The possibilities of earthquake prediction

More knowledge and better instruments are needed before prediction can become a reality

by Louise Purrett

When a populated area is struck by a large earthquake, such as the one that hit southern California last week, the public is suddenly reawakened to the need to have been better prepared. The ultimate form of preparation would be an accurate means of prediction. Considerable progress has been made toward this goal, but the knowledge and tools needed are not yet all in hand.

Once looked upon with suspicion, earthquake prediction has in the last few years become a scientifically respectable topic. A number of scientists now believe that acquiring an understanding of the basic processes of earthquakes may eventually lead to an ability to predict their occurrence with at least a reasonable degree of certainty.

Proposals for prediction techniques have proliferated, drawing relationships between earthquakes and such phenomena as variations in the earth's magnetic and gravity fields, changes in water levels in wells and even the occurrence of lightning.

Interior

The 1964 Alaska quake was more intense than last week's California tragedy.

The most obvious method of studying the potential for earthquakes is to measure the accumulation of strain along a fault. Earthquakes, it is generally agreed, result from the sudden release of built-up stress in the earth's crust. Sudden changes in the amount of strain, measured by various instruments such as strainmeters placed along the fault, may be precursors of earthquakes. Prior to a destructive Japanese quake in 1964, 15 out of 20 instruments recorded a vertical expansion of the ground.

Another form of crustal deformation is ground tilt. In 1943, a Japanese seismologist obtained a record showing anomalous ground tilt for several days preceding a Japanese quake. The record shows a gradual increase in tilt up to the occurrence of the quake.

A similar observation was reported recently by three California scientists (SN: 1/2/71, p. 8). They had found that about 29 days before the first of two earthquakes that struck Danville, Calif., last June, the entire San Francisco Bay area began to tilt slightly in the general direction of the quake epicenter, increasing steadily up to 10 hours before the tremor actually occurred.

Some scientists have suggested that the pattern of minor seismic activity preceding an earthquake may be a forecasting element. Laboratory studies of rocks under pressure show anomalous strain release prior to rupture corresponding to small earthquakes.

Similarly, recurrence curves have been plotted for various faults, such as the San Andreas, showing the frequency with which earthquakes of a given magnitude occur along the fault (SN: 10/31/70, p. 352).

Several studies have suggested that world seismic activity has varied with time. About 20 years ago, Dr. Hugo Benioff made a summation of the strain released by the largest earthquakes and noticed five periods of high seismic activity between 1904 and 1951, each separated by quieter periods and each of successively shorter duration. In the Jan. 25 NATURE PHYSICAL SCIENCE, Drs. Geoffrey F. Davies of the California Institute of Technology and James N. Brune of the University of California at San Diego plotted against time the cumulative moment sum for fault movement throughout the world since 1897. They found that earthquake activity prior to 1908 was much greater than it has been since that time, and that this pattern is worldwide. Since activity is now below that of the average for the past several million years, they conclude, an increase in seismic activity can be expected in the future.

More than 30 years ago Japanese scientists noted that certain great earthquakes were accompanied by marked changes in the configuration of the earth's magnetic field. A little over an hour before the disastrous Alaskan earthquake of 1964, there was a magnetic field disturbance. Such magnetic changes could be the result of the effect of stress on the magnetic susceptibility of rock masses.

Ultimate settlement of the question of whether local magnetic changes do precede earthquakes has had to await development of more sensitive magnetometers. Such an instrument was developed early last year by two scientists from the Environmental Science Services Administration's research laboratories and a colleague from the Joint Institute for Laboratory Astrophysics at Boulder, Colo. The new magnetometer will be used operationally for the first time this summer in a study of the effects of reservoir loading on the local magnetic field at Grand Coulee Dam in Washington. The device is ten times more accurate than the best instruments currently in continuous use.

Another recurring proposal is the monitoring of subterranean gases. In March 1969 a German geologist successfully predicted an aftershock to an

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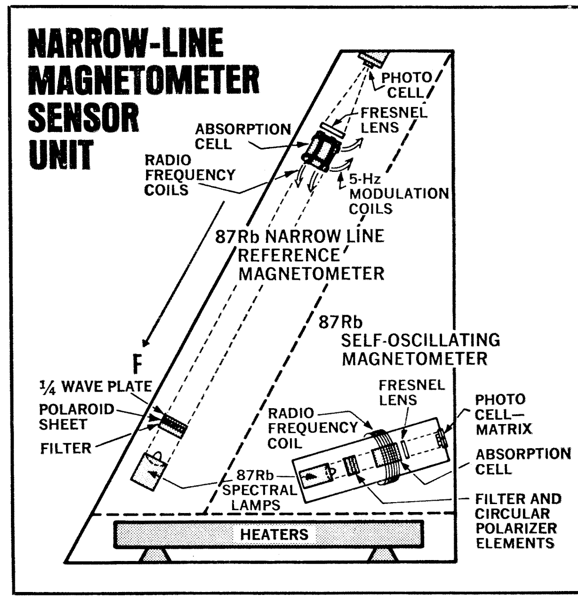
San Andreas Fault in 1906: Can't predict the next major release.



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New magnetometer will be operated this summer.

earthquake in southern Germany by observing an abnormal concentration of methane gas in a research shaft. He surmised that earth movements of the kind that precede quakes were permitting a greater than usual amount of the gas to rise through a fault. A rare radioactive gas, radon, has been used in a similar manner by Soviet geophysicists.

In some parts of the world, earthquakes are often accompanied by various forms of lightning. Two scientists recently suggested (SN: 12/12/70, p. 453) that this correlation may be due to the ability of quartz in the earth's crust to develop electrical charges when subjected to elastic deformation, as in a quake. Observations of such electrical precursors to earthquakes, they propose, may be useful in prediction.

These are all forerunners of earthquakes that may be instrumentally detected. But no single one of them, says Dr. Jerry Eaton, chief scientist of the National Center for Earthquake Research (NCER) in Menlo Park, Calif., will do an adequate job. "We're trying to get away from the crystal ball approach to earthquake prediction," he says. What scientists are aiming for now, he explains, is a thorough understanding of the physical processes and materials involved and an adequate monitoring system to tell the physical state of a region at any given time.

"We're trying to predict earthquakes in the same way that physicists like to predict the outcome of experiments before they do them—through a thorough understanding of the principles involved."

These principles have yet to be firmly established. The focal region of earthquakes is inaccessible to direct observation, so theories of the earthquake mechanism are based on the movements of surface rocks above the focal region, the behavior of samples of rock stressed in the laboratory under the high temperature and pressure conditions found deep within the earth and the radiation pattern of seismic waves.

On a global scale, the new understanding in geophysics and geology brought about by the recently developed theory of plate tectonics (SN: 11/8/69, p. 430), an outgrowth of sea-floor spreading theory, has shown that most earthquakes are apparently manifestations of activity at the edges of large plates of the earth's crust and upper mantle that can move horizontally several inches a year. But the specific mechanisms by which these gross processes produce the local events we call earthquakes are little understood.

Studies of rock movements during the 1906 San Francisco earthquake led to the elastic rebound theory, which explains earthquakes as the result of strain release caused by sudden shearing motion along a fault. This theory is also supported by the nature of seismic waves and by the behavior of laboratory rocks. If a rock is stressed under conditions similar to those in the crust, it cracks, usually violently.

In another theory, creep fracture plays an important role. According to the theory, creep can occur through viscous grain-boundary sliding. At an advanced stage cavities form, instability develops and the rate of strain increases suddenly. This sudden increase might produce an earthquake.

Some very deep earthquakes seem to be caused by a physical process involving abrupt changes in volume and density, such as a sudden phase change of earth materials under high pressure.

A major development that has greatly increased the understanding of earthquake mechanisms, says Dr. Louis Pakiser, another NCER scientist, is the documentation of man-made earthquakes.

The first clue came in 1945 when Dr. D. S. Carder documented approximately 600 local tremors during the 10 years following the formation of Lake Mead in Arizona and Nevada. Since then it has been found that the filling of other reservoirs has been accompanied by tremors.

In 1966 another researcher demonstrated a correlation between the rate of injection of waste fluids and the frequency of earthquakes in the vicinity of the Rocky Mountain Arsenal well near Denver (SN: 2/8/69, p. 138).

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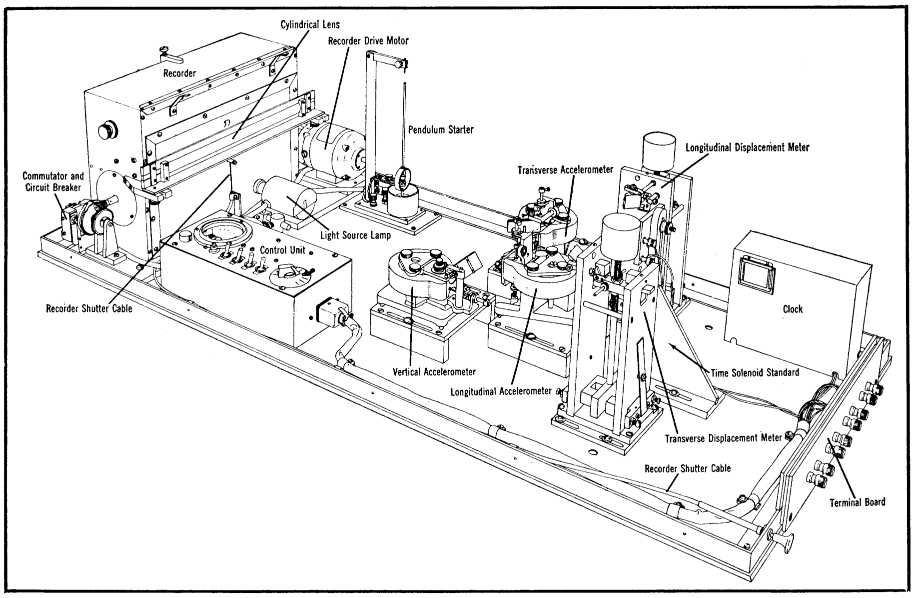
Pakiser: Possibly in 3 to 5 years.



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Seismographs monitor all earthquakes, but better instrumentation is needed.

A similar correlation was found at the Rangely oil field in northwestern Colorado, the site of a secondary recovery operation involving the injection of water under pressure.

Similarly, underground nuclear explosions in Nevada have caused numerous small earthquakes close to the test sites (SN: 2/23/69, p. 153).

In addition to providing new insight into the mechanisms of earthquakes, these discoveries provide a potential means for modifying or controlling them. In some cases fluid injections or small explosions may gradually release built-up strain in a series of minor, harmless quakes. Conversely, in regions where high subterranean pore pressure increases the danger of quakes, as when reservoirs are filled, extraction of fluids could act as a safety valve. A U.S. Geological Survey project now underway at Rangely uses pumps at four wells to reduce fluid pressure in the earthquake focal region.

Scientists at the NCER are concentrating their field work on fault zones in California and Nevada, and the physical and chemical nature of rocks and their behavior under stress are being studied in laboratories. The faults are mapped and identified by type and movements. A network of seismometers continuously records shocks along the faults.

As a result of these studies, says Dr. Pakiser, NCER scientists now have a good working knowledge of the mechanism of earthquakes in California. He estimates that within three to five years they will have sufficient scientific knowledge to make predictions of specific earthquakes. But, cautions Dr. Eaton, this does not mean prediction can be effected operationally. The theoretical knowledge cannot be used without an adequate monitoring system.

The consensus seems to be that an adequate prediction system would entail the monitoring, with the greatest possible sensitivity, of all possible indicators foretelling the occurrence of earthquakes—ground tilt, strain, seismic activity, fluctuations in the magnetic field, as well as periodic measurements of rock stress in drill holes and of physical properties that are stress-dependent.

Once the recent history of a fault is established as background, says Dr. Eaton, phenomena such as magnetic field variations can be used as specific indicators of impending quakes.

Dr. Pakiser believes, though the scientists haven't yet reached a point where a warning system could be developed, "We are at a right stage to make a real move forward in the whole field of earthquake prediction."

What remains for the California seismologists, he says, is to estimate how near the breaking point the San Andreas Fault is. One way to find out, he believes, would be to inject fluids into an area under very controlled conditions and increase the pressure just to the point where tiny tremors occur. The researchers could then extrapolate to find the amount of stress needed to trigger a major quake.

But much remains to be done. Right now, says Dr. Pakiser, the recurrence interval for the San Andreas Fault can be estimated as anywhere from 200 to 50 years. The last major quake along the fault was in 1906. "On the basis of present knowledge, we can't say for sure whether the next major quake is 14 years overdue or we have 136 years to wait." □

films OF THE WEEK

HYDROLOGY. 8mm, color, silent, series of 12 film loops. Explain the action of water in a variety of geological conditions. Titles include: Water Cycle in the Ocean, Water Cycle on Land, How Rivers Receive Water, Laminar and Turbulent Flow, Dry Channel and Flood Flow in Rivers, Wind Set-up on Lakes, Turbidity Currents on Lakes, Cross-channel Flow in Rivers, Flow in Meandering Rivers, Movement of Groundwater, Surface and Sub-surface Streams, and Influence of Rock Structures. Audience: elementary, junior high. Purchase $20 each or series of 12 for $240 from BFA Educational Media, Dept. SN, 2211 Michigan Ave., Santa Monica, Calif. 90404.

JOURNEY INTO SELF. 16mm, b&w, sound, 47 min. Film is a documentary of an intensive basic encounter group. Eight total strangers from various parts of the country meet for the first time in front of the cameras to share some of the most intimate contacts of their lives. The group is led by Drs. Carl Rogers and Richard Farson, two of the country's foremost psychologists. The film focuses on four group members, and contains highlights of the most emotional moments of their interaction. Audience: psychologists, psychology students, general. Purchase $250 or rental $60 from Western Behavioral Sciences Institute, Dept. SN, Film Library, 1150 Silverado, La Jolla, Calif. 92037.

THE KINGFISHER. 16mm, color, sound, 15 min. Shows several members of this family of birds whose distribution is worldwide, and then explores in detail the life-cycle of the European or Common Kingfisher. The two adult birds live along a small river. They mate in early spring, and set about digging a nest in the bank above the river. The nest with the hatched fledglings is seen in a cutaway shot which allows the viewer to watch the growth and feeding of the baby birds. When the young birds emerge from the nest, they must learn the difficult art of diving and catching a fish. Those who reach maturity must search out new home grounds since the food supply is not adequate for more than one adult pair. Next year, a new generation of kingfishers will appear. Audience: general. Purchase $190 from ACI Films, Dept. SN, 35 West 45th St., New York, N.Y. 10036.

THE LASER. 16mm, color, English soundtrack, 25 min. The laser is a light source which is coherent in both space and in time. The film shows the basic notions of time coherence and space coherence by means of simple models such as coupled pendulum circuits. Once these notions have been established, it is shown that Einstein's discovery, in 1917, of stimulated emission, makes it possible to imagine a light emission medium as a circuit of coupled oscillators, on the condition that population reversal can be brought about. When this is done, a feedback system must be created in order to obtain an auto-oscillator; it is the laser. Applications also shown. Audience: technical. Rental $6.00 from Society French American Cultural Services and Educational Aid, Dept. SN, 972 Fifth Ave., New York, N.Y. 10021.

Listing is for readers' information of new 16mm and 8mm films on science, engineering, medicine and agriculture for professional, student and general audiences. For further information on purchase, rental or free loan, write to distributor.

Correction: We are informed that purchase and loan information about the film Ground Water: The Hidden Reservoir, noted in the Jan. 16 issue, should be directed to John Wiley & Sons, Inc., Educational Services Dept., 605 3rd Ave., New York, N.Y. 10016