2003 SCEC Progress Report, 17 November 2003

Title: High Resolution Earthquake Source Parameters and Earthquake Nucleation

PI: Rachel E. Abercrombie

Institution: Boston University

Proposal Category: B: Science

Amount: $10,000

Disciplinary Committee/Focus Groups:

A(4) Fault and Rock Mechanics, and B(3) Earthquake Source Physics

Summary:

The purpose of this ongoing project is to improve our resolution of the source processes of small earthquakes. It also has the aim of increasing collaboration between Seismology and Rock Mechanics. The project consists of two parts:

1. To improve our resolution of small earthquake source parameters such as stress drop and radiated energy, and then to investigate the constraints that those parameters impose on our understanding of the dynamics of earthquake rupture. The PI has been collaborating with Prof. Jim Rice (Rock Mechanics, Harvard) on this project. Re-analysis of small earthquakes recorded at Cajon Pass combined with aftershocks of the 1994 Northridge earthquake, and a number of large southern California earthquakes led to the proposal of a non-linear, slip-weakening relationship. A manuscript describing these results was submitted to *Geophysical Journal International* in August 2003; *"Can observations of earthquake scaling constrain slip weakening?, Abercrombie and Rice.* The abstract of the paper is attached, and we are still waiting to hear from the *Journal*. This is SCEC publication 728.
2. Detailed analysis of small earthquake sources is improved by accurate location. The PI is working with Prof. Peter Shearer (UCSD) to include picks from the deep borehole station at Cajon Pass in the relocation of Southern California earthquakes. This will both improve the locations of earthquakes near Cajon Pass, and also help to determine uncertainties in locations without such clean, deep borehole recordings – in particular excellent *S* wave arrivals. This work is progressing. The first 30 earthquakes for relocation have been identified. Currently formatting issues are being addressed as both the borehole catalogue and waveform data are stored very differently from the SCSN data for which the relocation process was developed. This work is planned for completion in 2004. Funding remains in the award for two months of graduate student funding and travel for both the student and the PI to the 2004 SCEC meeting.

Can Observations of Earthquake Scaling Constrain Slip Weakening?

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The SCEC contribution number for this paper is 728.

Abstract. We use observations of earthquake source parameters over a wide magnitude range (M_W ~0-7) to place constraints on constitutive fault weakening. The data suggest a scale dependence of apparent stress and stress drop; both may increase slightly with earthquake size. We show that this scale dependence need not imply any difference in fault zone properties for different sized earthquakes. We select 30 earthquakes well-recorded at 2.5 km depth at Cajon Pass, California. We use individual and empirical Green's function spectral analysis to improve the resolution of source parameters, including static stress drop (Ds) and total slip (S). We also measure radiated energy E_S. We compare the Cajon Pass results with those from larger California earthquakes including aftershocks of the 1994 Northridge earthquake and confirm Abercrombie (1995): $mE_S / M_0 << Ds$ (where m = rigidity) and both E_S / M_0 and Ds increase as M_0 (and S) increases. Uncertainties remain large due to model assumptions and variations between possible models, and earthquake scale independence is possible within the resolution. Assuming that the average trends are real, we define a quantity $G' = [Ds - 2m\ E_S / M_0]S/2$ which is the total energy dissipation in friction and fracture minus $s_1 S$, where s_1 is the final static stress. If $s_1 = s_d$, the dynamic shear strength during the last increments of seismic slip, then $G' = G$, the fracture energy in a slip-weakening interpretation of dissipation. We find that G' increases with S, from ~10^3 J/m^2 at S = 1 mm (M1 earthquakes) to 10^6 - 10^7 J/m^2 at S = 1 m (M6). We tentatively interpret these results within slip-weakening theory, assuming $G' \approx G$. We consider the common assumption of a linear decrease of strength from the yield stress (s_p) with slip (s), up to a slip D_c. In this case, if either D_c, or more generally $(s_p - s_d)\ D_c$, increases with the final slip S we can match the observations, but this implies the unlikely result that the early weakening behaviour of the fault depends on the ultimate slip that the fault will sustain. We also find that a single slip-weakening function $s_F(s)$ is able to match the observations, requiring no such correlation. Fitting G' over S = 0.2 mm to 0.2 m with $G' \propto S^{1+n}$, we find n ~ 0.3, implying a strength drop from peak s_p - $s_F(S) \propto S^n$. This model also implies that slip weakening continues beyond the final slip S of typical earthquakes smaller than ~M6, and that the total strength drop $s_p - s_d$ for large earthquakes is typically >20 MPa, larger than Ds. The latter suggests that on average a fault is initially stressed well below the peak strength, requiring stress concentration at the rupture front to propagate slipping.