A Volcanic Crisis for Ancient Life?

Isotopic dating has made the largest volcanic eruption on land the leading suspect in the largest mass extinction ever. Now the geo-prosecutors are checking possible alibis

In the search for cause and effect in paleontology, timing is everything. The link between a giant meteorite impact and the great extinction 65 million years ago that swept away the dinosaurs and perhaps half of all other species was debated for years, until timing clinched the case. The impact and many of the extinctions turned out to coincide precisely, to the limits of resolution of the geologic record. Now the same questions about coincidence and causation are swirling around another mass extinction—the greatest of all—and a cataclysmic geologic event: the most voluminous volcanic eruption known on land.

Early last month, Paul Renne of the Berkeley Geochronology Center in California and his colleagues announced in the pages of *Science* and at a paleontology workshop at the Smithsonian's National Museum of Natural History that they had identified a geologically precise correlation between a million-year-long series of eruptions in northern Siberia and the great mass extinction 250 million years ago that ushered in the reign of the dinosaurs by wiping out the majority of the species then on Earth. Isotopic dating, Renne and his colleagues argued, reliably places the beginning of the eruptions and the extinctions at the same geologic moment.

To many, this apparent coincidence of two unparalleled events is strong circumstantial evidence. The eruptions poured out more than 2 million cubic kilometers of lava, forming the vast basalt pile known as the Siberian traps. And the mass extinction was the closest life has come to oblivion since it burgeoned 500 million years ago. "What are the odds of that being coincidental?" asks paleontologist Steven Stanley of Johns Hopkins University. "I was very struck by the coincidence. I wouldn't say for sure there's a causal connection, but I certainly think it makes it an excellent prospect."

But now that Renne and his colleagues have pushed the volcano-extinction link into the limelight, Stanley and other researchers are scrutinizing its details—and raising the inevitable questions about timing. Geochronologists aren't certain yet that the dating points to as close a match-up as Renne is arguing. And some paleontologists see signs that the extinction wasn't the single event most paleontologists would expect from a volcano—that the extinction had a precursor. Then again, there are no other widely accepted volcanic extinctions for comparison (see box), and no one knows just what kinds of deadly environmental changes would follow a titanic eruption.

The Siberian traps had long been a suspect in the extinction, known as the Permo-Triassic because it falls at the geologic boundary between the Permian and Triassic periods. It was at this boundary that 80% or more of the animal species in the ocean and about 70% of all vertebrate families disappeared forever (*Science*, 26 November 1993, p. 1370). Entire ecosystems crashed: Coal-producing plants disappeared from the record for millions of years, as did coral reefs and silica-producing animals like sponges. This mass destruction demanded a fearsome cause, and earlier dating work had shown that the eruptions and extinctions took place within 10 million years of each other.


SMITHSONIAN NATIONAL MUSEUM OF NATURAL HISTORY

Victims of a volcano? Some of the marine species that lost out in the Permo-Triassic extinction, including a crinoid *(upper middle)* and brachiopods *(lower left and right).*

Building a case

Renne and Asish Basu of the University of Rochester began laying the groundwork for a tighter link in 1991, when they used argon-argon isotopic dating to pin down the age of the first massive outpourings of the Siberian traps to 250.0 million years ago. Now Renne, Basu, and their colleagues have dated the Permo-Triassic boundary in rocks from South China and come up with exactly the same age, within the limits of the technique. More quantitatively, the start of the Siberian traps eruptions preceded the boundary by 20,000 years, give or take 360,000 (*Science*, 8 September, p. 1413). Says Renne: "I don't see how you could contemplate hundreds of millions of years of [geologic] record, see two events of such magnitude, and say, 'This is a coincidence.' "

But other geochronologists don't think the case is airtight. "Technically it's a very nice piece of work," says Samuel Bowring of the Massachusetts Institute of Technology. "I would agree that [the two events] are the same age within some uncertainty, but I think the errors are a bit underestimated."

For one thing, Bowring notes, years passed between Renne's analyses of the samples from the traps themselves and from the Permo-Triassic boundary, which raises doubts about the calibration of a key step in the dating. The argon-argon technique is designed to read a radioactive clock that ticks within every mineral after it is formed: the steady decay of potassium-40 to argon-40. To find out how much potassium-40 the mineral originally contained, geochronologists look at its potassium-39, a stable isotope that is incorporated into minerals in a constant ratio to potassium-40. And in order to measure both the potassium-39 and the argon-40 simultaneously, they convert the potassium into argon-39 by bombarding the sample with neutrons in a reactor; they then extract and analyze the two argon isotopes.

That's where Bowring's doubts come in: Neutron fluxes vary within a reactor and between reactor runs. Monitoring the fluxes helps, but for the most precise dating comparisons, geochronologists say, it's best to irradiate all the samples at the same time.

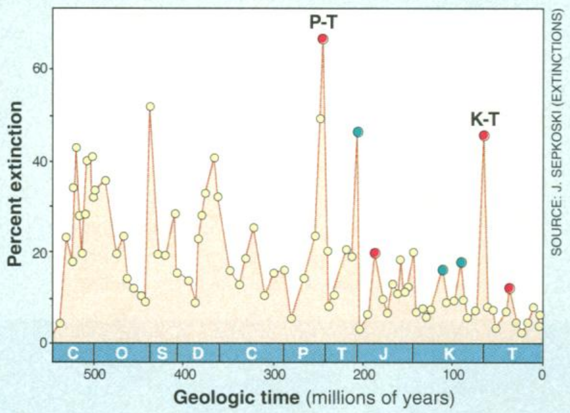
Brent Dalrymple of Oregon State University, who has argon-argon dated the Siberian traps, raises another source of uncertainty: rock weathering. "It doesn't take much alteration in the basalts to mess up the ages a little bit," says Dalrymple, who saw evidence of the process when he dated lavas from the traps themselves and rock that later intruded into the traps from below. His dates for the traps were comparable to Renne's, but the intrusion appeared older, not younger as it must be. Over time, Dalrymple concludes, some of the argon-40 had leaked out of the trap's rocks, making them look 1 or 2 million years younger than they are.

Renne, however, says he is "very confi-

Searching for Volcanic Extinctions

If massive volcanism devastated the biosphere once—perhaps causing the Permo-Triassic extinction 250 million years ago (see main text)—could it have done so again? The record of the last 250 million years includes some eight major extinctions still looking for a cause, and at least that many continental flood basalts—the largest land eruptions. But so far, the search for other eruption-extinction links has come up with little more than tantalizing hints.

The volcanic extinction hypothesis is so hard to test because dates for most flood basalts and extinctions are uncertain by millions of years. But even before Paul Renne of the Berkeley Geochronology Center came up with evidence for a tight correlation between eruptions in Siberia and the Permo-Triassic extinction, three researchers—Richard Stothers of the Goddard Institute for Space Studies in New York, Michael Rampino of New York University, and Vincent Courtillot of the University of Paris—had cast a broad net for other volcano-extinction links. They were inspired by work begun in the 1980s, which showed that the Deccan Traps of India was erupting at the time of the extinction that ended the reign of the dinosaurs. Even though a giant impact won out as the likely cause of the extinction, the timing suggested that volcanism and the resulting climate changes could have softened up the biosphere before the meteorite struck (*Science*, 14 June 1991, p. 1496).



Coincidence and causation? Giant volcanic eruptions and major extinctions coincide in four instances *(red)* and perhaps more *(blue)*.

To see what other coincidences the record might hold, Stothers, Rampino, and Courtillot recently presented comparisons of the published dates for the 10 or 12 continental flood basalts of the past 250 million years and the 10 or 11 "significant" or "possible" major extinctions. Details vary among the three researchers, but they find that besides the Deccan and the Siberian eruptions, two other flood basalts—the Ethiopian and the Karoo in Africa—coincide with major extinctions within a few million years. Each of the three researchers also has his own list of other possible links.

"I believe the coincidence [of eruptions and extinctions] is quite close to being demonstrated," says Courtillot. Many others, including Renne, disagree. "In detail the relationship breaks down," he says. For example, Renne has evidence that the Paraná flood basalt of Brazil—which all three researchers suggest as a potential cause of the late Jurassic extinctions—actually followed the extinctions by at least 10 million years. Still, Renne's own work is likely to spur other efforts to find some company for the Permo-Triassic.

–R.A.K.

dent about our new data." He and his colleagues monitored the neutron fluxes in both tests in more detail than anyone else does, he says, and they did extensive argon-argon analyses that contradict Dalrymple's conclusions about alteration of the trap rock. It's not that the trap rocks lost argon, Renne believes; instead, the intrusion carries extra argon-40 picked up before the minerals formed, giving a falsely older age.

Most paleontologists have yet to be exposed to this give-and-take about the dating, so they tend to take the coincidence between the eruptions and the boundary at face value. At the Smithsonian workshop on the Permo-Triassic, for example, "most people were simply impressed with the correlation between the traps and the dates for the Chinese sections," says workshop organizer Douglas Erwin of the Smithsonian. Renne "has got a very good case that the Siberian traps were involved in the whole business." But the paleontologists have their own reservations. "I didn't see enough in what Renne had to convince me the Siberian traps were the sole cause," says Erwin.

An ambiguous extinction

Again, the problem is timing—in this case the relative timing of the extinction and the geologic boundary. Renne may be able to place the Siberian traps at the boundary, workshop participants noted, but some paleontologists are starting to think that the extinction itself wasn't a one-shot deal. "I think there was more going on before the very end [of the Permian] than a lot of people have been focusing on," says Richard Bambach of Virginia Polytechnic Institute and State University. "The eruption of the Siberian traps could have contributed ... the coup de grâce."

Supporting that contention, independent analyses of the fossil record reported at the workshop by Bambach and by Stanley suggest that a separate pulse of extinction—one rivaling that at the boundary—preceded the boundary by millions of years. Such a double-pulse extinction could be the product of an incomplete fossil record, cautioned David Jablonski of the University of Chicago. But he called a part of Stanley's analysis, which relied on microscopic marine fossils called forams, the first strong evidence that all was not business as usual before the Permo-Triassic boundary.

Adding to the impression that something was amiss before the end of the Permian, Henk Visscher of the University of Utrecht in the Netherlands reported signs of a most mysterious phenomenon: During millions of years leading up to the boundary, fungi accounted for a growing proportion of the spores and pollen found in sediments, becoming nearly the sole source at the boundary. Presumably, the continents were littered with fungus-covered dead wood for millions of years before the boundary. But participants could not agree about why there should have been so much dead wood for so long.

And then there's the question of how eruptions in one part of the globe could have devastated life worldwide, wreaking such havoc that some ecosystems could not recover for 5 million years or more. The usual volcanic suspect is sulfur, either in the form of a rain of sulfuric acid or an aerosol haze of acid droplets that blocks sunlight and chills the climate. The problem is that no flood basalts have ever erupted in historical times, so geologists can't say just how drastic their environmental effects are.

Until the uncertainties can be resolved, the best argument that volcanism really was responsible for the biosphere's near-death experience at the end of the Permian is the sheer scale of the Siberian traps. The lava floods came in hundreds of pulses, separated by tens of thousands of years. Each pulse was a thousand times more potent than the eruptions known in historical times. Says Renne, "If ever there was a flood basalt that could do it, the Siberian traps is it."

–Richard A. Kerr