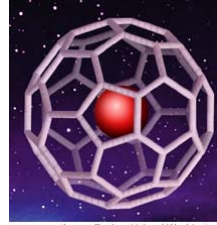


## Hot Idea

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# Buckyballs and Gases May Mark Massive Extinction



(Luann Becker, Univ. of Washington.)

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The Permian period ended with a massive extinction event that might have lasted only several thousand years. Over 90% of marine species, 70% of vertebrate land dwellers, and most land plants perished. Scientists have proposed several hypotheses to explain this environmental catastrophe, including massive volcanic eruptions, meteoroid impact, large changes in sea level, and severe climate changes. A huge volcanic complex in Siberia occurred at about the time of the extinction (251 million years ago). Now a group of scientists led by Luann Becker (University of Washington, Seattle) report evidence for an asteroid impact. They discovered fullerenes (nicknamed "buckyballs"), which are cage-like carbon compounds consisting of 60 or more carbon atoms, at the boundary between the Permian and Triassic periods. The buckyballs at the Permian-Triassic boundary contain trapped helium and argon with isotopic compositions like those in meteorites called carbonaceous chondrites, and very different from those on Earth. This led Becker and her colleagues to conclude that impact of a 9-kilometer asteroid deposited the buckyballs. An unanswered question is whether this impact caused the mass extinction by itself or did so in collaboration with the Siberian volcanism and possibly unrelated climate changes.

### Reference:

Becker, Luann, Robert J. Poreda, Andrew G. Hunt, Theodore E. Bunch, and Michael Rampino (2001) Impact event at the Permian-Triassic boundary: evidence from extraterrestrial noble gases in fullerenes. *Science*, vol. 291, p. 1530-1533.

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## Impacts and Extinctions: The Dinosaur-Killing Example

Fossil experts recognize the end of the Cretaceous Period by the extinction of about half the species on Earth, including the dinosaurs. Scientists still debate the cause of this mass extinction, but we now know that two dramatic events took place at about the same time, 65 million years ago: massive volcanic eruptions and the impact of a large (about 10 kilometers) asteroid.

The volcanic event took longer than the asteroid impact, but is nevertheless very impressive. Layers of lava cover over 500,000 square kilometers of India. They might have covered three times as much before erosion. The total volume of the lava was an astonishing 1.3 million cubic kilometers. That's enough to cover the state of Texas under a layer of lava about 1.3 kilometers thick or the entire surface of the Earth under two and a

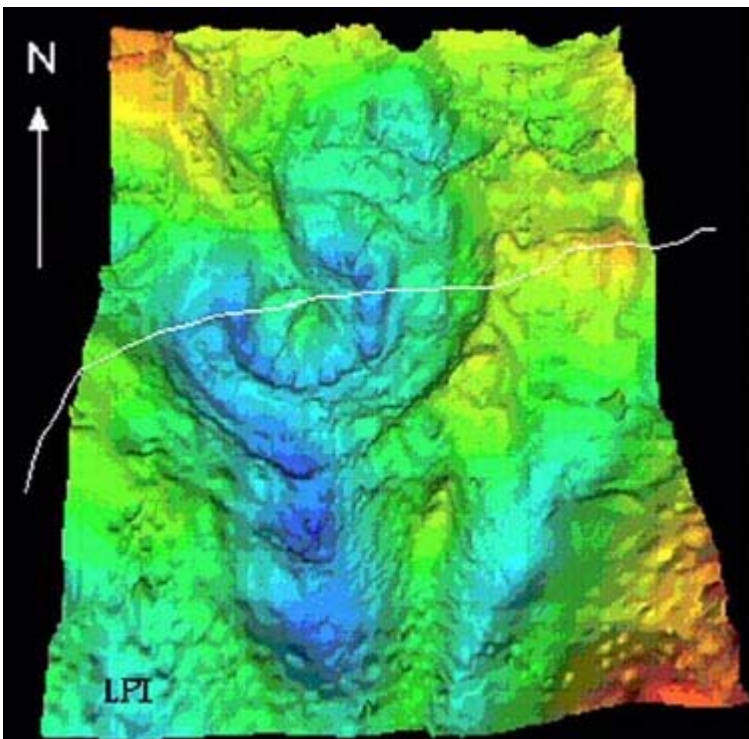
half meters of lava. Rock ages indicate that most of the lava erupted over a period of about a million years beginning before and ending after the big extinction event 65 million years ago.



(Courtesy of Laszlo Keszthelyi.)

Layers of basalt lava, called the Deccan traps. These voluminous lava flows cover over 500,000 square kilometers of India. They erupted 65 million years ago.

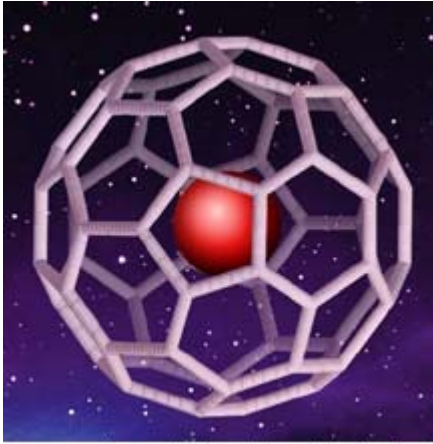
In 1980, Walter Alvarez and his colleagues at the University of California, Berkeley, advanced the idea that an asteroid whacked into the Earth causing the end of the Cretaceous Period. They had found exceptionally high concentrations of the element iridium at the boundary between the Cretaceous and Tertiary periods. Iridium is rare in the crust of the Earth, but much higher in abundance in meteorites. This led Alvarez to propose that the enrichment is due to an asteroid or comet impact. Since then geochemists have found iridium anomalies at the Cretaceous-Tertiary boundary worldwide. It is often accompanied by shock-damaged quartz, an unequivocal indicator of meteorite impact. To top it off, in 1991 A. R. Hildebrand and his colleagues identified the crater buried under a kilometer of sediments. Called Chicxulub, it straddles the Yucatan peninsula and the Gulf of Mexico. Samples of the impact melt collected by drilling into the crater give an age of 65 million years. (For more information about Chicxulub, go to the [Chicxulub Scientific Drilling Project](#).)



(Virgil L. Sharpton)

This map shows the variations in gravity over the buried Chicxulub structure. The crater is about 200 kilometers across. The white line indicates the shoreline between the Yucatan and the Gulf of Mexico.

Last year, Luann Becker (then at the University of Hawai`i), Robert Poreda (University of Rochester), and Ted Bunch (NASA Ames Research Center) reported finding fullerenes at the Cretaceous-Tertiary boundary. Fullerenes are unique carbon molecules with structures that resemble geodesic domes. Because of this they were named "buckminsterfullerenes" after R. Buckminster Fuller, inventor of the geodesic dome. The long name is usually shortened to fullerenes or buckyballs. Buckyballs have two important properties: they seem to be very stable, even surviving arrival by impact; and they have a large volume in their interiors that can trap gases.



(Luann Becker, Univ. of Washington.)

The soccer-ball structures of fullerenes allow the molecules to trap gases inside. Luann Becker and her coworkers have found that the gases in buckyballs from the Cretaceous-Tertiary and Permian-Triassic boundaries are similar to those in extraterrestrial buckyballs.

Measurements of the gases in Bob Poreda's laboratory showed that the Cretaceous-Tertiary samples contain helium and argon with isotopic abundances like those in meteorites. The compositions are much different from those in typical Earth rocks or sediments. In fact, Becker and her coworkers argue that the isotopes and the buckyballs that house them must have formed in stars, long before our star and its Solar System formed. In any case, the discovery of buckyballs and unusual isotopes at the Cretaceous-Tertiary boundary, where an asteroid impact definitely took place, indicates that buckyballs and their gases can be used as a fingerprint for cometary or asteroidal impact.

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## Impact at the Permian-Triassic Boundary?

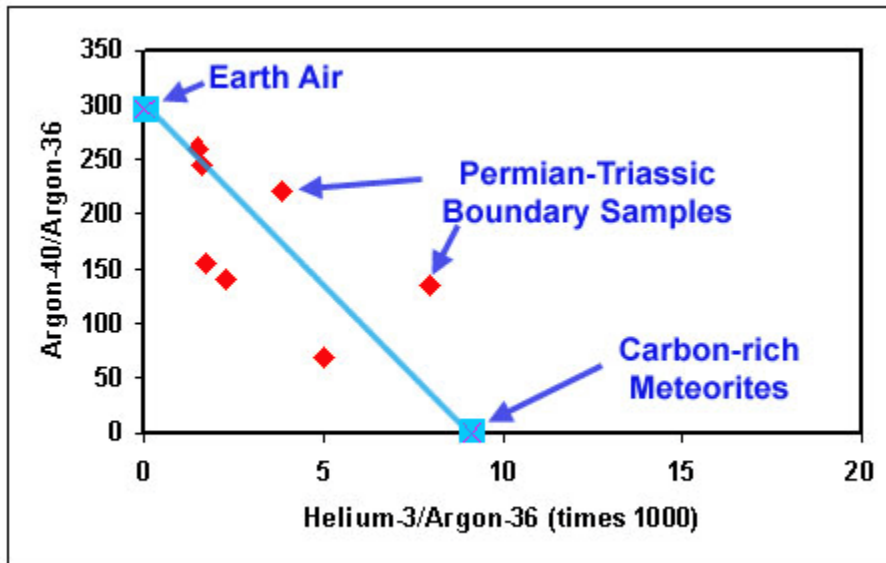
Whatever happened at the end of the Permian Period nearly wiped out all life on Earth. Over ninety percent of ocean-dwelling species perished. Seventy percent of land species died off. Paleontologists call it "The Great Dying." It was Armageddon. It may have been fast, too. Recent work suggests that it might have taken only several thousand years, or less--a snap of the fingers in geologic time. Some scientists disagree, arguing that it took half a million years.

The Permian ended 251 million years ago, at the same time the huge Siberian flood basalts formed. These lava flows are not quite as voluminous as the Deccan lavas that erupted at the Cretaceous-Tertiary boundary. Their volume is a mere 1.5 million cubic kilometers versus 8 million for the Deccan. Nevertheless, if spread evenly on the surface of the Earth, they would make a layer about 30 centimeters thick. You'd be up to your knees in lava. Like the Deccan episode, most of the Siberian lavas erupted during an interval of about a million years.

Could there have been an impact at the Permian-Triassic boundary, too? Geochemists have searched carefully for iridium anomalies in places where the boundary is accessible, but they did not find any enrichments in iridium. Nor has anyone found other indicators of impact, such as shocked quartz. This has led many investigators to favor volcanism as a major contributor to the massive extinction event, but Becker and her colleagues put impact back in the running by finding buckyballs with extraterrestrial noble gases in them.

To search for the buckyballs, Becker crushed each sample and used acids to dissolve most of the rock. She then used organic solvents to extract fullerenes from the residue. She found not only buckyballs with 60 carbon atoms, but those with 70 to 160 carbon atoms as well.

The detection of buckyballs by themselves is ambiguous. They can be made on Earth by forest fires. Analysis of samples from just above and below the boundary in Japan, China, and Hungary indicate that the buckyballs are concentrated there. More importantly, there is a sharp increase in the abundance of helium-3 at the boundary. The ratio of helium-3 to helium-4 is typical of helium trapped in carbonaceous meteorites, and much different from Earth rocks or atmosphere. The ratio of argon-40 to argon-36 is well below that measured in our atmosphere, and trends towards values typical of buckyballs in meteorites. Becker and colleagues conclude that the gases and their buckyball containers are extraterrestrial. A big impact spread them all over the world.



(Modified from Becker et al., 2001, Science, v. 291.)

Buckyballs extracted from sediments at the Permian-Triassic boundary have very different abundances of the isotopes of helium and argon than Earthly materials, such as the atmosphere. They appear to fall on a line between abundances in carbonaceous meteorites and air.

## A Tangled Web of Processes?

Becker and her collaborators make an excellent case for an impact having taken place at the end of Permian, 251 million years ago. Certainly more research needs to be done, especially a search for independent evidence such as an enrichment in iridium or the presence of impact-damaged minerals. Nevertheless, the case seems strong.

But does it have anything to do with the great extinction at the Permian-Triassic boundary? That's the big question. It appears that huge volcanic eruptions occurred around the same time as the huge impact. Other studies show that the end of the Permian was accompanied by an astonishing change in sea level--a drop of about 100 meters. Could all these have combined to cause life to be almost wiped out? Perhaps the largest extinction events happen only when two or more dramatic geologic events coincide, such as huge outpourings of lava and the impact of a large asteroid.

Impacts of multi-kilometer asteroids are not very common. Neither is the formation of flood basalts. Nevertheless, the two could happen at the same time surprisingly often. There have been ten huge flood basalt eruptions on the continents starting with the Siberian eruptions 251 million years ago. Each lasted about one million years (actually somewhat longer, but the majority of the lava squirted out in a relatively short span of time). This means that for the past 251 million years, large eruptions have been going on for 10/251, or 1/25 (4%), of the time. For any random large impact there is a 4% chance it will hit during a huge eruption. For two impacts, the chance of one of them hitting is double that, 8%.



Studies of the ages of impact craters on Earth and the number of asteroids in orbits that cross Earth's orbit indicate that impactors 10 kilometers or larger hit the Earth once every 100 million years. Thus, during the past 250 million years, Earth would have been smacked by two or three 10-kilometer asteroids. The chances are 8 to 12% that one of them would have corresponded to a flood basalt eruption. Five-kilometer asteroids hit once every 6 million years. In this case, it is extremely likely that one will happen during a flood basalt eruption. However, impacts of five-kilometer asteroids have a much smaller affect on Earth than do larger ones (roughly in proportion to the cube of the radius).

This means that we should not be too surprised that both the Permian-Triassic and Cretaceous-Tertiary extinction events have both huge volcanic eruptions and large impacts associated with them. (It also means that the impacts did not cause the volcanism, though it does not rule that out, of course.) Possibly the largest extinctions occur when two or more geologic processes operate at the same time. This would not occur frequently, and neither do immense extinction events--fortunately for us.

Acknowledgement: PSRD would like to thank Gerard Fryer and Ralph Moberly (both at the University of Hawai'i) for an enlightening email discussion about the probabilities of impacts and huge volcanic eruptions occurring together.

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## Additional Resources

[Asteroid and Comet Impact Hazards](#), from NASA Ames Space Science Division.

Becker, Luann, Robert J. Poreda, Andrew G. Hunt, Theodore E. Bunch, and Michael Rampino (2001) Impact event at the Permian-Triassic boundary: evidence from extraterrestrial noble gases in fullerenes. *Science*, vol. 291, p. 1530-1533.

[Chicxulub Scientific Drilling Project](#).

[Near Earth Objects](#), report of the UK task force.

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