DOI: 10.24425/academiaPAS.2021.139443

Krzysztof Gaidzik, PhD

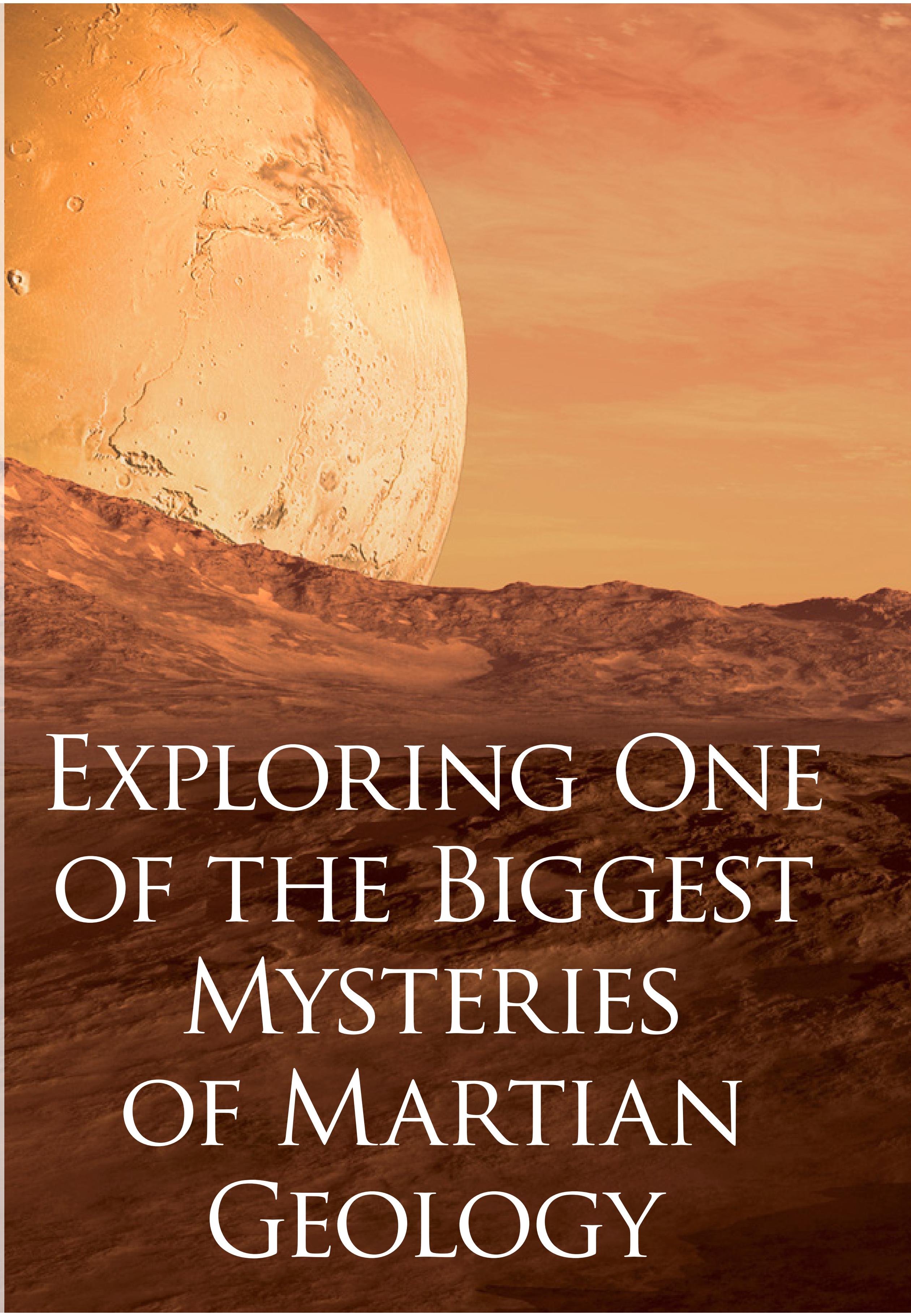
studies neotectonics, paleoseismology, archaeoseismology, plate tectonics (especially in Latin American countries, such as Peru and Mexico). His interests also include planetary geology and geomorphology. He is a member of Mars Society Poland and a juror evaluating the science task in the international competition European Rover Challenge.

krzysztof.gaidzik@us.edu.pl

Justyna Ciesielczuk, PhD, DSc

is an Associate Professor at the University of Silesia. She is a mineralogist studying hydrothermal alterations around magma bodies, changes occurring during the burning of coal-waste dumps, and coal-seam paleo-fires. She is president of the Petrology Group of the Mineralogical Society of Poland. She is interested in astrogeology.

justyna.ciesielczuk@us.edu.pl



Exploring One of the Biggest Mysteries of Martian Geology

3000AD/SHUTTERSTOCK.COM

Modern technologies have helped us push the boundaries of geology and begin exploration of other planets. Great strides have been made in the study of Mars, which is slowly yielding up its secrets.

Krzysztof Gaidzik
Justyna Ciesielczuk
Monika Fabiańska
Magdalena Misz-Kennan

University of Silesia in Katowice

Pádhraig S. Kennan

University College Dublin, Ireland

Despite being available as an object of direct and indirect study, our Planet Earth still holds numerous mysteries that continue to perplex generations of geologists, geographers, and geophysicists. Mars may be one of Earth's neighbors, but we only know it thanks to remote sensing techniques, and we have no direct contact with the rocks present there. For this reason, many of the objects identified on the Red Planet are still shrouded in mystery, with their origin and evolution being investigated by scientists from various disciplines. Unfortunately, it will be impossible in many cases to verify their opinions and hypotheses until a geologist actually sets foot on the surface of Mars. It is likely then that we will solve the mystery of the origin of Martian spherules – or "Martian blueberries" as they are also known. How did they come about?

Spherules of hematite

We now know that Martian spherules are spherical structures formed of hematite, a mineral with the chemical formula $\alpha\text{-}Fe_2O_3$. They were identified on the surface of Mars in the Meridiani Planum region by the Opportunity Rover, which operated from 25 January 2004 to 10 June 2018 despite the initial modest expectations of 90 days of operation. The spherules are hard, more-or-less perfect spheres of an unknown internal structure that measure <6.2 mm in diameter (two size populations are known: larger spherules with an average size of 4.2 ± 0.8 mm, and smaller ones, measuring 0.8 ± 0.1 mm in diameter). In false-color images first published by NASA, the hematite spherules appear blue against the background,

Prof. Monika Fabiańska

studies the organic geochemistry of fossil fuels, waste from fossil fuels mining, and the products of their processing, with a special focus on environmental aspects.

monika.fabianska@us.edu.pl

Magdalena Misz-Kennan, PhD, DSc

is an Associate Professor at the University of Silesia. She studies organic matter in coal and other rocks and its alterations in technological processes. Her research includes self-heating of organic matter found in coal rocks and coal mining waste. She cochairs a working group on this topic at the International Committee for Coal and Organic Petrology.

magdalena.misz@us.edu.pl

Pádhraig S. Kennan, PhD
is a retired member of University College Dublin (Ireland). He spent many years studying the origin and distribution of granites, their aureoles, and related mineral deposits. His work led to the discovery of relationships between manganese quartzites and tourmaline-rich metasediments in the bedrock.
pskennan@gmail.com

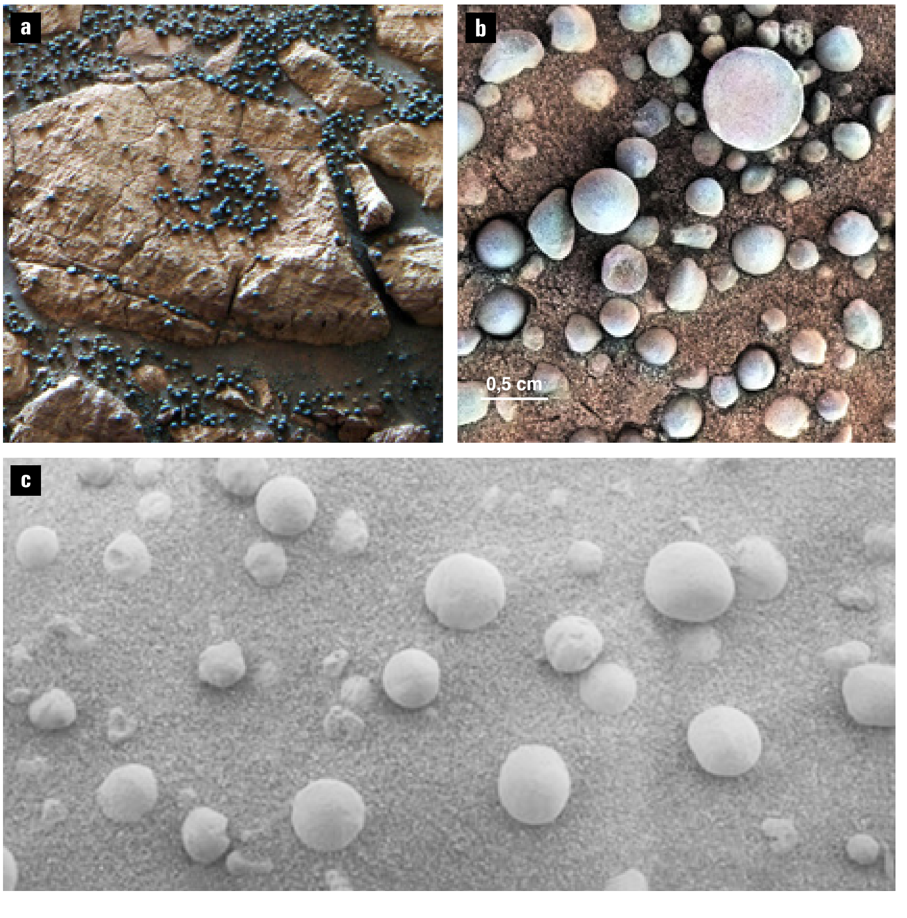
and so they were dubbed "Martian blueberries" and the name has since stuck. The hematite that forms these spheres and gives them their distinctive color is iron(III) oxide, a common mineral found on Earth. Its name is derived from the Greek word *haema* (*haima*), which means "blood" (*haimatites* – bloody), due to the distinctive cherry-red color this mineral has in powdered form. It is also a very common iron ore, with high but not the highest iron content (70% Fe).

Martian blueberries discovered

Martian spherules were first recorded and photographed in 2004. But to understand the history of their discovery, we must go back to 1996, when NASA sent Mars Global Surveyor (MGS) on a mission to Mars. The probe was fitted with a thermal emission spectrometer, which enabled the mapping of the mineral composition of the planet's surface. In the following years, maps of the distribution of potential minerals on the Martian surface were obtained, and the presence of crystalline hematite was identified in an area of over 175,000 km^2 in a region called Sinus Meridiani. This observation, if it were confirmed, could indicate the presence of water in Mars' geological history. For this reason, the region became an obvious target for detailed analyses by subsequent Martian missions. On 24 January 2004, the Opportunity Rover, a robotic geologist, landed in Eagle Crater at Meridiani Planum (the western part of Sinus Meridiani). A few days later, it sent back the first images of Martian spherules. These were then examined using various on-board tools, which confirmed that the spherules were indeed composed of hematite. Since then, intensive research has been underway to find terrestrial counterparts of these structures and, consequently, to try to answer the question of their origin and evolution. So far, however, the geological processes leading to the formation of these structures are not fully known.

The origin of spherules on Mars

The first images of Martian blueberries were obtained over 15 years ago. Since then, scientists have proposed many hypotheses to explain their origin, mechanism of formation, and distribution on the surface of the Red Planet. Their formation is relatively often linked to water activity, which means that their mass occurrence could provide indirect evidence in favor of the presence of water in the geological history of Mars. Although most scientists tend to agree with this hypothesis, comparing spherules to the concretions known from Earth (masses of mineral matter formed through the gradual precipitation of minerals around some



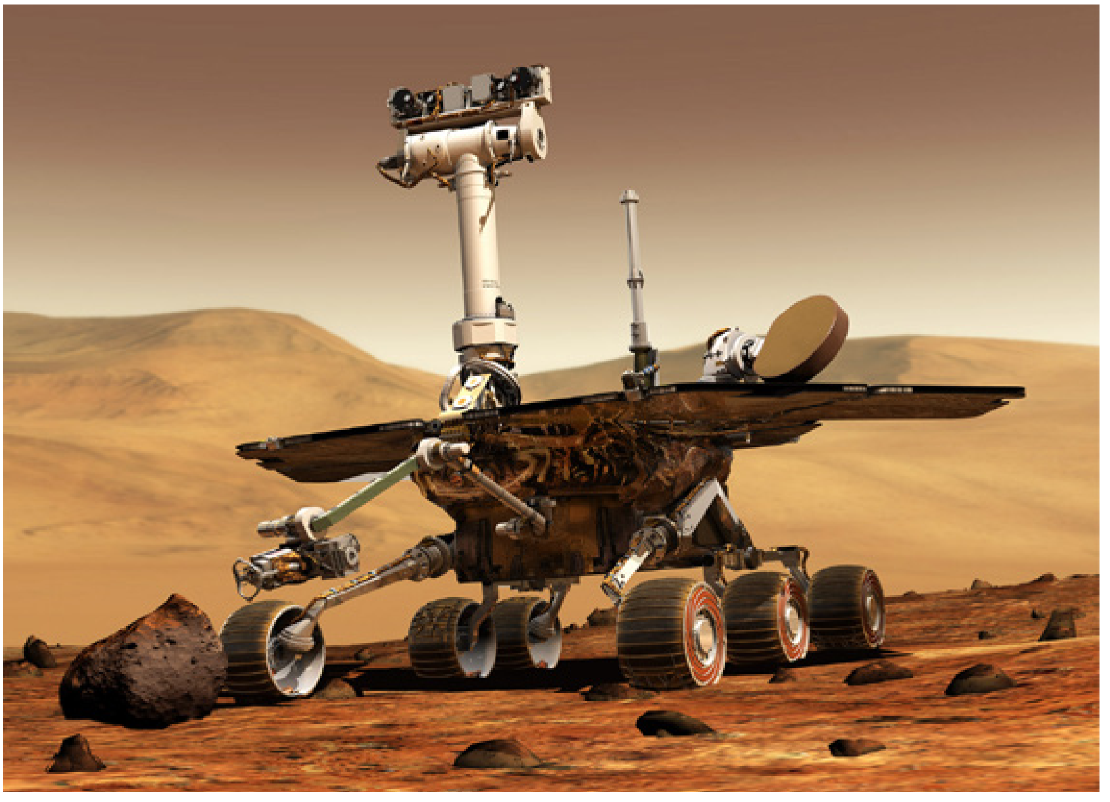
COURTESY OF NASA / JPL-CALTECH

Examples of Martian blueberries observed by the Opportunity rover:

(a) A Bowl Full of Blueberries,
Source: NASA/JPL-Caltech/Cornell University, https://www.nasa.gov/sites/default/files/5664h.jpg

(b) A close-up image of Martian spherules near Fram Crater captured by the Opportunity Rover during the 84th Martian day (19 April 2004).
Source: NASA/JPL-Caltech/Cornell University, https://mars.nasa.gov/resources/6944/martian-blueberries/

(c) The largest close-up image of Martian spherules captured by the Opportunity Rover near a part of the rock outcrop at Meridiani Planum called Stone Mountain.
Source: NASA/JPL-Caltech/Cornell University, NASA/JPL-Caltech/Cornell, https://mars.nasa.gov/mer/gallery/press/opportunity/20040212a/07-ml-3-soil-mosaic-B019R1_br.jpg



COURTESY OF NASA/JPL-CALTECH

An artist's concept of the Opportunity Rover, which was active on the surface of Mars from 25 January 2004 to 10 June 2018
Source: NASA/JPL-Caltech/Cornell, https://photojournal.jpl.nasa.gov/catalog/PIA04413

kind of a nucleus), the details in which these two types of objects differ are significant. The most commonly postulated water-related mechanisms include: (1) slow deposition in standing bodies of water, (2) crystallization from water during episodic flooding, (3) growth in stagnant groundwater, (4) growth in water flowing through sediments, etc. However, they mostly point to a similar environment, namely shallow, small bodies of water, only temporarily filled with water.

Another group of hypotheses points to links between Martian spherules and volcanic activity. In this group, we can also distinguish several detailed mechanisms, including direct precipitation and crystallization in hydrothermal environments (or crystallization from highly mineralized water solutions associated with magmatic processes) and, at a later stage, as a result of the reaction of volcanic ash and pyroclastic material with sulfur-rich water, and the effects of volcanic sediments and acidic hydrothermal fluids on rocks formed earlier. More exotic hypotheses connect the formation of Martian blueberries with the impact of an object such as a meteorite hitting the surface of the plant. Some scientists also point to potential links between these structures and life on Mars, treating them as a certain type of fossils associated with bacterial activity. As yet, however, it has been impossible to fully confirm or refute any of these hypotheses.

Since the mystery behind the formation of the Martian blueberries could not be definitively explained, various terrestrial analogs have been studied in detail to help explain the origin and evolution of these structures. Such analogs typically include spherules that are similar in form to the Martian ones and found in sandstones and other sedimentary rocks (chiefly in the United States, Australia, and China), which indicates their links to water activity during deposition. In addition, formations found in volcanic rocks on Mauna Kea in Hawaii are relatively often identified as terrestrial equivalents of these structures, which suggests their links to volcanic and hydrothermal environments.

The Future

Although scientists have been trying to resolve this mystery for more than 15 years using countless terrestrial analogs and research hypotheses, we still know very little about Martian blueberries. Most of the views that have been expressed are merely speculations or conjectures. It appears that only future manned missions to Mars and real contact with these structures will allow us to definitively confirm or refute specific hypotheses. We should remember, though, that even on Earth, which we can study directly, there are many structures that we do not fully understand. Martian spherules are just one of many examples of intriguing structures that have been observed on other celestial objects and continue to hold mysteries for scientists studying their origin and evolution. ■

Further reading:

www.nasa.gov

Chan M.A., Beitler B., Parry W.T., Ormo J., Komatsu G., A possible terrestrial analogue for haematite concretions on Mars, *Nature* 2004, 429.

Chapman, M. (Ed.). *The Geology of Mars: Evidence from Earth-based Analogs*. (Vol. 5). Cambridge University Press 2007.

Squyres S.W. et al., In situ evidence for an ancient aqueous environment at Meridiani Planum, Mars, *Science* 2004, 306.

Żaba J., *Ilustrowana encyklopedia skał i minerałów* [Illustrated Encyclopedia of Rocks and Minerals], Chorzów 2014, 1–504.