IDENTIFYING THE PRODUCTS OF VOLCANO-ICE INTERACTIONS IN THE MARTIAN SEDIMENTARY RECORD. C. C. Bedford[1, 2], E. B. Rampe[2], M. T. Thorpe[2], R. C. Ewing[3], M. Nachon[3], K. Mason[3], E. Champion[3], L. Berger[3], B. Horgan[4], P. Sinha[4], A. Rudolph[4], E. Reid[5], M. G. A. Lapôtre[6], M. Hasson[6], and P. C. Gray[7], [1]Lunar and Planetary Institute, USRA, Houston, USA (cbedford@lpi.usra.edu), [2]NASA Johnson Space Center, Houston, USA, [3]Texas A&M University, Houston, USA, [4]Purdue University, Lafayette, USA, [5]Mission Control Space Services Ltd., Canada, [6]Stanford University, USA, [7]Duke University, USA.

Introduction: Geological and mineralogical evidence suggests a "warm and wet" Mars in the Noachian to Hesperian geological periods [e.g., 1], however, computer modelling has struggled to recreate these conditions. As such, an icy highland hypothesis has been developed which requires episodic melting of highland ice to create features such as fluvial channels within ancient Martian terrain [e.g., 2]. One way to test the icy highlands hypothesis is to look for evidence of volcano-ice interactions. Volcano-ice interactions create unique landforms and lava morphologies (pillow, cube-jointed lava and hyaloclastite tuff), triggers large flood events known as jökulhlaups, and can create aqueous environments potentially suitable for life [3,4].

Many Mars rover missions are sent to sediment sinks, such as Gale crater. As such, it would be beneficial to identify the eroded products of volcano-ice interactions in the geological record using data from surface missions such as the current Mars Science Laboratory (MSL) and Mars 2020 missions. <u>We aim to characterize the geochemical and mineralogical fingerprints of volcaniclastic materials within fluvial and aeolian sedimentary systems that are eroded from glaciovolcanic landforms in Iceland and apply this knowledge to Mars.</u>

The SAND-E mission: In July 2019 the SAND-E: Semi-Autonomous Navigation of Detrital Environments analog mission to Iceland investigated three field sites of varying distances to the sediment source along a basaltic glacial-fluvial-aeolian sedimentary system analogous to Mars. The main science aim of SAND-E is to examine changes in the physical and chemical properties of sediments along a transport pathway from their source rocks. The 2019 field locality was situated in a ~15 km long glacio-fluvio-aeolian sedimentary system starting at the base of the Þórisjökull glacier. The Þórisjökull sedimentary system incorporated materials from the surrounding intraglacial and postglacial volcanoes, resulting in an ideal field laboratory for constraining how glaciovolcanic products contribute to Mars relevant sedimentary systems.

Methods: Geochemical data for SAND-E sediment samples were acquired using a hand-held Olympus Vanta XRF Spectrometer, selected to be an analog to the APXS instrument on the MSL *Curiosity* rover. XRF targets of sediments conducted in the field were classified by a visual assessment of the dominant grain size - pebble, sand, and mud - using images taken during analysis. When a pXRF sediment target was analyzed in the field, the sediment was collected for X-ray diffraction (XRD) analysis using a Rigaku MiniFlex 6G at the NASA Johnson Space Center to provide similar bulk mineralogical data to that acquired by the CheMin instrument on the *Curiosity* rover. Image data were collected in the field for each pXRF analysis using the Olympus Tough TG-6 camera microscope function. These close-up image data were acquired as an analog to close-up images taken using the MAHLI or WATSON instruments on MSL and Mars 2020, respectively.

pXRF, XRD, and close-up images were also acquired from the volcanic source rocks in the area, in addition to microprobe data of the hyaloclastite tuff, to understand how glaciation impacted the volcanic assemblages themselves. Source rock data are presented by [5].

Results: *Aeolian sediments:* Aeolian deposits were identified at the Proximal, Medial and Distal sites along the sedimentary system in ballistic ripple bedforms that had reworked fluvial deposits [6]. Aeolian sediments consist of well-sorted coarse sand grains that are subangular to subrounded. Most grains are vesicular with an aphanitic or porphyritic appearance to them and color variation ranging from dark blue/black to reddish orange. Aeolian sediment grain morphology is most similar to the subaerial, pillow, and kubbaberg morphologies of the intraglacial volcanoes, and the subaerial flow of the postglacial shield volcano [5].

Geochemically, aeolian sediments encompass a narrow compositional range. Deviations towards high FeO_T or TiO_2 compositions result from the analysis of red altered grains that likely formed through geothermal alteration [7]. Aeolian sediments plot in between geochemical endmembers of the volcanic source rocks suggesting that they represent a well-mixed average of the main volcanic units in the area.

Fluvial sediments: Fluvial deposits can be found at all sites as fluvial channels, mud/silt drapes, and pebble bars [6]. At the Proximal site, hyaloclastite tuff pebbles were identified in addition to pebbles from the glassy intraglacial units. At the Medial and Distal sites, the pebble and boulders were most similar to the nearby subaerial flow of the postglacial shield volcano.

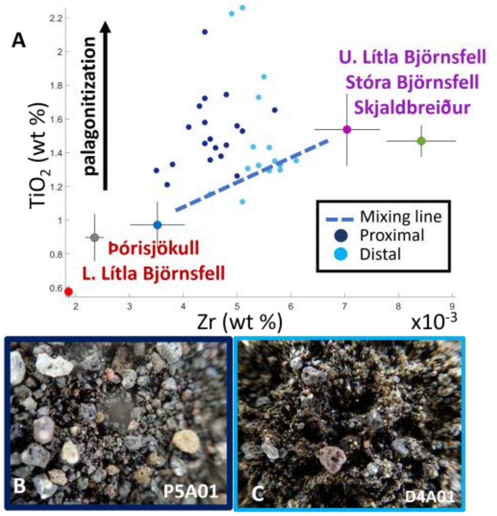

Figure 1: A) Geochemistry of fluvial sands with respect to volcanic endmembers from [5]. B) fluvial sands at Proximal (2 cm scale across), C) fluvial sands at Distal (2 cm scale across).

The sand grain size fraction decreases from Proximal site to Distal. At the Proximal site, sand grains are diverse, including yellow, friable, hyaloclastite tuff materials in addition to porphyritic vesicular grains from subaerial flows, and aphanitic/glassy grains from the pillow and kubbaberg units. Downstream, the presence of friable tuff disappears in the close-up images and an increase in monomineralic sand grains is apparent. TiO_2 concentrations are on average 1.5x higher for hyaloclastite tuff samples [5] and as Ti is an incompatible element in basaltic melts, it should not be affected by mineral sorting and can be related to the presence of tuff. X-ray amorphous abundances are also greater in tuff deposits [5]. Fluvial sands from the Proximal site show a large variation in TiO_2 concentrations and a higher amorphous abundance supporting the presence of hyaloclastite tuff in fluvial sands at this site. However, downstream, the geochemical composition of fluvial sands is situated along a trendline between the volcanic endmembers, with little to no amorphous abundance (Fig. 1A). This suggests that hyaloclastite tuff deposits are not well preserved in the sedimentary system.

Mud/silt deposits are light-grey and visually uniform across all sites. Geochemical variations for the mud/silt grain size fraction show an increase in Al_2O_3 and a decrease in CaO with distance from the source, which may indicate chemical weathering. The mud/silt deposits also have on average a greater abundance of feldspar minerals compared to the sand grain size fraction. This may relate to the greater abundance of feldspar in the groundmass of the volcanic source rocks, than as phenocryst phases, which makes it more likely to partition into the finest grain size fraction.

Mars implications: A combination of the X-ray amorphous materials in XRD data, images of the sediments, and high TiO_2 concentrations are the most useful for distinguishing volcaniclastic materials that are derived from volcano-ice interactions, with the altered hyaloclastite tuff morphology being the easiest to distinguish.

In our source-to-sink analysis, we have shown that aeolian sediments do not preserve the fine-grained, altered and friable tuff materials that make up the majority of intraglacial volcanoes. Instead, aeolian deposits preserve the lithic grains from subaerial flows and glassy pillow or kubbaberg units. Fluvial sediments do preserve hyaloclastite tuff deposits, but only close to the source. We hypothesize that once this altered morphology is weathered into finer grain sizes, they may bypass the studied sites and deposit farther downstream. Coarser, glass grains within the tuff may contribute to the glassy sand grain size fraction in fluvial and aeolian sediments, but the altered hyaloclastite cement is no longer present if so.

Gale crater is a sedimentary sink with an extensive fluviolacustrine geological record [8]. As such, if volcano-ice interactions initiated the fluviolacustrine sedimentary system for this locality through an icy highlands scenario, we would expect to see the altered, eroded products of volcano-ice interactions deposited here. The sediments in Gale crater do have a notable abundance of X-ray amorphous materials [9]. However, APXS data of relatively alteration-free bedrock and aeolian deposits show that TiO_2 abundances are relatively consistent across Gale at ~1.0 wt% [10], with no deviations indicative of large-scale input from a glaciovolcanic source. This suggests that the sedimentary provenance of Gale crater's materials was not derived from volcano-ice interactions, and that volcano-ice processes are unlikely to have initiated the fluviolacustrine system at this locality.

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