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Regulation of maximum earthquake sizes by the lithospheric rheology

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Shallow part of the Earth can be considered to behave as an elastic material such that earthquakes occur, whereas the deeper part deforms viscously. However, it still remains unclear how the seismicity changes with this viscous/elastic transition. On the other hand, the rock consisting the Earth is frequently modeled by a Maxwell fluid which behaves as an elastic material when it deforms at a time scale which is sufficiently shorter than the relaxation time scale. Here we perform shear deformation experiments of quasi Maxwell fluid under different strain rates, and show that the same material can cause earthquakes associated with elastic rebound as well as viscous flow. Around the threshold to cause earthquakes, both earthquakes in which ruptures propagate at a shear wave velocity and viscous relaxation occur simultaneously. The threshold is determined by the strain rate, relaxation time, shear modulus, and the adhesive stress. We construct a scaling applicable to a real faulting system by taking account of the fact that strain rates depend inversely on the faulting length scales. Our scaling predicts that a larger fault can relax the accumulated stress more and the maximum sizes of earthquakes which can occur on Earth becomes around Mw 9. The 2011 Tohoku-Oki Earthquake (Mw 9.0) resulted in a huge coseismic slip, but was insufficient to reconcile all the inter-seismic deformation since the previous earthquake. Our scaling suggests that this earthquake must be around the threshold and some part of the accumulated stress has relaxed viscously prior to the earthquake. Our scaling also explains the fact that only small earthquakes show repeatability and magnitudes of the slow earthquakes are small. Another important feature of our scaling is that the accumulated strain is not proportional to the accumulated stress. For an accurate risk assessment, accumulated stress should be evaluated rather than strain.

Keywords: Viscosity of the shallow Earth, Stress relaxation, Rupture velocity, Tohoku-Oki earthquake