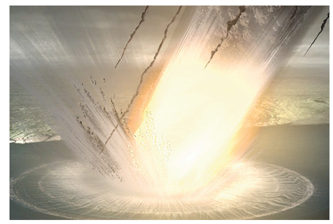
Do impacts trigger extinctions? Impact theory still controversial

The revolution started with a bang in 1980. For some, this revolution became a religion, even an orthodoxy. The true believers became proselytes and began to see signs supporting their viewpoint everywhere. But each time the proselytes claimed to have found yet another example in support of their "religion," naysayers and doubters emerged. Two sides formed, each loudly castigating and questioning their opponents.

This back-and-forth ideological debate describes both the historical and still-ongoing struggle over a purported cause of mass extinctions: the meteor impact theory.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It all started on June 6, 1980, when an article titled "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction: Experimental Results and Theoretical Interpretation" was published in Science. Written by Luis Alvarez, Walter Alvarez, Frank Asaro and Helen V. Michel, the 14-page paper was sandwiched between an advertisement for a symposium workshop on "halogenated aliphatic and olefinic hydrocarbons" and an article on no-tillage agriculture.

Basing their work on abnormally high iridium concentrations in 65-million-year-old limestones from Italy and Denmark, the Alvarez team proposed that a 6- to 14-kilometer-wide asteroid struck Earth at the end of the Cretaceous period. Dust from the crater rose to the stratosphere and restricted sunlight for several years, stopping photosynthesis and collapsing food chains. In the sea, this led to an almost complete extinction of foraminifera, a key part of the marine food chain, and subsequent loss of animals such as ammonites and marine reptiles. On land, Alvarez's team wrote, widespread plant death resulted in the extinction of any terrestrial vertebrate larger than about 25 kilograms, including the dinosaurs. Ultimately, 70 percent of all species on Earth went extinct.

The landmark paper prompted years of debates and discussions — some on levels less than academic and polite. The main sticking point: For all of their data, the authors still lacked the smoking gun — a crater dated to that time period.

The debate mostly ended in 1991 when a team of researchers described a 65-million-year-old, 180-kilometer-wide crater near the town of Chicxulub Puerto on the Yucatán Peninsula in Mexico. Along with the elemental evidence for an impact, there was now a crater to show where a meteorite hit.

There are still a few doubters, and every year a couple of papers are published or presented at conferences that purport another hypothesis for the end-Cretaceous mass extinction. But the majority of scientists agree with the impact theory. Earlier this spring, in fact, to respond to some of the naysayers and to commemorate the 30th anniversary of the Alvarez paper, a large group of scientists got together to re-examine the science behind the end-Cretaceous extinction and reaffirmed that the impact likely did cause the mass extinction.

Despite the handful of skeptics, in the 30 years since the Alvarez gang proposed a link between extinctions and meteorites or asteroids— both known as bolides, now the term of choice to describe an extraterrestrial impacting body — the idea has become accepted not just by geologists of all stripes but also by the media and the general public. One can argue that along with dinosaurs, meteorite-caused extinctions are the most attractive thing going in geology.

But some say that has not always been good for science or scientists — because of something that might be called the Alvarez Effect: The overwhelming evidence that a bolide caused a mass extinction at the Cretaceous-Paleogene boundary (formerly called the Cretaceous-Tertiary boundary) weighs so heavily in the minds of researchers that it can sway how they read the evidence related to other mass extinctions.

"For some, impacts have become a first choice for a sudden and puzzling geologic event. Instead of coming up with three or four more scenarios, they tend to settle on their beloved child," says Bevan French, a paleobiologist at the Smithsonian Institution in Washington, D.C., and co-author with Christian Koeberl, an impact specialist at the University of Vienna in Austria, of an article in Earth Science Reviews last January about impact structures. "Impacts are big, powerful and irresistible. They are the geological equivalent of the great white shark," French says. But, he adds, they aren't always the answer.

Impact Craters, Big and Small

It's not that impacts aren't frequent. Look up at the moon on a clear night and you can see that impacts have struck our nearest neighbor quite frequently through geologic time. They have left behind hundreds of craters that dot the surface. But the moon is not alone: All of the planets in our solar system are struck regularly, including Earth.

During the early years of Earth's existence, bolides struck the planet with great frequency — but the frequency of such strikes has tailed off significantly. Scientists estimate the likelihood of a bolide striking Earth in our lifetime at one in 50,000. But it is unlikely to be one of any significant size; in fact, most of the 50 to 150 tons of extraterrestrial material that collides with Earth every day is dust. If you're talking about the scale of impact that might end life as we know it — the kind that killed the dinosaurs — then the probability goes up to one every 50 million to 100 million years.

We know of fewer than 30 meteorites that have produced craters since modern humans began walking the planet. Most craters are covered over by erosion and other earth processes, are beneath the sea, or are hidden by dense forests, so we don't know the magnitude of many of these strikes. However, more than 170 objects have produced craters that remain identifiable today. North America has the most identified craters, with about 59, followed by Europe and Asia.

When matter does fall from the skies, people notice. Some of the earliest tools made by humans were from meteoritic iron. Pliny the Elder refers to such objects in his "Natural History," written around A.D. 77. He used the term "bolides" to refer to a type of falling star that "being entirely in a state of combustion, leave[s] a still longer track behind them." Medieval writers described "thunder stones" and "lighting stones," and in one account, locals supposedly ground up a meteor that fell in Russia and ate it. (No one knows why or what happened to the diners.) Not knowing the true origin, some thinkers, such as René Descartes and Antoine-Laurent de Lavoisier, proposed that the stones formed, or congealed, in the atmosphere, possibly due to lightning.

In 1794, German physicist Ernst Chladni proposed the first sound explanation that meteorites had an extraterrestrial origin, though it took many years for his ideas to be widely accepted. (There is an oft-told story that Thomas Jefferson didn't believe that meteors fell from the sky. Referring to a study by two Yale professors of a fireball that crashed in Weston, Conn., on Dec. 14, 1807, Jefferson supposedly wrote: "It is easier to believe that those two Yankee professors would lie than that stones would fall from heaven." According to Ursula Marvin, a senior geologist emerita at the Harvard-Smithsonian Center for Astrophysics, Jefferson wrote no such thing.) Not until the early 1900s, at Meteor, or Barringer, Crater in Arizona, did anyone find any acceptable evidence — meteorite fragments — that a crater had been produced by extraterrestrial impact. Even the U.S. Geological Survey didn't research impact craters until the 1950s.

From the 1950s onward, a small cadre of scientists became crater hunters. Some scoured the landscape via aerial photographs and satellite images for telltale bull's-eye-shaped structures. Others more closely examined sites previously thought to be craters. They found definitive clues such as shatter cones and microscopic planar deformation features (see sidebar). Another diagnostic came from Ries Crater in Germany, where in 1961, geologists Eugene Shoemaker and Edward Chao reported finding high-pressure forms of quartz known as stishovite and coesite, which could only be formed under the high pressures produced by a bolide impact.

Slowly, the evidence was mounting that Earth could be struck by extraterrestrial impacts. Then, when the Alvarez paper was published in 1980, the field exploded.

Did a bolide cause the Great Dying?

There have been five major mass extinctions:

Ordovician-Silurian, 445 million years ago, sea levels changed drastically due to glaciations, and 85 percent of all species died;

End-Devonian, 376 million to 350 million years ago, 70 percent of all species died due to unknown causes (though the rise of terrestrial plants led to a decrease in carbon dioxide);

Permian-Triassic, 252 million years ago, thought to have been caused by the eruption of flood basalts and the formation of Pangaea, 90 percent of marine species died and 70 percent of terrestrial organisms;

End-Triassic, 200 million years ago, again thought to have been caused by the eruption of flood basalts, killing 76 percent of all species;

End-Cretaceous, 65 million years ago, an asteroid struck Earth, leading to the death of 47 percent of marine genera, plus the dinosaurs.

Although the end-Cretaceous extinction is the only extinction event scientifically linked with an impact, several researchers say bolides played a role in other extinctions as well. In fact, impact theory reached its zenith in the early 1990s, when University of Chicago paleontologist David Raup proposed that impacts caused all five of the mass extinctions. In subsequent years, various researchers have taken Raup's proposal to heart by trying to link each of the major extinctions with a corresponding impact site.

That doesn't sit well with everyone. "Impact hypotheses should be used very sparingly and only when the evidence is extraordinary, because significant terrestrial impacts are rare and extraordinary events," says Mark Boslough, an asteroid impact specialist at Sandia National Laboratories in New Mexico. Indeed, over the past decade, nearly all big studies of meteor craters, particularly those linking impacts and mass extinctions, have been rejected or at least faced a steep uphill battle.

Foremost among these is the Permian-Triassic mass extinction. Known as the Great Dying, it had been the subject of numerous theories. In February 2001, bolide impact was added to the list: A team led by Luann Becker, then at the University of Washington in Seattle and now at Johns Hopkins University in Baltimore, Md., and Robert Poreda of the University of Rochester in New York reported that they had conclusive evidence for an impact at the end of the Permian. Their proof came from tiny geodesic dome-shaped carbon compounds called buckyballs, or fullerenes, that were found in Permian-Triassic sediments from Japan, Hungary and China, including the well-known clay beds at Meishan.

The buckyballs' cage-like molecular structures contained trapped helium and argon gases — but not the isotopes of these gases found on Earth, Becker and Poreda reported in Science. Instead, the gases were isotopic varieties typically associated with an extraterrestrial origin. The most likely mechanism of transport, Becker and Poreda hypothesized, was a 6- to 12-kilometer-wide bolide that crashed into Earth 252 million years ago, sending particles into the atmosphere that later rained down on seas and accumulated in marine sediments.

As with the end-Cretaceous impact, the report caused a brouhaha among scientists. Geochemists Kenneth Farley and Sujoy Mukhopadhyay of CalTech in Pasadena, Calif., were foremost among those questioning the new buckyball data. The pair re-examined the same Meishan sediments from China and found no evidence for impact-derived helium, as they reported in Science in 2001. At the time, Becker responded with a technical comment in Science, claiming that Farley and Mukhopadhyay had sampled the wrong layers and that their analytic method diluted the results.

Three years later, Becker and Poreda announced in Science that they had the final piece of evidence for an impact at the end of the Permian: They had found the crater. A circular feature under the ocean northwest of Australia, called the Bedout High, was the crater produced by the deadly bolide, they said. The skeptics pounced even more critically on this report, questioning the geophysical data, the chemical evidence, and even the dating of the "alleged Bedout feature." Becker responded again with a letter in Science, in October 2004, saying that skeptics "take an exception to each line of evidence we presented, but they offer no plausible alternative explanation for these data."

Becker has since moved on from impact theory and is now helping design an instrument for searching for life on Mars, but she still believes that she and her colleagues did not get a fair hearing. "How else can I interpret it? Some people will never be satisfied. They said we hadn't found an impact crater, but when we found one it made them more upset," Becker says. Meanwhile, other researchers continue to seek evidence for an end-Permian impact, including a 2006 report of a 500-kilometer-diameter crater beneath Antarctica. Few geologists, however, accept that a bolide triggered the Great Dying.

Did an impact trigger the Younger Dryas?

Researchers are also linking smaller extinction events with bolide impacts. About 13,000 years ago, abrupt climatic cooling — which some have proposed was triggered by catastrophic discharge of freshwater into the Atlantic Ocean as the Laurentide Ice Sheet melted — caused a massive die-off of megafauna, such as mammoths, mastodons and giant sloths, called the Younger Dryas extinction. The Clovis culture, the people who inhabited North America from about 14,000 to 10,500 years ago, also experienced a marked population decline at the same time. In 2001, Richard Firestone, a staff scientist in the Nuclear Science Division at the Lawrence Berkeley National Laboratory in California, and amateur archaeologist William Topping, a consultant based in Baldwin, Mich., wrote that supernova-induced cosmic rays led to this event.

Firestone and Topping's ideas of an extraterrestrial source for the megafaunal extinction 12,900 years ago attracted little attention until 2007, when they made more formal presentations at the American Geophysical Union (AGU) spring meeting in Acapulco, Mexico. Firestone and Topping, along with a team of 24 others, including Becker and Poreda, as well as other principal investigators Allen West of GeoScience Consulting in Dewey, Ariz., and James Kennett of the University of California at Santa Barbara, also published a lengthy article in Proceedings of the National Academy of Sciences later that year.

Based on data from organic-rich sediments — commonly called black mats — found at numerous Clovis-aged sites across North America, the team proposed that "one or more large, low-density [extraterrestrial] objects exploded … partially destabilizing the Laurentide Ice Sheet and triggering [Younger Dryas] cooling." The airbursts also sparked continent-wide firestorms that destroyed forests and grasslands and spawned devastating soot, ash and toxic fumes, producing the black mats, they hypothesized. The abrupt cooling that followed lasted for more than 1,000 years and precipitated a major faunal extinction, as well as the drop in Clovis population, they wrote.

Firestone and his colleagues described a host of features in the sediments that are often associated with bolide impacts. Several sites included fullerenes with extraterrestrial helium and magnetic grains with elevated iridium concentrations, they said. More widespread were carbon spherules, glass-like carbon containing nanodiamonds, and magnetic microspherules — more signs of extraterrestrial activity. And finally, they reported that the charcoal and soot in the black mats came from the catastrophic fires. West acknowledges that they had "no smoking hole in the ground." But they did have thousands of elliptical, shallow depressions scattered from Delaware to Florida, known as the Carolina Bays, which they say could have formed if a comet had broken up over the region.

Yet again, questions arose about the data, particularly at a session convened for the Geological Society of America's (GSA) annual meeting in October 2009 in Portland, Ore., where each speaker categorically rejected the idea that an impact caused the Younger Dryas cooling and megafaunal extinctions. They dismissed the carbon spherules as "clearly terrestrial," could not duplicate the high iridium concentrations reported by Firestone and Topping's team, and questioned the extraterrestrial interpretation of the magnetic minerals and microspherules. In the words of University of Wyoming anthropologist Todd Surovell: "We find no support whatsoever for a Younger Dryas extraterrestrial impact."

The reaction is not new to Kennett. "What we went through is the same as what Alvarez faced, not only sociologically but scientifically," Kennett says. "It's funny, I watched what happened then and was so glad I wasn't involved in that, but here I am. Famous last words."

Kennett contends that the naysayers made up their minds before any data were even presented. He cites three reasons. The first is that humans are involved, making the debate over the cause of our population decline more personal. Second is that the impact is so recent, and the closer we are to an event in time, the harder it is to look at it without any bias. The third results from the polarized nature of the debate over the Younger Dryas megafaunal extinction. (The leading and hotly contested hypotheses include climate change, overhunting by Clovis culture people and infectious "hyperdisease.") "For 30 years, we've had blood on the streets," Kennett says.

Two months after the GSA meeting, at AGU's annual meeting in San Francisco, Calif., both sides again presented their evidence. Firestone's team updated their evidence, which the skeptics again strongly refuted, and by the end of the meetings, it was pretty obvious that neither side had changed anyone's pre-conference views on the subject.

For now, many scientists, including Bevan French and Christian Koeberl, argue that support for a bolide-induced cause for the Younger Dryas is waning, or at least, those who question the evidence have mounted effective arguments against an impact.

The Value of Impact Theories

At this point in time, the end-Cretaceous mass extinction is the only one widely accepted as having a bolide impact as the central cause. Despite the challenges of proving the impact-extinction connection, it has wide appeal, not just because it's sexy but because it can answer many questions about the history of Earth. In addition, researchers such as French and Boslough note that when researchers do propose that an impact caused an extinction, it forces other researchers to be more thorough in their own work, and this in turn has helped advance the field of extinction research.

"The increased interest in meteor impacts will be productive. We've seen in the past years people finding many more impact craters," French says. "This is very exciting business. It's a totally new wild card mechanism for how Earth changes."

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