Energy Balance and Moment-Duration Scaling of Deep (25-55 km) Subduction-Zone Slow-Slip Events

YIN An

Department of Earth, Space, and Planetary Sciences, University of California, Los Angeles, CA 90095-1567, USA

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Abstract: Two fundamental questions with regard to deep (25-55 km) subduction-zone aseismic slow-slip events (SSEs) have not be well resolved: (i) why is scaling between seismic moments (M_0) and event durations (T) is scaling rather than the cubed relationship for fast earthquakes, and (ii) why is the rupture speed during a slow-slip event direction-dependent? Geological observations suggest that deep-subduction shear zones at depths of 25-55 km are anisotropic and viscoplastic; the anisotropy is due to the presence of dip-parallel lineaments of mafic fragments created by seamount subduction, whereas the viscoplasticity is due to the presence of mixed brittle mafic and ductile felsic materials in the shear zone. Here, I postulate that a mafic lineament in an overall felsic shear zone acts as a stress guide localizing initial rupture. Subsequent stress concentration along the edges of the earlier ruptured lineament leads to along-strike rupture through the felsic-dominated shear zone. The second-phase slip-area expansion maintains a constant dip-parallel rupture-zone length, inherited from that of the mafic lineament and bounded by the rheological transitions between plastic to viscoplastic deformation and between viscoplastic to viscous deformation. By combining an energy-balance equation with the proposed two-phase rupture model, an analytical expression of the observed linear scaling law in the form of $M_0 = c_0T$ can be obtained, where

$$c_0 = \frac{4\gamma_1 \Delta z G^2 L^2 \left[\frac{(\bar{\mu}_s - \bar{\mu}_d)\rho g H \Delta z}{\eta_e \cos(\delta)} + V_{FW}\right]}{\left[2L\Delta z(\bar{\mu}_s{}^2 - \bar{\mu}_d{}^2)(\rho g H)^2 - 4\gamma_1 G(L + \Delta z) - \rho \Delta z L G (V_{FW} + v_a)^2\right]}$$

and its observed value is between $10^{11.5}$ to $10^{13.5}$ J s^{-1}. In the model expression, L, H, Δz, δ, G, η_e, $\bar{\mu}_s$, $\bar{\mu}_d$ and are the length, depth, thickness, dip angle, shear rigidity, effective viscosity, and effective coefficients of static and dynamic friction of the viscoplastic shear zone, γ_1 is the surface-energy density of the mafic lineament from which the initial rupture starts, ρ is the overriding-plate density, V_{FW} and v_a are the plate and slow-slip velocities parallel to the shear zone, and g is surface gravity. The model, based on the assumed shear-zone anisotropy described above, successfully predicts fast (~100 km/hour) dip-parallel rupture along high-viscosity (~10^{20} Pa s) mafic lineaments and slow (2-10 km/day) strike-parallel rupture through low-viscosity (~10^{17} Pa s) felsic shear zone during a deep-subduction slow-slip event.

Key words: Slow-slip event, seismic moment, energy release during an earthquake, viscoplasticity.

References

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* Corresponding author. E-mail: yin@epss.ucla.edu