TECTONIC RESURFACING OF ICY SATELLITES BY PERIODIC NECKING INSTABILITIES: APPLICATION TO GANYMEDE AND ENCELADUS. M. T. Bland and A. P. Showman, University of Arizona (mbland@lpl.arizona.edu), University of Arizona (showman@lpl.arizona.edu).

Overview: Many of the icy satellites in our solar system include young, highly tectonized terrains. Two of the most prominent examples of such surfaces are Ganymede’s grooved terrain and Enceladus’ south polar tiger stripes, both of which appear to have ages of less than 1 Ga [1, 2]. While cryovolcanism likely has occurred and is occurring on these bodies, the lack of obvious cryovolcanic structures within the disrupted terrains themselves has lead many authors to suggest that tectonic processes alone were sufficient to completely disrupt the preexisting surface. Despite this, no quantitative investigations of tectonic resurfacing processes have been performed to date.

We present two-dimensional numerical models of extensional necking instabilities under conditions relevant to Ganymede at the time of the proposed tectonic resurfacing. These models help constrain the conditions necessary for the formation of the grooved terrain. Furthermore, if we assume that tectonic disruption via a necking instability is not unique to Ganymede, the models provide important insight into tectonic resurfacing on icy satellites such as Enceladus.

Background: Ganymede’s grooved terrain is composed of sets of roughly parallel, evenly spaced, gently undulating grooves with amplitudes of several hundred meters [3]. Groove sets are typically hundreds to 1000s of km long and ten to one hundred km wide [4]. Grooves visible in regional scale voyager and Galileo images have wavelengths of 4 km to 17 km with an average of 8 km [5, 6]. While groove morphology varies from one set to another, there does not appear to be any global pattern of groove wavelength or orientation.

Necking instabilities are the most likely formation mechanism for Ganymede’s grooved terrain [7]. The necking instability mechanism assumes that the lithosphere is composed of a stiff, highly viscous surface layer underlain by a ductile substrate. As extension of such a domain occurs, any thickness perturbation in the layers will grow at a rate determined by the horizontal length scale of the perturbation and the details of the rheology assumed [8]. This results in a surface layer that is deformed into a series of periodic, undulating pinches and swells.

Using a linearized analytical model, Dombard and McKinnon [9] applied the extensional necking instability model to the formation of Ganymede’s grooved terrain. They calculated growth rates of a necking instability as a function of wavelength and demonstrated that, under conditions of high heat flow, the fastest-growing modes have wavelengths and growth rates consistent with Ganymede’s grooves. However, questions remain as to whether nonlinearities influence groove formation. Linearized methods must assume infinitesimal strain and can only treat the initiation of grooves. It is expected that as an instability develops and strains become larger, the role of nonlinear effects on instability growth will become significant. Furthermore, it is important to elucidate how such instabilities respond to finite surface topography and whether they are capable of completely disrupting pre-existing terrain.

Methods: We use the two-dimensional, finite-element code Tekton to simulate the extension of a stiff surface layer overlying a ductile substrate. Domains are generally 40 km to 100 km long and 12 km to 24 km deep. A small (~10 m) topographic perturbation is imposed on the surface of the model to allow the instability to initiate. Such a perturbation is consistent with random topographic perturbations on Ganymede’s pre-grooved surface. The rheologic structure of the domain is set by imposing a constant temperature gradient with depth. Effective viscosities are calculated based on recent rheological data for dislocation creep, and grain-boundary-sliding. Newtonian volume diffusion is also included. Plasticity is implemented through the use of a Drucker-Prager rheology and plastic flow occurs only when local stresses exceed a depth independent yield stress. Free parameters in the model include the temperature gradient, strain rate, total strain, and initial topographic perturbation.

Results: Our models produce a strong “pinch-and-swell” morphology typical of Ganymede’s grooved terrain (figure 1). Modeled grooves have amplitudes up to 76 m and wavelengths of 2 km to 11 km. While groove amplitudes are a factor of 3 to 4 smaller than those observed, it is anticipated that decreasing the strain rate or increasing the total strain will lead to increased amplification. The plastic deformation of the surface produced by the necking instability may correspond to a disruption of the surface and tectonic resurfacing.

The development of a necking instability is a strong function of the temperature gradient. On Ganymede, moderate temperature gradients (15 K/km) produce the greatest amount of amplification of the initial perturbation (7.6x). Either increasing the temperature gradient (to 30 K/km or 45 K/km) or dease-
ing the temperature gradient (to 5 K/km) decreases the amplitude of the deformation. These results are inconsistent with the analytical results of Dombard and McKinnon [9], who found that higher temperature gradients produce the greatest amplification. This suggests that non-linear effects play a significant role in groove development.

Low temperature gradients produce the longest wavelength deformation with wavelengths decreasing with increased temperature gradient. This is likely due to the decreased thickness of the plastic layer at high thermal gradients and is consistent with analytical results.

**Enceladus.** Due to Enceladus’ smaller size, gravitational forces are an order of magnitude less than on Ganymede. This reduces the hydrostatic component of the stress and creates a thicker plastic region in the lithosphere. Simulations identical to those described above but without a gravitational stress component were performed and the results are shown in figure 3. Two significant changes are notable. First, dominant wavelengths are shifted to slightly longer values: 5 km instead of 4 km in the 15 K/km case. Second, the greatest amount of amplification occurs at lower temperature gradients: 5 K/km instead of 15 K/km. Furthermore the magnitude of the amplification is significantly larger than in the models with gravity, having a maximum amplification of 22.5 in the 5 K/km case. These results suggest that tectonic resurfacing via necking instabilities would be more efficient on smaller satellites.

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