Iceland Deep Drilling Project Finds Magma

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The first deep well of the Iceland Deep Drilling Project (IDDP), well IDDP-1, penetrated rhyolitic magma at a depth of 2104 m in the Krafla Geothermal Field in northern Iceland.

Drilling of the well began in March 2009 in the Krafla volcanic caldera, within an active rift zone in northeastern Iceland. A large magma chamber, located at 3-7 km depth at the center of the caldera, is believed to be the heat source for a geothermal system currently supplying steam to the 60 MWe Krafla power plant. The IDDP plan was to drill to a depth of 4.5 km with the aim of exploring for *supercritical* geothermal fluids.

View of the drill rig (now removed) for well IDDP-1. The well overlooks Viti, an explosion crater formed in an eruption in 1724 AD. PHOTO BY G.Ó. FRIÐLEIFSSON.

After about two months of slow drilling progress (including getting stuck, having twist-offs, and having to sidetrack three times), the reason became clear on June 24th at a depth of 2104 m. The weight-on-bit suddenly declined, while the rate of penetration and the torque shot up. After pulling up the drill string a few meters and maintaining circulation, colorless rhyolitic glass cuttings were returned, followed by abundant, darker, obsidian-like drill cuttings. It became clear magma had flowed into the drill hole. This intrusion of magma within the Krafla caldera presumably is related to eruptions that occurred nearby from 1975-84, and appears to be a sill or dike of unknown extent.

Well IDDP-1 was sited based on the existing geophysical models and data from nearby wells. Models based on the interpretation of magnetotelluric data suggested the magma chamber was deeper than 4.5 km at that site. Evidently the resolution of that method was not sufficient to identify the intrusion well IDDP-1 penetrated. As the intrusion still is molten, if it occurred during the eruptions from 1975-84, it must have a minimum thickness of at least 50-100 m. More detailed geophysical surveys will be necessary to map out the extent of the intrusion as part of estimating its resource potential.

Encountering active magma while drilling a geothermal borehole is a rare event and only two previous instances are documented, one in Iceland and a second in Hawaii. In both cases,

it was not possible to continue drilling and the wells were completed at a level above the magma. Similarly it was deemed not feasible to continue drilling deeper in well IDDP-1, given the equipment available. Therefore the well was completed with a cemented casing and a hanging slotted liner was set a few meters above the quenched magma.

A tracer test is underway to check connectivity with wells neighboring well IDDP-1, the closest of which lies only 70 m to the south. Surface valves are being installed and preparations being made for a flow test to evaluate the fluid chemistry, steam production, and potential-power output. Depending on the result of this flow test of well IDDP-1, future possibilities might include the creation of the world's *hottest Engineered Geothermal System (EGS)* by injecting water into the magma and producing superheated steam in the adjacent well. An advantage of such a strategy would be that the acidic gases likely to be given off by the magma could be neutralized with injections of suitably treated water.

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Colorless glass shard (~1 mm across) with spherical vesicles. PHOTO FROM *ISOR DAILY REPORT IDDP-1 NO. 127.*

Research on the samples and data from well IDDP-1 is being conducted by an international team, with members from 11 different countries coordinated by two principal investigators (Guðmundur Ó. Friðleifsson of HS Orka hf in Iceland, and Wilfred A. Elders of the University of California-Riverside, US). Preliminary studies indicate two slightly different rhyolitic melts are present and geothermometry suggests their temperature is ~1050 °C (Robert Zierenberg, personal communication). Further details will be presented at the Geothermal Resources Council Annual Meeting in Reno.

The drilling of well IDDP-1 was funded by the operator of the Krafla Geothermal Field, Landsvirkjun, the Icelandic National Power Company, and carried out by the Iceland Drilling Company Ltd. The intention was to drill the well to a depth of 3.5 km—when the IDDP consortium would have taken it over to deepen it to 4.5 km to investigate supercritical regimes. The IDDP consortium is composed of three Icelandic power companies—Landsvirkjun, HS Orka hf, and Reykjavik Energy—together with Orkustofnun (the National Energy Authority of Iceland), Alcoa Inc., and Statoil New Energy AS (a division of StatoilHydro). The International Continental Scientific Drilling Program and the US National Science Foundation were jointly funding the work of obtaining drill cores from the well for scientific studies. For further news, *see* the IDDP website: www.iddp.is.

Although drilling for supercritical fluids at Krafla has been abandoned for the present while the possibility of magma energy is explored, discussions are still active about continuing the search for supercritical-geothermal energy. If suitable funding can be arranged, two new wells, 3-4 km deep, will be drilled in 2010-2011 in southwestern Iceland at the Hengill and the Reykjanes Geothermal Fields—and subsequently deepened into the supercritical zone. In contrast with the freshwater systems at Krafla and Hengill, the Reykjanes geothermal system produces hydrothermally modified seawater on the Reykjanes Peninsula, where the Mid-Atlantic Ridge appears on land.

The IDDP has engendered considerable international technical and scientific interest. If the activities prove successful in Iceland, they could lead to major improvements in the economics of high-temperature geothermal resources in volcanic terrains, worldwide. ■