The Italian Solfatara as an analog for Mars fumarolic alteration

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ABSTRACT

The first definitive evidence for continental vents on Mars is the in situ detection of amorphous silica-rich outcrops by the Mars Exploration Rover Spirit. These outcrops have been tentatively interpreted as the result of either acid sulfate leaching in fumarolic environments or direct precipitation from hot springs. Such environments represent prime targets for upcoming astrobiology missions but remain difficult to identify with certainty, especially from orbit. To contribute to the identification of fumaroles and hot spring deposits on Mars, we surveyed their characteristics at the analog site of the Solfatara volcanic crater in central Italy. Several techniques of mineral identification (VNIR spectroscopy, Raman spectroscopy, XRD) were used both in the field and in the laboratory on selected samples. The faulted crater walls showed evidence of acid leaching and alteration into the advanced argillic-alunitic facies, with colorful deposits containing alunite, jarosite, and/or hematite. Sublimates containing various Al and Fe hydroxyl-sulfates were observed around the active fumarole vents at 90 °C. One vent at 160 °C was characterized by different sublimates enriched in As and Hb sulfide species. Amorphous silica and alunite assemblages that are diagnostic of silicic alteration were also observed at the Fangaia mud pots inside the crater. A wide range of minerals was identified at the 665 m diameter Solfatara crater that is diagnostic of acid-steam heated alteration of a trachytic, porous bedrock. Importantly, this mineral diversity was captured at each site investigated with at least one of the techniques used, which lends confidence for the recognition of similar environments with the next-generation Mars rovers.

Keywords: Mars analog, hydrothermalism, vents, fumaroles, alteration patterns, Solfatara, VNIR spectroscopy, Raman spectroscopy, XRD; Special Collection: Earth Analogs for Martian geological materials and processes

INTRODUCTION

Hydrothermal systems have often been proposed as a possible cradle for early life (e.g., Shock 1996; Nisbet and Sleep 2001) and therefore represent a prime astrobiology target. Hydrothermal environments have long been presumed to exist on Mars based on orbital observations, terrestrial analogs, and martian meteorites (e.g., Farmer 1996; Ruff et al. 2011; Carr and Head 2010). Evidence for warm and wet environments include the orbital detections by recent VNIR spectral-imagers of a wide range of hydrated minerals (Bibring et al. 2006; Murchie et al. 2009; Carter et al. 2013). In particular, the detection of chlorite, prehnite, epidote, serpentine, and carbonates provide evidence of aqueous alteration of Mars’ basaltic crust at high temperatures (e.g., Ehmann et al. 2009; Murchie et al. 2009; Carter et al. 2013). Alteration by hydrothermal circulation in the cooling crust and impact-generated hydrothermal alteration have both been proposed as a plausible formation mechanism (e.g., Abramov and Kring 2005; Ehmann et al. 2009, 2011; Carr and Head 2010; Carter et al. 2010, 2013). Hydrothermalism is also invoked as a likely source for alteration in localized surface environments (fumarolic fields or hot springs), leading to the formation of the clays, sulfates, and silica-rich deposits identified in Valles Marineris Chasma (Milliken et al. 2008; Thollot et al. 2012), the silica detections in the Nili Patera caldera (Skok et al. 2010) or the serpentine and Mg-carbonate detections in Nili Fossae (Viviano et al. 2013). However, the first definitive evidence for volcanic hydrothermal activity (continental vents) on Mars is the in situ detection of amorphous silica-rich outcrops (>90% wt opal-A) by the Mars Exploration Rover (MER) Spirit Miniature Thermal Emission Spectrometer (Mini-TES) instrument (Squyres et al. 2008). The detection of abundant opaline silica at Home Plate, combined with high Ti content in local soils, was interpreted as evidence for the dissolution of basaltic soils by low pH fluids (Squyres et al. 2008). Iron- and phosphate-rich soils detected nearby, at Paso Robles, were also interpreted as acid-sulfate alteration products in a hydrothermal (possibly fumarolic) environment of primary phosphate-rich materials (Hauersath et al. 2013). The nodular aspect of the Home Plate outcrops led to