PROBING REGOLITH DEPTHS ON ENCELADUS BY EXPLORING A PIT CHAIN PROXY. E. S. Martin and S. A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022, mart5652@vandals.udaho.edu, simkat@uidaho.edu.

Introduction: Pit chains are linear troughs comprised of circular to elliptical depressions [1], and are unique to Enceladus in the outer solar system [2] (Fig. 1). Pits are distinguishable from impact craters, because they lack raised crater rims, impact ejecta, or other flow features [1,2]. Formation of pit chains on Mars is closely associated with regions of extension [1,3]; motion along high-angle normal faults causes drainage of overlying loose regolith into the resultant dilational space along the fault plane, causing pit chains to form in the regolith [1]. Such dilational faults are common on Earth, Venus, and on small bodies like Phobos, Eros, Gaspra and Ida (review by [4]). Previously, [2] used high resolution Cassini ISS data to map pit chains on Enceladus. Isolated primarily within the old cratered terrains, [2] concluded that, like on Mars, pit chains on Enceladus are formed by drainage of loose material into a void formed through dilational faulting.

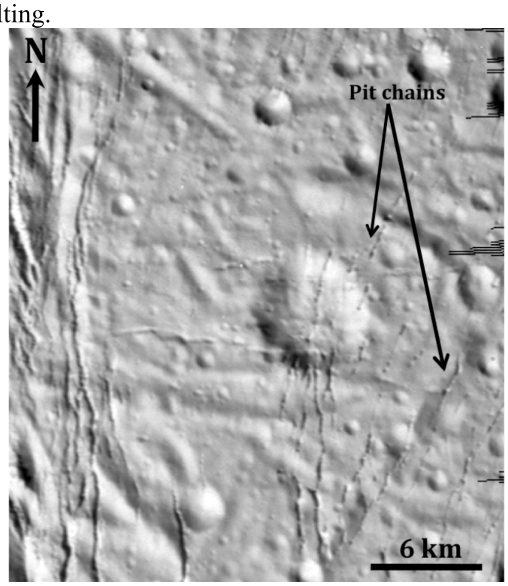

Figure 1: Pit chains in Enceladus's cratered terrain, centered at 5°N, 211°W. Image N14890500785.

Pit chains may prove to be a valuable proxy to measure the depths of surficial regolith, providing a powerful tool to probe planetary surfaces and how they are modified by regolith accumulation. Understanding the evolution of pit chain formation is critical to the development of such a proxy, as well as revealing the early stages of extensional faulting on icy surfaces.

Measuring regolith depths: The spacing of individual pits (pit center to pit center) within a pit chain has been used as a proxy for measuring regolith depth [2,5]. Such a proxy was experimentally determined by [5], who found a nearly one-to-one correlation between pit spacing and regolith depth. Using this method, [2] measured an average regolith depth on Enceladus of 250 m ± 20 m. We propose to apply the pit spacing proxy of [5] throughout Enceladus's cratered terrains to examine the spatial distribution of regolith depth. Fig. 2 shows a small region of Enceladus's cratered terrains, which show three distinct fracture sets, with crosscutting relationships that suggest they formed at different times in geological history. Thus, it is important that pit spacings be measured within individual fracture sets because each set of pit chains was formed at a different period of geologic time and thus represent potentially disparate regolith depths. We also aim to test the validity of the pit spacing proxy, which is based on experiments that assume pit chains formed above continuous fractures with uniform opening along the fault trace. The existing proxy also assumes that the pit spacing should be constant for a given regolith thickness; however, no mechanism has been described to explain why the initiation locations of pits along a dilating fault should be somehow controlled by the regolith thickness.

Based on both terrestrial field observations and spacecraft images of solid planetary surfaces, fractures are known to be highly segmented, with the maximum amount of opening occurring near the center of the fracture, and decreasing toward its tips. Near-surface dilation of high-angle normal faults is expected to produce identical patterns, given the analogous decrease in fault slip from the fault center to the tips. As the fractures propagate, fracture segments merge, creating fracture patterns that are much more complex than a single, continuous crack. Given the potential issues with the pit spacing proxy, we explore an alternate technique that uses pit diameter and an estimated angle of repose to trigonometrically resolve the depth of the regolith.

As loose regolith begins to drain into an underlying cavity along a dilating fault, a pit starts to form at the surface immediately above the drainage point. With ongoing drainage, the pit widens and deepens, with a maximum diameter necessarily controlled by regolith depth and the angle of repose. Hence, pits of variable diameter along a fault likely reflect a sequence of pit development. Variable diameters across a region may reflect changes in regolith thickness. If pits form close together, they may ultimately merge, requiring that the peripheries be carefully examined to see evidence of merged cones. In such cases, the pit-to-pit spacing is not a proxy for regolith thickness.

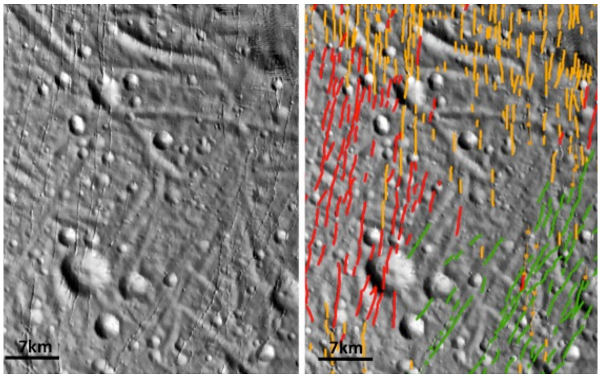

Figure 2: Three distinct fracture sets, with different relative ages, indicate a changing stress field through time. Green pit chains form first, then orange and red, respectively. Image No. N1489050442 centered at 4.7°S, 161.9°E.

Geologic history of pit chain formation: We have established a systematic history of pit chain formation (Fig. 2) within regions outside of the south-polar terrain (SPT) that are suggestive of a rotation of the stress field trough time, analogous to evidence from fractures within the SPT [6]. Mapped fracture sets containing pit chains are predominantly within Enceladus's cratered terrains and (consitent with results from [2]), based on crosscutting relationships, appear to be the youngest features on the surface. Individual sets of pit chains can therefore provide a preserved record of pit chain formation through time, with each set potentially forming at different stages of regolith thickness accumulation.

Extension-driven faulting is a dominant tectonic process on the icy moons but has not been explicitly described or characterized on Enceladus despite the high frequency of normal faults. Enceladus provides a unique opportunity to examine the evolution of normal faulting on icy surfaces. Pit chains are surface expressions of nascent normal faults [1,3] and the pervasively faulted, tectonically resurfaced leading and trailing hemispheres are tectonic plains of highly evolved normal fault systems.

Pit chains appear to be the youngest features in the region, cutting across all other features within the cratered terrains [1,2]. However, the lack of observed pit chains within the heavily fractured terrains of the leading and trailing hemispheres makes it difficult to determine the relative age of pit chains with respect to these other fractures. Further observations will resolve this conundrum if pit chains are located near and across the boundaries between these terrains.

More evolved pit chains show a series of merged pits within a chain and will eventually take on the appearance of a linear trough with scalloped edges, which are the only remnants of pits [3]. This pattern has been produced experimentally by [3], who note that as a crack continues to dilate, pits will begin to merge with one another. Pit chains that represent different stages of dilation were observed by [2] and matched experiments by [3,7]. However, both experiments and observations lacked a temporal component that can be deduced from crosscutting relationships between different sets of pit chains. Are fully merged pit chains relatively older than chains of isolated pits? Alternatively, if older pit chains have been rendered inactive, and mantling of the cratered terrains by plume and E ring material has been ongoing, do older pit chains take on a more subdued appearance?

Discussion: We will present the results of two independent pit chain proxies, and the respective inferred regolith depth. To develop an acceptable pit chain proxy, the formation of pit chains must be thoroughly understood. Thus, we will ultimately consider the spatial distribution of pit chains and their relative age relationships in both the SPT and Enceladus's tectonized terrains. We will also explore the relative ages of pit chains in various stages of formation (isolated pits through to fully merged pit chains). These results will further our understanding of the modification of Enceladus's terrain by the mantling of plume derived regolith and its dissection by normal faulting.

References: [1] Wyrick et al. (2004) *JGR* 109. [2] Michaud et al. (2008) *39th LPSC* Abs. #1678. [3] Ferrill et al. (2004) *GSA Today,* 4-12. [4] Wyrick et al. (2010) *41st LPSC* Abs., #1413. [5] Horstman K.C. & Melosh H.J. (1989) *JGR,* 12433-12441. [6] Patthoff & Kattenhorn (2011) *GRL*, 38, L18201. [7] Miller et al. (2012) *43rd LPSC* Abs. #2925.

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