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The Mechanism of Valles Marineris Formation

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The Valles Marineris is a distinctive system of canyons on the Martian surface. Considering the lack of any drainage network and tectonic structures, this system of closed depressions has induced a bewildering condition on the planet. The evidence from new images implies that very rarely can water have any role in the formation of these colossal structures. Furthermore, regarding the lack of any tectonic processes on the surface of the planet, the only legitimate origins of the Valles Marineris are the impact of asteroids and constant blowing of wind prevailing the Martian surface for millions of years.

Based on the morphological situation dominant on the planet, it appears that Valles Marineris has been created with its center at impact craters. Due to the fact that the platforms surrounding Tharsis rise incorporate sequences of thick wind deposition and thin volcanic ashes, this area is of high potential to form canyon networks. Put another way, at the collision site of impact craters, gale-force wind have transmitted sands from soft layers and brought about wall sliding thereby forming Valles Marineris which is comprised of two deep ridges at both sides of the crater. Accordingly, Valles Marineris, influenced by incessant gale-force winds for millions of years, and in freezing atmosphere of the planet, has gradually been created.

Keywords: Mars, Valles Marineris

1. Introduction

Mariner 9 imaging, for the first time, exposed valley networks and outflow channels of the Martian surface. Moreover, the evidence coming from Viking Spacecraft, Mars Pathfinder's and Mars Global Surveyor's (MGS) Mars Orbiter Camera (MOC) revealed awe-inspiring perspectives of Martian Valles Marineris (henceforth VM).

Today, VM as a canyon system has created unique features on the south of Martian equator 8 to 10 km Deep [1]. This system stretches around 4000 km and is 50 to 100 km wide in its central zone.

The majority of prominent paradigms and models imply that the origin of VM formation on the Martian surface dates back to the time when Mars was experiencing a hot (above 273 C) and humid climate [2].

The issue of the origin of canyon formation has remained extremely controversial, however. Different researchers have attributed the determinant of canyon formation to such miscellaneous origins as water erosion or tectonic subsidence [3]. In addition, several hypotheses related to the genesis of formation of deposited layers on the canyon floor have been presented among which are wind deposition, landslides, alluvium, lake sediments, and volcanic rocks [4, 5]. Nevertheless, determining the origin of these deposits could undoubtedly shed light on the evolution of VM, as well as the geological history of Mars.

The present article, based on VM morphology, attempts to offer a novel model for the formation of these striking structures.

2. Climatic Conditions of Mars

The Martian surface, currently, is freezing and arid, and by modeling, the researchers have been striving to reconstruct the climatic conditions of early Mars- when the sun was far fainter than today. Based on principal theories, early Mars has a thick atmosphere, which brought about overwhelming greenhouse effects [6]. Near the end of heavy bombardment, this warm climate underwent fundamental changes, and by falling of global temperature to below freezing along with atmosphere devastation, a new era of Martian evolution started [7].

The collision of asteroids and comets bigger than 100 km in diameter has created over 30 huge craters on the Martian surface [8]. Such evidence is indicative of an impact era of gigantic asteroids to the Martian surface. The energy induced by such impacts has injected a sheer volume of melted particles, dust and steam into the Martian atmosphere. The humidity caused by this warm era has probably brought about heavy rainfall for several years [9]. Accordingly, erosion by such heavy rainfall has been the fundamental determinant and origin of valley networks on the surface of the planet. Some other researchers, however, contend that asteroid impacts have, to some extent, stimulated hydrothermal phenomena and formed fluvial networks. Yet, asteroid impacts could not have been the leading factor for the formation of the entire valleys. Thus, the role of impacts in producing heat over the planet should not be given a big credit [6].

The new high resolution imaging by the laser altimeter on MGS has displayed significant evidence for the flow of water across the Martian surface. One astounding finding, however, is the non-existence of valleys less than 100 m across. Lack of drainage in these valleys indicate that due to low humidity and lack of surface runoff the role of surface water and precipitation in the formation of valley networks can not be taken into serious account [7]. Additionally, based on new acquired high resolution imaging, the ocean hypothesis is without adequate evidence due to absence of any shorelines [10].

Clifford [11] asserts that Mars enjoys huge volumes of a globally interconnected aquifer system most of which were formed during the heavy bombardment. According to this hypothesis, and also considering the scarcity of evidence for Martian surface runoff, Carr [7] points out that the sudden groundwater discharge has resulted in the formation of the majority of outflow channels on the Martian surface.

Nonetheless, due to our deficient insight into the climatic condition of early Mars as well as our uncertainty about the condition of the aquifer system, it appears extremely difficult to assume that the abrupt release of aquifer has led to the formation of Martian valleys. Accordingly, even though water might have played a crucial role in the evolution of Mars [12], the perplexing conditions of water related features and climatic conditions of early Mars has yet remained controversial.

3. The Geology of Valles Marineris

Based on geological divisions, the Martian surface is divided into northern and southern hemispheres. The information acquired from the laser altimeter on MGS attests that the plains in the southern hemisphere are roughly 5 km higher that those in the northern one [7]. The southern hemisphere, with an uneven surface, encompasses a great number of craters. These craters have been originated by heavy bombardment in the early era. According to the current models, in its primary stages of evolution, Mars has been dominated by major impacts [13]. Consequently, the southern highlands are older, and the northern lowlands are younger regions of Mars. Such binary nature existing on the two hemisphere, accompanied by volcanism phenomenon in certain spots and the absence of plate tectonics at present reveal a relatively elaborate history of Mars during evolution [14].

One of the leading volcanic centers of Mars is located in Tharsis zone. The volcanic activities of such highland plains have probably been formed under the influence of plume moving upward from the mantle [14]. Surrounding Tharsis rise, a high platform with the radius of 5000 km stretches which consists of a few impact craters (Fig. 1). Provided that the number of superimposed impact craters on the Martian surface is considered as a criterion for determining the age of various parts of the planet, this platform must have been formed after the heavy bombardment. The VM is located on the east of this even platform and depicts a gripping display of sedimentary layers in the platform. Based on the information acquired from TES spectrometry the leading minerals of VM geological units are pyroxenes, plagioclase, olivine, quartz and calcite [15]. Such a combination, undoubtedly, involves an extensive range of rocks, whose origin could be explored by other rock characteristics including morphology and resistance against erosion.

Currently, high resolution imaging, providing us with circumstances similar to the study of air/photographs, has revealed a new perspective of the layers on the floor of VM. The findings from the study of images indicate that, on the whole, VM comprises two major units. The first one involves very thick and loose layers which are probably made up of wind deposition and the other consists of thin inter-beds of hard sediments probably made up of volcanic ashes. The low resistance of sand layers against erosion together with the high resistance difference between the two major units have led to the formation of a step topography along with small protrusions on the canyon's floor (Fig. 2). Probably, during extensive volcanic activities of Ascraeus, Olympus, Arsia, and Pavonis, the wind deposition as well as volcanic ashes formed horizontal layers of a vast platform around Tharsis rise.

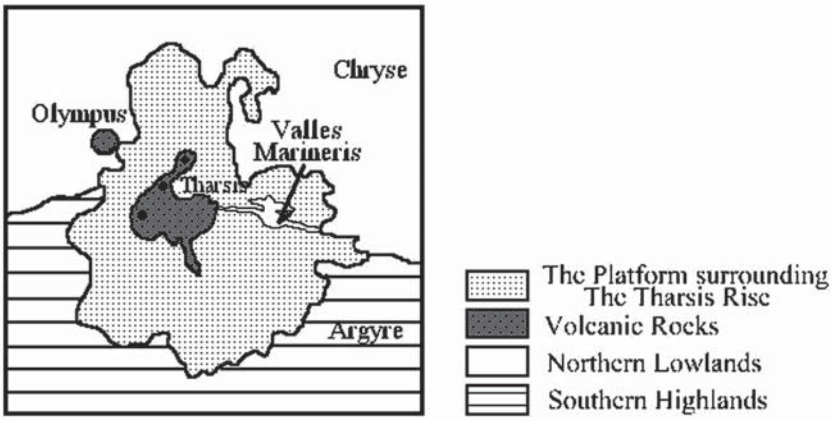

Fig. 1 The geological map of Valles Marineris and the platform surrounding the Tharsis rise.

Fig. 2. Smaller ripples on the floor of Valles Marineris and the linear rises remaining at the bottom of valleys. No. MOC2-232, 22 May 2000. (www.msss.com/mars_images/moc/may_2000/ridges/)

Due to the weak gravity of Mars, after volcanic eruption the scattered particles in the atmosphere gradually landed on the Martian surface during several weeks. The slow descent of particles, the freezing atmosphere of the planet, together with the gale-force wind have caused the volcanic particles to lose their temperature and descend on the surface of the planet as cold dust particles like wind deposition. Such particular circumstances have forced the volcanic particles of dust to scatter over long distances and, as layers of loose sands, accumulate over each other. At the end of the volcanic activities era, due to an increase in the temperature of the lower atmosphere, the hot particles have reached the ground surface and created layers of hard volcanic ashes. Therefore, during several eras of volcanic activities in Tharsis zone, a sequence of loose layers and hard layers has been deposited as an even platform.

After the formation of this miscellany, due to the absence of tectonic activities on the Martian surface, all the layers have remained virgin, and today VM has exposed a striking panorama of these layers.

4. The Role of Wind in Erosion of Valles Marineris

Undeniably, the foremost cause of erosion on the Martian surface is the continuous and gale-force wind dominating the planet over millions of years. Taking account of the difference between the present and the earlier conditions of the planet, probably at the end of the heavy bombardment, the constant and permanent blowing of wind all over the red planet has brought about a more severe erosion [7].

Today, the situation of sand dunes and smaller ripples being formed on the floor of the VM canyon system can specify the direction of wind motion over canyon valleys. The evidence witnessed in various sections of the VM indicates a direction from east toward west (Fig. 2). Furthermore, according to the new imaging, the floor of the valleys is mostly even. Compared with the terrestrial models, such conditions are not normally induced by the movement of flood.

Therefore, due to erosion by wind inside the VM, thick layers of loose sediment (probably Loess) have been eroded, and in the next stage, the upper harder layers (probably volcanic ashes) have slid. Concerning the fact that considerable volumes of sliding materials are made up of sand sediments, sliding masses have moved toward the floor of the valley like the flow of an avalanche (Fig. 3). Since then, again, wind has started eroding the sliding mass, and during thousands of years, it has paved the way for the succeeding slide. As depicted in Section A of fig. 3, induced by wind erosion, a window has been created over the sliding sediments and the older (dark) wind depositions have appeared. The emergence of such eroded windows over the sliding masses implies that the composition of landslides is loose sediment easily drifted by wind. These materials are definitely made up of tiny sands which exist as thick sequences of Loess in the canyon valley's walls. Thus, the repetition of wind-induced erosion process and landslide has brought about widening of canyon valleys over millions of years, and has controlled the present profile of valleys. During the wind-induced erosion, parts of the valley floor with higher resistance have remained as a miscellany of linear protrusions gradually being affected by erosion itself (Fig. 2). Such a process creates step topography on the walls of the valleys. But dimensions and the shape of the steps depend upon the thickness of loose layers. Samples of such step structures can be observed on all walls of VM.

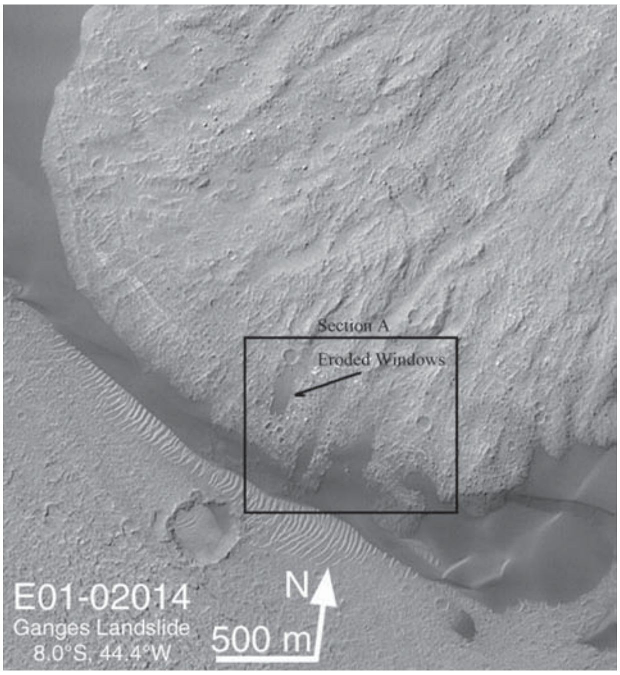

Fig. 3 A picture of landslide "Ganges" and the eroding windows afflicted by incessant winds. No. MOC2-295, 30 October 2001. (www.msss.com/mars_images/moc/10_30_10_releases/ganges/)

Consequently, continuous blowing of wind must have been the foremost determinant of erosion in the VM, and has created such distinctive structures. Nevertheless, rock material and the geometrical situation of the sediments covering this part of the planet have also paved the way for the creation of such structures.

5. Evolution Stages of the Valles Marineris

Many authors have attempted to compare and contrast the VM appearing on Mars as colossal structures to certain terrestrial features such as North American Grand Canyons, the East African rift, and the mid-ocean ridges. In most cases, the formation of these exceptional structures has been attributed to the tectonic subsidence [16]. Yet, no evidence for the occurance of tectonic activities on the Martian surface can be observed. Moreover, no evidence has yet been obtained for the existence of tectonic grabens in the walls of the VM. Generally, the most immediately observable structures in the VM are step structures, landslide, and eroded structures induced by the wind motion.

Morphologically, the VM is characterized as deep valleys with an eastern-western orientation and usually with a circular form in the central zone (Fig. 4). This circular section displays the position of an impact crater in all young canyon valleys, such as Tithonium. Accordingly, it can be hypothesized that the emergence of every canyon has been preceded by the collision of a huge asteroid. Further, based upon the newly acquired maps of altitudinal situation of canyons, the circular section appears to be the deepest point of the canyon, and the more we approach either end of the canyon valleys, the less is the depth of the valleys (www.the-planet-mars.com/valles-marineris/valles-marineris-canyon.html).

In sum, taking account of geological conditions, morphology, and the significant role of the incessant winds over the Martian surface, we can classify the VM formation into three stages as follow:

1. Initially, a huge asteroid impact on the platform has brought about the formation of an impact crater and the crushing of resistance layers.
2. Following the formation of an impact crater, both eastern and western sides of the crater, afflicted by ceaseless eastern-western wind, have been destroyed and a miscellany of ridges with an eastern-western orientation have been created on both sides of the crater (Section A and B in Fig. 4). Considering the fact that the deposited sediments in the platform contain thick layers of loose wind deposition and thin inter-beds of hard sediments, the breakage of hard upper layers has led to severe wind-induced erosion in sand layers.
3. The erosion induced by incessant winds accompanied by transferring sands from loose layers must have been followed by landslide and widening of the VM. In this way, afflicted by wind-induced erosion, without the presence of water, and in the freezing condition of Mars, the ridges have gradually been deepening and widening for millions of years.

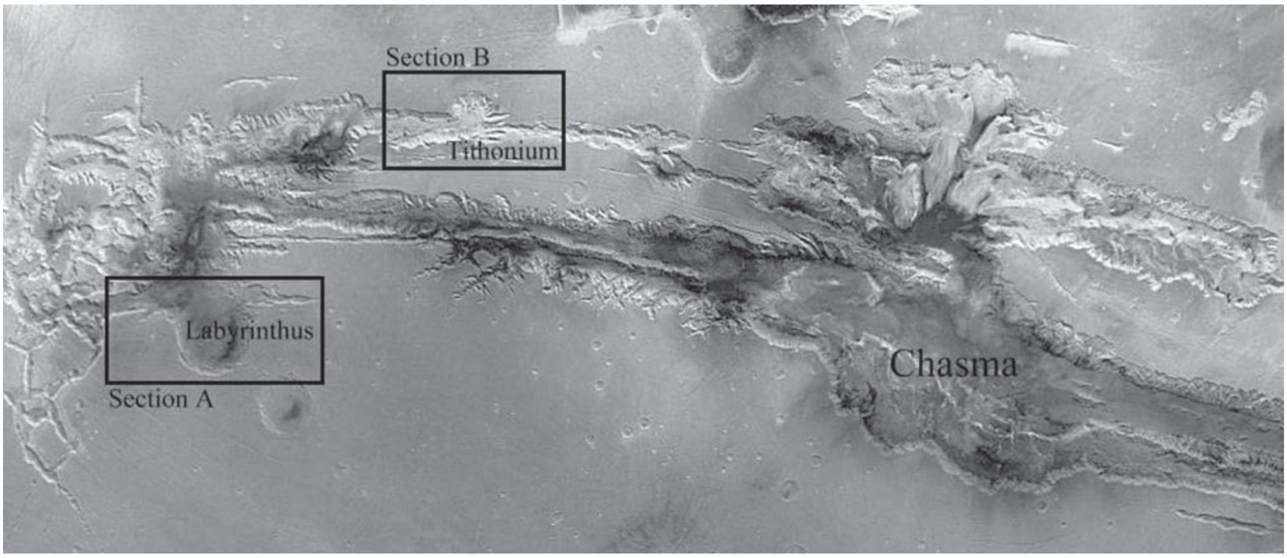

Fig. 4 A picture of Valles Marineris on the south of the Martian equator.
(http://pds.jpl.nasa.gov/planets/images/full/mars/marscany.jpg)

Having accepted this mechanism, the VM could be classified according to the era of impact crater formation, the shape of the crater and the depth of canyon valleys. As a result, the Lobyrinthus area, having small ridges adjacent to the central crater, is experiencing the birth of a canyon. In contrast, the Tithonium area characterized by shallow valleys and a complete central crater is in its young stage, whereas the Grand Canyon Chasma is depicting the old stage of a canyon on the Martian surface (Fig. 4). By determining the time of impact crater formation, one can find out the speed of VM formation. No doubt that the composition material of other areas on Mars, which, unlike the platform area, is not made up of loose sediments, has not provided the planet with the opportunity of the formation of such structures in other parts of the planet.

6. Conclusion

The evidence obtained from the new imaging implies that the role of water in the formation of the Martian canyon valleys has been far from significant. Moreover, the little evidence connected with the climatic conditions of the early Mars can hardly prove the possibility of reconstructing the morphological features based upon the former climate changes. Nonetheless, the two real causes of erosion on the Martian surface have been incessant winds and asteroid impact. These two elements have been active in all Martian evolution stages, without the presence of water and in the planet's freezing climate. The concurrence of the two erosion factors in the VM, comprising loose and erodible sediments, has led to the formation of immense valleys on the Martian surface. Consequently, the circumstances of the canyon valleys formation indicate that terrestrial structures similar to those of other planets' might have been created by different mechanisms.

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