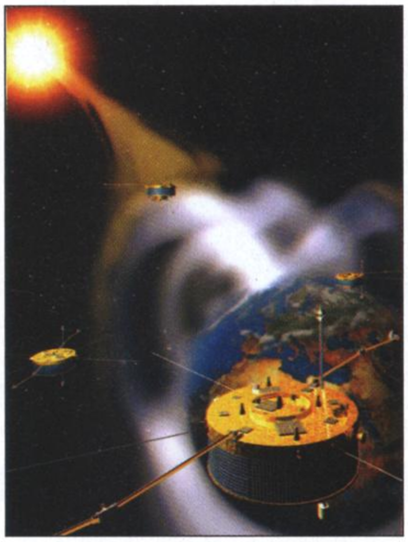
experiment. The magnetometer has two sensors on each craft that measure the intensity and orientation of Earth's magnetic field lines. Outside experts also are impressed. "I am surprised the team has been able to extract such exciting observations so soon after launch," says Alan Gabriel of the Institut d'Astrophysique Spatiale in Orsay and president of the French sun-Earth research program.



Sunstruck. A quartet of satellites carries dozens of instruments to monitor various solar phenomena and their impact on Earth.

The Cluster spacecraft began gathering data soon after crossing the magnetopause—the outer edge of the magnetosphere, where the influence of the sun's magnetic field takes over—on 8 November. Chancing upon one of the most violent solar storms in 25 years, the spacecraft watched a barrage of particles from the sun, carried on a supercharged solar magnetic field, compress the magnetosphere to about half its usual size. It was the first time that this phenomenon has been measured in detail, says Cluster project scientist Philippe Escoubet of the European Space Research and Technology Centre in Noordwijk, the Netherlands.

More data came pouring in last month when the satellites crossed a polar cusp, a funnel-shaped gap in the magnetosphere through which charged solar particles reach the atmosphere and set off the northern and southern lights. Refuting the classic view of polar cusps as relatively stable, the satellites found the northern cusp gyrating wildly like a top, moving at speeds of up to 30 kilometers per second.

The Cluster spacecraft have found that the magnetopause, thought to be smooth, is actually corrugated and undulates like an ocean wave buffeted by wind, says Nicole Cornilleau-Wehrlin of the Centre d'Etude des Environnements Terrestres et Planétaires in Vélizy. "For years, we had been trying to find out what happens to this shield," says Cornilleau-Wehrlin, whose instruments on the Spatio-Temporal Analysis of Field Fluctuations experiment detected waves in the magnetosphere that extended for 1000 kilometers and rippled along the magnetopause away from the sun—the first proof that these waves exist, says Escoubet: "That was not possible with a single spacecraft."

Cluster's findings could soon have some practical benefits as well. The sun is entering the peak of its 11-year cycle of activity, which is expected to bring powerful solar flares that trigger magnetic storms in Earth's atmosphere. Such storms can disrupt radio and satellite communications. "Cluster is well positioned at the most complicated phase of the solar cycle to try and work out what the solar storms do to the magnetosphere," says Balogh. A better understanding of these processes, he says, could lead to the development of early warning systems that would enable satellite operators to shut off their equipment before electrical circuits are damaged.

–BARBARA CASASSUS AND ALEXANDER HELLEMANS

Casassus is a writer in Paris; Hellemans is a science writer in Naples.

CREDITS: (TOP TO BOTTOM) ESA; JOSEPH VEVERKA/NEAR/CORNELL UNIVERSITY

PLANETARY SCIENCE

Strange Doings on a NEAR-Struck Asteroid

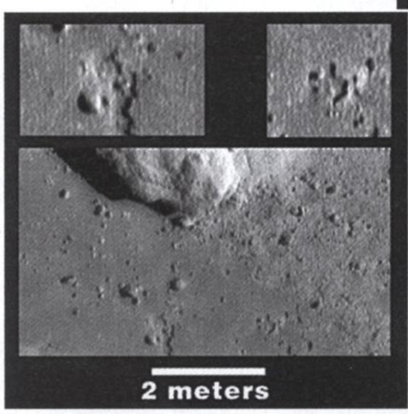
LAUREL, MARYLAND—Researchers here are puzzling over the last pictures returned by the NEAR Shoemaker spacecraft as it descended to its final resting place on the surface of asteroid Eros. At a press conference here last week at Johns Hopkins University's Applied Research Laboratory, team members showed pictures that reveal that something—no one knows quite what—is shaping the surface of Eros into bizarre "ponds" with "beaches" marked by "footprints." Something else is populating the surface with boulders. "Our jaws are just hanging out," says NEAR imaging team member Clark Chapman of Southwest Research Institute in Boulder, Colorado.

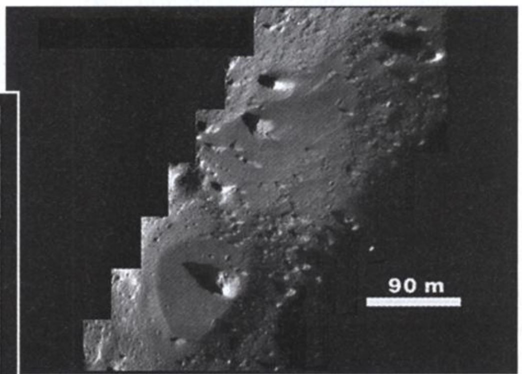
Never designed to land, NEAR Shoemaker made "perhaps the softest [planetary] landing ever" on 12 February in what was expected to be a mission-ending descent to the surface of the 33-kilometer-long asteroid. To the surprise of everyone, the spacecraft continued to beam a radio beacon back to Earth after touchdown. Telemetry was still being received 2 days later, prompting NASA to extend the mission for up to 10 days. With the barrel-shaped, half-ton spacecraft apparently propped on two solar panels, the gamma ray spectrometer was fired back up in hopes of refining the surface-composition measurements made from Eros orbit, according to spectrometer team leader Jacob Trombka of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

NEAR Shoemaker's picture-taking days are over, because its telephoto lens is nearly in the dirt. But the last images it sent back should keep planetary geologists busy for years. "I never would have imagined you'd see some of these things on an asteroid," says Chapman.

The mysteries start with an abundance of huge boulders—perhaps a million of them larger than 8 meters—visible on the surface. One explanation being considered by planetary dynamicist Erik Asphaug of the University of California, Santa Cruz, and his colleagues is seismic shaking: Large impacts might so shake Eros that the surface debris would settle like mixed nuts in a can, with the big, heavy bits rising to the top and the smaller ones falling to the bottom. This "Brazil-nut effect" might have caused boulders completely buried in the surface debris to rise into view, they say.

Another mechanism probably accounts for how the very finest material not only separated out but found its way to low spots, notes imaging team leader Joseph Veverka of Cornell University. Somehow, the finer looking material has filled in low





Something's funny here. On Eros, fine debris has somehow filled in low areas *(above)*; some places have collapsed into depressions (two spots at bottom of lower left image and enlarged in insets above).

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.

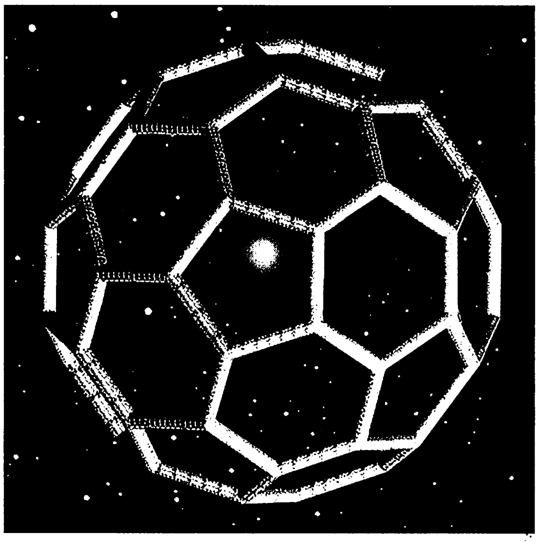
The first clue to the K-T impact, discovered in 1979, was an abundance of the element iridium at the geologic instant of the mass extinction. Because iridium is plentiful in meteorites, the iridium-rich deposit suggested impact debris, but some researchers argued that the layer could instead have been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

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