CLEAN MAGMA ENERGY FOR THE NORTH

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Although life and commerce in the North are energy-intensive and energy resources are rich, the needs and resources are often not aligned, so multiple solutions are needed. Geothermal energy generally occurs at tectonic plate boundaries, which for the north are the spreading boundary between the North American and Eurasian plates under Iceland and the convergent boundary between the North America and Pacific plates under Kamchatka, Russia; the Aleutian Islands, USA and Russia; and Alaska, USA. Geothermal is used effectively for electric power generation in Iceland and Kamchatka, but not at all in Alaska. Drilling discovery of magma and associated high reservoir permeability in Iceland suggests that geothermal resources may be greater than previously thought, and that exceptional productivity from magma geothermal may permit establishment of geothermal plants with less drilling and/or greater power output.

Krafla Caldera, Iceland

In 2009, drilling to planned 4-5 km depth by Landsvirkjun Power Co and Iceland Deep Drilling Project[1] commenced in Krafla Caldera to investigate the energy potential of super-critical fluids. IDDP-1 unexpectedly encountered rhyolite magma at 2 km depth instead. Over a depth interval of ~30 m, the temperature increased from 350°C to ~900°C. The magma contact zone is highly permeable, supplying enough 450°C steam through this single well to power 60,000 homes (30 MW_e). The shallow magma is rhyolite in a system that has erupted only basalt for almost 10,000 years, including during a 1975-1984 rifting event, and the robust seismic and geodetic monitoring since that time has detected no intrusive activity. It may be large and/or continuously regenerated, underlying more than 3.5 km^2 of the caldera[2]. A similar volcano to the south, Askja, unleashed a huge eruption of similarly hidden rhyolite magma during a basaltic rifting event in 1875[3]. A next step at Krafla is to drill a new well to magma for production and to extract continuous core from the margin of the body. These plans involve Landsvirkjun and an international science consortium, Krafla Magma Drilling Project (KMDP), respectively. KMDP is proposing the coring to the International Continental Scientific Drilling Program (ICDP) as a "well of scientific opportunity", i.e., an industry/academic partnership.

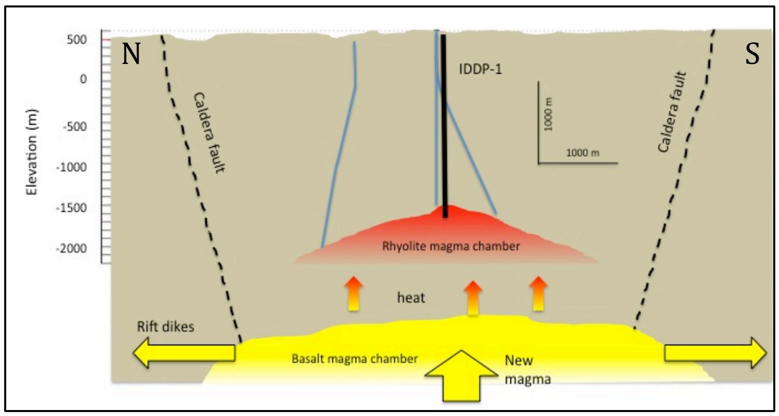

Fig. 1: N-S cross section through Krafla Caldera showing boreholes that reached magma or near-magmatic conditions.

Concept of rapid heat transfer from magma

IDDP-1 demonstrated that extracting energy directly from magma is both technically and economically feasible. IDDP-1 also demonstrated effective control of the magma, which is in theory capable of erupting as at Askja. The extreme temperature gradient and high permeability encountered by IDDP-1 and earlier drilling results from a lava lake in Hawaii suggest operation of a freeze-fracture-flow boundary[4]. Rapid cooling of magma causes crystallization and contraction, which in turn causes fracturing that gives water access almost to the magma. This process produces columnar jointing, evident in lava flows and shallow intrusions[5]. The entire zone, perhaps only a few meters thick, propagates into the magma body, maintaining a constant and very high heat flux from magma.

Applications in Kamchatka and Alaska

Mutnovsky geothermal field is operated by Geotherm SC on the flank of Mutnovsky volcano and produces 62 MW_e, a third the power consumption of Petropavlovsk-Kamchatsky[6], sustained by drilling new wells. However, magma is close to the surface as evidenced by magmatic temperatures in Mutnovsky's youngest crater and a rate of emission of SO_2 that requires convective degassing of shallow magma. Drilling to magma (previously proposed by USSR's Super Deep Drilling Program) might reduce the need for repeated drilling and/or expand power output to serve the entire needs of P-K, the northernmost ice-free, deep-water port on the Russian coast.

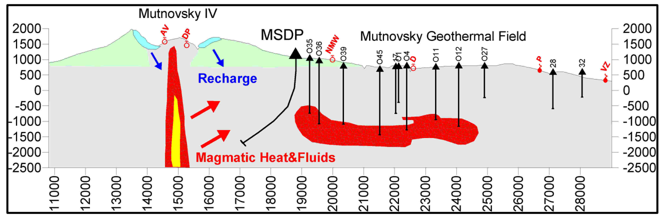

Fig. 2: Cross section through Mutnovsky volcano and associated geothermal system. A directionally drilled borehole such as "MSDP" could tap the magmatic heat source. (Kiryukhin, 2001x)

Two readily accessible volcanoes in Alaska that likely have magma bodies at shallow depth are Augustine volcano in Cook Inlet and Makushin volcano near Dutch Harbor/Unalaska. Data from Augustine's 2006 eruption indicate magma storage at 3.5-5 km[7]. A 100-km submarine cable could connect Augustine to the grid in Alaska's most populous region. Drilling infrastructure and expertise are nearby in an oil and gas field.

Fig. 3: Makushin volcano with Dutch Harbor in foreground (Google Earth).

Makushin volcano is only 25 km from Dutch Harbor/Unalaska, a seaport and fish processing community within the fishery producing half of USA's seafood production. Power comes expensively and uncleanly from diesel generators. Exploratory drilling conducted by the State of Alaska with funding from the US Department of Energy during the 1980s identified a viable conventional geothermal reservoir on the flank of Makushin (Updike[8]). Low-level eruptive activity at the summit indicates the presence of magma close to the surface. Cheap power would open the door to expanded commercial activity. As the only deep-water seaport (and ice-free) in the Aleutians, Dutch Harbor will have new power needs as trans-Arctic sea routes open.

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