MEETING OF JOIDES DOWNHOLE MEASUREMENTS PANEL

Texas A & M University
College Station

23-24 January 1990

EXECUTIVE SUMMARY

1. Panel is restating the following key recommendations from its previous meeting: these were reportedly not discussed by PCOM at the November 1989 PCOM meeting.

(i) High temperature logging remains the biggest challenge facing the Panel.

"A high-temperature logging tool combination rated to at least 350°C be developed by the logging contractor to address as many as possible of the following scientific needs identified by LITHP and listed below in decreasing order of priority.

1. Temperature
2. Borehole Fluid Resistivity
3. Formation Resistivity
4. Natural Gamma
5. Sonic
6. Caliper
7. Flowmeter
8. Borehole Fluid Pressure

The objectives are to be achieved by repackaging existing tools, not by the development of new tools."

[DMP Recommendation 89/17]

(ii) "Funds for the development of the high-temperature tool combination, currently allocated as $300,000 for tool hire during FY91 and FY92, should be made available as soon as possible to allow the redirected initiative to be brought to fruition before the estimated tool deployment date of mid-1991."

[DMP Recommendation 89/18]

(iii) "A JOI-supported inter-programme workshop on high-temperature logging should be planned, and scheduled to take place before mid-1990, in order to develop the necessary engineering science for the longer term."

[DMP Recommendation 89/19]

2. Panel is concerned that the downhole-measurement and lithosphere-basement objectives at site 801 have been compromised by the decision of the Co-chief scientists not to carry out downhole measurements in basement at this site. Panel asks PCOM to provide an explanation of why the scheduled downhole measurements were not made. Panel notes that had PCOM policy on downhole measurements been followed, the scientific objectives of Leg 129 could and should have been realised. Chairman is asked to raise these key questions with the PCOM Chairman as soon as possible.

3. "Since re-entry hole 801C is located just three days out of Guam, this hole should be re-entered and the aborted programme of downhole measurements carried out before the JOIDES Resolution leaves the Western Pacific. This is an important issue because hole 801C penetrates very old crust and there is no provision for ODP to drill crust of similar age in the future."

[DMP Recommendation 90/1]

4. Panel re-affirms its earlier recommendation re VSP deployment as it also did on a previous occasion (DMP Minutes, 6-7 October 1988). In view of the time required to set up and run vertical seismic profiling, zero-offset VSP does not give sufficiently greater information, relative to the sonic log, to justify VSP as a matter of routine. If there is a seismic interest in an area, VSP would be supported by DMP. If VSP is run, deployment is the responsibility of the logging contractor. Panel supports the SMP proposal that VSP data storage and processing become the responsibility of the underway geophysics function.

5. Panel reiterates its support for the concept of sealing instrumented re-entry holes as originally conveyed through DMP Recommendation 89/14.

6. In reiterating its earlier recommendations on high-temperature logging (89/17 - 89/19), Panel noted that the target for the short-term development of high-temperature logging technology was now February 1991. Within this shorter time frame the high-temperature slimhole logging needs of the JOIDES Lithosphere Panel in connection with EPR objectives cannot be fully met. The situation might be eased if reaming were a proven option under EPR conditions. In the current absence of this option, there is a need to draw up a schedule of realistic developments for different diametral constraints. This task is charged to a subgroup to meet after this DMP meeting. The minimum target should be those LITHP objectives which are the most readily achievable : temperature, formation resistivity and borehole fluid pressure. In addition, borehole fluid resistivity measurements should be investigated.

7. "Facilities be created to allow the development before February 1991 of a slimhole high-temperature downhole-measurement capability at least for temperature, formation resistivity and borehole fluid pressure, together with borehole fluid resistivity if technically feasible. The development is to be based on adapting existing tools."

[DMP Recommendation 90/2]

8. "The reaming option for hole enlargement from four to six inches in diameter under EPR conditions should be fully tested."

[DMP Recommendation 90/3]

9. There is a need for a long-range development plan for high-temperature technology. This should be based upon the ODP long range plan. The latter should be scrutinized and logging needs extracted. This information should be incorporated with pertinent messages from the JOIDES thematic white papers. Cost estimates should be produced and priorities listed. The task of developing a long range plan for high-temperature logging was assigned to a working group comprising Anderson, Worthington, Lysne and Sondergeld. The group may need to meet once in April in order to agree and finalize its submission.

10. Three courses of action have been agreed for improving the shipboard computer situation as it pertains to downhole measurements.

(i) The FMS-dedicated microvax and other downhole-measurement computers be incorporated into the shipboard VAX network (in view of the stated intention that FMS data would not be transmitted through ETHERNET).

(ii) LDGO joins with TAMU in the maritime maintenance agreement with DEC. (This currently costs around $18-22,000 in total and is unlikely to cost LDGO incrementally more than $5-6,000.)

(iii) The FMS-dedicated microvax be located in the machine room where the TAMU system managers will provide back up. (However, the system managers are not conversant with Schlumberger software.)

11. "TAMU and LDGO should work towards an integrated shipboard computer system which accommodates all log and core needs. An immediately identifiable goal is that log and core data be easily and simultaneously accessed, displayed and interrogated through one database management system."

[DMP Recommendation 90/4]

12. "Representatives of DMP, IHP and SMP should meet in a workshop session to identify user needs and develop data presentation styles for integrated log and core data. This workshop should take place before the proposed DMP/SMP joint meeting in October 1990."

[DMP Recommendation 90/5]

13. The Wireline Packer has been delivered to LDGO. The LAST tool is ready for deployment on Leg 131. The Geoprops Probe is unlikely to be ready for Leg 131 : however, the tool has been manufactured and there is a possibility that it can be assembled and tested in time.

14. "The BGR of FRG high-resolution borehole magnetometer should be scheduled for deployment in Hole 504B after deepening."

[DMP Recommendation 90/6]

15. In accordance with its adopted thematic thrusts, Panel reiterates its commitment to the creation of a database of global stresses. Panel regards the removal of basement objectives from Leg 138 as a potential loss of opportunity.

16. "Downhole temperature measurements, fluid sampling and drillstring packer experiments be carried out in Hole 504B during the third engineering leg (136) and before any engineering work is undertaken."

[DMP Recommendation 90/7]

17. "The following programme of downhole measurements, which complement existing data, should be carried out at Site 504B before recasing:

    Formation Microscanner
    Wireline Packer
    Flowmeter Packer
    Enhanced Resolution Tool
    Sidewall Coring (possibly through wireline re-entry)

    Options are to undertake this work during the third engineering leg (136), during a subsequent leg (139) dedicated to 504B, or during a subsequent minileg or segment of an EPR leg."

[DMP Recommendation 90/8]

18. Measurement-while-Drilling (MWD) technology should be very closely monitored as a basis for evaluating its possible deployment in ODP phase 2.

19. "The logging contractor through LDGO and on behalf of ODP should become a corporate member of the Conoco-led industry consortium for the testing of MWD and other downhole-measurement tools. This will require that $30,000 be budgeted for FY91."

[DMP Recommendation 90/9]

20. The next DMP meeting will take place on 28-29 June 1990 in Seattle, Washington. D Cowan to host.

    The subsequent DMP meeting is tentatively scheduled for 9-12 October 1990 in Brisbane, Australia. This four-day meeting would encompass a visit to the JOIDES Resolution and a one-day joint meeting with SMP. Date adjustments will have to be made if the schedule of the JOIDES Resolution changes.

Paul F Worthington
7 February 1990

MEETING OF JOIDES DOWNHOLE MEASUREMENTS PANEL

Texas A & M University
College Station

23-24 January 1990

MINUTES

<u>Present</u>

Chairman:	P F Worthington (UK)
Members:	B Carson (USA)
	J Gieskes (USA)
	M Hutchinson (USA)
	D Karig (USA)
	P Lysne (USA)
	R Morin (USA)
	C Sondergeld (USA)
	H Crocker (Canada/Australia)
	J P Foucher (France)
	H Kinoshita (Japan)
	O Stephansson (ESF)
	H Villinger (FRG)
Liaisons:	R Anderson (LDGO)
	K Becker (LITHP)
	A Fisher (TAMU)
	X Golovchenko (LDGO)
	M Langseth (PCOM)
	J Mienert (SGPP)
	T Pyle (JOI)
Guests:	W Kessels (KTB)
	*B Harding (TAMU)
	*D Huey (TAMU)
	*T Pettigrew (TAMU)
	*M Storms (TAMU)
	**R Merrill (TAMU)
	**J Foster (TAMU)
	+B Sanford (TAM, Inc)
	+L Sanford (TAM, Inc)
	+T Stancliff (TAM, Inc)
	+C Stokley (TAM, Inc)
Apologies:	R Wilkens (USA)

*Present for agenda items 10-13 only.
**Present for agenda item 13 only.
+Present for agenda item 16 only.

1. Welcome and Introductory Remarks

The meeting was called to order at 8.30 am on Tuesday, 23 January 1990. The Chairman welcomed DMP Members, Liaisons and Guests to the first DMP meeting of the new decade, especially those attending for the first time (Stephansson, Kessels).

Review of Agenda and Revisions

Additional items for inclusion

(i) New Item 5(vi) - Liaison report from JOI, Inc.

[PYLE]

(ii) New Item 27 - Thematic or Synthesis Publications.

[WORTHINGTON]

With these modifications the pre-circulated agenda was adopted as a working document for the meeting.

2. Minutes of Previous DMP Meeting, Windischeschenbach, FRG, 11-12 September 1989

The minutes were adopted without modification.

The Chairman signed the master copy for ODP records.

Matters Arising

Item 10 - Software

The Chairman reported that IHP Chairman is content to leave log archiving matters to LDGO.

The survey of options for reading LIS tapes is being pursued but has not yet been brought to fruition. Deferred to next meeting.

[ACTION: ANDERSON, HUTCHINSON]

It was noted that an AAPG format is under review based on the Schlumberger LIS 85. This is being promoted as a potential standard for the oil industry.

3. Chairman's Annual Review

The Chairman provided a review of Panel activities in 1989, as reported at the annual meeting of PCOM and Panel Chairmen held in Woods Hole, Massachusetts on 27-28 November 1989.

DMP operates primarily as a service panel (70%) with some thematic drive (30%). Panel complement is 15, comprising representatives of oil companies (4), JOIDES institutions (2), other universities (4), research laboratories or institutes (4), and consultants (1). One member is retiring at the end of 1989 : a replacement will be nominated shortly.

Three meetings were held during 1989, in Honolulu (16-18 January), La Jolla (23-24 May) and Windischeschenbach, FRG (11-12 September). Three meetings are planned for 1990, in College Station (23-24 January), Seattle (28-29 June) and Brisbane, Australia (9-12 October).

During the period November 1988 - October 1989 a total of 19 DMP Recommendations were transmitted to PCOM. Of these, 10 were accepted, two were not accepted, four drew no comment, and three had become redundant by the time of the PCOM deliberation due to Leg cancellations, etc.

A summary of the 1989 highlights was presented in terms of procedures, tools, profile and planning.

Procedures

A JOI-supported workshop on shipboard logging practices, held in April 1989 and involving previous JOIDES logging scientists, produced 20 recommendations for improvement directed at JOIDES, TAMU and LDGO BRG.

A Job Description has been formulated for the JOIDES Logging Scientist, from the DMP standpoint. This needs to be developed by TAMU for subsequent inclusion in the JOIDES Journal.

Procedures for controlling the development of Third Party Tools have been established and monitors appointed for each of the identified tools.

Tools

The miniaturized Formation Microscanner has been commissioned and deployed successfully.

The status of off-the-shelf technology for high-temperature and slimhole logging has been identified.

Priorities for the development of remedial high-temperature slimhole technology have been identified through inter-panel collaboration.

Profile

Two synthesis publications have been targeted - a multi-authored paper in Basin Research on "Scientific Applications of Downhole Measurements in the Ocean Basins", and a JGR thematic issue on ODP log applications derived from a poster session at the 1988 AGU fall meeting.

A paper on "Scientific Benefits of Downhole Measurements in the Ocean Drilling Program" was presented at an AGU Union Session.

A joint meeting with the German Continental Deep Drilling Project (KTB) in Windischeschenbach, Bavaria, in September 1989 served to increase mutual awareness of the logging activities and capabilities of ODP and KTB.

Planning

CEPAC DPG Chairman attended the May 1989 meeting of DMP at which logging programmes were identified for the major CEPAC themes.

A joint meeting with LITHP in FRG on 11 September 1989 provided for a useful exchange of cultures and resulted in an agreed strategy for the development of new logging technology, especially for high-temperature environments.

DMP has driven towards the development of a high-temperature logging capability, possibly for slimhole deployment : the inter-programme meeting held in College Station on 16 November 1989 constituted an important step in this direction.

1989 has been "data quality year". In addition to the progress made on third party tools, shipboard logging practices and inter-programme exchange, mentioned above, DMP has involved the logging subcontractor, Schlumberger, in one of its meetings in order to clarify maintenance and calibration procedures.

1990 will see a major DMP scientific initiative directed at lithosphere characterization. The aim will be to produce a drilling proposal for a multi-well leg which will involve core analysis for physico-chemical properties, well logging, cross-well electric and acoustic tomography and tracer studies, VSP and long-spaced electric logs, and surface seismic. Important questions to be answered include:

Do log and core data characterize oceanic lithosphere in a locality or are they merely samples of a wide statistical range?

Is lithosphere characterization a function of scale?

Can one reconcile data at different scales in the presence of heterogeneity and anisotropy?

Key issues are to identify technical needs (eg. downhole sources, tomographic software) and resource needs (eg. a second ship, re-entry system). Input will be sought from service panels on feasibility and from thematic panels on target localities and measurements. A draft drilling proposal should be available within 12 months or so.

Two causes for concern were expressed:

(i) The need for a high-temperature (slimhole) logging capability.

In the short term (before mid-1991) we should repackage existing tools to higher temperature ratings, rather than develop new tools for which there are insufficient time and funds. These repackaged tools may not fit down 4-inch holes and, if they do, the narrow annulus might make cooling impossible. Dummy runs should be planned during the second engineering leg. Funds are needed now. In the long term, the most favoured route is through interprogramme collaboration.

(ii) Shipboard availability of Formation Microscanner (FMS) data.

A major drive is to make logs available on board ship at the earliest possible time. FMS images are important for orienting/positioning core as well as filling in the gaps in core recovery. We need to establish the feasibility of FMS image processing on board ship. The goal may be too ambitious because of the complexity of FMS processing.

In summary, 1988 saw the scientific community becoming increasingly aware of the scientific benefits of logging. 1989 focussed on data quality. 1990 will see the continuation of the data quality initiative, the planning of a downhole measurements programme to characterize oceanic lithosphere, progress towards a high temperature (slimhole) technology for meeting thematic needs, and further contributions to the ODP profile.

4. PCOM Report

Langseth stated that he was unable to report since he had not attended any of the three DMP meetings in 1989 and had not been present at the last two PCOM meetings. He was further disadvantaged by the non-appearance of the minutes of the most recent PCOM meeting. It was, however, his impression that none of the key recommendations from the last DMP meeting, i.e. those relating to shipboard computers and high-temperature slimhole tools, had actually been discussed by PCOM. Langseth undertook to write to the PCOM Chairman to ask why there had been no endorsement of these important recommendations.

[ACTION: LANGSETH]

The Chairman expressed his disappointment at Langseth's report. The purpose of DMP recommendations was to solicit endorsement and, where appropriate, action from PCOM. The Chairman would identify the key recommendations from the previous DMP meeting. These would be re-directed to PCOM as part of the Executive Summary of this meeting.

5. Liaison Reports

(i) Lithosphere Panel

Becker reiterated LITHP's need for a high-temperature slimhole logging capability to be developed. In particular, it is essential to have available a high-temperature-rated tool for the downhole measurement of temperature. Without this, EPR objectives will not be achieved.

(ii) Shipboard Measurements Panel

The Chairman reported on the SMP meeting held at the Lamont Doherty Geological Observatory (LDGO) on 2-3 October 1989 (Annexure 1).

Key outcomes were a general acceptance of the common goal of integrating core and log data, support for the concept of a joint SMP/DMP meeting in a ship port of call during 1990, and a desire to incorporate responsibility for the processing of VSP data within the underway geophysics remit (see Item 9).

(iii) Sedimentary and Geochemical Processes Panel

Mienert reported that SGPP has defined five priority themes:

- sediment fluxes and depositional architecture;
- sea level as a record of eustatic change;
- fluid circulation through the sea floor and geochemical balance;
- metallogenesis;
- palaeocean-chemistry as a record of global change.

SGPP has reviewed, grouped and ranked about 54 proposals. The top ten groups are:

1. Cascadia
2. Chile Triple Junction
3. Atolls and Guyots
4. Sedimented Ridge Crests
5. New Jersey Margin
6. Hydrates
7. East Pacific Rise
8. Gulf of California
9. New Zealand
10. Barbados

Important logging targets are:

- High-temperature measurements at mid-ocean ridges
- Accretionary wedges
- Controls on flow, intergranular vs fracture
- Fluid properties, temperature, salinity and pressure, both in the borehole and in pores

- Gas properties; CO_2, H_2S, CH_4
- Physical properties; porosity, permeability, density, and sonic velocity
- Pressure core sampling to calibrate the logs
- Long-term monitoring of borehole temperatures, flow rates and pressures
- Gas hydrates

SGPP has suggested another DPG for the Cascadia accretionary prism.

(iv) CEPDPG

No report - Wilkens at sea.

(v) KTB

Kessels reported that the pilot hole had been completed in April 1989. Current efforts are directed at building up a database of downhole measurements, eg. thermal conductivity, wireline hydrofracturing using a downhole packer.

Fluid conductivity measurements with the AMS tool have suggested inflow in several places. Hydraulic tests have been carried out in the upper part of the borehole. These have indicated an inflow of high-salinity (16000 ppm NaCl equiv.) water to a depth of 3800 m.

The main hole is to be drilled using a new casing concept. The target depth is 10 km. Expected bottom hole temperature is 300°C. The hole must be completed by December 1994. The time allocation for logging is 6.2% of the total.

Further R&D is directed at developing tools which can operate at temperatures above 260°C and at high pressures (25000 psi). No service company offers tools that are designed to operate under these conditions for long periods:

For example, the Schlumberger HEL tools can only operate at 260°C and 25000 psi for periods of 4-5 hours. A questionnaire sent to all known companies has suggested no new opportunities.

A general strategy for developing high-temperature logging tools might be to build very simple analogue versions, ie. with no downhole electronics.

High-temperature/high-pressure tools currently under development for KTB are:

thermal conductivity (Univ. of Berlin)
magnetometer (Univ. of Braunschweig)
susceptibility (Univ. of Munich)

The FMS is too difficult to address. The WBK BHTV does not have a sufficiently high temperature rating.

Maximum permissible tool diameter is 5 inches.

(vi) JOI

Pyle reported that the first official moves to bring the USSR into ODP had started in Washington. JOI has agreed with FRG agencies to fund jointly a second digital BHTV for ODP use. The budget for FY91 is being developed. This is currently $39,600,000 of which $300,000 has been set aside for new technical developments. LDGO and TAMU have been approached to develop proposals for using this fund which is additional to the 4% allocation for special operating expenses. The NSB information briefing in connection with ODP renewal has been rescheduled for 15/16 March 1990. DMP Chairman is one of the invited presenters.

6. National Reports

(i) UK

The Chairman reported that a technical meeting on the BRIDGE initiative had been arranged for 8 February 1990 in London under the auspices of the Society for Underwater Technology. He is scheduled to present an invited paper on "Sensing in Hostile Borehole Environments". Two aspects are highly significant: (1) BRIDGE are anticipating temperatures of 350°C; (2) BRIDGE want to hear about the technology of downhole measurements at these temperatures. It was noted that formal liaison with ODP would be possible if there was the prospect of an inter-ridge organisation.

A second development is the establishment of an International Drilling and Downhole Technology Centre in Aberdeen. The aim is to provide research and development facilities possibly through the coordination of multi-client projects. There is a possibility of a hard-rock tool calibration facility to complement those in the USA.

The Chairman had no further information on the OBCAT programme.

(ii) France

Foucher reported on the new sediment magnetometer, developed by a consortium comprising Total CFP, CEA and Schlumberger, which has two constituent tools. The first measures the modulus of the magnetic field with a precision of 0.1 nT, the other records magnetic susceptibility with a precision of 10^{-6} SI units. The tools are separate, not combined, and have a diameter of 3.75 inches. A sea floor observatory is needed to measure temporal variations in the earth's magnetic field.

Discussions are ongoing with Schlumberger as to whether these tools can be made available to ODP. There is a proposal to deploy them during the upcoming Vanuatu Leg.

A magnetic susceptibility tool for basalts, with a precision of 5×10^{-6} SI units, has been deployed earlier in ODP. There is a coordinated programme to develop a three-axis magnetometer for use in the same holes as the susceptibility tool.

NADIA 2 - a new re-entry shuttle is proposed, but still controlled by a manned submersible. The principal transformations, to be completed before the end of 1990, are the inclusion of the main flotation in the frame, the ability to accommodate logging tools up to 4 m long, the introduction of a seven-conductor cable, the replacement of the cable length sensor, and the capability to remain for long periods on the sea floor.

Two field re-entry programmes are planned.

(i) SISMOBS : the aim is to place seismometers in ODP holes (eg. 504A, 320) for 3-4 weeks : date of commencement is October 1990.

(ii) DIANAUT : it is proposed to re-enter oceanic crust of different ages to study hydrogeological processes, and fracturation and its associated magnetic signature.

The re-entry programme is open to any proposals from ODP.

(iii) Japan

Kinoshita described five areas of activity.

(1) Sub-bottom seismic instruments

Deployment in Leg 128 of the Japan Sea. Data have been retrieved successfully. Recovery of the system is to take place this spring.

(2) Downhole Magnetometer

Revival of the tool damaged during Leg 111 with intended application to sediment sections. Aims are related to the dynamics of the earth's core.

(3) Trans Pacific Communication Cable System (TPC 1)

Old telecommunications cable is being replaced. Aim is to re-use this for geosciences when it becomes redundant. Major objective is a RIDGE-related programme in back-arc rifts. It is proposed to monitor long-term well-bore seismicity, tilt, temperature and pressure.

(4) Super-deep drilling

Test drilling to allow a high-temperature programme of downhole measurements directed at hydrothermal objectives, ophiolite (Kuroko belt) studies, and investigations of shallow earthquake foci.

(5) Electrical resistivity experiment on Leg 128

Data acquisition was successful but no further details are available yet.

(iv) Canada/Australia

Crocker reported that he had contacted the New Zealand geothermal programme : they have experience of high-temperature logging (>300°C) which they would be willing to share with ODP.

The Western Australian government has a standing committee to investigate standards for data transfer between oil companies and the government.

A new formation tester, the Modular Repeat Test Tool (MRTT), is due to become available from Schlumberger by April 1990.

Crocker reported that his own formation evaluation tool, which is a wireline formation tester, is being further developed. There is industry interest in slimholing the tool for high-temperature use.

(v) ESF

Stephansson reported that Sweden is active in developing borehole instrumentation for application to radioactive waste disposal. A key objective is to delineate major fracture zones away from a borehole and between boreholes. Major thrusts are cross-hole seismics and seismic tomography, and electromagnetic borehole radar. The radar system has been tested in an old iron-ore mine and has identified major fracture zones 500 m out from the wall. It is less efficient at seeing fractures that are close to the wall. Frequency is within the low MHz range.

Stephansson described his own research interest in stress measurement, in particular the World Stress Map Project and the determination of in situ stresses in Europe.

(vi) FRG

Villinger reported that the report on the ODP/KTB workshop held in Windischeschenbach on 13-14 September 1989 had now been issued.

BGR Hannover are developing a high-temperature (200°C) three-axis magnetometer. Expected completion date is mid-1990.

Arrangements have been completed for the leasing of a WBK digital BHTV to be used by Fuchs (Karlsruhe Univ.) in cooperation with Zoback (Stanford Univ.).

Both projects are looking for interesting Legs/technical targets (see Item 14(v)).

7. Interprogramme Meeting on Slimhole, High-Temperature Borehole Logging

The Chairman reported on the meeting on high-temperature logging held at ODP/TAMU on 16 November 1989 (Annexure 2).

The meeting was attended by representatives of ODP, DOSECC, CSDP, the US DoE Geothermal Program, and NSF. The aim was to identify common goals in the technology of logging small diameter (4-inch) holes in hot (>300°C) environments.

It was agreed that joint action should be initiated. As a first step two actions had been agreed:

- Tom Pyle to approach the Interagency Coordination Group (DoE, USGS, NSF) and the Geothermal Technology Division of DoE.

- Peter Lysne and Paul Worthington to co-author a technical paper for EOS in order to give the initiative appropriate profile.

It was generally considered that once the proposal for collaborative funding had been accepted, a work programme would need to be drawn up by an inter-programme task force.

8. ODP Geochemical Workshop

The Chairman reported on the downhole-measurement aspects of an ODP workshop on progress and opportunities in geochemistry held at the UCLA Conference Center, Lake Arrowhead, California during the period 9-12 January 1990 (Annexure 3).

Several key recommendations were formulated. Among them were:

- develop and implement improved procedures for the effective integration of core and log data, enhanced by a revision of shipboard scientific functions;

- quantify accuracies and precisions of the GLT, and develop/deploy methods for the enhancement of its spatial/spectral resolution;

- include a natural gamma (spectral) facility on board ship;

- investigate the global/regional/local validities of element-to-mineral transforms;

- develop pressure core-sampling techniques;

- deploy packers with fluid samplers, especially for tracer experiments;

- create instrumented boreholes with long-term sensors to measure temperature, flow, fluid conductivity and chemical compositions.

A full workshop report is to be issued in due course.

9. <u>Vertical Seismic Profiling</u>

The Chairman introduced an SMP recommendation that "if VSP becomes a routine part of the program (ie. a zero-offset VSP is run at each site where a sonic log is collected), underway geophysical operations should be integrated with the VSP program".

SMP has asked DMP to reconsider DMP's earlier recommendation that "VSP should not be a routine experiment on the ODP drill ship" (DMP Recommendation 87/2).

DMP Consensus

Panel re-affirms its earlier recommendation re VSP deployment as it also did on a previous occasion (DMP minutes, 6-7 October 1988). In view of the time required to set up and run vertical seismic profiling, zero-offset VSP does not give sufficiently greater information, relative to the sonic log, to justify VSP as a matter of routine. If there is a seismic interest in an area, VSP would be supported by DMP. If VSP is run, deployment is the responsibility of the logging contractor. Panel supports the SMP proposal that VSP data storage and processing become the responsibility of the underway geophysics function.

10. <u>Logging Contractor's Report</u>

Anderson reported on the logging operations during Legs 127 and 128. Although both these legs were in the Japan Sea, very different hole conditions were experienced. Leg 127 provided much trouble with borehole conditions : it was not feasible to use the SES because the drillers were running out of BHAs, and swelling problems had caused the supplies of KCl to become exhausted. In contrast, Leg 128 provided excellent hole conditions. Notwithstanding the bad bridging problems, all holes deeper than 400 m were logged during Legs 127 and 128, with the exception of Hole 795 (Leg 127) which had especially serious bridging.

Fisher, as a member of the shipboard party, reported on Leg 129 during which three sites were drilled (800, 801, 802). The wireline heave compensator did not work at the first site. SEDCO claimed that they were only responsible for the hydraulics and that since this was an electrical fault, it was outside their remit. The problem was finally solved by an ODP technician.

Site 800 produced poor core recovery over large intervals.

Hole 801C, designated a re-entry hole, penetrated virtually unique old Pacific crust, an outcome that had been seen as partly satisfying the objectives of the defunct geochemical reference proposal. At 801C the drilling objectives as per the scientific prospectus were achieved. Unfortunately the Co-chiefs elected to abandon all downhole measurements in the basement in order to obtain 30 m of additional core, the information from which did not materially enhance the drilling objectives. Hole 801C was the only hole programmed for logging within basement. Consequently, the deletion of this programme has meant that the downhole-measurement objectives of Leg 129 were not met. The option to log was available but was not discussed. It is understood that the Co-chief decision was known to the PCOM Chairman who did not enforce compliance with the pre-determined programme.

The Panel generally expressed regret at Fisher's report. Prior to Leg 129, and in response to requests from the community, the Chairman had made representations to the PCOM Chairman alerting him to the possibility of Co-chief-driven departures from the Leg 129 programme. More generally, at this time of renewal negotiations it is imperative that ODP should be seen to be professional on all fronts, including planning. This type of short-fuse decision making, carried out within the parochial context of a single leg rather than the global context of an international scientific programme, is not compatible with strategic planning. It has set back several years the evolution of a coordinated planning culture within ODP.

DMP Consensus

Panel is concerned that the downhole-measurement and lithosphere-basement objectives at site 801 have been compromised by the decision of the Co-chief scientists not to carry out downhole measurements in basement at this site. Panel asks PCOM to provide an explanation of why the scheduled downhole measurements were not made. Panel notes that had PCOM policy on downhole measurements been followed, the scientific objectives of Leg 129 could and should have been realized. Chairman is asked to raise these key questions with the PCOM Chairman as soon as possible.

[ACTION: WORTHINGTON]

In order that this unsatisfactory state of affairs might be redressed, Panel formulated the following recommendation.

DMP Recommendation 90/1

"Since re-entry hole 801C is located just three days out of Guam, this hole should be re-entered and the aborted programme of downhole measurements carried out before the JOIDES Resolution leaves the Western Pacific. This is an important issue because hole 801C penetrates very old crust and there is no provision for ODP to drill crust of similar age in the future."

Anderson reported on tool status. The Formation Microscanner (FMS) has already generated great excitement within scientific parties. It has logged more than 5 km of hole within ten boreholes. Shipboard processing has been stopped by system problems with the operation of the dedicated microvax workstation. The microvax is being recommissioned at LDGO. During Leg 129 temporary use was made of a TAMU user-room microvax.

The ship overhaul in Singapore provided an opportunity for all the logging tools to be checked at a Schlumberger operations base.

Japanese scientists were allowed to cut up the logging cable during Leg 128 in return for a new cable. Unfortunately the Japanese were unable to deliver the new cable in time for Leg 129, due to customs regulations. The new cable is now on board ship but its absence during Leg 129 compromised the logging operations. In retrospect, the decision to allow the cable to be cut was an operational mistake.

The sonic tool (LSS) is still being run uncentralized. The Schlumberger sonic digital tool (SDT), which ODP no longer runs because of poor performance, is being scrapped to be replaced by the dipole array sonic tool which will be especially useful for providing compressional and shear velocities in soft formations. ODP still has only the one-component VSP tool - this is the obsolete Schlumberger WST. Newer VSP tools will not fit through the drill pipe.

A calibration test of the GLT has been completed with high resolution samples from Leg 117. A joint analysis programme with KTB is planned.

During the past year there have been no tool losses in spite of hazardous logging in the Western Pacific where a number of BHAs were lost. This improved performance will result in a reduction in tool insurance premiums.

11. TAMU Briefing

(i) Packers

Pettigrew reported that the TAM straddle packer is now within ODP's domain of responsibility.

The TAM drillstring packer will be used with a new "go-devil" from around April/May 1990. This is designed to open the packer without pulsing the formation and to facilitate the deflating of the packer element.

Questions were raised as to whether the packers should incorporate a fluid-sampling capability and whether borehole fluid samples give good information. There are no TAMU engineering developments in this direction at the present time. However, a sampling go-devil from the OBCAT programme is being proposed for use with the drillstring packer. It seems appropriate to encourage communication between the OBCAT sampling go-devil and ODP sensors.

Pettigrew commented on Morin's proposal to run a downhole flowmeter in conjunction with the TAM drillstring packer in order to produce a "permeability log" of hole 504B (see Item 14, DMP Minutes, September 1989). TAMU engineers are 99 per cent certain that the goals can be achieved. The task will be facilitated by the new go-devil.

(ii) Side-entry Sub (SES)

Huey reported that the new SES, which (unlike its predecessor) does not have load limitations, allows both cable and logging tools to enter the drillpipe through the side entry port. This facility will be a major benefit when the pipe is stuck for it reduces the risk to logging tools. The new SES is characterized by:

- no depth or fatigue limitations;
- designed for faster rigging up and down;
- designed for faster changes of logging tools since tools and sources are located at rig floor level;
- safer for personnel because there is less work over the moon pool;
- greater downhole safety and flexibility for the drillstring since tools can be retrieved when the pipe is stuck, the drillstring can be overpulled, rotated, etc., and, in the worst case, string severing tools can be deployed via the axial throughbore;
- allows more efficient logging operations.

There are risks in SES deployment.

- A bad hole is still a bad hole : bridges place the drillstring at risk. Severing is costly, dangerous and time consuming.

- Logging tools in a tight-bore drill collar can act like a cork in a cork gun (e.g. the Leg 113 incident).

- The Kinley cutter/crimper can only be used if the logging cable is cut at the SES.

- Although improved, some extra rigging time remains with the new SES and this will be complicated by bad weather.

The JOIDES logging scientist should be aware of all these drawbacks.

The new SES will be ready for deployment in mid-1990.

(iii) Sealing of Re-entry Holes

Pettigrew reported on the development of a removable re-entry hole plugging device for projected deployment with instrumented holes in EPR, at sedimented ridge crests, and in Cascadia (overthrust) areas. The seal will be deployed from the ship and will latch into the re-entry cone. The sensor string will be run through the drillstring and latched into the seal. A data logger within the sealing mechanism will allow information to be gathered, perhaps via a submersible.

A project engineer is being designated. TAMU will be responsible for the hardware and seal. Earl Davis (Pacific Geoscience Centre, Canada) will be responsible for the data logger and sea floor interface. Keir Becker (University of Miami) and Bobb Carson (Lehigh University) will be responsible for the downhole sensors. Proposals for the latter two areas are currently in preparation.

DMP Consensus

Panel reiterates its support for the concept of sealing instrumented re-entry holes as originally conveyed through DMP Recommendation 89/14.

(iv) Diamond Coring System (DCS)

Storms reported that the DCS is being assembled at the Kremco facility north of Salt Lake City. The top drive has arrived from Midland, Texas. A new version of the barerock guidebase is under development. DCS hole size is 3.96 inches: core size is 2.2 inches.

The DCS will only be used where conventional drilling systems cannot be deployed. The aim is to introduce the DCS on the EPR during the third engineering leg (136) in February 1991. There has been discussion about some limited deployment during the Lau Basin Leg (135).

At present TAMU are not engaged upon any reaming activity.

12. <u>High-Temperature Technology</u>

The Chairman reviewed the current position. The DCS will probably be used initially on EPR in environments that are very hot (350°C) and pressured. The projected deployment date of February 1991 moves up the schedule for developing some high-temperature logging capability. In this short term there are only two viable options. One is hot slimhole logging through the repackaging/adaptation of existing logging tools. This is in accordance with the PCOM directive that LDGO should not develop new slimhole high-temperature tools for which, in any case, there is inadequate time and money. The other possible approach is that of hot non-slimhole logging, perhaps in DCS holes that are subsequently reamed. PCOM have voted to have a large-diameter (reamed (?)) hole at each DCS site for high-technology logging. A larger hole would admit a wider range of logging tools and would allow more effective circulation for hole cooling. However, in the absence of a proven larger-diameter (reaming) capability, it is important that all options be kept open.

DMP, through Recommendation 89/17 made immediately following the joint DMP/LITHP meeting in Windischeschenbach in September 1989, have requested that the logging contractor develop a high-temperature (but not necessarily slimhole) logging capability to address as many as possible of the following priorities, listed in decreasing order.

1. Temperature
2. Borehole Fluid Resistivity
3. Formation Resistivity
4. Natural Gamma
5. Sonic
6. Caliper
7. Flowmeter
8. Borehole Fluid Pressure

DMP added that these objectives are to be achieved by adapting existing tools, not by the development of new tools. Thus, the DMP recommendation is in accord with the PCOM directive to LDGO.

Anderson reported on progress to date. In view of the high expected temperatures, memory tools were preferred. A beneficial option might be to duplicate the Sandia memory tool for measuring temperature and pressure. This is rated to 400°C. An estimated $50,000 is needed so that Sandia can be subcontracted to adapt this (slimhole) tool for ODP use. Time required for building and testing is six months. LDGO are exploring ways of initiating a contract.

For formation resistivity a possible option is to double-dewar the ex-ARCO resistivity tool at an estimated cost of $20,000. This tool requires a cable but it could be logged going down. The prospect of success would be enhanced if a hole-cooling option could be provided. This would require a larger diameter hole (6 inches).

A continuous log of borehole fluid resistivity is conceptually straightforward but there might be engineering problems. The feasibility of adapting a simple tool should be evaluated.

[ACTION: LYSNE]

Lysne noted that the cost of meeting objectives 1-5 of the list drawn up by DMP/LITHP would exceed $1,000,000. Even if the money were available, the tools could not be developed within the available time.

DMP Consensus

In reiterating its earlier recommendations on high-temperature logging (89/17 - 89/19), Panel noted that the target for the short-term development of high-temperature logging technology was now February 1991. Within this shorter time frame the high-temperature slimhole logging needs of the JOIDES Lithosphere Panel in connection with EPR objectives cannot be fully met. The situation might be eased if reaming were a proven option under EPR conditions. In the current absence of this option, there is a need to draw up a schedule of realistic developments for different diametral constraints. This task is charged to a subgroup to meet after this DMP meeting. The minimum target should be those LITHP objectives which are the most readily achievable : temperature, formation resistivity and borehole fluid pressure. In addition, borehole fluid resistivity measurements should be investigated.

DMP Recommendation 90/2

"Facilities be created to allow the development before February 1991 of a slimhole high-temperature downhole-measurement capability at least for temperature, formation resistivity and borehole fluid pressure, together with borehole fluid resistivity if technically feasible. This development is to be based on adapting existing tools."

DMP Recommendation 90/3

"The reaming option for hole enlargement from four to six inches in diameter under EPR conditions should be fully tested."

The Chairman reiterated DMP's support for the recommendations of the Sedimented Ridge DPG and asked for a review of progress to date. These recommendations were considered in turn.

(i) The Barnes-Uyeda tool be modified for higher temperatures (up to 200°C) and be made stronger.

Progress to date

A new WSTP tool is being ordered from Ross Barnes. The WSTP is deployed by wireline after coring, is pressed into the hole floor, and can be decoupled from the pipe to avoid heave.

The new tool is rated to 100°C, has a larger water-sampling capability than the earlier version, and has a bigger chamber for the electronics. It is due for delivery in February 1990.

For high temperatures the strategy has been to retain the WSTP principle and to modify the components. The new version of the 100°C tool needs to be established first. For this reason, no money has been set aside for temperature re-specification. An obvious requirement will be titanium housings because H_2S can be expected in sedimented ridge environments. The high-temperature WSTP will be designed for operation at up to 200°C.

(ii) A slimline self-contained probe be developed or acquired to measure temperature up to 350°C.

Progress to date

This objective could be fully met through the adaptation of the Sandia temperature/pressure tool mentioned earlier.

(iii) A high-temperature fluid-sampling capability be developed.

Progress to date

High-temperature sampling of borehole fluids can be based on the Kuster sampler, currently rated to 350°C, but with different materials. Options are being evaluated.

A possibility is the Los Alamos tool which is a flowthrough, clock-operated, mousetrap-closure device manufactured entirely from a corrosion-resistant alloy of titanium. There is no communication with the tool during deployment. The tool was run in the KTB pilot hole in late 1989.

A second high-temperature tool, from U C Berkeley, departs from the Kuster principle by using a conductor cable. The tool is rated higher than the cable at 350°C.

Finally, the downhole determination of permeability was considered. The ODP straddle packer could be modified for use at 200°C but this would require special elements. An option for extending to higher temperatures might be to use a single packer in the casing and to carry out interval tests at intermediate drilling depths. Yet another alternative might be flowmeter-plus-injection surveys. Panel did not take a position on the high-temperature permeability issue, preferring to keep the options open at this stage.

<u>Working Group Report</u>

Following the main Panel meeting, many members stayed on for a special thematic session on high-temperature logging. Their deliberations were based on the foregoing information. The actions are reported here for consistency and completeness. Two principal actions were identified.

DMP National Representatives are asked to collect from within their countries all available data on the high-temperature tools that currently exist. Data should include tool diameter, temperature and pressure ratings, compatibility with Schlumberger tool connections, and whether the tool would be available on lease to ODP. This information should be sent to DMP Chairman no later than 30 April 1990.

[ACTION: NATIONAL REPRESENTATIVES]

This will allow time for the material to be synthesized and mailed out to DMP members with the agenda for the next DMP meeting.

[ACTION: WORTHINGTON]

There is a need for a long-range development plan for high-temperature technology. This should be based upon the ODP long range plan. The latter should be scrutinized and logging needs extracted. This information should be incorporated with pertinent messages from the JOIDES thematic white papers. Cost estimates should be produced and priorities listed. The task of developing a long range plan for high-temperature logging was assigned to a working group comprising Anderson, Worthington, Lysne and Sondergeld. The group may need to meet once in April in order to agree and finalize its submission.

[ACTION: ANDERSON, WORTHINGTON, LYSNE, SONDERGELD]

The aim is to mail the long range plan to DMP members with the agenda for the next Panel meeting.

[ACTION: WORTHINGTON]

The next DMP meeting will contain an agenda item which will address the comparison of the long range high-temperature logging plan with the reports of the national representatives. This will allow the identification of those scientific needs which are not accommodated by existing technology. Panel will develop a target list of required long-term technological developments for high-temperature logging.

13. Shipboard Computer Applications

Anderson outlined the current status from an LDGO perspective. A microvax had been purchased by LDGO with the intention that this would be dedicated to shipboard FMS processing using Schlumberger software. Without this processing facility, it would not be possible to provide FMS images corrected for speed and depth while the Leg itself was still underway. The estimated microvax processing time per FMS log is 30 hours. Unfortunately, the LDGO shipboard team had been unable to commission the microvax which has now been returned to LDGO so that the system can be rendered operational. The estimated time required to achieve this objective is two months. When the microvax is returned to the ship, LDGO staff will not have the experience to maintain the hardware.

Anderson is asking for TAMU help in providing the necessary operational support and maintenance. In the meantime LDGO are able to produce FMS images for shipboard use but these are not corrected for depth and speed.

Anderson also commented that the downhole measurements laboratory is not actively connected to the TAMU shipboard computer network (ETHERNET) at the present time. A log tape has to be physically carried from the downhole measurements laboratory to the vax installation. If logs are to become part of the itegrated shipboard database on the vax cluster, a computer link is essential. At present all log data are stored on MASSCOMP. This does not allow database interrogation so that selected logging data might be merged directly with core data.

Merrill reported that the logging system had been disconnected from the TAMU shipboard computer network because the shipboard computers could not handle the enormous amount of FMS data that it was proposed to transmit. The situation could be alleviated by the purchase and installation of an ETHERNET bridge which would constrain data transmission.

Anderson reported that it was no longer the intention to transmit FMS data through ETHERNET. Therefore, there was no danger of the system becoming overloaded if the downhole measurements laboratory was reconnected.

Merrill commented that the integration of logs into a vax database was a software problem. There is no point in transmitting log data to the vax cluster if there is no software data management system in place to allow the information to be interrogated. In turn, this software cannot be developed until there is an agreed user definition of output requirements.

Merrill further noted that operational maintenance for the TAMU shipboard computer system was derived through TAMU's subscription to a maritime maintenance agreement with Digital Equipment Corporation (DEC). LDGO had not become a party to this agreement without which the logistics of shipboard maintenance for the LDGO computers were difficult.

The Chairman asked what action could be taken to improve the shipboard computer situation as it pertains to downhole measurements. Merrill proposed three courses of action.

(1) The FMS-dedicated microvax and other downhole-measurement computers be incorporated into the shipboard VAX network (in view of the stated intention that FMS data would not be transmitted through ETHERNET).

(2) LDGO join with TAMU in the maritime maintenance agreement with DEC. (This currently costs around $18-22,000 in total and is unlikely to cost LDGO incrementally more than $5-6,000.)

(3) The FMS-dedicated microvax be located in the machine room where the TAMU system managers will provide back up. (However, the system managers are not conversant with Schlumberger software.)

Anderson welcomed and concurred with these courses of action.

Panel synthesized its overview of the above discussion into the following recommendation.

DMP Recommendation 90/4

"TAMU and LDGO should work towards an integrated shipboard computer system which accommodates all log and core needs. An immediately identifiable goal is that log and core data be easily and simultaneously accessed, displayed and interrogated through one database management system."

Noting the observation that user requirements have to be specified before a data management software system can be developed for the integration of log and core data, and in view of the fact that IHP is responsible for recommending software usage, DMP formulated the following further recommendation.

DMP Recommendation 90/5

"Representatives of DMP, IHP and SMP should meet in a workshop session to identify user needs and develop data presentation styles for integrated log and core data. This workshop should take place before the proposed DMP/SMP joint meeting in October 1990."

It was hoped that IHP and SMP would lend support to this initiative at their joint meeting in March 1990. Thereafter PCOM and JOI support for the workshop should be solicited.

[ACTION: WORTHINGTON]

The workshop session should be scheduled no later than August 1990. The product should be a "strawman" user definition of output requirements for the integration of core and log data. In addition to the Chairman, three other DMP members offered to participate, in one case by proxy : they were Hutchinson, Sondergeld and Wilkens.

14. Tool Monitor Reports

(i) Geoprops Probe

Karig reported that the entire tool is currently laid out prior to assembly, some minor changes are contemplated, and the current schedule provides for quick testing by mid-April. However, the unofficial aim is to try to complete the tool in time for Nankai. TAM, Inc, have agreed to accelerate development to the best of their ability. The chances of achieving the Nankai goal are slight.

(ii) LAST

Crocker reported that LAST-I is ready for use on Leg 131. Calibrations have been completed at onshore test sites. Because the onshore tests are at lower absolute pressures, the pressure transducer will be replaced for use on ODP. This replacement will be done by the end of January, followed by a final pressure test. Moran will transport and operate the tool on the Leg for its first use in ODP.

LAST-II components are completed (data collection module and pressure meter module). The final assembly is now underway at Fugro/McClelland in Houston and the onshore test will be done in Houston during the week of 29 January 1990.

(iii) VSP Nankai

No information available.

(iv) Long-term temperature tool

Kinoshita reported on progress towards the Nankai downhole observatory. The system comprises a thermistor cable with pressure and temperature gauges at top and bottom. Satisfactory tests have been carried out under temperature- and pressure-controlled conditions in the laboratory, in lakes and in the sea. Preparations for deployment are currently taking place in Guam.

(v) BGR borehole magnetometer

The Chairman read a letter from PCOM Chairman concerning the high-resolution, high-temperature (200°C) borehole magnetometer, developed by BGR of FRG, which is expected to be available in mid-1990.

Bosum and v. Rad have suggested that the first field trial be carried out in the deepened 504B. PCOM Chairman has asked for DMP's recommendation.

Panel noted the absence of good three-component magnetic data available from 504B. Therefore, the German proposal makes sound scientific sense. Furthermore, the expected bottom-hole-temperature in 504B after deepening is 200°C. This would not impede deployment of the tool.

DMP Recommendation 90/6

"The BGR of FRG high-resolution borehole magnetometer should be scheduled for deployment in Hole 504B after deepening."

15. Workshop on Log Data Quality

Progress towards fulfilling each of the 20 recommendations of the workshop held in Washington D.C. in April 1989 was not discussed. It was agreed that the Chairman would request JOI Inc, under whose auspices the workshop was convened, to approach for status reports the various parties at whom recommendations were directed. These would be reviewed at the next Panel meeting.

[ACTION: WORTHINGTON]

16. Wireline Packer

Larry Sanford (President of TAM, Inc) reviewed the background to the wireline packer. Through TAM's work for the oil industry, the company had become foremost in the development of inflatable packers that could "pass through the eye of a needle and inflate in the Houston Astradome". TAM had previously supplied permeability packers (1985) and a drilling packer (1986) to ODP. The contract for the wireline packer was signed in 1987.

Sanford reported that TAM had grossly underestimated the time taken to develop the wireline packer which had proved to be one of the most demanding projects they had ever undertaken. Although two tools, less the inflatables, had been made in under 18 months, there were problems with the pumps and motors. An improved pumping system was needed. This took a year to develop. Another improvement was to section the tool into four eleven-foot components joined by quick (dis)connects for easy handling. The tools have been tested under drawdown, not injection, conditions.

Two functioning wireline packers have been delivered to LDGO. Enquiries have been received from industry. TAM are currently manufacturing two assemblies similar to the ODP tools for lease by a major oil company. This is a clear benefit from ODP to industry for, without the ODP push to develop the prototype, the technology would not now be available for commercial use.

LDGO are to carry out an acceptance test on the wireline packer. These tests are scheduled for completion by 18 March 1990. The tools will be run in LDGO wells in the Palisades Sill. They will be deployed in several different sizes of casing to study inflation/deflation performance.

A higher temperature version is theoretically possible. The present electronics are rated to 100°C but the tool could be modified to run at somewhat higher temperatures. For example, it could operate as a single, rather than a straddle, packer.

The wireline packer is expected to be ready for deployment during Leg 131.

In response to an earlier Panel request, Anderson furnished the following chronology for the wireline packer.

<u>February 1987</u>

Contract issued to TAM for two wireline packers.

<u>October 1987</u>

In response to upcoming Leg 118, TAM offered a prototype tool (ahead of schedule) but without any testing. Review of the tool by Mark Zoback and Jorg Baumgartner (of Stanford) and Keir Becker (who would run the tool on Leg 118) indicated that although the chances of it working were quite small, it would be useful to have it on the ship in case the standard packers failed. As it turned out, the standard packer tests went quite well on Leg 118 and there would have been no requirement to run the wireline packer. This was especially fortunate as the wireline packer electronics were damaged during shipboard testing and the tool would not have worked if it had been needed.

<u>January 1988</u>

Tool returned to TAM for further development and completion of prototype.

<u>September 1988</u>

Zoback informed by TAM that the tool was nearly ready for field testing.

<u>October 1988</u>

Baumgartner and Erich Scholz of Stanford conduct a thorough evaluation of tool readiness. They identified a number of problems with the tool. While many of these problems were minor and easily solved, residual major problems were insufficient power from the electric motor in the tool and an inadequate flow rate from the pump.

<u>January 1989</u>

To try to break through the problems TAM were having with the pump and motor, Zoback and Larry Sanford (President of TAM) visited Amoco in Tulsa to see if it was possible to incorporate Amoco's proprietary pump and motor technology into the TAM tool. TAM undertook development of a pump and motor similar to those used by Amoco.

<u>March 1989</u>

Baumgartner and Scholz visit TAM again to review status of tool development.

May 1989

New, custom-built motor delivered to TAM.

June 1989

New pump completed and bench testing commenced.

August 1989

Packer testing in casing at TAM plant commenced. Zoback visits TAM to review tool status.

October 1989

Casing tests completed; search for appropriate field test site.

November 1989

Field testing at an Amoco test well in Oklahoma. Scholz attended the tests. Due to very heavy mud in the hole the packer was clogged and did not work properly. Scholz accompanied the tool to TAM for training and testing.

December 1989

Scholz participates in approximately one month of extensive training, attends casing tests (at TAM) of both wireline packers, and collaborates on final minor tool modifications.

January 1990

Tools shipped to Scholz, working at Lamont, for final field testing in the Lamont test boreholes prior to sending the tools to the ship. Scholz will go to sea to run the tool and train ODP personnel.

17. WPAC Planning

Golovchenko reported no further changes in the DMP-recommended logging programme.

Interest has been expressed in using the wireline packer to obtain water samples during Leg 133, N.E. Australia. The feasibility of this depends upon the tool performance during Leg 131 where the packer is to be deployed in casing only because of anticipated poor hole conditions. Every effort will be made to accommodate this request.

There is a vacancy for a JOIDES Logging Scientist on Leg 134, with no restrictions of nationality. In general, ODP/TAMU would be pleased to receive nominations of prospective candidates for future logging scientist positions. Panel members are encouraged to identify and solicit names.

18. CEPAC Planning

One major change has occurred. Leg 138, Eastern Equatorial Pacific, no longer has basement sites in the drilling programme. This will impact adversely on the proposed stress measurements. In order to re-establish the basement objectives, a drilling proposal would be needed for rotary drilling to basement and setting a re-entry cone. This would take an estimated three days.

DMP Consensus

In accordance with its adopted thematic thrusts, Panel reiterates its commitment to the creation of a database of global stresses. Panel regards the removal of basement objectives from Leg 138 as a potential loss of opportunity.

The matter is to be pursued through the World Stress Map Project of the International Lithosphere Programme.

[ACTION: STEPHANSSON]

19. Downhole Measurements at 504B during Third Engineering Leg

Becker reported that the Third Engineering Leg (136), scheduled around March 1991, has provision for 30 days of operations at 504B. The principal aim is to clean out the hole. If successful, a subsequent Leg (139) will be dedicated to deepening 504B. If unsuccessful, the efforts to clean will be truncated and there is then an option to commence drilling a second hole adjacent to 504B.

Hole 504B has the greatest penetration into basement of all ODP holes. It is important that a full suite of downhole measurements be obtained. Although fairly comprehensive, the existing suite needs to be augmented especially through recently-developed logging tools such as the FMS.

The proposed additional measurements are:

(a) Before engineering work

Temperature, fluid sampling and drillstring packer deployment.

(b) Before recasing

FMS, wireline packer, flowmeter packer, enhanced resolution tool and sidewall coring.

Becker outlined three options for carrying out these additional measurements:

(i) during Leg 136;
(ii) shared between Legs 136 and 139 if 504B is re-opened;
(iii) during a minileg or segment of the alternative EPR Leg 139, if 504B is not re-opened.

Panel concurred that all the proposed downhole measurements should be undertaken in order to complete the database at this important site and also to allow further science to take place.

DMP Recommendation 90/7

"Downhole temperature measurements, fluid sampling and drillstring packer experiments be carried out in Hole 504B during the third engineering leg (136) and before any engineering work is undertaken."

DMP Recommendation 90/8

"The following programme of downhole measurements, which complement existing data, should be carried out at Site 504B before recasing:

Formation Microscanner
Wireline Packer
Flowmeter Packer
Enhanced Resolution Tool
Sidewall Coring (possibly through wireline re-entry)

Options are to undertake this work during the third engineering leg (136), during a subsequent leg (139) dedicated to 504B, or during a subsequent minileg or segment of an EPR leg."

20. Lithosphere Characterization

The Chairman re-introduced the concept of a DMP-driven scientific initiative to characterize oceanic lithosphere at a multi-borehole site through detailed downhole measurements and interwell studies. The aim is to answer the questions "To what extent is an ODP drillhole representative of its locality/region? Is it merely a sample of a wide range of in-situ characteristics?"

Methods/techniques to be employed would include a full suite of downhole measurements in each borehole at a multi-hole site, comprehensive laboratory measurements of physico-chemical properties, borehole geophysics such as VSP, long-spacing electric log, etc., interwell acoustic and electrical tomography and tracer studies, all linked to detailed surface geophysics.

While there was general support for the concept, Langseth pointed out that there may be objections to a panel putting forward a drilling proposal. A solution would be to create a working group of panel members which met separately. The drilling proposal could then be submitted in the names of the proponents as individual scientists, rather than as members of the panel.

Morin pointed out that the RIDGE programme may have an interest in the concept since a ridge crest would be a possible target area for the study. Either way, he would like to participate in the working group. Other suggestions included targeting the programme around 504B which has already been well studied.

The Chairman said that he would try to progress the working group idea. Panel members who wished to participate should advise him accordingly. The matter will be discussed more fully at the next DMP meeting.

[ACTION: WORTHINGTON]

21. COSOD I Objectives

Deferred to next meeting. LDGO Liaison is asked to prepare a summary listing of COSOD I objectives together with notes on how these have been addressed/met through logging.

[ACTION: LDGO LIAISON]

22. Openness of ODP

Not discussed.

23. Panel Membership

A replacement is sought for Eddie Howell who left DMP at the end of 1989. The appointed "search committee" of Hutchinson, Worthington and Sondergeld discussed their prospects and identified a course of action. In accordance with PCOM policy, no names are being minuted. The aim is to propose an identified person, who is willing and able to serve, for PCOM approval at their next meeting.

[ACTION: HUTCHINSON, WORTHINGTON, SONDERGELD]

24. Measurement-while-Drilling

The Chairman raised the question of whether DMP should encourage the development of MWD technology for deployment in ODP phase 2. Panel view was that MWD is here to stay. At present it is incompatible with the DCS concept and it will be years before high-temperature systems are proposed. Nevertheless a realistic future logging scenario might be reconnaissance logging through MWD (natural gamma, resistivity, density, neutron and sonic) followed by wireline characterization logging over key intervals identified by the MWD logs. It is not realistic to propose that ODP develops its own MWD technology. A better course of action would be to keep abreast of the evolution of this technology so that ODP can be ready to draw upon it at the appropriate time.

DMP Consensus

Measurement-while-Drilling (MWD) technology should be very closely monitored as a basis for evaluating its possible deployment in ODP phase 2.

DMP Recommendation 90/9

"The logging contractor through LDGO and on behalf of ODP should become a corporate member of the Conoco-led industry consortium for the testing of MWD and other downhole-measurement tools. This will require that $30,000 be budgeted for FY91."

25. Integration of Core and Log Data

This matter has already been dealt with under Agenda Item 13, specifically through DMP Recommendation 90/5 and the subsequent actions.

26. Next DMP Meetings

Several members of the Panel are at sea during Leg 131 which ends on 2 June 1990. This suggests that DMP should not meet during its usual month of May. Yet, it would not be appropriate to defer beyond June. A compromise would be to meet at the very end of June, allowing Nankai participants the courtesy of a three-week recuperation period.

The next DMP meeting will take place on **28-29 June 1990 in Seattle, Washington.** D Cowan to host.

The subsequent DMP meeting is tentatively scheduled for **9-12 October 1990 in Brisbane, Australia.** This four-day meeting would encompass a visit to the JOIDES Resolution and a one-day joint meeting with SMP. Date adjustments will have to be made if the schedule of the JOIDES Resolution changes.

27. Synthesis and Thematic Publications

Becker reported that the JGR volume containing a thematic set of downhole-measurement papers, derived from a poster session at the 1988 fall AGU meeting, is shortly to be published.

The Chairman emphasized the need to maintain the technical profile of ODP, especially in view of the pending renewal negotiations. He suggested that the Basin Research paper on "Scientific Applications of Downhole Measurements in the Ocean Basins" be followed by a second paper on "Scientific Benefits ... ". A possible nucleus for such a paper is the presentation material used by the Chairman for a paper on the scientific benefits of downhole measurements in ODP within the ODP Union Session at the 1988 fall AGU meeting. This initiative should be pursued. The Chairman asked Anderson to share this task with him and invited any Panel members who wished to be active co-authors to come forward.

[ACTION: WORTHINGTON, ANDERSON]

28. Other Business

No new business.

29. <u>Close of Meeting</u>

The Chairman thanked Members, Liaisons and Guests for their contribution to the meeting, ODP/TAMU for their kind hospitality, and Dr A Fisher for his gracious hosting. The meeting closed at 3.25 pm on Wednesday, 24 January 1990.

PAUL F WORTHINGTON
7 February 1990

REPORT ON MEETING OF JOIDES SHIPBOARD MEASUREMENTS PANEL

Lamont-Doherty Geological Observatory
Palisades, New York

2-3 October 1989

1. Preamble

This meeting was attended in the capacity of Liaison from the JOIDES Downhole Measurements Panel (DMP) to the JOIDES Shipboard Measurements Panel (SMP). This report addresses those aspects of the SMP meeting which have implications for the ODP downhole measurements programme.

2. Standardisation of Shipboard Measurement Procedures

The need to standardise shipboard physical properties measurement procedures, e.g. for density and resistivity, is to be addressed through the formation of an ad hoc working group. This might best be done through a workshop along the lines of the recent DMP-driven workshop on improving log data quality through better data acquisition procedures. Participants would be former JOIDES physical properties scientists. Preferred scheduling is post-Nankai to allow input from that leg, which has a strong physical-properties emphasis.

3. Status of Shipboard XRF and XRD

Both XRF and XRD are working well. There has been concern that the XRD is not user friendly but, where there has been a strongly interested XRD scientist on board, it has proved an effective facility. When XRF and XRD are running together, substantial technical support is needed. At present there is no dedicated technician for XRD/XRF which constitutes an important laboratory complement to geochemical logging.

4. Computerised Core Barrel Data

A preliminary design of computer-generated barrel sheet was presented. All biostratigraphic data have been removed. Provision was made for three open tracks for plotting core data, e.g. P-wave velocity, and/or selected wireline log data, e.g. formation microscanner images which have a similar vertical resolution to core data. It is important that the real-time generated log data are compatible with this format. It is envisaged that the ultimate data storage system, of which the core barrel sheets provide a selective summary, would allow composite log-core comparison plots to be generated for any measured parameters.

5. **Visual Core Description**

Several technical improvements to visual core description were identified:

- digital colour scanner
- bench-top, automated XRD for routine compositional analysis
- video scanner
- image analysis of smear slides
- computer forms for data entry

6. **Relevant DMP Messages**

Five messages from the recent DMP meeting on 11-12 September 1989 were identified by DMP Liaison.

- The formulation of a Job Description for the JOIDES Logging Scientist, which might be a precursor to one for the JOIDES Physical Properties Scientist.

- High temperature logging remains the biggest challenge facing DMP : physical properties of core from these environments might have to be measured at high temperatures (and pressures) if they are to be meaningful.

- The deployment of the Formation Microscanner has been a major success : a laboratory image of core might be needed for correlation and orientation.

- A 1990 DMP science initiative is being pursued on lithosphere characterisation through interwell studies : this should involve SMP through the need for some calibrating laboratory physical properties.

- DMP hope to meet at a ship port-of-call in 1990. DMP also hope to hold a joint meeting with SMP. Both objectives could be achieved if DMP and SMP meet simultaneously in Brisbane in October 1990. Preliminary soundings have indicated that this is a viable proposition.

7. **DMP Working Group on Physical Properties**

Earlier recommendations of the ad hoc DMP Working Group on Physical Properties were summarised. Key points were as follows.

- For each parameter measured downhole there should be a corresponding measurement on board ship.

- Two types of shipboard data should be obtained, scanning of whole core and detailed measurements of core plugs.

- The major development need is for a core orientation facility.

- A spectral gamma sensor is needed for core-log depth merging.

8. <u>Developments</u>

The following developments were identified as highly desirable.

- A magnetic susceptibility tool to be run as a standard log, to complement the (excellent) shipboard physical properties data.

- A laboratory natural gamma (spectral) facility for sensing whole core, to facilitate the integration of log and core data.

9. <u>Preparation for 1990 DMP/SMP Joint Meeting</u>

A white paper should be prepared by each panel outlining measurement needs, capabilities and limitations both now and projected into the future. These should provide a framework for the joint discussions on log-core integration. The structure of each white paper should conform to the following general format.

- Nature and importance of scientific problems (from thematic white papers).

- What is needed to be measured?

- Development status and schedule (refer to Third Party Tool classification).

- Development costs.

Both DMP and SMP should initially prepare a list of the measurements that ought to be made. These lists should be merged early in 1990. The merged list should be used as a basis for the white papers.

10. <u>Report of Sedimentary and Geochemical Processes Panel</u>

Some dissatisifaction with the Barnes sampler was based on its perceived ship-time inefficiency, the fact that it returns only one sample per trip, its lack of reliability, and the risk to the entire hole in the event of massive failure. Although this criticism seems somewhat severe, the newly-designed pressure core barrel, which is still under development, was seen as potentially providing the most reliable fluid samples and thence geochemical data.

11. <u>XCB in Accretionary Wedges</u>

The XCB coring technique damages recovered core by breaking it up into "biscuits and gravy". This means that laboratory physical properties are unlikely to be useful for log calibration and correlation in friable lithologies. This might be a serious problem in accretionary wedges, e.g. Nankai.

12. <u>Core Photocopier</u>

A specially modified core copier, designed to produce a paper image of the outside of the core, has been recommended for acquisition. This would allow correlation with Formation Microscanner images and hence core correlation. Such a facility is in use at the German Continental Deep Drilling Project (KTB).

13. <u>Vertical Seismic Profiles</u>

A USSAC meeting held in Spring 1989 concluded that there should be a US national VSP laboratory with commitment to acquiring, processing and interpreting ODP VSP data, as previously encouraged by DMP. SMP endorsed that encouragement. As yet, the laboratory has not been identified. USSAC also indicated that some funds would be available for VSP tool purchase. USSAC felt that these initiatives would help to "regularise" the deployment of zero-offset VSP in ODP. DMP are responsible for the deployment rationale of all downhole measurements : this includes VSP. SMP are responsible for shipboard handling of geophysical data. DMP view remains that VSP should be run only in response to scientific needs. SMP view is that shipboard facilities are adequate to handle VSP data as needed. Both panels subscribe to the philosophy of the acquisition and integration of physical data measured at different scales. VSP is an important part of this philosophy. The establishment of a national VSP centre would encourage VSP data acquisition.

14. <u>Next SMP Meetings</u>

Target dates (venues) are February/March 1990 (TAMU, College Station) and October 1990 (Brisbane). The latter is to be a joint meeting with DMP during ship port-of-call.

<u>PAUL F WORTHINGTON</u>
5 October 1989

PFW/ECB

REPORT ON INTERPROGRAMME SCIENTIFIC MEETING ON SLIMHOLE HIGH-TEMPERATURE BOREHOLE LOGGING

Texas A & M University
College Station

16 November 1989

1. **Attendees**

The meeting was attended by representatives of the Ocean Drilling Program (ODP), the U.S. Continental Scientific Drilling Program (CSDP), the programme for Deep Observation and Sampling of the Earth's Continental Crust (DOSECC), the U.S. Department of Energy (DoE) and the U.S. National Science Foundation (NSF). In attendance were:

T E Pyle	(ODP/Joint Oceanographic Institutions (JOI), Inc.)
A Fisher	(ODP/Texas A & M Univ.)
L E Garrison	(ODP/Texas A & M Univ.)
M C Gilbert	(DoE/Texas A & M Univ.)
D Goldberg	(ODP/Lamont-Doherty Geological Observatory)
B W Harding	(ODP/Texas A & M Univ.)
E R Hoskins	(DOSECC/Texas A & M Univ.)
P Lysne	(CSDP/Sandia Laboratories)
B T Malfait	(NSF)
R Moberly	(ODP/JOIDES Planning Committee/Hawaii Institute of Geophysics)
C Otte	(DoE Geothermal Program/UNOCAL Geothermal Division)
E Pollard	(ODP/Texas A & M Univ.)
M A Storms	(ODP/Texas A & M Univ.)
H Wollenberg	(DoE Geothermal Program/Lawrence Berkeley Lab.)
P F Worthington	(ODP/JOIDES Downhole Measurements Panel/BP Research)

2. **Objectives**

The aim was to take a preliminary overview of technical issues pertaining to the logging of small diameter (4-inch) holes in hot (> 300°C) environments, and to identify ways in which any common perceived technical shortfalls might be addressed to the maximum benefit of the scientific community through a cooperative development programme.

3. **Philosophy**

Barry Harding (ODP/TAMU) set the scene by commenting that drilling and logging are integrated engineering sciences and should be approached as such. From the ODP standpoint, the development of a 4-inch Diamond Coring System (DCS) for hot environments will necessitate developments in logging technology.

4. **ODP Structure**

Tom Pyle (JOI, Inc.) gave an overview of the structure of ODP. A key issue has been the desire to broaden visibly the contact with other programmes.

5. **CSDP Drilling and Logging Technology**

Peter Lysne (CSDP) reviewed CSDP drilling efforts. CSDP represents three parties, the U.S. Geological Survey (USGS), DoE and NSF. CSDP logging requirements include logging in slim holes with high core recovery (similar to the ODP Diamond Coring System which is under development).

Large Holes:	Cajon Pass (cool) ODP - like logs used with success. Salton Sea (hot, 350°C) ODP & USGS tools used with limited success; most problems at greater depths.
Slim Holes (limited core):	extensive temperature logs successfully run.
Slim Holes (high core):	log for those parameters that cannot be obtained from core. Even this limited goal has not been attained.
CSDP Priorities:	core, temperature logs and fluid samples are of prime importance. In-situ stress, fracture orientation and bulk property logs are needed.

Novel engineering applications include the use of the borehole televiewer (BHTV) for identifying zones of lost circulation.

A major problem is what happens above 300°C. Memory tools (temperature/pressure, natural gamma) are being developed in order to overcome cable problems and these might be rated to 500°C. Fluid samplers are available to 400°C but further refinements are needed. Directional survey tools are being developed to 350°C.

In reality, 400°C is a useful target specification which will cover most of the situations that might be encountered.

Prognosis for memory tools:

Straightforward	gamma-gamma density neutron porosity
Medium difficulty	normal resistivity acoustic natural gamma spectral

Difficult	televiewer focussed electric
Very difficult	pulsed neutron tools induction
Exceedingly difficult	geochemical logging tool

6. <u>ODP Drilling Technology</u>

Mike Storms (ODP/TAMU) reviewed ODP drilling and coring technology. The standard method is still the rotary core barrel (RCB). The advanced piston corer (APC) has been developed for improved recovery in softer sediments : there is no rotation involved. The extended core barrel (XCB) is used to core harder sediments : the cutting shoe is ahead of the main bit to facilitate core recovery. The XCB has recently been modified for deployment in even harder sediments. RCB, APC and XCB are wireline coring systems.

The Navi-drill core barrel (NCB) is also a wireline-retrievable core barrel. The NCB system penetrates ahead of the XCB bit as coring commences. NCB produces a slightly smaller core. NCB enables diamond coring bits to be used within the operating window for which they were intended. NCB will also allow the Geoprops Probe to be emplaced.

A bare-rock guidebase has been deployed for bare-rock drilling, eg. near ridge crests.

A diamond coring system (DCS), based on the experience of the mining industry, is being developed with a top-drive concept. This is to be used in conjunction with a re-entry cone to secure a better core recovery in hard rock than has been achieved using ODP standard technology which is derived from the petroleum industry. Once again, DCS has a wireline-retrievable core barrel.

7. <u>ODP Logging Technology</u>

Paul Worthington (ODP/JOIDES Downhole Measurements Panel) gave an overview of current ODP logging capabilities. These comprise "standard" logs which are run routinely and "special" tools which are run according to particular scientific demand. Tool diameters are $3^5/_8$" and tools are rated to 170°C except where indicated. The logging cable is rated to 150°C.

Standard Logs

Three tool strings are used which include:

(i) Seismic-stratigraphic string:

Dual induction	(resistivity for porosity)
Long spacing sonic	(acoustic velocities)
Lithodensity	(density for porosity)
Neutron porosity	(porosity)
Natural gamma spectral	(depth control, K, U, Th)
Caliper	(hole size)
Temperature (100°C)	(heat/fluid flow)

(ii) Geochemical string:

Natural gamma spectral	(depth control, K, U, Th)
Aluminium clay tool	(Al)
Induced gamma spectral	(Ca, Si, ...)

(iii) Structural string:

Formation microscanner	(high resolution imaging)
Natural gamma	(depth control)

Special Logs

Borehole televiewer	(stress, imaging)
Magnetometer/susceptometer	(magnetics)
Dual laterolog	(resistivity)
Well seismic	(VSP)
Multichannel sonic	(acoustic velocities)
Fluid pressure/sampling	

Future needs for high-temperature slimhole applications would ideally encompass all the above. However, in the real world of ODP, not all standard tools can be slimholed. There is a need for deployment of high-temperature slimhole logs in mid-1991. In order to focus efforts, the following development priorities have been identified for a 4-inch hole with temperatures up to 350°C.

For ODP Logging Contractor (LDGO)

1. Temperature
2. Borehole Fluid Resistivity
3. Formation Resistivity
4. Natural Gamma
5. Sonic
6. Caliper
7. Flowmeter
8. Borehole Fluid Pressure

Items 1-5 are considered vital.

For ODP Science Operator (TAMU)

1. Permeability
2. Pore Pressure
3. Pore Fluid Sampler

In order to address the above logging objectives in the short-term, off-the-shelf logging tools should be re-packaged. These are currently rated to 260°C. Repackaging might achieve the target of 350°C but 300°C is more realistic. Hole cooling might extend the range above 300°C but it is risky. Above 300°C there are also cable problems.

Repackaging might allow some short-term objectives to be achieved but it does not provide a long-term solution. Key tools (eg. geochemical tool) are not available. The community needs a long-term (10-year) assessment of scientific needs so that technical shortfalls can be identified in the ability of logging to meet those needs. These shortfalls should be rectified collaboratively through inter-programme cooperation.

8. The DOSECC Position

Earl Hoskins (DOSECC/TAMU) reported that a new proposal is being submitted for two years' support but only at a very basic level. DOSECC are therefore unlikely to be able to offer any financial contribution to a collaborative logging-tool effort over this period.

9. Available High-Temperature Slimhole Tools

Dave Goldberg (ODP/LDGO) presented the results of a simulation study of the effectiveness of borehole cooling undertaken by Mark Langseth of LDGO. The principal conclusion was that cooling is unlikely to be effective in 4-inch holes because of the limited circulation through the narrow annulus around the tool. It is therefore necessary to use tools rated to 350°C for logging in hot slimhole environments.

A survey of off-the-shelf logging tools for hot and/or slimhole deployment has revealed that only one core service company slimhole tool is rated for temperatures greater than 300°C. This is the Atlas Wireline production logging tool designed for geothermal wells. The tool can operate at 315°C for twelve hours and measures temperature, pressure and flowrate.

Sandia Laboratories have developed a memory tool rated to 360°C that records temperature and pressure as a function of time. The high-temperature electronics developed by Sandia might be available to others.

Since the time to DCS deployment is so short, high-temperature slimhole tools need to be developed now. This should be addressed through the repackaging of existing tools rather than by the development of new ones. Self-contained digital memory units ought to be considered in order to avoid the need for special logging cables. There are good prospects that some of the conventional tools might be packaged and kept sufficiently cool in dewars to allow several of the standard measurements to be carried out.

In the period spanning FY91 - FY92, five of the seven ODP legs will require high temperature tools. Temperature and natural gamma memory tools are available now. In developing others we should concentrate on those measurements which cannot be made on core.

10. <u>Forward Strategy</u>

It was unanimously agreed that joint action should be initiated towards the development of slimhole high-temperature logging technology. To set the ball rolling and establish a suitable profile for the initiative, two actions were agreed.

(i) Tom Pyle to write formal letters of approach to the Inter-Agency Coordination Group (DoE, USGS, NSF) and to the Geothermal Technology Division of DoE. These letters should raise the question of co-funding identified logging developments of joint interest.

(ii) Peter Lysne and Paul Worthington to co-author a technical position paper on high temperature slimhole logging for submission to EOS. The aim is to give the collaborative initiative a high profile within the technical community.

It was generally considered that once the proposal for collaborative funding had been accepted, a detailed work programme would need to be drawn up by an appropriately convened task force.

PAUL F WORTHINGTON
17 November 1989

PFW/ECB

REPORT ON ODP WORKSHOP ON PROGRESS AND OPPORTUNITIES IN GEOCHEMISTRY

UCLA Conference Centre
Lake Arrowhead
California

9-12 January 1990

1. Preamble

The workshop was convened by G Brass (University of Miami) and M Kastner (Scripps Institution of Oceanography). The purpose was to review the status of Geochemistry in the Ocean Drilling Programme (ODP) and to develop strategies for the future. Specific targets were to identify future large geochemical efforts in ODP, to formulate plans and explore tentative proposals, to define effective sampling strategies, to identify necessary new tools, and to assess the potential for long-term monitoring in ODP holes. This initiative was timely because of the recent emphasis on thematic planning in ODP, the emergence of new facilities such as the Geochemical Logging Tool (GLT), and the drive towards higher-resolution sampling. These notes emphasise those aspects of the workshop which have implications for downhole measurements.

2. Structure

Working groups were formed to address each of the following issues which are classified as either scientific themes or data-acquisition technology.

Scientific themes:

Crustal Alteration (Layer 2)
Chemical Fluxes
Global Mass Balance
Palaeoceanography
Diagenesis
Organic Geochemistry

Data-acquisition technology:

Geochemical Logging
Downhole Tools and Techniques

3. Thematic Needs

Several broad needs emerged in terms of required downhole technology:-

continuous characterisation of inorganic solids with high spatial resolution;
(high-temperature) packers with samplers and probes for characterising individual horizons;
programme of routine organic geochemical data acquisition.

The technology groups considered the progress made to date in meeting these thematic needs and the opportunities that exist for future advancement.

4. Geochemical Logging

The working group on geochemical logging was led by P F Worthington (BP Research). The following is its report.

4.1 Summary of Recommendations

(1) Continue the policy of routinely obtaining logs with the Geochemical Logging Tool (GLT).

(2) Implement improved procedures for the effective integration of core and log data, requiring XRF and XRD shipboard measurements on samples from log-derived key intervals.

(3) Replace JOIDES logging and physical-property scientists with JOIDES physical and chemical characterisation scientists. Formulate job descriptions.

(4) Quantify intrinsic and field accuracies and precisions for the GLT.

(5) Develop signal enhancement procedure(s) for a target GLT vertical resolution of one foot (30 cm).

(6) Deploy an Enhanced Resolution Tool at the earliest opportunity.

(7) Include a core natural gamma spectral facility on board the JOIDES RESOLUTION.

(8) Investigate the global/regional/local validities of element-to-mineral transforms.

4.2 Introduction

In its broadest sense geochemical logging can provide information relating to the chemical composition of the oceanic lithosphere (both solids and fluids), to the way in which the chemical constituents are distributed, and to those dynamic processes which govern fluxes and flowpaths. Thus, temperature logs, porosity logs (density, neutron, sonic, resistivity), and permeability indicators (eg. sonic waveform logs) all have an interactive role to play. However, for present purposes we are taking a more specific view by focussing on the Geochemical Logging Tool (GLT), developed and operated by Schlumberger, which has already been widely deployed in the Ocean Drilling Programme. We shall consider logs measured using the GLT as "geochemical logs". In so doing, we shall concentrate primarily on the geochemical evaluation of solid rock as opposed to the interstitial fluids. We shall confine ourselves to inorganic geochemistry. Although there are promising indications from the oil industry that carbon/oxygen ratios measured by the GLT (in inelastic mode) can be used to derive total organic carbon (TOC) in sediments, this facility has only received limited application in ODP.

Here our aims are to assess progress made to date, to evaluate what can be done to improve data quality in the short term, and to identify opportunities for further developing the interpretative technology in the future.

4.3 Geochemical Logs

Properly calibrated geochemical logs form an important part of the scientific legacy of an ODP drill hole. They provide a continuous geochemical signature at in-situ conditions and with a spatial resolution of about 2 ft. (60 cm). Geochemical data at this larger scale of measurement constitute a useful basis for the calculation of fluxes. One cannot integrate and extrapolate core data to achieve the same end-product because of the complementary nature of core and log measurements, ie. core data have high resolution but relate to a small volume of rock, whereas log data have lower resolution but relate to a much larger (100 times) volume of rock. The key to successful geochemical characterisation is to use the high resolution, and thence greater accuracy and precision, of core data to calibrate the otherwise less accurate and precise log data.

The logs are not as accurate and precise as laboratory data. However, with core calibration the accuracy and precision of the signature can be enchanced. This is an important point because good geochemical logs are often obtained where core recovery is limited, eg. in (uncased) basement holes, and therefore the logs have to provide meaningful interpolation between core data locations. This continuity is essential for complete geochemical surveys of a drill-hole and for interpolation between sites.

Geochemical logs can provide a geochemical signature in the form of elemental concentrations, mineralogy in terms of a pre-specified mineral domain, and other derived products such as grain density.

4.4 Geochemical Signature

The geochemical signature takes the form of the absolute concentrations of 12 elements: K, U, Th, Al, Si, Ca, Fe, S, Ti, Gd, H, Cl. The establishment of absolute concentrations of Si, Ca, Fe, S, Ti, Gd, H, and Cl requires post-cruise processing. If core calibration can be incorporated, enhancement of accuracy is possible. Since H and Cl relate primarily to the fluids, they are not considered further. We shall think in terms of a ten-element geochemical signature which can be developed through post-cruise processing.

On board ship, it is possible only to provide a preliminary geochemical signature in the form of absolute concentrations of K, U, Th, and Al, and relative concentrations of Si, Fe, Ca and S (plus H and Cl). This information can be supplied in real time. It has two important uses:

(1) it sets in context the significance of geochemical changes as seen in measurements of (discontinuous) cores;

(2) it serves as a guide to subsequent core sampling for enhancing the accuracy of later determinations of absolute elemental concentrations.

Accuracy enhancement of the geochemical signature requires some controlling laboratory data, such as XRF and XRD. These facilities are underutilised on board ship. This is unfortunate, because core and log data are complementary in terms of resolution and scale. It is possible to derive maximum benefits by using the high resolution core data to calibrate the larger-sampling log data. This aspect will be developed more fully later.

4.5 Mineralogy

The availability of XRF and XRD data allows the controlled progression from the geochemical signature to mineralogy. XRF data allow the assumption of a ten-element domain to be verified. XRD data allow one to determine the 5-10 most common minerals in order to optimise the inversion process. XRD data also allow one to test the appropriateness of the oxide closure model, used to convert relative elemental concentrations to absolute values for Si, Ca, Fe, S, Ti and Gd. If these assumptions are all satisfied, the derived mineralogy will be realistic; if they are not satisfied, the elemental concentrations wil be erroneous and the subsequently determined mineralogy will contain artefacts. The key to controlling the interpretation procedure is the effective integration of core and log data.

Schlumberger claim other derived products that can be determined from the mineralogy. Some of these seem intuitively realistic, eg. grain density and clay types; others are less convincing, eg. permeability. The only derived product we consider is the mineralogy, and that is viewed as subordinate to, and less reliable than, the elemental signature for present purposes.

4.6 Case Histories

Here we give an example of the uses of geochemical logging to solve scientific problems within each of the thematic working groups on inorganic geochemistry established within this workshop.

(1) Alteration of the Oceanic Crust - Layer 2

In Hole 504B, permeability was measured by pumping below packers inflated in the hole. These measurements showed a marked drop in permeability 300 m into the oceanic crust, whereas the porosity values from the electrical resistivity logs indicated continued high porosities. How can high porosities be reconciled with the low permeabilities in the lower pillow basalts of the upper crust? The geochemical logs show strong correlations between (a) high Si and Mg content and low Al and Ca content and (b) high porosity values within this zone of the hole. The geochemical logs are detecting the stoichiometry, or the chemical composition, of clay minerals that were precipitated in fractures and pore spaces as a result of the sealing of hydrothermal circulation. Subsequent sampling and laboratory measurement of core samples verified that these alteration zones contain high cation exchange capacities that account for the "false" porosity indicators.

(2) Chemical Fluxes between the Crust and the Ocean

Also in Hole 504B, the continuous nature of the geochemical log-derived elemental abundances leads to a direct measure of the integrated chemical exchange between the basalts and sea water from bottom to top in the hole. The integrated differences between the compositions of the freshest dikes from the bottom of the hole and the altered basalts from the upper dikes and pillow units show that (a) there has been a significant addition of Si caused by quartz precipitation at the dike-pillow boundary, (b) Al has a lower concentration in the zone of maximum clay precipitation in the lower pillow basalts, (c) Ca is depleted and Mg enriched from the hydrothermal alteration of basalts, just as predicted from laboratory experiments, (d) significant Fe loss is from black smoker and off-axis, ridge-flank advection into the ocean, combined with some primary decrease in Fe and Ti content of the pillow basalts relative to the dike basalts, and (e) the K, which shows strong enrichment in the upper pillow basalts due to low temperature alteration, is derived from depletion in the dikes as well as from extraction from circulating sea water.

(3) Global Mass Balance between Subduction and Arc Volcanism

In the Bonin Arc, geochemical logs record the continuous sequence of arc volcanism back in tme. High-K dacites and rhyolites, found below high Fe and Mg boninites, require a source for the potassium enrichment either from subduction during the Oligocene of high-K oceanic sediments, contintentally-derived high-K sediments or basement rocks, or from massive fractionation of very large volumes of arc tholeiites into boninites and residual dacites.

(4) Palaeoceanography

On the western continental margin of Australia, geochemical logs record the sequence of onlap and offlap of sediments caused by the rise and fall of sea level in accordance with the Vail curve. Chemical changes in the sediments from high Al, Fe, and Ti clastic sediments to high Si sands, then high Ca carbonates, record the fall and rise again in sea level on the margin.

In the Japan Sea, high frequency cyclicity in Al and gamma-ray logs records the changes in climate on mainland Asia that resulted in changes in the flux of windblown dust deposited on the sea floor. The 41 ka periodicity of this log-derived cyclicity identifies the climatic forcing function to be Milankovitch orbital perturbations.

(5) Diagenesis

In the Peru continental margin, the Cl curve from the geochemical logs identified an inversion in pore fluid salinity from more saline fluids above to fresher pore fluids below a prominent seismic reflector. The changes in pore fluid chemistry reflect major causes and effects of diagenetic changes in sediments.

4.7 Integration of Core and Log Data

Calibrated logs are needed to set core data properly in perspective. We propose the following strategy for the effective integration of core and log data for optimised interpretation.

The recommended procedure is to use the preliminary geochemical signature, available on board ship in real time, to identify zones of apparent geochemical consistency within each major litho-unit. For each target zone, XRF and XRD data should be determined at regular sampling intervals (15 cm) and averaged over distances that correspond to the vertical resolution of the logging tool. Appropriate weightings that reflect tool response should be applied. These weightings and the vertical resolution vary between the three groups of elements determined by the three different tools in the same tool string. The averaged core data (XRF and XRD) provide the basic control on refined interpretations of elemental concentrations, and thence inferred mineralogy, which become available post-cruise.

This strategy would be better implemented by redefining the job descriptions of the JOIDES logging scientist and at least one of the two JOIDES physical properties specialists. It is proposed to replace these functions with two integrated functions that cover both logging and laboratory properties. These new functions are:

JOIDES Physical Characterisation Scientist (responsible for the physical properties log and core measurements);

JOIDES Chemical Characterisation Scientist (responsible for geochemical log and XRF/XRD core measurements).

4.8 Opportunities for Future Developments

(1) Accuracy and Precision

There is a need to define the operating limits of accuracy and precision for each element seen by the GLT. Intrinsic accuracy can be determined by comparing measured data with absolute standards, if these exist. Intrinsic precision is governed by the statistics of counting. Both accuracy and precision are degraded by the limited vertical extent and lack of physico-chemical constancy of the target beds. Studies directed at defining accuracy and precision should recognise that the intrinsic quantities might be influenced by variations in composition, while the field-measured quantities might also be borehole-specific.

(2) Enhanced Resolution Tools

It might be possible to determine the concentrations of other key elements, such as Mn and Ba, by adapting the existing geochemical logging tool. Other desirable elements that cannot be readily evaluated through conventional sodium-iodide detectors, as used in the GLT, might include Ni, Cr, V, Sr, La and P. The greatly improved spectral resolution attainable with solid-state detectors would allow some of these elements to be measured. Developments in enhanced resolution tools should be closely monitored with a view to deploying them in ODP at the earliest opportunity.

(3) Deconvolution/Signal Enhancement

A sharper spatial resolution for the GLT might be attained by deconvolution or by using other (high-spatial-resolution) logs to specify the boundary conditions. A one-foot (30 cm) vertical resolution would be a useful target. Any such technique would be retroactive, ie. it could be applied to logs obtained in the past. Among the obvious benefits of a sharper spatial characterisation would be better time resolution in sedimentary sequences.

(4) Element-to-mineral Transform

The applicability of element-to-mineral transforms needs to be established. Is there any case for a global transform and, if not, how extensive an application does a particular transform have? Unless these questions are answered, the use of the GLT to establish mineralogy will have limited acceptance. A key issue is the role of XRD calibration. With this control it might be possible to establish optimum transforms for each principal lithology.

(5) Shipboard Measurement

In addition to XRF and XRD, a core gamma spectral facility should be introduced to assist with core-log depth merging and to provide high resolution K, U, Th data. In the longer term, continuous whole-rock bulk-analysis methods should be encouraged.

(6) Logistics of Core-log Integration

If a casual approach to XRF and XRD data acquisition is allowed to continue, a piecemeal output can be expected. To avoid this situation, specific job descriptions should be developed for the two replacement, scientific positions proposed herein. In particular, it should be incumbent upon the JOIDES Chemical Characterisation Scientist to supply all identified XRF and XRD data to the ODP Logging Contractor as input for the advanced (research grade) processing of the GLT data.

4.9 Conclusions

The GLT is at the appraisal stage. We are still learning how to get the best out of it. The recommendations that have been formulated here will contribute to that goal. Geochemical logs do, of course, form but a part of the package of downhole measurements that are regularly deployed in ODP. The conjunctive use of all core and log data constitutes the optimum strategy for scientific formation evaluation.

5. Downhole Tools and Techniques

The working group on (other) downhole tools and techniques was led by K Becker (University of Miami). The following is its report.

Other than geochemical logs, a number of special downhole tools and techniques will be critical to achieving the scientific goals and priorities outlined elsewhere in this volume. The highest-priority goals include: sampling in-situ fluids and extracting them at in-situ conditions, measuring geochemical fluxes, and determining the flow patterns that account for these fluxes. A variety of samplers and experiments that will contribute towards achieving these goals are presently available or under development for ODP use.

Although the high-priority objectives cannot presently be met, the developments in progress offer great promise for future success, and the workshop encourages the necessary engineering effort. The workshop strongly endorses three particular tools/experiments for the highest-priority development effort:

1. the pressure core sampler
2. packers with fluid samplers and tracer experiments
3. instrumented boreholes with long-term sensors to measure temperature, flow, fluid conductivity, and chemical compositions.

In addition, it is critical that these experiments be engineered to function in the unstable or harsh (high-temperature, possibly corrosive) environments where goechemical fluxes may be most active and interesting.

Another promising new tool for the interrogation of fluids is the Nuclear Magnetic Resonance (NMR) tool.

The following is a summary of the status of geochemical sampling tools and experiments.

(R = routine from drillship: T = tested but not yet routine: D = under development: F = future development: Hi T? = usable or modifiable for use at 350°C: WLR? = possible deployment by wireline re-entry: Y = yes : X = no or not yet).

Tool/Experiment	Status	Hi T?	WLR?
A. Borehole fluids			
Kuster sampler	R	?	?
Gieskes sampler	D	?	Y
B. Sediment pore fluids			
WSTP (Barnes)	R	?	X
Pressure core barrel	D	?	X
APC sampler (?)	F?	?	X
Geoprops probe	D	X	X
C. Hard rock formation fluids			
Wireline packer	T	X	Y
Drillstring straddle packer	R	X	X
Cann OBCAT sampler	T	?	?
Rotatable single packer	T	X	X
'Probeless PWS'	T	X	X
D. Core samples			
Schlumberger sidewall corer	R*	X	Y*
Pressure core barrel (see B)			
Navidrill core barrel	T	?	X
Diamond coring system	D	Y	X
E. Instrumented boreholes			
Unsealed	R	X	Y
Sealed	F	Y	Y

* Schlumberger sidewall corer is routine in industry, but the tool is too large to fit down ODP drill pipe. It could be deployed by WLR, if permitted by Schlumberger.

6. A full workshop report comprising "white papers" from each of the working groups will be issued by JOI-USSAC in due course.

Paul F Worthington
16 January 1990

Basin Research (1989) **1**, 223–236

Scientific applications of downhole measurements in the ocean basins

Paul F. Worthington
BP Research,
Sunbury-on-Thames TW16 7LN, England

Roger N. Anderson and Richard D. Jarrard
Lamont Doherty Geological Observatory, Palisades, NY 10964, USA

Keir Becker
University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA.

J. Sebastian Bell
Institute of Sedimentary and Petroleum Geology, 3303–33rd Street NW, Calgary, Alberta T2L 2A7, Canada

Matthew H. Salisbury
Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2, Canada

Ralph A. Stephen
Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

ABSTRACT

The well logging activity of the Ocean Drilling Programme, which deploys the most technically advanced suite of downhole measurements available for routine use, is providing new opportunities for advancement in marine geoscience. Particular examples are cited of the application of wireline data to problems associated with global environmental changes, crust/mantle interactions, crustal fluid circulation in the context of a global geochemical budget, lithospheric stress and deformation, and evolutionary processes in oceanic communities. Further technological developments will expand the scientific role of downhole measurements still further, especially in terms of the integration of geophysical data at different scales of measurement, and the interpretation of these data in accordance with global scientific themes.

INTRODUCTION

A principal arena for scientific applications of downhole measurements is the Ocean Drilling Programme (ODP), the 'successor' of the Deep Sea Drilling Project (DSDP). This is an international partnership of scientists and governments who have joined together in order to explore the Earth's structure and history as it is revealed beneath the ocean basins. The ODP is one of the premier research programmes in contemporary geoscience and it is serving as a basis for strong advancements in our understanding of the Earth.

An important element of this growth in understanding is the *in situ* physical and chemical characterization of oceanic sedimentary and basement rocks. Downhole measurements in the form of wireline well logs provide a continuous record of petrophysical and geochemical properties at *in situ* conditions and at a measurement-scale which is intermediate relative to those of core analysis and geophysics. A comprehensive logging programme therefore allows the interpretation of drilling results from the ocean basins to be placed on a much sounder quantitative footing than is possible otherwise.

The assemblage of well logging tools available for ODP use constitutes the most technically advanced downhole-measurements capability that is being deployed routinely within the world today. These tools have been described previously (Worthington *et al.* 1987) and they are summarized for completeness in Table 1. In the absence of hydrocarbons, the response of virtually all logging tools is

Table 1. Shipboard logging tools.

Combination/tool	Principle of operation	Parametric objective
Seismic-stratigraphic		
Full waveform sonic	Traveltime of sound (eight receivers)	Sound velocity and attenuation (compressional and shear)
Dual induction	Induced current (deep sensing)	Conductivity (resistivity)
	Induced current (medium sensing)	Conductivity (resistivity)
Spherically focused	Alternating current (shallow sensing)	Resistivity
Gamma ray	Natural gamma-ray emissions	Gamma count rate
Caliper	Electrical monitoring of mechanical gauge	Hole diameter
Litho-porosity		
Neutron	Slowing down/absorption of neutrons from moderate energy source	Porosity
Spectral density	Scattering/attenuation of gamma rays	Bulk density (porosity)
		Photoelectric absorption factor
Natural gamma spectral	Natural gamma-ray emissions	Total gamma count rate plus constituent count rates for uranium/potassium/thorium
Geochemical		
Induced gamma spectral	Gamma-ray emissions from slowing-down/ absorption of neutrons from downhole accelerator	Gamma-ray energy spectrum (elemental analysis)
Aluminium activation	Gamma-ray emissions from slowing-down/ absorption of neutrons from low energy Californium source	Gamma count rate windowed for aluminium (elemental analysis)
Natural gamma spectral	Natural gamma-ray emissions	Total gamma count rate plus constituent count rates for uranium/potassium/thorium
Additional tools		
Dual laterolog	Alternating current (deep sensing)	Resistivity
	Alternating current (shallow sensing)	Resistivity
General purpose inclinometer	Orientated magnetic field and inclination	Vector components of magnetic field
		Hole azimuth and direction
Well seismic tool	Traveltime of sound between surface shot point and wellbore geophone	Sound velocity
		Depths to reflecting horizons
	Single-component waveform	VSP (single-component)
Seismic acquisition tool	As above but with three-component waveform	VSP (three-component)
Borehole televiewer	Ultrasonic reflection	Hole diameter
		Reflectivity (image)
Multichannel sonic tool	Traveltime of sound (12 receivers)	Sound velocity and attenuation (compressional and shear)
Temperature	Thermistor	Formation temperature
Water sampler	Pressure intake	Pore water chemistry
Large-scale resistivity	Direct current (very deep sensing)	Resistivity
Geomagnetic	Orientated magnetic field	Vector components of magnetic field, susceptibility
Drillstring packer (rotatable/ straddle)	Single/double element assembly for investigating hydrogeological properties	Pore pressure, permeability, temperature, pore water chemistry

governed by mineralogy, fluid salinity and porosity. A knowledge of mineralogy, and of fluid salinity (determined from pore-water samples), is a prerequisite for the determination of porosity from well logs. Permeability cannot be evaluated from well logs, merely estimated, and therefore packer experiments are carried out to evaluate permeability directly.

In this paper the role of downhole-measurement technology in addressing scientific objectives is discussed in terms of the five topics which have provided the technical framework for the Second Conference on Scientific Ocean Drilling (COSOD II, 1987). In this way an overview can be presented in the most contemporary scientific setting. It is hoped that this paper will generate an improved appreciation of the scientific value of well logging and its potential for the future.

CHANGES IN THE GLOBAL ENVIRONMENT

Rhythmic, cyclic and long-term environmental changes recorded in the mineralogy or grain size of marine sediments can be recognized in modern well logs provided that the sedimentation rate is sufficient to produce resolvable events. Logs are especially well suited for addressing problems of environmental change since the solutions frequently require a continuous stratigraphic record in order that the effects of variations in climate and ocean circulation upon sediment composition and texture can be recognized. Improvements in stratigraphic resolution are most likely through the combined use of seismic information, diverse well logs and bio- and lithostratigraphic data from core studies. The use of core data alone is inadvisable for these are rarely sufficiently continuous.

Environmental controls

Mineralogy or porosity changes that are log-detectable can be caused by climatic variables such as aridity/humidity, wind patterns, sea-level, water temperature, and oceanic upwelling.

(1) Aridity/humidity changes affect clay type and/or clay abundance. Changes in clay type are apparent in natural gamma spectral, spectral density, and aluminium activation logs. Changes in clay abundance are apparent in gamma ray, natural gamma spectral, and the combination of neutron and spectral density logs.

(2) Wind patterns affect the grain size and the abundance and type of minerals in pelagic sediments. Porosity, which is closely related to grain size for uncemented pelagic sediments, is very well determined from logs. Porosity is often the dominant variable controlling the responses of the sonic, resistivity and spectral density logs, whereas hydrogen content, a porosity indicator, is determined by the neutron and induced gamma spectral logs. Mineral abundance can be determined from inversion of either the physical property logs (sonic, resistivity, spectral density, and gamma ray) or the geochemical logs (Ca, Si, Al, Mg, Ti, K, Fe, Mn, S, Th, H, Cl, U, and Gd from the natural gamma spectral, aluminium activation, and induced gamma spectral tools): ODP generally uses both.

(3) Sea-level changes, like wind pattern changes, affect the grain size and mineral abundance of sediments. Log responses to these sedimentary changes have been described above. The logs cannot distinguish whether the sedimentary changes are caused by wind patterns or eustatic sea-level variations, but sedimentological studies of cores often remove this ambiguity.

(4) Changes in either water temperature or upwelling affect the type and abundance of biogenous sediment components. Biogenous components are determined in the same way as other minerals. Determination of calcite abundance is relatively straightforward; however, the logs do not distinguish whether the calcite is in nannofossils, foraminifera, or detrital grains. Determination of radiolarian and diatomaceous opal is more difficult, as most other minerals also contain silica. Changes in radiolarian and diatomaceous contents are more often indicated indirectly by logs, through their effect on porosity. This aspect is discussed more fully later.

Cyclic events

A major issue to be addressed by ODP is the enhancement of stratigraphic resolution through the recognition of the Milankovitch climatic cycles in ocean sediments. These climatic cycles are believed to be driven by Earth orbital variations (Hays, Imbrie & Shackleton 1976; Fischer 1986). These orbital changes will often cause some type of cyclic variation in the local pelagic sequence, though the most important climatic fluctuations will vary regionally. For example, Milankovitch climatic cycles in logs from the Labrador Sea are probably caused primarily by changes in oceanic current patterns, while Milankovitch cycles in logs from the Ontong–Java Plateau may be caused by changes in the foraminifera/nannoplankton ratio. Milankovitch recognized eccentricity changes at 95,000 year periods, obliquity changes at 41,000 years, and precession changes at 19,000 and 23,000 years. Verification of these cycles is a principal ODP objective to which logging can contribute strongly (Fig. 1).

For the study of Milankovitch cycles in ODP holes, logs have two powerful advantages over cores: (i) continuous uniform sampling throughout the drilling interval, independent of core recovery; and (ii) measurement of a wide variety of variables that may be climatically influenced. Accurate sedimentation rates from cores are needed in order to determine the temporal frequency of log cycles. Virtually all studies of Milankovitch cycles in DSDP and ODP cores have been limited to the Plio–Pleistocene, because only hydraulic piston cores have sufficient core recovery and they seldom can be used deeper than 150 m. In contrast, continuous sampling by logs is not limited to shallow depths.

An example of the recognition of the main Milankovitch climatic cycles is provided by data from ODP Leg 105, Site 646 in the Labrador Sea, where it was hoped to track the movement of an upwelling zone across the drill site from the Palaeocene to the Lower Pliocene. Fluctuations in the latitude of the centre of the upwelling zone across the well site are manifested by cyclic changes in porosity (Fig. 2). Micropalaeontology has indicated a sedimentation rate of 100 m My^{-1} above 335 m depth and 52 m My^{-1} below. Fourier analysis of the pseudo-porosity log calculated from a resistivity log through Archie's law (Archie 1942) has furnished amplitude spectra in terms of the number of log cycles over a reference depth interval. These can be scaled to amplitude spectra in terms of the number of log cycles over corresponding time intervals according to the prevailing sedimentation rates. From these spectra there is clear evidence for energy peaks at the 95,000 and 41,000 year periods for the higher sedimentation rate (100 m My^{-1}) and at the 95,000 year period for the lower sedimentation rate (52 m My^{-1}). The 41,000 year period is not strongly identifiable at the lower sedimentation rate because this period corresponds to 2 m of sedimentary

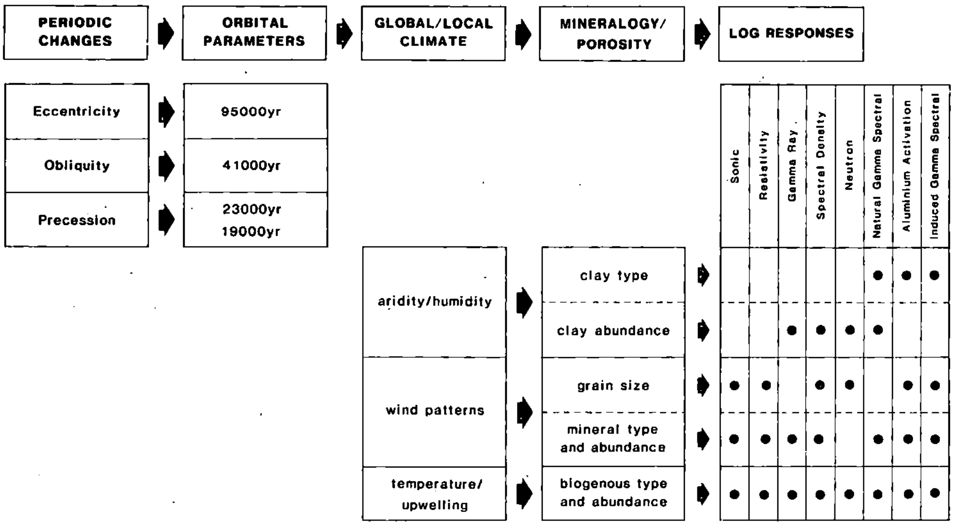

Fig. 1 Schematic depicting the recognition of Milankovitch cycles in logs through variations in mineralogy and/or porosity caused by orbit-induced climatic changes.

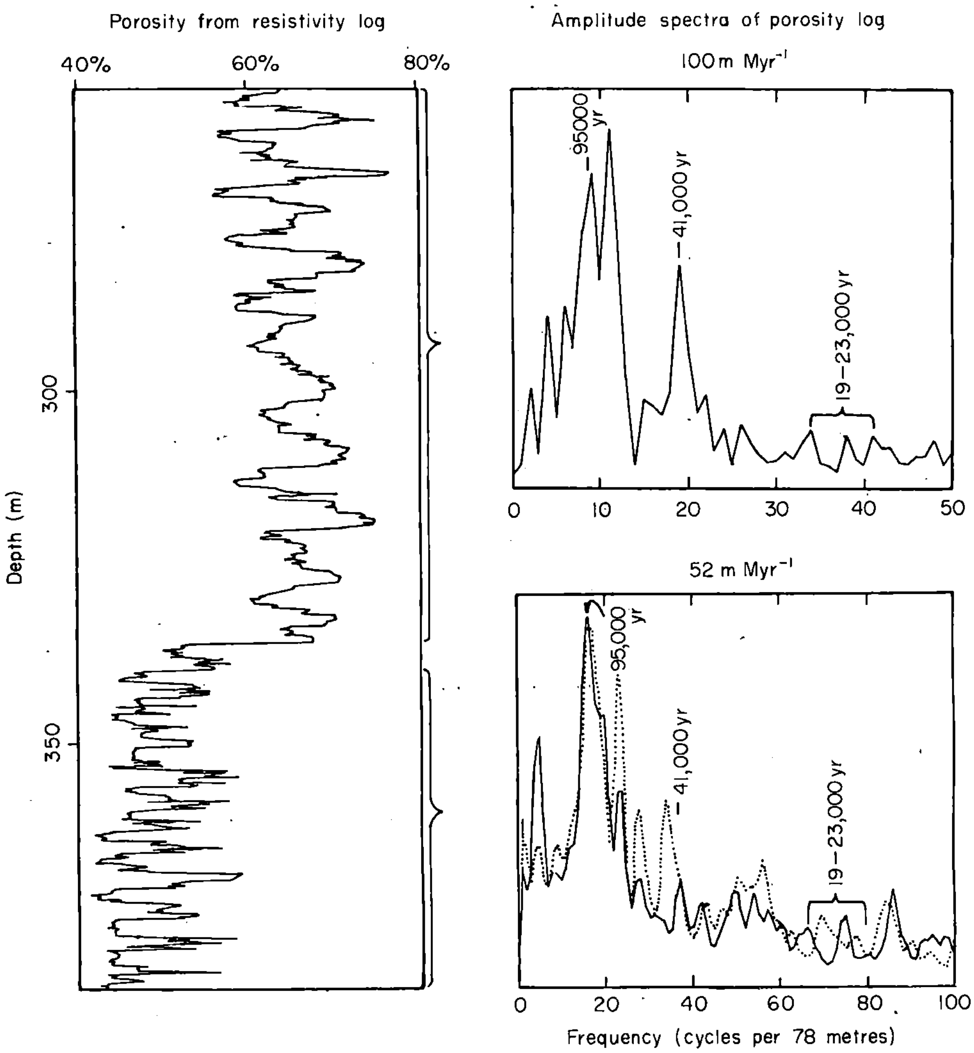

Fig. 2 Porosity values calculated from resistivity log at ODP Site 646 have produced amplitude spectra (solid traces) with energy peaks corresponding to the 95,000 and 41,000 year periods at higher sedimentation rate of 100 m Myr^{-1} above 335 m, and to the 95,000 year period at lower sedimentation rate of 52 m Myr^{-1} below 335 m. The higher resolution sonic log has produced an amplitude spectrum (dotted trace) which does indicate some correspondence of an energy peak with the 41,000 year period.

material which is only marginally greater than the vertical resolution of the induction tool that was used to measure the resistivities from which the porosity log has been calculated. Note, however, that the sonic log with its sharper vertical resolution (*c.* 0.6 m) does show a stronger energy peak corresponding to the 41,000 year period at the lower sedimentation rate.

The limits of vertical resolution of the induction and sonic tools also account for the absence of pronounced events at the 23,000 and 19,000 year periods, especially at

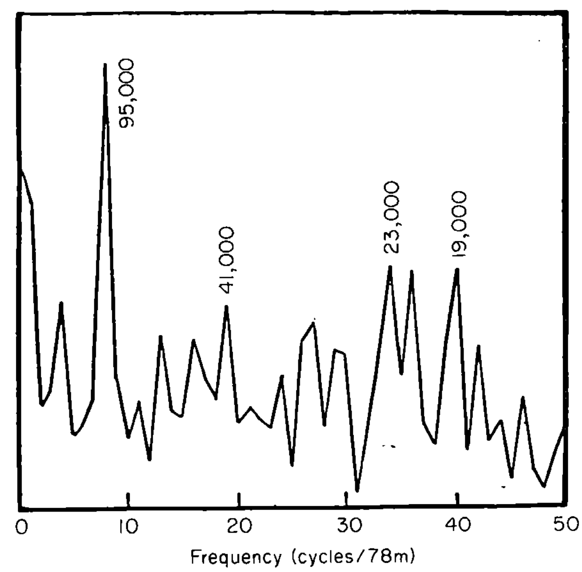

Fig. 3 Induced gamma spectral log at ODP Site 646 has produced a power spectrum of the calcium/silicon elemental abundance ratio with energy peaks corresponding to the 95,000, 41,000, 23,000 and 19,000 year periods at the sedimentation rate of 100 m Myr^{-1}.

the lower sedimentation rate. Yet, the higher resolution induced gamma spectral tool does have prominent energy peaks at these times. Figure 3 shows the amplitude spectrum for the elemental abundance ratio of calcium/silicon for a sedimentation rate of 100 m My^{-1}.

This means that the principal cycle periods of Milankovitch are potentially recognizable from well logs. This facility opens the door to climate-cycle identification from wireline measurements. Furthermore, if a clear Milankovitch cyclicity can be established, the cycles can be counted with depth thereby giving well logs an age-dating capability.

Seismic indicators

Environmental changes are often recognized on regional seismic lines rather than in cores. It is essential to have an accurate tie between core (or log) depth and seismic traveltime, so that one can either recognize the location in cores of regional seismic reflectors or extrapolate regionally from an environmental change recognized in cores. Most seismic reflectors are interference patterns caused by impedance variations over a 5–20 m interval; thus it is hazardous to try to tie core-depth to seismic traveltime based on either discrete physical properties measurements or observed sedimentological changes. Instead, sonic and density logs are routinely used to calculate a synthetic seismogram; matching of this to the seismic section yields a detailed and correct link between core depth and seismic traveltime.

CRUST/MANTLE INTERACTIONS

Downhole measurements including wireline logging and special borehole geophysical experiments have already played a major role in furthering our knowledge of oceanic crustal structure. Logging is an essential element of crustal drilling programmes because it provides a complete record of physical properties in the borehole, in contrast to the very sparse (25%) recovery of core material in hard rock. Borehole geophysical experiments expand the scale of the information acquired from the borehole from a few metres to a few hundreds of metres or kilometres, which is the scale of typical marine geophysical surveys. In sedimentary sequences it is common to assume that the structure intersected by the borehole and sampled at a lateral resolution of less than a metre extends horizontally for at least hundreds of metres. This assumption is not valid in oceanic crust, where strong lateral heterogeneities can occur over length-scales from centimetres to kilometres (Stephen 1987).

It is not the intention to summarize drilling objectives for problems in crust/mantle interaction. However, because of the scale of sampling associated with ODP, almost any conceivable objective will require that drilling results be placed in a regional setting. Wireline logging and special downhole experiments meet this need.

For example, virtually all models of crust/mantle interaction are constrained by seismic structure which is, in turn, affected considerably by porosity and fractures. It became evident in the early 1970s that laboratory-measured velocities of cores could not be directly correlated with refraction velocities because of the presence of secondary voids. Since integrated sonic logs and oblique seismic experiments did take account of these voids, they agreed much better with seismic refraction (Salisbury *et al.* 1979). Well logs and borehole seismic methods therefore have an important role to play in establishing the seismic stratigraphy of the oceanic crust which is an essential indicator of crust/mantle interactions.

An example of log-derived seismic stratigraphy is provided by data from Hole 504B on the southern flank of the Costa Rica Rift (Fig. 4). This hole has the deepest crustal penetration of any ODP hole and is also the most completely logged borehole. At this site the downhole measurements programme has already played a key role in correlating the drilling results with the ophiolite model of oceanic crust. Log-derived sonic velocities through the pillows, breccias and dykes of layers 2A, 2B and 2C show a rather gentle change in slope from top to bottom in 504B (Fig, 4) and agree well with the seismic profile obtained from an offset VSP experiment (Little & Stephen 1985). In contrast, the surface multichannel seismic section shows strong dipping reflectors within layer 2. This paradox can be resolved by reference to other available logging information (Fig. 5). These data do show slope changes at the layer 2B–2C, pillow basalt to dyke boundary. An impedance log computed from the sonic and density logs shows several gentle increases in impedance within the dykes, with lower impedance intervals within layer 2B. These unit boundaries produce larger reflectors within layer 2B than either the 2B–2C boundary (which is a broad slope change occurring over 100 m) or within layer 2C

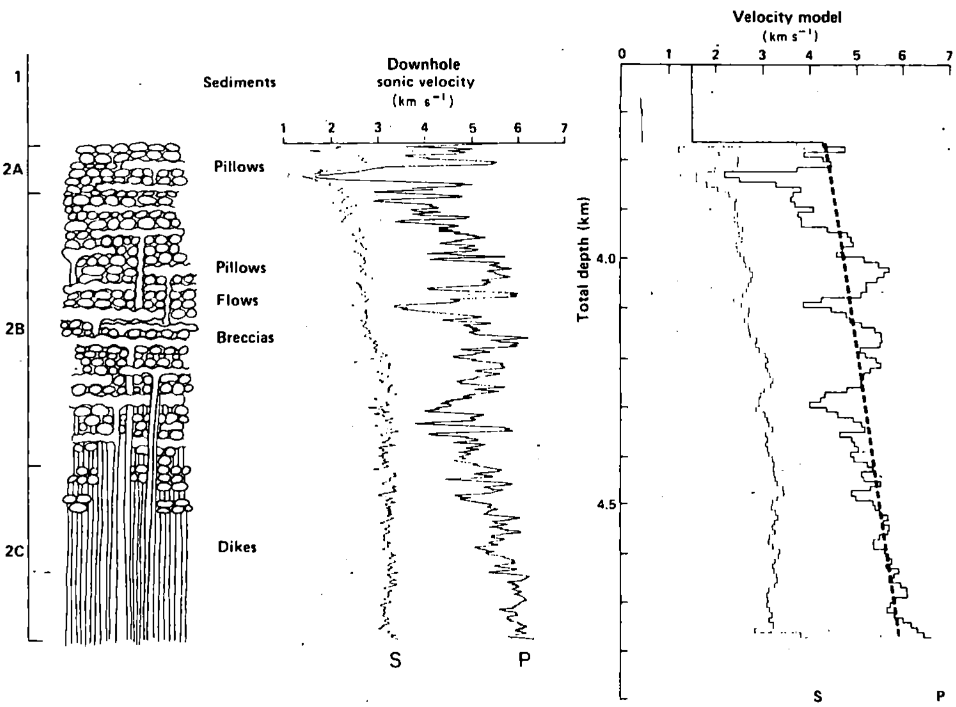

Fig. 4 Downhole sonic velocities in the upper 1 km of basement in DSDP/ODP Hole 504B. On the left is a schematic section indicating dominant lithologic units with depth. In the centre are 10-m running averages of the downhole P and S velocities. On the right is a simplified velocity model where the succession is divided into four units of which the basement units are further subdivided into 100 layers each of thickness 10 m.

itself (the upper section of which is predicted to be acoustically transparent). This example illustrates the effectiveness of well logs in identifying relative physical changes in oceanic crust.

At the same site neutron activation logs have shown that a listric fault, identified by a downhole magnetometer, is a major chemical boundary between titanium-depleted pillow basalts and dykes with chondritic abundances of gadolinium and titanium. This observation suggests different magma sources. It is noteworthy that these geochemical logs provide the only continuous chemical measurements in the oceanic crust.

FLUID CIRCULATION IN THE CRUST AND THE GLOBAL GEOCHEMICAL BUDGET

Drill holes provide unique opportunities to obtain invaluable data on the depth-patterns of fluid flow and the physical properties that control them in oceanic sediments and crust. By carefully applying currently available logging and experimental technology in ODP holes, reasonable estimates can be made of vertical flow rates and the two critical controlling properties, porosity and permeability.

Heat flow and pore fluid advection

As drilling penetrates deep into sediments and crust, it allows detailed measurements of temperature and thermal conductivity with depth. Concurrently, analyses of pore waters sampled *in situ* or from recovered cores yield complementary profiles of concentrations of important chemical species. Fitting the thermal and chemical data to one-dimensional advection/diffusion models yields independent estimates of vertical advection rates. A different kind of flow, in the form of vertical movement of fluids through the borehole column, provides important information relating to permeability and pore pressure within the drilled section. In stable holes this kind of flow can be monitored by detailed temperature logs.

The available temperature/water sampler tools should be considered routine for future scientific ocean drilling, even if their deployment sometimes incurs operational problems. Certain of these tools are presently useful only at temperatures up to 70–100°C; in contrast, some logging tools can be used to temperatures of 200–300°C and a few to 450°C (Dennis, Koczan & Stephani 1985; Miyairi & Itoh 1985).

Porosity and permeability

The properties that control fluid storage and flow in oceanic sediments and crust are porosity and permeability. Porosity is a measure of the total volume of rock occupied by fluids and it includes pore spaces that range over several orders of magnitude in size. Permeability is a measure of the ability of fluids to flow through a rock and is generally related to that proportion of porosity which is interconnected.

As the oceanic crust is a porous medium, nearly all of its bulk properties depend on porosity. Thus, most of the properties that are logged are sensitive to porosity, e.g. sonic velocity, electrical resistivity, density, neutron activation. However, nearly all the logs respond to porosity in different ways and over different scales, and it is unclear which log(s) can be interpreted to yield the most accurate estimates of porosity. This is partly a consequence of the calibration uncertainties for hard rock.

Present directions in log interpretation for porosity

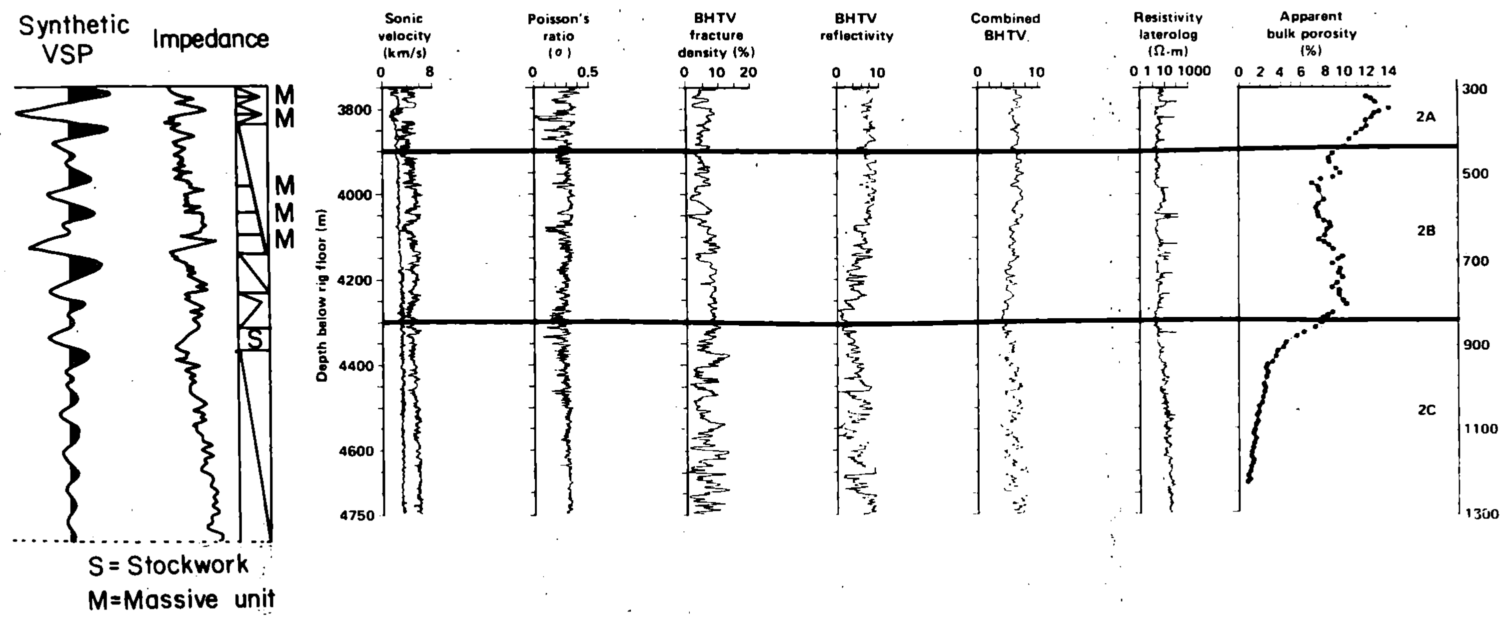

Fig. 5 Geophysical logs from Hole 504B, including fracture density and reflectivity from borehole televiewer imagery, and porosity from long-spaced electrical resistivity, show gradient changes from Layer 2A downwards into Layers 2B and 2C. Acoustic impedance calculated from velocity and density produces synthetic seismogram (left) which shows a strong reflector within Layer 2B and relatively few reflectors of low amplitude within the top of the dykes of Layer 2C.

include: (1) multi-log evaluation to yield the 'best' estimates of total porosity; (2) comparative analyses to try to separate the different components of porosity, particularly fracture porosity; (3) direct detection of fractures; and (4) analyses of neutron activation logs sensitive to geochemistry for the presence of alteration products that seal original porosity.

With present technology, permeability can only be measured *in situ* using a packer to isolate hydraulically the rock unit penetrated by the borehole. With such a hydraulic seal, the hydrological properties of the interval, including permeability and pore pressure, can be tested by applying fluid pressure or flow to the rock section.

Two drillstring packers have been developed during the first years of ODP:

(1) A non-rotatable, single- or straddle-packer that has worked reliably in stable re-entry holes in basaltic crust.
(2) A rotatable packer, intended for use in a coring bottom-hole-assembly or in unstable sedimentary sections, that needs further development following initial tests.

In addition, an electrically powered wireline packer, to be run as a special logging tool, is scheduled for completion during 1989. This packer is intended primarily for measurements of pore pressure and water sampling over short (1 m) straddled intervals. The non-rotatable packer and the wireline packer are intended for routine use in stable holes; further development of the rotatable packer is anticipated.

Basalt/seawater interactions

Hydrothermal circulation in young oceanic crust is accompanied by chemical exchange between crust and seawater. The most dramatic examples of this exchange are black smokers which are the surface manifestation of the chemical scouring of iron and manganese from oceanic crust by seawater. Assessment of the volumetric extent of basalt/seawater exchanges requires continuous geochemical analyses as a function of depth in the oceanic crust. However, core recovery in basalts is usually only about 20% and may be biased in favour of the least altered rocks: furthermore, core geochemical analyses are of very small volumes (about 1–5 cm^3) that may be unrepresentative. In contrast, geochemical logs provide a continuous record of major element changes throughout the drilled crustal section, with each data point representing an averaging over a rock volume of close to one cubic metre. Thus, geochemical logs might constitute the only viable approach to the estimation of the overall geochemical exchange between basalt and seawater.

Integrated use of packers and downhole geochemistry

Experience with packers in DSDP and ODP is limited (e.g. Anderson *et al.* 1985). During DSDP and the first years of ODP there were only 10 successful *in situ* measurements of permeability in holes penetrating oceanic basement. Of these, six were in different intervals in Hole 504B (Fig. 6). The most permeable interval was the upper pillow lavas (*cf.* Fig. 4) which proved too permeable for effective pulse tests, a permeability of 4×10^{-14} m^2 being determined from a constant flow test of 40 minutes' duration. Deeper in the hole, lower permeabilities of 4×10^{-15} m^2 in pillow lavas and 10^{-17} m^2 in sealed pillows and dykes were determined using several pulse tests, each up to two hours long.

Figure 7 compares the packer-derived permeability measurements with geophysical and geochemical logs. Total porosity has been calculated using the Archie relationship between resistivity and porosity (Becker 1985). Fracture porosity has been calculated from comparisons of the deep- and shallow-sensing laterolog responses. From 530 to 890 m bsf there is an anomalous zone of high apparent porosity and low permeability. This depth range correlates with a zone of high breccia content (*cf.* Fig. 4). The geochemical tool combination has allowed this zone to be characterized in terms of clay minerals filling fractures, and plagioclase and clinopyroxene basaltic contents. The clay minerals effectively seal the fractures thus accounting for the low permeability. The high apparent porosity might be attributable to a high electrical conductivity associated with the clays. This clay conductivity can influence the application of the standard Archie equation (Worthington 1975) and thereby cause the porosities so calculated to be overestimates.

This conjunctive use of hydrogeological, geophysical and geochemical downhole measurements has allowed recognition of a zone of palaeo-porosity in which fractures, now sealed with low permeability clays, were once open and able to impart a higher porosity and permeability to the oceanic basalts.

STRESS AND DEFORMATION OF THE LITHOSPHERE

The ODP's well logging and downhole measurement programme provides continuous records of information which, in turn, permits fine-scale hole-to-hole correlation of physical and chemical parameters pertinent to an improved understanding of the lithosphere. For investigations which involve documenting and accounting for stress and deformation of the lithosphere, three categories of information are available: (1) data for establishing the tectonic history of the drill sites and their surrounding areas, (2) data bearing on the physical properties of the drilled section, and (3) indications of ongoing tectonic activity.

Tectonic history

The subsidence/uplift record of a drill site is deciphered largely from core-derived palaeontological, sedimentological and geochemical data, as discussed previously. These

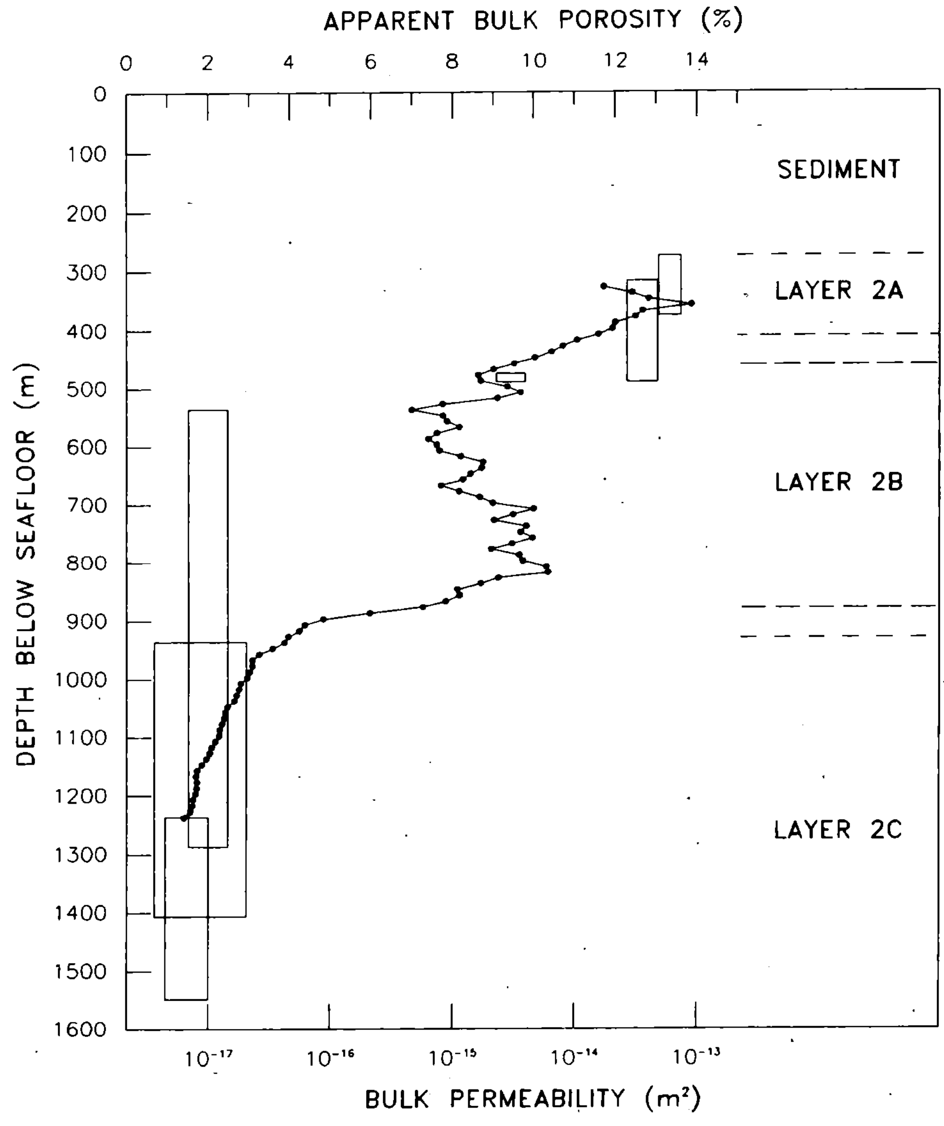

Fig. 6 Comparison of apparent bulk porosity calculated from resistivity log (dots) with packer-derived permeability (rectangles) and seismic stratigraphy in Hole 504B.

insights can, however, be augmented and focused by downhole logs. For example, the evaluation of decompaction and subsidence requires continuous and representative vertical records of density and porosity, parameters measured by logging tools on a routine basis. Logs can also provide lithological continuity where cores are lacking, pinpoint faults and unconformities, and often identify subtle stratigraphic cycles of tectonic significance, which are not immediately apparent from the samples. For example, past lithospheric flexure could have caused tectonic rotation or changed the bathymetry of an oceanic area through time. The former can be detected using a gyro-stabilized borehole magnetometer. The latter may be reflected in the chemical composition of the sediments which were deposited and this composition, in turn, may be detectable from well logs. Gamma ray spectral logs can directly identify some chemical variations; others may become apparent when the responses of several logging tools are cross-correlated. In addition, the thickness of the missing section at unconformities can sometimes be inferred from logs of porosity, density or acoustic velocity.

Perhaps the major contribution well logs make to unravelling tectonic history is in calibrating reflection seismic records, i.e. tying the traveltime of reflections to depth and thereby to actual rock in the drill hole. The only way to do this with precision is to measure the acoustic properties of the section either with sonic logging tools or by means of a velocity survey. This type of information is essential for definitive interpretations of structural history from seismic records. Log-derived acoustic and density data can also be used for seismic modelling of problematic reflection configurations.

Physical properties

Physical properties which can be measured by ODP logging tools and downhole measurement devices, or which can be derived from their records, include specific gravity, density, acoustic velocity, electrical resistivity, temperature, presence of fractures, elastic properties, shear strength, pore pressure, porosity, permeability, fluid content, rock composition, radioactivity and magnetic susceptibility. In one

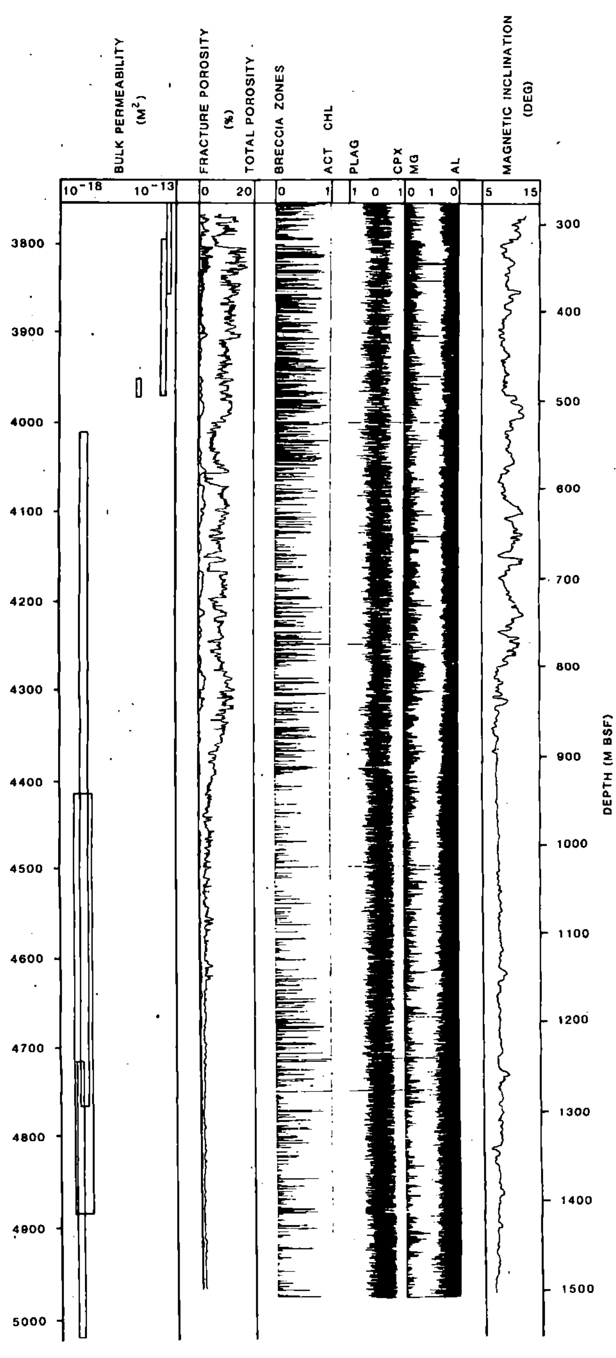

Fig. 7 Downhole measurements in Hole 504B. Left to right: bulk permeability measured by the packer experiment, fracture and total porosities determined from electrical resistivities, normative mineralogies and relative MgO and Al_2O_3 contents determined from spectral analysis of neutron activation logs, and magnetic inclination. Normative mineralogies were determined by recalculating elemental contents of Si, Al, Fe, Mg and Ca into the normative components actinolite (ACT), chlorite (CHL), plagioclase (PLAG), clinopyroxene (CPX), olivine and smectite, assuming typical local compositions for the normative minerals. Normative plot units indicate the fraction (unity signifies 100 normative weight per cent) of the rock formed by each normative component. Relative contents of MgO (MG) and Al_2O_3 (AL) are shown as counts, where unity signifies the maximum observed. Average amount of MgO is 7 weight per cent, and of Al_2O_3 is 22 weight per cent.

application or another, all these variables have figured in investigations of lithospheric deformation. For example, provided that the rock units are mechanically isotropic, their elastic constants can be derived from P- and S-wave velocities (from sonic waveform logs) and density (given by gamma–gamma density tools). Borehole televiewer records can provide excellent documentation of fractures, borehole geometry, and bed form (Broding 1981). Modified drill-stem-test tools with packers can sample formation fluids and measure pore pressure. Bed attitude in uncored sections is, however, difficult to record; borehole televiewer records are not ideal and a suitably robust dipmeter tool narrow enough to lower down the ODP drill string has only recently been developed. Nor can we yet derive reliable estimates of thermal conductivity from logs; measurements on samples are still required.

Ongoing tectonic activity

Ocean bottom seismometers operating remotely in abandoned boreholes can provide virtually noise-free records of earthquakes for epicentre location and first motion studies. The greatest contribution to ongoing studies of lithospheric deformation is likely to come from ocean-bottom-seismometer arrays set up to monitor all scales of earthquake activity around areas such as plate boundaries. Proposals are in hand for ODP ocean-bottom-seismometer deployment near plate margins offshore of Japan.

At this time there is particular interest in the geodynamics of accretionary prisms; the deployment of instruments to measure downhole temperatures, pore pressures, *in situ* stresses and a range of mechanical properties is currently at the planning stage. Without downhole measurements, we would have much more difficulty advancing our understanding of these active thrust wedges.

An interesting tectonic application of well logs is the determination of *in situ* stress orientations using the borehole televiewer, with an ultimate goal of producing a global horizontal stress azimuth map. When regional tectonic stresses are amplified around a borehole and exceed the strength of the wall-rock, and the horizontal principal stresses are anisotropic, failure will occur. The cavities so created are called 'breakouts'. Breakouts are detectable using the borehole televiewer. The orientation of breakout failure in a semi-vertical borehole is perpendicular to the direction of the larger horizontal principal compressional stress (Bell & Gough 1979). At Hole 504B, BHTV images within the basaltic oceanic crust show breakouts orientated WNW–ESE (Newmark, Zoback & Anderson 1984): this breakout orientation is maintained throughout the upper 1 km of oceanic crust (Figs 8 and 9). The larger horizontal principal stress direction is therefore NNE–SSW which, in this case, is compatible with ridge *push* from the Costa Rica Rift to the north and/or trench *pull* from the Peru Trench to the east–south–east. If ODP holes can also be used for the determination of mid-plate stresses at numerous locations, the prospects for compiling a crustal stress atlas become much greater.

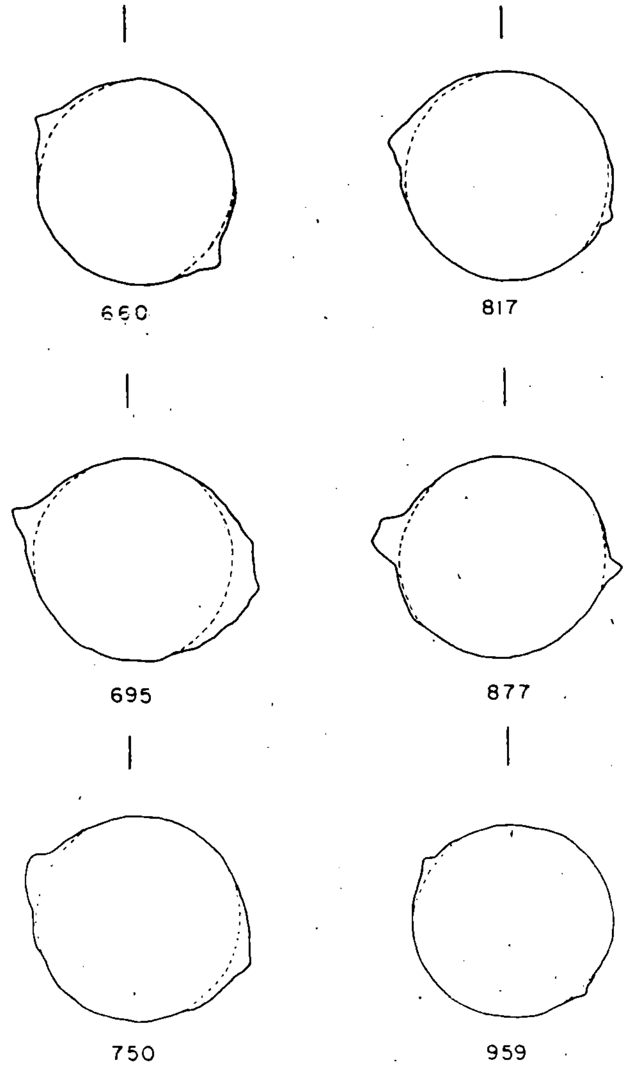

Fig. 8 Borehole breakouts imaged with a borehole televiewer in hole 504B at depths indicated (in metres).

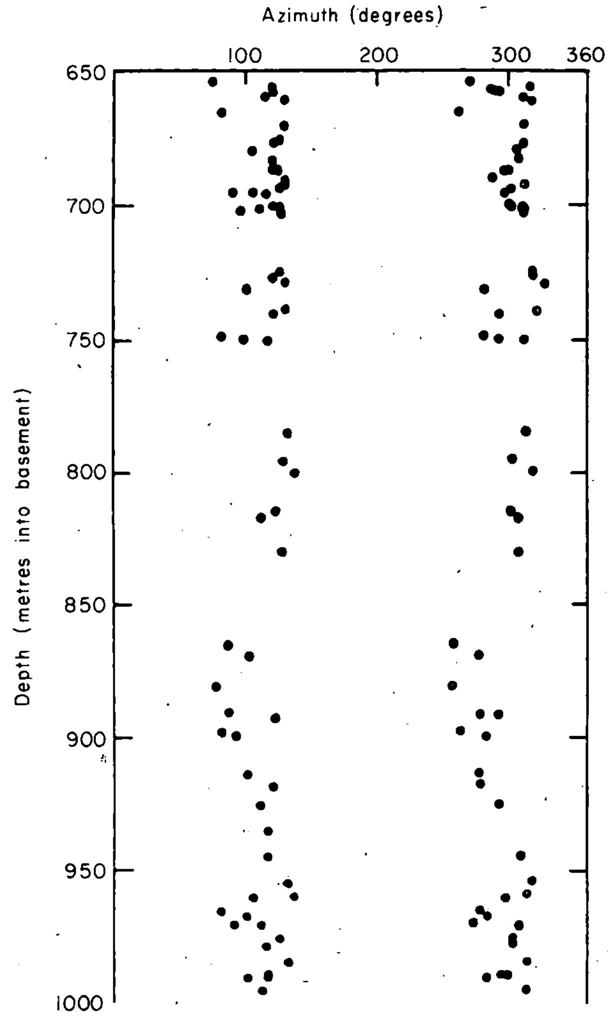

Fig. 9 Cumulative orientations of BHTV imagery in Hole 504B. Least compressive stress is horizontal and oriented 120 and 300 degrees.

The technology also exists to measure the magnitudes of these *in situ* stresses at depth by means of controlled open-hole hydraulic fracturing using currently available packers with drilling mud as the fracturing fluid (Daneshy *et.al.* 1986). Vertical stress magnitudes may be obtained by integrating density log records. In addition, a probe tool for direct three-dimensional *in situ* stress tensor measurement in semi-consolidated sediments is under development. This information may assume importance in the future, if recent hypotheses to explain coastal onlap/offlap patterns through time (Vail, Mitchum & Thompson 1977) are substantiated. Lambeck, Cloetingh & McQueen (1987) have suggested that the apparent changes in sea level may be explained in terms of an interaction between variations in the horizontal stress fields in the lithosphere and basin subsidence caused by lithospheric cooling and sediment loading. According to their models, uplift or subsidence of a few tens of metres may be produced by changes in horizontal stress magnitudes of the order of 100 MPa. Hence, comparing stress magnitudes from different ODP sites and different tectonic settings may provide insights of great significance.

EVOLUTIONARY PROCESSES IN OCEANIC COMMUNITIES

Downhole geophysical logs have yet to contribute substantially to the study of the evolution and extinction of oceanic biota. Logs have contributed only indirectly through their detection of environmental change in the sedimentary column. This approach to the history of biotic events is achievable through well logging provided that three important conditions are met. First, the emergence of a marine organic community, changes in its diversity, and its ultimate disappearance must be attributable to physical and chemical processes or other environmental factors that are manifested in the oceanic sedimentary record. Secondly, these diagnostic physico-chemical characteristics of sediments must be sufficiently distinctive in terms of electrical, nuclear or sonic properties that environmentally governed sedimentary zones can be recognized definitively. Thirdly, the time-scales must be such that the characteristic sediments are sufficiently thick to be resolved by contemporary logging tools.

An example of the indirect log recognition of biota evolution and extinction is provided by data from ODP Sites 646 and 647 in the Labrador Sea. At Site 647 porosities calculated from the resistivity log show an inverted sequence at 125 m below sea floor, i.e. porosity increases with depth (Fig. 10). Core data have corroborated the high porosities (>60%) indicated by the logs. The high porosities are associated with a diatomaceous ooze layer which supports a large void volume within its shell structure. At Site 646 we see a clear lower boundary to the ooze layer (Fig. 11). The emergence and abundance of diatoms can be attributed to a zone of upwelling nutrients which moved away from the sites at the age of the upper transition sediments. Such a change in oceanographic currents, with its consequent termination of the diatom occurrence, is indirectly manifested in logging data through tool response to diatom-induced porosity.

There are two ways in which future logging could make a powerful contribution to the study of evolution and extinction: (i) removal of the core-depth ambiguity, and (ii) using Milankovitch cycles to refine greatly the time-scale.

Core-depth ambiguity results from incomplete core recovery. If a zone boundary is found in the core with 10% recovery, then that boundary may actually occur anywhere within a 9 m interval. If the character of some property of the core can be correlated with a similar character in downhole logs, then the depth ambiguity is removed. The necessary prerequisites are similar high vertical resolutions (1–5 cm) in both core and log measurements, and a type of core measurement that is continuous, fast, and non-destructive. Two routine physical property measurements (density and velocity) are now run continuously on cores. Both properties depend primarily on porosity, and porosity-sensitive logging tools with similar 1–5 cm vertical resolution could eventually be introduced into ODP. However, the correlation problem would remain non-trivial, because core disturbance can dominate the core porosity structure and make log versus core comparisons difficult even with similar vertical resolutions. Furthermore, the ship's heave can introduce additional uncertainties in logging and coring depths.

Another aspect of core-depth ambiguity is unrecognized drilling slurry. Palaeontological analysis of drilling slurry is avoided whenever possible, because slurry can include cavings (and therefore microfossils) from any part of the hole. Drilling slurry is usually readily identified by its very high porosity in comparison to undisturbed core. However, some drilling slurry is only slightly higher in porosity than undisturbed core and it is in the recognition of these cases that a comparison of core and log porosities might be especially useful.

For many years the age precision of each palaeontological datum was limited by the 5% uncertainty of potassium–argon ages. In fact the length of a palaeontological zone could be uncertain by a factor of 2. A major increase in the accuracy of the time-scale occurred when palaeontological zones were linked to reversal stratigraphy. The next great increase in accuracy has already begun through the

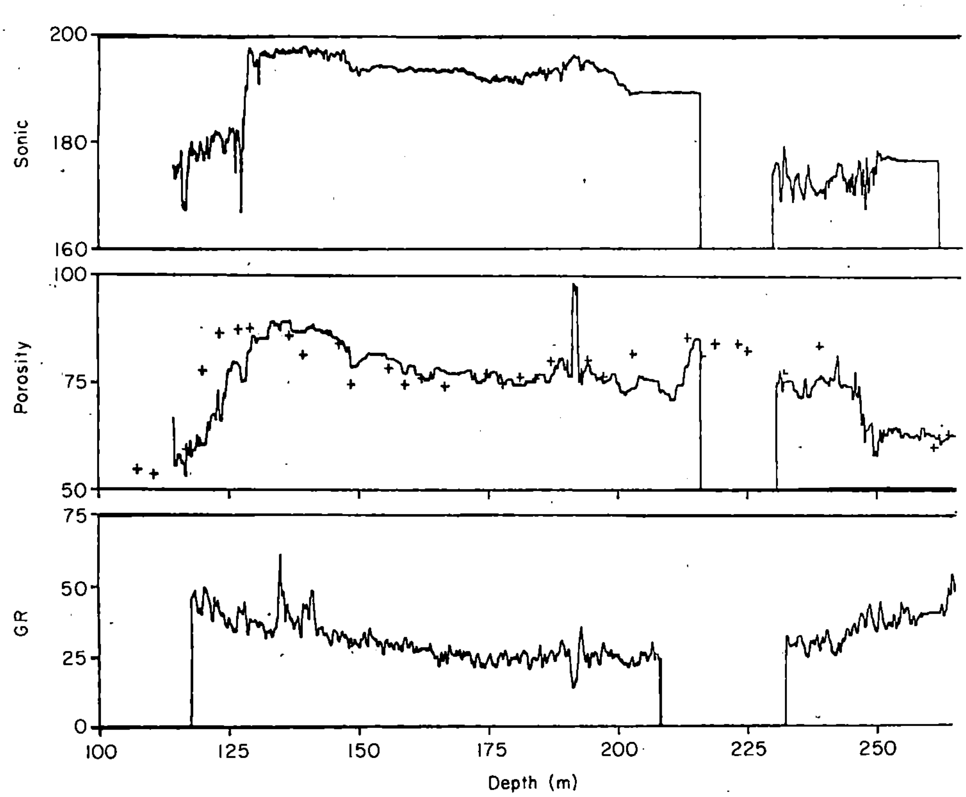

Fig. 10 Gamma ray (API units), apparent porosity (%, from resistivity) and sonic traveltime (μ sec ft^{-1}) logs at ODP Site 647, Labrador Sea. Crosses represent core porosities. Note porosity and traveltime inversion at 125 m bsf.

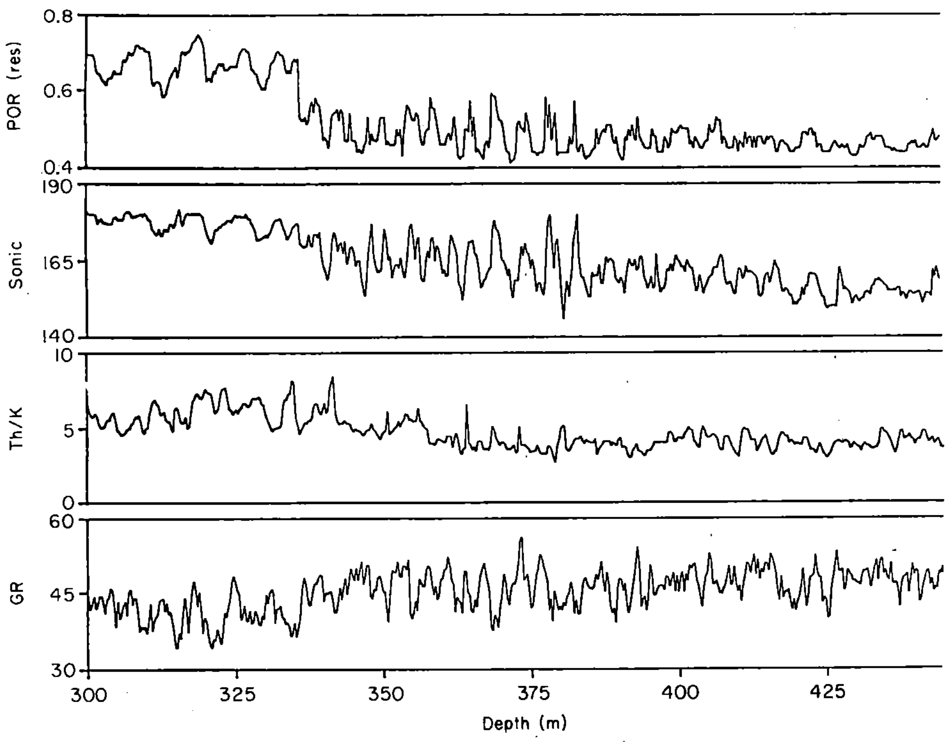

Fig. 11 Gamma ray (API units), thorium/potassium ratio ($\times 10^{-4}$), sonic traveltime (μ sec ft^{-1}), and apparent porosity (from resistivity) logs at ODP Site 646. Note sharp drop in porosity at 335 m bsf.

counting of Milankovitch cycles between magnetic reversals or between palaeontological zone boundaries. One must, of course, know the Milankovitch frequency being detected (19–23,000 years for precession, 41,000 years for obliquity, and 95,000 years for eccentricity). Milankovitch cycles in logs, coupled with biostratigraphy and reversal stratigraphy of cores, offers the potential for substantially improving the yardstick against which evolution and extinction of oceanic biota are measured.

In the much longer term two potentially useful logging tools for the study of sediment age and evolution/extinctions are at early stages of development. The first is a downhole magnetometer capable of determining reliably the reversal stratigraphy of sediments. The second is a geochemical logging tool with high elemental resolution that might measure iridium concentration directly. Iridium is a trace element found in cosmic dust and it therefore provides a marker for meteoric impacts. High iridium concentrations have been found at major extinction boundaries on land.

DISCUSSION

Although the logging tools deployed within ODP constitute the most scientifically advanced downhole measurements capability that is in regular use within the world today, further developments are needed to take maximum advantage of future drilling in the ocean basins. These developments have been reviewed previously (Worthington *et al.* 1987) and they are summarized for convenience in Table 2. Several key messages emerge: the need for reliable pore water samples for geochemical characterization;

Table 2. Future logging developments.

Tool	Principle of operation	Parametric objective
Wireline packer	Surface-commanded two-element assembly for investigating and sampling fluid regime	Pore pressure, permeability, temperature, pore water chemistry
Formation microscanner	Alternating current (micro sensing)	Resistivity (electrical image)
Cryogenic geochemical tool	Gamma-ray emissions from absorption of neutrons from downhole accelerator	High-resolution gamma-ray energy spectrum (elemental analysis)
Borehole gravimeter	Gravitational force	Bulk density (porosity)
Petrophysical probing tools	Micro sensor/packer probe in Navidrill holes ahead of drill bit	Pore pressure, permeability, temperature, stress
High temperature tools	Various, up to 450°C	Various
Measurement-while-drilling tools	Measurement of nuclear, electrical and sonic properties on the drill string	Gamma count rate, density, porosity, resistivity, sound velocity
Wireline re-entry tools	Various	Various
Long-term instrumentation	'Indefinite' recording at high temperatures of geophysical and geochemical properties and events	Seismic, magnetic and thermal properties, pressure, water chemistry

downhole imaging at the microlog scale for the identification of faults, joints, bedding, facies, and indications of stress directions; high-spectral-resolution elemental analysis; large-scale borehole density measurements; downhole petrophysical measurements while drilling; probing for mechanical properties; high-temperature logging; wireline re-entry tools; and long-term downhole observatories for temperature, pressure, fluid circulation, and seismic and magnetic events.

The usefulness of downhole measurements technology is very much a function of the vertical resolution of the different logging tools. This varies typically from a few centimetres to over 2 metres according to tool design. Well log interpretation benefits from calibration through the sharper resolution and more precise core data, if these are available. In order to be meaningful this calibration requires a corresponding core measurement for each log measurement with reconciliation being effected over equivalent scales. The benefit of this procedure is a calibrated well log interpretation which is continuous, relates to *in situ* conditions, and samples a volume many times greater than that of a discontinuous core column.

If all these developments and strategies are brought to fruition, downhole measurements will contribute even more strongly to geoscience in the 'Nineties. Areas of special emphasis are: event stratigraphy encompassing micropalaeontology, petrophysics, geomagnetics, isotope geochemistry and geoseismics; geochemical characterization of hard rocks and sediments; more effective determination of porosity and permeability for hydrogeological studies; and geotectonics through improved stress measurements. Further, the concept of wireline re-entry emphasizes that an ocean borehole is a scientific legacy from which future generations will benefit. It is important that this legacy be seen in a global perspective.

ACKNOWLEDGEMENTS

The authors wish to acknowledge those ODP scientists who have contributed to the acquisition of the data reported herein.

REFERENCES

ANDERSON, R. N., ZOBACK, M. D., HICKMAN, S. H. & NEWMARK, R. L. (1985) Permeability versus depth in the upper oceanic crust: *in situ* measurements in DSDP Hole 504B, eastern equatorial Pacific. *J. geophys. Res.* **90**, 3659–3669.

ARCHIE, G. E. (1942) The electrical resistivity log as an aid in determining some reservoir characteristics. *Trans. Am. Inst. Mineral Metall. Eng.* 146, 54–62.

BECKER, K. (1985) Large-scale electrical resistivity and bulk porosity of the oceanic crust, Deep Sea Drilling Project Hole 504B, Costa Rica Rift. In: *Init. Repts. DSDP 83*, (Ed. by R. N. Anderson, J. Honnorez, K. Becker *et al.*), pp. 419–427, US Govt Printing Office, Washington, DC.

BELL, J. S. & GOUGH, D. I. (1979) Northeast–southwest compressive stress in Alberta: evidence from oil wells. *Earth planet. Sci. Lett.* **45**, 475–482.

BRODING, R. A. (1981) Volumetric scan well logging. *Trans. CWLS Eighth Formation Evaluation Symp.*, Paper T, Canadian Well Logging Society, Calgary, Alberta.

COSOD II (1987) In: *Report of the Second Conference on Scientific Ocean Drilling*, (Ed. by G. B. Munsch), European Science Foundation, Strasbourg, France, 142 pp.

DANESHY, A. A., SLUSHER, G. L., CHISHOLM, P. T. & MAGEE, D. A. (1986) In-situ stress measurements during drilling. *J. Petrol. Tech.* 38, 891–898.

DENNIS, B., KOCZAN, S. & STEPHANI, E. (1985) High temperature borehole instrumentation. *Los Alamos Report LA*-10558-*HDR*, US Dept of Energy, 46 pp.

FISCHER, A. G. (1986) Climatic rhythms recorded in strata. *Ann. Rev. Earth planet. Sci.* **14**, 351–376.

HAYS, J. D., IMBRIE, J. & SHACKLETON, N. J. (1976) Variations in the earth's orbit: pacemaker of the ice ages. *Science* **194**, 1121–1132.

LAMBECK, K., CLOETINGH, S. & MCQUEEN, H. (1987) Intraplate stresses and apparent changes in sea level: the basins of northwestern Europe. In: *Sedimentary Basins and Basin-forming Mechanisms*, (Ed. by C. Beaumont and A. J. Tankard), pp. 259–268. Memoir 12, Can. Soc. Petroleum Geologists.

LITTLE, S. A. & STEPHEN, R. A. (1985) Costa Rica Rift Borehole Seismic Experiment, Deep Sea Drilling Project Hole 504B, Leg 92. In: *Init. Rep. DSDP 83*, (Ed. by R. N. Anderson, J. Honnorez, K. Becker *et al.*), pp. 517–528, US Govt Printing Office, Washington, DC.

MIYAIRI, M. & ITOH, T. (1985) Super high temperature geothermal well logging system. *Trans. SPWLA 26th Ann. Logging Symp.*, Paper Y, Soc. Professional Well Log Analysts, Houston, Texas.

NEWMARK, R. L., ZOBACK, M. D. & ANDERSON, R. N. (1984) Orientation of *in situ* stresses in the oceanic crust. *Nature* **311**, 424–428.

SALISBURY, M. H., STEPHEN, R., CHRISTENSEN, N. I., FRANCHETEAU, J., HAMANO, Y. & JOHNSON, D. (1979) The physical state of the upper levels of Cretaceous oceanic crust from the results of logging, laboratory studies and the oblique seismic experiment at DSDP Sites 417 and 418. In: *Deep Drilling Results in the Atlantic Ocean – Ocean Crust*, (Ed. by M. Talwani *et al.*), pp. 113–134, Maurice Ewing Series 2, Am. geophys. Union, Washington, DC.

STEPHEN, R. A. (1987) Borehole seismic experiments and the structure of oceanic crust. *Eos* **68**, 268.

VAIL, P. R., MITCHUM, R. M. & THOMPSON, S. (1977) Seismic stratigraphy and global changes of sea level, Part 3: Relative changes of sea-level from coastal onlap. In: *Seismic Stratigraphy – Applications to Hydrocarbon Exploration*, (Ed. by C. E. Payton), pp. 63–81. Memoir 26, Am. Assoc. Petrol. Geol.

WORTHINGTON, P. F. (1975) Quantitative geophysical investigations of granular aquifers. *Geophys. Surv.* **2**, 313–366.

WORTHINGTON, P. F., ANDERSON, R. N., BELL, J. S., BECKER, K., JARRARD, R. D., SALISBURY, M. H. & STEPHEN, R. A. (1987) Downhole measurements for the Ocean Drilling Programme. In: *Report of the Second Conference on Scientific Ocean Drilling*, pp. 131–136, European Science Foundation, Strasbourg, France.