

HYDRATED SILICA ASSOCIATED WITH GLACIER-LIKE FORMS ON MARS. N. A. Scudder¹, A. M. Rutledge², B. Horgan¹, and R. J. Smith³, ¹Purdue University (nscudder@purdue.edu), ²Northern Arizona University, ³Stony Brook University.

Introduction: Although early Mars was likely periodically warm and wet, cold and arid environments have dominated for most of its geologic history [e.g., 1]. Ice and glaciation in particular have been major geologic agents throughout the later Hesperian and Amazonian eras and persist today [e.g., 2], evidenced by widespread geomorphic features such as glacier-like forms (GLFs) and polygonal ground [2, 3]. In cold climates on Earth, chemical weathering of rock and sediment can occur subglacially [4,5], as well as through widespread periglacial freeze-thaw cycling and snowmelt [6,7]. If glacial and/or periglacial melting was significant on Mars, we should expect to see substantiating mineralogical evidence preserved in the geologic record. However, spectroscopic investigations of mineralogy associated with Amazonian glacial geomorphologies have been limited. To address this knowledge gap, we summarize our findings from field and laboratory investigations of cold-climate weathering on Earth and report new results from a spectral survey of GLFs using the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM).

Field and lab results: The Three Sisters volcanic complex in the Oregon Cascades is the most mafic glaciated terrain in the continental U.S. [8], and recent glacial retreat has freshly exposed glacial/periglacial material in a Mars-analog environment. We collected mafic proglacial sediment and subglacial rocks from two major glacial valleys in order to characterize the weathering products forming in this environment. In freshly deglaciated terrains, we observed thin coatings of poorly crystalline hydrated silica formed at the subglacial interface [5] (Fig. 1; Fig 2b). In the proglacial terrain, sediments showed an enhanced amorphous component compared to local bedrock sources as modeled in quantitative XRD and TIR analyses [9, 10], which we hypothesize is forming via low-temperature repeated freeze-thaw interactions with ice and meltwater similar to freeze-thaw related silica found in other polar regions [6]. Based on these results, amorphous silica-rich material is the major weathering product formed in mafic glacial/proglacial systems.

We began lab experiments to observe freeze-thaw related alteration of mafic material in more detail, but these were delayed in 2020. Results so far indicate that nanophase ferric oxides are formed in the first stages of freeze-thaw weathering in Mars-like bedrock [7].

CRISM study: We identified and investigated 42 Map-Projected Targeted Reduced Data Record (MTRDR) CRISM images covering or directly adjacent

to GLFs identified in the Souness et al. (2012) database (Fig. 2a). Analysis of 147 additional Targeted Reduced Data Record (TRDR) images is planned. After removing hazy/frost-bearing images, we used CRISM spectral summary parameters BD1900_2, BD2210, and BD2250 [11] to identify images containing possible spectral signatures of hydration or hydrated silica. We divided those images by spectra of dust or spectrally bland material in each scene to enhance mineral absorptions.

GLF spectra are largely bland, with dust obscuring any mafic or potential alteration mineralogy in the majority of scenes. Several images contain spectra consistent with mafic mineralogy (e.g., pyroxene) but lacked signs of alteration minerals. However, we identified potential hydrated silica at two GLF locations. The first showed spectral summary parameters indicative of hydrated silica co-located with a GLF, but spectral absorptions were too weak to be definitive. In the other we found 1.4, 1.9, and 2.20-2.25 μm absorptions indicative of hydrated silica spread throughout a GLF-adjacent periglacial mantling deposit (Fig. 2b-c). These spectra are similar to other silica deposits previously identified in potentially periglacial settings [12]. In particular, the position of the 1.4 μm absorption has been shown to correlate with geologic setting due to crystallinity differences, where the 1.43 μm position in our spectra are more consistent with more crystalline silica (e.g., opal-CT) that commonly occurs in aeolian/periglacial settings on Mars (~1.41-1.44 μm) than less crystalline silica (e.g., opal-A) that tends to occur in bedrock-related settings (~1.38-1.41 μm) [12].

Implications for Mars: These novel detections add to the findings of Sun and Milliken (2018), who identified hydrated silica in settings interpreted as periglacial in Hellas Basin and in a handful of locations throughout the mid latitudes. This detection is new compared to their database, as are the TRDRs planned for future analysis. They attributed the increased silica crystallinity in observed in periglacial settings to enhanced chemical weathering, one hypothesis for which is longer-term interaction with seasonally available water films. Our analog study results indicate that amorphous silica-rich material (most spectrally similar to opal-CT in VNIR under ambient conditions at our field site) can be produced authigenically in periglacial/glacial locations without needing to be sourced from pre-existing deposits. Because cold-climate alteration often occurs below the surface (e.g., at the glacial substrate, or in a permafrost active layer), and glacial/periglacial processes

were regionally active on Mars and occurred throughout much of its history, it is possible that the bulk of such alteration remains below the surface to be exhumed by erosion/physical weathering. If so, the current detections of periglacial hydrated silica may suggest more widespread alteration currently undetectable by surface spectroscopy [13]. Overall, freeze-thaw chemical weathering may be a more significant process in Mars' geologic history than previously considered.

References: [1] Fastook & Head (2015) *PSS*, 106. [2] Souness et al. (2012) *Icarus*. [3] Mangold (2005) *Icarus*, 174(2). [4] Hallet (1975) *Nature*, 254(5502). [5] Rutledge et al. (2018) *GRL*, 45(5). [6] Slavnyi & Vorobeva (1962) *Pochyovedenie*, 9. [7] Scudder et al. (2020) *LPSC LI*, #2338. [8] Hildreth et al. (2012) USGS Map 3186. [9] Scudder et al. (2018) *LPSC XLIX*, #2913. [10] Smith et al. (2017) *LPSC XLVIII*, #2465. [11] Viviano et al. (2014) *JGR:Planets*, 119. [12] Sun & Milliken (2018) *GRL*, 45. [13] Dundas et al. (2018) *Science*, 359.

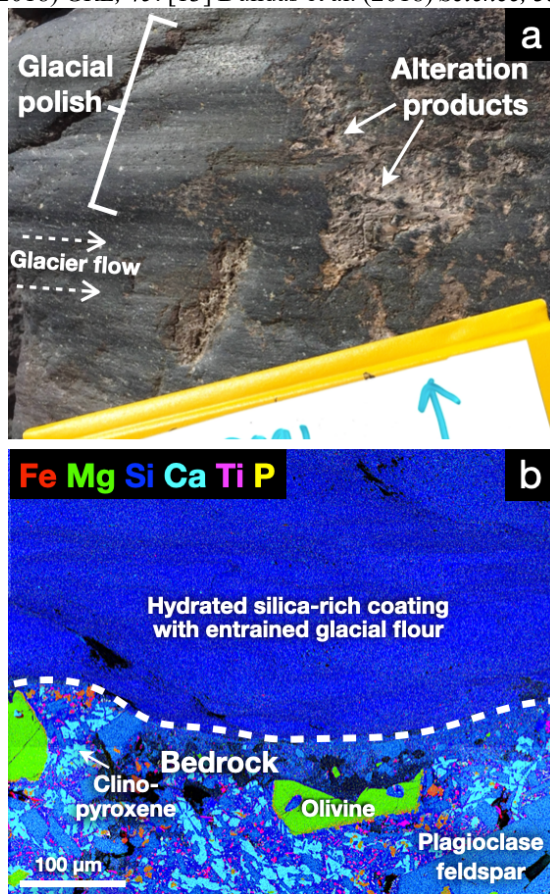


Figure 1. (a) Bedrock outcrop at Three Sisters showing shiny glacial polish and altered coatings formed in contact with the glacier. (b) Scanning electron microscope backscatter electron image of a coating, colorized by elemental abundance. The coating is significantly enriched in Si relative to the bedrock, indicative of a silica phase. VNIR spectrum is shown in Figure 2b.

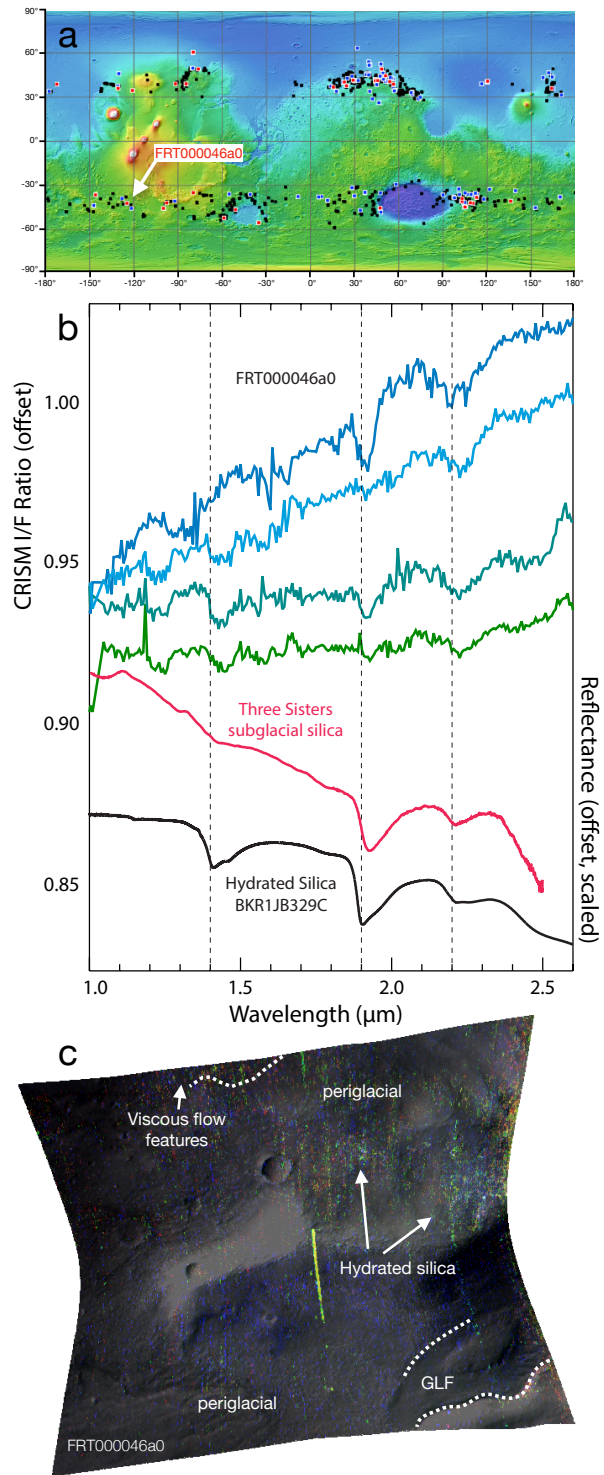


Figure 2. (a) Elevation map of Mars (MOLA) showing GLF locations [2] (black), MTRDRs measured in this abstract (red), and FRT TRDRs still to analyze (blue). (b) CRISM ratio spectra from FRT000046a0 showing hydrated silica absorptions compared to Three Sisters subglacial silica and a Yellowstone silica sinter (Re-LAB). (c) FRT000046a0 RGB using refined summary products MIN2250-BD2250-BD1900_2 over IR albedo.