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SCIENTIFIC DRILLING TECHNOLOGIES FOR DEC 0 1 1988

HOSTILE ENVIRONMENTS*

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Introduction

Deep research drilling will encounter temperatures exceeding those normally encountered in standard oil and gas exploration and production. The traditional oil field service companies have capabilities to temperatures of 120-150°C. Consequently, many problems occur with the drilling equipment, muds, and logging tools at higher temperatures. However, there is a wealth of technology in the geothermal drilling programs where well completions at 250°C are common, at 300°C are frequent, and at 350°C exist on a few wells. Also, materials, mechanical designs, and diagnostic techniques are developed for engines, gas turbines, and other systems that run at temperatures close to 1000°C. All of these systems can be tapped for technologies used in high-temperature deep drilling. The major limitation to such development is lack of commercial interest in high-temperature drilling and so companies are not willing to provide the needed field hardware.

This paper briefly reviews the current United States Department of Energy Continental Scientific Drilling Program for Thermal Regimes and the related technologies being developed for geothermal drilling. Plans for penetrating into a molten magma body at temperatures from 800 to 1000°C are also reviewed.

1. Current Research Drilling Activities

The U.S. Department of Energy has an active Geoscience Research Drilling Program which is largely oriented toward thermal regimes. Table 1 lists the various activities completed to date. These research programs usually involve technologies developed through the Department of Energy programs but include research supported by the National Science Foundation and the U.S. Geological Survey.

The Multiwell research listed in Table 1 is the only research not in thermal regimes, but was designed to understand the transport mechanisms for gas in tight gas sands. That project has been completed and extensively documented. A summary by Lorenz, et al. (1988) has recently appeared in EOS.

(INSERT TABLE 1 HERE)

All of the other research wells were drilled in areas containing hydrothermal and volcanic systems for the purpose of understanding heat and mass transfer in the earth's crust. These wells are shallow 500 to 3000m compared to the deep drilling programs of the USSR and FRG; however, some of these wells were drilled into formations at temperatures over 350°C.

A current drilling effort in the Valles Caldera, New Mexico, is at 1300m with estimated bottom hole equilibrium temperatures over 300°C. Temperatures at the final depth of 1800m are expected to exceed 350°C. This well is being continuously cored using a wire line coring rig.

Future plans include drilling into Katmai, Alaska, as discussed by Eichelberger, 1986, and into a magma chamber in Long Valley, California. The magma drilling will be reviewed later in this paper.

2. Currently Used Technologies

Technologies used in current industrial geothermal drilling to 350°C have been reviewed by Dr. Carel Otte (1988) at this conference. The technologies used for the recent drilling into a 355°C formation at the Salton Sea have also been described by Dr. Wilfred Elders (1988) at this conference. Thus, this paper will not discuss the drilling to 350°C other than to give the following summary.

The drilling and well completion technologies are available and being used for wells with bottom hole temperatures of 350°C. The logging capabilities are limited to a nominal 220°C with some

capabilities to 250°C. At higher temperatures, logging can be done in a cooled hole if temperature is not important to the measurement. Logging at higher temperatures is limited by the capability of the logging cables. Consequently, the self-contained, insulated logging tools have been used over 300°C. These are briefly reviewed in this paper.

3. Technologies for Temperatures over 350°C

Experience and theory in hydrothermal systems have shown that the maximum temperatures encountered in saturated systems follow the boiling point curves of the brines in the formation.

Consequently, temperatures exceeding 360-380°C are not anticipated until one moves out of hydrothermal regions. We anticipate that drill holes into magma bodies will have temperature profiles similar to that in Figure 1. Thus, the majority of drilling toward a magma body will be in thermal regimes for which technology currently exists.

(INSERT FIGURE 1 HERE)

Friedman (1980) studies the mechanical properties of igneous rocks at temperatures to melt and found all exhibited brittle failure and high strengths up to the solidus. Boreholes in

homogeneous stress fields (highly improbable) should be stable at temperatures to the solidus; cooling the borehole can improve the stability. Drilling at higher temperature will undoubtedly identify problems that have not been anticipated; neither can we afford to solve all potential problems that might be encountered. Current programs are addressing a few of the problems we know will be encountered.

There has been limited experience drilling into molten rock systems. Our experience in drilling into the Kiliuea Lava Lake in Hawaii (Colp, 1982) at temperatures of 1100°C used high velocity nozzels in the core bits to freeze the melt in front of the bit. Bjornsson (1980) described drilling through a lava flow in Heimaey, Iceland, at temperatures of 914°C. An overall review of possible plans for drilling into molten rock were reviewed by Traeger, et al, (1980) in early considerations of the magma research program.

An essential ingredient for successful drilling into hot rocks will be to maintain a cool wellbore. As we know, rock is an excellent insulator which allows hole cooling by circulation but also limits penetration of the cooling front into the rock mass. The latter leads to rapid thermal recovery of 66% of the well temperature within 8-12 hours after stopping circulation in a

well. This thermal relaxation time obviously depends on the permeability of the rock, the time of cooling, formation properties, etc. The overall formation can be maintained at cooled conditions for longer periods of time if fluids can be pumped into natural or induced fractures to extend the cooling area out of the wellbore; this cooling technique is often used in the research drilling of hydrothermal systems using cool fluids in the lost circulation zones to cool the formation for extended periods of time. In drilling a deep well, the fluid temperature is significantly affected by exchange of heat from the fluids in the annulus with fluid in the drill string as shown in Figure 2. Consequently, current designs for the magma drilling include an insulated drill string. Insulation thicknesses on the order of 2mm will allow drilling at all times with temperatures below the critical point of water and reasonable return temperatures as shown in Figure 2. Insulated tubulars have been built for use in steam floods and that technology is now being applied to drill string prototypes for evaluation.

(INSERT FIGURE 2 HERE)

All deep drilling to date has had problems with wellbore wall stability because of anisotropic in situ stresses. These

problems will be enhanced in drilling into these hot environments due to pore pressures and increased thermal stresses. These questions are being addressed, but there are no results to present at this time.

The other area of major concern is downhole measurements which are essential to successful drilling and for the research programs. As previously mentioned, the logging cables are the current temperature limiting component in logging technologies. The cables based on TFE are available and have been used to 300°C but only have useful lives below 280°C. Steel sheathed, magnesium oxide insulated cables can be used to 500°C, but have high dielectric losses and major handling problems, both limiting their use. Fiber optic systems have potential, but their availability and proven field capabilities are far in the future. Recent advances in semiconductor memory systems and microprocessors have led to self-contained, downhole measurement packages as used for temperature measurements in the Ocean Drilling Program and in inclination measurements in the KTB wells. Packaging these components in insulated systems with heat sink materials is within existing technology and available for measurements at high temperatures.

A need to measure temperature, pressure and flow at temperatures over 350°C in the Salton Sea led to the development of high-temperature mechanical and electronic tools. In addition, the same concept was used to power valves on fluid samplers. Specifications for these tools are given in Table 2. The systems were designed to survive 400°C for ten hours. There was no effort to do a sophisticated design or use some of the new high density circuits; current designs can be extensively improved.

(INSERT TABLE 2 HERE)

Applications at 355°C in the Salton Sea well had some problems such as seal leakage and the spinner flow tool provided the usual mechanical problems of all impeller tools. However, the mechanical and electronic temperature and pressure tools and the electronic power supply for the sampler all worked at 355°C. Temperature data obtained using the electronic tool are shown in Figure 3.

One logical approach to high-temperature borehole measurements is to use these self-contained systems. They provide the researcher the capability to do borehole measurements with the same flexibility that is available to the laboratory.

(INSERT FIGURE 3 HERE)

Summary

High temperatures should not be a major impediment to research drilling and measurements in deep boreholes. Commercial drilling has been done at 350°C in geothermal systems and commercial logging has been done to 250°C. Operations at these temperatures do require planning and care; direct use of oil and gas technology will not provide satisfactory results.

Drilling at temperatures higher than 350°C will probably require the use of insulated drill string and modifications for continuous cooling of the wellbore. These are technically and operationally feasible and are being investigated in the U.S. Department of Energy Magma Energy Program. Measurements can be done using self-contained, insulated tools as demonstrated in measurements at 355°C in the Salton Sea. Obviously, high temperatures will increase corrosion rates and metal fatigue. Material selections will be important but materials for high temperature, hostile environments are available.

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Table 1

Research Drilling - U.S. Department of Energy
and Sandia National Laboratories

<u>Site</u>	<u>Location</u>	<u>Date</u>	<u>Depth (km)</u>	<u>Description*</u>
Multiwell	Colorado	1981-1988	2.3-2.6	3 wells Lenticular Tight Gas Sands
Obsidian Dome	California	1984	0.5 0.9	30° slant through magma conduit 30° slant through magma dike
Deep Salton Sea	California	1985	3.0	Hydrothermal System; T = 355°C
Shallow Salton Sea	California	1986	0.08	Offshore; 18 heat flow holes
Shady Rest	California	1986	0.7	Hydrothermal System; T = 200°C
Sulfur Spring	New Mexico	1986	0.5	Hydrothermal System; T = 212°C
Inyo	California	1987	0.9	Intracaldera Dike Intrusion 30° slant hole
Baca Flats	New Mexico	1988	(2.0)	In progress; anticipated temperature 350-380°C
Magma	California	1989-	4.0-6.0	In design; anticipated temperature 500°C
Katmai	Alaska	-	-	Being defined; recent volcanism

*All wells, except Multiwell, were continuously cored.

ESTIMATED TEMPERATURE PROFILE FOR DRILLHOLE NEAR SOUTHERN END OF RESURGENT DOME

DRILLING FLUID TEMPERATURES

Figure 2

Fig 3