Shear strength and fluid over-pressure in world subduction zones estimated from the earthquake energy budget

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I estimated fault shear strength of global subduction zones based on calculations of the seismic energy budget during large earthquakes. Estimates of shear strength are based on the calculation of the total energy released during earthquake rupture, which is partitioned into radiated energy, fracture energy (G) and frictional (heat) energy. Radiated energy can be readily obtained from radiated seismic waveforms or using information of the source time function of earthquakes. Accurate estimates of fracture energy are more difficult to obtain, and for this purpose I use the Finite Width Slip Pulse dynamic rupture model, combined with information of the heterogenous fault rupture process of large earthquakes (208 fault rupture models of the NEIC finite fault slip database, from 1990 to 2022, and Mw>7). Estimates of G are largely influenced by the heterogenous distribution of fault rupture velocity, rise time and slip of earthquakes across the fault plane. In a previous study (AGU, 2021) I showed that fracture energy is underestimated by a factor of 5 when estimations do not account for the heterogeneity in fault rupture process of large earthquakes, as typically assumed by the calculations based on the difference between average stress drop and the apparent stress of earthquakes (known as G'). Furthermore, recent studies also suggest that megathrust earthquakes experience an almost complete strength drop during fault rupture (i.e. 2011 Tohoku). If a strong dynamic weakening typically takes place during fault rupture of large earthquakes (substantial stress undershoot) then frictional energy can be neglected, and therefore average shear stress and shear strength can be obtained. Based on this assumption I calculated lower bound estimates of shear strength across subduction regions and oceanic lithosphere worldwide. My results indicate a severe fault strength weakening during all megathrust earthquake ruptures (with a global average around 4 MPa), notably tsunami earthquakes belonging to the weakest faults (around 1 MPa), implying that fluids are extremely over-pressured across the majority of subduction regions worldwide. By using my shear strength results, I obtained a global average of lambda (the fluid pore pressure to lithostatic pressure ratio) of 0.98, for subduction megathrusts. In contrast, I showed that oceanic lithosphere at ridges, transform faults and fracture zones is 5 to 10 times stronger. This considerable difference indicates that fluid pressure plays a major role in controlling strength of earth's lithosphere. Furthermore, my estimations of average shear stress during fault rupture also enable the calculation of seismic efficiency. I obtained that average seismic efficiency for megathrust subduction earthquakes, is smaller than the average value for earthquakes in oceanic lithosphere.