PIT CHAINS ON ENCELADUS: A DISCUSSION OF THEIR ORIGIN. R. L. Michaud[1], R. T. Pappalardo[2], and G. C. Collins[1]; [1]Wheaton College, Norton MA 02766, [2]Jet Propulsion Laboratory, Pasadena CA 91109, michaud_robert@wheatoncollege.edu.

Introduction: The surface of Enceladus displays a collection of linear depressions, or pit-chains, mostly concentrated between 120° to 220° W longitude, and 30° N to 50° S latitude. Similar features have been found on Mars [1], Phobos [2], and even more locally in Iceland [1]. However, among the icy satellites of the outer solar system, Enceladus is the first place that we have recognized these features. Pit chains are distinct from impact craters in that pit chains lack elevated rims and impact ejecta, they may be sinuous or branching, and they occur in parallel rather than radial sets. Explanations for pit chain origins on other bodies have previously been examined [3], and thus we consider a variety of causes for the pit chains we see on Enceladus.

Observations/Methods: So far we have only observed pit chains in the cratered terrain east of Diyar Planitia. They are not observed in other areas with high resolution image coverage such as the high northern latitude cratered terrain or the younger resurfaced terrain. Even though most of the chains are concentrated within one large region of the satellite, they do not appear to stem from a single source. The chains appear for the most part in sets, where a given small region will exhibit one primary orientation of parallel pit chains.

We have observed that relative to other features, the chains appear younger. Chains cut across craters in many examples, and lay across other tectonic features. However in many cases the chains are located around other chaotic terrain, and thus the age distribution is difficult to determine. Ferrill et al. [1] modeled pit chain formation on Mars, and concluded that they originated from normal faulting. It appears that with increasing strain, the pits in a chain become increasingly merged. For our measurements, we selected pit chains where the pits were distinct from one another, but not fully merged, as in Fig. 1b - 1d below. There are many examples of troughs with scalloped interiors parallel to the pit chains, which may represent fully merged pit chains.

We are collecting measurements to quantify the geometry of these Enceladus pit chains. In our initial work we have measured approximately 30 pit chains, each of which contains between 5 and 15 individual pits. We then found diameters for these pits, most of which are in the 150 m range. The lower limit is around 100 m, while the upper is near 400 m. Unfortunately several sets of pit chains are only covered by images with resolutions approaching the pit radius, making exact quantification of diameter difficult.

Discussion of pit chain origins: There are several potential causes for the pit chains that we wish to discuss, shown below starting with the most likely.

Dilational Faulting: If normal faults cut through strong ice layers underneath the surface of Enceladus, dilational fault segments are formed, and can create a void in the sub-surface material (Fig. 2). A weak unconsolidated regolith layer can then fall into that void. This process would form the chain of linear depressions that we see on the surface. The material underneath the weak regolith layer must be strong enough to support open tension fractures. Given the low gravity on Enceladus, tension fractures can propagate deeper into the interior. This in turn can create more void space for material to fall into, potentially creating larger, more distinctive pit chains than on the Earth or Mars. In this scenario, associated normal faulting should produce signs of graben and en échelon faults, both of which are seen extensively around the pit chains of Enceladus. Though we

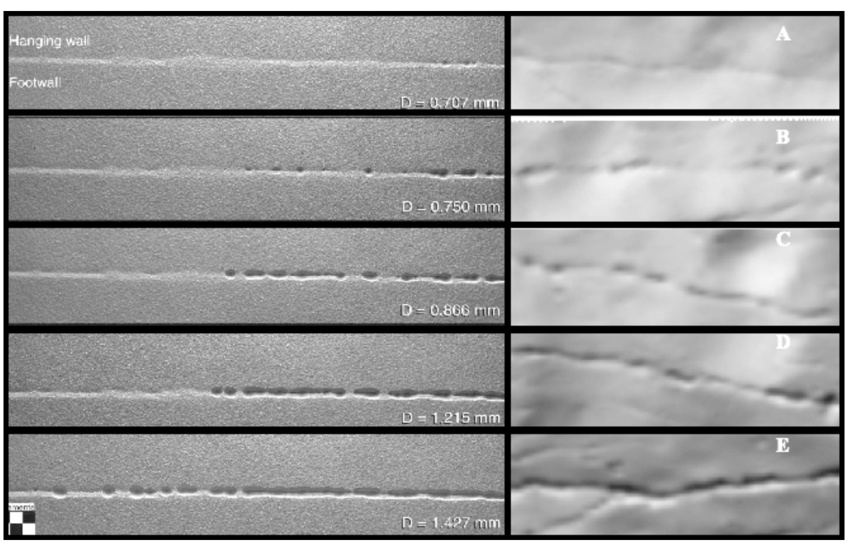

Fig. 1: Ferrill et al. [1] model of pit chain formation from normal faulting (left), compared with examples from the surface of Enceladus (right). Figures b-d are pit chains, while e shows a fully merged pit chain.

cannot absolutely say that these tectonic features are intrinsically related to the pit chains (since the age relationships are hard to determine) there is a tight correlation between these sets of features.

In a similar scenario, a blind fault can create an upward propagating graben and fractures underneath the surface. A void is once again formed, into which weak surface material falls, forming pit chains. As a result, extensional fractures (such as graben) should appear near the chains, which we observe on Enceladus.

Dikes: A dike can be formed as a melt propagates upward to the surface. Strain from the opening of the dike can cause graben to form. On a terrestrial planet, if the dike interacts with groundwater or some equivalent near the surface, vapor is released, and thus a void is formed. Material can then fall into that void, forming pit chains. An analogous process on Enceladus could be the heating and vaporization of near-surface materials such as clathrates, creating such a void. The pit chains appear in groups, but do not seem to come from a single source and are not associated with any other potential cryovolcanic features. They are also found on the oldest and presumably least active terrain on Enceladus – if subsurface heating was responsible, we would expect to see many more pit chains in the south polar region.

Lava Tubes: In basaltic lava flows, channels and tubes can form as the flowing lava is exposed to the colder surroundings. Once lava is no longer flowing through this tube, its rigidity is compromised and thus is prone to collapsing, potentially forming pit chains. Highly sinuous paths should be prevalent, stemming from a volcanic source. The pit chains we see on Enceladus are almost exclusively linear, and do not radiate from a single source. While pit chains from collapsed lava tubes mostly form on sloped topographic areas, Enceladus pit chains appear spread across a relatively flat plain, and cutting across preexisting topography such as craters.

Rolling boulders that create circular depressions have also been discussed in previous work [4], and thus are worth mentioning for the sake of thoroughness. But we find it very unlikely that 150m wide boulders are rolling across the flat plains of Enceladus to create the pit chains.

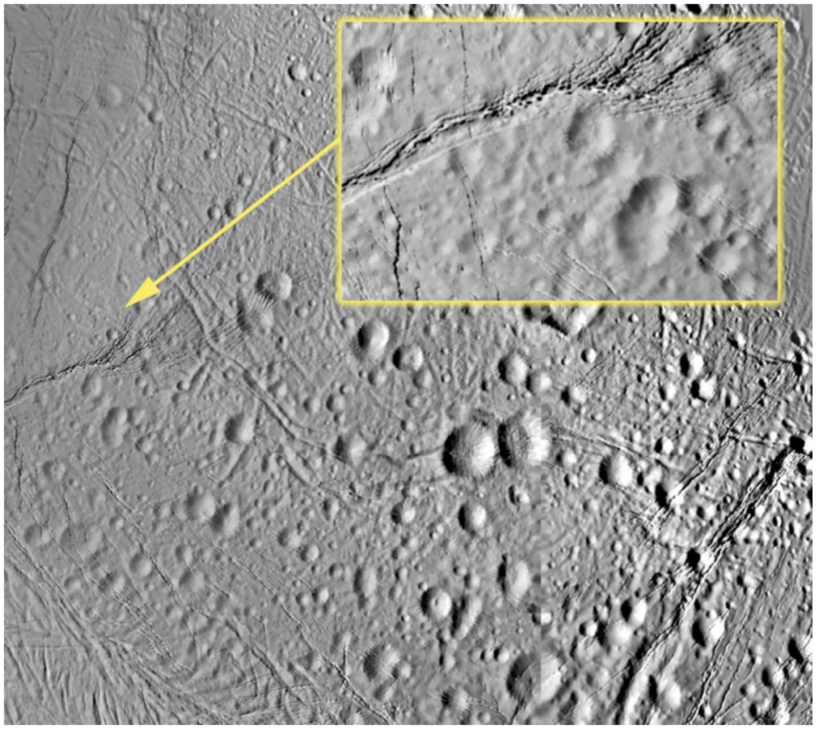

Figure 2: Area of Enceladus with a high concentration of pit chains, in the southern midlatitudes of the antisaturnian hemisphere. Inset shows close-up of some pit chains, with pits ~150 m in diameter.

Conclusion: The evidence suggests that the drainage of unconsolidated surface material into dilational-fault-induced voids seems the most likely explanation for the origin of pit chains on Enceladus. We will continue to quantify the properties behind fault drainage pit chains, to assess the depth of regolith layers and the strength of the material beneath this weak surface layer. Evidence of several parallel sets, associated graben, and en échelon trough patterns suggest evidence of normal faulting. A lack of impact crater and volcanic sources for the chains indicates those scenarios are not likely explanations for the chains. The presence of chains only in the older cratered terrain and not in adjoining resurfaced terrain probably indicates a much thicker regolith on the cratered terrain. Whether this regolith is derived from impact ejecta or plume fallout is an open question.

References: [1] Ferrill et al., *GSA Today*, 4-9, 2004; [2] Horstman and Melosh, *JGR*, 12433-12441, 1989; [3] Wyrick et al., *JGR*, E06005, 2004; [4] Head and Cintala, *NASA TM* 80339, 19-21, 1979.

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