USING COMPOSITION TO TRACE GLACIAL, FLUVIAL, AND AEOLIAN SEDIMENT TRANSPORT IN A MARS-ANALOG GLACIATED VOLCANIC SYSTEM. N. A. Scudder[1], B. Horgan[1], A. M. Rutledge[1], E. B. Rampe[2], [1]Dept. of Earth, Atmospheric, and Planetary Sciences, Purdue University (nscudder@purdue.edu), [2]NASA Johnson Space Center.

Introduction: Reconciling widespread evidence for abundant liquid surface water on ancient Mars with the inability of climate models to reproduce stable surface temperatures above 0°C during the same time period represents a long-standing problem in Mars science. One proposed solution to the Noachian Mars climate problem is a predominantly cold, icy early climate wherein occasional melting of regional snow or ice sheets formed the aqueous surface features preserved in the geologic record [*e.g.*, 1]. In this and related studies, we are investigating the mineralogy produced by icy weathering on Mars-like terrain, and evaluating the ability of a cold climate to produce the widespread alteration minerals observed on the ancient martian surface [2-5]. Here, we use composition to trace transport and modification of sediments through an analog system by aeolian, fluvial and glacial processes.

Field site: The Three Sisters volcanic complex (44º10'N, 121º47'W) is the most mafic actively glaciated terrain in the continental U. S., making it a good analog for the surface of Mars. We focus on three glaciers: Collier and Hayden have substrates of dacite, andesite, and basaltic andesite, and Diller has a primarily mafic substrate [6] (Fig. 1). All three glaciers have retreated rapidly in the past 100 years, revealing fresh subglacial and englacial moraine material [7]. The mineralogy of the sediments in these glacial systems is a combination of those products formed in contact with the glaciers and glacial meltwater, and those sourced from various altered and unaltered volcanic units within the edifices. The site provides the opportunity to investigate sediment input to the glacial system from various geologic units, disentangle preexisting from syn-glacial alteration, and draw inferences about the nature of glacial alteration products and their implications for ancient Mars.

Methods: We used one MODIS/ASTER Airborne Simulator (MASTER) spectral image from 8/27/2003 with 50 bands between 0.46-12.75 µm at ~25 m/pixel, in calibrated radiance. The ENVI Spectral Angle Mapper (SAM), a widely accepted spectral matching algorithm [8, 9], was applied to the image to map spectral similarity across the scene to various distinct units within the volcanic complex (Fig. 2). Visible to near-infrared (VNIR; 0.3-2.5 µm) spectra of <250 µm bulk sediment samples collected from a range of locations within the proglacial terrain were acquired using an ASD Fieldspec Pro 3 spectrometer to investigate the distribution of secondary minerals. We also analyzed mafic and silicic sediment distribution using thermal-infrared (TIR) data from the same MASTER image (Fig. 3; from [10]). For Collier spectra, we calculated the strength of the ~0.6 µm shoulder and ~2.30 µm absorption sensitive to ferric oxides and Fe/Mg phyllosilicates as proxies for these mineral groups (Fig. 4).

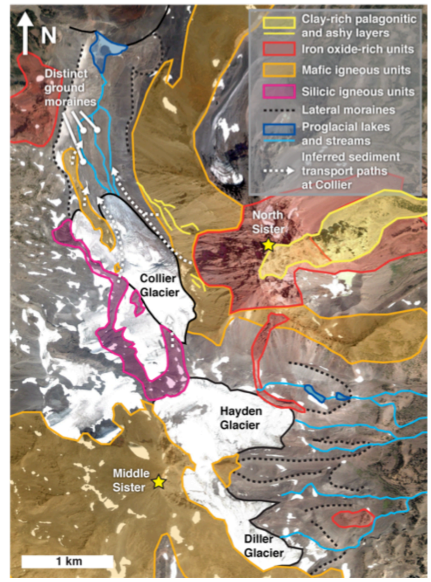

Fig. 1. Overview of glacial terrains at the Three Sisters.

Results: Compositional variability due to alteration and transport of material from source areas is captured in MASTER data and VNIR lab spectra of proglacial sediments. Pre-glacially altered units include those rich in syn-volcanic iron oxide minerals around the peak of North Sister and in the proglacial terrains of Hayden and Diller. Additionally, clay-rich hydrothermally altered ash layers occur on the east and west sides of the North Sister edifice. Unaltered mafic units are prevalent in the proglacial and subglacial terrain of all three glaciers, and the upper reaches of the Collier and Hayden regions consist of unaltered dacite (Fig. 1). Altered volcanic units contribute to glacial sediments in east Collier, where clay and oxide-bearing sediments travel downslope and are incorporated into the glacier margin and eastern moraine material downvalley, as well as east/northeast Hayden/Diller, where oxide-rich sediments contribute to the proglacial terrain (Fig. 2). At Collier, spectral signatures of these materials are strongest near the eastern glacial toe, decreasing mid-valley and increasing near the lake, indicating fluvial transport and accumulation at the end of the valley (Fig. 4). However, most typical moraine material appears more similar to unaltered units than to these altered materials (Fig. 2). Intriguingly, the proglacial terrains of all glaciers show an enrichment in high-silica material relative to mafic source rocks in TIR maps [10]. This is not consistent with transport and concentration of unaltered silicic volcanics, as outcrops of this material are relatively small and primarily contribute to moraine sediments west of Collier (Fig. 3).

Discussion: Clay and iron oxide minerals appear to be distributed similarly throughout the Collier glacial system. This distribution can be fully explained by glacial and fluvial transport of syn-volcanic alteration products without the need to invoke additional formation occurring within the proglacial terrain. While it is possible that minor glacial-melt-derived formation of these products occurs, lack of these signatures throughout glacial melt areas unexposed to altered units suggests that it is not significant.

In contrast, spectra from all other glacial sediments show a pervasive additional alteration component (Fig. 4) not easily explainable by transport from altered units, which we hypothesize is due to glacial alteration. This alteration is apparent in the field as precipitates on glacially scoured surfaces, which are spectrally similar in VNIR and TIR to an amorphous hydrated silica or other high silica phase [11]. The more widespread silica-enrichment in the TIR spectral signatures of the moraines and pro-glacial terrain may also be due to silica enrichment of glacially altered sediments. This is supported by discovery of silica-enriched X-ray amorphous material concentrated in the clay-size fraction of glacial flour samples [3, 5], and new evidence for high efficiency silica cycling in cold climates [4]. Fluvial processes move this glacially altered sediment down-valley, and aeolian processes may factor significantly in redistributing finer fractions both within and away from the system, especially onto moraines.

If alteration at Collier is typical of a cold-climate system, it implies that mafic glacial processes produce few to no crystalline alteration phases (e.g., clay or oxides), but favor the formation of poorly crystalline high-silica phases. These findings suggest that ancient glacial and periglacial environments on Mars were unlikely to have produced the widespread phyllosilicates observed on the surface. If environments at Gale Crater were primarily periglacial or snowmelt-driven as has been suggested [12], these findings do not support the formation and transport of the clay minerals observed there [*e.g.*, 13] from a glacial/periglacial environment upstream, but do not rule out the current hypothesis of authigenic formation in the lake [14].

References: [1] Head J. W. and Marchant D. R. (2014) *Antarctic Science*, *26*, 774-800. [2] Horgan, B. et al. (2016) *6th Mars Polar*, #6113. [3] Rampe E. B. et al. *this meeting*. [4] Rutledge A. et al. *this meeting*. [5] Smith R. et al. *this meeting*. [6] Hildreth W. et al. (2012) USGS Map 3186. [7] McDonald G. D. (1995) *Masters Thesis*. [8] Kruse F. A. et al. (1993) *Remote Sens. Environ.*, *44*, 145-163. [9] Dennison P. E. et al. (2004) *Remote Sens. Environ.*, *93*, 359-367. [10] Rutledge et al. (2016) *6th Mars Polar*, #6083. [11] Scudder N. A. et al. (2016) *AGU Fall Meeting*, #197747. [12] Le Deit L. et al. (2013) *JGR*, *118*, 2439-2473. [13] Thomson B J et al. (2011) *Icarus*, *214*, 413-432. [14] Bristow T. F. et al. (2015) *Am. Miner.*, *100*, 824-836.

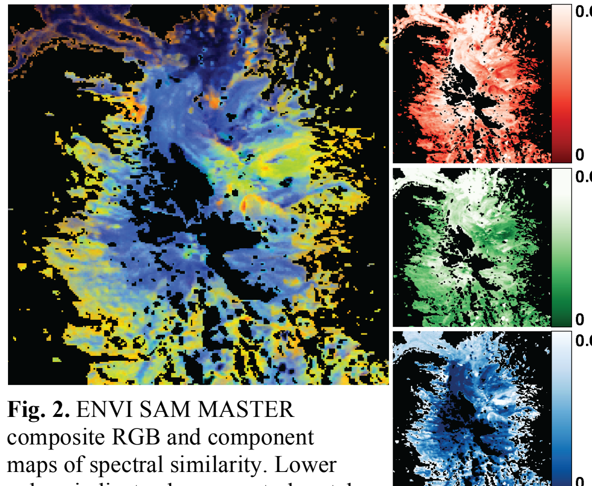

Fig. 2. ENVI SAM MASTER composite RGB and component maps of spectral similarity. Lower values indicate closer spectral match. Red = similarity to iron-oxide rich unit. Green = similarity to palagonite-rich unit. Blue = similarity to typical moraine material.

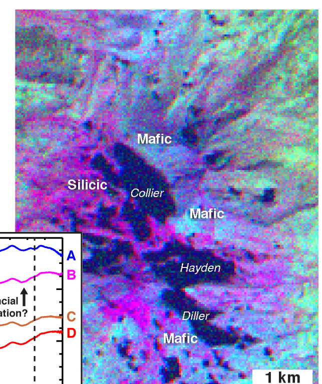

Fig. 3. (right) MASTER TIR decorrelation stretch highlighting silicic materials in pink-red, and mafic materials in blue (adapted from **[10]**).

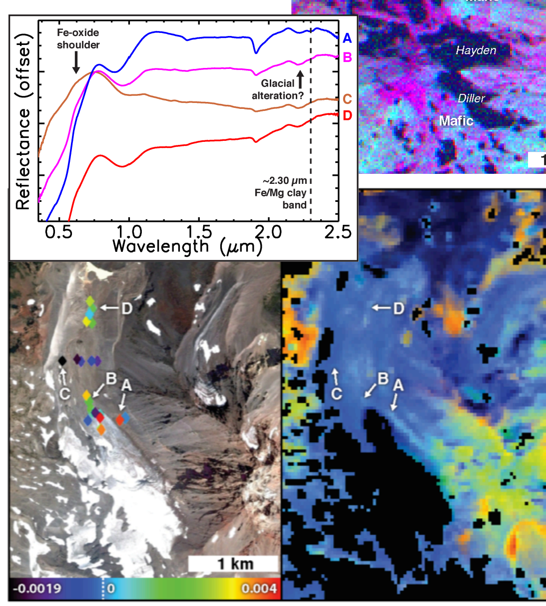

Fig. 4. Spectral band math calculations for Fe/Mg phyllosilicates (left; red = stronger bands) for sediment samples, with representative spectra (above), compared to SAM composite (right). Oxides are similarly distributed.