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EARTHQUAKES, FAULTS, AND STRESS IN SOUTH CALIFORNIA

Leonardo Seeber and John G. Armbruster
Lamont-Doherty Earth Observatory, Palisades, NY 10964

In 1998, this project has progressed in four related topics. All but the first one are the outcome of collaboration with other researchers. They are discussed in the order of our level of effort.

Stress interaction using data from the 1992 Landers sequence.
A fault rupture is symptomatic of two stress changes: one that brought that fault to failure followed by another one caused by the rupture. Thus, faults interact and the timing of a fault rupture is generally affected by previous neighboring ruptures. The mechanical state of a fault can be characterized by Coulomb stress. Following many others, we consider an interaction experiment where a change in Coulomb stress CS stems from a sequence of large causative ruptures, the 1992 Landers and related Joshua and Big Bear ruptures, and it affects a multitude of beacon earthquakes which are assumed to be too small to mutually interact. We have generated a large set of quality selected focal mechanisms that have been interpreted for the fault plane on the basis of spatial distribution (Seeber and Armbruster, 1995; Armbruster and Seeber, SCEC data center, 1998). CS are calculated on each of these planes and are classified as encouraging (E) or discouraging (D) for the earthquake. The effect of the rupture can then be assessed as an increase in E/D which is insensitive to spatial variations in the magnitude level that satisfy the quality criteria. A problem with this approach is that a subset of the fault planes are likely to be chosen incorrectly. It is a small subset because when the opposite nodal planes are imputed, the E/D signal is several times smaller than with the interpreted planes. One advantage to this approach is high sensitivity to stress changes. In the far field (27 km from any of the causative ruptures), E/D rises about an order of magnitude above pre-rupture values (1) and decays gradually. The E/D signal is still very significant (x5 pre-rupture level) a year after the maishock when the level of seismicity in this distance range is back to pre-Landers level. The size of the E/D signal is highly dependent on the friction coefficient. During the first 1.5 years after the rupture, a friction coefficient in the range 0.8-0.9 yields consistently optimal E/D signal. Finally, we demonstrate that seismicity can offer detailed resolution on stress change by deriving from off-rupture (>7.5 km) aftershocks a credible slip distribution for the Landers rupture. This is accomplished by an iteration that searches the distribution that yields optimal E/D signal. We have finalized the first stage in this work and have a preprint submitted to *Science*.

We are currently investigating the temporal decay of the seismicity burst that followed Landers. This decay appears to be characterized by two time constants: a more rapid drop-off during the early part of the sequence, followed by a more gradual decay that is still going on (Figure 1A). This characteristic is stable over a range of distances from the ruptures (0-100 km) and stress change (CS>0.2 bars). While CS is not a factor, its components may be. When positive (encouraging) CS=   ($_n$-p) 0.2 bars are partitioned into ones dominated by shear stress (> $_n$) and normal stress (< $_n$), they show distinct decay characteristics: more rapid and slower, respectively (Figure 1B). We are investigating whether this possible dependency of the duration of the nucleation process on the composition of the stress that triggers it may be related to the apparent double slope of the overall aftershock decay (Figure 1A). We are also testing whether poroelasticity can account for the dependency of the delay between trigger and earthquake on the composition of DCS (e.g., Beroza and Felzer, 1998).

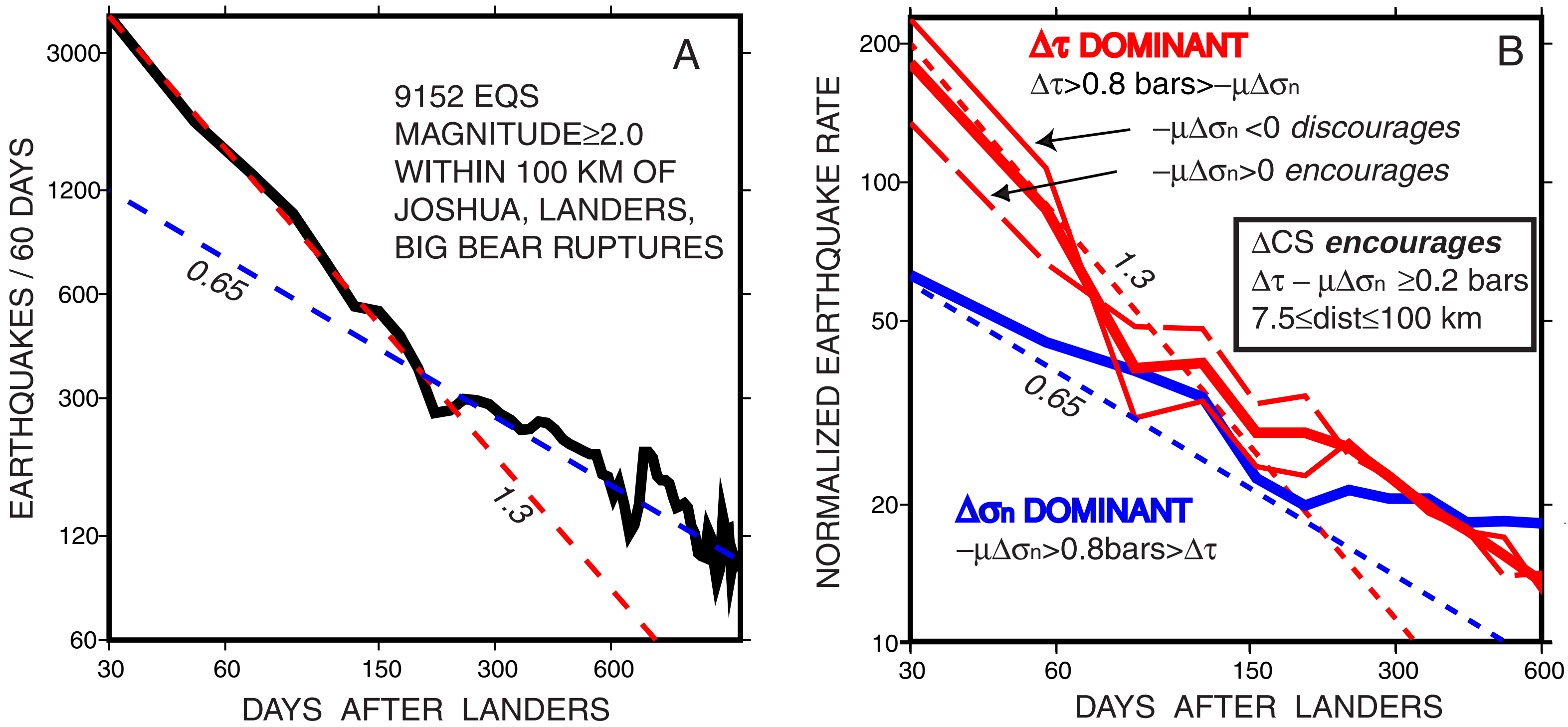

Figure 1. Temporal decay of Landers aftershocks. ML≥2.0 within 100 km of any segment of the composite rupture are plotted in A. All aftershocks from 7.5 to 100 km from the rupture for which we calculated an encouraging change in Coulomb stress, $\Delta CS=\Delta\tau - \mu\Delta\sigma n \geq 0.2$ bars are plotted in B. They are differentiated between earthquakes for which either normal stress (in blue; 453 events) or shear stress (in red; 174 events), are responsible for most of the stress rise, respectively. The latter are further subdivided into events for which the change in normal stress is discouraging (solid thin red) or encouraging (dashed thin red). From this and many other representations of the seismicity in terms of ΔCS components, we conclude that earthquakes encouraged by shear stress change tend to occur earlier than earthquakes encouraged by normal stress change. This behavior is consistent with a poroelastic response. The distinct decay functions of these two groups of aftershocks may account for the apparent slope change in the overall seismicity fall off.

Structural analysis of the western Transverse Ranges

Seeber has been collaborating with Christopher Sorlien (UC Santa Barbara) on interpreting active structure in the southwestern Transverse Ranges, particularly the offshore portion, and relating it to earthquakes. Sorlien, in collaboration with Nic Pinter and others at UC Santa Barbara is developing a high-resolution regional data set for that area, mostly from industry files. The main observations motivating this work relate to the >200 km long Santa Monica Mountain-Channel Island antiform (SMMCIA) which is at the southern front of the western Transverse Ranges (also Davis and Namson, 1994). This east-west striking regional structure is characterized by a gently-dipping north limb and a steeper south limb. We and others (Seeber and Sorlien, in review; Pinter et al. 1998) have demonstrated progressive tilting of the north limb. This progressive tilting involves uplift on the Islands and subsidence in the Santa Barbara Channel. For this and other reasons, tilting cannot be ascribed to differential compaction or filling of a pre-existing basin, and is tectonic. This tilting, however, is incompatible with classical ramp-flat models. We have proposed an alternative listric thrust-fault model (Seeber and Sorlien, submitted). This model can account for progressive north tilting in the channel and is attractive for two other reasons. First, it allows for wide limbs to be associated with relatively small fault displacements (unlike classical models where limb width is often associated with fault displacement). Wide fold limbs with small dip are common offshore south California (Davis and Namson, 1994). Secondly, many of the thrust faults in southern California are reactivated Miocene normal faults (e.g., Huftile and Yeats, 1996). Normal faults are often listric (e.g., Crouch and Suppe, 1993) and they are likely to remain listric when they are reactivated. We propose a slip rate of 1-1.5 mm/yr for the thrust fault related to the SMMCIA, based on tilting rate and our listric thrust model. In terms of hazard, the SMMCIA is a secondary structure in terms of slip rate, but it is regional and may be capable of very large earthquakes. This work is finalized in a Seeber and Sorlien paper which is conditionally accepted by the GSA Bull. New work is focusing on the discovery of young and deep erosional surfaces (Figure 2) and on the space/time distribution of subsidence. In collaboration with Peter Geiser, we are developing an interpretation that includes forward progression of the deformation and structural thickening in an accretionary wedge superimposed on regional subsidence (a foredeep) in response to loading by the advancing wedge. The data and hypotheses we are developing will provide the basis for quantitative models that include flexural response. Another important issue is the extension of the foredeep structure onshore, in the LA basin. In the foredeep of an advancing accretionary prism active structures are subtle because very young and they will be manifested primarily by seismicity.

Pressure solution and active structure in the Ventura Basin

Jan Vermilye (SCEC postdoc) and Nano Seeber are collaborating on a study of pressure solution in the active fold-thrust belt associated with the San Cayetano fault in the Ventura basin. In old exhumed mountain ranges, such as the Appalachians, pressure-solutions strains can be large. It is not clear, however, how much pressure solution can contribute to the deformation in active belts. In the Ventura Basin, one of the most rapidly deforming regions of southern California, we are documenting pressure solution in Plio-Quaternary sedimentary rock and finding good correlation between stress axes inferred from breakouts and earthquakes, strain axes from geodetics, and shortening directions from pressure solution markers (Figure 3). This correlation confirms that we are mapping pressure solution structures associated with the current regime. Bulk-rock penetrative shortening in Plio-Quaternary rock is of the order of 10% (Duebendorfer et al., 1998; Vermilye et al, 1998). This is a minimum value because it does not include shortening from loss of material along cleavage surfaces nor the aseismic component of slip on faults. Pre-Miocene rocks tend to exhibit multiple cleavages, some with evidence of reactivation as extension fractures. Some of this cleavage may record older tectonic phases. This work is ripe for a paper and is now beginning to expand into a new direction: downward. Published thin sections from cores in the study area show abundant evidence of cleavage (Wilson J& McBride, 1988).

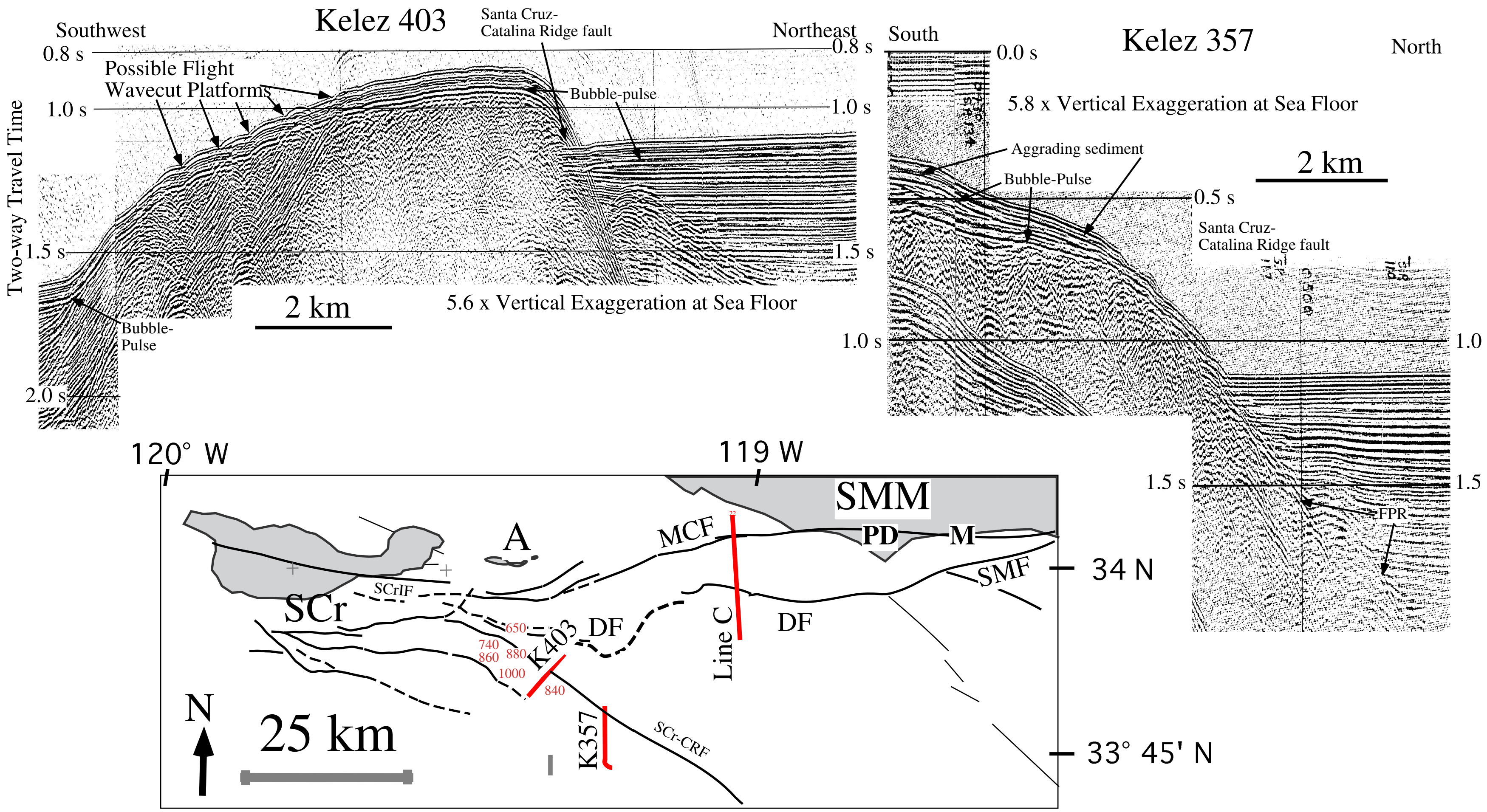

Figure 2: Single Channel USGS airgun seismic reflection profiles Kelez 403 and Kelez 357, located on the map. Note strong bubble-pulse. We interpret an erosion surface on Santa Cruz-Catalina Ridge to be wavecut; it is deeper in the NW (K403, 700+ m) nearer the front of the Channel Islands thrust. The right-lateral, net normal separation Santa Cruz-Catalina Ridge fault has a possible NE-dipping fault-plane reflection on K357 and a very obvious one on lines farther SE. Notches on the southwest part of the ridge may be wave-cut platforms or alternatively a landslide. Mapping from Sorlien, Pinter, and Scott, NEHRP-funded.

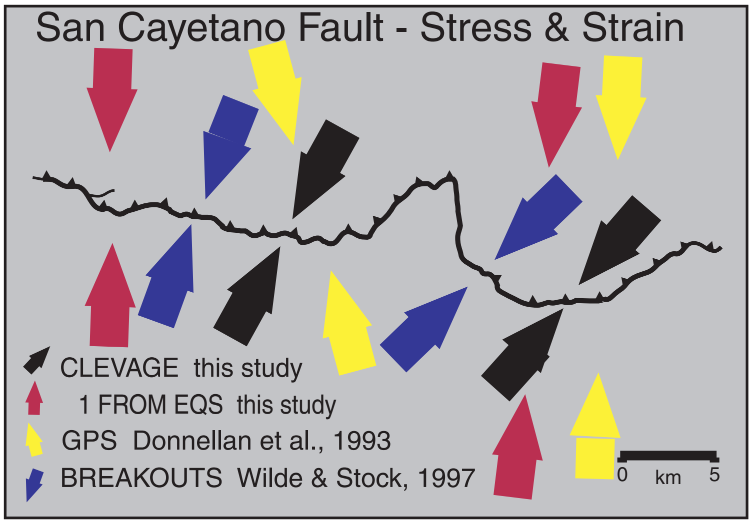

Figure 3. Direction of shortening from pressure solution compared with other results on stress and strain along the San Cayetano fault in the Ventura basin. The tectonic regime is dominated by thrusting and folding and the earthquakes yield a nearly horizontal axis of maximum stress. We examined pressure-solution structures along the fault both east and west of the Sespe creek re-entrant in order to characterize and evaluate deformation from pressure solution. Macroscopic spaced solution cleavage and microscopic dissolution grain-shape fabrics indicate consistent NE-SW shortening directions. very similar to stress directions from breakouts. Both of these are 15-30° clockwise from the earthquake and GPS directions. This discrepancy may reflect spatial variations in the stres/strain field since breakouts and clevage sample locally whereas earthquakes and GPS sample regionally.

Block Rotation vs Normal Faulting in Extensional Regimes. Both Mammoth lakes and the Salton Trough are rift zones where most of the prominent geologic and geomorphic features are normal faults, but where most of the recent earthquakes are strike slip. We are developing comparative tectonic models based on the idea that vertical-axis block rotation can account for extension, as long as horizontal shortening is also permitted. The initial break up of the continental crust is dominated by normal faults. Once established, crustal blocks can accommodate extension by vertical-axis rotation. Rotation may gradually become preferable because it does not work against gravity. At Mammoth Lakes we are collaborating with Peggy Johnson (SCEC postdoc); in the Salton Trough with Michael Steckler and Christopher Sorlien.

Recent and Expected Products and Publications

Armbruster and Seeber 1998, updated files of focal mechanisms and slip-planes for south California as well as a version of QKVIEW to visualize these data in SCEC data base.

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