FURROW TOPOGRAPHY AND THE ELASTIC THICKNESS OF GANYMEDE'S DARK TERRAIN LITHOSPHERE.

Robert T. Pappalardo[1], Francis Nimmo[2], Bernd Giese[3], Christina E. Bader[4], Lindsay C. DeRemer[1], and Louise M. Prockter[5]; [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Box 392, Boulder, CO 80309; [3]Department of Geological Sciences, University College of London, London, England; [3]DLR, Rutherfordstrasse 2, Berlin, 12489, Germany; [4]Michigan Technological University, 630 Dow Environmental Engineering and Sciences Bld., 1400 Townsend Dr., Houghton, MI 49931; [5]Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723.

Introduction: The effective elastic thickness of Ganymede's lithosphere tell of the satellite's thermal evolution through time. Generally it has been inferred that dark terrain, which is less tectonically deformed than grooved terrain, represents regions of cooler and thicker lithosphere [1]. The ancient dark terrain is cut by furrows, tectonic troughs about 5 to 20 km in width, which may have formed in response to large ancient impacts [1, 2]. We have applied the methods of [3] to estimate effective elastic thickness based on topographic profiles across tectonic furrows, extracted from a stereo-derived digital elevation model (DEM) of dark terrain in Galileo Regio [4]. Asymmetry in furrow topography and inferred flexure suggests asymmetric furrow fault geometry. We find effective elastic thicknesses ~0.4 km, similar to analyzed areas alongside bright grooved terrain.

Data and Analysis: A broken-plate elastic model has been applied by [3] to rift flank uplift identified alongside lanes of grooved terrain in stereo-derived topographic models. The lithosphere is modeled as a thin elastic plate that deforms in response to a tectonically induced negative load. In two regions alongside grooved terrain, minimum misfit elastic thicknesses of 0.9 km and 1.7 km are derived, with a corresponding heat flow ~100 mW m^{-2} during the epoch of grooved terrain formation [3].

We apply analogous methods to model candidate flexural uplifts identified aside ~10 to 20 km wide furrows in the more ancient dark terrain of Galileo Regio (Figure 1). We extracted topographic profiles across the Lakhmu fossae and Zu fossae furrows from a digital terrain model [4] derived from stereo images of a small portion of Galileo Regio.

The characteristic length scale for deformation induced by a load on an elastic plate is governed by the flexural parameter α, which is given by

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

where t_e is effective elastic thickness, E is Young's Modulus, ν is Poisson's ratio of the material, g is gravitational acceleration, and $\Delta\rho$ is the density contrast between the crust and the material above it [5].

We calculate the misfit [6] between the topographic observations and a model flexural profile of a broken plate (appropriate if the rift-zone bounding fault has penetrated the elastic layer). We vary α, the position of the break, and two geometric parameters using the method of [6] to minimize the misfit. We then determine t_e using the above equation.

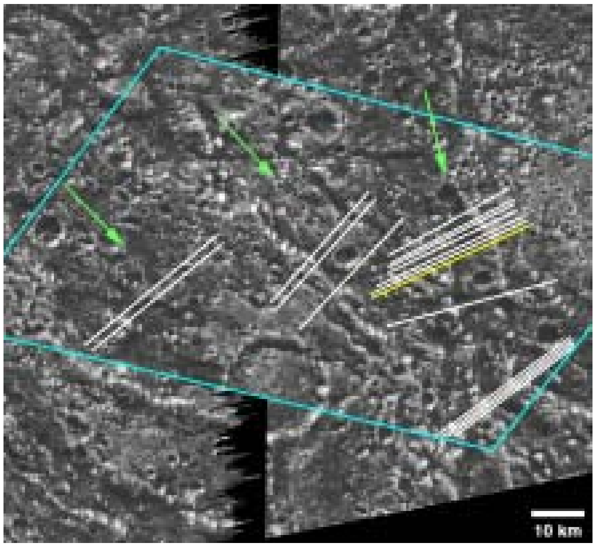

Fig. 1. Locations of representative topographic profiles across N-S-trending Zu Fossa (arrow, right) and two NW-SE-trending Lakhmu Fossae (arrows, center and left) within Galileo Regio, as imaged by the Galileo spacecraft during its G1 and G2 orbits. Yellow profile is illustrated in Figure 2. Blue outline delimits the region of stereo image coverage.

The Young's modulus of ice on Europa was assumed to lie between 6 x 10^7 and 6 x 10^9 Pa by [7] and has been measured in terrestrial laboratory samples at 9 GPa [8]. We use a nominal value of 1 Gpa for Ganymede based on terrestrial tidal flexure modeling [9]. We assume a Poisson's ratio of 0.33, a density of 1000 kg m^{-3}, gravity of 1.4 m s^{-2}, and surface temperature of 120 K. The mean thermal conductivity over the range 120 to 200 K is 3.6 W m^{-1} K^{-1}.

Fault Geometries: Past studies have assumed that Ganymede's furrows are graben, bounded by antithetically dipping normal faults that intersect near the brittle-ductile transition during the time of deformation [1]. This implied that lithospheric thickness is similar to furrow width (~10 km). However, we find marked asymmetry in furrow rim height and the corresponding sense of inferred flexural topography (Fig. 2a). This suggests asymmetry in fault geometry, specifically formation of the topographically more pronounced side as an uplifted footwall block, with associated rollover and antithetic faulting of the hanging wall block and lesser flexural uplift there (Fig. 2, inset). Thus, the assumed simple relationship between furrow width and lithospheric thickness of previous workers does not hold.

Model Results: Fig. 2 shows a representative spatial profile and flexural fit. (We note that secondary faults may occur along the fit profile, as in Fig. 2, but have been ignored here.) Our model results indicate effective elastic thickness in the range ~0.1 to 1.1 km for the Galileo Regio furrows, with most being fit by a value of ~0.4 km (Fig. 3). Consistent results are found by modeling the shape of the flank profile only (Fig. 2, red curve), or by modeling the flank profile given an assumed negative load caused by the furrow topography. Comparison to the results of [3] indicate a similar heat flux of ~100 mW m^{-2}.

Discussion: We find that both our dark terrain furrow profiles, and profiles along boundaries between dark and grooved terrains [3], can be fit to within 20% of the minimum misfit values by using an elastic thickness of 0.4 km. Thus, the available data do not require any significant difference in t_e among these locations. A similar effective elastic thickness in dark terrain and alongside grooved terrains contrasts with previous studies (in which all furrows and grooves were modeled as graben with bounding faults intersecting at the brittle-ductile transition). If these results can be generalized to Ganymede as a whole, then similar inferred effective elastic thickness in ancient dark terrain and alongside more recent grooved terrain suggests that either: (1) Ganymede's lithospheric thickness remained essentially constant from the period of dark terrain formation through the period of grooved terrain formation, or (2) Ganymede's heat flux was similar during the periods of dark and grooved terrain deformation but waned in between. The latter hypothesis might be reconciled with dark terrain deformation during an early warm period after satellite accretion, and grooved terrain deformation during a later epoch of heating, such as a tidal heating event [10].

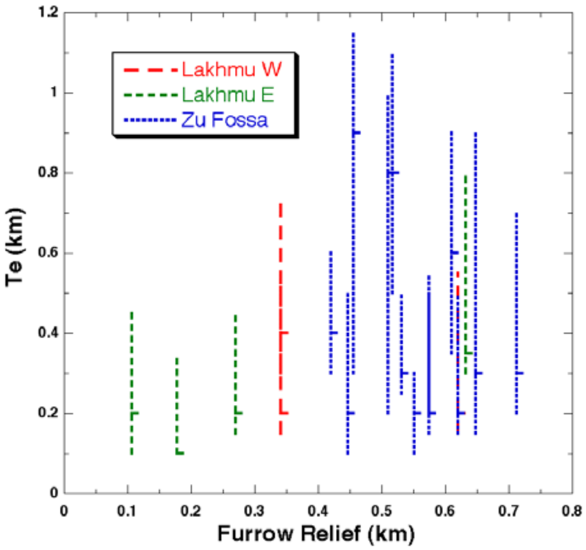

Fig. 3. Best fit elastic thickness vs. furrow relief for each profile. Furrow relief is defined as maximum floor-to-rim-crest furrow height (Fig. 2, blue arrow) minus the average profile height. Horizontal ticks represent best fit elastic thickness, and the vertical bar shows the estimated error based on misfit plots. These profiles indicate potential elastic thickness in the range of ~0.1 to 1.1 km, and most likely ~0.4 km, for a nominal Young's modulus of 1 GPa.

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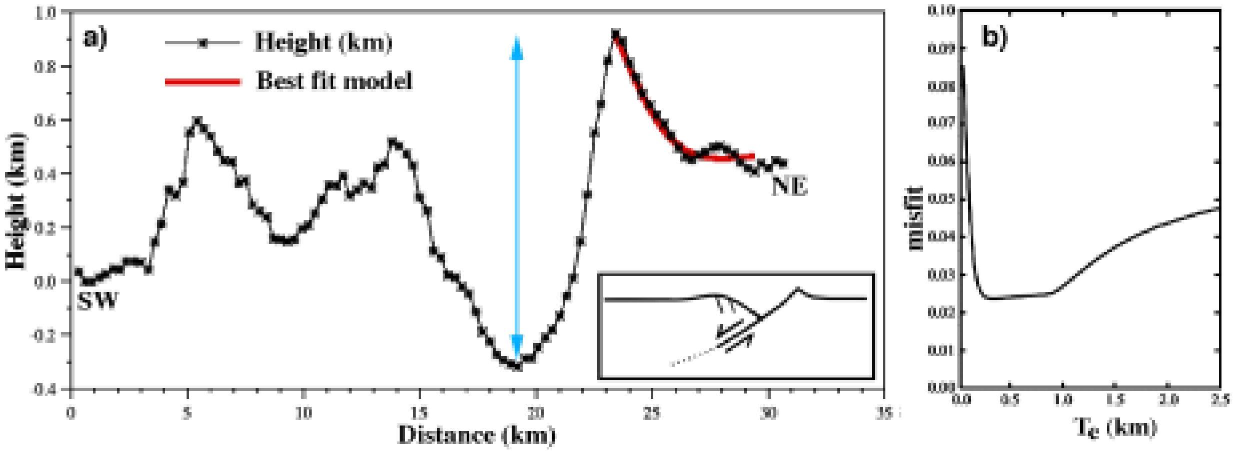

Fig. 2. (a) Profile across a Zu furrow in Galileo Regio (see Fig. 1). Best-fit flexure model is in red. The sense of topographic asymmetry suggests an asymmetric fault geometry, with a more prominent west-dipping fault (inset). (b) Associated misfit between the topography and the best-fit flexural model, with a minimum of Te = 0.3 km.