An Encouraging Long-Term Quake "Forecast"

The anticipation of the size and location of last April's Morgan Hill earthquake was two-thirds of a prediction; predicting a precise time remains out of reach

There was no prediction in it when published in 1980. Instead, the paper was a scholarly discussion of how the jogs and bends in the trace of a section of the Calavaras fault near San Jose, California, might control the earthquakes on the fault. But embedded here and there were oblique references to where the fault could first rupture and where the rupture might stop. And there was a clear statement that the past and present behavior of the fault suggested that an earthquake of magnitude 6 would strike there.

On 24 April 1984 the anticipated earthquake (magnitude 6.1) struck (see page 288 for a detailed report), causing $7.5 million in damage in and near the town of Morgan Hill. Seismologists regard this very modest though welcome success in earthquake forecasting as further evidence that similar earthquakes can strike the same section of a fault repeatedly at more or less regular intervals. Thus, it appears increasingly reasonable to look at other sections of the San Andreas and its branches to see where future earthquakes are most likely to strike. This time the interest is more than academic. The Morgan Hill earthquake may be the latest and largest event in a resurgence of moderate earthquakes in the San Francisco Bay area.

The 1980 paper (*1*) by William Bakun of the U.S. Geological Survey (USGS) in Menlo Park was intended to support his contention that what a geologist sees of a fault at the surface can control how and where the fault breaks at depth. As noted by Bakun and by others, a bend or offset in the trace of a fault should resist the slippage of one side of the fault past the other. Some irregularities would resist better than others, Bakun and his colleagues added. An offset that jumped to the right on the San Andreas would weaken and eventually fail as strain concentrated at it, whereas one that jumped to the left would be squeezed tighter, be strengthened, and act as a barrier to rupture.

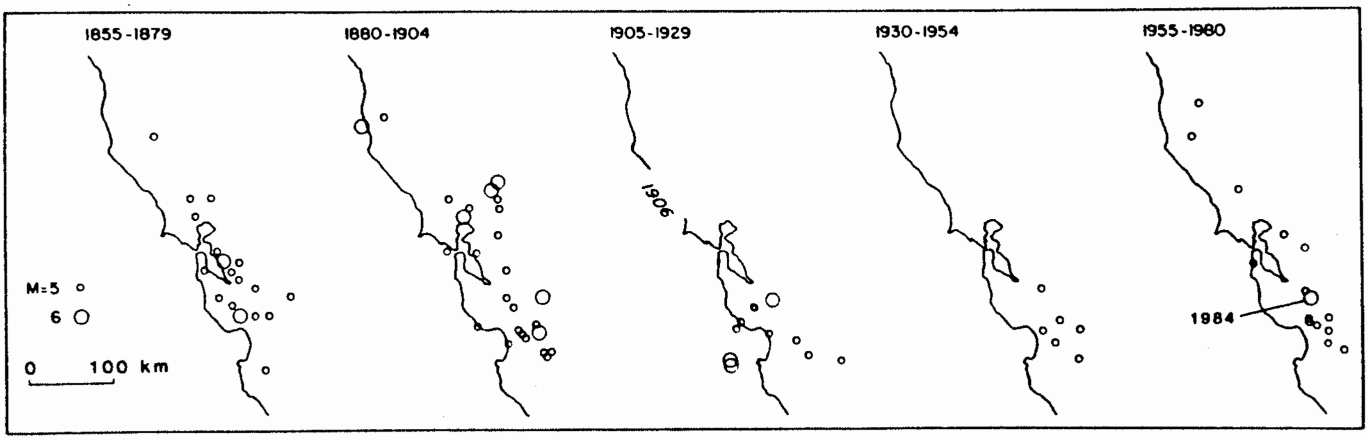
In the course of applying these principles to the southern Calavaras fault after the 1979 Coyote Lake earthquake, Bakun mentioned the locations of irregularities that in hindsight would become some of "the seeds of an earthquake prediction of sorts," to use his own words. A likely point for a rupture to begin was the weakest inference. To Bakun it seemed to be in Halls Valley, where he inferred a weak stuck point or asperity on the fault from the distribution and behavior of smaller earthquakes. The Morgan Hill earthquake began roughly 5 kilometers to the south between that apparent asperity and one recognized since.

The rupture did not make it very far to the northwest, apparently being stopped within a few kilometers or so of Bakun's asperity and a jumble of kilometer-long fault sections that he had identified as a barrier. To the southeast, the rupture seems to have stopped where Bakun had identified an offset barrier. He noted in particular that this barrier had probably been storing strain energy passed on to it from movement on adjacent sections of fault. When released, it would produce a "larger shock." A particularly strong part of the Morgan Hill shock originated near the proposed barrier.

Bakun never explicitly related these fault features to a coming earthquake. He did note that earthquake activity along the 35-kilometer fault section north of the Coyote Lake rupture could accommodate only about 1/60 of the recent motion across the fault. Something would have to give. In 1911 it was the southern 20 kilometers of that section that failed in an event of magnitude 6.1, "suggesting that a shock comparable to the 1979 Coyote Lake main shock [magnitude 5.9] might also occur" there again. About the same length of fault broke this time.

As disjointed as the "forecast" of the 1984 Morgan Hill earthquake was, it does reinforce the feeling that the behavior of earthquake faults makes enough sense that seismologists can consider which fault sections are most likely to rupture next, as has been done for some faults that have not ruptured so recently. The repetition of the 1911 event on a section apparently delineated by geometric irregularities is reminiscent of the earthquake characteristic of the Parkfield section of the San Andreas. That one has repeated perhaps as many as six times since 1857 (*Science*, 6 January, p. 37). It seems increasingly apparent that the concept of a seismic gap—a fault section lacking recent seismic activity but liable to rupture soon—and the concept of a characteristic earthquake—one that repeats on a given section—are applicable to even short sections of fault.

An interesting place to look for gaps



American Geophysical Union (2)

A resurgence of larger earthquakes for the San Francisco Bay area?

This mapping of seismic activity suggests increased activity before the great 1906 earthquake, quiescence after it, and renewed activity since 1955.

and their characteristic earthquakes should be the USGS's own backyard, the San Francisco Bay area. The San Andreas fault cuts right up the San Francisco Peninsula, but it also splays northward into a pair of fault systems of which the Calavaras is a part. These dissect the heavily populated East Bay region. Although the opposing sides of some of these faults appear to be harmlessly slipping by each other, the record of earthquake activity in the 19th century suggests otherwise.

According to historical records, the Bay area was far more active in the 19th century than it has been of late. In 1981 William Ellsworth and his colleagues at the USGS in Menlo Park pointed out that in the 50 years after the San Francisco earthquake of 1906 (magnitude 8) there were far fewer earthquakes larger than magnitude 5 than in the 50 years preceding that great earthquake (*2*).

Recalling the suggestion that great earthquakes are preceded by increased seismic activity and followed by relative quiesence, the USGS group added further weight to an earlier contention that a new stage in that cycle had begun in the Bay area in 1955 when the frequency of earthquakes larger than magnitude 5 seemed to increase. The 1979 Coyote Lake (magnitude 5.9) and Livermore (magnitude 5.8) earthquakes fit that increasing trend, as does the Morgan Hill event. It is the largest since 1911 and, says Ellsworth, is typical of the earthquakes of magnitude 6 to 7 that struck the area about once a decade on average in the 19th century. (An earthquake of magnitude 7 is 32 times more energetic than an event of magnitude 6.)

The Morgan Hill earthquake may have strengthened confidence in the forecasting of earthquakes, but the latest event to be "captured" by geophysical instrumentation provided no encouragement that their timing can be precisely predicted. This earthquake gave no detectable warning, despite a dense seismometer network and geodetic surveys only 1 week and 1 day before the main shock. It was another reminder that even the tiniest of foreshocks cannot be depended on to appear and that present routine geodetic surveys are possibly 100 times too insensitive to catch any premonitory slippage of a moderate earthquake.

—RICHARD A. KERR

Additional Reading

1. W. H. Bakun, *Bull. Seismol. Soc. Am.* 70, 1181 (1980).
2. W. L. Ellsworth, A. G. Lindh, W. H. Prescott, D. G. Herd, in *Earthquake Prediction*, D. W. Simpson and P. G. Richards, Eds. (American Geophysical Union, Washington, D.C., 1981), pp. 126–140.

First mRNA Splicing Intermediate

Seven years ago researchers in several laboratories discovered that many genes in nucleated organisms are interrupted by noncoding regions, called introns. Attempts to discover how introns are precisely excised from messenger RNA (mRNA) precursors have, to many people's surprise and frustration, borne little fruit. A major hindrance in these efforts has been the equally surprising failure to develop rapidly an efficient and reproducible in vitro splicing system, which is essential for experimental dissection of the components and intermediates involved. This barrier has been removed within the last year, and the new first insights into the mRNA splicing system are beginning to be reported.

Phillip Sharp and his colleagues at Massachusetts Institute of Technology (MIT) have just published in *Cell* a description of a "lariat-type" configuration for an excised intervening sequence in their splicing system (*1*). Michael Green, in collaboration with Tom Maniatis at Harvard, discussed a similar observation at this year's Cold Spring Harbor meeting on RNA processing. Until now there has been no unambiguous observation of an excised intron from a mRNA precursor. That the excised intron should be in the form of a lariat is particularly intriguing since such RNA structures are highly unusual.

Precursor RNA molecules have fallen into three classes as far as their splicing attributes are concerned. The first contains transfer RNA's (tRNA), which are tightly configured into striking secondary structures. The precision of intron excision appears to be determined not by sequences within the intron but by the structure of the tRNA itself. In ribosomal RNA (rRNA) and mitochondrial mRNA's splicing appears to depend in part on the presence of four short conserved sequences within the intron. Introns in the third group, nuclear mRNA, are always bounded by the nucleotides GT and AG plus short "consensus sequences," which presumably play a role in recognition of splice sites. Although there has been steady progress in working out the splicing mechanisms for tRNA and rRNA, mRNA processing has remained enigmatic, apart from the almost certain involvement of an additional small RNA species known as U1, part of which is very similar in sequence to one of the consensus sequences.

Using the in vitro splicing system developed in their laboratory last year, Sharp and his colleagues Paula Grabowski and Richard Padgett monitored the dynamics of intron excision from an experimental precursor. The universal failure to isolate excised introns has lead to the belief that normally they are rapidly degraded. As luck would have it, degradation activity in the in vitro system appears to be missing, allowing a glimpse of this elusive species.

While they were analyzing the products of the splicing reaction on various types of gels, the MIT researchers noticed slower than expected migration of several putative intermediates, including the intron itself. Following various manipulations and leaning heavily on the recent observations by Mary Edmonds and John Wallace, of the University of Pittsburgh (*2*), on branched structures in poly(A) molecules, Sharp and his co-workers realized they too might be dealing with a branched RNA molecule. They finally concluded that the branch was part of a lariat configuration. Although the *Cell* paper speculates on the possible addition of a small RNA molecule to the intron as part of the splicing process, Sharp and his colleagues now dismiss this idea and look to the intron itself to form the loop.

The MIT and Harvard results seem to exclude the still current idea that mRNA introns might be excised by attrition—a nuclease nibbling through the sequence. They also indicate that a sequence within the intron might be important in the splicing process, which is interesting in view of the observation that a large proportion of the intron can be removed without preventing splicing.—ROGER LEWIN

References

1. P. J. Grabowski, R. A. Padgett, P. Sharp, *Cell* 37, 415 (1984).
2. J. C. Wallace and M. Edmonds, *Proc. Natl. Acad. Sci. U.S.A.* **80**, 960 (1983).