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Pebbles on Mars likely traveled tens of miles down a riverbed, study finds

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The presence of rounded pebbles on Mars was evidence of a prior history of water on the planet. In a new study, researchers have used the pebbles' shape to extrapolate how far they must have traveled down an ancient riverbed. The analysis suggests they moved approximately 30 miles, indicating that Mars once had an extensive river system. Credit: NASA/JPL-Caltech/MSSS

While new evidence suggests that Mars may harbor a tiny amount of liquid water, it exists today as a largely cold and arid planet. Three billion years ago, however, the situation may have been much different.

In 2012 the Mars Curiosity rover beamed images back to Earth containing some of the most concrete evidence that water once flowed in abundance on the planet. Small, remarkably round and smooth pebbles suggested that an ancient riverbed had once carried these rocks and abraded them as they traveled.

To Douglas Jerolmack, a geophysicist at the University of Pennsylvania, and his collaborator Gábor Domokos, a mathematician at Budapest University of Technology and Economics, Curiosity's findings raised a fundamental geological question: Can we use shape alone to interpret the transport history of river pebbles—on Mars, Earth or any planet?

"Thousands of years ago, Aristotle pondered the question of pebbles on the beach and how they become rounded," Jerolmack said. "But until recently, descriptions of pebble shape have been qualitative, and we lacked a basic understanding of the rounding process."

Now that has changed. In a new report in *Nature Communications*, Jerolmack, Domokos and colleagues report the first-ever method to quantitatively estimate the transport distance of river pebbles from their shape alone. The researchers' estimate that the Martian pebbles traveled roughly 30 miles from their source, providing additional evidence for the idea that Mars once had an extensive river system, conditions that could support life.

Determining how far pebbles have traveled could also be useful for studies on Earth, for example in identifying sources of river-transported resources, such as gold.

Jerolmack, an associate professor in the Department of Earth and Environmental Science in Penn's School of Arts & Sciences and senior author on the paper, contributed expertise in geophysics to the study, while co-author Domokos developed the mathematical models on which the study was based. Tímea Szabó, the lead author, worked with Domokos as a graduate student and was then a postdoctoral researcher in Jerolmack's lab. John P. Grotzinger, at the California Institute of Technology, was until recently the lead scientist for NASA's Curiosity mission and collaborated on the work.

The development of a quantitative understanding of pebble shapes began with the work of Domokos, whose research was triggered by the discovery of the Gömböc, a curious three-dimensional object with just two static balance points. A Gömböc shape self-rights on a horizontal surface just like a Weeble Wobble, however, it has no added bottom weight. The self-righting property is the result of the shape alone, which is determined to 0.01 percent accuracy by its unique mechanical properties.

As the number of static balance points on an object tends to be reduced during natural abrasion, the Gömböc represents the ultimate goal of this process and illustrates how shape alone may carry vital information on natural history. Domokos soon realized that recent pioneering work in pure mathematics—the proof of the elusive Poincaré conjecture—could be adapted to describe the geometry of three-dimensional structures and how these shapes evolve.

"An object's shape can itself tell you a lot," said Domokos. "If you go to the beach, natural history is written underneath your feet. We started to understand that there is a code that you can read to begin to understand that history."

Rocks flowing in rivers evolve in shape from being abraded against other rocks in the riverbed, gradually losing mass and taking on a smoother, rounder shape. Existing geophysical theory links a pebble's transport history to the mass it loses due to collisions with other pebbles. But mass data is not available for Martian pebbles. So the researchers set the ambitious goal of determining the lost mass of a pebble solely based on its current shape.

"When you land a multi-billion dollar rover on Mars, you want to extra as much information from the data as possible," Jerolmack said.

Domokos' work showed that, when two particles of similar size bang together, the way in which they influence each other's shape can be reduced to a purely geometric problem, regardless of the rock's material or the environment in which it is moving.

The research team went to the lab to test this theory, rolling limestone fragments in a drum and periodically pausing to record their shape changes and mass loss. The pattern of the rocks' shape change closely followed the curve established by the mathematical theory.

Next the researchers went to a mountain river in Puerto Rico.

"We started at the headwaters, where chunks of angular rock are breaking off from the walls of the stream, and went downstream," Jerolmack said. "Every few hundred meters we would pull thousands of rocks out and take images of their silhouette and record their weight."

Plotting the data, they again found a trend between shape evolution and mass loss that agreed with the geometric model Domokos had developed.

As an additional confirmation, they performed a similar analysis on rocks in an alluvial fan, the characteristic fan-shaped sediment deposits built up by stream flows, at the mouth of a canyon in New Mexico, an environment that more closely mirrors the location where round pebbles were found on Mars. With these data, they demonstrated that they can infer the distance a pebble traveled from its source using only the silhouette of the pebble.

With lab and field data in hand, they turned to the extraterrestrial. Using publicly available images of rounded pebbles on Mars from the Curiosity rover mission, Szabó traced their contours and performed an analysis based on the models the team had established. The results suggested that the pebbles had lost approximately 20 percent of their volume.

To translate that mass loss into a distance traveled, they relied on the findings from New Mexico as well as previous lab experiments that involved running rocks of different material through artificial "rivers" and measuring their mass loss.

Applying these calculations to the basalt material found on Mars, with a correction that factored in the reduced Martian gravity, they arrived at the calculation that the pebbles had traveled an estimated 50 kilometers, or about 30 miles from their source. The distance meshed well with what Grotzinger and the Curiosity team had suspected about the pebbles' origin, based on other analyses of the rock's composition and clues as to the direction of water flow, that they were sourced from a crater rim located approximately 30 kilometers away.

Jerolmack noted that the study is not only exciting for what it implies about Mars but for opening up a new realm of possibility to quantify what before could only be described qualitatively.

"Now we have a new tool we can use to help reconstruct ancient environments on Earth, Mars and other planetary bodies where rivers are found such as Titan," Jerolmack said.

The work also shows how a seemingly esoteric piece of mathematics can find application in the real world.

"Once math enters the subject, the subject changes forever," Domokos said.

Provided by University of Pennsylvania