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A proposal of barrier invasion/fractal asperity model for the genesis of interplate earthquakes

Tetsuzo Seno[1]

[1] ERI, Univ of Tokyo

Seno (2002) proposed a barrier invasion model to explain the occurrence of tsunami earthquakes which break a shallow portion of the subduction boundary. This model postulates that the stable sliding frictional property in the shallow portion turns into a nearly zero-friction, with a negative a-b value, due to elevated pore fluid pressure (called barrier invasion), and if asperities break at the deeper seismogenic zone simultaneously, a tsunami earthquake occurs. I try to extend this idea to ordinary interplate earthquakes in subduction zones and transform faults.

The basic assumptions of the model presented here are: (1) the plate boundary fault zone consists of asperities and barriers, where asperities and barriers have negative and positive a-b values, respectively, (2) asperities are distributed in fractal, and (3) only the region where barriers are invaded can rupture as an earthquake.

I assume each asperity has a circular shape, and introduce order n such that order 0 defines the maximum-size asperity. Let an order n asperity have a number of Na order n+1 asperities inside, and the ratio of the radius of order n asperity to that of order n+1 asperity be lambda. The fractal geometry is then described by the parameters Na and lambda; for example, the fractal (capacity) dimension D is log(Na)/log(lambda). The stress drop (shear strength), displacement, and moment can be scaled against the order.

Based on the model above, I re-estimate fault areas for earthquakes in the Honshu subduction zone and the San Andreas Fault, for which distributions of fault slip have been obtained from analyses of strong motion data. Each fault area is divided into asperity, invaded barrier, and non-invaded barrier parts, where the invaded barrier part is an area without significant slip or aftershocks, and the non-invaded barrier part is an area with aftershocks. Re-estimated faults areas A are plotted versus seismic moments Mo in a logarithmic scale. I obtain log(A) = 0.83log(Mo) - 8.44. The coefficient is the same as in Nadeau & Johnson (1998). From this coefficient, I obtain D=1.4. On the other hand, the size ratio of the two neighboring repeating earthquakes off Kamaishi, northern Honshu (Igarashi, 2000) gives lambda=4.8. Then Na is determined to be 9.

Variations of the subduction zone seismicity is complex. For example, along the Japan Trench, large earthquakes, such as the 1994 Sanriku-haruka-oki and 1978 Miyagi-oki earthquakes occur in the northern segment relatively regularly, but large earthquakes are very rare in the southern segment. There seems no simple way to explain this variation in terms of general tectonic factors since the subducting Pacific and overriding plates are similar along the entire Japan Trench. Another example is the seismicity in Mexico, southwest Japan, and Cascadia, where oceanic plates of similar ages are being subducted, but the recurrence intervals of great earthquakes vary by an order of magnitude from 50 years to 500 years. It seems very difficult to explain this difference also.

If the seismogenic zone consists of fractal asperities and extent of barrier invasion has a regional and temporal variation, various modes of seismicity might be realized. If the barrier area invaded by high fluid pressures is small, only a small earthquake is generated; in contrast, if the area is large, a large or great earthquake is generated. The fractal distribution of asperities has scale invariance which leads to power laws such as the Gutenberg-Richter's relation if barrier invasion occurs in random over a region considered. In contrast, if a particular region is invaded repeatedly in a regular manner, this would result in characteristic earthquakes. Thus the model may resolve the contradictory aspect of earthquake seismology. The model should be tested in the future against various observations, in particular, temporal monitoring by 3D seismic reflection surveys.