Stalking the Next Parkfield Earthquake

Testing hypotheses at the Parkfield section of the San Andreas already bears a strong resemblance to earthquake prediction

Looking southeast from Middle Mountain toward Gold Hill, it is a subtle furrow in the grassy knolls of the Cholame Valley of California's Coast Range. To geophysicists, this 30-kilometer section of the San Andreas fault midway between San Francisco and Los Angeles is the most well understood, most intensely monitored fault in the world. As such, it is also the most likely place for American earthquake researchers to become earthquake predictors.

The present understanding of the fault has already prompted speculation that the next moderate Parkfield earthquake will strike in early 1988, give or take a few years. Moreover, the next rupture of the Parkfield section of the fault could get out of hand and create a much larger earthquake.

The Parkfield section, named after the town (population 34) that nearly straddles the fault, is the focus of prediction efforts in part because it is so well behaved. Researchers believe that it has broken during moderate earthquakes in 1857, 1881, 1901, 1922, 1934, and 1966, or about every 22 years. These events were severe enough to topple chimneys, water tanks, and cemetery monuments, rupture pipelines, and crack walls. William Bakun of the U.S. Geological Survey (USGS) in Menlo Park, California, and Thomas McEvilly of the University of California at Berkeley have argued from the records of the last three Parkfield earthquakes that, whenever the San Andreas ruptures near Parkfield, it produces nearly identical earthquakes of about magnitude 5.6. Each of the last three seemed to break the same 20- to 30-kilometer section of fault, to begin at the same point, to rupture in the same southeastward direction, and to release the same amount of energy within 10 or 20 percent. In the case of the two most recent events, the conformity extended to having a magnitude 5.1 foreshock precede the 1934 event by 17 minutes 25 seconds and the 1966 event by 17 minutes 17 seconds.

This astonishing replication of earthquakes apparently results from a subdividing of the San Andreas that sets the Parkfield section apart from the rest of the fault. All of southern California west of the San Andreas and the rest of the Pacific crustal plate are sliding at a rate of about 35 millimeters per year to the northwest past Parkfield and the rest of the North American plate. To the southeast of Parkfield, that motion occurs only during large or great earthquakes. The rest of the time, the opposite sides of the fault remain locked together until enough strain builds up to rupture the fault and produce the next earthquake. To the northwest of Parkfield, in the central part of the San Andreas, the plates steadily creep past each other without locking, accumulating strain, or producing significant earthquakes. The Parkfield section, the only one to break in frequent, moderate earthquakes, is a transition between the creeping and the locked sections of fault.

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According to one view, this subdivision of the San Andreas into creeping, locked, and transition sections owes its existence to two subtle irregularities in the trace of the fault. About 8 kilometers northwest of Parkfield, the fault bends 5 degrees. It is here that the typical Parkfield earthquake begins to rupture the fault. From there, the rupture rips the fault to the southeast about 20 kilometers and comes to a halt in the vicinity of Gold Hill, where the otherwise linear fault is offset 2 or 3 kilometers.

The bend north of Parkfield would seem to be a spot, called an asperity or barrier, where slip between the opposing plates is particularly difficult and strain builds faster than elsewhere (*Science*, 25 November, p. 918). When the strain becomes great enough, even the asperity fails, which sets off the rupture of the rest of the fault. The second asperity, at the offset at Gold Hill, is strong enough to stop that rupture. Allan Lindh of the USGS in Menlo Park, who is involved in the USGS Parkfield Prediction Experiment, has suggested that it is not so much the irregularities on the abutting faces of the fault that resist slip as an increase in rock strength from north to south along the fault.

Whether rock composition or fault shape wields ultimate control, the subdivision of the San Andreas in the vicinity of Parkfield has created a singularly well-behaved section of fault that geophysicists have found to be an irresistible target for testing their understanding of earthquake generation. As their understanding of the Parkfield fault has grown, Lindh, Bakun, and their colleagues at the USGS in Menlo Park have been making informal statements at meetings over the last few years about the timing of the next Parkfield earthquake, but in a forthcoming paper* Bakun and McEvilly come closer to making a formal earthquake prediction than any American scientist so far, except of course for Brian Brady and his poorly received and ill-fated prediction of a great Peruvian earthquake (*Science*, 31 July 1981, p. 527).

In a discussion labeled "A speculation" that follows an analysis of the various factors that could confound a prediction, Bakun and McEvilly suggest that, if the Parkfield fault continues to behave as well as it usually has in the past, a magnitude 5.6 earthquake should strike Parkfield "in January 1988 ± 4.3 years." How to measure the uncertainty of the timing of the next Parkfield earthquake is the main problem in its prediction. In meeting abstracts, Lindh and his colleagues, including Bakun, have stated that "the next event can be expected in 1987–1988, although estimates of the credible time window range from 2 to 10 years." In at least one of his presentations, Lindh gave the date as 1988 ± 1 or 2 years if their assumptions were correct. Their main assumptions were that the 1934 Parkfield earthquake, which arrived 10 years "early" if a 22-year periodicity is assumed, is the only errant child of the family and that events are back on schedule since the 1966 event.

Bakun and McEvilly also arrive at the date of January 1988 by dropping the time of the 1934 event from their calculation, but they put it back in to calculate the uncertainty. "I really thought a conservative approach would be better,"

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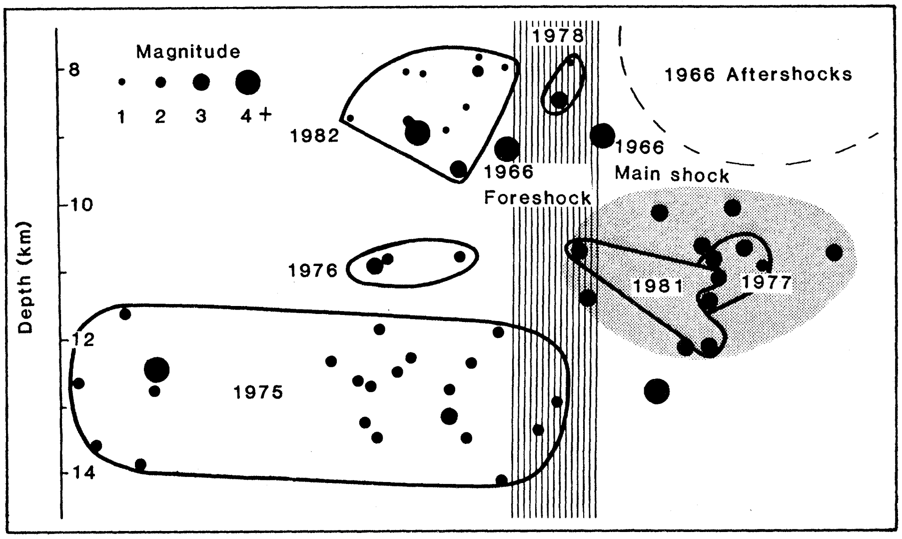
says Bakun. "In fact the 1934 earthquake happened. We all agree that the most probable date is 1987 or 1988. Putting a statistical error bar is where we begin to disagree." If the time of the 1934 event is ignored, a simple linear regression through the other five events predicts their times of occurrence within 1.5 years or less, and the predictions have a standard deviation of 1 year. When the 10.2-year prediction error of the 1934 event is put back in, which is Bakun and McEvilly's preferred approach, the standard deviation jumps to 4.3 years.

Researchers would feel much more comfortable with the narrower prediction window if they understood what caused the 1934 earthquake to arrive early. If strain accumulated at the same rate on the same section of fault that maintained the same strength, each earthquake would arrive on schedule, as seems to have happened five out of six times at Parkfield. But something was different in 1934. Lindh notes that a second foreshock of magnitude 5.0 preceded the 1934 but not the 1966 main shock by 2 days. A similar earthquake did precede the 1966 event, but by 10 years. Lindh suggests that in 1934, for reasons that remain unclear, the fault was ready to fail after only 10 years of strain accumulation rather than the usual 22 years. The earlier 1934 foreshock could thus have added enough strain to the vicinity of the asperity to precipitate the 17-minute foreshock and then the main shock. The fault seems to have avoided premature failure during the current cycle of strain accumulation—a magnitude 5 shock struck the Parkfield bend in 1975 without triggering a Parkfield earthquake. This would seem to increase the chances that the post-1966 cycle is progressing according to the typical 22-year pattern and that ignoring the 1934 event in prediction models is justifiable.

Researchers realize that scientific study at Parkfield is becoming indistinguishable from earthquake prediction. When they cross the line between scientific hypothesis testing and scientific prediction remains a matter of opinion. Lindh argues that "Sensible people don't try to predict detailed behavior of complex systems until they understand them, at least in outline. It seems to me that we're working the middle ground at this time" between vague forecasts and specific predictions, the latter being based on a more complete understanding of the workings of earthquakes. Other researchers agree that Bakun and McEvilly's 8-year window makes their statement a forecast or a hypothesis to be tested within the scientific community rather than a prediction. Predictions specify the time of an earthquake within days, weeks, or months, not years, some researchers feel, especially those working close to the testing of hypotheses.



Foreshocks of the next Parkfield earthquake?

This clustering of seismic activity around the site of the 1966 moderate Parkfield earthquake began in 1975. The shaded patch, just below the site of the 1966 main shock on the fault bend (vertical band), has been the site of small earthquakes every 39 to 41 months since 1971. All this activity may be adding strain to the central quiet area of the fault that will lead to a repeat of the 1966 Parkfield earthquake. [*Source:* A. Lindh]

So far, the U.S. National Earthquake Prediction Evaluation Council has also viewed Parkfield prognostications as vague enough to ignore. Its charter defines a prediction as "a statement on the time of occurrence, location, and magnitude of a future significant earthquake based on qualification of the uncertainty of those factors." The chairman of the Council, Clarence Allen of Caltech, and the vice-chairman, USGS Office of Earthquake Studies chief John Filson, both conclude that Bakun and McEvilly's stated uncertainty in the time of occurrence is too great to permit their hypothesis to be considered a prediction by this standard. In any case, Allen prefers that the National Council consider only short-term predictions unless the possible social effects are much greater than those of a moderate event in a relatively empty part of California.

The Council may have a chance to reconsider. Robert Wallace of the USGS in Menlo Park, James Davis of the California Department of Mines and Geology, and Karen McNally of the University of California at Santa Cruz have developed a definition of prediction that has been adopted by the Southern California Earthquake Preparedness Project, tentatively adopted by the California Earthquake Prediction Evaluation Council, but tabled by the National Council. Their definition requires specification of time, place, and magnitude "with sufficient precision so that the ultimate success or failure of the prediction can readily be judged. Moreover, scientists should also assign a confidence level to each prediction."

By this definition, says Wallace, who is a member of the National Council, Bakun and McEvilly's statement is an intermediate-term prediction, the predicted event falling a few weeks to a few years in the future. Other researchers agree; at least at Parkfield, the distinction between doing science and making predictions can no longer always be made. Explaining the difference between a hypothesis and a prediction to the public will be especially difficult, they add, a task that might be eased if the appropriate prediction evaluation bodies promptly tackled the problem.

The intermediate-term prediction of the next Parkfield earthquake has taken on added interest with the suggestion that it might break through the asperity at the Gold Hill offset and produce a major rather than the usual moderate shock. Kerry Sieh of Caltech and Richard Jahns of Stanford University have studied fault displacements of earthquakes of historic times and displacements revealed in the prehistoric offsets of stream beds that cross the San Andreas. They found that a 90-kilometer section of fault, including the Parkfield section and an adjacent portion of the locked fault to the south, "is likely to generate a major earthquake by the turn of the century."

South of these segments, near Wallace

Creek, the fault seems to rupture during large but infrequent earthquakes and is not likely to fail again in the next 100 years. However, between this particularly strong section and the Parkfield section, the fault seems to break about every 100 years; it last broke in 1857. Thus, a failure of this section conforming to the past pattern could come at any time. If combined with a Parkfield rupture, the resulting earthquake could be as large as magnitude 7, but the fault rupture would still stop well within the nearly empty region around Parkfield.

Even if study of past earthquakes does not prompt official consideration of Parkfield intermediate-term predictions, the fault itself is liable to call so much attention to itself before its next failure that the predictive nature of the scientific work will be agreed upon by all. Parkfield is the focus of prediction efforts not only because it has a long record of nearly periodic failure but also because in the past the fault has given warning of its imminent failure. During the few months before the 1966 main shock, small earthquakes migrated southeastward toward the eventual site of the main shock. Two weeks before, Allen and a group of touring Japanese scientists discovered fresh cracks across a road in the central Parkfield section. To the south, a water pipe across the fault broke about 9 hours before the main shock.

These 1966 precursory phenomena presumably reflected a gradual failure process that loaded additional strain on the asperity as the fault weakened and began to creep at progressively accelerating rates. The USGS, as part of the Parkfield Prediction Experiment (see box), is instrumenting the Parkfield section in an effort to detect such preparations for failure, perhaps years before the main shock.

So far, the only possible precursor is the clustering of small earthquakes just outside the points on the fault, called hypocenters, where the 1966 foreshock and main shock ruptures initiated (see diagram). At one site just below and to the southeast of the main shock hypocenter, notes Lindh, the small shocks have been striking every 39 to 41 months since 1971, almost like a clock ticking. Conceivably, the next one could trigger the next Parkfield earthquake, he says. According to its previous pattern, the next small one would be due in April 1984, another in July 1987 within months of the target date for the next Parkfield earthquake. At least on this section of the San Andreas, the earthquake hunting should be good.—**Richard A. Kerr**

How to Catch an Earthquake

Researchers are anxious to capture a good-sized earthquake in one of their monitoring networks, dissect the inner workings of a fault as it prepares to fail and then finally ruptures, and perhaps even predict the coming earthquake from premonitory shiftings of the earth. The 1979 Coyote Lake earthquake fell into the middle of their net on the Calaveras fault but struck without warning (*Science*, 2 November 1979, p. 542). The damaging Coalinga shock eluded intensive monitoring, but it too seemed capable of rupturing a fault in seconds without a sign that the fault was strained near the breaking point (*Science*, 25 November, p. 918).

Now, geophysicists are laying in wait at Parkfield, confident that their quarry, a magnitude 5.6 earthquake on the San Andreas, will arrive in the next 10 years, most likely around 1987–1988 (see main story). Leaving nothing to chance, they are festooning the Parkfield area with one of the most sophisticated and densest nets of monitoring instruments in the world. The components of this network reflect a recent consensus among researchers that they now know what is most important to measure and how to do it accurately and reliably.

As one part of a two-pronged approach, an array of different devices will monitor the shape of the crust as it deforms under the increasing stress that will eventually load the fault to the breaking point. The travel time of light between a two-color laser and a set of reflectors will soon be measuring on a nightly basis the deformation over 200 square miles to an accuracy of 1 millimeter in 10 kilometers. Portable laser devices already measure distances every 3 months along an intricate web of lines covering about 600 square kilometers. And dilatometers at the bottoms of two 200-meter holes are measuring strain continuously. The second prong of the attack is a system of about 20 seismometers that provide a three-dimensional picture of the release and redistribution of strain by earthquakes on the fault. Eight creepmeters stretched across the fault measure strain released without seismic activity.

Although not formally related to the Parkfield effort, a plan for a prediction network covering southern California [*U.S. Geol. Surv. Open-File Report 83-576* (1983)], prepared by James Dieterich at the request of a congressional committee, also emphasizes the measurement of strain and seismicity at the expense of monitoring such precursors as changes in natural spring flow, soil radon emission, or magnetic fields. Once held out as easy routes to prediction, these empirical precursors are now regarded as too poorly understood and too far removed from the strain changes that trigger earthquakes to be reliable.

The immensity of the effort required to follow this preferred approach to earthquake prediction is staggering. In order to monitor the southern San Andreas and one side fault, the plan calls for 36 sophisticated crustal deformation observatories on and near the fault. Current funding has allowed the development of two slightly less sophisticated sites, the one at Parkfield and one at Pearblossom to the south. That leaves 34 to go. The plan would also require the complete revamping of the present seismograph network and its telemetry lines and a quadrupling of the frequency of regional deformation surveying. Even then, "it cannot be stated with certainty that the prototype network described here will successfully predict the next great earthquake in southern California," according to the report.

One reason for the lack of guarantees, even with such a large monitoring effort, is the possibility that ruptures of great lengths of the San Andreas might be controlled by small sticking points or asperities on the fault like those at either end of the Parkfield section. The apparent imminent failure of one of these asperities might then be interpreted as precursory to a moderate or a great earthquake, depending on whether the rest of the asperities were ready to fail. A number of the fault sections in this domino view of the San Andreas have been identified, but the precise locations and past behavior of their asperities are far more poorly known than at Parkfield.—**R.A.K.**