Geophysics from Triton to the Deep Blue Sea

Geophysics is closing out the 1980s with a bang. October's Loma Prieta earthquake grabbed the spotlight at this month's American Geophysical Union's annual fall meeting in, of all places, San Francisco; the quake also closed down one of the official hotels, depriving hundreds of the 4500 attendees of rooms. Other hot topics of the late 1980s—Voyager's tour of the outer solar system and the greenhouse effect—got their share of attention as well.

New Quake Forecast: North by Northwest

While Los Angeles braces for its Big One and San Francisco recovers from its not-so-gentle reminder of what is in store for the Bay Area, Seattle and Portland might consider what awaits them. They are not in danger of being torn asunder by the San Andreas—that fault heads out to sea south of the Oregon border. Nor have they endured a big quake in the 200 years of their recorded history. But the Pacific Northwest sits atop a different sort of fault, the same sort that shakes up Japan and Alaska, and some geologists believe that giant quakes have happened there in the past and will again.

"The majority of people I've worked with agree that it's not a matter of whether they happened but how they happened," says geologist Gary Carver of Humboldt State University in Arcata in northern California. "There's just too much physical evidence."

Much of the physical evidence is preserved in the muck along the Pacific Northwest coast. Geologists discovered some of the evidence along 220 kilometers of Washington coast a few years ago (*Science*, 9 January 1987, p. 166), but those results were only suggestive. Now that initial evidence has been considerably strengthened. A number of groups have found alternating layers of peat and mud in estuarine sediments from northern Washington all the way to northern California, a distance of 700 kilometers.

Such a pattern indicates that the land had suddenly subsided and been submerged by the ocean. That is just what happens during great earthquakes along a coast beneath which an oceanic plate is sinking—the very process the Pacific Northwest is experiencing. "We all feel they [had] to be magnitude 8 earthquakes or larger to cause perceptible subsidence," says Wendy Grant of the U.S. Geological Survey at the University of Washington, who presented results for a consortium of four different groups.

In addition to sudden subsidence, great coastal earthquakes can cause tsunamis, and geologists have also found evidence that these have struck the Northwest. The evidence is thin sand layers lying just above the subsided peat layers. According to Mary Reinhart and Joanne Bourgeois of the University of Washington, the sand layers at sites along 220 kilometers of the Washington-Oregon border look so much like those laid down in Chile by tsunamis generated by the great 1960 Chile earthquake that they were almost certainly caused by one or more tsunamis.

Although there are skeptics who say that great earthquakes remain unproven in the Pacific Northwest, a consensus seems to be emerging—Californians are not alone in living on uncertain ground.

Loma Prieta Quake Unsettles Geophysicists

Nothing can stop the inevitable rending of rock that is an earthquake, but a little warning would be nice. Unfortunately, October's Loma Prieta earthquake was not that considerate. No one had an inkling that it would strike. Of course, there were signs that a large earthquake would some day break the 32-kilometer section of the San Andreas south of San Francisco, but "someday" could have been years or even decades away (*Science*, 18 August, p. 704). Of the short-term precursors, there were none.

Well, maybe one. There certainly were none of the conventional precursors, such as foreshocks, but, in hindsight, there was a curious series of fluctuations in the radio noise that pervades the atmosphere. Was this an unconventional short-term warning? Researchers wonder, and hope.

The shock that struck the Bay Area on 17 October certainly dashed any hopes that California's networks of conventional instruments would capture precursors to the next large earthquake. The most disappointing failure, geophysicists say, was their inability to detect any deformation of the rock surrounding the fault just before the quake struck. Theory and laboratory experiments had suggested that the slow distortion of the rock that accompanies the decades-long buildup of stress along a fault accelerates in the days or weeks before the fault fails.

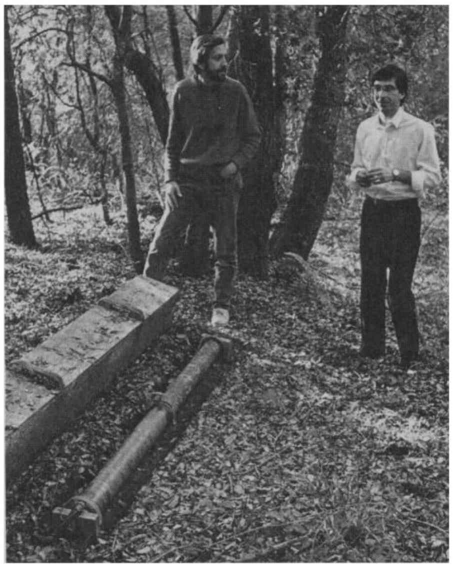
So, geophysicists hoping to catch this most fundamental of earthquake precursors had set out instruments at the bottom of boreholes to measure rock deformation with a sensitivity as great as one part in 100 billion. One instrument was 35 kilometers from the epicenter of the Loma Prieta quake and 10 kilometers beyond the southern tip of the eventual rupture. That put it closer than any such instrument had ever been to a good-sized earthquake, researchers say.

But it didn't help predict the earthquake. "We did not see anything," says geophysicist William Prescott of the U.S. Geological Survey. "It is fair to say it was not encouraging." If there was any crustal distortion occurring, it was small—involving the gradual release of less than one-thousandth of the energy of the earthquake itself—and was probably confined near the deeply buried spot where the rupture started.

This latest shot at catching an earthquake just before it happens may not have panned out, but researchers should have another, perhaps decisive, opportunity on the San Andreas near the tiny town of Parkfield. They expect only a magnitude 6 quake there (*Science*, 8 January 1988, p. 145), but a system for measuring rock deformation sits right on top of the spot where the rupture should begin. Malcolm Johnston of the USGS in Menlo Park, who operates some of the instruments there, anticipates that they will be able to detect the expected deformation if the fault ruptures. If Parkfield fails to produce a short-term precursor, he says, "that would imply earthquakes are runaways that start in a tiny area [of the fault] and grow outward." Earthquake precursors would then be scarce indeed.

But what about those radio noise signals? Antony Fraser-Smith and his colleagues in electrical engineering at Stanford University had no intention of getting into earthquake prediction when they set up their ultralow-frequency radio receiver just 7 kilometers from the eventual epicenter. It was just a convenient place to get away from San Francisco's radio-frequency pollution to study sun-related radio noise that could interfere with submarine communications.

But when they happened to check their data several weeks after the earthquake, they found something unusual in the 0.01 to 10-hertz frequency range. About 12 days before the earthquake, the radio background noise



Stanford University

RF oracle? *Did this remote radio receiver "see" the Loma Prieta quake coming?*

at all frequencies in that range went up. It dropped about 1 day ahead and then shot up to 30 times its previous level during the 3 hours before the earthquake. The Stanford group had seen nothing like these episodes in 2 years of monitoring.

Researchers in earthquake prediction are intrigued but cautious because of all the questions that remain. Are these radio anomalies connected to the earthquake? The juxtaposition of the third anomaly and the earthquake would suggest so. Would all earthquakes produce such precursors? How are they produced? And, most important, when will researchers get another chance to record them? Other sorts of cryptic anomalies have preceded earthquakes and not proved out, but researchers are still open to the possibility that radio waves might give them a view into deep-seated fault processes.

A Geologically Young Triton After All?

When did the deep-seated volcanoes on Neptune's moon Triton stop spewing streams of icy "magma" onto its surface? The answer ranged from billions of years ago to mere millions in the hours and days after Voyager 2 returned the first images of the moon's surface last August. Now, the instant science of the encounter has given way to more contemplative science and a consensus favoring the relatively recent death of volcanism on Triton—if it died at all.

"I'll go out on a limb," says Torrence Johnson of the Jet Propulsion Laboratory in Pasadena, "and say that I wouldn't be surprised if such activity is current, geologically speaking." Maybe some occurred as recently as a million years ago, he hazards.

The new found wide acceptance of the idea that volcanoes recently resurfaced Triton is something of a surprise in view of the diversity of opinion during the encounter (*Science*, 1 September, p. 928). The shift toward young volcanism came when researchers made a closer count of the number of craters formed by the impact of the outer solar systems's steady rain of comets on the moon's surface. "Craters on Triton are scarce," says imaging team co-leader Lawrence Soderblom of the U.S. Geological Survey in Flagstaff. That means that the frozen lakes, smooth plains, and wrinkled terrains of Triton must have formed not so long ago when ice deep below the surface melted, rose, and flowed onto the surface in a volcanic eruption.

"They are probably right" about relatively young volcanism, says planetary physicist David Stevenson of the California Institute of Technology. During the encounter, he had held out for older volcanism on a now inactive moon. "You probably are seeing the effects of water-ammonia volcanism," he says. This mixture melts at particularly low temperatures, making it the most likely candidate for the volcanism's "magma."

But where could enough heat come from to form even an icy magma on a tiny body billions of years after its formation? Stevenson had doubted that enough deep internal heat remained to drive true volcanism.

Recent Voyager data showed, however, that rock makes up a hefty two-thirds of Triton's mass. Thus, the heat could have come from the radioactive decay of the isotopes of uranium, thorium, and potassium that the rock carries. "There's probably a lot of heat available" in Triton's interior, says Johnson.

All this is quite a revelation after years of squinting at the point of light that was the pre-encounter Triton. But problems remain. "The real challenge is determining how and when the resurfacing takes place," Stevenson says. For that, researchers may need another spacecraft to orbit Neptune, a mission that is at least decades away.

Bringing Down the Sea Level Rise

Many coastal property owners—though certainly not all—would have gotten quite a lift had they attended last week's AGU meeting. Researchers consulting their crystal balls for a view of the greenhouse world of the mid-21st century reached an informal consensus that global warming will raise sea levels much less than had been predicted.

When glaciologist Mark Meier of the University of Colorado compiled the new results presented in nine separate talks in a special sea level session, he found that they yielded a rise of about one-third of a meter, give or take 0.4 meter, by the year 2050. Only a few years ago, experts writing a report for the National Research Council anticipated that sea levels would go up 0.5 to 1.5 meters.

Just how relieved you are about the revised prediction will depend on where you live. On average around the globe, a one-third meter rise would push shorelines back 30 meters, which would be quite a relief compared to the 100 meters once expected. But in low-lying areas like Louisiana or Bangladesh, even a rise of one-third of a meter would be disastrous.

The change in projections is largely attributable to new views on the effects of global warming on glaciers, especially in Antarctica. Researchers now think that one response to a warming will, in fact, be the net *growth* of some glaciers. For instance, they concluded that the Antarctic ice sheet will most likely accumulate snow faster than it loses ice, thereby tending to lower sea levels by 10 to 50 centimeters.

The key to this counter-intuitive effect lies in the air that blows across Antarctica. It is very cold and thus very dry. But the warmer it becomes, the more water vapor it can carry in from outside the continent. And more water in the air means more snow. As long as temperatures do not get warm enough to melt the snow in summer, which will not happen in Antarctica even with greenhouse warming, snow accumulation will increase. Researchers' reevaluation of future water vapor transport accounted for much of the drop in the estimated sea level rise.

Geophysicists have also reevaluated the effects of atmospheric warming on the smaller West Antarctic ice sheet, which normally slides slowly into the sea. Were the sheet to slip too quickly—and glaciologists had feared that the warming would accelerate the process—the sea level would rise a meter or two in a few decade. But it now appears that the response of the West Antarctic ice sheet to rising temperatures is slower than expected. That puts any catastrophe off for at least a few centuries.

From these adjustments made at the meeting, Colorado's Meier concludes that the warming of the Antarctic will actually lower sea level as much as half a meter rather than raising it as much as 2 meters, as scientists used to predict. By adding in new estimates of warming effects on other aspects of glacier dynamics, Meier came up with his modest but significant rise of one-third meter. Make your beach plans accordingly. ■ RICHARD A. KERR