A SHEAR HEATING ORIGIN FOR RIDGES ON TRITON. L. M. Prockter[1], F. Nimmo[2] and R. T. Pappalardo[3], [1]Applied Physics Laboratory, MP3-E128, 11100 Johns Hopkins Road, Laurel, MD 20723 (Louise.Prockter@jhuapl.edu). [2]Department of Earth Sciences, University of California Santa Cruz, CA 95064 (nimmo@ess.ucla.edu). [3]Laboratory for Atmosphere and Space Physics, University of Colorado, Boulder, CO 80309 (Pappalardo@lasp.colorado.edu).

Introduction: Triton is believed to be a captured satellite based on its retrograde orbit around Neptune [1, 2]. Both Triton and Europa have relatively young surface ages, as evidenced by the small number of visible impact craters. Europa's global mean surface age has been estimated as ~60 Ma [3], while Triton's surface may only be ~100 Ma [4]. Both moons are likely still geologically active [e.g., 5-7] and have similar surface compositions.

Ridge morphology: Voyager 2 images of Triton's Neptune-facing hemisphere and Galileo images of Europa show remarkably similar linear ridge sets that are not observed on any other planetary bodies (Fig. 1).

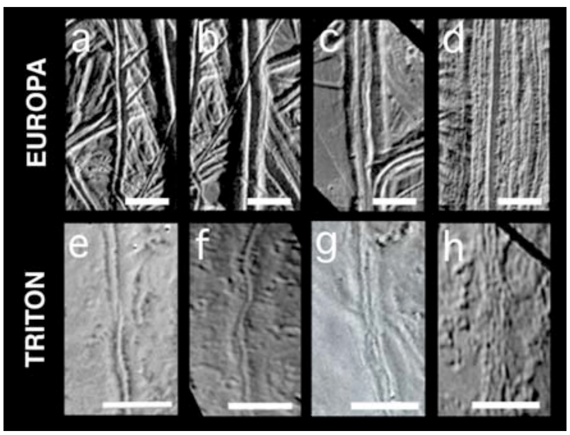

Figure 1: Comparison of Europa and Triton ridge morphology: (a) and (e) Raised flank trough; (b) and (f), Double ridge; (c) and (g) Triple ridge; (d) and (h) Complex ridge. Scale bars: 2 km for Europa, 50 km for Triton.

On both moons, single isolated troughs have raised rims, and double ridges are the predominant ridge type. Triple and multi-crested ridges are also present, but are rare. Triton's ridges tend to be morphologically subdued compared to Europa's, but are much larger in overall scale, having characteristic widths of ~10 km rather than a few km. Some differences in ridge morphology do exist, such as more complex termini and indistinct ridge intersections on Triton. Topographic profiles across a typical double ridge on Europa [9], and on Triton [6] show distinct similarities in ridge shape, despite differences in scale.

Several models have been proposed for the formation of Europan ridges. The shear heating model of [10] has advantages over other models in that it explains several of the morphological features such as the rough appearance of ridge crests and well-developed central troughs, and is the only mechanism consistent with the strike-slip offsets noted along many, if not most ridges [11]. We here argue that the shear heating model may also explain ridge formation on Triton, as a result of the high transient diurnal stresses this body experienced early in its history.

Stress modeling: Following capture into a highly eccentric orbit, tidal dissipation would have reduced Triton's semi-major axis, a, and eccentricity, e, over time. In modeling circularization of Triton's orbit, [12] show that there is a peak in dissipation during a brief period when semi-major axis is reduced but eccentricity remains relatively high. Employing the stress model of [13], we determine diurnal stresses on Triton through time, based on the coupled evolution of a and e after its capture as modeled by [12]. The model assumes an ice shell that deforms above a global liquid ocean, which is likely considering the tidal dissipation following capture by Neptune [14].

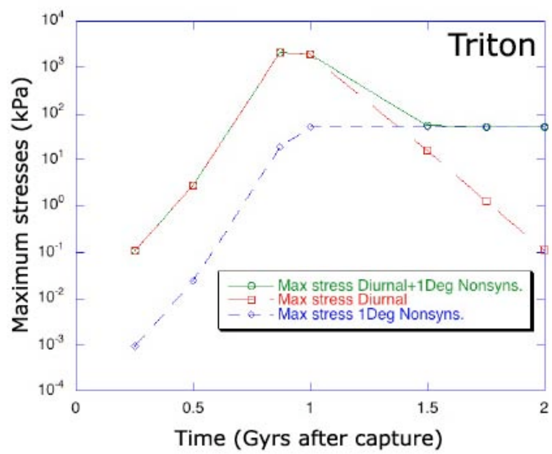

Figure 2: Preliminary plots showing evolution of Triton's stresses over time (after [12]).

Fig. 2 shows the evolution of maximum equatorial diurnal tidal stresses, which peak at ~2 MPa when a ~ 25 Neptune radii and e ~ 0.7. This diurnal stress is 2 orders of magnitude greater than that modeled for Europa [15]. We also plot the maximum stress for 1° of nonsynchronous rotation of Triton, which attains ~0.7 MPa as a decreases through time, then does not change because this stress source is independent of e. Diurnal stress would have been a very important stress source as Triton's orbit began to circularize.

Modeling of ridge formation: Diurnal stresses can lead to cyclic shear motion [16], which in turn may generate shear heating. Here we apply a slightly modified version of the shear heating model of [10] to the case of Triton. Shear motion generates heating in a near-surface brittle layer and a warmer, subsurface ductile layer. The model updates the coupled temperature and velocity fields until both are in steady state. The depth to the base of the brittle layer (BDT depth) is calculated self-consistently, and controls the width of the surface features generated.

Fig. 3 shows typical model results demonstrating that shear heating is a viable mechanism; given the very large uncertainties in important parameters, the exact parameters used should not be taken too literally. Fig. 3a shows the steady-state temperature field for a shear velocity of $2x10^{-9}$ m s^{-1} and a surface temperature of 40 K. The self-consistent BDT depth is 22.5 km and occurs at 112 K. By contrast, on Europa the BDT is estimated at 1-3 km, which likely explains the difference in ridge scale between the two moons. Fig. 3b shows the temperature in excess of the background temperature, and demonstrates that the maximum temperature rise (21 K) is at the base of the brittle zone, as expected. The maximum stress at the base of the brittle zone is ~2 MPa, consistent with the maximum stress derived from the orbital evolution calculations (Fig. 2) implying that the shear heating model is plausible. Fig. 3c shows the vertical topography which would be generated by the temperature anomaly in Fig. 3b and demonstrates that an amplitude of ~100 m can be generated while shear is continuing. The width of both the temperature and the topography anomalies are determined by the depth of the BDT, and are comparable to the observed present-day widths of ridges on Triton (Fig. 1). The temperature-related topography will decay rapidly once shear-heating ceases. However, the elevated temperatures are likely to lead to solid state flow and diapirism [10]; such effects can generate long-lived topography.

Conclusions: Morphologically similar ridges are present on the geologically young surfaces of both Triton and Europa, but have not been observed elsewhere in the solar system. Diurnal stresses are, or have recently been, important on both of these moons and are likely the driving mechanism behind ridge formation. Triton's ridges themselves are not necessarily young, however, but the young surface age and lack of impact craters implies that they formed relatively recently. Since diurnal stressing was important when Triton began to circularize its orbit (not too long after capture) and the surface is young, capture must be relatively recent IF diurnal stresses are an important mechanism for ridge formation. This argues for impact-related capture rather than gas drag capture.

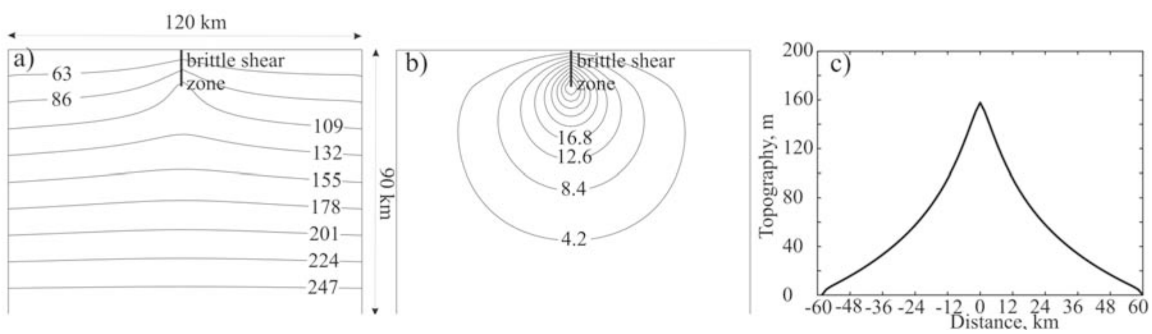

Figure 3: Model of shear heating with self-consistent calculation of brittle-ductile transition (BDT) depth. (a) Temperature structure, contour interval 23 K. Surface temperature 40 K, base temperature 270 K, 61 nodes both vertically and horizontally. BDT depth is 22.5 km. Reference viscosity 10^{14} Pa s, shear velocity $2x10^{-9}$ m s^{-1}, gravity 0.78 m s^{-2}, other parameters identical to [10b, Table 1]. (b) As for (a), but showing temperature in excess of background conductive temperature structure. Contour interval 4.2 K. (c) Surface topography from temperature structure shown in (b). Thermal expansivity assumed $1.4x10^{-4}$ K^{-1}.

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