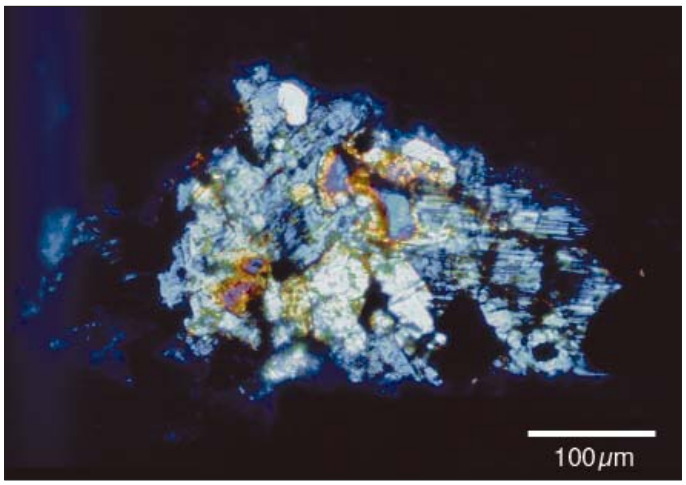
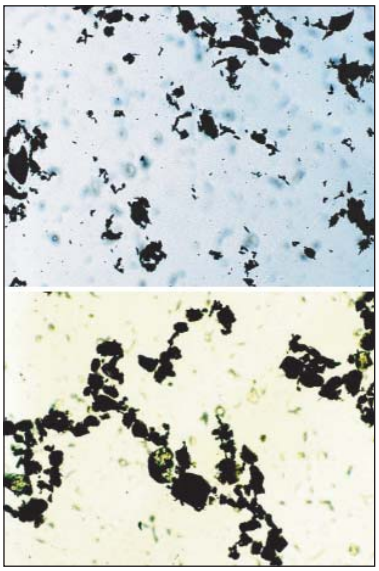
Researchers claim to have found more proof of a second major impact that triggered a mass extinction. But impact geologists say the newcomers still don't have the right kind of evidence to indict a second killer

Has an Impact Done It Again?

When geologists first proposed that the dinosaurs died off just when a meteorite plunged into the Gulf of Mexico 65 million years ago, the only evidence they offered was a geochemical oddity: an abundance of the rare element iridium. The metal must have been carried to Earth by the impact of a large meteorite, its discoverers argued. The scientific community was skeptical, but iridium eventually became one of two prime tools—the other being minerals scarred by the shock of impact—in the search for other extinction-triggering impacts.





E.T. messengers? Meteoritic fragments such as this one (*above*) are clearly extraterrestrial and come accompanied by exotic iron grains (*right*). But how could the fragments have survived for a quarter-billion years?

But 20 years later, that first generation of "impact geologists" is still looking for other impacts that also caused catastrophic extinctions. Part of the problem, say a growing number of researchers, is that geologists need more ways to recognize the traces of impacts in the geologic record.

On page 1388 of this issue, petrologist and geochemist Asish Basu of the University of Rochester, New York, and four colleagues offer one such new marker for an impact-extinction link: tiny bits of meteorite they found in Antarctica. The researchers say that the fragments were created at the geologic instant of the Permian-Triassic (P-T) mass extinction 251 million years ago, the biggest of the Big Five mass extinctions. These meteoritic fragments join other nontraditional impact markers—gas-filled molecular carbon cages called buckyballs and odd metal grains—reported from the same P-T boundary rock. The new work "is clear evidence of an impact at the P-T boundary," says Basu.

Impact geologists tend to disagree. The proposed meteorite fragments and gases surely came from beyond Earth. But "things just don't fit cleanly with what we know and think we understand" about impacts, says meteoriticist and impact geologist David Kring of the University of Arizona in Tucson. Problems raised include how the chemically fragile bits of meteorite survived unaltered for a quarter-billion years and why most analysts have such a hard time finding the gas-trapping buckyballs, also called fullerenes. There also are the persistent questions about why some of the world's largest volcanic eruptions seem to have shot off at the same geologic moment as great mass extinctions (see sidebar).

A plethora of putative impact markers

At the core of Basu and colleagues' claim of "new criteria for future investigations of the P-T and other boundary layers" is their discovery of 40 bits of meteorite 50 to 400 micrometers in diameter at what they take to be the P-T boundary at Graphite Peak in Antarctica. Microscopic inspection of mineral textures and electron microprobe measurements of composition show that the grains must be from a meteorite, says the group, which includes meteoriticist Michail Petaev of Harvard University.

The fragments are not contamination from the field or the lab, the researchers argue. That's because samples were recovered from 10 to 20 centimeters beneath the rock surface, collected and conveyed to the group by two different fieldworkers, and analyzed in a lab that had never seen meteoritic material before and was therefore devoid of potential contamination. A similarly handled sample from 80 centimeters below the boundary contained no detectable meteoritic fragments.

Basu and his colleagues also report a second, recently proposed type of impact marker in the same P-T boundary beds that yielded the meteoritic fragments: microscopic bits of nearly pure metallic iron. Their composition is neither terrestrial nor meteoritic, says the group, but they closely resemble particles reported at the reliably defined P-T boundary at Meishan, China, in 2001 by paleontologist Kunio Kaiho of Tohoku University in Sendai, Japan. Kaiho suggested that the iron—which has not been reported elsewhere—had condensed from the vapor of an impact cloud.

A third nontraditional impact marker—extraterrestrial gases trapped in fullerenes—has also shown up at the Graphite Peak P-T boundary. Geochemists Luann Becker of the University of California, Santa Barbara, and Robert Poreda of the University of Rochester—who are co-authors of the *Science* paper—reported this year in *Astrobiology* that they found gas-charged fullerenes there, as they had in Meishan, China (*Science*, 23 February 2001, p. 1469).

CREDITS: A. BASU *ET AL.*

Intriguing but puzzling

The latest signs of extraterrestrial debris at the P-T are getting a mixed reception. "I don't have any doubt that" the fragments are meteoritic, says meteoriticist Jeffrey Grossman of the U.S. Geological Survey in Reston, Virginia. "The mineral chemistry is the same, the texture is the same, there is some metal." So no one is denying that these Antarctic fragments came from outer space. But meteoriticists and impact geologists alike are stunned that tiny, fresh-looking, unaltered fragments of a meteorite should have survived burial for 251 million years. "It's astonishing, it's incredible, it's unbelievable," says Grossman. Adds Kring, "You have to ask how they got there."

Meteoritic minerals such as forsterite and metallic iron are "incredibly unstable at the surface of the Earth," Kring notes; meteoriticists like to say that "If a meteorite falls in the [rainy U.S.] Pacific Northwest, it's going to be soil the next year." Basu has no explanation for the extraordinary stability. "There's something peculiar about this deposit that needs to be worked out," he says.

Not every meteorite that falls to Earth weathers away without a trace, of course. Chunks of large impactors have in fact been recognized in the geologic record. Geochemist Frank Kyte of the University of California, Los Angeles, convinced colleagues that a few-millimeter piece of totally altered rock he found in 65-million-year-old North Pacific sediments is probably a bit of the dinosaur killer. And geochemist Birger Schmitz of the University of Göteborg in Sweden has found fist-sized meteorites in 480-million-year-old sedimentary rock in southern Sweden, although nothing unaltered was left except traces of the exceptionally resistant mineral chromite. Microscopic, unaltered meteoritic fragments surviving a quarter-billion years "would really be remarkable," says Schmitz. "I get the gut feeling it's wrong."

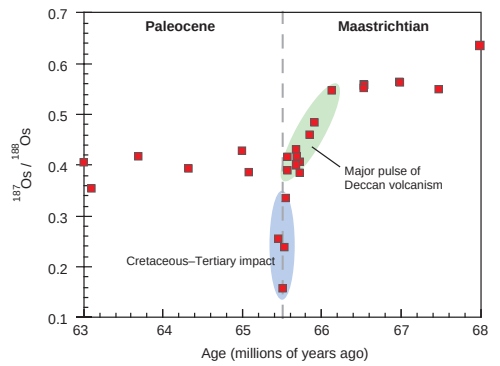
Schmitz had the same feeling about the essentially unaltered micrometeorites found in samples of 1.4-billion-year-old sandstone from Finland. In their 1998 report in *Nature*, meteoriticist Alexander Deutsch of the University of Münster in Germany and three colleagues demonstrated that the spherules were without a doubt meteoritic. But they offered no explanation at the time of how the submillimeter objects survived a clearly hostile environment that long.

The answer, it turned out, is that they hadn't. Deutsch and some of his colleagues from the *Nature* paper resampled the Finnish sandstone and concluded that it does not contain any micrometeorites whatsoever. They have failed to find any obvious route of contamination in the field or lab, however.

Extinction by a Whoosh, Not a Bang?

Ever since scientists realized that a huge impact gave the dinosaurs their comeuppance 65 million years ago, extraterrestrial whacks have become the leading suspect in almost every mass extinction (see main text). But some say that massively erupting volcanoes are capable of similar mayhem. One new study fingers the largest volcanic eruption ever as the leading cause of the greatest mass extinction 251 million years ago. At the same time, however, in this issue of *Science* (p. 1392), a second study seems to diminish greatly the role of another great eruption in the death of the dinosaurs.

The problem with volcanoes as extinction triggers has been the difficulty of pinning down when they spewed their noxious, climate-altering gases. The stunningly exact coincidence of the impact 65 million years ago with the disappearance of numerous creatures in the sea was obvious once scientists recognized impact debris in the geologic record within a hair's breadth of the last fossils of doomed animals. But the huge, although relatively quiet, nonexplosive lava eruptions called flood basalt eruptions didn't leave an obvious mark in the records of mass extinctions. So it's been up to geochronologists to link the two events by dating both eruptions and extinctions.



Eruption, then impact. A declining osmium isotope ratio denotes an earlier volcanic eruption, and a downward spike marks the dinosaur-killer impact.

What may be the best possible geochronological tie between eruption and extinction appeared in the 10 September issue of *Earth and Planetary Science Letters*. Geochronologist Sandra Kamo of the University of Toronto and her colleagues reported a new uranium-lead radiometric age for the beginning of the Siberian Traps eruption—the most voluminous known—of 251.7 ± 0.4 million years. According to her second new date, 6.5 kilometers of lava and ash—most of the Siberian Traps production—had erupted by 251.1 ± 0.3 million years ago. And the midpoint of this eruption falls exactly at the uranium-lead age for the great Permian-Triassic mass extinction, as determined in 1998 by Samuel Bowring of the Massachusetts Institute of Technology and his colleagues.

Similar improvements of radiometric ages for eruptions and extinctions are tightening the links between a number of mass extinctions and flood basalts. But uncertainties of many hundreds of thousands of years remain. Already, a paper in this issue of *Science* looks to break up another proposed eruption-extinction pair.

Geochemists Gregory Ravizza of the University of Hawaii, Manoa, and Bernhard Peucker-Ehrenbrink of the Woods Hole Oceanographic Institution in Massachusetts propose a new geologic marker of volcanism: the mix of stable osmium isotopes recorded in ocean sediments. In sediment cores from around the world, they trace a steady decline in the ratio of osmium-187 to osmium-188 starting about 66.0 million years ago, followed by a sharp downward spike 65.5 million years ago. Ravizza and Peucker-Ehrenbrink attribute the initial decline to the Deccan Traps of India. As the traps weathered, they fed low-ratio osmium into the sea. Half a million years later, the asteroid or comet that took out the dinosaurs dumped even more low-ratio osmium, say the geochemists, causing the downward spike.

The Deccan Traps eruption came half a million years too soon to trigger the extinction. However, the greenhouse gases from the eruption probably set off the warming recorded then, Ravizza says. That warming possibly weakened the biota before the devastating impact. If this timing is correct, one thing is certain: Impacts trigger extinctions, but they don't trigger great eruptions. **–R.A.K.**

A failure to replicate

Impact geologists would like to see Basu's findings replicated before they accept them. But if fullerenes—the other hot alternative impact marker—are any example, that could take a while. Ten years after the first report of fullerenes in a geologic sample, "their origin and occurrence remain elusive," wrote Peter Buseck of Arizona State University, Tempe, in a review last year. His 1992 paper in *Science* (10 July 1992, p. 215) was the first to report the detection of natural fullerenes, from a sample of an odd, organic-rich rock from western Russia called shun-

CREDIT: G. RAVIZZA *ET AL.*

gite. Since 1993, he's had a harder time of it. "We have flat-out failed at finding fullerenes" in anything since, he says. "We've given up. The only one that's been strikingly successful is the Becker group."

Becker and Poreda have indeed reported considerable success. They have published detections of fullerenes in three different organic-rich meteorites and in debris from three large impacts—the putative P-T impact (at Meishan, Graphite Peak, and Sasayama in Japan), the Cretaceous-Tertiary (K-T) impact at the end of the dinosaur age (five locations), and in the 250-kilometer Sudbury impact crater of Canada. Some analyses have supported the existence of natural fullerenes. Geochemist David Mossman of Mount Allison University in Sackville, Canada, and his colleagues reported in the March issue of *Geology* that they found fullerenes in a Sudbury sample, although they found none in a shungite that they also examined. And Dieter Heymann of Rice University in Houston, Texas, and his colleagues reported fullerenes at the K-T boundary in a 1994 *Science* paper (29 July 1994, p. 645).

But the number of failures no doubt outnumbers the reported successes at finding fullerenes. No one but Becker and Poreda has identified fullerenes in meteorites, despite considerable effort, most of it unpublished. Roger Taylor, one of the group at the University of Sussex, U.K., that first made fullerenes in the lab, reported in 2000 that a K-T sample lacked fullerenes at the part-per-trillion level. And geochemist Kenneth Farley of the California Institute of Technology in Pasadena has come up empty after looking for the helium-3 (but not fullerenes) supposedly trapped in fullerenes at the P-T boundary at Meishan and another location in China. "Fullerenes in the geologic record are still awaiting confirmation," says organic geochemist Iain Gilmour of the Open University in Milton Keynes, U.K., who has had his share of failures in meteorites and at the P-T. "There's not a great incentive for people to chase things and not find them," he says.

Why all the conflicting results? Becker points the finger at her critics. "We're not talking about the same samples or doing the same experiment," she says. "There's no attempt to replicate my results. You have to do the organic chemistry" the way she does in order to produce a clean extract containing the fullerenes.

Many researchers see a larger problem in the samples being analyzed. No two analysts work on exactly the same boundary sample, despite sometimes receiving parts of a field sample from the same source. But Becker says they will be distributing Graphite Peak P-T samples to a number of different groups. There is also talk, but nothing more, of someone providing samples for a blind test, as happened in the course of the K-T debate.

Just one impact extinction?

Acceptance of the K-T impact has led to impacts being proposed for most other major extinctions. Just last June, a group of scientist proposed that a comet triggered the Paleocene-Eocene extinction of 55 million years ago, and another presented evidence for the latest of several impacts in the mid-Devonian 380 million years ago. But all depend on iridium anomalies that are too small, unconvincing shocked minerals, or impact markers as yet not generally accepted.

Twenty years after the K-T impact gained convincing support, some impact geologists are getting discouraged by their failure to find a second example. "I've tried for 10 years to look for impact layers," says Schmitz. "I almost ruined my career. I have lots and lots of negative data in my drawers. This is evidence for the uniqueness of the K-T boundary."

But Schmitz is not giving up. Basu and colleagues "say the haystack is a needlestack," he says. "Who knows, maybe they are right," and bits of killer meteorite will soon be turning up everywhere.

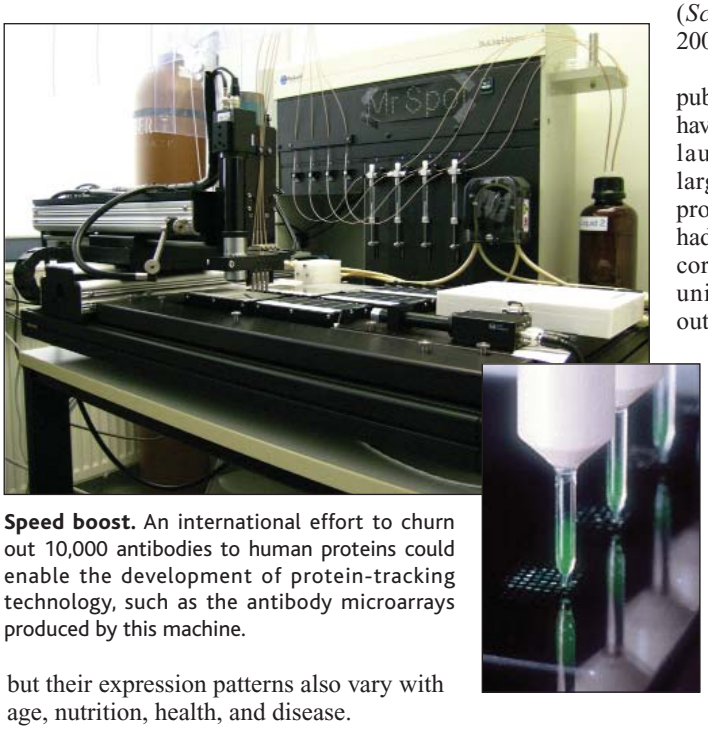
–RICHARD A. KERR

Proteomics

Public Projects Gear Up to Chart the Protein Landscape

Researchers in industry as well as those in the public sector seek the protein equivalent of the human genome sequence

MONTREAL, CANADA—With the human gene sequence now in hand, researchers have moved on to a new goal: identifying all the body's proteins. The task is massive. Not only does each of the body's 252 cell types harbor its own complement of proteins, but their expression patterns also vary with age, nutrition, health, and disease.



Speed boost. An international effort to churn out 10,000 antibodies to human proteins could enable the development of protein-tracking technology, such as the antibody microarrays produced by this machine.

CREDITS: THOMAS JOOS/NMI, REUTLINGEN, GERMANY

These difficulties haven't deterred researchers who want to determine the body's complete set of proteins—the proteome, as it's called. Buoyed by hopes that their efforts will identify proteins that can serve as both markers for disease and targets for new drug therapies, the pharmaceutical industry jumped into the research a few years ago, investing hundreds of millions of dollars in high-speed protein-tracking technology (*Science*, 7 December 2001, p. 2074).

More recently, the public funding agencies have gotten into the act, launching their own large-scale proteomics projects. They say they had little choice, as the corporate push has left university researchers out in the cold. "Companies don't open their resources for academics," says Marius Ueffing, a proteomics researcher at the German Society for Proteome Research and the Institute of Human Genetics in Munich.

To fill that gap, four separate public international proteomics initiatives have been launched over the past year and a half. Three of them, spearheaded by researchers in the United States, Germany, and China, are