But that still left the problem of knowing when in the rock's cooling history the clock started ticking. In 1977, physicists Derek York and Glen Berger of the University of Toronto came up with a way to get the answer: Heat the mineral sample in steps and measure how readily argon diffuses out of it at each temperature. York and Berger showed that through the lens of some complex mathematics developed 4 years earlier by Martin Dodson of the University of Leeds, these measurements could be deciphered to learn the temperature at which the cooling mineral had originally "closed." From that point on, the argon-40 generated by radioactive decay was locked in the mineral, and the clock was running.

In the past 5 years or so, however, researchers noticed that crystals of feldspar—one common potassium-containing mineral—didn't seem to play by the rules. Graphs showing how argon seeped out of the mineral as it was heated sported curious kinks. And the ratio of the two argon isotopes in the released gas—the measure of the sample's age—didn't tend toward a single value as the mineral was heated to higher and higher temperatures. Instead it changed in steps. "We noticed that something was wrong if we treated samples as single spheres or slabs," recalls Richter.

Along with Zeitler and other workers, Richter and his colleagues began weighing the possibility that feldspars might be more diverse than they had thought—that the odd kinks and steps might reflect separate zones in the crystal that had locked in their argon at different temperatures. Those same domains would then be giving up their argon at different points in the laboratory reheating. That, researchers speculated, might be the answer to the mineral's puzzling behavior. To Lovera, Richter, and Harrison, it was also an opportunity.

As Harrison puts it, "Because we have these strongly contrasting domain retentivities [for argon], we could get age information over an extremely broad range of temperatures" from a single grain. Once the workers had devised the right mathematical techniques for extracting all that information from argon measurements, a single grain could open a long view of geologic history. In a slow-cooling mass of granite, a feldspar whose different domains closed at temperatures ranging from 400°C to 150°C might provide a nutshell record of 100 million years of cooling.

This was the first time geochronologists had ever talked about getting that kind of information from a single mineral grain—though the Lovera group's innovation is not the first strategy for learning a rock mass's cooling history. York and his colleagues, for example, have long exploited the fact that most rocks are a potpourri of different minerals that have distinctive radioactive clocks and closure temperature. By using dates from neighboring mineral grains that start recording time at successively lower temperatures, they can join the dots to get a cooling history.

But Harrison argues that that strategy, because it relies on a few isolated ages, carries the risk that "you completely miss the inflections"—the dips and plateaus in a cooling history that reflect faulting, mountain-building, and other tectonic processes. Now that he and his colleagues can trace complete segments of cooling histories, he says, they should be able to see these fleeting inflections. "For instance, we can say, 'This fault moved abruptly X million years ago.' That wasn't possible until this breakthrough."

Some other geochronologists aren't sure the technique is as precise as all that. "Approximately, it works," admits Tullis Onstott of Princeton University. But he brings up problems that, though they plague all argon-argon dating, loom especially large when so much information is being wrung from a single grain. Extrapolating from the way the sample loses argon in the laboratory to what happened in the natural setting is tricky, he says, because the laboratory temperatures are several times higher. At laboratory temperatures of around 1000°C, he says, "the feldspars undergo changes in the population and types of structural defects, which could affect their [apparent] thermal histories." In the face of these uncertainties, he asks, "How much faith do you place in the final numbers?"

Harrison and his colleagues say they have taken care to rule out such effects. As a token of faith in their technique, they enlisted it in an effort to decipher the history of uplift in Tibet. The results fit neatly into one picture of the mountain building—but it's a controversial picture (see box on p. 1589). Harrison professes to be happy with this challenge; the controversy is drawing attention to the technique, and he hopes that geophysicists who have yet to focus on the method will now find it an eye-opener. ■ TIM APPENZELLER

Solar Neutrinos: Still Missing

It's official: The solar neutrino problem is real. Thirty tons of liquid gallium in a detector deep in the Caucasus have convinced physicists that the sun's nuclear reactions pour out less than half the expected number of these elusive particles. The shortfall spans the energy spectrum—not just the specific energy range observed in earlier experiments. After a year and a half of double-checking their data, researchers in the Soviet-American Gallium Experiment (SAGE) are publishing their result this week in *Physical Review Letters*. Now the group is ready to start searching for an explanation, says project scientist Kenneth Lande of the University of Pennsylvania.

Hints that the sun was putting out fewer neutrinos than the accepted picture of its nuclear processes predicted first came 20 years ago from a chlorine-filled detector in a South Dakota gold mine, then from a detector in Japan. But those instruments could only capture the relatively energetic neutrinos that come from a secondary nuclear process that is sensitive to small temperature differences in the sun's interior. That left open the possibility that the neutrino shortfall stemmed from some lack of understanding of the sun's interior rather than from some new effect in particle physics. SAGE was meant to solve that dilemma by catching the garden-variety low energy neutrinos that pour out independently of temperature.

It wasn't easy. Neutrinos are so reluctant to interact with matter that fewer than one each day registered in the gallium detector, changing a gallium atom to an isotope of germanium. It took the investigators 5 months in 1990 to gather enough events to be certain of the shortfall. But the results leave little doubt that the root of the problem lies in the properties of neutrinos rather than in the physics of the sun.

The most popular explanation for the deficit, first proposed in 1986, holds that electron neutrinos—one of the three neutrino species—can "oscillate," changing into muon or tau neutrinos and thereby escaping detection. They could pull off that feat only if they carried some small mass, something that's by no means certain. But Lande and his colleagues see a way to test the hypothesis. While the gallium experiment only records electron neutrinos, another kind of detector can pick up a few of the other two types, though it can't distinguish them from electron neutrinos. By running the detectors concurrently and comparing the results, Lande says, neutrino physicists could check the sun's output of the other neutrino types.

Physicists at Fermilab are considering another line of attack: Send a beam of neutrinos from the lab, near Chicago, to a detector near Cleveland, Ohio, and check for signs that neutrinos are switching species along the way. Call it a Midwestern particle physics bait-and-switch trick. ■ FAYE FLAM