Continued Examination of the scaling of rupture velocity from small to large earthquakes

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The goal of this proposal was to constrain the rupture velocity, v_r, of small earthquakes on important seismogenic faults in Southern California. This is a vital yet essentially unknown quantity in earthquake physics. It's importance lies in being a macroscopic observable that is directly connected to the microscopic physics during rupture. In large earthquakes, ruptures propagate close to (or above) the theoretical limiting speed, a well established observation which implies that a relatively small fraction of the available energy is used to create new fractures. This is not unexpected given that laboratory estimates of the critical slip distance over which friction decays from "static" to "dynamic" values are many orders of magnitude smaller than the slip in large earthquakes (i.e. microns vs meters). By constraining the rupture velocity of earthquakes that only slip a cm or less, I want to constrain the frictional weakening process at a spatial scale that is unobservable in complicated large earthquakes owing to the filtering/smoothing in those inversions

Determining the rupture velocity of small earthquakes on real faults is difficult because the far-field seismograms typically available for such earthquakes in practice do not allow a unique determination of a densely parameterized finite-fault model that is relatively free from imposed assumptions about slip/rupture evolution [*Venkataraman et al.*, 2000]. The simplest parameterization of an earthquake rupture that contains information about the rupture propagation without imposing any a priori physical model on a particular earthquake is known as the second moments (or variances) of the rupture. These quantities measure the length, width, duration, and directivity in a weighted average sense [*Backus and Mulcahy*, 1976b] [*Backus and Mulcahy*, 1976a; *Backus*, 1977a; *Backus*, 1977b; *McGuire et al.*, 2001; *McGuire et al.*, 2002]. The six parameters that need to be estimated to determine the second moments are linearly related to the variances of the Apparent (or Relative) Source Time Functions (ASTFs) that result from standard Empirical Green's Function (EGF) deconvolutions [*McGuire*, 2003]. Thus, the most straightforward way to infer information about the spatial extent and rupture propagation of small (magnitude ~3-5) earthquakes is to perform the standard EGF analysis, but then interpret the azimuthal variation in the duration of the resulting time functions in terms of the second moments.

Attempts to find the best dataset for determining v_r in small earthquakes:

- The San Simeon aftershock dataset (USGS-SCEC) was poorly designed for earthquake source studies beyond location as the station distribution is time dependent and vary sparse to the west. While many of the individual sites that were selected are of high quality and hence produce good EGF deconvolutions, overall there were to few sites or they were poorly distributed for all of the larger aftershocks. Similarly the Landers and Hector mine aftershock datasets were poor in this regard.

- The ANZA network remains the best dataset in SC for my work and I am actively collaborating with Frank Vernon and Yehuda Ben-Zion to get a temporary expansion of the network funded by earthscope. As part of this exercise, we determined which potential site locations would be most helpful in expanding the network. Some of our high priority sites are being encorporated into the new PBO borehole sitings, and hence will improve the use of the ANZA network for source studies. The current network is sufficient for finite source studies for most M>~4.2 earthquakes, and there are clear finite source signatures for events down to M~3.5. Events in the M3-3.5 range often lack any clear difference in their main P+S arrivals from much smaller M1 events, indicating that for most ANZA stations, the finite source information is essentially lost to attenuation around M3.0. There have been several M4+ events in the ANZA region this year and we are currently in the process of studying these events.
- After the frustration of the Landers, San Simeon, and Hector Mine aftershock datasets, I tried evaluating the strong-motion networks in Japan. In combination they have sufficient (K-net and kiki- net) station coverage to image finite source propertied of M~5.0 events and larger. Below this, these stations do not usually record the smaller EGF events well enough for use in the second moments technique.

I am currently in the process of combining the best constrained events from the ANZA, Japanese, Parkfield, and a PASSCAL deployment in the creeping section, into a BSSA paper on the constraints we can place on rupture velocity in the Mw 3.0-5.0 range. The main conclusion of this study appears to be that at least some ruptures in this range are quite fast (>.6 of the shear-wave speed).

Comparision of Rupture Velocity in M3-5 vs M6-7 Rupture on the Same Fault

One promising approach to looking at the scaling of rupture velocity is to compare my second moment estimates for moderate (M3-5) earthquakes with vr estimates from finite fault inversions of larger earthquakes on the same fault. Owing to the aftershocks which follow these mainshocks, these types of comparisions can be made in regions of good station geometries. Below are two examples, one from Parkfield and one from the Niigata earthquake in Japan. In both cases, the rupture velocity of the smaller quake is comparable to that of the larger one. If we assume that apparent stress scales like the square of the ratio of rupture velocity to the shear wave speed, then for the Parkfield earthquake, we can say that at most, the apparent stress of the M6 rupture was at most a factor of 3 larger than that of the M3 rupture, and we cannot rule out that these two events had identical rupture velocities in the location of the M3 rupture. For the Niigata earthquake, The rupture velocity of the M5 aftershock near the up-dip end of the rupture is indistinquishable from and possibly greater than the average rupture velocity of the M 6.7 mainshock.

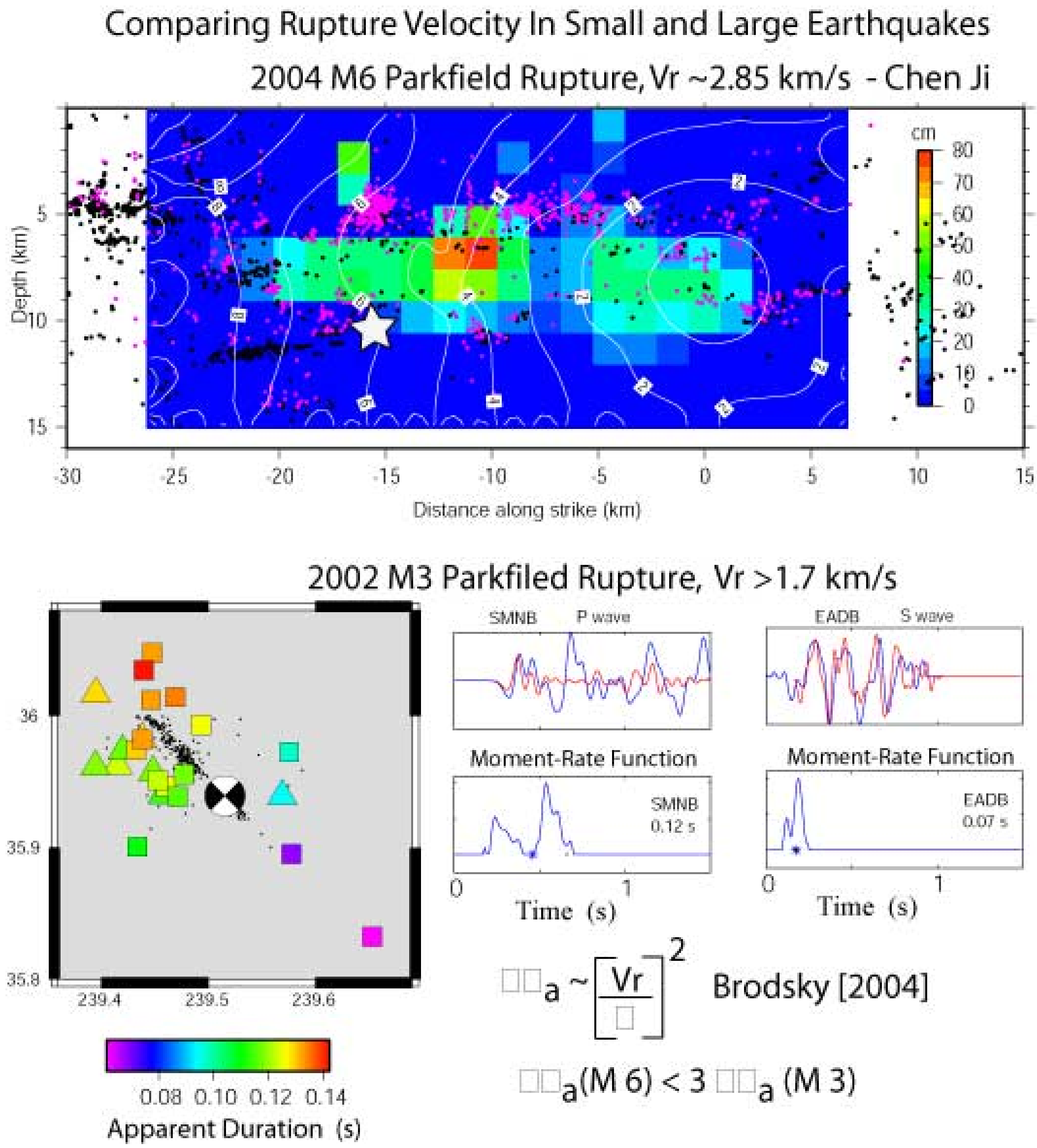
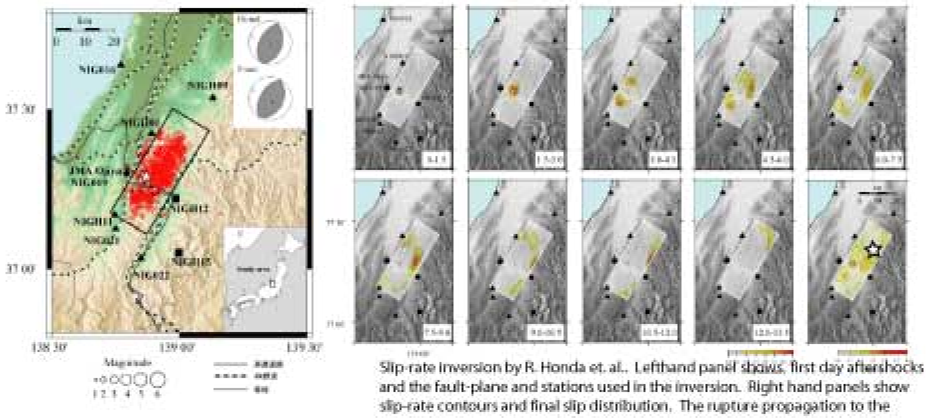
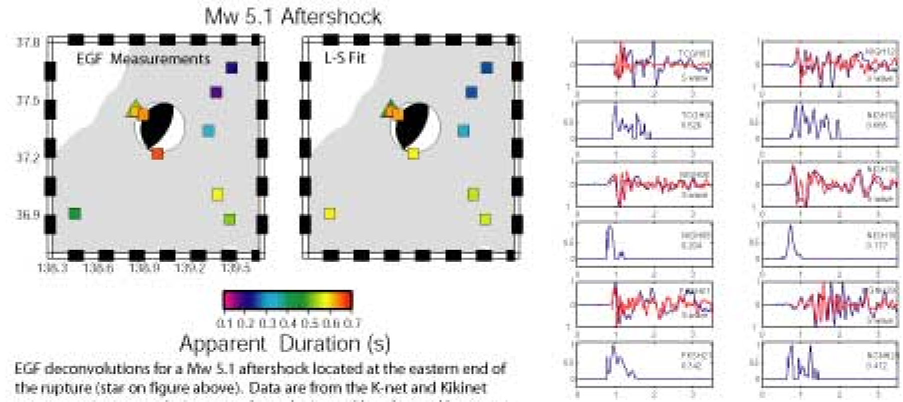


Figure 1. Comparision of the rupture velocity in a M3 and M6 rupture of the Parkfield segment. The relatively short apparent durations to the SE of the M3 event compared to the longer durations to the NW indicate a rupture velocity in excess of 1.7 km/s to the SE. This earthquake occurred in the northern half of the main parkfield rupture (above), which had a average rupture velocity of about 2.8 km/s (Chen Ji). If apparent stress scales as (vr/B)^2, then the apparent stress of the M6 was at most a factor of 3 bigger than the M3.

2004 Niigata-Ken Chuetsu M6.7 Earthquake and M 5.1 Aftershock



Slip-rate inversion by R. Honda et. al.. Lefthand panel shows first day aftershocks and the fault-plane and stations used in the inversion. Right hand panels show slip-rate contours and final slip distribution. The rupture propagation to the east occurs at about 2.2 km/s, which is about 67% of the shear-wave velocity.



EGF deconvolutions for a Mw 5.1 aftershock located at the eastern end of the rupture (star on figure above). Data are from the K-net and Kikinet strong-motion networks integrated to velocity and bandpassed between .3 and 5 Hz. Blue traces are the Mw 5.1 event and red traces are from a ML3.7 event. The bottom panels for each station show the resulting moment-rate function. Each moment-rate function is labelled with its apparentduration (2 time the square root of its variance) in seconds. The map shows the apparent durations measured for P (triangles) and S (squares) wave. Relatively short moment-rate functions are obsreved to the NE and relatively long ones directly above and SW of the hypocenter. Inversion of these measurements results in estimates of the characteristic rupture length of 1.8 km, the characteristic rupture width of 0.8 km, and a lower bound on the rupture velocity of about 2.3 km/s.

Summary

I have determined rupture velocity constraints for a suite of M3-5 earthquakes and am currently preparing a BSSA paper that I hope to have submitted by early 2006. While it is not possible to resolve the rupture velocity of every earthquake in this range (or even the majority) owing to propagation effects and station geometry, my essential conclusion is that many moderate rupture propagate at relatively high speeds. Moreover, many of these events are indistinquishable from the average rupture velocity in the M6+ mainshocks on the same fault. This indicates that either the fracture energy is extremely small at all magnitudes >3, or that it scales with magnitude in such a way that M3s and M7s see essentially the same amount of resistance to rupture.