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FEATURES OF VOLCANIC AND IMPACT STRUCTURES IN THE RELIEF OF MARS.

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Abstract. Remote sensing of the surface of Mars and its study using orbital vehicles have shown that a significant part of the planet's surface is covered with old and young craters. Among them, craters of volcanic origin and the so-called impact craters were found. Their age ranges from more than 4 billion years to only a few months, and possibly days. Volcanic activity has historically played an important role in the evolution of geological features and in the formation of the surface relief. Traces of volcanism are gorges, canyons and faults several kilometers deep, hundreds of kilometers long and tens of kilometers wide. It is not excluded that volcanic activity on Mars continued much longer than previously thought. There is some evidence of recent volcanic activity on Mars.

Key words: Mars, volcanic activity, surface relief, volcanic and impact craters.

Introduction. Even during remote studies of the surface of Mars, and then its study with the help of orbital vehicles, it was indicated that a significant part of the planet's surface is covered almost equally with old and fairly young craters, as well as flat erosional deposits [2, 7, 34]. Among the craters, both volcanic and so-called impact or meteorite craters were found [1, 3, 30]. Their age ranges from more than 4 billion years to only a few months, and possibly even days [4].

Moreover, in the southern regions of the planet, significantly more craters were found than in the lowlands in the north and on the lowland plains of Hellas Planitia [28] and Argyre Planitia, which are located in the southern hemisphere in the middle of huge ring structures (Fig. 1).

Volcanic activity has historically played a rather important role in the evolution of the geological features of the terrestrial planet Mars. It is she who allowed to form the relief on a significant part of its surface. Volcanism on Mars [9, 24-26, 29] led to the formation of some of the highest and most powerful volcanic formations in the entire Solar System. That is, remote observations of the planet Mars [34] revealed distinct traces of volcanism and tectonic activity, such as gorges, canyons and faults; some of them are several kilometers deep, hundreds of kilometers long and tens of kilometers wide.

Volcanic and impact craters on Mars. An extensive fault system is located on the eastern and western edges of the Mariner Valley, which could have arisen during the movement of the Tharsis Regio region (Fig. 2).

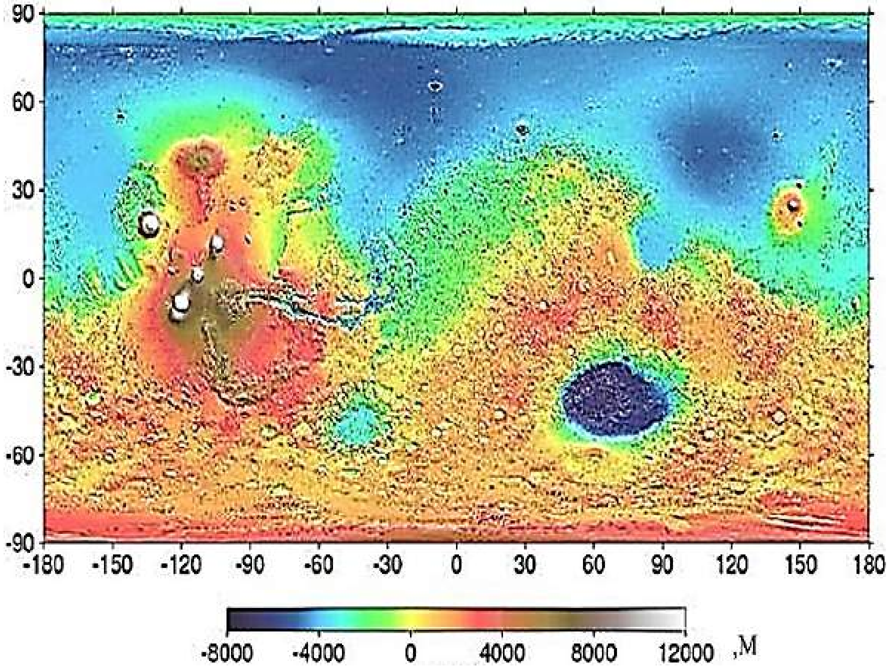

Fig. 1. Relief of the entire surface of Mars according to data from the Mars Global Surveyor spacecraft (SC) (http://photojournal.jpl.nasa.gov/).

Fig. 2. Three giant volcanoes in Tharsis Regio, Olympus Mons and Valles Marineris (http://photojournal.jpl.nasa.gov/).

When the very first images from the Mariner 4 spacecraft were obtained, it was concluded that the surface of the planet Mars closely resembles the relief of the Earth's satellite, the Moon (Fig. 3a).

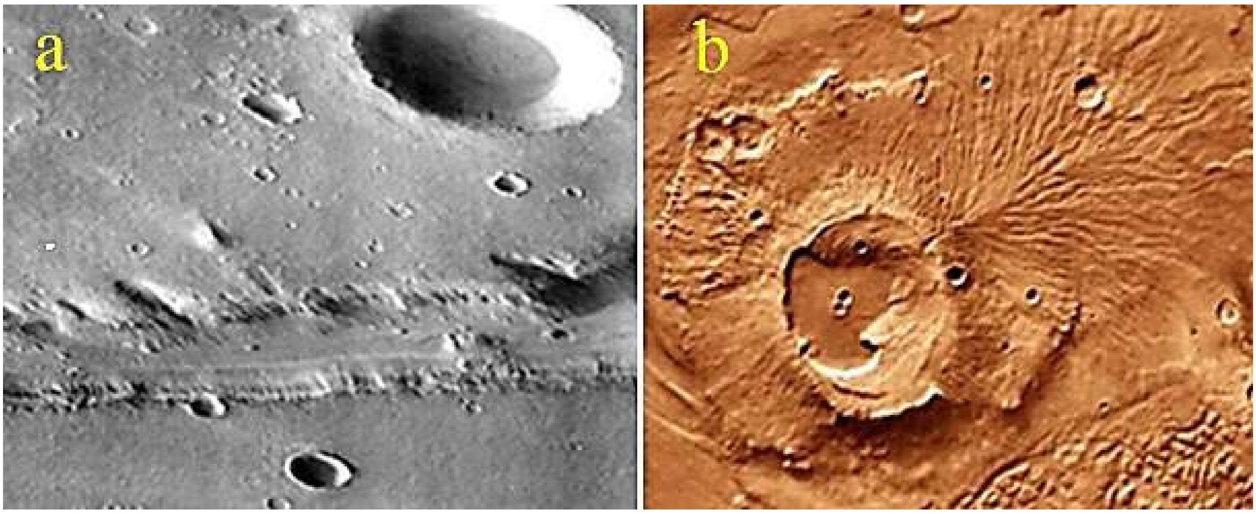

Fig. 3. a – Large and small craters and valleys found on the surface of Mars (http://photojournal.jpl.nasa.gov/). b – Apollinairs Patera volcano on Mars (http://photojournal.jpl.nasa.gov/).

The appearance of specific details was supplemented by images obtained with the help of later missions and landing modules.

The entire surface of Mars was dotted with reddish-colored stone blocks (most likely due to the presence of impurities with trivalent iron oxides there). They could be, for example, fragments of volcanic rocks formed by the fall of meteoritic bodies, or as a result of wind [5] or water erosion processes. With the exception of a few plains, the rest of the surface of Mars was significantly cratered [32, 35]. However, all craters are much more destroyed compared to similar objects on Mercury [10] or the Moon [6, 26]. It was also found that significantly more craters were found in the southern hemisphere of Mars than in its northern part. According to their origin, craters are divided into impact (or meteorite) and volcanic. Mostly they are quite old. However, some of them turned out to be very young.

Almost half of the surface of Mars is covered with old craters, and on the other part young plain deposits are found [18, 19]. Most craters are found in the southern regions of the planet. Although low-lying formations are also located in the southern hemisphere in the middle of such giant ring structures as, for example, Hellas Planitia and Argyre Planitia; and their surface has a minimum density of craters.

The results of observations indicated that the shape of impact and volcanic craters is quite different. It was recorded that impact craters have almost circular ring ridges and external and internal terraces. Depending on their size, they may also have central elevations (in fairly large craters), or an additional internal ridge in extremely large craters. Whereas volcanic craters are characterized by smooth edges, and their environment is porous with lava flows. Most of them are located on the tops of dome-shaped formations. The most obvious representatives of such volcanic crater formations are the craters on the tops of the four highest volcanoes of Mars: Olympus, Arsya, Pavonis and Askraeus. In addition, all craters of significant sizes are covered with smaller crater formations (Fig. 3b). And a very small number of fresh impact craters of large sizes have a developed field of ejecta and ray structures. While in the vast majority of them the ejecta field is noticeably destroyed and/or covered by later ejecta. A characteristic feature of "young" craters are significantly thick layers of ejecta around each of them and rather low ridges on their outer edge. And on "young" lava flows, three times more secondary craters are observed than their number on plains or mountains. Such young craters are divided into the following six types.

Type 1 includes craters with a single shaft and diameters less than 10 km. Type 2 includes craters of slightly larger size, but with two shafts around them. Type 3 includes craters around which several smaller craters are located. Type 4 includes craters with a radial structure of the outer shaft and whose dimensions are in the range from 10 to 30 km. Craters with a diameter of less than 10 km do not have a structure similar to the above types. While the structure of craters with diameters greater than 30 km is much more complex. Therefore, they were assigned to type 5. Type 6 includes the so-called "pancake" craters, whose diameters are less than 5 km. Young lava flows have three times more secondary craters than flat or mountainous areas, and an order of magnitude more than old, heavily eroded areas of the surface.

All volcanoes on Mars have been divided into the following 3 types: large shield volcano-like volcanic formations, domes, and sinking calderas or pateras. The presence of the latter type of volcanic structures makes the surface of Mars noticeably different from the surfaces of Mercury and the Earth's moon, the Moon.

Estimates of the amount of lava flow from Martian volcanoes calculated using the example of Mount Arsya were about 3.5×10^5 m^3/s. The morphology of lava flows around volcanoes located in Tharsis Regio indicates a very low viscosity of the lava material. It turned out to be much lower than for the material of lunar seas, and much lower compared to the lava of volcanoes on Earth. For this reason, with a lower gravity, lava flows on the planet Mars spread over significantly greater distances. Observational data on the density of impact craters on the slopes of the largest volcanoes on Mars indicate their relatively young age.

For example, for the Olympus and Pavonis volcanoes, the age of surface lava flows is about 300 million years; and for the Arsya and Askraeus volcanoes (Fig. 4a) – almost 400 million years [29, 30]. All four volcanoes on Mars are impressive in their size; and on their slopes, lava flows, channels, and ridges with a width of several units and a length of hundreds of kilometers radiate out. That is, they are much larger than their terrestrial counterparts, and their lava flows are much longer (Fig. 3b).

The reason for this may be the fact that very hot volcanic regions under the Martian crust have been fixed in one place on the planet's surface for hundreds of millions of years [31]. Whereas on Earth, tectonic plates moved along rather hot volcanic regions, and therefore this did not allow the formation of volcanic formations of significant sizes. In addition to the so-called giant shield volcanoes, there are also more modest in size, but much more numerous volcanic formations on the surface of Mars: the so-called volcanic domes (Fig. 4b).

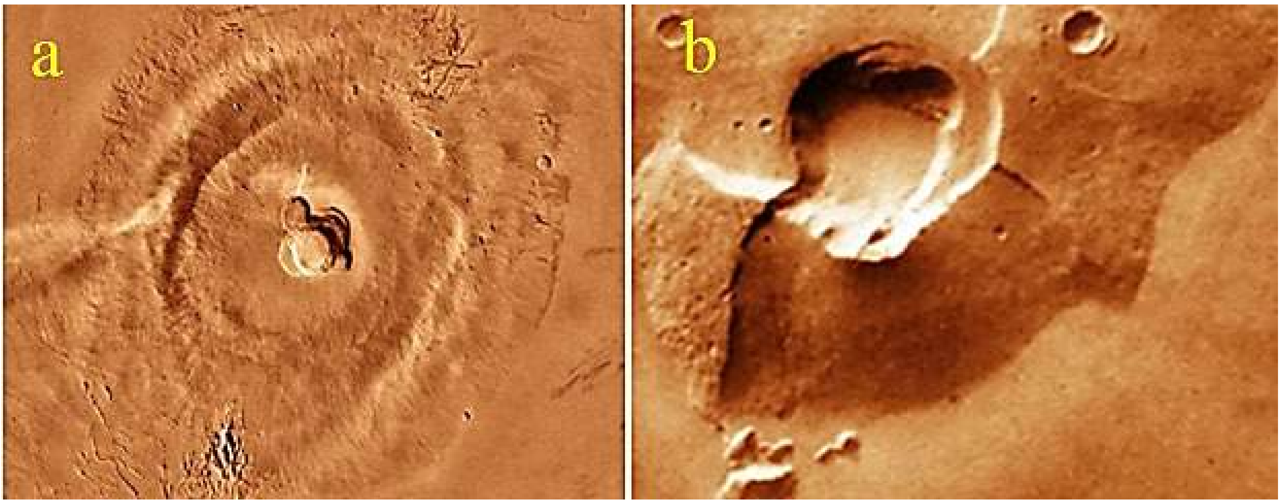

Fig. 4. a – the caldera of the volcano Ascraeus Mons is composed of several discrete depressions; the lower wall of the caldera is over 3 km high (http://photojournal.jpl.nasa.gov/). b – one of the domes in the Tharsis Tholus region (http://photojournal.jpl.nasa.gov/).

The majority of them are also located in the Tharsis Regio region. The height of these domes is less than 8 km; but their tops are often complicated by multi-tiered caldera-type depressions. The largest volcanic dome on Mars is called Hecates Tholus and is located in the Elysium Planitia region. Its diameter is about 200 km. In contrast to large shield volcanoes, domes are characterized by a significantly higher surface density of impact craters and a relatively higher ratio of the caldera diameter to the dome diameter.

It can be assumed that at least some of the domes in Tharsis Regio are the remains of ancient and most likely, larger volcanic formations, which were partially covered by somewhat later eruptions. Some of the smaller domes than are typical of shield volcanoes are more convex and have much steeper slopes all around. Such differences between domes and shield volcanoes may be due to the fact that the lava material erupted from the domes was somewhat more viscous; or the eruption sites from which the domes were formed occupied a smaller volume; and therefore the lava flows accumulated closer to their source.

The next type of volcano is the so-called Paterae, which have quite different shapes. The inclination of their slopes is insignificant; they have radial channels on their slopes; and some of them are noticeably modified by erosion. Due to the strong sensitivity of paterae volcanoes to erosion, it can be assumed that they are composed of fairly light materials such as ash flows.

Alba Patera (Fig. 5a) is unique among them. It is comparable in size to Mount Olympus (about 1,600 km across) and has a central caldera. However, its height above the surrounding plain is less than 3 km. This suggests that Alba Patera was formed by lava flows that were either significantly more powerful or perhaps much longer than similar flows in other regions of the planet.

The presence of very significant erosion in some of the paterae also suggests that these formations may be among the oldest volcanoes [36] on Mars.

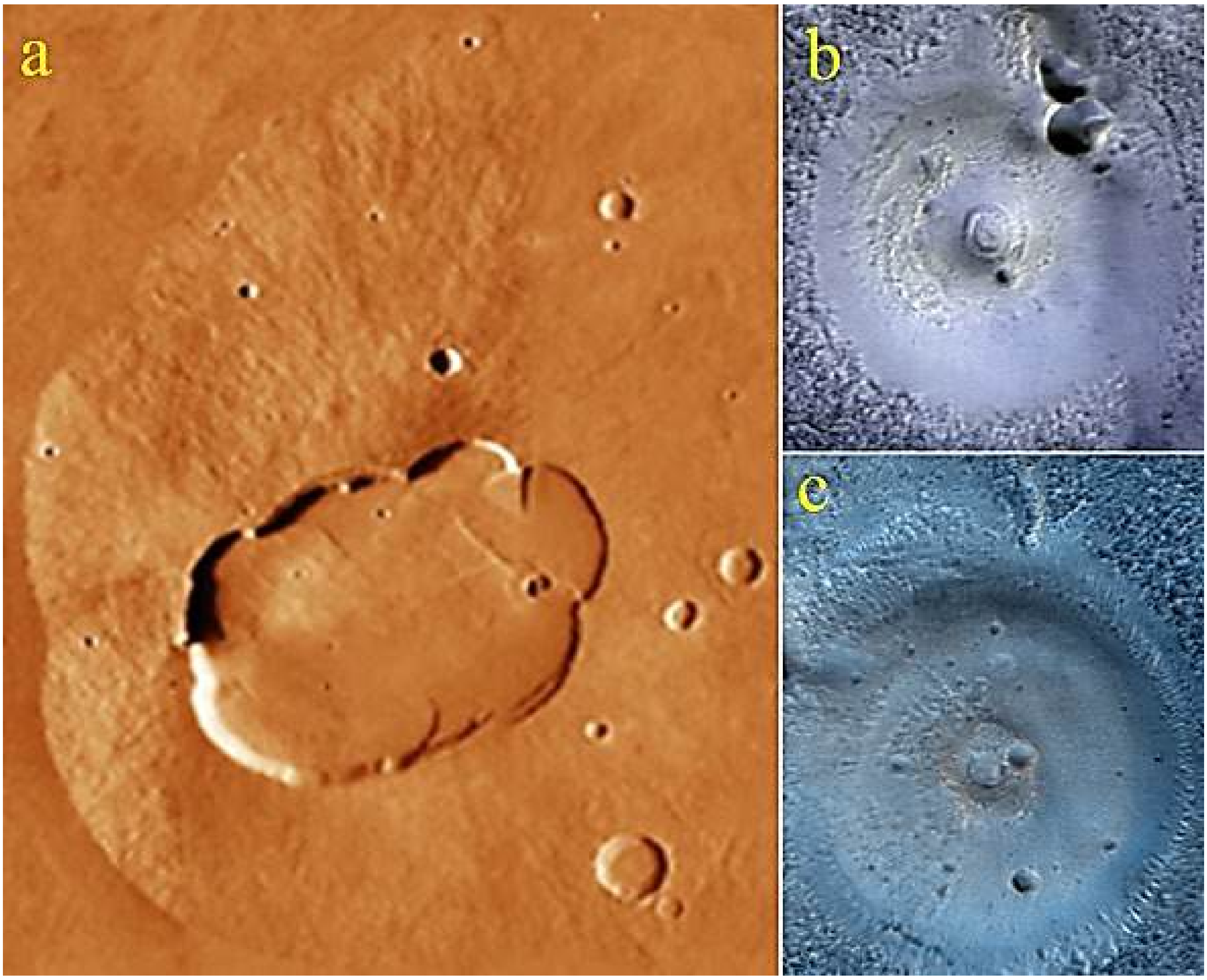

Fig. 5. a – the dome of the Alba Patera volcano (http://photojournal.jpl.nasa.gov/). b – possible mud volcanoes with a diameter of more than 100 m in the Acidalia Planitia area (http://photojournal.jpl.nasa.gov/).

It is also possible that volcanic activity on Mars continued much longer than previously thought. Updated estimates based on the number of volcanic craters in images from the "Mars Express" spacecraft showed that volcanoes could still be active only 1-20 million years ago. While until now their active activity was estimated at 500-600 million years ago. The longest volcanoes could be active in Tharsis Regio (Olympus volcano and 3 other largest volcanoes). It was even suggested that volcanic activity continues now. Therefore, for example, it is necessary to search for signs of hydrothermal activity on the planet. With the "Mars Reconnaissance Orbiter" spacecraft in the Vernal crater in the Arabia Terra region, it was first possible to register elevations similar to hydrothermal springs. They have an elliptical shape and a small height. And in their appearance, these formations are very similar to hot springs found on Earth.

Shown in Fig. 5 (b, c) elevations on Mars may be so-called mud volcanoes. Their infrared images show that during the day these hills cool faster than the surrounding rocks. Therefore, it is believed that these formations may be dried mud. And the colors of these hills are in good agreement with the assumptions that they can be formed in the presence of water [8, 13, 20, 27]. And the gas jets in which methane was found could be emissions from mud volcanoes, if only this warm mud contains microorganisms that can produce methane.

Usually, such cones were found not far from large Martian volcanoes, such as Olympus. Dried riverbeds were also found next to them. This suggested that this type of cones could be formed as a result of heating by heat from the volcano. A specific reservoir of volcanic heat could be located under a layer of water ice. And when the ice was able to evaporate, water vapor could pierce holes in the soil through which it came to the surface of the planet. If the elevations shown in Fig. 5 (b, c) are still mud volcanoes, then it is in these places that it is necessary to search for traces of microbial activity [11, 12, 16, 17, 21–23]. Amazonis Planitia is a plain in the northern equatorial region of Mars. It is quite young, with the age of rocks on the surface about 10-100 million years. Studies have shown that some of these rocks are cooled volcanic lava. However, there are no volcanoes themselves, which look like mountains with a crater in their center, in this area. Therefore, it is believed that the lava could simply have poured onto the surface through cracks in the Martian crust.

It is very interesting that numerous traces of large volcanic lava flows, which occurred here repeatedly [69], were found on the surface; moreover, the lava flowed along the same system of channels as water (or ice). Based on the study of these multilayer structures, which were formed during repeated lava eruptions, a conclusion was drawn about the possibility of volcanic activity on this planet even now. The very first studies of the planet Mars with the help of the “Opportunity” rover indicated the validity of the statement about the predominantly volcanic formation of the relief of the planet's surface. They confirmed the fact that the rover moves on soil with several sand layers with granules of almost spherical shape interspersed in it (Fig. 6, a).

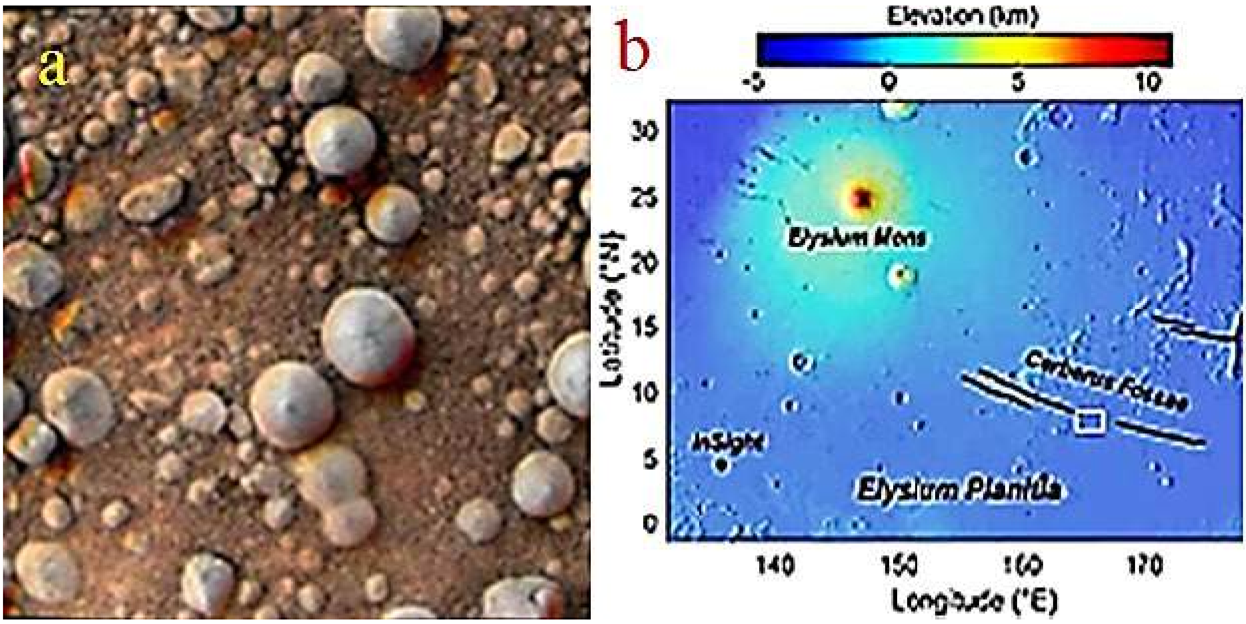

Fig. 6. a – spherical granules on Mars (http://photojournal.jpl.nasa.gov/). b – the white frame shows the region of recent volcanism and the location of the InSight lander at the bottom left (https://ostannipodii.com/data/anatoliy/images/-21-05/mars.jpg).

Such granules are clearly of volcanic origin. They are processed by jets of hot gas that came from the planet's mantle. Unlike the aqueous solutions of volcanic materials on Earth, the fluidity of mud lava on Mars could be determined by fluids of possible compositions including carbon disulfide (CS_2), carbon chloride (CCl_4), or hydrochloric anhydride (Cl_2O_7). The granules shown in this figure have a shiny surface that could be determined by the above substances. Although the final composition of the liquid components of these Martian volcanic materials will only be determined by direct chemical analysis.

Volcanism there occurred approximately 3-4 billion years ago. However, there is some evidence of fairly recent volcanic activity on Mars, in which volcanic eruptions could have occurred even in the last 50 thousand years. For example, using observations from an orbiting satellite of Mars, it was possible to find evidence of a very recent eruption in the Elysium Planitia region (Fig. 6, b). This entire volcanic region has high thermal inertia, and the soil on the surface includes pyroxene-rich material with a fairly high calcium content. It is such a soil that is symmetrically distributed around the cracks of Cerberus Fossae in the Elysium Planitia region; and it is very atypical for the predominantly aeolian deposits in this region. Similar properties are possessed by dark spots on Mercury and the Moon, which are also attributed to volcanic origin.

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