OVERVIEW AND INITIAL RESULTS OF DIGMARS: DIGGING ICELAND GEOLOGY FOR MARS ANALOG RESEARCH SCIENCE.

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Introduction: Preserved in the sedimentary rocks of Mars is a rich record of ancient surface environments and burial diagenesis. Sequences of sandstones and mudstones that indicate sedimentation in deltaic and lacustrine environments have been encountered by the *Curiosity* rover in Gale crater and likely will be by the *Perseverance* rover in Jezero crater [1-3]. The compositional variability in these sedimentary rocks points to a complex diagenetic story that bears significantly on the basin history and early martian environment. Because interaction of percolating groundwaters and with unconsolidated sediments is a process commonly observed in lacustrine environments on Earth [4], groundwater has been invoked to develop a sedimentary history for Gale crater [e.g., 5-9]. Unique conceptual models, each with their own implications for the paleoenvironment and hydrologic conditions have been put forward. However, we currently lack a terrestrial reference frame for groundwater-driven diagenesis in a basalt dominated watersheds on Earth. The Digging Iceland Geology for Mars Analog Research Science (DIGMARS) project aims to close this research gap, with the goal of exploring groundwater-sediment interaction from lakes around Iceland. Here, we present the initial results for the 2021 field campaign and the laboratory analysis of aqueous and sediment samples.

Site Selection and Methods: DIGMARS has two overarching goals, (i) characterize the compositional changes induced by early diagenesis in sediments from a basaltic dominated watershed and (ii) identify the influence of lacustrine groundwater discharge on alteration processes. This project targets Iceland because the source rock lithology is predominantly basalt (*Fig. 1a*), largely consistent with the sediment provenance on Mars, and the cold and icy climate of Iceland is a reasonable candidate for the paleoclimate of regions of Mars [10].

In the summer of 2021, the DIGMARS team conducted 10 days of field work in the Lake Sandvatn catchment in southwest Iceland, a proglacial lake system. During this field campaign, the team sampled source rocks in the upper reaches of the watershed, detritus from source to sink along stream inlets, sediments at the surface within the lake and along the shoreline, river water, lake water, and groundwaters, and buried sediments (Fig. 1b). The team also

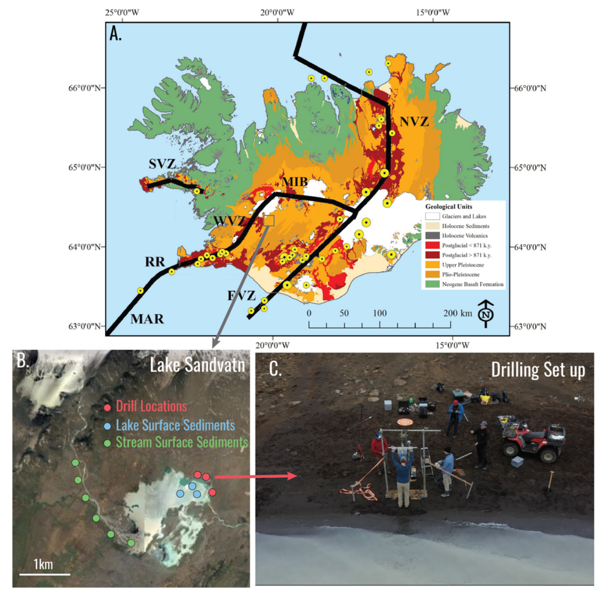

Figure 1. *The source rock lithology of Iceland (a) is dominated by basalt and watersheds like Lake Sandvatn (b) serve as valuable martian analogs. The DIGMARS team collected surface and buried sediments, with drilling performed on the lake shoreline of Sandvatn (c).*

performed drone flights with a thermal attachment to detect temperature anomalies in the lake water and aid in identifying locations for potential groundwater discharge. To access sediments at depth, trenches were dug and logged, and a VibeCore-D system (Specialty Devices) was used with a custom-built A-frame to drill sediment cores (Fig 1c). Sediment drilling locations were on the lake shoreline adjacent to groundwater sampling locations, collected using a steel-tip drive-point piezometer, screened at various depths and equipped with a peristaltic pump.

Back in the lab, sediment and source rock samples were prepared for mineralogical and geochemical analysis. Laboratory methods following the field campaign for water and sediment analysis included thin section analysis of source rocks [11], grain size and shape analysis, XRD, XRF, ICP-MS, TEM, and image processing and analysis. The sedimentology of split cores was also logged (Fig. 2), and the analysis of element concentration of cores was performed at regular intervals along the core using a handheld X-ray fluorescence spectrometer.

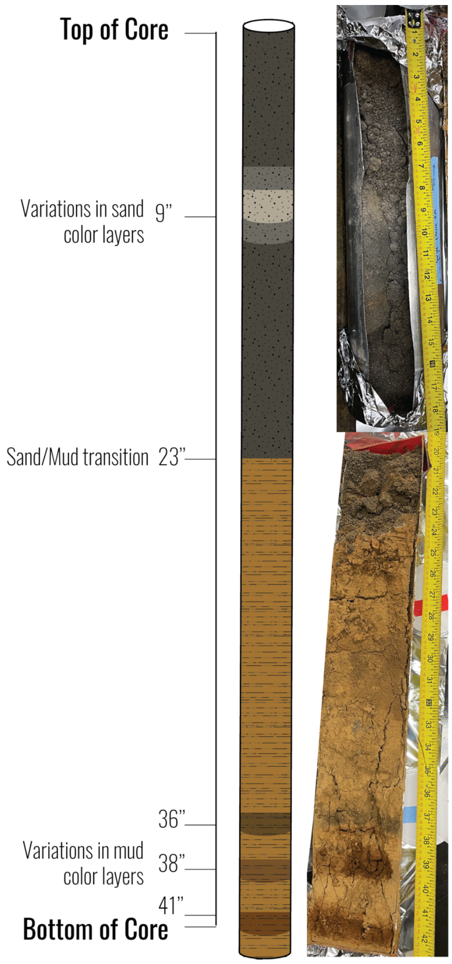

Figure 2. *Sediment core from location 2B with the sedimentology and sediment color interpretated on the left panel.*

Results: In the field, three successful cores were obtained (Fig.1b). At each drill location, groundwater samples were sampled from shallow boreholes that intersected the water table. Offshore surface sediments were additionally collected. The deepest sediment core (~1.5 m) of the 2021 field campaign displays a transition from fluvial to lacustrine sediments (Fig. 2). Importantly, in the lower lacustrine sediments, distinct layers are identified with variations in sediment color.

Preliminary mineralogical analysis of source rocks suggests that the dominant lithology around Lake Sandvatn is basaltic [11]. The XRD results from lake surface sediments display a sediment mineralogy that is dominated by primary basaltic minerals (e.g., plagioclase and pyroxene, Fig. 3) and little to no secondary clay minerals are observed in the bulk sediment. The lacustrine sediments buried at depth display a similar mineral assemblage, but show an increase in X-ray amorphous materials, as identified from an increase in the scatter above the background in the XRD pattern (Fig. 3). There is little evidence for clay minerals in the bulk samples from buried lacustrine sediments.

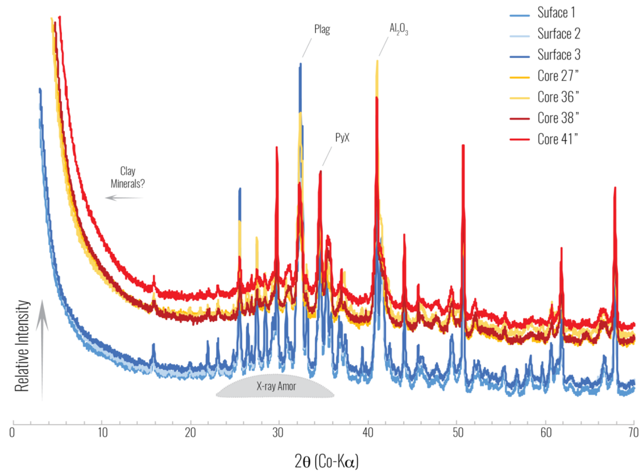

Figure 3. *XRD patterns for bulk surface and buried sediments.*

Implications: Early results from the 2021 DIGMARS field campaign suggest that sediments generated and transported downstream can ultimately carry a mineralogical assemblage consistent with a pristine basaltic progenitor. It is not until these sediments are buried and interacting with groundwater that the mineralogy begins to show evidence for alteration. Early diagenesis in buried sediments from Lake Sandvatn suggests that groundwater discharge is the principal process preserved in the secondary mineralogical record of these sediments. Moreover, aqueous samples show that groundwater discharge and mixing lake waters creates a unique geochemical gradient in the subsurface. This combined with TIR mapping from around the lake illustrate that groundwater discharge in this environment can vary spatially, and almost certainly, temporarily.

When this terrestrial reference frame is applied to regions of Mars (e.g., Gale crater), it becomes clear how early diagenesis from sediments interacting with percolating groundwaters could have a profound impact on interpretations of the sedimentary history of lacustrine environments. Sediments from the ancient lake of Gale crater likely interacted with discharging groundwater and this unique subsurface mixing zone likely played a key role in shaping the sedimentary rock record.

DIGMARS 2022: The second field campaign for DIGMARS will take place in the summer of 2022 and will target lakes that are influenced by the discharge of hydrothermally influenced groundwater fluids. A few lakes in southwest Iceland are the target location for this trip, as this region is characterized by both cool and warm groundwater sources. In addition to a second field site, the DIGMARS 2022 drill rig will be deployed from a boat, with the hopes of obtaining deeper sediment cores (e.g., 3 m).

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References: [1] Grotzinger et al., 2015. *Science 350*(6257), [2] Goudge et al., 2015, *JGR: Planets 120*(4). [3] Mangold et al., 2015, *Science 374*(6568). [4] Meinikmann, Lewandowski, and Nützmann, 2013, *Journal of Hydrology 502*. [5] Hurowitz et al., 2017, *Science 356*(6341). [6] Rampe et al., 2017, *EPSL 471*. [7] Rampe et al., 2020, *JGR: Planets 125*(12). [8] Bristow et al., 2021. *Science 373*(6551). [9] Thorpe et al., *submitted*. *JGR: Planets*. [10] Thorpe et al., *JGR: Planets 126(2)*. [11] Putnam et al., *this conference*.