REPORT OF WORKSHOP No. 2 OF THE ICELAND DEEP DRILLING PROJECT, NESJAVELLIR, ICELAND, OCTOBER 13-15, 2002

EXECUTIVE SUMMARY

The Iceland Deep Drilling Project (IDDP) is an investigation of supercritical phenomena in hydrothermal systems within the mid-ocean rift system in Iceland. This study will require drilling wells and sampling fluids and rocks to depths of 3.5 to 5 km and at temperatures of 400-600°C (See the IDDP web page at www.os.is/iddp/). Workshop No. 2 of the IDDP was primarily concerned with formulating a comprehensive science plan and discussing research proposals submitted by the international science community to participate in the IDDP. About 40 separate scientific proposals were considered at this workshop.

Workshop No. 1, the previous workshop in the series, was held in March 2002 and was concerned with optimising the strategy of drilling into and sampling supercritical conditions. That workshop led to a clearer definition of the conditions likely to be encountered and developed guidelines for planning the necessary drilling, coring and fluid sampling. Workshop No. 2, on the other hand, provided the framework for detailed planning of a scientific program integrated with the drilling and sampling strategy. The outcome was an enthusiastic endorsement of the project by both industrial and scientific partners.

Workshop No 2 was followed by a meeting of SAGA, the science advisory group of the IDDP. Specific recommendations of the SAGA meeting included (a) Performing an immediate review of existing geothermal wells in Iceland that could be utilised by the IDDP for scientific studies. (b) Discussing opportunities for drilling and sampling of pilot holes to obtain scientific information and to test technologies for later use in the hot, hostile environment of the deep boreholes that will be drilled by the IDDP. (c) Continued planning of and preparation for, the long-term program of deep drilling.

INTRODUCTION

The IDDP plans to drill a series of deep boreholes to penetrate into supercritical zones thought to exist beneath three currently producing geothermal fields in oceanic ridge-type spreading centers in Iceland. Deep Vision, a consortium of Icelandic energy companies, is partially supporting the IDDP. The main aim of the consortium is to produce fluids for electrical power production that have significantly higher enthalpies and flow rates than are currently available to the worldwide geothermal industry. If such enormous gains in energy output from supercritical reservoirs can be developed, it would enable the geothermal energy industry to exceed current estimates of its potential for meeting long-term energy demand by a substantial amount, not only in local or regional markets, but globally. Current estimates of potential geothermal contributions to global energy demand are in the range of a few percent of total installed electrical power. A five- to ten-fold increase in energy output per well from high-temperature geothermal reservoirs would make the economics of geothermal energy more competitive globally, particularly in conjunction with a hydrogen-fueled transportation system in countries like

Iceland that lack sources of hydrocarbon fuels. Therefore, the success of this project can have important environmental as well as scientific benefits.

Deep Vision is conducting a feasibility study, with a budget of more than US $500,000, to examine three candidate sites in Iceland and to consider the economic and engineering issues of drilling to greater depths and higher temperatures than are currently drilled. Deep Vision has invited the participation of the scientific community to use these wells for scientific studies that are of mutual advantage to both industrial and scientific participants. Accordingly a start-up meeting was held in Reykjavik in June of 2001, with funding from the International Scientific Continental Drilling Program (ICDP), to begin planning a scientific program. A ***Science Applications Group of Advisors*** (SAGA), with both Icelandic and international membership was formed (see Appendix 1) to develop the guidelines for a scientific program within the IDDP.

Workshop No. 1, funded by the ICDP, was held at Nesjavellir, Iceland, March 17-19th 2002, to assess the progress of the feasibility study, and to discuss the options for meeting the challenges of drilling at high temperatures while maximizing the sampling and measurements essential to the scientific program. That workshop began with presentations on the pressures, temperatures, fluid characteristics, lithologies and reservoir properties expected in supercritical zones underlying geothermal fields in Iceland. This was followed by a wide-ranging discussion by international drilling experts about possible drilling strategies and costs, leading to guidelines for planning the operational program of the IDDP.

This document is a report of Workshop No. 2, also supported by the ICDP, that focused on the science program, held at Nesjavellir on October 13-15, 2002. About 70 participants, guests and observers were present. Appendices 2 & 3 show the Agenda of the Workshop and the List of Attendees. Apart from Icelanders, participants came from Japan, New Zealand, Italy, France, Germany, Norway, Canada and USA. The SAGA committee met on October 16-17th to review the input from Workshop No. 2 and to discuss integration of the science program with the overall IDDP drilling program.

BACKGROUND

Why Study Supercritical Conditions?

The physics and chemistry of supercritical fluids in the Earth's crust are of considerable interest in understanding problems as diverse as the cooling of igneous intrusions, contact metamorphism, the formation of hydrothermal ores, and submarine hot springs on mid-ocean ridges, known as black smokers. Superheated steam produced from a fluid in the supercritical state can have a higher enthalpy than steam produced from a two-phase system. Large changes in physical properties at, and near, the critical point in dilute fluid systems can lead to extremely effective rates of mass and energy transport. Similarly, because of major changes in the solubility of minerals above and below the critical state, supercritical phenomena play a major role in high temperature water/rock reaction, and the formation of ore bodies. Hitherto, study of supercritical phenomena has been restricted to either small-scale laboratory experiments or to investigations of "fossil" supercritical systems in boreholes, mines and outcrops. Furthermore mathematical modeling of the chemistry of supercritical fluids is hampered by a lack of a reliable thermodynamic database over the range of temperatures and pressures of the supercritical state.

Why Drill in Iceland?

Iceland is the largest landmass straddling a mid-ocean ridge. This diverging plate boundary results in active rifting and volcanism that provides the heat source for a geothermal industry that plays an important role in the economy and quality of life in Iceland. Very high heat flows within this active tensional regime indicate supercritical temperatures should exist at drillable depths in several places in Iceland. Temperatures greater than 300°C are commonly encountered in wells drilled to only 2 km. The likely existence of permeable regions in brittle basaltic rock at supercritical temperatures at still greater depths beneath some of these geothermal fields is inferred from the distribution of hypocentral depths of seismic activity that continues to below 5 km. For example, seismicity is observed below 5 km depth in the area of the Hengill volcano where the temperature should certainly be higher than the critical temperature. A low value of the ratio V_p/V_s is also observed in the Hengill area. A temperature of 380 °C was measured in a feed zone at 2200 m depth in well Nesjavellir No. 11, drilled in 1985 on the northern side of the volcano. This feed zone caused an underground blowout for about one week due to inter-zonal flow from the depth of 2200 m up to the level of 1100 m where the fluid exited into the formation.

The three sites selected for consideration by the IDDP display different stages in the tectonic development of the mid-ocean ridge. The Reykjanes site represents an immature stage of rifting with a sheeted dike complex as a heat source. Fluids produced by 2 km deep geothermal wells in this system are evolved seawater. At Nesjavellir, the Hengill central volcano is the heat source for a geothermal reservoir in a graben recharged by meteoric water. The Krafla high-temperature geothermal field is developed above a magma chamber in a mature, active caldera. It produces evolved meteoric water with some addition of volcanic gases.

It is clear that the objectives of the IDDP overlap with those of drilling being considered on submarine ocean ridges by the international ocean-drilling program. Indeed Iceland might be considered as a *"Mission Specific Platform"* for drilling at a divergent plate margin. . There are clear logistic advantages to drilling on land rather than at sea. Similarly, because of its location on the Mid-Atlantic Ridge, at the center of a Large Igneous Province, Iceland is perhaps the most attractive site world-wide for drilling in support of investigations that address a wide range of world-class scientific questions involving active igneous and hydrothermal processes at divergent plate margins. These include the formation of ophiolites, and the hydrothermal activity leading to ore formation and black smokers.

GOALS AND ORGANIZATION OF IDDP WORKSHOP No. 2

This project takes advantage of the unique geologic setting of Iceland to gain a deeper understanding of fundamental processes that lead to creation of energy resources and mineral deposits. Specifically this project will drill and investigate an accessible high-temperature, magma-hydrothermal system within an ocean-spreading centre on land, to a depth that reaches into the realm of supercritical phenomena. The outcome of Workshop No 1 was reassurance that, in spite of the difficulties, drilling and sampling supercritical conditions in Iceland can be carried out safely and economically. Workshop No 2 reviewed the progress of the feasibility study, discussed a wide range of exciting scientific studies, and then split into panels to discuss (A) Rock studies (B) Fluid studies, (C) Reservoir property studies, and (D) Technical issues.

REPORT OF THE PANEL ON ROCK STUDIES

The purposes of the proposed petrological and geochemical studies are to :

(1) determine the protoliths and the volcanological, hydrothermal and tectonic history of the site(s) chosen for deep drilling. This is relevant to elucidating the formation of ophiolite sequences and ocean crust, and the volcanic processes, magma evolution and fluid movement at spreading centers.

(2) determine mineral parageneses and calculate mineral-fluid equilibria in the subcritical to supercritical regions. The geochemical, mineralogic, and geophysical data will be used to evaluate solution-mineral equilibria under both subcritical and supercritical conditions. Mineralogic phase relations and parageneses will be combined with thermodynamic properties of mineral components and fluids, to compute chemical affinities of pH and redox sensitive reactions. This will provide a basis for developing reactive mass transfer models.

(3)evaluate mass transfer. The effects of protolith (compositional as well as petrophysical) properties, of temperature, of metamorphic grade, and of fluid composition on mass transfer will be evaluated. Quantifying volume changes due to water/rock reaction can be addressed by assuming conservation of mass for one or more immobile components. Another approach is to quantify trace element mobility during basalt alteration. Comparative analyses of trace element concentrations of geothermal fluids and secondary minerals from the production zones in specific drillholes will allow evaluation of the degree to which trace element concentrations of aqueous solutions are controlled by partitioning equilibria with secondary minerals.

(4) model the magma-hydrothermal system including the supercritical regime. Investigation of the dynamics of hydrothermal activity and near-critical behavior will involve establishing the thermal stages of the system from analysis of thermal gradients, micro-seismic and conductivity datasets, distribution functions of fluid inclusions, and curvature of thermal fields. The chronology of fluid percolation paths and the nature of alteration mineral assemblages and mineral zonation patterns will help detect near-critical behavior, and provide input for computation of models of magma-hydrothermal interaction.

Sample Requirements. In view of the very small amount of drill core available from the geothermal systems being considered as targets by the IDDP, it is desirable to obtain as much core as possible. The highest priority is for cores below 2000 meters depth, in or near the supercritical zone, and specifically near zones from which fluid samples are obtained. If the IDDP drills a core hole by re-entering and deepening an existing well it would be desirable to consider collecting side-wall cores in the open interval in that well, or else coring a slim hole alongside it, if costs and technical considerations permit.

Similarly preexisting rock samples and data already available from a borehole that is to be deepened should be retained and curated by the IDDP for study by the project.
Studies During Drilling. Because of the need to recognize supercritical zones in real time, and to anticipate potential hazards during drilling, it will be necessary to operate a petrographic laboratory at the well site equipped with at least fluid inclusion and thin section capabilities. Otherwise sample handling and curation will be patterned on past ICDP projects (for example the Hawaiian Scientific Drilling Project). A formal sample-handling protocol will be implemented. The basic core description should include lithology, alteration, stratigraphy, structural and extrusive/intrusive relations, and pre-drilling fracture distribution, orientation and cross-cutting relations.
Post-drilling Studies. Subsequent petrographic descriptions should start with detailed descriptions of primary mineralogy and textures and secondary or alteration mineralogy and textures. These studies should address alteration and replacement of primary minerals and deposition of secondary minerals in open spaces and within vesicle- or vein-wallrock zones adjacent to healed fractures. Geochemical studies of whole rocks, minor and trace elements and stable and radioactive isotopes will then follow, according to the needs of specific investigators. Samples will be selected for geochronologic and petrophysical characterization including porosity and permeability, electrical resistivity, seismic velocity, natural gamma/neutron density, and magnetic susceptibility and paleomagnetism.
Integration and Interpretation. Most importantly these data will be integrated with regional geologic and geophysical data, paying specific attention to the nature and history of the fracture network and to the relationship of this network to the tectonic and geothermal history of the system on local, regional and global scales. All of these proposed studies are relevant to furthering our understanding of the origin, nature and economic potential of the supercritical zones in Iceland. In terms of global geoscience these studies also relate to issues such as:

(1) the time and spatial relationships in fluid chemistry, alteration minerals, and isotopic systematics during evolution of sub- to super-critical geothermal systems on an ocean-spreading ridge;
(2) the mantle contribution to volatiles in ocean-spreading ridge hydrothermal systems;
(3) and global geochemical cycles that control, for example, ocean chemistry. Another example would be mechanisms for the generation of methane and higher hydrocarbon compounds in water-basalt geothermal systems, with implications to the global methane flux.

REPORT OF THE PANEL ON FLUID STUDIES

The fluid studies panel outlined a program of study that addresses fluid sampling, analysis, and interpretation, and it identified tasks that must be completed before and during drilling. The panel discussed the relative merits of the three areas being considered for drilling and concluded that drilling into supercritical conditions could give valuable results in all of them. However, drilling at Reykjanes would be of more interest to the international scientific community primarily because of the interest in black smokers, ophiolites, and mid-ocean ridge processes.

One of the principal emphases of the fluid sampling program should be to obtain matched fluid and rock samples at fluid production points in the deep reservoir, since the chemistry and thermodynamics of the geothermal system can only be adequately described and interpreted from a knowledge of the total rock-water system. Such paired fluid-rock samples would be among the most valuable scientific products of the drilling. Such samples will optimize the ability to interpret both fluids and minerals, and would open opportunities for novel thermodynamic studies.

Depending on costs, a second desirable goal would be to core the entire length of the drill hole. Among reasons for such coring is the embarrassing lack of information from cores in Icelandic geothermal systems in general, and ability to address specific questions such as why δD in deep fluids at Reykjanes is ca. -20 $^{0}/_{00}$ even though these fluids are apparently modified seawater.

Ideally every fluid-producing horizon should be sampled during drilling, and, ideally, each productive horizon should be cased off or cemented so as to prevent mixing of fluids from distinct aquifers. This would entail suspending drilling for a period to allow thermal recovery and to flush out drilling fluids by the production of fluids from the well. If drilling were to be stopped immediately when total loss of circulation occurs, a roughly representative sample of the fluid could likely be obtained after two or more days of discharge. Unfortunately, such an extensive program of sampling would be time-consuming, expensive, and technically difficult. However the scientific value of the fluid samples is great. A further concern is that repeated thermal cycling would be detrimental to the integrity of the well casing due to thermal stresses and possible damage by corrosion or scaling. Some participants argued that this plan for sampling is contrary to the concept of the “pipe”, that was discussed extensively at Workshop No. 1. This “pipe” is a replaceable liner intended to protect the well casing against corrosion and scaling.

Owing to various problems with discharge samples (e.g. loss of material to scale, indefinite fluid-gas ratio), it would be most beneficial to obtain downhole fluid samples in addition to well head samples. Downhole samples still require well flushing to clear drilling fluids and to recover the aquifer temperature and pressure, so there is no benefit in that respect. Downhole samples can be obtained by mechanical, electronically controlled devices, or by a novel approach using artificial fluid inclusions. High temperature downhole samplers are under development in New Mexico and Canada that might be deployed for this project. Techniques for artificial fluid inclusion sampling, including potential millimeter-scale inclusions, still need to be developed experimentally, partly involving methods under development at Tohoku University.

Preferably, fluids would be analyzed for nearly all elements of the Periodic Table as well as for key anionic species and light stable isotopes (H, B, C, O, N, S etc.). Sampling and analysis of both filtered and unfiltered samples is necessary. Quantification of many trace elements is considered a valuable contribution of the project that sets it apart from previous studies. Large, ultrafiltered samples for the determination of organic constituents may well be of interest to many scientists. The cost of complete fluid analyses would be small compared to the cost of obtaining the samples.

Recovery of hypersaline brines produced by supercritical phase separation would be of great interest internationally. A careful consideration is required of the nature and the likely residence, of such brines in supercritical systems.

Modeling of fluid properties before drilling will be useful. Such modeling should include boiling of fluids to identify potential mineral scale deposition and fluid pH, thereby aiding in site selection and well design. Such modeling will be tested when the "pipe" is later removed to identify scale minerals formed at each set of discharge conditions. A combination of modeling and experimental work based on produced fluids and rock samples would lead to the derivation of the thermodynamic properties of solid solution end members such as manganese and nickel chlorites, which are not available at present. A study of chemical species involved in slow redox reactions, such at the CH_4-CO_2 and the SO_4-H_2S equilibria, would be of great interest. Such a study would probably require rapid analysis of fluids at the wellhead.
Interpretation of fluids and minerals. The interpretation of the fluid chemistry will rely on fluid analyses, measurements of physical parameters, and on minerals identified in rock samples matched to fluids. Concentrations of incompatible components in altered rock, fresh rock and fluid are essential to constrain the origin of the fluid and to gain a quantitative understanding of water-rock reactions and water-rock ratio. Isotopic data on minerals and fluids in combination with theoretical modeling of mineral saturation in reconstructed fluids with comparisons to the actual observed minerals will enable the development of a well constrained model of the fluid and mineral origins.

Summary. Ideally, we would like to sample fluids from every significant fluid inflow point in the well during drilling, then case off or cement those inflows so as not to mix fluids from separate aquifers. In each aquifer, we would like cored rock samples to match to the fluids. In practice, this ambitious sampling program would most likely have to be scaled down, and focused on the zones of greatest interest. All fluids should be analyzed for a very large set of major and trace elements, light stable isotopes and key molecular species. Using such analyses in conjunction with matching whole rock analyses and analyses of individual minerals, and with numerical modeling methods, we expect to be able to reconstruct the physical and chemical evolution of the supercritical geothermal system.

REPORT OF THE PANEL ON RESERVOIR STUDIES

From the point of view of reservoir studies the well itself has the highest scientific value. The well itself will confirm or reject the existence of an economic resource at depth. Temperatures higher than the critical temperature have been measured in wells in Italy, the United States and Japan, confirming the presence of potential high-enthalpy resources at those locations. However, the well Nesjavellir No. 11 seems to be one of the few examples world-wide where a mass flow has been observed at such high temperatures. Two other examples are the San Pompeo No. 2 well in Larderello, Italy, and the Wilson No.1 well near The Geysers, California.

There will be substantial difficulties in obtaining representative values of reservoir properties from the IDDP well. Coring or any type of drilling will most likely cause some fracturing of the rocks and the parameters measured on the core in the laboratory will most likely reflect only approximate *in situ* values. The same situation also can be true for the fluid that may be contaminated or changed by phase separations before sampling.

There are several problems in state of the art reservoir simulation. At present most simulations of fluid behavior in reservoirs assume properties of pure water, while in reality saline solutions or, alternatively, dilute solutions containing high concentrations of dissolved gas are likely to be present. Temperatures and pressures of critical points of these natural fluids, and their densities and viscosities at and near their respective critical points may be significantly different compared to pure water. Also, even in the case of pure water, physical properties exhibit singularities near the critical point, and these circumstances cause difficulties in conventional simulation work. Simulation with relatively coarse grid has been carried out with reasonable results, but simulations with a fine grid close to the critical point become unstable. Present computer codes are not well suited to describe the behavior close to the critical point and better knowledge about the physical properties of the fluid are needed. Some laboratory experiments could improve the situation. On the other hand, the porosity structure of the rocks (porous versus fractured media) would not have much influence on simulation work in the supercritical region as mobility of a very dilute fluid, or the gas phase boiled off from a highly saline brine, is expected to be very high in the supercritical region.

Recommended Pre-drilling Activities. a) Numerical simulation. Carry out a parameter study describing how a supercritical system could be feeding a conventional sub-critical geothermal system. b) Laboratory experiments on the physical properties of the fluid. c) Detailed mapping of earthquake hypocenters in the drilling areas in order to map the minimum depth of the brittle crust. d) Magneto-telluric measurements to locate the top of the critical zone.

Recommended Activities during Drilling. a) A pressure temperature (P/T) memory tool should be attached to the core barrel at all times. During core recovery, a new tool would be attached. The pressure and temperature would be recorded immediately after the return to surface giving a fairly continuous record of the P/T conditions in the well during the core operation. (No extra rig time. Highest priority). b) Another P/T memory tool should be attached to the outside of the drill pipe. This tool would be retrieved when the drill bit is changed. The purpose of this P/T registration is to achieve pressure- and temperature gradients in the well during drilling. (No extra rig time. Medium priority). c) When significant loss of circulation is observed, an injection test should be carried out in order to record the transmissivity of the well. (The rig time required is 6-12 hours. Highest priority.) d) Downhole logging should be carried out every time the bit is changed. Each log should cover the depth interval from the last change of the bit. (Rig time required 6-12 hours. Medium priority.) e) A microseismic and an SP array should be arranged at the drill-site providing a continuous record of these parameters. Recording would start some months or a year before the drilling operation starts and continue for at least one year after the drilling has been completed. (No extra rig time. Medium to high priority.) f) Continuous recording of gases in the flow line. The equipment would record both the concentration and the type of gases coming up with the circulation fluid. (No extra rig time. Highest priority) g) Upgrade numerical simulation during drilling, if required. (No extra rig time. Lowest priority.) h) A detailed mud logging will be carried out. The usual Icelandic procedure can serve as an example. (No extra rig time. Highest priority.) i) A complete logging program, including lithological logs will be carried out for the whole open hole section at the end of drilling. (Rig time required 24-36 hours. Medium priority.) j) Stimulation of the well by massive cooling of the open hole section

and/or by placing a packer into the well and pumping water under pressure into the zone below the packer. (About two days of rig time required. Highest priority.) k) Repeat the wire line logging in order to detect any changing in the condition of the formation due to cooling of the well. (Rig time required 24-36 hours. Highest priority.) l) Vertical seismic profiling and walk away seismic profiling should be carried out in the cold well. (Rig time required 24-36 hours.)
Recommended Post drilling activities. a) Temperature and pressure logging during the thermal recovery of the well. The recovery time might be of the order of weeks or even months. Higher frequency of logging is required at the beginning of this time than in the end. These logs give the most reliable information about the location and the nature of the feed zones in the well. (Highest priority.) b) Recording in the seismic and the SP array should continue for about one year after the drilling has been completed. (Medium priority.) c) Down-hole fluid sampling can be done in connection to other logging activities performed at this time. (Lowest priority). d) The panel recommends strongly that "the pipe" (the pilot plant) will be constructed in such way that it can be heated by external source (induction heating?) and provided with sensors to monitor the temperature of "the pipe". By keeping the pipe at constant temperature above the critical point (say at 400°C), the formation of acid by hydrolysis reactions can be avoided. At the same time, keeping the pressure gradient from the bottom to the top of the pipe as small as possible will minimize the risk of scaling in the pipe.

REPORT OF THE PANEL ON TECHNICAL ISSUES

This panel was concerned with drilling, well completion and sampling. It benefited from the extensive background provided during IDDP Workshop No. 1. Importantly, there do not appear to be any insuperable technical problems with completing either a pilot hole or a hole deep drilled from the surface to satisfy the scientific objectives of the IDDP.

The Workshop No. 1 recommended two different options for drilling and coring to a depth of 5000 m. Rough preliminary cost estimates for completing the Well Design A, the most expensive option, range between approximately US $10 to $15 million, including all the on site and downhole science, testing, and sampling. This well was designed for the collection of continuous core from a depth of 2400 to 5000 m. The well design and cost estimates were based on extensive experience in drilling geothermal wells in Iceland. The heavy casing needed by this option would require a rotary rig that is larger than that presently available in Iceland. Iceland Drilling Ltd. is evaluating a new rig for completing this work, that would have a capacity of 250 tons with a 1000 hp draw works and two 1000 hp pumps.

An overriding concern is the safety of any drilling into or near supercritical conditions. This concern was expressed in a discussion of the casing program as well as cycling the well during flow tests and attempts to acquire fluid samples. A number of options for sampling fluids from the well without flowing were discussed. These options included down-hole sampling devices as well as the growth of artificial fluid inclusions. At the Kakkonda hole in Japan (> 500 ^{o}C), a form of reverse circulation drilling was used to acquire a fluid sample.

Information on new technologies that could be of value for this project was presented. This included concepts of drilling with casing and of expandable casing. Expandable casing can be used to case a well without size reduction. This is accomplished by inserting casing through an existing string and then expanding the casing once it is in place. Similarly, the Sandia National Laboratory of the USA is working on the development of high-temperature tools for the geothermal industry. Some of these prototype tools could probably be made available for use in an IDDP well.

The high projected cost of the IDDP wells is of obvious concern. Additional recommendations from the scientific panels that a well be cored from the surface to TD would increase the drilling cost estimates. An alternative option is to enter an existing well and drill or core to a greater depth. This option could be considered as a "pilot hole" or "well of opportunity" since it would be testing coring and sampling technology in the pressure-temperature zones defined as being of highest scientific interest. The option has a cost advantage since much of the large diameter drilling and casing would already have been installed. The panel listed the wells that would potentially fulfill the role of a "well of opportunity" (Table 1).

The general condition of these wells and the willingness of energy companies to make such a well available to the IDDP needs to be addressed. According to the data listed in Table 1, the most likely candidate wells would be No. 18 at Krafla and NJ-12 at Nesjavellir. The relative merits of these options involve the present condition of the wells, their scientific advantages, and the need for permission by the owners for IDDP to gain access to the wells. Orkustofnun, the National Energy Authority of Iceland, was given the assignment of reviewing the files and making a recommendation to SAGA and to the Principal Investigators.

GENERAL CONSIDERATIONS AND FUTURE PLANS

If Deep Vision's long term goals of economic energy production and mineral extraction from supercritical geothermal resources are realized, the approach could improve the economics of high-temperature geothermal resources world-wide. This will require a great deal of technology development over the coming decades. However the first step is to drill in search of such supercritical fluids. The feasibility study, being carried out by the Orkustofnun and its subcontractors, appears to be well on track. The wide-ranging discussions at the workshop reassured participants that the IDDP wells can be drilled and sampled, using available technology and that exciting science of world-wide significance will result.

Discussions with representatives of Deep Vision were very productive. They reaffirmed the commitment of the consortium to the IDDP and their willingness to facilitate scientific studies. Meetings with the power companies will take place shortly to present the ideas discussed above and on site selection. Choice of the site for the first deep well will depend partly on business decisions on financing and partly on environmental permitting. However, the long term expectation is that deep wells will be drilled at all three sites by the power companies, and that these wells will be made available for deepening and coring for scientific studies. From a scientific viewpoint all three sites are appealing.

This prospect opens up the opportunity for a comprehensive scientific program investigating the anatomy of a mid-ocean rift zone, by tying together land–based and ocean-based deep borehole studies with complementary geological and geophysical studies. At a meeting of the SAGA group at the conclusion of the Workshop, the following recommendations were made: 1) As a preliminary step we should consider the options of drilling a pilot hole or further drilling using existing holes. 2) Any preliminary work proposed should address the key scientific and technical issues that are important to our future program of deep (> 4km) drilling. 3) Such preliminary work would be a logical step in the development of the overall program.

Table 1 – Wells of opportunity for IDDP drilling in Iceland

FIELD	WELL	DEPTH (m)	TEMP (oC)	CASING	COMMENTS
REYKJANES	11	2247	320	13-3/8" ~800 m 12-1/4" open	Main feed @ 2200 m
	10	2050	320	9-5/8" liner	
TROLLADYNGJA	TR-1	2308	325	13-3/8"" to 750 9-5/8" liner to TD	1000-1600 entries Poor producer
SVARTSENGI	6 12	1998 1488	240 236	9 5/8" to 617 13 3/8" to 606	No liner No liner
NESJAVELLIR	13,16,19	1400-2265	325 @ 1500	9-5/8"" to 800 8-1/2" open w/ 7" liner	All producing
	11	2265	>380	9-5/8" <600	gravel pack 1600-TD New casing required
	12	1856	325 @ 1500	9-5/8" to 775m	Not on production Too far from plant
KRAFLA	6	2200	300		Damage @ 1200 m
	18	2215	278	9-5/8" to 674m 8-1/2" open to TD	Poor permeability
	25			9-5/8" to 1100	fish @ 1100 m 2000 m entry pH 2-4 above magma chamber
	26	2200	340		on injection
	23	2000	240	9-5/8 tp 600 8-1/2 open to 2000	
NAMAFJALL	4	1130	270		erupted tephra in 1977 cemented

APPENDIX 1 IDDP - Membership of SAGA :

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