

The dust cloud created by the collision of the DART mission and the Dimorphos asteroid, as observed from Earth by a telescope in Chile

DO LOOK UP!



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Every day, about 100 metric tons of extraterrestrial matter falls onto the Earth, most of it comprised of imperceptible particles.

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Tiny pieces of extraterrestrial matter, the size of grains of sand, enter the atmosphere all the time. As they heat up they leave behind a glowing trail, which we observe as “shooting stars.” Such events are completely safe, and some people even consider witnessing them to be a lucky omen. But when much larger pieces of matter, asteroid-sized, strike the Earth, they may have truly catastrophic consequences.

Danger from space

Around 66 million years ago, the Earth was hit by one such asteroid, about 11 km in diameter, and the impact drastically affected the lives of all organisms

on the planet. The event occurred in what is today Mexico, and the asteroid left behind a 180-kilometer crater named Chicxulub. Everything within a radius of 1,000 kilometers or more was engulfed by a fireball, anything within a few thousand kilometers was destroyed by a devastating shockwave, and territories as far away as today’s Canada and even West Africa were hit by hurricane winds so strong that they sent giant trees flying like toothpicks.

For most of the organisms living still further away, the impact of the asteroid had little immediate effect. But even their world changed beyond recognition just a few hours or days later. A dense veil of dust blasted into the atmosphere by the impact enveloped the sky, turning day into dark evening. As a result, the temperature fell rapidly, perhaps even by more than 10 degrees Celsius. After that, plants stopped growing, which in turn caused herbivorous organisms to starve. Carnivorous animals and scavengers initially enjoyed an unexpected feast, but they were soon also left with nothing to eat. The largest particles of the



material ejected into the air settled relatively quickly – up to a few hours later. But the smallest particles of dust stayed suspended in the atmosphere for at least several months, perhaps even years. The impact was so immense that these particles left behind a geological layer that can be observed all over the Earth. Composed of a mixture of asteroid and terrestrial rocks, its thickness varies from over 50 meters in Mexico to just a few centimeters in regions on the other side of the globe.

Long-term aftermath

The collision caused the Earth to experience rapid climate variations that continued for thousands of years, perhaps tens of thousands. Due to the specific location of the collision, the effects of the impact were disproportionately large given the size of the asteroid itself. The Chicxulub impact happened to strike a shallow, warm sea that had long been abundantly inhabited by organisms whose skeletons had formed carbonate rocks – composed mainly of calcium carbonate (CaCO_3), albeit with a sizable addition of sulfur dioxide (SO_2). When the asteroid slammed into the Earth, those rocks heated up, instantly releasing a huge amount of carbon dioxide, raising the temperature of the atmosphere. However, a significant amount of sulfur oxide was simultaneously ejected into the air, and this compound, especially if it reaches the strato-

sphere, causes the atmosphere to cool. Consequently, the subsequent tens of thousands of years were characterized by erratic shifts between warm and cold, as well as dry and wet periods. These chaotic changes in climate conditions were so rapid that organisms that had been perfectly adapted to life in the stable, warm climate of the Cretaceous (such as *Tyrannosaurus rex*) had no chance to adjust. The organisms that did survive were ones that were versatile and capable of easily adapting to change.

The Chicxulub catastrophe 66 million years ago is nevertheless the only case of a global extinction event that was caused by the impact of an extraterrestrial object. Stretching 180 kilometers across, the Chicxulub crater ranks as the world's third-largest impact crater – after the Vredefort structure in South Africa (about 300 km across) and the Sudbury structure in Canada (originally 200 kilometers). We do not really know what effects these two gigantic impacts had on our planet, but they both occurred roughly 2 billion years ago, back when the Earth was still inhabited only by relatively simple, single-celled organisms resembling today's bacteria, which did not go extinct that time.

Small asteroids

Smaller, but still relatively large collisions, with asteroids more than a few kilometers in diameter, are also

Don Davis's artistic concept of an asteroid impact with the Earth 3.5 billion years ago. The work was done by Bern Oberbeck and Dr. Kevin Zahnle of NASA's Ames Research Center. Source: NASA <https://images.nasa.gov/details/ARC-1991-AC91-0193>

very rare. On average, they happen every few million years, or perhaps every few tens of millions of years – the larger they are, the longer we have to wait for the next impact of similar size. The human race has typically witnessed collisions with smaller asteroids, ranging from a few meters up to tens of meters in diameter, which in turn may result in the formation of craters from tens of meters up to a few kilometers wide. These smallest events are relatively frequent, occurring once every few decades to every few hundreds of years. For example, over the past 120 years, we have seen five such notable collisions, and only some of them resulted in the formation of a crater.

The most recent important event of this kind happened in 2013, when a rocky asteroid exploded in the atmosphere over the city of Chelyabinsk in central Russia, causing a shockwave leaving more than 1,500 people injured. Previously, in 2007, an asteroid around half a meter in diameter slammed into a field in Peru near the village of Carancas, creating the youngest and smallest impact crater on Earth. In 1947, an “iron rain” descended upon the Sikhote-Alin Mountains, about 300 kilometers north of Vladivostok, creating a group of impact craters and giving quite a scare to the Soviet troops stationed there (this came, after all, not long after the use of the atomic bombs in nearby Japan). But it was back in 1908 that what may have been the largest extraterrestrial body in recent history exploded over Siberia near the Tunguska River. It was probably slightly over 50 meters in diameter, but despite the huge swath of destruction it left behind, there was no crater – it is suspected to have been similar to a comet, composed mainly of dirty ice. Its explosion while still in the atmosphere caused large trees located even 30 kilometers from the impact site to snap like matchsticks.

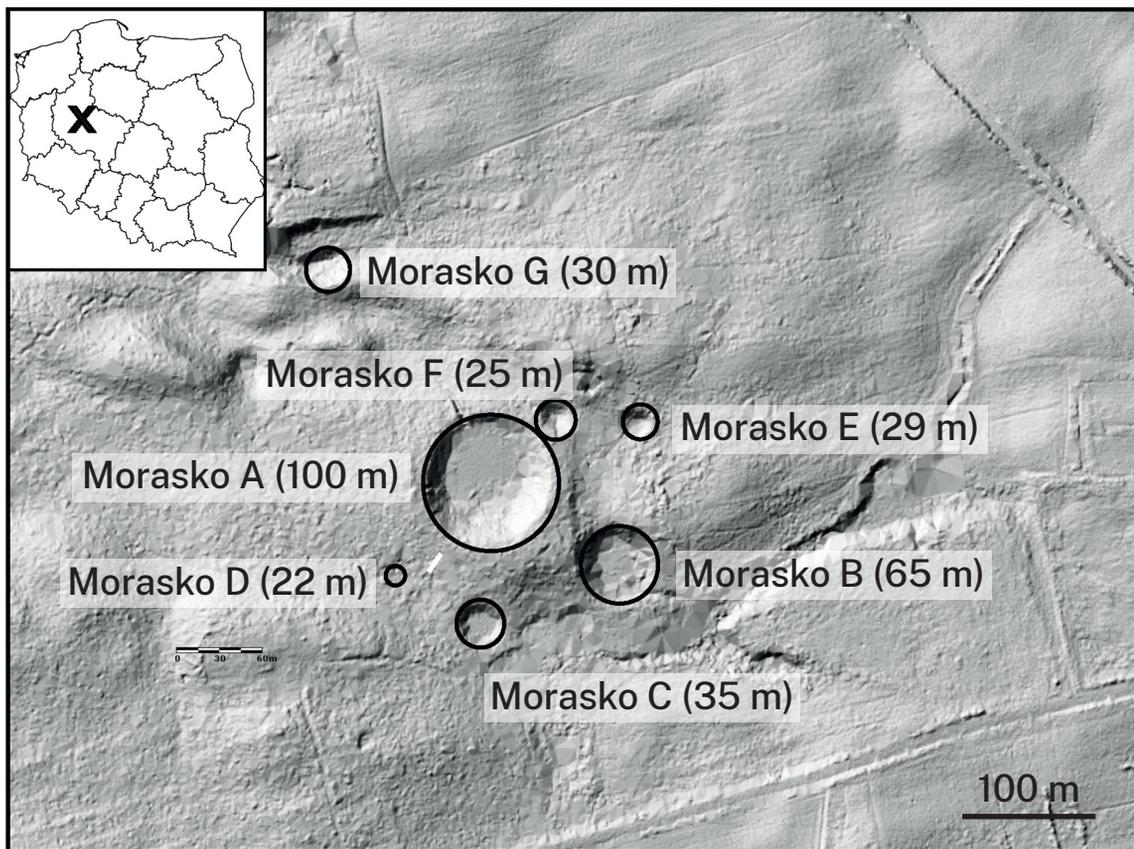
Most such events, impressive as they most certainly were at the time they occurred, do not leave lasting traces in the geological record. If we had not seen the explosion over Chelyabinsk with our own eyes, after several weeks or months, we would have been unable to distinguish the effects of such a sizable explosion from those of an ordinary storm. The traces of the explosion over Tunguska remained visible for about 20–30 years, but they were later covered over by the regrowing forest. The Carancas crater also disappeared almost without a trace within a few years – the small hole in the ground came to be filled in by sediments carried by a nearby river. The only recent impact whose traces will still remain visible for at least several hundred years is that caused by the Sikhote-Alin incident.

Traces left by collisions

If we can't identify the traces of such local microcataclysms, then how can we study them? Fortunately, some of them do leave scars on the Earth's surface, which remain recognizable for thousands of years. On Earth, we currently are aware of a dozen-odd such crater impact sites, ranging from 15 meters up to a few hundred meters in diameter. One such site is situated in Morasko, on the outskirts of the Polish city of Poznań. It is actually a group of seven craters, all of them formed at the same time, when a roughly 20-meter iron asteroid broke apart while passing through the atmosphere. When the largest such fragments struck the Earth at a speed of several kilometers per second (several times faster than a bullet fired from even the very best sniper rifle), they literally exploded. Consequently, a fragment that was itself about a meter in diameter formed the main crater, nearly 100 me-

Photo of the author
at Estonia's largest crater,
named Kaali





A digital terrain model showing the Morasko group of craters (based on data from geoportals.gov.pl)

ters across and tens of meters deep. Several similar, but smaller structures were formed nearby, and the entire area was showered with iron meteorite fragments. Over the past several thousand years, similar events have occurred in various locations on the Earth. Examples include the Kaali crater in Estonia and the Campo del Cielo craters in Argentina.

It has recently turned out that even impacts from such tiny asteroids can have truly catastrophic consequences, albeit on a very local scale. Scientists have dug through material ejected from four different impact craters located on two continents. They took samples in three different countries: Estonia (the craters Kaali Main and Kaali 2/8), Poland (the Morasko crater), and Canada (the Whitecourt crater). Those craters were formed thousands of years apart, but they had one thing in common – all of them contained charred fragments of organisms that had died during the cosmic catastrophe.

Planetary defense

The diameter of an impact crater is usually 10–20+ times larger than the diameter of the asteroid that formed it. For example, an asteroid with a diameter of about 100 meters that moves at a speed of about 20 kilometers per second will form a crater 1.5–3 kilometers in diameter. The exact size and

range of the destruction zone depends on the angle of impact, the type of the asteroid, and the type of material it collides with, and many other factors. But if a similar celestial body decided to target Warsaw's Old Town Square, for instance, the ejected fragments of our capital city would reach Berlin, Prague, or even Budapest. Such a collision would trigger an earthquake that could damage buildings in Vilnius and hurricanes that would shatter windows in Gdańsk, and any people who happened to be outdoors within a radius of about 30 kilometers from the impact site, or up to the Warsaw suburb town of Nowy Dwór Mazowiecki, would suffer first-degree burns. Most of Warsaw would be covered by a several-meter layer of ejected material, leaving behind a hole in the ground that would be around 3 kilometers wide and 650 meters deep.

Fortunately, as long as we know early enough that such a danger is approaching, we can do our best to mitigate it. This year, we witnessed the space mission named DART (Double Asteroid Redirection Test), which included the first real test of the planetary defense system. A tiny spacecraft that weighed just 600 kilograms collided with a small 160-meter asteroid and successfully altered its orbit. And so, as long as we draw the right conclusions from the movie *Don't Look Up*, we still do have a chance to prevent a true disaster. ■

Further reading:

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