Northeast Striking Cross Faults, Detachments, Crustal Blocks and Strain Partitioning in Southern California: A Search for Changes in Seismicity and Focal Mechanisms Precursory to Major Earthquakes

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Objective:

For the past 5 years we have been studying the detailed distribution of earthquakes, focal mechanisms, rotations of small crustal blocks, N.E. striking cross-faults, the existence of shallow-angle detachment faults and premonitory changes before large earthquakes along the southern San Andreas and San Jacinto faults in southern California. Major emphasis has been given to the large tectonic knot centered near San Gorgonio Pass and to 2 recent earthquakes near the southern end of the Salton Sea. Little of the present seismic activity occurs on the major throughgoing faults themselves. Instead much of it is situated on secondary faults and detachments. Seismicity in the months before the 1986 North Palm Springs earthquake appears to be concentrated on a detachment fault that determined the lower limit of the rupture. Secondary cross-faults at the two ends of the rupture were active during the aftershock sequence. The purpose of this study is to use relocated hypocenters and single-event focal mechanisms to examine precursory changes in three regions near the San Jacinto and southern San Andreas faults that contain prominent cross-faults and detachment faults. One includes small earthquakes associated with a magnitude 6 event on a cross-fault near the southern end of the Salton Sea that was a short-term precursor to a larger event in 1987 on the Superstition Hills fault. A temporal sequencing of activity along NW and NE trending conjugate faults of the Brawley zone has been identified and is being examined in detail. Future changes in activity on the next cross fault to the north of the one that ruptured in 1987 could be a precursor to a larger event that would rupture the southern San Andreas. We have developed computer programs to automatically determine hundreds of focal mechanism solutions of high quality so as to examine in detail the hypothesis that the San Andreas is a weak fault. Moderate earthquakes prior to the 1989 Loma Prieta earthquake in central California, most or all of which are outside the ensuing rupture zone, show a pattern of accelerating moment release. In light of this precursory change in seismicity in a region of complex fault interaction, we have begun re-examining seisimicity of moderate-to-large earthquakes in southern California to establish if such changes also occur before large earthquakes on the San Andreas system in southern California.

Results:

Two large strike-slip ruptures 11.4 hours apart occurred on intersecting, nearly orthogonal, vertical faults during the November 1987 Superstition Hills earthquake sequence. This rupture was investigated in the paper "Cross-fault triggering in the November 1987 Superstition Hills Earthquake Sequence, Southern California" that was published in Geophysical Research Letters in February, 1989 by Hudnut, Seeber, and Pacheco. They show evidence that this sequence is the latest in a northwestward progression of earthquakes (1979, 1981, and 1987) rupturing a set of parallel left-lateral cross-faults that trend northeast between the Brawley seismic zone and the Superstition Hills fault. It is inferred that the observed northwestward progression of ruptures on cross-faults may continue. The next cross-fault expected to rupture intersects both the San Andreas fault and

the San Jacinto fault zone. They hypothesize that slip on the cross fault decreased normal stress on the main fault and triggered main strand rupture after a delay that was caused by fluid diffusion.

The paper "Seismicity and fault interaction, southern San Jacinto fault zone and adjacent faults, southern California: implications for seismic hazard" by Petersen, Seeber, Sykes, Nabelek, Armbruster, Pacheco and Hudnut shows waveform inversion results for the Borrego Mountain earthquake of 1968 and the Coyote Mountain earthquake of 1969. They found evidence for precursory seismic activity along some of the secondary faults of the region and redefined the extent of seismic gaps along the San Jacinto fault zone. The Anza seismic gap may be longer than previously proposed. Hazard in California was also assessed in the paper "Regional probabilistic seismic hazard analysis for the San Francisco Bay area" by Petersen, Jacob, Sykes, and Pacheco. This paper analyzes the seismic hazard using the 30-year probabilities determined by the Working Group (1990). The paper indicates that the 30-year probability for exceeding 50 cm/s pseudo-velocity response at 1 s period is between 40-60% for much of the Bay area that is located on mud or alluvium.

An abstract "Seismicity changes in the San Francisco Bay region before the Loma Prieta earthquake of 1989" by Jaumé and Sykes establishes a pattern of accelerating moment release prior to 1989 Loma Prieta earthquake. Most, if not all, of the $M \geq 5.0$ earthquakes in the 35 years prior to this earthquake are outside the ensuing rupture zone. In the paper "Seismic activity on neighbouring faults as a long-term precursor to three large earthquakes in the greater San Francisco Bay area," Sykes and Jaumé show that accelerating moment release has occurred before three large earthquakes in central California and also before the 1948 Desert Hot Springs earthquake in southern California.

In the paper "Fault kinematics in the 1989 Loma Prieta rupture area during the 20 years before that event" by Seeber and Armbruster, they studied changes in the frequency of occurrence of small earthquakes recorded by the USGS Network within about 75 km of the rupture zone of the 1989 Loma Prieta Earthquake. They relocated several thousand earthquakes using station corrections that were developed from quarry blasts. Those station corrections were allowed to vary spatially so as to correct for large variations in seismic velocity across several of the major faults in the area. They divided earthquakes on the Calaveras and other surrounding faults into two classes -- those that were expected on the basis of a dislocation model for the 1989 earthquake to have their shear strain either augmented or decreased in the 20 years before 1989. For a large number of small earthquakes they then formed the ratio of those for which the shear strain was expected to be increased to those for which shear strain was expected to be decreased. They found that this ratio increased in the few years before the 1989 earthquake.

In the abstract "Historic earthquakes along the Loma Prieta segment of the San Andreas fault" by Tuttle, Sykes, and Jaumé, the magnitudes and locations of historic damaging earthquakes in the San Francisco Bay region were re-interpreted from intensity data based upon experience from the Loma Prieta earthquake. In the preprint "Re-evaluation of historic earthquakes in the vicinity of thye Loma Prieta segment of the San Andreas fault" by Tuttle and Sykes, they suggest that the June 1838 earthquake ruptured both the Peninsular and Loma Prieta segments of the San Andreas fault, that the 1868 Hayward earthquake was of the same size of the 1989 Loma Prieta earthquake, and that the 1865 Santa Cruz Mountains earthquake occurred northeast of the Loma Prieta segment and was of magnitude 6.3 to 6.6.

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