MODELING PRESENT-DAY MELT PRODUCTION AND ERUPTION IN EUROPA'S SILICATE MANTLE.

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Introduction: The presence of active volcanism on the seafloor of Europa is critical to the habitability of its subsurface ocean. In order to maintain the chemical disequilibrium necessary to support a sunlight-free active biosphere, geochemical interchange both above (the surface ice shell) and below (the silicate mantle) the ocean must regularly renew its inventory of energy-producing reactants [1][2][3]. However, little is known about the current state and behavior of Europa's silicate mantle due to its relative inaccessibility underneath approximately 100 km of water and water ice [4]. Our aim, therefore, is to characterize the present thermal and magmatic state of Europa's silicate mantle and evaluate the likelihood of regular volcanism on its seafloor.

Two recent modeling studies of the silicate mantle [5][6] have provided some insight on the presence of seafloor volcanism. [5] produced a robust three-dimensional mantle convection model to argue that volcanic processes are present throughout Europa's history. However, [5] treats all melt generated in the mantle as immediately extracted, neglecting various obstacles to eruption magma may encounter and the effects of lingering melt on the mantle's thermal evolution. [6] sought to address this by studying the physics of magma transport through the lithosphere via dike emplacement. Our broad goal is to apply the ideas of [6] to the mantle convection modeling of [5] to better characterize the relationship between mantle melt production and subsequent volcanic extraction. Here, we describe our preliminary efforts. First, we build a model in the mantle convection code StagYY [7] and then we benchmark it by reproducing mantle conditions similar to [5]. Finally, we investigate other melt extraction treatments currently present in StagYY and describe our next steps.

Model Overview: We have constructed a model of Europa's silicate mantle in mantle convection engine StagYY [7]. Our model domain is defined as a two-dimensional spherical annulus 1421 km in radius with a core-mantle boundary set 600 km above the center, leading to a layer thickness of 821 km. Temperature is set to 273 K and 1600 K at the upper and lower boundaries, respectively. Model viscosity is treated as Newtonian temperature-dependent diffusion creep due to the low pressures (< 4 GPa) and convective stresses (< 1 MPa [5]) present in the mantle. Unlike [5], we also account for melting-driven viscosity reduction in our models. Heat is produced in the model by both radiogenic activity and tidal flexure, similar to the approach of [5]. We use the present-day radiogenic inventory of LL chondrites [8] to account for radiogenic heat production in the mantle. In order to achieve a steady-state model with a constant baseline heat production, we ignore radiogenic decay. We add to the radiogenic activity heat produced by tidal flexure. We use [9]'s viscosity-dependent treatment of tidal heating, using appropriate elastic properties for Europa's mantle. We vary tidal heat sinusoidally between the equator and the poles of the model to capture its spatial dependence [10] (Fig. 1, right). We match this spatial amplitude of this tidal heat production to the range of heat production at the CMB obtained by [5]. Melting in the model is

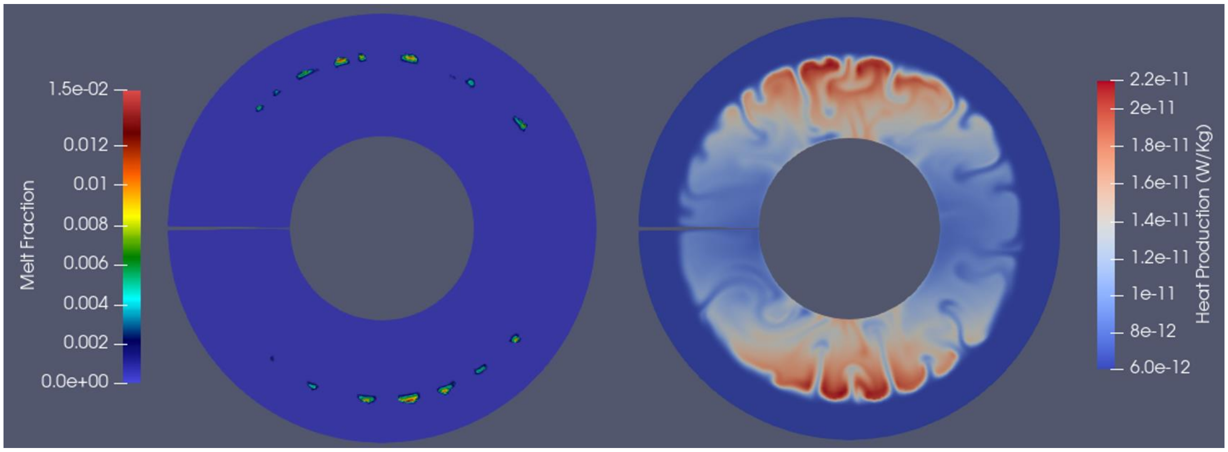

Figure 1: Model snapshots depicting the distribution of melt (left) and variation in internal heat production (right) at the final timestep. The "freezing" model case is shown here to better visualize melt distribution.

handled by StagYY [7] with a modified Herzberg-Boehler solidus [11] matching the solidus used by [5]. We run the models to steady state for ~250 Myr to obtain our results.

Preliminary Results: We consider 3 model cases: a benchmark model where all melt produced is immediately extracted ("All Melt"; Figs. 2 and 3), a model where generated melt lingers until it cools to freezing and is then extracted instead ("Freezing", Figs. 1, 2, and 3), and a model where melt pooled at the base of the thermal lithosphere (T_L = 1400 K) is extracted ("Lith"; Figs 2 and 3).

Benchmark Model. Our aim with the benchmark model is to match the mantle conditions described in [5] as closely as is possible in StagYY. We compared the distribution of internal heat (Fig. 1) and the interaction between the model geotherm and solidus curve (Fig. 3, blue line) of the two models and found them to generally agree. We find that, while the spatial distribution of melt produced in our model (Fig. 1, left) matches [5] well, it currently suggests a lower eruption rate (Fig. 2) than [5], likely due to differences in the model domain and the treatment of melt production between the two models. Work is ongoing to understand the implications of model assumptions on melt production and eruption.

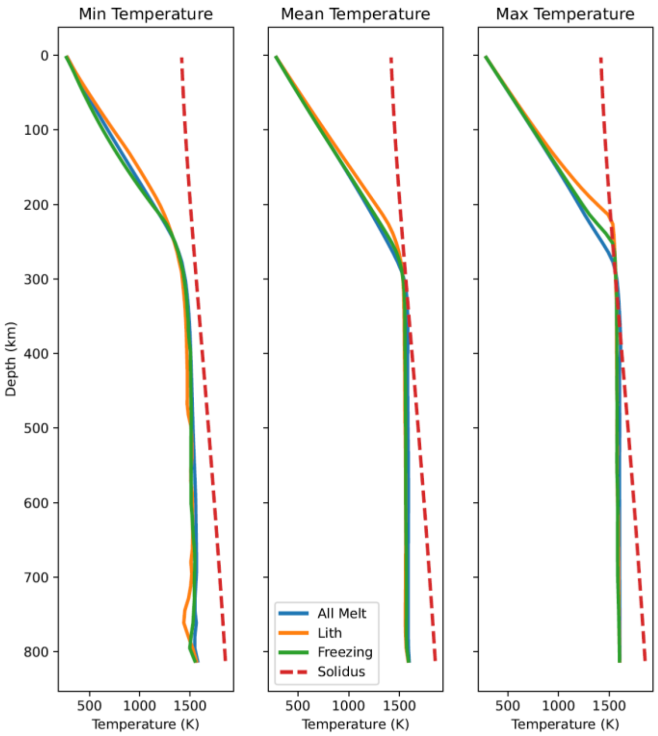

Figure 3: Interaction between the modeled solidus curve and the minimum (left), mean (center), and maximum (right) geotherm for the three considered model cases. Melting occurs where the temperatures exceeds the solidus.

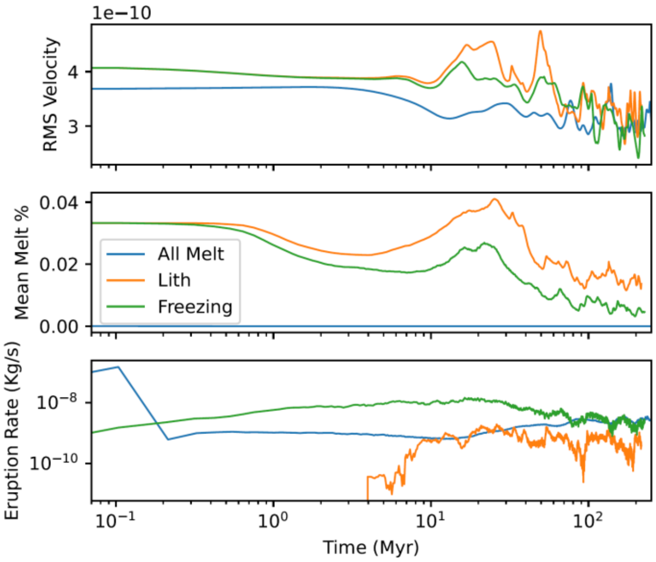

Figure 2: Time series evolution of RMS Velocity (top), mean melt fraction (center), and eruption rate (bottom) for the three considered model cases.

Other Extraction Treatments. We find meaningful differences in mantle evolution when considering other extraction cases. In the "Freezing" model case, we find that extrema in eruption rate are smoothed over (Fig. 2) when compared to the benchmark, leading to increased heat production in low-viscosity areas of partial melt. On the other hand, the "Lithospheric" model case demonstrates that with a more self-consistent extraction criteria, produced melt will linger at depth, as shown by the higher melt fraction and lower extraction rates for this model. Allowing produced melt to linger in the mantle locally thins its thermal lithosphere by up to 100 km (Fig. 3), which may ease the difficulty of dike-driven volcanism.

Next Steps: We are continuing to refine our benchmark model. After this process is complete, we plan to develop within StagYY a melt extraction treatment simulating the emplacement of and magmatic transport through lithospheric dikes after [6].

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