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A shallow subsurface hydrologic system on Europa?

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Abstract

Evidence for water being involved in the formation of Europa's surface geology abounds. The search for such water is a prime driver of the Europa Clipper (NASA) and JUICE (ESA) missions. Among the most promising features are Europa's chaos terrains, thought to form when shallow melting occurs within the ice shell. We discuss further evidence for shallow water systems on Europa associated with it's chaos terrain.

1. Introduction

Thera and Thrace Macula are two closely spaced chaos features on Europa's anti-jovian hemisphere characterized by dark coloration and the appearance of disaggregated ice. Brine mobilization, by analogy to sea ice, was suggested to form Thrace Macula [2]. While sea ice is a poor analog for Europa's ice for many reasons, moving subsurface water may still be the best explanation for the morphology of these features. As a consequence of the formation and evolution of large water bodies associated with chaos terrain, hydraulic direction of subsurface water provides a means to explain these features.

2. Geomorphology of Thrace and Thera

Thera Macula is likely forming above a melt lens that is liquid at present time [1], thus Galileo data in a sense capture chaos formation in a state of suspended animation. Here [Fig 1A] we see evidence for matrix formation to the South (SC), and to the North (NS), ice shelf rupture above a down-drawn surface. There is also evidence from swelling ridges intersecting Thera Macula for direction of water out of the lens as the result of hydraulic gradients emplaced as the feature evolved.

At Thrace Macula is evidence for modification of Europa's surface morphology by subsurface water. Here, there is evidence for swelling and modification of preexisting structures that is consistent with infiltration and refreeze of water from the subsurface. Thrace Macula's domed appearance, mottled texture, and irregular margins support such a conclusion. Its topography (overall raised with respect to the background terrain) is an indication that the feature is older than Thera Macula. Evidence for embayment into low-lying regions appears at the margins of Thrace Macula where ice thickness gradients can drive water outward. Like Thera Macula, ridges intersecting the feature are swollen but preserved; no matrial flow has entered the depressions and valleys between these ridges as might be expected from an extrusive flow. Hints of the preexisting terrain exist—preserved fractures and absence of ice blocks in this portion of the feature indicate slow modification of the ice by brine inflow and freeze out. The change in thickness between the modified and unmodified ice along these ridges is consistent with ~30% increase in volume post-infiltration, consistent with estimates [1].

3. Models of subsurface hydrology

The behaviour of subsurface water will be controlled by hydraulic gradients as well as the material properties of the ice. Such gradients can evolve as the surface undergoes diurnal forcing from tides, but also may migrate outward from the lens as a result of material freeze out within it, causing the water to flow into hydraulic lows. Discontinuities in material properties, such as between brittle and ductile or porous and solid ice may create pathways for such flow of water.

We used COMSOL to model the present-day hydraulic conditions that would occur at both Thrace and Thera Macula were a subsurface water volume to exist. We use Galileo data to provide the approximate heights of the high and low-lying terrain, and the water depths, volumes, and ice properties described in [1] to calculate the models.

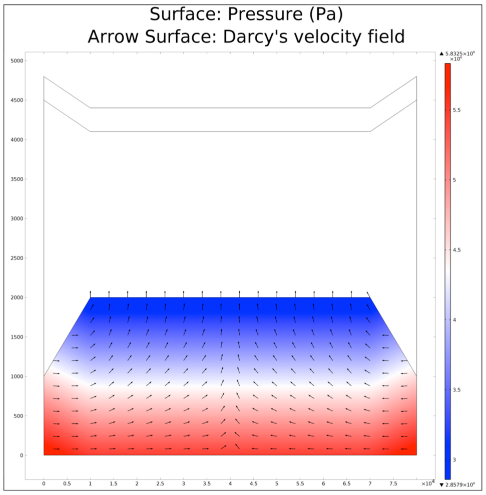

Figure 1: Pressure head and Darcy velocity field within a 2km deep lense 3km from the surface of Thera macula.

We confirm that Thera Macula's present state and topography implies that the lens-collapse model is a good fit for the observations, by demonstrating the hydraulic potential within the lens prior to rupturing. Using this model, we conclude that sufficient pressure head exists within the lens to force water uphill into surrounding areas as the feature ruptures, explaining swollen adjacent features and predicting the site where the feature ruptured.

For Thrace Macula, we confirm that water in a subsurface reservoir under either solid ice or partially refrozen ice will experience hydraulic gradients that could cause embayment of adjacent, low-lying terrain. We also show that within such a reservoir, the overburden of the thick ice above it creates sufficient pressure head to drive water into the shallow subsurface from a reservoir meters to kilometres below if a pathway to the near surface from the reservoir exists, such as fractures or permeable ice.

4. Summary and Conclusions

Using both geomorphology and hydraulic modelling, we show evidence for shallow water mobility within Europa's crust. These bolster the case for a presently active Europa, with abundant shallow water, and place constraints on water flow and the material properties of the ice. We show that this water is governed by surface topography that determines hydraulic potential for subsurface water. We also discuss the impact of composition and material properties of the ice. Overall, these results imply that the present-day habitability of Europa may be strongly coupled to an evolving subsurface hydrological system that can be characterized by ice penetrating radars onboard Europa Clipper and JUICE.

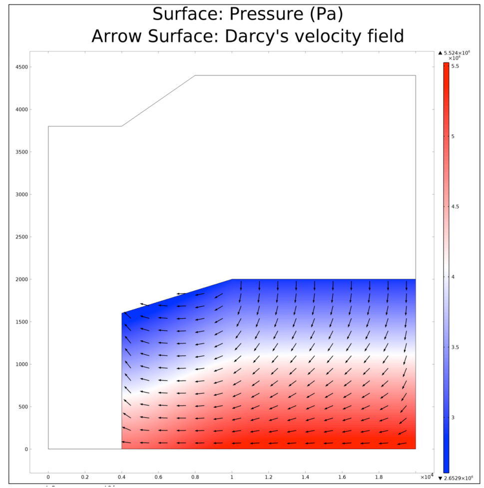

Figure 2: Pressure head and Darcy velocity field within Thrace Macula.

References

[1] Schmidt, B. E. et al. (2011) Nature 479 502-505.

[2] Head, J.W., R. Pappalardo, (1999) JGR, 104, 27143.