EPSC Abstracts
Vol. 12, EPSC2018-470, 2018
European Planetary Science Congress 2018

Heat and water generation in the vicinity of Europa's strike-slip faults

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Abstract

In this study, we investigate the onset of melting below Europa's recently active strike-slip faults and assess the stability of generated meltwater. We extend our previous study of water generation and its transport in the vicinity of strike-slip faults on Europa [3] by improving the model of internal heating due to frictional and bulk deformation. This is achieved through coupling of the original code with a model of tidally-induced deformation of a viscoelastic Maxwellian body. Our preliminary results indicate that the dissipation at the fault may be large enough to generate liquid water thus confirming the previous results. However, the new approach allows us to investigate the process of melting on the fault in a more self-consistent way.

1. Introduction

Jupiter's moon Europa has a very young surface with an abundance of unique terrains that indicate recent endogenic activity [2]. Morphological models and spectral observations suggest that it might possess shallow lenses of liquid water within its outer ice shell [5, 6]. We revisit our previous study on generation and transport of water below the strike-slip faults on Europa [3] where a constant heating amplitude was prescribed and improve the model of heat generation.

Following up the work of [4] we compute the response of a Maxwellian body subjected to shear motions that mimick the tidal forcing. As a result, bulk and frictional dissipation is calculated which provides a heat source in the two-phase convection model presented in our previous study [3]. Thermal evolution computed by the convection code in turn determines the parameters that govern the slip at the fault and thus the associated dissipative heating.

2. Numerical model

For the convection part of the model, the equations for two-phase flow of a compressible mixture of ice and liquid water [3] are employed. These allow us to consistently address melting of ice and the subsequent meltwater advection by Rayleigh-Taylor instabilities.

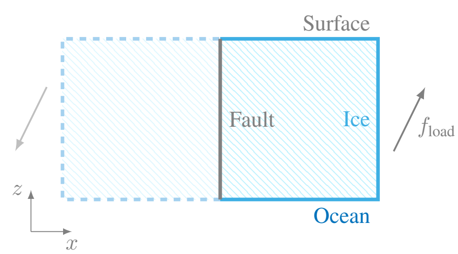

Figure 1: Sketch of the physical model. The arrows indicate the tidally-induced strike-slip forcing, the computational domain is represented by solid lines.

The response of a Maxwellian body is computed by solving the Stokes equation:

$$\text{div}\,\sigma = 0, \tag{1}$$

where σ is the Cauchy stress tensor described by incompressible Maxwell rheology:

$$\sigma = 2\mu\mathbb{D}_d(\mathbf{u}) - \frac{\mu}{\eta}\int_0^t \sigma(t')\text{dt'}, \tag{2}$$

where $\mathbb{D}_d(\mathbf{u})$ is a deviatoric part of the symmetric displacement gradient, μ, η are shear modulus and viscosity, respectively, and t is time.

We can further simplify the previous equations by allowing the strike-slip motion only along the fault plane and by neglecting other than gravitational and tidal forces. Then, the problem can be rewritten in the form of a single vector equation:

$$\nabla_{x,z} \cdot (\mathcal{K}\,\Sigma) + \nabla_{x,z} \cdot (\mathcal{L}\,v) = 0, \tag{3}$$

where $\mathcal{K}, \mathcal{L}$ are parameters dependent on viscosity, shear stress and time step according to the applied rheology (viscoelastic or the viscous/elastic limits), $\Sigma = (\sigma_{xy}, \sigma_{yz})$ and v is the velocity. The tidal loading is then enforced through a boundary condition on the right side of the domain (cf. Figure 1).

On the left side, the fault is described through the Navier-slip boundary condition, where the slip velocity equals one half of the relative slip rate.

The fault behaviour is simulated through a pseudo-plastic stress-limiting viscosity dependent on the yield stress σ_Y, which, in our model, represents the friction coefficient and controls the depth of the fault:

$$\eta = \frac{\eta^\infty}{\left\{1 + \left(\frac{\eta^\infty |v|}{\sigma_Y}\right)^\alpha\right\}^{\frac{1}{\alpha}}}, \tag{4}$$

where α is a parameter and η^∞ is a background viscosity.

Our model is implemented in the open-source finite element software package FEniCS [1], consequently we present equation (3) in the weak form and discretized in time:

$$\begin{aligned} &\int_\Omega \mathcal{L}^{k+1} \nabla_{x,z} v^{k+1} \cdot \nabla_{x,z} v' \,\mathrm{dx} \\ = \;& -\int_\Omega \mathcal{K}^{k+1} \Sigma^k \cdot \nabla_{x,z} v' \,\mathrm{dx} \\ - \;& \int_{\partial\Omega_L} 2v \frac{\eta^\infty}{\left(1 + \left(\frac{2\eta^\infty |v|}{\sigma_Y}\right)^\alpha\right)^{1/\alpha}} v' \,\mathrm{ds} \\ + \;& \int_{\partial\Omega_R} f_{\mathrm{load}}(t^{k+1}) v' \,\mathrm{ds}, \end{aligned} \tag{5}$$

where the indices $k, k+1$ indicate the time step, $\Omega, \partial\Omega_L, \partial\Omega_R$ denote the computational domain and its left and right boundary, respectively, f_{load} is the loading force and v' is the test function. In the numerical scheme, we employ a fixed point iteration to ensure better approximation of the slip velocity in the viscosity expression (4).

3. Preliminary results

In our reference simulation, the domain is strained by a force equivalent to 3×10^5 Pa. Figure 2 shows the preliminary results for the slip velocity (left) and the temperature (right). In this setting, the fault propagates to approximately one third of the domain's depth. Deformation on the fault and the associated dissipation lead to substantial heating and increase in temperature at the fault tip. A parametric study and comparison with the previous results will be presented at the meeting.

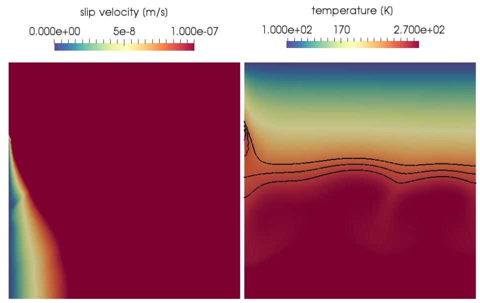

Figure 2: Preliminary results of simulation with the loading force equivalent to 3×10^5 Pa prescribed on the right boundary: slip velocity (left) and temperature (right, contours mark $230, 240$ and 250 K). Note the temperature increase in the vicinity of the fault tip.

Acknowledgements

K.S. acknowledges support from Charles University through projects GA UK (project number 304217) and SVV-2018-260447. This work has been supported by the IT4Innovations Centre of Excellence project (project number OPEN-12-21) and by Charles University Research program No. UNCE/SCI/023 (O.S., K.K.).

References

[1] Alnaes, M. S., et al.: The FEniCS Project Version 1.5, Archive of Numerical Software, vol. 3, 2015.

[2] Bierhaus, E. B., et al.: Europa's crater distributions and surface ages, in Europa, pp. 161–180, Univ. of Arizona Press, Tucson, 2009.

[3] Kalousová, K., et al.: Water generation and transport below Europa's strike-slip faults, JGR-Planets, 121, 2444–2463, 2016.

[4] Nimmo, F., and Gaidos, E.: Strike-slip motion and double ridge formation on Europa, JGR, 107, E45021, 2002.

[5] Roth, L., et al.: Transient water vapor at Europa's south pole, Science, 343, 171–174, 2014.

[6] Schmidt, B. E., et al.: Active formation of chaos terrain over shallow subsurface water on Europa, Nature, 479, 502–505, 2011.