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The end-Permian mass extinction and a possible massive impact

by Rebecca Teed, Wright State University

What Do We Know About Massive Meteor Impacts?

Meteors crash into Earth's atmosphere every day, but almost all crumble into dust before they reach the surface. Occasionally, a larger fragment, called a meteorite, makes it all the way to Earth's surface. There have been cases of people injured and property damaged by meteorites. One of the more spectacular recent atmospheric impacts occurred over Chelyabinsk, Russia, in 2013. The meteor exploded in the air, generating a shockwave that shattered windows all over the city, sending over a thousand people to the hospital. To make matters worse, the impact occurred in February, during very cold weather, and it was hard to heat those homes until the windows could be repaired. Russian scientists recovered several meteorite fragments months later; they had fallen harmlessly into a nearby lake. In 1908, the atmospheric explosion of a comet or meteor over Tunguska in Siberia flattened trees in such a large area that the devastation was still visible 21 years later when a scientific expedition came to investigate the blast. Historical records from China describe a meteor shower, during which stones the size of goose eggs fell out of the sky and killed thousands of people in AD 1490.

As terrible as these impacts were, none of them left craters. According to the Earth Impact Database (PASSC, 2015), there are almost 200 verified craters on Earth's surface from even bigger impacts, almost none of which occurred during recorded human history. Oddly, most of them were not identified as impact structures until the late 20th century. Geologists generally attribute features like craters and canyons to events we can see taking place today or in recorded history, like erosion by rivers, gradual movement of rocks on either side of a fault by earthquakes over time, volcanic eruptions, etc. Craters



Figure 1: Satellite image of Barringer or Meteor Crater, Arizona U.S.A. The dark rectangle at the top is a museum. (<http://earthobservatory.nasa.gov/IOTD/view.php?id=39769>)

left behind by massive meteor impacts resemble those created by explosive volcanic eruptions, but with one critical difference: there's little or no igneous rock in impact craters (unless the crater was in igneous bedrock). When geologists were forced to come up with explanations to explain structures like Coon Butte (now called Barringer or Meteor Crater) in Arizona, USA (Fig. 1) and Ries Crater in Germany, they debated whether they had been created by meteor impacts or by cryptovolcanism, volcanic explosions that left little or no ash or igneous rock behind.

Over the 20th century, the scientific community gained a better understanding of impacts, but found no evidence for cryptovolcanism anywhere. Very few scientists accept cryptovolcanism now. Craters and impacts big enough to leave them have been observed on the moon and elsewhere in the solar system using technology like

telescopes and spacecraft with cameras. Also during that time, geologists discovered minerals that could be used as reliable indicators of asteroid impact. Coesite and stishovite were created as artificial crystals in laboratory settings and later found in nature as minerals at Barringer Crater. They were also found at nuclear-weapon testing sites, along with shocked quartz. Shocked quartz has become very useful for scientists because the linear patterns that distinguish it from ordinary quartz are easy to recognize under a microscope (Fig 2). Another important feature of shocked quartz is that it forms under high pressure, but only under a range of temperatures similar to those found at Earth's surface, as opposed to the high-temperature conditions inside a volcano or a magma chamber.

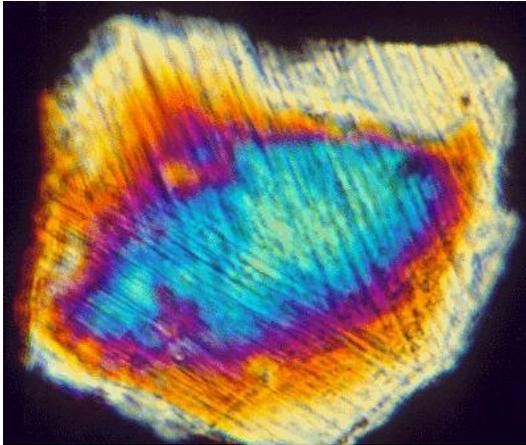


Figure 2: a shocked-quartz grain from the Chesapeake Bay Impact structure. Image from USGS-NASA.

Barringer Crater is a simple crater (Fig. 3a). Meteors big enough to leave a crater actually explode before or on impact. The crater is formed by the force of the explosion rather than by the impact itself. The heat from the meteor is intense enough to melt some of the surface rock. The blast shatters the rest. The pressure on the solid bedrock layers beneath is so intense that the bedrock becomes temporarily capable of stretching and bending, even though it is still solid. The crater forms as the bedrock is pushed away from the explosion. However, the rock quickly loses that flexibility, becoming rigid again, before it can regain its original shape. The resulting crater is much larger than the meteor that originally formed it.

More severe impacts leave behind complex craters (Fig. 3b). In this case, the bedrock in the middle of the crater remains flexible long enough to not only bounce back to its original elevation, but to keep going. The bedrock becomes rigid again before it can descend again, leaving behind a hill in the middle of the crater called the central uplift.

How Could a Massive Impact Cause a Mass Extinction?

The force of a massive impact alone will crush every multicellular organism in the crater. The blast wave it generates will kill organisms across an even greater distance, but it will have to trigger a series of other effects to cause a global pattern of extinction.

When a large meteor explodes at or near the surface of the Earth, pulverizing surface rock, the shockwave will scatter the dust from both the meteor and the impact site high into the atmosphere. The explosion may also generate enough heat to trigger forest fires or grass fires, which will produce ash that is also blown into the atmosphere. These solid particles can block or reflect sunlight. They can remain suspended in the air for months and will be spread around the hemisphere by high-altitude winds.

Historians observed similar effects from the eruption of a stratovolcano, Tambora, in the early 19th century, which ejected so much ash that the amount of sunlight reaching the Earth's surface was significantly reduced as it spread over Northern Hemisphere. The following year was called "The Year without a Summer" because the weather was so cold. Crops that survived the frost provided a meager yield because they could only photosynthesize slowly with weak sunlight.

A multi-year “impact winter” caused by a massive impact could be even colder and darker, blocking so much light that plants might not be able to photosynthesize at all for months, and could kill plants that are vulnerable to frost. Rain and gravity will remove the dust in a few years, just as it does the ash from

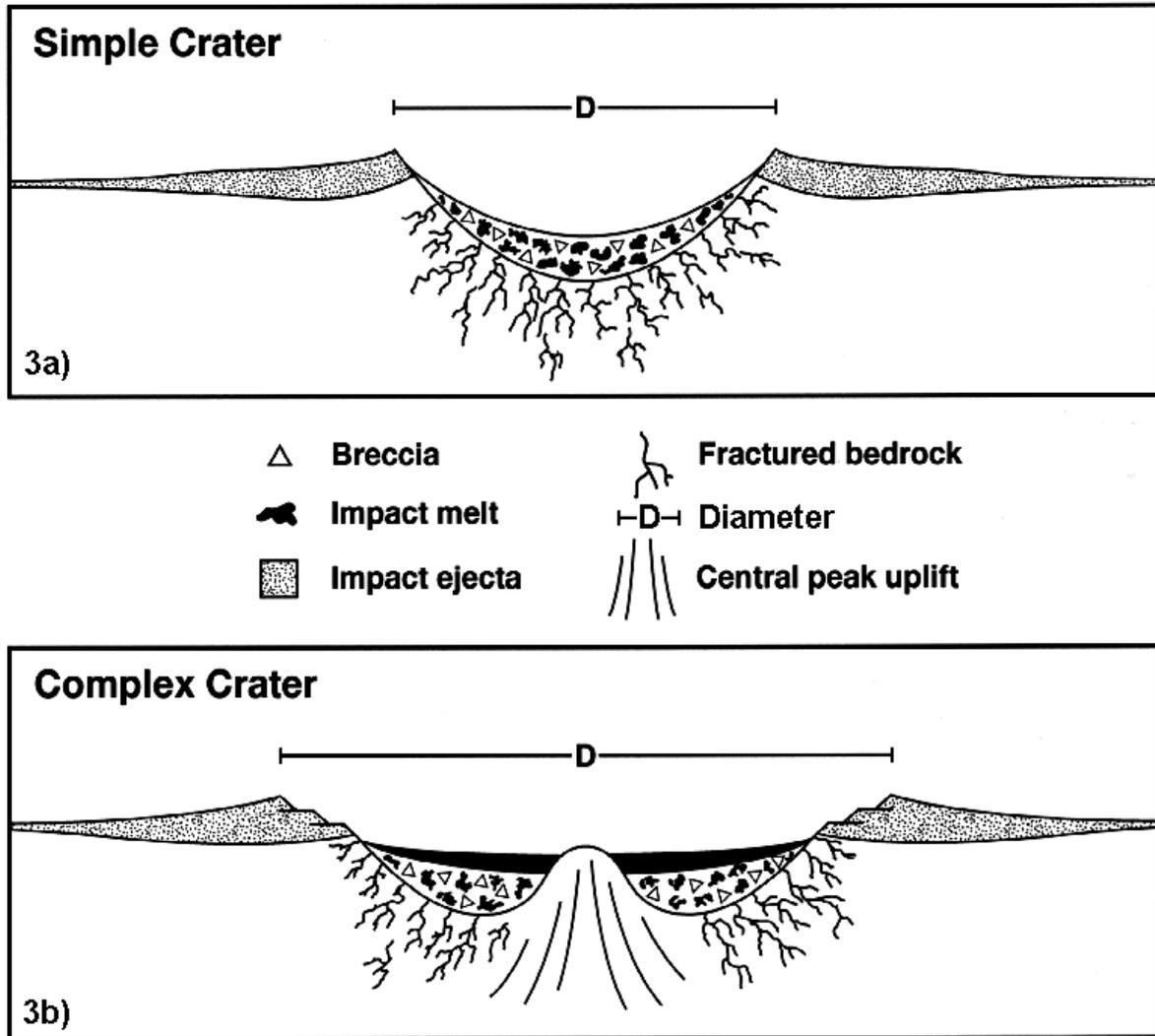


Figure 3: Diagram showing a cross-section of a) a simple crater and b) a complex crater. Modified from <http://craters.gsfc.nasa.gov/assests/images/craterstructure.gif>

a stratovolcano. But a few years of impact winter will have destroyed vulnerable populations of large animals that cannot migrate or go without food for months at a time. Herbivores would starve first, then carnivores.

Impact winter has nothing to do with the Pleistocene ice ages when woolly mammoths and saber-toothed tigers roamed the Northern Hemisphere. During a Pleistocene ice age, climate cooled gradually over tens of thousands of years. Also, the Pleistocene ice ages only began between three and two million years ago. There is currently no evidence for glaciers or ice sheets anywhere on Earth at the end of the Cretaceous or afterwards for millions of years.

Impact Structure	Age (millions of years ago)	Original Crater Diameter (km)	Associated Extinction Event
Barringer Crater (W. U.S.)	0.05	1.25	none
Ries Crater (Germany)	14	24	none
Chesapeake Bay (E. U.S.)	35	85	none
Popigai	36	100	none
Chicxulub (S.E. Mexico)	66	180	end-Cretaceous
Lac Manicouagan (central Canada)	214	100	none
Sudbury (Canada)	1,850	250	unknown
Vredefort Dome (S. Africa)	2,000	300	unknown

Table 1: Characteristics of several well-known impact sites.

Most verified massive impacts are not associated with a mass extinction event, or even a minor extinction. However, the largest crater less than a billion years old dates from the end of the Cretaceous (near Chicxulub, Mexico). Smaller impacts may not add enough debris to the atmosphere to cause a really devastating impact winter. Also, there are no verified large craters the same age as the four older major mass extinctions. However, craters tend to fill with sediment over time, and their rims and central uplift areas are vulnerable to erosion. Older craters in the ocean are likely to have been subducted into the mantle as part of the process of plate tectonics. Still other potential impact craters cannot be examined by geologists. For example, there is a large structure, possibly a huge compound crater, in Wilkes Land, Antarctica, but it is under several kilometers of ice.

What is the Evidence for a Massive Impact at the End of the Permian?

There are multiple lines of evidence for a massive impact at the end of the Cretaceous, 66 million years ago. However, there is no clear sign of a massive impact at the end of the Permian, 186 million years before that. Part of the reason may be that the Permian occurred so much further back in time that any evidence may have been buried, eroded away, or destroyed by plate tectonics. Also, there was a series of intense volcanic eruptions at the end of the Permian which left behind the Siberian Traps, a huge expanse of volcanic rock 2 million km² after erosion and burial. These eruptions would have released gases into the atmosphere that would have reacted with ozone, acidified water, and warmed the climate.

However, many scientists still have doubts about whether the Siberian Traps alone caused the worst extinction in the fossil record, one that wiped out 90-97% of all marine animal species. Scientists who favor the Siberian Traps eruptions as the sole cause of the mass extinction describe it as a gradual process, with species succumbing one after another as the oceans deteriorated under millions of years of chemical inputs from the volcanoes. Instead, the extinction was very sudden. Burgess et al. (2014) studied the end-Permian marine beds near Meishan in China. These contain huge numbers of tiny, well-preserved plankton shells that can be classified to species. There appear to be multiple extinction events in different layers. But according to radiometric dates, the first and last extinctions were only 60,000 (\pm 48,000 years) apart.

A number of scientists have discovered chemical and geological indications of impact in end-Permian rocks, but their discoveries were either overturned or could not be replicated. Moreover, end-Permian rock is generally not enriched in iridium or other materials that are more common in meteorites than in Earth's crust. If a big meteor had struck the Earth, its dust should have spread through the atmosphere

and been deposited all over the planet, leaving a chemically distinctive layer like the high iridium concentrations in end-Cretaceous sediments. However, an impact by a massive comet is unlikely to leave behind such evidence because comets are mostly ice. A cometary impact could kick up a lot of dust from Earth's surface, blocking sunlight, but that dust would not contain an unusual chemical signal once it settled.

The biggest problem for end-Permian impact theories is that no one has verified a large impact crater between 249 and 253 million years old (or even close to that range). A large comet would leave one, just as a meteor would. There is a circular gravity anomaly under Wilkes Land, Antarctica, similar to ones seen under impact craters on the moon. That impact crater would be bigger than any yet verified on Earth (almost 500 km in diameter). However, the rocks in and around it can't be sampled because they are under the East Antarctic Ice Sheet. Its age is estimated between 500 and 100 million years old. The Bedout High, an underwater mountain northwest of Australia, may be the central uplift area of another huge compound crater (roughly 200 km in diameter). It is about 250 million years old, according to radiometric dating. But it formed in basalt, which contains impact-like features. So the identification of shocked minerals and other impact indicators at the Bedout High may be erroneous.

An alternative explanation for the Wilkes Land gravity anomaly is that the mantle in that area was thickened by an upwelling of magma that never broke through the crust to form a volcano. Likewise, the Bedout High may be an unusual plate-tectonic feature. However, these explanations, like massive impacts, describe events that people have never been able to observe them directly.

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