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Non-volcanic tremors near Parkfield, CA triggered by teleseismic earthquakes

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Non-volcanic tremor (NVT) is a weak, long-duration seismic signal with no clear body wave arrivals. It has been observed along the circum-Pacific subduction zones [Obara, 2002; Rogers and Dragert, 2003; Kao et al., 2005; Schwartz and Rokosky, 2007] and the San Andreas fault (SAF) system in California [Nadeau and Dolenc, 2005]. NVT is often associated with episodic slow-slip events [Rogers and Dragert, 2003], and can be triggered by surface waves of teleseismic events [Miyazawa and Mori, 2005; 2006; Miyazawa and Brodsky, 2008; Rubinstein et al., 2007; Gomberg et al., 2008]. However, the underlying mechanisms of triggered tremor generation remain unclear. Some studies propose that fluid flow due to changes in dilatational stresses associated with the Rayleigh waves is responsible for triggering tremors [Miyazawa and Mori, 2005; 2006], while others suggest that perturbation of Coulomb failure stresses on the fault interface instantaneously trigger NVT [Miyazawa and Brodsky, 2008; Rubinstein et al., 2007].

Here we show clear evidence of NVT around the Parkfield section of the SAF triggered by 2002 Mw7.8 Denali earthquake. We identify tremors as bursts of non-impulsive extend-duration seismic signals in the frequency range of 2-8 Hz that are coherent among many stations and are modulated by the surface waves. The tremor emanates from at least two source regions deep within the SAF. The first source region is ~50 km NW of the SAFOD in the creeping section of the SAF, and the second region is ~45 km SE of the SAFOD near Cholame, close to the location where the ambient NVT has been found previously [Nadeau and Dolenc, 2005]. NVT is excited when the Love waves promote right-lateral shear motion along the SAF strike, indicating a simple frictional response to the driving stress. The NVT originates at 10-25 km depth around the lower edge of the seismogenic zone, suggesting a complex transition from locking to steady deformation at greater depths.

In addition, we conduct a systematic survey of NVT at Parkfield during and immediately after the arrival of seismic waves generated by 56 teleseismic events with $M \geq 7.5$ since 1996. We qualitatively judge the clarity of tremor observations and find 10 earthquakes triggered clear tremors around Parkfield. Many tremors are initiated and modulated by the Love waves. However, in several cases tremors continue after the passage of the surface waves, and the tremor amplitude does not appear to be solely controlled by the surface wave amplitude. These observations indicate a mixture of driven, instantaneous, perhaps Coulomb-friction response with an added component of self-sustaining activity more suggestive of fluid flow. The tremor-triggering threshold at Parkfield is about 2.5 KPa, smaller than the 30 KPa threshold for regular earthquakes [Gomberg and Johnson, 2005]. The relatively low-triggering threshold suggests that the effective stress at the tremor source region is very low, most likely due to near-lithostatic fluid pressure [Liu and Rice, 2007]. This is compatible with recent observations of tidal modulations of tremors [Shelly et al., 2007; Rubinstein et al., 2008], indicating that tremors are more sensitive to transient stress perturbations than regular earthquakes. Since tremors appear to occur near the transition from the locked to the freely creeping portion of an active fault, which is a universal feature for many crustal faults [Scholz, 1998], we hypothesize that tremors and the associated slow-slip events may exist at a wide range of active tectonic environments.