spots to form flat deposits resembling ponds. A transition zone from smooth pond to rougher surroundings resembles a beach, notes Chapman. And in the last image returned by NEAR Shoemaker from an altitude of 125 meters, some spots the size of a footprint—though irregular in shape—seem to have collapsed a few centimeters, as if the fine material was somehow compressed.

One way fine material might move around would be for sunlight to charge it up electrostatically, notes Veverka. That could levitate dust and allow it to move downhill, as happens on the moon to an inconsequential extent and as has been suggested for Jupiter's moon Callisto. But nobody's betting on the accuracy of any of these theories. "We're facing processes we're not familiar with," says Veverka. "I truly don't know what's going on."

–RICHARD A. KERR

PALEONTOLOGY

Whiff of Gas Points to Impact Mass Extinction

Two hundred fifty-one million years ago, as the Permian period gave way to the Triassic, Earth experienced its greatest mass extinction ever. Ninety percent of all marine species, including the last of the trilobites, disappeared, while on land pervasive extinctions opened the way for the rise of the dinosaurs. But despite the magnitude of this "mother of all mass extinctions," its cause has remained mysterious.

A new analysis of rock that marks the Permian-Triassic (P-T) extinction now suggests that it was caused by the hypervelocity impact of an asteroid or comet similar to the one thought to have killed off the dinosaurs 65 million years ago. The evidence that some catastrophe triggered the P-T extinction has been building for the last 5 years. Although it was once thought to have lasted for 8 million years, it now appears to have occurred in a geological heartbeat—perhaps even instantaneously. So sudden does the extinction now appear, in fact, that many paleontologists presume it had a single, abrupt cause—a mega–volcanic eruption, a catastrophic release of toxic chemicals from the ocean's depths, or an impact. But no one had been able to implicate such a catastrophe by placing it at the geologic moment of extinction.

That's where the new work comes in. On page 1530, geochemists Luann Becker of the University of Washington, Seattle, Robert Poreda of the University of Rochester in New York, and their colleagues report that they have detected the noble gases helium and argon apparently trapped in the molecular cages of carbon "buckyballs," or fullerenes, extracted from rock laid down at the P-T extinction. Analysis of these gases shows, the researchers say, that their isotopic compositions are much more like those found in meteorites than on Earth. Thus, they conclude that a giant impactor delivered the chemicals to Earth just when the extinctions occurred.

Some researchers find the argon and helium analyses persuasive. "It's the noble gases that make the case" for an impact, says physicist Robert Pepin of the University of Minnesota, Twin Cities, who works on noble gases in meteorites. Still, claims of finding buckyballs—closed lattices made of nothing but 60 or more carbon atoms—in natural samples such as impact debris and meteorites have been controversial. Indeed, the suggestion that they provide a marker for a P-T impact recalls the early days of the controversy over the impact at the Cretaceous-Tertiary (K-T) boundary, 65 million years ago.

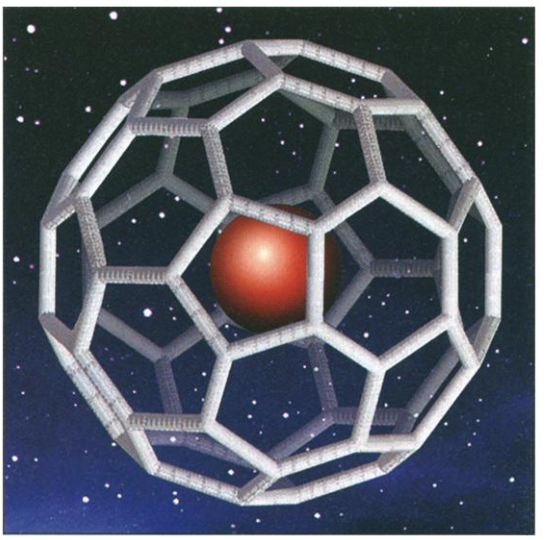
The first clue to the K-T impact, discovered in 1979, was an abundance of the element iridium at the geologic instant of the mass extinction. Because iridium is plentiful in meteorites, the iridium-rich deposit suggested impact debris, but some researchers argued that the layer could instead have been produced by the iridium-rich exhalations of volcanoes.

Fullerenes are also proving to be a suggestive but unconvincing impact marker. Previous work by others showed that they are present in rock at the K-T boundary, a finding confirmed by Becker and her colleagues, who also detected them in two meteorites. Together these findings suggested that fullerenes are impact markers like iridium. That prompted Becker and her colleagues to look for the compounds in rock at the P-T boundary at the classic site at Meishan, South China, and at Sasayama in southwest Japan. The researchers did in fact detect fullerenes in boundary rock, but not in similar rock a few centimeters to meters above or below the boundary. But fullerenes can have more mundane sources than meteorites. They are produced by forest fires and even by the mass spectrometers used to separate and identify them.

In the case of the K-T mass extinction, the clincher was the discovery of shocked quartz, distinctively veined crystals made only in the extreme pressures of large, hypervelocity impacts. Shocked quartz has not been confidently identified at the P-T, but noble gases may yet serve to make the case. Because of their structure, fullerenes can trap gas atoms like birds in a cage. When Becker and her colleagues then analyzed the gases trapped in fullerenes from P-T–boundary rocks, they found that the abundance of helium-3 jumped 50-fold above what it was above or below the boundary. The ratio of helium-3 to helium-4 entrapped there was typical of that found in meteorites—not in earthly atmosphere and rock. And the ratio of argon-40 to argon-36 in boundary fullerenes is well below that of air and approaches that of meteorites. The recovery of such fullerene-encapsulated gases, says Becker, is "the best case for an extraterrestrial event coincident with the P-T extinction." And she adds, "it was likely the trigger."

Researchers who study fullerenes aren't so sure. "The [fullerene] work of Luann Becker and colleagues has been a bit controversial," notes microscopist Peter Harris of the University of Reading, U.K. "Some people have found it hard to accept that fullerenes can survive for billions of years." Although Becker claims to have detected fullerenes in two other impact deposits and in two meteorites, he notes, only the K-T fullerenes have been found by an independent group, despite a number of searches. Still, Harris has recently reported that transmission electron microscopy reveals what look like fullerene molecules in a meteorite, so he is "fairly convinced" that the fullerenes and noble gases mark an impact at the P-T. But "I'm perhaps in a minority," he says.

Among noble gas workers, the reception has been warmer, however. Geochemist Kenneth Farley of the California Institute of Technology in Pasadena calls the anomalously low ratio of argon-40 to argon-36 "astounding. I can't imagine how



Bird in a cage. The carbon lattices of molecular buckyballs can trap gases, some of which suggest a mass extinction by impact 251 million years ago.

CREDIT: LUANN BECKER/UNIV. OF WASHINGTON

you could have any other interpretation" than an impacting meteorite that carried in the noble gases. "There appears to be an extraterrestrial component in the [P-T] boundary layer," agrees Pepin. "I think they've demonstrated that rather convincingly." Still, even noble gas workers want to see more. "This result needs to be replicated by somebody else," says Farley, "as any such measurement does."

–RICHARD A. KERR

ASTROPHYSICS

New Headaches for U.S.–Russia Experiment

MOSCOW—A tug-of-war over 60 tons of precious gallium is threatening to undermine a major neutrino experiment. This week, officials at the Baksan Neutrino Observatory in Prielbrusye are asking a court to stop a government order to sell off some of the liquid metal, which serves as an underground detector. It's the latest round in a long-running battle over the fate of the material, which has a market value of $500 to $600 per kilogram.

Under siege. Major solar neutrino detector may be shut down early if court affirms gallium sale.

A child of the Cold War, the $60 million Soviet-American Gallium Experiment (SAGE) is one of the largest collaborations between Russia and the United States. Its 60-ton gallium detector sits in a mine shaft in the Caucasus, deep below Mount Andyrchi. Run since the mid-1980s by Moscow's Institute for Nuclear Research, the detector studies neutrinos streaming from the sun. Low-energy neutrinos can transform gallium nuclei into germanium-71 atoms, which are extracted and counted. SAGE is best known for confirming an unpredicted shortfall of solar neutrinos.

The tussle over the silvery white metal began in 1997, when the Ministry of Fuel and Power Production asked the Cabinet for permission to sell the gallium, at a third of its market value, to Russia's State Research, Development, and Design Institute of Rare-Metal Industry (GIREDMET) plant in Moscow. It presumably would resell the gallium to foreign buyers—it's used in gallium-arsenide semiconductors—and reap the profits (*Science*, 11 April 1997, p. 193). SAGE officials caught wind of the impending gallium grab and organized a protest letter from 12 Nobel laureates to then–Prime Minister Viktor Chernomyrdin, followed by an appeal from U.S. Vice President Al Gore. The strategy worked: Chernomyrdin halted the transaction.

Later that year, however, a deputy prime minister decreed that at least 7 tons of gallium should be handed over to the fuel ministry. Project scientists resisted, arguing that the detector's sensitivity would be so diminished that the experiment would no longer be worth running. (It's slated to continue through next year.) Shortly after, thieves bungled an attempt to break into the observatory and steal the gallium (*Science*, 14 November 1997, p. 1220).

Last summer, President Vladimir Putin told Prime Minister Mikhail Kasyanov to review that order, which had not been carried out. In the meantime, the fuel ministry and the GIREDMET plant lodged a complaint against Baksan, arguing that observatory officials were interfering with efforts to procure and sell 7 tons of gallium. In December, the Arbitration Court in Moscow ruled for the plaintiffs; a hearing on the observatory's appeal was scheduled to begin on 22 February.

But the GIREDMET plant isn't waiting for the court's decision, which could take weeks. Earlier this month, GIREDMET experts, who accuse Baksan officials of "squandering," or hoarding, the gallium, showed up to measure the metal while escorted by local police. The process involves removing the liquid from its tank and weighing it. Partway into the exercise, however, the GIREDMET team gave up and read the calibration marks on the tank.

Vladimir Gavrin, Baksan's director, believes that he has smoothed things over with local authorities: "Very soon, the militia understood that there was no squandering of the gallium, and we started to treat each other with respect." But he can't say the same for the GIREDMET staff, who he claims were intent on finding some infraction that could be used to justify the gallium's removal.

If the observatory loses its appeal, Gavrin says that his last hope is a government decision to rescind the order.

–VLADIMIR POKROVSKY AND ANDREY ALLAKHVERDOV

Pokrovsky and Allakhverdov are writers in Moscow.

ENDANGERED SPECIES

West's Energy Woes Threaten Salmon Runs

The combination of a dry winter and a power shortage could be bad news for endangered salmon in the Pacific Northwest. Last week, California's energy crisis forced the Bonneville Power Administration (BPA), the region's energy supplier, to exceed federal guidelines for the release of water through its turbines. But with reservoir levels already low, the utility might not have enough water available this spring and summer to help juvenile salmon on their run to the sea.

"What we see time and time again is that when the going gets tough, fish take it on the chin," says Rob Masonis, who heads northwest conservation efforts at American Rivers in Seattle. "That's untenable and irresponsible. We need a real commitment to salmon recovery in the region, not just a few museum fish in the river," he says.

BPA spokesperson Dulcy Mahar concedes that the spring water releases may fall short, but says that the agency has no choice. BPA is required to supply power to its customers. In this case, releasing extra water was the cheapest way to do it. "We are seeking to appropriately balance the needs of fish and electricity consumers during a serious drought," says acting BPA administrator Steve Wright.

In normal years, BPA buys power from California suppliers during the cold winter months, when demand peaks in the Northwest, and sells it back to California in the summer, when demand peaks there. This year, however, California hasn't had a megawatt to spare. What's more, because of low rainfall and smaller-than-normal mountain snowpacks, BPA's system of 29 federal dams has been able to generate only about 80% as much power as usual. The agency has been forced to buy the excess at market rates, at up to 10 times the usual price, putting a big dent in reserves earmarked for repaying its federal mortgage. Says Mahar:

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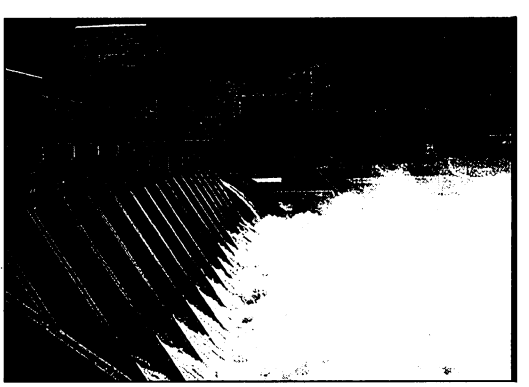

Thirst for power. Dam spills to generate more electricity this winter may threaten salmon runs in the spring.