Domes, pits and small chaos on Europa produced by water sills. M. Manga[1] C. Michaut[2], and C. Culha[3]
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Introduction: The surface of Europa is littered with quasi-circular features a few to a few tens of km in diameter. They may be uplifted (positive relief ``domes'') or depressed relative to their surroundings (negative relief ``pits''). In some cases they show evidence of resurfacing or disruption of the crust (small ``chaos''). Collectively we refer to all these features an lenticulae. As they have an endogenic origin they provide an opportunity to study properties of, and processes within, Europa's ice shell.

One means of bringing liquid to the near-surface is by injecting horizontal bodies of water, called sills, within the ice shell [1]. The water may be injected from a subsurface ocean owing to high overpressure [2]. Water sills have also been implicated in the formation of double ridges [3-4].

We present a model for the evolution of water bodies within an ice shell, building on previous calculations [5]. We then map the geometry of lenticulae [6] and show that the dimensions are consistent with the expectations for features produced by water injection.

Conceptual model: Figure 1 illustrates conceptually the different stages in the emplacement and solidification of the sill. The first stage is the intrusion of water into the part of the ice shell that deforms elastically, at least on emplacement time scales. If the sill is intruded deep enough, it will deform the ice-ocean boundary and this topography will relax by viscous flow. After emplacement, the water in the sill will start to freeze. The heat transferred to the surrounding ice will decrease the thickness of the elastic layer above the sill, increasing preexisting stresses in the ice shell. The dense water sill will sag downward, supported by the strength of the underlying ice. Compensation of this internal load will depress the surface of Europa, forming a pit. Final solidification of the sill and the volume expansion of the water will raise the surface, forming a dome, provided that complete isostatic equilibrium was not achieved.

Mathematical model: The propagation of the sill is determined by solving the for the fluid flow and pressure in the sill and the elastic deformation of the surrounding ice.

Results. Shallow sills never reach thicknesses more than a few meters and spread for many 10s of km. In contrast, propagation of deep sills is limited by the fracture toughness of ice and they attain lateral dimensions of O(1-10) km and thickness that can exceeed than 1 km. The large O(100) m relief of lenticulae requires thick, and hence deep, sills.

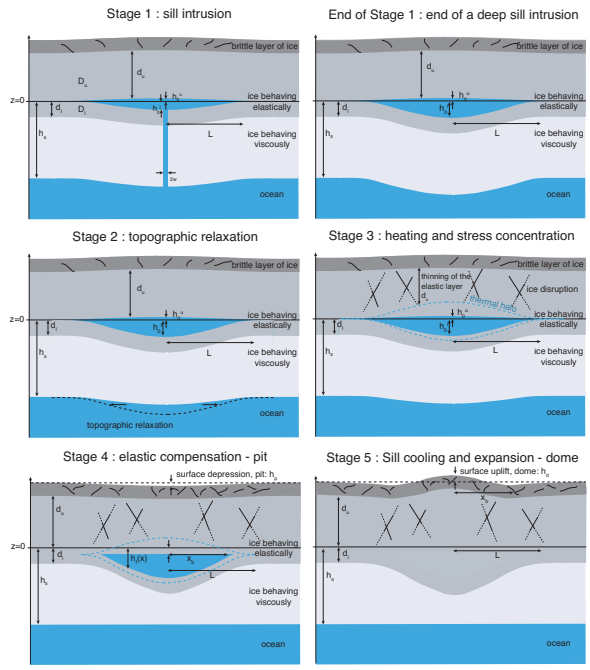

Figure 1: Conceptual stages in the evolution of a water sill in Europa's ice shell.

Mapping lenticulae: We map the location, dimensions and shapes of lenticulae and their interactions with other lenticulae and lineaments. This exercise builds on previous mapping [e.g.,

We find that (1) pits and domes have similar sizes; (2) chaos are larger than the other lenticulae; (3) pits are clustered within the trailing antijovian quadrant and the leading subjovian quadrant whereas domes, dome/chaos, and chaos terrains are more uniformly distributed; (4) the areal density for all lenticulae is not uniform; (5) lenticulae do not divert the path of younger lineaments such as ridges.

The similar size and shape of pits and domes (Figure 2) suggests that one may evolve into the other. Because domes are more numerous and more uniformly distributed than pits, they are more likely to represent the end stage of this evolution, assuming the end-stage leaves a longer-lasting surface expression. Models also predict that larger features are more likely to disrupt the crust [12], which is consistent with dome/chaos and chaos being larger than pits and domes.

We find no examples of lineaments offsetting pits but lineaments do cross some chaos. Pits also have a preferred orientation, but not domes, dome/chaos, and chaos. If lenticulae orientation is influenced by crustal stress, then pits may have formed during a shorter time interval than the other features. As a result, pits may be younger than domes, dome/chaos, and chaos, consistent with pits being the earliest stage in the evolution of lenticulae. We find no strong evidence that lineaments are deflected by lenticulae, implying either that the stresses created by lenticulae are too small to influence lineaments, or that the complete evolution of lenticulae occurs on a time scale that is short compared to the time between the formation of lineaments at a given location.

If lenticulae are the surface expression of sills, then our observations would confirm that pits evolve into domes. Liquid sills cool and solidify over time scales that are shorter than the topographic relaxation timescale for domes, which would explain why pits are shorter lived than domes. Since pits are clustered the implication is then that the other lenticulae also formed in clusters but they are now too numerous to preserve information about the initial distribution.

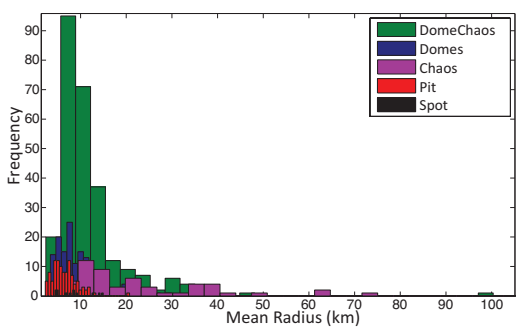

Figure 2: Histogram of lenticulae sizes (mapped from Galileo SSI high-resolution images).

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