A MELT-HYDROFRACTURE MODEL FOR THE FORMATION OF EUROPA'S CHAOS TERRAIN. B. E. Schmidt[1] and D. D. Blankenship[1], [1]Institute for Geophysics, U T Austin (britneys@ig.utexas.edu).

Introduction: Chaos terrain is unique to the surface of Europa, and as such may be diagnostic of the properties and dynamics of the shell that gave rise to it. The chaos region for which we have the most complete set of observations is Conamara Chaos (Fig. 1), a 150 by 150 km feature characterized by large iceberg-like blocks and rafts of broken-up older surface material entrained in a dark hummocky background matrix. This feature has become the archetype of chaos terrain, thought to be a site of surface overturn and possibly exchange between the deep ocean and the surface.

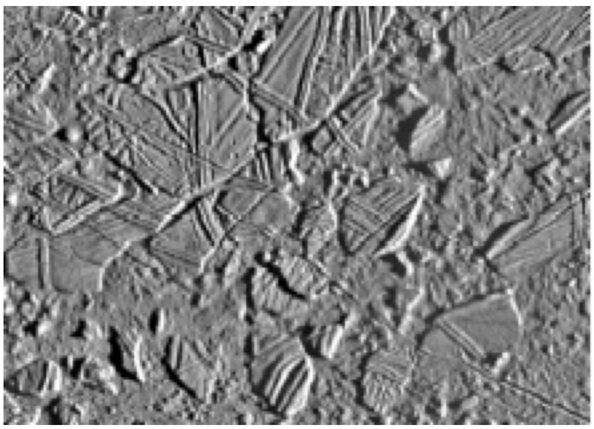

Figure 1: Galileo image of Conamara Chaos. Note the large rafted blocks and background hummocky matrix. Credit: NASA/JPL.

In addition to Conamara, there are numerous other chaos features, the spatial scales of which may be diagnostic of their formation mechanisms. "Mottled Terrain" is a generic term given originally to any features that are characterized by appearances like the matrix in the floor of Conamara. Murias Chaos, for instance, is a "mitten" shaped large chaos absent of any blocks that has been suggested to be formed when an ascending plume or large diapir broke through the lithosphere and flowed out on the surface[1]. "Lenticulae" refers to "freckles" on Europa's surface: small scale features called pits, spots and domes are also likely formed by smaller scale thermal anomalies.

Recently, key observations that any chaos formation model must explain in order to be correct have been outlined. Three of these observations have arguably been unsatisfactorily addressed by either the melt-through or warm-ice models: a) the formation of matrix material, b) the preservation of rafted blocks often broken along preexisting fractures, and c) chaos terrain is generally topographically higher than surrounding plains [2]. Of these three, it is the heights of the chaos features that are most problematic for previous work. It is vital to recall that the melting of ice creates a net negative volume change: since ice is less dense than water, when it melts, it takes up a smaller volume. In the case that the shell is thin and melts through [3], as the matrix material refreezes it can never refreeze higher than the surrounding material. There is no physically plausible explanation for why the crust would thicken relative to the background plains after melt-through. In the warm-ice model [4], thermal contrast from a diapir causes the ice to expand and dome upward. However, once the thermal contrast of the plume disappears, the surface will again sink back to its previous level, removing any topographic contrast.

In order to form a new model of chaos terrain formation, we turn to lessons from the Earth's cryosphere to contribute new perspective on the behavior of ice-water systems that can be applied at Europa.

Terrestrial Analogues: We will draw upon two separate analogues for the formation of chaos terrain, as well as the behavior of water in terrestrial ice systems. Two observations of water in terrestrial systems are relevant. First, subglacial and englacial water moves along hydraulic rather than gravitational gradients, according to [5]:

$$\nabla\phi_b = (\rho_w - \rho_i) g \nabla z_b + g\rho_i \nabla z_s \quad (1)$$

where ϕb is the fluid potential, ρw is the density of water, ρI is the density of ice, g is gravity, zb is the thickness of the overlying ice and zs is the elevation of the surface relative to the geoid. On the right hand side of the equation, the first term expresses the gravitational potential, and the second term the water pressure. Due to the contrast between the ice and water density, the surface slope is a stronger control on the behavior of the water than is ice thickness change. The second analog is the role played by brine infiltration and hydrofracture in ice shelf break up in terrestrial ice sheets.

Subglacial Volcanoes. As subglacial volcanos become active, they melt the ice sheet, in an analogous fashion to how thermal plumes on Europa can produce melt lenses as they pass eutectic horizons within the ice. As melt is produced in the caldera, the surface deflects in response to the net negative volume change [6]. This process regularly occurs at Grimsvotn, a large subglacial volcanic crater in Iceland. The surface slope at the flanks of the crater increase, dipping downward creating a hydraulic seal preventing the escape of the water, as well as pushing the melt upward into a domed lense. This creates a stable, longlived water body beneath the ice that can grow and evolve. The same process can occur at Europa, where horizontal motion of the water is prohibited by both the hydraulic seal and the continuous ice shell, and downward draining is prohibited both thermally and from the lack of pore space.

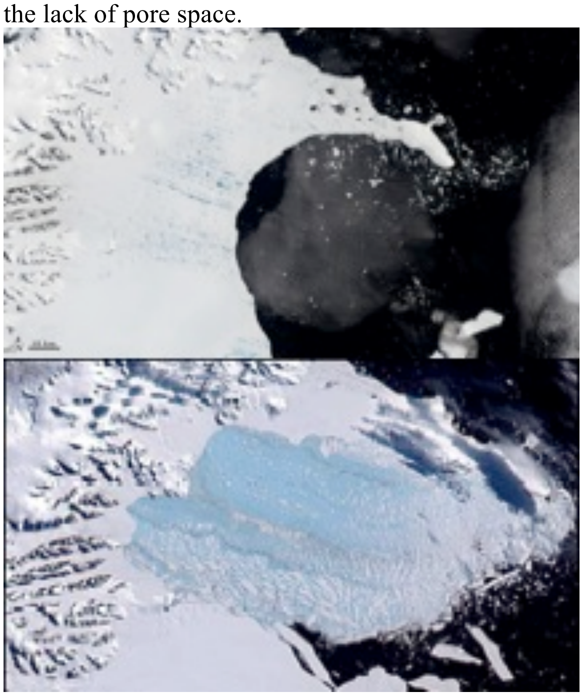

Figure 2: The break-up of Larsen B ice shelf in February 2002. The blue areas (top) are tidal cracks where water infiltrated and eventually disrupted the ice(bottom) over about a month. Credit: NASA.

Ice Shelf Collapse. Studies of the Wilkins and Larsen Antarctic ice shelves reveal that saltwater, or brine, can infiltrate the porous layers and tidal cracks of ice shelves and when combined with meltwater, can contirubte to rapid ice shelf collapse [7]. The hydrofracture of tidal cracks by surface melt and internal brine pockets occurs rapidly and produces large blocks of solid ice that flip and translate, as well as fine-grained material between the ice bergs. On Europa, as the surface deflects due to the formation of a melt lense, extensional stresses along the ice can promote downward cracking and provide a conduit for the trapped water to escape and relieve hydraulic pressure. As this water flows upward to the base of the brittle ice layer, regions of high fracture concentration and porosity will preferentially entrain melt.

Results: The melt-hydrofracture model can readily explain the heights of the chaos terrain, the preservation of ice rafts and the disruption of older plains material into matrix.

Heights. As cracks propagate downward, a conduit for the trapped water to escape upward is produced. In order to explain the topographic relief of chaos above the surface, we require only that the plume be larger than the eventual chaos feature, as is required at any rate to create a hydraulic seal. As the water escapes, melt from the flanks of the lense is pulled into the central lense, increasing the total volume of water in the comumn below the chaos feature. As this water freezes, the surface above the lense and infiltrated ice will be pushed up, creating enhanced topography of the chaos terrain.

Ice rafts. In order for water to reach the near subsurface and form chaos features, cracks must form to allow the water to escape upward. As the surface deflects, extensional stresses will occur across the deforming central region of the ice. The ice will be most likely to break along areas of weakness, and previously active faults may thus be the initial fracture points. Conversely, solid ice will be less likely to break, allowing for large ice rafts to persist.

Matrix formation. The melt-hydrofracture model predicts that water will become entrained into highly fractured and porous ice. Thus, it predicts that older plains material (relative to wide ridges and bands) should become more water rich thus reducing the shear strength of the material and allowing it to be more readily disrupted than solid ice blocks. This is consistent with the observation that plains material seems to be preferentially removed in the formation of chaos terrain [8].

Implications for the Ice Shell: The melt-hydrofracture model is consistent with a shell that is thick enough to require thermal exchange between the surface and interior via solid-state processes such as convection or diapirism. In addition, applying this model can inform us about the porosity structure of the upper Europan ice layer and the scale of the thermal plumes that give rise to their formation. We will discuss these implications, as well as extend our model to chaos features of differing scales.

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