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Water production and transport in the ice shell of Europa

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Abstract

Ice melting and water flow through the icy crust of Europa is investigated. We solve the equations for a two-phase incompressible mixture of water ice and liquid water in 1D geometry. Formation and time evolution of the molten water reservoir depends on several parameters. Our first results show that water produced at shallow depths by tidal heating is transported downward on relatively short timescales. The probability of water accumulation at shallow depths within the ice shell seems therefore quite low.

1. Introduction

Tidal heating in the ice shell is expected to melt ice at relatively shallow depths (<5-10 km), e.g. [2, 5]. Tidally-induced melt production may play a key role in the formation of chaotic terrain [5, 3] as well as along the most active tectonic faults [2]. However, the accumulation of water at shallow depths is challenged by the ability of water melts to migrate downwards.

The presence and movement of liquid water through the ice layer can dramatically change its state and transport properties. The aim of our work is to treat the problem as a flow of a two-phase mixture of ice and water (of small volume fraction - porosity) and to assess the range of typical time scales for the transport phenomena through the ice layer and the probability of water accumulation near the surface.

2. Model and Numerical Method

We use the equations derived in [7] (which correspond to the set derived in [1] if the effects of surface tension are neglected) in 'zero compaction length approximation' (e.g. [6]). We investigate a simple 1D Cartesian case. To complete the system, zero matrix velocity at the bottom boundary and fixed temperatures at both boundaries are considered.

Depending on temperature, ice can be present in two different states - cold ice (ice below melting point with no water) and temperate ice (ice at melting point with a small amount of water). Two different dynamical contexts are considered - one is to simulate the evolution of a column of ice beneath a strike-slip fault (green lines in Fig. 1), the other to simulate the evolution of ice within a hot plume (red lines in Fig. 1). Considering only 1D equations, the thermal convection is neglected in this simple investigation. However, we mimic the thermal context of a hot plume. For both scenarios, temperature-dependent tidal heating is computed following the approach described in [8]. In the first case, the heat dissipated through shear motions on the fault is added (for details see [2]). For a proper treatment of the nonlinear partial differential equation for porosity advection, the Essentially Non-Oscillatory schemes [4] are employed. The explicit Euler method is used to integrate in time domain.

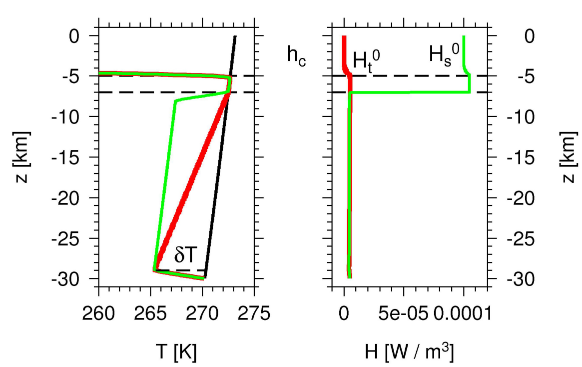

Figure 1: Detail of the initial temperature profiles (left) and corresponding heating (right) for the scenario mimicking the hot plume (red lines) and colder region beneath the strike-slip fault (green lines). Melting temperature is indicated (black line in left panel).

3. Results

The time evolution of porosity profile for the scenario including both, tidal and shear heating is depicted on Fig. 2. The first melt appears at the fault where the initial temperature was highest. Gravitationally unstable water then starts flowing downward.

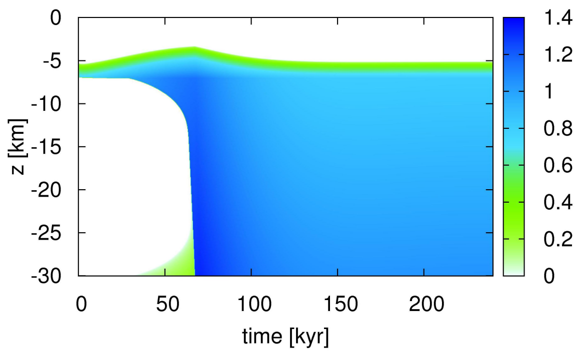

Figure 2: Time evolution of porosity profiles (in %) for the case with tidal and shear heating and $k_0 = 10^{-10}$ m^2.

We have investigated several parameters which influence the evolution of liquid water in the ice layer - permeability prefactor k_0, amplitude of tidal and shear heating, H_t^0 and H_s^0, respectively, thickness of the upper cold layer h_c and distance of initial temperature from the melting point δT. Figure 3 shows the effect of k_0 on the time evolution of height of water column in the domain. The smaller k_0, the larger the amount of molten water. Also, more time is needed for the porosity wave to reach the bottom boundary. At that moment, the maximum amount of water is present in the layer (maximum of each curve in Fig. 3), then the outflow begins. The other parameters infuence the initiation of outflow (H_t^0, δT) as well as maximum amount of water in the layer (H_s^0, h_c). When only volumetrically distributed tidal heating is considered, the outflow of water starts earlier (due to initiallly higher temperature) but the total amount of molten water is smaller.

4. Summary

Solving equations for the incompressible two-phase mixture of ice and water in 1D geometry allows us to quantify the timescales of water production and transport for different sets of parameters. We show that these timescales are primarily determined by the amplitude of tidal heating H_t^0, the distance of initial temperature from the melting point δT and the permeability prefactor k_0. The amount of produced water depends on the permeability prefactor k_0, the amplitude of shear heating H_s^0 and the thickness of cold upper layer h_c. The effect of other parameters (surface temperature, thickness of the whole layer, percolation threshold) will be further investigated. Based on these first results, it seems unlikely to accumulate large volumes of water near the surface on timescales larger than about 10^5 yrs.

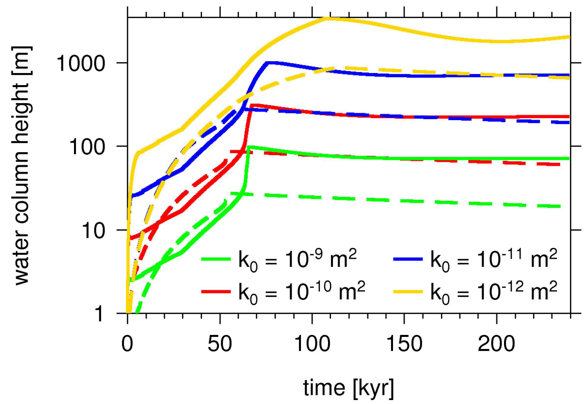

Figure 3: Time evolution of column integrated porosity for different values of k_0 and scenario with both, tidal and shear heating (full lines) or with tidal heating only (dashed lines).

Acknowledgements

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