EXPLORING ENCELADUS' GEOLOGIC HISTORY THOUGH TIME. D. A. Patthoff[1], R. T. Pappalardo[1], A. Maue[1,2], E. S. Martin[3], H. T. Chilton[1,4], P. T. Thomas[5], P. Schenk[6], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (Patthoff@jpl.nasa.gov), [2]Departments of Physics and Geology, Boston University, Boston MA, [3]National Air and Space Museum, Smithsonian Institution, Washington, DC, [4]Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, [5]Center for Radiophysics and Space Research, Cornell University, Ithaca, NY, [6]Lunar and Planetary Institute, Houston, TX.

Introduction: The surface of Saturn's moon Enceladus has a diverse array of geologic terrains that includes ancient cratered regions, young ridges, and numerous fractures. The youngest region is the terrain surrounding the south pole, which contains large fissures with jets of water vapor erupting from the surface [1] and a larger than expected heat flux [2]. Farther to the north (above ~55° S latitude), the moon can be broadly divided into the older Saturnian and anti-Saturnian cratered terrains and the younger terrains that dominate the leading and trailing hemispheres [3]. Portions of the trailing hemisphere may have experienced significant amounts of extension [4] in the past. We also observe compelling evidence for compression focused along the largest ridges in the region, the "dorsa" [5]. We suggest the leading hemisphere also contains evidence for a significant amount of compression related to the observed large ridges [5].

Regional tectonics: *Cratered terrains*. Dispersed among the numerous craters of the region are ancient ridges and troughs. The amount of cratering suggests the region has an age ~2 Gyr [6]. Many of the ridges and troughs are cut by all other identifiable features including craters and fractures, suggesting they predate all other deformation [7, 8]. These ancient ridges are generally small (>10 km long and 100 m high) and are cut by most of the ancient troughs, which can be ~15 km long (Fig. 1). Those cross cutting relationships suggest the ridges pre-date even the troughs in the region. Cutting across many of these ancient terrains is a young set of fractures, likely pit chains [7, 8] some of which can be traced to the south polar terrain (SPT) and have north-south orientations (Fig. 1).

Trailing hemisphere. In the trailing hemisphere are two main sets of ridges: a set of smaller ridges (~50 m high), and the larger dorsa (~50 km long, ~800 m high) which can bifurcate in a branching manner with branches that can intersect other dorsa near-orthogonally (Fig. 2). We support the suggestion that the dorsa are thrust faults, and they could accommodate ~10% shortening. Another set of north-south fractures cuts across the dorsa, and in some instances they appear to laterally displace the ridges.

Leading hemisphere. On the leading hemisphere are two different ridge types: a smaller set (1–20 km long, 10s m high), and a larger but less numerous set (~600 m high, 15–35 km long) that have a lens-like shape in map view (Fig. 3). The larger ridges we interpret to be large-scale thrust faults. Few fractures appear to transect this region; however, surrounding the terrain are a series of fractures that cut through some of the leading hemisphere ridges and have a north-south trend (Fig. 4).

South Polar Terrain. Encompassing the south pole is Enceladus's youngest terrain [1]. The region contains large double-ridge-like features (the "tiger stripes") and a ropy terrain consisting of smaller-scale ridges.

Discussion: We suggest the varying ages and styles of deformation found across Enceladus's surface point to four major stages of large-scale deformation. The oldest tectonism (~2 Gyr) is preserved within the cratered terrain, where the ridges imply a compressive history followed by an extensional event as evidenced by the troughs (Fig. 1). That cycle of contraction then extension could be caused by the formation of a large liquid ocean layer which later (partially) froze. When the lower ice shell melted, Enceladus experienced a global contractional event that contributed to the formation of the ancient ridges. When the ocean later began to freeze, the ice shell expanded and created the observed ancient troughs [8].

Following the ancient deformation is the compressional activity preserved in the leading and trailing hemisphere ridge terrains. Age dates for these hemispheres is on the order of >200 Myr [3, 7]. Evidence for any tectonism between the time of the ancient tectonism and the activity on the leading and trailing hemispheres is not apparent in the available data. Here we suggest the large amounts of contraction accommodated by the large ridges could be a result of a second stage of lower ice shell melting concentrated below the present-day leading (Fig. 2) and trailing hemispheres (Fig. 3). As the ice melted, each hemisphere may have collapsed and initiated a period of compressive tectonics resulting in the observed ridges.

The third stage of deformation is the currently active SPT. Contraction [9], extension [10], and shearing [11] have all been suggested to have contributed—and potentially still do contribute—to the tectonics of the region. Previous research has suggested the present-day thickest body of water is below the SPT [12, 13].

The final tectonic stage of Enceladus is tied to the young, near global, fracture network (black arrows, Figs 1 & 2). Cutting across almost all other features outside of the south polar terrain, the fractures suggest a near global-wide extensional event. We suggest the extension could be caused by a freezing of a subsurface liquid ocean causing the entire ice shell to expand.

It is possible that younger deformation could have erased evidence for additional periods of deformation that occurred between the formation of the ancient cratered terrains and leading hemisphere. However, it is difficult to account for the preservation of the oldest terrains on the Saturnian and Anti-Saturnian hemispheres for such a long time period if Enceladus experienced multiple episodes of tectonic deformation. Instead we favor the model of episodic overturn [14], which suggests Enceladus has experienced brief periods of intense geologic activity followed by long durations (> 1 Gyr) of relative quiescence. Presently, Enceladus is inferred to be in the twilight of the most recent episode of activity, and the once larger subsurface ocean layer is slowly freezing and causing a second stage of global extension.

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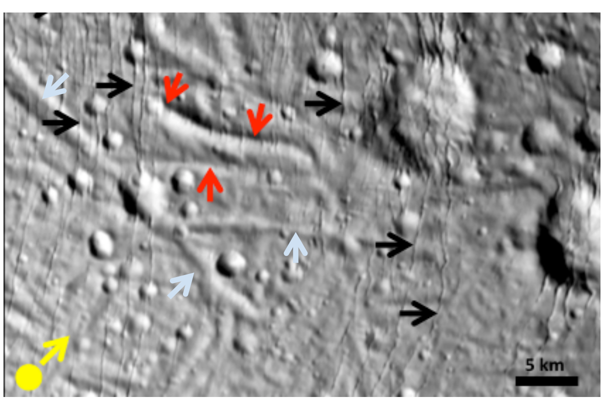

Figure 1: Cratered terrain. Red arrows point to ancient ridges and blue arrows point to ancient troughs. Black arrows highlight recent fractures.

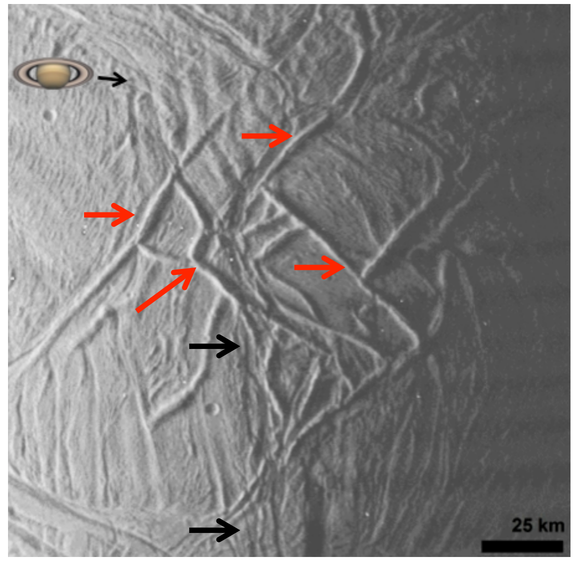

Figure 2: Saturn shine image of the trailing hemisphere. Red arrows show large dorsa and black arrows show younger fractures.

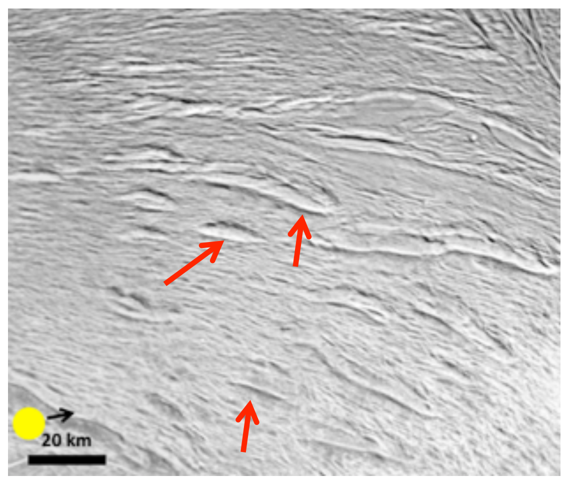

Figure 3: Leading hemisphere ridges. Red arrows point to the largest ridges in the region.

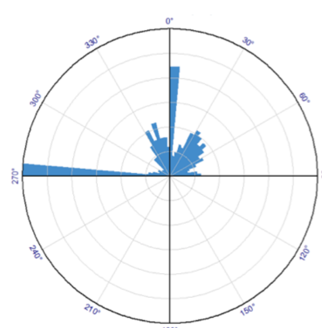

Figure 4: Rose diagram of leading hemisphere fractures. The east-west petal is composed almost entirely of fractures surrounding the south polar terrain.