Topography Based Surface Analysis and Morphological Correlation at the Northern Plains of Mars

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Abstract. Topography based surface analysis and morphology correlation for the northern hemisphere of Mars – The topographic analysis of the Martian surface might help to understand basic geomorphological connections and improve our understanding in the surface features of the Earth too. In this work we correlated the statistical topographic parameters and the remote sensed image based appearance of various locations along a meridional stripe at the northern hemisphere of Mars. The topographic location of nearly horizontal plains suggests that the erosion and re-deposition was not effective enough to transport the sediments at the topographic lowerst point at 50 km distance scale. Great difference could be identified between the topographic height distribution pattern of different analyzed terrains, suggesting different variability and complexity in the range in surface feature types there. Terrains resembling the pediment-like structures also could be at the analyzed terrains on Mars, but their firm identification requires more detailed analysis. The statistical based topography analysis could give useful input for detailed surface research in geomorphology.

Keywords: topography, geomorphology, Mars, GIS

1. Introduction

The understanding of the Earth surface processes could be improved by the analysis of other planets too. During the analysis of geomorphology of other planetary bodies remote sensed data plays critical role. Below a Hungarian research project’s first results are summarized that is being run at the Research Center for Astronomy and Earth Sciences, and which is connected to an international project at the International Space Science Institute in Switzerland “Mapping of the northern hemisphere of Mars”. In this research the northern plains of Mars is analyzed from the edge of the polar cap to the highland-lowland boundary close to the equator (Hargitai 2008).

The aim is to identify how much results from the topographic data with roughly 200 m horizontal resolution could be correlated to imaging results. Special emphasis was given to simple statistical analysis of the topography, comparison to knowledge and experience from the Earth in order to improve automated topography analysis on Mars to gain results in geomorphology. Automated topography analysis accelerates much the identification and separation of surface units with basic topographic characteristics – similar analysis is being carried out for the Earth recently as digital terrain analysis (Wilson and Gallant 2000; Li et al. 2009; Florinsky I. 2012) for tectonic (Frisch, 1997, Woldai et al., 2000), hydrological (Moore et al. 1991) and other structures, similar analysis might give results on Mars too (Kenny et al. 2008.).

2. Materials and Methods

During the work so-called CTX (Context Camera) images recorded by the Mars Reconnaissance Orbiter probe were used, which were acquired between 0.5–0.7 micrometer, covering 30 km wide stripes at 6 m/pixel resolution HRSC (High Resolution Stereo Camera) images of the Mars Express probe (Chicarro et al. 2004), acquired between 0.4–0.9 micrometer with 20 m maximal spatial resolution covering 10 km wide stripes. The topographic data acquired by the MOLA (Mars Orbiter Laser Altimeter) onboard Mars Global Surveyor probe was used (Smith et al. 1999), which has spatial resolution between 100-300 m horizontally and 0.4 m vertically.

For the statistical analysis of the topography ArcGIS 10 Spatial and 3D Analyst software packages were used, and the implemented topography analysis tools mainly slope and range calculator algorithms, and other classification tools were applied. We analyzed roughly 40 km diameter target areas. For the comparison the topography of the Earth Shuttle Radar Topography Mission (SRTM) data was used with 90 m horizontal resolution (Rabus et al. 2003). The slope was determined for a given pixel as the largest height difference between that pixel and the surrounding pixels, and was calculated as slope angle using the distance of the two neighboring pixels’ center. The range values were calculated for 5x5 pixel (1-2 km wide) matrixes, taking the difference between the largest and the smallest height data.

2.1. Target area

The analyzed area was a meridional stripe at the northern hemisphere of Mars along the latitude 180° which width changed between 200 and 800 km. The relatively homogeneous terrain made it an ideal target to analyze zonal, latitude dependent surface structures. The location of the surveyed stripe can be seen in Figure 1. where ellipses mark the analyzed locations at different latitudes.

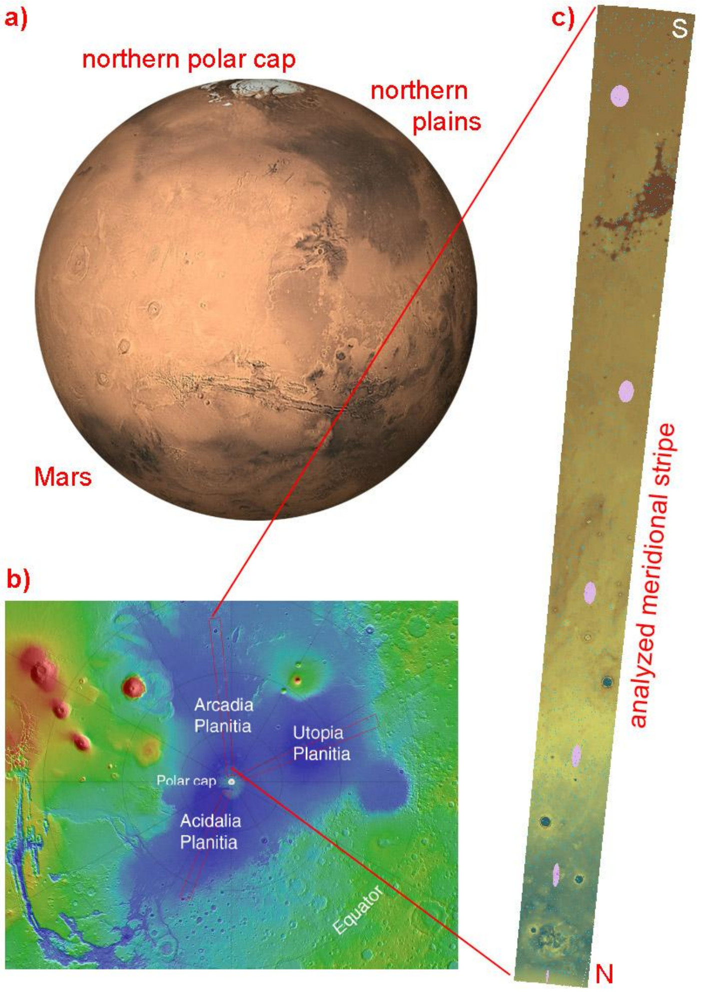

Figure 1. The location of the target area on Mars with the globe of Mars (a), the northern hemisphere in polar projection (b), and the analyzed meridional stripe with the locations of the 6 analyzed area.

3. Results

The numerical parameters of the analyzed areas can be seen in Table 1, where the third columns showed weighted averages according to the small differences in area between the different analyzed locations. To compare the morphological appearance of different structures/features, and topography can be seen in Figure 2. where different rows are for the six analyzed area and different columns are for different data types.

Id. no.	6	5	4	3	2	1
Average height (m)	-4649	-4664	-4379	-4095	-4032	-3923
Weighted average height (m)	-4632	-4755	-4415	-4153	-4032	-3923
Min. height (m)	-4775	-4875	-4477	-4220	-4075	-3935
Max. height (m)	-4522	-4375	-4276	-3927	-3984	-3910
Range (m)	253	500	201	293	91	25
Sd. of elevation	56.6	70.9	30.8	33.3	8.6	4.1
Max. slope angle (°)	2.5	12.0	3.0	6.0	2.5	1.0
Weighted average slope angle (°)	0.52	1.09	0.36	0.54	0.31	0.25
Number of data points	7091	21479	19807	17705	15542	12281

Table 1. Summary of numerical results. standard deviation

It is important to note that at the 6. area (first column in Table 1) a circumpolar dune field can be seen. The areas of 4th and 5th locations are relatively undulating, composed of several small caters and peaks, which might be of volcanic or pingo-like origin (Sakimoto et al. 2001 Sánchez-Bayton et al. 2011). The origin of the almost linear structures run vertically on the image is unknown, possibly they formed by some lava related movement, but several authors suppose that they formed by the help of ancient ice sheet at the area. While the almost horizontal striping in the 5th column show the characteristic tracks of dust devils that clear the bright surface dust cover along their tracks (Balme and Greeley 2006). Plains dominate at the 2nd and 1st area, especially at the 1st the result of topography smoothing infill is obvious. The origin of this later process is also questionable, might be related to sedimentary process but also could be produced by low viscosity lava flow (Fuller and Head 2002).

Figure 2. shows examples on the correlation between topography and surface morphology, where the height distribution is visible on the left in diagrams, toward the right the target area with shadow based height visualize

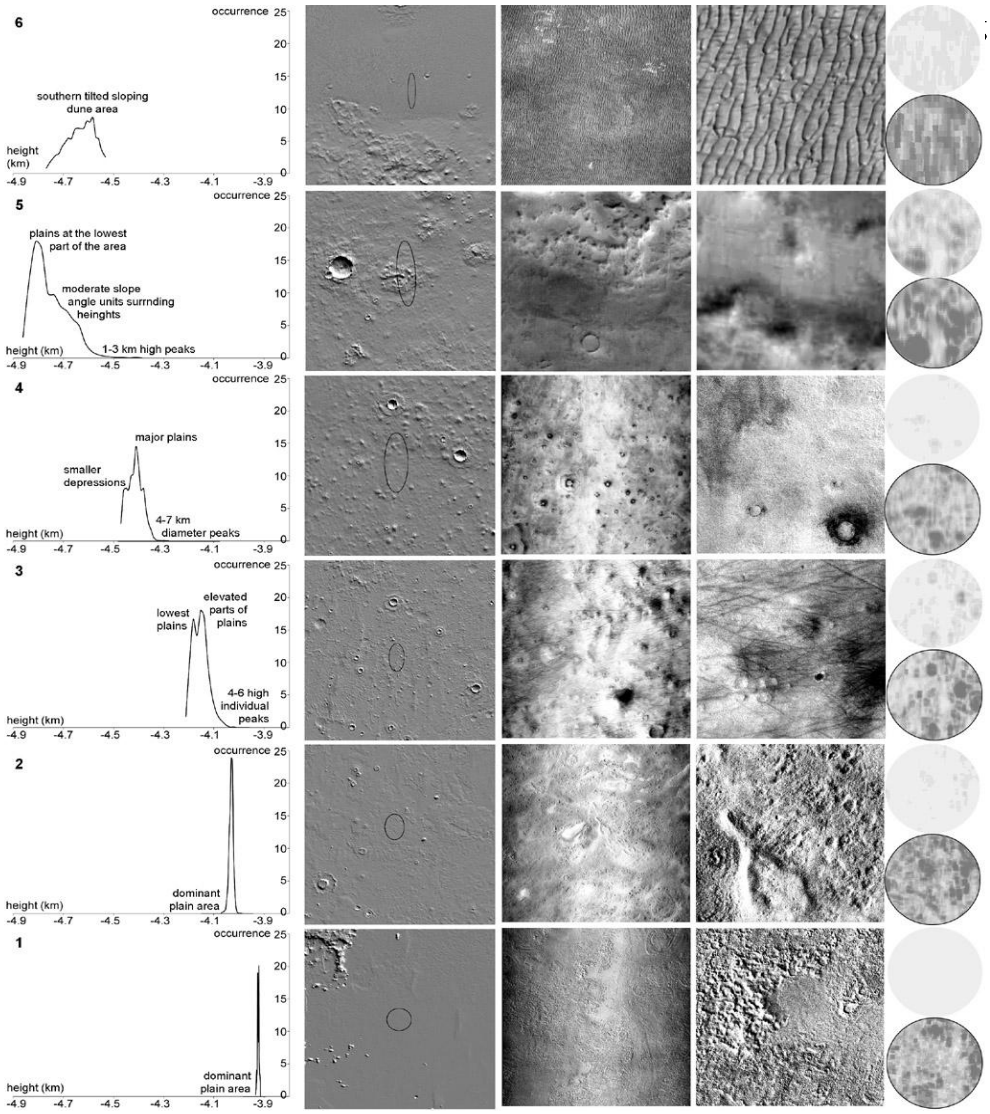

Figure 2. Example images of the different analyzed areas (different rows), indicating their height distribution histogram (1. column), general view of their topography with shading using MOLA data (2. column), characteristic section of 30x30 km (3. column), and 5x5 km (4. column) unit using CTX images. The rightmost column shows the distribution of range values (shading) calculating with 5x5 pixel moving matrix with two type of image scaling: the brighter circles show the distribution with unified with 20 m vertical spacing, while the darker (lower) circles surrounded with black arc show the distribution with values stretched to the given range of pixel values (where darker color mark the larger range values)

We grouped to the most important findings into three categories below, comparing the results gained analyzing both different parameters and different areas:

Numerical values:

- Neither the standard deviation of the height intervals, nor the absolute height values correlated with the absolute height, demonstrating that at the surveyed meridional stripe no global scale surface smoothing effect happened. Thus during the surface alterations not those terrains become more smooth (e.g. covered with more deposit), which are deeper – but the smoothing effect was regional or local scale.
- The smallest height range can be seen at the 1. area where sedimentary process or low viscosity basaltic lava covered the area. Taking only the width of the total height differences at any given area there is no evident correlation with this value and the occurrence of the observable sedimentary features there. But occasionally (especially at the 1. and partly at the 2. area) this data might point to the importance of sedimentary processes there in “lucky cases”.
- Although a given area, for example the 1. and the 6. might show similar smooth appearance on MOLA based topography and optical satellite images, the 6. shows much larger height range and a wider height interval of values because of it is tilted.
- The narrow range of height values coincide with optically smooth looking terrain at the middle column analyzing at 0.5–1.0 km resolution, while in the 4th column at 10–30 m resolution image and lighting based appearance is smooth regardless the shape of the histogram.

Shape of histograms:

- Elevated surface areas, which usually represent only small part of the analyzed terrains (flattening right end of the curves at the 3., 4. and 5. areas) represent scattered small heights, mostly peaks that might formed by volcanic or related activity (Sakimoto et al. 2001), while similar features can not be seen in the 2. and 6. areas both at the height distribution and at the images.
- The shape of the hypsographic curve resembles most to the Gaussian in the case of the 6th area, while the absolute height difference is substantial: 256 m. Here smooth plains are tilted relatively to the horizontal plane, confirmed by the optical image analysis, showing dune covered surface.

- There are no small peaks at the 6th area suggesting very homogeneous terrain, in agreement with the images that show dune coverage at the whole area.
- Terrains with several maximum at the height distribution curves represent more complex terrain and related geological history (3., 4., 5. areas) – while the distribution showing only one peak represent cases where only one dominant surface modification process worked and changed the surface. This simple statement is important as it demonstrates this method helps if someone searches for terrains on the planet where several different geomorphological agents worked together on the same terrain.
- The large peaks on the histograms of the 1. column represent characteristic topographic levels. These levels often coincide with sedimentary infilled terrains, especially at the 5th area. In the cases of the 1, and 2. areas the analyzed terrains are represented by a narrow height interval, and beside these peaks, the distribution is almost featureless and does not show other topographic levels exist. But in the case of 3. and 4. areas the peak producing terrains on the height distribution are not located at the deepest topographic level, but appears around the middle of the observed height range. This observation suggests if there were sedimentary processes, they were not effective enough (were not able to transport and redeposit sediments to accumulate them always at the lowest topographic point. Similar cases can be seen on the Earth at elevated basins surrounded by hills – but great difference exists here for Mars, all of these features appear inside a large sedimentary basin at the northern hemisphere of Mars.

Correlation with the morphology:

- The rightmost flattening end of the histograms (Figure 2 the 3., 4., 5. areas) represent small area of highly elevated locations. Based on the images, these came from scattered peaks.
- A general statement can be drawn on the impact craters which dominate the surface' on images usually: these impact craters are almost invisible in the height distribution and related analysis. The reason for this may be that the craters observable at the northern hemisphere are usually smaller than the southern and older terrains, and their effect is weakly appears on the visualization of height distribution of topography with 200 m horizontal resolution. Beside this small craters are difficult targets to analyze with such topographic surveying method.

The slope angle distribution curves might point to the variability of the topography (Figure 3). These data values were calculated by analyzing the largest height difference between a given pixel and all of the surrounding pixels, taking the largest value for the slope direction and were calculated using the horizontal distance of two pixels' centre on logarithmic scale (to make the highest slope angle values also visible on one diagram. These is an evident observation is that the smallest slope angles can be found at the smooth plains. According to the expectations the steepest peaks can be found at the t. area, coinciding with the widest height interval and most undulating terrain among the surveyed area.

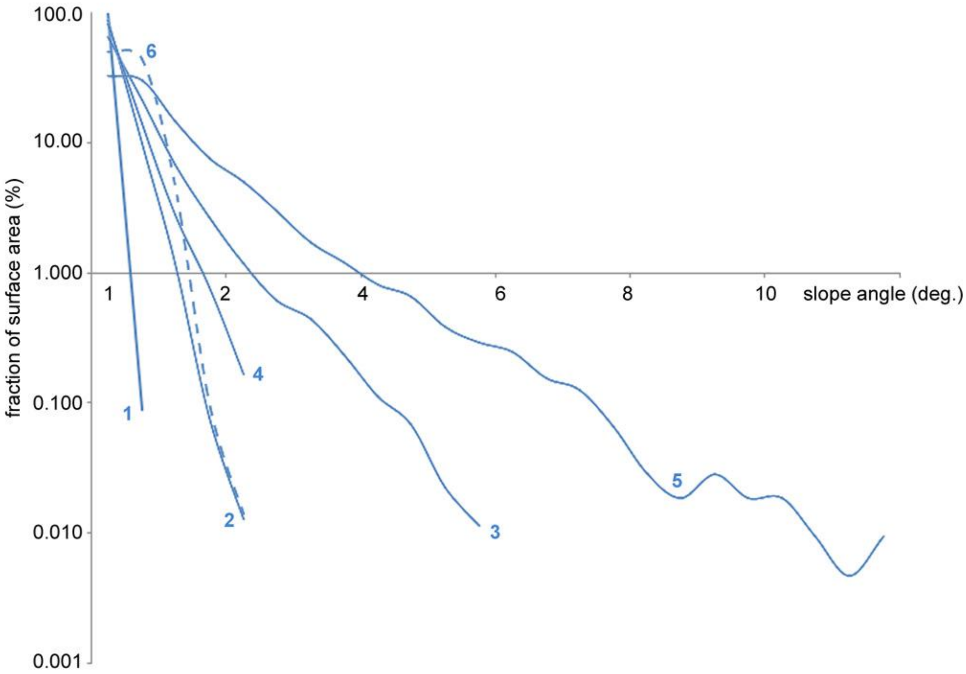

Figure 3. Distribution of slope angle values measured at 200 m spatial distance for the 6 analyzed areas. Comparing these curves to images in Figure 2., the low slope angles as plains can be seen in areas 1,, 2. and6, the locations of the steepest slopes at tareas 3., 6, can be seen as peaks on Fig.2. middle row.

It is interesting to compare Martian parameters to the similar ones measured on the Earth, analyzed same sized areas. Figure 4 shows example locations where areas on the Earth (in Hungary) were compared to Martian height distribution, using SRTM data. Although resemble surface conditions and geological history is not expected in Hungary as on Mars, the comparison points to which types of geomorphological characteristics might be observable using such curves. In the analyzed cases the height range of values is almost the same (25 m) at the Grate Hungarian Plain in Hungary, as on Mars at the smoothest analyzed area, what is surprising if that terrain were produced by lava flow on Mars. Hilly terrains also show similar height range on Earth and Mars (500–600 m), although this is not more than an interesting coincidence. At the same time the comparison of the shape of the hypsographic curves point to more importance. There is a moderately low height level on the curves just below the highest points representing hillsides at the southern slopes of Mátra. Such shoulder shaped sections of the curves might represent the pediment- or glacis-like landforms on the Earth. Important to note that similar shaped section of the curves on Mars can also be seen, but the analysis of this possible analogue connection requires more work beyond what is presented here.

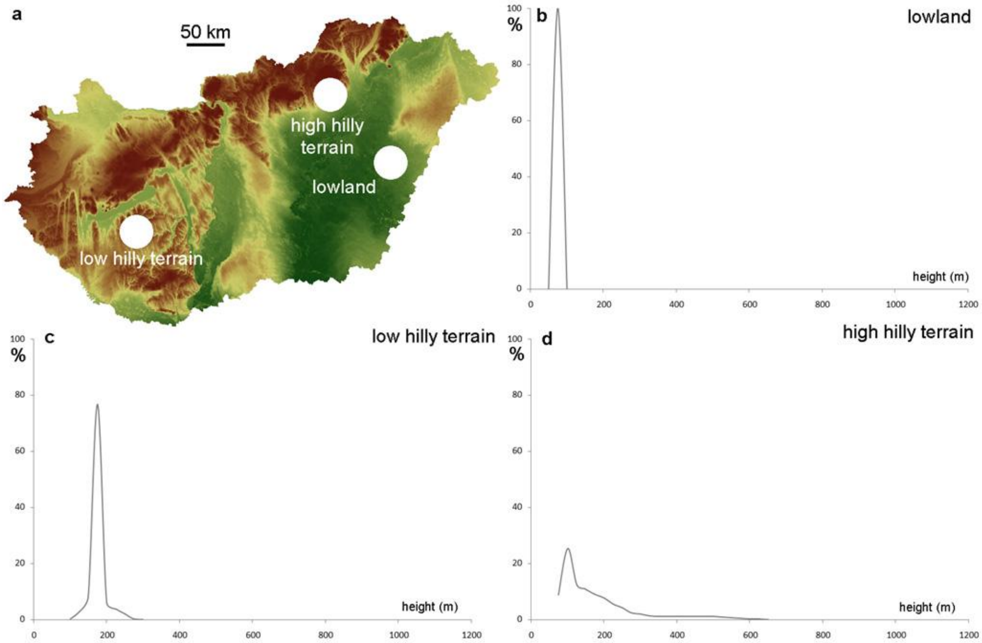

Figure 4. Three example areas in Hungary with their locations and corresponding hypsographic curves: (a) on lowlands (b), low-hilly- (c) and high-hilly terrains (d) with the same scaling as used for Mars in Figure 2.

4. Conclusion

The authors searched for the answers for the question: which topographic structures can be analyzed and extracted from simple topography analysis on Mars and can give information on the geomorphology of the Martian surface. Automated topographic analyzing techniques are important in planetary science as the accessible datasets are huge in these days, and their manual analysis requires too much time and effort. The automated methods might help effectively to identify such areas where detailed manual work gives important results. The important specific findings in this aspect can be summarized below grouped according to basic questions.

Which geomorphological structures can be seen analyzing statistically the topography of Mars? Using the restricted resolution of datasets it is already expected that structures with around or above km horizontal spatial scale can be identified. Histogram peaks of height distribution clearly show horizontal plains, The distributions also show these topographic levels do not always coincide with the topographic deepest locations, suggesting the surface equilibration was not effective enough in many cases. This fact might be in connection with the only episodic (and not continuous) surface modification and the highly inactive long intervals between these short active periods. The smaller isolated peaks appear as flat sections at the right end of the distribution curves – although this topography distribution and surface morphology correlation requires the manual correlation of the topographic level with morphology of images..

What kind of results can be gained comparing different analyzed areas? The different shape of curves at different analyzed areas point to the existence of various, occasionally several and diverse surface modification agents. While sedimentary infill produced large smooth plains on Mars in the case of 1. and 2. areas, resembling smooth units also appear at the 4.,and 5.terrians – but here together with other type of topographic structures, suggesting more heterogeneous surface modification in the later cases.

What is expected about the characteristics of surface modifying processes based on the statistical calculations? The observations point to that surface smoothing processes happened in the analyzed areas, the process of sedimentary infill probably did not reach such an “equilibrium-like“ level, where the plains are concentrated at the lowest topographic points. The large, moderately elevated units (beside the highest peaks and the lowest plains) might formed by some redeposition. These structures might resemble to planation surfaces at the foothills of the Earth which might point to specific processes on a given planet.

Summarizing the correlated the topographical – image based morpholgycal analysis of Mars might provide above all general information of the surface and help to outline the probable occurrence of some processes, influenced large areas. In the future we aim to develop the method further, and use such specific topographic evaluation methods like morphological filters, to better separate different units at the Northern plains of Mars.

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