Ambitious search for reliable predictions

EARTHQUAKES

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By SANDRA BLAKESLEE
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Using techniques and insights gleaned over the last two decades, geologists have made great strides in their ability to make long-term predictions about earthquakes.

They can say, for example, that a given earthquake fault stands a 50 percent chance of producing a magnitude 7 earthquake within the next 30 years. Indeed, four groups of geologists made just such a prediction for a segment of the San Andreas fault that ruptured three weeks ago, causing widespread damage in Northern California.

But ask geologists to make a short-term prediction — name the odds that a fault will rupture tomorrow, next week or even next year — and they are unable to comply.

"This last earthquake shows we can make probabilistic earthquake predictions over a period of time," said Dr. Frank Press, president of the National Academy of Sciences and an expert in earthquake prediction.

Long range forecasts are useful, he said, in knowing where to reinforce the construction of schools, highways, tall buildings, dams and other structures.

But Press said such forecasts are not adequate to predict the day and place of an earthquake "in terms of evacuations and other specific actions." It may turn out that earthquake mechanisms are inherently chaotic and unpredictable, Press said, "but we are not giving up."

"Our long-term forecasts are working," said Lynn R. Sykes, an expert in earthquake prediction at Columbia's Lamont Doherty Geological Observatory in Palisades, N.Y. "We should now attempt to move from the decade scale of prediction to the few years scale."

This could be accomplished with current technology and knowledge, he said, by deploying large time to prepare for worse to come.

Sykes is a world leader in the evolving science of earthquake prediction.

Since the early 1970s, he and his colleagues have successfully forecast a dozen maior earthquakes around the world.

Such long-range predictions, Sykes said, are based on the seismic gap hypothesis, developed by a Japanese scientist not long after the 1906 San Francisco earthquake.

The scientist, Dr. Akitsune Imamura, made a list of all earthquakes going back hundreds of years on the massive fault that runs the length of the Japanese archipelago.

After mapping the earthquakes to the fault, Imamura found that some regions had remained eerily quiet for centuries. These regions, he said, were seismic gaps — fault segments that had not released strain for long periods and hence were more likely to rupture.

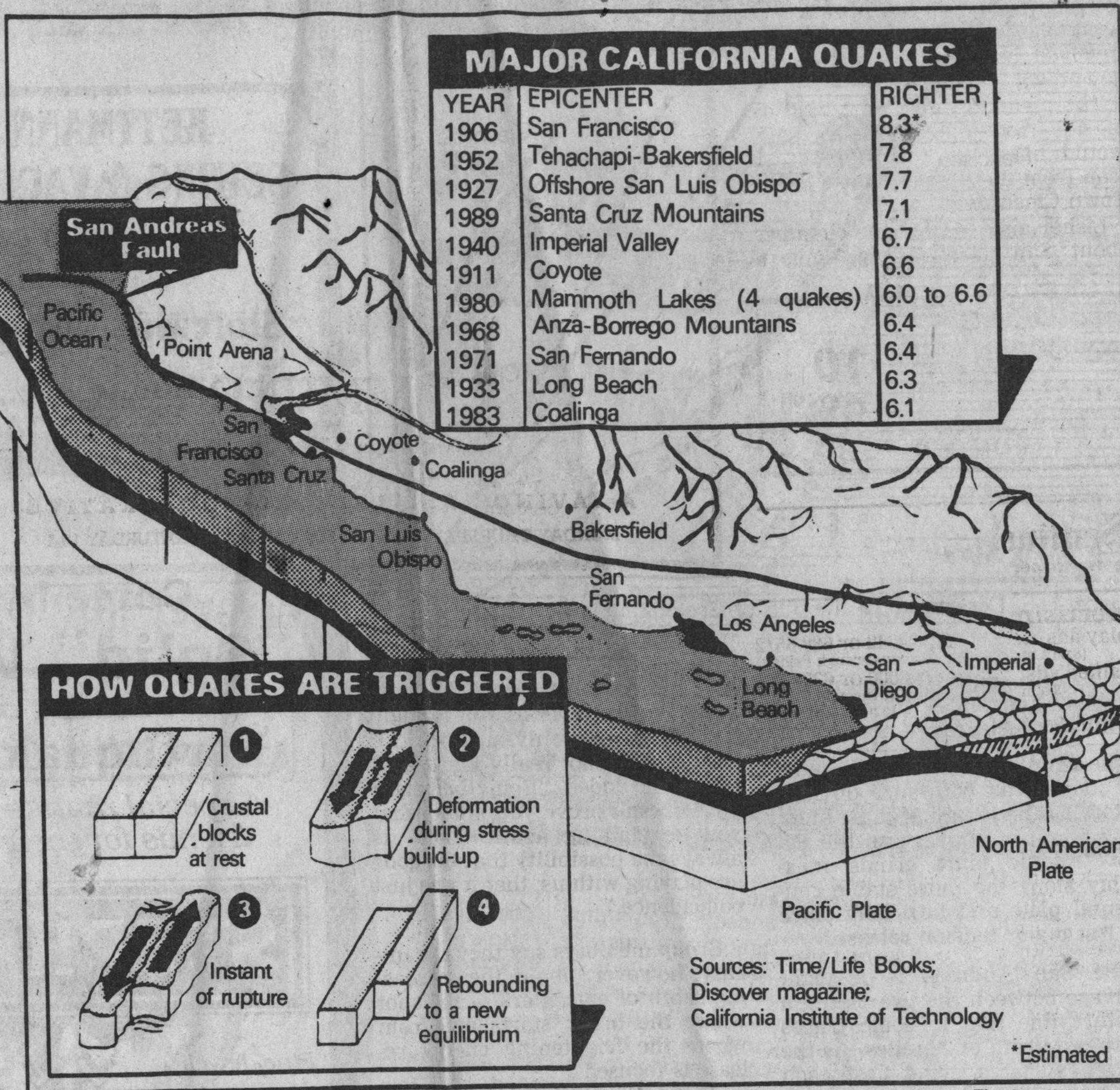
Immamura noted that Tokyo was astride a seismic gap and for more than a decade tried to warn the people to prepare for a major earthquake. "No one listened to him," Sykes said.

In 1923, a magnitude 8.2 earthquake struck Tokyo, killing 140,000 people.

After the Tokyo earthquake, most people continued ignoring Imamura's ideas, Sykes said, because geologists had no fundamental theories to explain why earthquakes occur much less why faults would remain inactive for long periods before breaking.

All that changed in the 1960s with the advent of plate tectonic theory, said Dr. Kerry Sieh, a geologist at the California Institute of Technology.

Some scientists had begun to suspect that the earth's crust is composed of a dozen or so massive plates that float atop a hot, sticky mantle 6 to 10 miles deep.



MAJOR CALIFORNIA QUAKES

YEAR	EPICENTER	RICHTER
1906	San Francisco	8.3*
1952	Tehachapi-Bakersfield	7.8
1927	Offshore San Luis Obispo	7.7
1989	Santa Cruz Mountains	7.1
1940	Imperial Valley	6.7
1911	Coyote	6.6
1980	Mammoth Lakes (4 quakes)	6.0 to 6.6
1968	Anza-Borrego Mountains	6.4
1971	San Fernando	6.4
1933	Long Beach	6.3
1983	Coalinga	6.1

Sources: Time/Life Books; Discover magazine; California Institute of Technology

*Estimated

The Associated Press

areas. In Chile, 177 people died.

These ideas work well for subduction zones, Sieh said, where the rate of plate motion, the slip rate, can be calculated from records of ocean floor spreading and earthquake history.

But the San Andreas, a strike-slip

break in a massive earthquake.

Other fault segments seem to be made of weaker rocks, he said, so that the rocks break more often, generating smaller earthquakes.

One segment in Central California is known to "creep" at the rate of nearly two inches a year with nary an earthquake.

For example, a stream bed that crosses the fault along the Carrizo plain has been dramatically altered.

When the stream was new, 3,700 years ago, it crossed the fault in a straight line. Today, after many earthquakes, the stream flows toward the fault on one side, is

due for an earthquake, Jones said.

A segment deemed unlikely to break in the next 30 years runs from San Francisco to Cape Mendocino in Northern California. It ruptured 21 feet in the 1906 earthquake and has not had enough time to reaccumulate a large amount of strain.

The 21-mile Santa Cruz Mountains segment that snapped last month was considered one of the most likely to break in northern California.

Geologists were puzzled, however, when the magnitude 7.1 earthquake failed to break the surface.

At first people doubted their ability to predict behavior on the San Andreas, Sieh said. But a closer look at the data changed that.

The records from the 1906 earthquake along the Santa Cruz Mountains segment were never good, Sieh said. In fact, it is more than likely that the 1906 earthquake did not break the surface.

This segment, therefore, is behaving in an entirely predictable fashion. The methodology for making long range forecasts is strengthened.

Nevertheless, the fact that 7.1 magnitude earthquake along the San Andreas can take place without breaking the surface leaves many geologists uneasy.

There may be other segments of the San Andreas, particularly in the rugged mountains near San Bernardino, that are capable of magnitude 7 earthquakes but that have not left a calling card in the form of surface rupture.

An overriding problem, the geologists said, is that predictions are only as good as the data: estimated slip rates, estimated dates of past earthquakes and incomplete historical records. Most of the data, they said, are terrible.

If geologists could deploy modern instruments along the San Andreas to collect better data, Sykes said, it he said, by deploying large numbers of sensitive instruments up and down the San Andreas and other major faults zones in the United States.

This costly endeavor would still leave citizens uncertain whether an earthquake was due this year, or the next, or the one after that.

To know that an earthquake is coming within hours, days, or weeks, researchers say they must be able to detect subtle changes in the ground that is about to rupture. By closely monitoring many fault zones, they hope to detect physical patterns that indicate an earthquake is imminent.

In the nation's most ambitious search for such knowledge, scientists have deployed a vast array of instruments around a particularly active fault in Parkfield to monitor warning signals that may precede the next earthquake there.

With sufficient funds, Sykes said, geologists could right now establish a "real time" earthquake warning system that could provide a minute or so of advance warning.

A network of advanced seismometers would instantly relay information about an earthquake as it happens, via satellite, to nearby cities and towns.

Depending on their distance from an earthquake's epicenter, people would have, say, a 30-, 60- or 90-second warning that earthquake shock waves were headed their way.

Such warning, although slight, might save a few lives and could almost certainly be used to trigger an automated shutdown of computers whose destruction would be catastrophic.

Since some earthquakes are foreshocks to larger events that happen minutes or hours later, the warning system could also give people

mantle 6 to 10 miles deep.

But there was no way to explain how the plates moved until researchers discovered that new crust material is slowly oozing up from the mantle through long rifts in the Pacific and Atlantic ocean floors. The constant push of new crust, they discovered, produces the forces that drive the plates.

In some parts of the world, like Japan, the edge of one plate is driven beneath another plate, producing deep "subduction" earthquakes.

In other parts of the world, like California, two plates scrape past one another producing shallow "strike-slip" earthquakes.

The rate at which new crust is formed, Sieh said, can be measured from sediments on the ocean floor. The rate at which oceanic crust slips beneath continental plates at subduction zones, he said, can also be inferred from these measurements.

These discoveries allowed Sykes to begin predicting earthquakes along the the world's major subduction zones.

For example, the Gulf of Alaska is situated along a 1,800 mile subduction zone where the Pacific plate is diving under the North American plate at a rate of 2.5 inches a year.

Major earthquakes occurred along different parts of this zone in 1957, 1958, 1964 and 1965. The areas that did not break, Sykes said, were seismic gaps where strain had not yet been released.

The seismic gap hypothesis was used to successfully predict the 1979, magnitude 7.7 earthquake in Alaska; the 1978, magnitude 7.7 earthquake in Mexico and the 1985 magnitude 7.8 earthquake in Chile.

The Mexico and Alaska earthquakes occurred in unpopulated

quake history.

But the San Andreas, a strike-slip zone, was more difficult to decipher.

First, California's recorded earthquake history is blank before 1812 and notoriously spotty before 1906. The record does not show, as in Japan, that parts of the fault have been quiet for 300 years. The best it can do is indicate that some areas have been quiet since 1812.

Second, slip rate is hard to figure, Sieh said.

All along the San Andreas there are many smaller, parallel faults that absorb some of the relative plate motion. While scientists estimated that the Pacific and North American plates were moving past one another at a rate of two inches a year, Sieh said, the exact slip rate along different segments of the San Andreas could be much less.

Earthquake forecasting along the San Andreas, Sieh said, was impossible until two new techniques, paleoseismology and neotectonics, came along in the the late 1970s and early 1980s.

The first technique stems from the notion, first suggested in the late 1960s, that the 600-mile long San Andreas fault can be divided into segments created in part by physical properties of different rocks.

About six miles down, where the rocks are hot and mushy, the plates are moving at the steady rate of about two inches inches a year.

Rocks above the mushy zone, however, are cold and brittle. They get dragged along, reluctantly, by the plates below.

Some rocks are stronger than others, said Dr. Allan Lindh, a scientist at the U.S. Geological Survey in Menlo Park. They accumulate strain for hundreds of years until a critical point of resistance is overcome and the rocks

fornia is known to "creep" at the rate of nearly two inches a year with nary an earthquake.

To reconstruct the earthquake history of each fault segment, Sieh and his colleagues developed the technique of paleoseismology.

They went to various segments of the San Andreas and excavated trenches. There, in the dirt, they uncovered a record of past earthquakes going back a thousand or more years.

The earthquakes can be seen, Sieh said, in the ways sediments are deposited. Sediments laid down during normal years are undisturbed whereas sediments laid down during the year of an earthquake show clear signs of being shifted.

Undisturbed layers above and below the earthquake sediments can be dated using standard techniques, yielding a rough date for when the earthquake occurred.

The trenches revealed that some segments of the fault typically build up large amounts of strain before breaking, on an average of every 300 years, Sieh said. When such segments break, the ground moves 30 or more feet in the blink of an eye. Other segments break more often, say every 130 years, and typically break 15 feet each time.

These findings led to the idea that each fault segment produces a characteristic earthquake, said Dr. David Schwartz of the USGS. "Each time a fault segment ruptures, it tends to produce earthquakes of roughly the same magnitude" and surface rupture.

The second technique, neotectonics, permitted scientists to calculate the slip rate of each segment. Geologists went to the field and identified landmarks that have been displaced by repeated earthquakes along each segment.

straight line. Today, after many earthquakes, the stream flows toward the fault on one side, is diverted 400 feet as a result of ground rupture, and then resumes its course on the other side of the fault.

The San Andreas near San Francisco is slipping at a rate of .78 inches per year while the Hayward and Calaveras faults across the Bay in Oakland and Berkeley are slipping between .27 and .39 inches a year.

Long-range earthquake forecasts, Sieh said, are based on these calculations.

If one knows the slip rate, how often the fault segment breaks and when it last broke, he said, the timing of the next earthquake can be estimated. It's magnitude is likely to match past events.

Last July, USGS geologists released a report on earthquake probabilities along 11 segments of the San Andreas using this approach.

The segment with the highest probability of rupture is an 18-mile zone near the town of Parkfield, half way between San Francisco and Los Angeles.

For reasons that baffle scientists, Parkfield has produced a magnitude 5 earthquake on an average of every 22 years since the mid 1850s. The last occurred in 1966. The segment is assigned a 90 percent probability of rupture in the next five years.

Another segment likely to rupture is a 60-mile stretch of the fault from Palm Springs to the Salton Sea. The record shows this segment produces large earthquakes with 24-foot surface displacements on an average of every 250 years, said Dr. Lucy Jones, a USGS geologist based in Pasadena.

The last event was in 1689. About 167,000 people live within five miles of this fault segment, which is over-

If geologists could deploy modern instruments along the San Andreas to collect better data, Sykes said, it might be possible to make mid-range predictions about earthquakes. The probability could be calculated in terms of one to five years.

To make mid- and short-term earthquake predictions, geologists are looking for changes in the earth's behavior before a fault ruptures.

They might be able to detect patterns — swarms of small quakes, typical kinds of foreshocks, periods of quiet — in the years or months before an earthquake.

They also hope to detect more immediate signs of an impending quake, like a rapid rise or fall in water tables, in the hours or minutes before a fault ruptures.

To learn if this is possible, the Parkfield area has been equipped with $1 million worth of instruments, including strain meters, creep meters, seismometers and other devices that detect subtle motions in the ground. Special wells have been drilled to measure fluctuations in the water table.

Measurements of the local terrain are made with lasers to see if the land is shifting the slightest fraction of an inch. Radon release is being monitored, and the electrical resistance of rocks is being measured. An array of seismometers has been deployed to measure small earthquakes along the fault.

If precursors to the next Parkfield earthquake can be detected, Lindh said, the lessons might be carried over to other fault segments.

In another approach to near-term prediction, Soviet scientists are experimenting with computers to see if machines can recognize the patterns that presage earthquakes.