OTHERWORLDLY SURFACES

Anna Łosiak, PhD
is a planetary geologist, studying small impact craters on Earth and the processes that shape the surface of Mars. She works at the Institute of Geological Sciences, Polish Academy of Sciences, and is also professionally affiliated with the University of Exeter.
anna.losiak@twarda.pan.pl

A conglomerate on Mars deposited by a river (Williams et al., 2013)

NASA/JPL-CALTECH/MSSS

DOI: 10.24425/academiaPAS.2022.144677

Studying the geology of planetary surfaces largely involves analyzing photographs and comparing the images to known terrestrial objects.

Anna Łosiak

Institute of Geological Sciences,
Polish Academy of Sciences in Warsaw

Just after it arrived back on Earth, the photo taken by the Curiosity rover on 14 September 2012 did not really impress the investigators overseeing the data transfer and pre-processing process. Just another picture showing some gray-red stones. However, when geologists saw the same shot, they immediately fell into a state of joyful excitement. The photo showed a slightly sloping rock layer consisting of rounded grains of varying diameters – the whole thing somewhat resembling poorly cast, fragmented "lean concrete." It was immediately obvious to the geologists that they were looking at an image based on which they could immediately write up an article for *Science* magazine. The photo presented unambiguous evidence that the Curiosity mission's landing site was well chosen and that in the past a river had flowed into the Martian crater Gale.

The rocks seen in the image, the ones that aroused so much excitement, are conglomerates. They are formed when flowing water breaks apart and displaces rocks located higher up, then carries them and deposits them in the depressions of the terrain. Based on measurements of the size of the rock fragments, the characteristics of the river that formed this exposure can be determined: the water was at least 0.9 meters deep, and the average speed exceeded 0.75 m/s. Judging by the degree of roundness of the rock fragments, it is even possible to conclude that the material captured in the photo had been carried in from a number of kilometers away. All this knowledge comes from analyzing just one simple image taken on the surface of Mars, but it is based on hundreds of years of analysis of how rivers fragment and deposit material on our own planet.

Image-based dating of planets

Determining the age of a given structure in planetary geology in practice involves superficial analysis of images. On Earth, particular geological formations, rocks, or areas can be dated by measuring the effects of natural radioactive decay, in which isotopes of one element are transformed into another. Such dating is a complex and time-consuming process, but it is routinely performed in many research centers around the world. It requires collecting properly selected rock samples and measuring their isotopic composition extremely accurately. Based on this, we can calculate the age of the sample. This works very well for terrestrial rocks, but cannot be applied to planetary geology, because we have very few samples from other celestial bodies whose locality we know. It is therefore necessary to use other, less accurate methods based on the analysis of satellite images.

The simplest of the dating methods applied on other planetary surfaces is based on the law of superposition, according to which a form situated above is younger than a structure found beneath it. Only the relative age of a given formation can be determined in this way – whether an object is older or younger relative to another object – but it is not possible to determine when exactly something was formed. This is very simple if we are considering the interrelationships of several clearly identifiable and closely situated rock forms. However, this ceases to be so clear when it is necessary to analyze the interrelationship of thousands of craters, lava outflows, landslides, river valleys, and forms whose genesis we are not sure of. Additional complications arise from the fact that only some of these forms come into direct contact with each other, as the boundaries may have been blurred by several billion years of weathering.

> To truly understand the geological history of a given planet, we need to determine the absolute age of geological events.

Determining the relative age is better than nothing, but to truly understand the geological history of a given planet, we need to determine the absolute age of geological events, that is, for example to say when exactly a particular volcano erupted. This is hugely significant because only then will we be able to ascertain if, for instance, the eruption in question occurred shortly after a sizeable asteroid struck the area, or if all river valleys across the planet stopped carrying water at the same moment. This has indeed been accomplished – but how was it done, without spending absurd amounts of money to bring back samples from all the interesting scientific sites on other planets? Thanks to a clever trick combining an extended superposition principle, radioisotope dating, and detailed geological mapping based on image recognition, using the "crater counting" method.

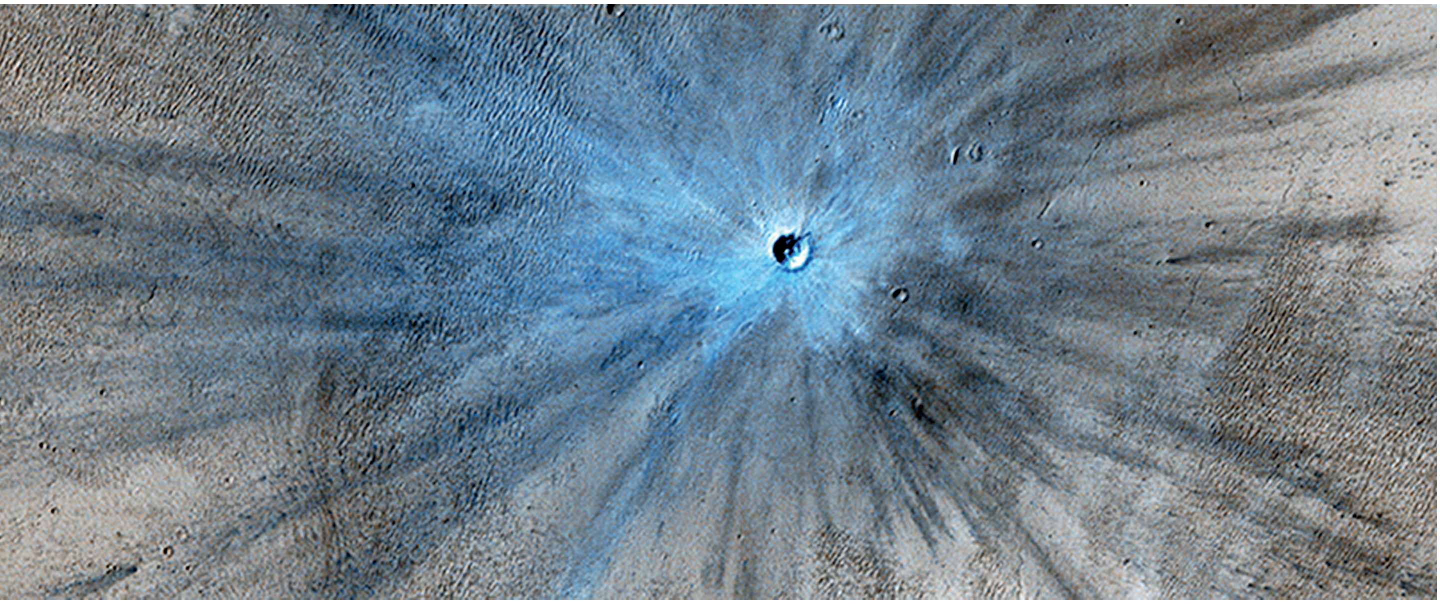
Counting craters

It is well known that all planets, moons, and asteroids are constantly colliding with other celestial bodies of various sizes, resulting in the constant formation of new craters on their surfaces. Based on this, we can conclude that the older a given surface is, the more craters can be found on it. If we count the craters visibly present in the image of a particular lava flow visible from orbit, and we know the frequency with which they were formed, we can easily calculate how long this surface has been bombarded – in other words, we can tell how old it is.

However, the accuracy of dating depends on how well we can gauge the frequency of crater formation. This can be done unequivocally if we have at least a few radioisotopically dated surfaces – meaning that we know exactly when a surface was covered with lava, and we can relate that to the number of craters on the surface. If we repeat this for several sites of differing ages, we can determine at what frequency the craters formed in the past and whether this frequency was constant over time. In practice, however, the only body in the solar system for which we have been able to do something similar is the Moon. Thanks to samples brought back to terrestrial radioisotope laboratories by the US Apollo manned missions and the Soviet Luna robots, it was possible to determine the frequency of crater formation for representative areas of our natural satellite. As a consequence, we can quite accurately date lava outpourings located anywhere on the Moon – even in areas where no spacecraft has ever landed.

But what about the other bodies in the Solar System? In their case, dating is subject to much greater error due to the lack of calibration points resulting from the lack of available rock samples. For example, to use the crater-counting method on Mars, the frequency of crater formation known for the Moon needs to be extrapolated to that planet. Extrapolation requires making numerous corrections, the magnitude of which is assessed on the basis of numerical modeling. The first correction is due to the fact that Mars is closer to the asteroid belt, so the frequency of crater formation should be higher than on the Moon. Second, Mars has much less mass than the Earth–Moon system, so it does not gravitationally pull asteroids to the same extent, and this lowers the frequency of crater formation. Third, the Red Planet has an atmosphere, which means that some small or particularly low-resistance bolides will disintegrate in the atmosphere, forming no craters (or forming significantly smaller ones than on the Moon). The current frequency of new crater formation can be estimated from a detailed review of existing images of the Martian surface in search of newly appearing craters, but the frequency in the past can only be calibrated once the first samples from Jezero Crater, where the Perseverance rover is currently traveling, are returned to Earth for dating.

At present, if you want to determine the age of a structure on the surface of another celestial body,



HiRISE Mars image showing a very young crater

NASA/JPL-CALTECH/UARIZONA

all you need to do is download a free program to your computer such as JMars, install a plug-in for counting craters, download satellite images of the area of interest, and mark the craters on it with circles. The program will do the rest for you. But keep in mind: it took half a century of analysis and testing to get to this point.

Camera lens better than the eye itself

Our eyes are an amazing research instrument, in some cases capable of detecting even trace amounts of certain elements. For example, a pure quartz crystal is transparent, but just a pinch of aluminum atoms turns it dark gray (smoky quartz), the addition of manganese or titanium results in a light pink color (rose quartz), while a hint of iron atoms can produce yellow (citrine) or purple (amethyst) crystals. However, the human eye does not stand a chance when compared with cameras that can accurately measure the amount of light in relation to a million different colors corresponding to different electromagnetic wavelengths. For example, a blue-green color corresponds to a wavelength of light of 520 nm.

With the help of these devices, we can also look at reality in completely different colors – analyzing light in wavelengths that our eyes do not perceive. Such analyses are important in geology, because some rock properties are best viewed in the infrared. For example, images taken at night by the THEMIS instrument aboard the US Mars Odyssey satellite show differences in how different terrains on Mars respond to heating, which depends on such factors as the chemical composition, fragmentation, and porosity of the rocks. Bright regions generally show places that warm up more during the day and give off heat (i.e. radiate in the infrared) more intensely than surrounding areas at night. This makes it possible, for example, to see geological boundaries which remain hidden in visible light. If our instrument can take pictures in very narrow wavelength ranges, we can even measure the mineral and chemical composition of rocks simply by looking at the images. This is how we know where there are deposits of ilmenite on the Moon, and where water ice can be found on Mars.

Geology on the micro scale

Sometimes taking a random photo can "save our lives" as scientists. Just after completing my doctorate, when I was leading my first-ever field research project, I convinced a group of people to come and dig in an impact crater in Estonia for more than a week. The plan was simple: under the layer of material ejected from the Kaali crater during the collision with the asteroid, we would look for samples of the original paleosol, which we would then date. Thanks to this, we would be able to finally determine in a relatively simple way when this cosmic collision occurred, and publish an article in a good journal. However, when after three days of digging we did not even find a trace of the ancient soil, I began to worry very much that maybe I was wrong and had wasted many days of very hard work by more than a dozen people.

Salvation came unexpectedly, in the form of some last-minute photos, taken with a flash because of the descending darkness. They turned out to show small fragments of black material, which were clearly distinguishable from the brownish background of the glacial till. With the naked eye it had been impossible to see the black specks one or two millimeters in size, but the flash made them visible. These were fragments of charcoal, which, as it turned out, specifically reflected the light of the flash, making them easier to spot. In this way we found pieces of charcoal, which turned out to be fragments of organisms buried in the material thrown out when the crater was formed. Thanks to this discovery, we were not only able to conclusively establish the age of the Kaali Crater at 3,500 years, but also to find similar traces in other impact craters in Whitecourt, Canada, in Campo del Cielo, Argentina, and in Morasko in Poland.

Spatial data is the primary source of information in geology – not only allowing us to understand what elements are present in a given place, but most importantly, showing unambiguously how the various pieces of the puzzle are arranged in relation to each other. Only on this basis can geologists use images to decipher clues about long-past events. ■

JURI PLADO/DRIVE.GOOGLE.COM

Searching for charcoal in material ejected from the Kaali Main crater at the time of its formation

Further reading:

The JMars program, being developed by the Mars Space Flight Facility group at Arizona State University, https://jmars.asu.edu/

Christensen P.R. et al., Morphology and composition of the surface of Mars: Mars Odyssey THEMIS results, *Science*, 2003, vol. 300, DOI: 10.1126/science.1080885

Łosiak A. et al, Small impact cratering processes produce distinctive charcoal assemblages, *Geology*, 2022, https://doi. org/10.1130/G50056.1