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Activity & Liquid Water Implied by Chaos on Europa

B. E. Schmidt and D. D. Blankenship. Institute for Geophysics, University of Texas, Austin, USA (britneys@ig.utexas.edu)

Abstract

One of the most interesting questions about Europa is whether its surface is currently active. Unique to the surface of Europa, chaos terrain is diagnostic of the properties and dynamics of its icy shell. While models have suggested that partial melt within a thick shell or melt-through of a thin shell may form chaos, neither model has been able to definitively explain all observations of chaos terrain. However, we present a new model that suggests large melt lenses form within the shell and that water-ice interactions above and within these lenses drive the production of chaos. This model is consistent with key observations of chaos, predicts observables for future missions, and indicates that the surface is likely still active today[1].

1. Introduction

What does it mean that chaos terrains can have such varied appearance? The archetype is Conamara Chaos, 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 matrix. There are observations of other features that are similar, but also some that are very different. Thera Macula for example also possesses iceberg like blocks and hummocky matrix, however rather than being expressed above the surrounding plains, the feature is subdued.

1.1 Observations & Previous Models

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.

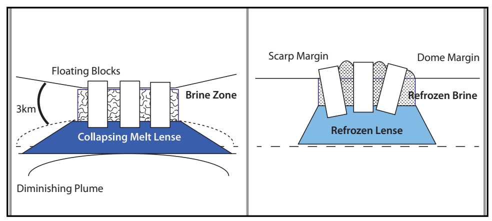

Figure 1: Schematic of stages 2-4 of the lens-collapse model [1]. The melt lense has formed and is sealed. Left: Fractures have opened, calving blocks and allowing brine infiltration, but the water is liquid. Right: The lens and matrix have refrozen.

2. The Lense-Collapse Model

The morphology of features like Conamara chaos suggests a four-phase formation [1]: 1) Surface deflection occurs as ice melts over ascending thermal plumes. 2) Resulting hydraulic gradients and driving forces produce a sealed, pressurized melt lense. 3) Extension of the brittle ice lid opens cracks, allowing brine injection and percolation within the ice, forming matrix. 4) Refreezing of the melt lense and brine-rich matrix results in raised chaos.

2.1 Terrestrial Analogs

Subglacial Volcanoes. As subglacial volcanos activate, they melt the ice sheet above. As melt is produced in a caldera, the surface deflects in response to the smaller volume taken up by the melt. This process regularly occurs at Grimsvotn, and other large subglacial volcanic craters in Iceland. The surface slope at the flanks of the crater is steepest, so that the hydraulic gradient drives water up and toward the center of the lense, creating a hydraulic seal that prevents escape of the water. The same process can occur if plumes melt ice at Europa as they cross the ice-impurity eutectic. Water cannot escape because of the hydraulic seal and horizontally continuous ice shell, and the buoyancy of the plume below prevents downward draining of the melt.

Ice Shelf Collapse. Studies of the Wilkins and Larsen Antarctic ice shelves reveal that brine can infiltrate the ice through the ice front and tidal cracks, percolate through the ice, and can contribute to rapid ice shelf collapse. The hydrofracture of tidal cracks by ponded surface melt and internal brine pockets occurs rapidly and calves tabular ice blocks as well as brine-rich granular material between the ice bergs. On Europa, as the surface deflects due to the melting ice, extensional stresses along the ice can promote cracking and provide a conduit for the trapped water to escape upward and relieve hydraulic pressure. As this water enters the ice, it can then percolate through the brittle ice layer, and regions of high fracture concentration and porosity will entrain more water.

2.2 Matching the Observations

Ice rafts. In order for water to reach the near sub-surface and form chaos features, cracks must form to allow the water to escape upward. As the surface de-flects, extensional stresses will occur across the de-forming 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. Solid ice will be less likely to break, allowing for large ice rafts to be calved and persist.

Chaos & Matrix Heights. Extensional cracks in the ice allow water to escape upward. The water is free to then enter the ice column in cracks and percolate into pore spaces, concentrating the ice in brines and adding water volume to the shell. As this englacial water freezes, the infiltrated ice will expand, raising the surface and creating the domed chaos terrain.

Impurity-rich Matrix. The lense-collapse model predicts that water will become entrained into highly fractured and porous ice. Thus, it predicts that porous and fractured plains ice should be converted to matrix, consistent with the observations. Increased water content reduces the shear strength of the material and allows it to be disrupted.

3. Activity & Liquid Water

Thera Macula may represent active chaos formation [1], containing a southern chaos area (SC), large ice rafts, and a circular northern subsiding area (NS), exactly how the lens-collapse model predicts active chaos to appear. The concentric fracture system encircling Thera Macula resembles those of collapsing ice cauldrons. Topography indicates that matrix freeze out is occurring in the SC, while the deflecting ice surface and blocks in the NS indicates that the lens below Thera Macula was liquid at the time of the Galileo encounter. Today, a melt lens of a minimum of twice the volume of Lake Superior may exist below Thera Macula.

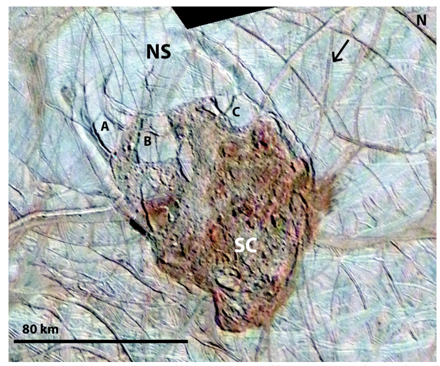

Figure 2: Thera Macula [1]. Credit: NASA/JPL/Univ. of Arizona. #PIA02099.

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