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Tidal walking on Europa's strike slip faults - insight from numerical modeling

Katerina Sladkova[1], Ondřej Souček[2], Klára Kalousová[1], and Marie Běhounková[1]
[1]Charles University, Faculty of Mathematics and Physics, Department of Geophysics, Prague, Czechia (kackasladkova@gmail.com)
[2]Charles University, Faculty of Mathematics and Physics, Mathematical Institute, Prague, Czechia

Introduction

The smallest Galilean moon Europa is differentiated into an outer ice shell, subsurface ocean, silicate mantle and iron-rich core (J. D. Anderson et al., 1997; Khurana et al., 1998). Its young surface exhibits a multitude of superposed crosscutting lineaments (Kattenhorn & Hurford, 2009), on some of which a lateral offset of a few kilometres was identified (e.g. Schenk & McKinnon, 1989). On Earth, strike-slip motion, thus potentially lateral offset, occurs either through a primary shear failure or through reactivation of the pre-existing faults and fractures (E. Anderson, 1905). On Europa, the latter case was confirmed so far (Hoppa et al., 1999; Sarid et al., 2002; Kattenhorn, 2004; Rhoden et al., 2012) and a process nicknamed "tidal walking'' (Hoppa et al., 1999) was suggested as a possible mechanism for producing the strike-slip offset through the reactivation of faults via diurnal tidal stresses.

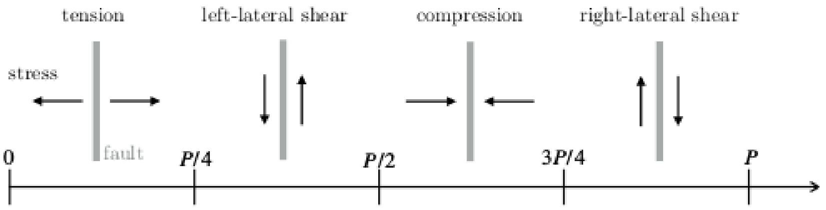

Figure 1: The sketch of tidal walking model.

In the simplest setting (see Figure 1), the tension opening the fault facilitates strike-slip motion in one direction, while in the reverse direction in the second half of the period, the motion is suppressed by compression. Consequently, after one period a certain strike-slip offset is accumulated. Our numerical model aims at testing the "tidal walking" model by simulation of the behaviour of Europan strike-slip fault and its surroundings.

Model

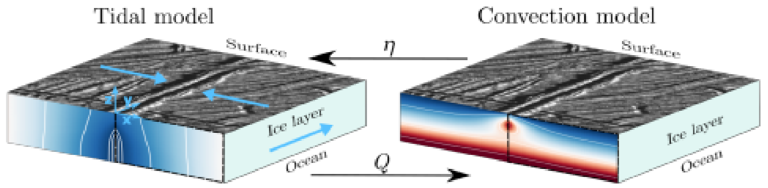

Figure 2: Sketch of the model: the tidal model (left) solves for the strike-slip motions due to diurnal tides, and the convection model (right) computes the long-term thermal evolution. The models exchange information through heating Q and viscosity η. Taken from Sládková et al., 2020.

The model consists of two parts reflecting the two timescale nature of the considered process, i.e. the diurnal timescale (~3.5 days) of the forcing stresses and the formation timescale (taken as 100kyr). The tidal model describes the fault and its surroundings as a viscoelastic (Maxwell) body with a pre-existing fissure in the middle of the computational domain, cf. right panel of Figure 2. This model is forced by shear and normal stresses, and it quantifies the tidally-driven heat production. Heat sources are used as an input for the second - convection - model operating on the time scale of tens of thousand years, describing ice as a non-newtonian fluid. The computed thermal evolution affects the viscosity in the tidal model, providing (together with the tidal heating) the coupling between the two modules.

Results

We performed an extensive parametric study of the behaviour of Europan strike-slip fault and its surroundings, varying ice shell thickness (D), the amplitude of loading stresses (shear and normal, σ_0), the phase shift between the shear and normal stresses and the coefficient of friction. The results depend strongly on the amplitude of the loading stresses and the ice shell thickness. Our calculations confirm previous results by Preblich et al., 2007 that the active part of the fault needs to reach a low viscosity zone or to penetrate to the ocean. The whole-shell penetration appears improbable as unrealistically thin (1km) shell and larger than present-day loading stresses would be required. However, our results indicate that a low viscosity zone at the base of the active part of the fault may form as a result of frictional and shear heating in the fault's vicinity (D=5 km ice shell and $\sigma_0=6 \times 10^5$Pa loading amplitude). Such a scenario shows that the thermo-mechanical coupling is vital for the complete understanding of the behaviour of strike-slip faults. A third option for producing observable offset is to assume that the cracks are partially filled with water from the internal ocean, then the hydrostatic pressure is partially compensated by the water column. Thus the active part of the fault can reach the bottom of the shell much more easily, in this setting the production of a significant offset is possible even for the present-date estimates of the tidal forcing amplitudes and ice-shell thickness of less or equal to ten kilometres.

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