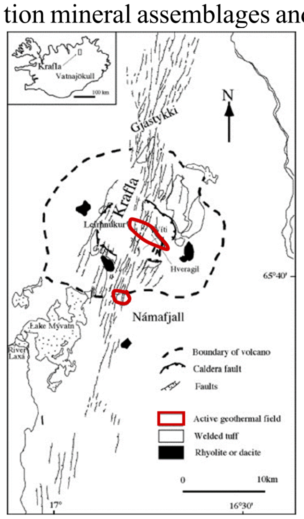
LEACHING, PRECIPITATION, AND OXIDATION IN AN ICELANDIC HYDROTHERMAL SYSTEM: COMPARISON TO COLUMBIA HILLS, MARS. G. L. Carson[1], L. J. McHenry[1], B. M. Hynek[2], B. I. Cameron[1], and C. T. Glenister[1], [1]UWM Geosciences, 3209 N Maryland Ave, Milwaukee, WI 53201 (kit.carson519@gmail.com, lmchenry@uwm.edu, bcameron@uwm.edu, glenist3@uwm.edu), [2]UC Boulder Laboratory for Atmospheric and Space Physics, 3665 Discovery Drive, Boulder, CO 80303 (Brian.Hynek@lasp.colorado.edu).

Introduction: Iceland's hydrothermal sites, formed in contact with high-Fe basalts, make it an excellent analog for potential Martian hydrothermal systems such as that explored by MER Spirit in the vicinity of Home Plate. Námafjall, a currently active hydrothermal area adjacent to Krafla volcano in northern Iceland (Fig 1), has gas-driven fumaroles and fluid-dominated mud pots and hot springs, with associated alteration aprons, in contact with both Holocene basaltic lavas and Pleistocene hyaloclastite substrates. This provides an opportunity to examine the effects of gas vs. fluid-driven acid-sulfate alteration, and the effects of substrate, on alteration mineral assemblages and element mobility patterns.



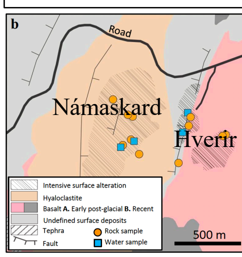


Figure 1: Map of Iceland and Krafla, showing location of Námafjall. Detail map of Námafjall, showing location of sample sites at Hverir and Námaskard hill. Adapted from [1,2].

Here we present mineralogical and geochemical data for a transect across a fumarole apron on a Holocene lava substrate at Hverir, the apron surrounding a mud pot with the same substrate, and the apron surrounding a mud pot on Námaskard hyaloclastite ridge.

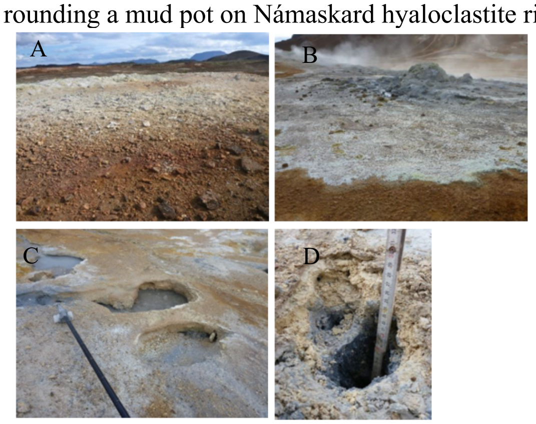


Figure 2: sample locations. A. Hverir fumarole. B. Hverir mudpot. C and D. Námaskard mud pot and sample pit.

Methods: 26 altered rock/soil samples were collected from the surface and 5 shallow pits at increasing distance from the Hverir fumarole. Five water or altered rock/ soil samples were collected from the Hverir mudpot, and 13 were collected from two mudpot aprons (and adjacent shallow pits) atop Námaskard hill. Soil, rock, and precipitate samples were analyzed by XRD (for minerals) and XRF (for bulk composition), with select samples analyzed by SEM. Temperature (T) was measured for each sample, and pH for all water samples. A Hydrolab sonde was used in the field to measure water parameters (oxidation/reduction potential (ORP), specific conductivity (SpCond), and salinity (Sal)).

Results: XRD results reveal a wide range of alteration products and precipitates, including many sulfates, sulfides, amorphous silica, clays, and oxides, with assemblages that change with distance from the source and (for the samples collected near mud pots) with depth. XRF results also show changes, with some altered samples only marginally changed from the volcanic substrate and others leached in most elements (except for Si and Ti, which are residually enriched).

Water analysis reveals uniformly acidic conditions (pH 2.15-2.42), with a range in salinity and ORP observed at both Hverir and Námaskard (Table 1).

Table 1: *In-situ* Environmental parameters for water

Sample	T°C	pH	SpCond (us/cm)	Sal (ppt)	ORP (mV)
Hverir-1	40	2.15	6163	3.41	-56
Hverir-4	59	2.42	2109	1.13	-136
Hverir-5	66	2.2	4024	2.19	-343
Námask-25	56	2.24	4241	2.32	-269
Námask-29	71	2.36	1456	0.77	-302

Discussion: For the fumarole transect (Fig. 3), samples near the source (~98°C) were rich in elemental sulfur, those at intermediate distances (~70°C) showed acid leaching and residually enriched Si and Ti (Fig. 4) (with associated amorphous silica and anatase), followed (~40°C) by kaolinite and alunite and jarosite-group sulfates, and finally smectite clays associated with minimally altered mafic minerals at the periphery (~25°C). No systematic trends were identified with shallow depth.

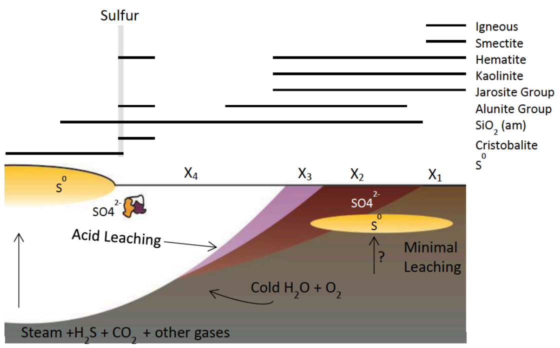


Figure 3: mineral distribution at Hverir fumarole. Transect is 8 meters across. The “sulfur” line shows oxidation of elemental sulfur (left) to sulfate (right).

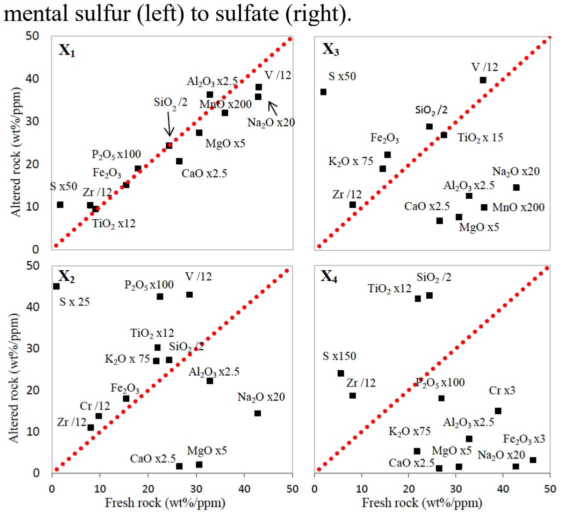


Figure 4: Isocon diagrams for example samples from the Hverir transect, positions X_1 to X_4 labeled in Fig. 3. Plotted against fresh basalt sample: elements above the line are enriched, those below are depleted. X4 shows the most leaching, with only Si, Ti, Zr, and S enriched. X2 and X3 show depletion of most mobile elements other than K, which is present in both clay and jarosite-group minerals.

For the Námaskard hill mud pot/ hot spring transects (and associated pits), sulfides, elemental sulfur, amorphous silica, and kaolinite are all found in the mud at the margin. With distance, sulfides and elemental sulfur are replaced by Fe^{2+} sulfates, which are then replaced by Fe^{3+} sulfates and hematite (Fig. 5). The oxidation front between sulfides, elemental sulfur, and sulfates lies near the surface; within the shallow pits, sulfides are identified at depth while Fe sulfates (rhomboclase, jarosite, ferricopiapite) are identified at the surface.

Mars comparison: The Fe-sulfate rich deposits compare favorably to Paso Robles class soils analyzed by MER Spirit, especially with the identification of ferricopiapite (e.g. [3]). However, the lack of Mg- and Ca-sulfates at Námafjall (compared to Paso Robles [4,5]) probably points towards more open-system alteration in Iceland than on Mars. The most soluble salts are more easily dissolved and their cations more easily lost from the system in the wetter environment at Námafjall.

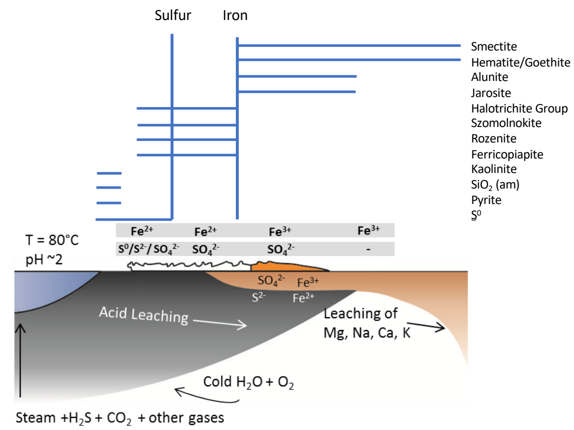


Figure 5: General mineral distribution for the Hverir and Námaskard mud pot transects (~2 meters across). Sulfur line indicates oxidation of sulfides and elemental sulfur into sulfates, iron line indicates oxidation of Fe^{2+} sulfates into Fe^{3+} sulfates (and the appearance of hematite). The oxidation fronts extend further from the source at depth.

The leached samples on the Hverir fumarole apron, with their amorphous silica, could be reasonable analogs for the Eastern Valley deposits studied by Spirit. [6] interpret these Opal-A rich deposits as silica sinters precipitated by near-neutral fluids rather than acid-sulfate leached deposits, based in part on the absence of accessory sulfate phases. The most Si-enriched portion of the Hverir fumarolic apron also lacks sulfate phases (and has sulfur concentrations under 1%), showing that acid-sulfate leaching in a fumarolic environment can lead to a Si-rich, S-poor leached deposit.

The redox gradients observed (both laterally, and with depth) could serve as energy sources for Fe- and S-reducing and/or oxidizing microorganisms; combined with the heat and liquid water associated with hydrothermal environments (on Earth or Mars), this could be attractive to acidophiles.

References: [1] Gudmundsson B.T. & Arnorsson S. (2005) *Applied Geochemistry* 20, 1607-1625. [2] Saemundsson K. et al. (2012), *Geological Map of the northern Volcanic Zone, Iceland. Northern Part. 1:100,000.* [3] Wang A. & Ling Z.C. (2011) *JGR* 116:E00F17. [4] Ming D.W. et al. (2006) *JGR* 111:E02S12. [5] Yen A.S. et al. (2008) *JGR* 113: E06S10. [6] Ruff S.W. et al. (2011) *JGR* 116:E00F23.

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