Frictional strength of the plate interface off northeast Japan inferred from the simulation of oceanic plate stress

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Steady plate subduction along a curved interface brings about stress changes at constant rates in the surrounding lithosphere (Fukahata and Matsu'ura, 2016). So, in subduction zones, not only frictional resistance at plate interfaces but also steady plate subduction causes tectonic stress fields. The stress field caused by frictional resistance is basically compressive, but that caused by steady plate subduction is basically tensile in a seismogenic depth-range. In northeast Japan, the Pacific plate is descending beneath the North American plate. Before the 2011 Tohoku-oki earthquake, the focal mechanisms of seismic events at and around the plate interface were thrust-fault type (e.g., Asano et al., 2011), indicating that the compressive stress field due to frictional resistance was dominant there. The remarkable increase of normal-fault type events after the Tohoku-oki earthquake could be interpreted as the change in stress regime from compression to tension. In this study, we estimate the lower limit of frictional strength at the plate interface through the 2-D numerical simulations of stress fields for descending oceanic plates. We model the lithosphere-asthenosphere system by an elastic surface layer overlying a viscoelastic substratum, and introduce a curved interface that divides the elastic surface layer into two parts; the oceanic and continental lithosphere. The geometry of the plate interface is taken to be the vertical section of the CAMP standard model (Hashimoto et al., 2004) crossing the main rupture zone of the Tohoku-oki earthquake in the direction of plate convergence. First, we computed the rates of stress increase produced in the oceanic lithosphere by steady plate subduction at 83 mm/yr. Then, we simply integrated them along the paths of mass transfer in Lagrangian description. The tensile stress obtained in this way takes the maximum at the uppermost part of the oceanic lithosphere, and gradually increases as moving downward along dip up to 1 GPa, which clearly exceeds the yield strength of the oceanic lithosphere. So, to overcome this inconsistency, we introduced a standard yield strength envelope for the oceanic lithosphere. When differential stress exceeds the yield strength, inelastic deformation (brittle fracture and/or plastic flow) would occur to release the excess stress. Based on such an idea, we cut out the excess stress at each step of the path integration of stress increments. The results of numerical simulations show that the tensile stress in the upper part of the oceanic lithosphere, which is almost controlled by the brittle strength, reaches 200 MPa at the depth-range of 10-20km. In order to reproduce the pre-seismic compressive stress field at and around the plate interface, the steady frictional resistance of the plate interface must be greater than 200 MPa at the depth-range of 10-20km.

Keywords: Subduction zone, Tectonic stress field, Steady plate subduction, Frictional strength of plate interfaces