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DOWNHOLE MEASUREMENTS AND EXPERIMENTS

IN DEEP SEA DRILL HOLES

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A report and planning document

by the JOIDES Downhole Measurements Advisory Panel

Pacific Geoscience Centre

Earth Physics Branch

Energy, Mines and Resources

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DOWNHOLE MEASUREMENTS AND EXPERIMENTS IN DEEP SEA DRILL HOLES

A. INTRODUCTION

B. INTEGRATED STUDIES OF PHYSICAL PROPERTIES

C. DOWNHOLE LOGGING

1. Physical Limitations
   - Glomar Challenger
   - Glomar Explorer

2. Tool Limitations and Calibrations

3. Cross-Plots and Multiparameter Analyses

4. Standard Logs
   - Spontaneous Potential Logs (SP)
   - Electric Logs
   - Sonic Logs
   - Formation Density Logs
   - Neutron Porosity Log
   - Natural Gamma Ray Log
   - Thermal Decay Time Log
   - Temperature Logs
   - Caliper

5. Special Logging Tools
   - Borehole gravimeter
   - Nuclear Magnetic Resonance
   - Borehole Televiewer
   - Gamma Ray Spectral Log
   - Neutron Activation
   - Complete Waveform Sonic Log
   - Downhole Formation Pressure Testers, Fluid Samplers and Geochemical Monitc
   - Borehole Permeability Tests
   - Downhole Magnetometer
   - Downhole Suceptibility Meter
   - Induced Polarization and Special Electromagnetic Tools
   - Ultra-Long Space Electric Log (USEL)
   - Special Temperature Tools

6. Log Recommendations

7. Logging Developments Needed

D. DOWNHOLE EXPERIMENTS (drill ship still on site)

1. Oblique Seismic

2. Large Scale Resistivity

3. Borehole to Borehole Experiments

4. Hydrofracture Insitu Stress Measurement

5. Overcoring Insitu Stress Measurement

6. Inhole Permeability Measurement

7. Temperature and Heat Flow Measurements

8. Geotechnical Downhole Measurements

E. DOWNHOLE RECORDING (after drill ship has left site)

1. Downhole Data Recording and Transmission

2. Downhole Recording Seismographs

3. Recording Strainmeters, Dilatometers, Tiltmeters and Gravimeters

4. Recording Magnetometers and Telluric Current Meters

5. Hydrothermal Water Flow Monitoring Devices
 - flow meters, thermometers, geochemical sensors

F. DOWNHOLE EXPERIMENTS OR RECORDING CARRIED OUT OR PLANNED

G. RELATED LABORATORY MEASUREMENTS (Core Analysis)

A. INTRODUCTION

This report was prepared by members of the JOIDES Downhole Measurements Panel as a source of information for the JOIDES Planning Committee, other JOIDES panels and for other organizations interested in deep sea drilling. It includes brief summaries of the downhole logging tools and instruments that have been or could be used along with the experiments and recordings utilizing deep sea boreholes that have been attempted or suggested. An effort has also been made to provide information on the scientific significance of the measured or recorded parameters.

The report is intended to provide planning information directed toward the present Glomar Challenger type of operation as well as toward future very deep hole, riser type drilling such as with the Glomar Explorer. It is clear that downhole measurements will play a much larger role in future deep sea drilling than they have in the past. "Just more drilling" generally will not interest and excite the most capable scientists nor convince granting agencies to provide funds. Holes drilled by the Glomar Explorer or by other ships with a riser system will be few and extremely expensive. There will be a demand that every possible piece of data be extracted from them.

We emphasize in a number of sections that a complete picture of the properties and structure of the deep sea floor sediments and crustal rocks requires the integration of data from a variety of sources, including geophysical site surveys, downhole measurements and experiments and studies of core samples.

The technical data that we present for instruments and experiments comes from a wide variety of sources. In particular, the details of most of the downhole experiments have come largely from proposals or post experiment reports. It is not practical for us to give detailed credits, but we acknowledge the contributions of many individuals and groups. We trust that nothing is included here that the scientists responsible would not wish as wide a circulation as possible.

More detailed information on most of the downhole tools experiment or recording systems can be obtained from the chairman of the Downhole Measurements Panel, from the Deep Sea Drilling Project Office or from the JOIDES office.

R.D. Hyndman
Chairman, JOIDES
Downhole Measurements Panel

B. INTEGRATED STUDIES OF PHYSICAL PROPERTIES

For a complete description of the physical properties and structure of the deep sea floor sedimentary section and the upper oceanic crust, it is essential that the results of downhole logging and experiments be integrated with the data both from regional or site survey geophysical studies and from ship and shore based laboratory measurements on recovered core. Laboratory measurements provide essential calibrations of downhole logs, although in many sections they will give different results because of core recovery biases, because of different effective sample sizes, and because of different physical conditions. The differences between core sample and log, and between log and regional geophysical survey physical properties give important information on the nature and extent of cracks, fissures and other large scale porosity, particularly in igneous rocks. Laboratory measurements also permit the determination of the dependence of physical conditions (e.g. temperature, pressure, porosity etc.) on physical properties. It is important for comparisons with downhole or regional geophysical studies, that laboratory measurements attempt to simulate insitu conditions, particularly those of temperature and pressure. A summary of desirable laboratory physical properties measurements from the report of an ad hoc committee of the JOIDES Sedimentary Petrology and Physical Properties, and Downhole Measurements Panels is included at the end of this report. Many of the measurements can be done in shore laboratories, but some are better done on board ship and some must be done on board ship because of rapid sample deterioration or alteration after recovery.

Regional and site survey geophysical studies are an essential compliment to borehole data. They show how typical or atypical a drilling site is, and put the drilling results in a regional context. They also provide physical properties data at large measurement scales. They include surface ship bathymetry, seismic reflection and refraction, magnetics and gravity, plus bottom measurements and surveys from lowered instruments and from submersibles, e.g. heat flow, bottom sampling, bottom photography, deep tow instrument packages, sea floor magnetotellurics etc.

A summary of the characterists of the four different types of physical properties measurements is given below:

1. Laboratory measurements of core samples: the measurement scale is of the order of centimeters; the measured properties may not be representative of the drilled section, particularly if core recovery is poor; insitu conditions must be simulated; the effects of variations in temperature, pressure, fluid saturation and other conditions may be studied; the measurement accuracy is generally high; a wide variety of parameters can be measured.

2. Downhole logging: the measurement scale is of the order of meters; the physical properties are usually but not always measured under insitu conditions of temperature and pressure, but the formation measured may be seriously disturbed by drilling, e.g. mechanical disturbance such as fracturing, and invasion of pores and fractures by drilling fluid; the measurement accuracy is frequently only fair due to poor hole conditions, tool calibration and variable response; a wide range of parameters can be measured.

3. In-hole, hole to hole and hole to surface experiments: e.g. oblique seismic and large scale resistivity; the measurement scale is of the order of hundreds of meters; the measurements are of largely undisturbed formation under insitu conditions; the accuracy is generally good; a limited number of parameters can be measured.

4. Regional and site survey geophysical measurements: the measurement scale is of the order of kilometers; the measurement accuracy is quite variable; only a limited number of parameters can be measured.

C. DOWNHOLE LOGGING

There are a multitude of wireline logging devices available in the hydrocarbon, mining and geothermal energy exploration and exploitation industries that could be used in deep sea boreholes. These logging tools are designed to delineate the detailed structure of the formations penetrated, to determine the composition, state and physical properties of the rock and to detect the presence of interstitial fluid. In general, the majority of devices are shallow investigating, being limited by spacings of electrodes, sources and detectors to the region within a meter or so of the hole. The vertical or 'bed' resolution is commonly limited to several meters. Listed below are the main standard logs used by industry. Most are available on a contract service basis, many are available for purchase.

1. Physical Limitations

Glomar Challenger - A riser system is not available on the ship so that all logging tools must pass through the drill pipe. A release mechanism has been developed that permits dropping the bit in the bottom of the hole so that tools may be run into the open hole. The minimum pipe ID at present (1979) is 3 3/4 inches (9.5 cm) permitting a maximum tool diameter of about 3 5/8 inches (9.2 cm). The maximum tool length is about 30 feet (9.1 m), and maximum tool weight about 700 lbs. (320 Kg) in air. The present Schlumberger logging winch uses a 7 conductor cable of resistance 10 ohms per 1000 ft. (33 ohms per Km) per conductor, that is rated at 1000 volts and 5 amps maximum. The ship is not at present equipped with a motion arrestor so that tool motion generated by the ship heave can be a problem. There is no return circulation so that drilling mud can be used only on a 'spot' basis. Thus logging tools and interpretation techniques requiring a mud cake on the borehole wall or a non-conducting borehole fluid cannot be used. Hole stability, washouts and hole enlargement are frequently serious problems.

Glomar Explorer - The main advantage of this ship for downhole logging is that it is planned to be equipped with a riser system, so that: a) larger tools (probably up to 5 3/4 inches or 14.6 cm diameter) should be accommodated and, b) mud can be circulated which facilitates the use of and the interpretation of the data from some logs and which helps maintain hole stability.

2. Tool Limitations and Calibrations

The majority of standard logging tools are limited in operation to temperatures less than 150° to $250^{\circ}C$ although much higher temperature tools are being or have recently been developed for use in very deep petroleum wells and for the geothermal energy industry.

Most standard logging tools are approximately 3 5/8 inches (9.2 cm) in diameter and some 4 inches (10.2 cm) (the latter too large for Challenger pipe). Some special tools such as the borehole gravimeter are even larger. However, there is continuing development of 'slim hole' tools as small as 1 11/16 inches (4.3 cm). The smaller tools frequently have lower accuracy. The accuracy is particularly degraded if a small diameter tool must be used in a large diameter hole (as required in Challenger operation).

It should be emphasized that most logging tools have been designed and calibrated for use in the petroleum industry. Scientific drilling will frequently penetrate rock types and conditions not encountered in industry so that special ranges, calibrations and tool modifications may be required.

Most logs can only be run in open holes with the exception of the various radioactivity logs which can be run through casing or drill pipe. However, even for these logs there frequently is a serious reduction in log quality when they are run through pipe or casing.

3. Cross-Plots and Multiple Parameter Analyses

Frequently, important information can be obtained from combinations, (usually computer processed) of two or more logs, that cannot be obtained from the logs separately. (For example the widely used Schlumberger Ltd. SARABAND program). Simple cross-plots of appropriate pairs of logs is also the most widely used technique for checking for obviously poor quality log data.

4. Standard Logs

a) Spontaneous Potential Logs (SP)

The spontaneous potential log measures potentials in the borehole generally generated between the borehole fluid and the formation fluid (electrochemical potentials). Ocassionally electrokinetic or flow potentials are generated. The log is a rough function of formation porosity and permeability and is used primarily to delineate between sand and/or limestone (high porosity and permeability) and shales (low porosity and permeability). However, the relations are complex and only qualitative. The SP log gives useable results only in the open hole and where borehole fluid resistivities are significantly greater or less than formation fluid resistivities. The tool diameter range from 1-11/16 inch (4.3 cm) to 3-5/8 inch (9.2 cm) diameter. The SP log is normally run in conjunction with a resistivity or conductivity log.

b) Electric Log

Electric logs consist of conventional resistivity, focussed resistivity (referred to as laterolog-type devices) and induction-type logs. Tools with various electrode and induction coil configurations are used to estimate the resistivity of conductive formations and the conductivity of resistive formations respectively. The data can be used to estimate porosity if the resistivity of the pore fluid and the water saturation are known. Comparison with other porosity sensitive logs (see below) can give qualitative information on pore structure and permeability (i.e. 'reservoir potential'). By using tools with various electrode spacing that provide different depth of investigation, resistivity logs can be used to estimate the depth of invasion of drilling fluid into the formation and thus, qualitatively, the effective porosity and permeability. This latter technique requires that the drilling fluid and formation pore fluid have different resistivity. Thus, it has not been employed on Glomar Challenger holes where both drilling and formation fluids are normally seawater. Resistivity logs are also used extensively for hole to hole formation correlations. Induction and resistivity devices must be run in the open hole. Resistivity tools range in size from 1-11/16 inches (4.3 cm) to 4 inches (10.2 cm) and induction tools from 2-1/4 inches (5.7 cm) to 4 inches (10.2 cm) in diameter.

c) Sonic Logs

Sonic or acoustic logs measure the speed of sound in the formation over vertical distances of several meters. The penetration or depth of investigation into the formation is only a few 10's of cm so the quality of the data depends critically on hole conditions. This log is particularly important for correlation with seismic reflection profiles. It also can give estimates of porosity if the velocity of the rock matrix and the fluid composition are known. Shear velocity data can be obtained from normal wave train or variable density-type displays (e.g. variable density log) (see below) permitting the elastic properties of the rock to be estimated (Poisson's ratio, Young's modulus, bulk modulus, shear modulus). Sonic attenuation sometimes can also be estimated. Acoustic logs must be run in open holes. Tool sizes range between 2-1/4 inches (5.7 cm) and 4 inches (10.2 cm).

d) Formation Density Logs

The formation density log is employed primarily to measure the insitu density of the formation penetrated. The primary phenomenon utilized is the Compton scattering of electrons by gamma rays from a radioactive source. The secondary gamma ray count is proportional to the electron density, from which the bulk density can be determined if the composition of the rock matrix and pore fluid are known. The shipboard laboratory GRAPE density system employs the same principle. The density log gives best results in open holes, but qualitative data can be obtained through casing or drill pipe. The tool sizes range from 2-1/4 inches (5.7 cm) to 3-5/8 inches (9.2 cm) diameter with the largest tools being the most accurate.

e) Neutron Porosity Log

This logging tool consists of a neutron source and a neutron or gamma ray detector. The rate of slowing and/or capturing of neutrons from the source depends primarily on the hydrogen content of the formation (thus the name hydrogen index device). The tool gives a good estimate of porosity if there are no hydrocarbons present, there is no bound water and there is complete water saturation. Tools range in size from 1-11/16 inches (4.3 cm) to 3-5/8 inches (9.2 cm) and may be run in open holes or through casing or drill pipe. The quality of the data is very dependent on hole conditions e.g. washouts or hole enlargement.

f) Natural Gamma Ray Log

Natural gamma ray logs are used primarily for correlation with SP or resistivity logs to delineate stratigraphic units. They frequently can be used to distinguish between sand, limestone and shale. The log measures the natural gamma radiation of the formation primarily from uranium, thorium and potassium. The standard tool does not differentiate among the elements (see special tools below). The log is very sensitive to large fractures and to chemical alteration in igneous rocks. Natural gamma logs can be run in open holes or through casing or drill pipe. Tool sizes range from 1-11/16 inches (4.3 cm) to 4 inches (10.2 cm) in diameter.

g) Thermal Decay Time Log

The Thermal decay time log measures the rate of decay in the formation of thermal neutrons generated by a radioactive source. It responds primarily to chlorine which is the common element with the highest capture cross-section. Thus it gives the porosity if there is complete saturation and the salinity of the interstitial fluid is known (and no hydrocarbons are present). The log can be run in open holes or through casing or drill pipe. Tool sizes range from 3-5/8 inches (9.2 cm) to 4 inches (10.2 cm).

h) Temperature Logs

High resolution temperature logs are used to obtain both temperature and temperature gradients (differential temperature) profiles in the borehole and to obtain bottom hole temperatures. Valid formation temperatures can be obtained only if adequate time is allowed for the drilling thermal disturbance to decay. This usually requires at least several times the drilling duration. Bottom hole temperatures are generally most reliable since there, the duration of drilling disturbance is shortest and the return to equilibrium most rapid. Borehole temperatures are very sensitive to fluid flow in the hole. Special high temperature tools are available. This log can be run in open holes or in those with casing or drill pipe. Tool diameters range from 1-11/16 inches (4.3 cm) to 4 inches (10.2 cm).

i) Caliper

Various caliper devices with two, three or four arms measure hole diameter. They are primarily run with other tools such as the sonic, neutron and density, to provide borehole diameter corrections. The four arm tool (dipmeter) can give information on the location and orientation of fracture zones and thus qualitatively the direction of principal stress. It can also give useful data on the ellipticity of holes. If mud is circulated, calipers can indicate porous and permeable zones by measuring the mudcake buildup associated with the invasion of drilling fluid into the formation.

5. Special logging tools

A great variety of downhole logging tools or equipment, although not widely used in industry, are either available commercially or are being developed. Some of these devices are not widely used because the data they obtain are not commonly of interest in the petroleum industry, although they might be of considerable value in deep sea scientific boreholes; others at present suffer from technical limitations or are difficult and expensive to operate.

a) Borehole Gravimeter

The borehole gravimeter measures formation density directly from gravity differences with depth in the borehole. It has only fair vertical density resolution but is by far the best tool for obtaining absolute densities. In the petroleum industry the tool has been used mainly to delineate density anomalies some distance laterally from the borehole (e.g. areas of large porosity in arbonates) because it has a very large effective depth of investigation in the horizontal direction. Present tool sizes range from 4 1/4 inch (10.8 cm) to 5 1/2 inch (14.0 cm) diameter (all too large for Challenger). They are very costly and in limited supply. The instrument is very sensitive to motion so must be stabilized or clamped in the hole. Development of smaller diameter, continuous operation and orientable 3-component borehole gravimeters would be very valuable indeed.

b) Nuclear Magnetic Resonance

Nuclear magnetic resonance logs measure the decay of the natural proton presssion in the formation, excited by an a.c. field produced by the tool. From the log it is possible to deduce porosity and qualitative estimates of permeability and pore size distribution. At the present time this tool gives the best available estimates of permeability.

c) Borehole Televiewer

Borehole acoustic televiewers are employed to detect and evaluate fractures and bedding in the wall of a borehole. An acoustic beam scans horizontally around the circumference of the borehole wall as the tool is moved vertically. Televiewers are very sensitive and can outline quite small features such as fractures, vugs or other large size porosity and bedding planes. The dip and orientation of fractures or bedding planes in the formation can frequently be determined. Acoustic televiewers are an essential part of hydrofracturing experiments (see below). They are also used to evaluate physical conditions within casing (e.g. perforations, splits), or drill pipe. Tool sizes range from 2 1/4 inches (5.7 cm) to 3 5/8 inches (9.2 cm).

d) Gamma Ray Spectral Log

This tool is an extension of the standard natural gamma ray log (above). It detects natural gamma radiation in three or more narrow energy bands, permitting quantitative separate estimates of the concentrations of potassium, uranium and thorium, and thus on radioactive heat production. Also, the thorium/potassium ratio can be used to indicate the presence of different types of clays such as illite and kaolinite, and the uranium/thorium ratios gives qualitative information on the oxidation state of the formation. The log can be run in open holes or through casing or drill pipe and the present tool size is 3 5/8 inch (9.2 cm) diameter. The log probably will see wide use only with the development of suitable solid-state detectors that can delineate very narrow gamma ray energy bands.

Neutron Activation

Coupled with a neutron activation source, a multiple channel gamma ray spectral log could be used to determine the mineral composition of the rocks penetrated by a borehole much more precisely than with any at present available logging tool. Multiple logging runs are needed and different logging speeds are required depending on the decay time of the different elements activated.

f) Complete Waveform Sonic Log

The complete waveform of the acoustic or sonic signal is recorded by this type of log generally as a variable density record. It frequently permits shear wave, as well as the normal compressional wave, velocity to be determined and thus the various elastic properties of the formation to be estimated. Development is needed on this tool to permit reliable shear velocities to be obtained, particularly in unconsolidated sediments.

g) Downhole Formation Pressure Testers, Fluid Samplers and Geochemical Monitors

Formation pore pressure measurement is usually combined with pore fluid sampling. A probe within a pad is held on the borehole wall with a packer while the formation pore pressure is measured and a fluid sample taken. Some devices permit multiple measurements and samples and new devices being developed also measure insitu eH, pH, fluid resistivity and temperature. The devices usually are effective only through a borehole wall mud cake. A number of parameters such as the seismic velocity and the geotechnical properties depend strongly on pore pressure. The pore fluid is of course of wide interest.

A special device has been constructed for Glomar Challenger boreholes and very successfully used in unconsolidated formations that forces a fluid sampler into the undisturbed sediments at the bottom of the borehole. Measurements are made at depth intervals, during drilling interuptions in a similar manner as the temperature probe described below.

h) Borehole Permeability Tests

Various arrangements of packers and pumping techniques have been, or could be employed to estimate formation permeability by monitoring the rate at which fluids can be produced or injected in sections of the borehole (also see below).

i) Downhole Magnetometer

Three orthogonal fluxgate sensors, and a separate fourth sensor for gradient, can give the variation of magnetic field intensity and direction and thus rock magnetization information. The tool may detect magnetic field reversals in basalts. It does not appear to have been used in industry probably because the magnetization of most sediments is too low for variations to be resolved using fluxgate sensors. Experimental tools are available at moderate cost.

j) Downhole Suceptibility Meter

The magnetic suceptibility of formation penetrated by a borehole can be measured using a solenoid coil system. This device appears to have been employed only in holes into basalt for research purposes. It probably would be difficult to have sufficient sensitivity to obtain useful data in sedimentary sections.

k), Induced Polarization and Special Electromagnetic Tools

A variety of special electrical properties can be measured in a borehole using devices of the type commonly employed from the surface on land for mineral prospecting. Some properties are particularly sensitive to the presence of small amounts of metallic minerals. Such measurements might be valuable in crustal boreholes into the sea floor.

l) Ultra-Long Space Electric Log (USEL)

The long space electric log is essentially an electrical resistivity logging device with a 'normal' but widely spaced (several hundred meters) electrode configuration. It can give the large scale average resistivity of a formation. This bulk resistivity is difficult to otherwise obtain in basalts or other rock types that have large fractures and other large scale porosity (see also large scale resistivity experiment below). The technique also can detect resistivity anomalies adjacent to, but not penetrated by the hole, although extensive modelling is usually necessary for quantitative interpretation of the results. The technique requires special cable and special hoisting arrangements.

m) Special Temperature Tools

Special tools have been developed to obtain temperatures in relatively unconsolidated sediments. A temperature sensor is forced into the undisturbed sediment at the bottom of the hole ahead of the bit. The measurements are made at a series of depths during interuptions in drilling. This technique has been employed quite successfully in Glomar Challenger holes using self contained recorders constructed for the purpose and lowered on the wireline (coretube recovery cable), but only a few temperature points have been obtained in any one hole.

A number of new tools for measuring high temperatures have been developed recently for use in industry and are now available.

6. Log Recommendations

LOG TYPE

	Challenger Program			Explorer	
	Has Been used	Recomm.	Prior.	Recomm.	Prior.
a) SP		X	2	X	2
b) Electric					
- normal	X	X	1	X	1
- lateral	X	X	1	X	1
- microresistivity		X	2	X	2
- induction	X	X	1	X	1
- USEL		X	2	X	2
c) Sonic					
- standard compensated	X	X	1	X	1
- full wave recorded (V_p, Vs)	X	X	1	X	1
d) Formation Density	X	X	1	X	1
e) Neutron Porosity	X	X	1	X	1
Natural Gamma Ray					
- total	X	X	1	X	1
- spectral		X	2	X	1
g) Neutron Activation		X(4)	2	X	2
h) Thermal Decay Time		X(2)	2	X	2
i) Borehole Televiewer	X(1)	X	1	X	1
j) Temperature					
- high resolution	X	X	1	X	1
- hole bottom penetrating	X	X	1	X	2
k) Caliper					
- 2 arm	X	X	1	X	1
- 4 arm		X	1	X	1
l) Borehole Gravimeter		X(4)	2	X	1
m) Downhole Magnetometer		X(3)	1	X	1
n) Suceptibility Meter		X(3)	2	X	2
o) Induced Polarization etc.		X(3)	3	X	2
p) Nuclear Magnetic Resonance		X(2)	2	X	2

Log Recommendations

LOG TYPE

	Challenger Program			Explorer	
	Has Been Used	Recomm.	Prior	Recomm.	Prior
q) Formation Pressure Tester		X(4)	2	X	1
r) Formation Fluid Sampler					
- sidewall		X(4)	2	X	1
- hole bottom penetration	X	X	1	X	1
s) Downhole Geochemical Monitor		X(4)	2	X	1
t) Downhole Geotechnical Devices		X(4)	1	X	1

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(1) single or infrequent trial

(2) at least one trail recomm.

(: mainly of value in igneous crustal rocks

(4) needs considerable development

General Priority:
1. strong need
2. moderate need
3. least needed

The priority depends strongly on the area, formation rock types and nature of the problems being investigated by the drilling.

7. Some Logging Development Needs in Rough Order of Priority

a) Downhole tool motion arrestor (ship motion).

b) Borehole graviter miniaturization and motion arrestor (e.g. clamping).

c) Shear wave velocity (Vs) accurate measurement.

d) Geotechnical properties measurement devices.

e) Spectral gamma ray (needs solid state detectors) and neutron activation capability.

f) Downhole magnetometer and suceptibility meter.

g) Borehole formation pressure and permeability tester, sidewall fluid sampler and geochemical monitors (development and miniaturization).

h) Nuclear magnetic resonance (miniaturization).

i) Induced polarization and other special electrical properties tool development (mainly for igneous rocks).

D. DOWNHOLE EXPERIMENTS

(with drill ship still over the hole)

A large number of downhole experiments have been proposed that provide information on the physical properties, and thus on the composition, state and origin of the deep sea floor rocks; or to measure some parameter (such as insitu stress) that can only be measured in place or that is of an ephemeral nature (such as unconsolidated sediment shear strength) so that measurements on core samples do not give values that are representative of those insitu. A number of downhole experiments are directed at measuring physical properties over the important scale lengths from a few tens of meters to a few hundreds of meters, intermediate between small scale laboratory core analysis (cm) or downhole logging (m), and large scale marine geophysical measurements (km). For example, the fractures and other large scale porosity that facilitate and control hydrothermal circulation in the crust, probably occur with such intermediate scale spacing. A variety of downhole experiments can provide information on the size, character, spacing, orientation and distribution of such fractures and large scale porosity.

1. Oblique Seismic Experiment: The large scale velocity structure in the area of a borehole may be obtained by recording in a hole with a clamped seismometer. A pattern of surface shots is fired from another ship at various azimuths and at distances up to several 10's of kilometers. The ray paths are thus from nearly vertical incidence to mantle refraction. The technique permits high accuracy estimates of both P and S velocity in the upper crust where normal refraction techniques have poor resolution of P wave velocity and give almost no information on S wave velocity. The P to S velocity ratio is a very sensitive parameter to crack and pore structure as well as composition, so having both velocities is valuable.

It is also possible to obtain estimates of seismic anisotropy in the upper crust that may reflect preferred crack and fracture orientation, and of attenuation which provides a useful restraint on the composition and structure. Noise levels also appear to be very much lower with recording in a borehole than on the sea floor or sea surface.

A simpler system that does not require a separate shooting ship but permits only near vertical ray paths is to shoot with an airgun source at the drill ship, i.e. the 'check shot' often used in the logging industry. The latter technique has been attempted several times with a hydrophone receiver suspended in the hole below the bit, but the noise levels were too high for the signal to be detected. Only a clamped geophone appears to give adequate signal to noise ratios.

2. Large Scale Resistivity Experiment: A configuration of widely spaced electrodes in a borehole permits determination of the bulk resistivity of a large volume of the rocks near the hole, (larger scale than USEL, above) although with poor spatial resolution. Combined with small scale sample measurements of "matrix" resistivity, the results permit estimates of large scale porosity and pore structure. This is a particularly valuable experiment for the oceanic crust where much of the porosity may be in widely spaced fractures and voids.

3. Borehole to Borehole Experiments: Detailed acoustic and electrical mapping may be possible between two nearby boreholes, say several hundred meters apart. However, since both holes must be instrumented, the difficult and time consuming installation used for long term recording packages is required in one of the holes, and instruments in that hole could not readily be moved up and down.

4. Hydrofracture Insitu Stress Measurement: The insitu stress field orientation and magnitude in the formation penetrated by a borehole may be estimated from the pressure required for fracturing the wall rocks in the hole and from the orientation of the fractures produced. The in-hole pressure is generated by rapidly pumping between two inflatable borehole packers or between one packer and the bottom of the hole. The orientation of the fractures generated may be obtained by detailed mapping with an acoustic borehole televiewer before and after fracturing. The technique has the potential of measuring earthquake generating stresses and the stresses driving plate motions.

5. Overcoring Insitu Stress Measurement ('doorstopper' technique): In this technique strain guages are first attached to the rock at the bottom of the hole, then they are overcored such that they remain on the top of the core that is still attached to the bottom of the hole. Finally a cylindrical hydraulic jack is installed surrounding the projecting core. Pressure is applied to the jack until the strain guages give their original readings. It may also be possible to attach the strain guages on the bottom of the hole, overcore, recover the core and apply the jack in the laboratory. Oriented stress estimates require that the strain guages attached to the bottom of the hole be oriented, and that the recovered core be oriented if the jack is applied in the laboratory. Remanent magnetism measurements may give adequate orientation in some formations. The overcoring technique has been extensively used in shallow holes on land.

6. Insitu Permeability Measurement: A wide variety of pumping tests are used in the petroleum industry to evaluate permeability, producibility etc.

Some of these can be applied to deep sea boreholes although some require a riser for return circulation. A straight forward technique to estimate permeability is to pump between borehole packers or between a packer and the bottom of the hole as for the hydrofracture experiment, except that moderate pumping rates are used that do not generate fractures. The main problem with this technique is the difficulty of determining the extent of leakage past the packers.

7. Temperature and Heat Flow Measurements: The high resolution temperature log is one of the standard tools in commercial logging. However, large temperature disturbances are generated by the drilling fluid circulation, that decay slowly. As a result, useful estimates of insitu formation temperatures are rarely obtained in routine logging although water flows in the hole, for example from fractures will be obvious. In the unconsolidated sedimentary sections, the disturbance problem has been overcome on Glomar Challenger by making temperature measurements in the undisturbed sediments below the bottom of the hole. A self contained temperature recorder is mounted in the corebarrel with a thin sensor that extends through and beyond the bit. At intervals, drilling is suspended and the instrument sensor lowered through the bit. The thermal conductivity required, with the temperature gradient, to compute the heat flux, has been measured with the needle probe technique or the Japanese (QTM) transient technique. It also may be possible to obtain insitu thermal conductivity at the points of temperature measurement by transient heating of the downhole temperature probe.

In indurated sediments or in igneous rocks, the above technique cannot be used and temperatures can only be measured in the hole. Reliable temperatures require either careful extrapolation of the decay of the temperature disturbance to equilibrium, or that the hole be left for a long period of time to equilibrate before measurement. The disturbance is least and the re-equilibration fastest near the bottom of the hole. Acceptable temperatures have been measured through the drill pipe.

Heat flow measurements in deep sea boreholes provide an important check on the results of shallow penetration oceanographic heat probes. The temperatures are also essential for the evaluation of the alteration processes in the sediments such as diagenesis and hydrocarbon maturation, and in crustal rocks. Temperature measurements in deep crustal holes should permit the outlining of the patterns of hydrothermal circulation that must occur in the crust, since any significant circulation system penetrated by a borehole will be very obvious in the temperature-depth profile.

8. Geotechnical Downhole Measurements

It is critical that some geotechnical measurements be performed in the borehole from the drill ship rather than on recovered core because the properties of unconsolidated and slightly indurated sediments change significantly on recovery and cannot be recreated. Once the insitu stresses are relieved, the critical properties of shear strength and the stress-strain relationship are permanently changed. The development of a hydraulic piston corer and a pressure core barrel will reduce but not remove the problem of recovering insitu properties. The above two properties are critical to an understanding of the processes of diagenesis, erosion, transport and redeposition, for the geologist, and to predict the sedimentary behaviour (for example slope stability) and the response under static and dynamic loads (for example the behaviour of structural foundations and the penetration of objects into the seafloor), for the engineer.

Two areas involving serious geotechnical questions are the disposal of highly radioactive wastes and the recovery procedures for subsea oil and gas. In sedimentary, metamorphic and igneous rocks, geotechnical measurements are needed to determine the process of formation and the nature and distribution of fractures, which control the distribution of fluids.

Virtually no insitu geotechnical measurements have been attempted in the sediments of deep sea boreholes, although a number have been made in shallow water petroleum wells. To measure shear strength, we envision instrumenting an inner core barrel assembly that can hydraulically pushed in front of the bit. The assembly would hold a quasi static core penetrometer, with the data recovered in a self-contained recorder or transmitted through the logging cable to the surface (the design and constructuion time required is estimated to be one year and the cost about $100,000.).

To measure the stress-strain relationship, we also envision instrumenting an inner core barrel assembly, in this case with a recording pressure sensor that could be hydraulically extruded in front of the bit. Development of such a device is at present underway in Europe for North Sea petroleum operations (such a device for deep sea boreholes probably could be designed and constructed in one or two years after experience has been gained in shallow water and at shallow burial depths. It is not feasible to estimate the development cost at present).

E. DOWNHOLE RECORDING

(after ship has left the site)

A deep sea borehole provides a desirable and sometimes necessary site for a number of important recording instruments. For example, a borehole provides a very low noise, stable site for seismometers, recording tiltmeters, gravimeters, magnetometers and telluric meters. A borehole is necessary for strainmeters and dilatometers and a specially selected borehole may permit monitoring of time variations in temperature, chemistry and fluid flow rate in a crustal hydrothermal system. Three types of instrument packages and deployment procedures are possible 1) small diameter packages can be placed in the hole through the drill pipe (3-7/8 inches diameter maximum at present). 2) large diameter packages may be installed as part of the drill string 3) a large diameter package up to the hole diameter could be implaced by a free wire (the drill ship is not required). Only the first method has so far been used. The third method would permit small oceanographic ships to deploy packages in existing holes. The U.S. Navy has been examining techniques for guiding a cable end in deep water so this method may soon be possible.

1. Downhole Data Recording and Transmission

The most difficult problem with most downhole recording experiments, is data recording and recovery after the drill ship has left the site. The first problem is getting the data from the downhole sensor to the sea floor. This is most readily done by multiconductor or multiplexed single conductor cable which also can carry power down to the sensor if it is required. It is possible to transmit data to the sea floor (and to the sea surface) through either an FM or digital acoustic link, but the sensor and data transmitter would then require sufficient self contained battery power to last for the duration of the recording period.

The second problem is how to get the data to the sea surface and how to recover it. The simplest technique is to attach sufficient data transmission cable from the sensor in the hole to reach the sea surface where a data recorder is attached. The installation of such a cable required a special operation on the drill ship of stripping the drill pipe off the cable one length at a time. A long length of buoyant rope is then attached to the recorder which is lowered to the bottom. The buoyant rope, weighted at intervals is then laid out on the bottom. The data package is recovered by dragging for the rope. The data may then be read out and if desired, the package refurbished and redeployed on the bottom without disturbing the sensor in the hole. This technique has been employed successfully in the Hawaii Institute of Geophysics downhole recording seismometer. It is also possible to attach the data cable to a long term surface recording buoy. However, experience with weather, oceanographic and geophysical data buoys has indicated that ordinary buoys rarely survive for more than a few weeks and frequently only for much shorter times. Either wind, waves or currents tear them loose or fishermen and others cut them off. If the problem of maintaining a buoy can be solved, the data could be recovered and the recording package serviced through periodic visits by an oceanographic ship. If the site is within about 100 km of an island or other land, the data could be recovered continuously through a UHF radio link. A more elegant data recovery system is to employ a satellite data link to a land receiving station. High data rate satellite information transfer such as a continuous seismic signal is at present very expensive, but event detection and triggered recording for earthquakes and narrow recording time windows for explosion seismology will permit intermittent and slower than real time data transmission. Smaller data rate signals such as strain, tilt, temperature etc. are much less of a problem. Satellite transmission also removes the need for a highly accurate, independent time base within the instrument for seismic recording. We also note that tape capacity for buoy or bottom continuous seismic recording is limited to several months for direct analogue recording (which has very poor signal fidelity and limited dynamic range) to less than a week for FM recording (which has good fidelity but still poor dynamic range) and to less than a day for digital recording (which has good fidelity and good dynamic range). Thus, event detection is desirable in any long term recording system.

Data transmission and recovery from the deep sea floor is a problem for all sea floor recording instrumentation and is being examined by a number of institutions. Close contact should be maintained with these groups.

2. Downhole Recording Seismographs: In-hole seismograph stations have two important advantages over seafloor or sea surface recording. 1) they avoid strong and variable surface layer effects that complicate and confuse the principal seismic arrivals e.g. long resonance or ringing from trapped Sv waves in the low velocity surface sediments and the arrivals from P to S and S to P conversion at the base of the sediments 2) The background noise level in a borehole may be an order of magnitude lower than on the sea floor or sea surface, since most noise appears to be transmitted as surface or near surface trapped waves that attenuate rapidly with depth

in the crust. In-hole long term seismic recorders are useful for both earthquake recording and for detailed explosion seismic experiments.

3. Recording Strainmeters, Dilatometers, Tiltmeters and Gravimeters:

Deep sea boreholes, particularly into the crust, provide stable, low noise sites for strainmeters (piezoelectric or other directional devices), dilatometers (bladder and capillary tube or other volumetric strainmeters), tiltmeters (mercury tube, bubble, pendulum) and gravimeters. These devices are used for two types of studies 1) studying the elastic and viscous properties of the earth from the deformation produced by gravity tides and by ocean water tidal loading 2) examination of local deformation from tectonic processes, for example along different types of plate boundaries. Of particular interest is the transient strain associated with earthquakes. Special types of strainmeters could even be installed in an actual shear zone penetrated by a borehole, for example the shear region in an active subduction zone or in a transform fault.

4. Recording Magnetometers and Telluric Current Meters: These devices can be used for magnetotelluric studies of the electrical properties of the ocean crust and upper mantle and for studying the effects associated with transient earthquake strains, e.g. seismomagnetic and seismoelectric effects.

5. Hydrothermal Water Flow Monitoring Devices: Where a borehole penetrates a water flow system, time variations in flow rate, temperature and water chemistry. For example, much might be learned about the nature of the cracks, fractures or other flow channels from the variations of these parameters with the earth tide and over longer times. Variations also

might be observed associated with earthquakes. Several boreholes have penetrated flow systems but so far the flow has always been down the hole from the sea floor.

F. DOWNHOLE RECORDING AND EXPERIMENT IN GLOMAR CHALLENGER BOREHOLES (to December, 1979)

Leg 45
d Atlantic ridge)

1. Downhole hydrophone and surface airgun (Lamont) - operationally successful but noise level too high to hear airgun.

Leg 46
id Atlantic ridge)

1. Downhole Hydrophone and surface airgun - again noise level too high.
2. Oblique seismic experiment (Cambridge) - operating technique developed but no suitable hole drilled.

Leg 52
ermuda rise)

1. Olbique seismic experiment (Cambridge) - good results giving P and S velocity profiles of upper crust even though available hole had only shallow penetration into crust - excellent integration of results of experiment with logging and laboratory data.

Leg 60
hillipine Sea)

1. Large scale resistivity experiment (U.K.) - operating technique developed but some cable failure and hole not deep enough for significant results.

Leg 65
ulf of Calif.)

1. Downhole recording seismograph (H.I.G.) - deployment technique developed; operated well with cable attached to ship but recording unit failed.
2. Oblique seismic experiment (Cambridge, WHOI) - good results.

Leg 67
uatemala Margin)

1. Downhole recording seismograph - very successful, bothactive program of recording explosive shots and passive recording of earthquakes.

Leg 68a
osta Rica Rift)

1. Hydrofracture and televiewer (Lamont, U.S.G.S. Amoco) - single packer successfully tested, excellent televiewer results (e.g. cover JOIDES journal Oct. 1979)
2. Large scale resistivity experiment (U.K.) - good results
3. Downhole magnetometer (Soviet Union) - good results in basement section.

Leg 69
osta Rica Rift)

1. Hydrofracture and televiewer - good results, remarkable resolution by televiewer.
2. Downhole magnetometer - good results.

Not listed individually above - on numerous legs, temperature measurements and sediment pore fluid samples.

G. RELATED LABORATORY MEASUREMENTS

Glomar Challenger Program

1. Ship Laboratory

   a. Seismic velocity at atmospheric temperature and pressure (compressional and shear velocities) and some axial pressure would be valuable.

   b. Density: bulk density and grain density[(a)]

   c. Porosity[(a)]

   d. Electrical Resistivity[(b)] and thermal conductivity at atmospheric temperature and pressure only

   e. Natural gamma might be valuable

   f. Composition and texture of rock samples

2. Comments on Ship Laboratory

   a. Bulk density by weighing in air and suspended in degassed and distilled water and by GRAPE; porosity and grain density by drying at 110°C for 24 hours in a vacuum (as a check in shore lab, grain density should be measured directly by crushing the rock).

   b. Electrical resistivity is the only proposed addition. It can be done easily and cheaply, is a valuable compliment to logging and other priorities measurments, and the poor fluid composition may change significantly with time.

3. Shore Laboratory[(c)]

   a. Magnetic properties[(a)]: direction and intensity of magnetization, susceptibility, Curie temperature, etc.

   b. Seismic properties[(b)]: compressional and shear wave velocities, dynamic elastic modulii and pressure and temperature dependence

   c. Density, bulk and grain[(d)]: grain density using standard techniques on crushed rock - as a test of simple drying technique

d. Porosity

e. Electrical properties[b]: resistivity, loss tangent and other frequency dependent properties, temperature and pressure dependence

f. Thermal conductivity, diffusivity or heat capacity, and temperature and pressure dependence

g. Permeability

h. Petrofabric[a]: deformation structures in cores for stress and strain analysis and tectonic interpretation

i. Mechanical properties: strength, static elastic modulii, and creep under simulated in situ conditions[a]

j. Composition and texture of rock samples, if not recorded at sea

4. Comments on Shore Laboratory

a. An attempt should be made to orient core samples for magnetic and some seismic velocity measurements and for meaningful structural interpretation and evaluations of anisotropy. Where strata are inclined, approximate orientations can be obtained from dipmeter surveys.

b. Most physical properties measurements require that samples be kept fluid saturated. For electrical measurements, the original fluid composition should, if possible, be preserved.

c. As many as possible of the shore laboratory measurements should be done at DSDP to ensure continuity, standardization and quality control. Alternatively, long term commitments should be sought from other labs.

d. Grain densities, measured on sediments or rocks representative of major lithological sections, are of particular importance for use with electrical resistivity logs to calculate in situ bulk density.

<u>Glomar Explorer Program</u>

Since deeper drilling will require more time on site, perhaps more of the laboratory work should be done on the ship. However, only that work that is required for real-time decisions or for which rapid sample deterioration or alteration are a problem <u>must</u> be done aboard.