Paleoseismic Evidence of Large Slip Earthquakes on the Sierra Madre Fault in Altadena, California

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The potential for earthquakes along reverse faults in the Los Angeles region has been dramatically illustrated by the damaging San Fernando, Whittier Narrows, and Northridge earthquakes in 1971, 1987, and 1994 [Kamb et al., 1971; Hauksson and Jones, 1989; Hauksson et al., 1994]. These earthquakes have sparked fundamental questions regarding the potential size of earthquakes generated along reverse faults in the greater Los Angeles region.

Previous work suggests that the Sierra Madre portion of the frontal fault system appears to have a significantly lower slip rate than other portions of the frontal fault system, namely the Cucamonga fault to the east and the San Fernando fault to the west [Bull, 1978; Crook et al., 1987]. Yet some of the highest topography of the San Gabriel Mountains is located above the Sierra Madre fault that is presumed to be less active.

We recently excavated across the Sierra Madre fault, just east of Lincoln Avenue and north of Loma Alta Drive in Altadena (Figure 1). Geomorphic evidence of prehistoric deformation along the Sierra Madre fault at the Loma Alta Park site consists principally of a >4 m scarp that cuts a late Quaternary geomorphic surface. The trench crossed the well-exposed scarp immediately north of the parking lot of Loma Alta Park. This uplifted terrace no longer receives active deposition and lies between the deeply incised Millard Canyon on the west and West Ravine and Chiquita Canyon on the east.

In the excavation, the lowest exposed stratigraphic unit is crudely stratified and locally imbricated, boulder to pebble size gravel with a coarse sand matrix (Figure 2, unit 1). Overlying the coarse gravel is a fine sandy gravely loam (Figure 2, Unit 2). A paleosol (B_t horizon), up to 50 cm thick, is exposed within the fine-grained alluvium and the uppermost coarse gravels. Overlying the fine-grained alluvial unit is a wedge-shaped deposit of massive, pebbly, coarse to fine sand (Figure 2, Unit 3). Based on the its massive texture, matrix support, and shape, we interpret this unit as a scarp-derived colluvial wedge. The two alluvial units, the buried soil, and colluvial wedge are found in the lower plate of a gently north dipping fault. Only the coarse alluvium is present in the upper plate. A massive unfaulted unit of boulders and gravel in a silt and sand matrix (Figure 2, Unit 5) overlies the fine-grained alluvium and colluvial wedge. This gravel unit thins southward and laterally grades into silty sand and represents a colluvial wedge that formed from the collapse and modification of the scarp following the most recent surface rupture.

The Sierra Madre fault appears in the trench wall as a single trace, with minor faults in a zone about 0.5 m wide within the upper plate of coarse alluvial gravels. Locally imbricated beds of gravels are cut by the fault. Radiocarbon analysis of detrital charcoal from both colluvial wedges is in progress at the Accelerator Mass Spectrometry Laboratory at the University of Arizona.

The trench exposed stratigraphic evidence of at least two prehistoric earthquakes. The two colluvial wedges represent deposits formed immediately following surface rupture. The lower colluvial wedge (Unit 3), fine-grained alluvium (Unit 2), and buried soil have been faulted and subsequently eroded from the upper plate. The colluvial wedge that contains southward-thinning coarse gravels (Unit 5a) lies directly above the fault zone and is the primary evidence for the most recent earthquake. In order to resolve slip from the most recent earthquake, we restored the dip slip component of motion along the fault. Restoring the tip of the upper plate to the tip of the lower colluvial wedge (Unit 3) gives a minimum of ~3.8 - 4.0 m of slip from the most recent earthquake. This restoration reveals the approximate geometry of the alluvial and colluvial beds prior to the most recent earthquake. Several lines of stratigraphic evidence indicate a penultimate earthquake on this fault. The presence of a second colluvial wedge (Unit 3) and the truncation of the sub-horizontal fine-grained alluvium (Unit 2) and B_t horizon below the fault zone is evidence for a previous event. Restoration of the upper plate to below the B_t horizon yields a cumulative minimum slip of ~9.5 m for the last two events. Here, we assume the B_t horizon and the fine-grained alluvium was continuous across the upper plate and use projection of the average dip of the base of the B_t horizon to constrain the reconstruction. If the upper surface of the scarp is palinspastically restored to yield a smooth initial paleosurface, total cumulative slip is ~10.5 m. Work is continuing at the Loma Alta site to better constrain the age of the surfaces and soil correlation's across the fault.

Based on the slip in the most recent earthquake, we can infer the size of this event. One approach is to use the regressions relating the parameters of maximum surface displacement and average surface displacement to moment magnitude [Wells and Coppersmith, 1994]. Using 4 m as the maximum displacement yields a M_w of 7.1 If we assume 4 m represents the average surface displacement, the relations predict a M_w of 7.4. Another approach to estimating earthquake magnitude is to calculate the seismic moment. Assuming an average slip of 3.0 to 4.0 m, a strike-length of 65 km (Tujunga to San Antonio Canyon) to 90 km (Tujunga to San Jacinto fault), and a seismogenic depth of 15 to 20 km, the estimates of the seismic moment for the most recent earthquake range between 1.13×10^{27} dyne-cm and 3.49×10^{27} dyne-cm. Converting the seismic moment to moment magnitude, using the equation $M_w = (\log M_0 - 16.1/1.5)$ [Hanks and Kanamori, 1979] yields a M_w from 7.4 to 7.7 for the most recent earthquake. The large amount of slip in the penultimate event also suggests an earthquake of similar size. Until more paleoseismic studies along the fault yield information on rupture length and distribution of slip, there will be significant uncertainty in estimating the size of past earthquakes. However, our paleoseismic data from the Loma Alta site implies that the past two earthquakes were M7+ events.

The prehistoric earthquakes at the Loma Alta site appear to be significantly larger than other historical earthquakes along reverse faults in the greater Los Angeles region in 1971, 1987, and 1994. Large displacements suggest that the Sierra Madre fault breaks across multiple, relatively short segments [as defined by Crook et al., 1987], unlike the 1971 event that ruptured a single segment.

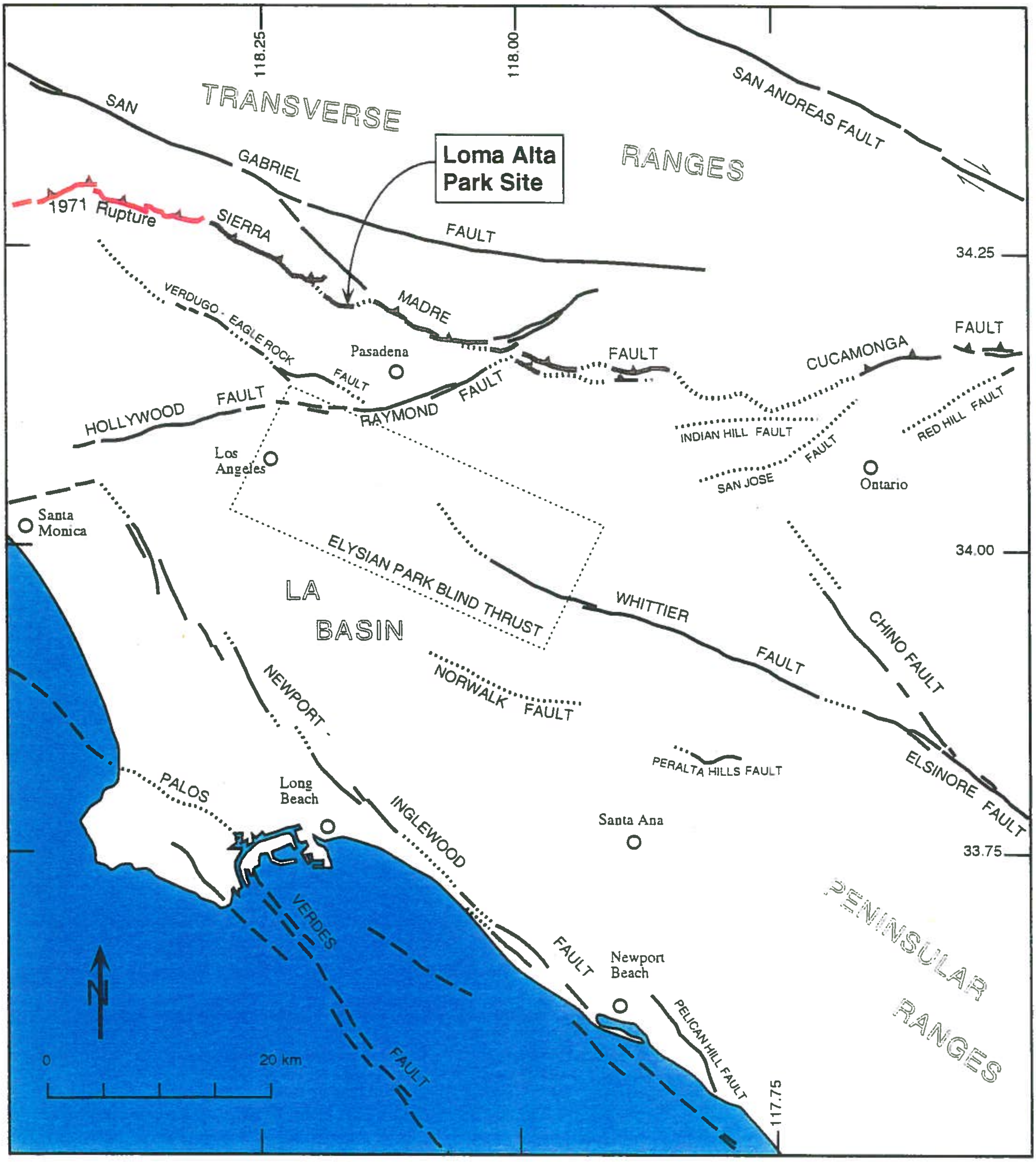

Figure 1. Location of the Loma Alta Park Site. The 1971 San Fernando surface rupture is shown in red; the Sierra Madre segment is shown in brown.

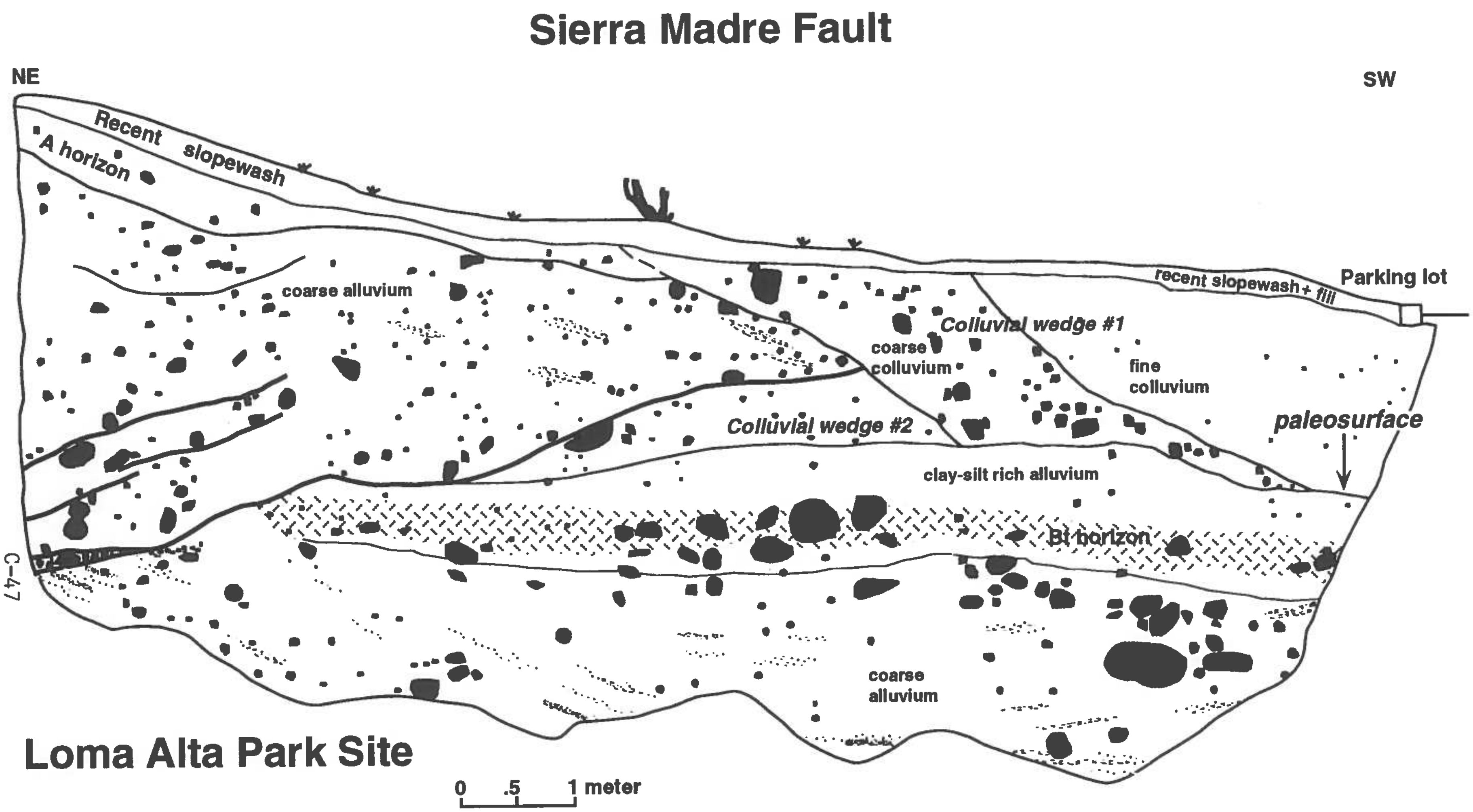

Figure 2. Cross-section showing fault traces and stratigraphic units on trench wall.