Determining Elastic Thickness on Dione from Flexure.

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Introduction: Dione is an icy satellite of Saturn with a radius of 561 km and a density of 1480 kg m^{-3} [1]. Like many of Saturn's moons, its surface shows evidence of extension, with numerous faults and grabens that comprise the region known as Wispy Terrain [2][3][4]. We measure the topography of these tectonic features to understand the elastic thickness, the portion of Dione's ice shell that behaves elastically. This is an important parameter because it can be related to Dione's heat flux and thermal evolution [5].

Methods: It was first noted on the Earth that topography, such as ridges and normal faults, impose loads on the lithosphere, causing it to bend in response. The thickness of the elastic layer controls the wavelength and amplitude of the bending[6]. This behavior, known as flexure, has been observed on the icy satellites of Ganymede, Europa, Enceladus and Tethys [7][8][9][10]. We observe flexure on Dione to make estimates of the moon's elastic thickness.

Flexural deformation is difficult to measure, since its magnitude is often small relative to the topography. Therefore high resolution topographic data are required. We construct digital elevation models using Ames Stereo Pipeline[11], an automated stereo program which uses camera pointing information from ISIS and the parallax between features to determine the elevation of each pixel. As input we use Cassini ISS images between 200 and 400 meters per pixel.

Observation and Theory: We take 4 profiles across Janiculum Dorsa, a 500 km long ridge trending north-south on the leading hemisphere. Figure 1 shows the ridge is 1.5 km high, with a 35 km wide, 300 meter deep depression on each side. We assume this depression results from the flexing of a broken elastic plate, in which case the width of this depression is equivalent to $\frac{3}{4}\pi\alpha$, where α is the flexural parameter [6]. The flexural parameter is related to the elastic thickness by

$$\alpha = \left(\frac{E \cdot T_e^3}{3 \cdot (1-\nu^2) \cdot \Delta\rho \cdot g} \right)^{\frac{1}{4}},$$

where $\Delta\rho$ is the density contrast between the mantle and the overlying material, g is gravity, ν is Poisson's ratio, E is Young's Modulus and T_e is elastic thickness. Using values of $\Delta\rho = 1000$ kg m^{-3}, $g = 0.233$ m s^{-2} , $\nu = 0.3$, and $E = 9 \times 10^9$ Pa (from laboratory experiments[12]), we calculate an elastic thickness of ~2 km.

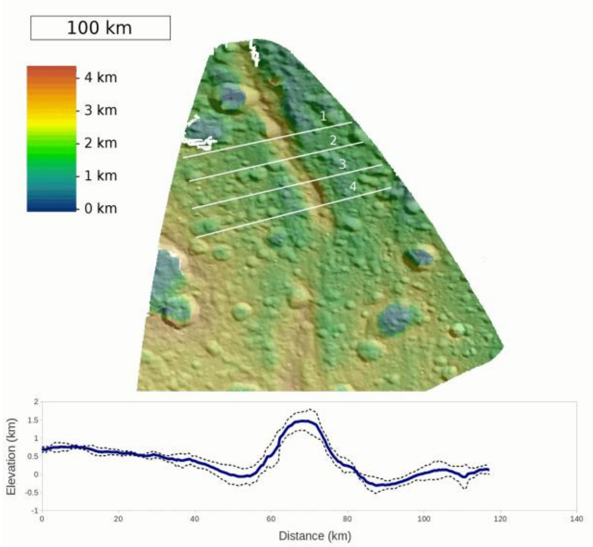

Figure 1: *Digital elevation model of Janiculum Dorsa constructed with Cassini ISS images N1507741140 and N1665975398. Color denotes elevation, white lines represent profiles. Blue line in plot represents average of 4 profiles. Dashed lines show +/- 1 standard deviation.*

We also measure rift flank uplift across a graben in Palatine chasmata, a 1000 km long rift system on the trailing hemisphere. Figure 2 shows the average of 4 profiles across the graben compared with several theoretical profiles of an unbroken elastic layer. An elastic thickness of 3 km matches the data well, but since the elastic layer is likely broken by faults which extend below the surface, the capacity of the elastic layer to support loads is reduced, requiring an increase in the corresponding elastic thickness [6]. We estimate an elastic thickness of ~5km for Palatine chasmata.

Discussion: These values of 2 and 5 km for Janiculum Dorsa and Palatine chasmata are the first local elastic thickness estimates for Dione. We ignore membrane stresses caused by the curvature of Dione [13], which is appropriate given the short wavelength of these features. These local estimates are completely consistent with the global estimate of 1.5-5 km, based on limb profile data, obtained by [14].

Elastic thickness estimates allow us to calculate the heat flux at the surface during the time when the load was emplaced. [5] suggests the temperature at the base of an elastic layer in an ice shell should be 120 – 140 K for strain rates of 10^{-15} – 10^{-17} s^{-1}. Assuming a surface temperature of 80 K and a thermal conductivity of 3 $Wm^{-1}K^{-1}$, elastic thicknesses of 2 and 5 km correspond to heat fluxes of 60 – 90 mWm^{-2} and 24 – 36 mWm^{-2}, respectively.

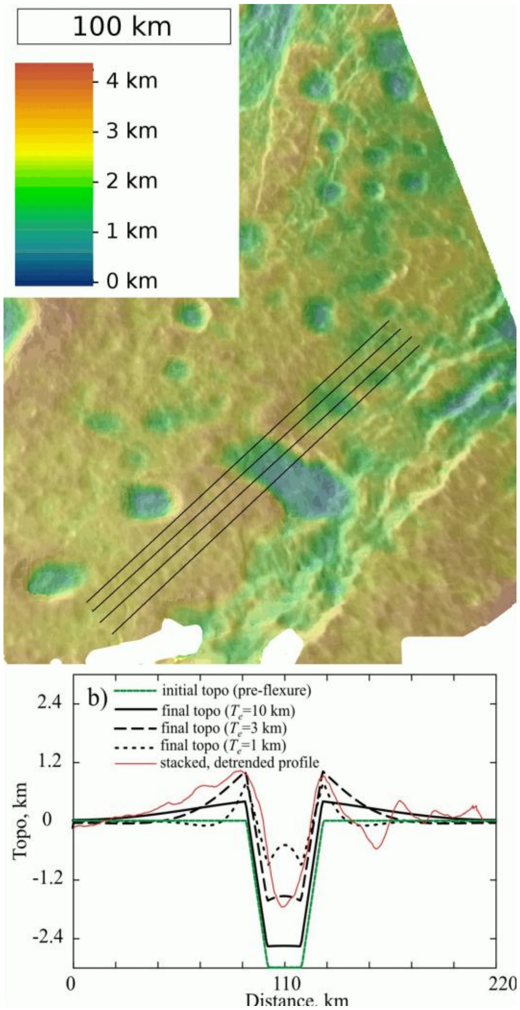

Figure 2: *Digital elevation model of Palatine chasmata constructed with images N1662193216 and N1662195991. Color denotes elevation, black lines show locations of profiles. Panel b) shows average profile in red compared to modeled topography, assuming various elastic thicknesses.*

Janiculum Dorsa had a significantly higher heat flux at the time of its formation than Palatine chasmata. This is important because Janiculum Dorsa is more heavily cratered and thus likely to be older, so a lower heat flux when Palatine chasmata formed is consistent with Dione cooling throughout its history. This result could be coincidental however, as regional variations in heat flux could also be responsible for the difference.

In both cases the heat flux inferred is much greater than that expected due to radioactive decay, but is similar to estimates obtained for other moderately-deformed icy bodies [e.g 10]. These enhanced heat fluxes may have been caused by a warm upwelling of ice during extension or ridge formation. It is also possible they were caused by an early period of high eccentricity during which significantly more tidal heating occurred [cf. 15].

Future Work: We will compare our heat flux estimates derived from flexure with a thermal model of Dione. The viscous relaxation of large craters can also place constraints on heat flux, so we will compare our heat flux estimates with those acquired from a separate study on crater relaxation[16]. We will also conduct a thorough examination of displacement-length ratios for faults on Dione. The displacement-length ratio can be related to the shear strength of the ice shell [7], and the maximum fault length might be influenced by the thickness of the seismogenic zone [17]. These techniques will help us understand the behavior of Dione's ice shell and increase our knowledge of tectonics on icy satellites.

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