### Introduction

Hydrothermal acid-sulfate alteration of Mars’ crust was likely widespread in ancient times, owing to the ubiquitous presence of water, widespread volcanism and high heat flow. Results from orbiters and the Spirit Rover attest to acidic, high temperature alteration of basaltic materials and secondary mineral assemblages include abundant sulfates, silica, and some phyllosilicates [e.g. 1-2]. Different suites of alteration minerals occur across Mars, which is likely a result of environmental variables including fluid and parent rock composition, temperature, pH, and duration of volcanic activity. Thus, the alteration mineralogy holds clues to the paleoenvironments of early martian hydrothermal systems [3-5].

### Methods

- Major field campaign in August, 2012
  - Coordinated measurements of environmental parameters with field samples.
  - Characterized pristine to heavily altered materials.
- Measured in situ mineralogy with the CheMin equivalent Terra XRD/XRF instrument and CRISM and OMEGA-analog VNIR reflectance spectroscopy with ASD’s TerraSpec 4 (see also Marcucci et al., this meeting).
- Bulk solid/liquid chemistry from XRF and IC-AES.
- Trace mineralogy from thin-section petrography, electron microprobe & SEM-EDS.

### Aqueous Alteration Mineralogy

#### Table 1. Typical major, minor, and trace minerals identified in five types of environmental settings in Nicaraguan volcanoes.

<table>
<thead>
<tr>
<th>Environmental Setting</th>
<th>Major Phases</th>
<th>Minor Phases</th>
<th>Trace Phases</th>
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</thead>
<tbody>
<tr>
<td>Fumaroles: pH = 1.0 to 1.5; T = 100°C</td>
<td>sulfur; Si (amorphous): SiO2, cristobalite and tridymite; gypsum (CaSO4·2H2O);</td>
<td>hematite (Fe2O3); muscovite; nontronite; montmorillonite</td>
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<tr>
<td>Fumaroles: pH = 4.0 to 5.5; T = 50°C</td>
<td>jarosite (KFe3+3(SO4)·6H2O); alumin (KAl (SO4)·0H2); Fe2(SO4)3; sodum alumin (Na2SO4·12H2O); alumin (Al2(SO4)3·17H2O); goethite (FeOOH); zeolite; montmorillonite</td>
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<tr>
<td>Fumaroles: pH = 6.0; T = 60°C</td>
<td>calcite (CaCO3); gypsum</td>
<td>brushite (CaHPO4·2H2O);</td>
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<tr>
<td>Outwash Basins: T = ambient</td>
<td>gypsum; alunite; goethite</td>
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<tr>
<td>Mudpots: pH = 1.5 to 4.0; T = 75°C</td>
<td>kaolinite; montmorillonite</td>
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</tbody>
</table>

### Geochemical Model

Schematic of Nicaraguan fumarolic systems with moderate and extreme acidity and their major alteration products and distributions. Si = amorph. silica, SiO2 represents high temperature phases, and gypsum = gypset.

### Conclusions

- Field work was conducted at five acid-sulfate volcanic environments in Nicaragua to characterize the geochemical pathways of mineral alteration.
  - Mars-relevant instrumentation was used and VNIR and XRD give similar, yet different, results.
  - Environmental parameters were correlated with alteration mineralogy to assess the controls on weathering.
- Alteration mineralogy is similar to findings from Mars.
  - pH ~ 0 and highest T (~130°C) fumaroles resulted in high-T SiO2, amorphous Si, and some gypsum.
  - pH ~ 4, T ~ 100°C fumaroles led to amorphous Si, abundant sulfates and substantial phyllosilicates.
  - pH ~ 6, T ~ 60°C fumaroles yielded calcite & gypsum.
- High fluid:rock ratios lead to numerous hydrated sulfate phases and widespread phyllosilicates.
- Many clay minerals can form under acidic conditions.
- The results serve as a conceptual model for interpreting hydrothermal paleoenvironments on early Mars.

### References