Nonvolcanic Tremors Deep Beneath the San Andreas Fault

Robert M. Nadeau* and David Dolenc

We have discovered nonvolcanic tremor activity (i.e., long-duration seismic signals with no clear *P* or *S* waves) within a transform plate boundary zone along the San Andreas Fault (SAF) near Cholame, California, the inferred epicentral region (*1*) of the 1857 Fort Tejon earthquake [moment magnitude (M_w) ~7.8]. The tremors occur at depths between 20 and 40 km, below the seismogenic zone (i.e., the upper ~15 km of Earth's crust where earthquakes occur), and their activity rates may correlate with variations in local earthquake activity.

Analysis of triggered event data from the borehole High Resolution Seismic Network (HRSN) at Parkfield, California, revealed tremorlike signals originating in the vicinity of Cholame (Fig. 1). Seismic data recorded continuously with 20-Hz sampling frequency by two stations of the Southern California Seismic Network (SCSN) (Fig. 1) and with 250-Hz sampling by the HRSN were processed with the methods of Obara (*2*) and used to identify and analyze tremor events within a ~15-km radius centered ~5 km southeast of Cholame (Fig. 1). For the 3-year search period from 23 December 2000 to 22 December 2003, when the M_w 6.5 San Simeon earthquake occurred (*3*), 110 tremor events lasting between 4 and 20 min were identified. Their locations indicate that, within the search radius, the tremors are confined to a ~25-km segment of the SAF and occur at depths of between ~20 and 40 km.

Previously, nonvolcanic tremors have only been observed in subduction zones, which are predominantly thrust fault boundaries. The depth, frequency content (generally 1 to 10 Hz), *S*-wave propagation velocity, and waveform character of the SAF tremors are similar to those of the subduction zone tremors (*2*, *4*). However, the SAF tremors are less frequent (fewer than 5 events detected in any 24-hour period), have shorter durations (less than 20 min), have smaller peak amplitudes (<M_w 0.5 earthquakes), and release less energy (energy equivalents < M_w 1.5).

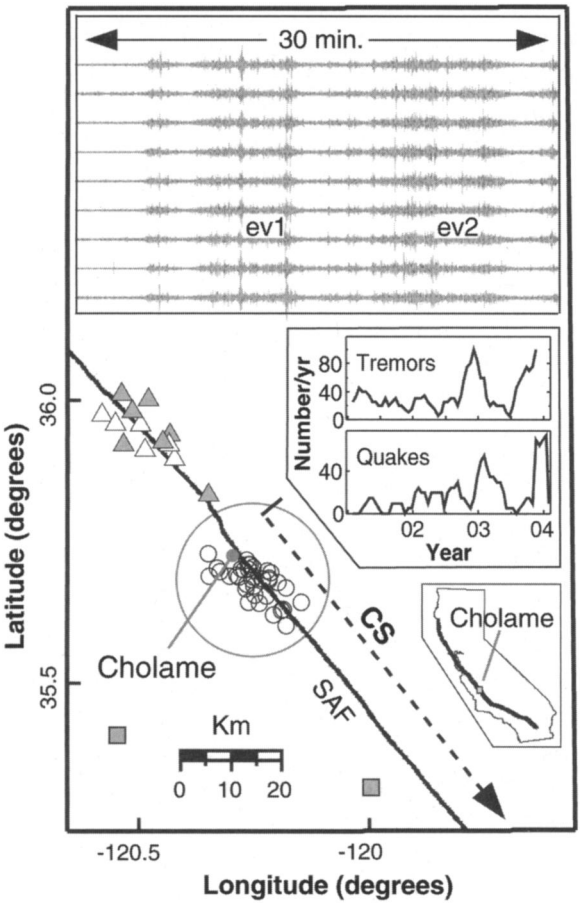

Fig. 1. Thirty-four well-located tremors (small circles) along the northern Cholame segment (CS) of the SAF. Triangles and squares represent seismic stations of the HRSN and SCSN, respectively. The large circle is the ~15-km-radius search zone. (Top inset) Horizontal component velocity seismograms (3- to 8-Hz band-pass filtered) of two tremor events (ev1 and ev2) recorded by the stations shown in gray. (Middle inset) The occurrence rates of 110 tremors and 58 microearthquakes (M_w < 2.1, occurring in a 25-km square box centered on the tremors, oriented N45°W, and including events within 0.2 years after the San Simeon earthquake), computed every 0.05 years with a 0.2-year smoothing window. Correlation of the rates is 0.75 when earthquake rates are delayed 0.15 years and 0.28 with no delay. Randomized tremor and earthquake times produce correlations ≥0.75 less than 1% of the time. (Bottom inset) The location of Cholame, California.

Fluids from subduction processes may be important for generating subduction zone tremors (*2*, *4*). Because subduction does not occur along the central SAF, either fluids are not important for the SAF tremors or an alternative fluid source exists below the seismogenic zone in this area.

In Cascadia, the correlation between subduction zone tremor rates and subseismogenic zone slow slip events is called episodic tremor and slip (ETS) (*4*). Stress changes from ETS events are expected to increase stress and possibly trigger earthquakes on the shallower seismogenic fault (*4*). The apparent correlation between tremor and local earthquake rates at Cholame (Fig. 1, inset), therefore, suggests that ETS may be taking place in this area. The tremor rate changes at Cholame also appear to precede changes in earthquake rate by several weeks (Fig. 1, inset), suggesting a possible causal relationship.

The Cholame segment of the SAF above the tremors last ruptured in, and possibly nucleated (*1*), the great M_w 7.8 Fort Tejon earthquake in 1857. This segment has an estimated earthquake recurrence time of 140 years (+93, –69) (*5*), and it is now more than 140 years since the Fort Tejon event. Because stress changes from ETS events may trigger large earthquakes (*4*), future increases in SAF tremor activity may signal periods of increased probability for the next large earthquake on the Cholame segment.

References and Notes

1. R. E. Wallace, Ed., *U.S. Geol. Surv. Prof. Pap. 1515* (Government Printing Office, Washington, DC, 1990).
2. K. Obara, *Science* **296**, 1679 (2002).
3. For ~3 months after the San Simeon earthquake (located ~60 km to the west), seismic signals from intense aftershock activity frequently mixed with the lower amplitude tremor signals, making accurate analysis of the SAF tremors infeasible.
4. G. Rogers, H. Dragert, *Science* **300**, 1942 (2003).
5. Working Group on California Earthquake Probabilities, *Bull. Seismol. Soc. Am.* **85**, 379 (1995).
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Berkeley Seismological Laboratory, 211 McCone Hall, University of California, Berkeley, CA 94720–4760, USA.

*To whom correspondence should be addressed. E-mail: nadeau@seismo.berkeley.edu