Water Activity of Europa’s Ocean: Temporal Variability and Implications. E. M. Spiers¹ and B. E. Schmidt¹,
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Introduction: Europa, a satellite of Jupiter, has proven to be a geologically active body [1][2][3] with evidence for harboring a global, subsurface ocean [4][5]. Europa’s scientific relevance is partially due to the habitability implications of this liquid water ocean, which is maintained by tidal heating. Tidal heat inputs to Europa’s interior have varied with the evolution of the Laplace resonance, possibly becoming oscillatory at times [6][7]. This possible thermal oscillation can drive oscillations in other systems within Europa’s interior. One such factor that should be affected by the thermal state of Europa’s interior is the thickness of the ice shell [8][9][10]. As seen on Earth, when ocean water freezes, brine rejection out of the ice will occur [11]. Conversely, when ice sheets melt, fresh water is injected into the water body. On Europa, the overlying ice shell may have varied by tens of kilometers over its evolution, leading to significant brine rejection into the ocean during periods of freezing, and injection of fresh water to the ocean during periods of melting. These could lead to non-negligible variability of Europa’s ocean salinity. In this work we examine the variability in geochemical processes of Europa’s rocky mantle due to thermally-driven changes in water activity through ice shell thickness, and the implications of that variability on habitability.

Variation in Ocean Salinity: Current estimates of Europa’s mantle heat production, \(H(t)\), after formation of the Laplace resonance incorporate both radiogenic and tidal heating [6][7]. The model for heat production where tidal dissipation is restricted to the silicate layer is incorporated here [6]. The ice shell thickness, \(Z_{Ice}\), will vary with the mantle heat production and is modeled by assuming a single layer, conductive ice shell. The salinity and composition of the European ocean are unknown, so a range of estimates are considered for initial salt abundances. These include an ocean of purely halite (NaCl), purely magnesium sulfate (MgSO4), an estimate based on Europa bulk composition [12], and an Earth seawater equivalent. The change in ocean salinity in weight percent, S, is calculated by measuring the change in liquid water mass, \(M_{H_2O}\), due to freezing, relative to mass of available salt, \(M_{salt}\). Figure 1. The mass of available salts is calculated through abundances of individual ions per kg of water.

Water Activity of Europa’s Ocean: The water activity of a solution describes the degree of water available for hydration of materials, with a common water activity living limit for all life forms on Earth, including Archea, Bacteria, and Eukarya [13]. Water activity is closely

![Figure 1: Variability in Europa’s ocean salinity due to variations in ice shell thickness. In the ice shell model used, shell thicknesses vary from less than 1km to nearly 60km. Four different salt abundances are considered: a purely NaCl salt composition, a purely MgSO4 salt, and a Europa estimate consisting of combined NaCl and MgSO4 abundances as well as 0.014M of NaSO4, derived from bulk composition [11]. The final salt composition is an Earth ocean analog related to salinity of a solution, where increased salinity decreases water activity. However, not all salts affect the potential for hydration in the same way [14]. Some ions strengthen hydrophobic interaction, allowing for higher levels of hydration potential for biological molecules. In contrast, ions that are chaotropic will reduce the potential for hydration, creating environments that are weakly hydrated. The composition, and by association the water activity, of Europa’s ocean will evolve as the thermal state evolves over time. The previously calculated variable ocean salinities, are converted to composition specific water activity using experimentally derived tables [15][16].

Implications for Geochemistry: Water activity of Europa’s ocean has implications for water-rock reactions, as a low water activity will have a reduced potential for hydration reactions. If the water activity of the ocean and/or pore fluids within the mantle is variable, then the rates of hydration reaction will vary as well, placing limits on production of biologically relevant chemistry due to these reactions, such as hydrogen, methane, or carbon dioxide.

The reaction rates for low temperature serpentinization depend on the composition of the mantle. Due to the inability to directly measure the Europan seafloor composition with currently available resources, its assumed that the composition of the seafloor is similar to that of Earth’s, composed primarily of olivine (70%) and pyroxene (7%) [17]. The reaction equation for low
temperature serpentinization due to the hydration of fayalite, and end member of olivine is listed in Equation 1.

\[3\text{Fe}_2\text{SiO}_4 + 2\text{H}_2\text{O} \rightarrow 2\text{Fe}_2\text{O}_3 + 3\text{SiO}_2 + 2\text{H}_2\g\]  
(1)

Rates of serpentinization are evaluated using laboratory studies [18] [19] [20]. For lower water activity levels, the rate of reaction is faster, and for higher water activity levels the rate of reaction is slower [18]. The water activity for pore fluids is likely to be higher than for the bulk ocean, so salinities that define the rate of reaction. Pore fluids are likely to have higher salinities than bulk ocean, so salinities that are double and triple the bulk ocean composition estimates are included.

Figure 2: Reaction of due to hydration of Europa's mantle for various ocean salinities. Mol of each species are scaled to total mol of rock that is fluid accessible due to cracking, showing the abundances of each species at a given time. Salinities are converted into a composition dependent water activity that defines the rate of reaction. Pore fluids are likely to have higher salinities than bulk ocean, so salinities that are double and triple the bulk ocean composition estimates are included. For fluid access to previously unexposed mineral surface area [23] [24]. The rate of reaction is competed against a model of the rate of fracture opening due to cracking [17, 25] and in turn, the rate of new fayalite exposure, Figure 2. As Europa approaches a colder thermal equilibria, the extent of cracking will increase further into the mantle [17, 25].

**Initial Results and Implications:** For high water activities (lower salinities), the reaction proceeds faster than new rock is exposed via cracking for hydration. This limits the overall release of hydrogen as the reaction becomes supply limited in olivine. As Europa enters an oscillatory thermal period, the release of byproducts mimics this oscillation, creating a stepped release. For low water activities (higher salinities), the system is entirely reaction rate limited. While the overall production of hydrogen increases with an increase of fluid accessible olivine, the fluid accessible area does not become supply limited as in the low water activity case. This produces a more constant, yet lower production of hydrogen over time, and implies that release of hydrogen due to serpentinization of fayalite is dependent on the water activity of pore fluids. Other similar rock-water hydration reactions are likely to be similarly influenced. The stepped release of hydrogen during periods of thermal oscillation may have broad consequences on redox state of the ocean, and consequently habitability of Europa’s interior.