SEISMOLOGY

Working Up to the Next Big One

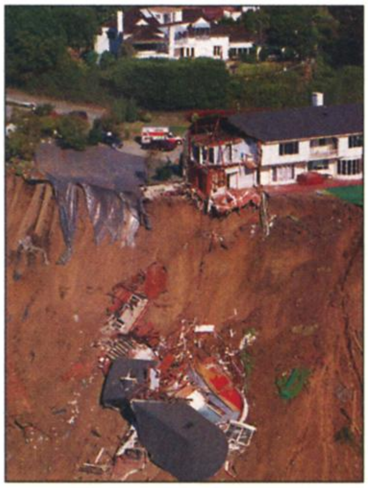
The chatter of faults breaking in moderate earthquakes may give warning of the larger quake to come in Southern California

Earthquakes speak to one another. But what are they saying? That's an important question in Southern California, where scientists are trying to understand whether a resurgence of lesser earthquakes there heralds the big one or is meaningless babble.

A pair of geophysicists has found that each of California's nine large quakes of the past 50 years was preceded by a rising chorus of regional seismicity. The finding prompts speculation that some major quakes could be anticipated years ahead. But in a field with a history of overreaching, researchers are probably more excited by the analysis being grounded in basic geophysics.

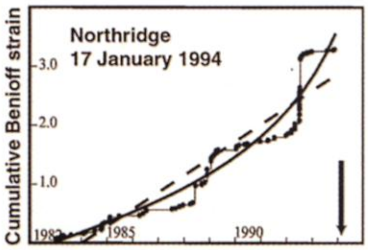
"It's a significant step, a much more rational approach than anything done previously on seismicity patterns," says fault mechanics specialist James Rice of Harvard University. "It's such a breath of fresh air, compared to what preceded it."

Attempts to read the meaning of regional seismicity patterns began modestly. In 1980, seismologist William Ellsworth of the U.S. Geological Survey in Menlo Park, California, noted an abundance of moderate quakes in the decades before the great 1906 San Francisco earthquake and their absence in the 50 years after the quake. The heightened regional seismicity before large quakes and quiescence after them became known as the seismic cycle.



Russian seismologists led by Volodya Keilis-Borok, of the Institute of Earthquake Prediction Theory and Mathematical Geophysics in Moscow, then taught a computer algorithm to recognize patterns of unusual seismic activity that they thought appeared late in the seismic cycle over regions hundreds of kilometers across (*Science*, 15 March 1991, p. 1314). But the highly empirical—some would say mysterious—method failed to win over most U.S. seismologists.

The seismic cycle started to make more sense, however, after seismologists began listening to conversations among earthquakes (*Science*, 16 February 1996, p. 910). In general, when a fault ruptures under stress and slips in an earthquake, stress levels increase beyond the tips of the rupture and decrease in broad areas on either side of the fault. The changes are greatest at the fault and decline with distance. Thus, one fault can relieve a distant one of some stress and delay its rupturing, if the second fault falls in the "stress shadow" around the first. Seismologist Lynn Sykes of the Lamont-Doherty Earth Observatory in Palisades, New York, showed, for example, how the great earthquake of 1857 cast an equally great stress shadow over much of Southern California. That stress shadow induced a broad, century-long seismic quiescence, at least among moderate and large quakes.



Up, up, and away. A rising curve of seismic activity pointed toward the Northridge quake (arrow).

Turning that theory into a more detailed forecast has proven difficult. Now, geophysicists David Bowman of California State University, Fullerton, and Geoffrey King of the Institute of Earth Physics in Paris have refined the search for seismicity patterns and applied their method to all nine large (magnitude 6.5 and greater) earthquakes in California in the past 50 years. They reasoned that the clearest signals would come from listening to seismicity changes within the original stress shadow of a fault's most recent large quake, a region they could calculate by running the quake in "reverse" in a computer and observing the stress changes.

When Bowman and King analyzed California seismic records, they found that all nine large earthquakes were preceded by not just heightened seismic activity but increasing activity that, in hindsight at least, accelerated toward the large quake. In eight of the nine cases, the rate of acceleration seemed to point toward rupture of the fault within a year or less of the actual time of the quake. The "hindcast" for the time of the ninth quake, the Northridge quake in 1994, was off by 18 months.

Seismologists insist on a plausible physical mechanism before they'll accept a forecasting method. Bowman and King think they have found one in the shrinking of the stress shadow. It is deepest and "darkest" at its center, so as the steady grinding of tectonic plates slowly adds stress across the region, the first faults to return to stress levels near the breaking point are on the fringes of the stress shadow. Renewed activity begins there and extends inward as the shadow shrinks. The accelerating intensity of seismicity reflects the increasing area subjected to fault-rupturing stresses as the quake-dampening shadow shrinks. As the shadow edge approaches the main fault, which has remained quiet through the seismic cycle, it triggers foreshocks and then the main shock.

Researchers are generally relieved to see the new work. "This is the right approach, one based on the physics of stress transfer," says seismologist Bernard Minster of the Scripps Institution of Oceanography in La Jolla, California. "If confirmed, it is a major step toward understanding the physics of earthquakes." Seismologist Stefan Wiemer, of the Swiss Federal Institute of Technology Zurich, is "more skeptical. It comes from my experience with earthquake prediction research. The next logical step is … predictions of the next earthquake. That's when things often fall apart."

In fact, Bowman and King have applied their method to the two long segments of the San Andreas fault that broke in the great 1906 and 1857 quakes. They found no seismic acceleration in the San Francisco Bay region but did find it in Southern California. The fault seems to be building toward another rupture there, but, as King notes wryly, "prediction is particularly difficult when it concerns the future."

The curve-fitting that the researchers did to hindcast past earthquakes so accurately simply predicts that the main event in Southern California will begin shortly after the seismic record ends. And their approach depends on knowing which fault segment is liable to fail next, knowledge that has been lacking in most recent large quakes. So the next steps must be more geologic studies of faults and their history of rupture.

–RICHARD A. KERR

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