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The role of mud volcanoes in the evolution of Hecate Tholus Volcano on the surface of Mars

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Abstract

Hecate Tholus Volcano has undergone numerous changes in its history of evolution. Further, the phenomena occurring on the surface of this volcano endow us with a remarkable perspective of recent martian geological changes. In the vicinity of this volcano cone, most of the lava is covered with a thick layer of loose sediments (probably clay). The presence of such sediments at the base of the volcano cone has led to the formation of several major landslides. Moreover, liquid water flow on the volcano cone has created a myriad of radial channels. The formation of such structures on the cone of a volcano is only plausible as a result of eruption of a mud volcano from its crater. Besides, the constant discharge of mud-like materials as well as hot water from the volcano paves the way for the growth and evolution of hydrothermal organisms.

Keywords: Mars; Hecate Tholus Volcano; Mud volcano

1. Introduction

The images and topographic maps of the martian surface accessed during the last three decades have revealed copious details of features carved by the water flow on the surface of this astounding planet [1]. The existence of such structures on Hecate Tholus Volcano cone is an indicative of the diversity of locations with high potential of the presence of water on Mars' surface. The discharge of hot water and mud-like sediments from a volcano cone, undoubtedly, provides a congenial atmosphere for the growth of some resistant creatures. In addition, the study of such young sediments sheds light on certain geological and climatic changes of the planet over the last several million years.In the present article, an attempt has been made to take account of the role of mud volcanoes in the evolution of Hecate Tholus Volcano and to introduce the vicinity of inactive volcanoes of Mars as one prominent potential for life.

2. Hecate Tholus Volcano

Martian surface enjoys extensive volcanic areas. Volcanic activities in the southern highlands ceased over three billion years ago; nevertheless, the majority of young and colossal martian volcanoes, which were active during the last two billion years, lie in the northern lowlands. These volcanic centers are limited to three regions, namely, Tharsis, Elysium, and Hellas, which were all active under the influence of hotspots

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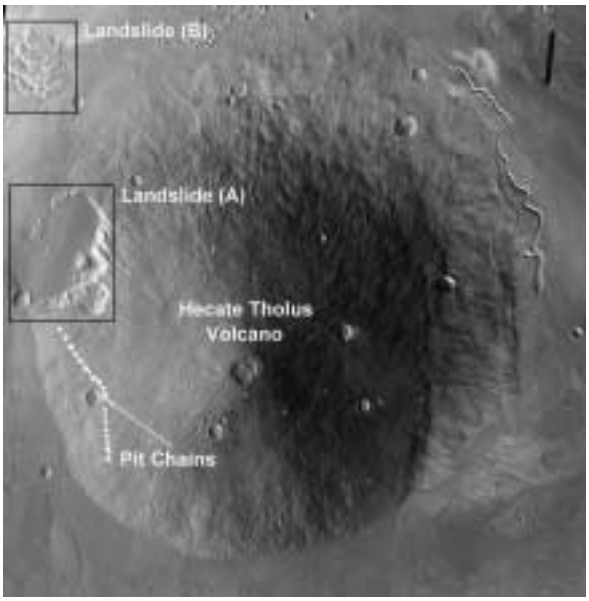

Fig. 1. The position of landslide and pit chains on Hecate Tholus Volcano. Original image from http://www.spaceref.com/news/viewsr.html?pid=13730 (*Source*: ASU THEMIS Science Team) North is at the top.

in mantle. The last volcanic activities pertaining to this region is related to lava flow on Mt. Olympius, which took place 20–200 million years ago [2].

Hecate Tholus Volcano, located at 150° East and 31.7° North, lies on the northern side of Mt. Elysium. This 5300 m-high volcano has a caldera with a diameter of 10 km and depth of 600 m (http://www.esa.int/export/SPECIALS/Mars_Express/SEMTXD2PGQD_0.html). The concentration of impact craters on the eastern side of the volcano indicates its considerable age; however, the nonexistence of impact craters on the western side indicates eruption of materials burying the impact craters of this region. High-resolution imagery of the crater of this volcano received on March 1, 2004 by Mars Express (HRSC) cameras manifests the presence of water flow on the cone of this volcano. Furthermore, due to water eruption of the volcano, the caldera rims were cut by two deep channels (Fig. 1).

3. Landslide on the slope of Hecate Tholus Volcano

Images taken by Mars Odyssey (THEMIS) have brought to light the occurrence of several major landslides in eastern and northeastern Hecate Tholus Volcano (Fig. 1). Based on the assessment conducted, the thickness of sliding materials in this region is between 200 and 300 m. Considering the fact that landslides occur mainly in fine materials (such as clay and silt) saturated with water, it seems that a considerable layer of mud-like materials has covered most parts in the vicinity of the volcano cone. Given the nonexistence of impact craters on most parts of these regions, it appears that during the recent volcanic activities, these materials erupted through the crater and were deposited as substantial masses of mud in the vicinity of the volcano.

4. Mud volcanoes

During volcanic activities, in addition to rock, lava, volcanic ash and gases, anomalous products are occasionally generated. These products, often consisting of volcanic dust particles and water, erupt from the volcano crater as liquid mud, and are called mud volcanoes. The activities of mud volcanoes typically start with several deafening explosions. Afterwards, a noticeable quantity of black and malodorous mud accompanied by scalding water and gas discharge out of the volcano crater. The boiling of water and the emission of mud cause a plentitude of mud to accumulate around the volcano. Thus, the mud-like materials cover a wide expanse of the mountain's base and a lot of grooves are created through loose mud by water flow. Among such stunning terrestrial volcanic activities, mud volcano eruption in Sicily, Jave, and Azof Sea can be named [3].

Based on high-resolution imagery taken from Hecate Tholus Volcano, it is likely that radial lines as well as the two main channels radiating from the caldera were dug as a result of water flow. On the other hand, the loose sediments of the western crater do not resemble volcanic lava. Rather, these materials are analogous to terrestrial products of mud volcanoes (Fig. 2). Accordingly, it is probable that, during recent activities of Hecate Tholus, abundant quantities of mud-like material along with boiling water burst out of the volcano and gets deposited at the mountain's base as loose sediments. These sediments, saturated with water, provide a high potential of landslide at the base of the volcano cone.

5. The formation of pit chains on western Hecate Tholus

The high-resolution imagery has revealed countless cone-shaped pit craters on the martian surface. The pit craters lack raised crater rims or erupted sediments. These cone-shaped figures bear a great resemblance to structures resulting from the collapse of loose materials

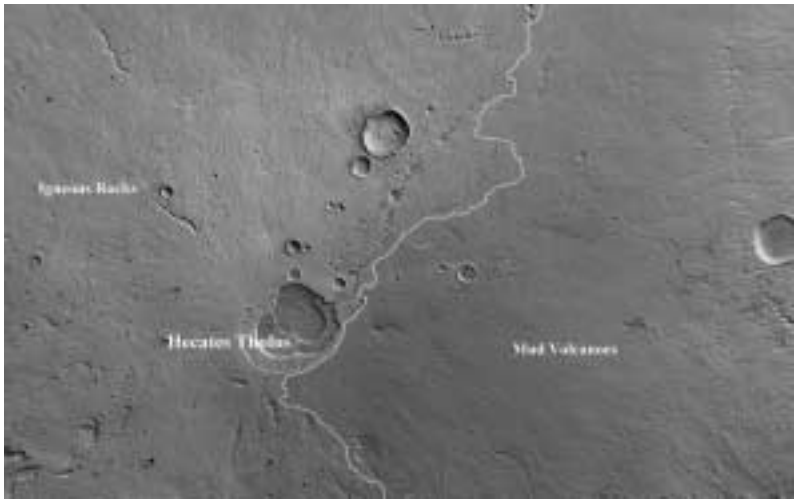

Fig. 2. The location of sediments resulting from Mud Volcano in relation with the Hecate Tholus Volcano crater. This image was taken by (HRSC). The image center is located at 150° East and 31.7°North. South is at the top. Original image from http://esamultimedia.esa.int/images/marsexpress/019-240204_1-0032_02-6-v-3595-300.jpg.

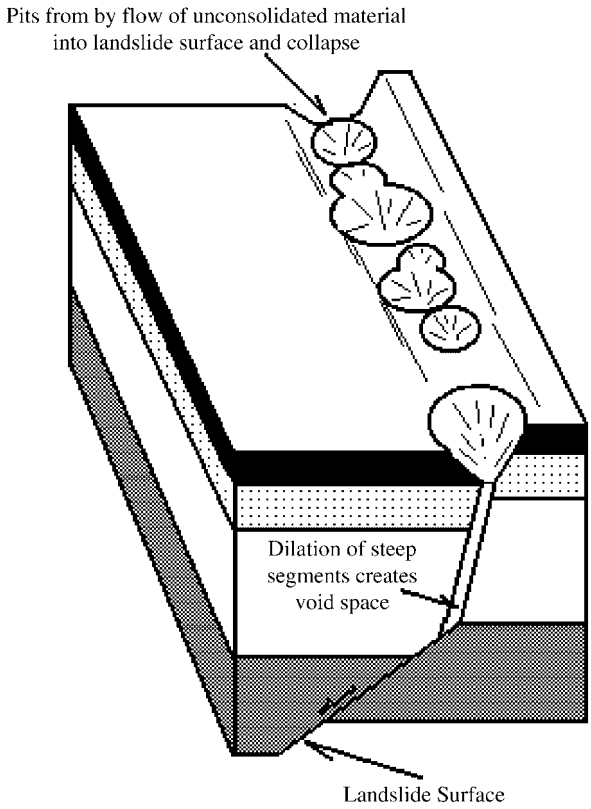

Fig. 3. A three-dimensional figure of pit chain evolution on the surface of landslide.

into the subsurface void [4]. Laboratory modeling signifies that pit chains on the red planet have formed along normal faults. Dilation of normal faults, influenced by the reduction of their slope in depth, occasions the formation of voids and collapse of loose surface sediments. Such a process leads to the formation of conical pits along normal faults [5]. The pit chains on the surface of Mars are overly similar to the pits induced by dilational fault slip in Iceland [4].

One of the most imposing pit chains lies on the western Hecate Tholus (Fig. 1). This area of volcano slope, which has formed by the products of mud volcano, has a high potential of landslide. In this area, a great many tension cracks with a northern/southern orientation on the slope have formed. The creation of tension cracks is one salient sign prior to slope fracture. Similar to normal faults, these tension cracks create voids in deep subsurface and cause upper layers to collapse and form pit chains on the surface (Fig. 3). Therefore, these arced pit chains on the western Hecate Tholus is a sign of a new landslide experiencing its primary stages of evolution.

6. Flow channels around Elysium Planitia

In Elysium Planitia, from north towards south lie three volcanoes, Hecate Tholus, Elysium Mons, and Albor. A multitude of flow channels, mainly created during the last several million years, surround this volcanic area. These channels, generally having a radial pattern, originated from three major volcano craters and, in some cases, have extended several hundreds of kilometers. Deposited sediments on the bottom of these channels demonstrate overflowing of rivers containing sheer volume of water mingled with mud. One stunning

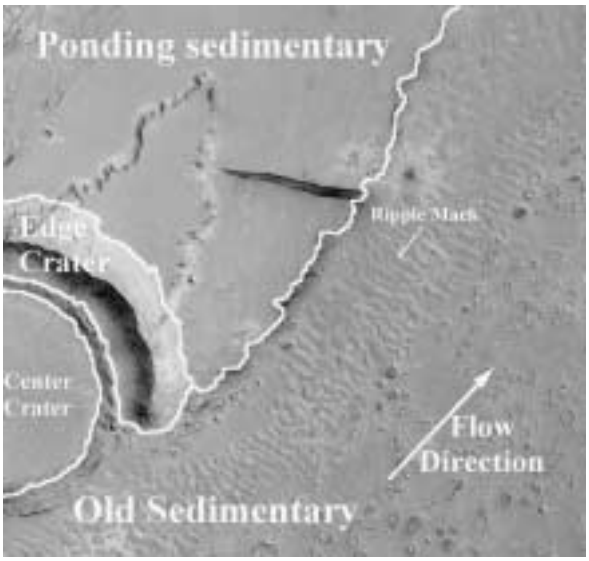

Fig. 4. Erosion caused by diluvial flows in Athabasca Vallis on the southern Alor Tholus Volcano. The image center is located at 9.7 N, 203 W. (Original image from http://www.spaceref.ca/news/viewsr.html?pid=9625.)

sample of flow channel is Athabasca Vallis, located on the south of Albor Thous Volcano (Fig. 4). Geological evidence indicates that this channel was generated by diluvial flows during the last several million years [6,7]. The sediments on the bottom of Athabasca Vallis have a hydrothermal origin being deposited on the bottom of the channel due to flowing water and mud [8]. Thus, it is likely that over several million years, major eruption of water and mud took place not only in Hecate Tholus Volcano, but also in other volcanoes in Elysium Planitia.

7. Microbiological communities near mud volcanoes

A switch in volcanic activities from lava eruption to water and mud eruption might provide an appropriate condition for microbiological communities. Such conditions can be witnessed in hot spring [9]. Such hydrothermal organisms with various metabolisms can survive in different unsuitable circumstances and exploit iron compositions as well as other existing sources of energy [10]. Therefore, it can be predicted that living organisms inside mud sediments of regions like the margin of Hecate Tholus Volcano and other volcanoes in Elysium Planitia are accessible as microbial organisms in the form of stromatolites and microfossils.

8. Conclusion

The radial channels and two conduits radiating from the caldera of Hecate Thlous Volcano have been originated by water flow. In addition, the occurrence of a number of major landslides and the formation of pit chains on the western volcano is an indicative of accumulation of a substantial volume of mud-like sediments at the base of this high volcano. These loose sediments formed during the last stages of volcanic activities due to mud volcano eruption. This manifest transformation in the quality of volcanic activities can be a sign of a new era of volcano evolution on the surface of Mars. On the other hand, it is likely that during mud and water eruption from the volcanic crater, microbiological communities inside mud-like sediments have evolved and are currently accessible as microfossils.

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