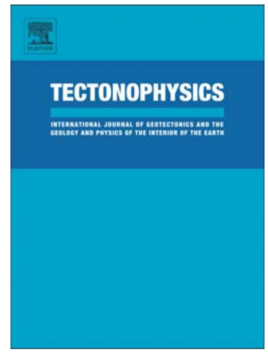
Accepted Manuscript



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PII: S0040-1951(17)30446-8
DOI: doi:10.1016/j.tecto.2017.10.021
Reference: TECTO 127659

To appear in: *Tectonophysics*

Received date: 20 May 2017
Revised date: 14 October 2017
Accepted date: 20 October 2017

Please cite this article as: Allison, Kali L., Dunham, Eric M., Earthquake cycle simulations with rate-and-state friction and power-law viscoelasticity, *Tectonophysics* (2017), doi:10.1016/j.tecto.2017.10.021

Earthquake cycle simulations with rate-and-state friction and power-law viscoelasticity

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October 26, 2017

Abstract

We simulate earthquake cycles with rate-and-state fault friction and off-fault power-law viscoelasticity for the classic 2D antiplane shear problem of a vertical, strike-slip plate boundary fault. We investigate the interaction between fault slip and bulk viscous flow with experimentally-based flow laws for quartz-diorite and olivine for the crust and mantle, respectively. Simulations using three linear geotherms ($dT/dz = 20$, 25, and 30 K/km) produce different deformation styles at depth, ranging from significant interseismic fault creep to purely bulk viscous flow. However, they have almost identical earthquake recurrence interval, nucleation depth, and down-dip coseismic slip limit. Despite these similarities, variations in the predicted surface deformation might permit discrimination of the deformation mechanism using geodetic observations. Additionally, in the 25 and 30 K/km simulations, the crust drags the mantle; the 20 K/km simulation also predicts this, except within 10 km of the fault where the reverse occurs. However, basal tractions play a minor role in the overall force balance of the lithosphere, at least for the flow laws used in our study. Therefore, the depth-integrated stress on the fault is balanced primarily by shear stress on vertical, fault-parallel planes. Because strain rates are higher directly below the fault than far from it, stresses are also higher. Thus, the upper crust far from the fault bears a substantial part of the tectonic load, resulting in unrealistically high stresses. In the real Earth, this might lead to distributed plastic deformation or formation of subparallel faults. Alternatively, fault pore pressures in excess of hydrostatic and/or weakening mechanisms such as grain size reduction and thermo-mechanical coupling could lower the strength of the ductile fault root in the lower crust and, concomitantly, off-fault upper crustal stresses.

Keywords: earthquake cycle, viscoelastic flow, power-law rheology, strike-slip, brittle-ductile transition,