for Developmental Biology in Tübingen has shown that this gene is important for head formation in the fruit fly and no vertebrate *bicoid* relative had been reported. What's more, *goosecoid* is turned on in the organizer region of the *Xenopus* embryo early in development. "What he [De Robertis] has found is a gene that very accurately marks the Spemann organizer," Melton remarks.

Those results suggested that *goosecoid* activity in the organizer might lead to axis formation, and in their more recent work, De Robertis and his colleagues tested this hypothesis by injecting *goosecoid* messenger RNA into the ventral side of *Xenopus* embryos. The result: exactly what Spemann saw when he did his transplantation experiments. "We got twinned embryos that have complete heads. We think it [*goosecoid*] establishes the axis in the animal," De Robertis said at the Crete meeting.

What's more, treatment with ultraviolet light, which suppresses axis formation in *Xenopus* embryos, suppresses *goosecoid* activity, whereas treatments that enhance axis formation also enhance the gene's expression. "We would like to conclude that this gene follows very closely the biology of the organizer," De Robertis said.

The next step is to find out more specifically how *goosecoid* exerts it effects. Since the proteins encoded by homeobox genes are generally thought to be transcription factors that regulate gene expression, the supposition is that the *goosecoid* product turns on other genes in the organizer and that their products work to bring about the formation of the head-to-tail axis.

But tracing all the genes that participate in head-to-tail axis formation won't be easy. Most researchers predict that the organizer's function, as well as its formation, will be complicated, with many homeobox genes involved. "People are just cloning these things like crazy," says Kimelman, whose own group is among those doing the cloning.

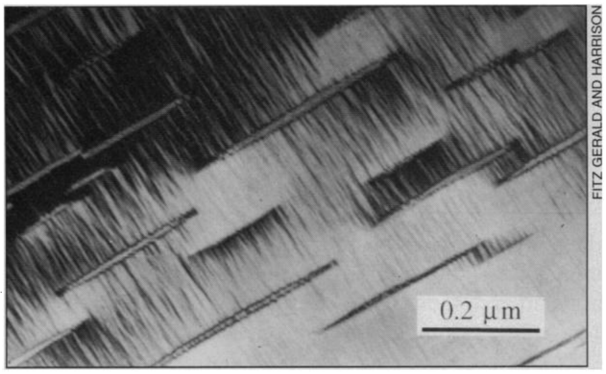
And homeobox genes won't be the only ones involved. Recently, for example, Smith's group, working with Bernhard Herrmann of the Max Planck Institute in Tübingen, identified the *Xenopus* equivalent of the mouse gene *brachyury* (meaning short tail). Genetic evidence indicates that the gene participates in mesoderm formation in the mouse, and the same now appears to be true in *Xenopus*, Slack says. It, too, is turned on very rapidly by the mesoderm-inducing growth factors activin and bFGF. What's likely to be happening in axis formation is a cascade of gene activities that starts with the Wnts and other growth factors and proceeds through the homeobox genes and their targets, until ultimately the organism's body plan is established. ■ JEAN MARX

# Reading History From a Single Grain of Rock

*A group of earth scientists deciphers tens of millions of years of geologic change from single specks of mineral*

TO CALTECH GEOPHYSICIST OSCAR LOVERA and his colleagues, the tiny grains glittering in a chunk of crystalline rock like granite are more than inert bits of minerals—they are history books, waiting to be read. With Frank Richter of the University of Chicago and Mark Harrison of the University of California, Los Angeles, Lovera has developed a technique for reading the cooling history of a sample of rock—and, by extension, the tectonic forces that shaped it—in single, millimeters-long grains of mineral. It is "the major new thing in thermochronology," declares Peter Zeitler of Lehigh University.

Not every geophysicist is so enthusiastic, though, and that guarantees an especially lively session at a meeting of the American Geophysical Union in San Francisco this week. One topic of discussion will be the team's first demonstration of the technique: tracing the grandest tectonic process of recent geologic history, the rise of the Tibetan plateau (see box on p. 1589). Questions—some hostile—are guaranteed, since the team's findings have placed them on one side of a contentious debate about the choreography of mountain building in Asia. And even the technique itself has been encountering skepticism; critics accuse the group of minimizing its drawbacks and overstating its potential.



FITZ GERALD AND HARRISON

**Pages of geologic history?** *These boundaries may separate feldspar regions recording different stages of cooling.*

Lovera and his colleagues might have expected to encounter a few storms, for they have been pushing geologic dating techniques into uncharted waters. Geochronologists, as Lovera and his ilk are called, have traditionally concentrated on getting a single date from each mineral grain, a date derived from the steady, clocklike decay of some radioactive element that was locked into the mineral when it crystallized. One problem has been that the clock doesn't always start ticking at the moment the mineral grain crystallizes from magma or hot solutions, but millions of years later, when the crystal structure cools enough to trap the timekeeping element's decay product. Thus most samples actually give a single point in a drawn-out history of cooling—a history that, for a large rock mass cooling deep underground, may stretch across hundreds of millions of years.

Now Lovera, Richter, and Harrison are claiming to have found a way to read the full sweep of that cooling history. That's something researchers have long been eager to achieve, for the cooling record holds clues to the events that sculpt Earth's surface. "Virtually every important tectonic process involves discontinuities in heat flow," says Harrison. When swift erosion or faulting exposes a rock mass, its cooling rate can accelerate sharply. Sedimentation or mountain building, on the other hand, can bury a rock more deeply, slowing its cooling.

Lovera, Richter, and Harrison unveiled their single-grain technique in the December 1989 *Journal of Geophysical Research*. It builds on work that began in the 1940s, when researchers first realized that potassium-40, a radioactive isotope that decays to form the gas argon-40, could serve as a natural timekeeper in potassium-containing rocks. By extracting both potassium and argon from a rock sample, researchers could find the ratio of parent element to decay product—and thus get a measure of the rock's age. But extracting two different elements from the same sample was cumbersome, and in the 1960s workers came up with an elegant refinement: Put the rock in a reactor, where neutrons transform some of its potassium to argon-39. Then heat the rock to extract both the argon-40 decay product and the argon-39—a proxy for the parent potassium—in a single step. The ratio of the two argon isotopes would then give an age.

# Grains of Truth in a Tibetan Controversy?

What could be a grander testing ground for a novel geologic dating technique than the lofty landscape of Tibet? That's why Mark Harrison, Oscar Lovera, and Frank Richter decided to bring their new technique for tracing a rock's cooling rate to bear on a key issue in the geologic history of Tibet: Did the mountains and plateau of southern Tibet experience a growth spurt some 20 million years ago, or have they risen more gradually? Their results line up squarely in favor of a pulse of rapid uplift.

The trio had found that by modifying a form of radioactive dating known as argon-argon dating and applying it to grains of a common mineral called feldspar, they could get a long-term record of the mineral's temperature (see main text). Working with Peter Copeland of the University of Houston, they speculated that the history of cooling recorded in single Tibetan feldspars would show how fast the rock masses in which they were riding had been brought to the surface by erosion or some other process. While the rock lingered at depth, it should have cooled slowly; as overlying material was worn away, the cooling rate should have picked up.

The result for a feldspar sample collected at an altitude of about 15,000 feet just south of Lhasa: "All hell breaks loose about 20 million years ago," says Harrison. For almost 20 million years before that, the cooling rate suggests that the overlying terrain was eroding "no faster than New England or upstate New York," says Harrison. But then the cooling curve steepened so sharply that Harrison estimates the erosion rate must have briefly increased by a factor of 30.

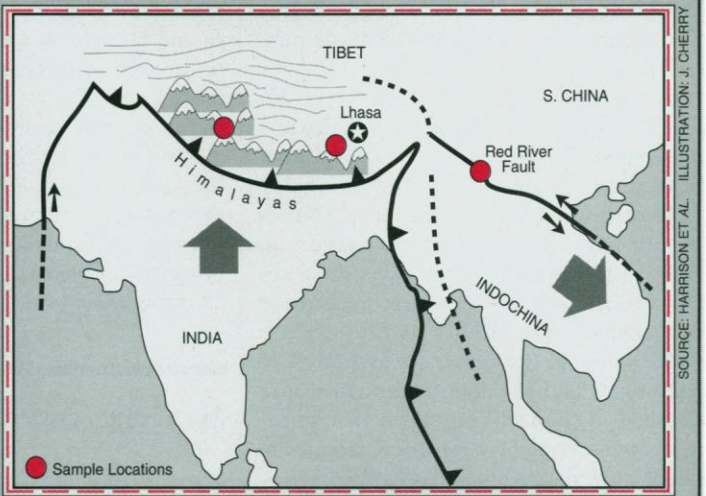
Published in the July *Earth and Planetary Sciences Letters*, the result has since been joined by similar cooling history traced in a feldspar from another site, a finding described by Copeland this week at a meeting of the American Geophysical Union in San Francisco. Other experts in Asian tectonics aren't disputing the cooling curves themselves. But the Harrison group's interpretation of the results is another matter: They are citing the feldspar histories—together with a host of other evidence for a pulse of erosion—in support of the idea that southern Tibet experienced a surge of uplift. They argue that the slow pace of erosion before 20 million years ago suggests fairly low-lying terrain; erosion then sped up when mountain building produced steeper grades and harsher weather.

Not so fast, responds Peter Molnar of MIT, who since the early 1970s has been studying the processes reshaping the landscape of Asia. The abrupt onset of erosion might have been driven not by sudden mountain building but by a worsening climate, he says. He admits that "it would be hard to sell a global climate change around 20 million years ago," but says, "that doesn't mean that there wasn't some local change."

Alternatively, Molnar says, the feldspar might have been cooled not by erosion but by faulting—so-called normal faulting, in which the crust cracks apart and the block on one side of the fracture slides downward, exposing once deeply buried layers on the other face. "There are some big normal faults just to the south [of the sampling site]," he notes, "and dating puts them at about 20 million years old." Either way, southern Tibet could have risen long before 20 million years ago.

Harrison agrees that the feldspar may have recorded normal faulting—but that wouldn't weaken the case for rapid uplift, he argues. The mountains have to rise, he says, before they can fault apart—and yet there's no sign of such "collapse structures" in Tibet much before 20 million years ago. What's more, he says, the idea that there was a pulse of uplift around that time fits into a broader picture first proposed in 1975 by Molnar himself and Paul Tapponnier of the Institut de Physique du Globe in Paris.

Molnar and Tapponnier suggested that the relentless collision of India with Asia was squeezing parts of Asia eastward, out of the collision zone. This "continental escape," they said, was relieving some of the pressure that would otherwise have gone into uplift. The question, says Harrison, was "when did the continental escape end?" One key phase, he thinks, ended 20 million years ago, sending the full force of the collision into mountain building.



SOURCE: HARRISON ET AL. ILLUSTRATION: J. CHERRY

**Battle lines.** *Feldspar samples suggest Indochina stopped sliding out of the way 20 million years ago and rapid uplift began.*

Harrison's evidence comes from yet another set of feldspars, collected along the Red River fault, a vast gash running from Tibet southeastward to the South China Sea. According to the continental escape scenario, horizontal slippage along the Red River fault allowed the crust bearing Indochina to slide out of the way during the early stages of the continental collision. Harrison (who is working with Tapponnier on this study) found that these feldspars too reveal a distinct speedup in cooling that started about 20 million years ago. Based on the local geology, Harrison, Tapponnier, and their colleagues think the sudden heat loss recorded in these feldspars marked the end of Indochina's escape act 20 million years ago, when the horizontal slippage ended and changed into normal faulting that exposed—and cooled—deeply buried rocks. That, they conclude in a paper in press at the *Journal of Geophysical Research*, may be the event that spurred the mountain building.

Molnar, who has downplayed the importance of continental escape in recent years, demurs, suggesting that continental escape—if any—would have taken place only after Tibet had already risen to a respectable height. "Their cause is my effect," he says. Molnar pictures Tibet as a soufflé that pushes other crust outward as it sags. "When you elevate Tibet you get a pressure head"; it's only then, he argues, that continental escape is likely to get started.

New studies of feldspar cooling will soon enter the fray. Already Harrison, Copeland, and their colleagues are planning a major new assault on the history of Tibet. They've just been funded, says Harrison, to go back to Tibet and collect samples along a line all the way from Lhasa to the sacred peak of Mt. Kailas, 1500 kilometers to the west. ■ T.A.

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**

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# 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**