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3D RUPTURE SIMULATIONS OF FAULTS WITH COMPLEX GEOMETRIC SEGMENTATION

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Abstract.
The Sierra Madre-Cucamonga fault zone is a 95-km-long arcurate thrust fault system along the south edge of the San Gabriel Mountains adjacent to the Los Angeles urban area in southern California. Paleoseismic investigations have determined large slip (~5 m) during the past two prehistoric earthquakes (inferred M ~7.5 each) and concluded that such large slip events require long, multi-segment rupture.

The east end of the Sierra Madre-Cucamonga fault zone intersects the San Jacinto fault zone and the San Andreas fault. The issue is that large earthquakes on the Sierra Madre-Cucamonga fault zone may either rupture through the intersection and continue onto the San Andreas and/or San Jacinto faults, or trigger earthquakes on the later faults via stress transfer. (Conversely, earthquakes on the San Jacinto and San Andreas faults may break the Sierra Madre-Cucamonga fault zone).

However, the ability of rupture to propagate through the intersection depends critically on the geometric details of the intersection, including the presence or absence of connectivity between the faults. To this end, we use published studies and hypocenter patterns to investigate the geometry of the Sierra Madre-Cucamonga fault in the area of the intersection. We find that the Cucamonga fault joins the San Andreas at depth, without being separated by the San Jacinto fault.

Introduction. A fundamental problem in assessing seismic hazard from an active fault zone is determining the extent of rupture of a potential future earthquake. The area of rupture on a fault controls (for a given stress drop) the magnitude of the earthquake, and thus plays an important role in determining the intensity and areal extent of strong ground motion. It has been recognized that fault zones are discontinuous, and that fault rupture may be physically bounded in extent by geometric discontinuities, such as fault-plane offsets, branches, and bends, in the fault zone. A goal of this project was to simulate ruptures on discontinuous thrust faults, such as the Sierra Madre-Cucamonga fault zone.

The Sierra Madre-Cucamonga fault zone is a 95-km-long arcurate thrust fault system along the south edge of the San Gabriel Mountains adjacent to the Los Angeles urban area in southern California. The east end of the Sierra Madre-Cucamonga fault zone (the Cucamonga fault) intersects the San Jacinto fault zone and the San Andreas fault. Paleoseismic investigations have determined large slip (~5 m) during the past two prehistoric earthquakes (inferred M ~7.5 each) and concluded that such large slip events require long, multi-segment rupture (Rubin et al., 1998).

The issue is that large earthquakes on the Sierra Madre-Cucamonga fault zone may either rupture through the intersection and continue onto the San Andreas and/or San Jacinto faults, or trigger earthquakes on the later faults via stress transfer. Conversely, earthquakes on the San Jacinto and San Andreas faults may break the Sierra Madre-Cucamonga fault zone.

However, the ability of rupture to propagate through the intersection depends critically on the geometric details of the intersection, including the presence or absence of connectivity between the faults. Thus, we investigate the geometry of the Cucamonga fault near its intersection with the San Jacinto and San Andreas fault zones.

Observations of Sierra Madre-Cucamonga fault zone attitude. Dips of the Sierra Madre-Cucamonga fault zone measured at the surface vary widely from <20° to 70°N (Crook et al., 1987). Observed Cucamonga fault dips at the surface also vary (Morton and Matti, 1987), with a preferred dip at depth of 35° to 40°N (D. Morton, pers. comm., 2003).

The 1971 San Fernando earthquake occurred on the San Fernando-Sunland segment of the Sierra Madre-Cucamonga fault zone (Ehlig, 1975). Aftershocks define a plane dipping about 40°N (Mori et al., 1995). The M 5.8 1991 Sierra Madre earthquake is thought to have occurred on the Sawmill-Clamshell fault (Hauksson, 1994), a fault in the hanging wall of the Sierra Madre-Cucamonga fault zone. Dip estimates of the event are 49° to 57°N (Dreger and Helmberger, 1991; Wald, 1992; Hauksson, 1994; Ma and Kanamori, 1994). These dips are not compatible with the 40° dip measured on the Sawmill-Clamshell fault at the surface: they imply that the causative fault would have to steepen as it nears the surface (see Figure 8b of Hauksson, 1994). Instead, the earthquake may have been on the Sierra Madre-Cucamonga fault, below the depth where the Sierra Madre-Cucamonga fault and the Sawmill-Clamshell fault presumably merge.

Sierra Madre-Cucamonga-San Andreas-San Jacinto fault zone connectivity. Matti and Morton (1993) summarize observations indicating that the San Jacinto fault does not have a through-going connection to the San Andreas where the faults approach one another in the San Gabriel Mountains near the eastern end of the Cucamonga fault. Morton and Matti (1993) propose that the Cucamonga fault merges with the San Andreas at depth. In their view, the San Jacinto fault does not intervene between the Cucamonga and San Andreas faults because the San Jacinto is not a continuous feature there, but instead is a discontinuous series of new and reactivated features accommodating the compression caused by the interaction of San Andreas and San Jacinto slip (Morton and Matti, 1993).

Seismicity observations. We examine 1981-1993 hypocenters and focal mechanisms of events recorded on the Caltech-USGS southern California seismic network and relocated in a joint hypocenter-3D velocity structure inversion as described by Magistrale and Sanders (1996) (Figure 1).

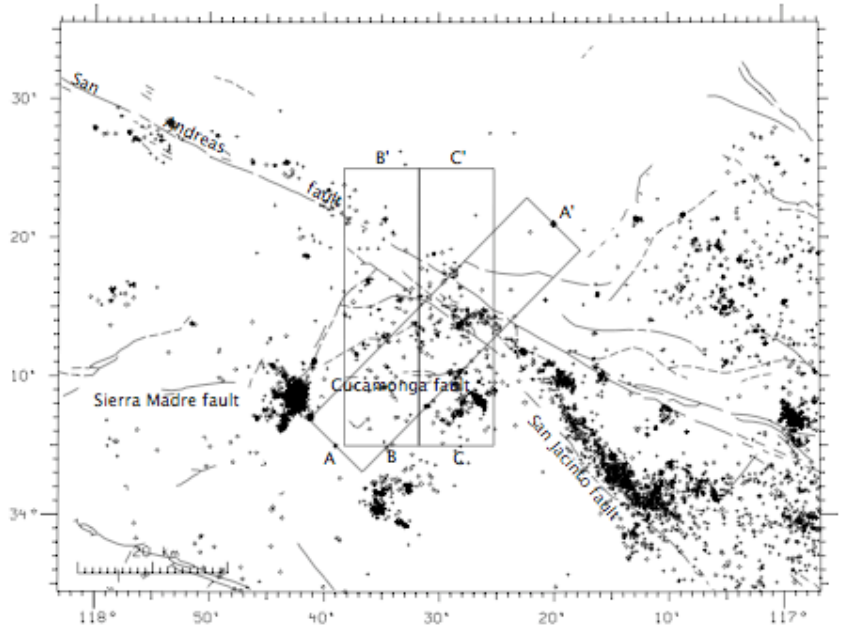

Figure 1. Map of the study area. Dots are earthquakes, size scaled to magnitude. Black lines are faults. Labeled rectangles show location of cross sections in Figure 2.

In cross section AA' (Figure 2) the Cucamonga fault is defined as a hypocenter lineation within a broader dipping zone of hypocenters, rooting into the San Andreas fault. The apparent dip is ~45°NE, which corrects to a true dip of 35°N for the east striking Cucamonga fault. Focal mechanisms (not shown) do not show a coherent pattern. Cross section BB' does not unambiguously define fault attitude.

In cross section CC' (Figure 2) the Cucamonga fault is defined as a hypocenter lineation with a dip of 35° to 40°N. That lineation is above a vertical lineation of hypocenters that defines the San Jacinto fault. The San Jacinto fault is not defined in the hypocenters above the plane of the Cucamonga fault.

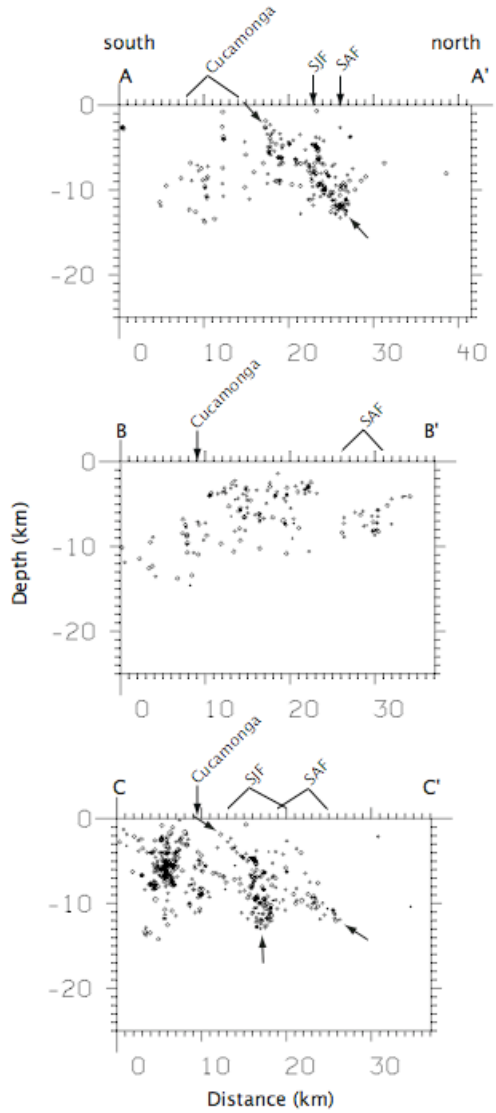

Figure 2. Cross sections, location shown on Figure 1. Arrows within frames indicate hypocenter lineations discussed in text. Abbreviations: SAF, San Andreas fault; SJF, San Jacinto fault.

Conclusions. Seismicity observations indicate the Cucamonga fault dips north at about 40° and reaches the San Andreas fault. The San Jacinto is not well defined above the plane of the Cucamonga fault, consistent with a lack of surface connection between the San Andreas and San Jacinto faults. These observations are consistent with the geologic based conclusions of Morton and Matti (1993). The attitude of the Cucamonga fault is similar to that of the Sierra Madre fault further west.

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