# Earthquake Prediction: Progress in California, Hesitation in Washington

Earthquake prediction is becoming a scientific reality at a rate that demands serious consideration of operational warning systems and procedures to handle the social consequences of prediction. Within the past year, premonitory movements within the earth's crust have been detected prior to more than a dozen earthquakes along a portion of California's San Andreas Fault. These observations culminated in a successful if informal forecast of a potentially damaging quake that occurred Thanksgiving Day near Hollister, California. Substantial progress is also being reported in Japan, in the Soviet Union, and especially in China, where a large group of trained workers and a widespread network of observing stations gather data that has resulted in many public quake warnings (and some false alarms). Among earth scientists in the United States, optimism is high that earthquake prediction is now achievable.

Despite these developments, warning systems for major urban areas such as Los Angeles and San Francisco do not appear likely within the coming decade because of the low priority given earthquake prediction efforts within the federal government. Only one prototype network of sensing instruments is now under construction—the one south of San Francisco in central California in which the precursors to the Thanksgiving Day quake were detected. The network includes tiltmeters that measure deformation of the earth's surface and instruments that monitor the velocity of seismic waves and the earth's local magnetic field. But few measurements have been made of the earth's electrical resistivity, radon emissions, water levels in wells, and other phenomena known from work in other countries to be precursors to many earthquakes. Analysis of the data that are collected is hampered by a lack of computing facilities.

The Geological Survey is charged with conducting the U.S. program in earthquake hazard reduction, which has been held to an essentially constant budget of about $11 million (of which about $3 million is for earthquake prediction research) for the last several years. It would take "a very long, long time" to reach an operational system with the present program, according to Joseph Ziony of the Survey. A proposal last year to increase funding enough to establish a second monitoring network near Los Angeles and to begin some monitoring near other urban areas fell victim to the energy crisis within the Department of the Interior, whose enthusiasm for the program has been modest at best. Interior officials are reportedly showing new interest on the strength of the forecast of the Thanksgiving Day quake, and they are now considering a Survey proposal for a supplement to the recently announced fiscal year 1976 budget.

University scientists are eager to work on earthquake prediction. The Survey, which is now the major source of research funds in this field, received proposals for nearly ten times the $2 million it made available for extramural research last year and would have funded three to four times as much had money been available, according to extramural manager Jack Evernden. Survey scientists, who are at present doing the bulk of the work in developing and setting up monitoring systems, are equally enthusiastic, but they are also beginning to feel the social stresses that earthquake prediction will entail. They are concerned that public expectations of quake warnings will advance more rapidly than their monitoring capability, leading to recriminations if a major earthquake in a sparsely instrumented area should catch them by surprise. And they are uncertain how to handle what they see as their dual responsibility as cautious scientists and concerned citizens in the increasingly likely possibility that their instruments will show anomalies that may be precursors of an earthquake large enough to be dangerous.

The Thanksgiving Day earthquake, which was of magnitude 5.2 on the Richter scale, is a case in point. A year's worth of data from seven extremely sensitive magnetometers emplaced in the Hollister region was analyzed last November and showed a marked change in the local magnetic field between two of the stations. The field increased by as much in 1 day as it had previously changed in 6 months (about 1 gamma), and then gradually decreased toward its earlier value over a period of a week. More compelling was preliminary evidence from an array of tiltmeters. Their records are continuously telemetered to the Survey's National Center for Earthquake Research in Menlo Park, California, where they are reduced and transmitted to a large computer at the University of California at Berkeley for analysis.

The tilt data for late October and early November were in hand by the evening of 27 November, and though not yet plotted up, they clearly indicated that a major change in direction of tilt began to take place at the same time as the magnetic anomaly. The change was evident on two of the instruments located 6 kilometers apart, an indication from the size of the affected area that any subsequent quake would probably be larger than magnitude 4. (A magnitude 5 quake is considered potentially dangerous.)

At a meeting that evening of the Pick and Hammer Club, an informal group of local earth scientists, Malcolm Johnston of the Menlo Park Center described the magnetic and tilt data as "the sort one would expect to see before a quake," if not yet sufficient for a formal prediction. He and his colleagues believed that the quake, if one was indicated, would occur soon. "Maybe tomorrow" one Survey scientist, John H. Healy, proposed, mostly in jest, only to gain instant local fame when the quake did in fact occur Thanksgiving afternoon. What is not a jesting matter to Johnston, Healy, and their colleagues, however, is the realization that had the data processing been as much as a week closer to "real time"—a goal they hope to achieve within a year for the existing network—the Survey would have been faced with making a formal prediction and warning public authorities despite the still substantial uncertainties as to the reliability of their forecast.

There turned out to be a third potential indicator of the 28 November earthquake. The velocity of seismic waves recorded near the quake site also showed variations before the event, although the data were still in a computer at the time of the earthquake. The seismic anomaly is of the same type observed as a precursor to many earthquakes elsewhere, but the effect was so small that there is some doubt about the interpretation. Nonetheless, it is the first time that three different precursors have been identified for an earthquake in this country.

Despite this success, the status of the monitoring networks is indicative of the preliminary stage of the U.S. earthquake prediction program. Inexpensive borehole tiltmeters were not available until recently, for example, nor were magnetometers highly thought of or widely employed among U.S. earthquake researchers until this past year. But gross changes in the direction of tilt have been observed with the 14 instruments now in place for more than a dozen earthquakes, and the phenomenon has not occurred without a quake occurring too. More than 100 additional instruments are on order.

Magnetometer signals associated with the Thanksgiving Day quake are, Johnston claims, the first convincing magnetic precursor phenomena detected. More than 125 magnetometer sites covering some 1200 kilometers of fault are now periodically surveyed as a check for a long-lived magnetic anomaly that might signal a major earthquake, but only half a dozen (those near Hollister) are continuously operated.

The seismic network is the most extensive of the monitoring systems now in place, and it extends across much of central California. Automated detection of incoming seismic waves is now being tested at Menlo Park, but it is not yet as accurate as the more time-consuming human analysis of the data. The seismic data are also the most voluminous and require more computer time to reduce than, for example, the tiltmeter data. For all three networks, however, the lack of computing facilities dedicated exclusively to the earthquake program is a major stumbling block—especially to analysis of the data rapidly enough to provide warnings before quakes occur.

By comparison to the U.S. program, those of the Soviet Union, Japan, and China are larger and in many ways further along, in the opinion of scientists who are familiar with these countries. China's program was particularly impressive to a delegation of American scientists who recently toured that country. They found some 10,000 trained workers involved in operating 17 observation centers and monitoring 250 seismic stations and 5000 additional instruments or indicators. The Chinese are apparently very catholic in their approach to earthquake prediction, studying potential precursors ranging from the radon content of wells (which is reported to increase before a quake as new cracks in radium-containing rocks open, releasing the short-lived gas) to the behavior of animals (snakes are said to emerge in great numbers before a quake).

China is also of interest to U.S. earthquake researchers because of its frequent earthquakes and generally high level of seismic activity, a property it shares with Japan and parts of the Soviet Union. More than 400 earthquakes of magnitude 6 (the size of the disastrous 1971 San Fernando quake in California) have been recorded in China since the turn of the century, compared to roughly 40 in the United States. Why China should be so earthquake prone has been something of a mystery to geophysical theorists, but one explanation, suggested recently by Peter Molnar and Paul Tapponier of the Massachusetts Institute of Technology, is that China is being squeezed and nudged by the continuing collision of the Indian subcontinent with Asia. Whatever the explanation, China has several belts of earthquakes that appear to be generated by lateral sliding motions, analogous to the motions along California's San Andreas Fault, but which occur deeper in the crust. Thus earthquake data from China could perhaps supplement the information being accumulated more slowly from earthquakes in this country, and U.S. researchers are eagerly eyeing the possibility of cooperative efforts with the Chinese.

#### Quakes from Coalescence of Cracks?

A similar cooperative effort is already underway with the Soviet Union, whose earthquake research program goes back many years. It was, in fact, Soviet data that stimulated the rebirth of earthquake prediction efforts in this country a few years ago. Now a major theoretical debate about the physical basis for earthquake prediction is underway, with Soviet geophysicists proposing one explanation and many, but not all American geophysicists espousing another. According to the Soviet theory, a buildup of stress in a section of crust produces an avalanche of new cracks in the rocks which gradually align themselves and coalesce, leading to physical failure of the rocks and hence a quake. The dilatancy-diffusion theory, on the other hand, proposes that swelling of stressed crustal rocks along a fault, a phenomenon known as dilatancy, leads to a reduction in pore pressure. This temporarily strengthens the rocks' resistance to failure, but diffusion of fluids into the dilatant region again increases the pore pressure and leads to a quake, although whether the fluid is necessary is now increasingly questioned.

Evidence exists to support both theories, although proponents disagree on how convincing the data are. The Thanksgiving Day earthquake in California produced little evidence of dilatancy, however. The pattern of crustal deformation, according to Johnston, was asymmetric around the fault, and not symmetric as predicted by some dilatant models. The theoretical problem is compounded by differing regional geology—between central California and the Garm district of the Soviet Union, for example—which may be just as important in deciphering observations as a particular mode of failure. One clear distinction between the two theories concerns the stress in crustal rocks; according to the Soviet version it should peak and then decline prior to an earthquake, but according to the dilatant model it should continue to increase.

Cooperative programs would have the advantage of providing U.S. scientists with the experience needed to resolve such disputes far more quickly than they could otherwise obtain it. Earthquakes of magnitude 5, for example, occur in the instrumented section of central California—one of the most seismically active sections of the San Andreas Fault—only every 2 or 3 years. Nonetheless, Survey scientists also would like to instrument part of the San Jacinto Fault near Los Angeles and then expand both networks to cover the adjacent urban areas. This could be done and the warning system made operational within 5 years, Ziony estimates, provided the money was made available.

This fiscal year, as any program manager in Washington can tell you, is a terrible time to ask for new or expanded programs in nonenergy areas of science and technology. So the chances of a larger and more serious effort to understand and to provide warnings of earthquakes may be dim. But since major earthquakes with their attendant destruction and loss of life appear to be inevitable in California, Alaska, and possibly other parts of the country, it would be shortsighted in the extreme not to take advantage of what appears to be a very rapidly developing capability for earthquake prediction.—ALLEN L. HAMMOND