# Shaking Up Seismic Theory

## *Are you any better off after an earthquake?*

By RICHARD MONASTERSKY

The way seismologists look at the world, Santa Cruz, Calif., appears safer than most other spots in the geologically restless Golden State. Two years ago, the scenic coastal city suffered severe damage from a quake that originated on the nearby San Andreas fault. So by the reckoning of most experts, Santa Cruz should remain free of any large jolts for quite some time.

David D. Jackson, however, doesn't subscribe to the prevailing wisdom about Santa Cruz's safety. On the basis of his own seismological research, Jackson says, "I feel that's the most dangerous place in California right now."

Jackson's disagreement with mainstream seismology extends far beyond the confines of Santa Cruz. He and colleague Yan Y. Kagan argue that earthquake investigators around the world have followed the wrong theory for the last decade and a half, and now the two researchers believe they have the evidence to prove it. If correct, this pair of University of California, Los Angeles, researchers will force seismologists to revise the way they assess whether particular regions face the threat of large earthquakes.

Kagan and Jackson challenge an idea called the seismic gap hypothesis, which holds that earthquakes along major faults follow a specific cycle — namely, hazard is low immediately following a large tremor but increases with time. According to this theory, a big quake releases most of the stress that has built up along a fault, making it difficult to spark another severe tremor in the near future. Only after decades of dormancy does enough stress accumulate to make a major jolt possible.

Although scientists discussed the gap theory in the early 1900s, it failed to capture much support until the 1960s, when the plate tectonics revolution swept the earth sciences. Guided by a new vision of great plates shifting around the Earth's surface, geoscientists discovered a mechanism to explain why stress continually builds up along faults that define the boundary between two plates.

As these plates collide or slide past each other, the edge of one snags on another and remains immobile until the stress grows so great that the plates suddenly jerk forward, generating a seismic shock. The process repeats itself as the edges snag again and stress once more accumulates along the fault.

Spurred by the hope of predicting earthquakes along these active plate boundaries, researchers from Columbia University's Lamont-Doherty Geological Observatory in Palisades, N.Y., began exploring the implications of the seismic gap hypothesis. In 1979, the Lamont team applied the idea to assess the hazard around the entire Pacific Rim — the so-called Ring of Fire that is particularly prone to great tremors, such as the 1964 Alaskan quake.

The scientists divided the circum-Pacific region into more than 100 segments and assigned a hazard level to each segment based on the most recent large earthquake to hit that region. Segments that had gone a century or more without a major jolt received a red label, indicating the highest hazard level. Orange denoted an intermediate threat, assigned to segments that had spent 30 years free of large earthquakes. The least dangerous regions, colored green, had felt a large tremor in the last 30 years.

Using the seismic gap hypothesis, William R. McCann and his colleagues from Lamont forecast that the red segments faced the greatest immediate risk of an earthquake above magnitude 7.0.

Over a decade later, Kagan and Jackson decided to test that forecast and the seismic gap hypothesis in general. From several different earthquake catalogs, they culled all jolts larger than magnitude 7.0 that had occurred since 1979 along the Pacific Rim.

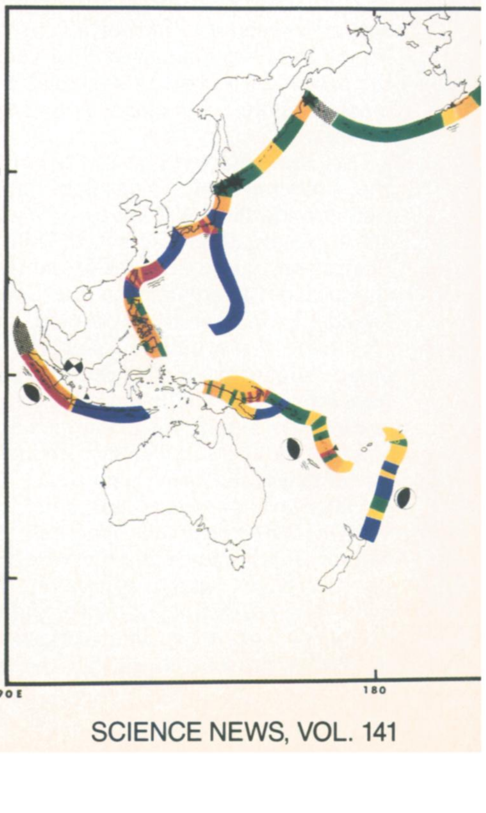
Contrary to what the Lamont group had predicted, the red zones around the Pacific did not tally the most large earthquakes during that period, Kagan and Jackson report in the Dec. 10 JOURNAL OF GEOPHYSICAL RESEARCH. In fact, the opposite held true. Large earthquakes hit green zones about five times as often as they rattled red zones. Orange zones proved just about as active as the green ones.

In all, the predictions made with the seismic gap hypothesis fared miserably, both in the 1979 Lamont analysis and in a 1973 report from the same institution. Most people off the street could have compiled a better record by picking zones off the hazard map at random, Jackson and Kagan say.

Strong as their results appear, the two UCLA researchers' work will not sink the seismic gap hypothesis. Indeed, supporters of the theory say these findings fail to point out anything new. "What they have proved is what we have known qualitatively for a long time," says Stuart P. Nishenko, a seismologist with the U.S. Geological Survey in Golden, Colo., and a former Lamont student who participated in the 1979 study.

The two forecasts tested by Kagan and Jackson relied on an early, simple version of the gap hypothesis that evolved during the 1970s. Since that time, seismologists have recognized flaws in the original idea and have amended it, making the hypothesis increasingly complex, says Carl Kisslinger, a seismologist at the University of Colorado at Boulder.

Much of the theory's development over the years has centered on the question of quake size. In their 1979 paper, the Lamont group had focused on tremors measuring magnitude 7 and above, but they quickly realized this limit was far too low. Nishenko explains that most fault segments appear to have a "characteristic" earthquake — one that repeats in a similar form, over and over. For some regions, the characteristic quake might be a magnitude 7. But other spots are prone to great earthquakes as large as magnitude 8 or magnitude 9, which release 30 and 900



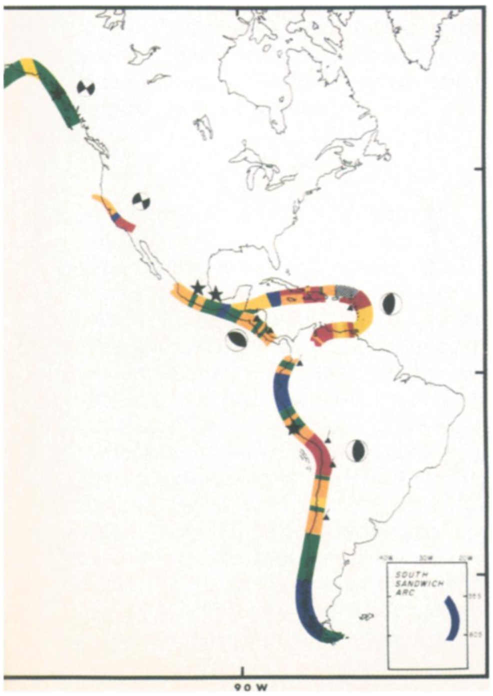
McCann *et al.*/PURE AND APPLIED GEOPHYSICS times the energy of a magnitude 7 shock, respectively.

Nishenko suggests the seismic gap hypothesis really applies to the characteristic earthquake of a particular segment. As an example, consider the coastline of southern Chile, which suffered a magnitude 9.5 earthquake in 1960 and three other temblors of similar size in the last 400 years. The gap hypothesis suggests this region would face little risk of another magnitude 9 earthquake so soon after the 1960 shock. However, a magnitude 7 tremor could occur in the decades following that superquake.

By grouping together magnitude 7 jolts and those hundreds of times stronger, Kagan and Jackson are really mixing apples and oranges, says Lynn R. Sykes, a Lamont seismologist who began working on the seismic gap theory in the early 1970s.

McCann criticizes the UCLA team's study, saying it used highly specific statistical tests that were inappropriate to the extremely generalized hazard map in the 1979 paper. "The end result of trying to quantify something that was meant to be qualitative really doesn't do justice to the [seismic gap] theory," he says.

In their report, Kagan and Jackson acknowledge that the gap hypothesis has passed through many different incarnations since the Lamont group presented its hazard assessments. But they reason that all theories must be tested, and it is impossible to evaluate a moving target. To conduct a statistically meaningful test of the gap theory, Kagan and Jackson say they needed to pick a time period with a sufficient number of earthquakes, which meant going back to the theory as presented in 1979. By this criterion, seismologists will have to wait a decade or more to test a current version of the seismic gap theory.



*In their 1979 paper, researchers from the Lamont-Doherty Geological Observatory categorized regions according to seismic potential. Red indicates highest potential, followed by orange, then green. Yellow signifies regions of unknown hazard, while blue areas have no record of great earthquakes and may be incapable of producing them.*

The stakes in the debate run quite high. Far from being an arcane theory with little practical value, the gap hypothesis and corollary ideas shape the way seismologists assess earthquake hazards, both in the United States and abroad. When a working group of earth scientists periodically assembles to evaluate risk areas in California, they rely heavily on a modified version of the gap hypothesis, says Nishenko, one of the panel members.

Kagan and Jackson argue that scientists have adopted the gap hypothesis without really testing it. "I would view that [idea] as really unsupported by any data. It's a desire to rationalize, to understand what's going on with the simplest sort of model that one can get away with," Jackson says.

From their own work, the two Los Angeles seismologists draw a different theory about earthquakes. They propose that stress in the Earth's crust remains at a high level all the time, meaning that faults are always near the breaking point, ready to generate an earthquake.

"Once a zone starts having earthquakes, it keeps having them and then for reasons we don't understand, it runs out of gas and then there's a relatively long interval before the next one comes," says Jackson.

For people living near faults, Jackson says his message is, "Earthquakes are likely to hit where they've been hitting."

He applies the same logic to regions that have remained quiet, such as the southern end of the San Andreas. The California working group pegs this stretch as particularly hazardous because it has passed several centuries without a major quake. Jackson, however, ranks this region as safe relative to other parts of the San Andreas that have faced large tremors more recently.

Supporters of the gap theory turn the tables on Kagan and Jackson, charging that the earthquake evidence just does not support their forever-stressed theory. If the crust could spawn major quakes at any time, then a fault segment prone to magnitude 9 quakes should occasionally generate two such jolts within a few years or decades of each other. Seismologists should then spot some of these tag-team great quakes if they looked over the entire globe. So far, however, no such example has turned up. Some geoscientists might point to the two great earthquakes of 1811 and 1812 that struck near New Madrid, Mo., but Nishenko says it remains unclear whether this pair originated on the same segment of a fault or on two adjacent segments.

Although he rejects Kagan and Jackson's hypothesis, Nishenko believes their observations may fit in with a modern version of the gap hypothesis. As experts learn more about past earthquakes, they have found that some regions pass through clusters of activity. While a particular fault segment only experiences one characteristic jolt during the cycle, that same segment or nearby faults may spark smaller quakes near the time of the characteristic quake.

Nishenko points to the San Francisco region to illustrate the idea of seismic clustering. Historical records show that prior to the great 1906 San Francisco earthquake (estimated magnitude approximately 8.2), the Bay Area passed through 70 years of increased seismic activity, when 16 quakes of magnitude 6 or greater occurred there.

Following the 1906 shock, the region spent 40 years in a seismic drought, free of any sizable jolts. In the 1950s and 1960s, the seismic unrest gradually returned, growing more pronounced in the 1970s and 1980s, when three magnitude 6 quakes struck the Bay region. The year 1989 brought the magnitude 7.1 Loma Prieta earthquake, which started on a section of the San Andreas fault running through the Santa Cruz mountains.

What does all this mean for residents of Santa Cruz? If Kagan and Jackson have read the Earth correctly, a quake very similar to Loma Prieta may well come rolling out of the mountains on its way toward Santa Cruz anytime in the next few years. Nishenko, Sykes and their colleagues, however, believe the San Andreas near Santa Cruz has used up all of its magnitude 7 earthquakes for some time. That doesn't rule out smaller earthquakes though. This patch of the San Andreas and other nearby faults could produce magnitude 6 or 6.5 jolts that would shake Santa Cruz, albeit with much less force than the 1989 disaster.

Unfortunately, seismologists have only one real method for testing the two rival predictions. They must wait and see. □