News & Comment

Reading the Future in Loma Prieta

October's earthquake was disastrous enough, but its successful forecast and the lessons of history suggest worse is in store, perhaps within the next decade

TO SEISMOLOGISTS WHO ACCURATELY predicted the location and size of last week's earthquake years before it happened, the Loma Prieta earthquake looks like only the first in a succession of damaging quakes in a time of higher seismic activity in northern California.

Scientists at several research centers are concerned that the devastation that hit the San Francisco Bay Area may echo the high earthquake activity that rocked the same area during the 19th century. Even as they watch the Loma Prieta aftershocks begin to fade away, researchers are mulling over two equally disturbing possibilities: One is that a historical pattern of large, paired quakes—involving faults on the San Francisco (Peninsula) and the Oakland (East Bay) sides of the Bay—may be about to repeat itself. If it does, the East Bay would be the next site of a large, but not enormous, shock, perhaps within a few years. The second possibility is that the stress between tectonic plates on the Peninsula side has now been increased significantly by the slippage in the Prieta area to the south, causing the segment of the San Andreas fault running toward San Francisco to be the next to rip.

"We're not looking for a repeat of the great 1906 San Francisco earthquake yet, but it won't matter," says seismologist Allan Lindh. "As horrible as this one is, it's just nothing compared to when we get an earthquake this size in the urban areas [farther north]. It's really going to be dreadful."

Nineteenth-century residents of the Bay Area had a taste of what the coming years may hold. The 70 years leading up to the great 1906 earthquake saw numerous shocks strike northern California, in sharp contrast to the quiescence for five decades after. The quiet ended in the 1950s, according to Lindh, William Ellsworth, and others at the U.S. Geological Survey field office in Menlo Park, California. They have discerned a distinct shift toward increasing seismicity beginning at that time, and they conclude that, as they put it in their paper, the pattern may "imply that magnitude 6 to 7 earthquakes (such as the 1836 and 1868 earthquakes on the Hayward fault) [on the east side of the Bay] . . . should be expected . . . at the rate experienced in the 19th century." According to the three researchers, this would mean an average of about one magnitude 6 to 7 quake each decade. But because many of the quakes would occur in more populated, heavily developed areas, they would be expected to inflict serious damage and significant loss of life, they say.

The scary part is that in the 19th century, those Hayward fault shocks of about magnitude 6.7 were each matched within 2 to 3 years by ones of magnitude 6.5 to 7 on the opposite (San Francisco) side of the Bay, along the San Andreas. The pattern of fault movement was East Bay (1836) followed by the Peninsula (1838) and then Peninsula (1865) followed by East Bay (1868). The second pair included a Loma Prieta shock similar to the one last week.

Is October's Loma Prieta quake therefore simply the first half of a new pair of major earthquakes, with a sequel soon to appear on the Hayward fault? Even before the question of earthquake pairing came up, a USGS-sponsored working group concluded in 1988 that each of two parts of the Hayward fault, which slices through Oakland and Berkeley, has a 20% probability of creating a magnitude 7 earthquake in the next 30 years. That alone has been something to think about.

Lindh declines to speculate about the possibility of future pairing. But he does note that the 1865–1868 pair was preceded by a cluster of five moderate quakes over 10 years just to the north of where the Hayward forks toward the East Bay as part of a branch system of the San Andreas. It is perhaps no coincidence that seismologists have been following a similar flurry of moderate earthquakes in the same general area, stepping gradually northward since 1979 on the Calaveras fault toward the Hayward. Lindh, David Oppenheimer, and William Bakun at Menlo Park have forecast a magnitude 5.5 to 6 quake in the next few years to continue the progression (*Science*, 21 April, p. 286).

While some thoughts turned to the East Bay, seismologists were also trying to decide whether the Loma Prieta rupture had hastened the failure of any part of the rest of the San Andreas. Lindh and his colleagues at Menlo Park, 40 kilometers south of downtown San Francisco, did not have far to look. The Loma Prieta earthquake broke a segment of the San Andreas extending 50 kilometers northward from San Juan Bautista, placing the northern end of the rupture just 30 kilometers south of Menlo Park. But while a recent rupture can boost the threat from adjacent sections of fault, seismologists immediately discounted any trouble on one section—the part of the San Andreas to the south of San Juan Bautista. There, the two sides of the fault slip steadily past each other, so that they never stick and then suddenly slip—the kind of motion

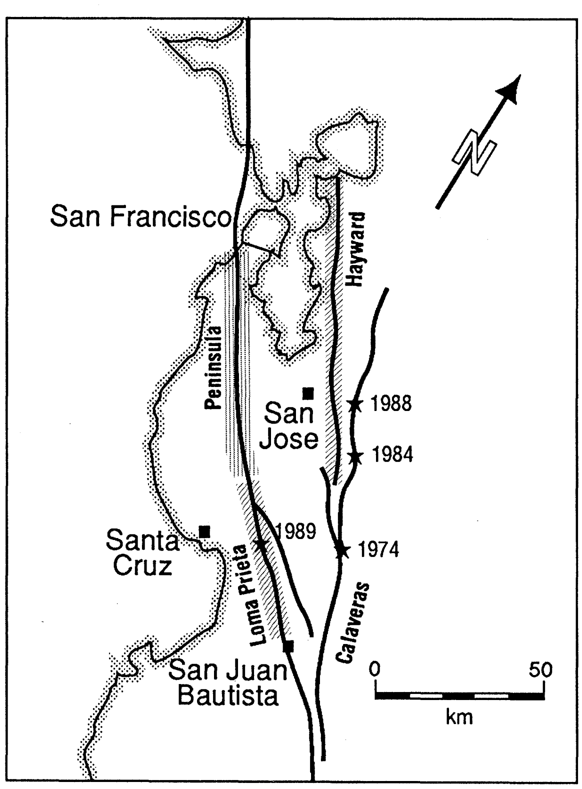

Illustration by Julie Cherry

The target area. *The San Francisco Bay Area is embraced by faults that were quiet after the great 1906 earthquake but began to come to life in the 1950s.*

that creates major earthquakes.

To the north of the recent Loma Prieta break, though, along the San Francisco Peninsula toward Menlo Park and downtown, things do not look so good. The San Andreas there has been locked tight since 1906, as had the Loma Prieta segment until last week. This Peninsula segment sweeps by Santa Clara, Palo Alto, Menlo Park, and San Mateo, to San Francisco's doorstep. Whether it will soon fail, too, or will wait a century or more to break as part of the next great earthquake is a question that is being debated. But even the most conservative observers are now giving the possibility of a second Loma Prieta–like earthquake a lot more thought.

"This [earthquake] clearly has increased the stress on the remaining 50 kilometers of the fault," says Wayne Thatcher of the USGS in Menlo Park. "The probability [of it rupturing] has certainly gone up."

Determining just what the probability is for another sizable San Andreas quake—this time closer to San Francisco—involves a calculation much like the one used to figure when a traveler will arrive at his destination. You have to know when he left, how fast he is moving, and the distance to the destination.

In the case of the San Andreas, the traveler is the crustal plate to the west of the fault, carrying northwestward with it Santa Cruz and the coast. Its speed past the rest of North America is 1 to 2 centimeters per year, on average. Unlike most travelers, globe-girdling plates move steadily while their edges that meet at a fault can snag and stick. Sticking edges only catch up with the plates during the moment of an earthquake, as the snag breaks and the edge snaps back. The last time the Peninsula segment moved was during the 1906 quake, so in a sense its next trip, the one that will end in its next rupture, began then. The third essential number, the length of the trip, is the distance that the sides of the fault slip past each other during a quake, which is a matter of some meters.

The recent Loma Prieta earthquake has done much to validate this approach to the long-term prediction of earthquakes, but, unfortunately, neither the amount of slip in 1906 nor the average slip rate on the Peninsula segment of the fault is well known. The uncertainties in such essential information were only too obvious in recent years as conflicting forecasts for the Loma Prieta segment appeared in print. In 1983, Lindh suggested that the 45 kilometers of fault north of San Juan Bautista had a 47% probability of failing during the next 30 years and creating a magnitude 6.5 quake. In 1985, Christopher Scholz of Columbia University's Lamont-Doherty Geological Observatory weighed in, predicting an equally probable 75-kilometer break. The next year Thatcher countered that Scholz's 75-kilometer segment had only a low probability of breaking. The debate hung on one uncertain number—how much slip occurred in 1906.

In the summer of 1988, the USGS working group sorted through the same conflicting data and used the same basic technique to reach a consensus about the probabilities of large quakes striking the San Andreas (*Science*, 22 July 1988, p. 413). For a 30-kilometer Loma Prieta segment, it found a 30% probability that it would generate a magnitude 6.5 shock during the next 30 years. That was one of the highest probabilities for any part of the San Andreas, but it was assigned one of the lowest levels of reliability.

Some of this uncertainty began to dispel this summer, at least for some researchers, when the second of two magnitude 5 shocks struck the San Andreas at the northern end of Lindh's forecasted rupture (*Science*, 18 August, p. 704). At the time, Lindh was quoted as saying: "Now we've had two of these magnitude 5's where we didn't have anything. I thought it was a dangerous segment before anything happened; I can only be reinforced in that feeling now."

"The earthquake Al Lindh forecast took place," says Thatcher. "It really was a vindi-

Bad Vibes at Stanford

Major corporate and academic research facilities in the San Francisco area survived last week's Loma Prieta earthquake in remarkably good shape. But buildings on Stanford University's main campus suffered up to $160-million worth of damage, according to a preliminary estimate issued by university president Donald Kennedy 3 days after the quake struck.

Stanford may have to foot the bill for the repairs itself. The university's earthquake insurance was canceled in 1985 when insurance companies pulled out of a lot of high-risk policies. The university subsequently established a special earthquake fund, but it contains only $3.5 million, says Robert Beth, director of risk management. Stanford is not alone: Beth says no California university currently has earthquake insurance.

The damage was confined mostly to older buildings, including two sandstone structures built in the late 19th century that were already closed for remodeling. Most newer buildings, including the Beckman Center, suffered just superficial damage, Beth says.

The quake also hurled fragile equipment and glassware from shelves and benches in many Stanford labs. But there was at least one saving grace—electric power was maintained, so cultures and other materials stored in freezers were preserved.

In contrast, the Berkeley and San Francisco campuses of the University of California suffered relatively minor structural damage. One telling indication: the Lawrence Berkeley Lab's synchrotron was up and running the day after the quake hit.

The Stanford Linear Accelerator Center (SLAC) also came through virtually unscathed, thanks in part to the fact that it sits on what is essentially a single granite slab. At worst, a few magnets may have to be realigned, says SLAC spokesman Michael Riordan. ■ COLIN NORMAN

Stanford University

Quake debris. *A typical lab in the Stanford Medical Center.*

cation of the long-range approach we've taken." The Loma Prieta earthquake broke the first 50 kilometers of fault, reaching a bit north of the point Lindh predicted, but the rupture was contained within the nearly uninhabited Santa Cruz Mountains.

Given this vindication, some seismologists are once again tackling a long-range forecast for the Peninsula segment, uncertainties or no. The USGS working group had estimated that the Peninsula segment had a 20% probability of generating a magnitude 7 shock during the next 30 years, compared with 30% for Loma Prieta. The earlier debate on Loma Prieta reveals how seismologists would like to revise this risk estimate for the upper Peninsula. Scholz sees the rupture of the first 50 kilometers of his 75-kilometer segment justifying his entire analysis. "I would upgrade the remaining 25 kilometers," says Scholz, to the next-to-highest probability category possible, something between 50% and 90% probability of failure during the next 30 years. More subjectively, "it's likely in the next 5 years," he says.

Thatcher doubts that. "I'd be surprised if it ruptured, but certainly we should keep an eye on it." Unlike Scholz, who relies on 1906 slippage as revealed in fault movement at the surface, Thatcher prefers surveys of crustal distortion, which reflect slippage deep within the fault. Thatcher's geodetically determined movement appears to be so large that the fault would not rupture again until the next great earthquake, perhaps a century or more from now.

Lindh, who has one good call to his credit, takes a middle ground. "We clearly got an increment of strain added [to the Peninsula segment] by this earthquake. We've got to worry about it. Whether we have to upgrade the probability, I don't know." However, he points out that if the actual distance traveled during the 1906 slip is much below Thatcher's estimate, and if the slip rate is at the high end of current estimates, "the arithmetic starts getting scary." Lindh sees a possibility that the segment that could fail is 50 to 70 kilometers long, not just Scholz's 25 kilometers, which would make for another magnitude 7 ripping right up to San Francisco.

Although this reading of seismic entrails leaves something to be desired, it is likely to provide the best forecast available for many years. And while the debate on the timing and location of the next big event will continue, the Loma Prieta tragedy has already strengthened one grim prediction on which geologists agree: The San Francisco Bay Area faces a new, increased likelihood of being hit by severe earthquakes.

■ RICHARD A. KERR

Japan Boosts Genome Research

After a lumbering start, the Japanese government is picking up the pace of its various genome initiatives. Several new programs have been launched in the past few months and another is slated to begin next year, reported Nobuyoshi Shimizu of Keio University School of Medicine at the recent Human Genome I meeting in San Diego.

But, while Japanese spending is up, it is still just a fraction of the $90 million the United States has committed to its genome projects at the National Institutes of Health and the Department of Energy for next year. Said Shimizu: "Our bureaucracy goes very slowly, no matter how hard you push."

Moreover, efforts remain fractured among several different agencies, which are all vying for a lead role. In fact, the interagency rivalries in Japan make the early turf battles between NIH and DOE here seem tame by comparison.

Human Genome Program. The core of Japan's efforts is the new Human Genome Program launched by the Ministry of Education, Science, and Culture about 2 months ago, said Shimizu, who is involved in the program. Directed by Kenichi Matsubara of Osaka University, it involves researchers at 30 different institutions. Although the budget, at $4.5 million for the first 2 years, is still small, Shimizu expects a tenfold hike in the next budget cycle.

As now envisioned, the program will focus on five areas. The first is human genome analysis, which includes genetic and physical mapping and chromosome analysis.

The second aim is to construct high-quality complementary DNA (cDNA) libraries for specific tissues, such as brain, liver, and heart—an ambitious goal that no other country has taken on, said Shimizu. A cDNA library is a collection of pieces of DNA that correspond to the expressed genes. A mere 5% of the human genome codes for proteins, but that 5%, obviously, is of prime interest both biologically and medically. A cDNA library will allow investigators to home in on these regions first.

Until now the problem has been that not all expressed genes show up in such libraries. Genes that are expressed at very low levels—that is, that make just one or a few copies of messenger RNA—are typically underrepresented. The Japanese program will focus on new methods to "amplify" these rare genes so that all the expressed genes are equally represented in the library.

The third area focuses on innovative DNA sequencing technologies—not improvements to the current generation of sequencing machines, said Shimizu, but entirely new approaches.

The fourth area includes both efforts to improve existing databases and to devise new software for genome analysis.

Finally, as in the United States, the Japanese program will focus on obtaining the maps and sequences of model organisms, such as nematode, *Drosophila*, or certain plant species. An ambitious project to se-

Congress Set to Pass R&D Budgets

Although Congress is still trying to decide how to bring the 1990 budget deficit down, the funding picture for the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) is becoming clearer. A House-Senate conference committee has finally agreed on appropriation levels for the agencies—2 weeks after the start of the new fiscal year.

NSF is slated to receive $2.07 billion, up from $1.9 billion in 1989. While overall agency funding increases 10%, NSF's research spending account rises just 7% to a total of $1.69 billion. As expected, science education received more than the $190 million requested by the Administration—$206.7 million. Another $153.6 million is appropriated for NSF's Antarctic research program.

NASA is to have its budget increased to $12.4 billion, a large boost from the $10.9 billion in 1989. Funding for the space station is $1.8 billion, which is $200 million less than NASA sought from Congress. The budget for construction and operation of the space shuttle orbiter is $3.4 billion, $425 million below NASA's request.

As *Science* went to press, the budget picture for NSF and NASA remained clouded by the possibility that the funding bill covering independent agencies and the Department of Housing and Urban Development (HUD) could be amended. A possible change in one HUD program could require an across-the-board reduction of 1% for all agencies covered in the giant appropriations bill. NSF, NASA, and other research agencies may face additional reductions when Congress decides how it wants to reduce the federal deficit. ■ M.C.