faces at room temperature. But these molecules were difficult to control when pushed by an STM tip, so the researchers couldn't use them to represent numerical information (*Science*, 12 January, p. 181).

For the current experiment, Gimzewski and his colleagues Maria Teresa Cuberes and Reto Schlittler tried soccerball-shaped buckyballs on copper. Researchers have known for some time that metal surfaces are rarely perfectly flat; rather they resemble a series of flat terraces separated by atomic-scale steps. Researchers have also noted that buckyballs cling to metal surfaces, and they preferentially line up along the steps, where they share the most attractive electronic interactions with neighboring metal atoms. The team decided to try to use one of these steps to keep the buckyballs in line, much as an abacus's wires hold the beads in place.

And it worked. After depositing buckyballs on a copper sample, the researchers used the STM to take a look at the surface. As they had hoped, they found a row of buckyballs lined up along the step between two terraces. Then they pushed the buckyballs along the step with the STM tip, one at a time, much like one would push abacus beads. After moving each buckyball, they used the atomic-imaging tip to take a new picture of the surface. Finally, they pieced together the 10 images into one composite image (previous page).

While the current demonstration doesn't store numbers as computer-friendly binary 1s and 0s, it's easy to imagine how to change the setup to make binary data storage possible, says Cuberes. One approach would be to create tiny grooves in the copper surface, just wide enough for one buckyball to fit inside and only long enough for it to move back and forth when pushed by an STM tip. One side of the groove would be the 0 position; the other side, the 1. The researchers are nowhere near accomplishing this, Cuberes acknowledges. But if they can pull it off, this nanoscale device, like the original abacus, could create a bit of history of its own.

–Robert F. Service

EXTINCTIONS

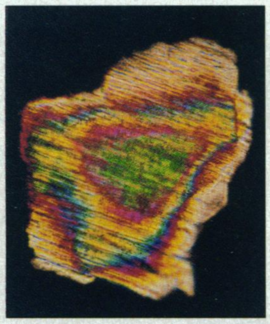
A Shocking View of the Permo-Triassic

DENVER—The great whodunit of the dinosaur extinctions has a likely suspect—an asteroid impact. But what of the largest mass extinction of all time, 250 million years ago at the Permo-Triassic boundary? This great dying marked the end of the 300-million-year reign of the "old life" of the Paleozoic era—typified by the last of the trilobites—and made way for more diverse and predatory life, including the dinosaurs. Its cause has long been a mystery, with theories ranging from anoxia in the oceans to massive volcanic eruptions on land (*Science*, 1 December 1995, p. 1441).

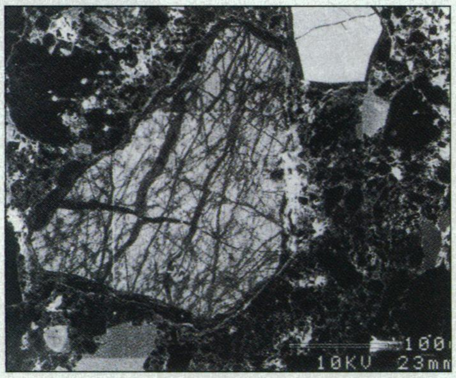
Now, at the annual meeting here of the Geological Society of America, paleontologist Gregory Retallack of the University of Oregon has presented pictures of microscopic quartz grains that he claims are the "first unequivocal evidence of an impact," implicating a comet or asteroid in this extinction too. The hallways buzzed with paleontologists and geologists exchanging opinions on Retallack's photos, which purportedly showed faint bands of glass-filled fractures within the grains. Retallack thinks the fractures formed in the shock of a massive impact and notes that similar grains have been linked to the Cretaceous-Tertiary extinction. The hallway buzz was more cautious. "There may be something there," says petrologist Glen Izett of The College of William and Mary in Williamsburg, Virginia, "but photographs don't show what your eye does through a microscope."

If Retallack and his Oregon colleagues Abbas Seyedolali and David Krinsley are right, then the Permo-Triassic extinction will have not only a new cause but also a new time scale. Most paleontologists have seen the crisis as a protracted "event" or even as two separate pulses of extinction. But an impact extinction would have happened in a geologic instant. It is a crucial question, notes paleontologist Douglas Erwin of the National Museum of Natural History, because "if the Permo-Triassic extinction hadn't happened the way it did, you would find a whole different bunch of beasts" alive today.

Although intrigued, many of Retallack's colleagues are not yet convinced. The quartz grains are old and fractured by more recent, mundane stresses, notes Philippe Claeys of Berlin's Museum of Natural History, making it difficult to see the faint traces that might have been left by an impact. Truly shocked quartz is riddled with thin, straight, parallel planar structures called planar deformation features (PDFs), which form sets that intersect at predictable angles depending on the crystal structure of the quartz. Photomicrographs of the Oregon group's grains, which come from the Permo-Triassic boundary near Sydney, Australia, and from the Transantarctic Mountains in Antarctica, reveal one set of possible PDFs, says Claeys. But he argues that several sets intersecting at the correct angles would be required for conclusive proof.



GLEN IZETT/COLLEGE OF WILLIAM AND MARY



G. RETALLACK, A. SEYEDOLALI, D. KRINSLEY/U. OF OREGON, EUGENE

Shock effect? Permo-Triassic quartz grain *(above)* is fractured, but the banding characteristic of an impact doesn't show as clearly as in a truly shocked grain *(top)*.

Retallack counters that Claeys and others haven't yet seen all there is to see. Under the microscope, where the full depth of a quartz grain can be viewed by changing the depth of focus, all the grains can be seen to have at least three sets of PDFs, he says; one has seven.

If other claims of shocked quartz are any guide, it may take a while to convince the community. Researchers have searched the rock record from one end of geologic time to the other for signs of impacts coinciding with biological crises, and the only success so far has been at the end of the Cretaceous. Some claims of shocked quartz have been summarily rejected, while others, such as possible shocked quartz from the Jurassic-Triassic boundary 202 million years ago, have interested but not yet persuaded researchers (*Science*, 11 January 1991, p. 161).

Ideally, experts would like their own three-dimensional look at Retallack's grains. Barring that, they want numbers: more quantitative data, such as the refractive index of the grains, which is altered by shock, as well as the orientations of PDFs. The Oregon group says they are gathering those data in cooperation with colleagues. They are also examining their samples for iridium—another telltale sign of an impact, abundant at the Cretaceous-Tertiary boundary. Better pictures, specifically transmission electron microscopic (TEM) images that can identify the shock-generated glass unique to PDFs, would help too. Retallack "has got a fairly good chance," says Claeys, "but he's got to do the TEM." Otherwise, his data may not be so shocking after all.

–Richard A. Kerr