

CHARACTERISATION OF TWO MARS-ANALOGUE GEOTHERMAL ENVIRONMENTS IN ICELAND. A. Moreras-Marti, M. Fox-Powell, A. Zerkle, C. Cousins, School of Earth and Environmental Sciences, University of St Andrews, Irvine Building, North Street, Fife, UK, KY16 9AL, (amm48@st-andrews.ac.uk).

Introduction: Due to their ability to support chemolithotrophic life on Earth, martian relic hydrothermal systems remain a key target for exploration. Hydrothermal systems can provide basic elements necessary for life and energy sources, based on phototrophic or redox reactions [1]. We investigated two hydrothermal environments in Iceland: rhyolite-hosted hydrothermal environments at Kerlingarfjöll; and basalt-hosted hydrothermal environments at Kverkfjöll. In both locations, geothermally-sustained ephemeral pools host lithotrophic microorganisms adapted to anoxic, oligotrophic environments. By investigating both rhyolite- and basalt-hosted systems, differences in microbial biogeochemistry can be identified, allowing for the recognition of biosignatures unique to the basaltic systems that are more typical of Mars. This study will help constrain the water chemistry, sediment mineralogy, and organic C $\delta^{13}\text{C}$ values on an early martian hydrothermal analogue to inform which biosignatures may be detected.

Geological setting: The Kerlingarfjöll volcano is situated to the SW of the Hofsjökull ice cap in central Iceland. The volcanic complex was formed under the ice between 331ka and 156ka and its composition is largely rhyolitic [2]. Kverkfjöll is a partially-subglacial basaltic volcano on the NW margin of the Vatnajökull glacier [3]. The volcanic eruption of Kverkfjöll took place during the Holocene through fissure eruptions. The eruptive materials are tholeiitic basalts [4] with hyaloclastic pillow lava and fine-grained tuff sequences [5]. Both volcano complexes feed a high-temperature geothermal area with a surface manifestation of hot springs, mudpots and fumaroles created by the melting of glacial ice and snow due to geothermal heat (Fig. 1).

Methods: We sampled four small pools in Kerlingarfjöll and three in Kverkfjöll (sizes range from 0.5m to 3m long) during a field campaign on August 2017.

In-situ measurements of pH, temperature and Dissolved Oxygen (DO) were taken. Water samples were collected from the ice-melted pools for major anion and cation concentrations, and δD and $\delta^{18}\text{O}$ stable isotope measurements. Sediment samples were collected for XRD, Visible-Short Wave Infrared (Vis-SWIR) reflectance spectra, Total Carbon (TC) and $\delta^{13}\text{C}$ analyses.



Fig 1. A. Kerlingarfjöll geothermal area. B. Image of Kverkfjöll geothermal area and the sampling team.

Results and discussion: Rhyolite- and basalt-hosted pools show clear geochemical distinctions. Kerlingarfjöll pools have higher temperatures from 20 to 60°C with circum-neutral pH and 0.06 to 0.8 mg/L DO. Kverkfjöll pools have lower temperatures of 16.8 and 20°C, an acidic pH of 1.7 and 2.7 compared with Kerlingarfjöll, and a higher DO (0.26, 1.57mg/L). Kverkfjöll has extremely high concentrations of SO_4^{2-} (0.61 to 171.04 mM), where Kerlingarfjöll SO_4^{2-} ranges from 0.91 to 9.8 mM. Cl^- concentrations are 0.02 to 0.05mM in Kerlingarfjöll and 0.004 to 0.5mM in Kverkfjöll.

The disparity in water pH (Fig.2) between the two locations may be related to the sulfidation state of the volcanic systems, referred to be the oxidation state of sulfur in the magmatic fluid/vapor chemistry and the interaction with the host rock. Kverkfjöll appears to be a high sulfidation state system proximal to the volcano where the fluid/vapor involved is usually very acidic (pH 1-3) and transports in it oxidized sulfur species. Therefore Kverkfjöll pools waters show very high sulfate concentrations delivered by the vapor released through fumaroles. The acidity of the waters also causes leaching in the host volcanic rocks, releasing most of the major mobile elements. Conversely, in low sulfidation systems the fluid involved is near neutral pH with reduced sulfur species in the fluid/vapor as H_2S , and the fluids have equilibrated with their host rocks with a stronger meteoric signal [6]. Kerlingarfjöll hydrothermal activity is produced by boiling of groundwater rather than being of magmatic origin [7]. It also shows low sulfidation system features having minor SO_4^{2-} concentrations and neutral pH pool waters.

The δD against $\delta^{18}\text{O}$ plot for the water presents a large variation on the oxygen isotopes (-10.64 to 0.55‰) and a constrained range of deuterium isotopes (-44.19 to -87.16‰) with similar trends for both Kerlingarfjöll and Kverkfjöll sites. The trends do not follow the meteoric Icelandic line, the slope is instead

defined by constant evaporation of the pool's water in different conditions of temperature and relative humidity. This shows how the pools have a discontinued flux of melted water, where ground temperatures results in fast evaporation cycles. The pools with higher δD were the ones that had smaller sizes in the field and no input or output of water. Water-rock interaction might also be affecting the oxygen isotope values.

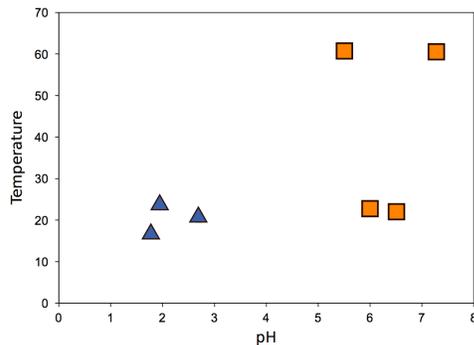


Fig. 2. Temperature against pH plot. Triangle blue = Kverkfjoll and orange squares = Kerlingarfjoll.

XRD and Vis-SWIR reflectance spectra from pool sediments show the presence of hydrated, Al- and Fe-bearing minerals throughout both locations and different pools (Fig.3). Kerlingarfjoll pool sediments have predominantly Quartz, Montmorillonite, Pyrite and Heulandite-Ca, related to the weathering of rhyolitic rocks. Kverkfjoll pool sediments comprise Dickite, Alunogen, Pyrite and Saponite, more typical of a basaltic weathered site.

The $\delta^{13}C$ isotope values for Kerlingarfjoll range from -16.72 to -1.42 ‰, and from -24.58 to -1.37 ‰ for Kverkfjoll sediments. Total Carbon values given in % range from 0.32 to 3.95 in Kerlingarfjoll and 0.08 to 3.43% in Kverkfjoll, with a majority of the samples showing lower values. A mineral crust around one of the Kverkfjoll pools shows the lightest values of -24.58 ‰ with TC values of 0.27%.

Conclusion: There is a clear differentiation between Kerlingarfjoll and Kverkfjoll locations based on the water chemistry and pH, which in turn is reflected in the resulting secondary mineral phases and associated Vis-SWIR reflectance spectra. Both Kerlingarfjoll and Kverkfjoll pool waters have undergone similar evaporation processes as δD and $\delta^{18}O$ stable isotope measurements prove. The big array of $\delta^{13}C$ results suggests that the values range from abiotic to biotic influenced processes in both locations. The Total Carbon % are higher in average on Kerlingarfjoll, probably due to the higher carbonate content of the rocks.

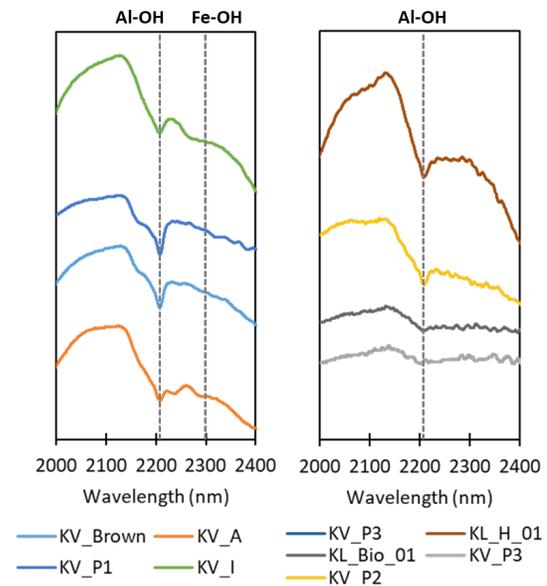


Fig. 3. SWIR reflectance spectra showing metal-OH absorptions in Kerlingarfjoll (KL_) and Kverkfjoll (KV_) sediments.

Upcoming work: TOC and $\delta^{13}C$ values will supplement the TC values, to identify fractionation processes specific to inorganic and organic C. Results will be coupled with 16S rRNA phylogenetic assays to establish the indigenous microbial communities present for future detailed investigations into microbial sulfur and carbon isotope fractionation processes.

References: [1] Hays, L. et al. (2017). *Astrobiology*, 17(4), 363-400. [2] Flude, S. et al. (2010). *Bulletin of Volcanology*, 72(5), 523-538. [3] Cousins, C.R. et al. (2013). *Journal of Volcanology and Geothermal Research*, 256, 61-77. [4] Jakobsson, S. P. et al., (2008). *Jökull*, 58, 117-138. [5] Oladottir B.A. et al., (2011). *Bulletin of Volcanology* in press. [6] Robb L.J. (2005) Introduction to ore-forming processes. [7] Grönvold, K. (1972) Structural and petrochemical studies in the Kerlingarfjöll region, central Iceland. Ph.D. thesis, *University of Oxford*.

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