ICE LITHOSPHERE THICKNESS ON EUROPA FROM IMPACT BASIN RING-GRABEN.

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Introduction: Craters are well known probes of planetary surface and interior properties [1]. Here we examine graben surrounding the two largest multiring basins on Europa, Tyre and Callanish, for clues to the thickness of the ice shell. The radial extension necessary to form these graben is presumably caused by asthenospheric drag of more ductile ice and/or water flowing towards the excavated center of the crater under a brittle lithospheric lid [e.g., 2,3]. Measurements of graben depths result in estimates of displacement, strain, and stress experienced by the material. Graben widths are used to estimate the intersection depth of the bounding normal faults, a quantity related to the brittle-ductile transition (BDT) depth that approximates the elastic shell thickness. Heat flows at the time of crater formation and total shell thickness are also constrained.

Mapping: Base mosaics and topography were generated from Galileo images. For Tyre (~38 km in diameter, centered at 33.6°N, 146.6°W), the base mosaic has a resolution of 170 m px^{-1}, and topography was derived from photoclinometry only. Stereo-controlled photoclinometry was available for Callanish (~33 km in diameter, 16.7°S, 334.5°W). Although only the southern half of Callanish was imaged, there are two image sequences: one at 120 m px^{-1} and another at 45 m px^{-1}.

Graben outlines were mapped and marked as tentative in some places. Both basins have 6-7 concentric graben. Graben widths and depths were measured along profiles extending radially from the basin centers. The center of each basin was selected by a least-squares fit to the radius of curvature of the surrounding graben and concentric ridges [4,5]

Morphometric Results: To sample and characterize graben widths, measurements were made at intervals of 5° around the basins. Similar to previous results [5] graben widths vary, with Tyre graben slightly larger (mean of 2.0 ± 0.8 compared to 1.4 ± 0.7 km for Callanish) (Fig. 2). Graben widths generally decrease away from the crater. Graben *spacing* varies but in general the widest separations are found farther from the crater center. Average graben spacing is 9.3 ± 3.6 km for Tyre and 7.2 ± 1.4 km for Callanish.

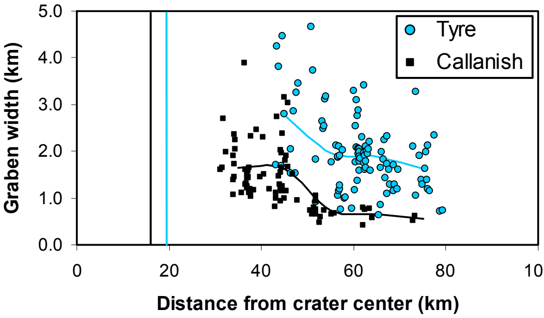

Figure 2. Graben widths as a function of distance from the basin centers. Solid curves show a moving average (10 km windows) and vertical lines indicate the final, "equivalent" basin radius (based on ejecta deposit scaling [1]).

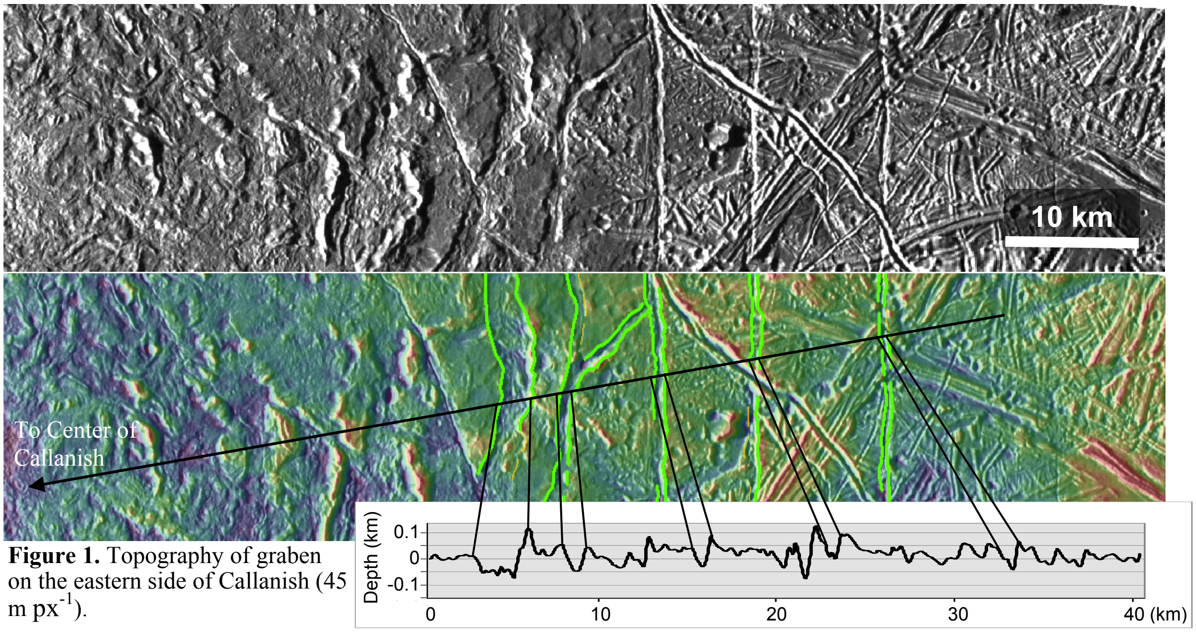

Figure 1. Topography of graben on the eastern side of Callanish (45 m px^{-1}).

Graben *depths* were measured directly from topographic profiles (example in Fig. 1) and are in the range of 50-150 m for Tyre, and 30-100 m for Callanish (average for the inner and outer footwalls). Shadows obscure the full depth of some graben; thus some values here may be minima.

Strain: Using the average measured graben depths (d) given above, the radial displacement (Δr) across each graben was calculated assuming both bounding normal faults dip at $\theta = 62°$ (based on [6]). For each wall $\Delta r = d/\tan\theta \approx d/2$, but when added the total displacement is ≈equal to the average depth of the graben in question. Thus inward radial displacements per graben are in the range of 50-160 m and 30-105 m for Tyre and Callanish, respectively.

Radial strain (ε) was calculated for 9-10 profiles per crater (Fig. 3) by incrementally summing the displacements for all graben in the profile from the outside in: $\varepsilon(r) = \Sigma\Delta r/(r+\Sigma\Delta r)$. Values for maximum radial strain reach ~1% for the innermost graben, which imply circumferential lithospheric stresses (i.e., those parallel to the graben strike) of order 100 MPa, in the absence of secondary faulting. Such stresses are compatible with prompt collapse of the transient cavity but not with long-term isostatic adjustment. Similar or even greater stresses may be responsible for the rugged topography (annular massifs, displaced and possibly rotated crustal blocks [7]) inward of the grabens at both structures.

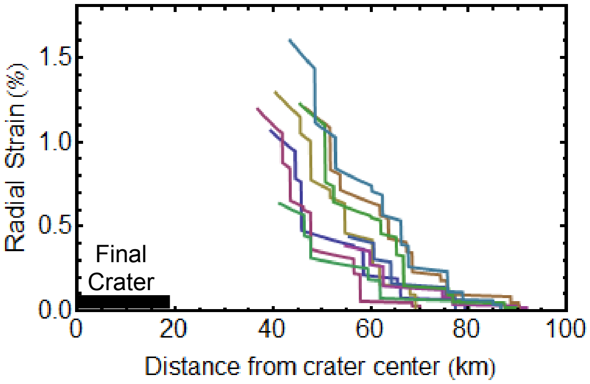

Figure 3. Strain vs distance profiles for Tyre; each graben wall represents a jog in total strain, with strain accumulating from outside (right) towards the inside of the basin (left).

Depth to BDT and Implications for Heat Flow: The intersection of the two graben bounding normal faults provides a lower limit on the depth to the brittle-ductile transition (keystone or "V" model). However, numerical modeling and terrestrial field studies suggest a depth up to twice as deep may better mark the BDT (hourglass or "X" model [8-11]). What does seem clear is that the troughs surrounding Tyre and Callanish are indeed graben (preexisting surface structures within the downdropped blocks are noted) and that the graben formed in response to thin-skinned extension over a decoupling layer (as at Canyonlands [11,12], the Silverpit structure [13], and possibly the Praia Grande structure [14]).

We envisage the ring graben forming in sequence – from the inside out – via some combination of asthenospheric drag and gravity sliding. If the brittle yield strength and viscous creep stress are equal at the BDT (and assuming the radial stresses are what matter), then the temperature at the BDT is determined for a given strain rate [e.g., 5,15,16]. Values of heat flow q can be inferred if the thermal conductivity structure of the lithosphere is known. For an airless body such as Europa, unclosed fractures in the upper lithosphere [e.g., 17] must greatly reduce conductive heat transport, as fracture surfaces are vacuum interfaces across which heat is only conducted at asperities.

Strain rates for a collapsing transient crater are on the order of the inverse gravitational free-fall time, but decline with a r^{-4} radial dependence [2,18], as the ocean on Europa implies asthenopheric flow is not channelized. We find, e.g., strain rates for the outer graben at Tyre (transient diameter ~23 km [1]) of ~5 x 10^{-6} s^{-1}. For BDT depths of 3–4 km, the implied heat flows for solid ice conductivities [19] are ~150–200 mW m^{-2}. Realistic (lower) conductivities reduce these heat flows to values easily compatible with other geophysical estimates [20,21]. Detailed lithospheric structure and heat flow models will be presented for both Tyre and Callanish.

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