requires paleoseismologists to find the right spot on the fault. At the Wrightwood site in the San Gabriel Mountains, the fault cuts through a small valley; storm waters carry gravelly debris down into the boggy valley. Researchers have dug more than 40 trenches across the fault in the past decade, exposing the spot where fault ruptures have disrupted new storm deposits as well as the organic-rich bog layers that can be carbon-14 dated.

All told, researchers have identified and dated 27 earthquakes at Wrightwood in two time intervals, 500 C.E. to the present and 3000 to 1200 B.C.E. The fault there has slipped 3.2 centimeters per year on average, Scharer and her colleagues reported at the meeting. That's just how fast modern geodetic measurements say the San Andreas as a whole has slipped, suggesting that the Wrightwood paleoseismic record is not wildly off base.

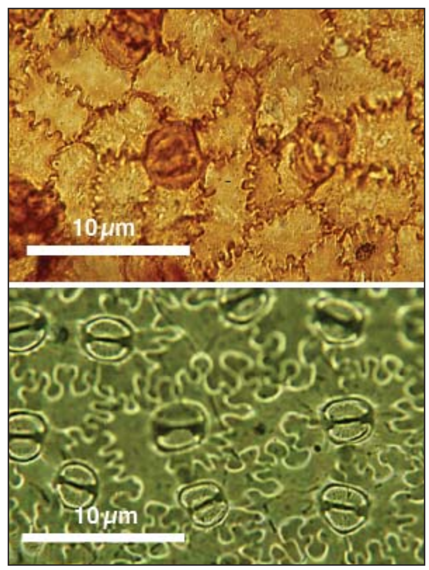
But the earthquakes that rupture the Wrightwood site vary greatly. In the younger time interval, the average time between quakes is about 105 years, but the interval between quakes ranges from 10 years to 224 years. Fault slip per quake ranges from 1 meter to 7 meters. Scharer sees little prospect of predicting the time to the next earthquake at Wrightwood. However, the record is not devoid of pattern. Quakes tend to come more frequently and perhaps be larger for a time, she says, which reduces the strain on the fault. Then quakes tend to be less frequent and smaller, allowing strain to build back up. At the moment, strain is relatively high, according to Scharer's reading of the Wrightwood record, a condition that has typically been followed within a few decades by a very large quake or a flurry of average to large ones.

If most faults behave as erratically as the Wrightwood site seems to, seismologists wouldn't be able to place much faith in their long-term earthquake forecasts (*Science*, 18 June 1993, p. 1724). But forecasting shouldn't be abandoned just yet, says seismologist William Ellsworth of the U.S. Geological Survey in Menlo Park, California. "I would urge caution in interpreting what is an extremely important record" at Wrightwood, he says. For one, Wrightwood may be atypical. The 450-kilometer southern San Andreas is thought to be composed of six segments. If, as some have suggested, the southernmost segments break together in large quakes, the northernmost ones break together in their own large quakes, and all break at once in great quakes, then the central segment bearing the Wrightwood site might get caught up in quakes largely driven from the south or the north, making a hodgepodge of the Wrightwood record. Resolution will come with more long records, says Ellsworth, and a fundamental understanding of how faults work.

Vicissitudes of Ancient Climate

Earth has often swung between chills and fever. Paleoclimatologists generally seek an explanation in swings in the abundance of greenhouse gases such as carbon dioxide (see p. 306), because CO_2 levels have seemed to rise as the world warmed and to fall as it cooled into the great ice ages. But conventional thinking invites challenges, and last year it took a hit when a pair of researchers published an analysis indicating that past CO_2 levels are not closely correlated with long-term climate variations. Now comes the response. At the meeting, paleoclimatologist Dana Royer of Pennsylvania State University, University Park, and geochemical modeler Robert Berner of Yale University reported that an updated record of CO_2 variations during the past 500 million years does indeed produce a good fit between CO_2 levels and both model predictions and one record of major climate swings. "It's a restatement of the importance of CO_2," says Royer. Many, but not all, researchers find it persuasive.

Carbon dioxide was in need of a boost after geochemists Nir Shaviv of the Hebrew University of Jerusalem and Ján Veizer of the University of Ottawa, Canada, published a paper in last July's *GSA Today* in which they found a poor correlation between CO_2 and Veizer's temperature record derived from the oxygen isotope composition of carbonates deposited on the ocean floor. But his isotopic climate record did fit well with the expected variations in the flux of cosmic rays during the past 500 million years. Cosmic rays, they suggested, might have modulated climate by affecting cloud brightness.



CO_2 gauge. The sparser pores (roundish features) on fossil leaf (*top*) show that CO_2 levels were higher 65 million years ago.

CREDIT: BARRY LOMAX/UNIVERSITY OF SHEFFIELD, U.K.

Royer and Berner weren't convinced. First they updated the record of atmospheric CO_2 levels. This 450-million-year record is based on measurements of atmospheric CO_2 preserved in the geologic record, including the carbon isotopic composition of fossil soil carbonates and the abundance of gas-exchange pores on fossil leaves. The merged record of four such measures shows a double-hump curve of CO_2 concentrations. High values more than 400 million years ago fall through 2000 parts per million to a few hundred ppm by about 300 million years ago, peak again about 200 million years ago, and fall once more toward the present's several hundred ppm. "I was surprised with how a consistent pattern has emerged," says Royer.

Not only are different CO_2 measurements consistent with each other, says Royer, but the composite curve bears a strong resemblance to what many researchers expected. Computer models that simulate the processes controlling the abundance of CO_2, such as rock weathering and the burial of organic matter on the sea floor, produce much the same double-hump pattern as the proxies do. And the great ages of glacial ice—the past 30 million years or so and the 60 million years around 300 million years ago—fell in the deep dips in CO_2, whereas only a few, brief glacial intervals came during periods of higher CO_2 levels, Royer and Berner noted.

Royer and Berner also adjusted Veizer's isotopic curve for the effects of changing seawater pH, a factor only recently recognized as important. That brought some periods more in line with other temperature indicators, says Royer, and much reduced the prominence of coolings that Shaviv and Veizer attribute to the cosmic ray effect.

Veizer and Shaviv, in turn, are not convinced that the two-hump pattern of CO_2 and climate is better than their plot of cosmic rays and climate, which has four peaks rather than two. They find the pH correction "an interesting modification," but they believe Royer overdoes it, making the oceans at times unrealistically acidic. A more reasonable correction, they say, leaves the four-peak climate pattern intact. And that pattern of isotopic temperature is reasonably consistent with other climate indicators and the inferred flux of cosmic rays, they say.

Many researchers are sticking with conventional thinking. "You can't say CO_2 explains everything," says paleoclimatologist Thomas Crowley of Duke University in Durham, North Carolina, but "it does explain a heck of a lot," at least in the broad-brush picture of climate. No doubt, more details need to be painted in before everyone sees the same picture.

–RICHARD A. KERR