Report from the ICDP-PI-SAGA Meeting June 22-27, 2001

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INTRODUCTION

The Iceland Deep Drilling Project (IDDP) plans to drill one or more boreholes deep enough to penetrate into the supercritical zones believed to be present beneath three currently exploited geothermal systems in oceanic ridge-type spreading centres in Iceland. The main aim is to produce much higher enthalpy fluids for power production than are currently being utilized. The IDDP is being funded by Deep Vision, a consortium of Icelandic energy companies. A feasibility study, which has a budget of approximately US $ 300,000 is currently under-way and is examining the three candidate sites as well as the economics and engineering issues of drilling to greater depths and higher temperatures.

Responding to the invitation of Deep Vision, a meeting funded by the International Scientific Continental Drilling Program (ICDP), was held in Reykjavik, June 5th-June 27th 2001, to help defining tasks for the feasibility study and to begin planning a scientific program to take advantage of the IDDP borehole (see list of participants, Appendix 1). A **Science Applications Group of Advisors (SAGA)** with both Icelandic and international membership (see Appendix 2) has been formed to formulate and oversee these plans.

Iceland is a particularly favourable location for research on very high enthalpy fluids. It is hoped that such fluids can be produced at high flow rates. In Iceland the repeated seismicity and volcanic activity in the rift environments create high permeability and high temperatures at drillable depths. Temperatures greater than 300°C are commonly encountered in wells drilled to depths of 2 km in
high-temperature geothermal fields in Iceland. The likely existence of permeable regions in brittle basaltic rock at supercritical temperatures at still greater depths beneath the candidate geothermal fields is inferred from the distribution of hypocentral depths of seismic activity that continues to below about 5 km depth. These circumstances are the product of the special geological environment of Iceland, a coincidence of a mantle plume with the divergent plate boundary at the mid-Atlantic Ridge. Thus the IDDP offers the international geoscience community a unique opportunity to:

- investigate the magmatic and fluid circulation character of the Mid-Atlantic Ridge (on land), and
- study and sample fluids at supercritical conditions.

These aspects of high-temperature hydrothermal systems have rarely been available for direct observation. **SAGA** convened panels on **drilling techniques**, on **geosciences**, and on the **pilot plant**. (see Appendix 3)

DRILLING PANEL

The assignment of the drilling panel was to evaluate a drilling strategy to meet the engineering goals, and to consider the additional steps and the costs involved of also meeting the science goals. After a description of the workplan and division of responsibilities by S. Thorhallsson, the panel on

drilling technique, with advice from other panels on the likely ranges of depth, temperature, fluid pressure and
fluid composition in the supercritical regime, considered a wide range of options for achieving the engineering and scientific requirements of the IDDP. These options included drilling:

- a "standard", albeit deeper, production well drilled with conventional geothermal technology with limited spot coring at casing points, near major stratigraphic boundaries, and within reservoir rocks
- a "standard" production well as in (A), above, with wireline sidewall coring to interpolate between conventional cores
- a cored pilot slim hole, followed by reaming out the hole to a production-diameter well using "hybrid" rotary-coring technology
- two wells, one a cored slim hole for science and the other a "standard" production well for engineering,
- a "standard" production well to 3.5 km depth and then continuously core a slim hole 1-1.5 km deeper using hybrid rotary-coring technology.

A schematic overview of the 5 options above is presented in Figure 1.

During discussion by the SAGA committee, a strong consensus emerged that option E offers the best compromise to meet both the engineering and science goals within realistic budget constraints. The largest drilling rig currently in Iceland ("Jötunn") has the capacity to drill and case a production hole as deep as 3.6 km. A continuous coring system with top-drive, such as the DOSECC coring rig, used successfully in a number of scientific drilling projects in the USA, could then be adapted to Jötunn, or to a similar rig, to deepen and core a slim hole into the supercritica zone. If flow testing this slim hole proved successful, sufficient information for proof of the concept of producing energy from supercritical conditions would be obtained. At the same time the science program would obtain abundant data and samples from the supercritical regime and rock samples from the deeper part of the Icelandic late Quaternary – Holocene Rift zone.

GEOSCIENCE PANEL. The assignments of the geoscience panel were firstly to develop criteria for evaluation of three candidate sites which have been proposed for the IDDP, and secondly to develop a basic science program essential to the scientific success of the project. The three geothermal systems of Reykjanes, Krafla and Nesjavellir were considered as candidate sites from both geoscientific and environmental perspectives. Given what we know at present of these systems, supercritical conditions are almost certainly likely to be found at drillable depth at all three sites. The current production zone at the Nesjavellir geothermal field, at the north side of the Hengill Central Volcano, was provisionally ruled out for environmental reasons. However, two 2 km-deep exploratory wells will be drilled in the south side of the Hengill volcano this summer. Depending on the findings from these wells, the Hengill area remains a candidate site for the IDDP.

Table 1, under the heading Drilling Target, summarizes findings of the Geoscience Panel with respect to the criteria for evaluation of the candidate sites. In the upper part of the Table are the best estimates of the anticipated conditions likely to be encountered at depths at the three candidate sites. At Hengill and Krafla, target temperatures of 500°C are sought which should be well into the supercritical zone at 5 km depth and 4 km depth respectively. At the Reykjanes geothermal system the produced fluid is evolved sea-water so that it is deemed advisable to avoid fluids at temperatures high enough to result in deposition of salt in the well during production. This requires target temperatures below 420°C.

Potential problems are listed below the statements about the drilling target at each site. Environmental restrictions are probably more likely at Krafla than at Reykjanes, but more information about possible environmental restrictions at Hengill is necessary.

The panel recommends that the focus of a basic, essential, minimum science program should be on the deeper hotter supercritical part of the borehole, but not to the total exclusion of the upper cased production well. A minimum program in the production well should include collection of drill cuttings for petrological study, and at each casing point, logging, obtaining spot cores, and determining the state of stress by hydrofracturing and the use of borehole televiewer.

In the continuously cored part of the well, below the production casing, real-time study of fluid inclusions and mineral assemblages while drilling could be used to help identify the proximity of the supercritical zone. Taking advantage of any massive loss zones, slim hole logging of this deep zone should be attempted. Similarly extensive fluid sampling and flow testing of loss zones in the supercritical
regimes should be an important goal of the program for both engineering and scientific reasons.

A number of activities during the feasibility study were also discussed. These included mapping earthquake hypocentres and determining focal mechanisms in the candidate sites and setting up a working group of geochemists to estimate likely chemical parameters of the fluid to help design the fluid handling system, as well as for environmental contingency planning.

PILOT PLANT PANEL. Until more is known about the nature and volume of fluids likely to be produced from this borehole, the main objective of the pilot plant must be to obtain as much data and information as possible on the fluid and its properties. On the basis of this information further plans for utilizing the fluid will be laid out. Thus the panel suggests a pilot plant in steps where the first step is designed to be as simple and flexible as possible. At Reykjanes the target is a brine at 380-420°C containing 3-5 % by weight salt with an enthalpy of 2000 kJ/kg or higher. Because the critical point is elevated to higher temperatures and pressures by increased salinity, a supercritical zone may not be present at this tempereraturе. At Hengill and Krafla the target is 450-500°C fluid with an enthalpy of 3000 kJ/kg, possibly containing 0.1-0.2 % by salt. However, there is a high uncertainty about the P, T and chemical composition, and the likelihood of encountering acid fluids which would present technical and environmental hazards. The panel finds it of highest priority to carry out a chemical study of the expected conditions of the supercritical fluid.

The study should also address the possibility of discharging such fluid to the surface without the risk of rapid plugging of the well.

The preliminary design centres on a downhole tubing system consisting of a suspended solid liner to convey the fluid to the surface to allow fluid sampling at the surface and studies of corrosion and scaling downhole. In this preliminary design only low mass flows are planned. In this way the properties of the fluid can be investigated and the danger of scaling assessed without risking plugging the well. When the properties of the fluid have been established, more extensive surface installations will be required to further explore the possibilities of utilization and process design, for both energy and chemical production. Also at this stage the production part of the well could be readied for more extensive flow testing for scientific, chemical engineering, and reservoir engineering purposes.

GENERAL CONSIDERATIONS

Funding.
Assuming that the feasibility study is favourable, for example that it appears that supercritical fluid can be produced, and that the chemical study shows that it is likely the supercritical fluid can be discharged to the surface without a high risk of plugging the well in a short time, the SAGA committee endorses the principle that the Deep Vision Group should fund activities that are primarily for the engineering requirements of a production well. On the other hand, the science program should seek funding for the incremental costs of engineering and drilling which is primarily for the science program. Negotiations on cost sharing where activities achieve both engineering and science purposes might be envisaged.

Source of Science Funding.
The funding of the basic science activities can be divided into two parts, firstly the incremental costs of drilling the well due to science activities, and secondly the cost of the science itself. The SAGA committee will seek

to fund incremental engineering costs, and the basic science program, including curation and distribution of samples and data, by submitting proposals to international and national funding agencies. The committee will also solicit proposals from international investigators to develop a well rounded and focused science program beyond the basic on-site activities mentioned above. The committee will also welcome for review various add-on scientific projects that might be proposed.

A wide ranging discussion of possible funding sources included the International Continental Scientific Drilling Program, the Integrated Ocean Drilling Program, the European Union, the European Science Foundation, and the Ridge program of the US National Science Foundation, among others.

A science workshop on the IDDP is planned to be held in Reykjavik on March 15th-22nd 2002 with 50-75 participants. A meeting of SAGA will be held immediately after the workshop. A supplement to the ICDP funding would be desirable for this workshop. By the end of July this year, a notice requesting expressions of interest and one page science preproposals will be issued, with the deadline of November 1st. SAGA will review preproposals and issue invitations for the workshop early in January 2002. Consideration of submitting a second request for funding to the ICDP in January 2002 is still an open issue.

If drilling is to begin early in 2004, major proposals seeking funds for the science program and associated engineering should be submitted in late 2002 and early 2003 (see table 2). Finally, the members of SAGA are encouraged to publicize internationally the scientific opportunities of participating in the Iceland Deep drilling Project (IDDP).

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