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# Time scales of cryomagma eruptions on Europa

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## Abstract

Smooth plains and lobate features are identified on Europa's surface, and seem to involve sub-surface liquid water reservoirs at shallow depth. Our study aims at modeling the ascent of liquid composed of pure or briny 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. For chamber radius varying between 10 and few hundred meters, the freezing time-scale varies between $10^2$ to $10^3$ years for a pure water cryomagma and from $10^2$ to $10^4$ years for a briny cryomagma.

## 1. Introduction

Data acquired by the Galileo spacecraft between 1995 and 2001 show smooth plains cover parts of the surface, and their morphologies and relationship to the surrounding terrains suggest that they result from viscous liquid extrusions [1]. Recent literature involves the presence of liquid reservoirs beneath the surface to explain the emplacement of common features, such as double ridges [2], lenticulae [3] and chaos [4].

We model the ascent of liquid water through a dike or a pipe-like conduit, from a sub-surface reservoir to Europa's surface and derive the eruption time-scale and the total volume extruded at the end of the eruption, depending on the chamber volume and depth. We also estimate the freezing time of the sub-surface reservoir necessary to trigger an eruption. Considering available data for density and eutectic temperature of salt impurities recently proposed for Europa [5], we discuss their effect on the cryomagma freezing time and ascent.

## 2. Model

Based on the work by Fagents [6], we consider the following mechanism summarized in Fig. 1: a liquid water pocket is present in the subsurface and the cryomagma contained in the chamber freezes and pressurizes over the time. When the stress applied on the chamber walls reaches the critical value, the walls break, and a fracture may propagate to the surface. The remaining fluid flows out at the surface through a dike or a pipe-like conduit. A numerical model calculates the evolution of flow velocity and chamber pressure with time.

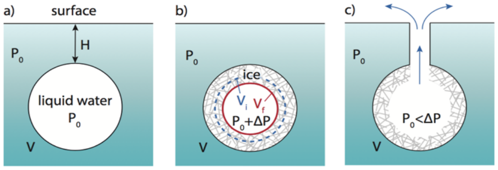

Fig. 1: Model used in this study. a) A hot liquid water lens is at isostatic pressure $P_0$ and depth $H$. b) The cryomagma freezes and the liquid is compressed from a volume $V_i$ to a volume $V_f$, generating an overpressure $\Delta P$. c) The eruption begins when the pressure reaches a critical value and ends when the chamber is back at isostatic pressure.

The pressure increase generated by the cryomagma freezing is related to the liquid volume decrease through the water compressibility $\chi$. The critical fraction of liquid $n_c$ that has to freeze to generate the critical overpressure $\Delta P_c$ and begin an eruption is given by:

$$n_c = \frac{\exp(\chi \Delta P_c) - 1}{\frac{\rho_l}{\rho_s}\exp(\chi \Delta P_c) - 1} \qquad (1)$$

where $\rho_l$ is the liquid density and $\rho_s$ is the solid density.

In order to get an order of magnitude of the freezing time of the chamber and to evaluate the time necessary to reach the critical overpressure, we solve the Stefan problem in 1D using cartesian coordinates [7]. The freezing time scale $\tau_c$ is:

$$\tau_c = \left( \frac{n_c{}^{1/3} R_{chamber}}{2\lambda\sqrt{\kappa_s}} \right)^2 \qquad (2)$$

where $R_{chamber}$ is the chamber radius, $\lambda$ is a parameter computed from the temperature gradient between the chamber and the surrounding ice and the solidification latent heat, and $\kappa_s$ is the thermal diffusivity in the solid part of the cryomagma.

These calculations are derived in two cases: 1. a pure water composed cryomagma and 2. a briny cryomagma. As suggested by recent studies [8], a plausible composition for the Europa's ices and cryomagma is a mixture of $H_2O$, $MgSO_4$ and $Na_2SO_4$. In that second case, we modify accordingly the densities $\rho_l$ and $\rho_s$ in Eq. (1).

# 3. Results

For plausible volumes and depths varying between 0,1km$^3$<V<10km$^3$ and 100m<H<10km, 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. The freezing time-scale of the cryomagma pocket varies with the cryomagma composition: as shown in Fig. 2, it differs of few percent for a briny or a pure water cryomagma. The freezing time-scale varies between $10^2$ to $10^3$ years for a pure water cryomagma and from $10^2$ to $10^4$ years for a briny cryomagma [8]. The freezing timescale, within the life-time of putative liquid water lenses which varies from $10^3$ to $10^5$ years [3], indicates that eruption should be possible.

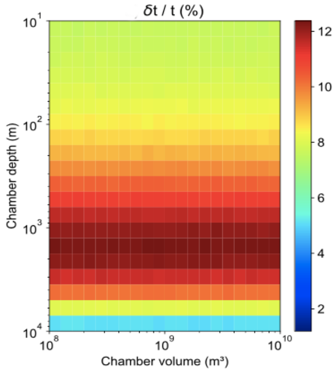

Fig. 2: Modification of the eruption duration between the case with a pure liquid water composed cryomagma and a mixture of $H_2O$, $MgSO_4$ and $Na_2SO_4$.

We plan to compare these results with the Galileo observations by carrying out a stereoscopic study of some lobate features in order to define plausible locations of cryovolcanic active areas on Europa. These results could be useful for the two missions JUICE (ESA) and Europa Clipper (NASA).

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