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Strength of megathrust faults and its control on subduction-zone seismotectonics

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Predicting where devastating subduction-zone earthquakes could occur requires identification of key fault parameters from geophysical observations. Global and regional-scale comparisons of subduction-zone seismicity against gravity and bathymetry anomalies show that a large percentage of the moment released by co-seismic slip during megathrust earthquakes concentrates over regions characterized by gravity and bathymetry lows. This has been interpreted after assuming that high interplate friction implies high mechanical coupling between the subducting slab and the overriding forearc and, therefore, a depressed forearc topography leading to low gravity anomalies. This interpretation supports the accepted paradigm as to that seismic asperities (areas of large co-seismic slip) are strong patches of the plate interface characterized by high friction. Attempting to test this idea from a physically compelling perspective, we apply a wavelet formulation of the classical spectral isostatic analysis to invert grids of gravity anomalies and bathymetry/topography into maps of flexural rigidity for several subduction zones worldwide. Flexural rigidity explicitly links those surface observables with the integrated mechanical strength of the lithosphere. For the special case of subduction zones where two tectonic plates are in contact along a low-angle fault, it can be argued that local- to regional-scale lateral variations of flexural rigidity are mostly due to spatial changes of the shear strength along the interplate fault caused by the physical conditions of the subduction channel, which supersede large-scale variations of thermo-mechanical properties of both converging plates. In our interpretation, high/low flexural rigidity along subduction zones means high/low shear stress supported by the megathrust fault and, therefore, high/low friction and/or low/high pore pressure along the subduction channel. We use the gravity model EIGEN-GL04C, which combine data from satellite missions with marine and land gravity measurements, to calculate flexural rigidity for most subduction zones worldwide. In addition, we compile a seismicity catalogue for moderate to giant earthquakes ($5.5 < Mw < 9.6$) occurred during the last hundred years along those subduction zones. Comparing flexural rigidity at the epicentral location of subduction earthquakes, with their moment magnitude, released seismic moment and the slip distribution of giant megathrust events, we confirm that subduction-zone earthquakes tend to nucleate at regions of the interplate fault characterized by high strength. However, a large portion of the total seismic moment accounted by subduction earthquakes during the last hundred years was released by rupturing weak segments of the plate interface characterized by low flexural rigidity, a tendency which is dominated by the growing pattern characterizing the three giant earthquakes ($Mw>9$) occurred during the twenty century (Kamchatka 1952, Chile 1960, Alaska 1964). The unexpected Mw9.3 Sumatra-Andaman 2004 earthquake is anomalous with respect to other giants because it propagated throughout several high-strength segment of the subduction zone. Paleoseismological studies in Chile and Sumatra suggest that giant earthquakes in the later region have a recurrence interval that is 2-3 times higher than the interval between giants in the former region. This intriguing behavior fits into a model suggested by our results, as to that the common way for an earthquake to grow toward giant magnitudes is for the rupture front entering a conditionally-stable, weak segment of the megathrust (the case of twenty century giants); a less common scenario (typified by the Sumatra-Andaman 2004 earthquake) supposes the synchronized rupture of several high strength patches of the interplate fault that are all loaded near a critical shear stress. Our findings partially contradicts previous interpretations based on the correlation of gravity and bathymetry anomalies with seismogenic behaviour and can potentially change paradigms forming the physical basis to understand processes associated with the initiation and growth of subduction earthquakes.