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FRACTAL NATURE OF MARTIAN TERRAIN

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Abstract

Fractal analysis is performed on the topography to investigate the terrain of the planet Mars. Several hypsometry layers and areal analysis revealed the diversity of the Northern and Southern hemispheres – the first one dominated by basins, the second by mountains. The calculated fractal dimensions (FD) are a simple measure of the fragmentation of the determined layers. The analysis of the values of those dimensions reveals similarities and differences between the divided hypsometric layers. The results obtained give a possibility to announce a hypothesis of the domination of external factors in the shaping role of marsodynamics in the formation of the terrain, both in the past geological times and in recent times.

Introduction

Mars is one of the small worlds within the Solar System, but at the same time, it is one of the most mysterious. The Martian topography is extremely diverse, with the hypsometry ranging from -7800 m to +21,000 m. (Fig. 1) Mars is distinguished by landforms that have no analogue on Earth, from prominent impact craters to towering extinct volcanoes. These features of Mars make it interesting for research by representatives of various scientific disciplines. One such unifying multidisciplinary approach is fractal analysis. Recently, representatives of various sciences have successfully applied the fractal approach to the analysis of the Martian topography [1], [2], [3], [4], [5], etc., drainage basins [6], local plateau landforms [7], impact craters [8] and gravitational field [4]. All these investigations revealed different aspects of marsodynamics and discussed the problems of the primary influence of the creation of the planet and the following modifications of the topography by surface forces acting over the Martian crust.

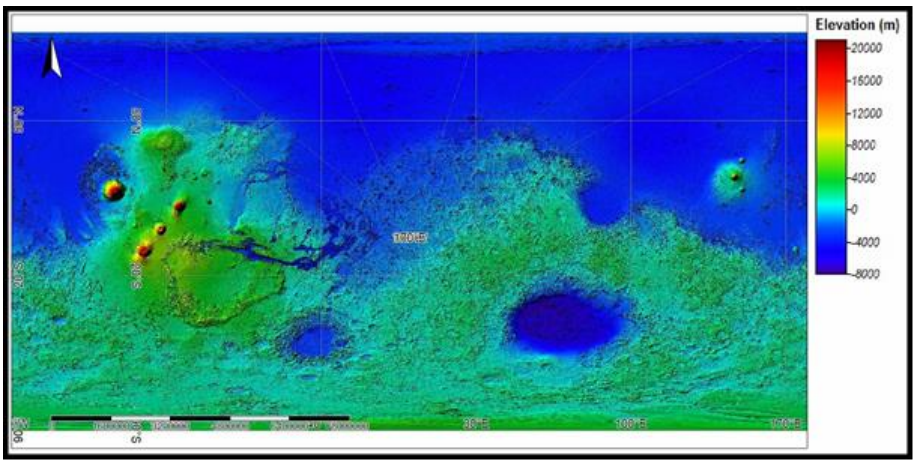


Fig. 1. Digital Elevation Model (DEM) of Martian topography

This research shows the results of fractal analysis of Martian topography. For this purpose, the terrain of Mars is divided into four hypsometric classes, Fig. 2: basins (-7800 m – 0 m), lowlands (0 m - 200 m), hilly lands (200 m - 600 m), and mountain lands (600 m – 21 000 m).

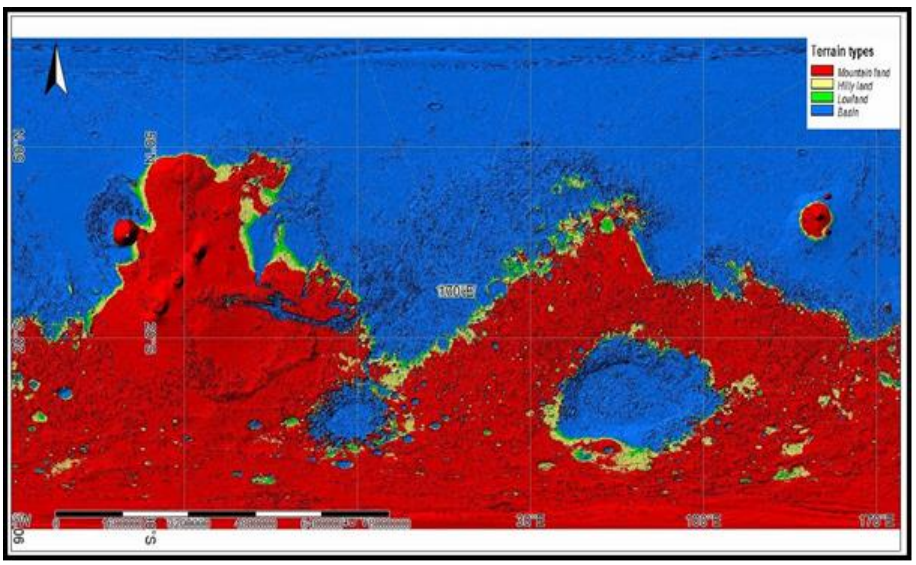


Fig. 2. Classified terrain map of Mars

The obtained results and determined fractal dimensions (FD) of the conducted research clearly confirm the fractal geometry of the topography of Mars and provide prerequisites for various new interpretations and hypotheses.

Methods and data

In this study, the FD of Martian topography is calculated using the radial method. In this approach, each point of the investigated pattern is surrounded by a small square (or circle) window. Only one counting point is considered, located anywhere in the investigated pattern (most often at the center of the pattern). A counting window is drawn around the counting point. Its size grows at each iteration step r_i. The number of points N_i within the window is counted. The shape of the counting window is a square for raster data and a circle for vector data, Fig. 3.

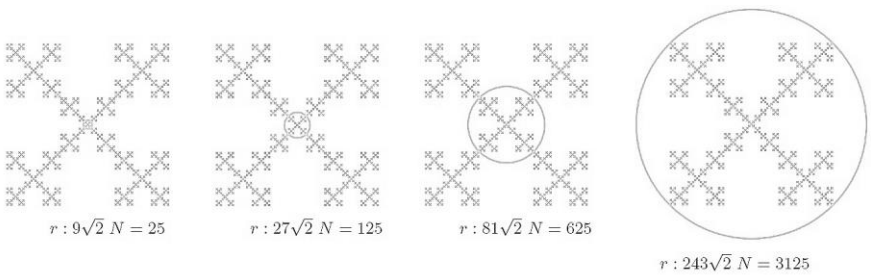


Fig. 3. Estimation of fractal dimension using the radial method

Data and software

The topography analysis of Mars was performed using a digital elevation model (DEM) based on data from the Mars Orbiter Laser Altimeter (MOLA) [9], an instrument on NASA's Mars Global Surveyor (MGS) spacecraft [10]. The elevation data is available in GeoTIFF format and has a resolution of 463 m per pixel.

The topography analysis has been performed using free Geographic Information System (GIS) – SAGA-GIS [11]. The fractal analysis is performed using Fractalyse 3.0 software [12].

Results and discussion

The table of the percentage distribution of the four hypsometric classes (Table 1) shows the domination of the Basins and Mountain lands, accounting for about 95%. The dominance of these morphology units is probably due to the combination of external and internal factors – i.e., the initial formation of the planet and the following actions of the marsodynamics. (The impact meteoritic craters and volcanoes are not presented as separate units). Further marsodynamics shaped the

formatted morphology, adding mountains and volcanoes. The following erosion transformed the landforms – eroding mountains and producing masses transported to the lowlands. The smaller sizes of lowlands and hilly lands are due to the active marsodynamics and are developed mainly around the mountain lands.

Table 1. Mars's areal terrain types percentage distribution

Terrain type	Distribution (%)
Basins (-7800 m – 0 m)	51.51
Lowland (0 m – 200 m)	1.32
Hilly land (200 m – 600 m)	3.48
Mountain land (600 m – 21 000 m)	43.68

Fractal analysis of Martian topography only on positive and negative landforms is presented initially in Fig. 4.

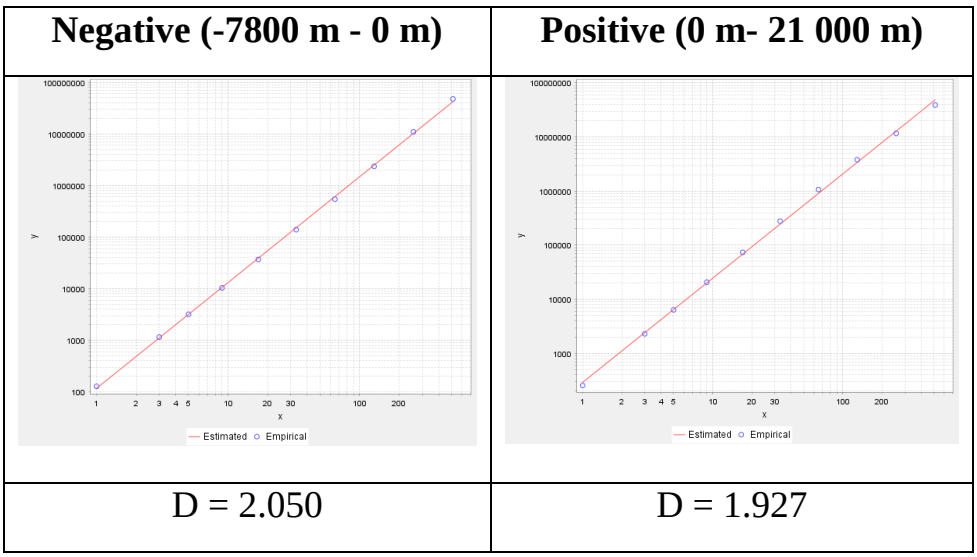


Fig. 4. Fractal dimensions of the positive and negative areal landforms of Mars – empirical values (dots) and estimated approximation (line)

There are two general classes of landforms: negative (–7800 m – 0 m) and positive (0 m – 21 000 m), including the highest volcano in the solar system - Mount Olympus.

The fractal dimensions are different but close as numbers. It means consistency in the fractal distribution, which is why the more detailed analysis was performed further on, covering all four hypsometric classes.

The results of Martian detailed fractal terrain analysis are presented as follows: the distributions for the distinguished terrain classes, the empirical and estimated distributions, and the fractal dimensions for each of them. An interpretation of the obtained results is made further.

Graphical fractal analysis of Martian topography by four classes:

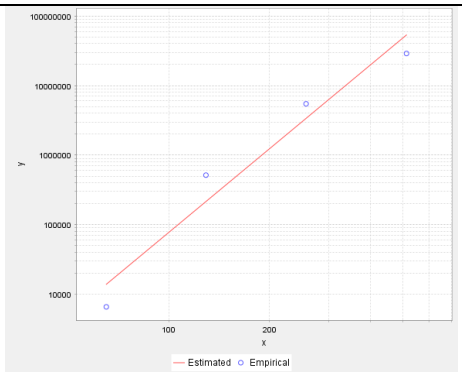
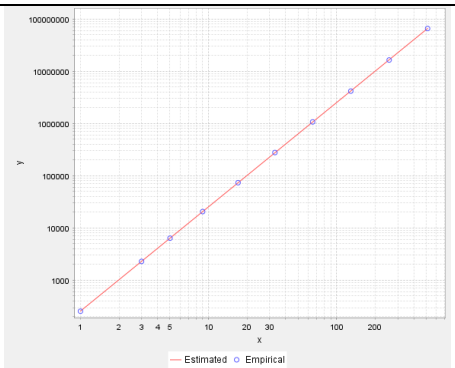
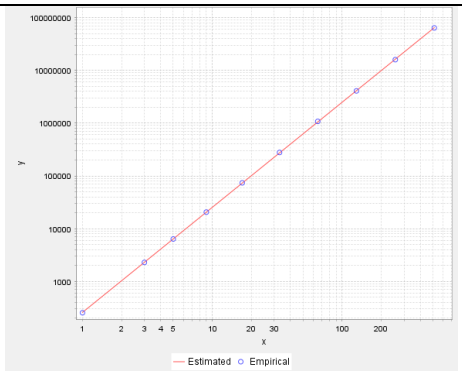
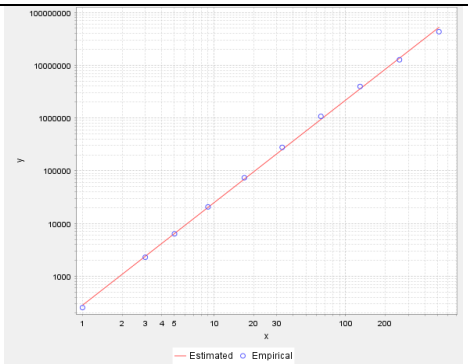
Basins (-7800 m – 0 m)	**Lowlands (0 m- 200 m)**
	
D = 2.991	D = 1.996
Hilly lands (200 m- 600 m)	**Mountain lands (600 m – 21 000 m)**
	
D = 1.990	D = 1.942

Fig. 5. Fractal dimensions calculated for the four hypsometric classes

At first, the obtained results confirm the fractal nature of the Martian topography. As can be seen, the fractal dimension (D) varies from 1.942 to 2.991 for the individual terrain categories. The negative landforms represented here by the basins are distinguished by the highest values of fractal dimension (D = 2.991). It is normal for them to have highly non-linear behaviors due to the fact that many of the negative landforms have an impact origin, and over the course of its geological history, Mars has been subjected to intense asteroid bombardment. On the other hand, according to the results, it is evident that the positive landforms on Mars are the product of tectonic processes with a distinctly fractal nature. This makes Mars very similar to the Earth.

Special focus is targeted at the fractality of the Northern and Southern hemispheres of Mars. As mentioned above, the Northern one is dominated by negative forms and the Southern one by positive forms, Table 2.

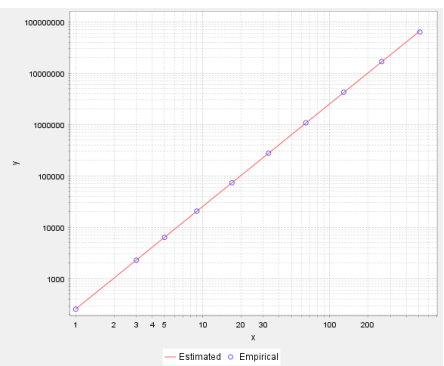
Table 2. Fractal dimensions of the North and South hemispheres of Mars

Mars hemisphere	Positive landforms, [areal %]	Negative landforms, [areal %]	Fractal dimension (D positive)	Fractal dimension (D negative)
Northern	13,27	86,73	1,994	0,458
Southern	83,54	16,46	3,009	1,974

Mars hemisphere analysis

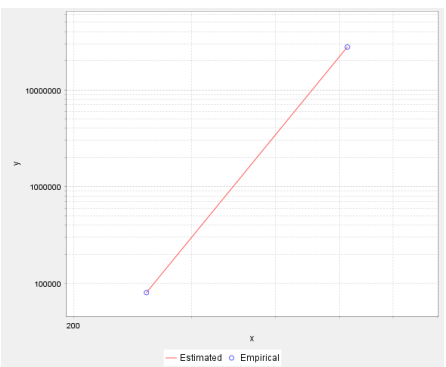
Northern hemisphere

Positive (0 m – 21 149 m)



D = 1.994

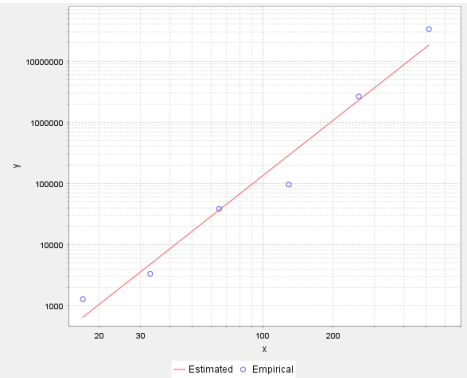
Negative (–7017 m – 0 m)



D = 0.458

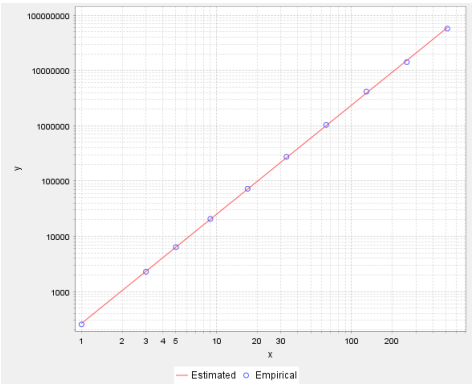
Southern hemisphere

Positive (0 m – 17 642 m)



D = 3.009

Negative (–8112 m – 0 m)



D = 1.974

The specifics of the terrain peculiarities show that both hemispheres have very similar positive/negative fractal dimensions (1.994 and 1.974) of the dominant landform areas and completely different negative/positive fractal dimensions (respectively 0.458 and 3.009) for the minor areal percentage. This could be interpreted as meaning that both hemispheres in major areas have been under similar acting forces of the marsodynamis, practically independent of the distribution of negative/positive terrain classes.

Conclusion

The obtained results of the Mars topography fractal analysis show the clear fractal structure of the spatial distribution of hypsometric belts and topography types within the terrain of the Red planet. The distribution of the four main topographic classes within the planet Mars (basins, lowlands, hilly lands, and mountain lands) in altitude is investigated. The fractal dimensions established are used for analysis of the morphology of the Martian surface terrain. A new hypothesis about the effects of marsodynamics in both directions – acting internal forces (during the initial stage of the planet formation and modification effects of the external factors like atmosphere (and might be hydrosphere) producing erosion and deposition of some masses during the more recent geological times. Further investigations follow for clarification and verification of the results obtained.

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ФРАКТАЛНА ПРИРОДА НА РЕЛЕФА НА МАРС

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Резюме

Направен е фрактален анализ върху топографията на планетата Марс за изследване на нейната повърхност. Няколкото хипсометрични слоя и площният анализ разкриват разнообразието на Северното и Южното

полукълбо – първото, доминирано от низини, второто – от планини. Изчислените фрактални размерности (FD) са проста мярка за фрагментацията на определените слоеве. Анализът на стойностите на тези размерности разкрива приликите и отликите на разграничените хипсометрични слоеве. Получените резултати дават възможност да се предложи хипотеза за доминиране на външните фактори за формиращата роля на марсодинамиката върху формирането на терена – както в миналите геоложки времена, така и в по-съвременните.