SEISMOLOGY

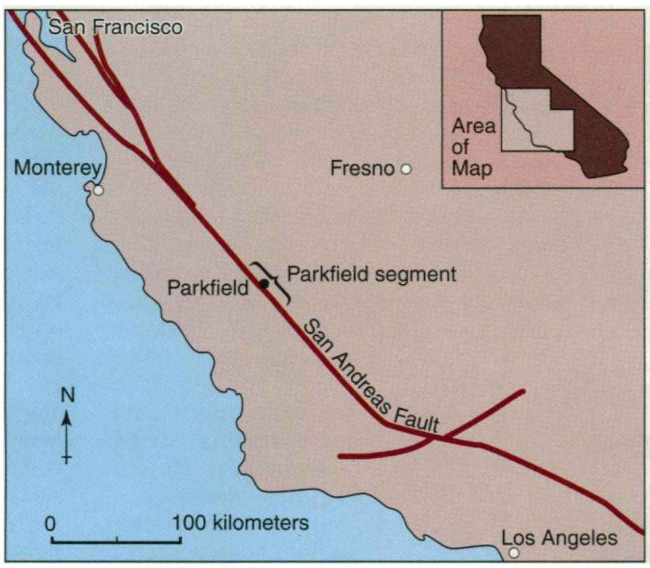
Seismologists Issue a No-Win Earthquake Warning

Eight years ago, a group of three geophysicists made a bold prediction: By 1993, a magnitude 6.0 earthquake would rupture the San Andreas fault near the tiny central California cattle town of Parkfield. With only 10 weeks to go before time ran out on the forecast, researchers last week thought the long-anticipated event might be about to happen. On Monday 19 October, a magnitude 4.7 quake struck just north of Parkfield (population 34), and U.S. Geological Survey (USGS) geophysicists immediately called for an alert. They assumed that this could be a foreshock and that the long-predicted main event might follow within 3 days. By week's end, however, the researchers were still waiting—and puzzling over what was going on. (As *Science* went to press, a magnitude 3.9 quake struck on 26 October. This was not the anticipated major quake, but could be another foreshock.)

But the geophysicists who made the prediction aren't necessarily all that upset that Parkfield hasn't gotten its shaking. If a strong quake had followed hard on the heels of Monday's temblor, it would have vindicated the 1985 forecast (*Science*, 19 April 1985, p. 311), but, ironically, it would have been something of a setback for predicting earthquakes elsewhere. The reason: Aside from the foreshock itself, there have been no indicators that the fault was about to rupture—indicators that would be useful elsewhere.

Shortly after the initial quake, seismologist Allan Lindh of the USGS in Menlo Park, where Parkfield is being monitored, said, "The fault's just sitting there. There hasn't even been another aftershock [of Monday's earthquake]. None of this fits any scenario we had fixed up. I don't know whether it's just thinking about what comes next or it's done." And that leaves researchers in something of a bind: Either their long-term prediction is about to fail or—if the expected quake strikes in the next few days or weeks—the prospects for short-term prediction will suffer a serious blow.

Monday night's magnitude 4.7 wakeup call did at least refocus geophysicists' attention on the Parkfield Earthquake Prediction Experiment, which involves the world's densest fault-monitoring network. After years of waiting in vain for something to happen at Parkfield, researchers had begun worrying whether the experiment would ever live up to the high expectations with which it was launched 8 years ago. The quake, which struck near where the expected quake should get started, immediately triggered the first official short-term earthquake prediction in the United States. It warned that "there is now a greater than 37% chance that the predicted earthquake will occur within a 72 hour window," according to the California Office of Emergency Services.



D. DEFRANCESCO

Central California's turn? Attention has turned to the Parkfield segment of the San Andreas.

Seismologists might have had more confidence in the alert if the fault was doing anything else to suggest imminent failure. In theory, a fault can begin to fail weeks or months before the sudden rupture of the earthquake. Around a patch of fault where the two sides are locked to each other, failure can start at the edges and eat inward. Undetectable at first, the peripheral slippage accelerates faster and faster until it runs away in a full-blown rupture that races down the fault. Parkfield instruments measuring the deformation of rock near the surface should be able to detect the effects of such a precursory slip well before the quake, according to computer models of the Parkfield fault segment, such as those run by Terry Tullis of Brown University and William Stuart of the USGS in Pasadena. And since no such slippage has been detected, says Stewart, theory would suggest that "Monday's earthquake is not a foreshock."

But there are some doubts about the theory. "I'm not terribly hopeful that there's going to be much out there in the way of precursors," says James Rice, a specialist in fault mechanics at Harvard University. "Some earthquakes do seem to have precursors, others don't; we'll be lucky sometimes and other times we won't. We may just have to live with that." In fact, of the three typical Parkfield earthquakes of the past 60 years, one had no foreshocks. And of the seven quakes in the magnitude 4.5 to 5.0 range, only three were foreshocks. The other four were followed by nothing at all.

And as the 3-day alert window was drawing to a close at *Science*'s press time, that's where researchers thoughts were turning: from the possibility of a Parkfield earthquake without precursors to the prospect of no quake at all. "We're getting toward the end [of the prediction window of the 1985 forecast]," notes Lindh, "and there's a nagging fear that nothing will come of all that we've put into [the Parkfield experiment]." That worry had, in fact, been around for a while; doubts about the prediction have mounted in recent years.

The original prediction was based on the more or less regular recurrence of earthquakes at the same place every 22 years—on average. The last Parkfield quake struck in 1966, so the next one was predicted to occur in 1988, give or take 5 years. But the 22-year figure is an average derived from some widely varying intervals: 24, 20, 21, 12, and 32 years. But as the originators of the Parkfield prediction—seismologists William Bakun of the USGS in Menlo Park, Lindh, and Thomas McEvilly of the University of California, Berkeley—saw it, the 1934 quake, which was preceded by a 12-year interval, probably came "early," and the subsequent long 32-year interval got things back on track. So they decided, in effect, to average out the short and long intervals to two 22-year intervals, thereby greatly reducing the uncertainty of their prediction.

That assumption may seem arbitrary, but, in fact, it was not purely ad hoc. Bakun and colleagues saw signs that, about halfway through a Parkfield cycle, the stress seems to become high enough to start triggering quakes about the size of Monday's. Two such quakes were foreshocks in 1934, suggesting that they triggered the early quake. Yet two more in 1975 failed to trigger anything, encouraging the seismologists to assume that the current cycle would be of an average length.

Statistician Mark Matthews of the Massachusetts Institute of Technology, who specializes in the statistics of seismology, argues, however, that such a presumption of regularity in earthquake cycles "is based on wishful thinking that there is simple physics behind earthquakes. The empirical evidence is to the contrary. These things are very complicated and difficult to predict." Instead of a prediction of 1988±5 years, Matthews argues that 1983±20 years would be more justifiable.

No matter which error range you favor, Parkfield is causing problems for would-be earthquake predictors. But Bakun can imagine a happy ending. "If all this is leading to a larger earthquake, it's proceeding differently [from other Parkfield quakes]. Maybe we're looking at a more protracted preparation time, and we're going to see a few more things before the earthquake happens." Then again, he says, their model of how Parkfield behaves could fail this test. "We go through phases" in seismology, he says, "where we see things that confirm our previous paradigms, and we're confident. Then come the surprises, and we're not so bold about predicting the future." The next few months may well offer a foretaste of earthquake prediction's next phase.

–Richard A. Kerr

SEISMOLOGY

Good Forecast, But Missed Prediction

If seismologists are uneasy about their soon-to-expire forecast of a moderate earthquake in central California (see previous story), they can at least take some small comfort from the modest success, announced in this issue of *Science* (p. 726), of a forecast of the deadly Nicaraguan quake that struck early last month. A group of seismologists report that their 1981 forecast that a large quake would occur off the coast of Nicaragua within a few decades was bang on as to location and pretty close on its magnitude. But politics and Mother Nature conspired to frustrate any short-term warning.

From a scientific point of view, the outcome is "encouraging," says David Harlow of the U.S. Geological Survey (USGS) in Menlo Park, the lead author of the forecast that appeared in the 7 August 1981 issue of *Science*, but he concedes that they have not come up with a sure-fire route to long-range prediction. "When we wrote that paper, I was much more optimistic about predicting earthquakes," he says. New theories for earthquake prediction were gaining support, including the sort of analysis of seismicity patterns that Harlow and his colleagues employed in their forecast. But these theories have not fulfilled their promise of providing broadly useful forecasts, and even the patterns on which Harlow based his forecast have not shown up reliably. "I've grown more pessimistic over the years," says Harlow.

Combining two forecasting methods to look decades into the future, Harlow and his colleagues drew on two seemingly related features—a small zone of seismic quiescence wrapped in a broader region called a seismic gap. The gap was defined by an absence of large earthquakes, greater than magnitude 7, off the Pacific coasts of northwestern Nicaragua and El Salvador for more than 50 years. Early in this century, major quakes had rocked the region, where an oceanic plate dives under the edge of the plate that carries Central America, but nothing big had hit since. The longer the period since the last large earthquake in a gap, the reasoning went, the more likely one would strike within years or decades.

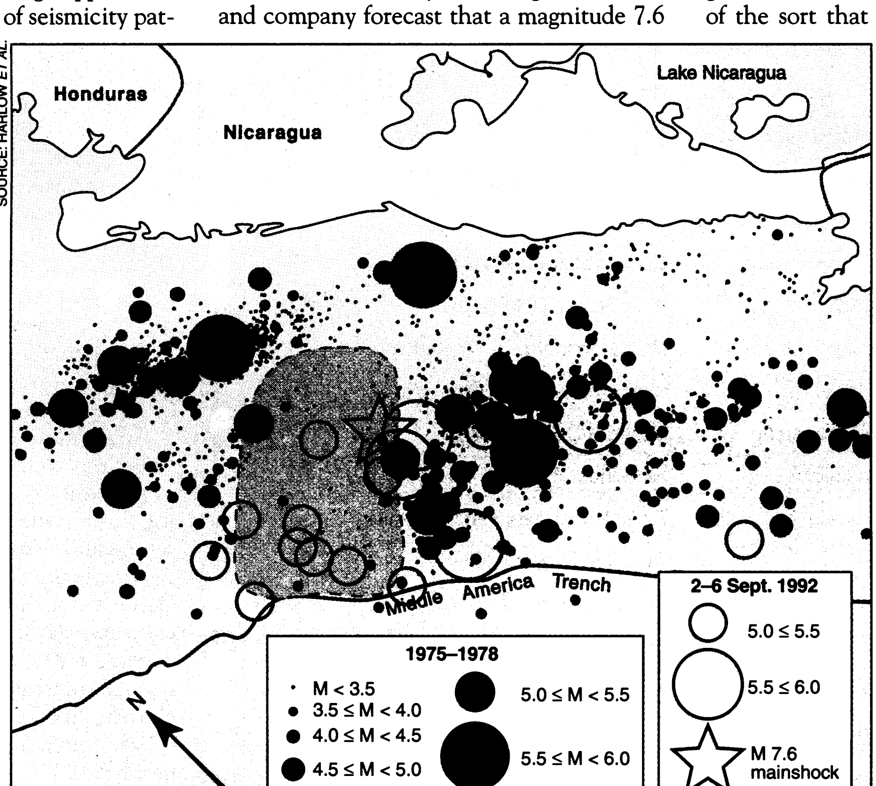
Nestled within this 400-kilometer-long seismic gap, Harlow and his colleagues found a 50-kilometer-wide zone that was even quieter. Virtually no earthquakes larger than magnitude 2 occurred there from 1975 through 1978, when a cooperative U.S.-Nicaraguan seismograph network was operating onshore, while numerous moderate quakes up to magnitude 5.7 struck nearby. Simple empirical analysis of seismic records suggested to some researchers that such quiet zones indicated where stress was building toward the next large quake. Adding in such factors as the seismic history of the region, Harlow and company forecast that a magnitude 7.6 to 7.9 quake would break the silence sometime in the coming decades.

On 2 September, the seismologists got what appeared to be the long-forecasted earthquake when a magnitude 7.6 shock struck at the southeast corner of the quiet zone. "This is an example of what you can do with good, modern data in a subduction zone," says seismologist William Ellsworth of the USGS in Menlo Park. "In general, this is pretty encouraging for long-term forecasting." He notes that the Nicaraguan quake's rupturing of the quiet zone is another example of the way low-level seismicity can outline a section of fault that is preparing to break in a larger earthquake (*Science*, 21 April 1989, p. 286). Seismologists recognized several such cases, including the Loma Prieta quake, in the 1980s, but usually too late to make a forecast.

Encouragement aside, the Nicaraguan quake had its disappointments, too. Following the 1979 Sandinista revolution in Nicaragua, operation of the local seismograph network collapsed and scientific relations were nearly severed. And last August, U.S. seismologists long out of touch with Nicaraguan researchers missed several "preshocks" of the sort that heralded Loma Prieta, because the August report from the worldwide seismic network had not yet arrived.

Even if the preshocks had been recognized as such and a warning had gone out, large loss of life may have been unavoidable. The last major earthquake to strike the vicinity of the quiet zone, a magnitude 7.5 in 1898, heavily damaged towns tens of kilometers inland. In contrast, last month's quake left those towns untouched but swept away coastal villages with a tsunami. Something was different about this quake, and figuring out what it was may have more than the usual urgency about it: The 1898 quake was followed by three more over the next 28 years.

–Richard A. Kerr



SOURCE: HARLOW ET AL.

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Filling the seismic hole. The quiet zone (dashed line) bounded by small and moderate quakes of the 1970s (filled circles) became noisy in September (open star and circles).