Earthquake Prediction: Mexican Quake Shows One Way to Look for the Big Ones

Historical records now serve as a starting point for chain of forecasts

The successful prediction of the location and size of last November's earthquake near Oaxaca, Mexico, has dramatically pointed up one possible solution to a basic problem of earthquake prediction: Where should efforts be concentrated to have the best chance of closely observing a large earthquake? Geophysicists believe that without instruments on the scene before highly destructive earthquakes, reliable predictions, including exact location, magnitude, and time, will be impossible.

But earthquake belts stretch for tens of thousands of kilometers around the world and there are only limited resources for setting up local observational networks. The Oaxaca earthquake showed that a practical method may exist in some cases for narrowing the choices of where and when to look for the subtle and variable warning signs of an imminent large earthquake. The anticipation of the Oaxaca quake and the valuable data collected because it was anticipated are considered encouraging developments in a field in need of a lift. But they are seen as only small, limited steps toward reliable prediction.

The results of two different types of studies suggested that a large earthquake (magnitude greater than 7) might be expected near Oaxaca. One study argued that an unusual absence of moderate earthquakes (magnitude 4 to 7) near Oaxaca was the harbinger of a large quake. Researchers first noticed this seismic quiescence in 1975. The results of a less publicized method, the seismic gap method, buttressed this forecast (a forecast is a prediction that does not specify all three aspects of a quake—time, location, and magnitude). In 1973, it was pointed out that the same area near Oaxaca was a seismic gap, a normally active area that has not experienced a large quake for some time and is therefore more likely to have one in the future. Seismologists often use the term gap to describe a quiescent zone (an absence of moderate quakes), but gap properly refers only to a lack of large earthquakes.

Awareness of these two kinds of forecasts for the Oaxaca area prompted the installation of a local seismic network. With some luck, that network was in place to record the pattern of low-level seismic activity that occurred shortly before the large shock. Researchers regard such patterns, which are undetectable with distant sensors, as one of the most promising methods for short-term prediction of earthquakes.

Long-range forecasts based on the identification of seismic gaps, the first step toward the recognition of possible short-term precursors, are proving to be reliable, if not very specific. For example, in 1965, S. Fodotov of the Soviet Union, the first to do extensive work of this kind, identified seismic gaps along the Kuril Island chain from northern Japan to the Kamchatka Peninsula. Within 8 years of his forecasts, large earthquakes ruptured five of these seismic gaps.

Fodotov's seismic gap forecasts depended on a repetition of the characteristic behavior of earthquakes in areas such as the Kuril Islands. The Kuril-Kamchatka Trench, which parallels the Kuril Islands, marks the point at which the thin Pacific crustal plate dives beneath the edge of the Eurasian plate. Fodotov recognized the tendency of the same sections of the plate boundary to snag, build up stress, and suddenly snap apart as the two plates slide past each other. This sudden release of stress is an earthquake. Most of the slippage between plates occurs during large earthquakes, not during small or moderate ones. Thus, following a large earthquake, stresses due to plate motion slowly build up again in that section of plate boundary until the next large earthquake releases them.

No large earthquake had released the stress along a section of the Mid-America Trench off Oaxaca since 1928. In 1973, John Kelleher of the Nuclear Regulatory Commission, Lynn Sykes of Lamont-Doherty Geological Observatory, and Jack Oliver of Cornell University designated the Oaxaca section and eight nearby sections as seismic gaps (Fig. 1). They reasoned that in this area, 50 years or less is enough time to build up the stress necessary to cause another large earthquake. The Oaxaca gap and one other have been filled by a large earthquake since 1973. Overall, the experience with the seismic gap method is considered to be good.

According to William McCann of Lamont-Doherty, who along with Stuart Nishenko, Sykes, and Janet Krause has produced the most recent list of seismic gaps around the Pacific and the Caribbean, nine large earthquakes in all have occurred within areas previously designated as seismic gaps. But McCann emphasizes that the most impressive success of the method has been the absence of any large earthquakes in areas considered to be least at risk, defined as plate boundaries that have been ruptured by a large earthquake within the last 30 years.

Some of the limitations of forecasting on the basis of seismic gaps are illustrated by the situation in southern California. The San Andreas fault in southern California is among the seismic gaps considered to have the highest potential for producing a large earthquake. High-risk gaps, those that have experienced a large shock in historical times but not within the last 100 years, also include plate boundaries along the coasts of Sumatra, central Japan, Peru, and Chile (Fig. 2). The only large earthquake that has broken the southern San Andreas, from above Cholame Valley in the north to near San Bernardino in the south, was the great Fort Tejon quake of 1857 (magnitude greater than 8). Thus, the time between successive earthquakes there cannot be found in the historical record and the geological record gives only a wide range of recurrence times, McCann says. Similar problems apply to most seismic gaps.

In an effort to build on the general forecasts provided by seismic gaps, researchers are trying to identify indications that a particular gap will break in the near future. In the case of the Oaxaca gap, the indicator was an unusual absence of remotely detected, moderate seismic activity throughout the gap. Masakazu Ohtake of the International Institute of Seismology and Earthquake

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Engineering, Tokyo, and Tosimatu Matumoto and Gary Latham of the University of Texas, Galveston, noticed this seismic quiescence in 1975. It appeared that earthquakes strong enough to be recorded by worldwide seismic networks (magnitude greater than 4) had ceased within the Oaxaca gap in 1973. Similar quiescence had been noted by other investigators prior to some earthquakes, but this one struck Ohtake's group as particularly significant because quiescent periods appeared to have preceded the most recent earthquakes beyond either end of the gap. Taking into consideration the length and location of the quiescent zone, they forecast a magnitude 7.5 ± 0.25 quake centered between Oaxaca and the coast.

This forecast had a mixed but generally positive reception when it was presented a year ago. Karen McNally of Caltech was sufficiently impressed to set up a local seismograph network in the Oaxaca area following the resumption of moderate activity last summer within the zone of quiescence. McNally began operating the network on 1 November in cooperation with Lautaro Ponce of the University of Mexico's Institute of Geophysics.

Although Ohtake's group had suggested that a resumption of moderate activity might be expected shortly before the large event, McNally and Ponce were interested in microearthquakes (magnitude less than 4), which provide more detailed information than the sparser moderate quakes can. They found that even microearthquake activity was depressed within a 100-kilometer-diameter zone centered on the gap. This activity remained low until about a day before the main event, when a center of activity (magnitude 3.6 and below) developed at one edge of the gap. During the next 12 hours, this center slowly migrated to the eventual location of the large event, and then the activity ceased. Eighteen hours later, the large earthquake struck.

The forecasts based on the seismic gap and seismic quiescence seem to have been borne out. McNally and Shri Krishna Singh of the Institute of Engineering of the University of Mexico found that the main shock released stress within the section of the plate boundary defined by the seismic gap. Thus, the gap was filled about 50 years after the last large quake there, the reported average recurrence time for the area. The magnitude was 7.5 to 7.8, as forecast, although some stations in Mexico reported magnitudes of about 6.5. The location was only 50 kilometers closer to the coast than forecast.

Perhaps of most interest to seismologists was the observation of two different types of short-term precursory phenomena. One was the resumption of moderate activity after a period of quiescence. These foreshocks were apparently associated with the coming large earthquake and were strong enough to be detected at a great distance. The detailed pattern of microearthquake activity, which would have gone undetected without the local network, is unique, according to McNally, although its pattern of quiet-activity-quiet is a familiar one. Thus, a sequence of precursory phenomena occurred from a seismic gap, through seismic quiescence, moderate foreshocks, and finally microearthquake patterns.

Unfortunately, this exact sequence is not likely to be repeated before many

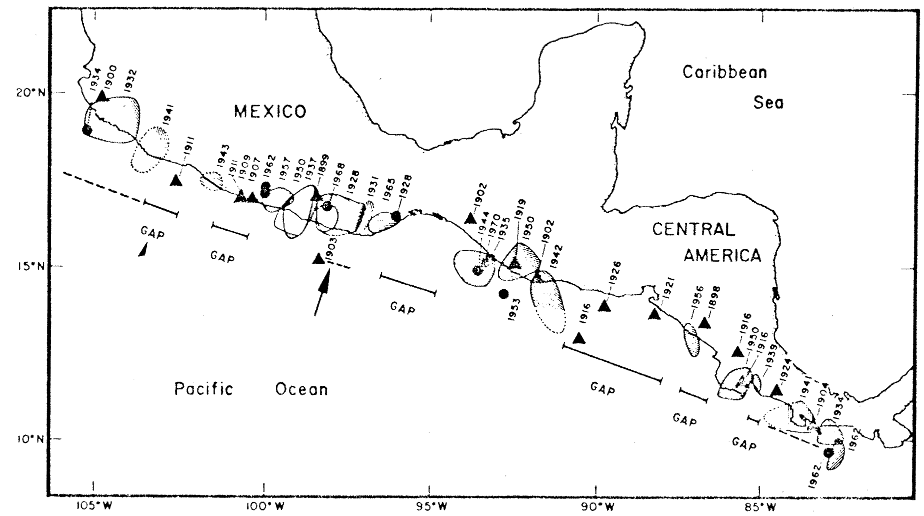

Fig. 1. Seismic gaps along the Mexican and Central American coasts as determined in 1973. At that time, six gaps had not ruptured for about 45 years or more (solid bars) and three areas last ruptured between 30 and 45 years earlier (dotted lines). Since then, two gaps have been filled by large earthquakes, the Colima gap (arrow to left) and the Oaxaca gap. The locations of large earthquakes before (triangles) and after (circles) 1928 are indicated along with the zones (shaded areas) in which stress has been released by a large quake since 1928. [Source: J. Kelleher, L. Sykes, and J. Oliver, in *Journal of Geophysical Research*]

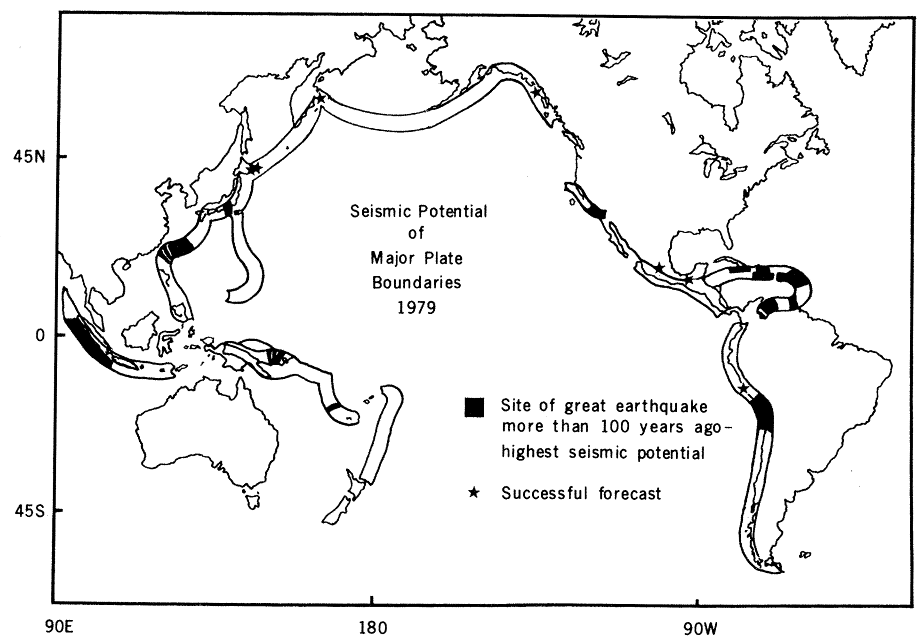

Fig. 2. Forecasts of large earthquakes made on the basis of the seismic gap method by McCann, Nishenko, Sykes, and Krause of Lamont-Doherty Geological Observatory. The bands surrounding the Pacific Ocean and the Caribbean Sea mark the boundaries of plates where plate motions produce large earthquakes. The shaded areas, designated on the basis of historical and geological criteria, are considered the most likely candidates for large earthquakes within the next few decades. The more southernly star in southern Mexico marks the successful forecast of the Oaxaca quake of November 1978.

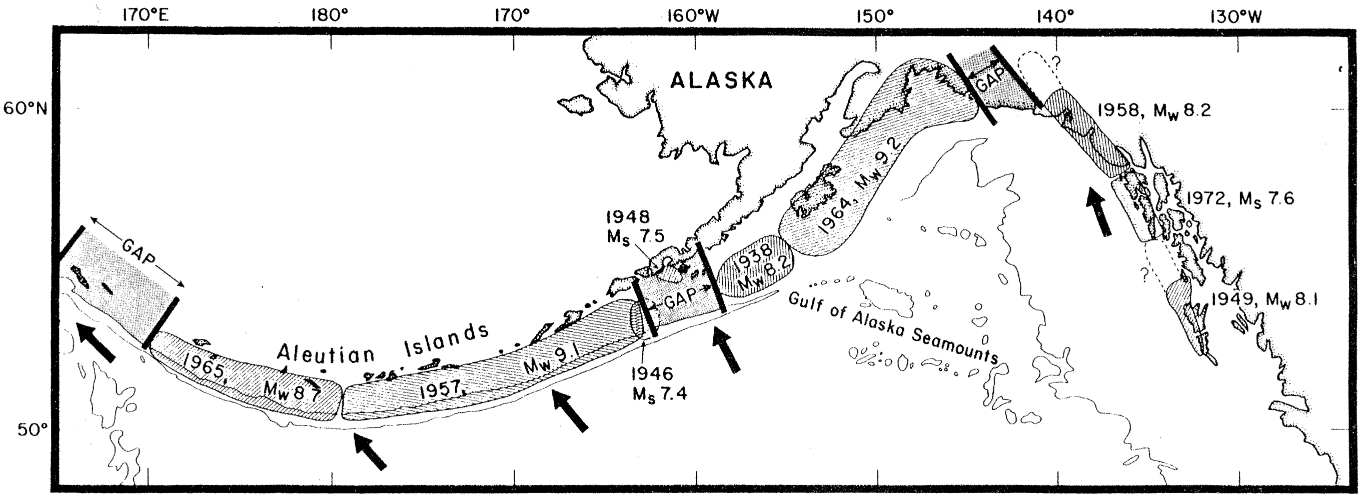

Fig. 3. Recent large earthquakes (shaded areas with year and magnitude) and three gaps of the Alaska-Aleutian seismic zone. The arrows indicate the direction of the Pacific plate's motion as it dives beneath the Aleutian Islands on the North American plate. The Shumagin Islands gap is the middle one of the three. [Source: W. McCann, Lamont-Doherty Geological Observatory]

other large earthquakes. Matumoto points out that the presence of quiescence seems to depend on the type of movement along the fault during the main shock, being more likely before the thrusting motion of the Oaxaca quake than before the strike-slip motion of the San Andreas. And the question remains whether quiescence is always followed by a large quake. There even seems to be some question as to how to define quiescence. McNally now believes that the quiescence began in 1966, not 1973, and may even have begun in 1960. In addition, Lucile Jones and Peter Molnar of Massachusetts Institute of Technology have found that only about half of all large earthquakes are preceded by moderate foreshocks. Because no single precursor is expected to be reliable for all cases, geophysicists are anxious to identify other signs that a seismic gap may be about to break.

Unusually high stress within a seismic gap is one such sign that is receiving particular attention. Two different methods have been used to detect such stress in the gap near the Shumagin Islands, Alaska (Fig. 3). McCann and his coworkers assign this gap, located at the southern tip of the Alaska Peninsula, high but uncertain potential for a large earthquake because its seismic history is unclear. But they believe that this gap warrants particular attention in light of the measured high stress and other possible precursors.

Detection of the high stress within the Shumagin Islands gap depended on the interpretation of seismic waves generated by moderate earthquakes in the gap. In one approach, Charles Archambeau of the Cooperative Institute for Research in the Environmental Sciences, Boulder, Colorado, compared the amplitudes of seismic waves that traveled along the earth's surface with those that traveled through the body of the earth. The difference in amplitudes depends to some extent, Archambeau says, on the drop in stress levels during the earthquake. He found exceptionally high stresses, as high as 1000 bars (1 bar = 1 atmosphere), within the seismic gap, and more typical stress release, usually tens or a few hundreds of bars, elsewhere along the Aleutian Islands.

Leigh House and J. Boatwright of Lamont-Doherty found high stresses by analyzing the manner in which the earth ruptured during two moderate quakes in the gap. They constructed likely mathematical models of the rupture process and compared the seismic signals produced by the models with those actually observed in the field. A good match required stresses of 600 to 800 bars.

Other possible signs of a forthcoming large earthquake within a gap have been suggested. Kelleher pointed out in 1970 that a pattern may exist in the occurrence of past large earthquakes near Alaska (Fig. 3). The pattern includes the quakes of 1949, 1958, and 1964. If this progression were continued, the Shumagin Islands gap would be the next likely site.

Volcanic activity on plate boundaries is also being watched. The reasoning is that increased stress before a large earthquake might induce increased discharges of magma from subterranean chambers, like squeezing toothpaste out of a tube. McCann notes that the volcano Pavlof, on the Alaska Peninsula adjacent to the Shumagin Islands gap, has shown increased eruptive activity in the last few years.

Klaus Jacob of Lamont-Doherty, who is in charge of the network on the Shumagin Islands, cautions that although these phenomena are intriguing, there are still no signs of an imminent quake.

Researchers are now using seismic gaps to guide the siting of observing networks around the world. Networks have been set up along seismic gaps on the Izu Peninsula of Japan near Tokyo, on the North Anatolian fault near Istanbul, on the Assam fault zone in northeast India, on the west coast of Nicaragua south of the now filled Oaxaca gap, and elsewhere. Many of these networks are being operated as cooperative ventures between the U.S. Geological Survey or USGS-funded American universities and institutions in the host country.

As yet, no procedures, official or unofficial, exist to guide American participants in such projects in the event that possible precursors, such as those preceding the Oaxaca earthquake, are observed. Conflicts can be expected between desires to communicate data to colleagues and considerations for the reaction of the country involved. The difficulties of such a situation were highlighted last spring when word of the University of Texas' Oaxaca forecast reached the Mexican press. The announcement happened to coincide with a seer's prediction of a Oaxaca quake on 23 April 1978. The excitement, and reported speculative real estate deals, did not subside until after that date in spite of official efforts to calm the local populace. It appears that the guidelines needed to deal with these problems will be worked out in the near future on an informal basis under the pressure of another ticklish situation.—RICHARD A. KERR

Additional Reading

Proceedings of Conference VI–Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps (U.S. Geological Survey, Menlo Park, Calif., 1978).