Continental Scientific Drilling (CSD):
Technology Barriers to Deep Drilling
Studies in Thermal Regimes

Workshop Summary
The DOE Coordinating Group
on Continental Scientific Drilling
September 17, 1986

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WORKSHOP SUMMARY
OF THE DOE COORDINATING GROUP ON CONTINENTAL SCIENTIFIC DRILLING

CONTINENTAL SCIENTIFIC DRILLING (CSD):
TECHNOLOGY BARRIERS TO DEEP DRILLING STUDIES IN THERMAL REGIMES

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WORKSHOP SUMMARY

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TECHNOLOGY BARRIERS TO DEEP DRILLING STUDIES IN THERMAL REGIMES

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1. SUMMARY

The primary thrust of these discussions was to identify the major or key technology barriers to the Department of Energy (DOE) supported Thermal Regimes CSD projects and to set priorities for research and development.

The major technological challenge is the high temperature to be encountered at depth. Specific problems derived from this issue were widely recognized among the participants and are reflected in this summary. A major concern for the projected Thermal Regimes CSD boreholes was the technology required for continuous coring, in contrast to that required for drilling without core or spot coring. Current commercial technology bases for these two techniques are quite different. The DOE has successfully fielded projects that used both technologies, i.e., shallow continuous coring (Inyo Domes and Valles Caldera) and deeper drilling with spot cores (Imperial Valley-SSSDP*). It was concluded that future scientific objectives may still require both approaches, but continuous coring is the most likely requirement in the near term.

The sense of the workshop discussions is illustrated by the following prioritized listing of the major requirements for CSD projects in higher temperature environments:

(1) Drilling and Coring:

- Long-life bits.
- Control of drilling fluid circulation.
- A systems approach.
- Temperature upgrading of bits, motors, bottom hole assemblies, and continuous (wireline) coring hardware.
- Side wall coring systems.
- Improved core quality and recovery.

*Salton Sea Scientific Drilling Project.

(2) Logging and Instrumentation:

- Logs and instrumentation for reliable service at 350° to 400°C.
- Higher temperature cables and alternatives (pump-down tools and downhole recorders).
- Tools for in situ fluid chemistry and rock mineralogy analyses.
- Determination of drilling parameters while drilling or coring.

(3) Downhole Sampling, Testing, and Experimentation:

- Development and deployment of high-temperature VSP* and VEP* equipment.
- Borehole packer assemblies for determining in situ rock properties, sampling formation fluids, and measuring stress state.
- Sensors for downhole use.

Four other areas of concern, or question, were considered important constraints to the understanding and projection of specific future R&D needs for DOE CSD projects:

- (1) Major drilling and coring requirements and improvements appear to be mostly engineering research and development issues, and therefore, should not be solved with funds intended primarily for earth science research.
- (2) Maximum temperature and depth limitations must be defined.
- (3) Is continuous coring, or drilling and spot coring, or some combination of the two methods, the most desirable drilling and coring approach? Without resolution of this question capabilities will not be enhanced and scientific results may continue to be limited.

*Vertical seismic profiling and vertical electric profiling.

- (4) A relatively large bottom hole diameter, i.e., 20 to 30 cm (8 to 12 in.) is required to assure sufficient space for passage of logging sondes, flow testing, and installation of long-term observation instruments. (It was pointed out that coring in larger diameter holes is more difficult than in slim holes with wireline methods.)

Apparently only two new proposals for deeper or hot hole scientific drilling are currently under consideration for DOE/OBES support (Valles Caldera, New Mexico, and Katmai, Alaska). Extension of the SSSDP project in 1987, requested by the House, appears to require conventional drilling and spot coring because of time constraints. However, the need for a lower cost, more effective alternative for other projects was clearly indicated. Future thermal regime projects will require a decision from the participating scientists and principal investigators regarding the need for continuous or spot coring and hole diameters. The scientific objectives of Thermal Regime CSD projects should define the parameters of depth and temperature. Critical to the future of scientific drilling is the long development time necessary for the technology improvements, which now constrain the scientific opportunities.

Development of improved coring, drilling, and logging capabilities must be initiated now to be ready for use in the next three to five years. The questions posed are: (1) Is there a versatile, flexible drilling/coring system approach that can meet anticipated needs? A major decision would be the need for continuous coring below 3 to 5 km, where top-drive rotary techniques will be limited. (2) How often will temperatures greater than 400°C be encountered? It was further pointed out that many ultradeep CSD projects may encounter temperatures in excess of 300°C (e.g., the GUIDE project in the geopressured San Marcos Arch of Texas). While current slim-hole, wireline coring technology may suffice for some CSD projects, this technology should be temperature upgraded. In addition, mention was made of strategies that combined slim-hole

continuous coring with large-diameter drilling to satisfy the often conflicting requirements of continuous core and deep drilling at large diameters.

Another area of concern for any program requiring extensive coring is the very important role played by experienced, deep coring engineers and technicians. A cadre of experienced individuals should be identified and retained to direct all CSD operations. Training of new engineers for each CSD project was judged to be impractical because success or failure of such operations requires knowledgeable and experienced teams. This is probably true for the other areas of thermal regime technology support as well, e.g., logging and testing.

Some efforts associated with deeper scientific drilling other than thermal regimes projects have similar problems and requirements. Given limited resources, pooling of total Federal resources could be cost effective and perhaps attract more industrial support and funds.

The participants were severely constrained in making recommendations and setting priorities by the perceived lack of definition in the statements of scientific need. The sense of the workshop recorded below should be considered with these constraints in mind.

It was also pointed out that needed drilling and engineering developments have historically been considered the responsibility of industry and the private sector, while advanced instrumentation and sensor development have traditionally been considered scientific ventures and often supported by the Federal Government. It was suggested that this traditional approach to drilling R&D may need to be changed to provide the specialized high temperature coring and sampling techniques required by CSD Thermal Regimes projects.

Presentations at the workshop were intended to focus on future Thermal Regimes CSD projects and discuss (1) the state of the art (domestic and foreign), (2) major problem areas, and (3) suggested research directions.

2. INTRODUCTION

Thermal Regimes CSD project planners should anticipate severe rock temperatures and highly corrosive fluids. Improved effectiveness both in exploration for hydrothermal resources and in scientific investigations of fundamental crustal processes and evolution will require increasing depth and temperature capability from the supporting technologies. The workshop presentations and discussions delineated the major technological barriers to achieving these capabilities.

This summary provides a sense of the workshop discussions. The three workshop topics, Drilling and Coring, Logging and Instrumentation, and Downhole Sampling, Testing, and Experimentation, are complex subjects that could be addressed in separate workshops. These topics are strongly interdependent, and for CSD they must be developed in an integrated and coordinated manner. For example, the borehole diameter must allow the use of the most advanced geophysical logging or downhole testing tool. In fact, any selection of current technologies for large-diameter drilling and spot coring or continuous wireline core drilling will limit, to some extent, the scientific yield. Discussions were severely constrained by lack of definition of the scope of future DOE CSD Thermal Regimes projects. However, there was a clear sense that improved tools and technology to reduce costs, enhance flexibility (e.g., a combined drilling and continuous coring system), allow downhole measurements to 400°C, and generally extend the potential for significant experiments and downhole tests will benefit the projects. Target depths of 4 to 6 km (12,000 to 18,000 ft) with maximum temperatures in the range of 400° to 500°C are probably attainable. The long lead time and high cost of some important technological improvements will require funding higher than present levels.

Pooling funds and talents from the different government agencies, and the private sector may prove an effective way to achieve higher funding levels.

Most technical developments in drilling and coring come from the commercial sector. These firms will ultimately fabricate and supply most of the drilling and coring hardware. On the other hand, the Federal Government has supported, and continues to support, the development of instrumentation, electronics, sensors, downhole measurement and sampling tools, and materials through national laboratories, universities, and commercial sources.

The presentations and discussions covered (1) state of the art (at home and abroad), (2) major obstacles (in order of priority), and (3) research and engineering directions.

3. DRILLING AND CORING

The drilling and coring presentations were from four different perspectives: (1) high-temperature geothermal production drilling, (2) coring technology, (3) the recent Salton Sea Scientific Drilling Project (SSSDP) experience, and (4) ultradeep coring and drilling. The primary generic problems or barriers to progress, from all four views, centered on temperature upgrading of equipment and hardware. While the objectives and perspectives of these four areas are somewhat different, there was a consensus on the major obstacles. It was emphasized that the goal of any development or engineering effort would be to reduce cost and increase effectiveness of drilling and coring for CSD projects. It would be expected that many technological spin-offs (to the geothermal industry especially) could result.

- Increased Bit Life. Larger diameter drilling and coring bits are needed for hot hole (300° to 500°C) conditions. These improvements will decrease the number of trips of the drill pipe into and out of the hole. Bits capable of

higher rotation speeds (with high-temperature downhole motors) will improve rates of penetration and enhance core recovery and quality.

- Lost Circulation Control. Thermal Regimes CSD projects will often encounter hard, fractured rocks with severe lost circulation zones. Materials and procedures to control lost circulation in high-temperature environments will reduce costs and improve scientific evaluation. Drilling fluid additives, special placement tools, and practical procedures must be considered.

- Dedicated Deep Scientific Coring Systems. A hybrid, or combined, drilling and coring system should be developed based on established continuous wireline coring methods and hardware developments from the ocean drilling program (ODP). The major effort should be on continuous wireline core recovery with the flexibility to switch to straight drilling. System effectiveness equal to or better than deep drilling with spot coring should be the goal. Temperature upgrading will be a major problem, and a systems design approach will be required.

- Sidewall Coring. Several methods of sidewall coring are available or are under development. These should be enhanced for increased depth and temperature. The utility of such systems should be made more widely known to the scientific community.

- High-Temperature Downhole Motors. These tools can be used to enhance coring effectiveness (both conventional and wireline), to control hole deviation (and reduce downhole drilling problems), and to increase penetration rates.

- Pressure Control. Coring and drilling in high-temperature formations containing hot, high-pressure fluids require pressure control downhole and at the wellhead. Valves and seals will require high-temperature elastomers to achieve effective pressure control.

- Drilling/Coring Data. Monitoring several drilling-related parameters downhole can enhance drilling/coring effectiveness significantly. Direction, pressure and temperature, bit dynamics conditions, and coring assembly performance (core barrel filling or blockage conditions especially) should be monitored.

- Team of Experts. It was pointed out that experience plays a very significant role in the effective design and use of all coring and drilling equipment, especially new or advanced systems, and a team of experts should be available for all CSD Thermal Regimes projects. This experienced team is especially important to the success of coring operations.

- Other. Drill string inspection, drilling fluids, corrosion control, and core disk and borehole stability were other areas mentioned as important topics in need of consideration.

Drilling and coring in hot crystalline rock, SSSDP, and other recent CSD projects, provided valuable recent experience for the workshop. The experience indicates that

- (1) Most ultradeep coring and drilling below depths of 10-km (30,000-ft) will encounter temperatures of 300°C and higher.
- (2) In conventional spot coring in hard fractured formations, the amount of core recovered and its quality and the penetration rate decreases with increasing depths.
- (3) The minimum hole diameter is an important consideration for logging, testing, and installation of long-term observation instrumentation.
- (4) Deep drilling operations to 400°C have been successfully conducted (Hawaii, Italy, Indonesia, and Japan). Coring has been accomplished at rock melt temperatures at 150 m (500 ft) depth (Hawaii), 340°C at 1.5 km (5,000 ft) depth (Coso), and 310°C at 4.3 km (15,000 ft) depth (Fenton Hill, New Mexico).

As opposed to drilling for resource development and production, the CSD objectives are to obtain data and core samples. As a result, there are sharp contrasts in the priorities, planning sequence, and execution of these two different types of drilling projects:

Resource Production:

1. Drill hole (Rig selection) + 2. Core/log + 3. Analyses of core/logs

Earth Sciences Research:

1. { Requirements for core, sample analyses, tests, etc. } + 2. { Core/drilling selection of strategy and balance of objectives } + 3. { Rig and equipment selection to drill/core hole, obtain samples, measurements, etc. }

4. LOGGING AND INSTRUMENTATION

Nearly all the usual downhole logging instruments could be temperature upgraded and packaged for 300°C service. This requires dewars or a high-temperature measuring method and a sensor that does not require downhole electronics. Extension of tool and sonde development can be expected to have an upper temperature limit of about 400°C with dewar protection. The other two major components in downhole measurements are cables and cableheads (connections), which are currently limited to about 300°C service. However, modifications may provide a useful range as high as 400°C. To extend to the 500°-600°C range requires hardened components (no dewar protection) and ultra-high-temperature electronics (currently under development).

In summary, logging and instrumentation can be divided into two categories: (1) tools, equipment, and items that can be extended in temperature and (2) new approaches or new types of downhole measurements. Many of the scientific

priorities for downhole measurements have been covered in earlier CSD workshops and are outlined as follows:

A. Tool and Equipment Development

- Extend appropriate logging tools for reliable operation in the 300° to 400°C service environment.
- For higher temperature cables, consider refractory oxide and graphite insulators and fiber optics applications.
- Alternatives for high-temperature cables should be evaluated. These are downhole recording systems, fiber optic cables, and "pump down" and retrieval of tools through tubing.
- Develop a measurement while drilling (MWD) system for CSD to drill and core more effectively. Reliability, simplicity, and low cost were emphasized.
- Development of high-temperature sensors was mentioned for several applications. Included are gamma ray, pressure (precision), force, temperature, and dynamics (accelerometers and velocity gauges).

B. New Measurements/Instruments

- Downhole fluid chemistry detectors were suggested for development.
- Development of a 400°C lithologic identification tool for depth and stratigraphic correlations and a possible extension of the basic natural gamma sensor for density, porosity, and spectral gamma determinations. The latter is an excellent candidate for early upgrading to 400°C service.
- Improved temperature and rock material property calibrations. The accuracy of tools at high temperature is an especially important issue.

- A downhole logging tool should be developed to determine the mineralogy of rocks in situ. This tool would feature a californium-252 source and would detect aluminum, potassium, thorium, uranium, carbon, silicon, calcium, iron, sulfur, oxygen, chlorine, and hydrogen.
- A high-temperature gravity tool would resolve a number of rock features, structures, and density contrasts away from the borehole.

5. DOWNHOLE SAMPLING, TESTING, AND EXPERIMENTATION

Downhole scientific experiments in CSD boreholes need to be conducted. However, the lack of high temperature testing and measuring systems is the major generic barrier to these important activities. The primary needs are in the following areas:

- Development of high-temperature vertical seismic profiling (VSP) and vertical electrical profiling (VEP) systems for evaluating fracture characteristics and rock properties away from the borehole.
- Development of a variety of downhole fluid sampling tools, both wireline and test-string-deployed (DST) tools must continue. (Note: Not all core- or boreholes will flow so fluid sampling during drilling is very desirable.)
- High temperature packers are needed for both open hole and cased hole use. Extension of the present capability (about 5,000 psi and 260°C) would allow valuable tests and experiments in permeable zones, sampling of fluids from productive zones, determination of stress state, and other in situ determinations of rock properties. These data are needed to correlate with geology and structure and for input to hydrologic and reservoir models.
- The temperature and pressure capability of existing (commercial) pressured core barrel technology should be extended.

6. OTHER CONSTRAINTS, BARRIERS, AND COMMENTS

The workshop participants identified other barriers to the development of needed CSD technologies. These include:

- (1) CSD drilling and coring are a very costly investment. Therefore, efforts should be made across the board to reduce costs.
- (2) In the short term, it would be worthwhile to consider the possible cost reductions of a CSD project strategy that incorporates larger-borehole, rapid-drilling to the target depth with no coring to learn of the subsurface conditions and to provide a large-diameter hole for logging, testing, etc. Detailed geologic samples could be obtained from a nearby smaller diameter continuously cored hole. This avoids the problems, risks, and high costs of spot coring in a large diameter hole. Depending on the geology, it might be advantageous to exchange the sequence because slim-hole coring can often be accomplished in formations that have extensive lost drilling fluid zones. It is possible to diamond core drill without fluid and cuttings-returns to the surface. This strategy is appropriate with essentially off-the-shelf hardware to 3 km (10,000 ft) depth and 400°C.
- (3) Slim-hole, wireline coring technology should be temperature upgraded to achieve more cost-effective continuous core drilling at shallow depths (less than 3 km) in high-temperature environments (to 400°C).
- (4) Without knowledge of anticipated temperature levels and depths for future CSD Thermal Regimes projects, early solutions to long lead time technology problems will be delayed. Lack of cost-effective, deep hot hole drilling and coring technology will constrain scientists who are considering important CSD projects involving deeper and hotter targets.

- (5) Scientific testing, logging, and especially long-term instrumentation installation, require a relatively large diameter borehole. Minimum useful downhole diameter limits are also an impediment to design of tools and to selection among coring and drilling technology options.
- (6) The current paucity of funds for these rather costly drilling technology developments for Thermal Regimes CSD projects appears to some to argue strongly for pooling of resources among several organizations.

It was observed that increasing borehole depths and increasing subsurface temperatures tend to increase CSD costs exponentially. Further, experienced personnel are essential to efficient conduct of these more demanding operations at greater depths and higher temperatures.

7. TENTATIVE CSD THERMAL REGIMES GOALS

Considering the critical impact of CSD technology development on Thermal Regimes CSD projects, it appears sensible to establish tentative drilling depth and temperature goals:

A. Short Term

- (1) Depths to 4 km.
- (2) Temperatures to 400°C.
- (3) Bottom hole diameter greater than 12.5 cm (5 in.).
- (4) Ability to recover long lengths of continuous core.

B. Longer Term

- (1) Depths to 7 km.
- (2) Temperatures to 500-600°C.
- (3) Bottom hole diameter greater than 20 cm (8 in.).
- (4) Recovery of significant quantities of continuous core will still be required.

8. SUGGESTIONS DERIVED FROM WORKSHOP

From informal discussions and notes forwarded to the compiler, some general topics that workshop participants wished to consider are:

- (1) Forming a technology coordination group to offer advice and help guide CSD technology developments. Included should be representatives from national laboratories, universities, industry, and agencies active in CSD projects and knowledgeable about engineering and hardware needs. The drilling and coring aspects should be emphasized initially. (This was suggested also by D. Weill at the CSD workshop in South Dakota.)
- (2) Organizing several technology orientation and tutorial workshops for scientists interested in CSD.
- (3) Study of the Ocean Drilling Program (ODP) drilling and coring system for possible modification and adaptation for a CSD Thermal Regimes deep drilling system. Realizing that funds, knowledgeable personnel, and time are finite, the ODP technology could form the basis for development of a cost-effective drilling and coring system for future thermal regimes projects.

Acknowledgment

Notes and input from several participants guided the preparation of this summary. The compiler would like to acknowledge those persons who took notes, who provided input in the form of copies of visuals for attachment to this summary, and who reviewed the draft of this summary.

9. LIST OF PARTICIPANTS AND AGENDA

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*Informal presentations; copies of visuals attached.

10. COPIES OF VISUALS USED

A. Drilling and Coring

DEVELOPMENTS NEEDED

ROCK BREAKING

- DOWNHOLE MOTORS
- HIGH SPEED BITS

FLUID CIRCULATION

- COOLING OR INSULATION

PRESSURE CONTROL

- ELASTOMERS

DIRECTIONAL CONTROL

- TELEMETRY SYSTEMS
- HIGH TEMPERATURE MOTORS

CURRENT DRILLING METHODS

ROCK BREAKING

FLUID CIRCULATION

PRESSURE CONTROL

DIRECTIONAL CONTROL

Figure 4

Figure 5

TYPICAL WIRELINE, CONTINUOUS CORE, RIG CAPABILITIES

<u>DEPTH</u> <u>km (ft)</u>	<u>HOLE SIZE</u> <u>mm (In)</u>	<u>CORE SIZE</u> <u>mm (In)</u>
0.98 (3000)	133 (5.250)	85.0 (3.345)
1.7 (5300)	100 (3.990)	63.5 (2.500)
2.8 (8500)	75.7 (2.980)	43.5 (1.713)

Figure 6

TYPICAL DIAMOND CORING RIG DEPTH CAPACITIES vs CORE SIZE

		<u>B</u>	<u>N</u>	<u>H</u>	<u>P</u>		
CORE SIZE	mm	36.5	47.6	63.5	85.0		
	(in)	(1.432)	(1.875)	(2.500)	(3.305)		
HOLE SIZE	mm	59.9	75.2	96.1	123.7		
	(in)	(2.360)	(2.980)	(3.787)	(4.872)		
RIG TYPE	{	LY 38	m	810	548	244	120
		(ft)	(2000)	(1800)	(800)	(400)	
		LY 44	m	1070	915	760	365
		(ft)	(3500)	(3000)	(2560)	(1200)	
BB-56	m	1372	1220	853	426		
	(ft)	(4500)	(4000)	(2800)	(1400)		
CP-50	m	2286	1981	1372	762		
	(ft)	(7500)	(6600)	(4500)	(2500)

(a)

Figure 9

Figure 10

(a)

29

(b)

Figure 13

GLOMAR CHALLENGER - DEEP SEA DRILL SHIP
DERRICK IS 196 FT (60 M) ABOVE THE SEA

CORE STUB ROLLER CONE WITH
TUNGSTEN CARBIDE INSERTS

Figure 19

Shoe pressed into soft sediment by disc spring pack. Washing of soft material prevented by projecting cutting shoe ahead of bit.

Shoe pushed back to bit face by hard layer; drive gear engaged.

IN THE ELEVATOR

ID BAR CODE STRIP,
TYP. AT 90°

IN THE ELEVATORS

ON THE RACK

NOTE: MAGNETIC SENSOR
CONFIGURATIONS REQUIRED
FOR THESE THREE SITUATIONS.

Figure 22

COMPARISON OF ROTARY DRILLING PERFORMANCE—12¼" BITS

Figure 27

TABLE II

CORING PERFORMANCE^a COMPARISON FOR THE 6 – 3/4-in. NAVIDRILL,^b
 DRILEX,^b AND ROTARY DRIVE IN AN 8 – 1/2-in. HOLE

PERFORMANCE PARAMETER	NAVIDRILL MACH-1	DRILEX D3-172	ROTARY TABLE
Average core length/trip (ft)	59.4	52.7	40.7
Average recovery/trip (ft)	57.0	50.3	35.3
Average recovery rate (%)	96	95	87
Number of trips/jam	1.8	1.4	1
Average ROP ^c (ft/h)	18.6	14.4	5.4
Total number of trips	14	54	6
Total core lengths (ft)	832	2845	244

^a NORTH SEA AND ONSHORE EUROPE AT 3.7 to 4.6-km (12000 – 15000 ft) DEPTHS, RUN WITH 20m (60 ft) CORE BARREL.

^b POSITIVE - DISPLACEMENT DOWNHOLE MOTORS.

^c ROP = RATE OF PENETRATION

CORING PC

TRIPPING PO

SITION

SITION

Figure A-2

<p>CHRISTENSEN DIAMOND PRODUCTS CO. SALT LAKE CITY, UTAH</p>
<p>RETRACTABLE BIT 3 PAD STAGGERED - FLOATING PAD 3 PS - FP BIT SIZE: 9 7/8" x 2"</p>

Figure 29

TABLE A-I

HIGH TEMPERATURE SHOCK ABSORBER FIELD RESULTS (TWO DESIGNS)

TEMPERATURE	400 ° F (200 ° C), 12 HOURS SOAK NO DAMAGE; DESIGNED FOR 530 ° F (275 ° C) 4 HOURS
LENGTH & DIAMETER	3½ AND 12 FEET; 7¾ INCHES
NOMINAL LOADS	AXIAL - 35,000 LB _f TORSIONAL - 1200 FT-LB _f SPRING RATE - 40,000 LB _f /INCH DEFLECTION
STRENGTH	EQUAL TO 5 INCH O.D. STEEL DRILL COLLAR
OPERATING LIFE	GREATER THAN 50 DRILLING HOURS

(a)
 GRIFFITH

(b)
 MUSTANG

ULTRA-DEEP CORING MAJOR TECHNOLOGY PROBLEMS

- **SYSTEM DESIGN**
- **CORE**
- **BOREHOLE**
- **DRILL STRING DESIGN**
- **DOWNHOLE MOTOR CORING**
- **CORE BITS**
- **OTHER**

● SYSTEM DESIGN

TYPICAL

SCIENTIFIC

BIT SELECTION MODULE

● CORE

- CORE DISCING
- CORE BLOCKAGE
- CORE QUALITY

Wedge Blocking

Wedge While Entering
Inner Tube

Wedge After Mud Has
Lubricated Plane

● BOREHOLE

- BOREHOLE SPALLATION/STABILITY
- BOTTOMHOLE ASSEMBLIES
- DOGLEGS
- DIRECTIONAL SURVEY TOOLS
- PORE FLUIDS
- LOST CIRCULATION

● **DRILL STRING DESIGN**

- MINING OR OILFIELD**
- NEW DESIGNS, FLUSH I.D.**
- ALTERNATIVE DRILL PIPE MATERIALS**

MINING

**WIRELINE
TRIP WITH CORE**

**SCHEMATIC
BARREL**

OILFIELD

**PIPE TRIP
(double tube)**

**SCHEMATIC
BARREL**

● DOWNHOLE MOTOR CORING

- AVAILABILITY AND SUITABILITY
- CONVENTIONAL OR WIRELINE
- CORE QUALITY

Navigation Motor Coring System

Motor and Core Barrel on Wireline

- Stationary
- Rotating
- Retrievable

Wireline Coring Through PDM

- Stationary
- Rotating
- Retrievable

Turbo Corer

- Stationary
- Rotating
- Retrievable

Retrievable Rotor and Core Barrel

69

- Stationary
- Rotating
- Retrievable

● CORE BITS

- MINING, OILFIELD, OTHER
- LIFE
- PERFORMANCE

● OTHER

- MWD SYSTEMS
- DRILLING FLUIDS
- SURFACE EQUIPMENT
- DRILL STRING INSPECTION
- CASING WEAR

SALTON SEA SCIENTIFIC DRILLING PROJECT
PROGRAM PLAN
Geothermal Environment

Hierarchy of Problems

Drilling

Lost circulation/flow control \$640K

Directional drill/Bit usage \$390K

Conventional Coring (725 ft recovered) \$550K

Trip times

Follow-on reaming run below 6,000'

Lost circulation, poor hydrodynamics at bit

Drill string stability including torque-up

Logging - USGS-key roles

Need for high temperature reliable tools

Commercial logs - temperature limited

Scientific logs - temperature and pressure - good
- geophysical - generally acceptable
with some component failures

Sampling - LANL, LBL, Leutert-key roles

Need for high temperature reliable tools

LBL worked 1:1 liq only

LANL worked 1:5 liq + gas

Leutert 0:3

Limits of Technology with Depth

- multiple loss circulation zones
- drill pipe + tool(s) fatigue and corrosion
- wireline strength/fatigue
- temperature/pressure/corrosive effect on all components

Barriers to Going Deeper

- materials of construction
- tool design and packaging to withstand temperature and pressure

Barriers to Getting More Core

- trip time
- stability
- bit hydrodynamics
- rock stress relief (core discing)

Barriers to Obtain Better Logs and Samples

- materials of construction and packaging especially seals
- wireline strength and fatigue
- conductor cable temperature limits.

Sandia National Laboratories

September 12, 1986

Dr. George Kolstad
GPN, G-226
US/DOE
Office of Basic Energy Science
Washington, DC 20545

Dear George:

Subject: Recommendations for Drilling, Logging and Instrumentation
Technology Development.

This letter is in response to your request of July 14, 1986, that the GRDO supply to you a list of recommendations concerning Drilling, Logging and Instrumentation technology development for your Thermal Regimes Program. The task proved to be large as is evidenced by the length of this letter. The task was timely since your program is fast approaching a point of major decision; specifically should it continue drilling shallow holes or should it seek out appreciably deeper and hotter targets. To accomplish the latter goal will require an investment in DLI technology.

At the outset of the necessary review, I found no clear consensus of what is meant by DLI technology. Thus, for the purposes of discussion, I have adopted the following definitions. Drilling means making stable hole and taking continuous core specimens. Likewise, the definition of logging is broadened to mean making scientific measurements downhole using more or less conventional sondes as well as research sondes and sampling devices. Finally, instrumentation is a catch all for other measurements and measurement facilities such as logging for the purpose of making drilling decisions and cables, winches, computers and other equipment of general utility.

While the above definitions separate drilling, logging and instrumentation, DLI technology should be an integrated system. For example, the hydrocarbon industry has chosen a system that achieves its goals in a cost effective manner. It emphasizes making hole rapidly, it produces few core specimens and it relies on an extensive suite of logs to make the necessary production

decisions. Conversely, in Thermal Regimes, some investigators have become accustomed to achieving 95% core recovery and, hence, use logging for only those parameters that cannot be obtained from the core, e.g. temperature. The situation may change; if you choose to drill deeper and into hotter formations, our ability to obtain stable hole and good core will decrease. A forewarning of the future is provided by the all too numerous major drilling difficulties experienced in Long Valley, Valles Caldera and in the SSSDP. The time is appropriate for a review of your options.

Heedless of the previous words, in this memo I organizationally separate DLI into its component parts. I start with Drilling since deficiencies in this technology will force changes in Logging and Instrumentation. At the expense of being verbose, I have included background material where appropriate.

I. DRILLING

Presently the technology does not exist to obtain 95% core recovery in deep hot holes. The difficulty lies in the simultaneous requirements of coring, maintaining a stable hole and controlling corrosion of the downhole components. The easiest and least costly solution to the latter two difficulties is to maintain, as best as one can, the circulation of a large quantity of relatively cool drilling fluids that contain corrosion inhibitors. Neither of the drilling concepts used in Thermal Regimes to date had this capability. The diamond coring rigs used in Long Valley and Valles Caldera are inherently incapable of circulating large volumes of fluid. The rotary coring rig used in the SSSDP did not have the capability of wireline retrieval of core. In this type of operation the entire drill string is pulled for each core run and circulation is not maintained during this process. The resulting thermal cycling of the hole exacerbates stability problems.

If a deep, hot coring capability is desired in the future, a development effort should begin soon. To be quantitative, let me assume (1) that we initially strive to take continuous core at 6 km depths in holes in which the equilibrium formation temperature is 500 degrees centigrade and (2) the portion of your budget allocated to DLI technology allows this program to advance at a modest, but active rate. In regard to assumption (2), I would look for the system to be on line in five years. These basic assumptions are used throughout this letter.

The budget/time constraint, coupled with the systems approach to DLI, means that any coring concept must be nearly an off-the-shelf technology. For example, while the usage of downhole turbines to turn the bit is desirable in very deep holes and may have advantages in the shallower holes considered herein, the development of high temperature, coring versions of this component

at the expense of delaying development of other system components is not a plausible option. The most favorable position for your Thermal Regimes Program is to choose directions such that it can take advantage of appropriate technology when it matures in other programs. Development within the Thermal Regimes Program would be limited to upgrading components to meet its unique environmental constraints. This approach is, of course, contingent on the present availability of drilling technology not too far removed from the needs of Thermal Regimes.

The needs of Thermal Regimes are somewhat unique. These needs differ from industrial drilling due to the scientific emphasis on obtaining core. The DOE/GTD program in magma energy does require drilling in a thermal regime environment at extreme temperatures, but again core recovery will not receive major emphasis. The technology that DOSECC is considering for its very deep holes is neither in the immediate interests of Thermal Regimes nor is it presently available. Fortunately, the goals of the Ocean Drilling Program are similar to those of Thermal Regimes, and their equipment design is available. However this equipment has not been designed for a hot environment.

Drilling technology has been under development for over fifteen years in the ODP. It has an impressive string of successes and, most importantly, it is supported by a strong and active infrastructure. Presently, routine hard rock coring aboard the JOIDES RESOLUTION is accomplished using a wireline retrievable inner core tube. This core tube is not very different from the tubes used in the Thermal Regimes operations in Long Valley and the Valles Caldera although the hole is cut with a large-diameter main bit. In softer rock, a cutting surface is placed on the core tube and the tube itself extends ahead of the main bit thereby obtaining better core and core recovery. Finally, a hybrid coring concept utilizing a downhole motor is under development at Texas A & M. This concept shows promise of obtaining better quality core than either of the present systems.

To appreciate the differences between the ODP technology and that used in previous Thermal Regimes drilling, requires an explanation of the various coring concepts and a statement of the features of each that either aids or hinders the Thermal Regimes problem or otherwise influences one's choice of coring concept. This comparison is done in matrix form and it is relegated to an appendix. Note (i) the ODP concepts have attributes of both concepts used previously in the Thermal Regimes Program, (ii) they have a good chance of achieving the aforementioned depth and temperature goals, (iii) if Thermal Regimes were to adopt the available ODP wireline retrievable systems, core recovery would be reduced from our present standards, (iv) the developmental hybrid coring concept is likely to achieve the requisite core recovery and (v) all ODP concepts are vulnerable to massive lost circulation zones such as those encountered in the SSSDP.

The Geothermal Technology Division of DOE has had an active program in drilling technology development for over ten years. This effort is directed at reducing the costs associated with drilling geothermal wells. Much of this technology can either be used directly or improved for thermal regimes drilling. Examples include development of lost circulation materials, water jet augmented drill bits, and high temperature instrumentation. In addition, analytical tools and test facilities have been developed to evaluate drilling options in terms of dynamic and thermal response. The GTD magma energy program is developing a concept for drilling in high temperature thermal regimes that utilizes insulated drill pipe. This system results in the delivery of low temperature fluids to the bit face and maintains the entire mud system below critical operating temperatures.

Based on the above discussion I recommend the following drilling plan for your Thermal Regimes Program:

- (a) Initiate a detailed analysis of the ODP concepts as they pertain to the Thermal Regimes environment. If this analysis proves favorable to the more complicated hybrid concept, proceed directly with its development working jointly with Texas A & M. In the more likely event that the hybrid concept is not presently feasible: (1) adapt the available ODP technology to the Thermal Regimes environment and (2) participate in development of the hybrid concept (Note that all of the ODP concepts are interchangeable, i.e. the less complicated techniques can be upgraded to the hybrid concept at a later date.).
- (b) Evaluate geothermal industry drilling practices and GTD drilling technology development to determine applicability to thermal regimes drilling. (Note that in general this technology addresses many of the anticipated drilling problem areas but not the requirement for continuous core recovery.)
- (c) Initiate field tests of the chosen coring system and technology pieces in a geothermal environment. These tests should be a joint effort among OBES, GTD, DOSECC, the ODP (Texas A & M) and the geothermal industry and it should take place in FY 88 or FY 89 if the deep hot coring capability is to be on line in FY 92.
- (d) Initiate an evaluation of options and strategies available to Thermal Regimes in the event of massive lost circulation problems. This problem is the bane of all geothermal drilling, and a cooperative effort with established industry and GTD efforts is appropriate.

II. LOGGING

A. Scientific Measurements

The thoughts of the previous section were intended to leave you with the feeling that while Thermal Regimes should not resign itself indefinitely to attaining poor core recovery, it should prepare itself for such a situation for the indefinite future. This means that a review of the logging strategies is in order since log data will be required to extrapolate knowledge through portions of a hole in which core is not available. Furthermore, log derived data is necessary for those parameters that cannot be gleaned from core and, since logs interrogate a much larger volume of formation material than is available in core, they often provide better statistical information on parameters of interest.

Logging science has been under development for 50 years. Most of the effort has been directed to support the petroleum industry where the parameters of prime interest are porosity, density, oil/gas saturation and rudimentary lithology information. Other, more geologically oriented goals are to be found in the mining industry. Perhaps the best example of mining logging is that of the uranium industry. Much work was done during the old NURE Program in which a combination the physical and geological sciences developed a suite of logs that provided vectoral information as to the direction to an ore body. Such interdisciplinary efforts are requisite to the development of logging tools and logging strategies.

Generally speaking, logging tools are based on the laws of mechanical, electromagnetic and nuclear sciences. Example properties measured downhole are sonic velocities, formation resistivities and the transport, scattering and absorption characteristics of the formation for neutrons and gamma rays. These properties are important in their own right. They allow a mapping from one hole to another and they are necessary for the quantification of surface seismic and electrical surveys. Other formation properties of interest may be gleaned from the above measured properties, e.g. porosity from the formation resistivity, lithology from the spectral decomposition of natural and induced gamma radiation.

At this point it is instructive to review how the ODP has responded to the logging problem. Three points are essential to this program. First of all the ODP Downhole Measurements Panel, has established a policy of logging every hole deeper than 400 meters with a standard suite of Schlumberger sonic, electrical and nuclear logs. These logs continuously update a baseline data set which is consistent since all data are taken with the same tools. This logging strategy is important for two reasons.

Reason 1: an idiosyncrasy of logging tools is that they interrogate some average of the borehole and formation materials. This averaging is dependent on the tool design and tools from one company may not read the same parameter values as tools from another. The sole source policy of the ODP mitigates this problem. Reason 2: the consistent data set allows information from any given hole to be processed using data reduction techniques that involve all past experience. This tack is necessary since the Schlumberger tools (or the tools of any other company) are calibrated in sedimentary formations, not the igneous formations of interest in much of the ODP work.

Secondly, the ODP recognizes that the Schlumberger logs are directed toward the hydrocarbon industry and that some issues of scientific interest are not addressed in the standard suite of logs. Thus a few research-oriented logging techniques are under development. The initial direction taken was the development of logs for the determination of in situ stress. More recently, neutron activation techniques are being developed to aid the lithological interpretation.

Finally, the ODP has assigned one group the task of coordinating the day to day logging activities. This task includes arranging for the appropriate technical and support staff to be aboard the JOIDES RESOLUTION, training this staff, maintaining the data base and its associated data reduction facility, maintaining the logging budget, writing the necessary contracts and performing some of the research work. This group reports regularly to the Downhole Measurements Panel which returns guidance and input to the logging effort. This panel, in turn, is responsive to the needs of the scientific community as they are defined in occasional workshops.

There are two important differences between the present ODP effort and the needs of Thermal Regimes. Obviously the thermal regimes environment is severe. Thus some of the logs used in the ODP are unavailable, at least in their present form, to Thermal Regimes. Secondly, the ODP effort involves many more holes than ever envisioned for the the Thermal Regimens Program. Thus, even if it were desirable, the Thermal Regimes Program would have difficulty in establishing an independent base of log data. Otherwise, due to the joint interest in igneous formations, there is commonality of needs. Furthermore, this commonality is likely to extend to other programs in the worldwide scientific drilling program.

Perhaps it is too early to suggest the formation of an interagency or international logging panel to address the logging needs of all scientific programs even though the magnitude of the required development is large and a coordinated and cooperative effort is justified. I do make the following recommendations:

- (e) Establish or join an existing downhole logging panel. DOSECC has already formed such a group and it may be appropriate for Thermal Regimes to become part of this entity. This panel would:
- (f) Identify a consistent suite of generic logs to be run in all major Thermal Regimes holes and choose a set of tools to make these measurements. The log data should be merged, as best as possible, with those of other scientific drilling programs. Furthermore, a cooperative effort to calibrate the logs for usage in igneous formations should be instituted.
- (g) Identify special scientific logs necessary to Thermal Regimes and initiate their development. In time, some of these specialty logs will become generic.

The question of thermal hardening of logging systems is a generic hardware problem and appropriate recommendations are made in Section III.

B. Downhole Sampling

Downhole sampling means taking core or fluid specimens using wireline techniques. Tools for these processes are available either from the logging industry or from within the Thermal Regimes Program.

Sidewall coring tools are devices resembling miniature diamond core drills. They bore into the side of the hole, remove a sample and place it into a storage magazine. They are not designed to work through casing although this capability might be possible with some redesign of the diamond bit assembly. In this sense they are a candidate to be considered in recommendation (g). Since sidewall coring devices are tricky to use, it is not likely that they will replace taking of continuous core in the drilling process. They could be used to advantage if the initial core is lost and the logs indicate a zone of significance.

The removal of virgin formation fluids from a well is a complicated process. First of all there is a legal ramification in that, no matter how small the specimen, the well is technically in production. This situation changes the status of the permits and the effect on the operation must be reviewed on a case by case basis. Secondly, drilling in thermal formations is always difficult in the sense that the holes are not stable and formation fluids are corrosive. Thus, to alleviate these problems, additives are placed in the drilling fluids and these additives contaminate formation fluids in the vicinity of the well and especially in lost circulation zones, i.e. aquifers of scientific

interest. This contamination may be removed by massive production of the well but the cost is considerable. Furthermore, if the circulation loss is significant, the hole will be in jeopardy unless the zone can be plugged. These thoughts lead me to the following recommendation:

- (h) Commission the scientific community to write a position paper on the necessity, requirements and feasibility of obtaining fluid specimens. This paper should address the question of acceptable levels of various contaminants, assess the risks the community is willing to take in producing the well and give estimates as to the cost of obtaining the requisite specimens. One might begin with a review of the situation in the SSSDP.

III. INSTRUMENTATION

A. Logging for Drilling

Logging for drilling decisions is aimed at both satisfying permit requirements and insuring that a hole is engineered such that it satisfies the scientific requirements in a cost effective manner. Sometimes logging for scientific and drilling reasons are identical. This situation occurred in the Shallow Salton Program where detailed temperature measurements for heat flow studies also satisfied a permit requirement. The opposite situation occurred in the Shady Rest Program where the approach of the hole to temperature equilibrium was not of scientific importance and only approximate temperatures were obtained while drilling. Other measurements of importance to the drilling operation may be obtained from cement bond logs, caliper logs, total gamma logs (for depth correlation), casing inspection logs and directional survey logs.

Permitting requirements are generally aimed at insuring that a well is drilled in a safe and environmentally acceptable manner. Exactly what this entails is not clear since Thermal Regimes drilling will be entering unexplored regions of knowledge. The experience of the GRDO indicates that the permitting agencies will be reasonable, they will examine each well on its own merits and they will be open to our suggestions. For the most part the agencies desire that the upper part of the hole be safe and well engineered. Since the upper part of a hole is likely to be cool, it may be logged with existing service company equipment.

In view of both the diverse nature of the logging-for-drilling problem and the fact that some scientific logs will be available for engineering decisions, I make the following recommendation regarding the logging-for-drilling question:

- (i) Do not seek general solutions at this time; the problems are difficult to define and we may solve some that do not exist. Rather examine each well on its own basis and act accordingly.
- (j) Charge the cost of rental or development of special equipment and services to the drilling budget of the well in question.

B. Thermal Hardening of Downhole Equipment

Present logging capabilities are limited from the viewpoint of the temperature requirements of the Thermal Regimes Program. Most commercial and developmental tools that utilize conductors within a logging cable have an environmental restriction of about 300 degrees centigrade. Other, generically called "Kuster" tools, record data mechanically or electronically downhole, they are powered by a wound spring or battery and they enter the hole on a slick line. Such tools were used in the SSSDP, and they show promise as long as the power requirements of the measurement are not large and real time data are not requisite. Furthermore, one can envision with realism a suite of generic tool components such as a battery pack, a "slick" line with a fiber optic data link and a data transmission package, all temperature hardened to 500 degrees centigrade. An investigator, say working under the auspices of recommendation (g), would develop the measurement unit, attach it to the battery and transmission packages and proceed with the logging operation. Such a tack would minimize or eliminate the duplication of efforts.

Since the above mentioned ideas are either tried or plausible, I recommend:

- (k) A program be initiated to develop the supportive hardware for thermally hard logging systems. The measurements to be made would be compatible with recommendations (f) and (g).

C. Other Instrumentation and Needs

The GRDO will continue to upgrade its inventory of equipment of general utility as time and budgets permit. However, some drilling programs will have the need for special equipment and services that are not in the GRDO inventory. The cost of these items should be borne under recommendation (j).

IV. IMPLEMENTATION

The plan detailed above is a set of ideas that should lead to a balanced DLI program for deep, high temperature drilling for

scientific purposes. Certainly as one delves into this plan some of these ideas will change. Furthermore, the important question of cost is yet to be addressed and the formation of alliances between scientific, governmental and industrial institutions is a task to be accomplished. Should you choose to adopt this plan the first step is for you to make an assignment of implementation responsibility. Should this responsibility fall into the GRDO, an augmentation of its FY 87 budget of one FTE will be requested through an FTP defining the first year's efforts.

V. IN CONCLUSION

In conclusion I would like to reiterate some of the thoughts developed above. The Thermal Regimes Program is fast approaching an important decision point. It could continue with the shallow drilling effort using diamond or rotary coring technology. In this case past experience indicates that holes more ambitious than those already drilled will be difficult if not impossible. On the other hand the decision could be made to advance to deeper and hotter environments. Such advancement will require an advancement of DLI technology. The lead time for this technology development is about five years and it will be costly. Fortunately much of the required drilling technology development has been or is being addressed in the Ocean Drilling Program and the GTD Geothermal Technology Program. The Ocean Program has also developed a plausible logging plan. If these ideas and plans, along with similar contributions from industry, are incorporated into the Thermal Regimes Program the technology for drilling deep and hot holes may be achieved at a relatively low cost. Certainly the implementation of an ambitious drilling program for Thermal Regimes will draw on the capabilities of many institutions and it will require the dedication of administrators, scientists and engineers with many diverse backgrounds.

VI. APPENDIX

- (a) Matrix Rows: Drilling/Coring Concepts in order of departure from diamond coring technology

1. Diamond Coring

Diamond coring has been developed and used extensively in the mining industry. It is characterized by light, often truck mounted rigs; high rotational velocity of the bit compared to "rotary" techniques; light drill rods; small kerfs and tolerances; low mud flow rates and the ability to take excellent core. Smaller diameter rods can be nested within the next larger size. Thus, if a hole runs into difficulty, it may be easily stepped in size and continued simply by leaving the "old" rods in the hole as casing. In competent rock, holes with depths of nearly 5 km have been drilled using this technology. However, twist offs are

common at much shallower depths in igneous rocks. Furthermore, the low mud flow rate (a few tens of gallons/minute) does not adequately cool the hole thereby compounding corrosion, bit wear and rod strength problems.

2. ODP Hybrid System (ODP notation: NCB)

The ODP hybrid system is presently being developed at Texas A & M. It consists of a down hole mud motor which turns a diamond core barrel and this barrel protrudes a foot or so ahead of a donut-shaped main bit. The slowly turning main bit reams the hole to a nominal 10 inch diameter and this portion of the hole can be cooled by large mud flow rates. The faster turning diamond bit is cooled with a modest amount of mud. When the core tube is full, the entire mud motor/core barrel assembly is returned to the surface using wireline techniques. This retrieval allows a servicing of the most critical components. Since the outer bit and its drill pipe remain in the hole during retrieval, circulation may be maintained. However, it is interrupted during changes of the main roller cone bit. This system has been tested on Leg 104 and other testing is imminent. Developmental work is needed, particularly that leading to a temperature hardened mud motor and mud pulse telemetry to the surface indicating the condition of the downhole components.

3. Extended Core Barrel (ODP notation: EXB)

The extended core barrel concept consists of wireline retrievable inner and outer core tube which is latched to the bottom hole assembly of the drill pipe, i.e. the outer parts of this device turn at the same rate as the pipe. The lower part of this assembly protrudes a variable distance through the center of the main bit and the leading edge of this protrusion is a cutting surface that machines the core which advances into the inner tube. This system works best in relatively soft rock. If hard rock is encountered, the outer barrel is automatically withdrawn into the bottom hole assembly thereby protecting the coring device.

4. ODP Wireline Retrievable (ODP notation: RCB)

This concept was the forerunner of the above ODP Systems and it remains the workhorse of ODP drilling in hard rock. It is based on the aforementioned donut shaped bit and the wireline retrievable core barrel is similar to the inner core tube found in diamond coring systems. However, since a roller cone bit rather than a diamond bit cuts the core, some comminution of the core occurs at the bit face and the high mud flow rates in this region carry smaller pieces of "core" up the annulus of the hole. This type of coring tends to be selective in that only competent material is retrieved. It is significant that all of the ODP concepts are interchangeable while drilling. This capability

suggests an interesting option. The simpler techniques could be used in most of the hole. If the rock became interesting, the more complicated hybrid system could be invoked.

4. Rotary Core

Rotary coring has been the standard technique used in the hydrocarbon industry for many years and it was used in the SSSDP. Good core can be taken in competent rocks of sedimentary basins, but the disadvantages of the ODP wireline retrievable bit system remain in igneous formations. A further major disadvantage is the necessity of removing the entire drill string for each coring run.

(b) Matrix Columns: Features

1. Maximum Depth

The maximum depth attainable in any drilling operation is dependent on many factors and these factors are integrated over the length of the hole. For example, if everything else is constant, one may expect to core deeper in a formation that is cool at the top than in a similar formation that is hotter even though the temperatures at depth are identical. Nevertheless, one can estimate the depths attainable with the various coring concepts, and these figures are listed. These estimates are based on experience with diamond coring equipment, an examination of the ODP systems and the requirement that any system have near off-the-shelf availability.

2. Hole Diameter

Hole diameter is based on the capacity of existing drilling rigs. The maximum hole diameter made by common diamond coring equipment (Longyear HD 600) is 5.25 inches, and it decreases to 2.98 inches at a depth of 5300 feet. By way of comparison, the bottom hole diameter of a common ODP hole is nominally 10 inches. This difference is significant since only the larger holes permit significant thermal shielding of down hole instrumentation packages.

3. Core Recovery

Core recovery is strongly influenced by the type of coring technology chosen for an operation. Numbers in this column are estimated from personal experience on Leg 104 of the ODP and coring operations at Inyo Domes. Both operations encountered a series of basalt flows which were similar in coring difficulty. At Inyo, core recovery exceeded 95% using diamond coring techniques; core recovery was 40% on Leg 104 where the ODP wireline retrievable technology was used. Furthermore, the ODP

technology was highly selective in that only competent material was required, i.e. the massive interior of the basalt flows.

4. Lost Circulation Problem

Some lost circulation problems can be minor and consequentially ignored. This situation is common in diamond coring operations at shallow depths. However, in deeper and hotter holes lost circulation can be very significant leading to hole instability or hole loss and the drilling conditions can become dangerous. Furthermore, without circulation, there is no sure way to lubricate or corrosion treat the drilling rods/pipe. Lost circulation problems are also related to hole temperature problems (see the next column).

5. Massive Cooling

Deep holes in thermal regimes can be expected to have significant length where formation temperatures are high. If energy is not removed from the hole and nearby surrounding rock, the downhole equipment will be subjected to the ambient formation temperature. This temperature may be reduced through the circulation of massive amounts of relatively cool mud. Such massive circulation is not possible with present diamond coring equipment. Furthermore, it is essential to avoid, as much as possible, thermal cycling of the hole since cycling exacerbates hole stability problems. Thus a wireline retrieval of the core through an appropriate lubricator assembly is very necessary. Rotary coring facilities do not have this capability.

6. Availability for Thermal Regimes Test

Diamond coring and rotary coring rigs have already been used in the thermal regimes environment. The time frames for the other coring concepts are estimated and, in part, based on the assumption that some components could be borrowed from the ODP.

7. Weak Point of Concept

None of the coring concepts have ventured into environments envisioned in the Thermal Regimes Program. Thus it is impossible to identify all weak points in the equipment of the systems. However, certain items stand out when referenced against the ODP wireline retrievable system which has been taken to be the minimum system that would satisfy the requirements of the program.

Sincerely,

Pete C. Lysne
Division 6242

PL:6242:ia

Concept	Approximate Depth in Thermal Regimes	Hole Diameter	Core Recovery (Estimated)	Lost Circulation	Massive Cooling	Availability	Weak Point of Hardware
1. Diamond Coring	3 km	Slim	95%	Minor	No	Present	Rod Strength
2. ODP Hybrid	6	Large	95%	Problem	Yes	2-5 yr.	Downhole Motor - MWD
3. ODP Extended Barrel	6	Large	75%	Problem	Yes	1-3 yr.	Core Tube
4. ODP Wireline Retrievable	6	Large	40%	Problem	Yes	1-3 yr.	Reference
5. Rotary Core	6	Large	40%	Problem	No	Present	Easier than Reference

B. Logging and Instrumentation

THE END OF THE WORLD

HIGH PRIORITY RESEARCH AREAS

1. DRILLING PARAMETERS
 - . MEASURE WHILE DRILLING
 - . HIGHER TEMP.
2. PROPERTY DATA
 - . IN SITU STRESS MEASUREMENT
 - . CALIBRATION OF TOOL FOR IGNEOUS ROCK
 - . HIGHER TEMP.
3. GEOPHYSICS
 - . DOWNHOLE INSTRUMENTS FOR HIGHER TEMP. SEISMIC, EM

LOGGING/INSTRUMENTATION MEASUREMENTS

I. DRILLING PARAMETERS

- . LOGGING - TEMP., PRESS., FLOW, GAMMA, HOLE DEVIATION, CEMENT BOND
- * . MEASURE WHILE DRILLING - WEIGHT ON BIT, TORQUE, TEMP., RPM.

II. IN SITU PROPERTY MEASUREMENT

- . MUD LOGGING - POROSITY, PERMEABILITY, DENSITY, MINERALOGY, LITHOLOGY
- * . STRESS STATE

III. GEOPHYSICS

- . PROPERTY DATA, STRUCTURE
- . ANOMALY CHARACTERIZATION
- * . FRACTURE MAPPING

INSTRUMENTATION LIMITS

TEMPERATURE (°C)

100 200 300 400 500 600

CABLES

STANDARD

TFE

BICC

OPTICAL

HOUSINGS

SENSORS

ELECTRONICS

PASSIVE

ACTIVE (Si)

INTERCONNECTIONS

DEWARED SYST.

INDIVIDUAL CONSTRAINTS

$f(P)$

$f(\text{time})$

BOREHOLE INSTRUMENTATION ALTERNATIVES

© NEW TRANSMISSION CONCEPTS

- FIBER OPTICS
- BICC TYPE MgO

© SELF CONTAINED

- POWER
- DATA GATHERING
- DATA PROCESSING
- DECISION MAKING

Example of high temperature stickline
tools for SSSDP: LANL ^{fluid} sampler
and Sandia battery pack shown before
installation in protective dewar/pressure
housing.

GEOHERMAL WELL LOGGING POTENTIAL

Current state-of-the-Art

300°C

**Maximum with Thermal Protection
(for Short Duration at Temperature)**

400°C

**Possible with Development of
High Temperature Electronics (HTC)**

500°C

Operating Specifications	
Temperature Rating	-- 350°C (662°F)
Fluid Pressure	-- 15,000 psi
Length	-- 35 in.
Diameter	-- 2.125 in.
No. of Conductors	-- 7 + Armor

Fig. A-1.
Cablehead assembly.

Operating Specifications	
Temperature Rating	-- 300°C (572°F)
Fluid Pressure	-- 15,000 psi
Length	-- 89 in.
Diameter	-- 5.0 in.
Weight	-- 229 lb ₃
Sample Size	-- 780 cm ³

98 Fig. A-2.
Borehole fluid sampler.

Operating Specifications	
Temperature Rating	-- 275°C (527°F)
Fluid Pressure	-- 15,000 psi
Length	-- 121 in.
Diameter	-- 3.25 in.
Weight	-- 175 lb
No. of Conductors	-- 3

Los Alamos National Laboratory
Earth Science Instrumentation

Fig. A-3.
Fluid tracer injector.

	Operating Specifications		
	Standard	Slimline	Heavy Duty*
Temperature Rating	350°C (662°F)	350°C (662°F)	350°C (662°F)
Fluid Pressure	15,000 psi	15,000 psi	15,000 psi
Length	73 in.	112 in.	117 in.
Diameter	2.625 in.	2.0 in.	2.0 in.
Weight	84 lb	76 lb	230 lb
No. of Conductors	4	6	4
Options	Collar Locator	Collar Locator	Collar Locator

*For use in pressurized boreholes through flow control packoffs.

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Earth Science Instrumentation

Fig. A-4.
Slimline temperature/collar locator tool

Operating Specifications

Temperature Rating	-- 300°C (572°F)
Fluid Pressure	-- 15,000 psi
Length	-- 112 in.
Diameter	-- 3.0 in.
Weight	-- 154 lb
Radii	-- 8-14-2 in. (Change Arm Length)

- 1 D.C. MOTOR HIGH TEMP
- 2 BALL SEALS NO 505
- 3 BALL BEARINGS NOH
- 4 LEAD SCREW (17-4 SST)
- 5 CENTRALIZERS (12)
- 6 ARM (13)
- 7 BEAD CHAIN
- 8 MAGNET ALNICO 5-7 (12)
- 9 POTENTIOMETER (3)
- 10 O RING
- 11 COVER
- 12 BULKHEAD FEED THROUGH

FEATURES

- A (13) INDEPENDENT ARMS
- B (13) INDEPENDENT CONTOURS ON STRIP CHART
- C MAGNETIC COUPLINGS
- D MOTOR OPENS AND CLOSES ARMS
- E HIGH SENSITIVITY

Los Alamos National Laboratory
Earth Science Instrumentation

Fig. A-5.
Caliper and contour tool.

Operating Specifications

Temperature Rating	-- 300°C (572°F)
Fluid Pressure	-- 15,000 psi
Length with Injector	-- 121 in.
Length without Injector	-- 95 in.
Diameter	-- 3.25 in.
Weight with Injector	-- 175 lb
Weight without Injector	-- 145 lb

- 1 QUARTZ AMPOULE
- 2 HEAVY METAL SHIELD
- 3 LEAD SCREW
- 4 D.C. MOTOR
- 5 CENTRALIZERS (12)
- 6 GAMMA - RAY DETECTOR
- 7 SEALS AND BEARINGS
- 8 PACKER

LEAD PIG ASSEMBLY FIXTURE

Los Alamos National Laboratory
Earth Science Instrumentation

Operating Specifications		
	Standard	Slimline
Temperature Rating	300°C (572°F)	300°C (572°F)
Fluid Pressure	15,000 psi	15,000 psi
Length	100 in.	101 in.
Diameter	4.0 in.	2.875 in.
Weight	200 lb	70 lb
Option	Temperature	Temperature

Fig. A-7.
Fluid velocity (spinner) probe.

Operating Specifications		
	Standard	Slimline
Temperature Rating	275°C (527°F)	275°C (527°F)
Fluid Pressure	15,000 psi	15,000 psi
Length	68 in.	152 in.
Diameter	5.5 in.	3.25 in.
Weight	160 lb	52 lb
Natural Frequency	30 Hz	30 Hz

Fig. A-8.
Geophone acoustic detector.

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Earth Science Instrumentation

Fig. A-9.
Acoustic transceiver transmitter.

Operating Specifications	
Temperature Rating	-- 275°C (527°F)
Fluid Pressure	-- 15,000 psi
Length	-- 192 in.
Diameter	-- 5.25 in.
Weight	-- 360 lb
Gain Range	-- 0-80 dB

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Earth Science Instrumentation

Fig. A-10.
Acoustic transceiver receiver.

Operating Specifications	
Temperature Rating	-- 275°C (527°F)
Fluid Pressure	-- 12,000 psi
Length	-- 14 ft
Diameter	-- 3.375 in.
Weight	-- 225 lb
Logging Rate	-- 10 ft/min

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Earth Science Instrumentation

Fig. A-11.
Borehole acoustic televiewer (BAT).

Operating Specifications	
Temperature Rating	-- 250°C (482°F)
Fluid Pressure	-- 10,000 psi
Length	-- 152 in.
Diameter	-- 5.75 in.
Weight	-- 520 lb
Detonator Size	-- 1.33 g

Fig. A-12.
Acoustic source detonator.

Fig. A-15.
Explosive fracture initiation device.

Operating Specifications	
Temperature Rating	-- 320°C (610°F)
Fluid Pressure	-- 15,000 psi
Length	-- 250 in.
Diameter	-- 5.0 in.
Weight	-- 215 lb

Fig. A-16.
Explosive sidetracking device.

Operating Specifications	
Temperature Rating	-- 320°C (610°F)
Fluid Pressure	-- 10,000 psi
Length	-- 225 in.
Diameter	-- 3.25 in.
Weight	-- 310 lb

Fig. A-15.
Explosive fracture initiation device.

Operating Specifications	
Temperature Rating	-- 320°C (610°F)
Fluid Pressure	-- 15,000 psi
Length	-- 250 in.
Diameter	-- 5.0 in.
Weight	-- 215 lb

Fig. A-16.
Explosive sidetracking device.

NEED HIGH TEMPERATURE GAMMA-RAY TOOL

TOOL MUST WORK IN TEMPERATURE ENVIRONMENT UP TO 400°C

IF A HIGH TEMPERATURE GAMMA-RAY TOOL IS AVAILABLE,
THEN THE LOGICAL PROGRESSION OF TOOLS USING THIS
GAMMA-RAY TOOL IS

- GAMMA-GAMMA DENSITY

A CHEMICAL SOURCE (^{137}Cs OR ^{60}Co) IS
ADDED TO THE TOOL

- NEUTRON ACTIVATION

A CHEMICAL SOURCE (Am Be or ^{252}Cf) IS
ADDED TO THE TOOL

- SPECTRAL GAMMA

A HIGH TEMPERATURE PHOTOMULTIPLIER TUBE OR
OTHER HIGH TEMPERATURE AMPLIFIER DEVICE IS
ADDED TO THE TOOL

MINERALOGY TOOL STRING

AMS mud resistivity and temperature

TCC or CCCB data communication

NGT

} K. Th. U

CNT - G

CALIFORNIUM ²⁵²

AACT

} Al

GST - A

} C. Si. Ca. Fe. S.
O. Cl. H. sigma

BORON SLEEVE
4.25 "

Specifications

Diameter_____ 4.25 " Length _____ 69 ft
Temperature___ 300 deg Fahrenheit
Pressure _____ 20,000 psi
Logging speed _ 300 to 600 ft/hr

Source 50 micrograms of Cf^{252} , 2.6 yr half-life
emits 1.2×10^8 neutrons/sec @ 2.3 Mev

APPLICATIONS of **ELEMENTAL CONCENTRATION** **MEASUREMENTS**

- 1. Enhanced Lithological Identification**
- 2. Mineral Abundance Estimation**
- 3. Clay Typing and Precise Vclay Determination**
- 4. Well to Well Correlation**

A A C T

**The Aluminum Activation Clay Tool
measures weight percent of
Aluminum in the formation.**

**In combination with the
NGT and GST,
it can provide logs of
12 elements in the formation.**

POTENTIAL APPLICATIONS **of** **MINERAL LOGS**

1. CEC determination
2. Vertical extension of limited core data
3. Improved grain density and porosity
4. Completion and production optimization
5. Sedimentary depositional environment/diagenesis
6. Source rock identification
(with the addition of Carbon and Oxygen)
7. Enhanced data set for re-evaluation of reservoirs

APPLICATIONS of ELEMENTAL CONCENTRATION MEASUREMENTS

- 1. Enhanced Lithological Identification**
- 2. Mineral Abundance Estimation**
- 3. Clay Typing and Precise Vclay Determination**
- 4. Well to Well Correlation**

TECHNOLOGICAL BARRIERS TO DEEP CONTINENTAL SCIENTIFIC DRILLING IN THERMAL REGIMES

Geophysical Methods

Seismic

Active
Passive

Potential Field

Electrical
Gravity

Element weight percentages are derived from the tools.

Aluminum weight percent is obtained by subtracting the background spectrum, correcting for environmental effects and accounting for source strength and detector system efficiency.

Potassium, Thorium and Uranium weight percents are obtained from the weighted least squares vector solution and environmental correction of the five window count rates from the NGT.

The combination of NGT + AACT + GST allows us, in most formations, to derive the absolute weight percentages of:

Al. Fe. Si. Ca. S. K, C, O

without arbitrary normalization to core data as the following examples illustrate.

THERMIONIC INTEGRATED CIRCUIT OPERATION IN HOSTILE ENVIRONMENTS

HIGH TEMPERATURE

500°C FOR OVER 13,000 HOURS, PIN SEAL

TOTAL RADIATION DOSE – TESTED TO

10^{17} neutron/cm², NO DEGRADATION

2.5×10^8 Rad(Si) (gamma), NO DEGRADATION

RADIATION DOSE RATE – TESTED TO

4.5×10^{10} Rad(Si)/sec (gamma)

2×10^8 Rad(Si)/sec (proton)

1.4×10^{16} n/cm²/sec

Los Alamos
ELECTRONICS DIVISION

TIC HARDNESS PROJECTIONS

>500°C FOR EXTENDED PERIODS

TOTAL DOSE - 10^{10} rad Si

> 10^{17} NEUTRONS/cm²

TRANSIENT RADIATION -

5×10^{11} rad/sec
(5-V LOGIC)

5×10^{12} rad/sec
(50-V LOGIC)

Los Alamos
ELECTRONICS DIVISION

116

A number of devices
on a substrate

C. Downhole Sampling, Testing, and Experimentation

1941-1942

COMMENTS ON
GEOHERMAL DOWNWELL SAMPLING

Presented to:

U.S. DEPARTMENT OF ENERGY
Germantown, Maryland

September 17, 1986

by

DON MICHELS ASSOCIATES
P.O. Box 895
Whittier, California 90608

SELECTED CONCLUSIONS

1. Downwell sampling addresses only a minor issue in the area of geothermal fluid characterization.
2. Downwell sampling is expensive, uncertain, and seldom gives something that cannot be gained more readily from surface sampling.
3. Promotion of downwell sampling appears to be based on some myths, such as:
 - a) An 'Intact' sample is better
 - b) A single "perfect" sample/analysis represents fluid from a production zone (and perhaps a well).
4. Acquisition of downwell samples often requires coordination with other equipment, such as open-hole packers, that are expensive and risky to deploy.
5. Downwell data must be augmented by other data in order to incorporate the results into a system design for energy utilization.

CHEMICAL ISSUES

FACTOR	CONCERN
BRINE COMPOSITION	
LAYERED RESERVIOR	COMPLETION OBJECTIVES
SCALE	SUSTAINED PRODUCTION
SLUDGE	
CORROSION	
MINERAL POTENTIAL	ADDITIONAL VALUES
PLANT DESIGN	
WELLBORES	CASING PROGRAM
SURFACE SYSTEM	
PIPELINES	REDUNDANCIES
	CLEANABILITY
• FLUID TREATMENT	SOLIDS FORMATION
	SOLIDS REMOVAL
FLUID DISPOSAL	INJECTOR PROTECTION

Slide 1: CHEMICAL ISSUES

The significant issues relate strongest to brine behavior in wellbore and plant. Although composition of the pre-flash brine is fundamental, good knowledge of it alone is far from sufficient to guide process design and plant configuration. If a reservoir is layered, the prime situation for which downwell sampling can yield unique descriptive data, then selection of which combination of layers to be produced still requires assessment of brine behavior in the wellbore and surface installation for the possible mixtures that might be produced/selected.

OBJECTIVES OF CHEMICAL STUDIES ON BRINE AND SOLIDS

1. CHARACTERIZATION OF PARENT FLUID

- a. Composition of liquid in vapor
- b. Steam yield and enthalpy content

2. CHARACTERIZATION OF SCALES AND SLUDGES FROM UNMODIFIED BRINE

- a. Composition
- b. Temperatures and locations of depositions

3. DETERMINE BRINE RESPONSE TO CHEMICAL ADDITIVES

- a. Dilution and Mixing
- b. Acid-Base Effects
- c. Added Particulates
- d. Scale Modifiers
- e. Heavy Metal Directors
- f. Electrolysis
- g. Combinations

Slide 2: OBJECTIVES OF CHEMICAL STUDIES

Besides characterizing the composition and energy content of the resource, a developer also needs to know the behavior of unmodified brine. Then, if some of those behaviors are unwanted, he needs to find how can they be modified.

Slide 3: PHASES IN A FLOWING WELL

Some wells penetrate layered reservoirs and completion methods can select which layers will be produced. Exclusion can be based on chemical compatibility deduced from downwell sampling. However, getting a pure sample of any fluid except from the lowest layer is difficult to impossible.

Since a well exists before it can be sampled, the fluid compatibility will be tested empirically in the course of flowing the well. One merely needs to "watch" what naturally happens.

FIGURE 1: BLENDING OF TWO BRINES IN A WELL

Slide 4: BLENDING TWO BRINES IN A WELLBORE

In this real example, the dilute brine was never sampled pure. However, had a downwell sampler been used it would not have got anything but a mixture (available at the wellhead) unless an openhole packer were also deployed. Selecting where to install the packer is a decision requiring good data.

The dilute brine composition was estimated in three ways:

- i. Comparing the wellhead mixture with the 'pure' hypersaline brine of an adjacent well.
- ii. Fluid densities in the wellbore determined by pressure and temperature measurements
- iii. Relict fluid inclusions in cuttings.

The dilute brine is suspected of being a carbonate scaler if produced alone. Blending with the acidic hypersaline brine yields a mixture that does not give carbonate scale upon flashing. The severity of siliceous scaling from the hypersaline component also appears to be reduced.

PRODUCTION FROM A WELL WITH CROSS-FLOW

Slide 5: PRODUCTION FROM A WELL WITH CROSSFLOW

This diagrammatic sequence shows that strong production zones partially recharge weak zones upon shut-in. The composition of a brine issueing from a weak production zone depends on when in the sequence of events a sample might be taken.

CO₂ IN TOTAL FLOW
EAST MESA - CLASS WELL

Slide 6: CO₂ IN A CROSSFLOW MIXTURE
AS MEASURED AT THE SURFACE

This is a real example for the situation diagrammed in Slide 5. The minimum CO₂ concentration in a production history represents the period of strongest flow from a zone with relatively low CO₂ content. The fact of crossflow is shown by this data, which was obtained at the surface. However, the proportions of flow from individual zones cannot be ascertained from the surface composition alone.

- CLEAN UP OF PRODUCTION ZONES
- CROSS-FLOW EFFECTS
- ESTIMATE OF MIXING VOLUME IN TRANSIT

Slide 7: CLEANUP FLOW AFTER A WORKOVER

High potassium (K) concentrations in workover fluid are systematically diluted and discharge approaches the reservoir concentration (30 ppm). Concentrations measured at the surface show a lag in time/production from what is going on at the production zone. The plunging minimum concentration is related to a shut-in period and shows that the most productive zone is more advanced in its cleanup. The subsequent rise in concentration beyond the earlier projection (linear trend) represents the still highly contaminated output from a readily depletable zone.

Samples were taken at the surface at intervals of 10 to 15 minutes. Downwell liquid sampling could not have resolved the detail. However, downwell measurements of electrical resistance could have given comparable data. Resistance measurements at multiple points in the production zone may have been even more informative. Continuous measurements of downwell temperature and pH could also be valuable. (A pH electrode suitable for downwell service exists, but has not been commercially produced due to lack of foreseeable commercial demand.)

FEE #5 13-DAY FLOW TEST SELECTED INDICIES FOR BRINE COMPOSITIONS

Slides 8 and 9: CHANGE IN FLUID COMPONENTS DURING A SEVERAL-DAY TEST

What do the trends mean? In Slide 8, ionic components show faint trends while in Slide 9, CO₂ cycles over +25%. What could be sought in downwell sampling to augment data such as these? Can the data from downwell sampling be precise enough to show such subtle trends; at what manpower levels and other costs?

Slide 10:

FLUID CHAMBER OF A FLOW-THROUGH SAMPLER

This flow-through design looks hard to flush clean, so how does one know what the sample represents. The mechanical design solves problems of sealing the chamber, but the sample is guaranteed unsanitary from the viewpoint of an analytical chemist. This means that no important decision could be based on the data.

Other sampler designs include evacuated chambers opened by twist-type valves and chambers filled by piston actions.

A variety of devices are used to time and actuate the chamber's open/closing operation. These include mechanical clocks, calibrated leak of a compressed gas, inertial mechanisms, etc.

ARCANE PROBLEMS OF DOWNWELL SAMPLING

EQUIPMENT FUNCTION

**VALVE FAILURES
TO OPEN, TO CLOSE, OR TO SEAL
PREMATURE FUNCTION**

CORROSION, DECOMPOSITION, SCALING

SMALL SAMPLE VOLUME

THERMAL EXPANSION EFFECTS

LARGE LOGISTICAL SUPPORT NEEDED

**EQUIPMENT DESIGN
MATERIALS SELECTION
FIELD CREW
RIG AVAILABILITY/COST
HIGH MAINTENANCE REQUIRED**

LOW SAMPLE FREQUENCY

100 feet/minute in a 10,000 foot well means 100 minutes travel time each way. With rig-up and rig-down times, plus opening the sampler, recovering the sample (in several parts), then dis-assembly and refitting of the sampler for the next run, expect one sampling effort per 8-hour shift by three or four persons.

CONTINGENCIES

**SAMPLER BREAKDOWN
RIG FAILURE
SAMPLER LOST IN HOLE
UNAVAILABILITY OF SKILLED PEOPLE
UNAVAILABILITY OF SPECIALTY PARTS**

THERE IS NO "INTACT" SAMPLE

A. As a sealed sample chamber cools the liquid contracts, leaving a vapor space which becomes occupied by the available gases. The contraction is nominally 20 percent of the chamber volume, more for really hot water.

B. If chemical deposition is initiated by cooling/degassing in the sample chamber, solids will be mainly on the chamber walls and other available surfaces. Adequate recovery of deposited solids requires simple internal shapes for the sampler, but complications always arise due to the presence of residual liquid. For example, if the solids were rinsed into a collection vessel by dissolving in acids, it is not possible to know how much was present initially. If they were scraped instead, the ability to scrape cleanly depends on the simplicity of the chamber's interior and the resistance of the chamber parts to being scratched and included in the scrapings.

C. Analysts cannot analyze intact samples anyway.

Gases are analyzed separately from dissolved materials

Analytical methods of choice differ for important components. If an analyst were given an 'intact' sample he would split it into at least six parts to make a typical total geothermal analysis. Some methods require dilution of the sample. The extreme case is for hypersaline brines which are diluted 50- or 100-fold (in moderate strength acid) to make an analyzable solution.

Operationally, it is better to make those splits and some dilution in the field, preserving selected components in the different kinds of splits.

SEISMIC METHODS

I. Active

A. Vertical Seismic Profiling (VSP)

1. Borehole Sources
Controlled, P, SV, SH Capability
2. 3-Component (V, Hx, Hy) Sensors
Arrays (5 to 10/ string)
3. Integrate interpretation with other disciplines
Integrate data in terms of hydrologic as well
as petrologic and lithologic data

B. Reflection/Refraction Profiling

1. Processing and interpretation in complex environments.

C. Data Processing/Formatting for Exchange

II. Passive

A. Microearthquake/Acoustic Emission Monitoring

1. Method to monitor wide-band (1 hz to 10 khz) signals in borehole, i.e., high T&P, long term
2. Important data for:
stress distribution
fracture genesis and distribution
fluid flow
3. Simultaneous monitoring with fluid injection/packer tests

POTENTIAL FIELD

I. Electrical

A. Development of equivalent methods to VSP, i.e., VEP

1. Borehole polarized receivers and sensors
2. Borehole polarized sources

B. Enhanced interpretation techniques

1. 3-d modeling
2. Joint inversion with seismic and gravity

C. Improved field instrumentation for deep sounding

1. Larger current sources
2. Improved real time processing

II. Gravity

A. Development of Higher Temp/Pressure Downhole Microgravimeters

Status of Borehole Methods for
Evaluating Subsurface Mass and Energy Transport
in High Temperature Thermal Regimes

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OBJECTIVES

- 1) Measure the in-situ physical properties (permeability and porosity) that control advective transport in porous and fractured rock.
- 2) Correlate transport properties with geological, geochemical, geophysical and thermal characteristics of the rock mass.
- 3) Provide hydrologic input for developing models of the natural heat and mass flow regimes deep within the earth's crust.
- 4) Predict and/or measure the quantity and value of recoverable resources (heat, fluid, dissolved chemical species and gas).
- 5) Predict and/or measure the transport of heat and/or various chemical species.

APPLICATIONS

- 1) Oil and Gas Exploration and Development *
- 2) Groundwater Use
- 3) Contaminant Transport
- 4) Nuclear Waste Isolation *
- 5) Geothermal Exploration and Development *
- 6) Aquifer Thermal Energy Storage
- 7) Hot Dry Rock *
- 8) Scientific Drilling *

* High Temperature Instrumentation Applications

Testing in a Borehole Environment

Physical Constraints

Size

Depth

Temperature

Pressure

Corrosive Fluids

Theoretical Constraints

Small window for observations

Radial geometry

Borehole length governs averaging

Influenced by drilling operations

IN-SITU PERMEABILITY MEASUREMENTS

DIRECT METHODS (permeability variations)

- 1) Downhole flowmeter surveys
- 2) Tracer tests (radioactive tracer logs, single well dilution, multiple well, and thermal)

INDIRECT METHODS

- 1) Pumping and flow tests (transient or steady-state)
- 2) Injection tests (transient or steady-state)
- 3) Drill-stem tests

MEASUREMENT DEVICE TEMPERATURE LIMITATIONS

INSTRUMENTATION REQUIREMENTS

1. Logging cable (conventional cable currently available to 300 ° C, metal sheath cable available to > 400 ° C)
2. Cableheads, seals, lubricants (prototypes available to 350 ° C)
3. Downhole flowmeter (prototypes available to 300 ° C, high temperature modification to 350 ° C probable).
4. Downhole Pressure Sensors (transducers are marginally available to 300 ° C)
5. Downhole Temperature Sensors (reportedly available to 1000 ° C)
6. Downhole Fluid Samplers (prototypes available to 350 ° C)
7. Open Hole and Casing Packers, Downhole Shut-Off Valves

Resolution of the spatial variability of the transport properties of subsurface formations is an integral part of understanding subsurface mass and energy transport.

- Fractured Systems
- Porous Systems

Tracer Recovery in a Sandy Alluvial Aquifer. Note three major returns, resulting from stratification.

Current Technology Limits Application of High Resolution In-Situ Testing

1. High temperature components and instrument packages are not available.
2. Borehole cooling affects thermally sensitive formation properties (permeability, porosity, degree and nature of near-bore fractures).
3. High resolution techniques for in-situ testing in a deep borehole environment have not been developed.

NEEDS

1. Development of high resolution measurement techniques for determining formation properties (drill-stem and single borehole tracer techniques are good possibilities).
2. Component and transducer testing at high temperatures and pressures.
3. Development of high resolution instrument and measurement packages for testing in deep, high temperature environments.
4. Development and application of testing-while-drilling techniques for evaluating transport properties.

ENVIRONMENTAL TEST CHAMBER

Figure 1. Artists conception of the environmental test chamber.

IN SITU DOWNHOLE MEASUREMENTS

**MIKE ANGEL
TOMAS HIRSCHFELD
PAUL KASAMEYER
MIKE BUETTNER**

OBJECTIVE: DEVELOP FIBER OPTICS MEASUREMENT SYSTEM FOR CONTINUOUS IN-SITU MEASUREMENTS IN GEOTHERMAL WELLS.

**TEMPERATURE
PH
FLUID CHEMISTRY
PRESSURE**

APPROACH: DEVELOP "OPTRODES" WHOSE FLUORESCENCE DEPENDS ON THE PROPERTY TO BE MEASURED.

**NO DOWN HOLE ELECTRONICS
HIGH TEMPERATURE
CORROSION RESISTANT
MANY PROPERTIES MEASURED AT ONCE**

Mike Angel, Richard Pearson, Tomas Hirschfeld
Lawrence Livermore National Laboratory

**Fiber optic temperature sensor for use
in a geothermal well**

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**Presented to— The Pittsburgh Conference
and Exposition on Analytical Chemistry and
Applied Spectroscopy March 10–14, 1986**

Fiber optic sensors offer several advantages for geothermal well monitoring

- 1. Measurements are made in-situ**
- 2. Measurements are made in 'real time'**
- 3. Total measurement time can be extended allowing for long term monitoring**
- 4. Sensor is inexpensive , rugged and not prone to failure**
- 5. Fiber offers fast data rate and multiplexed signals**
- 6. All instrumentation is above ground**

Temperature – the first step in the development of optical geothermal sensors

1. Develop the technology for all subsequent sensors
2. Use in the development of fieldable readout devices
3. Provide useful data NOW
4. Most other measurements will require the temperature to be known

**$\text{CaZrTi}_2\text{O}_7$ is a good host crystal to use
in corrosive environments**

1. It is one component of Synroc and was chosen for its extremely low leaching rate
- 152 2. It incorporates rare earth 3 ions readily into the lattice at high concentration
3. It can be made with very high porosity

Zirconolite
($\text{CaZrTi}_2\text{O}_7$)

○ Ca,

● Zr, U, actinides

Ti-O octahedra

Europium provides a strong fluorescent signal with large temperature dependence

1. Very intense sharp bands
2. Several low lying states populated at room temperature lead to large temperature effects
3. Many emission bands with opposite temperature response
4. Incorporates into the $\text{CaZrTi}_2\text{O}_7$ lattice

Laser Fluorescence Spectrometer Setup

Fiber Coupler

Tests are being conducted under simulated geothermal conditions

1. Temperature response not significantly changed
2. Pressure effects not significant
3. Sample survived initial tests
4. Allows us to test mechanical sensor holders
5. Long term tests not yet completed