EARTHQUAKE RESEARCH (1): Rethinking Prediction

The blush of optimism has faded from simple theories that promised early success in predicting quakes

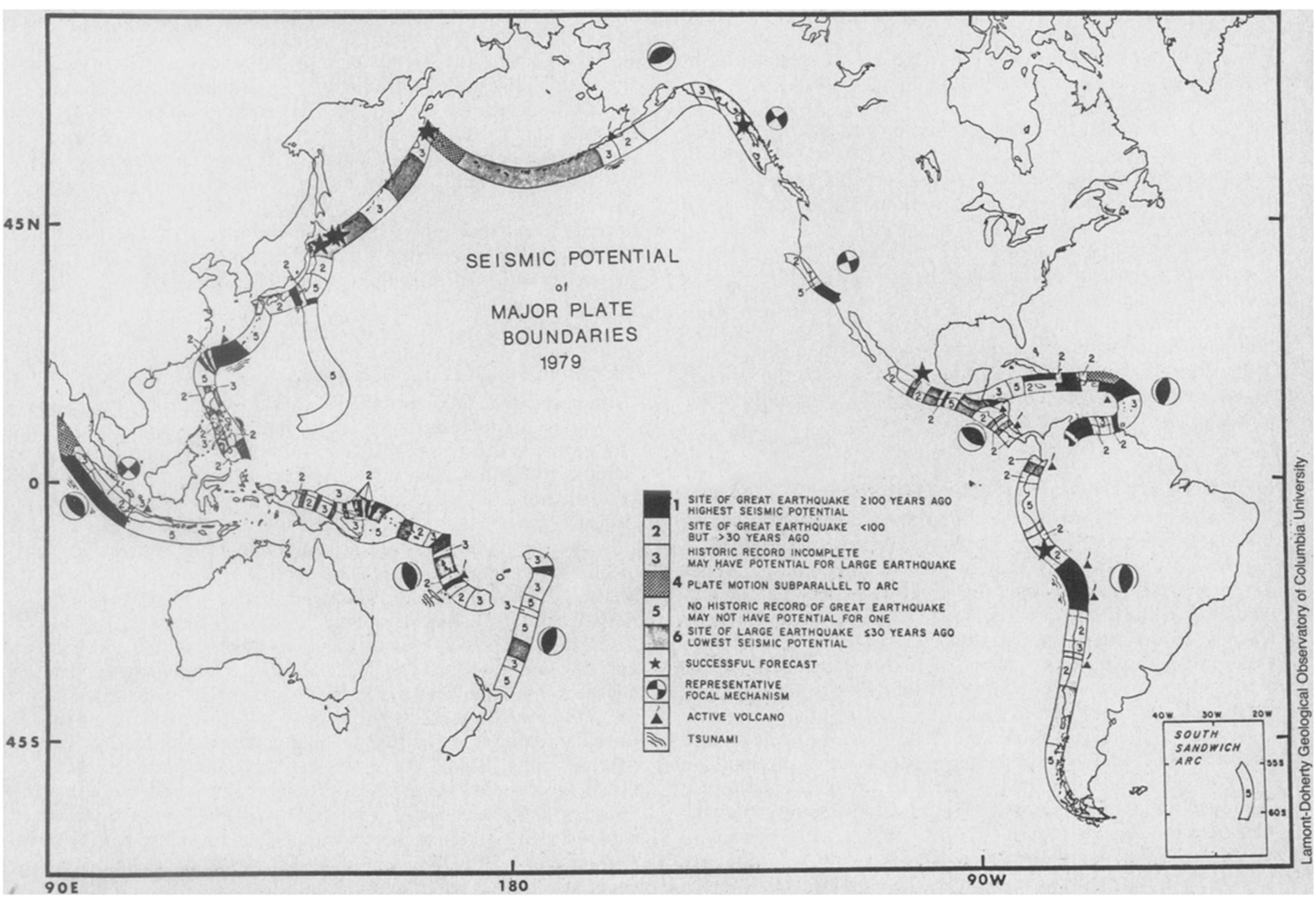
BY JOHN H. DOUGLAS

If life were only simpler! Just five years ago, geophysicists thought they had finally found a realistic model of how rocks along a fault act just before an earthquake. The model, it was hoped, could be used to predict future quakes (SN: 4/20/74, p. 252). According to this so-called "dilatancy theory," subterranean rocks begin to crack and swell under mounting stress, causing measurable changes in seismic wave velocity, underground water flow, electrical resistance and surface contour. Using such precursory phenomena, Chinese scientists successfully predicted a quake in Haicheng in February 1975, and the discovery of a suspicious "bulge" in Southern California led U.S. scientists to believe they might also be on the verge of predicting a major quake.

This is the first article of a two-part series on how research can help reduce the hazards of earthquakes. The first installment deals with attempts to predict quakes so that people can get out of the way. The second tells how damage can be reduced directly when relocation is impractical.

At the recent meeting of the American Geophysical Union in San Francisco, however, "dilatancy" had become a non-word, much like "detente" in the political world, and those who spoke of the Palmdale Bulge seemed unsure of either its significance or its true extent (SN: 12/30/78, p. 441). In the meantime, the Chinese had apparently failed to predict a major quake that reportedly killed more than 650,000 people in Tangshan, and the new mass of data on various "precursors" only made them appear more erratic and confusing.

The problem was not so much that the dilatancy theory was wrong, but rather that it was inadequate — different kinds of quakes have different kinds of precursors. Theoretical discussions now center on delineating various models for different quake mechanisms, with the hope of better understanding the fundamental processes that occur when subterranean rocks slide past each other. And instead of



Forecasting vulnerability: Regions labeled 1 and 2 are most likely to experience great earthquakes in the next few decades.

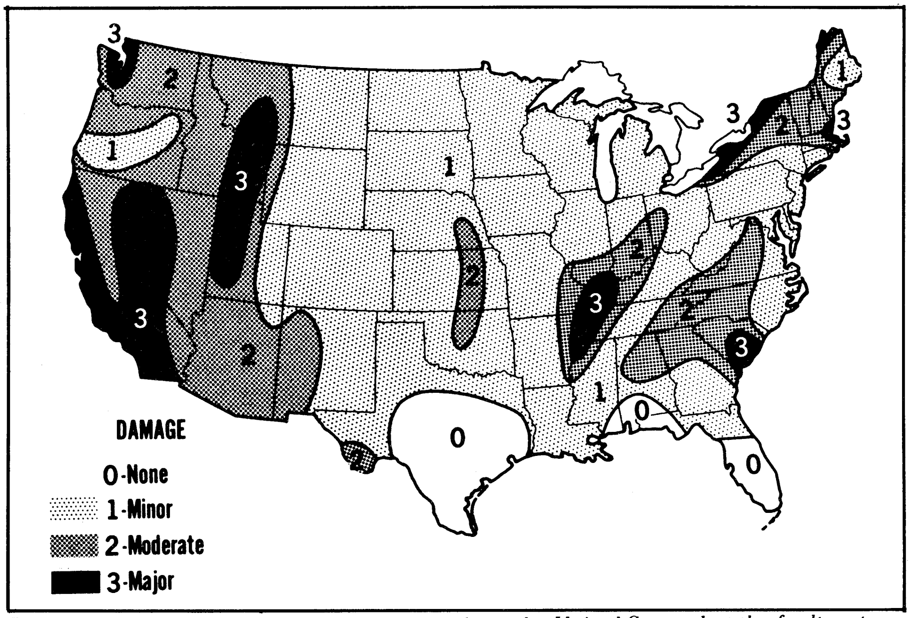
prediction — stating time, place and magnitude for an expected quake — the pragmatic work of geophysicists is now concentrated on the more modest goal of "forecasting," specifying those areas of the world that may be most susceptible to major quakes.

A major contribution to forecasting was unveiled at the AGU meeting by a team of researchers from the Lamont-Doherty Geological Observatory of Columbia University. William R. McCann, Stuart P. Nishenko, Lynn R. Sykes and Janet Krause presented a map (see diagram) showing the seismic potential of major tectonic plate boundaries of the world. In essence, the map amounts to a forecast of where quakes are most likely to occur soon along the "rim of fire" that surrounds the Pacific Ocean. Along this rim of active volcanoes, earthquake foci and colliding plate boundaries lie several "gaps" in seismic activity that appear likely to experience major earthquakes (magnitude 7.0 or larger) within the next few decades.

One such gap — marked by a star along the western coast of Mexico — has already been filled, by a major quake that struck the area last Nov. 29. An independent forecast had been made concerning the area by a University of Texas group (SN: 12/9/78, p. 404) and a quick-acting team of seismologists from the University of Mexico and the California Institute of Technology recorded the quake, together with a series of foreshocks and aftershocks (SN: 12/16/78, p. 422).

According to the Lamont-Doherty researchers, the areas of the Pacific rim most susceptible to an imminent quake are those where major temblors have occurred in the past, but not within the last 100 years. These include such heavily populated areas as Southern California, central Japan (SN: 4/29/78, p. 282), central Chile, Taiwan and the west coast of Sumatra. McCann told SCIENCE NEWS that scientists and government officials should "get more serious" about the threat of a major quake in the Los Angeles area and that the Indonesian government should reconsider its present policy of relocating people from overcrowded regions of Java onto the Sumatra coast — an area particularly susceptible to tidal waves following quakes.

The fine distinction between forecasting and predicting becomes even less clear when the study of seismic gaps is supplemented with evidence of other precursory phenomena. McCann and two other colleagues, A. J. Murphy and A. D. Frankel, have studied another active plate boundary — this one in the Caribbean. Since this was one of the first colonized areas of the New World, the historical record of quakes here goes back more than 300 years. Of particular interest is the observation that the volcano La Soufrière on Guadeloupe erupted just before great earthquakes in the region in 1690 and 1843, and before a large quake in 1897.



Danger of earthquake damage exists throughout the United States, but the fault systems responsible are not well understood in the East.

In 1976, La Soufrière erupted again and two swarms of quakes have occurred in recent years at the edge of the rupture zone inferred for the 1843 quake. These events, together with the unusual quiescence of the seismic gap near Antigua and Guadeloupe, lead the Lamont-Doherty team to conclude that underground stress may have reached a breaking point. Says Murphy: "We'd like to forecast occurrence of a great earthquake [magnitude 7.75 or larger] before the end of the century in this region."

Although the greatest seismic activity occurs where continental plates are grinding together, major quakes can also occur along faults far inland from a plate boundary. Such quakes are even harder to predict, since the fault boundary in solid rock may be buried under hundreds of feet of sediment. Also, the time between quakes may be much longer than the century or so expected along an active plate boundary. Some of the potentially most destructive quakes in the United States may belong to this group.

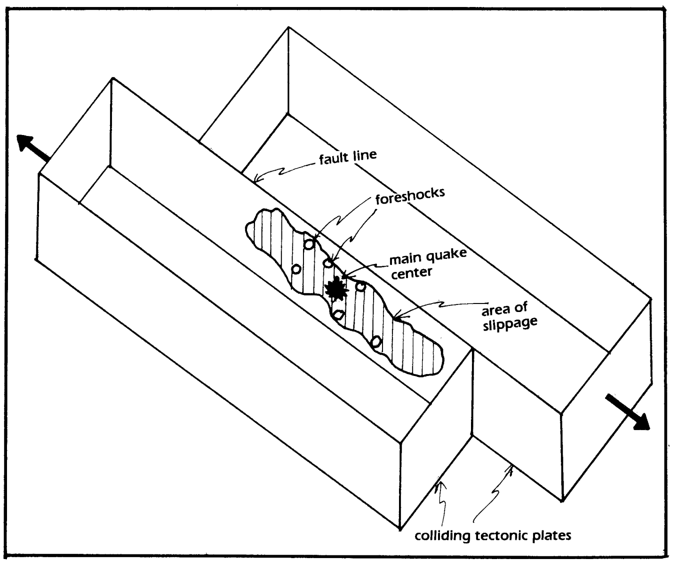
The seismic problems of California are familiar enough to most Americans to have become part of folklore — the subject of comedians' jokes and soothsayers' dire prophecies. The most spectacularly sinister of these is that, someday, because of its sins as well as its tectonic structure, California will break off and fall into the Pacific. Geologists reply that this could not happen because the ocean off California is not deep enough and no event like this has happened in the past 10 million years. In fact, three of the largest quakes in U.S. history have occurred in relatively stable areas thousands of miles to the east.

Just before the Revolutionary War, Boston suffered a major earthquake that reportedly toppled 1,200 chimneys. In 1811 and 1812, a series of three quakes shook the area around New Madrid, Mo., with such force that chimneys were toppled in Cincinnati and Richmond and shocks were felt as far away as Boston. Extensive ground changes took place, including rerouting of the Mississippi River. And in 1886, 90 percent of the buildings in Charleston, S.C., were damaged (although few were totally destroyed) by an earthquake felt as far away as Boston and Chicago. Yet almost nothing is known about where active faults underlie the eastern United States nor how frequently they may be expected to produce major quakes.

Even along well-known active faults, like the San Andreas in California, heated debate continues over what sort of movement is associated with large earthquakes. For some years it was believed, for example, that "creeping" along a fault was good, in the sense that tension was presumably being relieved without the need for a sudden release of stress by a quake. Now geophysicists aren't so sure. Robert D. Nason of the U.S. Geological Survey even goes so far as to propose a directly opposite interpretation — that creep is a sign of stress building up just before a major quake is triggered.

After studying creep along various fault traces in Hayward, Calif. (where the evidence is clearly visible in offset curbs and sidewalks), Nason concluded that the largest offsets occurred in weak clayey material along the fault zone, while the last major quake, in 1868, apparently broke the more solid material between the fault traces. He hypothesizes, then, that just after a major quake *no* creep occurs because tension has not yet built up. As the large land masses on either side of a fault continue to move, pressure builds up at the boundary, causing creep as weak clayey materials give way. Finally, when this tension release is no longer sufficient, an earthquake occurs.

Nason cites as further evidence for his



Model of an earthquake: A few small areas of moderate roughness ("asperity") give way as a series of foreshocks, followed by a break of the tightest-bound region (quake center) and movement along a broad area along the fault between tectonic plates.

theory the speeding up of creep along a segment of the San Andreas fault south of Hollister, Calif., just before a moderate-sized quake occurred there in 1966. This segment of the San Andreas has been creeping steadily for some time and most geophysicists have assumed therefore that the area was "safe." Nason, however, concludes that the creep in Hayward and south of Hollister may be signs of impending quakes in those areas. He told SCIENCE NEWS: "My guess is that the San Andreas was creeping like mad near San Francisco just before the 1906 quake."

Such disagreements emphasize the need for more fundamental research into the mechanisms underlying quake activity. Much recent theoretical work has been concentrated on describing fault movement in terms of asperity models—that is, trying to figure out how individual regions along a fault that interface with different roughness characteristics (asperities) will slide past each other. For example, it is hypothesized that in a very heterogeneous area between two tectonic plates, individual weak regions will give way first, causing a series of minor tremors in almost a "donut" distribution around a strongly bound region. A quiescent period may then occur as tension builds up further, making the region a seismic gap. Finally, the last bond breaks and the plates slip by each other, releasing tremendous energy in a large earthquake.

Models like this offer several advantages. They not only explain seismic gaps but also indicate—at least qualitatively—why quakes differ. For example, it has been noticed that major quakes in some parts of the world occur in doublets or even triplets. The model for such an occurrence shows two discrete areas of high asperity a few dozen miles apart; when one gives way, stress on the other mounts until it must also break loose. Also explained is the observation that the age difference of colliding plates is important in predicting whether they will move with sudden jerks. A heavy older plate pushing under a lighter young one, for example, will have relatively few regions of strong asperity.

Consideration of such models also helps illustrate why new measurements of quake magnitude and intensity are so badly needed. When people first began to assign numbers to "how strong" a quake was, they had only qualitative sensory effects to go by. Even today the most widely used measure of intensity—the Modified Mercalli scale — relies on vague criteria: Level I is "not felt except rarely"; Level VIII is "fright general, trees strongly shaken"; and Level XII (top of the scale) is "damage total, landslides etc. numerous."

Even if such value judgments were reliable, such a scale tells nothing about the extent of a quake or its total energy release. The next stage in measuring earthquakes came with invention of the famous Richter scale, in which "magnitude" is proportional to the logarithm of the amplitude of a particular ground motion wave. The important advantage of this scale is that the total energy released by various quakes can then be compared—for each unit increase in magnitude, the amplitude of ground motion increases 10-fold and energy released increases about 32-fold.

But now two serious problems have developed that limit the usefulness of the Richter scale. A purely technical difficulty is that procedures used to calculate magnitude of energy release from ground motion amplitude are simply inaccurate for very large quakes. The reason can be understood by referring again to the asperity model of a major quake: The total area of slippage may differ greatly between two tremors that cause similar local ground motions. The total amount of energy released over a large area of slippage will be seriously underestimated by considering only wave amplitude at the earth's surface.

To take an important example, both the San Francisco earthquake of 1906 and the Chilean quake of 1960 have been assigned a Richter magnitude of 8.3, but the area of slippage in the Chilean quake was many times as large, as was the total energy release. Hiroo Kanamori of the California Institute of Technology has devised a new method for calculating magnitude that would take account of this difference. He calculates the "seismic moment" of slippage by multiplying the area of a fault by the distance it moves in a quake. Then he works backward, calculating the energy release from the seismic moment and, finally, the true magnitude from the energy release. By this method, the true magnitude of the San Francisco quake is reduced to 7.9 and that of the Chilean quake is raised to 9.5—a substantial difference.

But an inherent difficulty of the magnitude scale still remains—it tells almost nothing useful about how severely some particular locality near the fault will be shaken. Robert Nason at USGS says *neither* the present magnitude scale nor the intensity scale is adequate. A specialist in examining the historical records of quake damage, Nason concludes that the destructive local motion resulting from a quake bears little relationship to total energy release or to traditional estimates of intensity in large quakes. He and others are trying to devise a third scale, for "severity of damage," which would measure the *cumulative* effect of ground motion, but no such scale has yet received wide acceptance.

Finally, the new theoretical models for quake mechanisms may someday give a better understanding of why precursory phenomena vary so much from quake to quake. Already they have increased awareness of how complex the sequence of events surrounding a quake can be, but so far they have provided little additional guidance to would-be predictors trying to sort through their data. The problem was emphasized in an interview with Robert E. Wallace, chief scientist, Office of Earthquake Studies, USGS.

Wallace says that the task of prediction has simply turned out to be more difficult than many scientists had hoped after early Chinese and Russian successes: "The problem is recognizing what is noise." He traveled to China and was deeply impressed by the scope of efforts there to detect such precursors as changes in well water and erratic animal behavior. But subsequent studies here, he says, have shown that such changes are not consistent before quakes and that they can also result from causes other than quakes. So their usefulness is limited. Asked what the chances are for predicting the next great California quake, he replied, "It will depend on luck."

Such uncertainty underscores the need to rely on more than prediction in current research efforts to reduce injuries and property damage caused by earthquakes. For this reason, a national hazard reduction program has been launched, scientists and engineers are studying more closely the local effects of quakes, and the fundamental philosophy of building codes is changing. These will be the subject of the second and final article in this series. □