

DIFFERENTIATING HYDROTHERMAL, PEDOGENIC, AND GLACIAL WEATHERING IN A COLD VOLCANIC MARS-ANALOG ENVIRONMENT. N. A. Scudder¹, B. Horgan¹, J. Havig², A. Rutledge³, E. B. Rampe⁴, and T. Hamilton², ¹Dept. of Earth, Atmospheric, and Planetary Sciences, Purdue University (nscudder@purdue.edu), ²University of Cincinnati, ³Arizona State University, ⁴Aerodyne – Jacobs JETS contract NASA Johnson Space Center.

Introduction: Although the current cold, dry environment of Mars extends back through much of its history, its earliest periods experienced significant water-related surface activity [1]. Both geomorphic features (*e.g.*, paleolakes, deltas, and river valleys) and hydrous mineral detections (*e.g.*, clays and salts) have historically been interpreted to imply a “warm and wet” early Mars climate [2]. More recently, atmospheric modeling studies have struggled to produce early climate conditions with temperatures above 0°C [2, 3], leading some studies to propose a “cold and icy” early Mars dominated by widespread glaciation with transient melting [*e.g.*, 2, 4]. However, the alteration mineralogy produced in subglacial environments is not well understood [5], so the extent to which cold climate glacial weathering can produce the diverse alteration mineralogy observed on Mars is unknown. This summer, we will be conducting a field campaign in a glacial weathering environment in the Cascade Range, OR in order to determine the types of minerals that these environments produce. However, we must first disentangle the effects of glacial weathering from other significant alteration processes. Here we attempt a first understanding of glacial weathering by differentiating rocks and sediments weathered by hydrothermal, pedogenic, and glacial weathering processes in the Cascades volcanic range.

Methods: Preliminary samples were collected during a 2015 survey from on and near glaciated regions of the Mt. Adams, Mt. Hood, and Three Sisters volcanoes in the Cascades volcanic province. Twenty-seven whole-rock and 10 sediment samples were taken from two locations on each volcano (Fig. 1). This suite samples a range of parent compositions. Mt. Adams and Mt. Hood are composed primarily of andesitic to dacitic rock [6, 7], but the Three Sisters are formed from less evolved basalt and basaltic andesite [8]. Ultimately we will study glacial weathering in detail at the Three Sisters volcanic complex, which as the most mafic glaciated terrain in the continental United States is a good analog for the largely mafic surface of Mars. Additional moraine sediment samples were collected from Three Sisters in 2013 [9].

To date, we have conducted visible to near-infrared (VNIR; 0.35-2.5 μm) spectroscopy at Purdue University on all distinct faces of each whole-rock sample using an ASD Fieldspec Pro 3 spectrometer at standard incidence and emission angles of 0 and 30 degrees. Qualitative observations of each sample were linked with its VNIR spectra to characterize the likely

alteration process. VNIR spectra of sediments as well as thermal-infrared spectra and X-ray diffraction (XRD) measurements will be acquired of all samples in the upcoming months.

Results from whole rock spectra: Alteration dominates the VNIR spectra in most samples, and we observe two distinct weathering patterns. The first group is visually similar to and interpreted as hydrothermal alteration, and the spectrally weaker second group is interpreted as either pedogenic or glacial alteration. Hydrothermal alteration is the most vigorous, and is most often seen as thick weathering rinds and coatings, and more rarely as whole-rock alteration. VNIR spectra of hydrothermally altered samples commonly exhibit strong Fe/Mg-smectite 2.30 μm bands, widespread 0.53 and \sim 0.8-0.9 μm bands due to iron oxides in the form of hematite and another unknown oxide, and one case each of sulfate 2.17 and



Fig. 1: Sample locations: A: Gotchen Glacier; B: Snow field outcrop; C: Eliot Glacier; D: Palmer Glacier; E: Jerry Lava Flow; F: Collier Glacier.

2.33 μm bands and an Al-clay 2.20 μm band. 2.21 and 2.24-2.25 μm doublets in spectra of thick siliceous coatings and precipitates are interpreted as hydrated silica, and are present in most other hydrothermal samples (Fig. 2). Hydrothermal alteration varies between sites: Mt. Adams exhibits primarily iron oxide as hematite; Mt. Hood shows significant hydrated silica alongside Fe/Mg smectites and iron oxides; Three Sisters shows mostly Fe/Mg smectites and oxide.

Samples from the second group do not exhibit clear visual signs of hydrothermal alteration and are interpreted to be pedogenically or glacially altered (Fig. 2). In these samples, alteration primarily appears as minor thin and particulate coatings, which manifest as significantly bluesloped spectra. Weak hydrated silica is also the primary alteration phase observed in these samples, highlighting the importance of hydrated silica in these weathering environments. In contrast to the hydrothermal samples, the hydrated silica in these samples exhibits only weak hydration bands and much lower spectral contrast. These samples also show minor iron oxides, and possible minor Fe/Mg smectites and carbonates. Relative strengths of hydrated silica and other alteration bands remain similar across sites. Such observations suggest either pedogenic or glacial processes are responsible for the alteration in these samples.

Rock samples from the Jerry Lava Flow near Three Sisters are expected to have never been glaciated or hydrothermally altered, leaving pedogenic alteration as the primary weathering mechanism. These spectra are similar to other weakly altered samples from glaciated locations, indicating either that glacial alteration is weak or overprinted in those samples, or that glacial and pedogenic processes produce similar weathering phases on rocks. To test these hypotheses, we will also acquire and compare thermal-IR spectra of these rock samples.

Sediments: Preliminary results suggest that sediments in these environments may contain a more diverse suite of alteration phases. Moraine sediment samples from Three Sisters [9] spectrally match the iron oxide in the rock samples, but contain relatively more aluminosilicate, less hydrated silica, and other phases of unknown mineralogy. XRD and thermal-IR spectra indicate that the sediments include a significant amorphous component. We hypothesize that the differences between rock and sediment alteration phases may be due to higher weathering rates in the sediments and accumulation of alteration phases in near-surface soils and fluvial sediments.

Conclusions/Future Work: Although qualitative visual examination of samples lends ease to differentiating modes of alteration, we find that VNIR spectroscopy alone can sufficiently distinguish high temperature hydrothermal alteration from low temperature

glacial or pedogenic alteration. However, there is ambiguity in disentangling pedogenic and glacial alteration on rocks with this method. We plan to address this during our future field campaign at Three Sisters by sampling a much greater variety of locations, including subglacial rocks and sediments and proglacial rocks and sediments along a transect leading directly up to and under the glacier, in order to measure a range of glacial alteration strength. We will also combine VNIR with mid-IR spectroscopy, useful for assessing silica content and estimating abundances, and with XRD to detect primary and crystalline mineralogy.

References: [1] Ehlmann, B. L., et al. (2011), *Nature*, 479(7371), 53-60. [2] Haberle, R. M. (2014), *8th Int'l Conference on Mars*, abstract #1270. [3] Forget, F., et al. (2013), *Icarus*, 222(1), 81-99. [4] Head, J. W., et al. (2014), *LPSC XLV*, abstract #1412. [5] Carrivick, J. L., & Tweed, F. S. (2013), *Quat Sci Rev*, 78, 34-52. [6] Hildreth, W., & Fierstein, J. (1995), USGS Geologic Investigations Series Map I-2460. [7] Sherrod, D., & Smith, J. (2000), USGS Geologic Investigations Series Map I-2569. [8] Hildreth, W., et al. (2012), USGS Scientific Investigations Map 3186. [9] Horgan, B., et al. (2015), *LPSC XLVI*, abstract #2923.

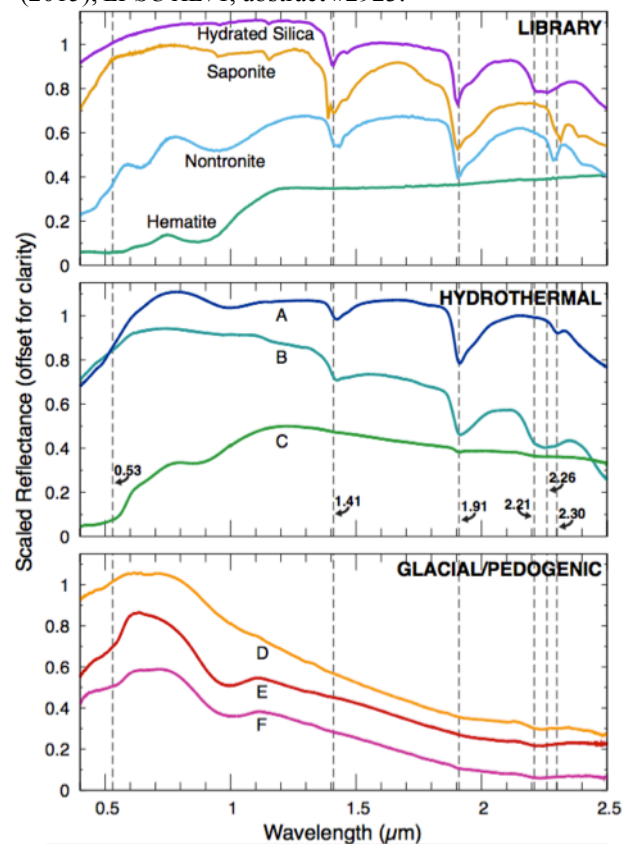


Fig. 2: VNIR spectra of selected altered rock samples. Samples are from Collier Glacier (Three Sisters; A and E), Eliot Glacier (Mt. Hood; B and D), and Gotchen Glacier (Mt. Adams; C and F).