**THERMAL AND TOPOGRAPHIC TESTS OF EUROPA CHAOS FORMATION MODELS.** 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)*, P. Figueredo, *Dept. Geological Sciences, Arizona State University, Tempe AZ 85287-1404, USA, (figueredo@asu.edu)*, W. B. Moore, *Dept. Earth and Space Sciences, UCLA, Los Angeles CA 90095-1567, USA, (bmoore@artemis.ess.ucla.edu)*.

The manner in which chaos terrain formed is the subject of considerable debate, and has important implications for the shell thickness, heat flow and astrobiological potential of Europa [1]. Here we investigate two models of chaos terrain formation, and conclude that neither model is entirely satisfactory for the areas studied. The diapiric melting model of Collins et al. [2] is unable to produce sufficient melting to explain the observations. The melt-through model of O'Brien et al. [3] requires implausible amounts of heating.

We investigated two areas for which we have access to topography data. Fig 1 shows two series of topographic profiles: one using high-resolution stereo data from the E15 orbit [4]; the other using photoclinometry across the Mitten (Murias Chaos) [5]. In both cases the chaos terrain is bounded by a steep scarp, and is lower than the immediately adjacent background terrain. However, both chaos areas are domed, so that their centres are higher than the background terrain. Below we investigate two mechanisms which may explain this topography.

**Subsurface diapirism** Observations of Conamara Chaos show that the area is elevated relative to the surroundings, and that individual blocks appear to have both moved laterally and tilted [6]. Collins et al. [2] suggested that these observations could be reconciled by a diapir model in which the ascending diapir melted near-surface, salt-rich ice. We propose that the lateral drainage of this melt could lead to subsidence and generate the marginal fractures and trough observed in chaos regions in a manner analogous to terrestrial caldera structures.

To test these suggestions, we modelled the amount of melt generated by a stationary, rectangular diapir beneath a low-melting temperature ice layer. Figure 2 shows a typical result, and demonstrates that only a small thickness of melt-water (250 m in this case) is generated, even for extremely low-melting temperature ice (170 K), and that the melting does not extend close to the surface. For more realistic melting temperatures (200 K or above), no melt is produced. Emplacing the diapir nearer the surface results in less melt being generated, because the surrounding ice is even colder. These small volumes of melt are insufficient to allow the chaos blocks to float. Although the draining of melt could potentially generate subsidence and chaos degradation, superimposed on uplift due to the diapir, the melting temperatures required to generate melting are much lower than that of any likely ice on Europa [7]. This is a fundamental problem for the diapirism model.

**Melt-through model** The first observations of chaos terrain suggested that liquid water had reached the surface [1], and that the local ice shell thickness was 0.5-2 km [8]. However, there are severe energetic difficulties in this scenario [2].

Assuming a 50/50 mixture of matrix and 2 km thick chaos blocks implies a mean ice thickness of 1 km. Maintaining such a mean thickness requires a heat flux of $500$ mW m$^{-2}$ or (for internal heating) a volumetric heat generation rate of $500\ \mu$W m$^{-3}$. Chondritic radiogenic heat production in Europa's interior is about $5$ mW m$^{-2}$, and tidal dissipation within the shell is unlikely to exceed $3\ \mu$W m$^{-3}$ [9]. Thus, unless these kinds of heating can be concentrated either in time or in space by a factor of $\sim$100, generating a melt-through event seems difficult to achieve.

A consequence of the melt-through model is that the melted ice will eventually re-freeze. If the marginal ice is anchored to the adjacent unmelted material, it will experience an upthrust due to Archimedes' principle as the ice thickens. This upthrust will result in doming of the re-freezing ice [1], the shape of which can be obtained analytically.

Figure 3 shows the result of fitting this model to the two areas shown in Fig 1. In both cases, the ice shell thickness $h$ exceeds the elastic thickness $T_e$, as expected. The values of $h$ obtained (1.4-2.5 km) are similar to those obtained by [8] using an independent approach, and suggest that, at least locally, the ice was relatively thin. A thinner ice shell is easier to melt. We note that the shell thickness thus obtained is relevant to that at the time of chaos formation, and is not necessarily the present-day value.

**Summary** The principal problem of the diapirism model is that it is exceedingly difficult for this model to generate appreciable quantities of melt. This problem might be reduced if tidal heating is concentrated in ascending diapirs [10], but it is by no means clear that such a mechanism is possible [11]. Similarly, although the melt-through model provides a reasonable fit to observations of chaos terrain, the source of energy required to cause such an event is unknown.

**References**

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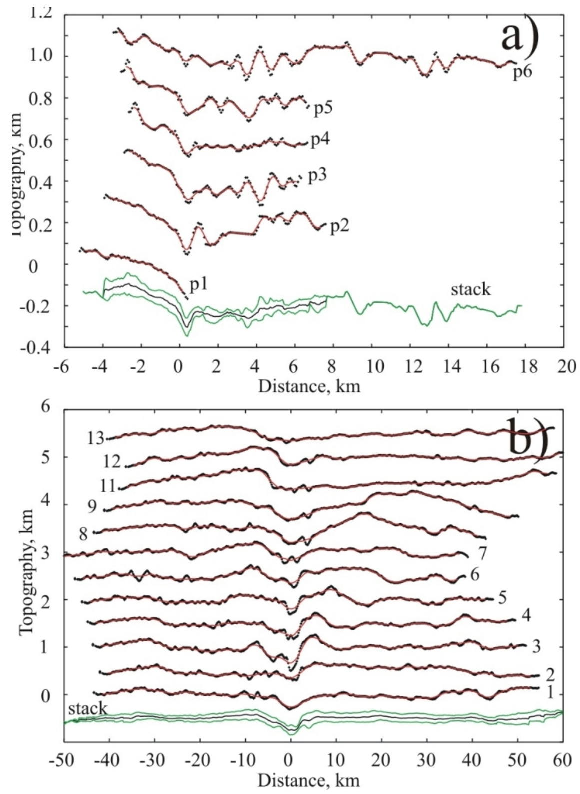


Figure 1: Stereo topographic profiles across E15 chaos area, using method of [12]. Profiles are radial, left-hand end at centre of chaos region. Successive profiles are offset vertically by 0.2 km and the mean elevation was removed. Black crosses are the raw data; red lines are the data, interpolated and filtered. The profiles are aligned on the steepest point of the filtered data within 6 km of the origin. The bottom profile is the result of stacking the observations, with the green lines showing ± one standard deviation (s.d.). b) Photoclinometric topographic profiles across Mitten area [4], left-hand end at centre of chaos region . Profiling and stacking as for Fig 1a, but with a best-fit line removed from each profile and using different parameters: vertical offset 500 m, alignment on the lowest point within the range 30-60 km.

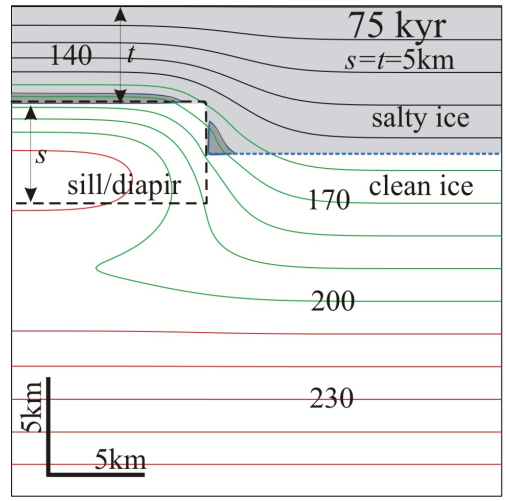


Figure 2: Typical outcome of melting models described in text, plotted at the instant of maximum melt production (75 kyr). Solid lines are temperature contours (in K). Initial diapir location denoted by dashed lines; initial diapir temperature 250 K. Light shaded area denotes location of salty ice (melting temperature 170 K). Dark shaded areas depict points at which partial melt generation occurs. The mean thickness of the meltwater lens overlying the diapir is 250 m.

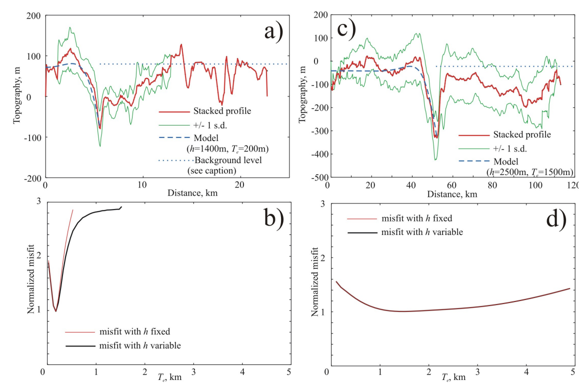


Figure 3: a) Red line is stacked topographic profile of E15 area, using the data from Fig 1a and detrended. Thin green lines are ±1 s.d. Dashed line is best-fit solution using the melt-through model described in the text. Best-fit ice thickness $h$ is 1400 m and $T_e$ =200 m. Dotted line indicates theoretical elevation of background terrain assuming same density and thickness as the re-freezing ice. b) Misfit, normalized to the minimum value of 0.37, as a function of $T_e$. Misfit is calculated over the domain indicated by the dashed line in a). Black line plots misfit when $h$ is allowed to vary for each value of $T_e$; red line plots misfit when $h$ is fixed at 1400 m. c) As for a) but using stacked, detrended version of profiles 7-13 from Fig 1b and the best-fit model uses $h$=2500 m and $T_e$=1500 m. d) As for b), except that minimum misfit is 0.63.