Parkfield's unfulfilled promise

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The idea that earthquakes are 'time-predictable' underlies many of today's probabilistic forecasts. In a key test on California's San Andreas fault the concept is found wanting, but the news may not be all bad.

How is the Parkfield Earthquake Experiment like technology stocks? They both seemed like a great bet at the time. As the first attempt to track a geological fault to failure, Parkfield (Fig. 1) is without peer anywhere in the world. This 25-km-long stretch of the San Andreas fault has hosted five (possibly six) shocks since 1857, all reaching magnitude 6 on the Richter scale. Not only were these earthquakes roughly the same in size and location, but they were also separated by about the same amount of time, with successive intervals between earthquakes of 24, 20, 21, 12 and 32 years. This pattern of roughly periodic events is bolstered by nearly identical seismograms for the three most recent earthquakes. In addition, the last two shocks, in 1934 and 1966, were both preceded by a magnitude-5 foreshock some 17 minutes before the main shock, several kilometres to the north.

Parkfield's behaviour anchored the concept of time-predictable earthquake recurrence, in which an earthquake strikes when a fault recovers the stress relieved by the previous event[1]. This means that the larger the earthquake on a fault, the longer the wait until the next one. With each Parkfield quake similar in size, and a constant loading rate, the next would occur in 22 years — in 1988 — with an uncertainty of about 10 years. And so, in 1986 the United States Geological Survey inaugurated a focused experiment to measure the strain accumulation, capture the nucleation of the next rupture, and watch it propagate[2]. But the earthquake never arrived.

Even though the timing of Parkfield earthquakes has turned out to be more irregular than envisaged, if the stress accumulated since 1966 has not exceeded the stress released in 1966, the earthquakes would still be time-predictable. But on page 287 of this issue, Murray and Segall[3] remove this last refuge. Drawing on 40 years of geodetic measurements, they rigorously estimate the 'seismic moment' of the 1966 event (a measure of the earthquake's size — a product of the fault slip, the area of slip and the elastic stiffness of the crust), and compare it to the accumulating 'moment deficit' (the moment associated with slip that has not occurred since the 1966 quake). Astonishingly, they find that the moment released in 1966 had been fully recovered by 1987. The expected earthquake is thus at least 15 years overdue, approaching a complete cycle.

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Figure 1 **The San Andreas fault near Cholame, California. Cholame lies at the southern end of the Parkfield region, which has suffered five or six magnitude-6 earthquakes at regular intervals since 1857.**

So have Murray and Segall dethroned time-predictability? The authors acknowledge a key caveat: faults are not stressed in isolation. Other earthquakes change the stress acting on the San Andreas fault, which could delay or advance the next Parkfield event. Candidates include the 1983 Coalinga earthquake, 25 km to the east and magnitude 6.5, which might have delayed the Parkfield earthquake by a decade[4]; and a 1993 event[5], magnitude 4.6 and a few kilometres beneath the focus of the 1966 quake, which might have advanced the next Parkfield earthquake. Although the effects of such stress changes might explain the delay, they cannot rescue time-predictability, because Murray and Segall measure the full moment deficit between 1966 and 1998, which includes the effects of the perturbing shocks. Thus, the moment imbalance remains inescapable.

But does a lone, overdue earthquake invalidate an earthquake-recurrence hypothesis? Its proponents would argue that it is based on rational physical principles, and that it works better than the Poisson hypothesis, which assumes the timings of earthquakes are random. Further, time-predictability, or at least periodic earthquake occurrence, has been found to occur for some very small 'repeating' shocks at Parkfield and elsewhere[6]. When applied to larger earthquakes, time-predictability works only crudely, and is thus applied with the explicit assumption of large expected variability. What is now needed are tests of time-predictability on other faults. The ingredients of a good test are fast fault-slip rates, moderate-sized earthquakes with short inter-event times, and dense geodetic coverage. All of this points to Japan, where the concept was born.

While the Parkfield experiment can no longer serve as a confirmation of time-predictability, it is very much alive as a test of slip-predictability, in which the longer the wait, the larger the next earthquake[1]. Murray and Segall argue that an earthquake of magnitude 6.6–6.9 would balance the moment deficit that has accumulated since 1966, and the magnitude increases with each passing year[7]. If, when the next Parkfield shock strikes, its magnitude approaches this expectation, the Parkfield experiment would be transformed from a lesson in patience to a prescient success — tracking the nucleation and propagation of a much larger shock with Parkfield's arsenal of instruments would be a bigger scientific prize. And the observing power at Parkfield has just taken a new leap, with the completion of a 2.2-km-deep pilot well with a string of down-hole seismometers, and the proposed 4.0-km borehole that will pierce the fault at seismogenic depths[8]. Perhaps in the end the delay will appear providential, and Parkfield will turn out to be an inspired long-term investment for science. ■

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