GROUND-PENETRATING RADAR INVESTIGATIONS OF TERRESTRIAL ANALOGS FOR MARS: ESKERS AT BREIÐAMERKURJÖKULL, ICELAND. A. Y. Li[1], B. Hills[2], A. M. Rutledge[3], K. A Bennett[4], A. Koeppel[3,5], C. S. Edwards[3], A. Lally[6], L. A. Edgar[4], M. R. Koutnik[1], M. Henderson[7], N. Jones[3], E. B. Rampe[8], H. A. Eifert[3]. [1]University of Washington (Contact: anli7@uw.edu), [2]Colorado School of Mines, [3]Northern Arizona University, [4]U.S. Geological Survey Astrogeology Science Center, [5]University of Maryland Baltimore County/NASA Goddard Spaceflight Center, [6]Queen's University Belfast, [7]NASA Goddard Space Flight Center, [8]NASA Johnson Space Center.

Introduction: While most ice deposits on Mars are considered to be cold-based, recent work has presented evidence for more wet-based glaciation [e.g., 1]. One example that has been increasingly detected in available imagery is sinuous ridges interpreted as eskers [e.g., 2], which form from sediment deposited by subglacial or englacial channels of meltwater and are indicative of wet-based glaciation. While other formation mechanisms have been proposed for these sinuous ridges, the leading hypothesis is glacial since these sinuous ridges do not follow topographic slopes [3], and their morphological similarity to terrestrial eskers is statistically significant [4].

Previous studies of terrestrial eskers have not examined eskers on volcanic bedrock, a substrate similar to what we might expect on Mars. In May to June of 2023, our team conducted geomorphic, sedimentological, compositional, and geophysical field analyses at an esker site sourced by sediment coming from mafic bedrock at Breiðamerkurjökull, a piedmont glacier in southeast Iceland (Figure 1). Previous work demonstrated that ground-penetrating radar (GPR) facies can be used to identify aspects of how eskers formed, such as by differentiating whether the sediment accretes vertically, upglacier, downglacier, or laterally [e.g., 5]. Future orbital radar missions such as the International Mars Ice Mapper are in planning to better constrain subsurface ice on Mars. Mars rovers such as Perseverance and Rosalind Franklin include GPRs to help characterize subsurface composition and vertical structure. Since radar imaging is a priority on Mars, we investigate GPR surveys of eskers on Earth to inform how future radar data from Mars can be used to identify which sinuous ridges are eskers and whether they are ice-cored. In addition, using radar data, this work aims to identify how the eskers at this site formed and evaluate how esker height varies with how the esker formed.

Methods: We collected 76 GPR survey lines using 100, 200 and 500 MHz antennas with the pulseEKKO radar system at three different eskers and at the terminus of the glacier. A Trimble NetR8 GPS was used for geopositioning.

We processed the GPR data using ImpDAR, an open-access Python package [6]. The processing steps included a "dewow" high-pass filter, time-zero correction, a horizontal de-meaning background filter, exponential range gain, and georeferencing with topographic correction. Depths on the y-axes were calculated from time using a constant wave speed.

Results and Interpretations: The three eskers include "Emerging Esker" which is an englacial ice-cored esker reaching a height of 5.4 m and is actively being exposed, "Trollercoaster" which has a maximum height of 2.5 m and was exposed by 2014 based on satellite imagery and the "Ring" which has a maximum height of 10 m and was exposed by 1961 [7]. This abstract focuses on the preliminary results from the glacier terminus and Emerging Esker.

Glacier terminus (Figure 2). We interpret the large-amplitude radar reflection that is ~5 m below the surface of the glacier as the glacier bed. From about 75 m along-track distance to the end of the glacier, the bed is discontinuously visible—possibly due to the ice cave, other shallow point reflectors such as debris and water inclusions, and poor dielectric contrast between the unconsolidated gravels comprising the subglacial bed and the debris-rich basal ice—and dipping slightly westward where it is detectable. From 0 to 75 m distance, there is no clear reflection for the glacier bed. Both the ice cave and ice tunnel were visually identified and flagged as the radar line was being collected and have distinct corresponding reflections. These reflections have polarity changes of -+- (black- white-black), indicating that the radar wave speed is changing and speeding up as it switches from passing through the ice in the glacier to the air in the ice cave and tunnel, which [8] also observed. Regions of fewer internal reflections (decreased radar scattering) likely correspond to cleaner ice (vs. debris-rich ice) according to [8]. Tephra bands dip toward the ice cave and Emerging Esker, providing a debris source to be incorporated into the englacial esker, along with other entrained debris sources [8].

Emerging Esker (Figure 3). In three parallel cross-sections of Emerging Esker, we identify buried ice in the esker using the changes in polarity due to shifts in radar velocity. As the radar wave passes from the esker sediment to the ice, the reflection polarity is -+- (black-white-black), consistent with a positive permittivity contrast (increasing radar wave speed). Then, as the wave exits the ice core into the underlying sediment it slows down again, as shown by the reversed polarity in the reflection +-+ (white-black-white). Stronger radar scattering below the ice core (Fig. 3c) is also present. This has been observed with water inclusions [e.g., 8] which we interpret here as water melting below the ice core.

Initial Findings and Future Work: GPR data is robust for showing the locations of features such as the ice tunnel, ice cave, tephra bands, and bedrock of the glacier, as well as buried ice in Emerging Esker. Future work will focus on GPR processing for data from Trollercoaster and the Ring, and examining radar facies to evaluate esker morphogenesis.

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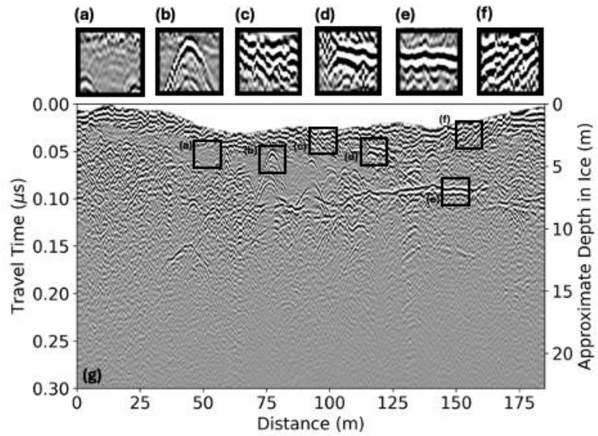

Figure 2. Labels indicate the location of a) potentially cleaner ice, b) ice bridge, c) and f) down-dipping tephra bands, d) ice cave, and e) glacier bed within g) the entire GPR line. The ice cave and ice bridge reflections have polarity changes of -+- for the radar wave, indicating the change in velocity of the wave as it passes from the ice of the glacier to the air in the ice cave and tunnel. Depths are based on a radar of 0.152 m/ns for wet ice [e.g., 8]. Both travel times and depths are labeled based on the highest elevation surface.

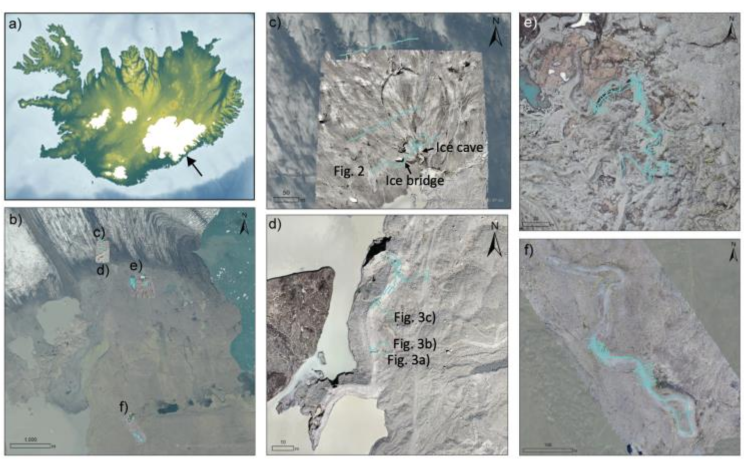

Figure 1. a) The arrow points to the location of our field site at Breiðamerkurjökull in southeast Iceland. Modified from [9]. b) Overview of the four sites where GPR data was collected. c) The terminus of glacier where 7 GPR lines were collected with the 200 MHz antenna. d) Emerging Esker where we collected 6 lines using the 500 MHz antenna. e) Trollercoaster esker where we collected 35 lines at 500 MHz. d) The Ring esker where we collected 27 lines using 200 MHz.

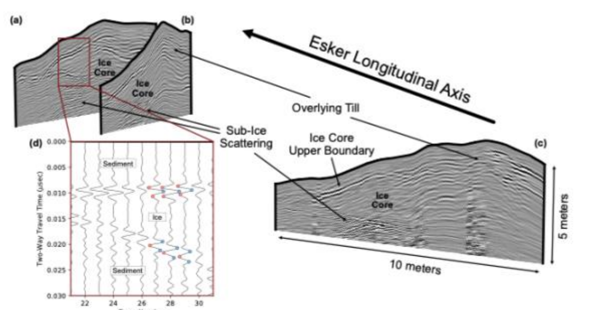

Figure 3. a), b) and c): Three cross-sections of Emerging Esker (see Fig. 1 for locations). a) is slightly further north than b) and c). All three cross-sections reveal polarity changes in the reflections. Increased sub-ice scattering is most evident in c) below the ice core, which may indicate water melting and pooling below the ice core. d) The top reflections are from sediment to ice with polarity changes of -+- as the radar wave speeds up in the ice core. The bottom reflections from ice to sediment have polarity changes of +-+ as the radar wave slows down once it reaches the sediment again. Red circles are - and blue circles are +.