NO MAGMATIC DRIVING FORCE FOR EUROPAN SEAFLOOR VOLCANISM.

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Introduction: For the Europan ocean to be habitable, regular geochemical input must be supplied to it from the overlying ice shell and underlying silicate interior [1][2][3]. Without this supply of reactants and reductants, the ocean will reach chemical equilibrium resulting in "thermodynamics-driven extinction" [4]. Due to strong tidal dissipation in Europa's interior, it is commonly thought that a possible contributor to oceanic habitability is reductants such as H_2, CH_4, and H_2S sourced from active volcanism on the seafloor [1]. However, no observations of Europa's deep seafloor have yet been made, so whether its silicate interior is capable of volcanism remains an open question.

In the absence of such observations, this question must be addressed by modeling. Běhounková et al. [5] developed a 3D model of Europa's mantle and found that melting can take place throughout the planet's entire history, but assumed all melt generated in the model is immediately extracted (a common approximation in mantle-scale modeling). However, magmatic transport through the mantle's rigid, brittle lithosphere is not guaranteed even in terrestrial contexts [7]. Bland & Elder [8] highlighted this fact in a study of the physics of magma transport through Europa's mantle lithosphere, developing analytical models of lithospheric-scale dike propagation to evaluate conditions that may be favorable for Europan dike ascent. These authors were not able to pair dike propagation with estimates of magmatic fluxes into the dikes, and were therefore unable to evaluate whether dike-driven seafloor eruption is actually possible [8]. In this study, we combine those earlier approaches [5] [8] to rigorously test the Europan mantle's ability to generate both melt and the magmatic driving force necessary to transport that through the lithosphere so that it can erupt on the seafloor.

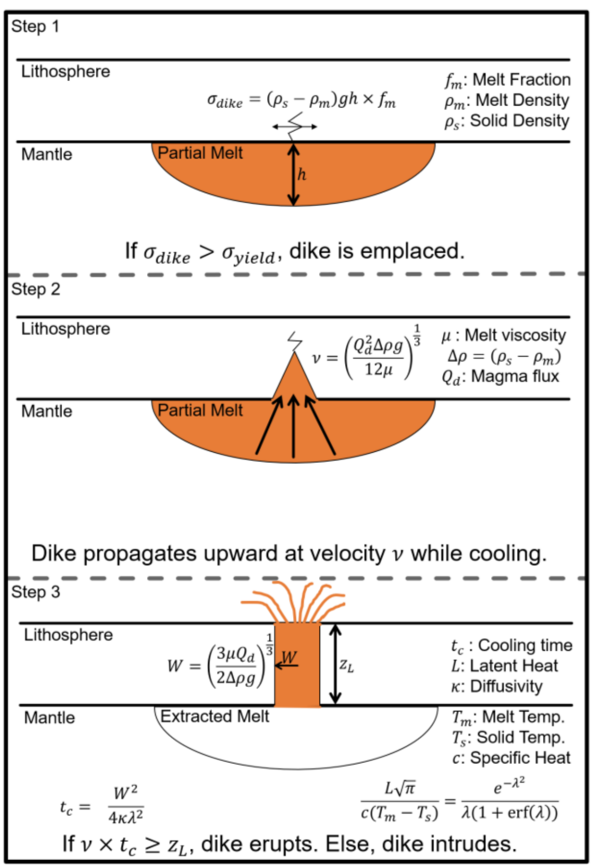

Figure 1: Schematic diagram of our dike extraction model.

Model Overview: We have constructed a model of Europa's mantle in the geodynamic simulation code StagYY [9] and designed and implemented a new melt extraction routine within StagYY (Figure 1) to evaluate the plausibility of Europan seafloor volcanism. The mantle model is a 2D spherical annulus 821 km in thickness with temperature ranging from 273 to 1600 K. Heat is generated within the model by radioactive decay [9] and tidal dissipation [10]. We benchmark internal heating to conditions in the models of Běhounková et al. [5] to ensure consistency with previous results. Melting occurs along a Herzberg–Bohler solidus curve [11] and is then transported upwards through the viscous portion of the mantle via Darcy pore-space flow along grain boundaries. When melt reaches the base of the thermal lithosphere (1400 K), it is then evaluated by the new dike–melt extraction treatment. In order to erupt, the magma must then satisfy two criteria (Figure 1): 1) magma must exert sufficient buoyancy stress at the base of the lithosphere to break it and initiate a dike; and 2) the dike must propagate upward through the lithosphere faster than conductive cooling solidifies the dike, halting it.

Results: We find that Europa is incapable of producing the magmatic driving force necessary for seafloor eruptions. A thermal lithosphere of 200 km thickness develops over a model run, which represents the distance a dike must travel to erupt at the seafloor.

Dike propagation is primarily controlled by the magma influx *Q*, which we find to be 10,000 times less than what is necessary to drive seafloor eruptions. This influx leads to maximum dike heights of ~2–10 km, or 1–5% the total lithospheric thickness (Figure 2). Magma volumes generated by Europa's mantle are small and diffuse, leading to small melt fractions which drive sluggish Darcy flow. Additionally, the buildup of large magma bodies is prevented by cooling and melt freezeout at the base of the lithosphere. Increasing interior heat generation in our models did increase generated magma volumes, but not melt fractions at the base of the lithosphere, and therefore had little overall impact on the prospect for seafloor volcanism. Increasing the mantle's permeability to thus enhance melt transport increased *Q*, but also thickened the thermal lithosphere in response, erasing any gains in dike penetration capability.

Our results indicate that a habitable ocean on Europa cannot be maintained by seafloor volcanism. For habitability to be maintained, volcanism must be occurring both presently and periodically [1] and our results indicate neither is happening. We find that dike initiation requires a lithosphere of low tensile strength (1–3 MPa) and, if a dike does form, the magma freezes before it reaches within 150 km of the seafloor, precluding even near-surface hydrothermal alteration driven by intrusion. Alternative habitability models that do not rely on seafloor volcanism must be considered in assessments of contemporary Europan ocean habitability.

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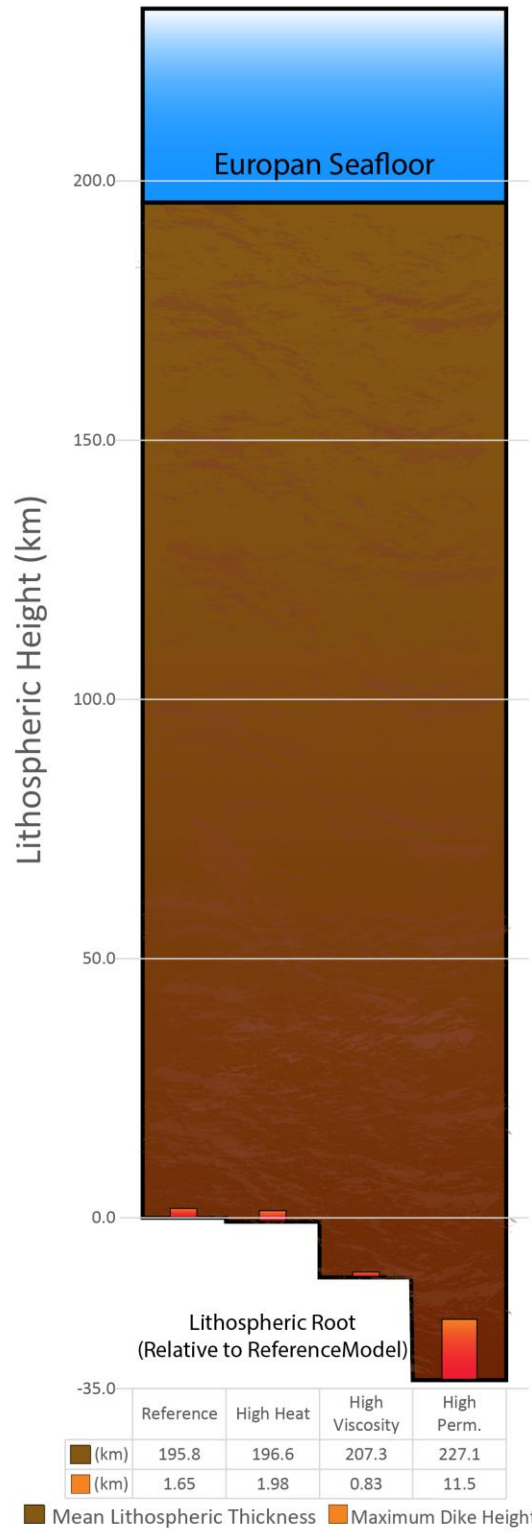

Figure: Maximum lithospheric penetration of modeled dikes for selected model cases. No modeled dikes are able to penetrate >5% of Europa's lithosphere. Table depicts lithospheric and dike heights for each case.