Hot Idea

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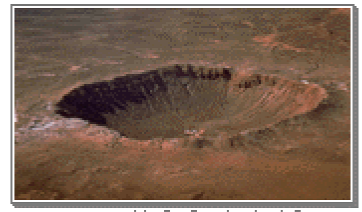
U. S. Geological Survey

Damage by Impact

the case at Meteor Crater, Arizona

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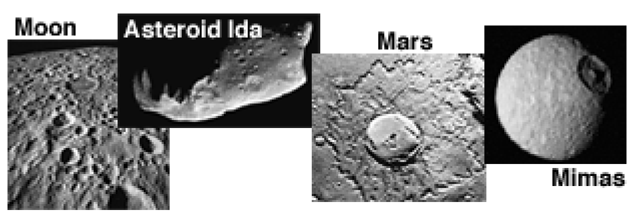
50,000 years ago mammoths, sloths, bison, and camels likely roamed the grassy rolling hills and woodlands of the Colorado Plateau in an area known today as northeastern Arizona. But in an instant, a meteorite impact disturbed this peaceful scene. What were the environmental effects? What happened to the animals living near the impact? According to David Kring of the University of Arizona, damage would have been swift and extensive. Casualties resulted from vaporization, burial by the ejected bedrock, and from the destructive air blast moving across the landscape. Kring calculated the magnitude and radial extent of the air blast produced by the Meteor Crater impact event using scaling relationships from nuclear explosions. His estimates show immediate vaporization of plants and animals at ground zero. Winds in excess of 1000 km/hour scoured the land within 3 to 5 km of the point of impact and led to swift devastation of the local population of plants and animals. Just how often does this sort of impact event occur on Earth? We'll examine the potential hazards.

Reference:

Kring, David A., 1997, Air blast produced by the Meteor Crater impact event and a reconstruction of the affected environment , *Meteoritics and Planetary Science*, v. 32, pp. 517-530.

A major phenomenon



Impact craters are found on the Moon, all the terrestrial planets, asteroids, and most moons of the outer planets. They are compelling evidence that impact cratering (collisions of solid objects) was a dominant and widespread geologic process in the early Solar System. Earth was similarly hammered but most of the telltale craters have been erased by volcanic processes, plate tectonics, and erosion by water, wind, or ice.

However, traces of some craters still remain. Using satellite images, aerial photographs, field observations, maps, and underground geophysical data, geologists have documented over 150 impact craters on Earth. Since no one has ever observed the production of an impact crater on any rocky planet, we must use the size and shape of the craters, the presence of excavated bedrock, the shape and extent of the ejecta, and over-turned rock layers in the crater rims to understand the cratering process. Researchers are gaining more understanding of the interplay between impact energy, target rock strength and structure, presence or absence of volatiles, and gravity from their studies of impact craters throughout the Solar System.

Impact cratering on Earth has an additional profound implication: catastrophic loss of life. Local and regional environmental changes and even global climatic variations on Earth have been attributed to impact events. The Chicxulub Crater on the Yucatan coast of Mexico gained celebrity status in the early 1990s as the most likely impact event possibly associated with the extinction of the

dinosaurs at the end of the Cretaceous period, about 65 million years ago (also known as the **K-T** impact.) It is known, however, from estimates of cratering rates that smaller impact events occurred more frequently and that there has been a decline in the rate of cratering through time.

So the question is: what did the smaller, more frequent impact events do to Earth? More important, what havoc could the smaller impact events wreck on our modern world? David Kring's focused study of the area at Meteor Crater, Arizona sheds light on the pre- and post-impact environments. This site-specific analysis can be used as a baseline for illustrating what happens to local and regional environments when an impact, like the Meteor Crater event, takes place. The explosive energy of the Meteor Crater event has been likened to a 20 to 40 megaton nuclear explosion.

Setting and Characters

Meteor Crater, Arizona (also known as Barringer Crater) is one of the classic impact sites in the world. A 1.2-km diameter bowl-shaped hole sits in the ground 60 kilometers southeast of Flagstaff, Arizona (35°02'N, 111°01'W.) The crater is approximately 180 meters deep with a rim that rises 30 to 60 meters above the surrounding plain. According to measurements made by Steve Sutton at Washington University in St. Louis, the crater formed about 50,000 years ago. (Steve is now at Brookhaven National Laboratory in New York state.)


Photograph courtesy of Twyla Thomas.

On the Meteor Crater rim, some of the ejected blocks tower over the trail. The tallest block in this photograph is about 10 meters high. There's a 2-meter-tall hiker with a blue shirt standing to the right of this block. In the background is the gently undulating plain. (See enlargement.)

Using current geologic and paleontologic evidence (such as lake sediments and packrat middens), Kring assessed what the landscape, vegetation, and animal life was like 50,000 years ago in this area of the Colorado Plateau. The flat to slightly rolling landscape had an average relief of about 5 to 10 meters over distances of about 0.25 to 1.0 kilometers. A shallow drainage system was already established carrying water to the northeast and toward what we now call the Little Colorado River. Basaltic cinder cones and lava flows existed about 11 to 29 kilometers to the south, west, and northwest of the impact site. With the exception of Sunset Crater (of volcanic origin; erupted less than 1,000 years ago) and possibly two other volcanic craters known as Strawberry Crater and O'Neil Crater, all of the topographic features seen today near Meteor Crater were present 50,000 years ago.

Fossils are rare in the area, but available data suggest that mammoths, sloths, bison, and packrats were probably on the Colorado Plateau at the time of the impact. Mastodons, mountain goats, camels, horses, and tapirs also may have been there. Quite a menagerie!

The air blast and its effects

From the point of impact, a blast wave swept across the landscape producing instantaneous overpressures at every point on the ground as the shock front moved out. The amount of damage due to air blasts has been studied with surface and atmospheric nuclear explosions. Damage was found to be a function of the yield and height of the explosion. Dave Kring used a range of 20 to 40 megaton explosive energy and an altitude of zero in his analysis of the magnitude and radial extent of blast wave conditions for the Meteor Crater event (see table below.)

Magnitudes of pressures and wind velocities as a function of distance for the Meteor Crater impact event

			20 megatons	40 megatons
Peak Overpressure (psi)	Peak Dynamic Pressure (psi)	Maximum Wind Velocity (km/h)	Distance (km)	Distance (km)
100	120	2300	2.8	3.6
50	40	1500	3.8	4.8
30	17	1100	4.9	6.2
20	8.1	800	5.9	7.4
10	2.2	470	8.5	11
5	0.6	260	12	16
2	0.1	110	21	27
1	0.02	60	32	40

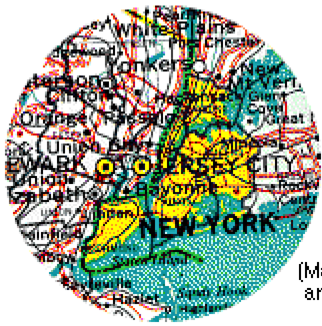
Source: Kring, D. A., 1997.

At the point of impact, the plants and animals, rock, and most of the meteorite were vaporized. Underlying bedrock was ejected and overturned, burying the land and anything else not already blown away by the air blast, out to a distance of between 1 and 2 km. The animals within 3 to 4 km of the impact site would have been subjected to winds exceeding 2000 km/hour and killed. A 50% casualty rate would occur between 9 and 14 km of the impact site due simply to bodies being picked up by the air blast and accelerated to a few to tens of kilometers per hour before being slammed back down again.

Overpressures (the pressure above normal atmospheric pressure) would cause death to anything living within a radius of 2.7 to 3.2 km of the impact site and cause lung damage within a radius of 6.5 to 9.3 km for a 20 megaton explosion. In the case of a 40 megaton explosion, these distances would increase by an additional 1 to 2 km. Animals as far away as 16 to 24 km would have been injured severely. Vegetation would have been almost completely destroyed over an area of 800 to 1500 km^2 around the Meteor Crater impact site. Fortunately, as Kring points out, the impact effects would have been severe only within that 800 to 1500 km^2 area. No global extinction would have resulted.

Potential Hazards

Kring's work is important because it provides insight into Earth's impact record and the potential consequences to the inhabitants of the area. In this case, a 40-km diameter region around Meteor Crater corresponded roughly to the mean of severe to moderate woodland damage calculated for 20 and 40 megaton blasts. Peak overpressures greater than 1 psi would have been felt 80 kilometers away from the actual impact site.

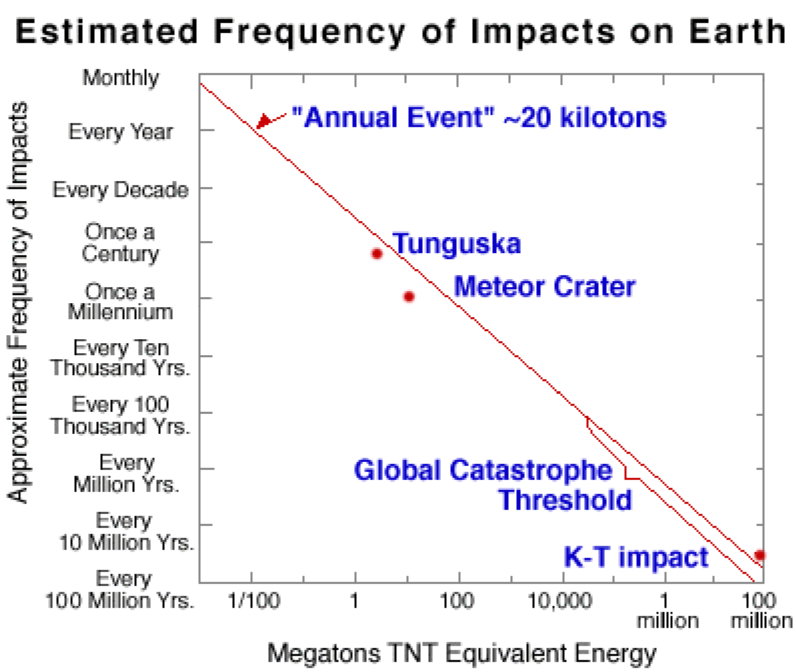


A Meteor Crater-sized impact would be catastrophic in the New York metropolitan area. This circle is 80 km in diameter and shows the possible extent of moderate to severe damage.

(Map courtesy of U.S. Geological Survey and Now What Software.)

What, then, are our odds of seeing an impact event take out a city in our lifetime? The answer is unknown because the number of Earth-crossing asteroids or comets is unknown, but we can make some good guesses.

In 1992, "The Spaceguard Survey" was proposed by the NASA International Near-Earth Object Detection Workshop to coordinate international observations to increase the rate of discovery of near-Earth asteroids. The Survey was never funded, nevertheless smaller groups of scientists are making routine searches for objects whose paths may cross the Earth's. Tracking and cataloging the orbits of asteroids and comets could lead to advanced warnings of a threatening impact strike. Evacuations, similar to those issued for floods or hurricanes, may be all that's needed for a Meteor Crater-sized impact event. The graph below shows estimates of the frequency of impacts of varying sizes and is a compilation of information from sources listed in the "Additional Resources" section at the end of this article.



(PSRD graphic, based on figure on page 278 in C.R. Chapman and D. Morrison, 1989, **Cosmic Catastrophes**. Plenum Press, New York, 302 p.)

An impact large enough to produce a crater the size of Meteor Crater occurs every 1000 to 2000 years somewhere on Earth. Taking 1500 years as a reasonable estimate, this means that the chances of such an impact occurring this year is 1 in 1500, an uncomfortably large probability. Fortunately, the chances of you being demolished by an impact are much smaller. The area devastated around Meteor Crater was 800-1500 km^2; let's say about 1000 km^2. The surface area of Earth is 510 million km^2. So, the chances of the 1000 km^2 you happen to be standing in being destroyed is only about 1 in 500,000. Combining the frequency (1 in 1500) with this results in a low probability of any one of us being killed by a Meteor Crater-sized impact -- only 1 in 7.5 billion. Whew!

It turns out that the chances of a much larger impact doing you in is much higher, in spite of their less frequent occurrence. A 100,000 megaton impact, about the threshold for a global catastrophe, occurs about once every 500,000 years. Assuming that 1 in 4 people would perish in such a global catastrophe, the chances of any one of us dying in such an event during the next year is 1 in 2 million. For comparison, your chances of being killed in a car accident is about 1 in 5,000.

An uncertainty in these scary calculations is how large an impact leads to a global catastrophe. The "Spaceguard Survey" suggests that the threshold is about 100,000 metagons, which would make a crater 10-20 km in diameter. However, this is highly uncertain. There is no geological evidence for global catastrophes associated with the formation of many well dated craters 20-30 km in diameter. So, the threshold for global catastrophe may be much higher, making the odds of one affecting you that much lower.

Can anything be done to prevent or lessen the damage from a meteorite impact? Studies like Dave Kring's are an important first step as they detail the effects of an impact. Beyond that, we need to find as many Earth-crossing asteroids as possible, as advocated by the "Spaceguard Survey." If we found an asteroid on a collision course, then perhaps we would have a chance to deflect it away from Earth. Given enough warning, a small nudge, perhaps from a solar-powered motor attached to the asteroid, could cause a significant shift in the asteroid's orbit and take Earth out of harm's way.

Additional Resources

L. W. Alvarez, W. Alvarez, F. Asaro, and H. V. Michel, 1980, Extraterrestrial cause for the Cretaceous/Tertiary extinction, *Science*, v. 208, pp. 1095-1108.

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R.A.F. Grieve, 1990, Impact cratering on the Earth, *Scientific American*, v. 262, pp. 66-73.

A.R. Hildebrand, 1993, The Cretaceous/Tertiary boundary impact (or the dinosaurs didn't have a chance), *Journal of the Royal Astronomical Society of Canada*, v. 87, pp. 77-118.

Impact cratering hands-on classroom activity, (upper elementary and above) for learning about impact craters presented by the Hawai'i Space Grant Consortium.

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M. Lindstrom and others, 1997, *Exploring Meteorite Mysteries: A teacher's guide with activities for Earth and space sciences*, NASA publication EG-1997-08-104-HQ and accompanying slide set EG-1997-08-001-HQ.

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Spaceguard Australia unofficial homepage.

The Spacewatch Project at the University of Arizona's Lunar and Planetary Laboratory.

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