INVESTIGATING THE DYNAMICS OF DIKE-FED CRYOVOLCANISM.

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Introduction: The geologic process termed cryovolcanism, or, the eruption of a liquid water solution, has long been postulated for icy satellites possessing an ice shell crust and a liquid water ocean [e.g. 1]. Direct observation of this process includes most notably, the plumes on Enceladus [2, 3], and the observations of possible plume activity on Triton [4], and more recently, Europa [5]. While mechanisms for eruptions on Triton include sublimation of methane [6], eruptions on Enceladus and Europa can be considered "top-down" style eruptions. I define "top-down" eruptions as events where fracturing is induced within the ice shell by processes such as tidal flexing [7], and then propagates downwards, tapping the ocean, and inducing explosive volatilization of the ocean materials [8]. This style of volcanism is starkly different from standard silicate volcanism where accumulating mantle melts impinge on the base of the crust, form a fracture, and propagate upwards towards the surface in the form of a dike. While there have been several putative identifications of morphologies that would be associated with this dike-fed, "bottom-up", style of volcanism [9, 10, 11], there exist several long-recognized mechanical problems with the process.

The single largest mechanical barrier to dike-fed cryovolcanism is that liquid water is denser than the overlying ice shell, and thus will not propagate unless grossly overpressurized. As a result, much of the literature surrounding the mechanisms of cryovolcanism focuses on the addition of salts and other solutes to decrease the density of the cryomagma, and make propagation more favorable [e.g. 12].

However, we suggest that such exotic compositions might not be necessary to allow for dike-fed propagation of cryomagmas. Using a series of analyses recently applied to the Moon (another body with magma denser than the overlying crust) [13, 14, 15], we explore how dike-tip degassing, and in-transit magma exsolution might aid cryovolcanic transport.

Dike Propagation Mechanics: Dike propagation is governed by the balance of magma overpressure against the fracture toughness of the crustal material. The equation is as follows [16]:

$$K = \Delta P(H/2)^{1/2} + 0.5g\Delta\rho_m(H/2)^{3/2}$$

The fracture toughness of the crustal material is K, the excess pressure in the magma is ΔP, the height of the dike tip above the base of the crust is H, g is the gravitational acceleration, and $\Delta\rho_m$ is the density difference between the magma and the surrounding crustal material. Figure 1 shows dike propagation scenarios for 3 different bodies and 3 different ice shell thicknesses using an H_2O + NaCl brine. In no case does the dike propagate to the surface or shallow subsurface. However, this implementation (and most others from the literature) assumes a constant value for $\Delta\rho_m$, despite evidence that this assumption is not always valid. Head et al. [2002] [13] recognized that because the dike tip is inherently a vacuum environment, there will be a pressure gradient in the top of every dike, and this low pressure environment will encourage the exsolution of volatile species in this portion of the dike. The formation of bubbles leads to a magmatic foam with a lower density than the nominal magma density [14, 15, 17]. We will apply the mechanism outlined in [13] to three putative cryomagma compositions, 1) pure H_2O, 2) H_2O+NH_3, and 3) H_2O+Mg, Na salts (brine) to determine if dike-tip degassing is sufficient to allow for propagation of a cryomagma dike to the surface or shallow-subsurface of an icy satellite. We will also examine the possible morphologies associated with this process, and whether it is capable of generating effusive morphologies, in addition, to explosive plumes.

Figures:

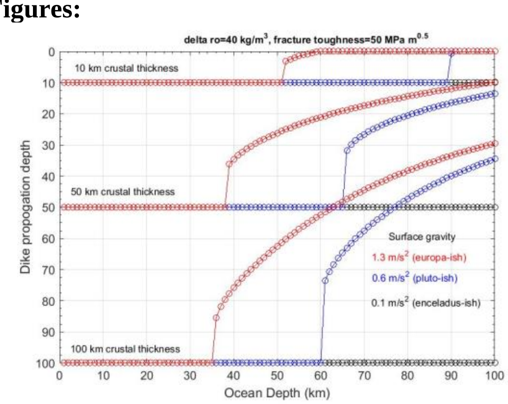

Figure 1: Propagation scenarios as a function of varying gravitational acceleration and ice shell thickness given a constant ice fracture toughness and cryomagma density contrast.

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