"It is paradoxical," says Levy. No one knows the answer and some are even skeptical of the findings.

"We're dubious about estrogen as a risk factor," says Estelle Ramey of Georgetown University School of Medicine. "It is inconsistent with what is known about the roles of estrogen and testosterone in the development of cardiovascular disease." She and her associates find that, in rats, estrogen protects against heart attacks. Postmenopausal women who take estrogens have fewer heart attacks than those who do not. And, she points out, women who have their ovaries removed are at an increased risk of heart disease unless they take estrogen. The recent studies of estrogen as a risk factor are "just not consistent," she says.

High doses of estrogen do, however, seem to increase the risk of heart attacks in men. In the 1960's, men who had had heart attacks were given estrogen in the hopes of protecting them from subsequent attacks. The experiment was ended prematurely because the estrogen seemed to be increasing the likelihood of heart attacks. Also in the 1960's, the Veterans Administration conducted a study in which men with prostate cancer were given estrogen. Once again, these men died prematurely of heart attacks.

If estrogen increases the risk of heart attacks in men, how does it do so? Different investigators have wildly different hypotheses. Phillips thinks it increases the development of atherosclerotic plaques. Castelli thinks it increases blood clotting. Klaiber suggests it increases the workload of the heart. And Luria proposes that it causes coronary spasms. But, no one knows.

Another unknown is where this excess estrogen comes from. It may be a matter of individual differences or it may reflect the life-styles of these men. For example, Klaiber suggests the excess estrogen may result from stress—which already is implicated in the etiology of heart disease—or from smoking, which raises blood estrogens. Castelli thinks it may result from a high fat diet. Vegetarians seem to have very low blood estrogen concentrations—they even excrete estrogens in their feces. Another possibility is that many of the men with high levels of blood estrogens are simply too fat. Estradiol is made by fat cells.

So, coincidentally, the advice these researchers would give men with high levels of blood estrogens is exceedingly familiar: relax, stop smoking, go on a low-fat diet, and lose weight. But, at the present time, no one feels ready to stress the estradiol hypothesis as a justification for this prudent life-style. For one thing, all the investigators would like to see a prospective study in which symptom-free men are followed for years to see whether those men who eventually get heart attacks are those who have high levels of blood estrogens.

The Framingham investigators are now initiating such a study. Castelli believes the study will show that estradiol is a risk factor for heart disease because every time a factor was discovered to correlate with heart disease in those who already had it, it turned out to predict who is at risk among those who have not yet developed the disease. The prospective estradiol study will take 5 or 10 years. But, Castelli says, he is a type B. He can wait.—GINA KOLATA

Additional Readings

1. M. H. Luria *et al.*, *Arch. Intern. Med.* **142**, 42 (1982).
2. E. L. Klaiber *et al.*, *Am. J. Med.* **73**, 872 (1982).
3. G. B. Phillips *et al.*, *ibid.* **74**, 863 (1983).

New Signs of Long Valley Magma Intrusion

The effects of the January earthquake swarm and reevaluation of the 1980 shocks suggest that magma is forcing its way upward

Salt Lake City. Geophysicists keeping watch near Mammoth Lakes, just east of Yosemite National Park, California, have new evidence that magma from an 8-kilometer-deep chamber is forcing its way into rock as shallow as 3 kilometers, setting off earthquakes and swelling the crust as it goes. Researchers accept the expansion of the underlying magma chamber as indisputable and view shallow magma intrusion as plausible, even probable. It is certainly the simplest explanation for much of the recent activity. The final outcome cannot be foretold, but whatever has been driving the recent activity did not abate after the January earthquake swarm.

At a meeting* here in early May, researchers presented several kinds of evidence for the injection near Mammoth Lakes of magma, or at least some fluid under high pressure. Last year, Alan Ryall of the University of Nevada pointed out that swarms of earthquakes had repeatedly struck the same small area 4 kilometers southeast of the village of Mammoth Lakes near the southern rim of Long Valley, the oblong depression or caldera marking a huge volcanic eruption 700,000 years ago (*Science*, 18 June 1982, p. 1302). Since four earthquakes of magnitude 6 hit just south of the caldera in May 1980, eight episodes at the swarm area have included rapid-fire series of small earthquakes resembling the spasmodic tremor of volcanic areas. The presumption was that magma or magmatic gas was rupturing brittle rock in the area of the swarms. The expansion of the magma chamber beneath the caldera, driven apparently by the deep injection of new magma, tended to support the injection idea. Still, spasmodic tremor alone seemed only suggestive. Then the January swarm, including two events greater than magnitude 5, struck the same area.

Perhaps the most intriguing evidence of fluid injection in Long Valley is the swelling of the ground over the January earthquake swarm. James Savage of the U.S. Geological Survey (USGS) in Menlo Park told the meeting that precise measurements of distances and elevations within a network of reference points in Long Valley "support the formation of a dike. I think it's fairly convincing." Savage has fit the apparent expansion and uplift over the swarm area to a model of the subsurface that includes fault motion along the trend of the swarm as well as fluid injection. The slip on the fault is strike-slip motion, the horizontal sliding of adjacent blocks past each other along a fault. His best fit requires one-quarter meter of strike-slip motion and about one-half meter of widening of an idealized vertical conduit or dike. The dike ranges from a depth of 8 kilometers to 3 kilometers and is about 8 kilometers long. He improved the fit by adding an angled leg to the dike leading back toward the magma chamber.

*Annual meeting of the Seismological Society of America, 2–4 May.

It is "not an overwhelmingly convincing fit," Savage noted, "but it's hard to fit anything else to the data." James Whitcomb of the University of Colorado and John Rundle of Sandia Laboratories in Albuquerque have also found that their gravity measurements match a model of a vertical dike having a feeder conduit at its base. Leveling surveys across a broader area of the caldera are also consistent with recent ground deformation concentrated over the swarm area, Savage notes.

Ryall has now found that earthquakes within a larger area on the edge of the caldera could reflect the injection of magma as well. Since May 1980, earthquakes have filled in an oblong area stretching 30 kilometers to the southeast from the caldera swarm area. That is largely outside the caldera. All of the earthquakes shallower than 9 kilometers were on nearly vertical faults and had strike-slip mechanisms. Judging from the crosscutting orientations of slippage, extensional stresses that tend to stretch this region seem to be splintering the entire area, Ryall says. He suggests that the strike-slip style and the fault orientations resemble a pattern familiar from swarms in volcanic areas. In 1977, David Hill of the USGS in Menlo Park attempted to explain such swarms as the result of intrusions of magma along vertical dikes that could generate strike-slip earthquakes where the ends of the dikes overlapped.

A reinterpretation of the Mammoth Lake earthquakes of May 1980, which included the largest events since the sequence began in 1978, also suggests that magma has been pushed toward the surface just south of the caldera. The four earthquakes of magnitude 6 to 6.5 have caused considerable problems for seismologists, who were finding different failure mechanisms when they analyzed different kinds of seismic waves from the same earthquake. Two groups, using methods that combine a wide variety of seismic waves in a single analysis, have now shown that at least two of the May 1980 events were of a type never before encountered. They cannot be described in terms of two blocks of rock sliding by each other in any one direction along a single fault; they do not fit the standard double-couple model of fault failure.

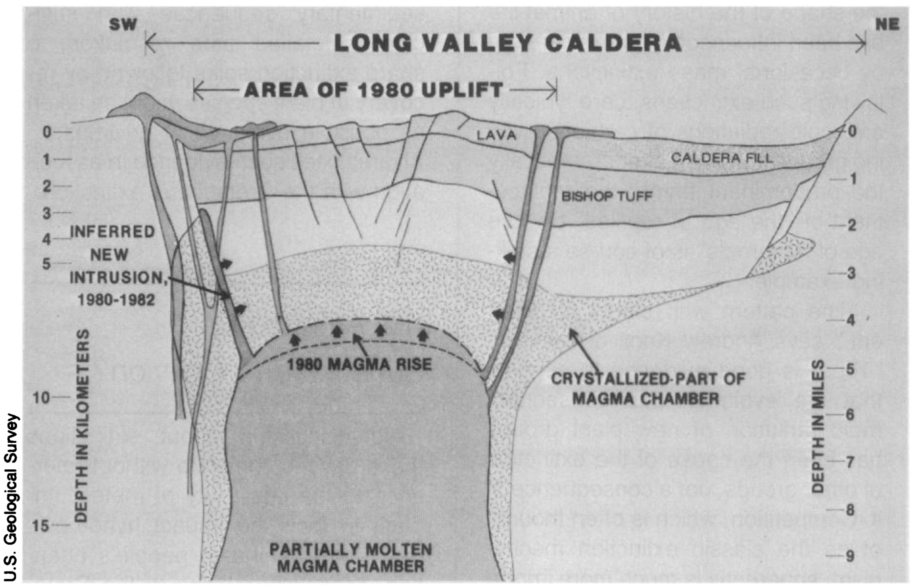
Bruce Julian of the USGS in Menlo Park reported that the seismic waves from the first and fourth earthquakes in the sequence, which struck the seismic zone south of the caldera, match almost perfectly those waves produced by the opening of cracks under extensional stress. But cracks at the depths of these earthquakes could never open without fluid being forced in under high pressure; the fluid could be water, Julian says, but he cannot eliminate magma.

There are alternative interpretations of these non-double-couple earthquakes. Göran Ekström and Adam Dziewonski of Harvard University also found that the first and fourth quakes did not fit the double-couple model (*Eos*, 3 May 1983, p. 262). The 1978 event that led off the sequence did not fit either. But they believe that similar seismic wave patterns could possibly result from simultaneous slippage on two adjacent faults, a type of failure that the orientation of stress in the area could favor. Some researchers also wonder how magma, or any fluid for that matter, could flow into a crack fast enough to produce such large earthquakes.

Curiously, Ekström and Dziewonski found that the third Mammoth Lakes earthquake, the one that fell on a line between the first and fourth events, has an ordinary strike-slip mechanism. Julian's reaction is that such an arrangement might be explained by Hill's injection mechanism, as proposed earlier for the same area by Ryall on the basis of a single type of seismic wave. Because it was smaller and followed the first event of the sequence so closely, no one has been able to determine the mechanism of the second event, which occurred on the edge of the swarm area.

The observations in hand point to fluid injection, at least beneath the swarm area inside the southern edge of the caldera. That is also a reasonable place to see magma injection. The swarm area is in the caldera moat between the caldera rim and the resurgent dome, an ancient uplift centered just 7 kilometers to the northeast and overlying the magma chamber. The pressure on the chamber that has caused the surface to bulge about 45 centimeters during the past 5 years or so could also be driving magma toward the surface. Magma from the chamber reached the surface in the caldera moat 500,000, 300,000, and 100,000 years ago, noted Roy Bailey of the USGS in Reston, Virginia. Even if the injection involved only water driven by the heat of the underlying magma, a breakthrough to the surface would produce a phreatic eruption, the sort of steam-driven eruption that began the activity at Mount St. Helens.

Whatever is going on at Long Valley, there are strong signs that it did not end with the January swarm. Dan Dzurisin of the USGS in Vancouver, Washington, and his colleagues reported that they have measured increasing ground tilt in the south caldera moat since January. Malcolm Johnston and his colleagues at the USGS in Menlo Park reported that a steady increase in the magnetic field over the southern edge of the caldera first noted in 1977–1978 is continuing. Johnston considers the increase to be a measure of the growing strain within the rock of the caldera, which affects the magnetic properties of minerals. He expects a sharp increase before any eruption. Or, he notes, the magnetic anomaly could decline steadily, marking the end of the whole Mammoth Lakes episode. No one is hazarding a guess which it will be.—Richard A. Kerr



U.S. Geological Survey

A view of the suspected intrusion of magma

Geophysical evidence suggests that a vertical intrusion of magma is pushing toward the surface beneath the southwest part of the caldera moat. Three inactive dikes are also shown that reached the surface from the magma chamber during the past half million years.