SAND-E: A ROVER-BASED MARS ANALOG STUDY OF A MAFIC SEDIMENTARY ENVIRONMENT, ICELAND.

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Introduction: Most studied rock exposures on Mars are sedimentary [1] and mafic [2], however, it is not well understood how physical fractionation and aqueous alteration affect mafic sediments during glacial, eolian, and fluvial processes [3-4], inhibiting the use of sediment composition to decipher martian paleoenvironments. Therefore, analog studies of sediment-grain properties and mineralogy in complex mafic mixtures are needed to bridge this gap [6-7]. Semi-Autonomous Navigation for Detrital Environments (SAND-E), a NASA-supported Planetary Science and Technology through Analog Research (PSTAR) project, aims to both advance the current state of rover operations and science framework within a mafic detrital environment by conducting Mars analog research in the glacio-fluvial-eolian landscapes of Iceland. This study investigates the material and grain-size dependent effects of chemical and physical weathering on sediments subjected to glacial, fluvial, and eolian processes in a cold and wet basaltic environment. Simultaneously, a rover-based semi-autonomous terrain analysis and an unmanned aerial system (UAS), simulating NASA's 2020 Mars Helicopter, is integrated within science workflows to test for efficiency in navigating and characterizing terrains as well as selecting science targets. Currently, automated geologic terrain maps are not used extensively for science in rover operations [7-8]. Incorporating terrain data captured by the rover into science operations has the potential to improve operation protocols towards greater tactical efficiency[9-11].

Fieldwork: Skjaldbreidauhraun and Dyngjusandur are glacio-fluvial-eolian sand plains (Fig. 1A) surrounding volcanic systems in the cold and wet mafic environment of Iceland [12-13]. Katabatic and regional winds drive eolian transport across sand sheets, which are characterized by ripples, dunes, wind-sculpted bedrock, wind-deflated rocky plains, and sand drifts similar to martian landscapes [13-14]. Skjaldbreidauhraun sands are dominated by crystalline phases, whereas Dyngjusandur contains abundant glass, making it directly relevant to Mars [15-16]. For initial reconnaissance of the site, we created false color images from Google Earth imagery using a Digital Correlation Stretch (DCS) [17], which reveal color differences that are largely due to variability in the composition of sediments (Fig. 1C,D). The fluvial system flows across a glacial outwash plain from a known basaltic source, and was divided into three locations for field work (Fig. 1B) - proximal, medial, and distal.

At each location, various science operations scenarios were implemented using the Mission Control Space Services, Inc., (MCSS) rover Argo J-5 (Fig. 2A). The rover, suited for soft soil and rough terrain, is mounted with a stereo camera, hazard cameras, a high-resolution mast camera, and a computer for navigation. Besides providing real-time estimates of trafficability metrics such as wheel sinkage, skid, tilt, etc., the rover classifies terrain type and predicts traversability using machine learning algorithms employed by the Autonomous Soil Assessment System (ASAS) [7-8,10-11]. Our various science-operation scenarios integrate combinations of automated terrain analysis, UAS images (3.2 cm/pixel), simulated HiRISE images (25 cm/pixel), field-of-view rover images, science data, and on-site geologists (Fig. 2).

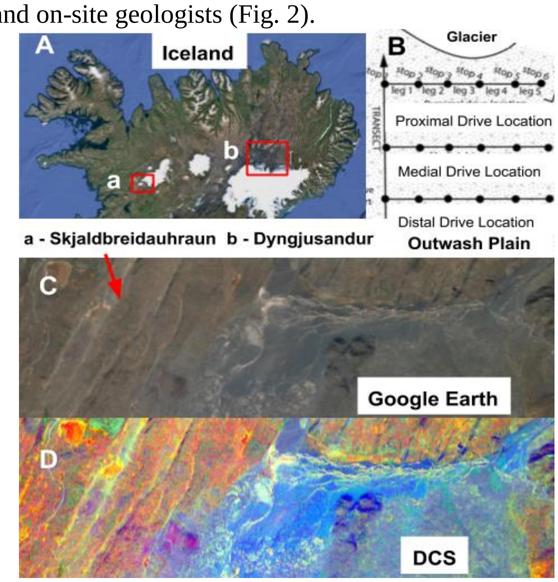

Figure 1: (A) Location of study sites in Iceland, (B) each operation scenario was tested at proximal, medial, and distal sites on the sedimentary transect in the direction away from basaltic source, (C&D) true color image is compared with DCS image to highlight compositional variability at Skjaldbreidauhraun.

Field work was conducted at Skjaldbreidauhraun in July of 2019 and is scheduled for the summer of 2020 at Dyngjusandur. Operation scenarios were designed to quantify operational efficiency with and without ASAS and UAS in combination with other inputs. Parameters such as time of operation, distance travelled, bandwidth, usefulness and accuracy of target, traversability and terrain assessment are all considered to measure effectiveness of autonomy for driving and target selection in comparison to human validation. Concurrent science data include X-ray fluorescence (XRF), visible/near infrared (VNIR) reflectance spectra, context imagery, and high resolution targeted imagery, all taken using portable instruments and camera by field scientists to simulate the rover payload. Ground scientists in simulation were confined to the Ground Control Center (Fig. 2B) and were tasked to plan traverse maps and select science targets based on returned rover inputs. Additionally, samples were collected for laboratory X-ray diffraction (XRD), thermal-IR emission spectroscopy, scanning and transmission electron microscopy (SEM and TEM), and Camsizer particle analysis at the end of the field season.

Potential Impacts: Science results from the SAND-E project will shed new light into the variability of weathering along a glacio-fluvial-eolian transect in a cold and wet environment, and constrain its dependence on type/source of mafic materials, grain size, and sediment sorting. The cold and wet basalt-rich sedimentary environments of Iceland may serve as analogs to sedimentary and geochemical processes occurring during ancient icy climate episodes or in more recent times at/around the polar layered deposits (PLD) on Mars (although likely at different rates and intensity). The PLD garners significant interest from the scientific community as it preserved Mars' recent climatic records [18]. Detrital ice-rich sediments within the PLD are a complex mixture of mafic minerals and weathering products from multiple sources and is continuously reworked [18-21]. Insights from this study may provide new constraints for modelling polar chemical and physical processes, mechanisms and rates of weathering for both crystalline and amorphous silicates in and around the PLD, and as such, provide new avenues to interpret Mars' polar deposits in terms of climatic signals. Establishing a reliable relationship between mineralogy, grain size, transport pathways, water activity, and weathering will directly feed into our understanding of the processes that prevail at the PLD and other glacial terrains on Mars. Additionally, integrating terramechanics in the science workflow of rover missions can make traversing longer terrains feasible (e.g., 10s of km across a polar trough), driving in more complex terrains (e.g., ice-rich sedimentary surfaces), speed up identification of high-quality science targets, etc., ensuring more science returns within the lifetime of a putative PLD rover mission.

References: [1] Malin M. C., & Edgett K. (2000) *Science*, 290(5498), 1927-1937. [2] Hurowitz J. et al. (2006) JGR: Planets, 111(E2). [3] Siebach K. et al. (2017) *JGR: Planets*, 122(2), 295-328. [4] Lapotre M. et al. (2017) *JGR: Planets*, 122, 2489-2509. [5] Rampe. E. B. GRL, 45, 9488-9497. [6] Fedo C. et al. (2015) *Earth Planet Sci Lett*, 423, 67-77. [7] Stack K. et al. (2016) *Icarus*, 280, 3-21. [8] Yingst R. et al. (2017) *Acta Astronautica*, 132, 268-281. [9] Arvidson R. et al. (2017) *J. of Terramechanics*, 73, 73-93. [10] Wong C. et al. (2017) IEEE conference, pp 237-244. [11] Gonzales R. et al. (2017) *J of Field Robotics*, 35, 231-247. [12] Mangold et al. (2011) *Earth & Planet Sci Lett*, 310(3), 233-243. [13] Baratoux et al. (2011) *Earth Surface Processes and Landforms*, 36(13), 1789-1808. [14] Ewing R. C. et al. (2017) *JGR: Planets*, 122, 2544-2573. [15] Horgan et al. (2014) Icarus 234,132-154. [16] Horgan et al. (2017) *JGR: Planets*, 122, 172-202. [17] Gliiespie A. R. et al. (1987) Rem. Sen. of Envi., 20, 209-235. [18] Smith I. B. et at. (2018) *Keck Institute of Space Studies Report*. [19] Tanaka K. (2005) *Nature*, 437, 991-994. [20] Massé et al. (2010) *Icarus*, 209(2), pp.434-451 [21] Sinha et al. (2019) *LPSC Abstract*, vol 50.

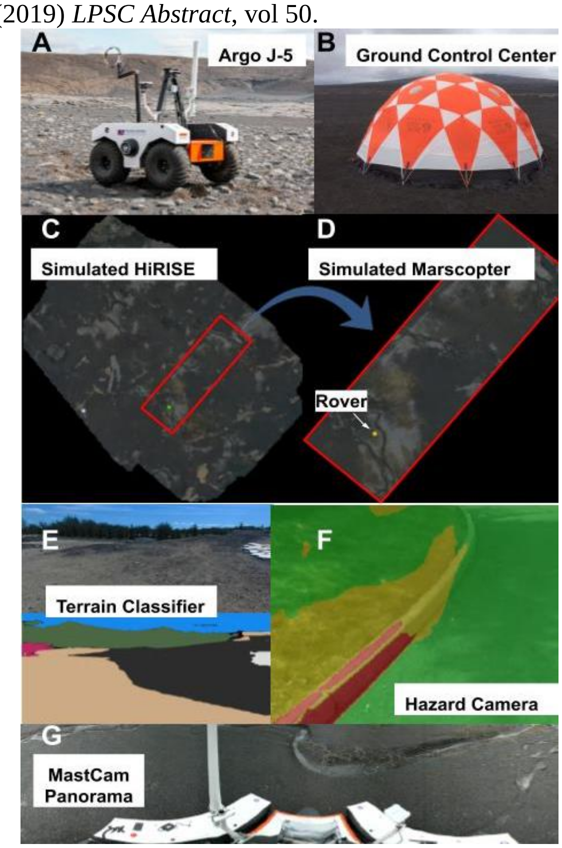

Figure 2: (A) MCSS rover Argo J-5, (B) Ground Control Center for science operation, (C) Simulated HiRISE image of a test site captured by UAS at 25 cm/pixel, (D) Simulated Mars Helicopter image at a higher resolution of 3.2 cm/pixel, (E) ASAS-generated terrain classification map, (F) pixel-wise hazard map from rover, (G) rover field of view for path planning and target selection within the workspace.