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Iceland Deep Drilling Project (IDDP) - 10 Years Later – Still an Opportunity for International Collaboration

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ABSTRACT

At the WGC-2000 in Japan the Iceland Deep Drilling Project (IDDP) and its initial plans were announced, and presented as an opportunity for international collaboration (Friðleifsson and Albertsson, 2000). Now 10 years later we review our accomplishment and announce the near future drilling and research plans of IDDP. A consortium from the Icelandic energy industry was established to fund the project and after some 5 years of preparation, IDDP intended to accept an offer from Hitaveita Suðurnesja hf., one of the consortium members, to deepen a 3082 m deep production well at the Reykjanes high-temperature system in SW-Iceland. The goal was to drill for 400–600°C supercritical fluid, in order to significantly increase the power output of geothermal wells relative to that possible from wells producing a subcritical mixture of steam and water. The Icelandic energy consortium agreed to fund the drilling and testing operation, and funds for obtaining drill cores for scientific study were awarded jointly by the International Continental Scientific Drilling Program (ICDP) and the US National Science Foundation (NSF).

Unfortunately, the 3 km deep well of opportunity at Reykjanes became blocked during a production test in November 2005 and the well was abandoned in February 2006 when attempts to recondition the well failed. In 2006 IDDP decided to move to another drill field, namely the Krafla high temperature field in NE-Iceland, to attempt drilling into supercritical conditions. Alcoa Inc., an international aluminum company joined IDDP consortium as funding partner in 2007, and StatoilHydro ASA, a Norwegian oil company, joined the consortium in 2008.

The first full scale IDDP-1 well was meant to be completed late summer 2009 and the first flow test to be performed some months later. However, that drilling operation was abruptly terminated by late June at 2104 m when drilling penetrated molten rock. Rapidly quenched magma of rhyolitic composition was returned to the surface in the form of quenched obsidian glass that plugged the lowest 20 m of the hole. Fortunately, due to earlier drilling problems, the well had been cased down to 1958 m depth, and was completed with a slotted liner down to 2080 m depth. This was in preparation for a flowtest of the superheated regime just above a magma chamber, which should be performed autumn 2009.

Despite the fact that the primary goal of IDDP-1 to drill down to and test a hydrothermal system at supercritical condition was not met by the first IDDP well at Krafla in 2009, the IDDP program intends to move forward . IDDP plans to drill wells IDDP-2 and IDDP-3 in 2010-2012, at the Hengill and the Reykjanes geothermal systems in SW-Iceland. Additional funding for completing both these wells to target depths and subsequent flow and production testing is required – an opportunity for further international collaborations in IDDP.

1. INTRODUCTION

The purpose of this paper is to describe the history and evolution of the Iceland Deep Drilling Project, to discuss the first deep well, and to speculate about future activities. It is written in the hope that this account of our activities will be helpful to other groups contemplating organizing other projects of comparable size and scope. A project of this magnitude requires the combined efforts of many people and organizations over many years, and inevitably is subject to various vicissitudes, both internal and external.

The IDDP was founded in the year 2000 by a consortium of three Icelandic energy companies: Hitaveita Suðurnesja (now HS Orka hf) (HS), Landsvirkjun (LV) and Orkuveita Reykjavíkur (OR), and Orkustofnun (OS), the National Energy Authority of Iceland. The basic idea for the IDDP concept was introduced internationally the same year, at the WGC-2000 in Japan (Friðleifsson and Albertsson, 2000). Now – 10 years later – it is appropriate to quote from the abstract of that paper the statement, "International participation is welcomed to this challenging and advanced project, which has a high potential payoff." It further concluded, "The foreseeable need for deep drilling for exploitable hydrothermal fluids in Iceland during the 21st century calls for research on supercritical hydrous fluids in nature." In the same paper the authors tentatively proposed the Reykjanes geothermal field as a suitable target for producing supercritical geothermal fluids, and a bit optimistically perhaps suggested that: "Preparation for this deep drilling programme at Reykjanes will take 2-3 years. The drilling may be realized in 2003 and an operating pilot plant a year or two later." (Friðleifsson and Albertsson, 2000). Eight years elapsed before the deep well was begun, so it is timely explain the circumstances by reviewing the IDDP history since then.

The IDDP logo, which is indicative of the concept behind the project, is explained in the caption to Figure 1.

At the WGC-2000 in Japan we laid the foundation for the international collaboration which ever since has been an IDDP trademark. We established a team of three Principal Investigators (PI's) composed of Friðleifsson, Elders and the late Professor Seiji Saito. In June of 2001 we began with "Start-up Workshop" and invited a group of leading scientists and engineers to advise the IDDP by establishing the SAGA group ("Science Application Group of Advisors"). Our dear colleague Seiji Saito (deceased 2003) insisted that we would need a drilling technology workshop before planning the science program, if we were to drill both deeper and hotter than any geothermal well previously drilled. Since this first workshop there have been numerous workshops and planning meetings (Table 1).

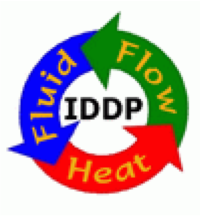

Figure 1: The IDDP logo shows the essential parameters behind the concept of thermal mining. The improvement of this basic idea by the IDDP is to drill deep enough into the roots of a conventional high temperature hydrothermal system to produce water at *supercritical conditions* and bring it to the surface as 400-600°C superheated steam, at subcritical pressures (<220 bar). In the case of low permeability systems, by injecting cold fluid into the hot rocks fractures can be induced to complete the thermal mining cycle

2. ACTIONS LEADING UP TO DRILLING IDDP-1

At the start-up meeting, it was emphasized that the IDDP would offer the scientific community unique opportunities to (a) study and sample fluids at supercritical conditions, and (b) to investigate the magmatic and fluid circulation of the Mid-Atlantic Ridge on land, environments of high-temperature geothermal systems that have never before been available for direct observation. The Drilling Panel evaluated five different strategies for achieving these goals. The consensus was that the most preferable option was to drill a "standard" production-type well to 3.5 km deep well and then continuously core a slim hole 1-1.5 km deeper using a hybrid-rotary coring technology. The GeoScience Panel developed criteria for selecting the sites that would be drilled from both geoscientific and environmental perspectives. Three geothermal fields, Reykjanes, Hengill and Krafla, were selected as best fitting the criteria of being well enough studied to ensure a high probability of encountering a permeable supercritical reservoir at drillable depth (see Figure 2).

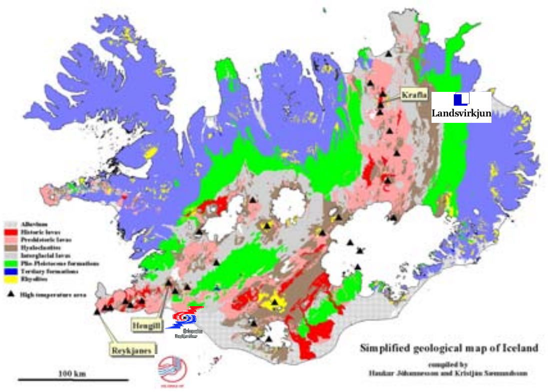

Figure 2: Simplified geological map of Iceland showing the volcanic rift zone through the island and the three active volcanic systems where the IDDP drillholes will be drilled, IDDP-1 at Krafla, operated by Landsvirkjun, IDDP-2 at Hengill operated by Reykjavik Energy and IDDP-3 at Reykjanes operated by HS Orka hf

The Fluid Handling Panel faced the problem of uncertainty about the pressure, temperature, chemistry and volume of the fluids likely to be produced, and therefore suggested a pilot plant that was as simple and as flexible as possible. They recommended considering a preliminary design for a downhole tubing system to sample the fluid at low flow rates so that its nature could be accessed before extensive flow testing was attempted.

At this meeting a guiding principle was adopted that the IDDP consortium would be responsible for finding the funding for the engineering and testing of the wells, but not for any incremental costs incurred by the science program. There are two kinds of costs for the science program, firstly the costs of acquiring the drill cores and other sciences samples and data, and secondly the costs associated with their study. The P.I.'s agreed to be responsible for the first kind of costs, whereas individual investigators would be responsible for the second kind.

Accordingly they submitted proposals to the International Continental Scientific Drilling Program (ICDP) to run planning workshops. The first, in March 2002, was on the technology of drilling deep and hot wells. With some reassurance that it could be done a science planning workshop was held the following October. At that time also, the Icelandic IDDP energy consortium had already set the course by requesting a feasibility study on the IDDP concept, and had formed three consulting groups, one on the GeoSciences (GS-group), another on the Drilling Technology (DT-group) and the third on a Pilot Plant, a group that later was called Fluid Handling and Evaluation group (FHE-group). These three groups of consultants, coming both from the energy companies themselves, as well as from consulting companies, had the mission to evaluate the IDDP concept. The energy companies funded the study. At the "Start-up meeting" the domestic experts met with the forum of foreign experts and laid the foundation for the future. Since then, there has been a continued series of review meetings and workshops on the IDDP, listed in Table 1. The reports of these activities are described in the SAGA Reports, all of which are available at the website www.iddp.is.

Table 1. List of IDDP Planning Workshops and Organizational Meetings.

(1) Start-up	June 2001
(2) Drilling Technology	March 2002
(3) Science Program	October 2003
(4) Site Selection	June 2004
(5) Crisis	March 2006
(6) Site Selection	March 2007
(7) Kick-off Meeting	March 2009
(8) Fluid Handling	September 2009

The science planning workshop was attended by investigators from some 11 different countries and considered some 40 different science proposals. It discussed science activities to be done before, during and after the drilling. Among the topics were the volcanological, hydrothermal and tectonic history of the three sites chosen for deep drilling, determination of mineral parageneses and mineral-fluid equilibria in the sub-critical to supercritical regimes, evaluation of mass transfer, and modeling the magma-hydrothermal system at supercritical conditions. An important aim should be to obtain matched fluid and rock samples at fluid production points, and their interpretation.

At that time the IDDP consortium had funded a two year long feasibility study that was completed and published in 2003. Part I dealt with geosciences and site selection (Friðleifsson, et al., 2003), Part II with drilling strategy (Þórhallsson, et al. 2003), and Part III with fluid handling and evaluation (Albertsson et al., 2003). Modeling done as part of the feasibility study indicated that power output from a supercritical well could be enhanced by an order of magnitude relative to that of a typical geothermal well in Iceland. The report selected three high-temperature geothermal fields, at Reykjanes, Hengill, and Krafla, as sites for such deep drilling (Figure 2), all three of which exhibit temperature gradients that imply that supercritical conditions exist within 5 km of the surface. However the report made it clear that drilling to supercritical temperatures and pressures at any of these sites would be expensive and could cost more than USD 20 million, using the approach of continuous core drilling for the lower 1-1.5 km.

Early in 2004, the operator of the Reykjanes geothermal field proposed that the IDDP should take over a 3 km deep well to be drilled there and to deepen it into the supercritical zone and this suggestion was accepted. Because the reservoir fluids on the Reykjanes Peninsula have seawater salinities, the geothermal field at Reykjanes more nearly resembles the black smokers of the mid-ocean rift systems than do other of geothermal systems in Iceland which in general are occupied by dilute fluids derived from meteoric waters.

Accordingly Friðleifsson and Elders submitted preliminary proposals to the ICDP and the NSF for funds to support scientific sampling from at deepened well in Reykjanes. The issues of specific site selection, science aims and activities, and well design at Reykjanes were taken up at an international workshop held in June of 2004.

The RN-17 well at Reykjanes was completed to a depth of 3.1 km, in 2005 but, before surrendering it to the IDDP for deepening by core drilling, Hitaveita Suðurnesja decided to perform a flow test before casing the well. Unfortunately, while flowing during this test in November 2005 it collapsed and became blocked. Subsequent attempts at reconditioning the well failed, and this borehole was abandoned in February 2006. This set-back caused the idea of starting the first deep well at Reykjanes to be reevaluated.

This reevaluation took place at a workshop in April 2006. By this time the IDDP consortium had signed an agreement that committed funds for the deepening the well, and the ICDP and the NSF had committed funds for the science program. At the workshop, while there were strong arguments for deep drilling at Reykjanes, the focus of attention moved to Krafla in northern Iceland. There Landsvirkjun, the operator of the geothermal field, offered to drill a 3.5 km deep well that would then be deepened to 4.5 km. The idea was to put the subcritical part of the formation behind casing, and then drill deep into the supercritical zone to produce supercritical fluid unmixed with the shallower subcritical fluids. After discussion the decision was made to move operations to Krafla. It was also decided to better characterize the reservoir at Krafla by additional MT survey and micro-seismic monitoring studies.

The next international workshop was held in March 2007 to review progress, and projected costs. After considerable discussion of the likely problems of drilling a slim core hole at great depth and high temperatures, it was decided that continuous core drilling was too risky and too expensive. Instead it was decided to drill a wider diameter hole that could be cooled more easily, and to take only spot cores using the rotary drilling rig alone. Similarly the fluid sampling program was scaled down so that all the equipment would be on the surface instead of downhole, where costs are lower and problems can more easily handled. These changes were consistent with the answer to the question, "What are the minimum criteria for success in the first deep drilling enterprise in Iceland?" The initial aims are to successfully drill into the supercritical zone and obtain sufficient data and samples to significantly improve our understanding of its nature and economic potential.

Refinements of the drilling and casing program followed and there were lengthy negotiations to finalize the contracts necessary for drilling and related services, and to obtain the specialized casings and wellhead equipment. During this time additional funding was being sought and Alcoa, an international Aluminum Company and StatoilHydro, a Norwegian oil and gas company became formal members of the consortium and both made financial commitments to the project. A coring system specially designed for spot coring at very high temperatures was designed and manufactured and given a highly successful test in the well RN-17B at Reykjanes and resulted in 100% core recovery (Skinner et al., 2010).

There were also comprehensive discussions of the optimum location for the deep drilling at Krafla that resulted in a site being chosen in the northern part of the field close to a magma-phreatic eruption crater that erupted in 1724. Spudding-in of the IDDP-1 well at this site occurred in the summer of 2008 and a surface casing was set to 90 m depth, taking advantage of the availability of the necessary equipment. After a hiatus, when a larger rig was mobilized an intermediate casing was set to 800 m in December 2008 , and then, as planned, the project was closed down for the winter.

The final drilling plans were reviewed at a "Kick-off Meeting" in early March 2009. It was then estimated that drilling from 800 m to 4500 m should take a further 115 days (Þórhallsson 2010). The plans for integrating the engineering, logging and science sampling program were finalized and arrangements for equipment and supplies and for staffing were reviewed. In addition to having the usual logging services and mud logging system in place, a fully equipped core handling and curation facility, with a comprehensive petrography laboratory on site was organized.

Drilling commenced late in March 2009 and at first proceeded normally, until a series of untoward problems of stuck pipe, twist-offs and necessary fishing operations, occurred, that are described elsewhere at this Congress (Hólmgeirsson et al., 2010). These required cementing off a lost fish and sidetracking three time, and caused several weeks delay of the drilling operation. Another result was that the first intermediate casing of 13 3/8" was set to only 1958 m instead of the planned 2400 m depth. This enforced decision turned out to be most fortunate when the reason for all the drilling problems became clear. When drilling into the 2104 m depth range for the third time without getting stuck (i.e. well IDDP-1C), quenched rhyolitc glass (obsidian) was returned to the surface. Thereby it came clear that we had drilled into a magma. In order for the magma to stay liquid since the last volcanic episode in 1975-1984, the so called "Krafla fires" , the magma body is estimated to be at least 50 m thick. The drillhole naturally plugged its bottom by about 20 m thick obsidian plug, and as the 1958 m production casing was already in place, the well could be completed with a 9 5/8" slotted liner to the bottom. A total loss feed zone was in the open bottom section of the well, which was injected for 2-3 months by cold water before the well was allowed to heat for the flow test, scheduled to take place autumn 2009. The well was expected to yield superheated dry steam (~400-500°C hot) at subcritical pressures (about or over 100 bar). The completed progress of the well completion and its initial flow testing results will be reported in a series of papers at this Congress (Hólmgeirsson et al., 2010, Friðleifsson, et al., 2010; Elders and Friðleifsson, 2010, Ingason et al., 2010).

The first flow test autumn 2009 had not been completed at the time of the preparation of this paper. However, if the well will not sustain superheated steam production for acceptable time for the field operator (Landsvirkjun), creation of the world hottest Engineered Geothermal System (EGS) by injecting water towards the magma through neighbor wells and produce superheated steam through the deeply cased IDDP-1 well. This EGS concept has a high potential for continuing international collaboration on the IDDP.

3. COLLABORATIONS RELATED TO IDDP-1

An international collaboration has already been established in relation to IDDP-1 well at Krafla, and the preceding "Well of Opportunity" RN-17 at Reykjanes. It will be modified and refined depending on the results from the IDDP-1 drilling at Krafla during 2009 and the flow tests to follow.

Contracts already exist on the funding contributions made by our international collaborators, Alcoa and StaoilHydro. Similarly, contracts exist between the PI's and the ICDP and NSF for funding contributions to the science program, mostly for spot coring, but also for studies by the USA team, a considerable part of which was used up for studies related to Reykjanes. Most of the other international collaborators will provide their own funding for their scientific contributions, for the well IDDP-1 at Krafla or elsewhere.

Several science studies in relation to the RN-17 well at Reykjanes are already published, in press, or submitted to international journals, and a few more are expected, mostly from our USA and Italian colleagues (Freedman et al., 2009, Olsen et al., 2010, Marks et al. 2009, Pope et al. 2009, Pope et al. 2010, Raffone et al. 2009 A, B, C). Publications from the French and Russian teams are also to be expected shortly.

When this paper was completed we knew that our initial goal of drilling into a geothermal system at supercritical condition had not been achieved as we had drilled straight into a ~1000°C hot magma body within rocks only altered to greenschist facies, but the result of the first flow test was not known. Nevertheless, studies on the rock cuttings from the IDDP-1 well, as on other wells by our science teams have already begun and publication are to be expected in due course. The possibility of turning the IDDP-1 well and neighbor wells into the world hottest engineered geothermal system (EGS) is also an open issue that will be discussed seriously by the IDDP international team.

4. COLLABORATION ON IDDP-2 AND IDDP-3

During 2010-2012 the Reykjavik Energy (OR) and HS Orka hf (HS) intend to drill wells IDDP-2 at Hengill, and IDDP-3 at Reykjanes, at their own cost, down to approximately 4 km depth and cement in the production casings. Already, OR has purchased all the casings to production depths and a 2500 class master valve. The cost of each of the new IDDP wells is expected to be of similar magnitude as IDDP-1 cost estimates. Both wells will be made available for deepening into the supercritical zone by the IDDP, with possible participation by the scientific community. As yet the funding issue for the deepening of wells IDDP-2 and IDDP-3 to ~ 5 km is an open issue. As before the IDDP consortium welcomes international participation in our effort to study the natural supercritical hydrothermal regime (Friðleifsson et al. 2010). Applying the lessons learned in the IDDP-1 well in Krafla, to the IDDP-2 and -3 drillholes should improve our chances of investigating supercritical hydrothermal processes directly in nature, for the first time worldwide. The geothermal supercritical systems at depths in the volcanic systems of Iceland are still as much of a challenge as they were 10 years ago. And our principal goal of producing supercritical fluid to enhance the economics of the geothermal industry is also as much of a challenge as it was 10 years ago – and even more urgent in view of increasing attention to climate change, energy safety issues and the need for green sustainable energy. Accordingly we seek funding and scientific partners for collaboration.

5. CONCLUSION – AN INVITATION

The international geothermal industrial and scientific society is invited to seriously consider participation in the completion of wells IDDP-2 and IDDP-3, flow testing and pilot studies for energy production. The completion of the program is expected to take place during 2010 to 2015. Information on the IDDP project and its progress will be announced at our website: www.iddp.is.

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