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Woods Hole Oceanographic Institution

SeisCORK Engineering Design Study

by

Ralph Stephen, Tom Pettigrew, Robert Petitt, Jr.

Woods Hole Oceanographic Institution
Woods Hole, MA 02543

May 2006

Technical Report

Funding was provided by the National Science Foundation under Contract Nos. OCE-0221832 and OCE-0450318.

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Executive Summary

The one line "science justification" for SeisCORKs is: "we want to make simultaneous and co-located seismic, pressure, temperature, pore water chemistry and pore water biology measurements in the seafloor" (Figure 1).

The idea of putting seismometers on CORKs to install them in the seafloor has a broad range of applications. To provide some focus to the work, we are targeting the Juan de Fuca Hydrogeology program. In previous CORK experiments on and near the Juan de Fuca Ridge Earl Davis and others have observed pressure transients correlated with seismic events. The hypothesis is that the seismic events change the stress in the rock which affects the pressure on fluids in the pores of the rock. So borehole fluid pressure (and chemistry and biology) may provide precursors to the seismic activity. This is exciting. We want to see the small events (nano- and micro-earthquakes, a nano-earthquake is comparable to breaking a baseball bat) for three reasons: 1) After an event fluid may flow in the formation in response to the changing stress regime. Down to what magnitude of event do the pressure transients in the well respond? 2) Fluid flow causes small earthquakes. One mechanism for example is by changing the temperature of the rocks which expand and contract, altering the stress regime. We want to look for this fluid flow. 3) Laboratory studies of rock deformation show that shear fracture is preceded by the coalescence of interacting tensile microcracks which are observed as "acoustic emissions". By placing high frequency geophones next to faults it may be possible to observe these "acoustic" precursors to rock failure. The "acoustic" events may occur for other reasons as well but, since in reservoirs on land they appear in the frequency band 400-800Hz, no one has yet tried to observe them on oceanic crust.

Passive micro seismic monitoring is becoming an established technique in petroleum reservoir monitoring and characterization and we can exploit tools and techniques that are already being developed for the petroleum industry.

Observing the seismic activity with OBS's has four problems: 1) The seafloor is a noisy seismic environment; the borehole is quieter. This let's you see smaller earthquakes on borehole seismometers. 2) The borehole sensors are closer to the earthquake events, the sound doesn't travel as far, there is less propagation loss and you see smaller events, 3) The systems we are looking at have a passband from about 30-1000Hz compared to a typical OBS passband of 1-100Hz. Based on the petroleum reservoir experience, the very small earthquakes emit their energy in the higher band, and 4) The coupling of OBS's sitting in the seafloor is often too poor to observe horizontally polarized shear waves. Borehole sensors are usually better coupled.

SeisCORKs also obviate the considerable logistical, administrative, and clearance difficulties associated with scheduling a shooting ship to run offset VSPs. The offset VSP could be run any time after the instrumentation is installed.

The specific goal of this study was to spell out the SeisCORK concept in sufficient detail that we could assign tasks to specific groups and get realistic cost estimates. There are at least three possible configurations for SeisCORKs in riserless boreholes:

1) single sensor below the CORK-II - electrical cable replacing the Spectra cable,
2) a separate array of sensors that we can just wash-in or mud-drill into sediments next to the CORK hole, and
3) a dedicated SeisCORK hole with sensors on the outside of various sections of casing.

We resolved to go with configuration 2C for the SeisCORK program on Juan de Fuca in 2008. This would consist of four three-component sondes at 50m separation lowered on the outside of 4.5casing (or drill pipe) inside 10-3/4casing run to just above or just into basement (about 250m) at the Juan de Fuca Hydrogeology Site (near ODP Site 1027 and the Leg 301 operations area).

Our goal is to develop an engineering design for SeisCORKs that will be compatible with existing CORK systems which acquire data in an autonomous recording mode and that also will be compatible with the new real-time Ocean Observatory Infrastructure.

Introduction

Although the idea of combining seismometers with other CORK measurements (SeisCORKs, Figure 1) is rather obvious, our concepts of how this might actually happen started to gel at the "Workshop on Linkages Between the Ocean Observatories Initiative and the Integrated Ocean Drilling Program" Held in Seattle, WA on 17-18 July, 2003. Earl Davis presented observations of pressure changes in CORKs associated with regional seismic activity and was proposing increasing the sampling rate on the pressure sensors to observe the "seismicity" in the pressure (acoustic) record. This sampling rate (frequency band) overlaps the short period seismic band (1-100Hz) traditionally observed on Ocean Bottom Seismometers and VLF borehole seismic systems. By measuring the three components of ground motion rather than just the pressure we could compare the borehole seismicity directly to other seismic observations and we could use techniques such as compressional and shear wave arrival times and polarization analysis to locate the small, local events that might be associated with fluid flow.

Further progress was made during the Downhole Tools Workshop held in Washington, D.C. on May 24-25, 2004 and an Associated CORK workshop on May 26. The scientific merit of combining sensors was taken for granted and the challenge was to merge the CORK community (largely ODP/IODP), with the high frequency borehole seismology community (largely hydrothermal reservoir and petroleum monitoring work on land) and the long-term seafloor observatory community (oceanographic research). Under funding from an NSF SGER grant we ran a workshop in Houston on November 15-16, 2004 to identify potential vendors of appropriate borehole seismic gear. In the process we learned that significant progress was being made in petroleum reservoir and hydrothermal system work (on land) by monitoring fluid flow in the band 5-1000Hz (a decade higher in frequency than originally planned).

We held a meeting at the Sercel Downhole Division in Les Ulis (near Paris), France on November 15, 2005 to develop a SeisCORK Engineering Design Study. We are in the process of bringing together the necessary expertise to actually build and install a SeisCORK system and we anticipate submitting a proposal to NSF-IODP for this project by the February 15, 2006 deadline. We regret that SeisÇORKs were not passed through the IODP planning process sooner. Although we have been proposing to do SeisCORKs on the Juan de Fuca hydrogeology program since 2003, only recently (November 2005) have we had a realistic development plan.

General Science Goals and Justification for Borehole Seismology in the Seafloor

Borehole measurements will play an important role on IODP. Experience on the previous drilling programs has indicated that there are three basic styles of borehole geophysical measurements: 1) conventional well logging, 2) two-ship borehole experiments (such as offset VSP's that require the drill ship to be on site) and 3) long-term borehole experiments (CORK's, strain installations, ION broadband seismometers, etc). All three categories apply to both riser and non-riser holes. In addition to enabling new styles of borehole geophysical studies, the new observatory infrastructure (ORION) can facilitate and expand the utility of some conventional borehole measurements that are usually made from the drill ship. Most of what follows is based on borehole seismic experiments of various kinds but other borehole geophysical measurements have similar issues.

Validating Surface Seismic - Scales of Observation

Few question the wisdom of drilling a borehole to provide "ground-truth" to the analysis and geological interpretation of seismic and other data acquired at the surface. Of course this is one of the primary motivations behind past, present and future ocean drilling programs. Because of the large differences in the scales of observation, however, the section intersected by the well (with observations from cores at horizontal scales less than 6cm and observations from well logs at horizontal scales less than a few meters) often does not correlate well with the seismic section (with horizontal scales of 100's of meters or more). For this reason, regardless of the geological scientific justification for drilling there is ample geophysical scientific justification for normal incidence Vertical Seismic Profiles (VSPs) [Balch and Lee, 1984; Gal'perin, 1974].

Validating Surface Seismic - Interference and Multi-path Effects

There have been many examples of the importance of normal incidence and offset VSP's on the DSDP and ODP programs including the origin of mid-sediment reflectors (from interference effects in thin layers) [Bolmer, *et al.*, 1992], the nature of Layer 2/Layer 3 boundary in oceanic crust [Detrick, *et al.*, 1994], and the investigations of gas hydrate deposits [Holbrook, *et al.*, 1996]. In these cases and others it has been very useful to acquire VSP's using sources with similar bandwidth to the seismic sources in order to resolve the interference and multi-path effects that often affect the character of reflections on seismic record sections. The thorough ground-truth that boreholes and VSP's provides often demonstrates the importance of sophisticated seismic techniques such as true amplitude processing, amplitude versus offset (AVO) analysis, 3-D seismic, three-component seismics (with polarization analysis to study the effects of anisotropy) and pre-stack migration. Normal incidence VSP's provide a direct analog to the "normal incidence reflection profile" which is a common step in the multi-channel data analysis process. Offset and walkaway VSP's are often just as important as normal incidence VSP's in validating surface seismic because of shear waves (which are not usually excited at normal incidence but are frequently observed on offset profiles), other amplitude versus offset effects, and anisotropy.

Extrapolating the Geological Structure Away from the Well

Knowing how the seismic wave field correlates with the geological structure at the borehole gives more credibility to interpretations of the seismic data in the same region but away from the borehole [Stephen, 1988; Stephen, *et al.*, 1980]. On NantroSeize for example, significant lateral heterogeneity exists along the decollement reflection (as indicated by "bright spots") but it would be prohibitively expensive to directly sample each category of reflection along the decollement either along or across strike. There is no alternative but to use seismic record sections to interpret the subduction zone region, so we should understand the evolution of the seismic wavefield at the few borehole locations that we can afford. Results from detailed studies at the borehole can then be extrapolated throughout the region.

Monitoring Time-Dependent Effects

The notion of "time lapse" seismology goes back at least 20 years when Aki proposed the method for analysis of hydrofracturing in petroleum and geothermal wells [Aki, *et al.*, 1982]. The character of the seismic reflections in subduction zones can vary with time for at least three reasons: 1) when the state of stress on a horizon of interest varies with time a) as a result of an earthquake on the fault (over seconds), b) as a result of an earthquake in the region which changes the regional stress pattern (Coulomb stresses, over days, months and years), or c) as a result of slow deformation (over tens of years); 2) when the drilling process itself changes the *in situ* pressure conditions on the fault by relieving whatever pressure anomaly may have originally existed (over hours to years); and 3) when the seismic acquisition system changes. Reasons 1) and 2) have significant geological consequences and will affect the application of seismic methods to understanding subduction zone processes. Reason 3) is a common phenomenon. It is often very challenging to get similar seismic profiles from two different but similar surveys at the same place. There are a lot of reasons for this, including changes in small scale lateral heterogeneity and changes in frequency and wavenumber content of the observed field, but it is good practice in time lapse surveys to change as few aspects of the acquisition system as possible.

Some Typical and Proposed Borehole Seismic Experiments

1) Conventional Well-Logging and Normal Incidence VSP's

It is unclear at the moment how conventional well logging will be run on the IODP platforms. Well logging is very important because the core recovery, particularly in hard formations is incomplete. Also cores are frequently disturbed and logging provides measurements of conditions in situ. Clearly "routine" logging needs to be carried out at various stages of the drilling process. For example, some measurements need to be made in the open hole before casing is installed. We recommend that normal incidence VSP's be carried out with the borehole seismometer clamped in the open hole before the casing strings are installed.

Since our best images of the interior of the earth are based on seismic methods, one important goal of many deep boreholes is to provide ground truth and to calibrate seismic record sections. Borehole seismology is one of the few tools we have to link the borehole scale (defined by cores and well logging) to the regional scale (defined by multi-channel and refraction seismics). Also given the significant lateral heterogeneity observed along strike in all subduction zone environments, extrapolating the borehole results along the subduction zone will require a thorough knowledge of how the reflected seismic wave field is created and how it relates to the borehole observations. Normal incidence VSP's have proved very useful in the past in correlating core and well log observations with regional multi-channel and single-channel seismic records.

2) Two-ship Experiments and Offset VSP's

Offset VSP's are another style of borehole seismic experiment that have proved useful in the past particularly to define shear wave velocity structure (since shear waves are not usually generated at normal incidence). A second ship to fire seismic sources out to ranges of 30km or more is used in addition to the drill ship which records the borehole seismic data. Offset VSP's have been used in gas hydrate and crustal and upper mantle anisotropy studies [Shearer and Orcutt, 1985; Stephen, 1985]. Since the borehole equipment is very similar to the VSP tools used in conventional logging (usually a three component seismometer instead of a single vertical component seismometer), it is often convenient, but not always necessary, to run the offset VSP's while the drill ship is on site. A permanent borehole array installed as a component of a borehole observatory would facilitate repeat offset VSP's. The borehole seismic data would be acquired by the observatory infrastructure, and only a shooting ship would be needed.

3) Time-lapse VSP's

Time lapse VSP's require dense strings (typical sensor separation of 10m or less) of VLF sensors. These can be particularly valuable in subduction zone settings since as the state of stress and fluids along faults changes so will the character of the seismic reflections. Since these reflections are often the consequence of complicated interference and multi-path effects VSP data is often useful in understanding what changes in *in situ* properties are causing changes in the seismic data. Also since VSP data provides the link from borehole to MCS scale, it is an important tool in extrapolating the results from the borehole throughout the region. If a dense string is permanently deployed in a borehole, it can easily be used for offset as well as normal incidence VSP's.

4) Long-term Borehole Experiments and "Spin-off"Projects

There is ample geophysical scientific justification and an excellent historical track record both in the petroleum industry and in deep sea drilling for the above VSP projects. Any drilling program to seismic targets in subduction zones should include normal incidence VSP's, offset and/or walkaway VSP's and time-lapse VSP's. However when we start to consider the necessary infrastructure for time-lapse VSP in particular there are other spin-off scientific projects that could be carried out. The infrastructure for long-term borehole seismology is similar to that for CORK's and strain meters. Additional long-term borehole seismic experiments also fall into a number of categories:

a) Monitoring and locating micro-earthquakes

For time-lapse VSP discussed above, it would be best if we had a permanent array of closely spaced VLF (about 5-100Hz), three-component sensors either in the well or in the adjacent casing. Once the array is in place why only use it periodically for VSP's? It would make sense to record the data continuously to detect micro-earthquake events. The vertical array would help to improve the locations of events already being observed by land surface and seafloor seismometers, but also being closer to the fault and potentially in a lower noise environment, the vertical array may detect smaller events than the other systems. Passive micro-earthquake monitoring would be a natural extension of the VSP infrastructure. (A permanent array just for seismic monitoring would not need the same sensor spacing as a permanent array for VSP's. Some modeling would be required but perhaps only a sensor every 50m's for monitoring versus a sensor every 5-10m's for VSP.)

b) Cross-well tomography

Also with a permanent VSP array in place, there is the potential to carry out cross-well seismic tomography if a second hole is drilled near-by. In a tomography experiment seismic "volume" anomalies are detected using transmitted paths. Sharp discontinuities which are necessary to generate reflections from "surfaces", for multichannel surface seismic surveys for example, are not required for tomography. Although it is unlikely that a hole would be drilled just for cross-well tomography, it is possible that closely spaced holes may be drilled for other cross-well experiments (water sampling, permeability, etc) or for sampling different sections along a fault (bright versus dull spots for example).

Dense strings (as for time-lapse VSP's) of VLF sensors provide the data necessary for cross-well tomography. To work properly the wells must be drilled deeper than the horizons of interest and they need to be drilled close together (separations comparable to depths) to get adequate ray coverage. Too often wells stop at the horizon of interest and cross-well tomography becomes difficult to implement.

c) Broadband Seismometer Installations (ION)

Broadband seismometers (typically 0.001-10Hz) in boreholes on the ocean floor have been proposed by ION to extend the global seismic coverage to the ocean basins. These installations are usually justified on the basis of global studies (for whole earth tomography, for example), but they can also be used in regional studies to improve earthquake locations and source mechanisms in critical areas such as offshore Japan or California. It would make sense for any seismic monitoring effort in a subduction zone to include a strong motion and broadband seismometer. These sensors would provide direct measurements in the near-field of any earthquake activity along the fault being drilled. Being in a borehole they also would have a better ambient noise environment and would have improved coupling for observing local, regional and teleseismic events.

The proposed work is innovative because merging seismic technology with hydrogeological and microbiological technology on CORKs has not been attempted before. CORKS have evolved as a scientific tool in the riserless drilling community and are distinctly different from anything in the petroleum exploration community. Whether or not we have the capability to merge these instruments on CORKs will have implications for long-term monitoring strategies for riser boreholes as well as for observatory networks (ORION/OOI). "Do we need separate boreholes for seismology and hydrogeology/microbiology or can we make simultaneous measurements in the same borehole?"

Reservoir Monitoring in the Petroleum and Geothermal Energy Industries

The SeisCORK concept builds on some very exciting recent developments in the petroleum reservoir monitoring business where micro- and nano-earthquakes have been used to track fluid flow, hydrofracturing, subsidence and other geological processes associated with reservoirs. These techniques have a logical extension to scientific problems where we seek to observe fluid flow due to pressure changes associated with earthquake activity. The key to the success in passive reservoir monitoring has been to acquire data in the frequency band 100-1000Hz about an order of magnitude higher than the traditional OBS band of about 5-100Hz. At these frequencies seismic energy is rapidly attenuated so it is necessary to place the sensors down boreholes in order to get as close as possible to the relevant quakes.

Typical permanent downhole sensors used for this work with some examples of data are discussed by Bathellier and Czernichow (1997). Paulsson et al (2004) review some of the advantages of using dense arrays of three-component high-frequency borehole sondes in imaging reservoirs and doing time-lapse seismics with controlled sources. Rod et al (2005) review a case history from the North Sea where fractures are mapped based on micro-earthquake activity. In reservoir monitoring and characterization, permanent borehole sensors in 4-D time lapse seismics have been provento be essential [Calvert, 2005; McGillivray, 2005; O'Brien, *et al.*, 2004].

An example of a permanent downhole data acquisition system in a petroleum reservoir is the Al Noor reservoir in South Oman [Bell, *et al.*, 2000]. This system consists of tubing conveyed triaxial geophones and pressure and temperature gauges. In this field hydraulic fracture stimulation is used to increase production rates from micro-Darcy rock. Micro-earthquake locations are used to assess flow barriers and dynamic reservoir behaviour. Micro-earthquake events in the band 500-800Hz gave different and complementary information to the events observed in the 10-100Hz band.

Good reviews of microseismicity associated with geothermal and petroleum reservoirs are presented in the MIT Theses by Rieven [Rieven, 1999] and Sze [Sze, 2005]. Early work was done at the Fenton Hill, New Mexico geothermal site by Los Alamos National Laboratory [Phillips, *et al.*, 1997, for example], the Hengill-Grensdalur volcanic complex in Iceland [Foulger, 1988, for example], the Geysers geothermal area in California [Ross, *et al.*, 1996, for example], and the Coso geothermal area in California [Fialko and Simons, 2000, for example].

A Site Specific Scenario for the Juan de Fuca Hydrogeology Program

Science Goals

The one line "science justification" for SeisCORKs is: "we want to make simultaneous and co-located seismic, pressure, temperature, pore water chemistry and pore water biology measurements in the seafloor." The idea of putting seismometers on CORKs to install them in the seafloor has a broad range of applications. To provide some focus to the work, we are targeting the Juan de Fuca Hydrogeology program. In previous CORK experiments on and near the Juan de Fuca Ridge Earl Davis and others have observed pressure transients correlated with seismic events. The hypothesis is that the seismic events change the stress in the rock which affects the pressure on fluids in the pores of the rock. So borehole fluid pressure (and chemistry and biology) may provide precursors to the seismic activity. This is exciting. We want to see the small events (nano- and micro-earthquakes, a nano-earthquake is comparable to breaking a baseball bat) for three reasons:

1) After an event fluid may flow in the formation in response to the changing stress regime. Down to what magnitude of event do the pressure transients in the well respond?

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Andy Fisher, who has been leading the Juan de Fuca Hydrogeology Program, has written supporting letters for the SeisCORK concept (Appendix 1).

The Hydrogeologic Architecture of Basaltic Oceanic Crust

The investigation of the hydrologic architecture and deep biosphere of basaltic oceanic crust is an exciting initiative of the new Integrated Ocean Drilling Program (IODP)[Integrated Ocean Drilling Program, 2001, pages 18-33]. IODP began this investigation on the Juan de Fuca Ridge in the eastern Pacific Ocean. The goal of the first leg of IODP (Leg 301) was to study the compartmentalization, anisotropy, microbiology, and crustal-scale properties on the eastern flank of Juan de Fuca Ridge. A detailed discussion of the scientific goals and drilling and instrumentation strategy is given in the Leg 301 Prospectus [Fisher, *et al.*, 2004], the Leg 301 Preliminary Report [Shipboard Scientific Party, 2004] and the Proceedings of IODP for Leg 301

[Fisher, *et al.*, 2005]. To provide some background for this proposal the Introduction of the Prospectus is repeated here:

"Thermally driven fluid circulation through oceanic lithosphere profoundly influences the physical, chemical, and biological evolution of the crust and ocean. Although much work over the last 30 years has focused on hot springs along mid-ocean ridges, global advective heat loss from ridge flanks (crust older than 1 Ma) is more than three times that at the axis [Parsons and Sclater, 1977; Stein and Stein, 1992] and the ridge-flank mass flux is at least ten times as large [Elderfield and Schultz, 1996; Mottl and Wheat, 1994]. Ridge-flank circulation generates enormous solute fluxes, profoundly alters basement rocks, supports a vast subseafloor biosphere, and continues right to the trench, influencing the thermal, mechanical, and chemical state of subducting plates [Alt, 1995; Ranero, *et al.*, 2003, for example]. These processes crosscut all three primary themes motivating the Initial Science Plan for the IODP.

"Despite the importance of fluid-rock interaction in the crust, little is known about the distribution of hydrologic properties; the extent to which crustal compartments are well connected or isolated (laterally and with depth); linkages between ridge-flank circulation, alteration, and geomicrobial processes; or quantitative relations between seismic and hydrologic properties. **IODP Expedition 301 comprises the first part of a two-expedition experiment** to explore these processes and relations and to address topics of fundamental interest to a broad community of hydrogeologists working in heterogeneous water-rock systems: the nature and significance of scaling phenomena and the applicability of equivalent porous-medium representations of discrete fracture-flow processes. Expedition 301 benefits from operational and scientific achievements from Ocean Drilling Program (ODP) Leg 168 [Davis, *et al.*, 1997], which focused on hydrothermal processes within uppermost basement rocks and sediments along an age transect across a young ridge flank. The primary goals of Expedition 301 include replacement of long-term observatories established in two reentry holes during Leg 168 and establishment of two new observatories, creating a three-dimensional observational network in upper oceanic basement. These observatories will be used to passively monitor thermal and pressure conditions in basement and to collect long-term chemical and microbiological samples. **During a later expedition, researchers will use these observatories for a series of multidisciplinary crustal-scale experiments.** Other primary goals of Expedition 301 include coring, sampling, and short-term downhole measurements. Secondary objectives include drilling, coring, and sampling one or more holes in a region of known hydrothermal seepage, where sediment thins above a buried basement ridge, and drilling, coring, and sampling a much thicker sediment section to the east, where basement temperatures and alteration should be more extreme."

Notes on Juan de Fuca Hydrogeology Program

The Juan de Fuca Hydrogeology Program consists of three drilling legs and associated ROV cruises (Figure 2). The first drilling on the Eastern flank of the Juan de Fuca Ridge was carried out on ODP Leg 168 and this was followed-up by drilling on IODP Leg 301 in August-September 2004. A second IODP leg is planned in 2008 to conduct the first multidimensional, cross-hole experiments attempted in the oceanic crust, including linked hydrologic, microbiological, seismic, and tracer components [Fisher, *et al.*, 2005; Shipboard Scientific Party, 2004].

Figure 3 [Shipboard Scientific Party, 2004] summarizes the holes drilled on Leg 168 as a transect of the Juan de Fuca Ridge Flank eastward from the Endeavour Segment. On Leg 168 holes were drilled at Sites 1023 to 1031, with re-entry cones and CORKs installed at Sites 1024, 1025, 1026 and 1027. On Leg 301 the CORK in Hole 1026B was replaced and CORKs were installed in new Holes U1301A and U1301B, both near 1026 (Figure 4). So the region around Site 1027 is an intensive study area (Figure 5) and is a potential node on the Neptune Canada offshore-cabled observatory (Figure 6). Borehole observatories like SeisCORK are also an integral component of the planned regional cabled observatory in the US, Neptune (Figure 7). The third drilling leg is planned for 2008 and it will replace the CORK in 1027C and drill and install a packer at a new site, SR-2, between Sites 1026 and U1301 on Second Ridge (Figure 8). Cross-well packer and tracer experiments will be conducted between these four close spaced CORKed holes. A proposal was submitted to NSF for the February 15 target date to develop a SeisCORK to be deployed next to SR-2 to monitor seismic activity associated with the hydrologic experiments. An APL for a dedicated hole for the SeisCORK installation was submitted to the IODP-MI for the April 1, 2006 deadline.

A future expedition to Juan de Fuca will include an offset-VSP to assess seismic velocity anisotropy and heterogeneity. If a SeisCORK is installed in Summer 2008, it would be a natural receiver for the offset VSP. It would not be necessary to coordinate the shooting ship schedule with the drill ship. The shooting could be done anytime after the SeisCORK is installed.

The following notes on the Expedition 301 VSP have been excerpted from the leg proceedings [Expedition 301 Scientists, 2005]. "Expedition 301 included a conventional vertical seismic profile (VSP) experiment to help assess interval velocities and identify gross seismic layering in the upper crust. The conventional VSP used one or more geophones clamped within an open or cased hole and a seismic source at the surface. They used the three-component Well Seismic Tool (WST) and an air gun source run from the drillship. Conventional VSP data from Sites U1301 and SR-2 may allow us to assess earlier interpretations of a seismically distinct boundary at 600 m into basement based on multichannel seismic (MCS) data (e.g., Davis et al., 1996). "

"Even though the WST checked out several days prior to deployment, there were problems getting the tool to respond on deck prior to running in the hole. The back-up WST tool was deployed instead. While running in the hole with this tool the arms appeared to keep opening. The deployment took 2 h to reach the seafloor because of the tool's light weight. On several occasions descent was stopped to close the arm. The initial deployment speed was ~1000 ft/h, and this increased to 7700 ft/h with depth. Based on caliper observations, three potential intervals were identified for WST stations. Clamping and data were recovered at depths of 3075, 3050, and 3025 mbrf.

While pulling out of the hole they slowed down to ~2500 ft/h to allow the rig floor crew to work on the AHC and then subsequently increased the speed to ~9000 ft/h. At the rig floor they noticed that at least one arm was fully extended although it had been previously closed before entering the pipe. In support of the VSP program the generator injector gun was used. The gun configuration consisted of a 45 in3 generator volume, a 105 in3 injector chamber volume, and a total pressure of 2000 psi. Data were recorded at 1 ms sampling interval, and the monitoring hydrophone was attached to the generator injector gun, which was placed 2 m below sea level. The delay time used for all shots was 40 ms, and the recording length was 5 s with a starting point at 0 ms. At 1500 h on 2 August the logging sheaves were rigged down and the wireline logging program in Hole U1301B was completed." This VSP sounds like a "check shot survey".

Scenarios

The initial scientific focus for SeisCORKs is the Juan de Fuca drilling program in 2008 at the off-axis sites near IODP SR-2. The "new" riserless drill ship is scheduled to work in this area in 2008. The goal of the meeting with Sercel on November 15, 2005 was to define at least three scenarios of borehole seismic installation that could be used on the Juan de Fuca drilling. The earliest we could expect funding would be July 1, 2006. We targeted being ready for an installation from the drill ship by January 1, 2008. The IODP Guidelines for Third Party Tools (Appendix 2) requests that all acceptance criteria be met six months before the cruise. Could we do all this in 18 months including component laboratory acceptance tests, an installation rehearsal, system tests (off the dock at WHOI and in deep water (4,000m) off WHOI or SIO), and a coupling test in a wet borehole with 10-1/2inch casing (eg Pinon Flat Observatory in CA)?

Assuming that instrumenting any deep riser holes (such as the NantroSEIZE 6km hole off Japan) would be a separate effort, there are three basic types of borehole seismic installation for riserless holes: 1) adding a single open-hole seismometer at the bottom of a CORK-II by replacing the Spectra cable with an electro-mechanical cable, 2) washing (or mud drilling) a string of sensors into soft and semi-indurated sediments by placing the sensors on the outside of 4-1/2inch casing, and 3) drilling a dedicated riserless borehole with sensors on the outside of each casing section (where they can be coupled to the formation by collapsing sediment or by cement or possibly by bow-springs).

Juan de Fuca holes are typically 320m deep with about 250-265m of sediment in about 2500m water depth. In IODP in general the focus would be on deployments in wells that are less than 2000m deep (typically 300-600m below sea floor) in water depths up to 5500m with sediment thickness of 250-500m. These holes are riserless (no BOP - Blow-out Preventer) and are generally left with a re-entry cone about 4m in diameter with 10-3/4" casing from the cone to upper basement and open hole below that. (The top of the IODP standard re-entry cone is actually an octagon inscribed inside a 12ft diameter circle.) Pressure housings, cables and connectors should be designed to operate to depths of 7500m (750atm or 11,250psi in water). Typical temperatures in the upper basement at the Juan de Fuca sites are less than 70°C. A target design specification can be set at the military spec for solid state chips of 125°C.

In the APL we described two scenarios for installing a prototype SeisCORK on the Juan de Fuca Hydrogeology Program in Summer 2008. In order not to jeopardize the already complex CORKs, both scenarios involve installing a SeisCORK in a separate, dedicated hole.

The first scenario, about three days, involves drilling a single-bit hole in the sediments (about 250m) and dropping a free-fall funnel with a short casing. We could then re-enter this hole with the SeisCORK and lower it through the open-hole into the sediments just above basement. The second scenario, about a week, requests drilling a dedicated re-entry hole with a standard cone and cased and cemented into upper basement. This takes more time than the first scenario and is more expensive but since the SeisCORK is installed within casing there is less risk. Also the bottom sensor on the SeisCORK could be installed in the upper basement, which would be a useful reference for future experiments. In either scenario we are requesting a hole in the Leg 301 operations area, near (within 50m of) ODP Site SR-2.

Extendability

Although the focus of our immediate planning is the Juan de Fuca Hydrogeology Program in 2008, we should keep in mind that there are many other potential applications of "SeisCORKs" such as drilling at Endeavor Segment (the ridge axis node on the Neptune Canada cable) or Barkley Canyon (the hydrates site on the continental margin on the Neptune Canada node). Since April/05 there have been other programs interested in the SeisCORK concept. These include NanTroSEIZE and SCIMPIs. The NanTroSEIZE program is a large multi-phase project to study earthquake activity in the Nankai trough off Japan. There will be multiple "non-riser" holes (most likely drilled by a ship like the JOIDES Resolution) and at least one very deep (6km below seafloor) hole (drilled by the new Japanese "riser" vessel, Chikyu). SCIMPIs are a concept developed by Kate Moran at URI to "wash-in" sensors into soft sediment. Her program is targeting a test at the MBARI borehole test site (MARS) and an installation on Hydrate Ridge (off Oregon). Although the focus of our Spring proposal will be the Juan de Fuca drilling, it would be nice to develop a system that could meet the science objectives of the other projects. A modular system with different interchangeable components depending on hole conditions, casing scenarios and science goals, is an excellent concept. Although the primary science goal is micro- and nano-earthquake monitoring, if possible, we should think about installing permanent arrays suitable for VSPs and time-lapse VSPs.

The deepest hole so far in ocean crust (about 2km) had bottom hole temperatures of 200ºC. Many seismic installations can be satisfied with a temperature spec of less than 125ºC, but there may be individual sites where we need at least some sondes at 175ºC.

Fit with the Initial Science Plan Objectives

Using boreholes for long-term measurements after the drill ship has left has become increasingly popular over the past twenty years. The major science programs that operate in this mode include hydrogeological and biogeochemical measurements in the oceanic crust and deep biosphere (Initial Science Plan, ISP pages 18-33) as well as borehole seismic installations to study solid earth cycles and geodynamics (ISP pages 53-70). Borehole observatories for a broad range of measurements are an integral part of many programs such as the seismogenic zone initiative (ISP Figure 36) and CORKS (ISP Figure 2)(ISP page 82). One of the "Principles of Implementation" in the ISP (ISP page 73) is "Coordination with Observatory Sciences - IODP plans to continue the productive collaboration with seafloor observatory science programs, especially in the long-term monitoring of subseafloor physical parameters and seismicity, in active experiments and in regional-scale characterizations of sub-seafloor conditions. ... A firm foundation of observatory science, both as part of IODP and in coordination with other international programs, is a priority." Observatories are also highlighted in the "Implementation Plan for Initiatives" (ISP pages 78-79).

Background on Sercel Borehole Seismic Tools

There are two families of seismic sondes. The "wireline deployed" family are relatively large (about 3.3inches) clampable sondes that are lowered and separated by cables. Connections are made-up with o-rings and these systems are not usually considered for "permanent" (say 1 year or more) operation, particularly if temperatures exceed 100degrees C. VSP tools can be clamped in casing (when the casing is adjacent to the formation) or in open hole. "Maxiwave" and "Geowave32" are Sercel 24-bit products and SAM43 is a Sercel 16-bit slim-hole product.

The "permanent family" consists of "tubing conveyed" and "behind casing" sensors that are intended for permanent installation at high temperatures and they are relatively small (housings less than 1.5inch). "Behind casing" sensors are welded to the casing and coupling is done by formation subsidence or cement. "Tubing conveyed" sensors are typically coupled with a bow spring. The bow springs are always extended and simply contract as the casing string is pushed into the hole. In our application they would be attached to the outside of 4.5inch casing. Seis-Num is the Sercel product name for the monitoring system which consists of a combination of permanent tool strings and the necessary acquisition hardware and software.

Both wireline deployed and permanent sensors come in two temperature systems, 125degreeC and 175degreeC. Note that although the systems are compatible, the high temperature version is a different electronic and housing design from the low temperature version. It is not simply a matter of replacing components with higher spec versions. (There is also an issue called the "purple plague" which involves migration in metallic contacts and impacts the length of time systems can operate at high temperatures.)

Usually wireline tools are used for inside casing or for open hole. The relative weight of the sondes to the cable makes it relatively easier to see if they get hung-up. They are OK for up to a year of low temperature (<100degreeC) operation.

Usually tubing deployed sensors are used only in casing. Their weight relative to the weight of the drill pipe is so small that it is difficult to see if they get hung-up. They are designed (electron beam welding instead of o-rings, for example) to withstand high temperatures (up to 175degreesC) for long periods (5years or more).

A discussion of the compatibility of the Sercel systems with IODP practice is given in Appendix 4.

Discussion of Various Configurations

There are at least three possible configurations for SeisCORKs:

1) single sensor below the CORK-II - electrical cable replacing the Spectra cable (Figure 9),

2) a separate array of sensors that we can just wash-in or mud-drill into sediments next to the CORK hole (Figure 10), and

3) a dedicated SeisCORK hole with sensors on the outside of various sections of casing (Figure 11).

Tom presented schematics for the three configurations (Figures 9-11) and these were discussed in detail. It was felt that adding a single open-hole seismometer to the CORK-II systems at Juan de Fuca, Configuration 1 (Figures 9 and 12), would unnecessarily complicate an already complex installation. There are already issues with seals, for example, on these systems. Just getting these systems to work well is already a challenge without adding the additional complexity of a seismic system. It seemed to make sense to install and test the seismic components of a SeisCORK by themselves, in an adjacent well, before merging these with the hydrogeological sensors. One major advantage of configuration 1 is that the boreholes exist and we know in advance the depths of the holes and the size and depths of the casing strings.

In configuration 2 (Figure 10) the idea was to put geophones with their associated electronics on the outside of 4.5inch casing and then install the casing into sediments without rotary drilling. The casing would be jetted as far as possible into the soft sediments and then a mud drill could be used to penetrate through indurated sediments (but not basaltic basement). At the Juan de Fuca sites we estimate washing in about 40m and then mud drilling the remaining 200m or so. The concern with configuration 2 is that the vibration associated with the mud drilling could potentially damage the electronics in the seismometers. Until we have a quantitative measure of the magnitude of these accelerations we should not assume that we can install the seismic string in this fashion.

In configuration 3 (Figure 11) the idea is to install sensors on the outside of various casing strings. An electrical pass through at the casing hanger would be designed for each section of casing to connect the seismometers to the acquisition unit in the well head. The idea of connecting separate digital data lines into a single acquisition unit is possible with the Sercel 400 Series land/OBC data acquisition system. Unfortunately it is not possible yet with the Sercel borehole systems. The Sercel Seis-Num system is a multi-well, multi-level, micro-seismic monitoring system that could potentially be used in this configuration. Unfortunately the system was not designed for remote operation. It is quite power hungry and has a form factor that is not compatible with a PC104. Substantial NRE would be required to run this configuration in autonomous mode. So for now we need to think about single sensor strings to cover the whole well. If we assume that we do not need a sensor in the upper 40m where we have the 16 or 20inch casing attached to the reentry cone, and if there were only one (perhaps 10-3/4inch) section of casing for the remainder of the hole, we could assume that this section was well coupled to the formation either by the cement or by the sediments subsiding against the casing. Then we could use a string of VSP style sensors clamped into the center of the casing. Unfortunately, in order to drill the rubble in upper basement at Juan de Fuca, the uppermost casing is 20inch (for about 40m), there is a 16inch casing to 3m into basement and then 10-3/4inch casing to 15m into basement. (This is based on the casing strategy for Hole 1301, see Figure 12. Note that the sediment is about 250m thick.) It was felt that a VSP style sensor string lowered into the center of two or more casing strings would not be sufficiently well coupled. This problem would get worse as we went to other deeper holes with more complex casing strategies. Furthermore, since experience at Juan de Fuca indicates that drilling into basement with multiple casing strings is difficult, we don't recommend this approach for now. Let's call this 3A.

We also discussed a version of configuration 3 (call this 3B) where the casing strings are used to get us through the rubble zone and then there is a substantial section of open hole in well-consolidated basement (say 200m or more). We could install sensors in the lowermost section of the innermost casing and in the open hole by attaching them to the outside of 4.5inch casing using bow-spring clamping. Running the 4.5inch casing with external sensors in open hole was viewed as a very risky activity. Our concern is not with the sensors, but with possible buckling of the flimsy 4-1/2" casing relative to buckling. Using heavier walled casing, like drill pipe, is a possible solution. (Also a hole with 200m of penetration into well-consolidated basement does not exist yet at Juan de Fuca and could be substantial effort in itself.) Alternatively in a hole like this we could lower a conventional VSP string for instrumenting the open hole in basement, but this would not be compatible with adding hydrogeological CORK sensors in the future.

Two additional configurations were considered. In configuration 2B (Figure 13), we considered minimizing the mud-drilling by setting a re-entry cone (with 40m or so of 16inch casing) and rotary drilling a hole to just above basement. Then we would re-enter with a 4.5inch casing string with attached sensors (as in configuration 2) only using the mud-drill and jetting to get through possible bridges. The problem with this is that Sercel have never deployed tubing-conveyed sensors in an open hole. Configuration 2C (Figure 14) is like 2B but cases to just above or a short distance into basement. It could be cemented at the bottom in basement to eliminate possible contamination of the other, near-by holes. Sondes are then conveyed using 4.5" casing with bow springs and are always inside casing. Configurations 2A, 2B, and 2C have the advantage of leaving an open hole in the 4.5inch casing for water sampling and osmo-sampler operations like 1301. Also putting sensors on the outside of casing/tubing is more consistent with the SeisCORK philosophy.

Some notes on the compatibility of the Sercel Systems with IODP Borehole Installations is given in Appendix 4. A summary of the seafloor hardware necessary for each of the above configurations is given in Table 1.

So we resolved to go with configuration 2C for the SeisCORK program on Juan de Fuca in 2008. This would consist of four three-component sondes at 50m separation lowered on the outside of 4.5casing (or drill pipe) inside 10-3/4casing run to just above or just into basement (about 250m) at Juan de Fuca. The array would draw 10Watts. Sercel would provide two data acquisition boards to go in the WHOI data acquisition bottle. All of the sub-seafloor connections would be made-up on the ship.

SeisCORK System Overview and Design Challenges

Borehole seismic acquisition systems in the frequency band 1-1000Hz are commercially available, however they are designed to be installed and operated on land with essentially unlimited power and data storage and with reliable data telemetry. In a SeisCORK system modifications will be necessary to install the borehole equipment with the traditional CORK systems either from the drill ship or from a conventional research vessel (using a Control Vehicle or ROV). There are also hybrid designs where the basic CORK is installed from the drill ship but a slim sensor string could be installed later by ROV.

In the Control Vehicle/ROV mode, after the SeisCORK sensor string is lowered in the borehole, the ship's tether cable remains attached to the seafloor system while the sensors are clamped in place and/or surrounded by a fill material to improve coupling to the surrounding formation, while state of health is verified and while final adjustments are made. When the sensors are judged to be operating correctly the tether is removed and the system is left to operate in autonomous recording mode. In a second step the system could be plugged into an OOI/ORION style network node.

For SeisCORK installations located far from an observatory network, sensors must run in autonomous mode. In autonomous mode power is derived from batteries, fuel cell or another local power source and data is archived on a seafloor, mass storage device for subsequent recovery. To run a 10W seismometer/data logger for a year on the seafloor requires roughly 1000 lithium DD cells. Power cycling of high current drain loads such as computers and disk drives can significantly increase the battery count. A subset of the sensors could also be power cycled. For example we could install a string of sensors in the borehole, acquire data continuously from one sensor and then "turn on" the other sensors for controlled source shooting or after a significant event. Also in autonomous acquisition mode, serial data is collected by a dedicated microcomputer housed in the data acquisition unit. The computer buffers incoming data in RAM and then at regular intervals stores the data on its magnetic hard drive or optical drive.

To integrate a SeisCORK system into a seafloor observatory network the power/telemetry interface must be compatible with observatory standards. The data telemetry backbone of future seafloor observatories will be Ethernet-based with data carried between seafloor guest port connectors and shore via network packets. A shore lab located near the cable landfall is tied into the Internet by a secure, high speed connection to facilitate scientists direct, real time interaction with their instruments. Thus a network-ready instrument connected to a sub-sea guest port will be accessible via the Internet . Metadata are added to the data stream in real time in a community acceptable standard and would be compatible with IRIS protocols. Data are also archived by a dedicated server located in the shore lab which continuously harvests data files from the instruments as they are written. This provides security from data tampering and protects data from problems with the connection to the Internet.

The seismometer requires an accurate and precise timing reference. Accuracy of 10 ms and timing resolution of 1ms are needed to effectively resolve geological structure and to determine the source of seismic events. In autonomous recording mode SeisCORKs will require clocks similar to those used in a typical OBS. The required time base precision is achievable by the use of a free running, temperature corrected crystal oscillator. Future observatory networks will distribute high precision timing signals over dedicated optical fibers to each seafloor node. The timing information will maintain a local precision time standard which is available to all science users. Instruments with less stringent timing requirements can use the Network Time Protocol (NTP) to synchronize to a GPS clock running at the shore lab.

Further Design Considerations are reviewed in more detail in the November 2004 meeting report (Appendix 3) [Stephen, *et al.*, 2006].

System Summary

The SeisCORK system consists of the following components (Figures 15 and 16, Table 2):

1) A string of three component geophones mounted on the outside of 4-1/2" tubing with each geophone pressed against the 10-3/4" casing with bow springs. The number of geophones depends on the scientific objectives, cost and power constraints but is typically four. Each "geophone channel" is digitized at the sensor with a passband of 5-1000Hz, at 24bits per sample. The geophone sondes are connected by armored co-axial cable. The data rate for a four channel system would be about 0.7Mbits/sec (24bits/word x 2400 words/sec x 12 channels).

2) A downhole telemetry unit transmits the data to the seafloor.

3) At the seafloor the borehole array is hardwired to a junction box which permits swapping out of various pieces of equipment using underwater wet matable connectors. The junction box, which is mounted on the wellhead, connects the various pressure cases and provides an access panel for the bulkhead U/W matable connectors. In addition to the downhole cable, the logging cable uplink and an acoustic communication unit are hard-wired into the junction box. Supplementary batteries and the main pressure case connect via U/W matable connectors on the junction box access panel.

4) The seafloor acquisition case contains an up-hole telemetry unit, a PC104 computer, data storage, clock and a power control unit (with a 1W-year battery pack on board). In autonomous recording mode this whole unit would be replaced each time that the data is recovered by ROV. The data acquisition system, when running at the full 2 ksps rate, would generate about 1.2 Tbyte of data per year assuming 2:1 data compression ratio.

5) Additional batteries can be plugged-in and replaced through the junction box. The pressure cases are detachable from the wellhead frame for recovery in case of failure or to upgrade hardware/batteries. The additional battery packs could be packaged on the wellhead during deployment, could be lowered to the re-entry cone deck and connected via the WHIC, or could be placed next to seafloor and connected by ROV.

6) Communication to the surface is enabled by both an underwater matable connector to the WHIC sled and an acoustic modem. Both are hardwired to the junction box (Figure 17),

7) There is also a wet matable connector to a seafloor cabled network should one be installed at a later date. This could also be used for communicating with the system by ROV.

When the system is converted to "network cable" mode the power and timing reference will be supplied over the cable and data will be telemetered over the network in real time to shore.

Deployment and servicing of wellhead frame

The wellhead frame is deployed with all pressure cases attached and all connectors mated. After deployment the system can be powered and checked for correct operation by mating to the WHIC camera sled through a U/W matable connector.

The wellhead frame is rigidly attached to the downhole casing string and thus can't be recovered for servicing. However, individual battery cases can be replaced by unplugging their U/W matable connectors from the jbox panel and lifting the case out of the frame. This work requires the use of an ROV or manned submersible. The data acquisition system can also be recovered for repair or upgrading using the same procedure. Replacement battery packs might be more conveniently located in a deployable frame placed close to the wellhead. When a seafloor network node is installed, the system can be connected with a jumper from the network U/W connector on the junction box frame to a node user port.

Power Consumption

A reasonable estimate of the power consumption of the Seiscork system is 29W: 4 W for the logging computer and 25 W for the Sercel four-level Geowave sensor system. Other power users in the SeisCORK system are either inherently low power or they can be power cycled to minimize average power drain. The Sercel sensor array includes a telemetry link for operation over a long cable. Significant power savings can be realized by eliminating this link for short cable deployment. A 12 W-year battery pack for this system can be constructed from parallel diode-isolated banks of series-connected lithium DD cells. The packs are configured to fit conveniently into cylindrical pressure housings of 10" I.D. Each 1 W-year pack occupies 15" of housing length so a 12 W-year system would require three 5 ft long pressure cases and would run a power optimized SeisCork system for more than 6 months or for 1 year at 50% duty cycle.

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FAQs

1) How do we get seismic data from the seafloor to the ship for QC etc? Do we just bring back sample files over an acoustic modem at low data rate?

We are very reluctant to install the SeisCORK "blind" - that is put it in the hole and hope that it works until the site is revisited by ROV. Although some command, control and data retrieval can be accomplished by acoustic modem it would be better if we could electrically connect the borehole gear to the ship via a wet connect at the well-head. The concept of a Wellhead Interconnection (WHIC) sled is outlined in Appendix 5.

2) How are temperature and pressure sensors incorporated into the system?

The Sercel Data Acquisition System has low data rate auxiliary channels already built in. These would be sufficient to entrain the pressure and temperature data into the seismic data stream. A strategy would need to be designed, however, to build housings, connectors and pre-amps for appropriate transducers.

3) What other programs could use the SeisCORK system?

There are other programs interested in the SeisCORK concept. These include NanTroSEIZE and SCIMPIs. The NanTroSEIZE program is a large multi-phase project to study earthquake activity in the Nankai trough off Japan. There will be multiple "non-riser" holes (most likely drilled by a ship like the JOIDES Resolution) and at least one very deep (6km below seafloor) hole (drilled by the new Japanese "riser" vessel, Chikyu). SCIMPIs are a concept developed by Kate Moran at URI to "wash-in" sensors into soft sediment. Her program is targeting a test at the MBARI borehole test site (MARS) and an installation on Hydrate Ridge (off Oregon). Although the focus of our Spring 2006 proposal will be the JdeF drilling, it would be nice to develop a system that could meet the science objectives of the other projects.

4) I don't know how this usually works - are we identifying a site and asking that a hole be drilled there or is the hole already drilled?

This is probably not the place for a complete review of all the JdeF work. The JdeF Hydrogeology program is an ongoing multi-leg project. Some CORKs have already been installed. The drill ship was working there in Summer 2004 and further work is planned in 2008. So there are four possibilties: 1) existing CORKs may need to be replaced, 2) at least one new hole may be drilled for a new CORK installation, 3) it might make sense to wash-in a SCIMPI style SeisCORK, or 4) install the SeisCORK in a dedicated borehole (either a traditional re-entry hole or a hole with a free-fall funnel.

5) To what extent do we need to get the CORK community behind the proposal?

This is a good question. See Andy Fisher's letter (Appendix 1) supporting our Design Phase proposal in August 04. The CORK community submitted a proposal in February 05. We were originally scheduled to include SeisCORKs at this stage. Andy decided not to include SeisCORKs for two reasons: 1) He thought that extending the proposal to include the seismic science would make the proposal too confusing for reviewers. and 2) Some of Andy's CORK colleagues thought that adding seismometers to the already complex CORK-IIs would increase the risk of failure. Andy suggested leaving the SeisCORK component to the JdeF program as a separate proposal that would be submitted after the Feb 05 proposal was funded.

This is where we were in April 05 when we submitted the DOEI (in-house WHOI) proposal. " In order for SeisCORKs to be viewed favorably in the NSF review process we need a credible design with realistic costs. Reviewers need to be convinced that we can add seismometers to traditional CORKs without compromising the other measurements and at reasonable cost." Although various mechanical configurations of adding seismometers to CORKs were summarized in the November 2004 meeting report (Appendix 3), we needed a credible system including the analog and digital electronic components.

The whole project became a lot easier when Ralph visited Sercel in Paris in July 05. They were already making borehole seismic systems for reservoir monitoring. They had already demonstrated existing systems working in land boreholes. The challenge just becomes adapting their system for seafloor applications.

The focus of our effort should still be in integrating seismometers onto one or more CORK designs. We will need this for deep penetration holes into hard rock that are planned for NanTroSeize. We should continue to think about a wash-in array, like SCIMPIs.

6) What is the nature of the Sercel group?

Until 2004 they were "Createch Industrie S.A." Createch had built the borehole seismometers used in the deep (10km) KTB borehole in Bavaria. Createch was founded by Jean Czernichow, who had worked in Schlumberger, Clamart. He retired when the company was sold to Sercel. Sercel is the electronics and equipment division (or subsidiary) of Compagnie Generale de Geophysique. We worked with CGG twenty years ago on the LFASE project. Createch became the Downhole Division of Sercel in March 2004. Jean-Eric Negre is the head of the Downhole Division and Thierry Bovier-Lapierre is the Sales Manager. When I visited them in July their offices (in Ulis, a suburb of Paris) were in a separate building (and site) from both CGG and Sercel.

Check-out the Sercel Downhole Acquisition web site at: http://www.sercel.com/en/Products/Downhole-Acquisition/ . They have three sets of products: GeoWaves, MaxiWave, and Micro-Seismic Monitoring.

7) Are they consultants who put together systems built from commercial components or are they engineers at Createch?

Createch was a small firm that essentially built and assembled borehole seismic systems. They built some components themselves, bought other components and assembled systems. A lot of their work was one-off, or small production stuff, with a lot of "non-recurring engineering". Although they have a lot of experience in borehole seismology and can provide lots of advice I would not call them consultants. They actually build and sell hardware. It is not clear how Createch might change now that it is a division of Sercel. When I asked Negre this question in July he said that the WHOI project was exactly the sort of thing they did in the old Createch. He seemed interested in our project but he did not know how the project would be viewed by management at Sercel.

8) Do they have experience in deep ocean applications?

The Sercel Downhole Division does not have deep ocean experience. They have deployed their gear from land rigs and offshore platforms where there is a permanent wellhead facility. Sercel has an Underwater Acoustics Division (the Vice-President is Jean-Michel Coudeville) in Brest. Check out their marine products (streamers, acoustic modems, ocean bottom seismic cables (down to 2000m depth), marine sources, hydrophones, underwater ARGOS beacon, AUVS, etc) at
http://www.sercel.com/en/Products/ .

9) It seems as if the systems they advertise are land based though the specs suggest they would work in the deep ocean.

Borehole equipment is rated to work in deep holes filled with water so land and marine boreholes are similar. The deck units are typically designed to work from a permanently installed wellhead on land or an offshore rig. Two objectives of the Paris meeting are 1) to sort out what needs to be done to get the gear to work in a remote seafloor application and 2) how will installation differ.

10) We've spoken about a number of deployment scenarios involving networked or autonomous operation, seismometer as part of the CORK sensor string or outside the casing pipe, replacing spectra cable with coaxial cable for seismometer data and possibly tying in CORK sensor data. Do we want to choose a configuration (even as just a strawman) and run with it or do we want to present all the options with associated costs?

We need a core configuration that will accomplish at least some of the science objectives. Simpler is obviously better for the first time. It is important however to have a roadmap for extension and development to more complicated systems. The JdeF progam would almost certainly start as an autonomously recording system under battery power with its own clock. Holes Sr-2,1027C, 1026B, 1301A and 1301B are on the planned Neptune Canada cable route as a "branching unit". When the cable is installed and the borehole observatories are running it would just make sense to hook them up.

Politics play a role here. To start I would focus on the single sensor lowered through the 4.5inch casing on an electronic wire replacing the Spectra cable to a location in open hole. Since this configuration involves working with the complicated full-up CORKs and has "risk" issues, we should consider back-up systems such as 1) just wash in a vertical array (250m sediment) at these sites or 2) go with a dedicated "seismic" borehole. The latter could either a) involve sensors on casing (keeping the center of the well open for future drilling or instrument strings or b) just drill a hole with the necessary conventional casing strings and clamp a string of geophones in the center of it.

11) Are there big pieces of this project that we want to borrow from past systems?

Probably. The old LFASE borehole seismic gear still exists at WHOI.

12) For example ROV operations around CORKs must be pretty common so can we use the landing/instrumentation platform design?

Sure. Tom Pettigrew will have a lot of experience with this.

13) Anything we can steal from OSN-1?

We could use the BCU frame, some large pressure housings, perhaps some cables and connectors. Let's not let used equipment drive the design. We will need a new equipment van.

14) Are we looking to sell this as an element of ORION with associated data standards and protocols (Andy Maffei can help a lot here)?

Yes. JdeF holes will be on Neptune Canada which they assure us will have the same protocols as ORION. Clearly if we have a system that meets ORION standards and protocols we will be able to apply the gear to more problems. My idea is to have a system that can be deployed and operated independently of the ORION cables but can be plugged into an ORION network when it becomes available.

15) As an element of GSN (Have you had a chance to talk to Rhett)?

Ralph last spoke with Rhett in Fall 2005 for about 45minutes. We talked about a lot of stuff but not SeisCORKs. There is room for confusion here. GSN stations have a pass band of 0.001-10Hz. The borehole stations use "broadband" seismometers built by either Guralp (CMG-3TB) or Teledyne (KS 54000). This frequency band is good for global and regional seismology. You need one of these stations every 2000km. SeisCORKs are focusing on the band 1-800Hz which is more suitable for nano- and micro-earthquake studies. You want multiple sensors deployed within a few hundred meters of each other to locate the events. Although it is conceivable that you may want to put a broadband sensor (they are 10m long and cost $80K each) in the same well as the short period sensors, I think it is reasonable for now to assume that it would be too complicated. The goal of SeisCORKs is to add short period seismometers to CORKs for hydrogeological studies. We are not proposing to add short period sensors to broadband GSN stations or to add broadband sensors to CORK installations. For these two cases there is little scientific justification. Just because all this gear is designed to fit in a well doesn't mean we have to do it. In fact for logistical convenience it is best to keep CORKS/SeisCORKs and broadband systems separate.

16) If we go for autonomous operation short term do we need to make the system network-ready without redeployment?

This is the dream. At the seafloor we will need the Sercel control and acquisition electronics for both autonomous and cable systems. Ideally this "Sercel box" would not change between systems. The autonomous operation would need battery, clock and storage units. On cable operation we would still need these units for periods when the cable is down. If you design for a year of autonomous operation then presumably a year of cable down-time would be acceptable.

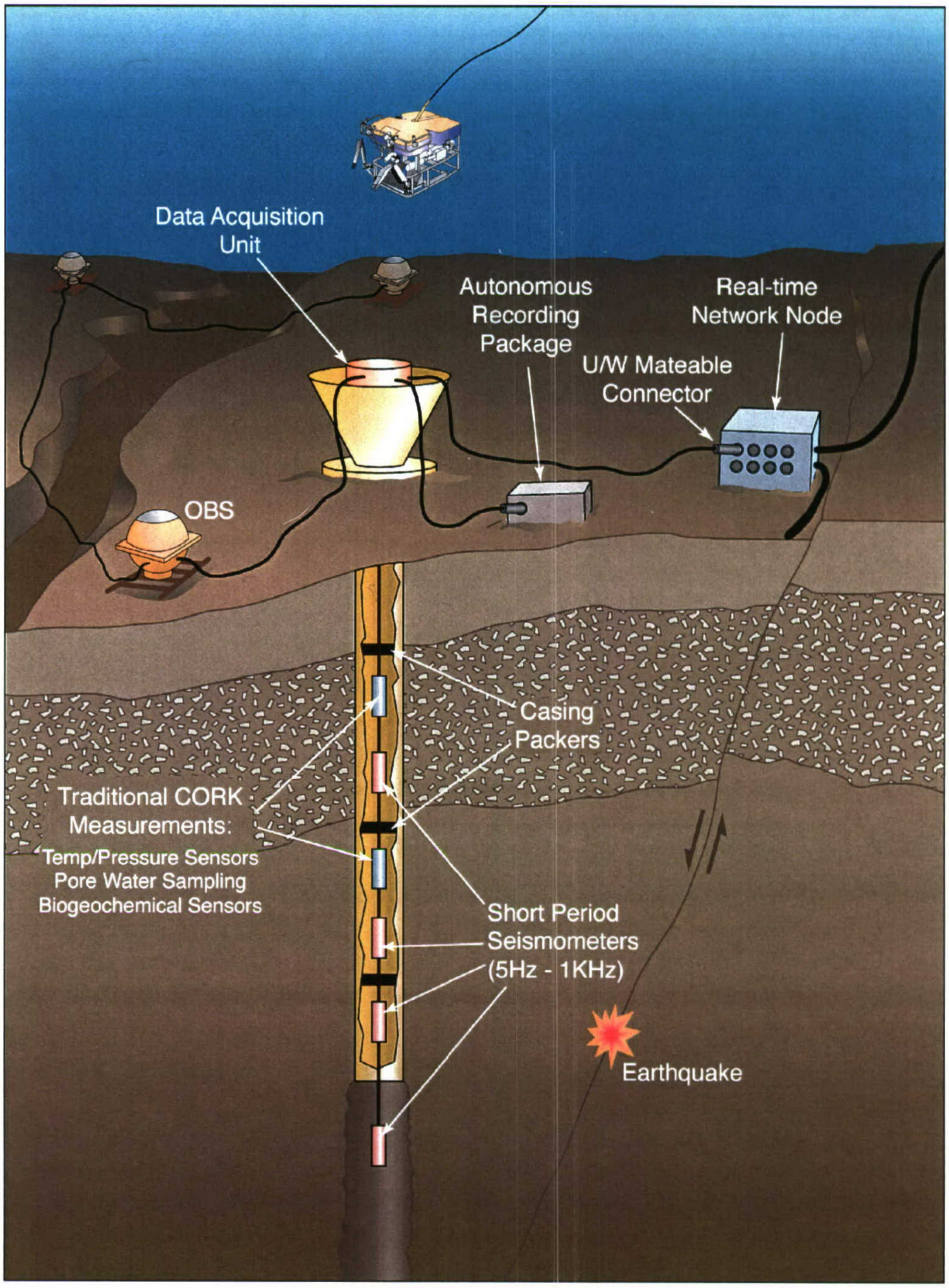


Figure 1: The SeisCORK concept is to incorporate at least one VLF seismometer with a traditional CORK system in order to make simultaneous observations of in situ bio-chemo-geo-hydrology properties with seismicity. The goal is to study bio-chemo-geo-hydrology events that may be associated (possibly as precursors) with earthquakes. Image provided courtesy of Woods Hole Oceanographic Institution (www.whoi.edu) and Jack Cook.

Figure F1. Regional bathymetric map showing major tectonic features and the locations of IODP Expedition 301 drill sites and the ODP Leg 168 drilling transect. Bathymetry from Smith and Sandwell (1997). FR = First Ridge, SR = Second Ridge, DR = Deep Ridge.

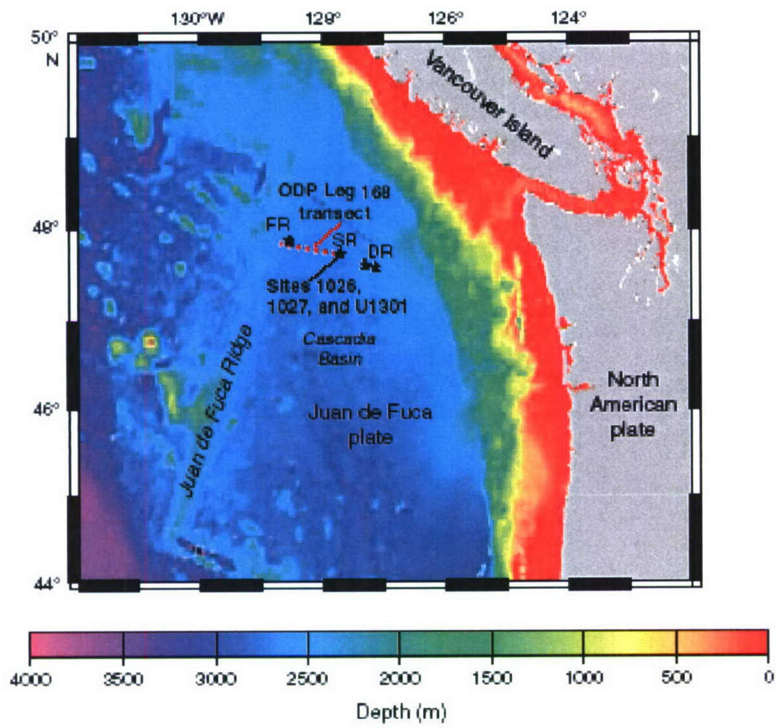


Figure 2: Regional bathymetric map showing the locations of IODP Expedition 301 dill sites and the Leg 168 drilling transect. [Shipboard Scientific Party, 2004]

Figure F2. Summary of selected results from ODP Leg 168 and related experiments. **A.** Interpreted composite cross section from the active spreading center to the west, across the Leg 168 drilling transect, and continuing to the east. Vertical lines show locations of Leg 168 boreholes. Triangles at seafloor show locations of reentry cones and CORK observatories installed during Leg 168. CORK systems in Holes 1026B and 1027C were replaced during Expedition 301, and new CORKs were emplaced in Holes U1301A and U1301B, along the same buried basement ridge as Site 1026. **B.** Summary of thermal data. Solid circles are upper basement temperatures, based on in situ measurements and (in some cases) short extrapolations to basement depths. Open squares are heat flow values determined with Leg 168 temperature and thermal conductivity data, after applying temperature corrections and accounting for thermal conductivity anisotropy (Pribnow et al., 2000). Solid squares show the same values after correction for the effects of rapid sedimentation (Davis et al., 1999). Data from Sites 1030 and 1031 were not sediment-corrected because sediment cover is very thin and because the calculated correction is based on a one-dimensional approximation that is not valid where there are large variations in basement relief below thin sediments. The thin jagged line shows estimated heat flow values across the Leg 168 transect based on seismic and drilling data (Davis et al., 1999), after applying a sedimentation correction. The smooth dotted and dashed curves show lithospheric reference models by Parsons and Sclater (1977) and Stein and Stein (1994), respectively. **C.** Chemistry of basement fluids, as determined from extrapolation of basal pore fluid gradients to the basement depths and (in the case of Hole 1026B) from direct sampling of formation fluids. Magnesium data show fluid alteration largely as a function of reaction temperature (Davis, Fisher, Firth, et al., 1997; Wheat and Mottl, 1994). ^{14}C data show a consistent progression in apparent age from west to east at the western end of the transect, but samples from Sites 1031 and 1026 are considerably younger than waters to the west (Elderfield et al., 1999).

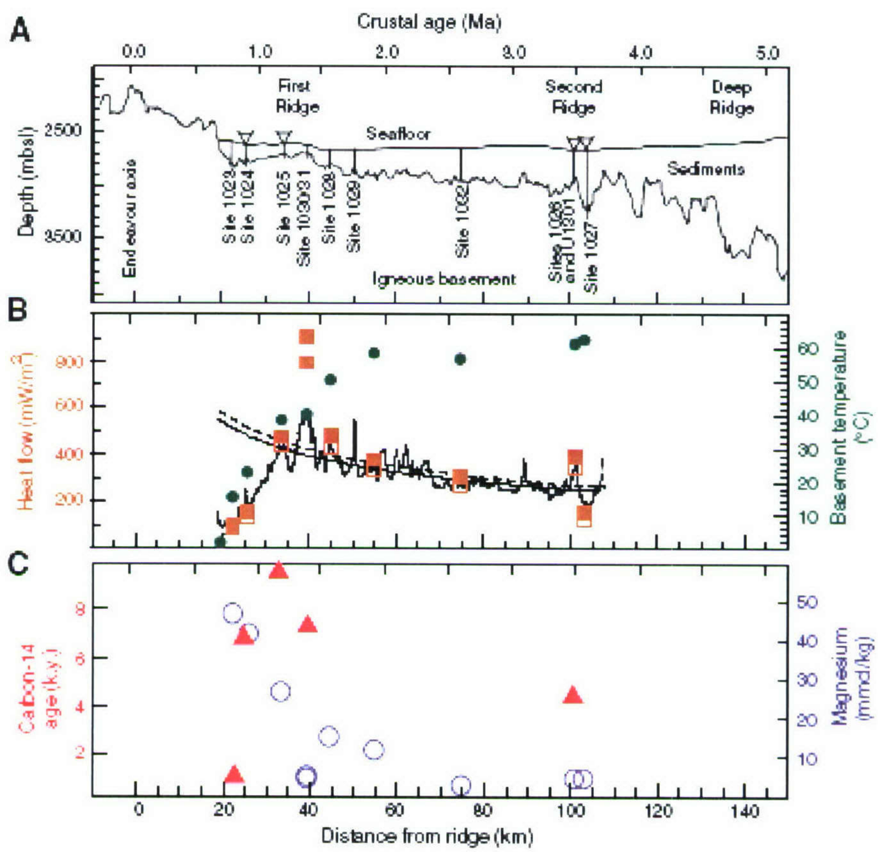


Figure 3: from [Shipboard Scientific Party, 2004]

Figure F8. Cartoon illustrating selected features of the three CORK borehole observatory systems installed during IODP Expedition 301. Approximate total depths (TD) listed in meters subbasement (msb) are correct as shown, but drawings are not to scale and do not indicate precise locations of casing, cones, packers, sampling and monitoring lines, or downhole instruments. Hole 1026B was created during ODP Expedition 168, whereas Holes U1301A and U1301B were created during IODP Expedition 301. All three CORKs monitor multiple depth intervals. The CORKs in Holes 1026B and U1301A monitor shallowest basement and the zone between the casing packer and the seafloor CORK seal. The CORK in Hole U1301B monitors three basement intervals, with the uppermost interval including the interval that extends to the seafloor seal. Instruments deployed at depth in all three CORK systems include various numbers of osmotic samplers for fluid chemistry, microbiological incubation substrate, and autonomous temperature loggers distributed within basement. See Fisher et al. (in press) for additional details regarding CORK configuration and deployment.

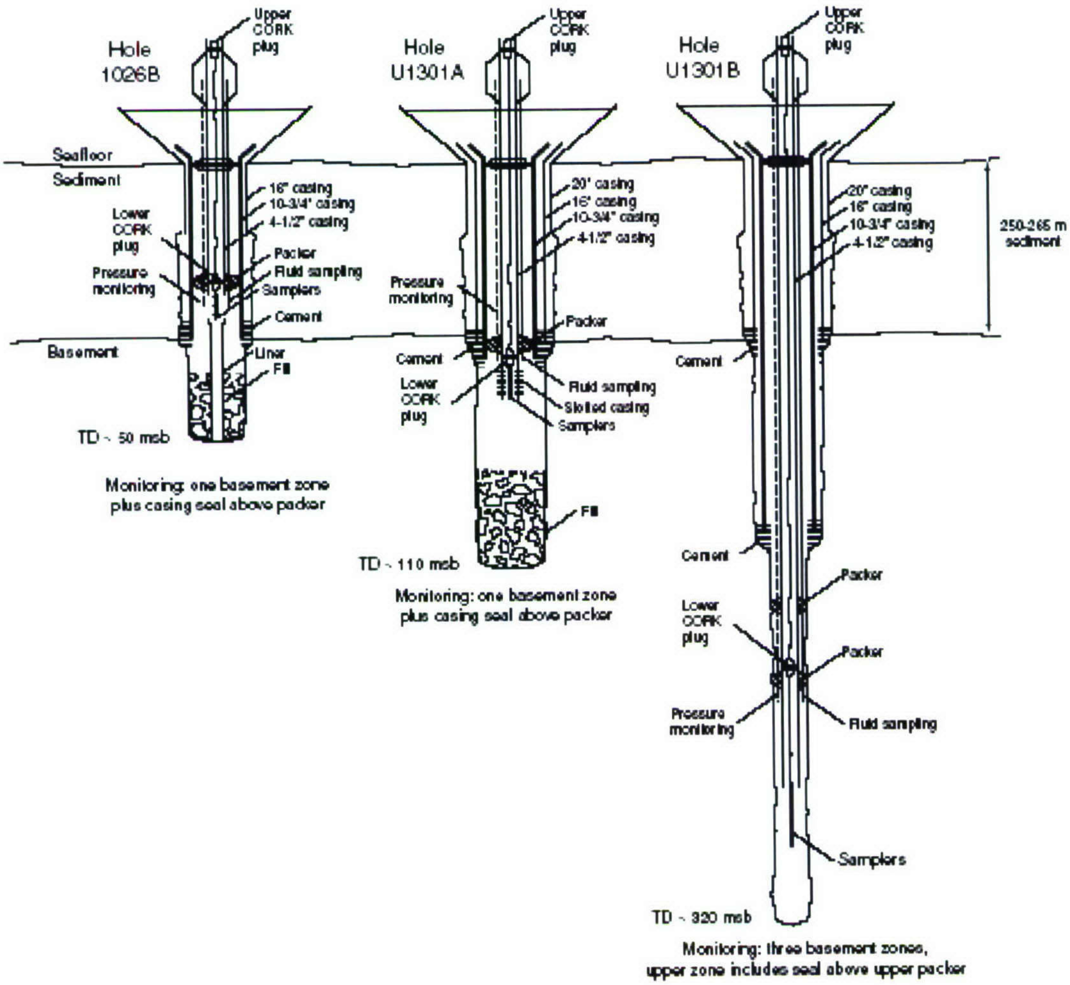


Figure 4: Configurations of the three CORKS installed on IODP Leg 301.

Figure F3. Second Ridge maps. A. Topographic map showing Second Ridge and surrounding region (modified from Fisher et al., 2003). Locations of ODP and IODP holes are shown, as are locations of outcrops that penetrate regionally continuous sediment cover. B. Basement map of Second Ridge drilling area, showing ODP and IODP hole locations. Data are based on bathymetry shown in A and interpretation of ~25 seismic lines collected during the 2000 *Sonne* expedition (ImageFlux). Holes at Site SR-2 will be drilled during a subsequent expedition.

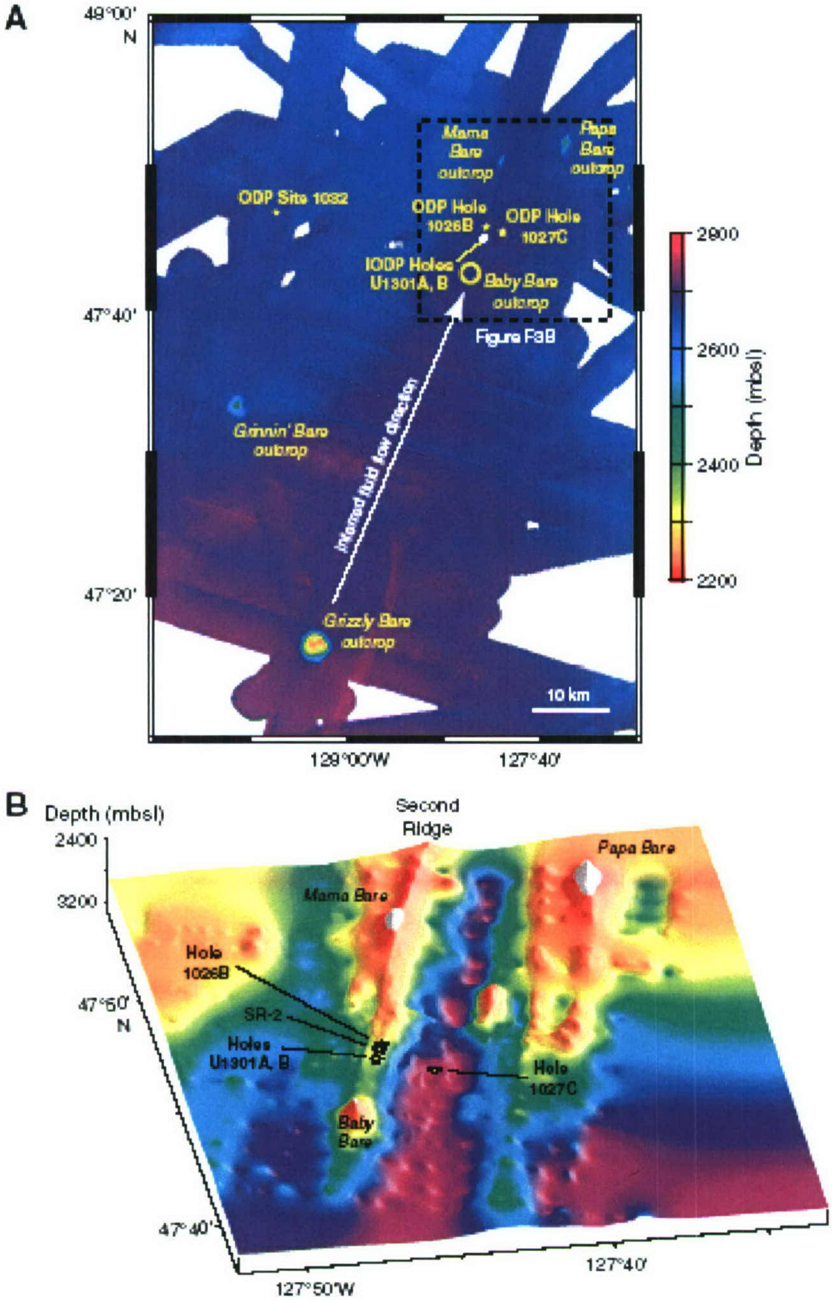


Figure 5: from [Shipboard Scientific Party, 2004]

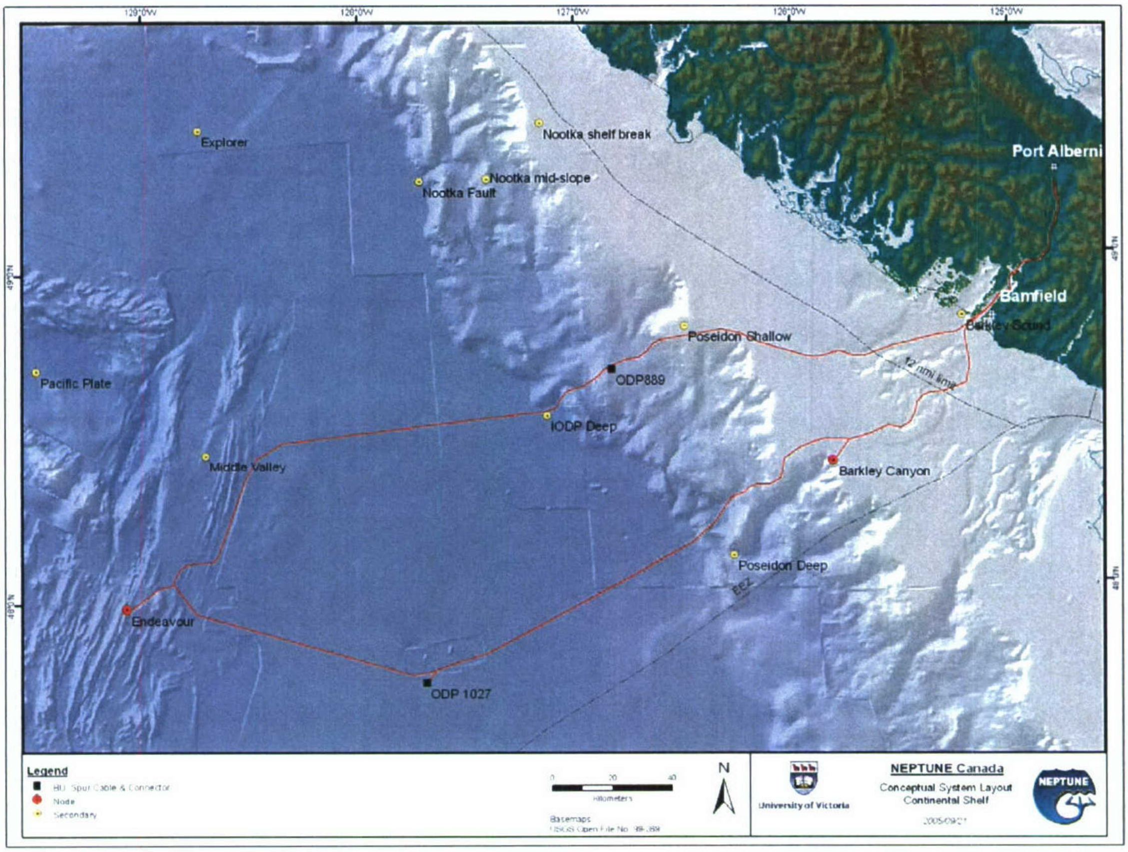


Figure 6: Planned cable route for the Neptune Canada seafloor observatory to be installed in 2007. A take-out is available near Site 1027 (1026 and U1301) for possible connection of borehole observatories to shore.

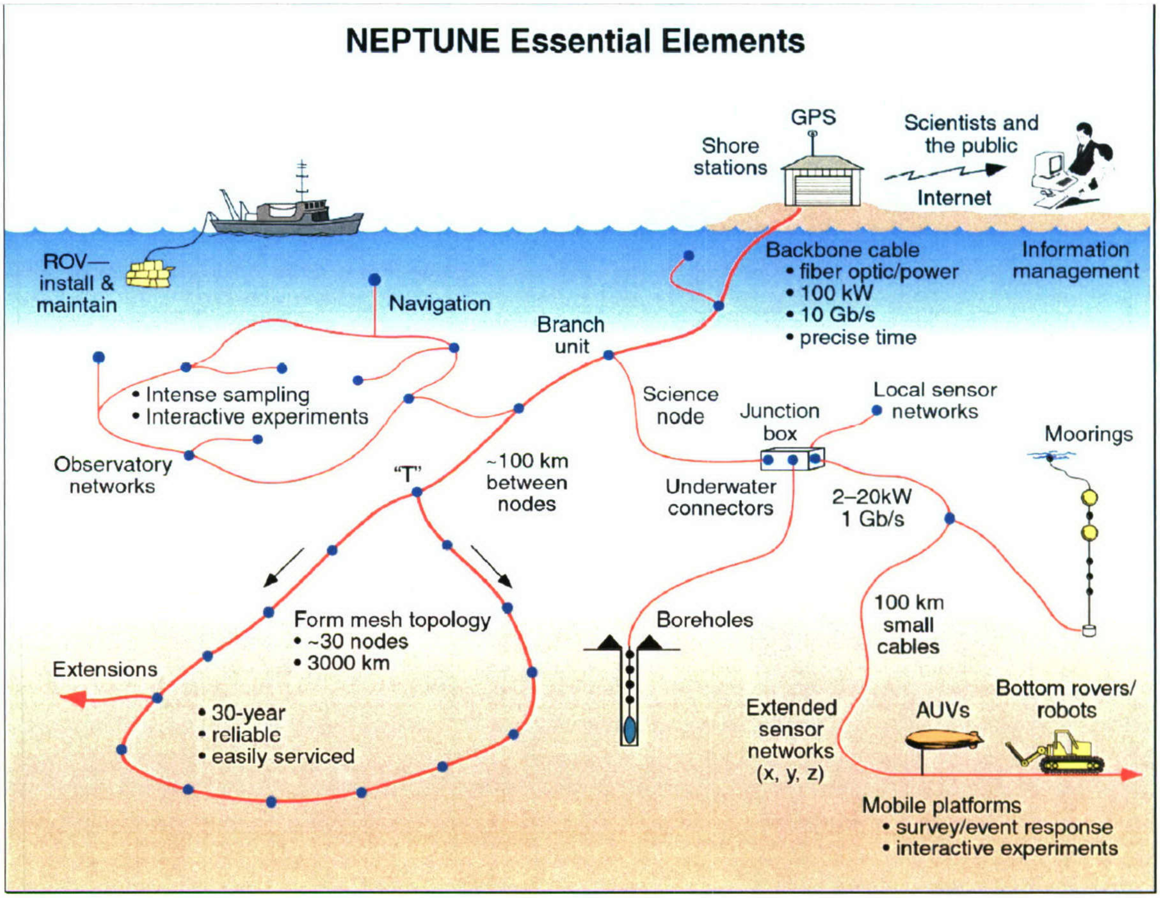


Figure 7: Borehole observatories like SeisCORK are an integral component of the planned regional cabled observatory, Neptune. (Image provided courtesy of the NEPTUNE Project (www.neptune.washington.edu) and Paul Zibton)

Figure F6. Crustal-scale hydrogeologic testing associated with IODP Expedition 301 and related experiments. **A.** Map view indicating spatial relations between CORK observatories (colored circles) in Holes 1026B, 1027C, U1301A, U1301B, planned Site SR-2, and nearby basement outcrops (gold bathymetric contours). Inset shows relative locations of pumping (P) and observation (O) wells for cross-hole experiments. Depth contours in meters. S = storativity, T = transmissivity. **B.** Calculated cross-hole responses to pumping and free-flow borehole experiments between wells at Sites SR-2 and 1026, separated by 200 m. **C.** Calculated cross-hole responses to pumping and free-flow borehole experiments between wells at Sites SR-2 and 1027, separated by 2200 m. Sites SR-2 and U1301 are 800 m apart, so the anticipated response is intermediate between the examples shown. Assumed formation properties are based on previously completed packer, free-flow, and CORK experiments. Differences in formation-scale values of T and S relative to those used would shift the curves as indicated by the arrows in A. Pumping tests in DSDP and ODP were typically only 20 min long (dotted vertical line); Expedition 301 tests were as long as 2 h. Future tests will begin with 24 h of pumping (dashed vertical line), and ultimately will last 1–2 y or more through venting of overpressured holes and pumping at the seafloor.

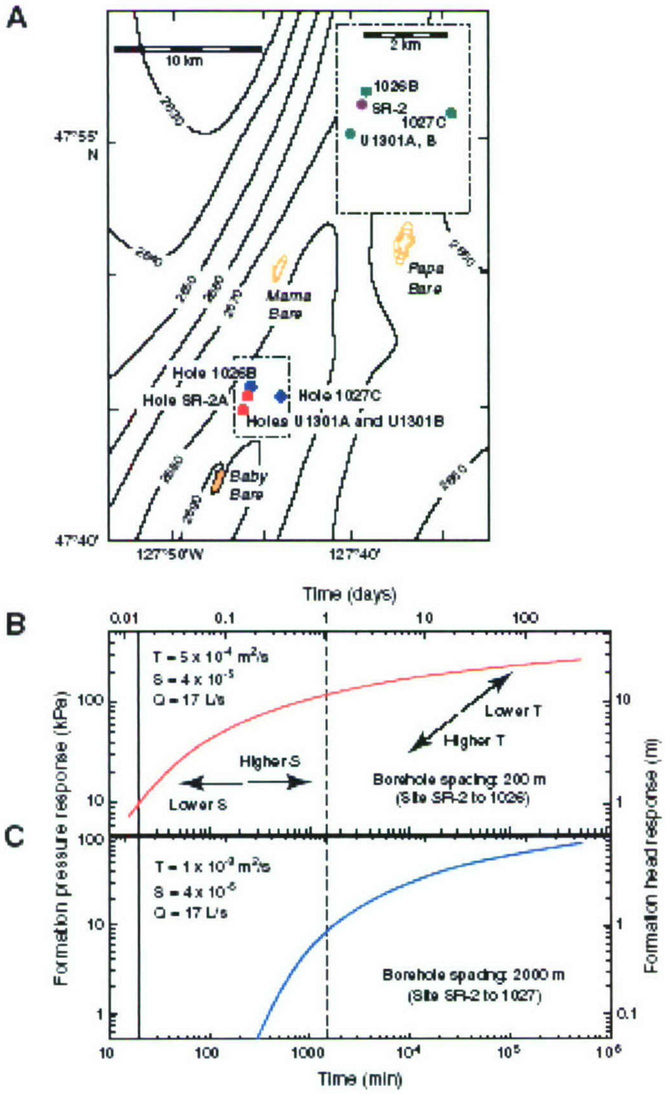
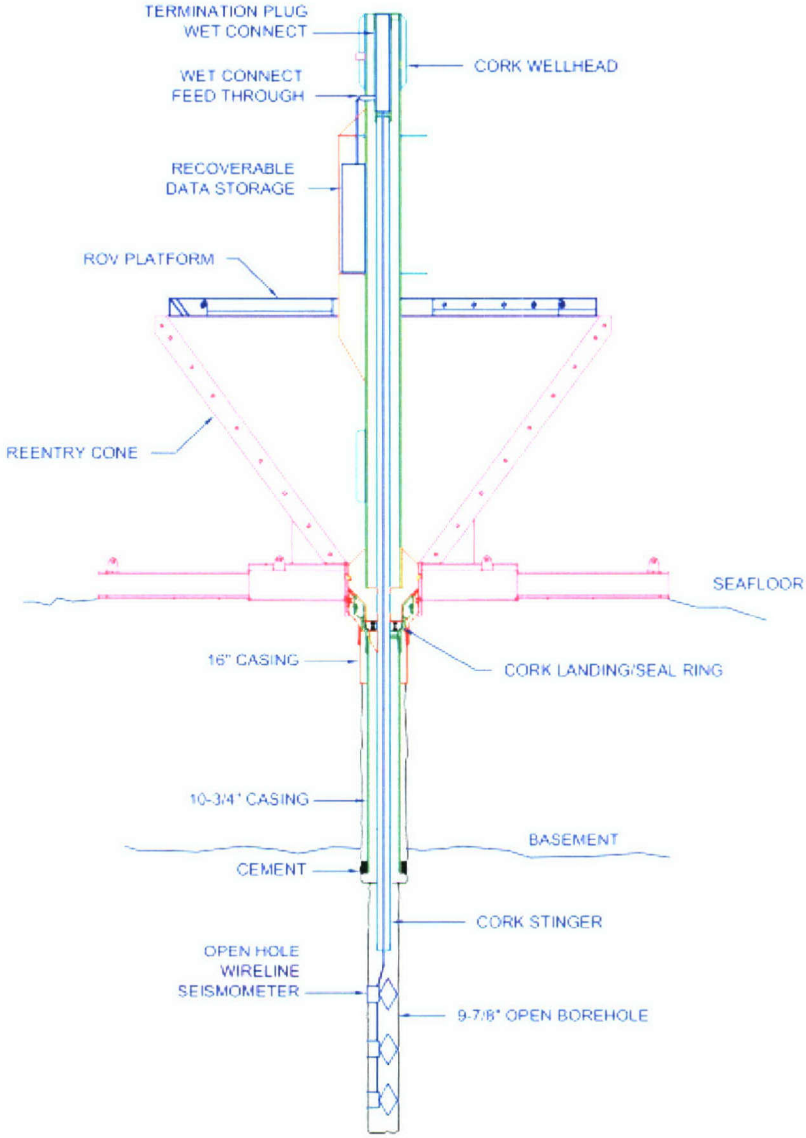
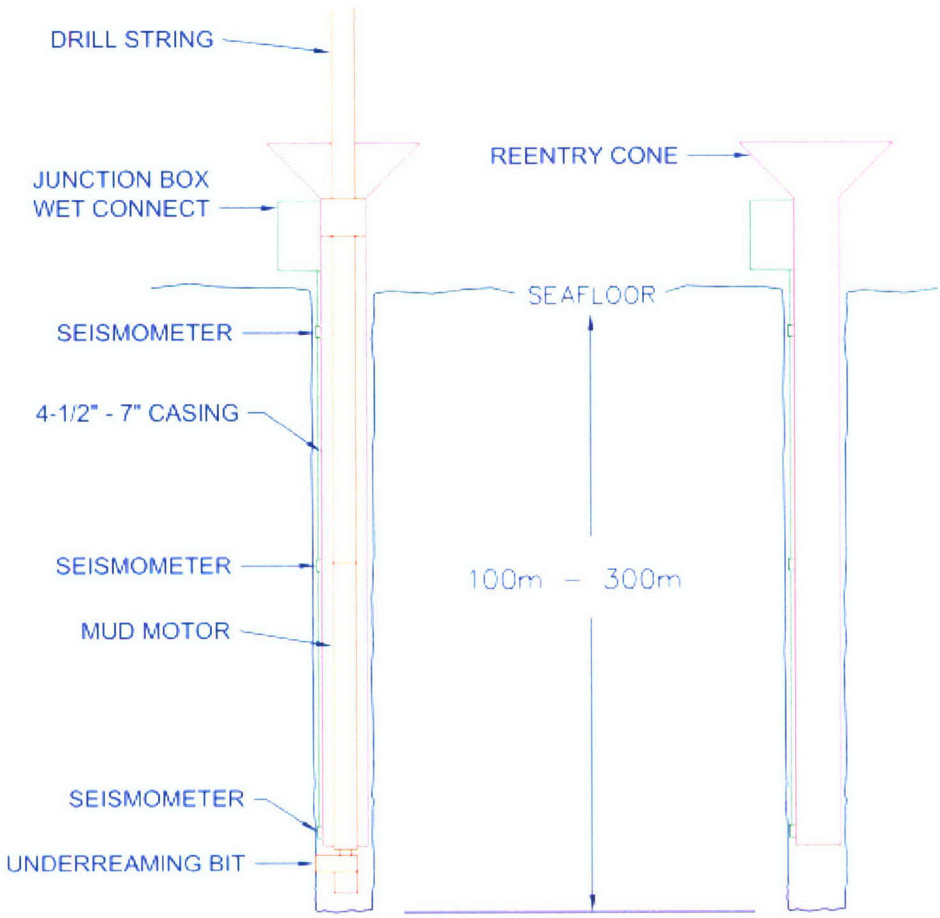


Figure 8: from [Shipboard Scientific Party, 2004]



Configuration 1: Open Hole Wireline Seismometer Deployment

Figure 9: Configuration 1 consists of a single sensor (or string of sensors) below the end of the 4.5inch casing on a CORK-II - electrical cable replacing the Spectra cable.



Configuration 2A: Drill-In Seismometer Deployment

Figure 10: Configuration 2 (also called 2A) consists of a separate array of seismic sensors installed on the outside of 4.5inch casing that we can "just" wash-in or mud-drill into sediments next to the CORK hole.

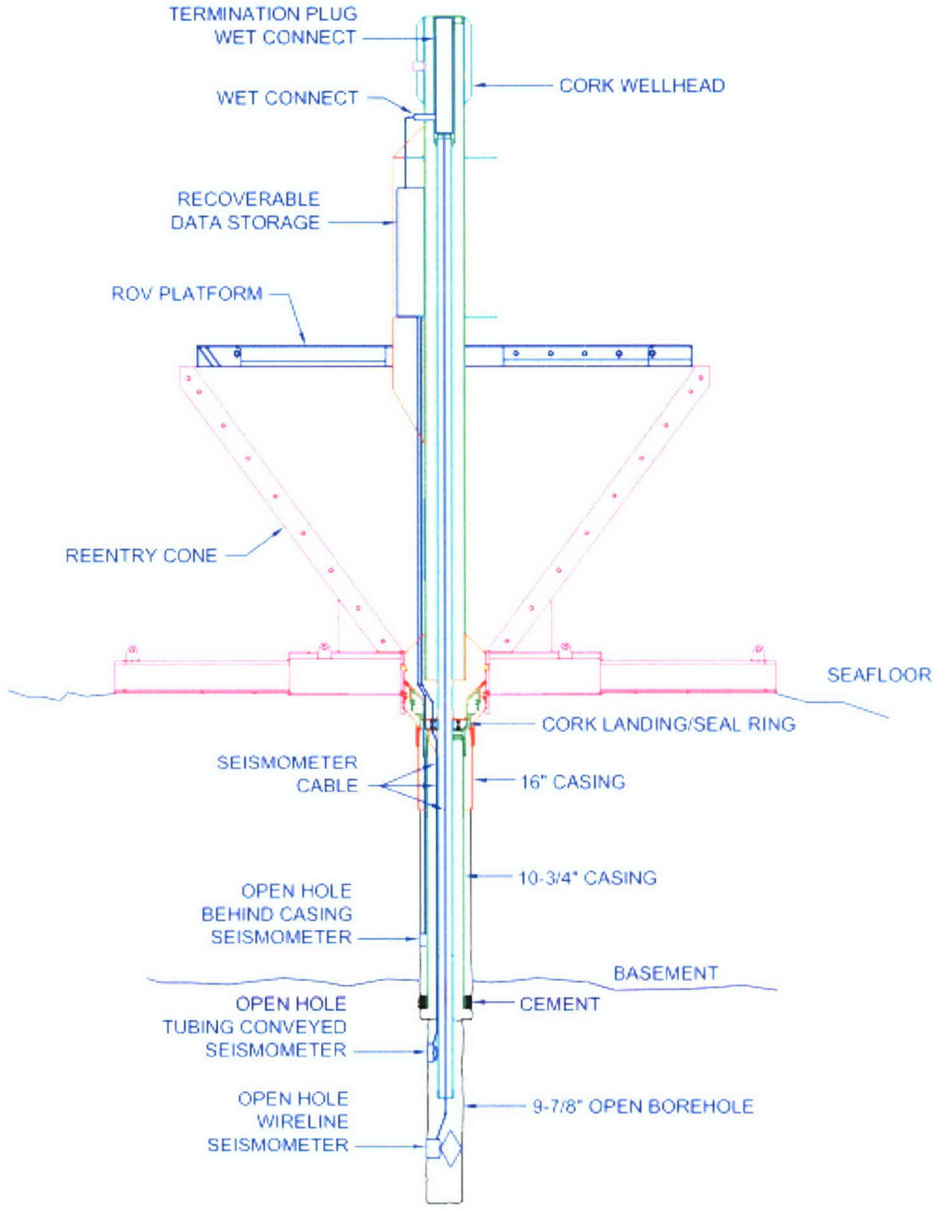
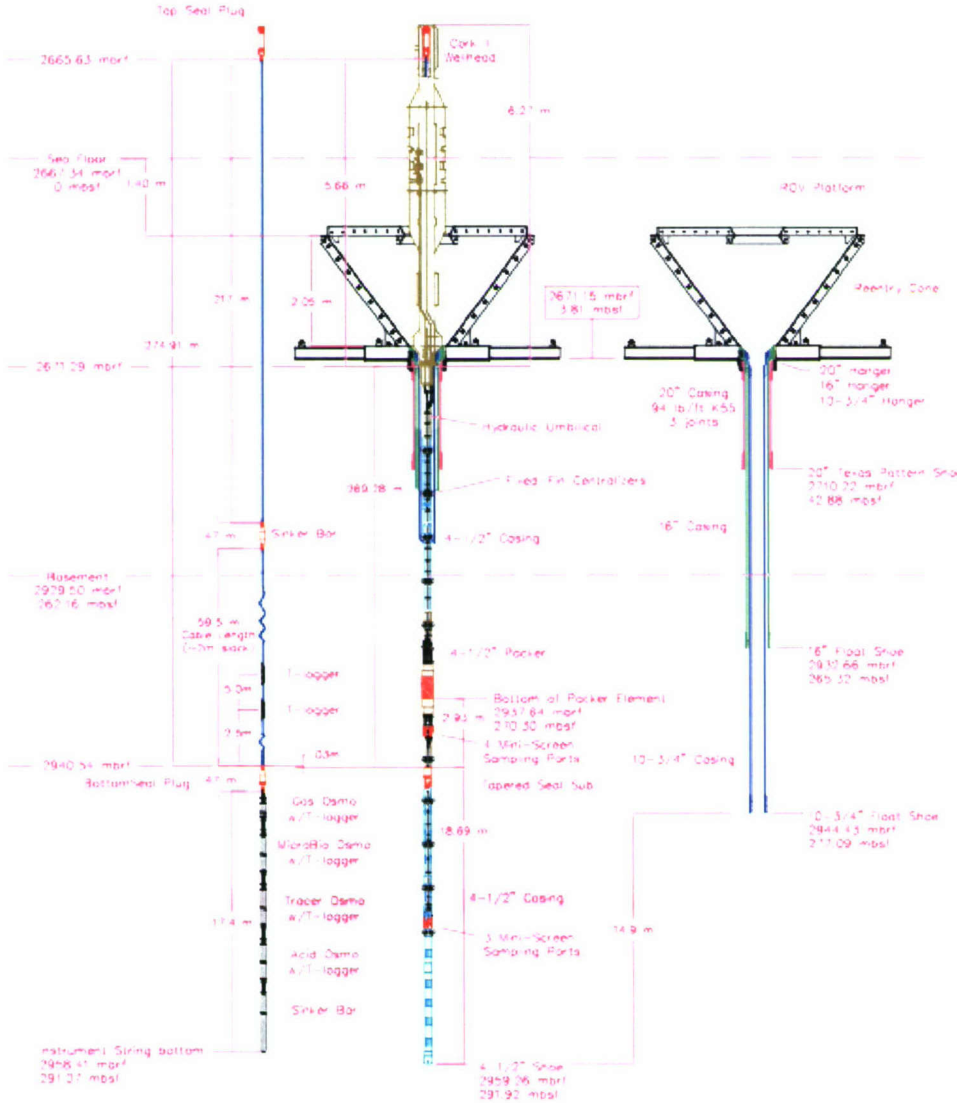
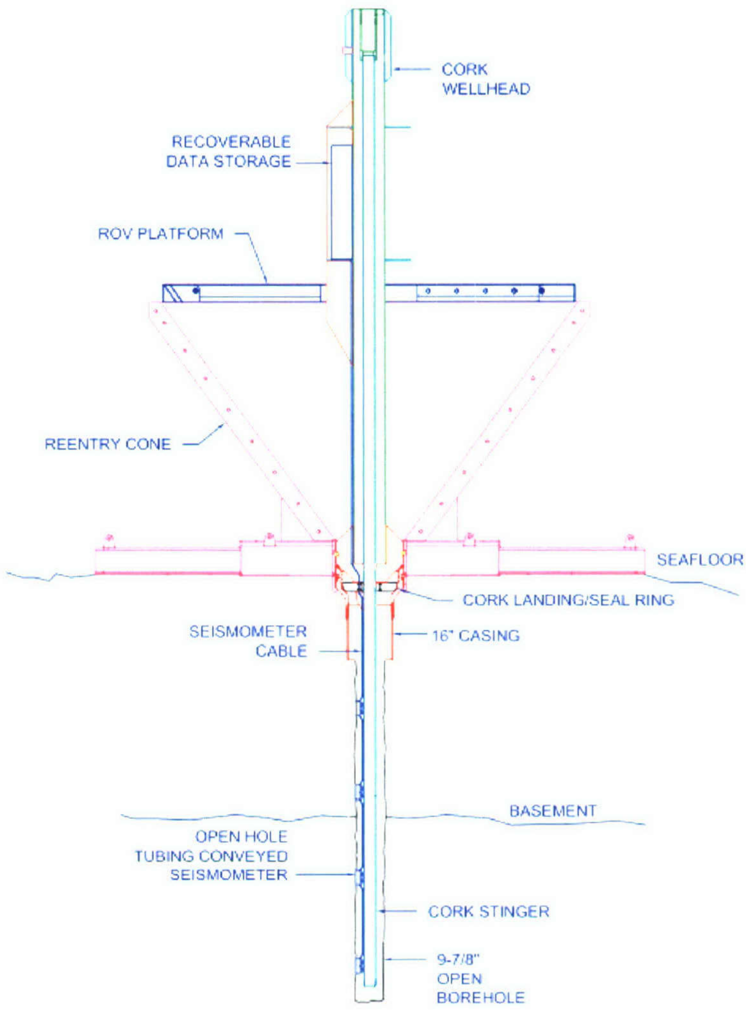


Figure 11: Configuration 3 consists of a dedicated SeisCORK hole drilled a substantial distance into consolidated basement with multiple casing strings. Sensors are deployed on the outside of various sections of casing, the leads pass through the casing hanger and are merged in the well head. The acquisition system in the well head synchronizes the data from the various strings of sensors.



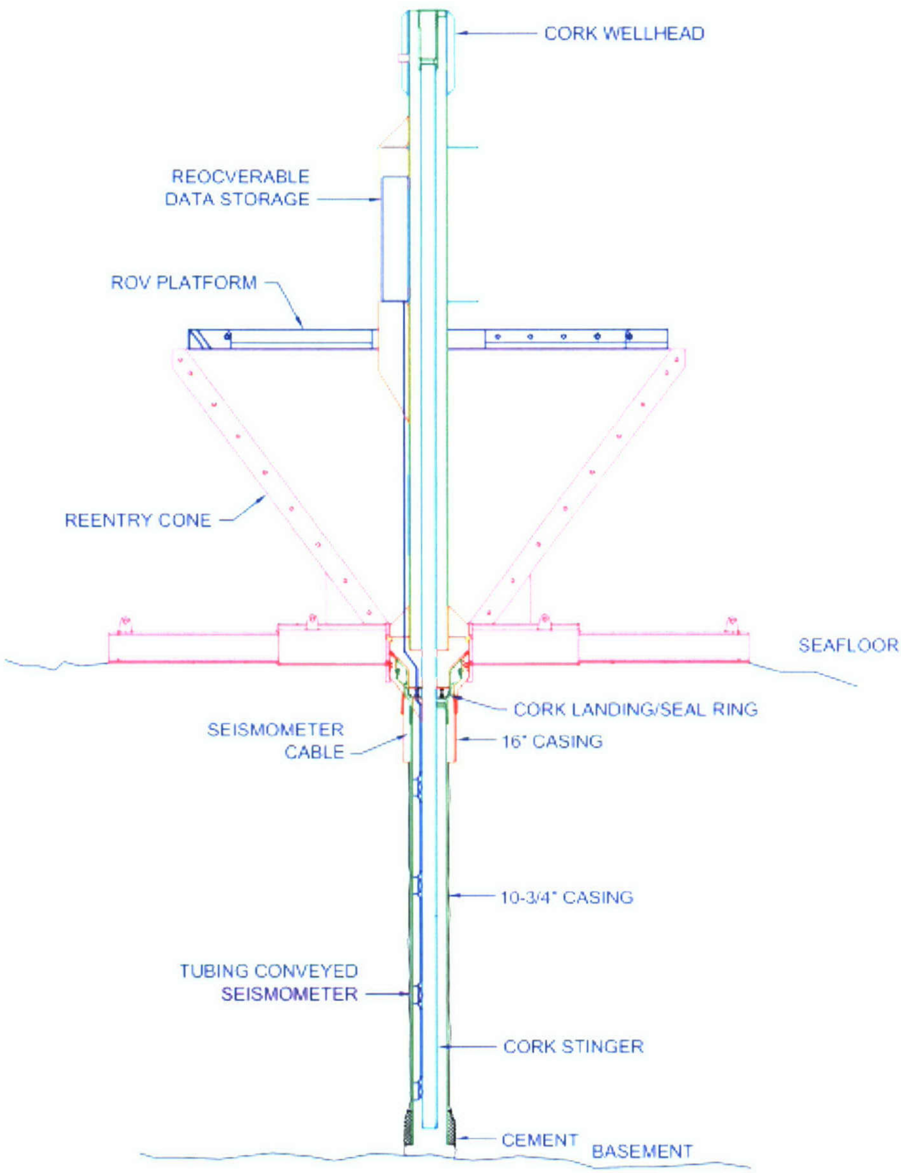
IODP 1301A CORK-II INSTALLATION

Figure 12: This is a schematic diagram of the CORK-II deployed in Hole 1301B. In discussing various SeisCORK options for the Juan de Fuca program we use the well depths and casing scenario of 1301B as "typical" of what we might expect.



Configuration 2B - Open Hole Tubing Conveyed Seismometer Deployment

Figure 13: In Configuration 2B a hole is rotary drilled through the unconsolidated and indurated sediments and perhaps upper basement. A re-entry cone is set with enough 16inch casing (about 40m) to penetrate the unconsolidated sediments. Then the sensor string described in Configuration 2A (attached to the outside of 4.5inch casing or drill pipe) is lowered into the open hole using jetting and mud-drilling only when necessary to get through occasional bridges.



Configuration 2C: Cased Open Hole Tubing Conveyed Seismometer Deployment

Figure 14: In Configuration 2C a hole is rotary drilled and cased (10-3/4inch) through the unconsolidated and indurated sediments to the top of basement. Then the sensor string described in Configuration 2A (attached to the outside of 4.5inch casing or drill pipe) is lowered into the cased hole only (no sensors in open hole). This is the preferred configuration for the first SeisCORK installation at Juan de Fuca.

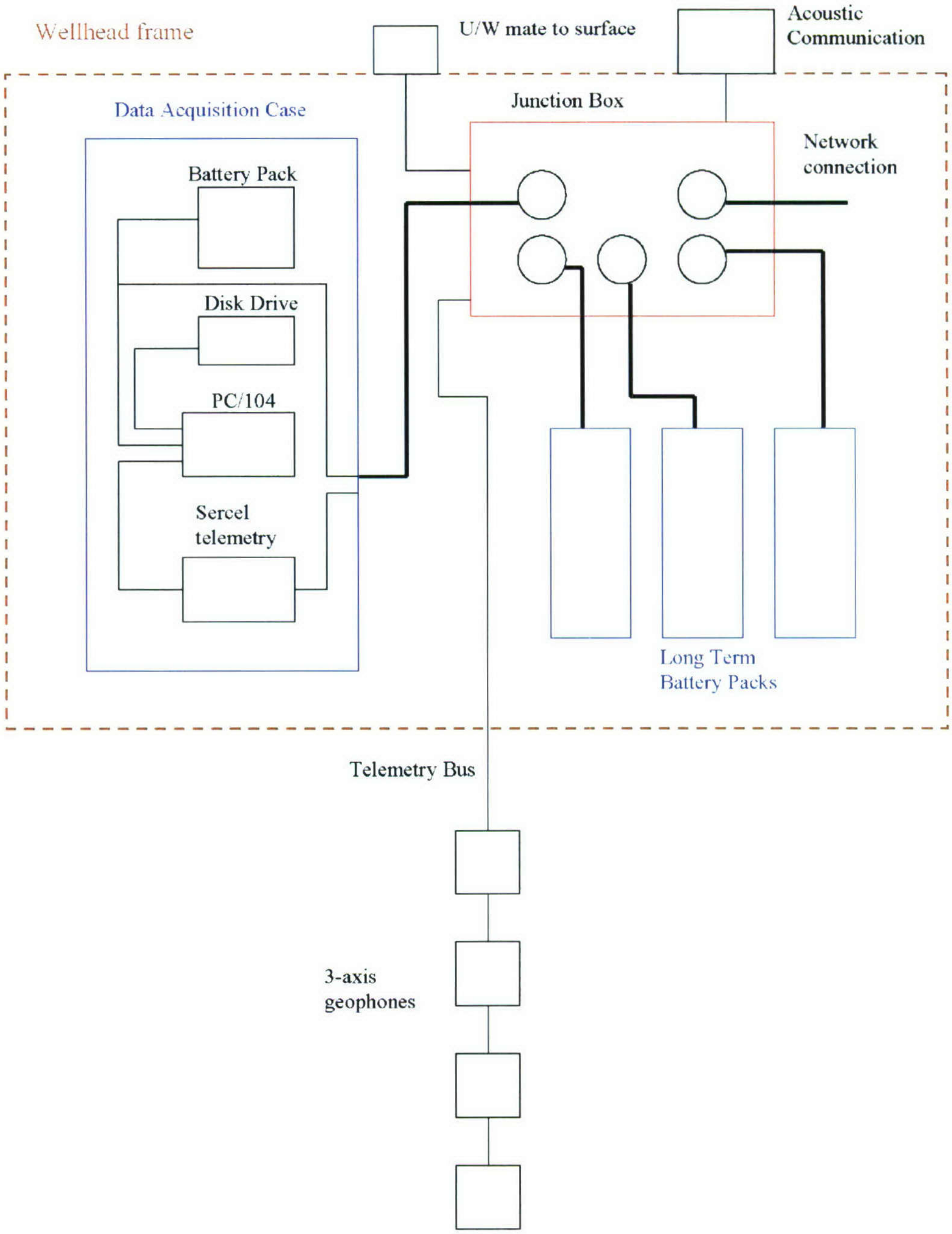


Figure 15: Summary diagram of the cables, pressure housings and junction box for the SeisCORK system. The "battery pack" in the data acquisition case also contains a power control board.

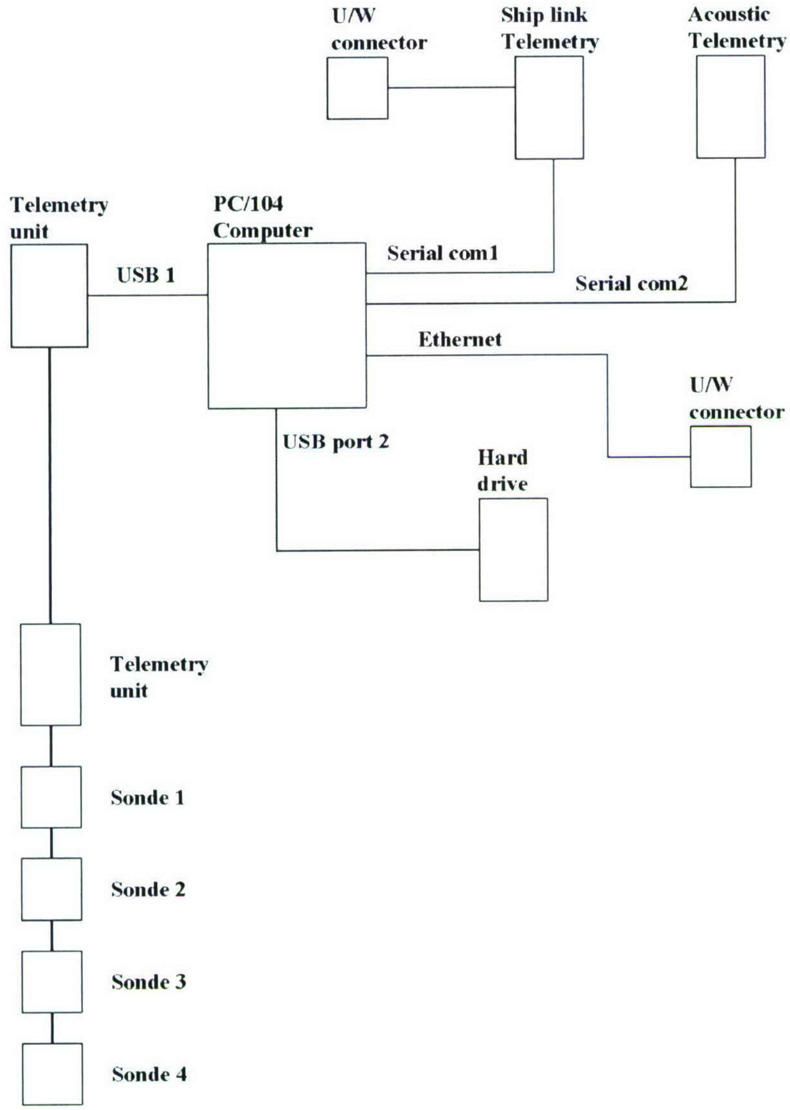


Figure 16: Functional block diagram of the borehole and seafloor components of the SeisCORK system showing the data communication protocols.

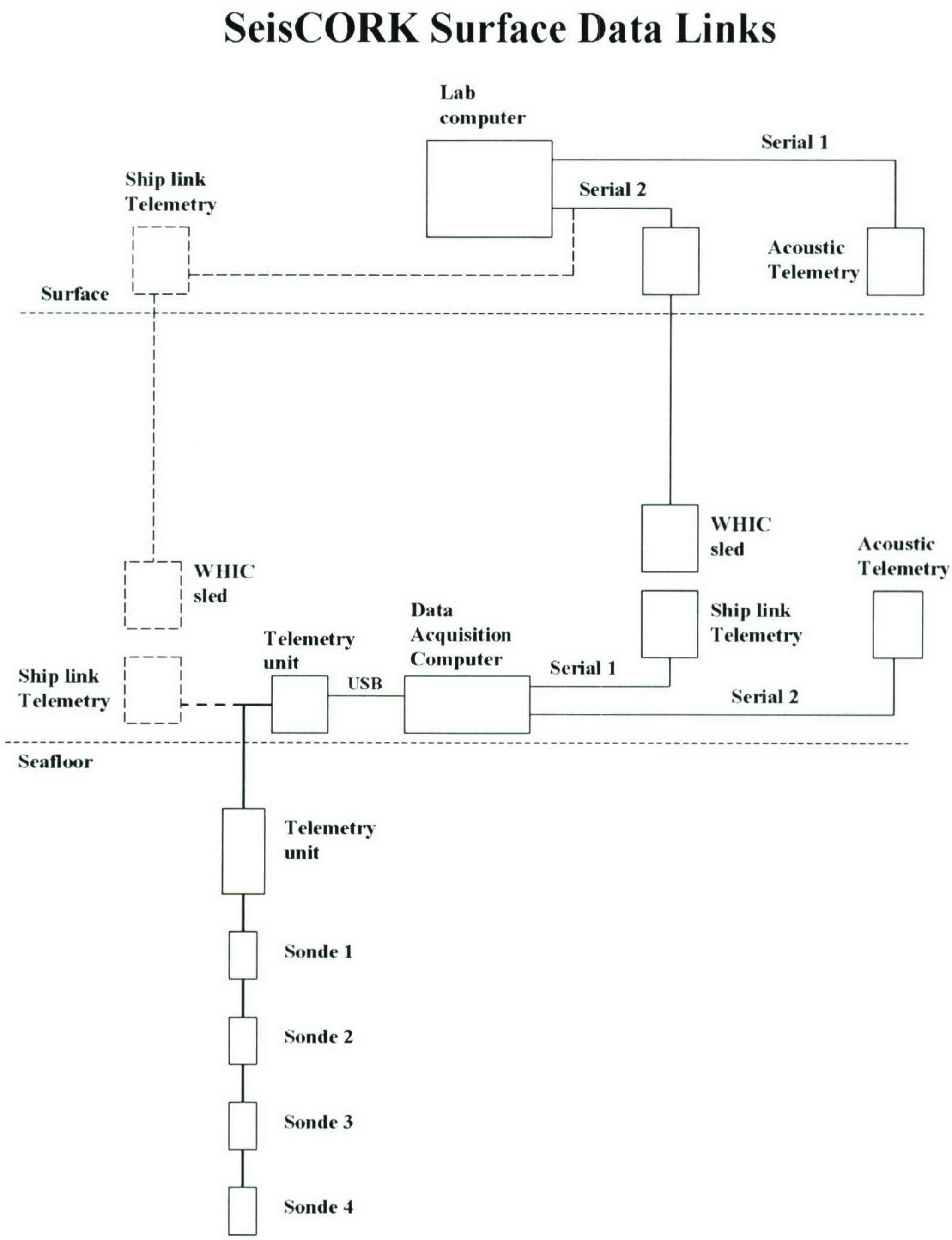


Figure 17: Summary diagram of two WHIC options for communicating between the borehole and seafloor gear to the ship during installation.

<u>Table 1: Summaries of SeisCORK Seafloor Hardware for Various Configurations and Projects</u>

Configuration 1: CORK Open Hole Wireline Seismometer Deployment

Item	Status	Responsibility	Notes
CORK wellhead	Modify existing design	IODP	Modified existing IODP design
Wireline seismic array termination P-case profile	New design	Mohr	Wellhead capability to land, latch, and seal array termination case
Thru sellhead wall internal/external wet connect	New design	Mohr - WHOI - Vendor	Electrical pass thru for data transmission from array to external data storage
Compatibility with packer inflation		Mohr - IODP	Must be compatible with existing CORK drill string packer inflation capability
Stiffer stinger	Used 5 - 6-5/8 drill pipe	IODP	Increase buckling strength
Array termination case	New design	Mohr - WHOI - Sercel	Wireline attachment and array termination point
Latch mechanism (modified TIC)	New design	Mohr	Modified existing lock mandrel technology
Mechanical actuated wet connect mechanism	New design	Mohr - WHOI - Vendor	Work with wet connect vendor to design and fabricate
Junction box - data storage - wet connect	New design	WHOI - Sercel	Incorporate Sercel technology
Wireline seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
ROV platform	Existing design	IODP	Standard IODP equipment
Reentry cone	Existing design	IODP	Standard IODP equipment
16 casing hanger	Existing design	IODP	Standard IODP equipment
16 casing	Existing design	IODP	Standard IODP equipment
16 casing guide shoe	Existing design	IODP	Standard IODP equipment
10-3/4 casing hanger	Existing design	IODP	Standard IODP equipment
10-3/4 casing	Existing design	IODP	Standard IODP equipment
10-3/4 casing cementing shoe	Existing design	IODP	Standard IODP equipment

Configuration 2A: Drill-In Behind Casing Seismometer Deployment

Item	Status	Responsibility	Notes
Drill-In casing head	Modify existing design	IODP - Mohr	Modify existing IODP DIC w/FFF design for smaller casing
5-1/2 - 7 casing	Existing	Vendor - IODP	Standard oil field equipment
5-1/2 - 7 casing guide shoe	Existing	Vendor - IODP	Standard oil field equipment
Underreamer bit	Existing	Vendor - IODP	Standard oil field equipment
Mud motor	Existing	Vendor - IODP	Standard oil field equipment
Junction box - data storage - WHIC wet connect	New design	WHOI - Sercel - Mohr	Incorporate Sercel technology, develop WHIC wet connect
Behind casing seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications

Configuration 2B: CORK Open Hole Tubing Conveyed Seismometer Deployment

Item	Status	Responsibility	Notes
CORK wellhead	Existing design	IODP	Existing IODP design
Stiffer stinger	Used 5 - 6-5/8 drill pipe	IODP	Increase buckling strength
Junction box - data storage - WHIC wet connect	New design	WHOI - Sercel - Mohr	Incorporate Sercel technology, develop WHIC wet connect
Tubing conveyed seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
ROV platform	Existing IODP design	IODP	Standard IODP equipment
Reentry cone	Existing IODP design	IODP	Standard IODP equipment
16 casing hanger	Existing IODP design	IODP	Standard IODP equipment
16 casing	Existing IODP design	IODP	Standard IODP equipment
16 casing guide shoe	Existing IODP design	IODP	Standard IODP equipment

Configuration 2C: CORK Open Cased Hole Tubing Conveyed Seismometer Deployment

Item	Status	Responsibility	Notes
CORK wellhead	Existing design	IODP	Existing IODP design
Stiffer stinger	Used 5 - 6-5/8 drill pipe	IODP	Increase buckling strength
Junction box - data storage - WHIC wet connect	New design	WHOI - Sercel - Mohr	Incorporate Sercel technology, develop WHIC wet connect
Tubing conveyed seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
ROV platform	Existing IODP design	IODP	Standard IODP equipment
Reentry cone	Existing IODP design	IODP	Standard IODP equipment
16 casing hanger	Existing IODP design	IODP	Standard IODP equipment
16 casing	Existing IODP design	IODP	Standard IODP equipment
16 casing guide shoe	Existing IODP design	IODP	Standard IODP equipment
10-3/4 casing hanger	Existing design	IODP	Standard IODP equipment
10-3/4 casing	Existing design	IODP	Standard IODP equipment
10-3/4 casing cementing shoe	Existing design	IODP	Standard IODP equipment

Configuration 3: CORK Type Seismometer Deployment

Item	Status	Responsibility	Notes
CORK wellhead	Modify existing design	IODP	Modified existing IODP design
Array termination case profile	New design	Mohr	Wellhead capability to land, latch, and seal array termination case
Thru wall internal and external wet connect	New design	Mohr - WHOI -	Electrical pass thru for data transmission

		Vendor	from array to external data storage
Compatibility with packer inflation		Mohr - IODP	Must be compatible with existing CORK drill string packer inflation capability
Stiffer stinger	Used 5 - 6-5/8 drill pipe	IODP	Increase buckling strength
Array termination case	New design	Mohr - WHOI - Sercel	Wireline attachment and array termination point
Latch mechanism (modified TIC)	New design	Mohr	Modified existing lock mandrel technology
Mechanical actuated wet connect mechanism	New design	Mohr - WHOI - Vendor	Work with wet connect vendor to design and fabricate
Tubing conveyed seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
Behind casing seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
10-3/4 Hanger electrical pass thru w/wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage
16 Hanger electrical pass thru w/wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage
Junction box - data storage - wet connect	New design	WHOI - Sercel	Incorporate Sercel technology
WHIC wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage
Wireline seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
ROV platform	Existing design	IODP	Standard IODP equipment
Reentry cone	Existing design	IODP	Standard IODP equipment
16 casing hanger	Existing design	IODP	Standard IODP equipment
16 casing	Existing design	IODP	Standard IODP equipment
16 casing guide shoe	Existing design	IODP	Standard IODP equipment
10-3/4 casing hanger	Existing design	IODP	Standard IODP equipment
10-3/4 casing	Existing design	IODP	Standard IODP equipment
10-3/4 casing cementing shoe	Existing design	IODP	Standard IODP equipment

WHIC Wellhead Inter Connection

Item	Status	Responsibility	Notes
New camera frame with added capabilities	New design	IODP - 3rd Party ?	A completely new camera system is needed with extensive new capabilities
Heave compensation	New design	IODP - 3rd Party ?	Tie in to drill string active heave control system?
Pan tilt zoom camera	Existing vendor design	IODP - Vendor	Add in vendor equipment
Electric or acoustic releases (multiple)	Existing vendor design	IODP - Vendor	Add in vendor equipment
Add on instrumentation capability	Existing vendor design	IODP - Vendor	Additional leads in coaxial/suspension cable
Seafloor package delivery capability	New design	IODP - Vendor - Mohr	Specific to IODP scientific needs and easily modified
Winch	Existing vendor design	IODP - Vendor	As required by new system specifications
WHIC wet connect	New design	IODP - Vendor - Mohr	Capability to make electrical connection with seafloor packages via camera coax

Engineering Development Projects

Item	Status	Responsibility	Notes
Wireline seismic array termination case profile	New design	Mohr	Wellhead capability to land, latch, and seal array termination case
Thru wellhead wall internal/external wet connect	New design	Mohr - WHOI - Vendor	Electrical pass thru for data transmission from array to external data storage
Wireline seismic array termination pressure case	New design	Mohr - WHOI	Wireline attachment and array termination point
Wet connect P-case latch mechanism	New design	Mohr	Modified existing lock mandrel technology
Mechanically actuated wet connect mechanism	New design	Mohr - WHOI -	Work with wet connect vendor to design and

		Vendor	fabricate f/wireline array
Junction box - data storage - WHIC wet connect	New design	WHOI - Sercel - Mohr	Incorporate Sercel technology, wet conn capability to connect log line to J-box
Wireline seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
Drill-In casing head	Modify existing design	IODP - Mohr	Modify existing IODP DIC w/FFF design for smaller diameter casing
Behind casing seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
Tubing conveyed seismometer array	Modify existing design	WHOI - Sercel	Modify existing Sercel design for WHOI specifications
CORK wellhead	Modify existing design	IODP	Modified existing IODP design
Array termination case	New design	Mohr - WHOI - Sercel	Wireline attachment and array termination point
10-3/4 Hanger electrical pass thru w/wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage
16 Hanger electrical pass thru w/wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage
WHIC wet connect	New design	Mohr - Vendor	Electrical pass thru for data transmission from array to external data storage

Table 1, cont'd: SeisCORK Seafloor Hardware
Tom Pettigrew 22 Nov 05

Item	Note
1 - 4	The required modifications to the existing IODP CORK wellhead for SeisCORK deployments are as follows: a) The interior of the upper wellhead has to be modified to accept the wireline seismic array termination pressure case. The pressure case must land in the wellhead, complete the seal of the wellbore, and latch in place. This will require that the existing profile be lengthened and possibly reconfigured. b) A through wall electrical pass through must be designed into the upper end of the wellhead, below where the wellhead running tool will latch. The electrical pass through is needed to provide an electrical connection between the wireline seismic array and the data storage unit attached to the outside of the wellhead. **Note:** Deployment of the wireline seismic array is not dependant on the electrical pass through. As a fall back, a jumper cable can be installed between the wet connect on top of the wireline array termination pressure case and the data storage unit using an ROV or submersible. c) While modifying the upper end of the existing IODP CORK wellhead, the capability to inflate downhole packers using drill string pressure must be retained. d) Electrical pass throughs must be added to the landing seal ring.
5	A stiffer CORK stinger is required to reduce the risk of buckling the stinger when deployed in open hole. The current 4-1/2" casing has a cross section moment of area equal to 6.896 in^4. By using used 5-1/2" drill pipe, the cross section moment of area can be increased to 24.789 in^4 which is 3.6 times stiffer than the 4-1/2" casing.
6 - 8	A termination pressure case must be designed for the Sercel wireline seismic array to provide the following functions:

	a) The pressure case must house the required array electronics. b) The pressure case must provide a vertical wet connect on the top for plugging in a coaxial cable for transmitting power and data. c) The pressure case must provide a latching point for the deployment wireline to latch on during deployment. d) The pressure case must provide a latching mechanism that will latch the pressure case into the wellhead in the event excessive positive wellbore pressure occurs and support the weight of the array. e) The pressure case should provide a mechanically actuated horizontal wet connect that will automatically make an electrical connection with the junction box/data storage unit attached to the outside of the wellhead. The horizontal wet connect will be automatically actuated when the pressure case lands in the wellhead and sinker bar weight is applied from above.
9	A junction box/data storage unit capable of storing all seismic data generated by the various seismic arrays must be designed that will attached to the outside of the wellhead and can be replaced using an ROV or submersible.
10	The Sercel wireline deployed seismic array will need to be modified for compatibility with IODP type instrumented borehole hardware and deployment procedures. These modifications include the following: 1) A top end termination pressure, refer to Item 6 - 8. 2) Increased anchor stroke to enable the array to pass through the drill string and anchor in a 9-7/8" open borehole. 3) Meet WHOI specifications.
11 - 18	Existing IODP and/or vendor supplied hardware that requires no modifications.
19	The existing IODP Drill-In Casing System needs to be modified for deploying smaller diameter casing.
20 - 23	Existing vendor supplied hardware.

24	Refer to Item 9.
25	The Sercel behind casing seismometer array may require modification to meet WHOI specifications.
26	Refer to Items 1 - 4.
27	Refer to Item 5.
28	Refer to Item 9.
29	The Sercel tubing conveyed seismometer array require modification to meet WHOI specifications.
30 - 34	Existing IODP or vendor supplied requiring no modifications.
35	Refer to Items 1 - 4.
36	Refer to Item 5.
37	Refer to Item 9.
38	Refer to Item 29.
39 - 46	Existing IODP or vendor hardware requiring no modifications.
47	Refer to Items 1 - 4.
48	Refer to Items 6 - 8.
49 - 50	Refer to Items 1 - 4.
51	Refer to Item 5.

52 - 54	Refer to Items 6 - 8.
55	Refer to Item 29.
56	Refer to Item 25.
57 - 58	The existing IODP casing hanger design must be modified to include an indexing mechanism to align wet connects and electrical pass through wet connectors.
59	Refer to Item 9
60	New design that allows the proposed new camera frame, WHIC (WellHead InterConnect) to make a wet electrical connection between the wellhead junction box and ship board electronics via the camera coaxial cable for real time monitoring of the seismic arrays.
61	Refer to Item 10.
62 -69	Existing IODP or vendor hardware requiring no modifications.
70 - 77	New camera system design, WHIC (WellHead InterConnect) with the following capabilities: a) Heave compensation of the coaxial suspension cable to eliminate so as a wet electrical connection can be made with the CORK wellhead junction box. b) Pan, tilt, and zoom camera to increase visibility. c) Integral to the frame acoustic and/or electrical release mechanisms to deploy seafloor instrument packages. d) Additional electrical and coaxial feeds to allow for external instrumentation to be attached to the frame, as well as, the wet connect for communicating with the wellhead junction box.

		e) New more powerful winch with fiber optics. f) Wet connect system for communicating with the wellhead junction box.

<u>Table 2: SeisCORK Project Categories</u>

Hardware

<u>Well Head Inter-Connection (WHIC) Sled</u> (Tom - separate proposal?)

- Wellhead wet connect (uphole side)
- Video camera and lights.
- Provides data link to ship (PC to PC) for arm release (if necessary), quality control and parameter adjustments prior to the drill ship departing the site. Revisiting the site with ROV to plug in recorders and battery packs for initial operation is not necessary
- Provides option to fly down additional housings and battery packs that are too big to fit on well head initially.
- Run this on same wire as VIT sled and let Sedco perosnnel fly it down. Once connected switch shipboard end to downhole measurements area.

<u>Well Hardware</u> – (Tom)

- Wellhead frame
- Borehole hardware, centralizers
- Wellhead wet connect (downhole side)

<u>Seafloor Hardware</u> (sits on the wellhead or on the seafloor next to the wellhead)

- Sercel data acquisition boards, PC/104, clock, and data storage.
- There may be two PC's: a low-power PC for autonomous mode (Quanterra bailer - ethernet based) and a high-power PC for cabled operation
- Battery housings
- Acoustic transponders
- Underwater mateable connectors for Data Acquisition bottle and battery housings plus the well head wet connect (see Well Hardware)

Sercel hardware

- four three-component sondes, rigged with bow springs and clamped to the outside of 4.5inch casing (or drill pipe) at 50m separation (depths of 100, 150, 200, 250m)

- data acquisition boards (possibly remove telemetry to reduce power)

Software

Seafloor software

Storage format (Quanterra-like SEED)
Instrument control
Timing
Metadata should be added as much as possible in real time (time, instrument params, etc).

Shipboard software

Data display
Samples of data
QC / pulse test
Sensor control

Observatory mode software

Local storage + streaming to shore
Server mode with metadata, time and SEED format

Personnel

Project/Electrical Engineer
Mechanical Engineer (Drill ship/Borehole)
Software Engineer
Mechanical Engineer (Seafloor/Cable Interface)
Mechanical Technician
Scientist

Table 3: SeisCORK Work Plan

Work plan for SeisCORK system - configuration 2C

System Design and Construction						
Item description	Status	Responsibility	Notes	Engineering	Technician	Parts cost
Data acquisition module						
Fabricate 10" I.D. pressure case	WHOI new design					
Design and build electronics chassis	WHOI new design					
PC/104 computer - includes power supply and I/O port boards w/ network interface	WHOI new design					
Data storage unit - hard drive based						
Power control board	WHOI new design					
Sercel Geowaves-style telemetry unit w/ USB interface	Sercel existing					
Sercel Geowaves-style Coupling Card	Sercel existing					
Junction box						
Fabricate jbox housing	WHOI new design					
Connector installation	WHOI					
Connector wiring and test	WHOI					
Battery packs						
Fabricate 10" I.D. pressure cases	WHOI new design					
Assembled battery packs	Battery vendor					
Assemble and test battery cases	WHOI					
Geophone array						
Acceptance testing	WHOI/Sercel					
System integration	WHOI					
Acoustic telemetry						
Integrate and test	WHOI					
Software development, system integration and test						
Data acquisition computer	WHOI					
Shipboard control computer	WHOI					
Complete at-sea system test						
System deployment						

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APPENDIX 1: Supporting Letters from Andy Fisher

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24 July 2004

Ralph Stephen
Woods Hole Oceanographic Institution
360 Woods Hole Road (MS24)
Woods Hole, MA 02543-154

Dear Ralph,

I am writing to express my support for your SGER proposal titled, "SEISMOMETERS ON CORKS: DESIGN PHASE" As you have noted, there is a need to explore options for merging seismic, hydrogeological, and microbiological objectives within a single CORK installation. As I see it there are two fundamental justifications for this effort, the first being scientific and the second being more technical and logistical:

(1) There are profound scientific questions regarding relations between seismic and other properties and processes, and these will never be addressed until we begin to collect data in the same locations and at the same spatial and temporal scales. Each kind of data acquired in the same borehole, at the same time, helps to leverage benefit from the other. Similarly, improving the nature of seismic data collection in subseafloor boreholes will help to link and leverage long-term goals of IODP and ORION.

(2) These holes and observatory systems are expensive, challenging to install, and take a long time to get onto the drilling schedule. We as a community have to grapple with the finite nature of resources, including access to drilling platforms. We all stand to benefit if we can figure out how to piggy-back experiments.

For these reasons, I consider your proposal to be both timely and important. In addition, with your long history of cutting-edge research in seismologty, borehole geophysics, and scientific drilling, you are the right person to lead this effort.

Let me also comment on some timing and logistical issues associated with the future drilling expedition. When iPC scheduled the first year of IODP riserless operations, proposal 545Full3 was forwarded to OPCOM for consideration as a complete package. SPC has since made it clear that it is their intention that the second part of the drilling science associated with 545Full3 is to remain with OPCOM and be considered for scheduling, pending submission of a report on IODP Expedition 301 results. At this point, we have successfully installed one CORK observatory on IODP Expedition 301, and have installed 85 m of casing into upper basement in preparation for a second CORK observatory, this one with multi-level monitoring. The other two IODP 301 CORKs are to be installed in Holes 1026B and 1027C, and these are technically much less challenging. We are presently on schedule to complete all planned work on IODP 301, and anticipate making a very positive report to SPC after the expedition. The next opportunity for a second expedition to complete the drilling part of this experiment will be in 2006, and this

Fisher, re: SeismoCORK *Page 1*

opportunity should be attractive to both OPCOM and the USIO. It will complete the part of the 545Full3 experiment that requires a drill ship (remaining work will be done from HOV and ROV) and will use only about 30-35 days of ship time. If it is possible to incorporate additional seismic objectives during a 2006 drilling expedition, it is important that we sort out several technical issues in the next few months in order to have time to fold these plans into a February 2005 NSF proposal (Fisher, Becker, Wheat et al.) that will be submitted for support of CORK-related experiments.

Finally, Keir Becker and I have talked about making sure that there is good communication among seismologists and others involved in CORK experiments, so that we do not compromise basic design features of these systems. My teaching and travel schedule for the fall is already tight, but Keir Becker has indicated that he should be available to attend one or more meetings with engineers, seismologists and others. I will contribute to discussions remotely and will read very carefully any documents produced as a result of these discussions. It is not clear at the moment that it will be possible to incorporate seismometers in CORKs deployed on the eastern flank of the Juan de Fuca Ridge in 2006, but this is an opportunity that we should not simply let pass. Making a definitive determination as to whether and how these various goals can be merged is essential to making good decisions during the next 1-2 years.

Please let me know if I can provide any additional information, and best wishes with your proposal.

Sincerely,

Andy Fisher

Andrew T. Fisher
545Full3 lead proponent
and co-chief on IODP Expedition 301

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23 February 2006

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Ralph Stephen Woods Hole Oceanographic Institution
360 Woods Road (MS24) Woods Hole, MA 02543

Dear Ralph,

I am writing this letter in support of your efforts to develop and deploy a sealed-borehole seismometer (SeisCORK) on the eastern flank of the Juan de Fuca Ridge, in coordination with a drilling program tentatively planned for Summer 2008 (part of IODP proposal 545Full, for which I am lead proponent). This work would leverage ongoing and planned drilling and post-drilling experiments, as described below, and in a broader sense would contribute significantly to efforts within the community to develop new capabilities for maintaining a long-term monitoringpresence on and below the seafloor to address a variety of fundamental problems.

As you know, the original operational plan described in IODP 545Full included an offset VSP experiment run in the same location as cross-hole hydrogeologic, tracer, and microbiology experiments. This offset VSP was to use an approach similar to that applied in other DSDP and ODP boreholes over the last several decades, with the drill ship deploying a multicomponent seismometer in a basement borehole and a second "shooting" ship moving around the borehole along a series of radial and concentric tracks firing a seismic source. It has become increasingly clear that it will be difficult to coordinate an operational plan such as this during the Summer 2008 drilling program. Even if we had a stable, cased basement hole already drilled and ready to go, there would be enormous challenges in scheduling an appropriate seismic vessel and dealing with new marine mammal requirements while holding the drill ship on station for a sufficient time. In fact, we will be creating new basement holes during Summer 2008, but it is virtuallyimpossible to know what the day-to-day operational schedule of the drill ship will be -it will need to remain flexible right through the drilling expedition to accommodate actual time requirements for drilling, casing, and CORK experiments, weather delays, and other factors.

Installing a SeisCORK obviates these scheduling and operational difficulties because it allows the offset VSP to be run essentially any time after the SeisCORK is installed. If a SeisCORK were installed as part of an APL during Summer 2008, as you and your colleagues have proposed, the offset VSP could be run later that fall or the following summer. In addition, by having the SeisCORK in place during Summer 2008 drilling operations, it would be possible to monitor microseismicity associated with changing stress conditions as a result of drilling and subsequent experimental operations, including free-flow experiments to be run using other

CORK systems during the subsequent 2-3 years. This approach has been taken on land in petroleum reservoirs and aquifers, but has not been attempted in the oceanic crust.

In addition, SeisCORK technology has the potential to contribute to solving important problems in a variety of settings, including subduction zones and areas of active volcanism. Developing a long-term monitoring presence on and below the seafloor, in dynamic locations, is part of an ongoing trend in marine geology and geophysics towards studying and understanding active processes rather than their products. These efforts are complex and difficult, but ultimately they are essential if we are to gain a genuine understanding of coupled processes within the ocean floor.

Best wishes with your proposal efforts, and please keep me informed as to your progress.

Sincerely,

Andrew T. Fisher

APPENDIX 2

SeisCORK Meeting Report

R.A. Stephen, T. Pettigrew , K. Becker and F. Spiess

November 15 and 16, 2004

Stress/Mohr Engineering,
Houston, Texas 77041-1205

Summary: The purpose of this meeting was to explore design options to simultaneously acquire borehole seismic data and hydro-geological data (pressure, temperature, fluid sampling and microbiological sampling) on a single CORK system. The scientific focus was to add a seismic component to the Juan de Fuca Hydrogeology program. By permanently installing a sensor string in the borehole our goal was to enable: 1) time-lapse VSP's and offset VSP's with sufficient data quality to study amplitude versus offset, shear wave anisotropy, and lateral heterogeneity; 2) monitoring of micro- and nano- earthquake activity around the site for correlation with pressure transients. Because of the difficulty in ensuring adequate coupling through multiple casing strings we concluded that it was impractical to install the vertical seismic array with 10m spacing (50-60 nodes) that would be necessary for VSP's and time-lapse VSP's. We did describe a scenario for a vertical seismic array with approximately 100m spacing (5-6 nodes) that could be used for offset-VSP's and seismic monitoring. This uses some unique technology and involves two seismic strings: one in the annulus between the 4-1/2" and 10-3/4" casings and one in the middle of the 4-1/2" casing.

I. Introduction

The purpose of this meeting was to initiate the development of equipment to simultaneously acquire borehole seismic data and hydro-geological data (pressure, temperature, fluid sampling and microbiological sampling) on a single CORK (Circulation Obviation Retrofit Kit) system [*Davis, et al.*, 1992; *Jannasch, et al.*, 2003; *Shipboard_Scientific_Party*, 2002]. (The attendees and their contact information are given in Appendix A.) Such a capability could be used for a broad range of borehole geophysical experiments targeted at various geological and seismic processes, however the scientific focus of this effort is the Juan de Fuca Hydrogeology program (see Appendix B for notes on the hydrogeology science program). This program consists of two phases. The first phase, IODP Leg 301, was at sea on the Juan de Fuca Ridge in Summer 2004 (Figure 1)[*Shipboard Scientific Party*, 2004]. Planning for the second phase is based on the results of Leg 301 and is taking place in Fall 2004. The challenge is to formulate a drilling and instrumentation plan that can be implemented while the riserless drill ship is still in the Eastern Pacific in Summer 2006, 2007 or possibly 2008.

Permanently installed borehole seismometers would enable both active controlled source and passive monitoring experiments (see Appendix C for more notes on the scientific justification for borehole seismometers on CORKs). Seismic mapping of the lateral heterogeneity and anisotropy of the upper crust will be necessary in order to provide the framework for the hydro-geological results. This will best be accomplished by a combined OBS (ocean bottom seismometer) refraction and offset-VSP (vertical seismic profile) experiment. Given the logistical difficulties of coordinating the operations schedules of two vessels on the high seas, the best approach for the combined seismic experiment is to integrate the VLF (1-100Hz) borehole geophones with the CORK which will be installed in 2007 or 2008. The OBS experiment can then be carried out after the drill ship has left the site. The offset VSP data from the seismometers in the CORK can be acquired on the seafloor as in a conventional OBS.

The borehole sensors themselves can be considered expendable and will stay with the CORKs for the duration of the hydro-geological experiments. During this phase, which would last at least three years post drilling, the borehole geophones can record ambient nano- and micro-earthquake activity associated with the hydrothermal processes. The Juan de Fuca hydrogeology site is a proposed node ("ODP 1027") on the Neptune Canada seafloor cabled observatory network. As the cabled observatory infra-structure becomes available the borehole seismic data could be made available in real time to shore-based labs. (Tentative design goals for the Neptune Canada system are to have a least 9KWatts of power per node, to have 2-4Gigabit/sec ethernet at each node and to provide absolute time to within 10microsec.) Some notes on CORKs, the IODP drilling program and the OOI/ORION/NEPTUNE observatory program are given in Appendix D. A summary of various CORK and seismic observatory configurations used on DSDP, ODP and IODP is given in Appendix E.

The focus of this meeting was to develop SeisCORKs for IODP **non-riser** drilling on the **Juan de Fuca Ridge**. These holes will be only a few hundred meters deep through about 250m of soft sediments and penetrating about 200m to 350m into hard basalt. Beyond the focus of this meeting there are other applications for SeisCORKs in different geological environments. For example, systems similar to the Juan de Fuca Ridge program could be deployed in **non-riser** holes drilled for the Nankai Trough or Costa Rica Trench projects. Many of the problems and solutions discussed in this report have general applicability to a broad range of IODP drilling objectives.

II. Design Considerations

a) Not to interfere

Not to interfere with the existing and planned hydrological observations.

b) Node description

Each "node" should consist of a three component seismic sensor and a hydrophone.

c) Sensor specifications

System noise floor, sensitivity, THD, phase response, etc should be sufficient to faithfully acquire ground motion and pressure in the band 0.2-100Hz with system noise less than the quietest observed seafloor and sub-seafloor ambient noise spectra (Figure 2). (For a comparison of ambient seismometer and hydrophone noise levels in a borehole on the seafloor see Stephen et al, 1994 and 2003.)

d) Well configuration and depth

The focus here is on deployments in wells that are less than 2000m deep (typically 300-600m below sea floor) in water depths up to 5500m with sediment thickness of 250-300m. These holes are riserless (no BOP) and are generally left with a re-entry cone about 4m in diameter with 10-3/4" casing from the cone to upper basement and open hole below that. (The top of the IODP standard re-entry cone is actually an octagon inscribed inside a 12ft diameter circle.) Pressure housings, cables and connectors should be designed to operate to depths of 7500m (750atm or 11,250psi in water)

e) Sensor configuration

For VSP's you would want a sensor every 10m at most (up to 60 sensors in a 600m hole). For offset VSP's and passive monitoring a nominal sensor separation of 100m (6 sensors in a 600m hole) is sufficient. This will of course vary depending on the geology intersected by the well. The number of channels would vary from 240 (assuming 10m separation for VSP's) or to 24 or less (assuming 100m separation for offset VSP's and passive monitoring).

f) Field assembly

CORK bodies and sensor strings need to be made-up on board ship because the well dimensions are usually not known in advance. Plans change depending on drilling progress and flexibility is essential.

g) Sensor coupling

Good coupling to the formation is essential for quality seismic observations. This must be assured through some form of clamping mechanism, cement, glass beads, etc. Boreholes drilled for hydrologic observations typically have multiple casing strings with packers and seals in various locations. Only the center of the innermost casing is readily accessible and this can be separated from the formation by up to four casings. It is generally felt that the response of a sensor clamped to the innermost casing would be attenuated and distorted from the true formation motion. Historically tube waves, casing resonances and even clamping arm resonances have been observed on borehole seismometers that are not adequately clamped to the formation.

h) Temperature

Typical temperatures in the upper basement at the Juan de Fuca sites are less than 70ºC; the deepest hole so far in ocean crust (about 2km) had bottom hole temperatures of 200ºC. A target design specification can be set at the military spec for solid state chips of 125ºC.

i) Outside Diameter

The available diameter through the center of a CORK varies depending on design. For the Juan de Fuca configurations gear that passes through the center of the 4.5" casing should have an OD of 3.5" or less. Gear that will be installed between casing strings should be 3.0" or less.

j) Power Consumption

SeisCORKs will be operated in both autonomous and cabled observatory modes. In autonomous mode, at least one node should be acquired continuously for a year or more with only battery power supplies. The design goal is 2Watts per node including digitizing and recording. More nodes would be turned on for various experiments such as the offset VSPs and a reasonable power strategy needs to be defined.

k) Installation and maintenance

Most CORKs have been installed from the drill ship although two have been installed by wireline re-entry. Maintenance such as changing power supplies, retrieving data modules, or downloading data is usually carried out by ROV or submersible.

l) Data Acquisition and telemetry

All SeisCORK configurations must be able to acquire data for up to a year in autonomous recording mode as well as to interface with the cabled observatory infrastructure. Even under cabled observatory operation there needs to be a back-up capability for those periods when the cable is down.

m) Timing

In seismic refraction experiments absolute time, to an accuracy of one second, is required to obtain ranges and bearings from the navigation data of the shooting ship. Accurate relative times from the shot to the receivers, to an accuracy of 20ms, is required to measure meaningful velocities and depths for studying earth structure. Advanced array processing of the digital data requires extremely accurate, to with 50microsecs, relative times between samples on adjacent channels [*Stephen, et al.*, 1994b]. The goal of seafloor networks such as Neptune Canada is to have absolute time available at the nodes to an accuracy of at most 10microsecs.

n) CORK Configurations

Figure 3 shows the three CORK configurations deployed on Leg 301 in the summer of 2004. Planning for the next phase in 2006 or 2007 is based on installing CORKs similar to the ones in Holes 1301A and 1301B. A 20inch casing string is used to stabilize the hole just below the re-entry cone. 16inch casing is used through sediments and 10-3/4inch casing is used through the poorly consolidated rubble at the top of basalt.

o) Keep Weight on the Seals

As configured for the Juan de Fuca holes, the instrument string that runs down inside the 4.5" casing consists of two seals that must come to rest on seats in the casing. There must be sufficient weight below the bottom seal to pull the seals into place. This places constraints on systems which rely on "landing" a sensor in the bottom of the well.

p) In-situ Check-out, Recovery, and Redeployment

Since borehole seismic systems often do not work correctly when first installed, it is prudent to have a system design that allows the sensor package to be checked-out in-situ and to be recovered and redeployed if necessary. Recovery is also a good idea if one wants to use the hole again for other measurements after the seismic work is done. For installation scenarios where this is not possible, extra effort must go into the design for reliability and redundancy.

q) Data Acquisition

For adequate dynamic range the system should have 24bit D/A's. Data from the borehole array must be acquired on the seafloor in an autonomous, battery powered package which would be recovered and maintained annually.

For eventual use with the Neptune Canada cable, the cable interface will be Ethernet with TCP/IP. Some battery powered buffering will be necessary for periods when the cable power goes down.

r) Electrical connections through packers, seals and plugs

CORKs are designed to seal off sections of the hole for pressure measurements and sampling and this requires various combinations of packers, seals and plugs (Figure 4). Electrical pass-throughs are possible but they should be kept to a minimum in order to reduce failure modes and costs. Ideally the pass-throughs would be single coax.

s) Programmatic Issues

The target date for the first SeisCORK installation from the drill ship would be Summer 2007 or summer 2008. There is arecovery cruise for the osmotic samplers in 2008 using either an ROV or submersible, but any seismic gear installed at that time would have to fit through the 4.5" casing.

t) Drill Collars

Experience on Leg 301 suggested that drill collars should be added to the bottom of 4.5" casing to keep the casing in tension during deployment. The collars would have a larger OD but same ID as the 4.5" casing.

u) Casing ID's

The 4-1/2" casing has an ID of 4.052"; the 10-3/4" casing has an ID of 10.05"; and the 16" casing has an ID of 15-1/8".

III) Design Narrative

The two major design considerations in our discussions were sensor coupling and sensor outside diameter. Bottom cables exist with 240, 4-component nodes that could be configured into a 2.5"OD to lower into a well. All borehole seismic experience over the past 40 years suggests that this is not good enough. The seismic sensors must be coupled to the formation either directly in the open hole (for example by clamping or by burying in glass beads) or by clamping to the casing which is in turn coupled to the formation (by cement or by the natural compaction of the overburden). It is reasonable to assume that in soft sediments the sediments over time will collapse against the casing [*Stephen, et al.*, 1994a, for example]. When a casing is installed in hard rock, enough cement is typically pumped into the well to rise up about 100m behind the casing (for the 16" and 10-3/4" casings in Figure 4 but not the 4-1/2"casing). (On the OSNPE for example the sensor was clamped in casing that had been cemented in the upper basement.)

Early in the meeting we concluded that a single string with sensors spaced every ten meters as conceived for time-lapse VSP's was impractical for the Juan de Fuca CORKs. (Similar systems are installed in tubing behind casing on land holes.) Even if a clamp were placed at each node, the top 300m or so would be in "double-", "triple-", or "quadruple-casings" and seismic coupling through the annulus would be poor. Also pumping cement in behind casing to improve coupling would interfere with the hydrological measurements. So we focused on a multi-tier seismic sensor strategy:

1) Sediments

For the sediments, it is quite likely that the drilling will require two casing strings (16” to get to basement and 10-3/4” to get through the rubble zone at the top of basement) with an “annulus of silence”. 1a) So for good coupling in the sediments we will need a separate SeisCORK that would be washed in. 1b) There is also on option to use a "dump bailer" arrangement designed by Tom Pettigrew (Figure 5) which could fill a short section in the annulus between casing strings with glass beads. This packing with glass beads may be sufficient to couple the inner casing with the formation. Given the potential pay-off of such a scheme it is probably worth testing it either on Juan de Fuca or during the MARS borehole tests. Then we could use a hydraulic clamp on the outside of the 4.5"casing to couple a sensor to the inside of the 10-3/4" casing at the depth of the bailer/basket.

Regarding the dump bailer, it can be made up to approximately 25 m long without hampering deployment from the ship. Hydraulic power to operate the dump bailer can be supplied via the packer inflation line or a separate dedicated hydraulic line. Note that when the dump bailer is actuated, no pressure pulse is introduced into the well bore. This is a good news/bad news situation. The good news is that the pressure meters and borehole proper will not see a pressure pulse from actuating the dump bailer other than the small change in volume created by the stroking action. Also, there will be small weep holes in the dump bailer to allow fluid to flow in and 1) equalize pressure during deployment, and 2) to account for the volume change during stroking and due to the glass beads draining out. The bad news is that the actuation volume change is so small that it will not be seen from the rig floor gauges. Thus the hydraulic lines will just have to be pressurized well above the shear pin setting and held for a period of time.

2) Upper Basement above the Packers

In the upper basement where there is just 10”casing next to the formation we could either 2a) use a hydraulic clamp on the outside of the 4.5” casing to couple a small sensor (about 3.0inch OD) to the wall of the 10”casing (Figure 6) or 2b) install a small sensor within a packer.

Coupling between the 10" casing and the formation may not be good but this scenario (coupling to casing with clamping arms) was used on the OSNPE with apparently good results. Since this is above any packers it is relatively easy to bring lines to the surface. Note that all lines between the 4.5" and the 10" casing need to pass through the "well head seal". This will require a bulk head style connector with cable terminations on either side of the seal and to simplify this and reduce failure modes we recommend making this a coax connection. This means putting signal conditioning electronics, digitisers and multiplexors in housings in the annulus below the "well head seal".

Regarding the ability to attach a 3" diameter instrument to the outside of the 4-1/2" casing, this should be possible by using eccentric centralizers that push the 4-1/2" casing off center. With a 3" instrument attached, the apparent OD would be around 7-1/2". Given that the packer(s) are about 8" OD, the 3" instrument attached to the off center 4-1/2" casing, shouldn't pose any more of a restriction than the packer(s). However, please note that use of the eccentric centralizers will require that the instrument be place in the middle of a 3 or 4 joint section of 4-1/2" casing. This minimum length is required to 1) make a smooth transition in the curve, 2) minimize the restriction to long instruments deployed inside the 4-1/2" casing, and to not hamper insertion in the borehole. Thus the instrument cannot be deployed immediately above or below a packer, a screen, or other tools with their mandrels on center.

Regarding the hydraulic clamp, it can be placed almost anywhere in the 4-1/2" casing string. It will become an integral part of the 4-1/2" casing string. As with the dump bailer it can be tied into the packer inflation line, the dump bailer hydraulic line , or have it's own independent hydraulic line. Also like the dump bailer, the hydraulic clamp actuation will not show up on the rig floor gauges.

3) Between or below the Packers

Between or below the packers we could use a hydraulic clamp but special care would be needed to get hydraulic and electrical lines to the surface through the packers.

4) Open Hole

In the open hole below the 4" casing and below the osmo samplers we could use a traditional mechanical clamp or glass beads to couple a sensor. This could be lowered as 4a) a stinger on the 4.5"string and could be larger than the 3.75" ID or 4b) it could be lowered through the 4.5" casing if it were less than 3.75". In 4b) electrical lines could go through the inside of the 4.5" casing so running through packers would not be a problem. In 4a) all electrical lines would need to pass through all packers and the well head seal. Also in 4a) we would need screened/slotted casing above the seismic section to permit fluid flow into the osmo-samplers. Note that in 4b) if the seismometer provides the weight to pull the seal plugs into their seats then the seismometer cannot land in the bottom of the hole. Once the seal is in place, the weight of the seismometer can be relieved by clamping or glass beads. This means that sufficient glass beads need to be installed to fill the hole below the sensor as well as the annulus around the sensor. In this case a "wireline bailer" (similar in function to, but mechanically quite different from, the "dump bailer" in Figure 5), would be deployed on the cable, above the seismometer, and below the lowermost seal. Alternatively a sinker bar - soft tether arrangement could be configured. Or possibly combining both schemes where the wireline bailer could be used as a sinker bar and the seismometer could land in the bottom of the hole and also be surrounded by glass beads.

Now also in 4b) the electrical wires are run up through the 4.5" casing to the drill ship. This has the advantage that during installation power can be provided to the sonde to extend the clamping arms, unlock the mass, level the sensor, and acquire test data. In order to make the connection to electronics at the well head the cable needs to be severed underwater. We propose a connector above the top plug/wellhead and approximately 10m up inside the drill pipe/BHA (ie several meters above the top of the re-entry cone). This connector would join the specialized electric cable in the well to the standard logging cable. When it comes time to disconnect, a burn wire can be activated at the connector. Just below the burn wire is a make/break underwater connector. Now most of the weight of the cables in the well will be supported at the well head by the top plug. Between the top plug and the burn wire connector the cable is made slightly positively buoyant either with floatation or a soft tether. After the burn wire release the logging cable is retrieved and the drill pipe is pulled off the floating cable. An ROV can then be used to plug the make/break underwater connector into the acquisition electronics on the well head.

In scenario 4b), the tops of the SeisCORKs should be reconfigured to enhance re-entry by wireline, ROV, or submersible assisted systems in subsequent rounds of instrumentation.

5) Separate Seismic Borehole

There is an obvious solution to go with a separate hole for the seismic work - but this would not be a "SeisCORK" and for now is not the focus of our discussions.

In the current design the CORK elements are mounted on a mechanical "Spectra Cable" which is lowered into the 4-1/2" casing. For SeisCORKS this would be replaced with electro-mechanical cable at least to the lowermost seismometer.

With respect to " In-situ Check-out, Recovery, and Redeployment", just about any system that places sensors on the casings will have at least two problems: a) Providing an electrical connection to the sensor from the drill ship will be difficult. Since the sensor is being lowered with the casing, it is awkward to maintain a cable connection while lowering the casing. (On Ngendie [*Adair, et al.*, 1987] the sensor was in a "stinger" on the end of the drill pipe and electrical connectivity was maintained to the sensor by using a side-wall entry sub.) These systems usually bring electrical cables to plugs on the seafloor and clamping and quality control tests are carried out on a later ROV or submersible operation. b) With the possible exception of the 4-1/2" casing (which is like drill pipe), it is often a tricky task installing casing in open hole, and once installed no one would want to recover the casing just for a faulty sensor (even if it were technically possible). Also once the glass beads are released it will be difficult to get them back or to pull the sensor back out of the beads. (There is the possibility of deploying a hydraulic vacuum for sucking the beads back out of the hole, but getting the beads back from between casings would not be possible). Only scenario 4b) - a wireline sensor deployed in open hole or clamped to the inside of the 4-1/2"casing, has the options of both in-situ check-out and conveniently recovering and redeploying the seismic sensor if it does not pass the tests

IV) SeisCORK Scenario for 2007/2008

Given the complexity of coupling a string of seismometers in multi-casing systems we do not recommend a single string with 10m node spacing for time-lapse VSP's on the Juan de Fuca project in 2007/2008. The best option for VSP's is to carry them out from the drill ship as a logging activity independent of the SeisCORK nodes, sequentially working the sections in which the casing at that time is the outermost or possibly even in open hole. For example, there is little point in doing a VSP in the 20"casing, but two VSP's could be done as follows: i) in the 16" casing (to get the sediment profile), ii) in the 10-3/4" casing (to get the upper, poorly consolidated, basalt layer) and in the open hole below the 10-3/4"casing before the 4-1/2" casing is installed (this should be in stable, open hole in consolidated basalt). Note that during this style of VSP the drill pipe is dangling and banging in the upper section of the hole reducing SNR. Some mechanism should be devised to clamp the drill pipe to reduce banging and other drill pipe related noise.

A borehole seismometer string with about 100m spacing could be installed using a staged approach. This string could be used for monitoring nano- and micro-earthquake activity, for offset VSP's with a shooting ship after the drill ship has left, and for time lapse offset VSP's. A SeisCORK scenario based on a CORK installation similar to Hole 1301B in Figure 7 is outlined in Table 1.

Table 1: Hypothetical SeisCORK installation in Hole 1301B

	mbrf	*mbsf*	*msb*
Seafloor	2668*	000	
Base of re-entry cone	2671*	003*	
Bottom of 20" casing	2710*	043*	
A - Mid-sediment Node (if necessary) (Tier 1b)	**2808**	**140**	
Basement	2933*	265*	000
Bottom of 16" casing	2939*	0271*	006
B - Upper-basement Node (Tier 2a - clamped inside 10-3/4"casing)	**2948**	**280**	**015**
Bottom of 10-3/4" casing	3019*	351*	086
C – Node (Tier 2a - clamped to formation)	**3033**	**365**	**100**
D – Node (Tier 2b - inside the top packer)	**3098**	**430**	**165**
Top Packer	3098*	430*	165
E – Node (Tier 3 - between packers)	**3133**	**465**	**020**
Bottom Packer	3141*	478*	
Bottom of 4-1/2" casing	3177*	514	249
Bottom of CORK instrument string	3199*	536*	271
F - Bottom Node (Tier 4 - buried in glass beads)	**3233**	**565**	**300**
Bottom of Hole	3251**	583**	318**

(mbrf - meters below rig floor,
mbsf - meters below sea floor,
msb - meters sub-basement,
depths have been rounded to the nearest meter.
** - Depths in U1301B from page 67 [*Shipboard Scientific Party*, 2004],
* - Depths in U1301B from Figure 7
Depths in Hole U1301B are used as "typical" values, the CORKs installed in 2007/2008 would be installed in new holes in a similar setting.)

In the scenario in Table 1, the electrical lines for the mid-sediment and bottom nodes (A and F) would run through the inside of the 4-1/2" casing. These sensors would be lowered after the 4-1/2' casing was installed and the electromechanical cable would replace the "Spectra Cable" in the CORK instrument string. This cable would run through the upper and lower "seal plugs". Nodes A and F could have an OD up to 3.5". Node F could be buried in glass beads for improved coupling and reduced convection noise. It will be necessary to recover this string to retrieve the hydrothermal sensors. If glass beads are used for coupling we would need to think about how well the node would pull out of the beads. These sensors could be replaced if necessary.

Nodes B, C, D and E are mounted outside the 4-1/2' casing and are installed with the casing. The electrical and hydraulic lines for these nodes run in the annulus outside the 4-1/2" casing and must pass through the "well head seal". Since we would like this pass-through to be a single coax some conditioning electronics (preamps, digitisers, multiplexors, etc) would need to be installed in the annulus between the 4-1/2" and 10-3/4" casings and below the "well head seal". Lines from node E would need to run through the upper packer. These nodes can have an OD up to 3.5". They are permanently installed.

V) Frequently Asked Questions

Why not use the LFASE sondes?

The OD of the LFASE sondes is 4.39"(112mm) which is too big to fit through the ID of the 4.5"casing/pipe which is nominally 4.125" (3.5" recommended working ID, the OD of the borehole seismometers used on ODP and DSDP was 3.62").

Why not increase the size of the innermost casing string from 4.5" to something large enough to accomodate the LFASE and other large sensors?

Increasing the diameter of the innermost casing would "telescope-up" the whole casing design strategy.

Why not use MEMS sensors?

MEMS sensors are OK for controlled source experiments such as VSP's but their system noise floor is too high [about -127dB re: ((m/s^2)/sqrt(Hz))] for monitoring small earthquake signals in the band 1-100Hz where background earth noise levels are typically -160dB re: ((m/s^2)/sqrt(Hz)). One advantage of the MEMS is that they provide a 1-100Hz response in a 2.5"OD housing.

Will SeisCORKs replace dedicated ION-style ocean seismic observatories?

No. ION-style ocean seismic observatories are targeted to meet the specifications in bandwidth, noise floor and dynamic range of the Global Seismic Network. For example, the noise floor for ION observatory sensors is required to be less than the USGS low noise model for the frequency band from 0.001 to 10Hz. This requires relatively expensive "observatory quality" sensors which are typically large and which must be carefully installed in dedicated boreholes. For example the sensor on the OSN Pilot Experiment was about 10m long, 8"OD and cost over

$80,000. For the controlled source and passive monitoring goals associated with hydrologic observatories, higher frequency, narrower band sensors are required (0.2-100Hz). These are similar to sensors used in petroleum exploration and are typically smaller and less expensive than broadband GSN style sensors. Furthermore there is very little overlap in the locations of boreholes for the ION-GSN network with the hydrological sites. For example the Juan de Fuca sites are close enough to GSN shore stations that they do not fill a significant gap in the global coverage.

Why not drill a separate hole for the seismic work associated with the hydrologic sites?

It is possible that the most cost effective approach (from the instrumentation perspective) is to install a seismometer string in a dedicated hole. Given drill ship costs, particularly for deep penetration holes, our goal is to maximize the scientific value of each hole. This meeting focused on installing seismometers in the same holes as the hydrologic sensors, although it was recognized many times that a dedicated seismic hole would be a lot easier. Note that for penetration into consolidated basement, a dedicated seismic hole would still require multiple casing strings and would have to address the coupling issues. A dedicated seismic hole would not have to contend with all of the plugs, seals and packers (but some packers might be necessary to block fluid flow). Also for a dedicated seismic hole a more concerted effort could be made at cementing the casing.

Why not configure the CORK top to facilitate wireline recovery of the central string and insertion of new strings?

This is a good idea that was only alluded to briefly in the report (last paragraph of Section III-4). A cone the diameter of the main body of the CORK would do, although the larger the quicker. That would assure that if the seismometer below the 4.5" casing (the most important in the installation) failed it could be replaced later by an ordinary research ship with only the CV (Control Vehicle). This would also allow for removal and replacement of the osmosamplers, second generation seismometer package installation or anything else one might want to install in the hole all without having to wait for availability of Alvin or the more complicated and expensive ROVs.

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Figure F1. Regional bathymetric map showing major tectonic features and the locations of IODP Expedition 301 drill sites and the ODP Leg 168 drilling transect. Bathymetry from Smith and Sandwell (1997). FR = First Ridge, SR = Second Ridge, DR = Deep Ridge.

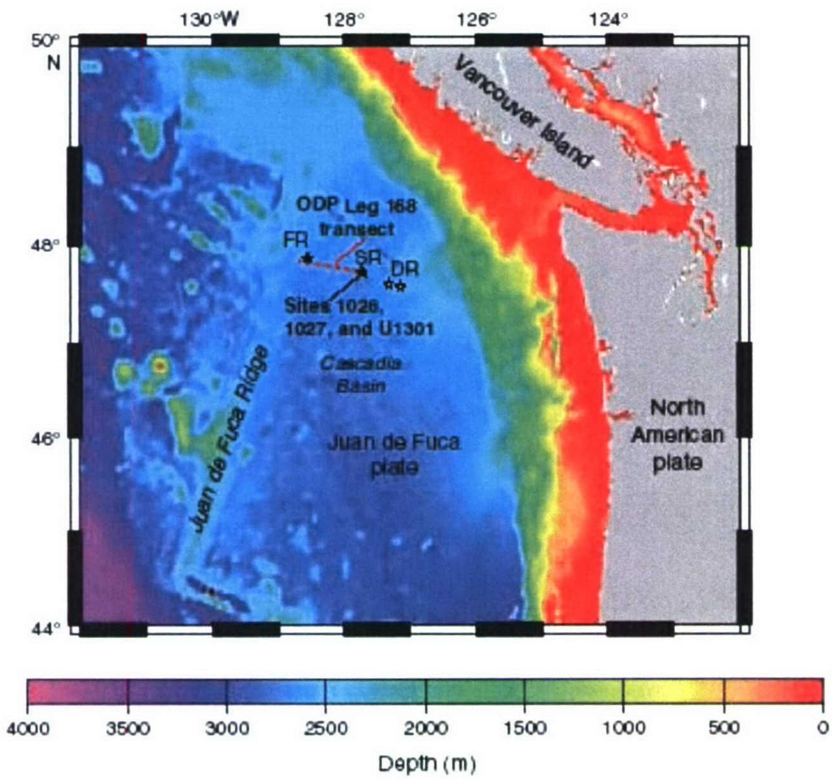

Figure 1: Location diagram of the Juan de Fuca hydrogeology drilling program (from [*Shipboard Scientific Party*, 2004])

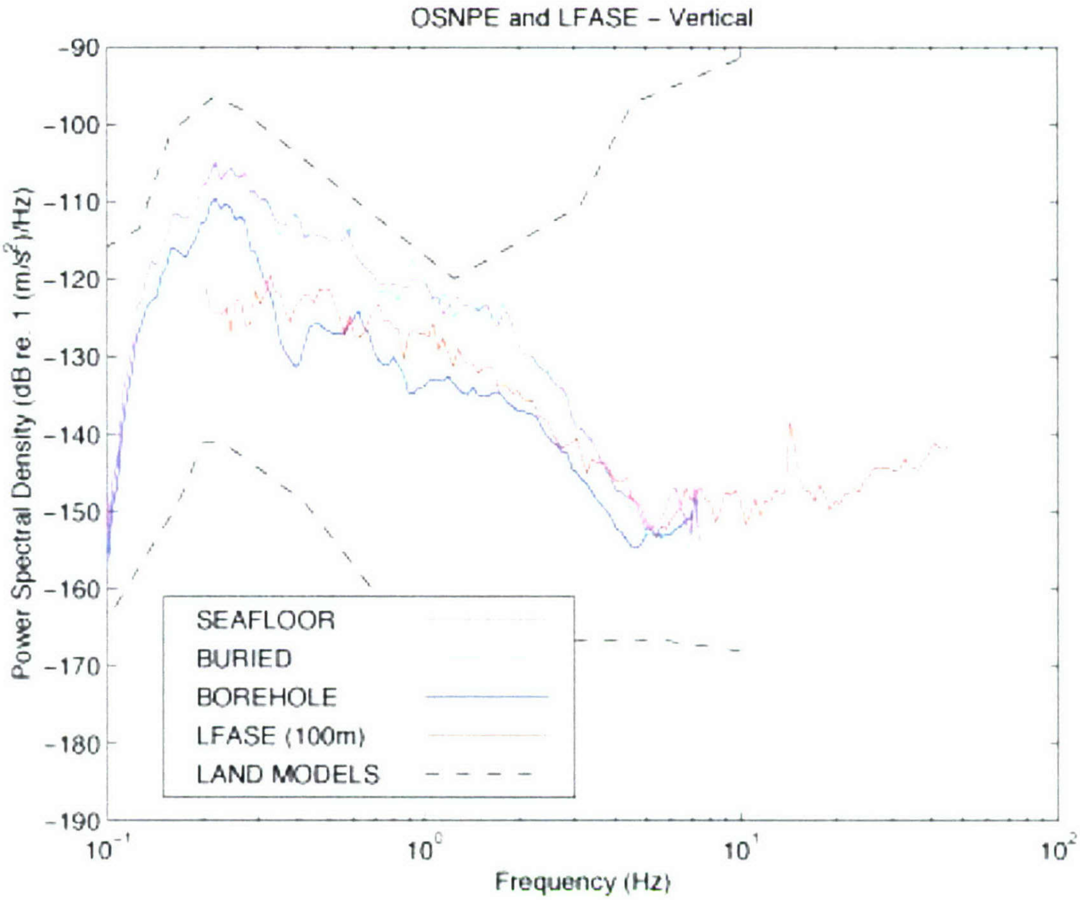

Figure 2: Power spectral densities of vertical component ambient noise in the band 0.1 to 60Hz for sensors on and beneath the seafloor [*Bradley, et al.*, 1997; *Stephen, et al.*, 1994b; *Stephen, et al.*, 2003].

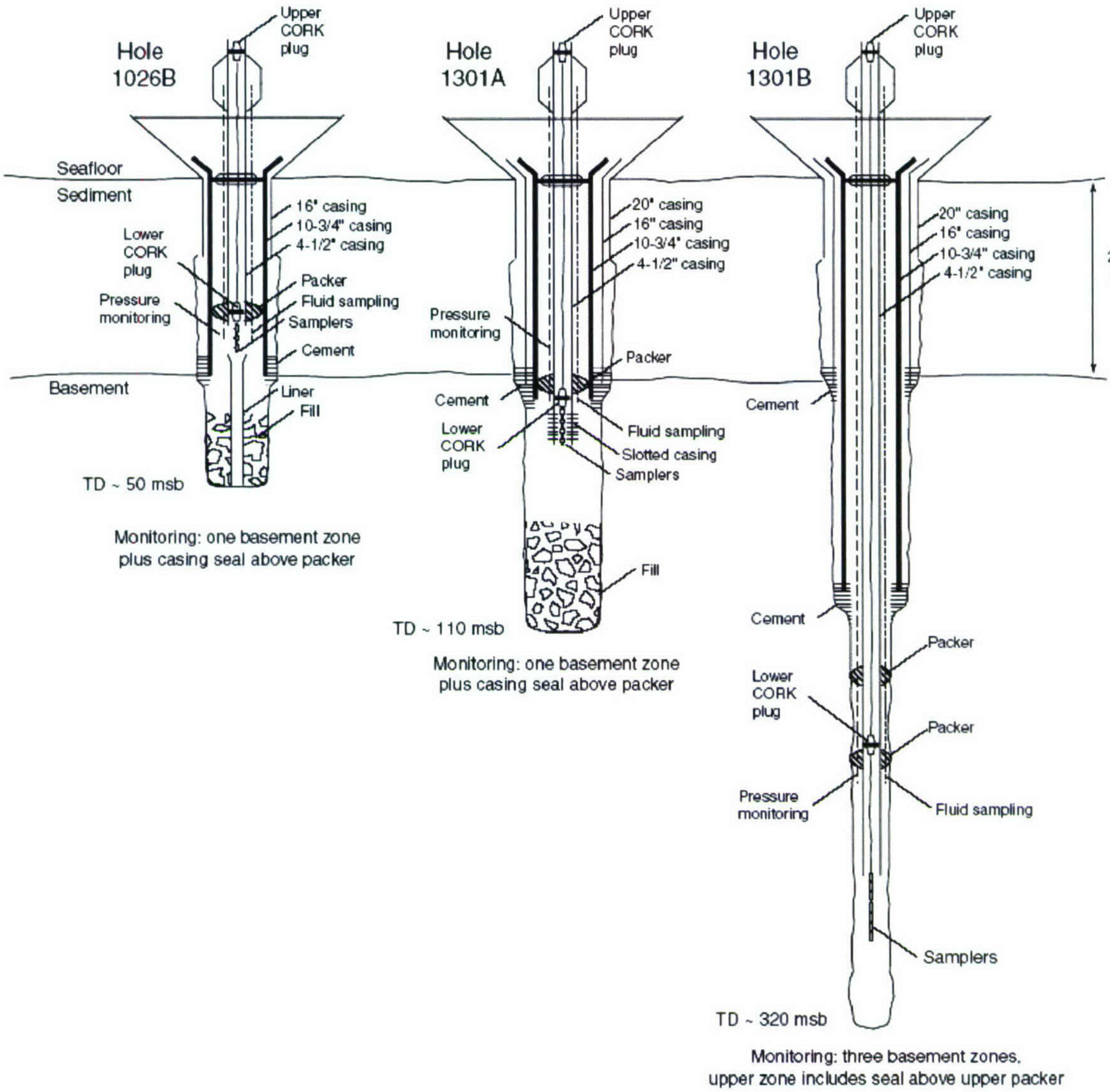

Figure 3: The three CORK installations made on IODP Leg 301 (from [*Shipboard Scientific Party*, 2004]. If a SeisCORK is deployed on the return program in 2006 or 2007 it would most likely be installed in a hole similar to U1301B.

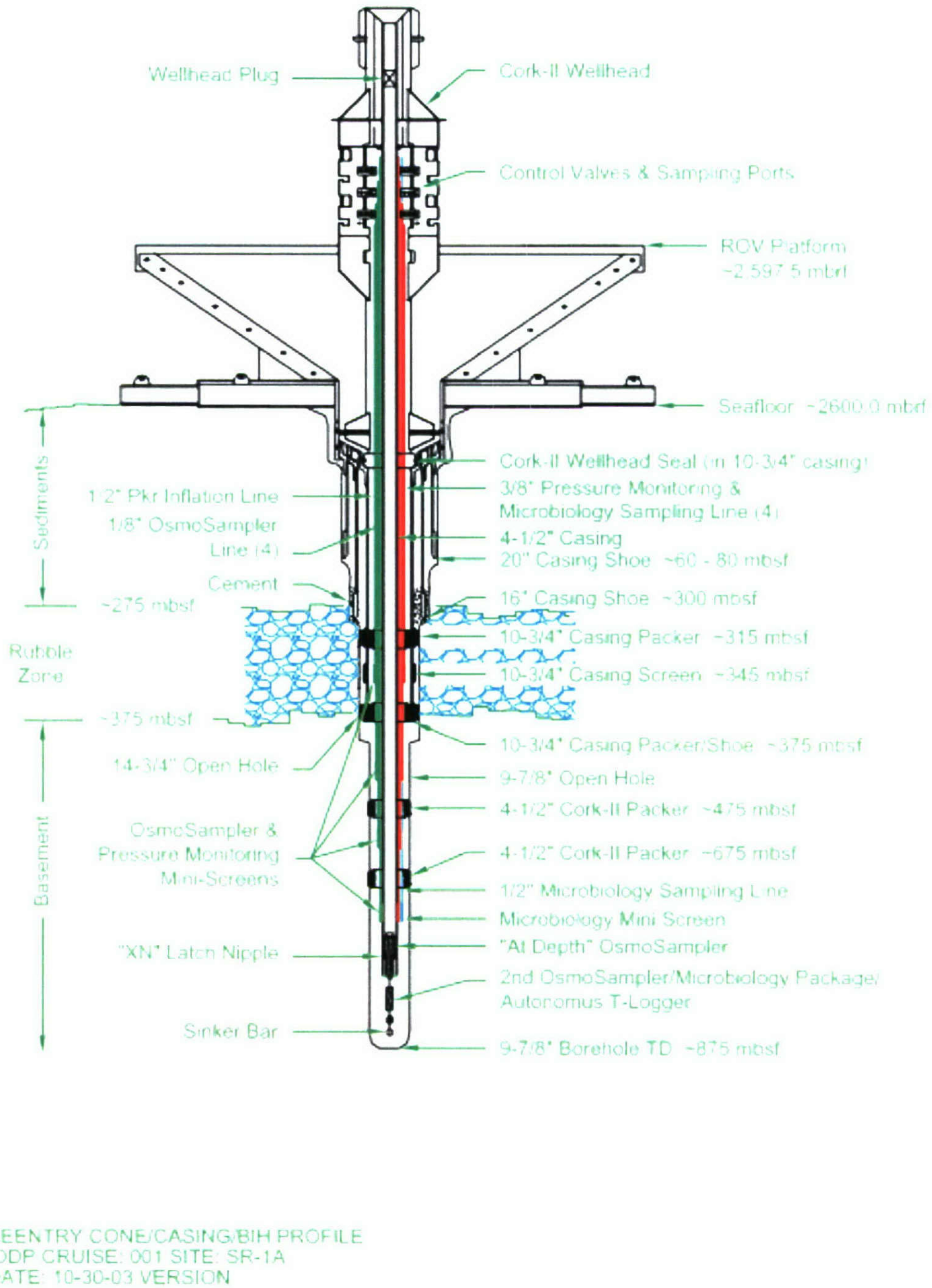

Figure 4: Schematic diagram of a typical CORK-II casing configuration.

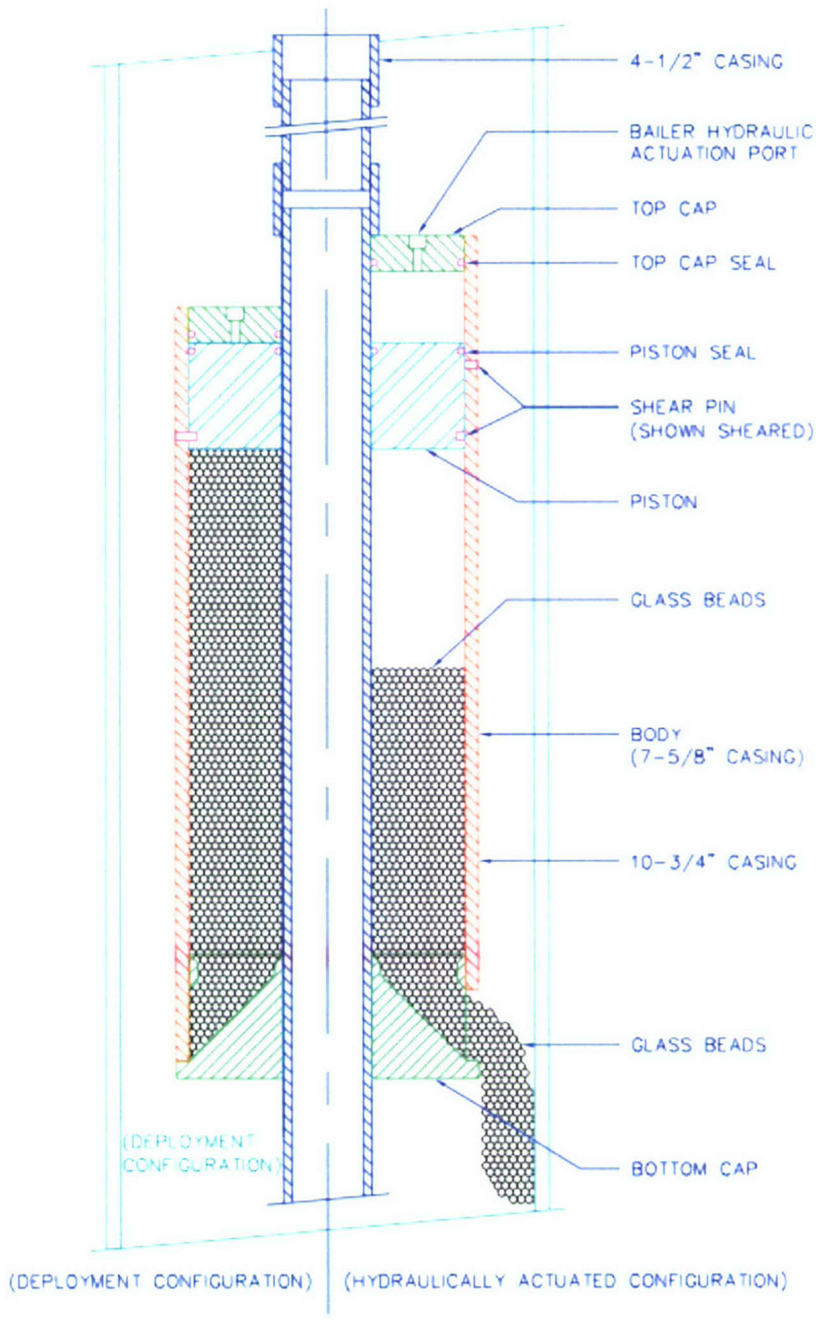

Figure 5: Hydraulically Actuated Glass Bead Dump Bailer Concept

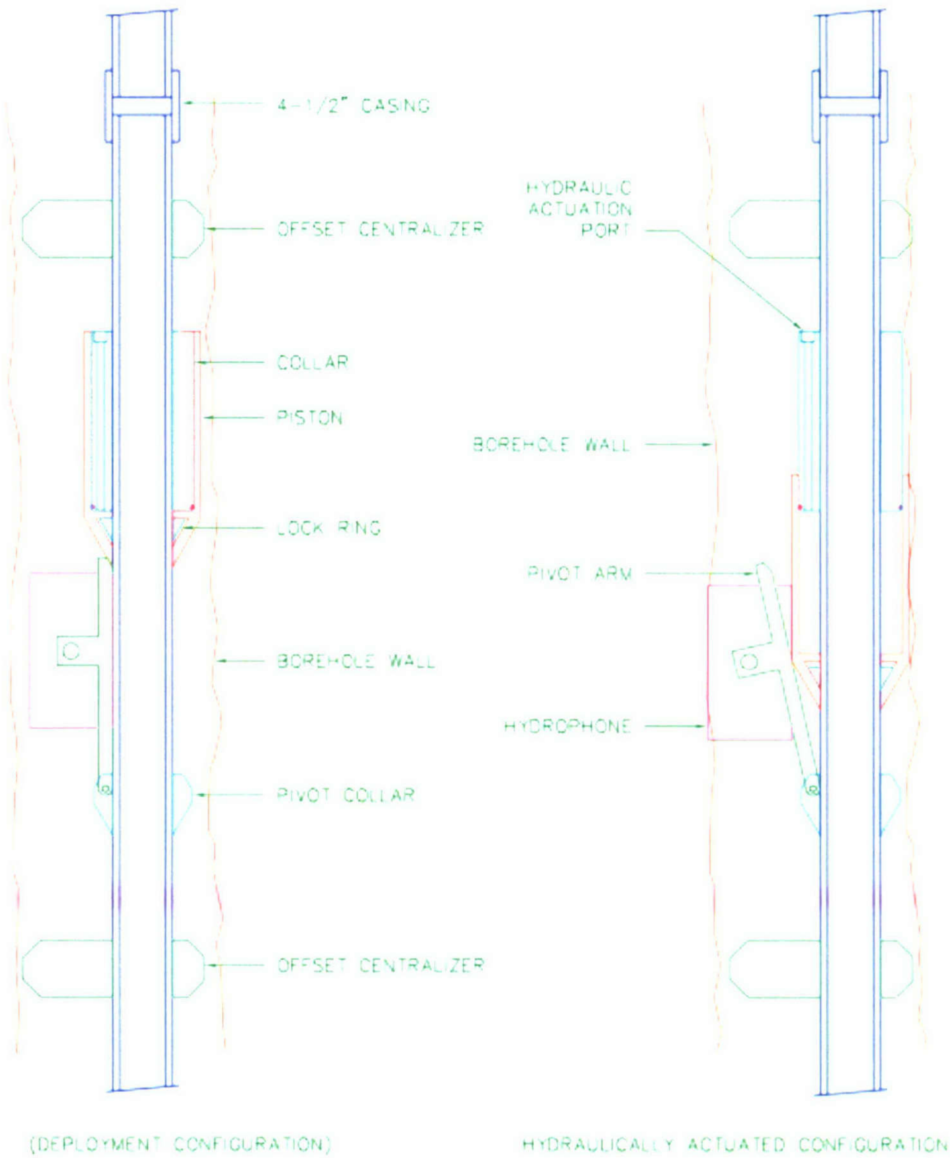

Figure 6: Hydraulically Actuated Hydrophone Clamp Concept

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Figure F17. Schematic showing the Hole U1301B reentry cone and borehole casing (right), CORK borehole completion (center), and the instrument string deployed through the 4½ inch casing (left). ROV = remotely operated vehicle.

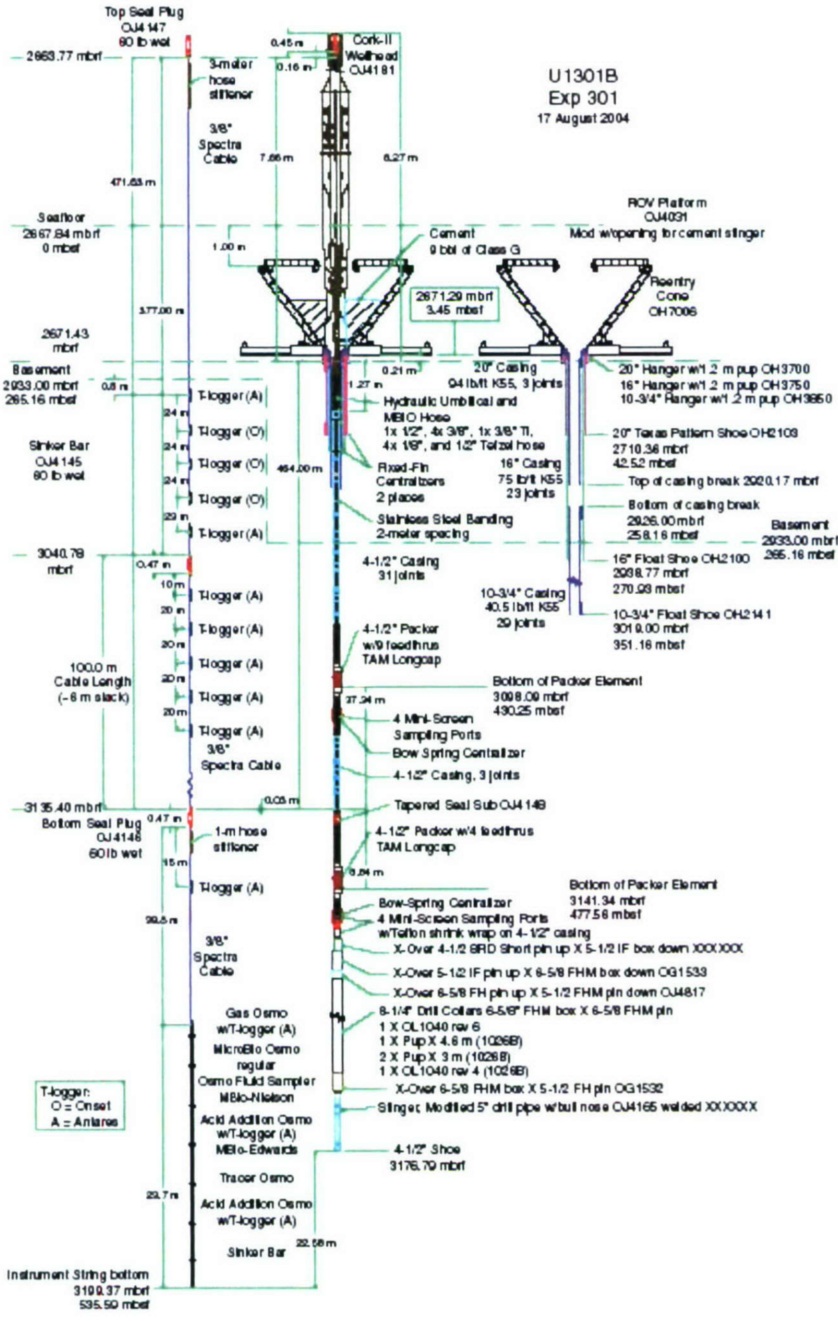

Figure 7: Detailed layout and dimensions of the CORK and casing strings used at Hole U1301B (from [*Shipboard Scientific Party*, 2004]).

Appendix A: Meeting Participants

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Appendices B through E have been removed for brevity.
See the original manuscript [*Stephen, et al.*, 2004].

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APPENDIX 3

Pages 156-159 of the IODP Science Planning and Policy Oversight Committee 4th Meeting, Nagasaki, Japan, 15-17 June, 2005.

Guidelines for the Development, Deployment, and Use of Third-party Tools in the IODP
Downhole, laboratory, and long-term observatory measurements form an integral part of the technology that is routinely used in the IODP. In addition to the standard tools that are available to all IODP expeditions, the ODP historically drew upon tools developed outside the framework of its primary contractors, and this is expected and encouraged to continue within the IODP. These tools are known as "third-party" tools. Support for the development, deployment, and long-term use of third-party tools can come from a variety of sources. In the United States for example, the National Science Foundation has generally supported third-party tool development using funds earmarked for ocean drilling and allocated to highly ranked, unsolicited proposals. International partners follow similar procedures.
In the IODP the term "tools" includes all forms of scientific instrumentation intended to be used during an IODP expedition, whether deployed in a borehole or at an observatory (borehole), used on an expedition platform or IODP support ship, or post-cruise at a core repository. Tools that are developed with this type of funding were specifically intended for deployment in the ODP and may be expected within the IODP. In addition, scientists sometimes wish to use existing tools that have been developed externally for different purposes. In both cases, it is important that third-party tools are certified as satisfying all the operational and safety criteria that the IODP applies to its own standard tools. Third-party tools are required to make a transition from the development stage to certification for deployment in the IODP under the management of the appropriate implementing organization (IO). To facilitate this transition, a set of guidelines has been formulated for the overall process of bringing third-party tools through development to deployment and use. The aim is to improve communications between the IODP and those outside investigators who wish to develop and/or deploy a third-party tool, with the objective of preserving the safe, secure, and scientifically beneficial operations of the IODP. In response to the revision of the IODP science advisory structure and the mandate of the Scientific Measurements Panel (SciMP) and its successor, the Science and Technology Panel (STP), the following guidelines for third-party tool development and deployment have been modified from ODP to reflect the fact that the IOs are responsible for assisting with and monitoring third-party tool developments and reporting status to the STP. These guidelines indicate a general progression through which new tools are introduced to IODP operations. More detailed technical specifications relating to operational constraints are available from each IO.

1. Classification
The IODP defines two types of third-party tools: development tools and certified tools.
A **development tool** is either a tool that is under development externally for use specifically in the IODP or a tool that has been developed outside the ODP and the IODP for other purposes and is being considered for IODP deployment.
A **certified t**ool is a tool that has been developed outside the ODP and the IODP, either for specific ODP or IODP application or for other purposes, and is now deemed to satisfy all the

criteria for scientific deployment in the IODP. Where there is likely to be a long-term requirement for the data provided by a certified tool, it may be a candidate to become an IODP mature tool. In ODP a **mature tool** was an established tool that had become part of the range of tools operated routinely by the IO. Such a tool was effectively owned by the ODP and was no longer a third-party tool. Consequently we do not address "mature" tools in IODP within the context of this document except in defining the minimum standard required for such a tool in meeting the minimum conditions applied to a certified tool.

Data acquired through the use of third-party tools are subject to the same dissemination rules as any other data collected by the IODP. Furthermore, the data produced through the use of third-party tools are the property of the IODP and therefore will be made publicly available after the moratorium period ends. With respect to databases, data from a development tool should be treated with caution and not automatically entered into the IODP database until a QA/QC assessment has been made. Data from a certified tool can be included in the IODP database.

2. Development tool

For a tool to be considered a development tool, several criteria must be satisfied.

(1) There must be an identified principal investigator who is the primary proponent for the use of the tool in the IODP.

(2) The principal investigator should formulate a development plan in consultation with the appropriate IO.

(3) The development plan should:

• indicate the usefulness of the proposed measurements and the financial and technical feasibility of making them

• include a brief description of the tool, schematic diagram(s), details of the operational procedure, and technical specifications such as dimensions, weight, temperature and pressure ratings, cable-length restrictions, cable type, etc.

• identify development milestones in terms of both the level and the timing of technical achievements

• make provision for initial testing on land

• satisfy safety considerations

• specify shipboard requirements such as the data processing necessary to make the information accessible on board ship, any special facilities (emphasizing where the tool is not compatible with existing hardware and software), and appropriate technical support

• make provision for transporting tools for shipboard testing, in terms of both cost and time

• contain a signed (pro forma) statement of (a) agreement with these requirements and (b) intent that the tool would be available for post-development deployment in the IODP.

(4) The development plan must be submitted for approval to the appropriate IO. The IO liaison to the STP is responsible for reporting to the STP and the IODP-MI the submission of development plans. The STP will bear the responsibility of determining action on these submissions relative to the panel mandate and will provide advice regarding further tool development. The IODP-MI will ensure that this third-party tools policy is enforced.

(5) If the IO and the STP when appropriate endorse the development plan, a liaison will be appointed by the appropriate IO to monitor the tool's progress through the development plan. The IO's tool liaison will be charged with providing status reports on the tool's progress to the STP and the IODP-MI at STP meetings, via the panel liaison.

(6) An IODP development tool can be scheduled for testing during an upcoming expedition. Development tools must be deployed in test mode. By their very definition they are not certified tools, and therefore the scientific success of an expedition should not be contingent upon the proper functioning of such a tool.
(7) Where it becomes apparent that the development plan is seriously behind schedule and that the tool is unlikely to have satisfied all the above criteria prior to its planned deployment, the expedition test should be canceled and agreement reached on a revised schedule if the expedition test requires IODP resources (operational time, technical support). In particular, if a development tool has failed to satisfy all the above criteria six months before the start of the test expedition, the IO has the right to withdraw the tool from further consideration for that expedition.
(8) It is incumbent upon the principal investigator to ensure that the appropriate IO is fully advised of the tool's status before the six-month deadline.
(9) A tool cannot be regarded as an IODP development tool, and therefore cannot be scheduled for testing in future expeditions, if the above procedures have not been followed. A development tool cannot be deployed on an IODP expedition unless the IO is fully satisfied that the terms of the development plan have been fully met.
3. Certified tool
For a tool to be considered an IODP certified tool, the following criteria must be met.
(1) The tool must have satisfied all the requirements for an IODP development tool.
(2) The tool must have been tested at sea during IODP expedition(s) and performed satisfactorily in the opinion of the relevant IO.
(3) The principal investigator should formulate a request for certification in consultation with the appropriate IO.
(4) The request for certification should:
• be prepared in coordination with the IO's STP liaison (or designate) to ensure adequate communication between the developer and the IO
• indicate the cost of routine platform operations including data processing
• outline the operational requirements for routine deployment and data processing
• detail the availability of spare components
• provide information on adequate maintenance facilities
• include an operating and maintenance manual
• satisfy safety considerations
• confirm the long-term usefulness of the data
• provide source code with documentation
• define performance specifications (pressure, temperature, vibration, shock limits, etc.)
(5) The request for certification must be submitted for approval to the appropriate IO.
(6) If the IO and the STP when appropriate endorse the request for certification, a certificate confirming the satisfactory conclusion of tests and compliance with all requirements will be issued to the principal investigator. A copy of this certificate should be forwarded to the STP chair.
(7) An IODP certified tool remains the charge of the third party. It can be scheduled for deployment during an upcoming expedition and would be expected to contribute to the scientific success of the expedition.

(8) Tools that do not possess a certificate cannot be programmed for scientific deployment on future expeditions.
(9) Certified tools may, subject to budgetary constraints, become part of an IO's equipment base once all these criteria have been satisfactorily met.

4. Protocol for development

Prospective proponents of third-party tools are requested to contact the appropriate IO at the earliest possible stage of their projects. Where it is unclear which IO is appropriate, or where a tool may be used across multiple platforms, the STP may be used as a means of ensuring cross-platform and cross-IO discussion. This is to ensure communication between the developer and the IOs as to operational specifications pertinent to tool development, and to identify redundant effort. Proponents will also be informed of the protocol governing the development and deployment of IODP third-party tools.

APPENDIX 4

Sercel Seismometer Review and Compatibility Assessment with an Integrated Ocean Drilling Program Type Instrumented Borehole Installation

26 September 2005

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Introduction

This report provides an overall engineering review of the Sercel seismometer line of products and includes an assessment of their functionality and compatibility in association with an Integrated Ocean Drilling Program (IODP) type instrumented borehole installation. This report only addresses the seismometers from the stand point of compatibility with IODP type shipboard operations and IODP CORK-II type instrumented borehole installations with regard to deployment and possible conflicts with typical CORK-II instrumentation. This report does not address the capabilities of the seismometers to capture, record, store, or transmit data, nor power requirements or any other issues specific to the seismometer's performance.

The Sercel seismometer strings are currently packaged for three types of deployment, on wireline, on tubing, and behind casing. All three configurations lend themselves to deployment in an IODP type instrumented borehole installation. In general, the seismometers are packaged in convenient, compact units that should make them easy to handle and deploy.

All of the following discussions are put forth as though the seismometer strings were to be deployed from the IODP drill ship ***JOIDES Resolution***. However, the same or similar deployment procedures and/or techniques could be adapted to other vessels carrying out similar operations or even similar land installations.

Wireline Deployed Seismometer Configuration

The Sercel wireline deployed seismometer string, designated SEIS-NUM SAM 1-11/16", has a maximum outside diameter of 1-11/16", a working pressure rating of 15,000 psi, a permanent installation temperature rating of 125 degrees C, and integral electrically actuated anchors for coupling to the formation. It employs a single coaxial cable for deployment, to supply power to the geophone(s) and their anchor(s), and to transmit acquired data to the surface and/or data logger.

The small diameter of the wireline deployed seismometer string lends itself to being deployed through the IODP drill string, CORK-II wellhead, and stringer, which typically have a minimum inside diameter restriction of approximately 3.5".

For deployment in a CORK-II type installation, the lower portion of the wireline deployed seismometer string can be configured to position multiple geophones in open hole below the stinger as desired. Integral water tight electrical connectors allow for configuring the geophone spacing "on the fly", or as deployed, as long as various lengths of spacer cables are available during the deployment.

The upper end of the seismometer string can be configured with a wet mate-able connector termination, housed in a modified lock mandrel. The modified lock mandrel would provide an attachment point to the deployment wireline, latch into the top of the wellhead, support the seismometer string weight, incorporate a data logger, incorporate a battery pack, and complete the borehole seal.

Note that since a wireline jar and sinker bar are required to shear release the wireline from the lock mandrel, real time communication with the wireline deployed seismometer string during deployment can not be easily achieved with the current deployment tools and techniques. However, it may be possible to design and fabricate a non-standard electrical release that would allow real time communication, including supplying power to actuate the anchors, actuate the lock mandrel, and release the logging line from the lock mandrel.

Once the seismometer string is latched into the wellhead, the wireline released and recovered, the drill string would have to be unlatched from the wellhead so as the logging line with mating wet connect could be inserted into the drill string. The drill string would have to be latched back onto the wellhead and the logging line lowered until the mating wet connector made up with the seismometer string connector. Then the geophone anchors could then be activated from the drill ship. Since the geophone anchors are of the screw jack type, they do not require a constant supply of power to maintain the anchor point. Thus, after setting the anchors, the logging line could be disconnected from the wellhead and recovered, leaving the seismometer string anchored in place, recording data.

The other option for setting the geophone anchors in the wireline deployed seismometer string is to access the wet connector using an ROV or submersible at a later date and applying enough power to the string to actuate the anchors.

Using an ROV or submersible, the wet mate-able connector in the lock mandrel could also be accessed at a later date to download the stored data. Also, if required, an external power source and/or data logger(s) could be attached to the seismometer string via the wet mate-able connector.

Potential Conflicts with Typical CORK-II Instrumentation

A thermistor string is typically deployed in a CORK-II Installation. The thermistor string is typically connected at the top to a special data logger configured to land, latch, and seal inside the wellhead. Thus, the thermistor string and wireline deployed seismometer string would have to occupy the same space if deployed in the same borehole. Although combining the thermistor string with a seismometer string should be possible, that specific configuration was not looked at within the scope of this project.

Another potential conflict is with "internal" long term fluid samplers which are deployed inside the CORK-II stinger. In the past, some of the long term fluid samplers have been designed such that they incorporate a lock mandrel which latches into a special perforated latch nipple made up in the CORK-II stinger. In this configuration, the typical internal fluid sampler would block the inside diameter of the stinger, thus preventing the seismometer string from passing by.

However, it may be possible to provide an electrical pass through in the fluid sampler lock mandrel similar to that proposed for the isolation packers and screens. The seismometer string could then be configured to hang below the internal fluid sampler. By employing a lock mandrel electrical pass through, an electrical cable could be attached to the fluid sampler recovery rope and run to the top of the wellhead.

Note that typically fluid samplers are recovered every 12 to 18 months using an ROV or submersible. Thus, the seismometer string would be recovered each time as well, and would have to be redeployed with the replacement fluid sampler.

Deployment and Recovery Concerns - Wireline Seismometer String

Deployment of the wireline seismometer string by itself should not pose any problems beyond those typical of open hole wireline instrumentation deployments. Note, this assumes that a lock mandrel with an electrical pass through and integral wet mate-able connector can be designed, fabricated, and attached to the top of the seismometer string.

Recovery will require a power supply to be attached to the seismometer string that can supply enough power to retract the geophone anchors. Recovery will then be dependent on open borehole conditions, most notably, collapsing of the open borehole around the seismometer string, preventing it from being recovered.

Deployment and Recovery Concerns - Wireline Seismometer String with Thermistor String

Deployment of a wireline seismometer string in conjunction with a thermistor string should not pose any insurmountable problems. The maximum diameter of the seismometer string allows it to be attached to a thermistor string and the pair lowered down the drill string, through the wellhead and stinger, and into the open borehole. Note, this scenario assumes that an electrical pass through can be incorporated into the thermistor string data logger or the data logger configured to record both the thermistor and seismometer data.

Actuating the geophone anchors does present the problems as discussed above regarding supplying power to the string.

Recovery will require a power supply be attached to the seismometer string that can supply enough power to retract the geophone anchors. Recovery will then be dependent on open borehole conditions, most notably collapsing of the open borehole around the seismometer string, preventing it from being recovered. It would also be prudent to incorporate a weak link in the seismometer cable above the first seismometer to allow the thermistor string to be recovered in the event the seismometers can not.

Deployment and Recovery Concerns - Wireline Seismometer String with Internal Fluid Sampler

Deployment of the wireline seismometer string in conjunction with an internal fluid sampler should not pose any insurmountable problems, but is considerably more complex than not having internal fluid samplers in the string. Additional sinker weight may have to be attached directly below the fluid sampler so that if the seismometer string lands on a bridge in the open borehole, the fluid sampler can still be latched into the stinger. Note, this scenario assumes that an electrical pass through can be incorporated into the internal fluid sampler.

Recovery of the seismometer/fluid sampler string will be dependent on 3 primary aspects. First, the overall "wet" weight of the string must be low enough that it can be released using an ROV or submersible and then be floated to the surface. Second, a "weak link" electrical connection will have to be installed in the seismometer electric line immediately below the fluid sampler. The weak link is required so that should the hole collapse in around the seismometer string preventing it from being recovered, the fluid sampler could still be recovered. And third, a power supply will have to be connected to the seismometer string to release the geophone anchors.

Note that the details of "floating" a fluid sampler recovery rope above the wellhead will have to be worked out. A finite amount of buoyancy can be passed through the drill string attached to the top of the recovery rope. Most likely it will not be possible to attach enough buoyancy to support the upper seismometer cable weight. However, a second lock mandrel, or landing go-devil, can be positioned at the top of the recovery rope which would support the weight of the seismometer cable, as well as, provide a pick up point for recovering the fluid sampler. Use of a second lock mandrel rather than a landing go-devil is highly recommended to ensure proper shear release of the wireline used to deploy the instrument string.

On-Tubing Seismometer Configuration

The Sercel On Tubing deployed seismometer string, designated SEIS-NUM STPG, has a working pressure rating of 20,000 psi, a permanent working temperature rating of 125 degrees C, and integral bow springs to provide coupling with the formation. It employs a single coaxial cable to supply power to the geophone(s) and to transmit data to the surface. It is a compact design which is attached to the outside of a conductor pipe such that an open conduit is maintained past the seismometer string to the bottom of the borehole. This type of configuration lends itself well to being attached to a CORK-II stinger for deployment in an IODP type instrumented borehole installation.

The coaxial cable can be attached to the stinger pipe and run to the wellhead. A sealing electrical pass through in the wellhead landing ring would allow the signal to be passed on up to a data logger attached to the wellhead.

In the case of a multiple zone isolation installation, electrical pass throughs must be provided in each of the isolation packers and screens, as well as, the wellhead. Adding an electrical pass through to the existing CORK-II packer, screen, and wellhead designs should not pose any problems.

Integral water proof connectors in the seismometer string provide some flexibility in positioning the individual seismometers along the stinger "on the fly" as the stinger is being made up. This flexibility requires that an assortment of different length cable runs be provided during the deployment.

Potential Conflicts with Typical CORK-II Instrumentation

If sealing electrical pass throughs are provided in the isolation packers, screens, and the wellhead, then there should be no conflicts with typical instrumentation deployed with the CORK-II.

Deployment Concerns

There are no deployment concerns with this configuration. The deployment would be similar to previous CORK-II installations where umbilicals were deployed.

Real time communication with the seismometer string during deployment can not be easily achieved with the current deployment tools and techniques.

However, it may be possible to design and fabricate a self aligning go-devil that would fit around the drill string, travel down the drill string attached to the logging line, and mate the logging line with the wet mate-able connector on top of the wellhead. This procedure would require recovering the reentry TV system without releasing the drill string from the wellhead during deployment of the wellhead. The go-devil would then be attached around the drill string and lowered to the wellhead on the logging line. After communications were established with the seismometer string and all data recovered, the logging line and go devil would be recovered.

Although the specific details of this type of deployment were not looked at within the scope of this report, they can be worked out to produce a successful deployment of this type.

Behind Casing Seismometer Configuration

The Sercel Behind Casing deployed seismometer string, designated SEIS-NUM SCPG, has a working pressure rating of 20,000 psi, a permanent installation temperature rating of 125 degrees C, and relies on cementing behind the casing, or hole collapse, to couple to the formation. It employs a single coaxial cable, to supply power to the geophone(s), and to transmit acquired data to the surface/data logger. The small size of the behind casing deployed seismometer string only adds 1.5" to the casing outside diameter, which lends itself to being deployed in an IODP CORK-II type installation or just about any installation where casing is deployed.

For deployment in a CORK-II type installation, the behind casing deployed seismometer string can be configured to position multiple geophones in open hole as desired. Integral water tight electrical connectors allow for configuring the geophone spacing "on the fly", or as deployed, as long as various lengths of spacer cables are available during deployment.

The upper end of the seismometer string could be configured with a water tight connector termination that could be connected to a casing hanger electrical pass through. The casing hanger electrical pass through would have a wet mate-able connector configuration inset in the top of the hanger landing ring. A mating wet mate-able connector would be configured in the landing ring of the wellhead. The wellhead landing ring would also be configured to align the wet mate-able connectors during deployment. This configuration would allow the mating wet mate-able connectors to mate when the wellhead is landed in the casing hanger while still maintaining the borehole seal.

Note that the above mentioned equipment casing hanger electrical pass through and alignment system are not part of the existing CORK-II hardware and thus would have to be designed and fabricated.

Using an ROV or submersible, the wet mate-able connector in the top of the wellhead could be accessed at a later date to download the stored seismic data. Also, if required, an external power source and/or data logger(s) could be attached to the seismometer string via the wet mate-able connector.

Potential Conflicts with Typical CORK-II Instrumentation

If sealing electrical pass throughs are provided in any isolation packers or screens deployed on the casing string, the wellhead, and casing hanger, then there should be no conflicts with typical instrumentation deployed with the CORK-II.

Deployment Concerns

Real time communication with the seismometer string during deployment can not be easily achieved with the current deployment tools and techniques.

However, it may be possible to design and fabricate a self aligning go-devil that would fit around the drill string, travel down the drill string attached to the logging line, and mate the logging line with the wet mate-able connector on top of the wellhead. This procedure would require recovering the reentry TV system without releasing the drill string from the wellhead during deployment of the wellhead. The go-devil would then be attached around the drill string and lowered to the wellhead on the logging line. After communications were established with the seismometer string and all data recovered, the logging line and go devil would be recovered.

Although the specific details of this type of deployment were not looked at within the scope of this report, they can be worked out to produce a successful deployment of this type.

Conclusion

In general the Sercel seismometer strings appear to be readily adaptable to an IODP CORK-II type instrumented borehole installation. Some additional tools and hardware will have to be designed and fabricated to carry out the installations but all are believed to be doable.

Should further interest in the Sercel seismometers with regard to deploying in an IODP CORK-II type instrumented borehole exist, then further detailed study should be undertaken for the specific application in mind.

APPENDIX 5

Wellhead Inter-Connection (WHIC) System

Concept Proposal

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17 January, 2005

a. Functional Requirements/Specifications

The Wellhead Inter-Connection (WHIC) system is intended as an upgrade to the existing Integrated Ocean Drilling Program (IODP) Vibration Isolated Television (VIT) system. The primary feature of the WHIC system is that it will be designed to land on the wellhead and to make an electrical connection with borehole instrumentation using wet-mateable underwater connectors. In addition the WHIC will expand the capabilities of the existing VIT 1) by providing pan, tilt, and zoom capability to the camera, and 2) by adding a release so that additional gear can be flown down to the wellhead.

The WHIC frame will incorporate an indexing feature that will automatically rotate the frame to align with a fixed point near the end of the drill string. In the case of the proposed SeisCORK, the fixed point will most likely be the CORK running tool. By providing a fixed orientation between the WHIC frame and the SeisCORK a single, or perhaps even multiple, wet connect(s) can be made between the frame and the SeisCORK. This approach would allow for real time monitoring of the SeisCORK after it has been installed in a borehole and before the drill ship departs the location. Thus the condition of the instruments would be known before the site is abandoned. This capability would also allow for power from the drill ship to be used to activate various electro-mechanical mechanisms downhole. In the case of the SeisCORK, the seismometer anchors could be opened and closed from the drill ship, thus reducing the drain on seafloor battery packs. With the proper configurations, the WHIC indexing wet connect would allow for down loading data from CORKs, SeisCORKs, and other similar seafloor installations via the drill ship.

The WHIC frame will incorporate removable outriggers with either acoustic or electrical releases for deploying instrument packages on the seafloor or CORK platforms from the drill ship. In the case of the SeisCORK, this capability along with the indexing wet connect capability would allow for external battery packs to be positioned on the CORK platform while simultaneously plugging them into the seismometer string. This technology can be applied to a myriad of similar instruments as well.

At least initially we do not believe that the WHIC system will replace the VIT. It makes sense to have separate systems for “routine reentry operations” and “ smart CORKs”. The former is clearly the responsibility of TAMU and the ship operator. The latter could and should be a tool for science, at least during the development stage. Since the WHIC sled is a "science" tool it should be treated like a third-party downhole measurements tool. The WHIC and VIT systems would use the same cable but the sleds would be totally different and the deck gear will be totally different. The deck gear for the WHIC sled would be located and run from the downhole measurements van. (Some thought should be given to coordinating the WHIC video with the winch operator since this will be critical when "landing" the sled on the wellhead.) We are assuming, however, that the existing copper coaxial cable used for VIT runs will be replaced with UNOLS standard fiber optic cable as part of the refurbishing of the riserless vessel. Winches and power systems may also be upgraded. If this happens it would make sense to upgrade the camera system on the VIT sled as well.

The WHIC circuitry would include:
1) A wet connect capable of mating with a wet connect on the wellhead and that can be used to transmit data and power to the instruments.

2) Pan, tilt, and zoom for the camera.

3) At least one release mechanism activated either acoustically or electrically (electrical preferred).

4) Spare circuits to enable communication with ancillary instruments attached to the frame itself. The instrument packages can also be powered from the drill ship via these ancillary wet connects. (For example, a 3.5KHz transducer can be mounted on the WHIC frame for high resolution sub-bottom profiling as was done on Leg 200.)

b. Rough Cost

Until the design phase is carried-out it is very difficult to estimate cost. We will attempt to make the WHIC development as cost effective as possible by leveraging the design with existing VIT and ROV camera/connector technologies.

c. What Problem will be Addressed/Benefits

The WHIC system has three tasks associated with drillship installation and maintenance of borehole observatories: 1) it will land on the wellhead and make an electrical connection with borehole instrumentation using wet-mateable underwater connectors, 2) it will provide pan, tilt, and zoom capability to the camera for more detailed and careful operations around the re-entry cone, and 3) it will expand the capabilities of the existing VIT by adding a release so that additional gear can be flown down to the wellhead.

The sub-sea electrical connection to the wellhead provides a substantial logistical improvement over existing CORKs because the present operation requires returning to the site with an ROV to plug-in the recording system and batteries to the borehole sensors. With the WHIC sled the complete system can be installed, made operational and tested all from the drill ship before leaving the site. Of course well-head systems still need to be designed to be maintained by ROVs in the long term.

Regarding typical IODP operations, the improved camera capability alone will immensely aid bare rock spudding, guide base deployments, drill-in casing deployments, hammer drill deployments, CORK deployments, seafloor surveys, fishing for lost tools on the seafloor, etc. With the addition of a remotely controlled telescopic camera arm, the additional camera capabilities can be enhanced even further.

As presently configured the wellhead must be small enough in diameter (about 36") that the VIT sled can slide over it to get to the bottom of the instrument string for re-entries. This limits the amount of hardware in general, and of battery packs in particular, that can be assembled onto the wellhead on the rig floor. Since this leaves a lot of room on the platform on the re-entry cone it makes sense to fly down additional equipment, release it onto the re-entry cone, and connect it to the wellhead using the WHIC sled. For example, for many applications it will be possible to fly down enough additional batteries to power the borehole system for a year before re-visiting the site with the ROV (or drill ship).

In conclusion, the WHIC system would not only improve overall IODP operations, it will open the door for new types of borehole and seafloor instrumentation to be deployed from the drill ship. The WHIC will be very versatile and can be reconfigured for a variety of instrument deployments. Ideally the WHIC should be designed so that it can be deployed from all IODP drilling platforms. We are receptive to feedback from the community as the design of the WHIC concept evolves.

d. Rough Schedule

At present, we will be including the WHIC development in the SeisCORK proposal being prepared for the NSF-IODP February 15, 2006 proposal deadline. We anticipate that the SeisCORK and WHIC systems will be developed and tested in parallel. A rough schedule follows:

1) NSF Proposal Deadline: February 15, 2006

2) Earliest start date for the project (assuming all reviews go well): July 1, 2006

3) Issue purchase orders for big ticket items (BTI's) such as pressure housings, wet mateable connectors, and cameras: July 15, 2006.

4) Delivery of BTI's and component acceptance tests: November 15, 2006

5) WHOI bench test of complete electrical system with mock cable: January, 2007

6) Wet test off the WHOI Dock (all housings, cables and connectors): March 2007

7) System dry-run at the Pinon Flat Observatory near Palm Springs - They have a 100m deep test hole with 10-3/4"casing. This is primarily a test of the SeisCORK borehole gear but it will also be an opportunity to test the complete WHIC sled system in a sub-aerial situation. April-May 2007.

8) Deep water test from a ship of opportunity (all of the seafloor gear, cables and connectors): May to August 2007 depending on ship availability (ideally a Jason equipped ship but must have UNOLS standard coax at a minimum. Since we are past the deadline for UNOLS 2007 ship time, there may be an opportunity to do a wet test off one of the drill ships (Chikyu or JOIDES Resolution) during an engineering cruise in Fall 2007.

e. Fit with the Initial Science Plan Objectives

Using boreholes for long-term measurements after the drill ship has left has become increasingly popular over the past twenty years. The major science programs that operate in this mode include hydrogeological and biogeochemical measurements in the oceanic crust and deep biosphere (Initial Science Plan, ISP pages 18-33) as well as borehole seismic installations to study solid earth cycles and geodynamics (ISP pages 53-70). Borehole observatories for a broad range of measurements are an integral part of many programs such as the seismogenic zone initiative (ISP Figure 36) and CORKS (ISP Figure 2)(ISP page 82). One of the "Principles of Implementation" in the ISP (ISP page 73) is "Coordination with Observatory Sciences - IODP plans to continue the productive collaboration with seafloor observatory science programs, especially in the long-term monitoring of subseafloor physical parameters and seismicity, in active experiments and in regional-scale characterizations of sub-seafloor conditions. ... A firm foundation of observatory science, both as part of IODP and in coordination with other international programs, is a priority." Observatories are also highlighted in the "Implementation Plan for Initiatives" (ISP pages 78-79). The WHIC sled is an important new technical capability to facilitate the installation and maintenance of borehole observatories from the drill ship.

f. Probability of Success (Risk Analysis)

By combining VIT and ROV camera/connector technologies into one system there are no new sensor technologies to develop. All of the components have been extensively tested in routine operations for over a decade. We also plan to field test various aspects of the system in appropriate at-sea environments prior to deploying the WHIC on an operational borehole observatory.

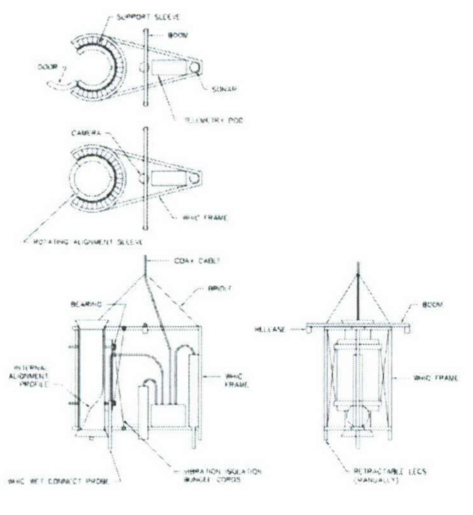

FIG 1 WHIC SLED CONFIGURATION

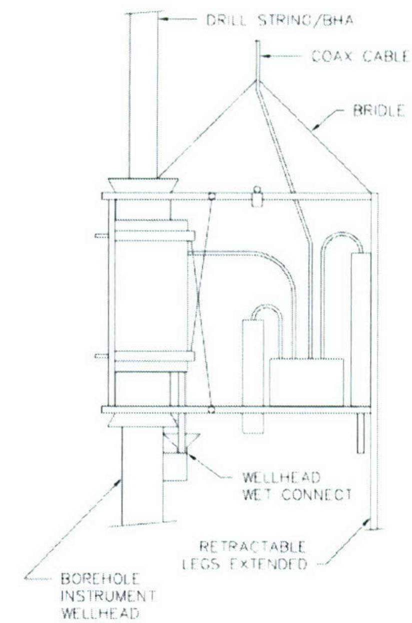

FIG 2 WHIC WET CONNECT STUNG INTO WELLHEAD WET CONNECT

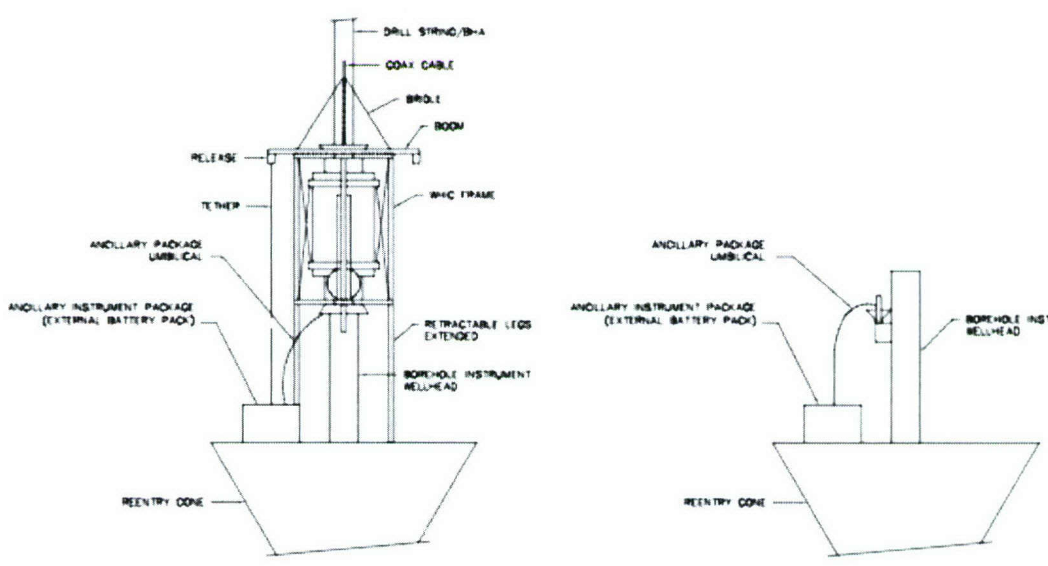

FIG 3 ANCILLARY INSTRUMENT PACKAGE DELIVERED TO REENTRY CONE PLATFORM AND CONNECTED TO INSTRUMENT STRING INSIDE WELL

Schematic diagrams showing 1) the WHIC sled, 2) the WHIC wet connect stung into the wellhead wet connect, and 3) delivery of an ancillary package.

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16. Abstract (Limit: 200 words)

The goal of SeisCORKs is to make simultaneous and co-located seismic, pressure, temperature, pore water chemistry and pore water biology measurements in the seafloor. We want to see the small events in the vicinity of the borehole for three reasons: 1) After an event fluid may flow in the formation in response to the changing stress regime. Down to what magnitude of event do the pressure transients in the well respond? 2) Fluid flow causes small earthquakes. One mechanism for example is by changing the temperature of the rocks which expand and contract, altering the stress regime. We want to look for this fluid flow. 3) Laboratory studies of rock deformation show that shear fracture is preceded by the coalescence of interacting tensile microcracks which are observed as "acoustic emissions". By placing high frequency geophones next to faults it may be possible to observe these "acoustic" precursors to rock failure. Since in reservoirs on land small events appear in the frequency band 400-800Hz, no one has yet tried to observe them in oceanic crust. SeisCORKs also obviate the considerable logistical, administrative, and clearance difficulties associated with scheduling a shooting ship to run offset VSPs. We resolved to start with a "tubing conveyed" SeisCORK configuration consisting of four three-component sondes at 50m separation lowered on the outside of 4.5in casing (or drill pipe) inside 10-3/4in casing.

17. Document Analysis a. Descriptors

borehole seismology
micro-earthquakes
ocean bottom seismology

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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