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FORMATION OF MARS' SURFACE FEATURES BY LAVA AND WATER

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Volcanism has been the primary mechanism for the initial formation and modification of the crust on Mars for billions of years. Much of the planet's surface bears traces of volcanic activity to varying degrees. Volcanic activity has also played a key role in creating some of the largest features of the Martian landscape. For example, the Elysium and Tharsis regions are vast topographical uplifts [2, 5, 9] that dominate much of the surface of Mars. They were formed over several billion years by the accumulation of lava and other materials erupted from the planet's interior.

Modern lava flows are the result of repeated outpourings of molten basaltic rock that occurred during non-explosive eruptions. In this case, the flows moved downward from the site of the eruption.

Moving over the newly formed surface, each subsequent time such flows expanded, creating new side branches. Therefore, they were able to extend for many hundreds of kilometers. Usually eruptions occur at a temperature of lava material of 1400-1500 K. Inside such lava flows, so-called lava tubes are usually formed, which look like peculiar pipelines through which lava flows with a fairly low viscosity. When such a lava flow spreads from the source of the eruption from the volcanic vent, the material on its surface slowly cools and hardens; and under the hardened layer, the lava inside still remains quite hot.

When the entire flow finally stops, the lava can only partially fill the space of the tube under the hardened layer, or it will drain completely down, leaving the tube empty. If the lava tube passes close enough to the surface, the roof can partially or completely collapse (Fig. 1, a). Moreover, the lines of the edges of such pits can repeat the course of the entire lava tube. Sometimes only a small part of the ceiling of the lava tube can collapse. In this case, only small openings similar to cave entrances or a “light window” will be visible on the surface (Fig. 1, b). Significant areas of the surface, and especially in the northern hemisphere of the planet, are covered with fairly smooth plains, which were formed during the outpouring of fairly fluid lava. The lava material on such plains filled older eruption craters and impact basins and depressions, leveling the overall relief [3, 4, 6, 10, 16].

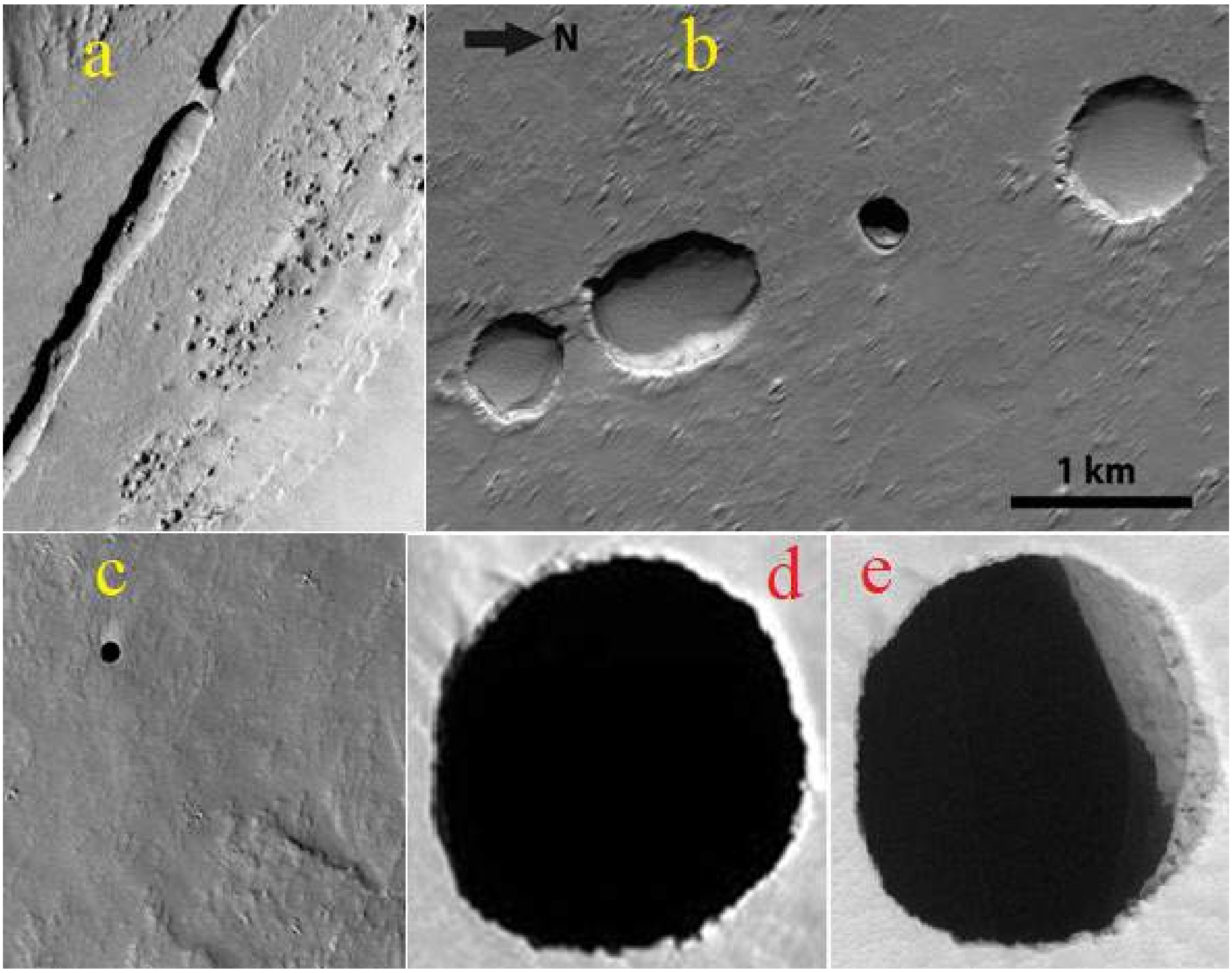

Figure. 1. a – a photo of a trough running through the center of a valley in the Tartarus Colles region (https://media-cldnry.s-nbcnews.com/image/upload/t_fit-1000w,f_auto,q_auto:best/MSNBC/Components/Photo/_new/111230-mars-lava-tube-hmed-142p.jpg). b – “light holes” that appeared when part of an underground lava tube on Mars collapsed (https://globalnews.ca/wp-content/uploads/2016/12/3-arsia8.jpg?quality=85&strip=all). c – one of the dark spots on the slopes of Arsia volcano (http://photojournal.jpl.nasa.gov/). The Jinn hole on 08.08.2007 is illuminated – d – vertically from above and – e – by oblique sunlight (http://photojournal.jpl.nasa.gov/).

Separate volcanic structures on the Martian surface are volcanic mountains [14, 18, 20]. Among their considerable number, one can distinguish such formations as the giant shield volcano Olympus and three other volcanoes in the Tarsis Regio region, such as Mount Arsya, Pavonis and Askraeus. All of them are the highest points on the planet and also dominate the landscape of this region [24]. Many of the channels on the planet's surface were carved, most likely, by water [22, 23, 26, 30], but not all. After all, molten rocks could also flow and create similar features that resemble the channels of water streams. However, lava behaves somewhat differently from liquid water. Therefore, to better understand the history of a specific region of Mars, it is very important to identify and distinguish between lava and water channels with possible remains of life forms [12, 13, 17, 19]. After all, Martian lavas are quite fluid. Therefore, the flow emerging from a volcanic vent can spread in a wide layer, which, until it cools and hardens, has the ability to cover large areas.

And if the eruption continues further, then the newer lava will have the opportunity to gradually erode the channels in the somewhat colder and harder lava layer. And such erosion of lava is quite similar in its effect to erosion by water.

One way to distinguish lava channels from water channels is to find dust, sand, small stones, and other smoothed debris [7, 8, 27, 31] at the bottom of a water channel. However, of course, water can also flow [29] through the channel created by lava later. So it is not always easy to distinguish one type of channel from another. As an example, we can cite the Cerberus Fossae region, in the soil of which a rather long crack was found, in which the remains of both water and lava flows were observed. For example, when lava rose to the surface through cracks in the crust [1], the lava on its way could melt water ice in the soil, which also broke through the cracks to the outside.

At the same time, the water flows also eroded their channels. And when the lava reached the surface layer, it also had the opportunity to pour out onto the surface. For the most part, the lava passed through valleys and channels carved by water; however, it could also spill over completely untouched terrain, covering it with lava for the first time.

Careful studies of the Martian surface indicate that the shape of impact craters of meteorite origin differs significantly from volcanic craters [15, 21]. Usually the shape of impact craters is almost round; around such craters there is a shaft with an inner and outer terrace. If impact craters are quite large, then they usually also have central peaks, and sometimes another inner shaft.

Whereas volcanic craters have fairly smooth edges; and their surroundings are covered with lava flows and cracks. They are usually located on the tops of dome-shaped elevations. The most characteristic volcanic craters are those located on the highest peaks of Mars, such as Olympus, Arsya, Pavonis, and Askraeus [28].

Recent large impact craters with a significant amount of ejected material have been recorded very few. And the vast majority of them have a very destroyed area with ejected material; and this area is always covered by later erosional formations.

In the early 2000s, in photographs of the volcanic plateau of Tarsis, obtained by the “Mars Odyssey” spacecraft [29], images of seven mysterious dark spots of a rounded shape were first seen. It is on this vast Martian plateau that the peaks of the largest volcanoes in the Solar System are located [28]. And on the slopes of one of them – the Arsya volcano – rather dark depressions were first noticed (Fig. 1, c), called the “Seven Sisters” with the following female names: Wendy, Dana, Jinn, Abby, Annie, Chloe and Nikki.

These dark spots on the Martian surface turned out to be depressions that could be entrances to extensive caves below the surface. That is, they are depressions in the ceiling of these large caves. The opening shown in Fig. 1, c has a size of 100□150 m, and it is very deep, since its bottom is not illuminated by sunlight. Fig. 1(d) shows the dark Jinn depression with a size of 150□157 m. It also lacks any hints of the existence of a bottom, walls or an external ramp around the perimeter, which are usually present in classic impact and volcanic craters. This photo was taken almost at noon, with the valley illuminated by vertical rays.

In the image in Fig. 1(e), on the eastern walls inside this object, due to their illumination by oblique sunlight, individual details became clearly visible. This happened when the Sun at the shooting location moved somewhat to the west [27, 28]. It is noticeable that in such a place the walls run almost vertically. However, it still remained unclear how deep this chasm is. It was only clear that at a depth of almost 80 m there is still no bottom. Since in this hole with almost vertical walls the bottom illuminated by the Sun is still not visible, it becomes clear that it cannot be a simple erosion-damaged chasm. Since all the above holes were found not far from volcanic craters at the summit, at the moments of their eruptions, flows of molten lava burn out voids under the surface, which gradually flow down the slopes of the volcano.

After a certain period of time, the outer layers of the soil can, for example, collapse into previously formed cavities due to earthquakes. The photographs in Fig. 1(d, e) show depressions with very little eroded and rather sharp edges. They may indicate the comparative youth of these formations.

After all, it is known that Mars has an atmosphere [25], albeit a weak one; therefore, winds there constantly move air masses, which constantly fill the newly formed pits with loose soil on the surface. The age of traces of the youngest volcanic activity on Mars is estimated from several tens of thousands to several tens of millions of years; and the age of individual areas on the Tharsis plateau is estimated at 0.5-3 billion years [20]. The diameters of the seven sinkholes found on the slopes of volcanoes were in the range of 100-252 m. Their study using infrared photography allowed us to find out that their temperature practically does not change during the day on Mars. This speaks in favor of the fact that these sinkholes are a kind of “windows” in the ceiling of volcanic caves.

Images obtained by the equipment of the “Mars Reconnaissance Orbiter” spacecraft indicated that similar sinkholes on the surface of Mars were found in other places. They all appear when rock collapses over channels that were formed after lava flows descended. Now in the Tarsis Regio province alone, the “Mars Reconnaissance Orbiter” has discovered more than a hundred such sinkholes of almost cylindrical shape with sharp edges. They have diameters from 50 to almost 350 m. According to the results of observations from the same orbiter, it was possible to detect a significant number of such sinkholes in the region of another volcanic region, somewhat older than Tarsis Regio – Elysium.

There, near one of the highest volcanoes – Elysium volcano, 16 km high, many sinkholes were also discovered. Sometimes they are located in the form of peculiar linear formations.

References

1. Bi H., Sun D., Sun N., et al. (2025) Seismic detection of a 600-km solid inner core in Mars. Nature. 645, p. 67–72.
2. Broquet A., Andrews-Hanna J.C. (2023) Geophysical evidence for an active mantle plume underneath Elysium Planitia on Mars. Nature Astronomy. 7, p. 160–169.
3. Churyumov K.I., Steklov A.F., Vidmachenko A.P., Dashkiev G.N. (2015) Observations of fragment of cometary nuclei in the atmosphere over Kiev. Astronomical School’s Report. 11(2), p. 99-102.

4. Churyumov K.I., Steklov A.F., Vidmachenko A.P., Dashkiev G.N. (2015) Observations of fragments of cometary nuclei in the atmosphere over Kiev in the summer of 2014. 17 International scientific conference Astronomical School of Young Scientists. 20-22, 2015, Zhytomyr, Ukraine. p. 84-85.
5. Clinton J.F. (2017) Preparing for InSight: An Invitation to Participate in a Blind Test for Martian Seismicity. Seismological Research Letters. 88(5), p. 1290-1302.
6. Frey H., Schultz R.A. (1988) Large impact basins and the megaimpact origin for the crustal dichotomy on Mars. Geophys. Res. Lett. 15(3), p. 229-232.
7. Morozhenko A.V., Vidmachenko A.P. (2017) What and how can affect the exploration of Mars. 19 International scientific conference Astronomical School of Young Scientists. May 24-25, 2017. Bila Tserkva, Ukraine. P. 67-69.
8. Morozhenko A.V., Vidmachenko A.P. (2020) Dust can affect on the mastering of Mars. 22 International scientific conference Astronomical School of Young Scientists. December 11-12, 2020. Kyiv, Ukraine. P. 71-73.
9. Morozhenko A.V., Vidmachenko A.P., Kostogryz N.M. (2015) Spectrophotometric properties of Moon's and Mars's surfaces exploration by shadow mechanism. Highlights of Astronomy, 6, p. 182-182.
10. Mouginis-Mark P. (1979) Martian fluidized crater morphology: Variations with crater size, latitude, altitude, and target material. Journal of Geophysical Research: Solid Earth. 84(B14), p.8011-8022.
11. Rummel J.D., McKay C.P. (2017) Water on Mars: A Status Report and Suggestions for Further Study. 48th Lunar and Planetary Science Conference, held 20-24 March 2017, at The Woodlands, Texas. LPICo No. 1964, id.2945.
12. Steklov A.F., Vidmachenko A.P. (2019) In What Places and What Exactly Can be the" Traces" of Life on Mars? Ninth International Conference on Mars. 2089, 6007.
13. Steklov A.F., Vidmachenko A.P. (2019) Where and What Exactly Can Be the "Traces" of Life on Mars? Mars Extant Life: What's Next? Held 5-8 November 2019, in Carlsbad, New Mexico. LPI Contribution No. 2108, 2019, id.5089.
14. Vidmachenko A.P. (2009) Research of the Mars by space vehicles. 11 ISCo AS YS, May 26-29, 2009, Kherson, Ukraine. P. 11-12.
15. Vidmachenko A.P. (2014) Study of Earth-like planets. 16 International scientific conference Astronomical School of Young Scientists. Kirovohrad, Ukraine. May 29–31, 2014. P. 12-13.
16. Vidmachenko A.P. (2016) The floating ices on the surface of Pluto. 18 International scientific conference Astronomical School of Young Scientists. National Aviation University, Kyiv, Ukraine, May 26-27, 2016, p. 10-12.
17. Vidmachenko A.P. (2017) What forms of life could have arisen in the ancient conditions of Mars? 19 International scientific conference Astronomical School of Young Scientists. May 24–25 2017. Bila Tserkva, Ukraine. P. 16-17.
18. Vidmachenko A.P. (2018) Features of volcanic activity on various bodies of the Solar system. Materials of the ISPCo The Objectives of the Sustainable Development of the Third Millennium: Challenges for Universities of Life Sciences, 5, May 23-25, Kyiv, p. 41-42.

19. Vidmachenko A.P. (2019) Traces of Martian Life Should be Sought in Places Around Hellas Crater, Where Water has Recently Spilled Out onto the Surface. Ninth International Conference on Mars, Pasadena, California, Jul 22-25, 2019, LPI Contrib. No. 2089, 6005.
20. Vidmachenko A.P. (2023) About volcanoes on Mars. Proceedings of 11 All-Ukrainian Scientific Conference “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY". ISBN 978-617-552-363-6. P. 76-81.
21. Vidmachenko A.P. (2023) Comparison of features of impact and volcanic craters on the surface of Mars. Proceedings of VIII International Scientific and Practical Conference. Progressive research in the modern world (April 27-29). P. 237-246.
22. Vidmachenko A.P. (2023) Features of volcanic structures on Venus. Proceedings of the 9th International scientific and practical conference. Modern directions of scientific research development. Chicago, 23-25.02.2022. P. 195-204.
23. Vidmachenko A.P. (2023) History of possible climate change on Mars. Proceedings of VII International Scientific and Practical Conference. Science and innovation of modern world. (23-25 March 2023). Chapter 54. Cognum Publishing House, London, United Kingdom, p. 336-345.
24. Vidmachenko A.P. (2023) Macrorelief of the surface of Mars. Proceedings of XIV ISPCo. Prospects for the development of science and the environment. (April 10-12, 2023). Chapter 7. P. 34-39.
25. Vidmachenko A.P. (2023) The atmosphere of Mars. Proceedings of VI International Scientific and Practical Conference. Scientific research in the modern world.(April 6-8). P. 283-293.
26. Vidmachenko A.P. (2023) Thermal properties of the surface of Mars. Proceedings of VII ISPCo. Progressive research in the modern world (March 29-31, 2023). Chapter 42. P. 243-252.
27. Vidmachenko A.P., Klimenko V.M., Morozhenko A.V. (1981) Apparent spectral albedos of the disk of Mars in September-October 1977. Solar System Research. 14(4), p. 157-159.
28. Vidmachenko A.P., Mozghovyi O.V., Steklov O.F. (2023) About volcanoes on Mars. Proceedings of 11 All-Ukrainian Scientific Conference “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY", p. 76-81.
29. Vidmachenko A.P., Mozghovyi O.V., Steklov O.F. (2023) Features of the relief on the surface of Mars. Proceedings of 11 All-Ukrainian Scientific Conference “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY". P. 66-71.
30. Vidmachenko A.P., Mozghovyi O.V., Steklov O.F. (2023) Historical aspects of climate changes on Mars. Proceedings of 11 All-Ukrainian SCo “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY". P. 56-61.
31. Vidmachenko A.P., Mozghovyi O.V., Steklov O.F. (2023) Peculiarities of dust storms on Mars. Proceedings of 11 All-Ukrainian Scientific Conference “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY". P. 87-92.