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Cryomagma ascent on Jupiter's moon Europa

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Abstract

Smooth plains and lobate features are identified on Europa's surface, and among other features seem to involve sub-surface liquid water reservoirs at shallow depth. Our study aims at modeling the ascent of liquid water from a freezing chamber to the surface, producing cryovolcanic eruptions. We show that if this kind of liquid flow takes place on Europa, the eruptions happen in a short time scale (tens of seconds to tens of hours), and the cryolavas travel to the surface at high speed (few tens of m/s) as a turbulent flow.

1. Introduction

Data acquired by the Galileo spacecraft between 1995 and 2001 show diverse geological features on Europa [3]. These features associated with a low craters density at the surface demonstrate an internal activity of the moon [5]. In particular, smooth plains cover parts of the surface, and their morphologies and relationship to the surrounding terrains suggest that they result from viscous liquid extrusions [9].

Recent literature involves the presence of liquid reservoirs beneath the surface to explain the emplacement of common features, such as double ridges [2], lenticulae [6] and chaos [10].

The aim of this study is to define the conditions and timing of ascent of liquid water, and whether or not liquid water extrusion from sub-surface reservoirs can produce the smooth plains and lobate features. In order to do this, we first model the ascent of water through a dike or a pipe-like conduit for Europa's surface conditions and different chamber depths and volumes.

2. Model

We first test one of the trigger mechanism proposed by Fagents [3]: at the first stage, a liquid water pocket is present in the subsurface. For instance, this pocket may either come from the global ocean underneath, captured by the convective movements within the ice shell [8], or may be due to local enhanced heat flux [4]. Second, the cryomagma contained in the chamber freezes and pressurizes over time. When the stress applied on the chamber's walls reaches a threshold, the walls break and the fracture may propagate to the surface. Third, the remining fluid (that did not crystallize) flows out at the surface through a dike or a pipe-like conduit.

We model the flow driven by the pressure difference between the cryomagma reservoir and the surface. After eruption initiation, the pressure in the chamber decreases with time and the eruption stops once the pressure in the chamber is equal to the hydrostatic pressure.

The overpressure required to fracture the chamber depends on the chamber depth H, the ice shell density ρ_i and the ice tensile strength σ_c [7]:

$$\Delta P_{max} = 2(\sigma_c + \rho_i g H) \qquad (1)$$

The pressure increase generated by the cryomagma freezing is related to the liquid volume decrease through the water compressibility χ:

$$\chi = -\frac{1}{V}\frac{\partial V}{\partial P} \qquad (3)$$

An estimation of the Reynolds number for such flow leads to a typical value of $Re = 10^7$. Assuming a turbulent velocity [1]:

$$U = \sqrt{\frac{D_h(P_c - \rho_w g H)}{2 f \rho H}} \qquad (3)$$

with H the chamber depth, P_c the overpressure inside the chamber, D_h the dike or pipe-like conduit hydraulic diameter, ρ_w the water density and f the friction factor inside the conduit. We calculate the evolution of flow velocity and chamber pressure with time. The simulation also returns the total volume of water extruded at the end of the eruption.

3. Results and conclusions

We investigate the influence of the dike/conduit geometry and the chamber depth and volume on eruption duration and emitted volume. We find that the results obtained depend mostly on the two last parameters.

As an example, Fig. 1 and 2 show respectively the evolution of the pressure in the chamber and the evolution of the mean velocity of the flow for a 2 km depth chamber, which has a total volume of 1km^3. We assume a dike of 100 m^2 cross-section through which the liquid water ascends to the surface.

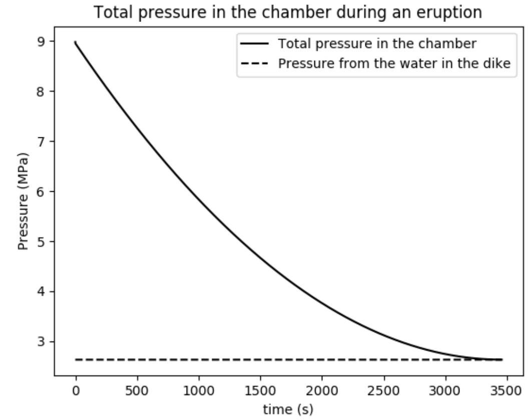

Figure 1: Evolution of the pressure inside a chamber of 1km^3, 2km depth, during a cryovolcanic eruption. The eruption stops when the pressure in the chamber equals the pressure of the water column into the dike.

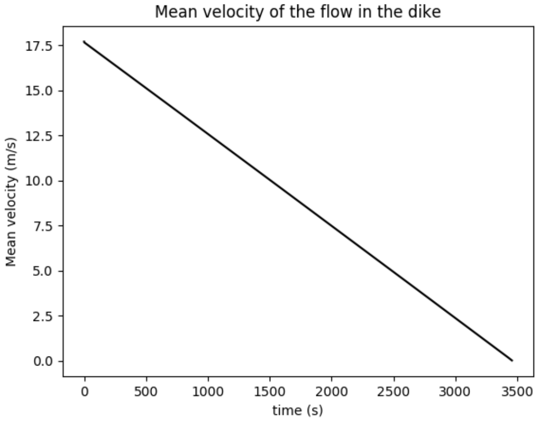

Figure 2: Evolution of the mean flow velocity from a chamber of 1km^3, 2km depth, during a cryovolcanic eruption. The eruption stops when the pressure in the chamber equals the pressure of the water column into the dike.

The eruption time-scale and total volume extruded at the end of the eruption depend on the chamber volume and depth. For plausible volumes and depths varying between $0.1\,km^3 < V < 10\,km^3$ and $100\,m < H < 10\,km$, the total extruded cryolava volume ranges from 10^5 to 10^8 m^3, and the time scale of the eruptions varies from few minutes to few tens of hours.

We plan to investigate the liquid water stability and thermal transfer when the cryomagma approaches the surface. Indeed, the zero pressure and 100 K at Europa's surface may affect the rheology of the flow and the eruptive style. In the future, it would allow us to compare our results with Galileo high resolution images.

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