MEETING GEOLOGICAL SOCIETY OF AMERICA

Geology Near, Far, and Long Ago

DENVER, COLORADO—Late last month, geologists and paleontologists gathered for the annual meeting of the Geological Society of America, which is headquartered here in the central part of the continent. Topics wandered out to an asteroid of uncertain parentage and back in time to geologic clocks and the death of the dinosaurs.

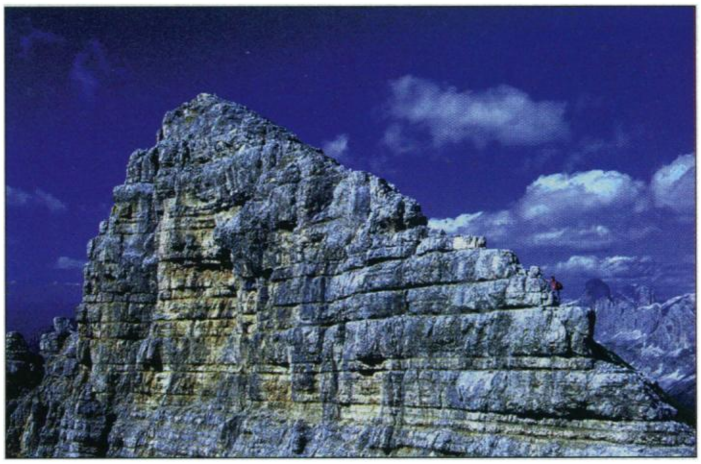
Measure for Measure in The March of Time

When your wristwatch and a wall clock disagree about the time, one (or both) of them is wrong. Geochronologists have a similar problem, but the potential consequences are more grave. In the limestone pinnacles of northern Italy's Dolomite mountains, a technique that marks time by counting sedimentary layers much the way tree rings are counted gives one answer for how long it took the rocks to form roughly 240 million years ago in the Triassic period. The uranium-lead radiometric technique—a pillar of geochronology—gives a very different answer.

"There's going to be a lot of work figuring out how much time is involved," says sedimentologist Bruce Wilkinson of the University of Michigan, Ann Arbor. Geologists and paleontologists are anxious to know which method they can trust to gauge the pace of evolution's Cambrian explosion, say, or the timing of huge volcanic eruptions relative to mass extinctions that they may have triggered.

Time is made visible, and perhaps even measured out, in the majestic Latemar limestones of the Dolomites. These rocks are a 600-meter-high pile of carbonate skeletons of marine animals laid down layer by layer on an ancient ocean floor. It all took 8 million years, sedimentologist Linda Hinnov of The Johns Hopkins University calculated by counting the meter-thick layers and making one crucial assumption: The clocklike orbital behavior of the planet controlled their deposition.

Astronomers know that Earth's tilt, the direction of its axis, and the shape of its orbit vary with periods of 20,000, 40,000, and 100,000 years, respectively, under the gravitational influence of other solar system bodies. During the past few millions of years, these orbital or Milankovitch cycles have driven climate changes and probably even set the pace for the comings and goings of the ice ages, leaving vivid records in deep-sea sediments. Like many other researchers trying to measure time in ancient sedimentary rocks, which generally can't be dated by radioactive decay, Hinnov assumed that the cycles had similar effects at earlier times in Earth history. So she looked for the fingerprint of the cycles in the pattern of the layers in the Dolomite limestones.



CREDIT: R. MUNDIL

Time as a peak experience. Sedimentary layering in the Dolomites may mark the passage of millennia. Scale: geologist, right.

In the Latemar sequence, for example, the layers seem to form bundles of five, with a thick layer at the bottom of each bundle and the four above it progressively thinning. In the 1980s, researchers theorized that, if orbital cycles somehow varied the productivity of the carbonate-yielding marine animals, each layer could be the product of 20,000 years of sedimentation under the influence of one cycle in Earth's axial orientation. The bundles of five would form the 100,000-year cycle; later work seemed to identify the 40,000-year cycle as well in the layered rock.

At the meeting, however, geochronologist Roland Mundil of the Berkeley Geochronology Center in Berkeley, California, and his colleagues presented evidence that the Latemar layers have nothing to do with orbital cycles. Using the radioactive decay of uranium-238 to lead-206, they dated two thin layers of volcanic ash sandwiched in the limestone, separated by 420 supposedly 20,000-year layers. If orbital cycles really had ticked off the limestone layers like a clock, the dated interval should amount to 8.4 million years; Mundil measured an age difference of only 2.1 million years between the ash layers. Even under the most generous assumptions, says Mundil, "you would never get the time span you need for Milankovitch."

Determining which clock is right will take some more work. The orbital method "is a very seductive hypothesis," says paleontologist Paul Olsen of the Lamont-Doherty Earth Observatory in Palisades, New York, who has used it to date other Triassic beds. "Sometimes the criteria for recognizing Milankovitch [cycles] are so loose you can see it anywhere." Yet the uranium-lead method has its difficulties as well. "The more you dig into the method," says Olsen, "the clearer it becomes that getting dependable results is not a trivial matter."

For example, rock containing zircon crystals that hold the uranium and its decay product can partially melt, millions of years after their formation in a volcanic eruption, in a new volcanic outpouring. The zircon can survive the melting and then grow a new layer of crystal over its old core. When the whole crystal is analyzed, the apparent age will be older than the age of the eruption that laid down the ash layer. Some geochronologists, including Mundil, say they address such problems in their standard methods, screening out zircons with old cores through inspection under the microscope. But others aren't so sure. They look to other techniques that can pick out chemically distinct cores that would otherwise be invisible. Telling which clock, if any, is right will obviously take more effort than dialing up the time lady.

Vesta Family Shunning Asteroid Braille

Just who was that masked asteroid? Early last August, 5 days after the Deep Space 1 spacecraft flew by the 2-kilometer chunk of rock called Braille, team members thought they knew. They hailed an "astonishing, exciting, and surprising result"—Braille's "color" in the infrared gave it "a very high probability" of being a chip off the 500-kilometer asteroid Vesta (*Science*, 13 August, p. 993). The kinship, they said, supported the idea that Vesta had suffered a catastrophic collision that blasted debris into space, including Braille and the rock that occasionally falls to Earth as an unusual kind of meteorite.

Now, with more time to reflect, planetary scientists are calling Braille's paternity into doubt again. Team member Daniel Britt of the University of Tennessee, Knoxville, says Braille "is looking more like an ordinary chondrite"—another, more common meteorite type. That's an exciting possibility, too, because astronomers have only been able to track down a few asteroids capable of supplying Earth with these meteorites.

The initial identification had seemed solid; after all, Deep Space 1 had inspected Braille at crucial infrared wavelengths from just 10 or 15 kilometers away. Braille's distinctive pattern of absorption in the infrared, Britt told *Science* at the time, "absolutely nails it as a vestoid"—one of a class of asteroids whose colors suggest a dark, basaltic rock. Besides resembling Vesta itself, these asteroids also resemble the colors of a small class of meteorites called eucrites. The tints have convinced many planetary scientists that vestoids and eucrites are former bits of Vesta, presumably blasted off by impacts. "The Vesta connection [for Braille] looked pretty firm right after the flyby," Britt says, "but now it looks less firm. I doubt it's [Vesta-like], but I don't want to rule it out. It will be a while until we're certain what this thing is."

The uncertainty arises because astronomers aren't yet fully familiar with the quirks of the spacecraft's infrared spectrometer. To identify a specific mineral composition, and therefore a particular asteroid type, scientists must make precise measurements of how much infrared light is absorbed at particular wavelengths. But variations in the operating conditions of the instrument, such as temperature, can affect the readings. For the highest precision, team members wanted to calibrate the spectrometer thoroughly after launch by targeting a number of objects with known spectra, such as certain stars or planets. Unfortunately, says Britt, "we just didn't have many opportunities before the encounter." Deep Space 1 is dedicated to testing new space-faring technologies such as its ion-drive engine, he notes, pinching the time available for science.

If Braille does turn out to be no relation to Vesta after all, astronomer Richard Binzel of the Massachusetts Institute of Technology won't be surprised. Before the encounter, he and his colleagues had concluded from ground-based observations at visible wavelengths that Braille most resembled ordinary chondrites, the most common meteorite and the rock type Britt is now leaning toward. If Braille continues to look like an ordinary chondrite, he says, it will join the growing clan of small, near-Earth asteroids that qualify as sources of 80% of Earth's meteorites (*Science*, 13 August, p. 1002)—not a bad bunch to have as relations.

Dinosaurs Went Out With Bang, Say Bones

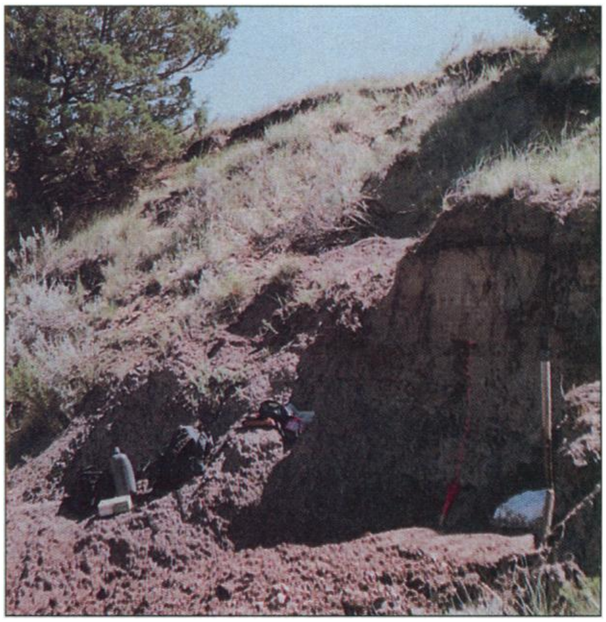
That big rock bearing down on *Tyrannosaurus rex* has become a standard image of dinosaur Armageddon for the public, but not for paleontologists. Although most of them now accept that a huge meteorite crashed to Earth 65 million years ago, many have been reluctant to believe that it killed off their favorite critters in one blow. Instead, they argue, dinosaurs were already gone or in decline before the impact; the meteorite was a mere coup de grâce. But at the meeting, two independent groups of paleontologists said that collections from the fossil fields of Montana and the Dakotas—perhaps the most thorough and systematic surveys of the last days of the dinosaurs—showed that these creatures were doing just fine until that big rock came by.

Both studies made use of volunteer field workers for the hard, sweaty summer labor of hunting up fossils in the badlands. Dean Pearson is himself a volunteer and an amateur, working out of the Pioneer Trails Regional Museum in Bowman, North Dakota. In 1983, at first alone and then with fellow amateur Terry Schaefer of the museum as well as professional paleontologists, he began collecting vertebrate fossils along the Hell Creek Formation, a 60-kilometer-long exposure in southwestern North Dakota and northwestern South Dakota.

The team eventually found and identified 10,034 vertebrate fossils scattered across the 100-meter height of Hell Creek sediments, which were laid down in the last 3 million years or so of the 160-million-year dinosaur age. Most of the taxa that they turned up—dinosaurs, fish, amphibians, lizards, turtles, crocodilians, birds, and mammals, among others—persisted throughout the Hell Creek sediments, said Pearson, suggesting that vertebrates as a group and dinosaurs in particular were not in decline. And the youngest dinosaur fossil found, a possible *Triceratops*, was just 1.8 meters below the thin layer of impact debris.

The pattern "is not compatible with a gradual vertebrate extinction," Pearson says. Paleontologist Peter Sheehan of the Milwaukee Public Museum and his colleagues reached the same conclusion from a volunteer-aided dinosaur fossil survey in the more northern exposure of the Hell Creek. In their latest analysis of the bones of at least 984 dinosaurs, they, too, found no sign of a gradual extinction; their survey turned up as many fossils in the last 3 meters of the formation as in most other 3-meter intervals throughout the Hell Creek.

Pearson's study is "the first that shows there's no trend" across the Hell Creek and therefore no decline, says vertebrate paleontologist David Archibald of San Diego State University, who has argued in the past for a gradual extinction of vertebrates. But he doesn't think the Hell Creek studies are enough to settle the question. "There's no statistical basis at this point to say whether [the dinosaur extinction] was rapid or slow," he says. Pearson found no fossils of any sort in the last 1.8 meters of the Hell Creek, laid down over some tens of thousands of years, he points out—not even fossils of taxa known to have survived the impact. Apparently bones simply did not get preserved during that interval, leading Archibald to conclude that the fossil record isn't good enough to say what happened.



One of the last of its kind. The bones of a possible *Triceratops* (jawbone in white plaster) lie just below the layer of debris from the giant impact (at edge of grass).

CREDIT: PEARSON/PIONEER TRAILS REGIONAL MUSEUM

Pearson and Sheehan are more sanguine. The dinosaurs had been around for a good 160 million years, Sheehan notes, and such hefty meteorites fall only every 100 million years on average. What are the chances that the great beasts died off just tens of thousands of years before the impact? "That probably didn't happen," he concludes.

–RICHARD A. KERR