

## **Mineralogy and bulk geochemistry of a fumarole at Hverir, Iceland: Analog for acid-sulfate leaching on Mars**

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### **ABSTRACT**

Iceland's Námafjall geothermal area exhibits a range of alteration environments. Geochemical and mineralogical analyses of fumaroles and hot springs interacting with Holocene basaltic lavas at Hverir, and with Pleistocene hyaloclastites atop nearby Námaskarð, reveal different patterns of alteration depending on the water/rock ratio, degree of oxidation, and substrate composition and age. The focus of this study is a transect of a Hverir fumarole that has formed a bullseye pattern of alteration of a Holocene basaltic lava flow. Surface samples and samples collected from shallow pits were analyzed by X-ray diffraction (XRD), X-ray fluorescence (XRF), and scanning electron microscopy (SEM) to constrain changes in mineral assemblage and major elemental composition with both distance and depth. Elemental sulfur is concentrated near the vent, with leached deposits with amorphous silica and anatase nearby and kaolinite, hematite, and jarosite/alunite-group sulfate minerals farther out, with smectites and less altered material at the margins, though smaller-scale mineralogical diversity complicates this pattern.

Silica phases include amorphous silica (most samples), cristobalite (some samples in the leached part of the apron), and quartz (minor constituent of a few samples). The silica was concentrated through residual enrichment caused by leaching and is accompanied by a significant enrichment in TiO<sub>2</sub> (in anatase). The presence of abundant cristobalite in a surface fumarole-altered Holocene basaltic lava flow most likely reflects cristobalite formed during the devitrification of volcanic glass or precipitation from fumarolic vapors, rather than high-temperature processes. Minor, localized quartz likely reflects diagenetic maturation of earlier-formed amorphous silica, under surface hydrothermal conditions. Natroalunite, natrojarosite, and jarosite are all present and even exhibit compositional zonation within individual crystals, showing that under surface hydrothermal conditions, these minerals can form a significant solid solution.

The high iron content of the substrate basalt and the prevalence of Fe-sulfates and Fe-oxide spherules among the alteration products makes this geothermal area an especially useful analog for potential martian hydrothermal environments. The residual enrichment of silica in the leached deposits of the Hverir fumarole apron could serve as an acid-sulfate leaching model in which amorphous silica forms without appreciable sulfur-bearing phases in many samples, a possible analog for silica-rich soils in the Columbia Hills on Mars. The coexistence of hematite spherules and jarosite-group minerals serves as an intriguing analog for a volcanic/hydrothermal model for hematite and jarosite occurrences at Meridiani Planum.

**Keywords:** Hydrothermal alteration, Mars analog, sulfate mineralogy; Earth Analogs for Martian Geological Materials and Processes