LITHOSPHERIC STRESSES IN EUROPA’S ICY SHELL: CAN SUBDUCTION INITIATE ON EUROPA?

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Introduction: Europa presents an exciting area of research to understand processes occurring on icy satellites and their astrobiological potential. Despite its small size, Europa is a dynamic world. Surface features indicate a young age and extensive tectonic activity. The widespread extensional features create extra surface that needs to be accommodated to preserve the strain balance on Europa. Previous modeling have proposed that this could be achieved by folding or passive thickening [1,2]. Another mechanism of balancing this extra surface area is subduction on the icy shell, suggested by the mapping analysis of Kattenhorn and Prockter (2014) [3]. This gives rise to the notion of plate tectonics on the icy shell, and this has important implications for the satellite’s evolution, surface environment, and thus habitability. Thus it is of great interest to explore the conditions favorable for plate tectonics to operate on Europa.

Initiation of subduction by sublithospheric convection: The dynamics for subduction initiation, which is considered the key factor for plate tectonics initiation, has been widely studied but is not yet well understood. For planetary lithospheres without pre-existing faults or weak zones, subduction initiation is difficult due to the high strength of the lithosphere. Sublithospheric convection has been proposed as a mechanism for subduction initiation for these planetary bodies [e.g., 4]. The stresses induced in the lithosphere from convection, caused by the dipping slope of the base of the lithosphere, may be large enough to overcome the yield stress of the lithosphere such that it can subduct. If Europa’s icy shell can develop a sufficiently wide convective cell, the stresses in the lithosphere will be higher and thus more easily exceed the yield stress to initiate subduction. We determine the critical value of yield stress and friction coefficient at which large-scale lithospheric failure can occur. The relationship between the yield stress and the time of subduction initiation can be derived from the simple model of Rayleigh-Taylor instability.

Application to Europa’s icy shell: Considering the range of possible thickness of the icy shell and the thickness of the icy lithosphere on Europa, we use scaling relations [5] to constrain the yield stress of the icy lithosphere so that plate tectonics can initiate within the lifetime Europa’s icy shell. The deformation mechanism of ice at depth is uncertain. We use parameters for diffusion creep in our scaling of critical yield stress and critical friction coefficient. The critical yield stress is estimated to range from 2 kPa to 1 MPa, and the critical friction coefficient from 0.006-0.33, depending on the thickness of the icy lithosphere compared to the depth of the convecting icy shell. The critical yield stress is low compared to experimental values for intact ice [6]. However if the icy lithosphere is thin, the critical friction coefficient is on the same order of magnitude as experimental values [7]. We note that scaling for stresses might be different when tidal heating is taken into account.


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Caption: Below, a numerical convection model (CITCOM) showing potential incipient subduction zone caused by the gravitational pull of a substantial lid slope. Such a slope (transition to warmer ice) could in principle be detected by REASON.