Hierarchical self-similar geometry of fault zones and size-dependent static stress drop: An analysis from seismic fault traces

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The complexity of the source process of earthquakes is caused by the strength heterogeneity of fault planes, one of which is the heterogeneity in frictional properties, and another is due to the complexity of fault zone geometry. Statistically, earthquakes tend to nucleate at depths below the point where surface fault trace is smooth, and seismic ruptures tend to hesitate or stop at the point of fault jogs or fault bents (Aki, 1989).

[I] Geometry of surface fault zones

Fault zones are composed of fault segments and jogs, and they are nested to form a hierarchical self-similar geometry. Letting a given hierarchical rank as i, and the segment length as L_S(i), and the length and width of the jogs as L_J(i) and W_J(i), respectively, the equations below hold for experimental faults (Otsuki and Dilov, 2005).

$L_S(i)=C_1*L_S(i+1)^{a1}$, $C_1=0.343$, $a_1=0.999$ ...(1)

$L_J(i)=C_2*L_S(i+1)^{a2}$, $C_2=0.0935$, $a_2=1.00$ ...(2)

$W_J(i)=C_3*L_S(i+1)^{a3}$, $C_3=0.0456$, $a_3=0.642$ ...(3)

We examined whether these equations are applicable also to 20 surface seismic faults in the world. As a result;

Eq.(1) holds exactly, where $C_1=0.791$, $a_1= 0.927$.

Eq.(3) also holds moderately, where $C_3=0.0598$, $a_3=0.798$.

However, meaningful results were not found for eq.(2), because L_Js do not appear clearly on the surface.

The results above indicate that the fault zone geometry is hierarchically self-similar over the very wide scale range from the order of mm to 100km. Moreover, C_1, C_2, C_3, a_1, a_2, and a_3 are the universal constants. This suggests that the strength distribution on a fault plane is fractal, and that it strongly affect the seismic source processes.

[II] Size dependence of static stress drop

In general, static stress drop is regarded as constant irrespective of the seize of earthquakes. However, according to Nadeau and Johnson (1998), who analyzed small to intermediate size earthquakes by the methods other than the traditional, found that the stress drop Sd decreases in proportion to seismic moment Mo to the power of -0.25.We tried to reveal this problem by using the slip distributions along 20 seismic surface faults in the world. For any fault segments of a given hierarchical rank the fault displacement D is largest around the center of fault segments and decreases (sometimes to zero) toward the segment ends. Since the ratio of the mean displacement D_m to the segment length L_S is a proxy of static stress drop, we examined the relation between them. As a result we found the relation below.

$D_m/L_S = C_4*L_S{}^{a4}$, $C_4=0.0348$, $a_4=-0.607$, $R^2 =0.397$ ...(4)

This relation is similar to the data from Nadeau & Johnson (1998) where $C_4=0.0234$, $a_4= -0.600$, $R^2=0.903$. Integrating our high quality data and those of Nadeau & Johnson (1998), we have $C_4=0.0225$, $a_4=-0.558$, $R^2=0.961$. This result indicates that static stress drop is size-dependent both the local and whole of fault zones; the smaller L_S, the larger stress drop.