National Aeronautics and Space Administration

Cryovolcanic Eruptions on Europa

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Context

Shallow subsurface brine reservoirs on Jupiter's icy moon Europa, if they exist, could represent accessible liquid water bodies in the outer solar system and be key for the exploration of Ocean Worlds and the search for life beyond Earth. Previous studies predict cryoreservoirs can erupt due to overpressure stresses generated by freezing, potentially explaining flow-like features observed on the surface. These studies do not take into account the viscoelastic behavior of ice, which may accommodate the internal overpressure by deformation of the reservoir wall.

Can cryoreservoirs embeded in viscoelastic ice be pressurized by freezing and trigger eruptions?

Methods

We propose a new analytical and numerical model to more accurately calculate the pressure evolution in a freezing reservoir. We model a cryoreservoir as a lens-shaped cavity in viscoelastic ice, filled with briny liquid water at melting temperature. The temperature decreases with time, and the cryomagma freezes, which progressively increases the reservoir internal pressure ΔP. Because of the pressure increase, the viscoelastic reservoir wall deforms and its radius increases. If and when the threshold overpressure is reached, a fracture propagates to the surface and an eruption is triggered.

Ice shell characteristics → Eruption characteristics

Cryomagma Freezing-Induced Eruption Simulation (CryoFRIES)

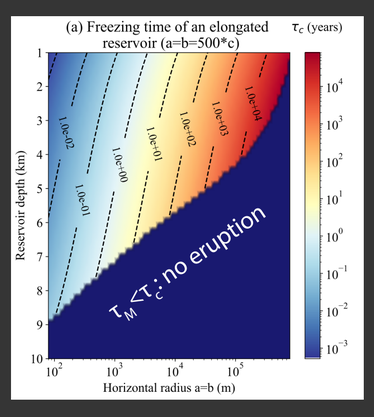
https://github.com/ElodieLesage/CryoFRIES

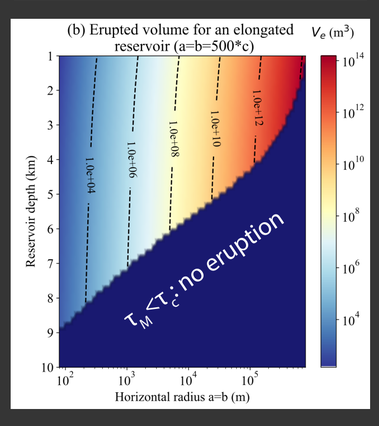
Results

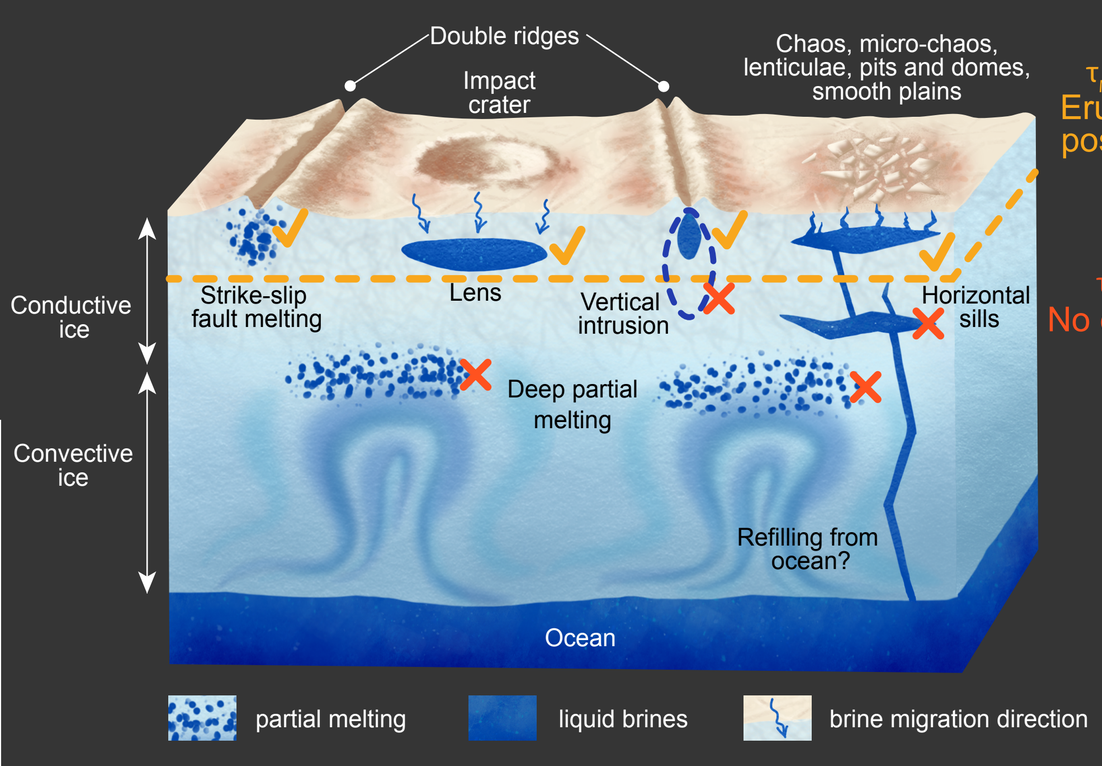
The Maxwell time of the ice τ_M is a key parameter to understand cryoreservoir behavior: $\tau_M = \eta / E$ with η the ice viscosity and E its Young modulus.

- Shallow ice: τ_M > freezing time (τ_c), ice behaves as a elastic material, deformation is moderate;
- Deeper: τ_M < freezing time (τ_c), ice behaves viscoelastically, deformation is important.

For reservoirs that can trigger eruptions, we predict the freezing time necessary to reach the eruption, the erupted volume, fluid ascent velocity, eruption duration,...



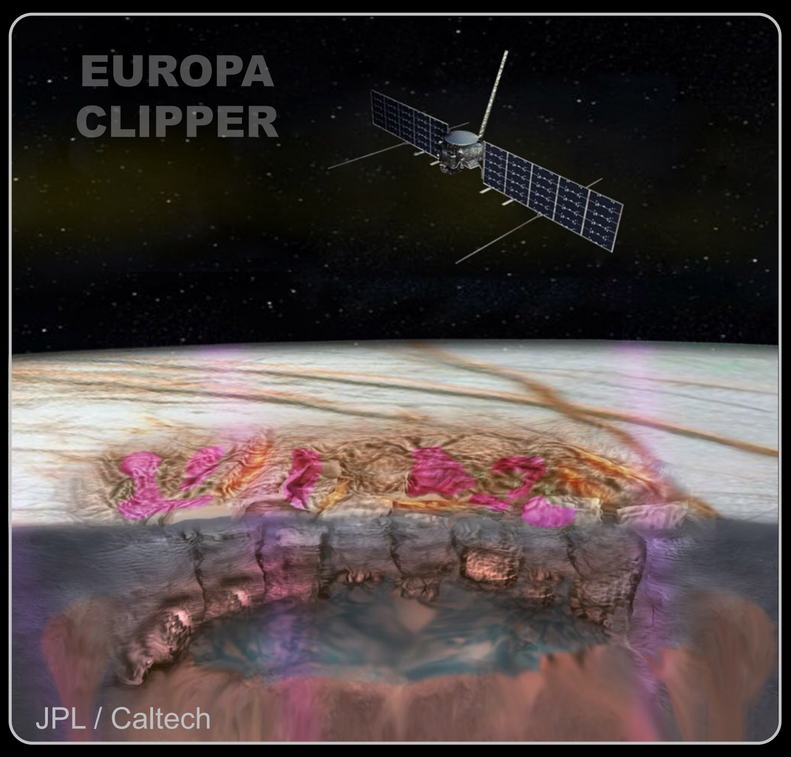




[Lesage et al., 2022]

Conclusions

- Freezing cryoreservoirs can deform up to several tens of meters and accommodate the internal pressure.
- Due to increasing temperature and thus ice relaxation with depth, **only reservoirs located in the outermost part of the conductive ice layer can trigger eruptions (<80% of cond. layer).**
- Spherical reservoirs can erupt small amounts of cryolava (<1 km^3), shallow **elongated lens-like reservoirs** are required to explain large cryovolcanic features on Europa's surface.



Implications for future exploration

If plumes or cryolava flows are observed on icy satellite surfaces, they could indicate the presence of shallow liquid reservoirs. The upcoming missions Europa Clipper (NASA) and JUICE (ESA) that will be able to test these results using radar probing and multi-wavelength imaging (visible, IR, UV). Our study also supports the development of subsurface access technologies (cryobots) that aim at sampling and analyzing liquid water at Ocean Worlds.

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Publications:

Lesage, E., Massol, H., & Schmidt, F. (2020). Cryomagma ascent on Europa. *Icarus*, 335, 113369.

Lesage, E., Schmidt, F., Andrieu, F., & Massol, H. (2021). Constraints on effusive cryovolcanic eruptions on Europa using topography obtained from Galileo images. *Icarus*, 361, 114373.

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