What are meteorites? I visit and study the craters they've left across our planet

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Credit: AI-generated image (disclaimer)

Tens of thousands of asteroids—that we know of—are roaming our solar system. These are building blocks made up of metal, silicates, and ice left over from the beginning of time when the planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune) and their moons were assembling.

For the most part, the asteroids quietly orbit the sun—but sometimes they collide with each other or the planets and their moons. An asteroid hitting a planetary surface is called a meteorite. When a meteorite moves at a hyper-speed, between 10km and 70km per second, the collision releases an enormous wave of energy and leaves something in its place on the planetary surface.

These meteorite or impact craters appear as scars. Some planets are more pockmarked with craters than others: the Moon is covered with thousands but the Earth has only 200 confirmed meteorite craters. There are several reasons for this. First, meteorites slow down or even burn out in our atmosphere before they can reach the surface. Second, 70% of Earth is covered with water—we can only see craters on land. Earth also has tectonic plates, which shift and constantly renew the surface.

I am a geoscientist who studies impact craters. I have visited 10 of Earth's confirmed crater sites, in places as diverse as the Amazon jungle, the Arctic polar circle, central Europe, and South Africa. I've even studied lunar samples collected by the Apollo missions.

Impact cratering is one of the most fundamental cosmic processes. It is responsible for the growth of planetary bodies through accretion (the accumulation of mass). For example, the Moon was created as a result of a collision between the young Earth and a smaller planet, Theia.

It has been proven that the extinction of dinosaurs was caused by a massive impact event. Thus, studying impact craters can broaden our understanding of the Earth's evolution and life, as well its possible future.

Studying impactites

I moved to the Free State province in South Africa after defending my doctoral thesis at Austria's University of Vienna. The closest, most interesting geological site was the Vredefort impact crater. It is the world's oldest and largest known impact structure, dating back some 2 billion years and spanning between 180km and 300km in diameter.

With fellow researchers, I visited Vredefort several times a year to collect a variety of data. Impact cratering research helps me to combine two of my big passions—metamorphic petrology (how rocks can be transformed from one type into another) and the deformation of minerals (how they change their shape and structure under stress).

So, what happens when an impact crater is formed? A combination of intense heat (reaching thousands of degrees Celsius) and pressure (millions of atmospheres) at the moment the meteorite hits the planetary surface. The meteorite is destroyed and part of the target evaporates.

That spot of collision is what's known as an impact crater; the ground around and below it is full of rocks called impactites. These cannot be found anywhere else: impactites are not formed by any natural processes, only by meteorite impacts. Unique deformation features form in the minerals that were already on the planet's surface.

Sometimes, new minerals are found—examples include coesite and stishovite, which are high-pressure modifications of quartz, and reidite—a high-pressure modification of zircon. Another one is impact diamond, called lonsdaleite.

Cutting-edge technology

Studying impactites isn't, of course, as easy as looking at them with the naked eye or even putting them under a conventional microscope. A technology called transmission electron microscopy (TEM) is driving the latest research in this field. It has been used for a few decades but, in recent years, there have been big improvements in its quality and precision.

TEM is a way to observe the micro- and nano-structures of impactites at an unbelievably high resolution. Using thin, specially prepared samples, features as small as a few nanometers in size—that's about 1/10,000th of the diameter of a human hair—can be characterized in terms of their composition, shape, crystalline structure and relationship with the surroundings. Individual molecules and their patterns in crystals can be recognized and imaged. We can even identify what mineral we are looking at by analyzing the arrangement of molecules.

This technology is opening the door to an entirely new world of impactite study. Our small-scale analyses will reveal ever more of the Universe's huge secrets.

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