Old Faithful Not So Faithful Anymore

For 90 years, Old Faithful geyser lived up to its name, erupting about every 65 minutes on average. But during the past 25 years, three major earthquakes have occurred outside Yellowstone National Park and have apparently knocked Old Faithful as well as other geysers and hot springs out of kilter.

At the fall meeting of the American Geophysical Union (AGU) held 3 to 7 December in San Francisco, Roderick Hutchinson of the park staff reported that the most recent jolt—the magnitude-7.3 Borah Peak, Idaho, earthquake of 20 October 1983—changed Old Faithful's average eruption interval from about 69 minutes to 74.5 minutes by December of that year and to 77.5 minutes by the following March. Old Faithful now seems to be partially recovering.

Hutchinson suspects that the lengthening of the cycle is due to a partial diversion of near-surface hot water. But seismologists hesitate to attribute that to a change in stress induced by earthquakes 50 to 240 kilometers away, although concerted stress changes across such distances have been seriously considered elsewhere (*Science*, 12 June 1981, p. 1258). How the relatively minor shaking that was felt at the geyser could gradually lengthen the cycle is not clear either.

Prospects for Short-Term Earthquake Prediction

Research is obviously heading in the right direction to determine whether short-term earthquake prediction is practicable, noted one speaker; looking ahead, another explained why in the end some earthquakes may be found to be very difficult or impossible to predict.

William Ellsworth of the U.S. Geological Survey in Menlo Park, California, speaking to a luncheon gathering of the AGU's seismological section, noted a new optimism about earthquake prediction research. Not that short-term prediction is right around the corner; rather, recent developments have led researchers "to important experiments that will get us to the bottom of this," Ellsworth said.

Prominent among these encouraging developments are detailed, testable hypotheses concerning how real earthquake faults operate. One component of this new realism is asperities, spots on the fault that are stronger than the surrounding fault and thus may play a central role in the fault's failure. Another crucial development is the increasing usefulness of long-term predictions based on the timing of past earthquakes. Long-term prediction has allowed researchers to concentrate their scarce resources on the sections of fault that are liable to rupture sooner rather than later, noted Ellsworth.

The current focus for attention is the Parkfield section of the San Andreas fault (*Science*, 6 January 1984, p. 36), where asperities delineate a segment that has "a very high probability of failing within the decade," Ellsworth said. But he cautioned that, although "we are on the verge of some very important progress," at least several Parkfield-type experiments will probably be needed even to begin to settle the question of short-term prediction.

Once those experiments are in hand, researchers may well find that many earthquakes cannot be predicted, said Nafi Toksoz and John Nabelek of the Massachusetts Institute of Technology in a technical session paper. The problem they foresee is that predicting the precise time of an earthquake will probably depend on the recognition of precursory phenomena induced by the increasing stress on the fault. If the stress must reach a certain threshold in order to induce precursors, as seems reasonable, the most likely place to find precursors would be at an asperity, where stresses are highest.

But, as first pointed out by James Brune of the University of California at San Diego, this early warning could be short-circuited. The fault could first rupture somewhere other than at the asperity, at a place where stresses may be too low to cause recognizable precursors. It could then propagate along the fault to break the asperity. A short, low-energy rupture for which no warning can be expected could thus snowball into a major earthquake.

Toksoz and Nabelek believe that they now have clear examples to support the existence of both predictable and unpredictable earthquakes. Neither the 1984 Morgan Hill nor the 1979 Imperial Valley earthquake was preceded by precursors, they point out, and both released the largest proportion of their energy nearer the rupture's termination than its initiation. That suggests to them that these unheralded ruptures began in areas of lower stress and propagated into high-stress regions. In contrast, earthquakes in 1976 and 1984 in the Gazli region of the U.S.S.R. apparently began at high-stress asperities, they said. Both produced precursors noted before the events, one a release of radon gas and the other a series of foreshocks.

Seismic Reflections from the Deep Mantle

Seismic reflection profiling can detect structure in the earth's mantle below a depth of 50 kilometers, but detectable structure may be the exception at those depths. That at least is the preliminary conclusion of the deepest such probing of the mantle, completed last summer west of the Orkney Islands, Scotland.

Drummond Matthews and Susan McGeary of the University of Cambridge and the British Institutions Reflection Profiling Syndicate (BIRPS) reported at the AGU meeting that BIRPS' latest profile—called DRUM, for Deep Reflections from the Upper Mantle—achieved a great depth of penetration because a seismic source having four times the normal power was used and a full 30 seconds was allowed for the return of echoes. That was long enough for echoes from a depth of 115 kilometers to reach the receivers. After preliminary processing, no coherent reflections from that great a depth appeared.

The DRUM profile also failed to reveal any pervasive deep-mantle layering. Other surveys had shown that the upper crust tends to appear transparent to seismic profiling, whereas the lower crust is often cluttered by more or less horizontal reflectors. Below the Moho, the boundary between the crust and mantle, the reflectors disappeared. If this changing reflective character is a response to changes in temperature, pressure, and composition with increasing depth, the reflectors might have been expected to return at depths not probed before. They did not.

The DRUM profile does contain reflectors at greater depths than ever detected before. The Flannan fault can now be traced from a depth of 27 kilometers, through the Moho, to a depth of about 70 kilometers before it apparently peters out. A 100-kilometer-wide, more nearly horizontal feature lies above the thrust at a depth of about 50 kilometers. There is also a 10- to 15-kilometer-long, nearly horizontal reflector at a depth of about 80 kilometers. What these reflection features actually are may become clearer as processing of the reflection data becomes more complete.

Caldera Watching Continues Here and Abroad

Several calderas, the scars of ancient cataclysmic volcanic eruptions, continue to hold the attention of geophysicists attempting to understand and, if possible, predict caldera behavior. According to several presentations at the AGU meeting, Long Valley caldera near Mammoth Lakes, California, continues to slowly inflate, apparently driven by the deep injection of magma.

The possible shallow intrusion of magma at Long Valley remains controversial. Terry Wallace of the University of Arizona and William Savage and Jeffery Barker of Woodward-Clyde Consultants, Pasadena, suggested, however, that such intrusions did not produce the major Mammoth Lakes earthquakes of 1980. Restudying the nearby earthquake series of 1941, they refined its position and found that it fell on the line formed by the 1980 series. But in 1941 there had been no broad inflation such as began about 1979. From this they inferred that the major 1980 earthquakes just south of the caldera were driven not by magma injection but by regional crustal extension, which would be consistent with their simulation of one of the 1980 earthquakes by multiple fault ruptures alone.

Over at Yellowstone caldera, slow inflation continues as well. Suzzette Jackson and Robert Smith of the University of Utah and Ted Olsen of Snow College in Ephraim, Utah, reported that the average uplift of about 17 millimeters per year measured for the period 1923 to 1977 continued through 1983, adding as much as 10.5 centimeters in height between 1977 and 1983.

At Rabaul caldera, Papua New Guinea, seismic activity and uplift continue but at rates below those of the crisis situation of the past year or two. Still, uplifts of five or more centimeters per *month* continue on land that juts toward the center of the ocean-flooded caldera. Suspecting even more activity in the center of the bay, Gary Greene of the U.S. Geological Survey in Menlo Park, D. Tiffin of the United Nations in Suva, Fiji, and C. McKee of the Volcanological Observatory, Rabaul, surveyed the submerged caldera floor and found what appear to be the very beginnings of a new volcano. A sea-floor bulge flanked by faults and slumping sediment sits in the middle of an encroaching ring of shallow seismicity, suggesting a shallow intrusion of magma.

Strontium Isotope Dating Achieves Useful Precision

At the AGU meeting, researchers presented the latest record of the changing strontium isotope composition of seawater, which can now be used to date some marine sediments laid down during the past 100 million years with unprecedented speed and accuracy.

Marine strontium isotope records had been expanding only incrementally until William Burke and his colleagues at Mobil Research and Development Corporation in Dallas published their extraordinary record—786 samples spanning the past 525 million years. In a way that only a major oil company could, the Mobil group traced a steady but uneven fall in the ratio of strontium-87 to strontium-86 that continued from near the Precambrian to about 150 million years ago. Then the ratio began a steadier rise to its present value. The broad dip and its superimposed squiggles tell the story, as yet not entirely deciphered, of a changing mix of strontium sources for the ocean that includes varying erosion of the continents and leaching of ocean crust by mid-ocean hot springs.

Unfortunately, like many of the contributions of oil companies to the open literature, the Mobil curve has some serious limitations. No isotopic values or ages were provided, and the samples are without documentation beyond a listing of which continents or ocean basins they came from.

The curve for the past 100 million years presented by Jennifer Hess, Michael Bender, and Jean-Guy Schilling of the University of Rhode Island (URI) traces the same trends as the Mobil curve but with somewhat less scatter. The ratio as determined from 130 microfossil samples recovered by the Deep-Sea Drilling Program first rose to a modest peak 66 million years ago (the time of the Cretaceous-Tertiary boundary), fell slightly, and then rose steadily until about 15 million years ago (a time of major Antarctic glaciation) when the rate of rise moderated.

The high precision of the URI curve should provide new precision in the dating of some marine samples. The improved results can be attributed to the particular care with which samples were checked for alteration that might have changed the isotopic ratio. The checks included scanning electron microscope inspection and chemical analysis of the samples and isotopic analysis of the surrounding pore water. With this precision, the URI group believes that sediment samples 15 to 40 million years old and perhaps those 66 to 100 million years old can be dated with a precision of 1 million years. That is significantly better than the precision of 3 to 4 million years achieved in some time intervals by the identification of microfossil species.

In related work, Donald DePaolo and Bonnye Ingram of the University of California at Los Angeles have further increased the possible precision of strontium isotope dating by refining the isotopic analysis itself and by analyzing larger amounts of strontium per sample. On the steep part of the curve between 10 and 40 million years ago, their precision can reach 0.1 million years, DePaolo says, equaling the best precision of the slower paleomagnetic dating technique.

—RICHARD A. KERR