EFFECTS OF NONSYNCHRONOUS ROTATION STRESSES ON THE SOUTH POLAR TERRAIN OF ENCELADUS. D. A. Patthoff[1], S. A. Kattenhorn[1], C. M. Cooper[2], [1]Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022, [2]School of Earth and Environmental Sciences, Washington State University, Pullman, WA 99164-2812, patt0436@vandals.uidaho.edu, simkat@uidaho.edu, cmcooper@wsu.edu.

Introduction: The geologically youngest region of Saturn's small icy satellite, Enceladus (~250 km radius), is the fractured area around the south pole [1]. This area, known as the south-polar terrain (SPT), contains numerous cracks and fractures, some of which are the source of eruptive plumes of water emanating from the surface [1, 2]. As much as 12.7–18.9 GW of thermal energy has been detected in the SPT with much of the elevated energy sourced along the four largest fractures [3, 4], known as the tiger stripes [1]. Previous studies have focused on these larger fractures and how they are affected by the present-day diurnal tidal stresses. Those models show that the tiger stripes may experience periods of strike-slip faulting during Enceladus's orbit around Saturn [5, 6]. The resulting friction from the sliding could help to explain the larger than expected thermal energy [7] observed along the fissures [4].

However, hidden within the numerous other fractures of the SPT (Fig. 1) is evidence that points to a history of nonsynchronous rotation (NSR) of the ice shell [8]. Many of the previous stress models of the SPT only take into account the diurnal tidal stresses and do not include a component of NSR stress. The diurnal tides have been shown to generate stresses only on the order of a few tens to hundreds kPa [6, 7, 9], likely too small to overcome the tensile strength of ice at Enceladus surface temperatures [10] and create the fractures or many of the other observed geologic and tectonic features. The addition of stress as a result of NSR is likely important for fracture initiation, propagation, and growth over a longer period. Here we aim to explore the effects of both NSR and diurnal tidal stresses on the fracturing of the SPT.

Stressing mechanisms: Two sources of stress, driven by Enceladus's gravitational interaction with Saturn and other moons in the system, are suggested to be large enough to contribute to deformation and create the observed geologic features. The stresses are divided into a weaker and shorter time-scale, diurnal stress, and a potentially stronger and longer term, nonsynchronous rotation stress [11].

The daily elliptical orbit of Enceladus around Saturn generates the diurnal tidal stresses that change with the moon's location in its orbit [12]. Previous studies of the these stresses assume a global ocean beneath the ice shell to amplify the tidal effects and create the stresses necessary to drive theorized fracture movement at the south pole and generate some of the observed heating around the south pole [6, 9, 13].

Enceladus is likely tidally locked, meaning the same side always faces Saturn; however, if the interior and exterior are decoupled by a liquid layer, the outer floating ice shell would be free to rotate faster than the interior due to gravitational interactions between Saturn and Enceladus's tidal bulge. From Saturn's perspective, the tidal bulge on Enceladus would remain fixed while the icy shell slowly rotated to the east. On Enceladus, the tidal bulge would appear to migrate in the opposite to the direction of rotation (west) generating additional stresses as the ice deforms [11]. The magnitude of the generated stress depends primarily on the relative rates of viscous relaxation and period of NSR. A lower viscosity of the ice shell, possibly due to higher temperatures, would allow the ice to more easily flow though the tidal bulge movements and relax the NSR stress. A very slow rotation rate of the ice shell would also allow the ice to behave viscously and again, relax the NSR stresses. However, if the shell is spinning relatively quickly and has a high viscosity, the ice will behave elastically on the NSR timescale and generate stresses [11, 14].

Together, diurnal and NSR stresses in the non-perfectly elastic ice shell release energy through tidal dissipation. The excess energy may result in a thermal plume being created within the ice shell beneath the south pole [15, 16]. The excess energy may also be released through the creation of fractures in the ice shell.

Modeling: To calculate the diurnal and nonsynchronous rotational stresses around the south pole, we use the program SatStress [11] and its graphical user interface (SatStressGUI) developed at the University of Idaho [17]. This model uses a 4-layer viscoelastic approximation of the satellite: an upper ice shell layer, lower ice shell layer, global ocean, and silicate core. The division of the ice shell into two layers allows for the creation of a more rigid layer (outermost and coldest) and a less rigid or viscous layer (innermost and slightly warmer).

The thicknesses of the layers, elastic parameters, and orbital constraints are approximated based on past work [7, 9], with the upper ice layer ranging from 2-4 km, the lower ice layer between 7 and 37 km, the liquid layer 55-87 thick, and the core kept constant at 156 km. We assume a Poission's ratio of 0.33, a bulk modulus of 9.3×10^9 Pa, an ice density, both upper and lower, of 0.92 g/cm^3, an orbital eccentricity of 0.0047, and semi-major axis of 2.38×10^8 km.

The model allows us to calculate the NSR and diurnal tidal stresses, either individually or together, over the entire surface of the moon. We use a rate of NSR between 10,000 and 1 million years for a single rotation of the ice shell. An example of the graphical output of SatStress is shown in (Fig. 2).

Discussion: The NSR stresses on Enceladus are likely larger than those created by the diurnal tides, depending on the rate of NSR, and could cause the initial fracture creation on the moon. However, the magnitude of the NSR stress is also also partly controlled by the location on the surface.

Our work will compare the global fracture patterns to the global NSR plus diurnal tidal stresses. The fractures across the surface of the moon should reflect the patterns of maximum stress across the ice shell. However, because most of the known more recent fracturing on Enceladus is concentrated near the south pole, any modeled rates of NSR should create stresses which will exceed the strength of the ice in the SPT but not in other regions of the moon. A workaround is if the localized fracturing is a result of differing ice shell thicknesses, with the thinnest (and therefore weakest) ice found near the south pole. The current version of SatStressGUI can only account for a single global ice shell thickness. To compensate for differing ice shell thickness that likely exist on Enceladus, multiple models will be run to simulate stresses on a thicker ice shell (representing the northern areas) and thinner ice shells (representing the southern portions of the moon).

Our work expands on previous models to include the other SPT fracture sets and NSR stresses in an effort to determine how the SPT ice-shell thickness may have changed through time. We compare the modeled NSR and diurnal stress patterns to the mapped geologic features in an effort to better understand the tectonic and geologic history of Enceladus.

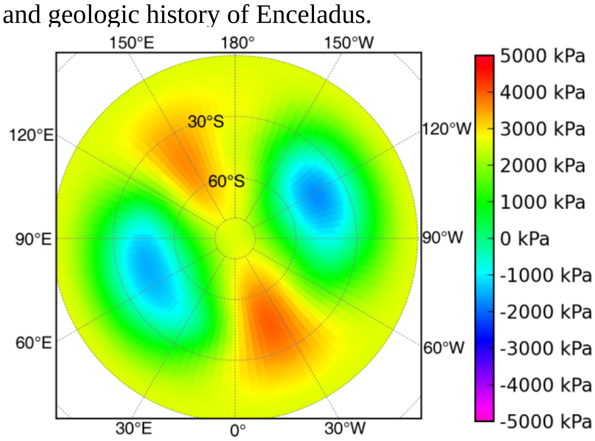

Fig 2: NSR stresses for a 100,000 year NSR period. Zones of maximum tension are shown in warm colors, whereas zones of compression are shown in cool colors. This shows the entire southern hemisphere of Enceladus.

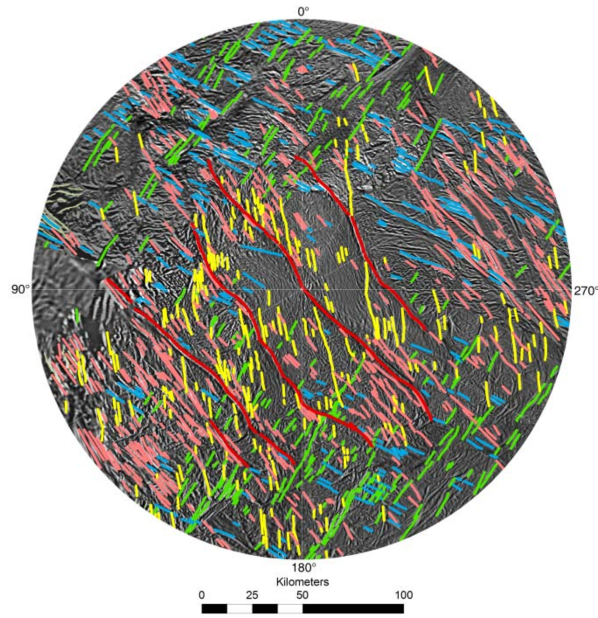

Fig 1: Fractures of the SPT. Fracture set 1 (youngest fractures) is represented by the dark red lines (tiger stripes) and pink lines. The next youngest set (2) is shown in yellow, followed by set 3 in green, and the oldest set (4) is shown in blue. The center of the image is the south pole, and the outer edge is 60° S. Image from [8].

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