SCIENCE OPPORTUNITIES CREATED BY WIRELINE RE-ENTRY OF DEEPSEA BOREHOLES

A Workshop held at
Scripps Institution of Oceanography
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Co-convenors:
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Sponsored by Joint Oceanographic Institutions as part of the U.S. Science Support Program for the
Ocean Drilling Program

BOREHOLE RE-ENTRY WORKSHOP,
February 23-24, 1987

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SUMMARY AND RECOMMENDATIONS

A Workshop was convened at the Scripps Institution of Oceanography, February 23 and 24, 1987 to discuss scientific opportunities that would be created if a reliable and affordable technology to achieve re-entry of existing deep-sea boreholes were available to the US geoscience community. Discussion at the Workshop was mainly focused on experiments and measurements that a re-entry system that could be operated from a conventional research ship would make possible. The Workshop discussions revealed that there is a sizeable community of scientists interested in using such a capability and that the scientific yield of the Ocean Drilling Program would be enhanced if such a capability were developed.

The number of re-entry holes where the probability is high of lowering an instrument to 75% of the original depth is small (See Table 1 in Section II). However, the open holes are mostly deep crustal boreholes, which would make rewarding targets for further downhole science. Other re-entry holes could be made ready for re-entry by the drill ship if it cleared the hole of sediment bridges and stabilized it with special muds or casing. Future ODP drilling could provide many more opportunities for downhole experiments and measurements by taking steps to stabilize the hole walls for re-entry before the drill ship leaves the site.

New Science Made Possible by Re-entry:

Re-entry capability would allow the use of recent advances in logging technology such as the Formation Microscanner and the digital borehole televiewer in boreholes where little or no logging has been done before. Large diameter logging devices that do not pass through the drill pipe could be used such as: borehole gravimeters, sidewall coring devices and more reliable wireline packers. Re-entry techniques can make significant improvements in data obtained by high resolution logging instruments that require isolation from the heave of the ship.

Borehole experiments to probe the oceanic crust such as the vertical and oblique incidence borehole seismic experiments, large scale resistivity measurements, and electromagnetic sounding could be carried out more efficiently and economically with re-entry techniques from a non-drilling ship. In the future hole-to-hole experiments such as seismic tomography would be made possible by the use of re-entry technology. In addition, re-entry from a conventional ship would save investigators conducting down hole experiments considerable time. Currently they must ride the ship for the entire Leg of 50-60 days waiting to do their experiment which often takes five days or less, or as sometimes happens, is never done at all.

Re-entry from a non-drilling ship will make possible innovative hydrogeological experiments. Temperature, pressure and pore-water chemistry measurements could be made in fully equilibrated crustal boreholes. Resealing of some of the crustal boreholes where flow through the hole has been observed would provide an exciting transient and steady-state experiment.

Wireline re-entry could be used to install long-term experiments and borehole observatories. Borehole observatories discussed at the Workshop include the emplacement of strainmeters to directly measure tectonic deformation of the oceanic crust, arrays of short period seismometers, some in boreholes, others on the sea floor to define the seismicity of the ridge axis and determine the existence and shape of magma chambers below the ridge axis. Certain boreholes would also provide a stable and quiet place to install broad band three component seismic observatories to fill a large hole (the Pacific Ocean) in the global seismic network.

Although wireline re-entry capability could be a powerful complement to the ODP downhole measurement program, it should not be regarded as a replacement for downhole measurements from the drill ship.

Status of re-entry technology:

The technology to achieve re-entry of boreholes currently exists. The task of placing a package for logging or in-strument emplacement can be achieved in at least three different ways; using a manned submersible, a remotely operated free-swimming or tethered vehicle or an electro-magnetic cable that has the capability of maneuvering a re-entry module to a re-entry cone. The French research organization IFREMER is planning a test of a re-entry system using a manned submersible in DSDP re-entry hole 396A in 1988.

A critical component of any re-entry system, the means to maneuver a package to a re-entry cone and carefully install it, will have wide application for placing instruments on the sea floor, carrying out precision measurements and sampling, and carrying out accurately navigated imaging of sea-floor features and creatures. Consequently, by proper planning, the cost of a re-entry system could be spread over a much larger number of marine geoscience projects.

A US borehole re-entry project:

A principal conclusion of the Workshop was that a program to develop and operate a facility to re-enter boreholes from a conventional research vessel would greatly enhance the scientific yield of the Deep Sea Drilling Project and the Ocean Drilling Program, and would be an important new component of the U.S. Science Support Program in association with the ODP.

Some Recommended guidelines:

The project to develop and operate a re-entry facility should be the responsibility of a single group or organization (the Project Director). The Project Director should be selected on the basis of competing proposals responding to an RFP issued by JOI.

Experiments or instruments that use the re-entry facility should be funded separately via unsolicited proposals from individual investigators.

An oversight group should be established that is representative of the user community to review, plan and schedule borehole re-entry activity in a manner similar to the "ALVIN Review Committee."

The system should incorporate existing technology, with the aim of minimizing the cost of development.

The design of the re-entry system should take into account the much broader application of the delivery system for emplacement of sea-floor instruments and precision measurements. Other applications could provide a main source of the support of the system and reduce the cost of re-entry operations.

In France, considerable progress has been made toward developing a workable re-entry system, thus opportunities to develop this capability as a multi-national cooperative program should be explored.

JOIDES will necessarily be involved in re-entry activity of DSDP and ODP holes. There will probably be future proposals for drilling holes specifically for long-term installations of instruments. A recent resolution by the Executive Committee of JOIDES states:

"The JOIDES Executive committee actively encourages the use of the Deep Sea Drilling Project and the Ocean Drilling Program boreholes for scientific purposes both by the D/V JOIDES RESOLUTION and independent vessels through wireline re-entry. The drilling program has historically sought to maintain a catalog of hole conditions for those sites with installed re-entry equipment in order to facilitate scientific planning. In order to maintain such a list and to protect

JOIDES interests in the future uses of these holes, the JOIDES Executive Committee requests that parties desiring to use any of these holes seek endorsement of the Executive committee prior to their use. In addition, a written report to the Science Operator on the state of the holes used is requested following the conduct of these experiments. We trust that all member institutions and governments will adhere to this agreement and will ensure that those announcements and reports are made in a timely fashion."

In addition to this general policy statement we recommend the following for consideration by the JOIDES planning structure:

1. We recommend that JOIDES develop plans and pro-cedures to preserve future re-entry boreholes for re-entry after the drill ship has left the Site.
2. We recommend that re-entry experiments, such as that planned by IFREMER next year, be encouraged and support given where possible.
3. In the event that a reliable re-entry technique is developed, we recommend a test be conducted that uses the drill ship to recover and stabilize an existing, scientifically significant DSDP of ODP borehole.

I. INTRODUCTION

The DSDP and ODP deep sea drill holes are a scientific resource of the international Earth science community. It has long been realized that the scientific yield from the boreholes would be extended, if they could be re-entered to make further downhole measurements, carry out experiments and obtain additional samples. Thus, there has been a long-standing interest in developing a capability to re-enter existing boreholes that could be used from a conventional research vessel. Such a capability is frequently referred to as wireline re-entry (WLR), and we will use this term in our report; although there are techniques to achieve re-entry that do not require a wireline.

There is considerable precedent for revisiting deep sea bore holes for the purpose of re-entry either to deepen the hole (e.g. Hole 504B and 462A) or to make additional downhole measurements and experiments (e.g. Hole 395A, and 418D). In each case significant new geological, geochemical and geophysical information was gained. The precedent is important because it recognizes that existing deep sea boreholes are a scientific legacy that is available for further exploration by the JOIDES Community and by other scientists or scientific groups if they coordinate their activities with JOIDES.

The Workshop

With the growing interest in the science that could be accomplished via wireline re-entry as expressed in proposals and documents, and the advancing technology, which makes such a capability feasible, it is time to move forward with a project to develop a capability that would be available to the U.S. marine geoscience community.

An appropriate focus for a U.S. program or U.S. participation in a multinational wireline re-entry development program is the U.S. Science Support Program in association with Ocean Drilling (USSSP). This program is supported through the Office of Ocean Drilling at NSF and is designed to enhance the research resources of scientists at U.S. academic institutions that participate in the ocean drilling program.

The U.S. Science Advisory Committee (USSAC) advises and assists JOI Inc. in administering the USSSP. Since its establishment in 1984 USSAC has recommended that a wireline re-entry capability be developed. In June 1986 USSAC recommended to JOI Inc. that it initiate a project to develop a wireline re-entry system via an RFP. Some initial steps were taken to this end: a subcommittee of USSAC generated a general technical description of a WLR system, and a work statement for a potential RFP. Before proceeding further the Office of Ocean Drilling at NSF felt that it was important to test the level of interest and to document the potential scientific yield of a re-entry program. To this end JOI Inc. sponsored a Workshop to bring together interested scientists to discuss the following major topics:

1. The science that could be done if a re-entry capability were available to the academic community.
2. The type of re-entry capability required to support potential experiments and instrument installations.
3. Discuss existing and proposed wireline re-entry systems.
4. Consider issues such as the trade offs between cost and complexity, jurisdiction over existing boreholes, and applications of a maneuverable deep-sea vehicle and precision positioning capability beyond borehole re-entry.

The Wireline Re-entry Workshop met at the Scripps Institution of Oceanography on February 23 and 24, 1987. A list of Workshop attendees is on the back of the front cover of this report. The two days of the Workshop were divided between plenary sessions, when all participants met together, and separate meetings of three working groups. The working groups covered three main topics:

A. Long-term observations in boreholes and on the sea floor.
B. Short-term experiments to probe the oceanic crust.
C. Borehole profiles and high resolution imaging of the crust.

The organization of the remainder of the report is as follows: Section II provides information on the availability of existing re-entry drill holes for re-entry. A table is included in this section that describes our current knowledge of each re-entry hole. Sections III, IV and V of this report summarize the discussions of the Workshop. Section III describes the science that non-drill ship re-entry capability would make possible. It is based entirely on contributions of Workshop participants. Section IV describes the status of current and future re-entry technology. This section contains general technical desciptions of three practical approaches to re-entering boreholes, and is based on presentations at the workshop and contributions from some participants. Section V recommends that a US project to develop and operate a re-entry capability be started under the auspices of JOI Inc. as part of the US Science Support Program in association with ODP. Some guidelines and recommendations relative to the structure and management of such a project are presented based discussions at the Workshop.

An appendix to the report provides individual descriptions of many of the experiments and instruments prepared by participants in the workshop and the requirements for a future re-entry capability to implement each experiment prepared by participants in the workshop. The agenda of the meeting can be found on the last two pages of this report.

Justification for a wireline re-entry capability

The strongest argument for wireline re-entry is that for a relatively small additional cost deep sea boreholes can be turned into long term scientific observatories, or they can be further probed to follow up earlier discoveries. Some of the ways that a reliable wireline re-entry capability could enhance the Ocean Drilling Program are:

1) Instruments or experiments could be deployed less expensively and with more logistical flexibility than from a drill ship.

Experiments that require two ships or time consuming deployments would greatly benefit from re-entry capability. For example, borehole seismic experiments have proved an essential tool in studying the structure of oceanic crust and hence constraining the models for crustal processes and tectonics. As our attention narrows to smaller scale features such as magma chambers, hydrothermal vents, etc., improved bore-hole seismic techniques that require several days to execute must be employed to address issues of anisotropy and lateral variability. Such experiments become economically feasible only with WLR.

2) Better quality data could be obtained for some types of measurements.

Tools with high spatial resolution such as the borehole televiewer, or a high resolution resistivity tool operate up to their full potential only if the tools are completely isolated from the surface ship motion. This stability can be achieved using wireline re-entry because a module can be set in the re-entry cone that provides a fixed reference for controlling lowering and hoisting of the instrument.

3) New types of measurements could be made that are not currently possible because existing tools or instruments are too big to pass through the drill pipe.

As an example one of the most important potential measurements in submarine boreholes is downhole gravity. Although existing downhole gravimeters do not pass through the ODP drill string, they could be run in open holes which are about 25 cm in diameter.

4) A wireline re-entry capability provides an opportunity to use new tools.

New logging technology has become available since many of the DSDP and ODP holes were drilled, e.g. in the past few years spectral gamma ray logs, broad-band full-waveform acoustic logs, shear-wave logs, and high resolution resistivity logs have become operational tools. Eventually there will be neutron activation logs for chemical analysis and high temperature tools that can be used to about 400° C. Important new science could be done if some of these remarkable tools could be run in existing holes.

5) Wireline re-entry provides an economical way to make repeated visits to a borehole to log a hole after it has thermally and hydrologically equilibrated, to retrieve data records, or to maintain borehole instruments.

6) Re-entry from a conventional research ship allows an opportuntiy to do complementary geophysics in the vicinity of the borehole from the same ship deploying the borehole package. This capability may be particularly valuable for establishing the regional context for long term experiments.

Although wireline re-entry capability could be a powerful new complement to the downhole measurement program, it was emphasized throughout the workshop that it should not be regarded as a replacement for downhole measurements from the drill ship. In many ways the drill ship is a much superior platform for making downhole meaurements, for example downhole measurements are done concurrently with sampling of the hole, which provides the best opportunity for exploitation of discoveries and correlation. The drill ship provides much greater capability and consequently, far greater assurance that downhole measurements will be accomplished when hole conditions are not favorable.

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Ralph Stephen of WHOI kindly provided the re-entry site evaluations presented in Table 1. John Orcutt, Chairman of USSAC was a strong source of support and encouragement. Editorial review and comments from R. Stephen, T. Pyle, E. Kappel, J. Orcutt, R. Williams, K. Becker, and F. Duennebier were extremely helpful to the preparation of this report.

The work of members of the USSAC subcommittee to develop the technical aspects of an RFP for wireline re-entry provided much useful background information for the Workshop and the report. Subcommittee members are M. Langseth (Chairman), D. Huey, R. Merkel, R. Frisbie, A. Schloesser, J. Orcutt and T. Davies.

II. AVAILABILITY OF DEEP-SEA BOREHOLES FOR RE-ENTRY

Status of existing re-entry holes:

In principal all re-entry holes drilled during DSDP and ODP are candidates for wireline re-entry. The critical question is how deep into these holes can instruments be lowered before hitting an obstacle? Information relative to this question can be found in the operations report of the last visit to each borehole. The drill ships have visited several boreholes for the purpose of re-entering and making downhole measurements or deepening the hole. These re-entry activities provide the best indication of the stability of the holes. In Table 1 (page 9) there is a short summary report on the condition of each of the re-entry sites based on the last visit.

Some general observations can be gleaned from Table 1.

1) Holes where casing has been installed through the sedimentary layer and cemented into basement are stable and clear from top to bottom if no equipment has been dropped in the hole. Successful re-entries at holes such as 398A and 504B have demonstrated their stability over nearly 10 years.

2) Holes into basement through a relatively thin section of uncased sediment (e.g. Site 482) are likely to be open.

3) Boreholes through a thick section of sediment are likely to be blocked at a shallow depth subbottom by slumping or swelling sediment. For example, recent re-entry at Hole 418A by the drill ship revealed numerous sediment bridges in the 320m of uncased section, that would certainly have prevented any instruments from being lowered to basement. The bridges were easily removed by washing through them with the drill string. In contrast, Hole 462A was re-entered on Leg 89 and the drill stem passed through a 66m uncased sequence of sediment without detecting an obstruction.

4) Boreholes through the sediment in tectonically active areas such as active accretionary prisms in subduction zones are intrinsically unstable and the probability is high that the hole has collapsed.

A fair conclusion from Table 1 is that there are about a dozen re-entry holes in highly interesting locations where the probability is high that an instrument could be lowered at least 3/4 of the full depth.

Remedial measures:

A wireline re-entry cruise will be expensive, therefore assurance that the measuring tool can be lowered to the planned depth is essential. Means for providing such assurance were discussed at the Workshop. An important device on any re-entry expedition would be a "pilot tool" to sound the borehole prior to committing expensive sensors or instruments. Participants at the workshop recognized a need for a tool that could be lowered on a wireline and remove or penetrate any weak bridges in a hole. Such a device would certainly be a good insurance policy for any re-entry activity. However, tools that do this job do not exist at present and development in the near future seems unlikely.

A more practical alternative would be to use the drillship capability to prepare and stabilize existing holes for future wireline re-entry. There are re-entry holes that are especially bright prospects for future re-entry because of location, depth, or geological setting, but it is uncertain whether they are open for re-entry. If in the progress of the drill program the drill ship passes near to one of these holes a short detour to recover and prepare the hole for re-entry would be valuable. Such an opporturnity may come up during the drilling in the Western Pacific when the drill ship will be close to Hole 462A.

Some deep boreholes do not have re-entry cones but might be rescued for future re-entry. The new video capability that was demonstrated on Legs 106 and 109 makes it feasible to re-enter a borehole that has no re-entry cone. If re-entry is accomplished the hole could be cleaned and stabilized and a "mini-cone" installed to allow futrue re-entry using wireline techniques.

If there is ever to be remedial work on existing boreholes it must be planned in advance and integrated into drilling legs. Recovering a hole will be costly. Proposals for recovery and re-entry of a program must first successfully work their way through the JOIDES panels and committees. However, if techniques to recover holes are not demonstrated, there will be a natural opposition to recovery proposals. Consequently a feasibility test should be planned to recover a scientifically important borehole as part of the wireline re-entry development project. Such a test might be done in concert with a special engineering and downhole techology leg, which has been seriously considered by JOIDES.

Re-entry of future boreholes:

No doubt drill holes near the axis of the mid-ocean ridge or on an accretionary prism will be very attractive places to set up long term experiments or install downhole observatories. In fact, some holes may be drilled primarily for such a purpose. Special actions should be taken for all re-entry holes that are deep or in a particularly interesting place to preserve them for re-entry. These include installing casing through to basement, filling the hole with an appropriate mud before leaving, and/or installing a low cost sleeving in the hole before leaving. There is an interest in resealing some holes to prevent free exchange of ocean bottom water and deep sections of the drill hole for hydrogeological studies (See Section III). The drill ship could be used to install the seal before leaving the hole.

Advance planning will be essential, if re-entry capability is to be used with full effect; otherwise, many opportunities to realize the maximum scientific potential of costly drilling efforts will be squandered.

Jurisdiction over JOIDES drill holes:

This topic received a brief discussion at the workshop. A statement by the downhole meassurements panel with some modifications would accurately represent the views expressed at the workshop. (See also the resolution by the JOIDES Executive committee on the use of DSDP and ODP boreholes for future re-entry).

(i) Considerable precedent exists for returning to DSDP holes for the purpose of re-entry and doing further science. This implies that JOIDES has always regarded the existing boreholes as a scientific resource that can be visited following appropriate consultation with and review by JOIDES planning bodies.

(ii) Efforts within the JOIDES community to re-enter deep sea boreholes for scientific purposes should be done with the full knowledge and approval of the JOIDES EXCOM. The approval process should include an evaluation of the scientific merit of the proposed work versus the potential jeopardy to the borehole for future use. Re-entry activity by non-drilling ships could be monitored by establishing strong communication before and after re-entry and requiring a prospectus and a report.

(iii) Neither JOIDES nor any other body has clear legal jurisdiction over the use of boreholes outside EEZs. Nevertheless considerable control over the use of the holes can be exercised by JOIDES because of the number and worldwide distribution of participating scientists.

TABLE 1: CONDITION OF EXISTING RE-ENTRY SITES: (June 1987)

146	Leg 15, 15° 06.99'N, 69° 22.67'W (Caribbean). Water depth 3957 m. 762 m sub-botom, 22 m sub-basement. Hole open. Old style cone. No logging or downhole experiments done.
288A	Leg 30, 5° 58.35'S, 161° 49.53'E Steward Basin and adjacent Ontong Java Plateau). Water depth is 3030 m and penetration below seafloor is 998.5 m. From 0 m to 550 m are Cenozoic nannofossil-foraminiferal chalk and ooze with some chert. Apparently, this hole is bridged at 105 m below seafloor.
319A	Leg 34, 13° 01.04'S, 101° 31.46'W: (Bauer Deep between the East Pacific Rise and the Galapagos Spreading Center). Water depth is 4296 m (pipe) and penetration below the sea floor is 157 m. From 110 m to 0 m are Miocene to Quaternary nannofossil forminefera ooze and clay. From 157 m to 110 m, basalt. The drill pipe was torquing when the site was abandoned; there may be loose basalt pieces or formation bridging in the hole.
320B	Leg 34, 9° 00.4'S, 83° 31.8'W: The site is on the east edge of the Nazca Plate (Peru Basin). Water depth 4487 m and penetration bsf is 183.5 m. From 155 m to 0 m are Oligocene to Quaternary nannofossil and radiolarian ooze. From 183.5 m to 155 m, basalt. The hole was abandoned after the drill pipe was sticking in the hole, which was possibly caused by loose pieces of basalt falling into the hole, thus the hole may not be completely open.
332B	Leg 37, 36° 52.8'N, 33° 38.6'W (Mid-Atlantic Ridge near FAMOUS area). Water depth 1841, hole depth 721 m, 582 m into basement. Casing is parted, little likelihood of re-entry.
333A	Leg 27, 36° 50.45'N, 33° 40.05'W (MAR, FAMOUS Area). Water depth ~1666 m. 529 m sub-bottom, 310 m sub-basement. Top 260 m of hole in basement open, but bottom 50 m plugged with stuck pipe. No logging or downhole experiments done.

395A Legs 45 and 78B, 22° 45.35'N, 46° 04.90'W (MAR). Water depth 4485 m. 664 m sub-bottom, 576 m sub-basement. 120 m casing (cemented into basalt). Hole is open; drilling terminated because of excessive torquing; sinker bar now at bottom. Extensive program of logging and downhole experiments completed on Leg 78B and Leg109.

396B Leg 46, 22° 59.14'N, 43° 30.90'W (MAR). Water depth 4465. 405.5 m sub-bottom, 255 m sub-basement , 153 m casing (cemented into basalt). Hole open; no gear in hole, but lost because of sand and gravel in bottom. Logged but no positioning devices used. French plan to re-enter this hole in 1988.

398A Leg 47, 40° 57.6'N, 10° 43.1'W (On Galicia Bank). Water depth 3900 m, total depth of hole is 1740 m. The hole is thought to be plugged by sediment bridges.

415A Leg 51, 31° 01.7'N, 11° 39.1'W (Atlantic margin, off Morocco). Water depth 2817 m. 1074.5 m sub-bottom, basement not reached. Cone buried or flush with seafloor, hole filled with cavings below 900 m, barite mud above. No downhole experiments run but hole logged through pipe with natural gamma tool.

416A Leg 51, 32° 50.2'N, 10° 48.1'W (Atlantic margin, off Morocco). Water depth 4203. 1624 m sub-bottom, basement not reached. Hole filled with drilling mud, occasional bridges. Logged but no downhole experiments run.

417D Legs 51 and 52, 25° 06.69'N, 68° 02.82'W (Bermuda Rise). Water depth 5489 m; 708.5 m sub-bottom, 363 m sub-basement. Top 250 m of hole in basement open, but bottom 100 m plugged by lost BHA. BHA possibly fishable. Sediments and top 125 m of basement logged (except for density). Oblique seismic experiment run in to 230 m of basement.

418A Legs 52 and 53, 25° 02.08'N, 68° 03.45'W (Bermuda Rise). Water depth 5519 m; 868 m sub-bottom, 544 m sub-basement. Hole revisited on Leg 102, bridges in the hole, but no logging tool was in hole as suspected. Oblique seismic experiment run.

433C Leg 55, 44° 46.0'N, 170° 01.26'E (Suiko Seamount). Water depth is 1861.8 m. Penetration below the sea floor is 550.5 m. From 550 m to 163 m are basalt flows with minor sand layers. From 163 m to 53 m are Oligocene reefal sand and minor sandy mud. From 52 m to 0 m are Miocene to Pliocene siliceous nannofossil chalk ooze. Hole 433C is probably open, but may have zones of fractured loose basalt which may make re-entry difficult.

442B Leg 58, 28° 59.04'N, 136° 03.43'E (Shikhoku Basin). Water depth is 4634.5 m, penetration 455.0 m. From 455 m to 355 m are pillow-basalt flows overlain by 5 m of Miocene limestone. From 375 m to 0 m are Miocene to Quaternary mud and clay, with minor ash. This hole is probably open, however, it was abandoned after the drillstring began torquing, thus there could be a bridge somewhere in the hole. Needs a surface casing.

462A Leg 61, 7° 14.5'N, 165° 01.9'E (Nauru Basin). Water depth 5186 m, penetration 1068.5 m bsf. 1068.5 m to 665 m dolerite sills and basalt flows, 665 m to 450 m Maastrichtian volcanoclastic sediment, 450 m to 390 m Eocene chalk with minor chert, 300 m to 0 m calcareous siliceous ooze. Sonic, caliper, natural gamma and neutron logs were run. Hole was visited on Leg 89 and found to be open to bottom. The hole was deepened on Leg 89.

482D Leg 65, 22° 47.31'N, 107° 59.51'W (12 km E of East Pacific Rise axis). Water depth 3008 m, penetration 186.5 m. From 186.5 m to 137 m are massive flows and pillow basalts. 137 m to 0 m Pleistocene hemipelagic clay. Upper 39 m of hole is open, bottom part of hole contains BHA. Hole 482C contains the HIG seismometer.

483B Leg 65, 22° 53.0'N, 108° 14.8'W (Tamayo Fracture zone). Water depth 3084, total depth of hole 267 m and basement penetration is 160 m. The re-entry cone is blocked, but it may be easy to clear.

504A Leg 69, 1° 13.6'N, 83° 43.95'W (Costa Rica Rift flank). Water depth 3458 m, penetration 277 m. 277 m to 264 m basalt flows, pillows and breccias, 264 m to 145 m Miocene to Pliocene limestone and chert, nannofossil chalk, 145 m to 0 m Pliocene to Pleistocene ooze. Hole is open, but drill bit cone is in the bottom of the hole. Density , caliper, gamma ray, and temperature logs have been run.

504B Legs 69, 70, 83, 92 and 111, 1° 13.61'N, 83° 43.81'W (S. flank Costa Rica Rift). Water depth 3460 m, penetration 1562.3 m. 1562.3 m to 264 m basalt basement, flows and pillows overlying stock work and sills at depth. Sediment section same as 504A. Many logs have been run in the hole, oblique and VSP seismic experiments have been run. The hole is open, but there is a diamond drill bit in the bottom of the hole.

534A Leg 76, 28° 20.6'N, 75° 22.9'W (Atlantic, E. of Blake Escarpment). Water depth 4976 m, penetration 1666.5 m, 27.5 m basement. Gamma, caliper, sonic, density and temperature logs run. Hole appears to be in good condition.

547B Leg 79, 33° 46.8'N, 9° 21.0'W (off Morocco). Water depth 3952 m, penetration 1030 m. 1030 m to 924 m mudstone, 924 m to 422 m Cretaceous-Jurassic mudstone and limestone, 422 m to 0 m Tertiary ooze. Hole is probably in good condition.

553A Leg 81, 56° 05.32'N, 23° 20.61'W (Rockall Bank). Water depth 2339 m, penetration 682.5 m, basement 500 m bsf. 682.5 to 500 m basalt, 500 m to 230 m Eocene volcanoclastic breccia, tuff, ash etc., 230 m to 0 m Pleistocene to Eocene ooze. Bottom 27.8 m of hole filled by sediment. Noisy sonic, gamma ray, dual induction, density, caliper and temperature logs run. Hole probably open.

595A Leg 91, 23° 49.34'S, 165° 31.61'W (near Tonga Trench). Water depth 5615 m, total penetration 124 m. Hole is probably open. The instrument for the University of Hawaii seismic experiment is still in the hole.

597C Leg 92, 18° 48.40'S, 129° 46.22'W (Galapagos Spreading

Center).Waterdepth is 4164 m, penetration 143 m, 91 m into basalt. Caliper and two televiewer logs. Hole is apparently in good condition.

638C Leg 103, 42° 09.2'N, 12° 11.8'W (Galicia Margin). Water depth 4673 m, depth of hole 547 m. Hole conditions are apparently bad with sand in the hole. The hole was filled with mud before leaving.

642E Leg 104, 67° 13.2'N, 2° 55.8'W (Voring Plateau, Norwegian Sea). Water depth 1289, hole depth 1229 m. The top of the cone is at the sea floor.

645E Leg 105, 70° 27.4'N, 64° 39.3'W (Baffin Bay). Water depth 2018 m, hole depth 1147 m. No surface casing, condition of hole is questionable.

648B Legs 106 and 109, 22° 55.3'N, 44° 56.8'W (On the axis of the Mid-Atlantic Ridge). Water depth 3341, hole depth is not known, probably about 45 m. A guidebase was installed at this hole. Last action in the hole was to detonate a charge at about 50 m sub-bottom in an attempt to free the BHA.

III. SCIENTIFIC OPPORTUNITIES:

A. Imaging the ocean crust:

Seismology has proved to be an essential tool for studying the structure of oceanic crust and hence constraining the models for crustal processes and tectonics. As our attention narrows to smaller scale features (ridges, fracture zones, magma chambers, hydrothermal vents, etc.), seismic techniques must be improved to address the new issues of anisotropy and lateral variability. Two innovative seismic experiments that contribute to an improved definition of the ocean crust are Vertical Seismic Profiling (VSP) and Oblique Seismic Experiments (OSE).

Vertical array seismic experiments: Vertical seismic profiling (zero offset) provides a detailed velocity-depth profile of the bore-hole and the reflection seismogram for the drill site. This seismo-gram and the accompanying well-logging information can be directly related to multichannel seismic (MCS) reflection profiles that defined the regional geologic framework of the drillsite.

The VSP experiment is done by clamping a seismometer in uncased as well as cased boreholes at 10 meter depth intervals. A surface ship positioned over the borehole, fires an airgun/watergun several times while the seisometer is at each clamped depth. The time required for a typical VSP experiment is 36-48 hours. While two successful VSP experiments have been conducted aboard the JOIDES RESOLUTION, this time requirement precludes routine VSP measurements at many drillsites. Accordingly, a wireline re-entry capability would allow essential VSP calibration of many more boreholes with the regional seismic profiles and the well logging information.

An oblique seismic experiment: (OSE) or offset VSP uses similar equipment to VSP but the seismometer (preferably three component) is clamped at relatively few positions in the borehole while a second ship fires explosive charges or airguns out to 12 km or more at a number of azimuths. The primary objective of the OSE is to image the 3-D seismic structure in the vicinity of the borehole. An important secondary objective is the detection of seismic anisotropy in the crust, which is related to crack orientation or preferred fabric directions.

An OSE generally requires five or six days to carry out and requires simultaneous scheduling of a shooting ship and the drilling vessel. Wireline re-entry would make OSE's more cost effective since expensive drill ship time is not being used for non-drilling activity. Also, the ability to carry out an experiment with only a single ship, which would be possible with wireline re-entry, would be attractive logistically and financially.

Borehole gravimeter: One of the most important potential measurements in submarine boreholes is downhole gravity. The rate of change of gravity with height, after correcting for the local earth radius and angular velocity, responds to the mean density of the formations over a considerable volume. The part of the rock disturbed by the drilling is a negligible fraction of the whole. The porosity observable in ophiolite exposures is notably heterogeneous. The extrusive and dike/sill complexes are almost always highly fractured and "massive" gabbros are jointed on a large scale The currently accepted wisdom that they are impermeable to fluid flow may be based on inadequate and intrinisically biased data. A very small amount of porosity dispersed over widely-spaced cracks can result in high formation permeability unmeasurable from a drill hole. A downhole gravimeter would provide a more representative indication of porosity, but existing downhole gravimeters cannot pass through the drillstring currently used by ODP, but wireline re-entry would allow their use in open holes that are about 25 cm in diameter.

The borehole televiewer: The borehole televiewer is a wireline logging tool that employs a rotating ultrasonic transducer coupled to a fluxgate magnetometer to produce an oriented image of borehole wall reflectivity. This tool can produce a detailed 3-dimensional representation of the borehole wall by processing of the televiewer data in travel-time. Borehole televiewer logs are especially useful in locating and orienting natural fractures and other discontinuities (pillow flows, voids, ets.) as well as stress-induced borehole elongation. In addition, this tool is essential to select smooth, in-gauge sections of the borehole for setting packers used in permeability, pore pressure, and stress measurements.

Although the borehole televiewer is now an integral part of the ODP downhole measurements program, only a few holes have been logged using the tool so far and most of these logs are of poor quality. The scarcity of televiewer runs results largely from the slow logging speeds required and drill rig time constraints. Even when time has been allocated for televiewer logging, data quality has been severely degraded by ship heave and the lack of a reliable wireline heave compensator.

It is essential to have high quality televiewer logs of holes before the setting of packers or the emplacement of some downhole measurement packages as part of a wireline re-entry program. One way of doing this would be to deploy an ocean floor winch system (similar to the IFREMER system described in section IV) that could be lowered from the surface ship and set into the re-entry cone. Because the winch would be decoupled from the ship heave, the image degradation that has plagued previous televiewer logs would be virtually eliminated in this system. One possible scenario for relieving the drill rig time constraints on future ODP legs would be to log each new hole from the drill ship using the televiewer at relatively high winch speeds in order to obtain a detailed 360° caliper log of the hole. A slower, consequently higher resolution televiewer survey could then be conducted by a wireline re-entry system at a later date.

Formation microscanner: A recent development in logging is a high resolution resistivity tool, called a Formation Microscanner. This tool is equipped with two pads that are held against the wall of the hole. Each pad is studded with many small independently recording resistivity buttons. As the tool is moved up the hole it re-cords a detailed resistivity map of the wall. The resistivity varies with lithology, porosity and permeability so the image recorded by the Formation Microscanner provides a complete high resolution picture of stratigraphy, fractures, contacts and breakouts. The size of the resistivity pads is small enough and the coverage complete enough that good records taken with the device resemble a core in the detail they provide. The Formation Microscanner also contains devices to record the orientation of the tool at all times, giving the orientation in space of features such as fractures and con-tacts. This tool and future modifications of this tool have the potential to revolutionize the interpretation of borehole data. For ODP science, the Formation Microscanner and the televiewer will allow accurate placement of core material in the context of the stratigraphy and structure of the drilled section.

The diameter of the current version of the Formation Micro-scanner is too large to pass down the ODP drill string. Schlumberger has shown interest in developing a smaller diameter tool that should allow it to be used from the JOIDES RESOLUTION. The Formation Microscanner is another tool like the borehole televiewer that must be isolated from heave of the ship to realize the full resolution of the device. Wireline re-entry would provide many opportunities to use this valuable new tool in holes that are drilled before the slim-line tool is available.

Side-wall sampling: It is well documented that, even with continuous coring, recovery is incomplete in both sediments and hard rocks. Softer materials, such as unconsolidated sediments or alteration products of crustal rocks, wash out and thus are poorly represented in the recovered cores. In some cases the unsampled interval represents critical biostratigraphic horizons. In igneous rocks the unsampled material may represent geochemically very important alteration products. Sidewall coring provides the only opportunity to sample these materials.

Although sidewall sampling tools could be deployed from the drill ship, multiple sample tools commonly in use in industry will not fit through the drill pipe used in ODP. Further, critical stratigraphic horizons that were not sampled may not be identified until sometime after drilling, at which time cost and scheduling difficulties might preclude the drillship returning to the site. For these two reasons a sidewall sampling capability deployed using wireline re-entry would be particularly valuable and cost effective.

Side-wall physical properties measurements: A probe that can be extended from a logging tool so that it penetrates the wall of a borehole could be instrumented to make measurements of temperature, thermal conductivity, permeability and shear strength. The tool could only be used in unconsolidated and semiconsolidated sediments. The probe, which would be hydraulically driven and telescoping, would be about 3.2 to 6.3 mm in diameter and 15 to 30 cm long. The larger hole diameter available with WLR would make the use of such a tool more feasible.

Downhole magnetometer: An instrument to measure the total and the three components of the magnetic field vector, and the weak field susceptibility would be an important complement to any logging done during reentry. Although downhole magnetometers have occasionally been run from the drillship, magnetic profiles were not run in many of the existing boreholes.

Future technologies: New wire-line logging tools are being developed at a great rate (mainly driven by the petroleum industry). These tools can determine rock properties (including rock type, porosity, density, permeability, fractures, structural dip, foliation, fluid saturation) from integrated interpretation of a suite of physical measurements. Measurements include resistivity, dielectric constant, nuclear properties (natural gamma spectroscopy, pulsed neutron spectroscopy) and full wave acoustic properties. Some of the properties can be measured through a drill pipe, but others (dipmeter, formation fluid tester, high resolution resistivity to map the surface of a borehole and televiewer) require an open hole. Wireline logs measure properties *in-situ*, and sample deeper into the rock formation than core dimensions. With the core data as guide, logs provide a continuous profile of rock properties and structures.

Many new logs have become available during the past few years, e.g. spectral gamma ray logs (detects Uranium, Thorium, Potassium abundances); broad-band full-wave-form acoustic logs (detects P & S velocities, attenuations, permeability and fractures); shear wave logs and the Formation Microscanner described above. Eventually there will be neutron activation logs for chemical analysis and high temperature tools that can be used to about 400°C. Wireline re-entry is essential if we are to exploit in a timely fashion new technologies in borehole measurements, and if we wish to apply state of the art commercial techniques to existing boreholes.

B. Hydrogeological Measurements in Thermally Equilibrated Boreholes:

In sections of oceanic basement that have temperatures above ambient seawater (up to 100°C), drilling and the associated seawater pumping chills the surrounding rock substantially. Since some downhole geophysical tools measure physical properties that are strongly temperature dependent, i.e. magnetic remanence, susceptibility, and electrical resistivity, these measurements are much more meaningful and useful if they are made when the wall rock is at temperatures that approach those of the original *in-situ* temperatures. As an example, the Curie temperature of unaltered extrusive submarine basalts is typically less than 200°C. Altered basalts and dikes have Curie temperatures that are higher (about 550°C), but the magnetic properties of these rocks can be substantially affected by magnetic viscosity at temperatures as low as 200°C. Most of the downhole geophysical measurements are most strongly influenced by the wall rock that is within one or two hole diameters from the center of the hole, and this is the volume of rock most affected by the chilling of the pumped seawater. In order to make meaningful logging meaurements of this type of warm crustal section, it is necessary to allow the wall rock to re-equilibrate to close to the original temperature prior to measurement. This would be best done by WLR, long after the drilling has taken place.

Borehole water chemistry: The major objective of the study of formation water chemistry is to determine changes as a function of age and overlying sediment thickness. DSDP/ODP pore water studies have inferred that there is a gradual evolutionary change in Layer 2 formation water chemistry. Mass balance considerations have suggested that circulation of formation waters down at least a kilometer into Layer 2 does occur.

Initial studies of borehole waters in Sites 395A, 418A, and 504B have indicated that substantial gradients in sediment pore water chemistry attributable to communication with underlying basement. A secondary objective is to determine possible chemical gradients with depth in formation water chemistry with depth into Layer 2, or to establish evidence for convective turnover in Layer 2, which should result in a nearly uniform composition with depth. Holes that penetrate deep into Layer 2 are preferred for this type of study.

In order to achieve these objectives, several approaches are conceivable. The basic problem in each case is to obtain a sample containing a substantial fraction of basement formation water, and to be able to determine the value of this fraction. This requires either 1) considerable time (generally months to years) or 2) negative differential pressure between the borehole and the wall rocks, to allow the formation water to enter the borehole and mix with the water already there. The first condition dictates a long-term experiment, requiring at least two visits to a hole; the second could be obtained on a single visit with a straddle packer. Both approaches involve sampling water with depth in the hole, and possibly also *in situ* chemical profiling. The long-term experiment could also include emplacement of an *in situ* analyzer.

Wireline packer: A wireline resettable straddle packer designed for pore fluid sampling, pore pressure determination, and permeability measurement is being purchased for the JOIDES RESOLUTION. The design is limited by the fact that the system has to fit through the 3 5/8" drill pipe and to inflate to seal a nominally 12" diameter borehole.

A downhole pump and valve system allows inflation/deflation of the rubber elements and pore fluid sampling from within the packed-off interval. Operational and chemical monitoring data are transmitted through a standard 7-conductor logging cable.

Operation: 1) Lower to pre-selected interval (requires a relatively smooth cylindrical interval about 5 meters long - such intervals can be found by borehole televiewer survey, for example).
2) Set the packer by inflating the rubber elements.
3) Close the valves to packers and open sample chamber to interval between packers - OR to section below lower packer.
4) Perform measurement -pore pressure, permeability or pore fluid sampling.
5) Deflate packers.
6) Move to next internal.

Pore Pressure: Requires stable continuous isolation of the measurement interval (either between or below packer). Monitor pore pressure as long as necessary to determine stable local value (perhaps several hours).
Permeability: There are two types of permeability measuring experiments: a) Stable flow condition (measurement accuracy questionable). b) Sudden draw-down or pressurization of sample interval, and monitoring recovery to *in situ* value. (Note this experiment provides a pore pressure value).
Fluid Sampling: Requires a long period (hours to days) of steady pumping while monitoring the fluid properties within the sample chamber. When equilibration is reached, the sample chamber is sealed. Samples from 10 to 1000 cc are possible.

Advantages of wireline re-entry: 1) Provides enough time to make the tests without using valuable drill-ship time. 2) Allows re-design with larger elements that can withstand higher differential stresses. The device can then pump harder without the risk of unseating and tearing the rubber elements. The present design cannot withstand much more than a few 100's PSI differential pressure without de-forming or failing.

A recovery experiment for crustal boreholes: Drilling holes into oceanic crust has a profound effect on the hydrogeology. The disturbance results from the opening of a low resistance hydraulic link between cold deep ocean water and warmer rocks in the crust. Temperature, geochemical and pressure data from crustal boreholes have indicated a variety of responses. The most commonly observed phenomenon is a flow of seawater into basement. In part this is due to the difference in temperature and density between the water column and the wall rocks, which produces an outward pressure of a fraction of a bar across the hole wall. In holes 504B and 395A, where pressures have been measured they are greater than one bar subhydrostatic, which cannot be explained by the temperature contrast. In one case (395A) evidence suggests that the flow has continued undiminished for nearly 10 years, whereas at 504B the drawdown has progressively slowed. An interesting example is hole 462. When initially drilled it showed no evidence of downward flow in the hole, however, a visit several years later indicated that a significant downflow had developed in the interval and was emptying into a cherty limestone and not into basement!

At other Sites, (e.g. Hole 482, drilled on Leg 65), an upward flow of water from the igneous crust has been inferred from temperature measurements in the bottom of the hole. Current thinking ascribes the anomalous pressures that drive these flows to active hydrothermal circulation in the igneous oceanic crust.

The flow of seawater in holes initiated by drilling into the crust presents problems and opportunities. On one hand opening the hole may permanently alter the hydrology from the original condition, on the other hand, opening the hole provides an experiment from which important hydraulic and chemical data representative of a large volume of the crust can be deduced. (E. g. the rates of flow combined with pressure measurements have been used to deduce the large scale permeability of the basement rocks.)

Applications of wireline re-entry capability: Most of what we know about disturbances of the hydrogeology of the ocean crust comes from opportunities to re-enter boreholes where flow was observed. A wireline re-entry capability will provide an opportunity to solve some outstanding problems of the hydrogeology near existing boreholes and take better advantage of opportunities presented by the penetration experiment.

The experiment created by drilling the hole can be at least partially reversed by re-sealing it, which would stop flow along the hole and allow the temperature and pore water chemistry to return to equilibrium. Observations during recovery of the hole, can predict accurate steady-state temperature profiles, *in situ* fluid pressures; pore water chemistry of adjacent formations; and other temperature and chemistry sensitive parameters such as magnetization and resistivity.

Re-sealing the hole provides a powerful transient experiment and the evolution of temperature, pressure and pore water chemistry provides strong constraints on the hydrogeological environment.

In summary, one of the most useful and revealing hydro-geological experiments that could be carried out with a wireline re-entry capability is a recovery experiment at a few deep drill holes at sites selected for diversity of hydrogeological environments. A recovery experiment could provide:

1. An accurate determination heat flow and temperature profile in the hole.
2. Reliable analysis of basement fluid chemistry (see below).
3. Accurate determinations of bulk hydraulic parameters of the oceanic crust
4. The *in situ* pressure in the hole.
5. Types and rates of rock/water reactions in the sediments and igneous basement.
6. Accurate *in situ* profiles of temperature and chemistry sensitive parameters, such as resistivity and magnetization.

<u>Long-term chemical experiment</u>: The objectives are to determine the composition of basement formation water and its variation with depth and temperature in the hole. Given sufficient time, whatever water occupies the hole at the time it is sealed (usually surface seawater) will be replaced by formation water from the wall rocks surrounding the hole, as a result of diffusive, reactive, and convective exchange. The experiment would consist of 1) an initial visit a) to sample the hole with depth, to determine its starting composition, and b) to emplace a plug or series of plugs with depth in the hole, followed by 2) a return visit months to years later to repeat the sampling with depth. In order to ascertain that the final sample is formation water, we would need to know the shape of the composition vs. time curve. This could best be determined by an *in situ* chemical analyser emplaced beneath the plug(s) on the initial visit, which would continuously monitor the change in certain chemical species with time. Under some conditions, we could infer the fraction of formation water present from various chemical species such as nitrate, ^{14}C, ^{3}He, and ^{3}H.

Primary sites of interest: 1. Deep basement holes in all provinces. 2. Shallow basement penetrations where there are significant chemical gradients in overlying sediments. 3. Selected continental margin sites where there is evidence of significant fluid advection. Monitoring of pressures and flow rates in selected hole intervals is of greatest interest.

Possible approaches: To carry out a Recovery experiment it is necessary to have a means to: stop flow through the hole; make measurements or run sensors through the hole without re-initiating flow; revisit the hole several times to retrieve data; collect samples or refurbish instru-mentation.

Conceptual approaches to meet these requirements are suggested below:

1. The hole could be sealed by filling it with a viscous fluid (e.g. a polymer mud) that would prevent flow along the hole and through the wall rock into the surrounding formations. The mud must be fluid enough to allow an instrument or array to be installed and retracted if necessary. This approach may prevent taking valid pore fluid samples for chemical studies unless access to the hole wall is provided.

2. Seal the hole by emplacing resettable plugs at citicial locations along the hole. These plugs would not experience large pressure drops across them (a few bars) and thus could be made of relatively compliant materials; however, it is required that these plugs be retrievable by the wireline re-entry system. The plugs could be incorporated into a pre-assembled "mast" that is lowered into the hole and fixed in place.

3. Install a plug and wiper assembly at the top of the hole. This assembly would be designed so that tools or arrays of sensors can be passed through the plug without leakage.

C. Long-Term Observations of Ridge Processes

Sea floor observations that require long-term monitoring of tectonic, seismic, magneto-telluric and other events have been a long-held dream of Earth scientists. The observatories that are described in this section (except for the deformation observatory) would most often be installed on the sea floor and less frequently in boreholes. However, the technology that is required to place a re-entry system in the cone of a borehole is in principle the same technology to accurately emplace and to maintain sea floor observatories. (See section IV). In view of this common need the Workshop identified and defined some geophysical observations that would be greatly enhanced by the establishment of borehole and/or sea floor instruments that could operate for periods of a decade or more.

Vertical and horizontal tectonic motions: Although there is consensus that plate motions are responsible for deformation of the earth's crust and lithosphere at the crests of mid-ocean ridges, in the shear zone of transform faults and at sites of subduction, there is great uncertainty as to the time and space scales on which motions are continuous or if the motions are episodic.

Ridge crest tectonics - At ridge crests the crust is observed to dis-tend and disrupt into narrow swarms of fissures, faults, elongate horsts and grabens. Volcanic outpourings are periodic, but the sites of volcanism are generally associated with faults and fissures. A first-order problem as yet unanswered, is whether the rise of magma into dykes and surface flows is a passive response to tectonic extension of the crust or if the extension is a response to crustal swellings caused by magma injection.

Borehole measurements and sea floor observations capable of long-term measurement of crustal strain, tilt, uplift/subsistence and collaborative seismic measurements of tectonic faulting and magma movements could address the interplay of extension and volcanism.

The experiment might consist of: 1) small aperture seismic arrays to detect and locate subsurface faults, the first motions and the rise and lateral flow of magma through the crust plumbing system; 2) precisely positioned seafloor bench marks could be used to measure patterns of strain accumulation using acoustic-ranging techniques, 3) tiltmeters to examine the rotation of fault blocks that accompany extension, and 4) strainmeters.

The growth and decay of crustal magma chambers should also occur at comparable timescales and these changes could be monitored geodetically using precision gravity meters. The gravity measurements would be made on the sea floor at fixed benchmarks on a repetitive basis using submersibles or ROV technology, and profiles would be made down boreholes on the magma chamber lid with wireline re-entry techniques.

Fracture zone tectonics - Analogous techniques would be used to measure *in situ* the slip-rates of transform faults. Vertical movements could be quantified by precision gravity and pressure measurements. Measurements and experiments in holes drilled into mafic bodies that are thought to rise vertically through the crust as diapirs in the traces of transform faults would be of high interest.

Active margin tectonics - Some active margins are sites of long-term convergence, but are today seismically inactive. Does this absence of earthquake activity indicate that there is no present convergence or that the convergence is not accommodated by brittle deformation?

The rates of convergence could be measured directly at ocean floor observatories across trenches. Changes in fluid pressure in boreholes at levels of decollement in accretionary prisms, tilting of overthrust imbricate slices, uplift and subsidence in forearc basins could all be measured by *in situ* instrumentation within and surrounding boreholes. Such measurements must be long-term if we consider the recurrence rates of large earthqukes (50-200 years).

Seamount tectonics- Very young seamounts are seen at and near the mid-ocean ridge axis using swath mapping and imaging sonars. Many of the small volcanoes have summit plateaus with craters. Craters occur within craters suggestive of numerous cycles of flooding and collapse. These seamount eruptions spread out onto the crust and cover faults and fissures created by ridge axis extension. The so-called "cover-ups" are useful in determining the width of the zone of tectonic disruption at the ridge crests, since the seamount will be cut by the ridge axis parallel faulting and fissuring if the seamount is still within the zone of disruption, otherwise the seamount remains intact.

Long-term measurements of the growth and deformation of these very young seamounts can indicate variations in the width of ridge axis deformation that might accompany major cycles of magma inflation/deflation that is episodic on scales of years to decades or more. Borehole instrumentation for seismic monitoring and repeated and very accurately navigated sonar imaging could detect the occurrence and magnitude of new lava flows and the subsequent breakup into fissures.

If we, as earth scientists, are to relate active processes that we can see and measure to the mechanisms that drive or regulate plate tectonics, we must first understand the time and spatial scale at which plate tectonics might be considered to be steady-state. These spatial scales of meters to kilometers and time scales of minutes to decades require improved and even new technologies. Some of the technologies involve borehole instrumentation and others the operation and maintenance of ocean floor observatories. Boreholes fill in the vertical dimensions of meters to kilometers and observatories add the appropriate time dimension.

<u>A small aperture, high frequency seismic array</u>: A small aperture, high-frequency seismic array should be established on and within the sea floor to monitor both local and regional seismicity. Horizontal component sensors are best coupled to the sea floor by emplacement and cementing in shallow boreholes. This array could be used for studying not only local rise axis structure, but the composition of purely oceanic wavetrains. Furthermore, the location, depth and episodicity of ridge axis microseismicity are crucial to understanding ridge crest tectonics.

A possible location of one of these arrays would be astride an intermediate to fast spreading ridge axis. Marine seismology has confirmed the presence of anomalous crustal structures that may be magma chambers below such ridge axes, which are probably important in the genesis and evolution of the young crust and lithosphere. Currently available seismic techniques, however, are restricted to mapping the lateral extent and variations in depth of the top of these anomalous zones. The seismic techniques provide information about the elastic properties of the very top of that zone which appears to be fluid. These techniques are not useful for an examination of the lateral and vertical extent of the chambers nor the elastic properties of their interiors.

Thermal and petrological models suggest that magma is produced at depths of tens of kilometers and there is no reason to believe that the lateral extent of the production zone is less than hundreds of kilometers. Except for some geochemical models, there are no constraints on the cross-sectional shape of this zone or the manner in which it varies toward the end of a ridge segment. The details of the plumbing system are unknown. For example, the oceanic crust is created within kilometers of the neovolcanic zone. This observation begs the question of how magma migrates vertically and laterally in such a way that eruptions concentrate so locally. A popular model for the formation of valley floors of ridge crests is through fluid head loss in the magma conduit. How is this hypothetical conduit related to the subaxial plumbing system discussed above?

The volcanological studies conducted to date on ridge crests and rise axes provide some information on the temporal behavior of volcanism responsible for the construction of the shallow crust. However, very little long term information is available that relates the volcanic cycles to crustal deformation and spreading. There may be discrete cycles of accretion with volcanic, strain, temperature and microseismicity signatures.

The answers to all these fundamental questions must be addressed with a proposed midocean ridge array. The shape and geometry of the axial magma chamber could be explored through the employment of seismic tomographic techniques. The array would have to be operated for a considerable period of time and employ artifical source (explosives), local microseismic and teleseismic data. Critical source locations and source-receiver paths could be filled in through repeated experiments over the course of years. The deep plumbing of the magma system, completely unapproachable from standard marine seismic measurements, could be explored with tomographic methods. These experiments would employ travel time delays, attenuation measurements and phase distortion observations to study the structure.

Tectonic cycles at ridge crests are best illuminated through long-term measurements of the temporal and spatial variability of microseismicity. Earthquake experiments, to date, have been restricted to extremely short durations which may have led to a very biased view of seismicity. Fault-plane solutions or other source characterization measurements would be invaluable in understanding the relevant tectonic processes. Active hydrothermal systems could be monitored with a small, high resolution array that was capable of detecting the flow of fluids and the propagation of cracking fronts.

The emplacement of small sea floor arrays at other sites on the sea floor is also extremely important. Marine seismic studies have done an extraordinary job of outlining the structure of the oceanic crust and uppermost mantle in the past and led to a viable hypothesis for the genesis and evolution of the crust. Studies of the deeper structure of the lithosphere and asthenosphere must exploit teleseismic data, since long range explosion studies are restricted in utility by the fairly homogeneous elastic parameters in the lithosphere and the apparent lack of a low compressional velocity zone, which might mark the lithosphere-asthenosphere transition.

Sea floor arrays in the ocean basin could be used to study the wavenumber content of regional phases. Such studies are critical to distinguishing between the scattering and reverberation models for the propagation and excitation of oceanic Pn, Sn and T phases. Once these phenomena are properly understood, these phases or wavetrains can be used for regional studies needed to understand lithosphere evolution, hot spot structure and the characteristics of features such as the eastern Pacific "superswell." The arrays, similar to those in Norway, would serve as useful elements for test ban treaty monitoring schemes and, coupled with a few broad band sensors, could be used for pure path surface wave studies of ocean structure.

D. Expanding Global Coverage to the Oceans:

Seismic measurements are a mainstay of geophysical investigation of the earth. An array of seismographs distributed over a relatively small area is even more valuable than a single instrument, because it makes possible the study of local geologic structure and seismic velocity distributions. Measurements of phase velocity particularly require an array of instruments and the intercomparision of records from them. In essence, an array of instruments allows the spatial derivative of a seismic disturbance to be recorded, and thus additional information is obtained in comparison to a single seismograph which records the displacement (or equivalently one of its time derivatives) alone. Traditionally, one thinks in terms of an array composed of matched instruments which are distributed over the earth's surface so as to sample the wave field without aliasing. Recent technological developments in borehole strainmeters and tiltmeters may change this view, and allow the spatial derivative of a disturbance to be determined from a set of measurements all made at the same location.

There are two kinds of borehole strainmeters, dilatometers that measure volumetric strain and extensometers that measure individual components of the strain tensor. There are about 85 borehole dilatometers currently in operation, mostly of the Sacks-Evertson design, and an unknown but probably much smaller number of borehole extensometers. Extensometers have been designed and installed in tectonically active, continental regions by the People's Republic of China, Japan, and the United States.

Tiltmeters measure the integrated effects of deformation over a relatively large region of the crust, in terms of the net rotation of the block containing the instrument. A potential advantage of a short baseline tiltmeter in a borehole, compared to a long base line instrument sitting on the sea floor, is that long-term stability may be improved, particularly where the sea floor is comprised of soft sediment. A tiltmeter can be installed alone in a borehole, or as part of an instrument package containing seismometers and other strainmeters.

A Marine Borehole Crustal Deformation Observatory (MBCDO): A marine borehole crustal deformation observatory would consist of a single instrument package comprised of a selection of individual modules that contain a three-component displacement, velocity or acceleration seismometer, an extensometer, a dilatometer or a tiltmeter. The assembled package would fit a stainless steel cylinder that would be cemented into oceanic basement rock. A precise thermometer is also desirable, to monitor possible signals related to changes in the temperature of the instrument package. A stable, long-term pressure transducer on the sea floor above the observatory would be required to permit identification of strain signals due to loading at the water-sediment interface. The information obtained from such an instrument package would be similar to that from a tripartite OBS array, and in addition would provide information about aseismic movement of the crust because the strainmeters have frequency response to essentially O Hz.

Much of the technology already exists to construct strainmeters and tiltmeters for use in marine boreholes. For example, deep continental dilatometers have been designed that accomodate water-filled boreholes several thousand feet deep although none have been operated at such depths. Some of the major problems will be to develop installation techniques and the technology for data storage and retrieval, and it is likely that the solution to these problems would involve the use of an ROV or a submersible.

The scientific problems that can be addressed using MBCDO data parallel those studied on land using strainmeter networks and seismograph arrays, and are a natural extension of ongoing marine seismic studies. Some examples of the kinds of problems that would benefit from MBCDO data are:

*measurements of the P and S velocity profiles through the crust beneath the observatory;

*determination of the relative amounts of seismic versus aseismic movement which occur in different tectonic regimes within the oceanic crust;

*observations of the dynamics of axial magma chambers along midocean ridges;

*studies of the rotation and emplacement of crustal blocks on the flanks of midocean ridges;

*studies of the kinematics and rate of deformation in a submarine accretionary sedimentary wedge; and

*comparison of the kinematics of the oceanic crust to the movement within the continental crust in ocean-continent collision zones.

Most of these problems have counterparts on land which are the subject of on-going research. For example, there is an array of nine Sacks-Evertson dilatometers in Iceland used for studies of vulcanism dynamics and the prediction of eruptions. Directional strainmeters, which are a more recent development, may re-duce the need to use a large number of instruments for similar studies at submarine locations on the ridge system.

<u>Broad-band, 3-component, borehole seismometers:</u> The determination of the structure of the Earth is limited by the locations of seismic observatories, which presently are sited on the continents and a few islands. Thus the oceans, which comprise about two thirds of the planet, are dramatically under-sampled. This very non-uniform sampling of the planet is manifested as spatial-aliasing in earth

studies. To some extent seismologists have worked around these problems by studying waves which propagate across the oceans (i.e., surface waves) or remotely sample the oceans (i.e., multiply reflected body waves like ScSn and SS) but such extrapolations from the continents or islands into the ocean interiors cannot replace *in situ* measurements. On the scale of the seismic study of the earth as a planet, there is no substitute for deep-ocean seismic observations.

Beyond the fundamental question of the earth's structure, the non-uniform seismic coverage of the planet poses problems in the study of seismic sources, both natural and man-made. The present continental and island siting of seismic stations leads to large gaps in receiver coverage and the lack of adequate coverage often introduces substantial uncertainty in the source mechanism of events. In California, for example, earthquakes are well-covered over about 180° of azimuth with seismic stations from Alaska to Central America. However, only sparse coverage in the oceans is available to sample the seismic energy radiating to the south and west. In monitoring nuclear testing, particularly in the southern hemisphere, the large gaps in seismic coverage in the oceans lead to a limited azimuthal paths from test sites, whereas better azimuthal coverage would improve the statistics in the determination of yield of the events and discrimination from earthquake sources. As in the case with earth structure, the gaps in coverage are a fundamental limitation to detection, and there is no acceptable recourse short of deep-ocean seismic observatories.

For both earth structure and seismic source studies high-quality, 3-component, broad-band seismic data from the deep oceans are important. Borehole deployment in basement is ideal in terms of platform stability, low-noise, and good coupling. Short of 3-component seismic instrumentation, long-period (1 hr to 10 sec.) gravity and pressure measurements can be very useful. Gravity and pressure measurements can be utilized to some extent in the study of the free oscillations of the earth. For the near future gravity and pressure instrumentation will have a greater sensitivity at the periods corresponding to the Earth's gravest modes (about 1 hour) than vertical component seismometers for oceanic borehole deployments. In time, however, oceanic borehole seismometers will likely follow the present on-land capabilities and challenge gravimeter and pressure gauge sensitivity. Coupled with the inherently lower noise of siting in the basement, the 3-component oceanic borehole seismometer will be a premier tool in advancing the seismic study of the planet.

High-resolution seismic studies of the Earth would be advanced by borehole observatories sited throughout the oceans and the results would affect many fields in the geosciences. The seismic structure of the Earth's interior relates to problems of geodynamics and mantle convection. Detailed tomography of mantle plumes has ties to mantle geochemistry and petrology. The structure of the core-mantle and the inner-outer core boundarys bear important relationships to geohydrodynamic models of the Earth's magnetic field. A detailed seismic structure of the oceanic lithosphere, both elastic and anelastic, will strongly influence models of the evolution of the lithosphere. Intrinsic attenuation of seismic energy is a thermally activated process and thus a knowledge of seismic attenuation within the Earth provides one of the best constraints on temperature variation in the Earth.

Seismology gives the Earth scientist the capability of mapping the anelastic and elastic properties of the planet. It is one of the few sciences in which an active experiment can be applied to investigate a feature deep within the Earth. The capability to move into the oceans greatly broadens this inherent capability present in seismology today.

Magneto-telluric measurements: The current (and past) distribution of geomagnetic observatories is limited by the large areas of the ocean without islands. This severely restricts the determination of many global parameters of the geomagnetic field. The secular change is poorly known over most of the Pacific and southern oceans and this lack of observational data can only be rectified with long term (multi-year) sea floor observatories. In addition to the internal field the morphology of the external field, storm time and solar daily variation would be greatly improved when observatories are expanded into the ocean areas.

Magneto-telluric measurements are also capable of determining oceanographic parameters directly related to the barotropic components of large scale ocean circulation. In conjunction with the WOCE experiment a large effort is going into the description of circulation all over the world. The advantage of ocean geo-electric measurements is that they estimate the water transport integrated over depth from surface to bottom, whereas the complete ocean surface topography measured by satellite altimetry provides only sea surface currents. The combination of pressure, electric and satellite observations would provide three independent data: sea floor currents, integrated currents and sea surface currents.

There are continuing programs to monitor change in electrical conductivity in seismically active regions to determine the applicability of the method for earthquake prediction. Sites in the offshore deformation zones of active subduction margins would provide a unique opportunity to study the region affected by major thrust earthquakes. There is a high probability of a large thrust earthquake in the Pacific Northwest (Oregon, Washington, southern British Columbia); thus this region deserves special attention.

Low frequency noise on the sea floor: The U.S. Navy currently has an interest in long term measurements in the ultralow (.001 Hz), infrasonic (1-20 Hz), and low sonic (greater than 20 Hz, but practically not more than 50 Hz) bands. These measurements would have to be continued long enough for temporal, spectral and spatial variabilities to be statistically defined. Several sources of noise are important in the ultralow frequency band. At frequencies less than 20 mHz low amplitude surface gravity waves with heights of millimeters cause pressure perturbations which reach to the sea floor. This pressure loading can potentially be used to determine upper mantle structure if the displacement response of the lithosphere can be measured in addition to the pressure field. At frequencies between 20 mHz and 100 mHz, noise levels drop to quite low levels and noise sources are confined to atmospheric waves and flow-induced pressure variations in the seafloor boundary layer. At these frequencies the seafloor pressure variations likely cause tilts in the bottom which will control seafloor and shallow sub-seafloor horizontal component noise. Above 100 mHz the classical Longuet-Higgins nonlinear wave-wave interactions are responsible for generating the globally-sensed microseismic noise. The amplitude of the microseisms decreases rapidly above frequencies of 0.5 Hz and is supplanted by other noise sources above 4 Hz. The infra-sonic frequency band contains strong tonals caused by ship's shaft and propeller rotations that are signals of interest to passive sonars. The low sonic band is apparently due to distant shipping, biologic noise, and surface winds - all highly variable over short time periods. The most desirable sensor geometry would probably consist of vertical arrays of hydrophones and geophones (that span the water-sediment interface) combined with some spatial distribution that would permit evaluation of horizontal and vertical coherence.

Obvously such an experiment would be part of another experiment, perhaps designed to monitor earthquakes or nuclear tests. Compromises on locations and instrumentation would be necessary. Current priority areas are the western and eastern Arctic Ocean, Norwegian Sea, North East Pacific, and Greenland-Iceland-UK gap. Interest in noise measurement is probably not sufficent to justify a dedicated installation but would be part of other measurement programs.

IV. POSSIBLE RE-ENTRY SYSTEMS:

A. Introduction

Although the primary purpose of the workshop was the discussion of research that would be facilitated or made feasible if the wireline re-entry capability existed, some time was devoted to exposing ideas about necessary hardware in order to verify that the entire approach would, in the long run, be feasible.

Deep sea wireline re-entry systems must include at least four elements: 1. the suite of measurement instruments, 2. means for recording or transmitting the resulting data, 3. means for providing power, and 4. a device for guiding the instruments into the hole. In addition, for some types of measurements or experiments, it is necessary to provide isolation of the instrument string from the motion of the ship above.

The actual devices that would be used in boreholes are expected to evolve from downhole experiments that have been run during the DSDP and ODP programs and conventional well-logging technology, and have been discussed already under the various research topics. In many instances the wire supporting the instrument string will have a signal-carrying core (copper or fibre-optic). Remote recording devices may be more appropriate for long term observations in which the ship will move away from the vicinity of the hole. Many of these problems have been solved satisfactorily in other contexts and can draw directly on existing proven technology.

The function of guiding the logging string into a deep ocean hole, without use of the drilling ship, is new. At this time we can visualize three approaches. In the first, a manned submersible is used to place a package or guide the bottom end of the wire into the hole. In the second, a remotely operated vehicle (ROV) similar to those now used in shallow water applications would replace the submersible. The third option involves suspending the instruments below a powered device that is, itself at the end of a logging cable. Examples of all three approaches were described during the workshop and will be summarized below, followed by a brief discussion of support ship requirements and methods for isolating the instrument package from the ship motion.

B. Submersible-assisted re-entry.

The first actual tests of a re-entry system have been carried out by IFREMER using the submersible NAUTILE. Their approach is the use of a special frame (NADIA - Navette de Diagraphie) to be fitted with a logging winch and 1,000 m of cable to be docked in the re-entry cone by the submersible. During the logging operation the submersible remains nearby, coupled electrically to NADIA, in order to control the operations, using real time information (tension, wire out, etc.) to monitor progress, detect stops caused by bridging, and record the logged data.

NADIA is a non-propelled, free falling device. Descent to the sea floor and the return to the surface are achieved by gravity and buoyance. The horizontal movement between the landing point and the cone location is achieved by the submersible propulsion system. NADIA is composed of four sub-systems (See Fig. 1):

1 - A main frame, built of welded aluminum alloy tubes, equipped with a winch and its hydraulic control system, the logging tool, sensors, the electro-hydraulic connector, a 10 m umbilical link to the sub, and various auxiliary equipment (mechanical releases, dead weight, cable cutter, etc...)

2 - A main flotation assembly supporting the weight of the main frame. It is fitted with an acoustic navigation beacon for tracking NADIA during the vertical trips and rendezvous with the sub.

3 - A secondary flotation assembly which is released to ballast the main frame and dock it in the re-entry cone.

4 - A descent dead weight.

A logging operation with NADIA proceeds in the following steps:

1 - Launching of the frame and two flotation assemblies. The system buoyancy is 50 to 100 N (11 to 22 lbs.). Launching of the descent weight when ship is in a position that gives the closest impact of the system to the cone (system negatively buoyant - 900 N)

2 - Landing at sea bottom. Length between descent weight and frame is chosen to prevent NADIA overshooting and hitting the sea floor.

3 - NAUTILE dives - Rendezvous with NADIA (acoustic navigation + flash light). NAUTILE holds NADIA with one arm, adjust her ballasts to become neutrally buoyant with NADIA and releases the descent weight. NAUTILE moves NADIA towards the cone using its propulsion system.

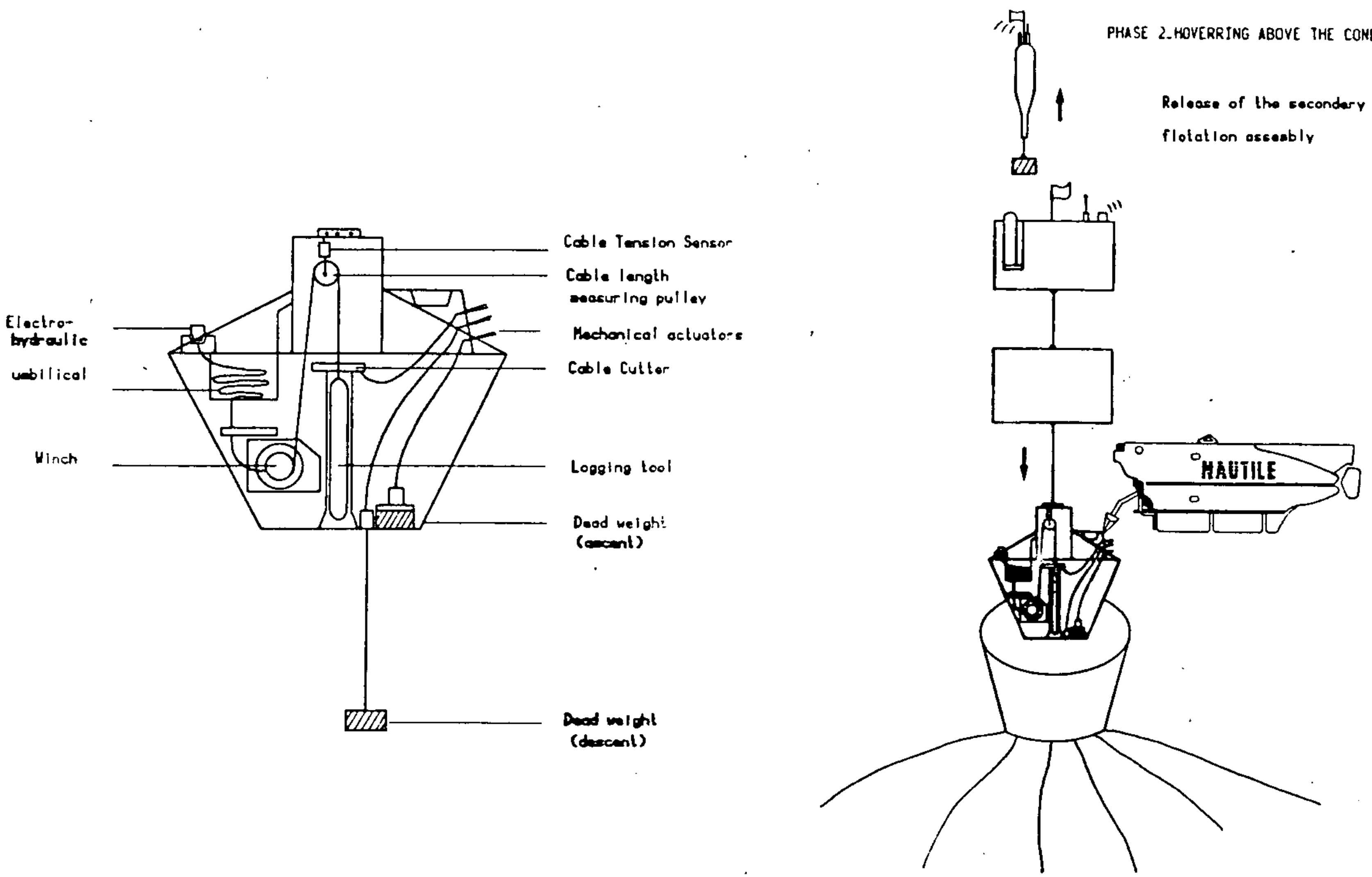

Figure 1. Left-The re-entry and logging module of the NADIA system. Right-The submersible NAUTILE maneuvering the module into a cone after releasing some flotation.

4 - Hovering of NADIA above the cone - secondary flotation assembly is released and NADIA is set in the cone with a 600 N negative buoyancy.

5 - NAUTILE connects with the electro-hydraulic link to NADIA, unspools it and sits on the sea floor within a 10 m radius.

6 - Lowering the logging tool - Winch control and data acquisition in the NAUTILE sphere. The lowering speed is constant. If the tool is blocked, the wire tension will show a decrease and the operator will stop the winch. When the decrease in tension reaches 600 N the frame becomes positively buoyant and it will rise until the cable is tightened again.

7 - Raising the logging tool - Operation is similar to phase 5. If the tool gets blocked in this phase, and if it cannot be worked free by operating the winch back and forth, two levels of security are available: a - A shear pin rated 6000 N provides a weak point at the cable head. A fishing neck at the tool upper end will permit the use of the fishing overshot in use on board the Joides Resolution. b - A cable cutter is fitted in NADIA frame. In case the shear pin does not work, the cable can be cut to release the downhole cable and instrument from the cone.

8 - At the end of the experiment, the logging tool is raised back in the frame. NAUTILE disconnects the electro-hydraulic link and replaces it in the basket.

9 - NAUTILE holds NADIA, lifts it up out of the cone and moves a few meters off. The ascent weight is released. NADIA is set free and pops up to the surface.

10 - The system is recovered on board the ship.

This system was tested using NAUTILE and R/V NADIR in May of 1986 in 2300 m of water in the Mediterranean using a simulated re-entry cone.Despite a significant current near the bottom, NAUTILE was able to perform the successive phases of the operation quite smoothly. The system was lowered down to the sea floor at a distance of 100 m from the cone. The displacement of the 3.5 ton

NADIA (plus the added mass of water) was accomplished by the NAUTILE without any difficulty. The docking of NADIA in the cone was instantaneous. The release of the secondary flotation assembly was ordered from the submersible and NADIA landed slowly in the cone. Then the NAUTILE connected the 10 m electro-hydraulic umbilical to NADIA. At the end of this first dive, the umbilical was disconnected and NADIA was lifted out of the cone and the ascent weight was released.

Operation of the winch was tested during a second dive. As a hole was not present under the cone, NADIA had to be moored 25 m above the sea floor to permit the cable to be payed out. The logging weight was lowered a few meters and then raised back in NADIA's frame.

The next step will be an actual trial re-entry in DSDP Hole 396B and logging of this hole using NADIA. After that if demand for re-entry operations is sufficient, IFREMER plans to replace the submersible, which in the long term is very expensive, by an ROV.

C. ROV Possibilities

This approach is being considered by the group at the Pacific Geoscience Centre (PGC) in Sydney British Columbia. A deep operating ROV is being built for PGC by International Submarine Equipment Co. (ISE) of Canada. The particular system under construction (Fig. 2) uses a cage (garage) at the end of a 5 km cable to house the nearly neutrally buoyant, unmanned maneuverable vehicle, Hysub 5000, that operates from the cage on a 300 m tether. The ROV has 6 thrusters, stereo color television, sonar, and a manipulator. The main cable will be 1 1/4 inches in diameter, transmit power at 1800 V using 3 conductors and will include 9 optical fibers for the broad band telemetry needed for televeision operation. The system is being built to serve a variety of needs, one of which could be borehole re-entry.

An ROV could be used in two ways to support re-entry operations. First would be as a substitute for the submersible in the approach taken by IFREMER. In this case the package (winch, logging tools, telemetry/recording) would be guided into the cone in nearly neutrally buoyant condition, deballasted and put into operation. The ROV might then stay on station, electrically linked to provide power, control and data transmission capability from the ship above, or it might depart, leaving the package to perform its function independently.

An alternate approach would be to use two wires down from the ship - one for logging and the other for the ROV. In this case the

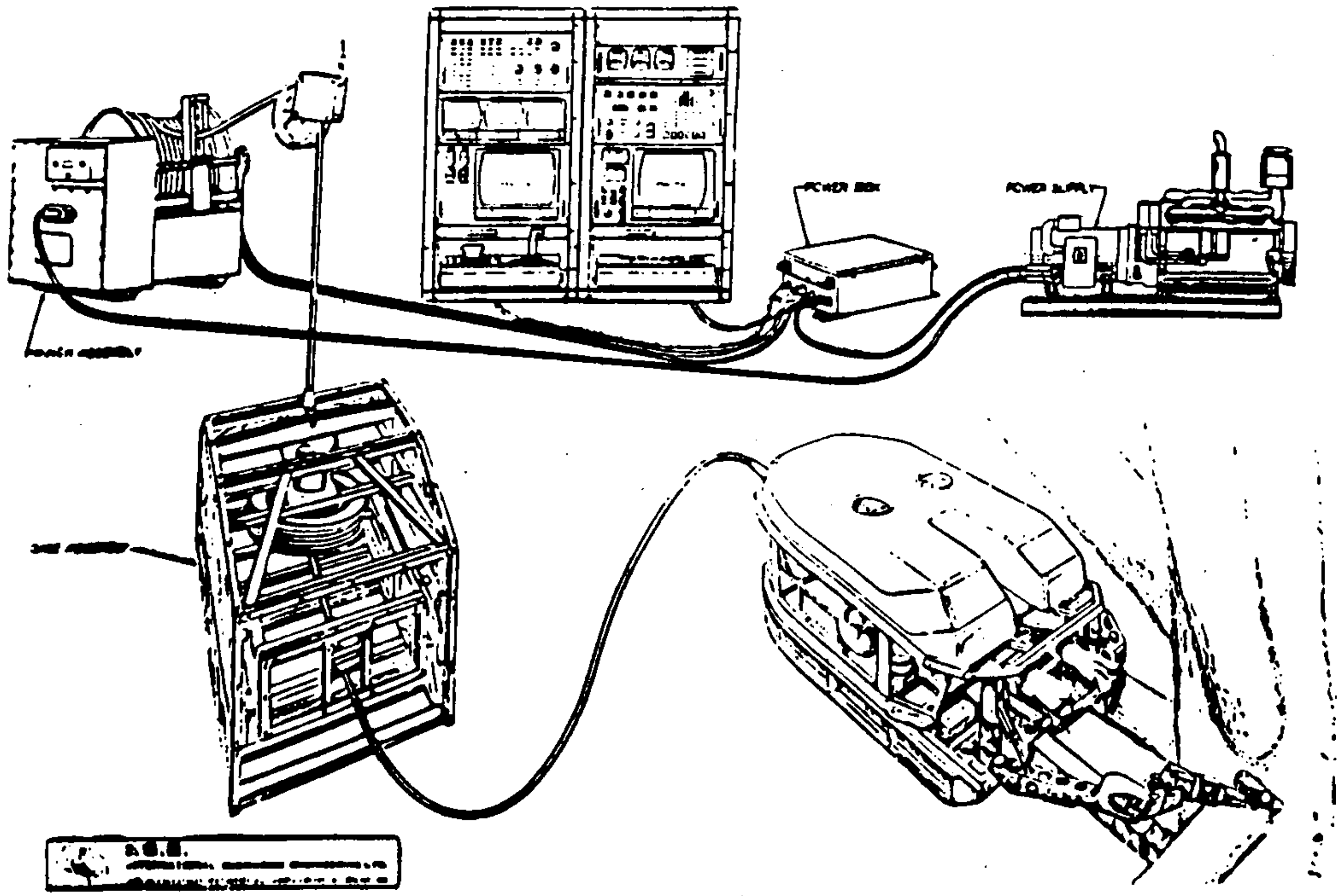

Figure 2. Components of the ISE remote operating vehicle that has been delivered to Pacific Geoscience Center in Sydney, British Columbia..

ROV would guide the bottom end of the logging wire into the hole and then return to the ship. The complexity of handling two wires during initial deployment would be balanced against the complexity of a sea floor winch and its remote operating problems. At this time the Canadian Group has not scheduled sea-tests related to either alternative.

D. Integrated Logging and Positioning System

In this approach the logging tools, geophones, and downhole logging wire would be topped by a package having its own thrusters to provide local positioning over the re-entry cone. The system would simply be suspended directly from the ship, with the full load taken by a single wire that would also provide power and telemetry for data and control functions. A thruster package that could support such a system has been built by the Marine Physical Laboratory of Scripps Institution of Oceanography with NSF support, and was described at this meeting in the re-entry context.

The basic vehicle consists of a maneuvering frame housing a variable pitch thruster driven directly by an electric motor and equipped with deflectors to orient the flow to provide torque on the vehicle. It is equipped with a scanning sonar, slow scan TV, echo sounder and telemetry capable of handling data and controls for a variety of other systems. The vehicle and its payload are suspended from a 0.68" electro-mechanical cable (coaxial core) of a type that has become standard for use on our larger oceanographic ships. It is navigated usually with a long baseline, near bottom acoustic transponder system. It has been used to take photographs in difficult terrain (e.g. at the base of the West Florida Escarpment) and to place ocean bottom seismographs within a meter of a desired location in 3800 m of water.

In a borehole re-entry operation the maneuvering frame could be used to place a free instrument package in the cone, but more appropriately the entire logging or instrument placement and recovery operation could be carried out with the maneuvering frame. A complete system in the latter configuration could be operated with wire and winch combinations available on most of the larger UNOLS ships and would consist of four parts (figure 3). At the bottom of the string would be a pilot probe containing a small TV camera, high frequency scanning sonar, an acoustic transponder interogation and receive system, and sensors (e.g. pressure, line tension) to facilitate proper wire payout and recovery operations. The pilot unit could carry the logging tools themselves or might be used alone to determine the condition of the hole. Immediately above this unit

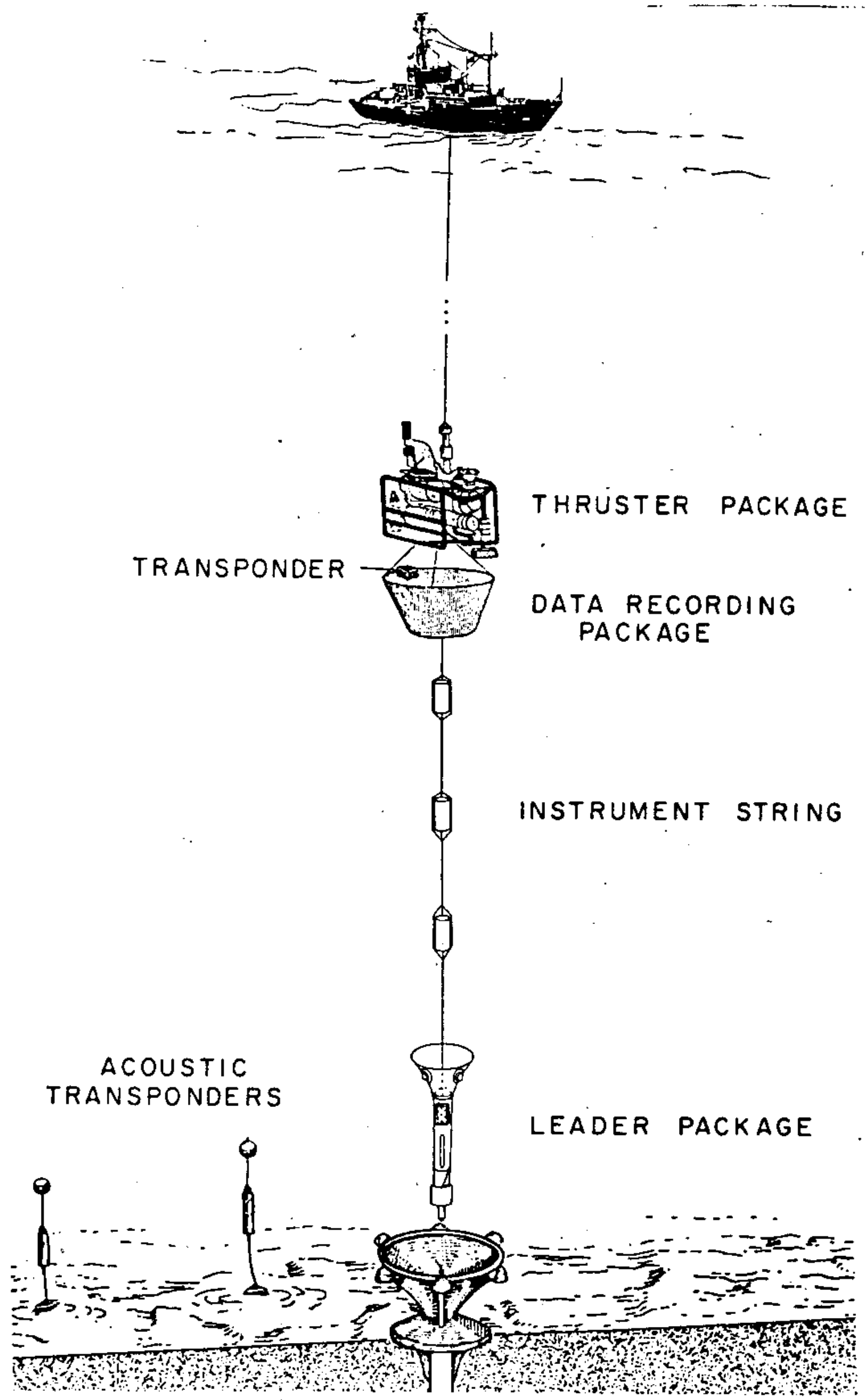

Figure 3. A conceptual re-entry system using a maneuvering frame based on the thruster package developed at the Scripps Institution of Oceanography.

would be a collar assembly having a hole through it that would allow passage of the wire and any other units in the instrument string and lights for illuminating the cone during entry of the pilot probe. The collar would rest in the cone upon entry to serve as a protective fairlead for the logging instruments and cable which are initially above the collar. Above the instrument string by an amount dictated by the useful depth of the hole (as determined by a reconnaissance lowering without the more complex downhole instruments) would be the maneuvering frame thruster package, itself at the lower termination of the 0.68" logging wire. In cases when geophones were being installed, a recording package could be included at the top of the instrument string just below the thruster. In that case, after equipment checkout, the thruster would be disconnected, the wire wound up, and the ship could move off to drop shots, or carry out other work, returning later to re-engage the recording package with the thruster and retrieve the entire assembly. Isolation from ship motion could be achieved by deploying the system through a center well in the ship and using an accumulator or an actively driven compensating suspension on sheave on board the ship.

Major advantages of this third approach are the ability to support payloads of several thousand pounds and the provision of a direct power and telemetry link between the tending ship and the downhole instruments. These functions, particularly the capabilities of maneuvering substantial payloads into position and retrieving them from the ocean floor, will be useful in other sea-floor research contexts as well.

E. SUPPORT SHIP

While the goal is to be able to operate from the UNOLS fleet, not all such craft are equivalent in this context. If a submersible is used to place the system, the support ship must then itself have a submersible handling capability (e.g., Atlantis II or Nadir). If a cable connected system is used, then the ship must have the winch capability to handle large electromechanical cable (e.g., 0.68") and the maneuverability to hold station within 100 m of a desired position for several hours to several days. For a few hours this can be achieved with attentive manual control (given an appropriate navigation system), however, an automated dynamic positioning system is more desirable in this context. Ships such as Melville or Knorr are obvious choices, with their good maneuverability and the capability of operating through a midship well to reduce ship motion problems.

F. Isolation from ships's motion

The problem of decoupling vessel motion from the downhole package applies primarily to the profiling-type measurements. Most stationary instruments have clamping arms that allow them to be positioned while slack is put into the cable (as in current shipboard procedures). Others that have only a single setting depth could be pre-spaced on a mast below a "stopper" that lands in the re-entry cone.

When decoupling is required there are several different approaches that can visualized at this time, and others will undoubtably emerge. Most obvious is the NADIA approach in which the entire logging assembly, instruments, cable and winch are placed in the re-entry cone and operated from a nearby submersible or ROV on bottom. It could even be completely independent, containing its own power suppply and data recoring, with control and monitoring signals transmmitted acoustically. Another variant would be to have the logging rig connected below the maneuvering frame described in section IV-D with a tether that could be slacked and yet maintain electrical connections for power and telemetry.

A somewhat different approach would be to build a frame containing a battery powered, acoustically controlled double-drum capstan that would initially be installed on the main wire just above the logging tools. The frame would rest in the cone and be used to raise and lower the main wire in the hole, using acoustic telemetry for control. The ship's winch would be operated to maintain a slight tension at the upper end of the capstan. The principal advantage of this system would be that the logging devices would be continuously connected to the ship electrically and/or with optical fibers. In addition the full lifting power of the main winch would be available simply by taking the slack out of the wire. The principal disadvantage would be that the main wire would have to well torque balanced to eliminate problems of kinking the wire when it is slacked above the capstan.

An obvious requirement is to first minimize the motion imparted by the heave and roll of the ship by operating through a center well and using the most stable vehicle available. One can then achieve good isolation by using some type of accumulator or motion compensating device on board the ship to reduce substantially the residual disturbance. Since the motion to be removed could be typically less than 5 m, it should be possible to use a single moving sheave or a rocking boom. Since one is directly coupled to the logging instruments and could have the maneuvering unit a few hundred meters above the logging devices, one could derive control signals from a variety of sources -pressure, near-bottom line tension, etc.- to operate the combination of main winch and motion compensation to produce a steady smooth downward speed for the instruments.

G. Summary

From the above it is evident that it is possible to make a reliable and safe re-entry of boreholes from a conventional research ship provided one of the larger ships is used. Techniques for placing a re-entry package in a cone are available such as manned submersibles, ROV's or maneuvering units on the end of cables. Guidelines that might serve in developing re-entry capability are:

1) The system should be designed for deployment from a ship of the Knorr/Melville class. The system should be transportable, and the operating costs should be held low by keeping the number of technicians required to go to sea with the system to a minimum.

2) The design of a re-entry system should build on exis-ting capabilities that could be used with minor modifications. The techniques and equipment required to position a re-entry package over a borehole will have wide applications for other investigations of the sea floor, for example, maneuvering of imaging devices near the sea floor, precision sampling of the sea floor, the emplacement of instrumentation or experiments, and the recovery and maintenance of sea-floor instruments. Thus, any new wireline re-entry system that is developed should incorporate, to the extent possible, components that have a broader use.

Most of the new development for scientific use of deep-sea boreholes using re-entry technology will be in the design and fabrication of specific experiments and instruments and the techniques to lower and hoist or fix them into position in the hole.

V. A PROJECT TO DEVELOP WLR CAPABILITY

At the Workshop there was a consensus that the new science that could be accomplished with a capability to re-enter deep-sea boreholes justified a decision to move forward soon with a project to develop and operate such a system. The experiments and observations that a WLR system makes possible would greatly enhance the scientific yield of the Deep Sea Drilling Project and the Ocean Drilling Program.

A borehole re-entry project using a non-drilling ship must be coordinated with the Ocean Drilling Program and the JOIDES decision-making apparatus. Coordinated experiments are anticipated for the future in which deep-sea boreholes will be specifically prepared for non-drill ship re-entry. On occasion the drill ship and a ship with re-entry capability will work together at a suite of holes to carry out hole-to-hole experiments. Consequently, the logical focus for a WLR project is the Office of Ocean Drilling at NSF. A WLR project would make an important new component of the U.S. Science Support Program associated with the ODP (USSSP).

The USSSP supports the efforts of US scientists who participate in the Ocean Drilling Program such as travel to and from the drilling ship and to attend JOIDES panel meetings, salary for the scientific staff on the RESOLUTION and for a short period of post-cruise data analysis and reporting. These funds are managed by JOI Inc. under a contract from NSF. Unsolicited proposals for studies that fit under the USSSP umbrella are funded by NSF through the Office of Ocean Drilling. The peer-review and evaluation of these proposals is coordinated by NSF. The USSSP also includes projects that meet specific needs of the drilling program, but are not suitable subjects for unsolicited proposals. These projects are initiated through Requests For Proposals (RFP's), and are managed by JOI Inc. The U.S. Science Advisory Committee (USSAC) provides advice and assistance to JOI Inc. with regard to the USSSP.

Because of the specific objectives of the WLR project, it should be initiated by an RFP issued by JOI Inc. JOI Inc. with advice from USSAC would provide oversight and review of the project in all of its phases.

Specific experiments designed to run in boreholes or instruments to be emplaced using the wireline re-entry system would usually be funded separately on the basis of unsolicited proposals from individual investigators and funded directly through the appropriate channel at NSF or other funding agency. Principal Investigators who are awarded grants or contracts to do borehole science using the wireline re-entry system must work closely with the project director of the WLR facility. It is possible that re-entry experiments may be proposed and done by scientists from other governmental agencies and other countries.

Project management:

Specific management arrangements for the development and operation of a wireline re-entry system were briefly discussed at the Workshop. In the summer of 1986 a USSAC subcommittee met to prepare technical requirements for an RFP to develop a WLR system. This subcommittee put forward some recommendations as to how the project would be managed and these recommendations were used as a straw man for further discussion at the Workshop. These recommendations were modified and amended based on discussions at the Workshop and are summarized below.

A) The group to direct the project (the project director) would be selected on the basis of competing proposals in res-ponse to an RFP issued by JOI Inc. The proposals would receive peer review and evaluation. The criteria that would be applied include:

+ Scientific and technical merit: responsiveness to the scientific requirements, understanding of both the background factors and the research objectives and applications, proposed technical approach, identification of key issues and/or problems, special capabilities or innovations being proposed which may resolve known or potential problems and may enhance the scientific usefulness of the system.

+ Facilities and personnel: relevant experience, adequacy of equipment and facilities, organizational and management structure, capability of the scientific, technical and operational personnel as evidenced by qualifications, experience, past performance and proposed level of effort.

+ Feasibility and cost: availability and commitment of proposer's facilities and personnel, proposed schedule, application of new techniques or technology, potential for productive use of available funds.

B) The project director will be responsible for development of the system, carrying out acceptance tests and operating the wireline re-entry facility for the scientific community. Considerable flexibility should be allowed in the approach to managing the development effort. The design and fabrication could be done "in house" or subcontracted to one or more commerical companies, or it could be done in cooperation with another institution.

C) The project director would have the responsibility to operate the WLR system for the U.S. geoscience community, and to work with a review and planning committee that represents the interests of the user community. This committee might function in a manner similar to the "ALVIN Review Committee." The USSAC with some augmentation from the community may be able to fill this need.

The Project Director's management tasks during the operational phase of the project include:

+ Provide shipboard technical and engineering support during use of the system. This includes providing adequate spare parts and accessories to operate the system effectively.

+ Providing logistical support for the transportation and installation of the WLR system.

+ Maintain a certain number of "general purpose" tools as part of the system such as:

1. a pilot probe to gauge the depth and diameter of the hole.
2. hole capping and cap-removing facilities
3. navigation
4. downhole data monitors/recorders
5. temperature logger
6. side-hole corer
7. pore water sampler

+ Providing a shore-based center for information, communication, maintenance and logistics. The shore-based center may serve as a focus for information to the scientific community and interactions with principal investigators using the system.

APPENDIX

SCIENCE REQUIREMENTS FOR EXPERIMENTS OR INSTRUMENTATION TO BE EMPLACED BY A WIRELINE RE-ENTRY SYSTEM

This appendix gives a brief description of instruments and experiments that could be run in deep sea boreholes using wireline re-entry. These are given as a guide to the types of requirements that will be placed on the design of a re-entry system.

1. MAGNETO-TELLURICS

Name and brief description of experiment or instrument:

Sea-floor magnetometer and telluric experiments:

Estimated package parameters :

Shape : Cylindrical

Size: Magnetometer, telluric recorder 6" I.D. , 8" O.D. 3' long
Mag. sensors, 3" I.D., 4" O.D. and 8" long.
Tellurics-long lines approx. 1km orthogonal array.

Weight: < 100 lbs.

Special emplacement conditions :
Nonmagnetic environment for sensors. No changing magnetic or electric fields produced by other instruments nearby. Stable site is required. Tilt must be accurately measured. A borehole provides this environment.

Observation period and related parameters:

Power requirement:
A few milliwatts, internal lithium batteries.

Data recovery modes, data rates:
Observation period >11 years.
Sample every 10 minutes stored in solid state memory.

Monitoring requirements during:
Installation:
Determination of tilt, assure stable emplacement.
Normal Operation: Unattended, no nearby changing fields.

Instrument recovery (yes/no, when, etc.):
Data read out and battery pack change every one or two years.
Instrument replaced only if defective.

Auxilliary support (Surface ship, visits, satellite uplink, etc.):
Servicing by surface ship with ROV or other suitable system.

2. NESTED PACKER ARRAY

Name and brief description of experiment or instrument:

Simple nested-packer arrangement capable of sealing borehole at one or preferably more depths to allow for equilibration of borehole fluids with formation waters. Profiling would be done prior to emplacement of system and following removal.

Estimated package parameters :

Shape (cylinder, array, etc): Could be mounted on a mast if positions of packers are predetermined (See figure 1 section III).

Size: > 100 m in length.

Weight: N.A.

Special emplacement conditions :

Would need to have packer elements that could be easily removed and not cause hole damage or effect other geophysical experiments.

Observation period and related parameters:

Power requirement: (N.A.)

Data recovery modes, data rates: Two possiblities 1) an insitu recording device in each isolated interval. 2) sampling tube(s) joining isolated intervals to surface platform/instrument that could be periodically sampled.

Monitoring requirements during:

Installation: Need to determine effectiveness of seals. Profile borehole prior to installation.

Normal Operation:

Depending on the sampling mode, may have to periodically retrieve water sample for analysis or retrieve data from in situ recorder.

Instrument recovery (yes/no, when, etc.):

Need to remove or destroy packer elements to allow removal of the array from the borehole.

Auxilliary support (Surface ship, visits, satellite uplink, etc.):

May need ROV's to retrieve samples; possible satellite uplink of data recovered by in situ recorders.

3. RESETTABLE STRADDLE PACKER

Name and brief description of experiment or instrument:
Wire line resettable straddle packer for pore fluid sampling, pore pressure determinations and permeability, incorporating chemical sensors to determine the characteristics of the fluid in the sample chamber.

Estimated package parameters :

Shape: cylinder

Size: 20 to 30 feet long ?

Weight: few hundred pounds

Special emplacement conditions : Locked in place with inflatable rubber elements.

Observation period and related parameters:

Power requirement: About 1 to 5 kilowatts.

Data recovery modes, data rates: Low rate, no more than a few samples/second transmitted up wireline.

Monitoring requirements during:

Installation: Continuous monitoring essential to operation.

Normal Operation:

Instrument recovery (yes/no, when, etc.): Recovered at end of tests.

Auxilliary support (Surface ship, visits, satellite uplink, etc.):
Wireline connection to surface ship, micro-computer controlled.

4. LONG TERM MONITORING AND SAMPLING OF PORE FLUIDS.

Name and brief description of experiment or instrument:

Long term monitoring and sampling of basement pore fluid chemistry. Objective: Chemical variations versus crustal age and regional sediment thickness. Necessary co-ordinated data are temperature and formation fluid pressures.

Estimated package parameters :

Shape: Cylinder:

Size: (3.5" O.D. X 10' long).

Special emplacement conditions:
Multiple balloon-type packers in basement hole after initial sampling/profiling.

Observation period and related parameters:

Monitoring requirements during:

Installation: Initial water sampling and chemical profiling need to determine integrity of the packer seals.

Normal Operation: In situ chemical monitor would need to be connected with data recorder, data transmission.

Instrument recovery (yes/no, when, etc.): After tests

Auxilliary support (Surface ship, visits, satellite uplink, etc.):
Surface ship in combination with ROV needed for initial placement and final recovery, satellite uplink would be desireable.

5. BOREHOLE GRAVITY

Name and brief description of experiment or instrument:
Borehole gravity measurements

Estimated package parameters :
Shape : Cylinder

Size: 8" X 9'

Weight: 150 lbs

Special emplacement conditions : Must be clamped in borehole every 10m, vertical alignment within 5°, position within 10 cm.

Observation period and related parameters:
Power requirement: 50 W at 110 V for clamping, 400 W for thermostat.

Data recovery modes, data rates: 16 bits/sec.

Monitoring requirements during: Continuous

Instrument recovery (yes/no, when, etc.):
Yes

Auxilliary support (Surface ship, visits, satellite uplink, etc.):
Surface ship on station and seafloor winch

6. SIDE-WALL SAMPLING

Name and brief description of experiment or instrument:
Side-wall sampling from unsampled intervals in sediments and hard rock.

Estimated package parameters :
Shape : "Standard logging tool".

Special emplacement conditions :
Uncased hole. Depth in hole must be known within 10 cm.

Observation period and related parameters:
Power requirement: Small; enough to detonate small charge.

Data recovery modes, data rates: None

Monitoring requirements during:
Installation: Depth control and continuous monitoring.

Normal Operation: Verification of detonation.

Instrument recovery : Yes

Auxilliary support : None

7. PHYSICAL PROPERTIES MEASUREMENTS

Name and brief description of experiment or instrument:
Physical properties measurement system, using instrumented side-wall penetration. Instrumented for: Penetration force, extension of probe, linear heat pulse along probe, temperature and differential pressure vs. time at center of sidewall probe. Measures: Shear strength, thermal conductivity and permeability.

Estimated package parameters :

Shape (cylinder, array, etc):
5' to 10' long, 6-8 " cyl., with small telescoping side-wall probe 6-12" long, 1/8 to 1/4" in diameter.

Weight: About 200 lbs

Special emplacement conditions :
Sequentially clamped against horehole wall.

Observation period and related parameters:

Power requirement: 5-10 W (Highest power for hydraulic motor to drive and recover sidewall probe, and heater pulse.

Data recovery modes, data rates: 1 to 10 BYTES/s, via wireline and/or stored in solid state memory in package.

Monitoring requirements during:

Installation: Accurate determination of depth, confirmation of clamping operation.

Normal Operation: Extension and retraction of sidewall probe, heat pulse.

Instrument recovery : Yes on-site.

8. MAGNETIC LOGGING

Name and brief description of experiment or instrument:

Downhole magnetic logging: Total field, 3-component field, weak field susceptibility. Basically same instrument that is currently being provided for logging on the drill ship.
Electric self potential.

Estimated package parameters :

Shape : Cylinder 3.5" X 6' long

Weight: < 100 lbs.

Special emplacement conditions : Non-magnetic housing required, shielded conductors through housing.

Observation period and related parameters:

Power requirement: 24 V, 200ma.

Data recovery modes, data rates: Preferred a measurement per cm. but a measurement per 10 cm is acceptable.

Monitoring requirements during:

Normal Operation: Can be run with other logging tools, no special monitoring required, If necessary, data can be stored in tool until recovery.

Instrument recovery : Yes, on-site.

Auxilliary support : Surface ship recording and monitoring of data is preferred.

9. OFFSET VSP

Name and brief description of experiment or instrument:

Offset vertical seismic profiling- A three component seismometer or hydrophone is clamped in the hole to receive shots out to 10 km or more, 3-component tool should be oriented.

Estimated package parameters :

Shape : Array of up to 10 cylinders.

Size: Each cylinder is 4" X 15'.

Weight: Each cylinder, 200 lbs.

Special emplacement conditions :

Instrument clamped in hole. Either shipboard or sea floor recording is possible.

Observation period and related parameters:

Power requirement: Largest power required clamping about 50 W.

Data recovery modes, data rates:

Event detection, windowing, analog recording, buoy or radio telemetry.

Rates: 1000 samples/sec X 4 channels/unit X 10 units X 16 bits/sample X 20 secs X 3000 shots.

Monitoring requirements during:

Installation: Continuous monitoring to check out instrument operation.

Instrument recovery : Yes, after experiment.

Auxilliary support : Seismic shooting vessel.

10. ZERO-OFFSET VSP

Name and brief description of experiment or instrument:
Vertical seismic profile with zero horizontal offset. Typical experiment duration: 150 depth points, 3000 shots. Total time 36 to 48 hours.

Estimated package parameters.

Shape: Cylinder, a three component geophone array plus hydrophone with azimuthal orientation to +/- 1 deg. Temperature tolerance- 200^{O}C, pressure 20,000 psi.

Size: 3.625" X 6' to 3.625" X 20'.

Weight: 50 - 300 lbs.

Special emplacement conditions :
Side wall clamping with 400 - 600 lbs force at 10 m depth intervals. Must be rigidly clamped and the depth known to 1 meter or less.

Observation period and related parameters:
Power requirement: 50 - 100 W for clamping.

Data recovery modes, data rates:
Shot records: 1 ms sample rate X 5 sec. record length X 16 bit/sample. Shot repetition rate about 12 to 15 sec. Timing must be accurate to 1 ms or better.

Monitoring requirements during:
Installation:
Continuous waveform monitoring at each depth to assess noise levels.

Normal Operation:
Real time monitoring of each shot record to allow summing of several shot records at each clamping depth.

Instrument recovery :
Yes, immediately after experiment:

Auxilliary support : Surface ship must have compressor capability to fire 1000 cu. in. airgun or 400 cu. in. watergun at 12-15 sec repetition rate. Ship must maintain position over borehole within 2^{O} of vertical.

11. CROSS HOLE SEISMIC EXPERIMENT.

Name and brief description of experiment or instrument:
Cross-hole seismic experiment between two holes 2 km or more apart. A sound source would be triggered at various depths in one bore hole and the seismic waves would be recorded in a second or possibly third hole at several (up to 10) levels. Look for seismic anisotropy due to cracks, P and S-wave polarization anomalies.

Estimated package parameters :

Shape: Cylinders. Vertical array of standard downhole 3-component seismometers in receiving hole. A cylindrical acoustic source in the other borehole such as an air or watergun, vibrator or impacting tool.

Special emplacement conditions :

Seismometers must be clamped, oriented and set in basement rock of the receiving hole. Depth of source and receiver must be known to one meter.

Observation period and related parameters:

Power requirement: Same as VSP.

Data recovery modes, data rates:

Radio telemetry from buoy or buoys over receiving holes to ship sitting over the shooting hole.
Rates are comparable to VSP or OSP.

Monitoring requirements during:

Installation: Assure good clamping and acceptable noise level before experiment.

Normal Operation:

Signals from receiving hole. Shot instants from shooting hole.

Instrument recovery :

Yes on site, after experiment.

Auxilliary support : Shooting ship. Could use second ship or a transmitting buoy for receiving.

12. BOREHOLE TELEVIEWER

Name and brief description of experiment or instrument:
Ultrasonic borehole televiewer: Borehole wall imaging device in which a high frequency transducer rotates about the vertical axis 3 times per second as the tool is pulled slowly (5 ft/min.) up the hole. Display of reflected intensity on 3 axis oscilloscope reveals fractures, large scale porosity, contacts, hole shape and other irregularities.

Estimated package parameters :

Shape: Cylinder.

Size: 3.5 " X 10'

Weight: 100 lbs.

Special emplacement conditions :
Wireline logging.

Observation period and related parameters:

Power requirement: ca. 300ma

Data recovery modes, data rates:
Data recorded on surface ship using photographic film and magnetic tape.

Monitoring requirements during:
Normal Operation:
Surface control panel, magnetic tape recorder 3-axis osc. with camera.

Auxilliary support :
Surface ship needed on location during logging run.

13. PERMANENT TRI-AXIAL SEISMIC STATION

Name and brief description of experiment or instrument:
Broadband triaxial permanent seismic staion. Recording earth motion from periods of DC to 0.03 sec (30 Hz). Sensitivity reaching to Earth noise levels. Package with gravimeter, pressure sensor, temperature sensor and tilt meters.

Estimated package parameters :

Shape (cylinder, array, etc):

Cylinder one per hole.

Size: 2 meters, 20 cm in diameter.

Weight: 170 kg (ρ = 2.7 gm/cu. cm. approx. that of surrounding rock.)

Special emplacement conditions :

1. Vertical within 4^{o}.
2. Permanently clamped to basement rock.
3. Depth known to 5m.
4. Azimuth known to 1^{o}. Can be determined with explosives.

Observation period and related parameters:

Power requirement: Approx. one watt in hole, mostly line driver. Recording package may need more.

Data recovery modes, data rates: Realtime data return is preferred, continuous digital recording is adequate. Data rate from the borehole approximately 5000 bits/sec. 3 channels X 64 samples/sec and one channel multiplexed with other sensors. 155 gigabits/year.

Monitoring requirements during:

Installation: Data stream from borehole, wire tension at tool, depth of tool in hole +/- 5m, clamping status.

Normal Operation: Power to tool through cable, and data returned in digital format up cable to surface package. Transmission to satellite?

Instrument recovery :

Yes- on depletion of consumables to refurbish and replace surface unit every 6 mos. to a year?

Auxilliary support : Permanent wire to shore ideal, satellite uplink probably not feasible at these data rates unless event triggering is used. Bottom recorder most likely mode of data recording.

14. PRECISION LONG-TERM PRESSURE MEASUREMENTS

Name and brief description of experiment or instrument:
Stable pressure measurements for long term observations of geological uplift (magma chamber inflation, etc.) an of climate, oceanographic phenomena.

Estimated package parameters :

Shape (cylinder, array, etc): Cylindrical pressure case 8" in diameter X 60" long.

Weight: 150 lbs

Special emplacement conditions :

Must be recoverable and replaceable with precision location. Observatory need not be in borehole but could be on concrete foundation stably sited on the sea floor.

Observation period and related parameters:

Power requirement: about 10 mW

Data recovery modes, data rates: In situ data storage (tape, RAM or other storage medium). Data rate about 40 bytes/day.

Monitoring requirements during:

Installation: Check correct operation after installation.

Normal Operation: Record on the sea floor.

Instrument recovery : Recovery of device to replace batteries and collect data once per year.

15. SHORT PERIOD PRESSURE MEASUREMENTS

Name and brief description of experiment or instrument:
Pressure measurements on time scales of a few thousand seconds to 0.1 seconds. Valuable for seismic observations and tsunami warning.

Estimated package parameters :

Shape: Cylinder

Size: 8 " dia. X 60 " long plus similar package for battery supply.

Weight: 300 lbs.

Special emplacement conditions :
Not critical.

Observation period and related parameters:

Power requirement: 100 mW.

Data recovery modes, data rates: Seismic data: Internal recording by tape or other solid state methods. Tsunami warning requires real time transmission ashore.

Monitoring requirements during:
Installation: Check operation after installation.

Instrument recovery :
Yes - Recover data as seismic observations. Replace batteries if not supplied by submarine cable.

Auxilliary support : Data transmission by satellite possible or direct radio link from surface buoy to shore or via submarine cable.

16. CRUSTAL DEFORMATION OBSERVATORY

Name and brief description of experiment or instrument:
Crustal deformation observatory: Triaxial seismometer and three component horizontal strainmeter and vertical extension.

Estimated package parameters :

Shape: Cylinder:

Size: 20 cm dia, 5 m long.

Weight: 400 lbs,

Special emplacement conditions :
Cemented into basement.

Observation period and related parameters:

Power requirement:
100-200 milliwatts continuously for the instrument package.
Unknown amount for the recording and telemetry.

Data recovery modes, data rates:
3 bytes/sec for seismic signals stored as one sample /5 seconds.
3 bytes /hour to record tidal periods and longer.
Seismic signals could be event triggered.

Monitoring requirements during:

Installation:
Standard geophysical and caliper logs prior to installation. Vertical position of the instrument package +/- 50 cm during installation. Azimuthal orientation of the package after installation.

Normal Operation:
Repower and retrieve data (see auxilliary support).

Instrument recovery : No.

Auxilliary support : A recording system/control unit/power source would be required, probably on the sea floor. Power would be fed down a cable and analog signals returned up the cable for digital recording. This recording system would require service 2 to 4 times per year, to replenish the batteries and recording medium.

17.VERTICAL SEISMIC ARRAY

Name and brief description of experiment or instrument:
Vertical seismic array to complement small aperture seismic array. Scientific justification: 1. "Noise" analysis as a function of depth, 2. Mode separation and identification, 3. scattering from body to quided waves (vice versa), 4. tomography using both surface array for local structures, magma bodies, etc. Types of instruments in order of preference ; 1. 3-component broad-band seismometer. 2. Vertical short period seismometer. 3. Hydrophones.

Estimated package parameters :
Shape: An array:
Vertical separation of sensors 50-250 m

Special emplacement conditions :
Should be clamped in borehole with power and data modules at ocean bottom integrated to small sea-floor array.

Observation period and related parameters:
Power requirement: Same as surface array.

Data recovery modes, data rates: Digitization 100 Hz, 12 bits/sample-
Should be same as surface array.

Monitoring requirements during:
Installation: Timing, event detection, A/D conversion should be integrated with and coordinated with sea-floor array.

Normal Operation:
Continuous operation in event triggered mode. Capable of being used in continuous mode for tomographic experiments with artificial sources.

Instrument recovery :
Preferably yes, but if only vertical seismometer or hydrophone is used recovery may not be necessary.

Auxilliary support : Same as small aperture sea-floor array.

18. HIGH FREQUENCY SEA-FLOOR SEISMIC ARRAY

Name and brief description of experiment or instrument:
High frequency sea-floor seismic array on a ridge crest or in an ocean basin.

Estimated package parameters :

Shape : Eighteen 24" spheres or 8" diameter cylinders for borehole emplacement. Eighteen sensor packages would be placed in a <10 km aperture array preferably in boreholes.

Weight: 200 kg per package.

Special emplacement conditions :

Packages must be leveled and preferably be cemented into boreholes for coupling.

Observation period and related parameters:

Power requirement: 500 mW per package. 1 to 2 W for the central package.

Data recovery modes, data rates: Data should be recorded centrally. Data recovery would be by periodic satellite telemtry, telemetry to shore, or package recovery. Cable to shore is preferred.
Data rates: 18 stations X 4 sensors X 100 samples/sec X 2 bytes per sample X 3.156 x 10^7 s/year X 10% duty cycle = 43 gigabytes/year.

Monitoring requirements during:

Installation:

It must be possible to monitor the operation of the individual instruments during installation in order to insure proper function.

Normal Operation:

Data will be recorded and/or telemetered by central station.

Instrument recovery :

Recovery of the instrument array will not be necessary although maintenance of the array will involve changing of components.

Auxilliary support :

Telemetry line to land to provide real time data and system monitoring and possibly power is the most desireable mode of operation.

DRAFT AGENDA FOR WIRELINE RE-ENTRY WORKSHOP

February 23, La Jolla

0830 Welcome and introductory remarks - (Spiess/Langseth)

0900 Review of condition of existing re-entry holes (G. Foss).

0930 A. Long term observations: (J. Orcutt, discussion leader).

1100 B. Short-term experiments to probe the oceanic crust. (R. Stephen, discussion leader).

1330 C. Borehole profiles: (K. Becker, discussion leader).

1515 IFREMER system, (J. LeGrand).

1540 Canadian ROV, (E. Davis).

1605 Scripps and WHOI developments (F. Spiess).

1630 Open discussion (M. Langseth).

February 24, LaJolla

0830 Working groups meet separately to define requirements of a re-entry system to accomplish the scientific objectives that were discussed at the Workshop.

1100 Workshop re-convenes to review working group results.

1130 Constraints on surface ships and on board equipment.

1330 Priorities within the constraints of feasibility and science.

1400 Tethered ROV's as a high resolution tool for marine geoscience.

1600 Summary, future activities and plans for report preparation.