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Analyzing pit chains in Iceland to constrain regolith thickness on Enceladus

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1. Introduction

The surface of Enceladus is mantled with a layer of regolith hypothesized to be sourced by both impact cratering and fallback from the south polar plumes [1]. This layer of unconsolidated regolith may contribute to muting surface morphology, erasing small craters [2], and insulating the surface [3–6]. In particular, the insulating effects of such a regolith layer would raise the effective surface temperature and have a significant influence on thermal models of Enceladus [6]. Therefore, it is important to understand the distribution and depth of regolith on Enceladus to better constrain thermal models, plume activity, and perhaps the longevity of the south polar plumes and a global subsurface ocean.

1.1 Measuring Regolith

The regolith distribution and thickness can be assessed on Enceladus using pit chains. Pit chains are linear assemblages of circular to elliptical depressions that form in regolith and are observed on planetary bodies across the solar system [7], including Earth. There are a variety of processes that may form pit chains [8], but pit chains on Enceladus typically form where regolith overlies extension fractures [8–11].

Previous work [12] has shown that pit chains (Fig. 1) can be used to measure local regolith depths, adopting a method established by [8] for terrestrial planetary bodies. The assumption of this technique is that a pit reaches the base of the regolith layer, thus pit depth is a proxy for regolith depth. Since the pit may not necessarily penetrate the entire regolith layer the measured pit depth is a minimum estimate of regolith depth. Orbital images can be used to measure the depth of individual pits by assuming each pit is a cone and its depth can be calculated based on geometric relationships [8].

Here, we ground truth this proxy by making measurements and observations of terrestrial pit chains in Iceland to determine (1) if the geometric relationships [8] accurately predict pit depth and (2) verifying whether the depth of the soil is equivalent to the depth of the pit. Measuring the distribution of regolith thickness across Enceladus using pit chains is a necessary first step in separating the contribution of plume materials from impact cratering in regolith production, and ultimately understanding the persistence of plume activity.

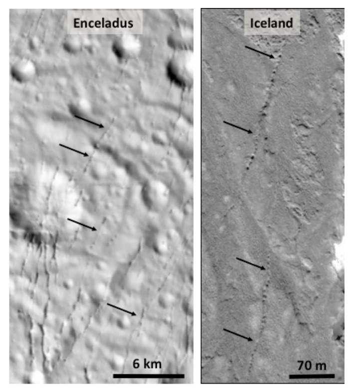

Figure 1: Pit chains on Enceladus (left) and in Iceland (right).

2. Methods

On Earth, pit chains have been identified in various locations [e.g. 13] and those around the Krafla volcano in northern Iceland serve as a representative analog for pit chains on Enceladus [10, 11] (Fig. 1). As extension cracks on Enceladus dilate, regolith drains into the existing void forming pits along the trace of the crack. Similarly, in Iceland cracks form in the underlying basalt, and the overlying soil drains into the underlying crack [10]. The cold icy crust of Enceladus behaves in much the same way as the basaltic bedrock in Iceland, making these basalts an ideal material analog for the water ice and snow-like regolith across Enceladus. The ice sheets across the Earth are too warm and behave too ductility to be appropriate analogs for pit chain formation on Enceladus.

In August, 2017 and May, 2018, we traveled to northern Iceland, just north of the Krafla volcano, to make morphometric measurements of individual pits within pit chains. Pit diameter was measured along strike and perpendicular to strike to characterize potential ellipticity [i.e. 8]. Pit depth was measured using a laser ranger instrument, and images were obtained to generate digital elevation models of pits to assess the validity of using a cone as a representation of pit shape.

In addition, soil depth was measured with both a ground penetrating radar (GPR) system and a tiling probe to more completely constrain the soil depth measurements. We used a GSSI SIR-3000 control unit with a 200 and 400 MHz antenna to collect GPR tracts adjacent to several of the measured pits (both sub-parallel and perpendicular tracks). The 200 and 400 MHz antennas were selected because they would be sensitive to the estimated regolith-bedrock boundary, rather than smaller-scale variations within the regolith like layering, rocks, or other debris.

3. Results

Data were collected from pits based on the preservation of their walls and floor to ensure accurate diameter measurements. As a result, all of the pits measured in Iceland were located the tips of their fractures where the least amount of extension has occurred, rather than in the central, or widest, portion of the fracture. Due to the similar location of measured Icelandic pits along the fractures, all of the pits are of approximately the same dimeter, ~5–8 m (Fig. 2). Comparing the ratio of pit depth and dimeter values with those measured for pits on Enceladus [12] and other planets (Mars [8], Earth [10]), Icelandic pits from this study are deeper than calculated on Enceladus using the proxy. The Icelandic pits depth to diameter ratios plot substantially close to a 1:1 line compared with the other planetary bodies (Fig. 2). While the Iceland pits are slightly more circular, these features are elongated perpendicular to the fracture trace. Additional data are required of both smaller and lager pits to more thoroughly test whether they are consistently deeper, or if the method for inferring depth of Enceladus pits needs refinement. Differences that are visible in the preliminary data may also be due variations in the material properties of basalt regolith and Enceladus's 'snow' regolith.

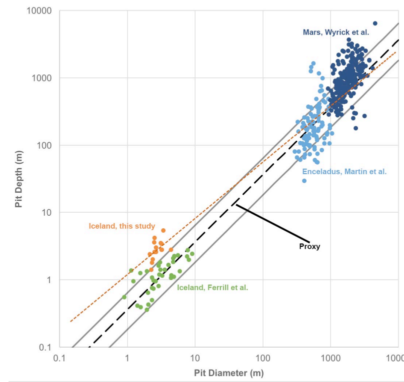

Figure 2: Measured (orange, green) and calculated (dark and light blue) [8] relationships between pit chain pit diameter and pit depth.

4. Summary

We will present processed GPR data of regolith depths near the 15 measured pits and compare Icelandic results with those inferred for Enceladus. We are returning to Iceland May of 2018 to complete data collection in the same lava fields around the Krafla volcano in northern Iceland. Additional measurements will be made in deltaic deposits along the northern coast of Iceland to characterize how the material properties of the regolith might influence the shape of a pit.

Acknowledgements

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