Section: Physical and Mathematical Sciences

DOI 10.70286/EOSS-02.02.2026.010.211-220

THE EVOLUTIONARY ROLE OF PROLONGED VOLCANISM ON THE FORMATION AND CHANGES OF THE MARTIAN ATMOSPHERE

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

Abstract. For billions of years, Mars has been a carrier of powerful volcanic activity. Volcanism provided the initial formation of the atmosphere and hydrosphere and continues to influence the dynamics of the modern gas composition and the activity of mantle plumes. The Earth is characterized by plate tectonics, which provides an exchange of volatile substances between the atmosphere and the mantle. The absence of plate movement on Mars led to the accumulation of magma in one place, and to the formation of huge shield volcanoes. Such a concentrated release of energy and mass had global consequences for the atmosphere, since each large eruption was able to throw into the air an amount of gases sufficient to temporarily change the climatic regime of the entire planet. In the early historical period, intensive degassing of the primary mantle occurred; this led to the creation of a dense atmosphere of CO_2 and H_2O. Martian volcanoes also emitted other gases. For example, the ratio of deuterium to hydrogen (D/H) on Mars is 5–6 times higher than on Earth; this indicates a selective loss of light hydrogen to space over billions of years. Similarly, volcanic nitrogen helped explain the observed 15N/14N ratio. The evolution of ideal gases, in particular xenon Xe, suggests that most of the atmospheric distribution of gaseous constituents occurred within the first few hundred million years of the planet's history. It was long believed that on Mars, as on Earth, the main sulfur-containing gas was sulfur dioxide SO_2. However, new modeling, taking into account the oxidation state of the Martian mantle, shows that Mars emitted mainly reduced forms of sulfur: hydrogen sulfide H_2S, sulfur S_2, and the powerful greenhouse gas sulfur hexafluoride SF_6. It retains heat thousands of times more effectively than CO_2. The presence of SF_6 on Mars also explains the existence of liquid water 3–4 billion years ago without the need to assume unrealistically high concentrations of CO_2. The results of the InSight mission and modern orbital observations have shown that Mars remains a geologically active planet.

Keywords: Mars, atmospheric evolution, gas composition, atmospheric modeling.

Introduction. Despite its current state as a cold and rarefied desert, Mars [2, 12, 20] has been the site of enormous volcanic activity for billions of years [23-26, 31]. But it is radically different from its terrestrial counterparts in terms of scale, duration, and geochemical consequences. Understanding how the planet's internal heat was transformed into volcanic eruptions and subsequent volatile outgassing is key to reconstructing the climate history of Mars [3, 33]. Volcanism not only provided the initial formation of the atmosphere and hydrosphere, but also continues to influence the dynamics of the modern gas composition [15, 16, 28] through passive outgassing processes and mantle plume activity.

Geodynamic principles of Martian volcanism. A fundamental difference between Mars and Earth lies in the tectonic regime. While Earth is characterized by plate tectonics, which allows for a constant exchange of volatiles between the atmosphere and the mantle, Mars evolved under conditions of a stable lithosphere [9]. Therefore, the outer shell of the planet remains intact and immobile relative to the convective flows in its mantle. This has led to the fact that mantle plumes, which are upward flows of hot material, remain stationary under certain areas of the crust for millions or even billions of years.

The stationarity of the plumes, combined with the low gravity of Mars, has led to the formation of giant volcanic regions such as Tharsis and Elysium. Low gravity (with a gravity acceleration of 3.72 m/s^2 compared to 9.8 m/s^2 on Earth) has a critical impact on magmatic processes; it reduces the buoyancy of magma, which requires much larger and deeper magma reservoirs to accumulate sufficient pressure before eruption. As a result, volcanic events on Mars occur less frequently than on Earth but are characterized by incredible volumes of erupted material and high rates of lava flow. And the lack of plate movement has led to the fact that all the lava and gases that were released above a particular plume accumulated in one place, forming colossal shield volcanoes.

For example, Olympus Mons is 100 times larger in volume than the largest volcano on Earth, Mauna Loa. Such a concentrated release of energy and mass had global consequences for the atmosphere, since each large eruption was capable of releasing into the air a quantity of gases sufficient to temporarily change the climate regime of the entire planet.

Heat flow evolution and volcanic chronology. The intensity of volcanism determined the entire thermal history of Mars [29]. During the Pre-Noachian (4.5–4.1 billion years ago) and Noachian (4.1–3.7 billion years ago) periods, the planet had a significantly higher internal heat flow, which supported global magmatic activity. Estimates of heat flow for the Noachian–Hesperian boundary suggest a gradual cooling of the interior [13]. However, even with the general decline in activity, large volcanic centers remained active throughout most of Mars' history.

The Pre-Noachian period saw the formation of a primary crust and intense degassing of the primary mantle; this led to the creation of a dense atmosphere of CO_2 and H_2O. The Noachian period saw the peak of the formation of the Tharsis Plateau; eruptions of enormous volumes of lava and gases occurred, coinciding with a period of intense river network formation. During the Hesperian period (3.7–3.0 billion years ago), eruptions through fissures dominated Mars and large plains of basaltic lavas formed; the chemical composition of the emissions changed towards an increase in the proportion of sulfur. During the Amazonian period (3.0 billion years ago – present), volcanic activity was localized in the areas of Tharsis and Elysium; however, eruptions become isolated, although they continue to significantly affect local conditions [7].

Volcanic degassing as a source of the Martian atmosphere and hydrosphere. Over a long geological time, volcanism has been the main source of atmospheric replenishment. According to calculations based on the studied volumes of volcanic rocks, volcanic degassing added about 0.8 bar of carbon dioxide CO_2 to the Martian atmosphere only during the late Noachian to Amazonian periods [6]. Other models suggest that the total CO_2 emissions from the Tharsis province alone could have increased the pressure by 1.5 bar. This is a huge amount, considering that the current atmospheric pressure on Mars is less than 0.01 bar.

But Martian volcanoes not only emitted greenhouse gases, but also enormous amounts of water vapor (Table 1). Estimates suggest that volcanism released about 1.1□10^{21} g of water, equivalent to a global water layer 46 to 120 meters thick. This water played a significant role in shaping the early Martian landscape. Once in the atmosphere, it condensed and fell as rain or snow, creating the river networks and lakes that we now see as dry riverbeds.

Table 1 – Estimates of Volcanic Emissions

Volatile substance	Estimated release volume (global equivalent)	Impact on atmosphere and surface
CO_2	0.8 – 1.5 bar	Main component of the atmosphere, greenhouse effect
H_2O	46 – 120 meters (water layer)	Formation of the hydrosphere, polar ice caps
SO_2 / H_2S	Up to 120 cm (acid layer)	Formation of sulfates, aerosol cooling/heating
N_2	~1.3 mbar	Effect on the isotopic composition of nitrogen 15N/14N

The study of the isotopic composition of gases in Martian meteorites and in the modern atmosphere allows us to trace the history of degassing and gas loss. For example, the ratio of deuterium to hydrogen (D/H) on Mars is 5–6 times higher than on Earth; this indicates a selective loss of light hydrogen to space over billions of years [6]. Volcanic degassing has continuously supplied “fresh” hydrogen from the mantle, which has a lighter isotopic composition (close to Earth's), partially compensating for the isotopic increase in the weight of the atmosphere. Similarly, volcanic nitrogen helps to explain the observed 15N/14N ratio [6].

The evolution of ideal gases, in particular xenon (Xe), suggests that the bulk of the atmospheric distribution of gas components occurred very early: in the first few hundred million years of the planet's history [16]. This means that later volcanism added gases to an already significantly modified atmospheric reservoir. Xenon, having a low ionization potential, could be removed from the atmosphere along with the flows of ionized components, and this led to its significant depletion compared to other noble gases. Recent data [3] have made radical adjustments to the understanding of the chemical composition of Martian volcanic emissions.

For a long time it was believed that the main sulfur-containing gas, as on Earth, was sulfur dioxide SO_2. However, new modeling, taking into account the oxidation state of the Martian mantle, shows that Mars emitted mainly reduced forms of sulfur: hydrogen sulfide H_2S and sulfur S_2. The most significant conclusion of the new research is the possibility of the formation of sulfur hexafluoride SF6 in the Martian atmosphere. This is an extremely powerful greenhouse gas, capable of retaining heat thousands of times more effectively than CO_2 [3]. The presence of SF_6, formed by the interaction of volcanic emissions, could have provided sufficient warming to maintain liquid water on the surface even with weak energy fluxes from the young Sun. Modeling of many degassing scenarios has shown that: reduced sulfur species (H_2S, S_2) dominated at the surface-level pressures possible at that time [3]; these gases contributed to the formation of an optically dense aerosol haze that regulated the energy balance of the planet.

The presence of SF_6 on Mars also explains the existence of liquid water 3–4 billion years ago without the need to assume unrealistically high concentrations of CO_2. Volcanic sulfur had another critical effect: it determined the mineralogy of the surface. Unlike Earth, where carbonates (limestones) are the main reservoirs of CO_2, they are much rarer on Mars. This is because volcanic gases were rich in sulfur compounds, which, when dissolved in water, created an extremely acidic environment [6]. Under low pH conditions, carbonates cannot precipitate, and sulfates are formed instead.

This transition is well documented in the geological record of Mars. After all, during the Noachian era, there was a more neutral environment, and clay minerals - phyllosilicates – formed in it. During the Hesperian era, powerful sulfur emissions during volcanic eruptions led to global acidification and the formation of significant deposits of sulfates such as jarosite and gypsum. The recent discovery of pure native sulfur using the “Curiosity” rover in 2024 confirmed model predictions about the precipitation of elemental sulfur directly from volcanic plumes containing S_2. Volcanism on Mars was not just a source of heat, but a complex regulator of water distribution. Studies [8] demonstrate that individual eruptions could initiate global or regional precipitation events.

Explosive and effusive volcanism. Powerful explosive eruptions were common in early Martian history (e.g., for the volcanoes Syrtis Major and Apollinaris Mons). They ejected huge amounts of water vapor high into the atmosphere. Due to the low temperatures, this vapor quickly froze and fell as snow or icy ash. Simulations show that a single such eruption could have covered the equatorial regions with a layer of ice up to 5 meters thick. Since the equatorial regions are usually too warm for ice to exist there in a stable state, this ice could have persisted for millions of years only if it was quickly buried under a layer of volcanic dust and/or ash that would protect it from sublimation.

Large lava eruptions, such as those at Cerberus Fossae, had a dual effect, either short-term warming or sudden cooling. For example, CO_2 and H_2O emissions created a temporary greenhouse effect. While the accumulation of sulfate aerosols and ash in the atmosphere increased the albedo of the entire planet, reflecting a significant part of the sunlight and plunging Mars into a volcanic winter for a certain time. It is precisely such temperature fluctuations that can explain the presence of such relief features [27, 32] as cones formed by the explosive interaction of hot lava with ice under the surface layer. This indicates that even in later eras Mars had significant reserves of ice, the distribution of which changed under the influence of volcanism.

The evolution of the Martian atmosphere is also the history of the struggle between its replenishment during volcanic eruptions and impact cosmic erosion. The critical moment was the disappearance of the global magnetic field [1, 14] about 4 billion years ago.

Without magnetic protection that deflects the solar wind, the upper atmosphere became defenseless against the streams of charged particles. Therefore, the solar wind crashed into the Martian atmosphere, ionizing gas atoms and “blowing” them into space. It is believed that “young” Mars lost most of its atmospheric oxygen and carbon precisely as a result of this process. Interestingly, weak residual magnetic fields in the Martian crust not only do not protect the planet now but may also accelerate the loss of the atmosphere. Modeling in [14] showed that a weak magnetic field can lead to the loss of ions even 6 times faster than the complete absence of the field. Magnetic field lines that emerge from the crust are deformed by the solar wind and create peculiar channels (“magnetic tails”) through which atmospheric ions easily flow into space. This paradoxical effect means that as Mars began to cool and lose its internal dynamo, the rate of atmospheric degradation increased significantly, despite ongoing volcanic degassing.

Ongoing geological and atmospheric activity on modern Mars. The results of the InSight mission [4, 5] and modern orbital observations have definitively shattered the traditional view of Mars as a “dead” planet. Mars remains geologically alive today, although the scale of its activity has certainly diminished compared to its early history. One of the most important geophysical discoveries of recent years has been the discovery of a giant active mantle plume beneath Elysium Planitia (Fig. 1). This plume, about 4000 km wide, is uplifting the planet’s surface, creating the Cerberus Fossae tectonic faults. Almost all of the Martian earthquakes recorded by InSight occur in this area.

Evidence of modern activity on Mars includes seismic signals indicating the movement of magma or the fracturing of rocks under the influence of heat; the presence of the “youngest” volcanic eruption on Mars – a small ash layer in Cerberus Fossae, which is only 53,000 years old; and an anomalously high local heat flow, which supports the possibility of liquid water or magma at shallow depths.

Methane CH_4 is one of the most important indicators of current activity on the planet. Since methane in the Martian atmosphere should be destroyed by solar ultraviolet radiation in about 300–400 years, its detection implies the presence of a modern source of its replenishment. The Mars rover “Curiosity” recorded seasonal fluctuations in background methane levels at values of 0.2–0.7 ppbv and repeatedly observed its sudden spikes to values of 7–20 ppbv [36]. Although the biological origin of methane is an attractive hypothesis, geological processes such as "microdegassing" are still more likely explanations. These include concepts such as the interaction of olivine with water in the presence of internal heat of the planet, which leads to the release of hydrogen H_2 and the subsequent synthesis of CH_4. Methane formed billions of years ago could also be trapped in ice clathrates and released now through tectonic movements or seasonal warming. Although the "ExoMars Trace Gas Orbiter" has not yet been able to detect methane on a global scale, local emissions in areas such as Nili Fossae and Syrtis Major remain the subject of intense research [11].

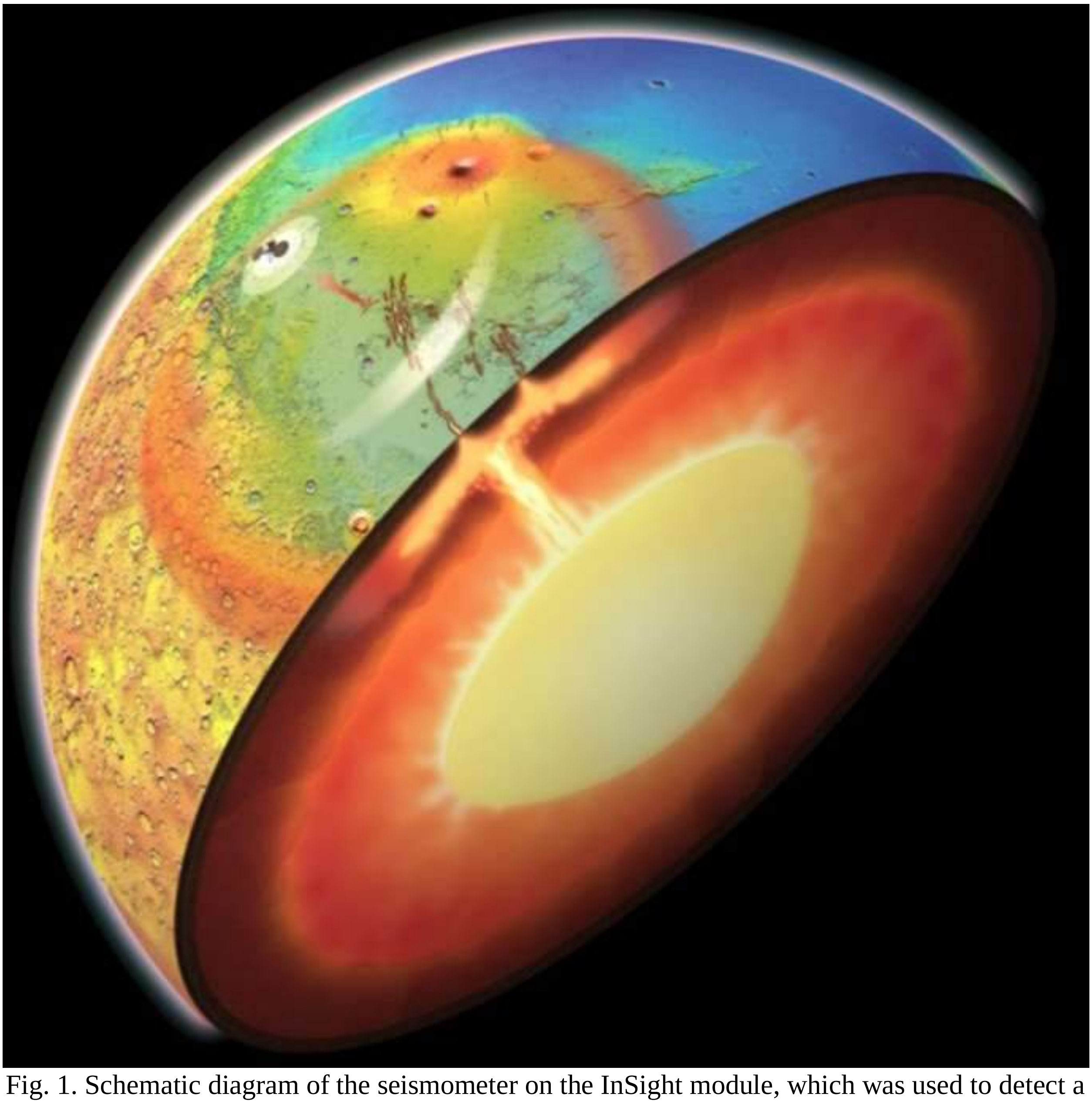

Fig. 1. Schematic diagram of the seismometer on the InSight module, which was used to detect a magma plume in the mantle of Mars. The plume rises from the depths of Mars and lifts up the Elysium Plain, where InSight landed.
(https://cdn.aapg.org/packflashitemimages/webready/insight-concludes-with-key-findings-fig4.jpg?width=1200)

In 2021, the "ExoMars Trace Gas Orbiter" first detected hydrogen chloride HCl in the Martian atmosphere. Initially, this was considered direct evidence of volcanism, but the fact that it appears simultaneously across the planet during dust storms [10, 30, 34, 35] suggests a rather complex photochemical cycle in which salty dust interacts with atmospheric moisture. Nevertheless, HCl remains an important indicator of the interaction between the planet's lithosphere and atmosphere, and its search, in combination with sulfur-containing gases, is a priority for this spacecraft to detect active volcanic plumes.

Analysis of Martian volcanism provides a new perspective on the evolution of the Earth. Mars demonstrates what can happen to a terrestrial planet if its heat engine cools more quickly due to its small size. The low atmospheric pressure on Mars has contributed to the fact that magmas degassed much deeper and more completely than on Earth. This means that Martian volcanism was extremely effective in bringing volatiles to the surface, but the lack of a mechanism for their return due to the absence of plate tectonics [17] made the atmosphere vulnerable to irreversible losses.

Conclusions. Volcanism on Mars was and remains a central process determining the fate of its atmosphere. From the initial creation of a dense gas envelope during the Noachian era to the maintenance of episodic warming through emissions of reduced sulfur and SF_6, volcanic activity has created habitable windows [10, 18, 19, 21, 22] on the planet. Modern Mars is not a "dead rock" but a planet in a state of late geological maturity. The presence of an active mantle plume beneath the Elysian Planitia, seismic activity in Cerberus Fossae, and mysterious methane emissions suggest that internal processes continue to fuel the atmosphere with volatiles.

Although the rate of atmospheric loss to space now outweighs the rate of its replenishment, each new marsquake or methane burst is a reminder that Martian activity is still present, continuing to influence atmospheric evolution. Understanding these processes is critical for basic science and for future exploration missions. Volcanic regions beneath the surface of Mars, where mantle heat can interact with subsurface ice, are the most promising places to search for modern regions where microbial life could exist in hydrothermal conditions similar to those on Earth. Thus, the volcanism that once created Mars' atmosphere now points the way to the search for life deep within its interior.

References

1. Acuña M.H. (2003) The magnetic field of Mars. The Leading Edge. 22(8), p. 769-771.
2. Atreya S.K., Gu Z.G. (1994) Stability of the Martian atmosphere: is heterogeneous catalysis essential? J. Geophys. Res. 99(E6), p. 13133–13145.
3. Bellino L.G., Sun Ch. (2025) Volcanic emission of reduced sulfur species shaped the climate of early Mars. Science Advances.11(36), p. 1-11. https://orcid.org/0000-0002-9768-2815.
4. 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.

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. Craddock R.A., Greeley R. (2009) Minimum estimates of the amount and timing of gases released into the Martian atmosphere from volcanic eruptions. Icarus. 204, p. 512–526.
7. Dohm J.M., Anderson R.C., Barlow N.G., et al. (2008) Recent geological and hydrological activity on Mars: The Tharsis/Elysium corridor. Planetary and Space Science. 56, p. 985–1013.
8. Hamid, S.S., Kerber, L. & Clarke, A.B. (2025) Precipitation induced by explosive volcanism on Mars and its implications for unexpected equatorial ice. Nature Communications.16(8923). https://doi.org/10.1038/s41467-025-63518-8.
9. Lenardic A. (2018) The diversity of tectonic modes and thoughts about transitions between them. Philosophical Transaction of the Royal Society A: Mathematical, Physical and Engineering Sciences. 376(2132), p. 1-22.
10. 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.
11. Oehler DZ, Etiope G. (2017) Methane Seepage on Mars: Where to Look and Why. Astrobiology. 17(12), p.1233-1264. doi: 10.1089/ast.2017.1657.
12. Pollack J.B., Kasting J.F., Richardson S.M., Poliakoff K. (1987) The case for a wet, warm climate on early Mars. Icarus. 71(2), p. 203-224.
13. Ruiz, J., Parro, L. M., Egea-González, I., Romeo, I., Álvarez-Lozano, J., & Jiménez-Díaz, A. (2025). The Surface Heat Flow of Mars at the Noachian–Hesperian Boundary. Remote Sensing, 17(2), 274. https://doi.org/10.3390/rs17020274.
14. Sakata R., Seki K., Sakai S., et al. (2020) Effects of an Intrinsic Magnetic Field on Ion Loss From Ancient Mars Based on Multispecies MHD Simulations. Journal of Geophysical Research: Space Physics. 125(2), p. 1-16.
15. Schmidt F., Chassefière E., Tian F., et al. (2016) Early Mars volcanic sulfur storage in the upper cryosphere and formation of transient SO2-rich atmospheres during the Hesperian. Meteoritics & Planetary Science. 51(11), p. 2226-2233.
16. Shorttle O, Saeidfirozeh H, Rimmer PB, et al. (2024) Impact sculpting of the early martian atmosphere. Sci Adv. 10(37), p. 1-19. doi: 10.1126/sciadv.adm9921.
17. Sleep N.H. (1994) Martian Plate Tectonics. J. Geophys. Res. 99(E3), p. 5639-5655.
18. 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.
19. 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.
20. 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.

21. Vidmachenko A.P. (2016) Traces of life on Mars must be sought around the valley Hellas in areas where the water coming out from under the planet's surface. 18 International Scientific Conference Astronomical School of Young Scientists. Kyiv, Ukraine, May 26-27, p. 14-16.
22. 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.
23. Vidmachenko A.P. (2018) Modern volcanic activity on the Moon. 20 International Scientific Conference Astronomical School of Young Scientists. May 23-24. Uman, Ukraine. P. 5-7.
24. 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.
25. 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.
26. 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.
27. 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.
28. 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.
29. 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, 2023). Chapter 42. P. 243-252.
30. 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.
31. 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.
32. 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.
33. 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.

34. 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. 1
35. Wang H. (2017) Major dust storms and westward traveling waves on Mars. Geophysical Research Letters. 44(8), p. 3493-3501.
36. Yung Y.L., Chen P., Nealson K., et al. (2018) Methane on Mars and Habitability: Challenges and Responses. Astrobiology. 18(10), p. 1221-1242.

YASSAT PROJECT - A STEP TOWARD MASTERING SPACE TECHNOLOGIES

Erkin K. Aktayev
Candidate of Physical and Mathematical Sciences,
Professor Palace of Schoolchildren, Turkestan, Kazakhstan
Annel N. Onalbek
Methodist of the Students' Palace
Zhakyp Olzhas
10th grade student, Schoolchildren's Palace,
Turkestan city, Kazakhstan

Abstract
This article examines the educational project **YasSat**, implemented within the club “Satellite Robotics and Space Communication” at the Palace of Schoolchildren in the city of Turkestan. The project is aimed at developing students’ engineering, research, and analytical competencies in the field of space technologies based on the STEM approach. Particular attention is given to the educational, scientific, and social significance of the project, as well as its role in preparing future specialists in space engineering.

Keywords: YasSat, nanosatellite, STEM education, satellite robotics, space technologies, supplementary education.

Introduction

In modern education, the integration of innovative technologies and the development of students’ research abilities are of particular importance. Stimulating interest in engineering and scientific fields is one of the priority tasks of the supplementary education system. In this context, the YasSat project, implemented at the Palace of Schoolchildren in the city of Turkestan, represents a significant educational initiative aimed at introducing school students to the fundamentals of space engineering and enhancing the scientific and technological potential of the country [1], [2].

The YasSat project is carried out within the framework of the “Satellite Robotics and Space Communication” club and constitutes an integral part of the UniSat