WHAT LURKS IN THE MARTIAN ROCKS AND SOIL? INVESTIGATIONS OF SULFATES, PHOSPHATES, AND PERCHLORATES

Alteration of Hawaiian basalts under sulfur-rich conditions: Applications to understanding surface-atmosphere interactions on Mars and Venus†

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ABSTRACT

A suite of Hawaiian basalts that were variably altered in the presence of SO2-rich gases during the current summit eruptive episode at Halemaumau crater, Kilauea, were studied to determine their alteration phase assemblage and reactive pathways using electron microscopy, Mössbauer spectroscopy, and X-ray diffraction. The alteration conditions represent an acid fog environment. Alteration rinds on the basalts vary in thickness from tens of micrometers to the entirety of the rock and are composed of amorphous silica rims (85–95 wt% SiO2) overlain by sulfates. Sulfate mineralogy consisted of gypsum, anhydrite, and natrialinurite-jarosite. No phyllosilicates were observed in any alteration assemblages. Phenocrysts and glass were both observed to be extensively reacted during alteration. The Halemaumau samples may provide good analogs for basalt alteration on other rocky planetary bodies, i.e., Mars, Venus, and Mercury, where S is ubiquitous and low fluid/rock ratios are common.

Keywords: Sulfate, Halemaumau, basalt weathering, Mössbauer spectroscopy, Mars, Venus

INTRODUCTION

Both direct measurements and compositions inferred from meteorites and remote spectroscopy suggest that the terrestrial planets normally contain ~1–4% S by weight (e.g., Nittler et al. 2011), with various mineralogical and geological hosts. Light elements like S are important constituents of both surface rocks and minerals and of planetary cores, where S lowers the melting temperature of pure Fe metal. In our Solar System, the history of sulfur distribution can be traced through studies of primitive and evolved meteorites (Ebel 2011) representing all stages of planetary accretion from impacts through differentiation to volcanism and subduction.

The motivation for this study lies in this ubiquitous occurrence of sulfur-bearing phases in surface rocks on terrestrial bodies and the types of processes, both alteration-driven and depositional, required to form them. For example, on the highly reduced planet Mercury with its Fe-poor surface, large quantities of sulfur would be soluble in silicate melts, providing a driving force for explosive volcanism (e.g., Blewett et al. 2011). The lack of an atmosphere on Mercury makes it likely that sulfides persist globally, as seen by workers such as Weider et al. (2012) who have mapped the ratio of S/Si across much of Mercury’s northern hemisphere. Nittler et al. (2011) reported up to 4 wt% sulfur on the surface of Mercury based on MESSENGER results, postulated to occur in the form of Mg- and Ca-rich sulfides based on X-ray spectrometry. This value is much higher than what is observed in differentiated asteroids, martian meteorites, the Moon, or bulk Earth, suggesting that Mercury never underwent the depletion in volatile elements experienced by these other bodies (Peplowski et al. 2011). So the high-sulfur distribution on Mercury’s surface is a primary characteristic, and likely results from the enrichment of sulfur into silicate melts under reducing conditions (Nittler et al. 2011).

By way of contrast, the sulfur cycle on Venus is controlled by secondary interactions between the basaltic surface and the S-rich atmosphere (Zolotov 2007; Fegley and Prinn 1989). Few constraints on the elemental composition and mineralogy of the surface and subsurface exist, though they are critically needed to test models of surface evolution and weathering based on understanding of the physics and chemistry of Venus’ crust and atmosphere. Three sets of XRF major element analyses from the Venera and Vega landers all suggest the presence of basaltic rock types along with variable amounts of sulfur, either primary or secondary from atmospheric interactions. Modeling based on these results by various workers (e.g., Zolotov et al. 1997; Treiman and Schwenzer 2009; Treiman and Bullock 2012) has provided the groundwork and experimental context for distinguishing the contributions of chemical weathering reactions in an attempt to see through the geochemical overprinting to infer primary igneous rock compositions and mineralogy. The key to understanding Venus geology is to work backward from the elemental and mineralogical compositions of surface-altered rocks to understand both the weathering products (and from them, rock-atmosphere interactions) and the rock type(s) from which they form.

The sulfur cycle on Mars is likely dominated by aqueous