ESTABLISHING A LONG-TERM FRACTURE HISTORY OF THE SOUTH POLAR TERRAIN ON ENCELADUS.

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Introduction: Enceladus is the sixth-largest moon of Saturn and has a diameter of approximately 504 km. The icy moon synchronously orbits Saturn at a distance of approximately 238,000 km once every 33 hours between Mimas and Tethys [1] but is locked in a 1:2 resonance with Dione resulting in an orbital eccentricity of 0.0047 [2]. However, Enceladus is very different from other Saturnian moons, which often have old, heavily cratered surfaces, because it has a region of young active crust and evidence for a dynamic interior, particularly around the south pole.

The ongoing Cassini spacecraft mission has imaged Enceladus, some pictures with resolutions better than 4 m/pixel, revealing numerous fractures with a range of orientations, densities and potential formation mechanisms. The surface of the moon can be divided into numerous domains defined by the fracturing and crater densities. The youngest terrain, and the focus of this study, is found around the south pole of Enceladus [3] (referred to as the the South Polar Terrain, SPT) where eruptive plumes of water ice have been discovered [2].

The presence of the plumes and fractures around the south pole raises the question as to whether the ice shell of the moon is underlain by a global ocean, similar to Europa, or a localized ocean beneath only the SPT. The presence of a global ocean would allow for a decoupling of the ice shell (which would make processes such as polar wander and nonsynchronous rotation possible) as well as promoting substantial tidal heating [4]. Unfortunately, the heat source required to create a global ocean is difficult to explain. The 1:2 resonance with Dione is unlikely to produce enough heat to melt water ice, allowing for a subsurface global ocean [2]. The interior of the moon could be composed of a mixture, such as water plus ammonia, with a lower melting temperature [3] but no ammonia has been directly detected on the surface of Enceladus or in its eruptive plumes [5]. However, molecular nitrogen has been found leading some authors believe that the presence of N_2 could be a result of thermal decomposition of ammonia [6]. Radioactive decay from a rocky core is unlikely to provide substantial heat to create a global liquid ocean [2].

There are alternative explanations for the active geology that is confined to the SPT which do not require a global ocean. Degree-one convection could explain the dichotomy between the active south polar terrain and the heavily cratered northern hemisphere [7]. Another possibility is that compositional diapirism within Enceladus resulted in density anomalies that induced a poleward shift of a region of diapirism to the south pole [8].

The fractures across the entire surface of Enceladus suggest a global source of stress, possibly tidal, that has driven tectonics for a long period of time. By mapping and correlating fractures of equivalent ages or orientation in the SPT, the spatial and temporal pattern of stress in this region of Enceladus can be unraveled. Evidence could be provided for or against a diurnal tidal stress field, or other contributing factors, and the role they play in the tectonics of Enceladus.

Fractures in the SPT: The global presence of fractures on Enceladus indicates that the surface has been tectonically active during its history. These fractures can form by dilation, compression, or by shearing. The type of fracturing helps to determine the stress regime that formed the fracture as well as to establish the pattern of stresses. The SPT has the highest concentration of fractures and appears to be currently tectonically active [9-11]. By studying the pattern and style of fracturing in the SPT, it could be possible to determine the cause of the stresses on the icy moon, especially those near and along the tiger stripes (the fractures from which the eruptive plumes emanate).

A first order examination of the fracture pattern in the SPT of Enceladus indicates a temporally (and perhaps spatially) heterogeneous stress field in the ice shell (Figure 1). Many of the fractures have the characteristics of dilational cracks, with no obvious lateral offsets of features cut by the fracture. Other fractures, especially in the area closer to the edges of the SPT, at the ends of the tiger stripes, appear to have transform fault properties [13]. The preliminary fracture map of the SPT shows four fracture sets where fractures with similar orientations have been grouped together. Using crosscutting relationships, relative ages for the fracture sets were established. From youngest to oldest, the fracture sets are believed to proceed from red, which include the tiger stripes, blue, green, and the oldest in yellow. Additional mapping will more firmly establish these relative ages. The older fractures could be remnants of older tiger stripe features which influenced the formation of the tiger stripes and reflect a very different state of stress in the SPT than the contemporary stress field that resulted in the tiger stripes.

Discussion: The nature of the stress field associated with a possible reorientation of the ice shell is mathematically predictable and can be compared to fracture characteristics. A diurnal tidal stress field could exist on Enceladus due to the eccentricity of its orbit which could produce sufficiently high stresses to create new fractures or cause strike-slip motions on existing fractures [9-11]. The stress history recorded in the fracture sequences, in the SPT as well as the rest of the moon, has not been established. There are distinct ages of fracturing in the SPT evidenced by the numerous fracture orientations. These orientations are not random, but are instead fracture sets that point to temporally unique stress states in the SPT that are different from the current stress states.

Using the most recently available high resolution images from Cassini, rigorous fracture maps of the SPT are being created in an ArcGIS environment in order to determine how the fracture history has evolved to its current state where the tiger stripes are the dominant active features. There are likely numerous ages and orientations of fractures which can be grouped into individual fracture sets based on crosscutting relationships between individual fractures. By examining these fracture sets and comparing them to one another, evidence for or against nonsynchronous rotation can be found. If the ice shell of Enceladus is decoupled from its silicate interior, then the diurnal tidal effects should be sufficient to induce tectonic deformation and influence the orientations of fractures and fracturing styles. Additional mapping of the moon could reveal additional fracture sets with more orientations providing additional clues to the internal processes and long-term tectonic evolution of Enceladus.

Conclusions: Given the complex fracturing history of the SPT, detailed analyses of the fracture types, orientations, and relative ages are necessary to provide a more complete picture regarding what the SPT is and how it has evolved. These fracture maps can be used to determine if there is a consistent change in fracture orientation through time and if the fractures can be related to a known stress-producing mechanism. The maps can also be used to help determine the geometric development of the tiger stripes by studying their mechanical interactions with the additional fracture sets.

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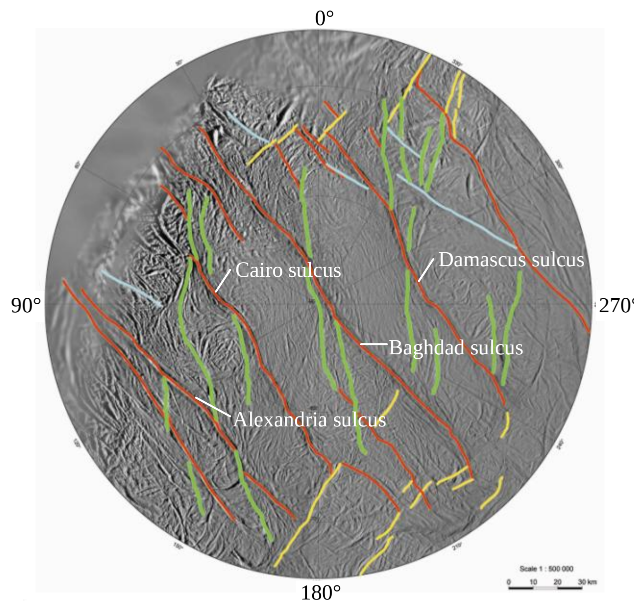

Figure 1: Polar projection of the South Polar Terrain on Enceladus. The scale bar is 30 km. Fractures show a progressive rotation of fracture orientations. From youngest to oldest, the fracture sets are believed to proceed from red, which include the tiger stripes, blue, green, and the oldest in yellow. Mosaic is from [9].