THE GEOMORPHOMETRIC SIGNATURE OF VALLES MARINERIS FROM M.O.L.A. D.E.M.

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ABSTRACT

Valles Marineris includes a series of troughs south of the Martian equator trending West to East for a distance of 4000 km. The aim of this paper is to derive the geomorphometric signature of this extraterrestrial feature on the basis of the digital elevation model derived from Mars Orbiter Laser Altimeter. More specifically, the canyon system was outlined and various geomorphometric parameters (elevation, massiveness, gradient, aspect, profile and planar curvature etc.) are computed in an attempt to characterize and segment the landscape. The geomorphometric data indicate that the Valles Marineris look more to an active tectonic zone of earth. In order to further verify it, the terrain within the canyon should be segmented to mountain and non-mountain terrain class and to compare the derived statistics to Great Basin (USA), Minor Asia and Zagros Ranges. Additionally isolated mountains, piedmonts and peneplains should be extracted and parametrically represented and compared to earth. Higher resolution elevation data is required too in order to examine the geomorphometry of valley mouths deposits and compare them to piedmont zones, alluvial fans and gravity cones of earth.

INTRODUCTION

New concepts, data, and methods, emergent in geographic information science in recent years have presented scientists with new opportunities to gain fresh insights into the study of landscape (Pike 1995, Pike 2000, Saura and Martinez 2001). Landscape dynamics is considered to involve scale, pattern and process that extend across various geographical domains through their spatial interactions. In the current approach, a) **scale** is regional or physiographic, b) **pattern** expresses the partition of landscape to elementary units and their representation on the basis of their spatial 3-dimensional arrangement (Evans 1981, Miliaresis 2001a) and c) **process** expresses the relationship between tectonics and topography (Merits and Ellis 1995, Summerfield 2000).

Towards this end the mountains were considered to form the elementary morphotectonic units at regional scale and their definition and modeling characterized the landscape (Miliaresis 2001a). The previous studies were based on the moderate resolution digital elevation models (DEMs) GTOPO30 and GLOBE. On the other hand nowadays, moderate resolution DEMs and imagery are available for Mars (MOLA Topographic Map 2002). For example the equatorial system of troughs was first seen on Mariner 9 images and was one of the most spectacular discoveries of this mission (Kieffer et al. 1992, Greeley 1994). The main trough system (Valles Marineris), was named in honor of the achievement of the Mariner 9 mission. Thus, it would be of a great research interest to study the planetary landscapes and compare them to the terrestrial one. This paper focus on the mapping and characterization of the landscape dynamics in Valles Marineris from the latest DEMs available (Figure 1).

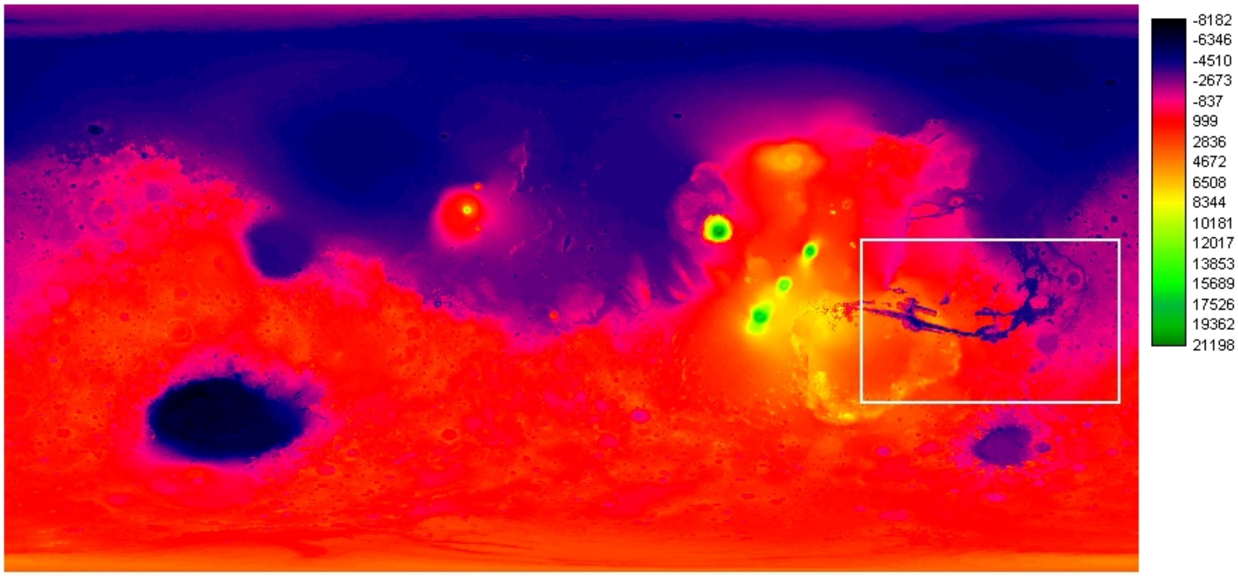

Figure 1. MOLA DEM of Mars and Valles Marineris within the square

METHODOLOGY

First the study area and data are introduced. Then the geomorphometric parameters used in landscape characterization are explored. Then selected general geomorphometric parameters (Evans 1980) defined for every node of the DEM are computed and the resulting statistics are used in an attempt to characterize landscape.

Geomorphometric Parameters

The easiest way to visualize the geomorphometric signature and the landscape pattern is by shaded relief maps (Pike and Thelin 1989). This approach allows the delineation of the major fault and ring structures and the characterization of the density-roughness of the landscape by visual interpretation. The major disadvantage is that we can not establish a metric system that could compare the landscape of two different physiograhic zones in a quantitative and less subjective manner.

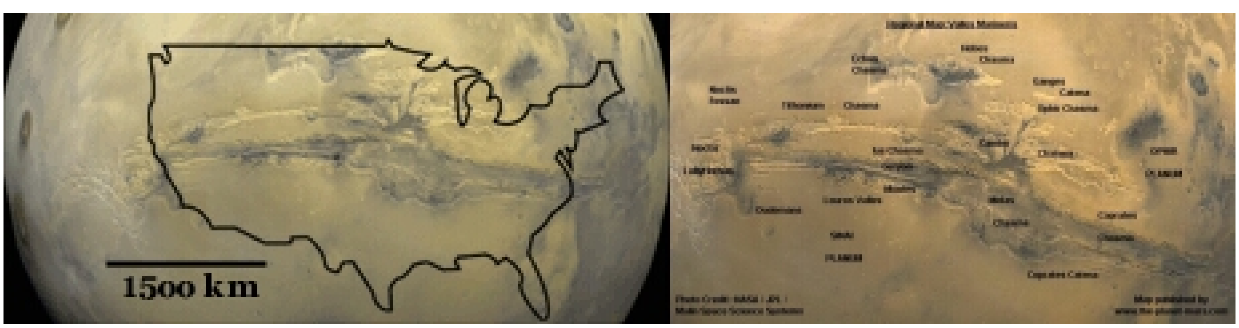

Figure 2. The USA border superimposed over the Valles Marineris (Mars Gallery 2002) and the map indicating the geographic names available for the study area (Map of Valles Marineris 2002).

From the other hand, hypsometric integral (HI) was used in classical conceptual geomorphic models of landscape evolution (Luo 1998). It should be noted that the styles of landscape evolution depend critically on the timescales of the tectonic processes in relation to the response time of the landscape and classical conceptual models may be valid under specific tectonic conditions (Kooi and Beaumont 1996). Descriptive statistics of the general geomorphometric attributes (Evans 1980) like elevation, gradient etc, were used to characterize the landscape either at local or even at planet scale (Mark 1975). These attributes were also used in a pixel based unsupervised classification procedure aiming to capture the geometric signature of landforms (Pike 1987). In a previous research effort, mean elevation (H), mean gradient (G), hypsometric integral (HI) and local relief (LR) that equals to the elevation range (Hmaximum-Hminimum) within a mountain feature, were used to parametrically represent the mountains in Zagros Ranges physiographic zone (Miliaresis 2001a).

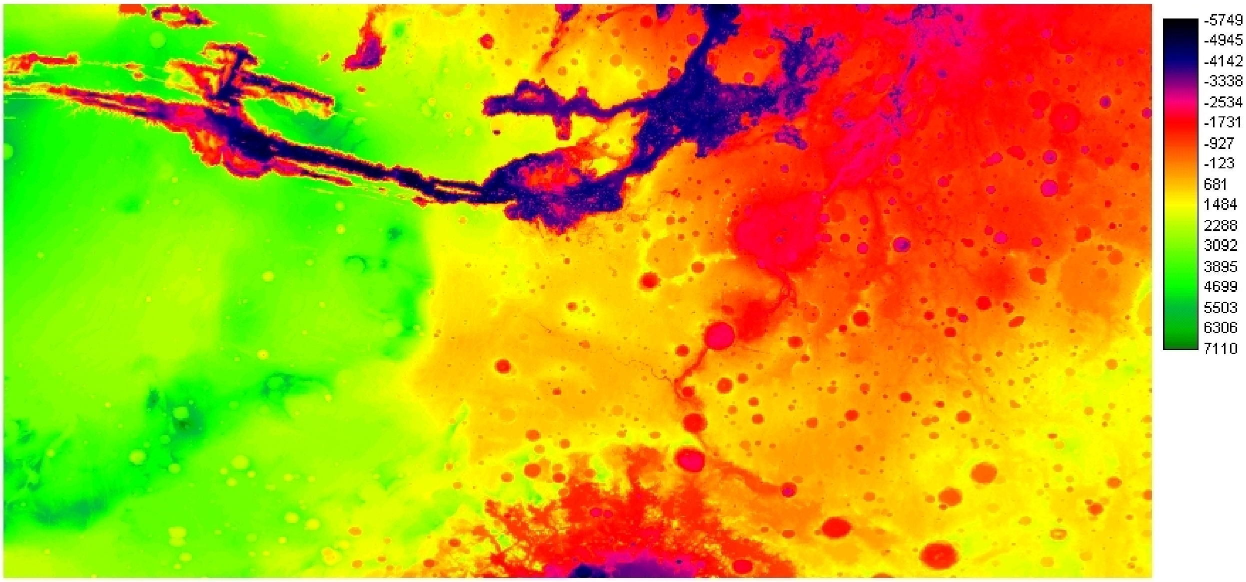

Figure 3. The DEM tile named megt00n270g.img.

Study Area

The Valles Marineris system includes a series of troughs just south of the Martian equator that trend N 75º W for a distance of 4000 km, from longitude 40º to 110º (Figure 2). The system includes the Noctis Labyrinthus network of troughs in the west, the Valles Marineris in the centre and troughs merging with chaotic terrains and outflow channels in the east (Lucchita, et al. 1992). The central individual troughs, generally 50 to 100 km wide, merge into a depression as much as 600 km wide. In places the canyon floor reaches a depth of 10 km, 6 to 7 times deeper than the Grand Canyon (U.S.G.S. 2002). Most researchers agree that Valles Marineris is a large tectonic "crack" in the Martian crust, forming as the planet cooled, affected by the rising crust in the Tharsis region to the west, and subsequently widened by erosional forces (landslides that partially removed the rim of the crater that is on the plateau adjacent to Valles Marineris). However, near the eastern flanks of the rift there appear to be some channels that may have been formed by water (Valles Marineris 2002).

Data

The M.O.L.A. Mission Experiment Gridded Data Record (EGDR) is a global topographic map of Mars created by binning altimetry values from the MOLA PEDR products. The EGDR has been produced at resolutions of 1, 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 degrees per pixel. The 1/64 degree resolution product is known as the MEGDR (The Mission Experiment Gridded Data Record), as it is derived from MOLA altimetry data for the entire mission (MOLA Topographic Map, 2002). In this study the DEM file (Figure 3) megt00n270g.img (one tile) was used that covers the geographic region with longitude 270 to 360 and latitude -45 to 0 (megt00n270g.img 2002). Note that one tile covers 45 degrees in latitude and 90 degrees in longitude. The maps are in simple cylindrical projection using the IAU2000 planetocentric coordinate system with east positive longitude. The DEM contains 5,760 columns and 2,880 rows while the spacing is 926 m (1/64 degrees per pixel). Each sample represents median observed topography within a 0.015625 by 0.015625 degree area. Where no observations lie within the area, an interpolated value is supplied. Owing to the polar MGS orbit, density is lowest near the equator, where about 55% of bins contain at least one MOLA shot. There are gaps, however, of up to 12 km between profiles. The minimum and maximum topography observations within the current data set are -8,208. and 21,300 meters.

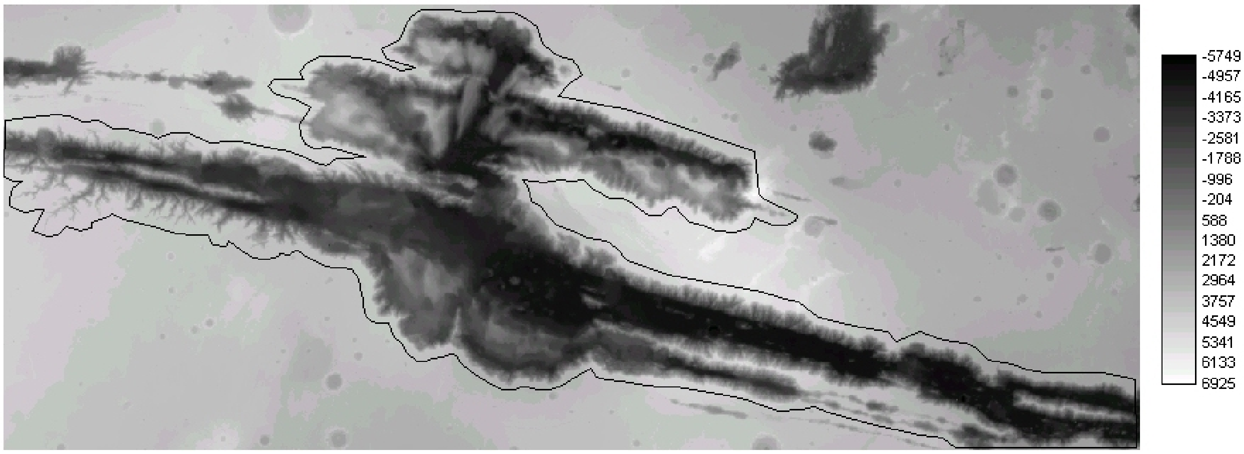

Figure 4. DEM and the borderline of the study area.

The study area (located in Valles Marineris region in Mars) is bounded by latitude -15.84375 to - -2.578125 and longitude 273.5 to 307.5. The DEM contains 2,176 columns and 849 rows while the spacing is 926 m (1/64 degrees per pixel). The elevation range is in the interval -5,692 to 6,710 m. The borderline of the Canyon system was interpreted and digitized (Figure 4). The geomorphometric analysis will be performed within the area outlined in Figure 4. Follows MOLA DEM visualization of a Viking image (drape) in a gorge within the Canyon system (Figure 5). The ridges along the sides of the gorge are clearly observable indicating the high information content of the MOLA DEM.

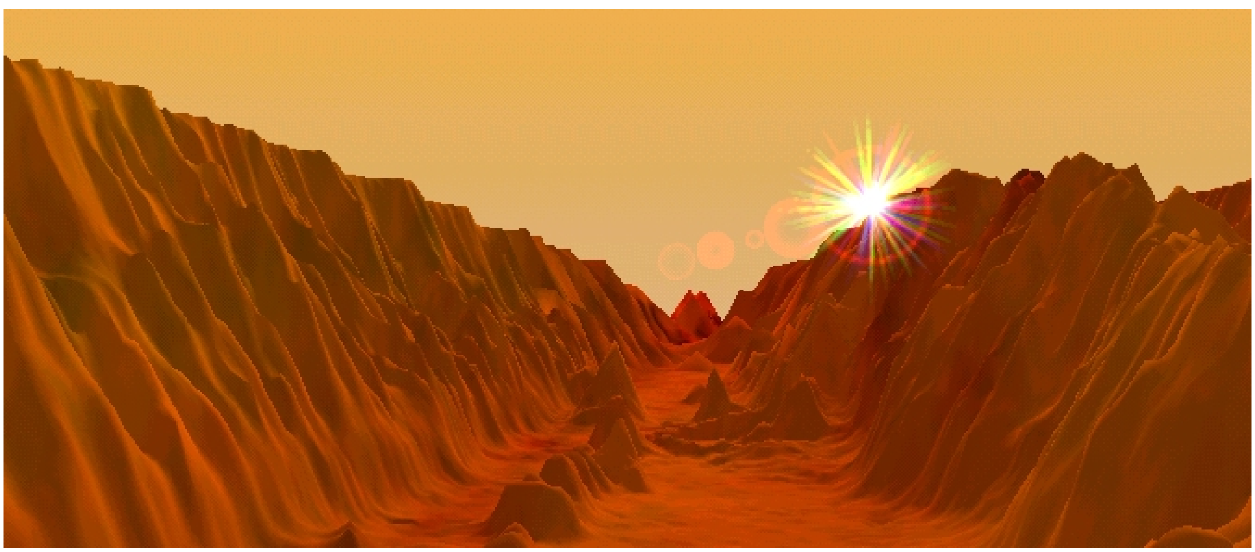

Figure 5. MOLA DEM drape of a Viking image. Vertical exaggeration equals 2. The position of the artificial sun indicates the illumination source (azimuth 100^o, height 23^o).

Hypsometry

A shaded relief map (sun position was in SE) and elevation profiles were used in an attempt to interpret the topographic features and the structure of the canyon (Figure 6). Profiles kk’ and bb’ are vertical to the tributary canyons observed on the peneplain surrounding the canyon. Profiles aa’, cc’, dd’, ee’ and GG’ are vertical to the main axis of the canyon and indicate the existence of a major ridge structures developed parallel to the main axis of the canyon. ff’ and bb’ indicate decrease of elevation from NW to SE.

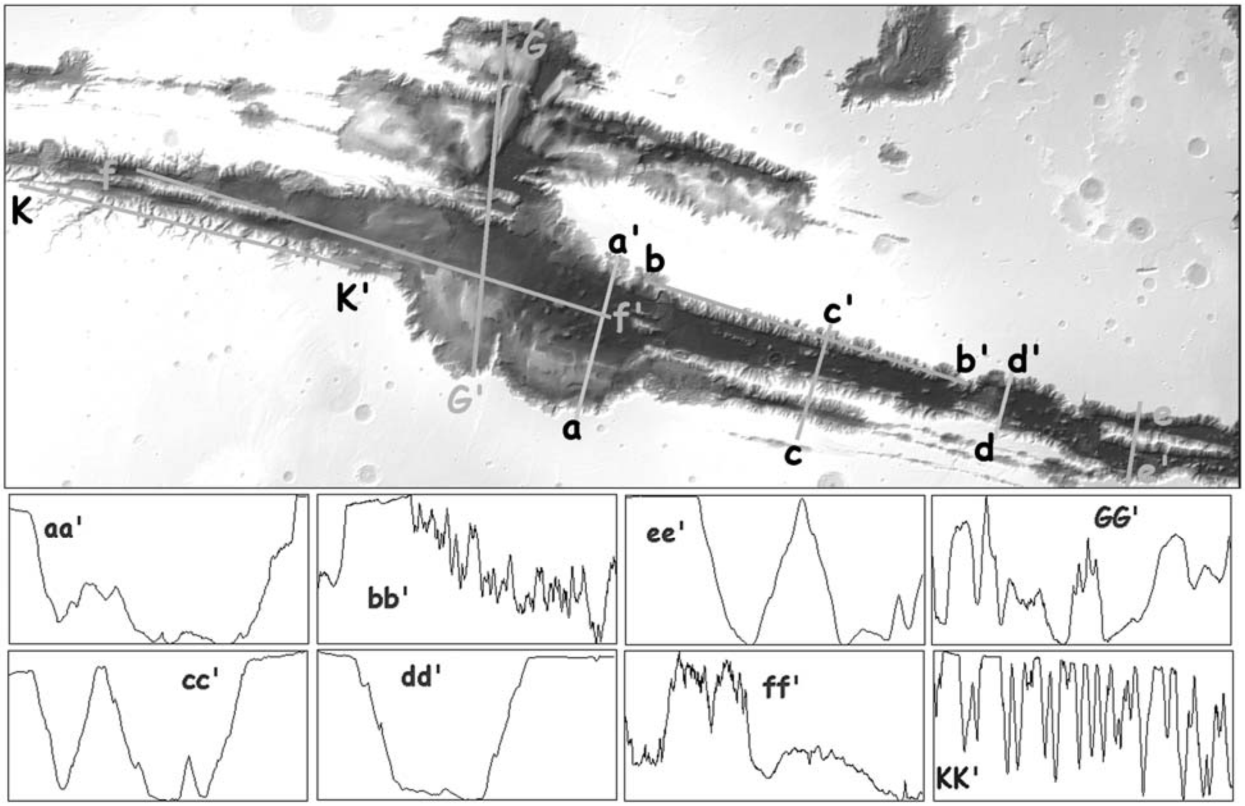

Figure 6. Shaded relief map and elevation profiles.

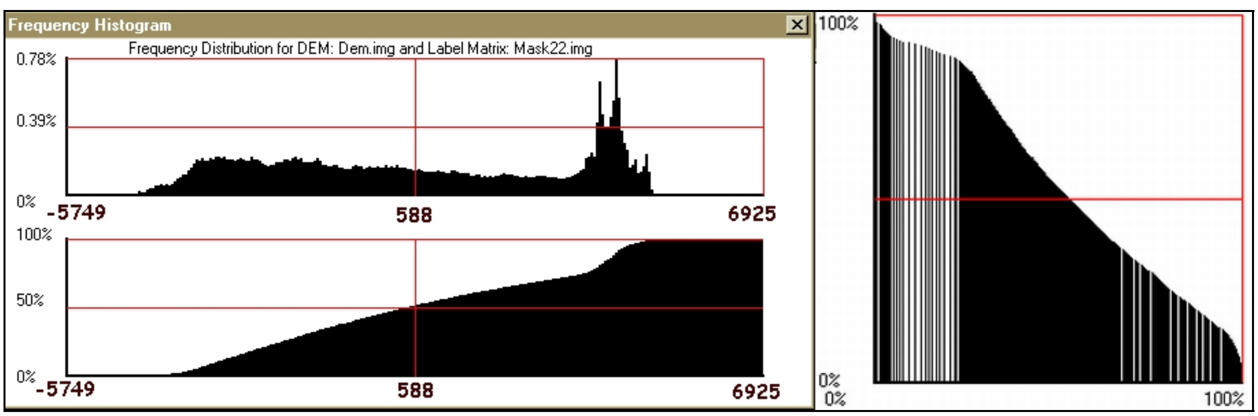

Figure 7. Elevation frequency & cumulative histograms of the DEM of the study area and the relative hypsometric curve.

Geomorphometric Signature

Hypsometric analysis and calculation of the slope is performed first (Figure 8).

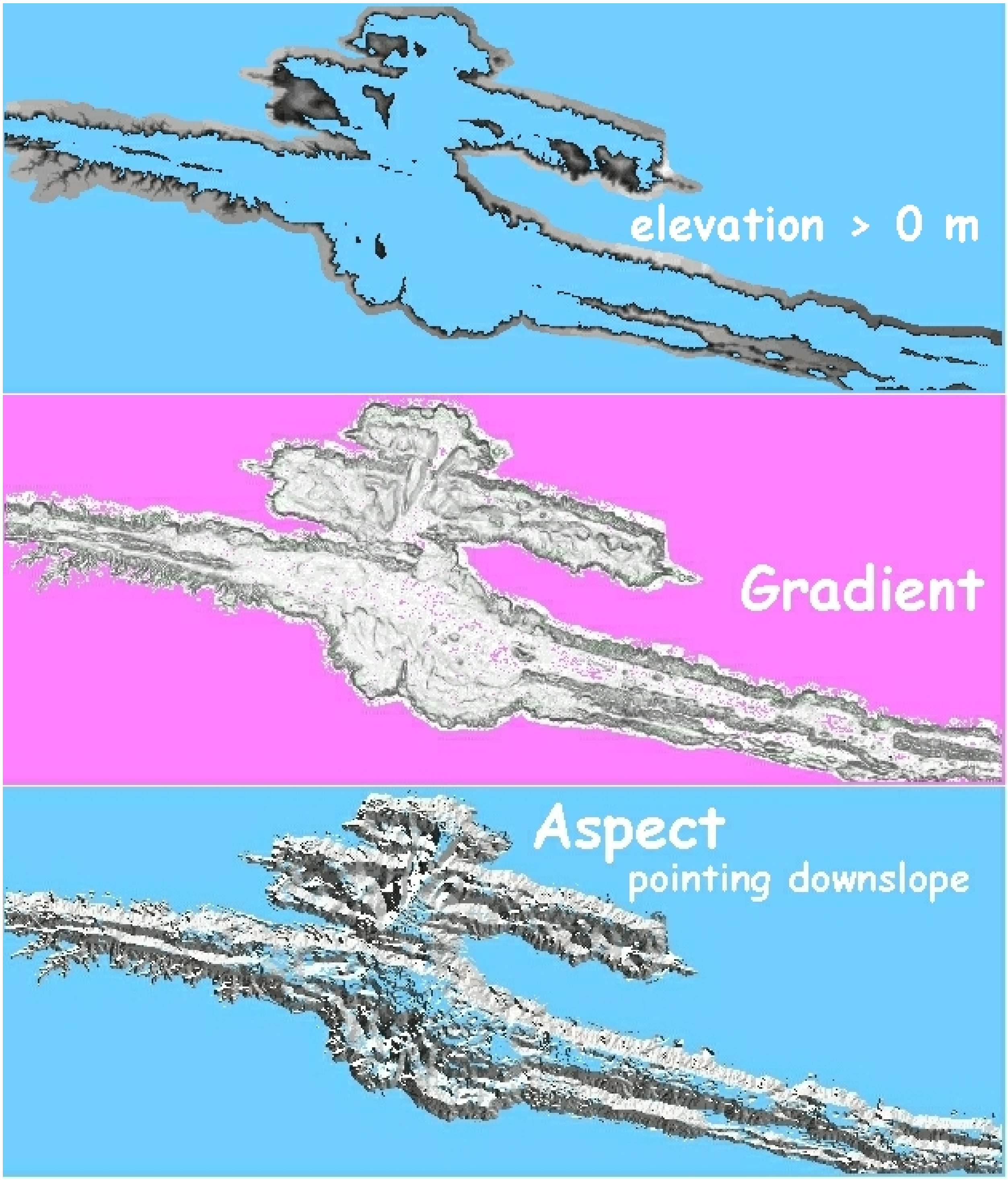

Figure 8. Elevation map (blue is used if h<0). Gradient (the brightest a pixel is, the lowest the gradient). Aspect standardised to the 8 directions defined in a raster image (see Figure 9), the blue was used flat terrain (if gradient < 2 aspect is considered undefined).

It is concluded that a small fraction of the Valles Marineris is above the base level (zero elevation). This portion is limited mainly to the surrounding peneplain. Note the tributary valleys developed at the edge between the canyon and the peneplain mainly in west. The tributary valleys oriented in NE to SW direction and indicate erosion of the peneplain and mass flow towards the canyon. It is assumed that due to the lack (?) of water flow, gravity forces (landslides) accompanied by Aeolian erosion (severe winds) could cause these movements. Areas with positive elevation within the canyon indicate the existence of mountains in the northern part and two huge elongated ridges oriented in NW to SE. The existence of the ridges and the mountains is verified in the gradient and aspect image. The rose diagram of aspect (Figure 9) indicates that the greater frequencies are observed along the direction of N-S and NE-SW, vertical to the main axis of the canyon and to the main ridges identified.

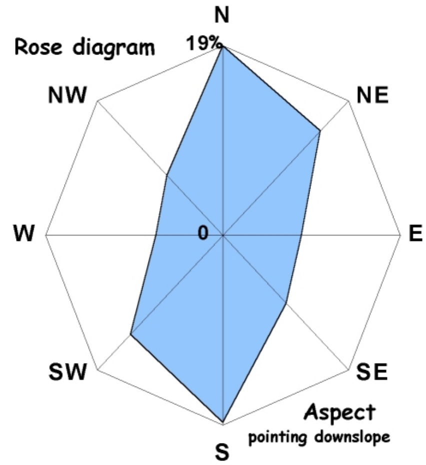

Figure 9. Rose-diagram.

The statistical data computed is given in Table 1. HI (0,41) indicates that Valles Marineris is in equilibrium erosion stage. Note that HI=0.48 (Hmean= -2,759 m) for the portion of land that it is in lower in elevation (h<0) than the baselevel elevation. This fact indicates that Valles Marineris is a quite massive due to the existence of mountains and elongated ridges within.

Table 1.Geomorphometric signature of Vales Marinelis

Aspect Direction	Number of pixels	Area pixel=926 m	Size (pixels)	674,634	**Curvatures**	
			Size for h<0	392,185	**A. Profile**	
E	45,000	Elevation (m)	*Mean*	-474	*Mean*	-0.00000041335
NE	79,469		*St.dev*	3,086	*St.dev*	0.00008637
N	101,416		*Maximum*	6,925	*Maximum*	0.0020587
NW	45,356		*Minimum*	-5,749	*Minimum*	-0.0016171
W	38,213		*HI*	0.41	**B. Planar**	
SW	74,479	Gradient (°)	*Mean*	9.89	*Mean*	0.00000139389
S	100,076		*St.dev*	9.07	*St.dev*	0.00008637
SE	51,093		*Maximum*	53	*Maximum*	0.0027597
Flat < 2^o	139622		*Minimum*	0	*Minimum*	-0.001491

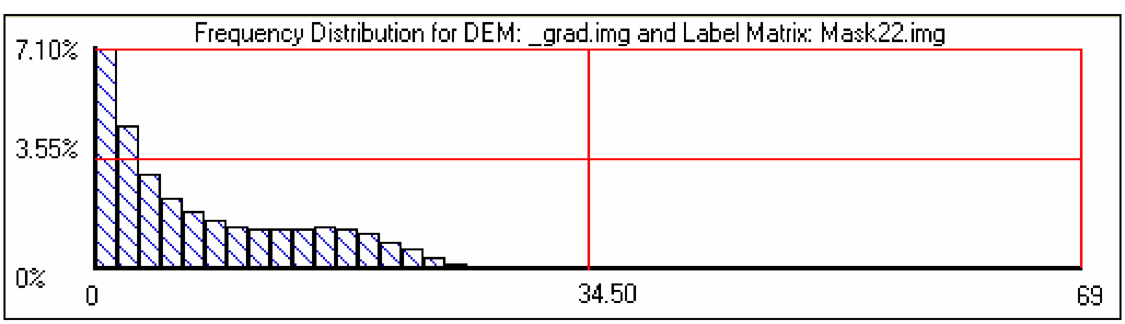

Figure 10. Gradient frequency histogram of the study area.

Geomorphometrical comparison (for example mean gradient and HI values) indicates that the Valles Marineris looks likes more to to Zagros Ranges than to Great Basin (Miliaresis 2001a). The same result is deduced if frequency histograms (figure 10) are compared. For example the elevation histogram indicates that if h<0 then the canyon surface is develop almost equally on all levels in the elevation domain, The same observation is valid for the mountain terrain class in Zagros Ranges.

CONCLUSION AND PROSPECTS

The geomorphometric data indicate that the Valles Marineris look more to an active tectonic zone of earth. In order to further verify it, the terrain within the canyon should be segmented to mountain and non-mountain terrain class and to compare the derived statistics to Great Basin (USA), Minor Asia and Zagros Ranges (Miliaresis 2001a). Additionally isolated mountains, piedmonts and peneplains should be extracted and parametrically represented and compared to earth (Miliaresis and Argialas 1999, 2002). Higher resolution elevation data is required too in order to examine the geomorphometry of valley mouths deposits and compare them to piedmont zones, alluvial fans and gravity cones of earth (Miliaresis and Argialas 2000, Miliaresis 2001b).

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