Krafla Magma Testbed (KMT): Creation of the First International Magma Observatory for Volcanology and Geothermal Innovation

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Summary

*Ac*cessing magma is a necessary next step in the exploration of our planet (Lavallée et al., 2025). Why so? It will allow us to modernize volcano monitoring, transform our understanding of mass and heat transfer in the earth system, and importantly, because magma offers a tremendous amount of energy. Recent exploratory geothermal drilling activities around the World have serendipitously encountered shallow magma bodies in Earth's crust. From these encounters, we learnt that the consequences may not necessarily be as dramatic as one might expect; instead, they may provide solutions to a sustainable living. Following these game-changing occurrences, the *Krafla Magma Testbed* (KMT) was established to develop new magma monitoring approaches and energy solutions. KMT aims to establish the first magma observatory – a world-class international *in-situ* magma laboratory with access to the magma-rock-hydrothermal boundary through wells, available for advanced studies and experiments. Here we will present experimental findings about the magmatic conditions at Krafla as well as how magma previously responded to drilling at Krafla; this will be followed by an introduction to the KMT science plan and its prospective benefits for next-generation energy solutions and volcano resilience strategy.

Context and Preliminary Findings from Previous Magma Encounters

Magma has (to our knowledge) been encountered on 5 occasions: in three wells at Krafla (Iceland); one at Puna (Hawaii, USA) and one at Menengai (Kenya) (Eichelberger et al., 2018). No encounters prompted eruption through the borehole, although all quenched-in magmatic glass chips, recovered from drilling muds, exhibit some degrees of petrological responses by magma. The best documentation of magma response to drilling spurs from the 2009 Iceland deep drilling project (IDDP-1) where drilling intersected a rhyolitic magma body at 2.1 km (Elders et al., 2014; Mortensen et al., 2014), highlighting the need to improve magma detection and imaging methods. This serendipitous encounter resulted in five key observations: (1) complete drilling fluid loss in the last 30 m to magma, which we attributed to extensive cooling contraction (Lamur et al., 2018; Lavallée et al., 2020); (2) the drill string got stuck into magma (and freed via thermal manipulation and vitrification; Lavallée et al., 2020); (3) trapped magmatic volatiles (H_2O, CO_2) exhibit concentrations lower than lithostatic conditions (Zierenberg et al., 2013), as magma vesiculated and fragmented due to P-T changes imparted by drilling (Birnbaum et al., in prep); (4) magma flowed ~10m up the well in about 15 minutes (Elders et al., 2014); and (5) magma quenched to glass by drilling fluids at rates constrained via calorimetric geospeedometry of 7-87 ˚C/min (Wadsworth et al., 2024). This limited upwelling of rhyolitic magma in a borehole stand in stark contrast to the event of 8 September 1977 (during the 1975-84 Krafla Fires), when 26 m^3 of basaltic magma erupted through a borehole (Larsen et al., 1977). Basaltic and rhyolitic magma are commonly regarded as rheological end-members; hence, we advance that the rheology and thermal properties of magma are likely key controls on magma eruptibility through a well. Combined analysis of the glass chips geochemical signature with the quench rate and drilling data is being used to assess magma response to drilling. Preliminary findings that magma respond to drilling in the last meters before interception. Importantly, this information indicate that magma may be manipulated and safely accessed provided that we develop appropriate drilling practices.

The Goal of the Krafla Magma Testbed

To revolutionize our knowledge of magma and enable safe access for future volcanology and geothermal research, we established the Krafla Magma Testbed (KMT). The vision of KMT is to become a world-class international in situ magma laboratory with access to the magma-rock-hydrothermal boundary through wells, available for advanced studies and experiments. The goals are to:

1. Characterize the magma-rock-hydrothermal transition zone and its evolution.
2. Design and construct stable wells for sampling and continuous long-term monitoring of magma bodies stored at depth and their immediate environment.
3. Test new materials, sensors and technologies at extreme conditions.
4. Develop new energy harnessing technologies.
5. Evaluate the response of magma and fluids to geothermal exploration and utilization.
6. Carry out experiments with controlled manipulation at the magma-rock-hydrothermal interface and in magma, coupled with high-resolution monitoring activity
7. Develop new monitoring methods and approaches capable of identifying, locating, and characterizing magma bodies.
8. Improve reliability of warnings of impending volcanic eruptions world-wide through improved understanding of subsurface volcanic processes and how to monitor them.

These goals are of broad nature and of importance for advancing our understanding of geothermal and magmatic systems, world-wide. In a first instance, we plan two wells to undertake these goals (Fig 1):

KMT-1 is designed as a well to systematically sample and instrument the magma-rock-hydrothermal transition. The well is planned to obtain first-order information on the magma body and its crystalline boundary. Together with information obtained from IIDDP-1, this second window into magma will provide a time series to assess magma evolution.

KMT-2 is designed to perform magma manipulation and carry out experiments at the rock-magma interface to assess and optimize energy production, and improve interpretation of near-magma signals detected at the surface by volcano observatories to monitor active volcanoes.

Each well bolsters a long series of objectives to fully characterize the system and achieve the goals with tremendous worth for the geoscientific and geoengineering community.

KMT is designed as an open-access infrastructure and we will discuss ways in which the community may join and contribute to this effort.

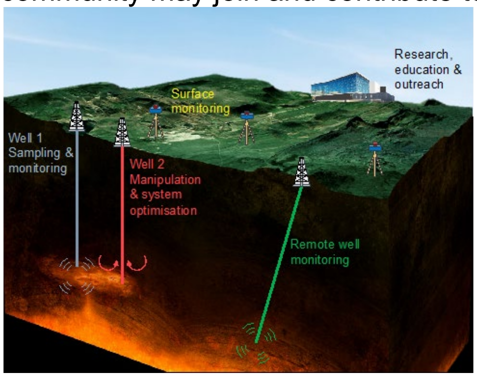

Figure 1. Conceptual illustration of the Krafla Magma Testbed infrastructure (seewww.kmt.is).

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