New Fault Picture Points Toward Bay Area Quakes

Recent earthquakes and a new way of looking at faults suggest that damaging quakes are closing in on the San Francisco area

EARTHQUAKE AWARENESS WEEK in northern California started off with a bang on Monday, 3 April, when a magnitude 4.8 quake struck 15 kilometers northeast of San Jose. The relatively small shock—its primary damage was the shattering of an air-control tower window—got the immediate attention of three U.S. Geological Survey seismologists in Menlo Park near San Francisco. David Oppenheimer, William Bakun, and Allan Lindh had forecast a nearby earthquake in a just completed manuscript, and this, they thought, might be it.

"We were in a meeting when we felt the earthquake," recalls Lindh, "and someone went to find out where it was. When we heard the preliminary location, we were elated. Dave Oppenheimer started accepting congratulations. But in a few hours, we could see that it had not filled in the gap that we had talked about." It was not their earthquake after all.

A setback for earthquake prediction? Not really. While the trio may not have anticipated this relatively small shock, it does fit into the improved scheme that they have just used to forecast a potentially damaging quake of magnitude 5.5 to 6 in the next few years near San Jose. More ominously, the recent northward progression of seismic activity on the fault, which their forecasted earthquake would continue, could lead to a disastrous shock in Oakland and Berkeley farther north in the East Bay area of San Francisco.

The Calaveras fault that splits from the San Andreas south of San Jose had attracted the notice of Bakun and Lindh some years before. By 1985, its behavior seemed mildly threatening. For one thing, there was a pattern to the way sections of the fault were breaking during moderate earthquakes. The 1974 Thanksgiving Day earthquake, magnitude 5.1, broke a section of a side fault near the southern end of the Calaveras. The 1979 Coyote Lake earthquake struck the Calaveras about 18 kilometers to the north, and the 1984 Morgan Hill quake broke 25 kilometers of the fault just to the north of that.

Their other concern was the relative quietness of the next 20 kilometers of fault to the north. The entire block of crust on the west side of the 70-kilometer-long Calaveras is sliding northward, generating moderate earthquakes wherever the fault sticks and then breaks suddenly. But this section of the fault had been disturbingly quiet for many decades. Could this northernmost section of the fault, or some part of it, be stuck and getting ready to break?

Then in June of last year the magnitude 5.1 Alum Rock earthquake ruptured a 1.5-kilometer section of the Calaveras in the middle of this northernmost 20-kilometer section. "We were struck by the northward progression" of the quakes, says Oppenheimer, "and they were too close in time" to be simply random. "Were they related?" these researchers asked themselves. Could they forecast the next earthquake in the series?

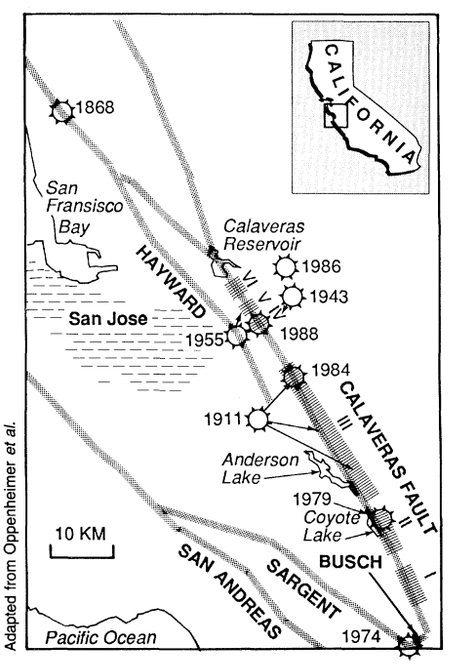
First they pulled out the records of microseismicity, events of magnitude 3 or less, for the Calaveras during the past 20 years. Plotted along the trace of the fault, no obvious pattern appeared, but when viewed in cross section from the side, six areas of little or no microseismicity appeared in the cloud of activity that tended to pervade the fault between depths of 5 and 10 kilometers. These holes in the microseismicity coincided with the areas of slip located 8 to 10 kilometers down that occurred during the three recent moderate earthquakes.

"The microearthquakes are mapping out where the slip regions of the main shocks are," says Oppenheimer. The part of the fault that slips during a moderate earthquake seems to be a section that is relatively strong and is thus locked tight between such events, making it seismically quiet. On the Calaveras, these stuck patches are separated by weak fault sections that slip more or less continuously, generating microearthquakes. Given the coincidence of stuck patches and holes in the microseismicity, the USGS group could locate the past as well as future locations of larger earthquakes. That was the first step in making a forecast.

The next step was figuring out which fault sections that tend to stick would be most likely to break next, so the USGS researchers considered when each of their six stuck patches might have broken in the past. Their resources included detailed modern seismic records, records from old seismographs still in operation, and historical accounts of the earthquakes. There are some loose ends, but these researchers are confident that the Calaveras section that broke in 1984 was broken by a nearly identical quake in 1911. Likewise, the 1988 Alum Rock event was a repeat of a 1943 earthquake. That suggested repeat times of 80 years and 40 years for those size quakes. The historical search also suggested that five of the six holes had been filled during the past 50 years by magnitude 5 or larger events, the sixth, unfilled hole being a 4-kilometer section near the northern end of the fault.

Being public employees and in the earthquake prediction business, the Menlo Park group included in their manuscript a "speculation" on the next earthquake on the Calaveras. They pointed to the northernmost stuck patch because no earthquake had broken it since at least 1903, giving the fault enough time to accumulate the stress needed to drive a magnitude 5.5 or larger rupture if the entire 4-kilometer section broke at once.

They could not say when the forecasted quake would strike this segment, but events seemed to be hastening its arrival. The cluster of northward migrating main shocks was no accident, they concluded. One was triggering the next, but with a delay. The delay was the time that the sudden slip of a main shock takes to propagate slowly through the intervening section of weak fault. This af-



The next Calaveras earthquake? *A northward progression of earthquakes on the Calaveras fault during the past 10 years points to the next one being just south of the Calaveras Reservoir (segment VI).*

terslip finally arrives at the next stuck patch, adds additional stress to the patch, and, if the patch is near enough to failure, triggers its rupture. Once gradually increased stress had brought most of the patches near failure, the failure of one would trigger a cluster of failures, as seems to have happened three times on the Calaveras.

"We were about to send the paper out [to the *Journal of Geophysical Research*] when we had this 4.8," recalls Oppenheimer. It broke a part of a fault segment farther south, one that they had assumed broke entirely in 1955. "The model is still appropriate," he says. "We're still waiting."

If the next Calaveras earthquake arrives at all as forecast, all eyes will be looking still farther northward. Activity on the Calaveras appears to jump to the Hayward fault, which cuts through the cities of Fremont, Hayward, Oakland, and Berkeley. It was a section of the Hayward that broke in 1868 in a magnitude 6.9 shock, preceded by a 10-year cluster of five events near the Calaveras. According to a state study, a magnitude 7.5 event, the largest credible rupture on the Hayward, might kill 1,500 to 4,500 persons, injure more than 50,000, and wreak social havoc among the 5 million residents of the area. ■ **RICHARD A. KERR**

AIDS Drugs—Coming But Not Here

The discovery that the AIDS virus can become resistant to AZT, the only drug currently approved by the U.S. Food and Drug Administration for combating it, has given increased impetus to efforts to expand the arsenal of AIDS drugs. It puts "tremendous pressure" on AIDS researchers to come up with alternatives for people who are failing on AZT, says Jerome Groopman of New England Deaconess Hospital in Boston.

A major effort is already under way. The National Institutes of Health will spend about $90 million on AIDS drug research in fiscal 1989. The amount of spending by the drug industry is not available, but nearly 60 companies now have AIDS drugs in various stages of development, according to figures compiled by the Pharmaceutical Manufacturers Association. None of the new drugs are likely to become widely available for at least a year or two, however.

The potential AIDS drugs being identified work in diverse ways, attacking the AIDS virus at several points in its life cycle. This meets the general goal of developing drugs with different modes of action that can be used in combination. Such combination therapies should help to prevent the development of drug resistance by the AIDS virus, and may also give better control of the virus. "We're going to have to have alphabet soup to treat this disease," says John McGowan of the AIDS Program of the National Institute of Allergy and Infectious Diseases.

The reverse transcriptase inhibitors—the "sons of AZT" they might be called—are among the most advanced of the new AIDS drugs. Reverse transcriptase is an enzyme that copies the viral genome, which consists of RNA, into DNA, an essential early step in AIDS virus reproduction. AZT essentially tricks the reverse transcriptase into terminating DNA synthesis.

Some half-dozen additional inhibitors of reverse transcriptase are now in or are entering clinical trials (see table). The furthest along of these is ddC (for dideoxycytidine), a product of Hoffmann–La Roche, Inc., of Nutley, New Jersey, which is progressing from phase II to phase III clinical testing.

Phase I trials determine the maximum drug doses that patients can take without intolerable side effects, and phase II trials begin to assess a drug's effectiveness in a relatively small number of patients. For ddC, the early trials have shown that AIDS patients can tolerate doses that appear to reduce AIDS virus reproduction.

Phase III testing to assess ddC's efficacy in AIDS patients will begin in a few months if all goes well, says Thomas Merigan of Stanford University Medical School, who chairs the Primary Infection Committee of the AIDS Clinical Trials group. Meanwhile, the drug is being tested in combination with AZT therapy.

Other potential AIDS drugs act by preventing the AIDS virus entry into cells. These include the protein CD4, a product of recombinant DNA technology. CD4 is a soluble form of the receptor to which the AIDS virus must bind in order to infect cells. Injecting the protein into the bloodstream may, the theory goes, tie up the virus and prevent its spread in the body. Phase I trials of CD4 are under way. Researchers are also trying to make the protein more resistant to degradation and linking it to toxins that could destroy virus-infected cells.

Dextran sulfate, which many AIDS patients have been acquiring from Japan and taking on their own, also inhibits AIDS virus uptake in laboratory tests. Clinical trials to date, however, have not found any therapeutic benefits when the drug is taken orally, apparently because it is not absorbed from the digestive tract.

A third category of drugs acts at the end of the viral life cycle, inhibiting the assembly or maturation of the viral particles. Castanospermine, a product of the Australian chestnut tree, belongs to this category. A phase I trial of a castanospermine derivative (SC-48334) made by G. D. Searle & Company is to begin in the next few months.

Hypericin, an antiviral chemical from the common flowering plant Saint-John's-wort, apparently also inhibits a late step in AIDS virus maturation in laboratory tests. Daniel Meruelo of New York University Medical Center, who is studying hypericin, says that discussions with the FDA about putting hypericin into clinical trials will be held later this spring but it will be some weeks before any decisions are made.

Researchers are also looking for compounds that inhibit the viral protease, an enzyme that releases the individual proteins from which the virus is assembled. Another strategy is to try to prevent synthesis of the viral proteins in the first place by tying up the messenger RNAs that direct protein synthesis. Neither of these approaches is ready yet for clinical testing.

Finally, several natural human products that bolster antiviral defenses or the immune system are in clinical trials. These include Imreg-1, interleukin-2, and the virus-fighting interferons. Another protein, granulocyte-macrophage–colony stimulating factor, may be useful for counteracting AZT's toxic effects on the bone marrow, which prevent as many as 50% of AIDS patients from taking the drug. ■ **JEAN L. MARX**

A Few Major Contenders

Drug/Source	Clinical Status	Mode of Action
AZT Burroughs Wellcome Co.	Approved by FDA	
ddC Hoffmann–La Roche, Inc.	Phase II trials	Reverse transcription inhibitor (suppresses viral DNA synthesis)
d4T, ddI, ddA Bristol-Myers Company	Phase I trials	
AZDU Triton Bioscience	Trial to begin in a few months	
Carbovir National Cancer Institute	Trial to begin in early 1990	
CD4 Biogen, Inc. Genentech, Inc.	Phase I trials	Inhibits viral entry into cells
SC-48334 G. D. Searle & Company	Trial to begin in a few months	Inhibits viral maturation