STRESS FIELD ABOVE AN ICE CAULDRON ON EUROPA.
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Introduction: Chaotic terrain on Europa are areas where blocks containing pre-existing surface material has been broken into discrete blocks and surrounded by matrix materials [1,2]. Chaos regions also commonly stand above the surrounding terrain [3] with a dome like topography.

Schmidt et. al [4] proposed a model of chaos formation based on a comparison on the topography at Conamara Chaos and Thera Macula. Both features are quasi-circular structures; however Conamara Chaos has a dome-like topography while Thera Macula is "sunken" in. Both had Thera Macula and Conamara Chaos have blocks of pre-existing material surrounded by impurity rich matrix. They proposed that Conamara Chaos and Thera Macula represent different stages of the crystallization of a melt lens within the ice shell.

In their model, they propose that an ascending thermal plume rises through the ice shell, crossing the eutectic point and potentially creating upwarping at the surface. The melting of the lens causes the overlying ice shell to be flexed downward, allowing for the formation of fractures in the ice. Brine from the lens could then be injected into the cracks, and crystallize, forming the matrix observed at the surface between intact blocks of pre-existing plain materials. The re-crystallization of the entire lens then creates the raised topography as the volume of the lens increases. In order for this model to match observations the cracks must vertically from the lens to surface to allow extraction of brine form the subsurface water body.

We use an axisymmetric finite element model to model the stresses induced by melting of a lens within Europa's ice shell and evaluate the cracking expected within the stress fields.

Thera Macula: Thera Macula (Figure 1) consists of a southern chaotic region and a semi-circular northern region. The chaotic region of Thera Macula sits below the surrounding terrain; however the northern region does not. At the boundary between the northern and southern regions, blocks containing pre-existing terrain have been broken and are now surrounded by matrix material. A circumferential depression runs around a majority of both the northern and southern regions of Thera Macula.

Modeling approach: We consider the elastic deformation of an ice shell under loads corresponding to the ascent of a warm ice diaper and the melting of a lens-shape region under the ice. The ice has initially uniform density. Its base is supported by restoring forces representing the response of the water layer below the ice.

Uplift induced by the diapir is generated by reducing the weight of a predefined region at the base of the crust. Two aspects of the melting of subsurface lens are implemented: 1) the increase in density 2) the reduction in shear strength. However, the material inside the melt body remains solid, only with modified material properties. In these preliminary models, we do not consider the possibility of failure in the surrounding ice. The stress field generated in our models gives a first indication of the failure mode of the ice. However, detailed estimates of crack propagation would need to take into consideration the how cracking modified the stress field.

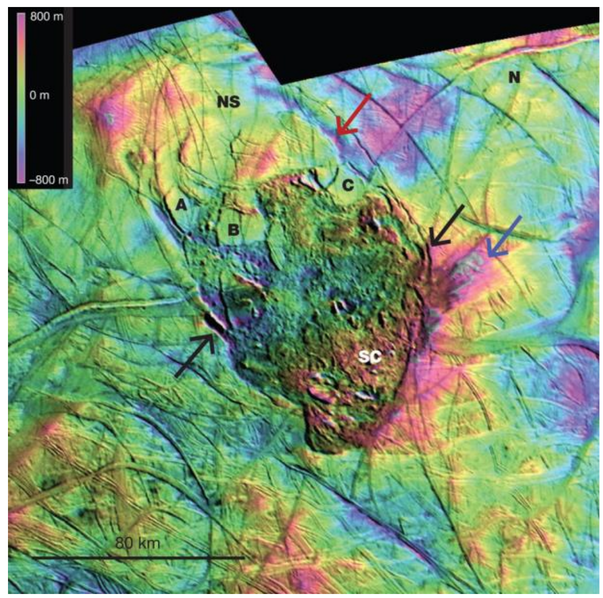

Figure 1. Image of Thera Macula from [4]. The chaotic region shows in the south has a lower topography. Blocks from the northern region have clearly broken away and are surrounded by matrix material. The red and black arrows point to a circumferential depression outlining Thera Macula.

Lens Melting and Stresses:

Figure 2 shows the variations in maximum stress (which controls crack formation) in the region surrounding in the ice shell follow diapir-induced uplift and densitification in the lens. We discuss the stress field in two regions, immediately above the melt lens, where Schmidt et al. [4] propose vertical cracks are forming, and in the flexural limb above the edge of the melt lens.

The stresses induced by the melting of the lens are incompatible with the formation of vertical cracks going up from the lens. As the volume of the lens decreases the overlying ice is dragged down toward the lens. The maximum tensile stress directly above the melt lens is in the vertical direction, causing cracks to propagate horizontally, rather than vertically. If cracking occur, it has the effect of separating a lens of ice from the roof of the melt body. However, there is no evidence that vertical cracks will propagated from the roof of the melt body.

When the upward force related to the negative buoyancy of the thermal plume is also included in the model (Figure 2), the upward flexure of the ice shell causes a region of radial cracking on top of the diapir. Interactions between that stress field and the melting-induced field can generate a thin region along the summit of the melt body where vertical cracks may be generated (Figure 2). The static view of the stress field shown here does not predict that cracks would propagate far from the melt body, but it is possible that dynamic stresses associated with crack propagation will make it possible to open a passage between the melt lens and the surface.

A vertical circumferential crack is expected to form at the surface in the bright red region above the edge of the melt lens (Figure 2). Cracks generated in this region may become unstable and propagate downward. However the static stress field in Figure 2 implies that these cracks would deviate away from the melt body. Therefore, they are not expected to serve as conduits for brine to reach the surface.

Geological Evaluation: The geology of Thera Macula shows a pronounced fissure circumferential to the structure. This is a possible analogue to the region of intense cracking present above the edge of the melt body in our models. The region above the melt body is dominated by horizontal compression if only melting is included, and by radial cracks if the diapir-induced stress field is dominant. Neither is observed in Thera Macula. We also do not predict connection between the melt body and the surface. Deviations for axisymmetry and the importance of reactivation of previous cracks may be responsible for the limited agreement between our model and observations. The dynamics of crack propagation must be studied next to evaluate whether the proposed model of diapir-incuded melting is able to capture the observations of Thera Macula.

References:

[1] Carr, M.H. et al. (1998) *Nature 391*, 363-365. [2] Spaun, N. A. et al. (1998), *GRL, 42*, 4277-4280. [3] Collins, G. C. et al. (2000), *JGR, 105*, 1709–1716. [4] Schmidt B. E. et al. (2011) *Nature, 479*, 502-505 .

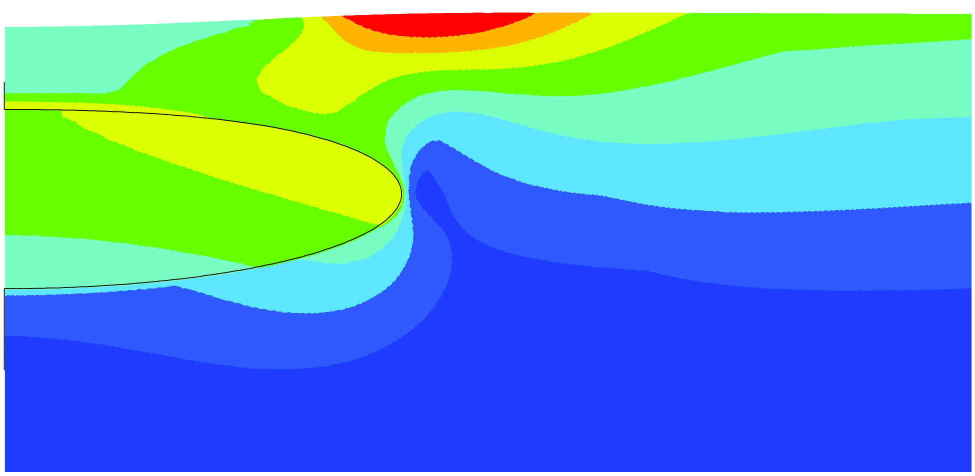

Figure 2. Variation of maximum principal stress in an axisymmetric model of the ice shell loaded by a reduced weight in diapir below the visualized area and by melting (density reduction) in the elliptical area shown here. The maximum principal stress increases from the blue to the red color.