Enceladus: Tectonics of Saturn’s Icy Satellite

MS Thesis Proposal

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Introduction

Since 2005, the NASA Cassini spacecraft has provided high-resolution images of tectonically active features on Saturn’s icy moon Enceladus. The South Polar Terrain (SPT) region displays highly fractured surfaces and the presence of plumes erupting water vapor and ice into space. These plumes originate from a series of at least four en echelon cracks located on the southern pole of the moon and are termed “tiger stripes” and named Alexandria Sulcus, Baghdad Sulcus, Cairo Sulcus, and Damascus Sulcus (Porco et al., 2006). As described by Porco et al. (2006), these set of fractures are approximately 130 km in length, as much as 2 km wide, and 500 m deep. They are aligned in a right lateral en echelon position in the SPT (Spencer et al., 2009) (Figure 1). The tips of the recognized tiger stripes terminate in either arcuate, “hook-like” or linear fractures (Figure 2).

Various hypotheses have been offered to explain these active features. Hurford et al. (2007) suggest that fractures in the SPT are tensile and compressive in nature due to tidal forces from Saturn and sister moon Dione. They propose that this opening and closing of the tiger stripes is the governing factor in plume eruptions. Others argue that shear forces associated with tidal forces are also at work causing friction and, thus melting ice and supplying the plumes (Nimmo et al., 2007). Ridge structures and troughs are said to be the result of unstable extension (Bland et al., 2007). Yet, Passey (1983) states that such structures may indicate compressional forces.

It is agreed that resurfacing is present on the moon, but its origin and process are disputed. A cyclic breaking of the upper crust is the mechanism of resurfacing described by Tobie et al., (2008). Others suggest an extrusion of fresh material onto the surface of the moon to be the means of resurfacing (Squyres et al., 1983. The presence or absence of sub-crustal water is a major issue of debate and a main reason for the study of Enceladus. By understanding the tectonics of the SPT, this may be proven or disproven. By analyzing the geometry and kinematics of the fractures, ridges, and craters in the SPT as well as in the leading and trailing hemispheres of Enceladus the proposed research will address the following questions:

- What is the relationship between the “tiger stripes” and the arcuate terminations and linear fractures that extend from their tips?
- What are the kinematics involved in the fracturing and resurfacing of the crust in the SPT?
- What causes the formation of other features flanking the tiger stripes such as ridge structures in the areas adjacent to Damascus, Baghdad, and Cairo Sulci (Figure 3)?
Background

Enceladus’ mean radius is 252.1 km and its shape is slightly elliptical (Spencer et al., 2006). Enceladus is just one of 62 different moons that circumnavigate our solar system’s sixth planet (Brown et al., 2006). Of Saturn’s main moons, it is sixth in line and orbits Saturn from an average distance of 238,037 km. Its orbital period of the planet is only 1.37 days or 32.88 hours (Porco, 2008). Saturn’s eighth moon in line is Dione, which has a distance of orbit of 377,396 km. Its orbital period is 2.74 days or twice that of Enceladus’.

Because of its small size, the geologic activity of this icy satellite has intrigued scientists since the Voyager 2 probe caught its first glimpses of the moon in the early 1980’s. Early images from the Voyager 2 mission showed a small moon with large expanses of uncratered, smooth terrain. This lack of craters in areas led scientists to believe that internal geologic activity may have been causing such anomalies (Porco, 2008). Passey (1983) and others suggested that resurfacing was taking place to cause these uncratered terrains. Since June of 2004, the Cassini probe has been delivering new images of the moon to NASA (Porco, 2008). This newer imagery has shown a present day active southern pole in the form of plumes spewing water vapor and ice thousands of kilometers into space (Collins et al., 2009). This observed activity makes Enceladus the smallest and the only icy body in our solar system that is geologically active (Kargel, 2006).

This activity, in the form of highly fractured terrain and active geysers in the SPT, is viewed as an anomaly because of the small size of Enceladus. A moon its size should not have the heat capacity to drive such activity. However, high thermal emissions emanate from the tiger stripes as seen in Composite Infrared Spectrometer (CIRS) imaging along the entire length of these features (Spitale and Porco, 2007). These higher temperatures along the tiger stripes are consistent as they have been observed on several of Cassini’s flybys (Abramov and Spencer, 2009). According to Spencer et al. (2009), the average temperature of the outer ice layer of the moon is around 75 K, yet the temperature of the surface around the tiger stripes has been recorded to be as high as 167 K. The fine particles being ejected from the plumes have been found to supply Saturn’s E-ring (Spahn et al., 2006).

Its composition, thought by some to be of pure water ice, gives Enceladus an impressive reflective ability (Porco et al., 2006). Hendrix et al. (2010) argue that Enceladus’ dark reflectance spectrum in far ultraviolet wavelengths is the result of the presence of small amounts of NH₃ and thiolin as well. The thickness of this outer layer
of ice has been a topic of dispute as well and is estimated to be anywhere from ~3-150 km in thickness. Therefore, the core of the moon is calculated to have a radius of ~100-250 km. Enceladus has a mean density of 1608.3 km/m³ and a mass of $1.08 \times 10^{20}$ and, so, is determined to have a solid silicate core (Kargel et al., 2006). Its semi axis measurements of 256.6, 251.4, and 248.3 km give the moon an overall ellipsoid shape (Porco et al., 2006). With an orbital eccentricity of 0, a planet or moon would have a perfect circular orbit. As the orbital eccentricity approaches one, the orbit deviates from its circular pattern and becomes more stretched or elliptical in shape. The orbital eccentricity of Enceladus, at 0.0047, characterizes its orbit as slightly elliptical (Hurford et al, 2007). Because of this noncircular orbit, there is a daily variation in tidal forces. The closer the moon gets to Saturn, the greater the pull of gravity it experiences, thus slightly stretching out its shape.

The icy satellite is located within the E-ring of Saturn between its sister moons Mimas and Tethys (Porco et al., 2006). Its proximity to the moon Dione, however, contributes greatly to Enceladus’ shape and the character of its orbit. The considerably larger moon Dione, with a radius of around 561 km, orbits Saturn once for every two times that Enceladus makes the rotation (Porco, 2008; Dombard, 2007). Moons tend to shift their orbital eccentricity toward zero or toward circular orbits. Yet, Enceladus’ periodic synchrony with Dione causes the moon to keep its orbit in an elliptical shape. This synchrony with Dione, combined with the pull of gravity from Saturn, results in the cyclical elongation and shortening of the horizontal axis of Enceladus (Porco et al., 2006). This constant overlapping pattern results in frictional sliding and could be a source of internal heating on the moon and its present geologic activity. This heating seems to be centralized on the southern pole of Enceladus.

The South Polar Terrain (SPT) of Enceladus is riddled with fractures, but there are very few craters present, which supports the idea that geologic activity is centralized in this region. The SPT is constantly being resurfaced, erasing evidences of any impact. Most of the ice particles that are spewed from the tiger stripes fall back to the surface of the satellite. This, combined with the tectonics of the region, account for the lack of craters (Porco et al., 2006). The SPT is encircled by mountains formed by compression forces. These circumpolar mountains surround the tiger stripes features (Spencer et al., 2009). The parallel fractures display an apparent dextral curvature with radii of approximately 10-20 km. Such curved fractures are best observed at the tips of Alexandria Sulcus. In contrast, at the tips of Baghdad and Damascus Sulci, both arcuate and linear fractures systems appear to propagate from the tips. Both type of fractures generally display a dextral turn with respect to the map view of the Sulci.
By addressing the questions outlined in this proposal, I plan to test the idea of the existence of subsurface water through the analysis of tectonic features at Enceladus’ surface. I also plan to investigate the tidal resonance of Enceladus as the primary driving force for geologic activity on the moon.

**Methodology**

The Cassini spacecraft has been able to observe Enceladus using several instruments which include the Ultraviolet Imaging Spectrograph (UVIS), the visible wavelength Imaging Science Subsystem (ISS), the Visual and Infrared Mapping Spectrometer (VIMS), the Composite Infrared Spectrometer (CIRS), the magnetometer (MAG), the Cosmic Dust Analyzer (CDA), the Cassini Plasma Spectrometer (CAPS), the Radio and Plasma Wave Science (RPWS) instrument, and the Ion and Neutral Mass Spectrometer (INMS) (Spencer et al., 2006). These images will be used to examine fracture/fault morphology, kinematics, geometry, and cross-cutting relationships. This will be accomplished through the following means:

- Mapping of structures in Adobe Illustrator and Photoshop
- Cataloguing features into tables to aid in organization
- Creating rose diagrams of the orientations of the fractures and other structures
- Comparing Enceladean features to Earth analogues so to provide boundary conditions for further modeling of the relationships between fracturing and the presence/absence of liquid water.
- Using ArcGIS to georectify images for accurate measurements
- Using Scale v 2.0 to precisely measure angles, orientations and dimensions of features

**Expected Outcomes**

Analyzing and mapping the structural geology of Enceladus over a variety of images has several objectives: 1) To prove or refute the idea of sub-crustal water in the SPT; 2) To test the theory of tidal heating as a driving mechanism for activity on Enceladus; and 3) To create a kinematic model for the SPT that is globally consistent.

**Plan of Work**

Work has already begun on the structural mapping of the South Polar Terrain. Future work will include mapping of the leading and trailing hemispheres of Enceladus. The research work will be presented at the following conference:

- Lunar Planetary Science Conference in March 2011
Budget

Since most of the thesis research will be based on Cassini images (which are provided free of charge), the expenses will not be extensive. They will include:

Adobe illustrator $275
Trip to LPSC Conference
  Registration fee $100
  Travel; from Lubbock to Houston $250
  Hotel; estimated @ $100/night for 2 nights $200
  Food; estimated @ $25/day for 3 days $75
Total $900

References


Collins, G.C., McKinnon, W.B., Moore, J.M., Nimmo, F., Pappalardo, R.T., Prockter


Figure 1. Polar stereographic projection of Enceladus’ “tiger stripes” (yellow) with 108 m /pixel resolution. Red lines represent fractures associated with a similar stress regime as the tiger stripes, while green lines represent fractures nearly orthogonal to tiger stripes.
Figure 2. Composite image with 350 m/pixel showing arcuate and linear fractures propagating from the tips of the tiger stripes.

Figure 3. Ridged or folded structures between Damascus, Baghdad, and Cairo in close Cassini flyby with 9-30 m/pixel.