# search & discovery

## Do earthquakes give advance warning signals?

Recent developments in seismology suggest that certain premonitory effects can be used to predict that earthquakes will occur in a given location. The developments have aroused great interest in the geophysics community, but some skepticism has also been expressed.

Christopher H. Scholz and Lynn R. Sykes of Columbia's Lamont-Doherty Geological Observatory, using the so-called "dilatancy model," believe there are some grounds for suspecting that there will be a major earthquake in the vicinity of Tokyo any time now or within the next few years. They believe there is some evidence for dilatancy in the Tokyo vicinity, but it is far from definitive. More studies will be needed to prove the presence of dilatancy; if it is proven true, then it should be possible to predict an earthquake in that area in the future, they say.

Speaking at the American Geophysical Union meeting in Washington in April, Scholz said that earthquake prediction appears to be on the verge of practical reality. Reporting work by himself, Sykes and Yash P. Aggarwal, he noted that many premonitory effects have already been observed, including crustal movements and changes in tilt, fluid pressures, electrical and magnetic fields, radon emission, decreased frequency of occurrence of small local earthquakes, and changes in the relative numbers of large and small shocks in a region. In the Soviet Union and Japan over the last five to ten years, strong programs to monitor premonitory effects have been instituted.

Dilatancy (which is an increase of volume due to cracking in reaction to a stress about half the breaking stress) is an old concept, but it was recently found to occur in rocks stressed in the laboratory. In the 1960's, William F. Brace at MIT showed that microcracks and voids appear in rocks stressed almost to the point of rupture. The rocks increased in volume, and changes in the electrical and elastic properties occurred. These laboratory experiments stimulated American workers to advance theoretical explanations to the Soviet, Japanese and their own observations of premonitory changes.

In 1969 I. L. Nersesov, A. N. Semonova and I. G. Simbireva (Institute of the Physics of the Earth, based in Moscow) reported on studies made in Garm, in the Tadzhik Republic, that showed that prior to moderate-size earthquakes, the ratio of the compressional velocity $V_p$ to the shear velocity $V_s$ decreased by about 6%. This decrease was not related to the magnitude of the earthquake. The larger the earthquake, the longer was the precursor time. For a magnitude-5 earthquake, one that would cause a small amount of damage in a populated area, the time was 1-3 months. The velocity ratio returned to normal at about the time the earthquake occurred.

The Lamont group visited the Soviet observers and became interested in observing the velocity ratio in the eastern part of the United States. Picking a site at Blue Mountain Lake in the New York Adirondacks, which recently had an earthquake, they installed six temporary stations within a few kilometers of the source, which they operated for several months. They observed thousands of very tiny earthquakes and some moderate-size events, which they could then trace back to their precursors. The Lamont group was able to see[1] decreases in the velocity ratio as high as 15%, Sykes told us, thus verifying for the first time that the Russian technique could be applied to a region other than central Asia. They, too, found that the decrease was not related to the earthquake strength. Sykes feels that the velocity-ratio technique can apply to any region in which there is so-called "thrust faulting," and would apply to Southern California, mainland Alaska, New Zealand, central Asia and probably to Japan.

In May, James H. Whitcomb, Jan D. Garmany and Don L. Anderson (Cal Tech) reported[2] a decrease of 10% in the velocity ratio had occurred prior to the 1971 earthquake in San Fernando, California. The lead time of the decrease was about 3½ years for the event, which was of magnitude 6.4.

The Cal Tech observers used two widely spaced stations, and the epicenters were approximately in line with the two stations. In this way, they were able to separately determine the compressional velocity and shear velocity. They found that most of the velocity variation is in $V_p$. The Cal Tech group says that this change in $V_p$ is compatible both qualitatively and quantitatively with the phenomenon of rock dilatancy and its effect on rock strength and fluid saturation. They find that the characteristic dimension of the affected region is proportional to the square root of the precursor time, Whitcomb told us. This diffusion relationship, he said, also supports the idea that migration of fluid into the enlarged rock voids is responsible for the time delay between the start of dilatancy and the quake.

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## Viscosity study suggests superfluidity

A group at Helsinki University of Technology headed by Olli Lounasmaa says[1] that it has strong evidence for superfluidity in liquid $He^3$ based on a viscosity measurement. The result[1] is the latest link in a chain of experiments delineating the strange behavior of $He^3$.

Last year Douglas Osheroff (now at Bell Labs), Robert Richardson and David Lee (Cornell) discovered two transitions below 3 millidegrees Kelvin, one designated "A" at 2.6 mK and one called "B" below 2 mK (PHYSICS TODAY, July 1972, page 17). At first, they interpreted the A feature as a transition in the solid. Subsequently, the three men plus W. J. Gully did a nuclear-magnetic-resonance study that showed both transitions to be in the liquid (PHYSICS TODAY, November 1972, page 17); this fact is also obvious from the viscosity measurements of the Helsinki group.

Since then, a variety of experiments have been done (and a number of theoretical explanations have been offered). For example the Cornell group showed that in a magnetic field, the A transition splits up into at least two transitions. These two components were then dramatically correlated with ultrasonic measurements. At the University of California at La Jolla, John Wheatley and his collaborators made quantitative measurements of ultrasonic attenuation at various frequencies. Then there were thermodynamic measurements by Wheatley, who reported that there is a finite discontinuity in the specific heat at A, a behavior characteristic of a second-order phase transithe $He^3$ is about half the viscosity of water at room temperature (0.01 poise). If one assumes that the viscosity of the normal Fermi liquid varies as $1/T^2$, which is to be expected from measurements at Cornell and La Jolla, then the viscosity at A would be about 33 times greater—about 0.15 poise, which is the viscosity of a light machine oil. Wheatley feels that at such a viscosity value the experiments cannot be interpreted. But by the time the temperature is well below the B feature, the amplitude of the wire has returned to its value at 15 mK so that the effective viscosity (that calculated assuming a normal fluid density equal to the actual density) has returned to half the room-temperature viscosity of water. "So this superfluid that you're talking about has a viscosity that is half the viscosity of water." In the case of $He^4$, in a bulk experiment, its normal viscosity has a minimum value of 12 micropoise, Wheatley says, a value 10 000 times less than the viscosity of $He^3$ just above the A transition. When one speaks of $He^4$ being a superfluid, at least one component of it has a zero viscosity; this is what the Helsinki experiment has not shown. He believes that the effective viscosity change is actually closer to 100 than 1000.

Nevertheless, Wheatley regards the Helsinki experiment as very important and has done a related experiment that supports the Helsinki observations. Richard Johnson reported these results at the Washington meeting of the American Physical Society in April. Collaborating with them are Thomas Greytak and Douglas Paulson. They have done a heat-flow experiment that they interpret in terms of the two-fluid model.

In the A fluid they find a critical velocity that may be associated with ordinary turbulence. In the B fluid, on the other hand, the La Jolla group finds no critical velocities. Wheatley feels that the hysteresis observed by the Helsinki workers (see figure) is probably connected with the ease with which the A fluid can be driven critical. The La Jolla experimenters also find that when you increase the temperature going from B to A, the thermal resistance suddenly jumps substantially. Wheatley believes the rapid decrease in damping when going from phase A to phase B, which was found by Lounasmaa and his collaborators, corresponds to a change from supercritical A to subcritical B. He believes that the experiments show that one can start thinking about a two-fluid model in $He^3$.

At Cornell, Richardson is enthusiastic about the Helsinki result. The Cornell group had attempted a similar experiment but because both liquid and solid are in the compression cell, the particular geometry they used tended to cause the solid to form on the wire and clamp its vibration; so they were unsuccessful. Richardson regards the Helsinki experiment as one more piece of evidence that the behavior is that of a superfluid. If one were to compare it with measurements in which one was trying to prove that a metal becomes a superconductor, it is as though one had found the electrical resistance to have dropped by a factor of 100 or 1000. To establish superfluidity, one would need to do something like forming a persistent current. In addition, it would be good to observe some special modes such as fourth sound—something that can only exist if the material is a superfluid. What Richardson hopes, however, is that maybe one is not seeing superfluidity at all, but something that no one has even thought of as yet. —GBL

#### Reference

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## NASA establishes lunar data program

With the end of the Apollo moon flights NASA is establishing a comprehensive program of lunar science data analysis to utilize the large amounts of data obtained over the past decade of US lunar exploration. The goal of the program, called the "Lunar Data Analysis and Synthesis Program," is to develop through multidisciplinary studies comprehensive models of lunar origin and evolution, of physical properties and motions and of the internal and external processes operating on the moon. The new program encourages the dissemination of new knowledge about the moon to laymen as well as scientists.

A wide variety of data will be available under the Lunar Data Analysis and Synthesis Program. Included is data acquired by experiments associated with the Apollo flights after the respective principal investigator's exclusive rights period has expired; metric and panoramic camera photographs from the orbiting modules on Apollo 15 through 17 as well as hand-held shots from orbit and the moon's surface; lunar cartographic and selenodetic information; data from the US automated flight program including Ranger, Surveyor, Lunar Orbiter and Explorer 35, and limited amounts of information from the USSR's Zond and Lunar flights. If analysis of lunar samples are needed beyond the ones already completed, it is possible that research can also be supported under the Lunar Sample Program and the Lunar Data Analysis and Synthesis Program concurrently. This is also true for the NASA Supporting Research and Technology Program, which funds meteorite studies, earth-based lunar observations, laboratory simulation and theoretical studies.

There is no closing date for the submission of proposals. Information about the program is available from the Lunar Synthesis Program, Lunar Programs Office, Code SM, NASA, Washington, DC 20546.

## Earthquakes

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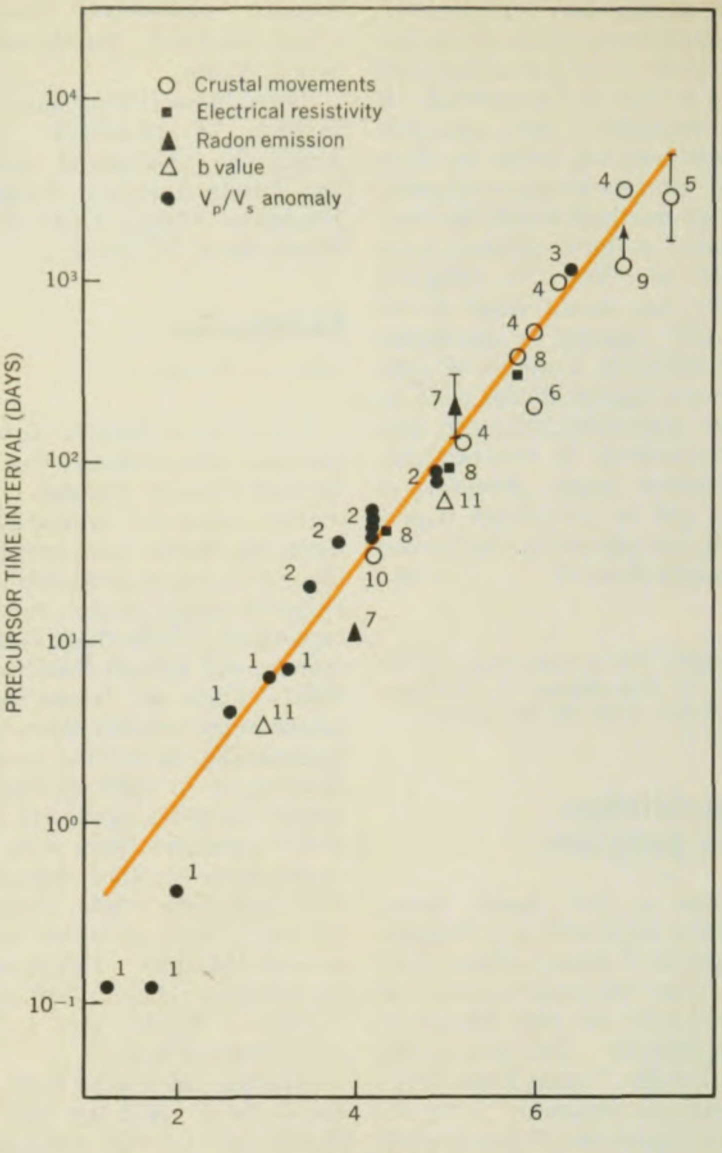
Amos Nur of Stanford first proposed[3] last year that dilatancy was responsible for the velocity changes. His paper, written before the Adirondack and San Fernando results were known, says that dry cracks can be produced in two ways: either by producing new cracks or by the expansion of fluid-filled cracks, so that there is not enough fluid to keep them filled. These dry cracks cause the decrease in the velocity ratio, Nur told us. Incidentally, he pointed out to us, E. F. Savarensky in 1968 reported data that clearly showed a decline in $V_p$. (Whitcomb maintains there is an alternative explanation for that data.) Nur also feels that more credit should be given for early work of some Japanese observers—Masami Hayakawa (Tokai University), Eichii Nishimura (University of Kyoto) and I. Tsubokawa (University of Tokyo).

Building on Nur's work, their own earlier paper, and the Cal Tech work, Scholz told us that the Lamont group (reporting at the AGU meeting) has used the dilatancy model to attempt to explain a wide variety of premonitory effects. When stress builds up, he explained, dilatancy occurs, $V_p$ drops sharply, the electrical resistivity changes, and because the volume increases, the crust will uplift. In addition, because the dilatancy increases the pore volume in the rocks, the pore pressure is reduced, which in turn strengthens the region, thus delaying the earthquake and stopping the dilatancy itself. When the dilatancy stops, water from the surrounding area fills up the cracks, Scholz says, and the pore pressure starts to return to normal, at which time the earthquake is triggered. Another premonitory effect, an increase in radon content in well water occurs because a greater flux of water is going through the region.

So far, all these precursory phenomena have been studied in retrospect. Scholz and Sykes, however, note that there are some hints that dilatancy may now be occurring in the Tokyo area, which was last struck by a large earthquake in 1923. In the 1923 earthquake, two peninsulas on Sagami Bay, just south of Tokyo, were uplifted. Since that time, which would be expected to be a period of elastic-strain accumulation, the peninsulas have been observed




**Duration time of precursory phenomena** as a function of earthquake magnitude. The *b* value is a parameter that measures size distribution of earthquakes. Earthquake locations are: 1. Blue Mountain Lake, N.Y., 2. Garm, USSR, 3. San Fernando, Calif., 4. Kitamino, Kitaizu and Omi, Japan, 5. Niigata, Japan, 6. Odaigahara, Japan, 7. Tashkent, USSR, 8. Garm, USSR, 9. Alma Ata, USSR, 10. Danville, Calif., 11. Fairbanks, Alaska. Plot from Christopher H. Scholz, Lynn R. Sykes and Yash P. Aggarwal.

to be going down. But in 1969, Japanese observers found that the peninsulas had risen a couple of centimeters; this uplift continued until at least 1971, when it began to tail off, Scholz told us. This reversal in direction of vertical movement was thought to be a precursor by Japanese seismologists who then started an intensive national earthquake-prediction program for the south Kanto province. The effort is directed by Tsuneji Rikitaki at the Earthquake Research Institute in Tokyo.

Scholz and Sykes feel that the 1969 uplift looks very much like what one would expect from dilatancy, resembling an earlier Japanese earthquake in Niigata. If dilatancy has occurred, it has been going on for at least four years. Using the Lamont time scale, this would imply that an earthquake of at least magnitude 7 would occur and that it would happen in the next few years. If it is delayed further, it would be of even greater severity. But, Scholz cautions, they have not yet proven that dilatancy has occurred—the only indication is the crustal uplift and this can be explained by other causes. Further investigations will be required to establish if in fact dilatancy is actually occurring.

Because the Tokyo area has not been struck by any small earthquake since 1969, Scholz told us, the velocity ratio could not be determined from measuring the arrival times from seismograms. Another way to measure the velocity ratio is by setting off an asymmetric explosion, Sykes explained. Setting off an explosion in air or water does not produce much shear, unlike an earthquake. But if one can set off an asymmetrical source or put it at a boundary such as at the bottom of the ocean, there is a better chance of producing shear waves. At present, the Japanese workers are only timing compressional waves, which now appear, on the basis of the Cal Tech results, to be all that is needed. Next month a US–Japan conference on earthquake prediction will discuss, among other things, the need for further observations. —GBL

### References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## Infrared telescope takes to the air

A new infrared astronomy instrument is scheduled to begin test runs this summer as NASA scientists go aloft with a 36-in Cassegrain telescope mounted in a Lockheed C-141. Based at the NASA Ames Research Center in Moffett Field, California, the C-141 has been modified so that the telescope can operate either through an open port or through an optical window and it can fly at altitudes of up to 13.7 km for up to 3.5 hours.

The telescope will be used in a wide variety of infrared studies. Among these is the analysis of the composition and radiation balance of planetary atmospheres and the study of cool gas clouds in the galaxy. The gas clouds radiate little energy in visible wavelengths, but often show high radiation in the infrared range; some may be in the process of forming stars. The telescope will also lend itself to studies of the extragalactic sources of infrared radiation including those galaxies that radiate primarily in the infrared and to studies of circumstellar dust clouds that radiate at a few micrometers.

The telescope itself was built by Fecker Systems Division of Owens-Illinois, Inc. and is mounted on a 16-in diameter spherical air bearing that, together with gyroscopes, inertially stabilize the telescope. When operating through the open port, pressure bulkheads around the telescope will separate the researchers from the high-altitude environment and a tertiary mirror on the telescope reflects the infrared light through the bulkheads to instruments. "Chopping," or rapidly oscillating the secondary mirror so that the telescope looks alternately at an object and the adjacent sky, will be used to increase the sensitivity of the telescope.

The airborne telescope is expected to be fully operational early in 1974, and formal proposals for research using the NASA instrument can be submitted. Information can be obtained from Robert M. Cameron, Mail Stop 211-12, NASA Ames Research Center, Moffett Field, California 94035. □