GEOMORPHOMETRIC MAPPING OF GRAND CANYON FROM THE 1-DEGREE USGS DEMS

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ABSTRACT:

In a previous research effort a terrain partition framework was defined allowing the partition of the landscape of Valles Marineris chasma (an elongated steep-sided depression located in Mars) to elementary objects. Each object was parametrically represented on the basis of its spatial 3-dimensional arrangement and mapped according to a terrain classification scheme. In the current research effort Grand Canyon is delineated from the one degree USGS DEMs and various geomorphometric parameters are computed in an attempt to capture the geomorphometric signature of the largest canyon in earth. More specifically, the landscape was described on the basis of the statistical parameters computed for elevation and gradient, histogram frequency distributions and rose diagrams. The geomorphometric comparison indicates that Valles Marineris is a steeper terrain with higher relief variability. The rectilinear mountain fronts are a key indicator of the tectonic forces that shape the terrain of Valles Marineris chasma. The terrain of Grand Canyon is developed parallel to fluvial process direction while in Valles Marineris the terrain flows vertically to the mountain fronts. Thus, the key factor controlling the development of the landscape in Grand Canyon is fluvial process versus tectonism in Valles Marineris. Valles Marineris is less massive than Grand Canyon but this is due to the much greater elevation range observed (12 km versus 2.5 km).

1. 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. A previous effort in characterizing the landscape of the Valles Marineris chasma has been completed and therefore various geomorphometric parameters is calculated (Miliaresis and Kokkas, 2003).
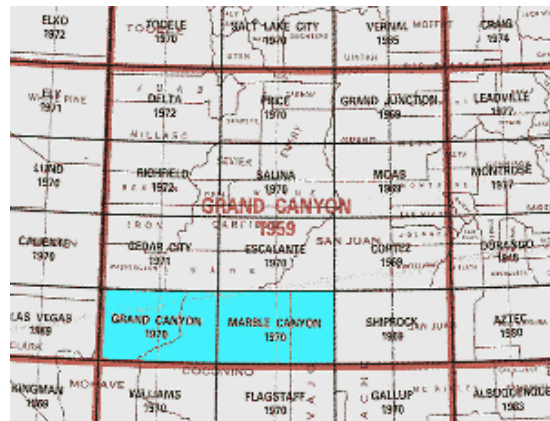

Figure 1. Index map of the one degree DEM available from USGS.

This paper focuses on the mapping and characterization of the landscape dynamics in Grand Canyon from the one degree DEM available from USGS (Figure 1). With the calculation of the geomorphometric parameters a comparison between the Valles Marineris chasma and the Grand Canyon will be performed.

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2. 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. Then a comparison between the computed geomorphometric parameters of the Valles Marineris and Grand Canyon is performed.

2.1 Geomorphometric Parameters

The easiest way to visualize the geomorphometric signature and

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
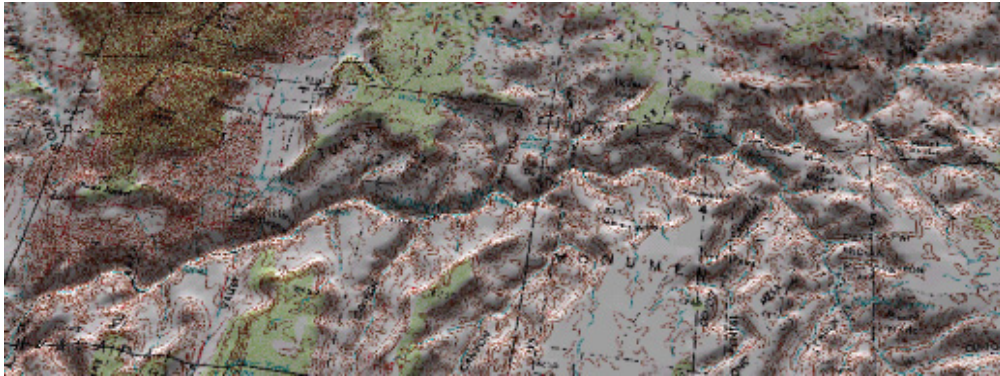

Figure 2. 3D visualization of the Grand Canyon. Draped topographic map on the Grand Canyon 1-degree DEM.

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-

range (Hmaximum-Hminimum) within a mountain feature, were used to parametrically represent the Valles Marineris chasma (Miliaresis, 2001a).
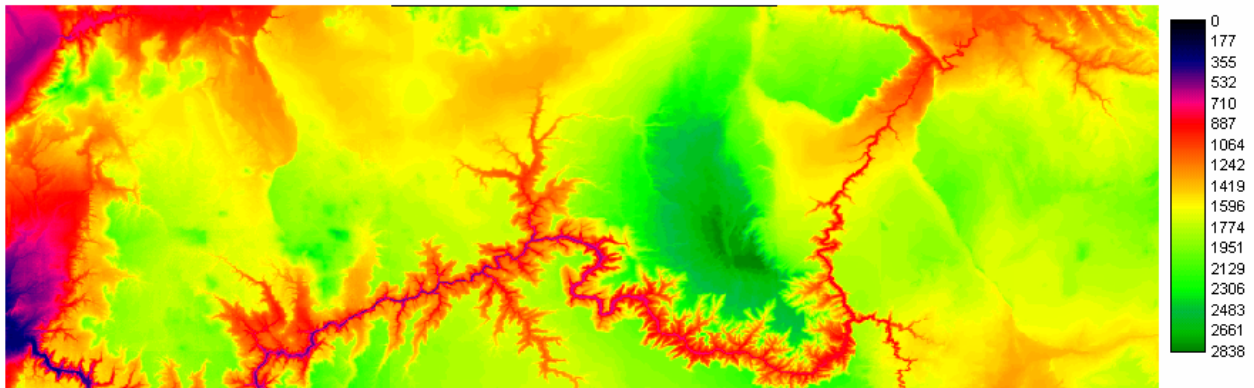

Figure 3. The 1-degree DEM of the Grand Canyon merged with the 1-degree DEM of the Marble Canyon.

roughness of the landscape by visual interpretation (Figure 2). The major disadvantage is that we can not establish a metric system that could compare the landscape of two different physiographic zones in a quantitative and less subjective manner. The tributary canyons of the study area are clearly observable in Figure 2 indicating a similarity with the formation of Valles Marineris canyon system.

2.2 Study area

The Grand Canyon lies close to the borders of Utah and Nevada. The canyon system trends from longitude -111º to -113 and covers an area of approximately 4937 sq. km. In places the canyon floor reaches a depth of 1800 m which is 6 to 7 times sallower compared to the depth of the Valles Marineris chasma. The width of the Grand Canyon varies from 16 km at the

narrowest place to 29 km at the widest. The width of the canyon indicates that it is 3 to 4 times narrower compared with the width of the Valles Marineris individual troughs. Most researchers agree that the shape of the Grand Canyon has been formed by a number of combined processes. The most important process is erosion, primarily by water and second by wind.

meters. The elevation range is in the interval 0 to 2838 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.
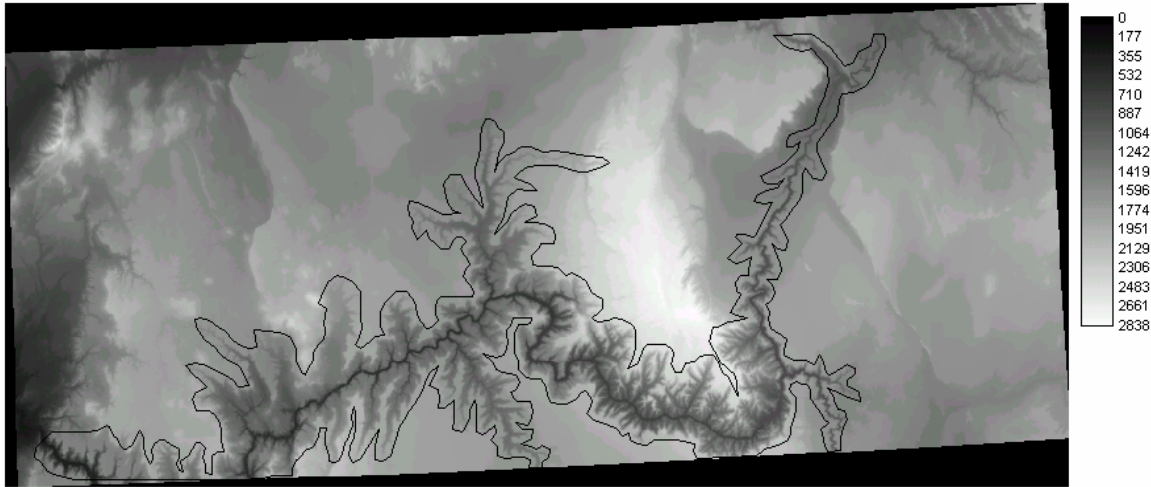

Figure 4. The DEM and the borderline of the study area.

2.3 Data

The 1-degree DEM are distributed by USGS and provide coverage in 1 by 1 degree blocks for all of the contiguous United States, Hawaii and limited portions of Alaska. Figure 3 shows the DEM that was used for the landscape characterization of the study area. The DEM in figure 3 was produced by merging 3 of the 1 by 1 degree blocks (figure 1). The majority of the 1-degree DEMs are produced from cartographic and photographic sources.

The elevation data from cartographic sources are collected from any map with scale from 1:24000 through 1:250000. The topographic features as the contours, the drain lines, ridge lines, lakes and spot elevation are first digitized and then processed into the required matrix form and interval spacing. The 1-degree DEMs consists of a regular array of elevations referenced horizontally on the geographic coordinate system of the WGS 84. Elevations are in meters relative to National

Geodetic Vertical Datum of 1929 in the continental U.S and local mean sea level in Hawaii. The 1 degree DEMs have an absolute horizontal accuracy of 130 m, and an absolute vertical accuracy of 30 m. The DEM in figure 3 covers a geographic region bounded by longitude -144 to -111 degree and latitude from 36 to 37 degrees. The DEM contains 3603 columns and 1202 rows, while the spacing is 80 m. Each sample represents median observed topography within a 0.0011102 by 0.0011102 degree area. The minimum and maximum topography observations within the current data set are from 0 to 2838 meters.

The study area (located in Grand Canyon) is bounded by latitude 36 to 37 and longitude -114 to -111 degrees. The DEM contains 3426 columns and 1545 rows while the spacing is 80

2.4 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 5).

- Profiles gg' and ff' are vertical to the tributary canyons observed on the peneplain surrounding the canyon.
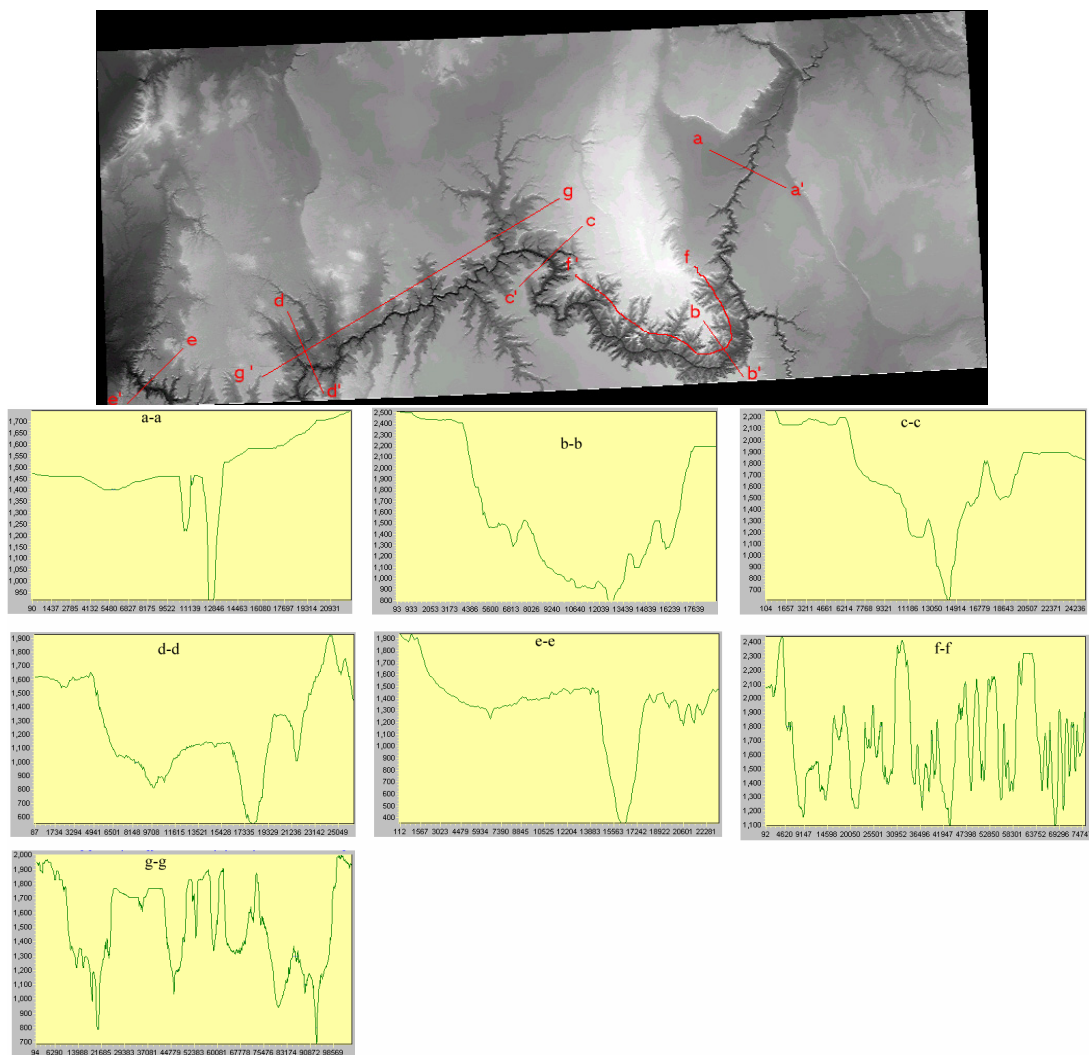- Profiles aa',bb', cc', dd' and ee' are vertical to the main axis of the canyon.

Figure 5. Elevation profiles of Grand Canyon

2.5 Geomorphometric signature

Hypsometric analysis (Figure 6) and calculation of the slope and aspect is performed in figure 8.
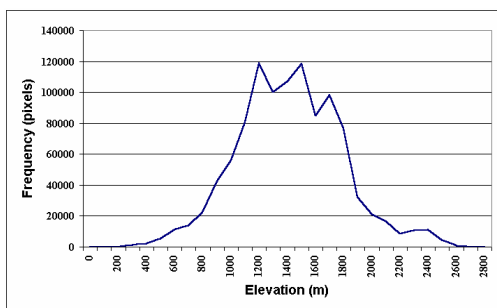

Figure 6. Elevation frequency histogram of the study area DEM and the relative hypsometric curve

The geomorphometric data indicate that the Valles Marineris look more to an active tectonic zone of earth (Miliaresis and Kokkas, 2003) on the basis of its comparison to various tectonic zones of earth (Great Basin, Asia Minor and Zagros Ranges).
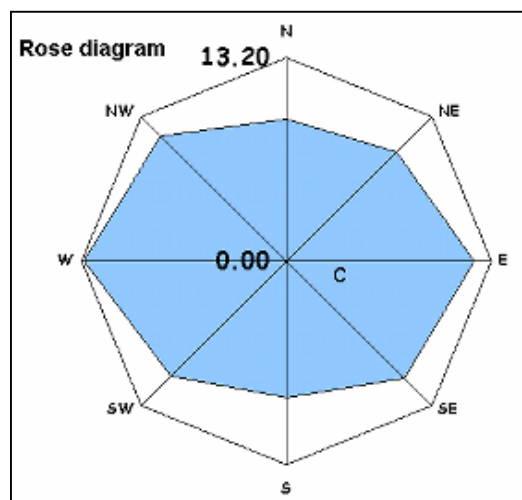

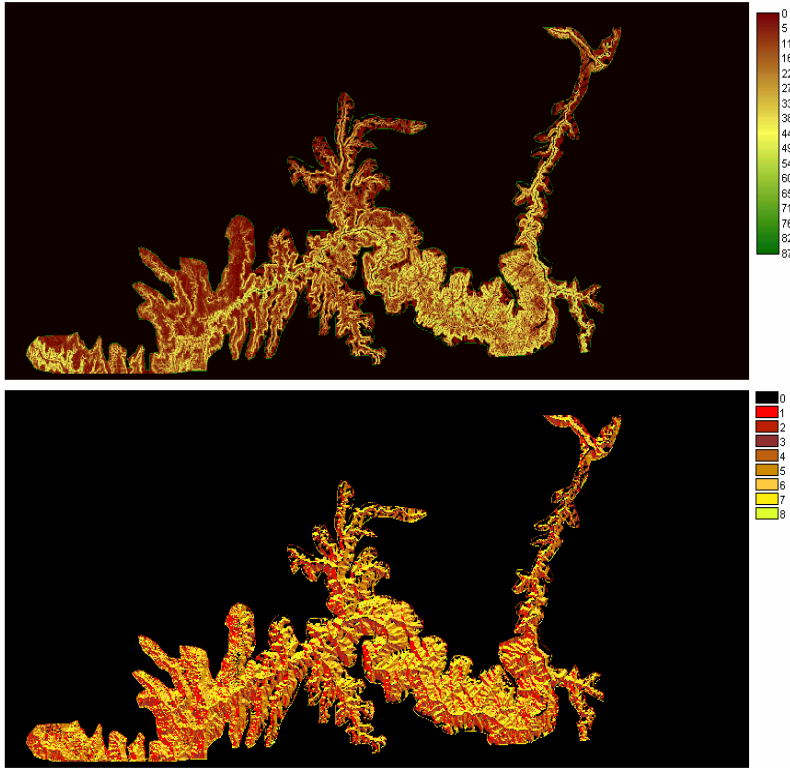Figure 7. Rose-diagram of Grand Canyon.

Figure 8. The computed gradient for the study area (top image). Aspect (bottom image) standardized to the 8 directions defined in a raster image (Figure 7), the black was used for flat terrain (if gradient < 2 aspect is considered undefined).
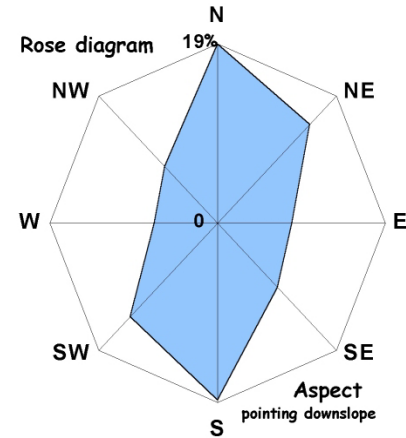
Figure 9. Rose-diagram of Valles Marineris.

Aspect Direction	Number of pixels	statistics		
E	126,468	Elevation (m)	Mean	1468.9
NE	105,115		St.dev	384.7
N	96,206		Maximum	2,703
NW	119,602		Minimum	294
W	136,523		HI	0.49
SW	110,128	Gradient (°)	Mean	18.45
S	92,650		St.dev	14.60
SE	112,594		Maximum	0
Flat < 2º	147,252		Minimum	75

Table 1. Geomorphometric signature of Grand Canyon

The overall comparison of the two features (Grand Canyon versus Valles Marineris) on the basis of the corresponding geomorphometric attributes (Tables 1 and 2) indicates the following:

- Grand Canyon is more massive since the HI (hypsometric integral) is greater.
- Grand Canyon is much more steep than
- Valles Marineris chasma that presents greater variability of relief with respect to both the standard deviation of elevation and the local relief (elevation difference)
- Valles Marineris presents remarkable straightness of mountain fronts in comparison to Grand Canyon.

- Aspect rose diagrams are completely different (Figures 7 and 9) although the main axis of both features is parallel to the East to West direction. More specifically, the Grand Canyon terrain is developed mainly in a East to West direction that is parallel to the fluvial processes main direction while the residual tributary canyons occur in a North to South direction.

Aspect Direction	Number of pixels	statistics		
E	45,000	Elevation (m)	Mean	-474
NE	79,469		St.dev	3,086
N	101,416		Maximum	6,925
NW	45,356		Minimum	-5,749
W	38,213		HI	0.41
SW	74,479	Gradient (°)	Mean	9.89
S	100,076		St.dev	9.07
SE	51,093		Maximum	53
Flat < 2º	139622		Minimum	0

Table 2. Geomorphometric signature of Valles Marineris

On the contrary in Valles Marineris chasma the landscape is developed mainly in a North to South direction that is vertical to the huge elongated mountain ranges that are evident with the chasma. This means that the landscape flow away from the mountain fronts and not parallel to a supposed fluvial processes along the West to East direction. In other words the process responsible for the shape of the rectilinear mountain fronts

should be responsible for controlling the development of the landscape in Valles Marineris.

3. CONCLUSION AND PROSPECTS

The geomorphometric comparison indicates that the terrain of Valles Marineris is not us steep us Grand Canyon but indicates higher relief variability. The rectilinear mountain fronts are a key indicator of the tectonic forces that shape the terrain of Valles Marineris chasma. The terrain of Grand Canyon is developed parallel to fluvial process direction while in Valles Marineris the terrain flows vertically to the mountain fronts. Thus, the key factor controlling the development of the landscape in Grand Canyon is fluvial process versus tectonism in Valles Marineris. Valles Marineris is less massive than Grand Canyon but this is due to the much greater elevation range observed (12 km versus 2.5 km).

Geomorphometric mapping is the key that can extract, represent, segment and map extra-terrestrial and terrestrial features from moderate resolution digital elevation models.

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