Circulation Obviation Retrofit Kit http://www-odp.tamu.edu/publications/tnotes/tn10/10toc.html
DIC	ODP	Drill In Casing http://www-odp.tamu.edu/publications/tnotes/tn31/dic/dic.htm
XCB	ODP	Extended Core Barrel http://www-odp.tamu.edu/publications/tnotes/tn31/xcb/xcb.htm
APC-Methane	ODP	Measures conductivity, pressure, and temperature of headspace on an APC core. (Ussler/Paull/ODP)—tracks phase changes as it comes out of water. Primarily used for hydrates. (D. Schroeder, personal comm., June 2003)
WSTP	9	Water Sampler Temperature Probe http://www-odp.tamu.edu/publications/tnotes/tn10/10toc.html

Tool Acronym	Status	Description.
IWS	10	Instrumented water sampler (cross between the Fissler water sampler and the DVTP-P). Run once (D. Schroeder, personal comm., June 2003)
MWD	11	Drilling Sub—for drilling dynamics (wt on bit, torque on bit, annulus pressure, and right on top of bit…can pull a core through it. Deployed once). (D. Schroeder, personal comm., June 2003)
DSP	12	Drill String Packer For Formation Testing http://www-odp.tamu.edu/publications/tnotes/tn10/10toc.html
BFS	3rd Party/ deve	Borehole Fluid Samplers http://www-odp.tamu.edu/publications/tnotes/tn10/10viiib.html
GeoProps	3rd Party/ devel.	Geoprops Tool Mechanical and Hydrogeological properties of sediments
LastI LastII Last2	3rd Party/ deve	Lateral strain measurement http://www-odp.tamu.edu/publications/tnotes/tn10/10viiib.html
Flow Meter & Logging Cable Go-Devil	3rd Party/ deve	Allows concurrent logging of pressure and flow rate in zone isolated by drill string packer http://www-odp.tamu.edu/publications/tnotes/tn10/10viiib.html
Active Fluid Sampling	3rd Party/ deve	Schlumberger rft device or Lamont-Doherty water sampler device http://www-odp.tamu.edu/publications/tnotes/tn10/10viiib.html

Attachment 3 - List of Attendees

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Attachment 4 - Working groups for Day One and Day Two

Day One – May 24, 2004

The Deep Biosphere and the Subseafloor Ocean
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K. Michelle Edwards, University of Miami
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Adam Schultz, College of Oceanic & Atmospheric Sciences, Oregon State University
Fred Spiess, UCSD/SIO/MPL
Geoff Wheat, University of Alaska Fairbanks

Environmental Change Processes and Effects
Leaders: R. Harris, B. Price

Bill Ussler, Monterey Bay Aquarium Research Institute
Alexei Milkov, British Petroleum
Brandon Dugan, USGS and Rice University
Bill Gwilliam, National Energy Technology Laboratory
Nathan Bramall, U.C. Berkeley
Gilles Guerin, LDEO/Borehole Research Group – Columbia University
Richard von Herzen, WHOI

Solid Earth Cycles and Geodynamics
Leaders: H. Tobin, R. Stephen

Keir Becker, University of Miami – RSMAS
Derek Elsworth, Penn State University
Sean Gulick, University of Texas Institute for Geophysics
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Elizabeth Screaton, University of Florida Geological Sciences
Heinrich Villinger, University of Bremen
David Huey, Stress Engineering Services, Inc.

<u>Day Two – May 25, 2004</u>

Measuring Physical State (e.g. temp, press, chemistry)
Leaders: A. Schultz, H. Villinger

Keir Becker, University of Miami – RSMAS
Matthew Chartier, Massachusetts Institute of Technology
Derek Elsworth, Penn State University
Gilles Guerin, LDEO/Borehole Research Group – Columbia University
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Martin Heesemann, University of Bremen, Dept. Earth Sciences
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Richard von Herzen, WHOI
David Huey, Stress Engineering Services, Inc

Collecting Discrete Samples (e.g. fluid, solids, gasses)
Leaders: B. Dugan, M. Kastner

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