Geophysical Research Abstracts
Vol. 15, EGU2013-8464, 2013
EGU General Assembly 2013

Length-displacement scaling relations and the development of faults

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Faults are complex systems whose growth and general evolution are still not well understood. Such an understanding, however, is important for several reasons: one is that seismogenic faults generate earthquakes and another is that faults are major conduits for fluids (groundwater, geothermal water, gas, oil, magma). It is widely accepted that faults normally initiate from 'flaws' or weaknesses in the rocks, but their subsequent development and growth and their seismogenic activity are less well understood.

Here we present results on the slip/displacement-length scaling relations, both for faults and co-seismic ruptures, from a single comparatively small area, namely the eastern flank of the volcano Etna, Italy (Sicily). Using these data, together with data from the literature and analytical and numerical models, we provide a general growth model for faults.

Following an earthquake in a fault zone, the co-seismic rupture length and the slip are commonly measured. Similarly, in a structural analysis of major faults, the total fault length and displacement are measured when possible. It is well known that typical rupture length - slip ratios are generally orders of magnitude larger than typical fault length-displacement ratios. So far, however, most of the measured co-seismic ruptures and faults have been from different areas and commonly hosted by rocks of widely different mechanical properties (which have strong effects on these ratios). The data presented here is composed of length-displacement ratios from 7 fault zones in Holocene lava flows on the flanks of the volcano Etna and 19 co-seismic rupture lengths-slips mostly from the same fault zones and thus hosted by rocks with largely the same mechanical properties.

For the co-seismic ruptures, the average length is 3,657 m, the average slip 0.31 m, and the average length-slip ratio 19,595. For the faults, the average length is 6,341 m, the average displacement 73 m, and the average length-displacement ratio 130. Thus, the average rupture-slip ratio is about 150-times larger than the length-displacement ratio. We propose that the differences between the length-slip and the length-displacement ratios can be partly explained by dynamic Young's modulus of fault zone being 101-2-times greater than its static modulus. In this model, the dynamic modulus controls the length-slip ratios whereas the static modulus controls the length-displacement ratio. We suggest that the common aseismic slip in fault zones is partly due to adjustment of the short-term seismogenic length-slip ratios to the long-term length-displacement ratios. Fault displacement is here regarded as analogous to plastic flow, in which case the long-term displacement can be very large so long as sufficient shear stress concentrates in the fault. In conclusion, this model explains, partly at least, the difference in the slip/displacement-length scaling relations between co-seismic ruptures and faults and also explains slow earthquakes and aseismic slip, features that are now known to be very common in active fault zones.