**ON THE POSSIBILITY OF ARC VOLCANISM ON EUROPA FROM SUBDUCTION.** S. M. Menten[1] (smenten@purdue.edu), M. M. Sori[1], and B. C. Johnson[1], [1]Purdue University, West Lafayette, IN

**Introduction:** Europa is an icy Jovian moon that demonstrates abundant evidence of tectonic activity [1]. This tectonic activity is proposed to be the result of a variety of stresses on Europa's ice shell, including tidal stresses and potentially even plate tectonics-like processes [2]. Previous work [2] proposed that some tectonic activity on Europa includes subduction. Kattenhorn and Prockter [2] identified a region on Europa's surface that included ~99 km of missing surface area after tectonic reconstruction. The authors proposed this missing surface area resulted from a type of subduction (called 'subsumption') of Europa's brittle uppermost ice shell into a warmer, convecting portion of the ice shell.

On what is identified as the overriding plate, circular features surrounded by lobate flows were identified as potential cryoflows [2]. These smooth flows are only observed on the proposed overriding plate [2]. Kattenhorn and Prockter (2014) suggest that these flows formed as a result of the subducting slab, similar to how volcanism occurs on the overriding plate due to subduction on Earth through flux melting. However, flux melting on Earth occurs because pressures experienced by the descending rocky plate cause hydrated minerals to break down and release water to the overlying mantle, a process would not be applicable to the icy system on Europa. The authors instead suggest that melting at depth could occur through friction between the subducting slab and the surrounding ice shell or through the addition of salts.

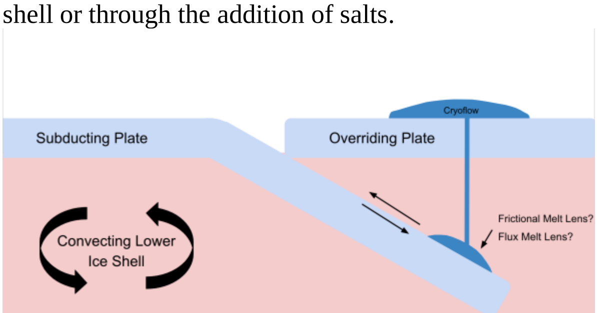


***Figure 1.*** *Diagram demonstrating the proposed cryovolcanism hypothesis, where melting that occurs along a subducting icy slab produces cryovolcanic eruptions on the overriding plate.*

Here, we seek to investigate if subduction induced cryovolcanism is plausible and to determine if a subducting plate could release liquid water at the same lateral distance away from the putative subduction zone as the proposed cryoflows [2]. We consider two potential melting mechanisms for a subducting Europan plate: the addition of salts and frictional heating. We hypothesize that melting in Europa's ice shell could be generated through either of or a combination of these methods. We consider constraints on the angle of subduction of the descending plate and the depth of melting, and the resulting implication for the feasibility of melting. A diagram demonstrating the proposed cryovolcanism hypothesis is shown in Figure 1.

**Salts:** Subduction provides a mechanism to transport salts into Europa's interior, so localized high salt concentrations on the surface of a subducting icy slab could potentially induce melting in an icy shell. We considered the potential of 4 different types of salts that could be present within Europa's ice shell: Mg perchlorates, Na perchlorates, Na chlorides, and Mg sulfates. Europa's surface contains spectral evidence of all these salts [3, 4]. Table 1 shows the changes in the melting temperature of water ice with the addition of various salt types and concentrations, and what depth we calculate they will begin melting within Europa's ice shell for different thicknesses of the conductive layer of the ice shell and assuming high weight percent of salts. This depth is a minimum because we use the highest reduction in melting temperature. We considered that Europa's ice shell has a conductive upper portion that linearly increases from a surface temperature of 100 K to a temperature of 250 K at the base, all above a convecting portion of the ice shell ranges in temperature from 250–260 K [5,6]. In reality, this ice shell structure and thickness are uncertain and the depth of potential melting will be sensitive to these uncertainties.

| Salt Type | Melting Temp | Melt Depth, 10 km conductive shell | Melt Depth, 20 km conductive shell |
|---|---|---|---|
| Mg Perchlorate (40 wt. %) [7] | 204 K | 6.9 km | 13.9 km |
| Na Perchlorate (50 wt. %) [8] | 236 K | 9.1 km | 18.1 km |
| Na Chloride (23.3 wt. %) [9] | 252 K | >10 km | >20 km |
| Mg Sulfate (15 wt. %) [10] | 260 K | > 15 km | > 25 km |

***Table 1.*** *Melting temperatures and depths of water ice with the addition of different salt types.*

Perchlorates could allow for melting at some depth in Europa's conductive lid, whereas Na chloride and Mg sulfates only allow for melting in the convective portion of the ice shell if there is no additional heat from friction. Mg perchlorates allow for melting in Europa's ice shell as shallowly as 6.9 km depth. Melting depths may all be shallower if plate velocities are fast and frictional heating is non-trivial.

We measured that the putative cryolavas appear up to 90 km from the identified subsumption band based on current mapping. This measurement yields a maximum subduction angle constraint for a given assumed shell thickness. For example, for a total shell thickness of 30 km, simple geometry suggests a maximum subduction angle of 18.4° for melting to occur at the base of the ice shell. As an endmember case, melting could happen at an angle at as shallow as 4.4° if there are high concentrations of Mg perchlorates at a conductive ice shell thickness of 10 km (i.e., melting occurring at a depth of 6.9 km). Thus, with our chosen constraints, the inferred a subduction angle is between 4.4°–18.4°.

**Frictional heating:** We next determined the temperature change due to frictional forces between a subducting ice slab and the overriding plate using the following equation [11]:

$$\Delta T = \frac{2\tau}{k}\sqrt{\frac{\kappa d_v u}{\pi \cos(\phi) \sin(\theta)}}$$

Where $\tau$ is the shear stress (assuming a coefficient of friction of 0.55), $u$ is the slab velocity, $k$ is the thermal conductivity of water ice (2.3 W/ m K), $\rho$ is the density of water ice (917 kg/m$^3$), $\phi$ is the angle between the direction of velocity and slab subduction (we assumed an angle of 0° for all cases), $\kappa$ is the thermal diffusivity, $d_v$ is the depth from the surface to the slab, $\theta$ is the angle of subduction, and $C$ is the specific heat capacity of water ice (2050 J/kg K). $\Delta T$ is the change in temperature.

We calculated the temperature change assuming the endmember depth and subduction angle constraints found previously for different salts with a slow, nominal, and fast velocity (0.2, 40, and 100 mm/year, based on suggested rates of potential spreading centers [12]). For a depth of 6.9 km and subduction angle of 4.4° (corresponding to the shallowest, high Mg perchlorate concentration endmember scenario), we found a temperature increase of 1.9, 26.5, and 41.9 K with our slow, nominal, and fast velocities. For a high concentration of Na perchlorates (depth 9.1 km, angle 5.8°) , we found a temperature increase of 2.5, 35.0, and 55.3 K. If the subduction angle is instead at a more typical Earth value of 45°, then at 10 km depth there would be a temperature increase of 1.1, 15.2, and 24.1 K. These calculations show frictional heating can be important and cause melting at shallower depths than would be predicted from salt concentrations alone if a plate is subducting at a fast velocity.

**Discussion:** Arc volcanism on Earth occurs due to the release of water from a subducting plate into the overlying mantle, which lowers the melting temperature of specific minerals and allows for flux melting. Arc volcanism on Europa may be possible due to the addition of salts and frictional heating. Localized high concentrations of salts on the subducting slab make the conditions for subduction more feasible [13], so this constraint is consistent with subducting plates.

If the ice shell is 30 km thick or less, the angle of the subducting plate must be <18.4° for melting to occur at the appropriate lateral distance before the plate reaches the ocean. These potential angles of subduction are shallower than most Earth plate subduction angles (a subducting plate typically dips $\geq$ 45° [14]). However, some plates on Earth are predicted to be subducting shallowly ($\leq$ 15° [14]). Future work can be used to model the expected dip angles of plates on Europa. Alternatively, a thicker ice shell could allow steeper angles.

**Conclusions and future work:** We find that arc volcanism and melt generation due to subduction is likely viable under certain conditions on Europa. For example, a subducting plate at an angle between 4.4°–18.4° with high concentrations of Mg perchlorate can create melt at 6.9 km depth 90 km away from a subduction zone if the total ice shell is 30 km thick and frictional heating is negligible. These subduction angles could be shallower if plate velocities are high and frictional heating is significant, or steeper if the ice shell is thicker or salt concentrations are lower. Ongoing work will model subduction angle, frictional heating, and salt concentrations together to fully constrain the parameter space in which melting can occur. In this work, we only tested whether melting could occur at the appropriate depth and distance away from the subduction zone. Future work on this topic could consider the mechanisms and forces that drive that melt to erupt on the overriding plate as a cryoflow.

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