BAND FORMATION AND OCEAN-SURFACE INTERACTION ON EUROPA AND GANYMEDE.

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Introduction: On Europa and Ganymede, the scars of tectonic activity are imprinted in water ice shells tens of kilometers thick that are inferred to overlay water oceans about an order of magnitude deeper [1]. The origin and formation of tectonic terrains on icy satellites is tied to processes that link the ice shell and the ocean, such as spreading, rifting, subduction, and cryovolcanism, causing the ice shell to evolve through time [2-4]. Understanding the tectonic material exchange mechanisms between the surface and the ocean is critical to understanding the potential habitability of these ocean worlds [5, 6].

Some of the most prevalent tectonic terrains on Europa and Ganymede are inferred to occur from extension in the ice shell, commonly producing long, linear "bands," an umbrella term we use to include both bands on Europa and groove lanes (sulci) on Ganymede. Bands are thought to be among the most recently geologically active features on Europa (< ~60 Ma) and Ganymede (nominally 2 Ga) [7], and played a primary role in the most recent resurfacing of each satellite. Linking observations of band characteristics to models of ice tectonics and interior flow may provide crucial insight into surface-ocean exchange processes.

Methods: To explore band formation and ocean interaction in 2-D, we extend the finite-difference code SiStER, developed for application to tectonic processes on Earth [8], to simulate fully visco-elasto-plastic extensional deformation in a solid ice I shell. Specifically, we implement a composite ice I rheology and track "fossil" ocean material that has frozen into the shell and then transported and deformed through geologic time.

Results: Rather than revealing different formation processes that produce different band types, we find a spectrum of related band formation processes that varies primarily as a function of lithospheric strength (Fig. 1). Strength is modified by lithospheric thickness, convection, pre-existing weaknesses, and the timescale of fault annealing. Thus, band type can potentially be used as an indicator of relative lithospheric at the time of formation

Diffuse faults produced in the weakest initial lithosphere rapidly coalesce to form a zone of plastic yielding about a depressed central axis as convection and extension thin the weak lithosphere. This exposes fresh surface ice that could be removed to palinspastically reconstruct the initial terrain. As the modeled strength of the lithosphere increases, fault coalescence requires greater strain, delaying smooth plastic yielding. Models with the strongest icy lithospheres produce surfaces dominated by fault scarps that obscure the initial surface over a wide area, even at very low strain. Because the original surface is overprinted by tectonic activity, the amount of fresh ice exposed is much smaller, rendering band reconstruction impossible. After large strain, these tectonically dominated lithospheres may plastically yield, producing a smooth band within the initial, highly tectonized surface.

We find that relatively weak lithospheres on Europa can convey fossil ocean material to the surface within the lifespan of the band (10s km of extension). For models without convection, fossil ocean material is not exposed at the surface even after 40 km total extension, which exceeds the width of most bands observed on Europa [11].

These models imply that the variety of band morphologies on Europa and Ganymede likely form by similar processes in lithospheres of different strengths. Extension of low-strength lithospheres can result in surface exposure of fossil ocean material, with implications for future astrobiological exploration.

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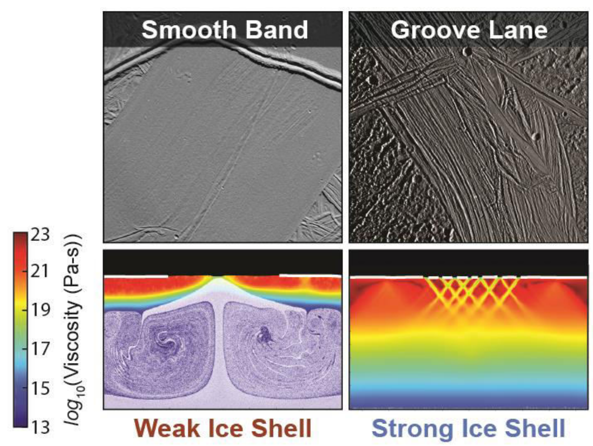

Figure 1: Band spectrum endmembers shown in map view from Galileo spacecraft images (above) and associated numerical models shown in cross-section (below). Maps show Thynia Linea (left) and Tiamat Sulucs (right). Model outputs of viscosity show the movement of fossil ocean material (white overlay) and formation of faults (yellow bands) within the ice shell.