SECTION: PHYSICS AND ASTRONOMY

DOI 10.70286/ISU-21.01.2026.013

GENERAL FEATURES OF THE INTERNAL STRUCTURE OF THE PLANET MARS

Vidmachenko Anatoliy Petrovych
Doctor Phys.-Math. Sci., Professor
Department of Physics
National University of Life and Environmental Sciences of Ukraine
Kyiv, Ukraine

Introduction.

Volcanism has been a fundamental force in shaping the geological evolution of Mars [21-24, 26, 28].

Large-scale volcanic formations span a vast geological time span, from the ancient Noachian period (over 3.7 billion years ago) to the relatively late Amazonian period (less than 500 million years ago). This suggests that the planet has been volcanically active throughout its history [13, 27].

Volcanism on Mars is a geological phenomenon that has been an important process throughout the history of Mars. That is, volcanism is a fundamental, long-term driver that has profoundly influenced both the formation of the surface [15-17, 19, 25] of the planet and its internal thermal dynamics. This implies a connection between the internal thermal state of the planet and surface formations and atmospheric chemistry, making volcanism central to understanding the overall evolution of Mars.

The chemical composition of Mars [1, 7, 9, 11] is quite similar to all terrestrial planets. Although there are some specific differences. For example, it is believed that the core of Mars is rich in sulfur iron. And for these elements, temperature values of 1300-1500 K are characteristic. Therefore, in the hot core they are in a liquid state. The radius of the core should be 800-1000 km and contain up to 10% of the total mass of Mars. Such a core should have formed during the first billion years [6, 7, 9]. Almost during the same time, the melting of silicate components in the mantle of Mars took place. Such a process should have been accompanied by volcanic eruptions and intense tectonic processes [12, 14, 22].

This should have allowed the substance in the mantle of Mars to become noticeably enriched in iron sulfate. Now quite a significant amount of it has been found on the surface of Mars when studying rocks [21, 23, 24, 26]. Although its content compared to other terrestrial planets is significantly lower.

Mars, like other terrestrial planets, also has a differentiated internal structure. It consists of a central core, a mantle of silicate rocks and an outer crust. The study of their size, general structure and composition of these layers are key to reconstructing the geological history of Mars and comparing it with the Earth.

Seismological studies of Mars.

A significant breakthrough in the study of the interior of Mars was achieved thanks to the "InSight" mission, which was launched in 2018 and operated until December 2022. Using the SEIS seismometer installed on it, seismic experiments were conducted necessary for studying the internal structure of this planet [2, 6]. Recording waves from marsquakes made it possible to “listen” to the interior of Mars. It was thanks to measurements with the "InSight" apparatus for the Martian interior that it was possible to obtain the first direct seismic measurements.

The operation of the SEIS seismometer made it possible to detect more than 1300 seismic events and record seismic waves generated during meteoroid impacts [3, 4] on the surface of Mars. The success of the "InSight" apparatus with the SEIS instrument in collecting these seismic events represents a significant improvement in knowledge about the interior layers of Mars, the thickness of these layers, their density and their state (solid or liquid).

In Fig. Figures 1a and 1b show a pair of images taken by the Mars Color Imager (MARCI) on the "Mars Reconnaissance Orbiter" (MRO) [8, 26], taken one day apart. A large impact crater is seen there as a result of a meteoroid impact [18]. The dark area on the right side of the image is up to 8 km across. Analysis of images from different orbiters has revealed more than four hundred “fresh” impact craters on the surface of Mars. "InSight" has recorded seismic events for more than 50 of these events; one of them is shown in Fig. 1c.

They were sufficiently clear to pinpoint their exact locations; the highest concentration of high-quality events was in the Cerberus Fossae region, which is a region of geologically recent volcanism [25].

This seismometer was designed to detect so-called P-waves and S-waves; they are crucial for mapping the possible scheme of the interior layers of Mars. In addition to seismology, another experiment was carried out on the “InSight” spacecraft using the radio antenna of the probe RI22SE (Rotation and Interior Structure Experiment). It made direct observational measurements of the subtle oscillations of Mars, which are influenced by the features of the planet's interior structure. These new data provided some constraints on the size of the layered structures inside Mars. They significantly reduced the uncertainties and provided a more reliable understanding of the formation and thermal evolution [20, 22, 27] of this planet (Fig. 1d).

The significant scientific impact of the groundbreaking work of the equipment on the InSight spacecraft is also manifested in the fact that its work may lead to a better understanding of the interior structure of the Earth, the Moon, and all rocky planetary bodies in general. The thickness of the current Martian lithosphere may be several hundred kilometers.

The upper part of the so-called crust should be rich in iron oxide and olivine. It is believed that these components give the surface of this planet its peculiar "rusty" colors [10]. The presence of significant amounts of iron hydroxide in the upper part of the soil is an important confirmation of the processes of lowering heavier chemical elements and rocks in the directions to the planet's core. This indicates the presence of a past occurrence of the phenomenon of gravitational differentiation of Mars.

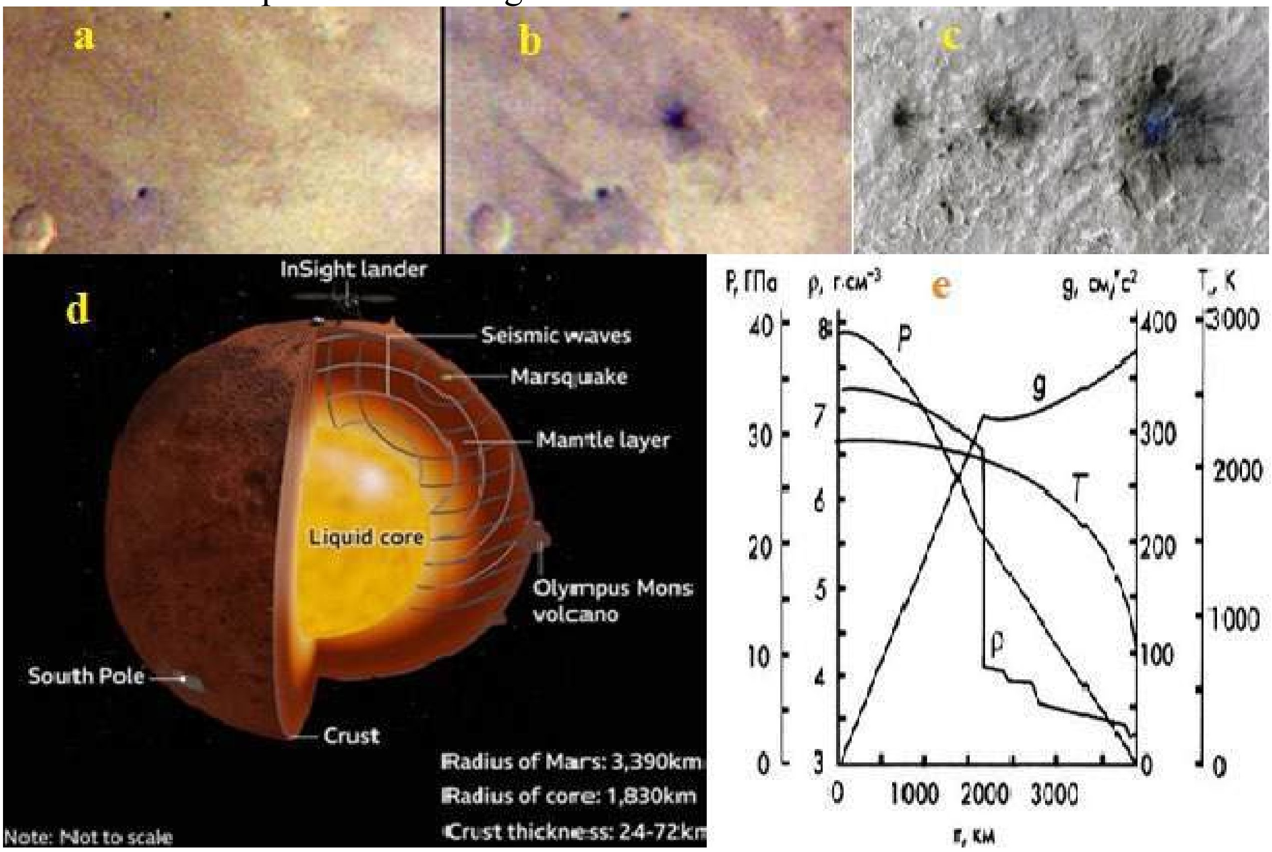

Figure. 1. Features of meteoroid impacts on the surface of Mars and characteristics of the internal structure. Meteoroid impact on the surface of Mars: a – image obtained by MRO on 03/27/2012, b – 03/28/2012 (https://d2pn8kiwq2w21t.cloudfront.net/original_images/jpegPIA18381.jpg). c – image from the Mars Reconnaissance Orbiter shows the crater (in blue) formed when a meteoroid collided with Mars on 09/5/2021 (https://d2pn8kiwq2w21t.cloudfront.net/original_images/insight_firstimpacts.jpg). d – shows a diagram of the internal structure of Mars (https://ichef.bbci.co.uk/news/800/cpsprodpb/9B2C/production/_119542793_mars_640-2x-nc.png.webp). e – model of the internal structure of Mars [24].

But its duration, most likely, was greatly prolonged, and it manifests itself less noticeably than it does on Earth. However, changes in the degree of concentration of the planet's mass from the surface to its center are associated precisely with the processes of differentiation of their components.

This characteristic is clearly reflected by the parameter, which is the value of the dimensionless moment of inertia equal to $I=0.366\pm0.002$. Its value was first determined from observational data obtained by the “Mars Pathfinder” space mission [5, 8]. It independently confirmed the insignificant dimensions of the metallic core of Mars.

The crust of Mars can withstand the load of even the heaviest mountain in the Solar System, Olympus Mons, which is close to 27 km high and has a diameter at the base of almost 1000 km, as well as three other huge volcanoes located nearby. This fact independently indicates the presence of a very thick lithosphere on this planet. The combination of models of the crust, silicate mantle and core in the work [1] made it possible to present a global model of the internal structure of Mars.

At the moment, an important parameter is the degree of correspondence of the accepted cosmogonic model with the ratio between the chemical elements Fe/Si=1.71 by mass, with respect to modern models of the internal structure of Mars. One of the models is shown in Fig. 1e.

The presence of a cold outer layer on Mars should be considered as one of the indirect confirmations that this planet has already passed the so-called “magma ocean” stage. After all, it is during this stage that there is a significant decrease in the content of radioactive energy sources in the mantle due to their removal to the crust as a result of volcanic activity.

References

1. Bertka C.M., Fei Y. (1998) A profile of Martian mineralogy and density up to core-mantle boundary. LPSC. V. 27. P. 107-108.
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 fragments of cometary nuclei in the atmosphere over Kiev. Astronomical School’s Report. 11(2), p. 99-102. 51
4. Churyumov K.I., Steklov A.F., Vidmachenko A.P., Steklov E.A. (2014) Some results of regular observations of the twilight bolides. In: Book of selected papers and abstracts. Edited by corresponding member of NAS of Ukraine prof. KI Churyumov.- Vinnytsia. September 29-October 2. P. 98-108.
5. Fonseca R.M., Zorzano-Mier M.-P., Martín-Torres J. (2018) Planetary boundary layer and circulation dynamics at Gale Crater, Mars. Icarus. 302, p. 537-559.
6. Goins N.R., Lazarewicz A.R. (1979) Martian seismicity. Geophys. Res. Let. 6(5), p. 368-370.
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. Vidmachenko A. P. (2009) Research of the Mars by space vehicles. Astronomical School’s Report. 6(1-2), p. 131-137.
9. Sexton M.R., Elwood Madden M.E., Swindle A.L., et al. (2017) Considering the formation of hematite spherules on Mars by freezing aqueous hematite nanoparticle suspensions. Icarus. 286, p. 202-211.
10. 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.
11. Vidmachenko A. P. (2016) Activity of processes on the visible surface of planets of Solar system. 18 International scientific conference Astronomical School of Young Scientists. National Aviation University, Kyiv, Ukraine, May 26-27, 2016. P. 23-27.
12. Vidmachenko A. P. (2016) Activity of processes on the visible surfaces of Solar System bodies. Astronomical School’s Report. 12(2), p. 14-26.
13. Vidmachenko A. P. (2016) Processes on the “young” Mars: possible developments of events. 18 International scientific conference Astronomical School of

Young Scientists. National Aviation University, Kyiv, Ukraine, May 26-27, 2016. P. 16-17.
14. Vidmachenko A. P. (2018) Comparative features of volcanoes on Solar system bodies. 20 International scientific conference Astronomical School of Young Scientists. May 23–24, 2018. Uman, Ukraine, p. 9-12.
15. Vidmachenko A. P. (2018) Features of volcanic activity on various bodies of the Solar system. Materials of the International Scientific and Practical Conference "The Objectives of the Sustainable Development of the Third Millennium: Challenges for Universities of Life Sciences", vol. 5, May 23-25, 2018, Kyiv, p. 41-42.
16. Vidmachenko A. P. (2018) Modern volcanic activity on the Moon. 20 International scientific conference Astronomical School of Young Scientists. May 23-24, 2018. Uman, Ukraine. P. 5-7.
17. 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.
18. 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.
19. 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.
20. 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. P. 336-345.
21. Vidmachenko A. P. (2023) Macrorelief of the surface of Mars. Proceedings of XIV International Scientific and Practical Conference. Prospects for the development of science and the environment. (April 10-12, 2023). Chapter 7. P. 34-39.
22. Vidmachenko A.P. (2023) Thermal properties of the surface of Mars. Proceedings of VII International Scientific and Practical Conference. Progressive research in the modern world (March 29-31). P. 243-252.
23. 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.
24. Vidmachenko A.P., Morozhenko O.V. (2019) Physical parameters of terrestrial planets and their satellites. Kyiv. Editorial and Publishing Department of NULES of Ukraine.-468 p.
25. 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.
26. 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.

27. Vidmachenko A. P., Mozghovyi O. V., Steklov O. F. (2023) Historical aspects of climate changes on Mars. Proceedings of 11 All-Ukrainian Scientific Conference “Astronomy and present day”, April 12, 2023. Vinnytsia, Ukraine. LLC "TVORY". P. 56-61.
28. Vidmachenko A. P., Steklov A.F. (2022) 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.