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Two alternative regimes in Nankai seismic cycles caused by depth dependent distribution of fracture energy

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Great earthquakes have occurred repeatedly along the Nankai Trough in southwestern Japan with recurrence intervals of 100?200 y. The magnitudes of Nankai earthquakes have varied throughout this recurrence history, with many studies to date asserting that an event's magnitude is controlled only by the number of broken segments arranged along the Nankai Trough. However, evidence for seismic slip on the shallowest part of the decollement has been found in cores from boreholes drilled along the trough. In fact, slip on the shallowest part of the plate interface became larger during the 2011 Tohoku earthquake, causing a devastating tsunami. Moreover, recent evidence suggests that large tsunami with recurrence intervals of several hundred years have occurred along the Nankai Trough. Therefore, it is now essential to reconsider the scenario of Nankai Trough earthquakes, including the possibility of seismic slip on the shallow subduction interface. Recently, model calculations of the interplate seismic cycle have been conducted using rate- and state-dependent friction laws. In these calculations, assuming heterogeneous distribution of fracture energy in the seismogenic zone and its shallower extension, both massive earthquakes with slips up to the trough axis and ordinary earthquakes in the seismogenic zone can occur in different seismic cycles. Here, we apply a similar heterogeneous distribution of fracture energy in the shallower plate interface of the Nankai Trough. In the model, we represent the difference in fracture energy by the difference in the characteristic slip distance L. To model the conventional seismogenic zone as a zone of low fracture energy, we set L to be 0.05 m at depths of 10?20 km. Conversely, the shallow plate boundary near the trough is modeled as a zone of high fracture energy. By applying various values of L ($0.05m<L<10m$) in the shallower region, we explain the effect of gaps in fracture energies on resultant seismic cycles. For small gaps in fracture energies ($0.05m<L<2.25m$), the rupture in the every earthquake propagates up to the top of plate interface. In cases of relatively high fracture energies on the shallow interface (i.e. $L >= 2.25$ m), however, two types of earthquake with different moment magnitude occur alternately. The recurrence interval of the larger type (i.e., that with the greater slip distance) is about 370 y, which is comparable to the recurrence interval of larger tsunami deduced from recent geological findings. Large coseismic slip (i.e., more than 10 m) extends to the trough axis during the larger types. In contrast, the smaller one, whose seismic slip is distributed only along the seismogenic zone, occurs after ˜200 y of the larger one. These results indicate the depth dependent distribution of fracture energy could be a factor which controls the large variation of seismic cycles along the Nankai Trough.

Keywords: numerical simulation, earthquake generation cycle, subduction zone, fracture energy heterogeneity, rate- and state-dependent friction laws