ESTIMATES OF EUROPA'S ICE SHELL THICKNESS FROM ELASTICALLY-SUPPORTED TOPOGRAPHY. F. Nimmo, *Dept. Earth Sciences, University College London, London WC1E 6BT, UK, (nimmo@ess.ucla.edu)*, B. Giese, *DLR, 12489 Berlin, Germany, (bernd.giese@dlr.de)*, R.T. Pappalardo, *Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, USA, (robert.pappalardo@colorado.edu)*.

The thickness of Europa's solid ice shell is uncertain, and has important implications for Europa's habitability and thermal history. Here we obtain an estimate for the ice shell thickness from observations of a plateau SW of Cilix impact crater ($3^\circ N, 182^\circ W$). A shell thickness of ≈ 25 km is compatible with our observations; a conservative lower bound is 6 km.

Fig 1 shows a Galileo image of the area, with Cilix in the northern portion. Fig 1 also shows a digital elevation model (DEM) of the same area, derived by combining the 120 m/pixel image shown with six 70 m/pixel Galileo images to form stereo pairs [*Giese et al.*, 1999]. Of particular interest is a 30-40 km wide plateau-shaped feature in the southern portion of the image, which is bounded on both the NW and SE sides by shallow topographic lows. Fig 2 shows a series of topographic profiles across this plateau. It demonstrates relatively steep scarps (slope $\approx 2^\circ$) to the north and south, with a moat outboard of the scarps.

Figure 3a shows the mean topography of profiles p1-p6, obtained by stacking them using the northern plateau scarp as a fixed point. The dashed lines show the standard deviation about the mean. The bold line is a best-fit model flexural profile, calculated by varying the assumed trapezoidal load geometry and the elastic thickness of the underlying plate until the misfit is minimized. The best-fit elastic thickness t_e is 6.0 km, and the fit to the topography is generally within one standard deviation, except at the far southern end of the profile. A study by *Figueredo et al.* [2002] of Murias Chaos, Europa, produced a slightly smaller value of $t_e \approx 4 \pm 2$ km, but these authors did not relate this value to the total solid shell thickness.

Figure 3b shows the local minimum value of the RMS misfit H as a function of t_e (solid line). The existence of a minimum misfit, H_{min} is apparent for the stacked profile; it is also clear that H increases rapidly for values of t_e less than the best-fit value. For a misfit range of $1.2H_{min}$, the acceptable range of t_e is 4.6-9.4 km. The dotted lines in Figure 3b are misfit plots of the fit to the individual profiles p1,p3 and p5 of Figure 2. They all show that small values of t_e produce unacceptably high misfits. Best fit t_e values for these profiles range from 4.9 km to 11.9 km.

The depth to which ice can maintain long-term elastic strength depends on both temperature and strain rate. At low strain rates or high temperatures, the ice will deform in a ductile fashion and the elastic stresses will be relaxed. There is thus a characteristic temperature T_R which defines the base of the elastic layer [*Nimmo et al.*, 2002]. For a conducting shell, the increase in temperature with depth depends on the total shell thickness; thus the elastic thickness may be used to constrain the crustal thickness. For the conducting part of the ice shell, in which conductivity varies as $1/T$, we have

$$\frac{t_c}{t_e} = \frac{\ln(T_B/T_S)}{\ln(T_R/T_S)} \tag{1}$$

where T_S is the surface temperature (105 K), t_c is the thickness of the conducting layer and T_B is the temperature at the base of this layer. The likely value of T_B is 260-270 K; for T_R both homologous temperature arguments and viscoelastic relaxation calculations [*Nimmo et al.*, 2002] suggest that T_R = 140-185 K. These values imply that $t_c = 1.6 - 3.3\ t_e$. Above, we estimated t_e to be 6^{+5}_{-2} km, implying that t_c is in the range 6-36 km, with a most likely value of 15 km. If the shell is convecting, the thickness range obtained here is a lower bound.

There are now at least three independent estimates of Europa's shell thickness which are mutually self-consistent: impact crater constraints ($t_c \geq 19$ km [*Schenk*, 2002]); convective tidal dissipation models ($t_c \approx 25 - 50$ km [*Hussmann et al.*, 2002]); and the flexural results presented here (t_c=$15^{+21}_{-9}\ km$). These results together suggest a uniform present-day shell thickness for Europa close to 25 km.

References

Figueredo, P., F.C. Chuang, J. Rathbun, R.L. Kirk and R. Greeley, Geology and origin of Europa's "Mitten" feature (Murias Chaos), *J. Geophys. Res., 107*, 10.1029/2001JE001591, 2002.

Giese, B., R. Wagner, G. Neukum and J.M. Moore, The local topography of Europa's crater Cilix derived from Galileo SSI stereo images, *Lunar Planet. Sci. Conf. XXX*, abs. no. 1709, 1999.

Hussmann, H., T. Spohn and K. Wieczerkowski, Thermal equilibrium states of Europa's ice shell: implications for internal ocean thickness and surface heat flow, *Icarus, 156*, 143-151, 2002

Nimmo, F., R.T. Pappalardo and B. Giese, Effective elastic thickness and heat flux estimates on Ganymede, *Geophys. Res. Lett. 29*, 10.1029/2001GL013976, 2002.

Schenk, P.M., Thickness constraints on the icy shells of the Galilean satellites from a comparison of crater shapes,*Nature 417*, 419-421, 2002.

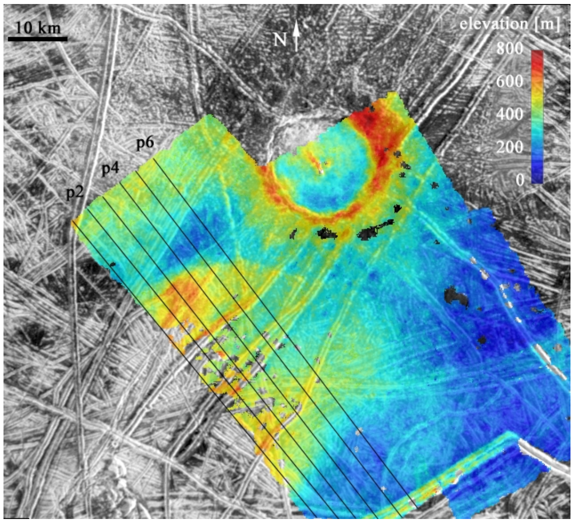

Figure 1: Galileo image of Cilix crater and surroundings with superimposed stereo-derived topography (colour). Background image resolution 120 m/pixel. Topography horizontal resolution 500 m, vertical resolution 30-60 m.

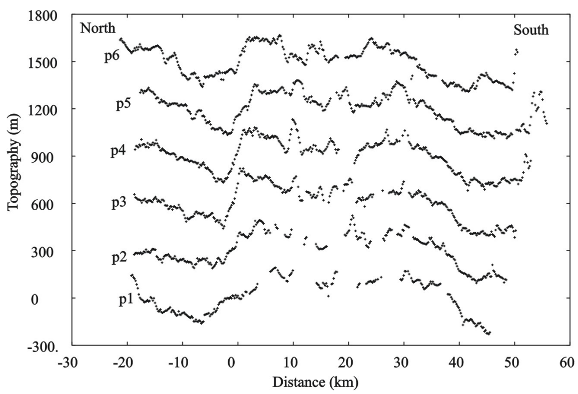

Figure 2: Topographic profiles p1-p6 (locations in Fig. 1). A vertical offset of 300 m was added to each successive profile. Profiles are aligned on the NW plateau scarp to enable stacking (see Fig. 3).

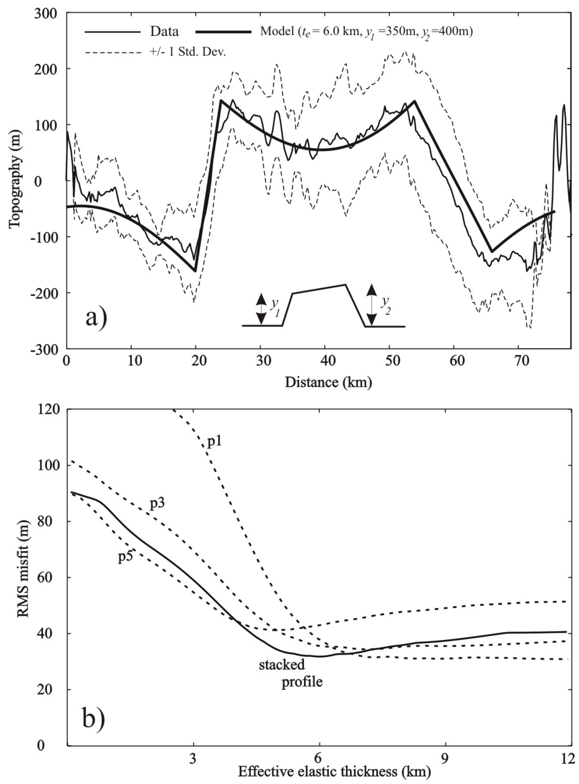

Figure 3: (a) Stacked topographic profile, after removal of mean and a linear trend joining the end-points. Raw data were linearly interpolated to 0.2 km spacing and a linear trend joining the end points was removed prior to stacking. Solid line is the mean; dashed lines are ± one standard deviation (std. dev.) plotted where the number of profiles exceeds 2. Bold line is best-fit flexural profile assuming an initially trapezoidal load geometry (see inset) with an elastic thickness t_e of 6.0 km, y_1 = 350 m, y_2=400 m. The zone of computation for the theoretical profile extends 20 km beyond each end of the figure. The constants assumed were: g = 1.3 $m\ s^{-2}$, $\rho_m = \rho_c$=900$kg\ m^{-3}$, E=1 GPa, ν=0.3. (b) Minimum RMS misfit as a function of t_e. Solid line is misfit function for profile in a); dashed lines are misfit functions for individual profiles as labeled.