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The data acquired in the Parkfield, California experiment are unique and they are producing results that force a new look at some conventional concepts and models for earthquake occurrence and fault-zone dynamics. No fault-zone drilling project can afford to neglect installation of such a network early enough in advance of the fault-zone penetration to have a well-defined picture of the seismicity details (probably at least 1000 microearthquakes - an easy 2-3 year goal for the M<0 detection of a borehole network).

Analyses of nine years of Parkfield monitoring data have revealed significant and unambiguous departures from stationarity both in the seismicity characteristics and in wave propagation details within the S-wave coda for paths within the presumed M6 nucleation zone where we also have found a high Vp/Vs anomaly at depth, and where the three recent M4.7-5.0 sequences have occurred. Synchronous changes well above noise levels have also been seen among several independent parameters, including seismicity rate, average focal depth, S-wave coda velocities, characteristic sequence recurrence intervals, fault creep and water levels in monitoring wells. The significance of these findings lies in their apparent coupling and inter-relationships, from which models for fault-zone process can be fabricated and tested with time. The more general significance of the project is its production of a truly unique continuous baseline, at very high resolution, of both the microearthquake pathology and the subtle changes in wave propagation.

In a series of eight journal articles since 1991 (see references) we have presented the evolution of a new and exciting picture of the San Andreas fault zone responding to its plate-boundary loading. Abstracts from two recent articles are useful summaries of our present knowledge:

Karageorgi, E.D., T.V. McEvilly and R.W. Clymer, Seismological Studies at Parkfield IV: Variations in Controlled-Source Waveform Parameters and Their Correlation With Seismic Activity, 1987-1994, Bull. Seism. Soc. Am., 87, 39-49, 1997.

Since June 1987 at Parkfield, California the ten-station borehole network of three-component sensors has been illuminated 52 times using a shear-wave vibrator in three orientations at seven source points, in a search for temporal changes in elastic wave P and S velocities, anisotropy or attenuation. The monitoring interval includes the beginning and end of a severe three-year drought and four earthquake sequences, two of which produced the only A-level alerts to date in the Parkfield Prediction Experiment. A comprehensive study of the entire data set reveals a progressive travel-time advance in the coda of S-waves propagating in a localized region southeast of Middle Mountain. The anomalous wave field exhibits high apparent velocities suggesting deep penetration of the fault zone, although similar changes are not seen in waveforms from repeating similar microearthquakes. Accompanying the changes in travel-time were systematic variations in spectral content and polarization in the same segments of the wavefield. These variations correlate well in time and space with significant features of seismicity, fault creep and water levels at Parkfield. A preferred mechanism for the phenomenon is changing hydrologic conditions along the affected stretch of the fault zone, possibly deformation-induced, that perturb the shallow-propagating S coda in the upper few hundred meters of section.

Nadeau, R. M. and T. V. McEvilly, Seismological Studies at Parkfield V: Characteristic Microearthquake Sequences as Fault-zone Drilling Targets, Bull. Seism. Soc. Am., 87, December, 1997.

Studies at very high resolution of microearthquakes at Parkfield, CA since 1987 reveal a systematic organization in space and time, dominated by clustering of nearly identical, regularly occurring microearthquakes ('characteristic events') on 10-20 m wide patches within the fault zone. More than half of the 4000+ events in our 1987-1996 catalog exhibit this trait. In general, recurrence intervals (0.5 to 2 yr.) scale with the magnitude of the repeating events for the on-scale range (Mw 0.2 to 1.3) in this study. The similar waveforms, superimposed locations, quasi-periodic recurrence and uniform size of these characteristic events permit relative hypocenter location accuracy of meters and predictable occurrence times within windows of a few months. Clustered characteristic events occur at depths as shallow as about 3 km, and these are feasible targets for deep scientific drilling and observation at the focus of a subsequent small earthquake within an active plate-boundary fault zone. At Parkfield the achievable location accuracy to which a hypocenter can be specified as well as the predictability of its occurrence time appear to be uniquely favorable for in-situ fault zone measurements.

A third paper presents even more tantalizing results: Nadeau, R. M. and L. R. Johnson, Seismological Studies at Parkfield VI: Moment Release Rates and Spectrally Independent Rupture Dimension Estimates for Small Repeating Earthquakes, Bull. Seism. Soc. Am., 87 (in press), 1998.

This last paper considers implications of the small areas and moment-dependent recurrence times of the characteristic events for the process of fault slip, deriving self-consistent scaling relationships among moment, area and stress drop that appear to hold over at least six orders of magnitude (up to the M6 events).Their dramatic and inescapable conclusion is that stress drop is clearly proportional to moment over that range, and that the smallest magnitude microearthquakes having slip surfaces no larger than a square meter must have stress drops of kilobars. This is a significant conclusion, often proposed and debated in the past, but without the convincing data provided by the Parkfield network.

The obvious implication (also often proposed before but unsubstantiated) is that the estimation of source radius from the displacement spectral corner is confounded by attenuation effects. The borehole data show convincingly that at magnitude in the range 0.5 to 1.0 the source-dependent corner frequencies exceed 100 Hz (see Nadeau et al., 1994). An interesting corollary to the scaling work is that the recurrence times represent slip rates on the fault surface at the cluster locations. These are seen to vary systematically in space and time, and further, they are clearly synchronous with the larger episodes of seismicity on the fault. These tiny clusters microearthquakes, observable only with borehole instruments and having recurrence times of months, thus can be viewed as local indicators of slip rate on the fault. It should now be evident that the nature of this data set -- borehole sensors in a quiet region giving a large magnitude range of on-scale recordings with high signal-to-noise ratio and minimum near-surface site effects, coupled with the clustered nature of the seismicity -- make it ideal for studies of fault zone dynamics and for seeking evidence of identifiable precursory phenomena prior to large earthquakes. Arguably the Parkfield experiment is the most significant and perhaps the only effort that will ultimately provide a definitive answer to the precursor question. The series of papers we have published with the borehole data at Parkfield illustrate what can be done to characterize at very high resolution an active fault zone.

The Corinth Rift Zone promises equally revealing and exciting discoveries if we can install a borehole network of several stations a few years before the deep drilling commences.

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