Assessment of Secondary Chemical and Mineralogical Trends at Lassen Volcano: Relevance to Early Mars Hydrothermalism

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Introduction
- Placing environmental and astrobiological constraints on relic hydrothermal systems identified on Mars relies on our interpretation of geochemical reaction pathways observed in altered terrestrial materials.
- The Lassen hydrothermal system discharges volatiles from fumaroles that yield acidic vapor condensates while acidic, oxidizing hot springs precipitate a variety of sulfate minerals and alter substrate into residual silica and phyllosilicates.
- Analysis of mineralogy and chemical enrichment/depletion trends combined with in-situ water sampling at hydrothermal sites allows us to place controls on the alteration occurring as secondary mineral phases develop.

Objectives
I. Observe how elemental makeup of substrate (andesite) affects how ions partition into secondary mineral phases in acid hydrothermal settings.
II. Understand how oxidizing nature of Lassen geothermal waters/vapor condensates impacts mineral diversity.
III. Build upon existing framework for interpretation of proposed hydrothermal sites tentatively identified on the Martian surface through orbital and in-situ measurement.

Pilot’s Pinnacle: XRF Results
- Relative to substrate, L-16-PP-07, a yellow crust, is uniformly depleted in all elements analyzed, though likely enriched in sulfur.
- SiO₂ and TiO₂, insoluble in acidic settings—sulfur precipitation dilutes this effect.
- L-16-PP-09, a beige altered clay, shows enrichment in SiO₂, TiO₂, Ba, Zr but is depleted in all other elements—typical of acid-leached samples.

Mineralogical diversity increases near hot springs—insoluble in acidic settings.

Geologic Context
- Lassen Volcano: largest hydrothermal system in the Cascades
  - Discharges ~41kg/s—steam—volatile vapors and boiled meteoric water [1]
- Volcanic materials range from andesite to dacite [2][3]
  - Vapor source at depth—boiled meteoric water undergoes phase-separation [1][4]
  - Acidic volatile components (e.g. sulfur) fractionate into vapor phase and emerge as fumaroles at higher elevations
  - Alkaline waters surface at lower elevations as near-neutral, C-rich hot springs

Field Sites
- Oct, 2015—Samples collected in Lassen Volcanic National Park
- Both Sites: Acid-Steam Fumaroles & Steam-heated Acid Hot Springs

Analytical Methods
- Mineralogy: Mineral and substrate samples were powdered by hand in a mortar and pestle and analyzed using a Bruker D8 Focus X-Ray Diffractometer (XRD) [8].
- Chemical composition: Dried samples were fused and analyzed using a Bruker S4 Pioneer X-Ray Fluorescence (XRF) Spectrometer [5] for major, minor, and trace elements.
- In-situ water samples: Water samples were measured for T and pH in the field, and then further analyzed for total dissolved solids (TDS), oxidation-reduction potential (ORP), specific conductivity (Cond), and salinity using a Hydrolab sonde.

Water Analyses
- Water analyzed at hot springs and fumaroles in this study reveal environments that are acidic, mildly hot, and oxidizing.
- The oxidizing conditions measured via Hydrolab are consistent with presence of significant sulfate precipitates and lack of reduced mineral phases.

Mars Hydrothermalism?
Columbia Hills, Gusev Crater:
- SiO₂ and TiO₂ enrichment in rocks and soils detected by Mars Exploration Rover (MER) Spirit at Home Plate [6]. Chemical/textural features favor biologically mediated sinter precipitation vs acid leaching [7][8]
- Variety of Fe-, Mg-, & Ca-sulfate minerals present in Paso Robles class soils near Home Plate suggest precipitation from fumarolic condensates with lower water/rock ratios [9]
- ~0.5km from Home Plate—Carbonate-rich Comanche outcrop observed—neutral-pH hydrothermal activity [10]

Observations suggest diverse hydrothermal conditions ranging from hot and acidic to more neutral, potentially habitable environments.

Implications
- Alteration products at Lassen dominated by Al-sulfates and Al-phyllosilicates
  - Lassen andesites are high in Al (~16.8 wt. %)
- Parent lithology significantly impacts alteration products
  - Martian basalts are high in Fe
- Smectites and kaolinite prominent in both sites—high W/R ratios in acidic settings
- Sr2+ prominent near fumarole centers where samples are in direct contact with acid-stem cloud
- Mineralogical diversity increases near hot springs where sulfates precipitate directly from solution.

References

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Analysed samples from Pilot’s Pinnacle

XRD Results: