Controls on pore fluid pressure near plate boundaries by fluid discharge and mesoscale mineralization during the seismic cycles of the Nankai Trough

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We report that temporal changes of impermeability of the upper plate occur due to fluid discharge and mesoscale mineralization during the seismic cycles. In the subduction zone, the periodic slow earthquakes cause the periodic stress loading onto the plate boundary fault and modulate the recurrence time of large earthquakes (Obara and Kato, 2016). Mode I cracks (extension cracks) with semi-vertical dip in the upper plate generated after the large megatheust earthquake cause the drainage upwards and decrease pore fluid pressure along plate interface (Sibson, 2013; Otsubo et al., 2020). In the Nobeoka Thrust, southwestern Japan, which is an on-land example of the megasplay fault at shallow depths in the Nankai Trough, semi-vertical dipping extension quartz veins (fossils of drainage upwards) were observed in the hanging wall (Otsubo et al., 2016). Such a permeable upper plate suppresses the occurrence of slow earthquakes such as tremors (Nakajima and Hasegawa, 2016). In other words, the impermeability of the upper plate is important for the occurrence of slow earthquakes such as tremors during the seismic cycles of the Nankai Trough. On 3rd December 2021, the M5.4 reverse faulting-type earthquake with a NW-SE compression occurred within the upper plate (hanging wall) at a depth of ~20 km in the western coast of Kii Peninsula. This earthquake occurred above the tremor zone in Kii Peninsula (Obara, 2002). After the 1944 and 1946 Nankai Trough megathrust earthquakes, two important moderate-sized earthquakes occurred in the same region: the 1948 M6.7 normal fault earthquake with an NW-SE extension and the 1987 M5.6 reverse fault earthquake with a NW-SE compression (from catalogs of JMA and Ichikawa, 1971). These three earthquakes are harmonic with the temporal stress changes from normal to reverse faulting type stresses after the large earthquakes in the subduction zone (e.g., 2011 Tohoku Earthquake; Hasegawa et al., 2012). In this study, we examined the kinetics of silica precipitation for the formation of the extension quartz veins by employing the vein size (Saishu et al., 2018) measured in the Nobeoka Thrust and the depth of the M5.4 earthquake. Because the depth of the earthquake is near the cut-off depth (D90) in the area (Omuralieva et al., 2012), we infer that the earthquake occurred in the deepest part of the brittle zone (temperature around ~300℃). The model considers the width (1.3×10^{1}–3.4×10^{2} μm; Saishu et al., 2018) and the length of veins (1.9×10^{0}–5.0×10^{1} cm; Saishu et al., 2018), fluid pressure reduction during each crack-seal event (lithostatic minus hydrostatic pressure at 20 km depth with an average rock density of 2600 kg/m^3, which yields ~314 MPa), and ambient temperature of 300˚C. The results of this modeling demonstrate that the veins can close in less than ~40 years. The results indicate that the fractures close with quartz within a seismic cycle of the Nankai Trough, which is consistent with the occurrence pattern of the above-mentioned moderate earthquakes in Kii Peninsula. Until the sealing by quartz is completed, the pore pressure around the plate boundary will be difficult to increase, and the occurrence of slow earthquakes may remain suppressed. Hence, the sealing time of fractures at the upper plate during the seismic cycle plays an important role in the increase of pore pressure required for the occurrence of slow earthquakes such as tremors.

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