Mem. S.A.It. Vol. 82, 334

Memorie della

Mars and Earth topography: a preliminary comparative analysis

C.R. Perotti and M. Rinaldi

Università degli Studi di Pavia, Dipartimento di Scienze della Terra, via Ferrata, 1, 27100-Pavia, e-mail: cperotti@unipv.it

Abstract. A comparison of the main topographic characteristics of the surfaces of Mars and Earth has been carried out by using digital elevation models of the planets at the same cell resolution. The frequency distribution curves of elevation on Mars and Earth show a similar bimodal pattern, probably indicating two different crustal typologies, but with differences especially between the two peaks of the curves.
The slope and curvature values of the surfaces of the two planets also show some differences, probably related to the intense impact craterization and the long period of geodynamic and morphological inactivity of Mars.

Key words. Mars and Earth topography – Mars dichotomy – Surface attributes

1. Introduction

Recently, the topography of Mars has been defined with great accuracy by the Mars Orbiter Laser Altimeter (MOLA), carried on the Mars Global Surveyor orbiter (Smith et al. 2001). By gridding and interpolation of MOLA data, a global digital elevation model (DEM) of the planet with a spatial resolution of about 460 m/pixel has been generated (Neumann et al. 2001). Such detailed characterization of the Mars surface allows a comparison with the Earth (Fig. 1), in order to investigate the geodynamic processes that acted on Mars during its geological history. Watters et al. (2007), for example, demonstrated the crustal hemispheric dichotomy on Mars by calculating Martian hypsography. However, the comparison between the topographic features of Mars and Earth must take account of some differences.

The Earth is an active planet, where geodynamic processes modify continuously the surface. Volcanism, magmatism, earthquakes and all the plate tectonic-related phenomena deform and modify the topography, inducing continual erosional and depositional events. On Mars there are no signs of active significant geological processes with the exception of wind and dust storms, and also since some new observations indicate that some depositional or morphological structures can be dated to few million years ago (Baker 2005, and references therein), the prevailing thinking is that Mars is a planet whose geodynamic activity has been essentially confined to the distant past, in the Noachian period. The erosion rate on Mars is extremely reduced. Observations made during the Mars Pathfinder mission indicate very low long-term deflation rates of 0.01-0.04 nm/yr (or m/Ga) since the end of the Hesperian (1.8-3.5 Ga), similar to less precise

Send offprint requests to: C. Perotti

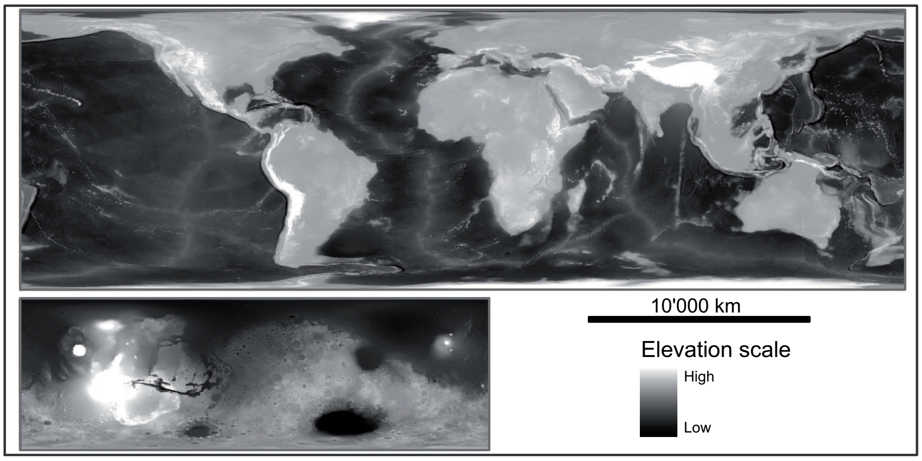

Fig. 1. Global digital elevation models (DEM) of the terrestrial and Martian surfaces (equal area projection).

rates of <1 nm/yr based on the preservation of craters at the Pathfinder and Viking 1 landing sites (Golombek & Bridges 2000). Growing evidence suggests that the present cold and dry environment was preceded by an earlier wetter environment with erosion rates orders of magnitude higher. What we observe today on the surface of Mars is the result of the endogenic and external processes that acted during the first phases of its geological evolution, while the erosion rate on Earth is much higher and the topography reflects essentially the present geological activity.

2. Data and methodology

A preliminary topographic comparison between Mars and Earth has been carried out by the analysis of surface attributes. For this purpose, MOLA-DTM (Smith et al. 2001) and GTOPO30 data (US Geological Survey) terrain digital models have been processed to a uniform raster spatial resolution and projection geometry.

In particular, MOLA-DTM has been resampled to a cell size of 963 m in order to make it comparable with GTOPO30-DEM, and this last has been reprojected to perform the analyses in the same equi-areal system in order to avoid areal and angular calculation errors (Fig. 1). Hypsographic and hypsometric charts have been calculated starting from the DTM elevation values of the Martian and terrestrial surfaces, respectively (Figs. 2 a,b). Moreover, elevation gridded data have been used to calculate the surface attributes (Roberts 2001). In particular, first and second surface derivatives have been considered, corresponding to the slope and curvature, respectively. As a result, new raster datasets have been produced and classified both for Mars and Earth to produce qualitative maps and to perform quantitative analyses, outlining a series of frequency distribution curves and histograms. Dip distribution of the surfaces of the two planets has been classified considering the percentage of the area with a slope $< 3°$ and $\geq 3°$ (Figs. 3, 4). Curvature distribution has been classified into two categories: negative and positive curvature areas, which represent irregular and nonplanar zones, and a class of curvature of about 0, corresponding to planar and subplanar areas (Figs. 5, 6).

3. Analysis of the results

Comparison between the distribution curves of Mars and Earth areas at different elevations shows differences and analogies. The clear bimodal distribution (Fig. 2b) on both

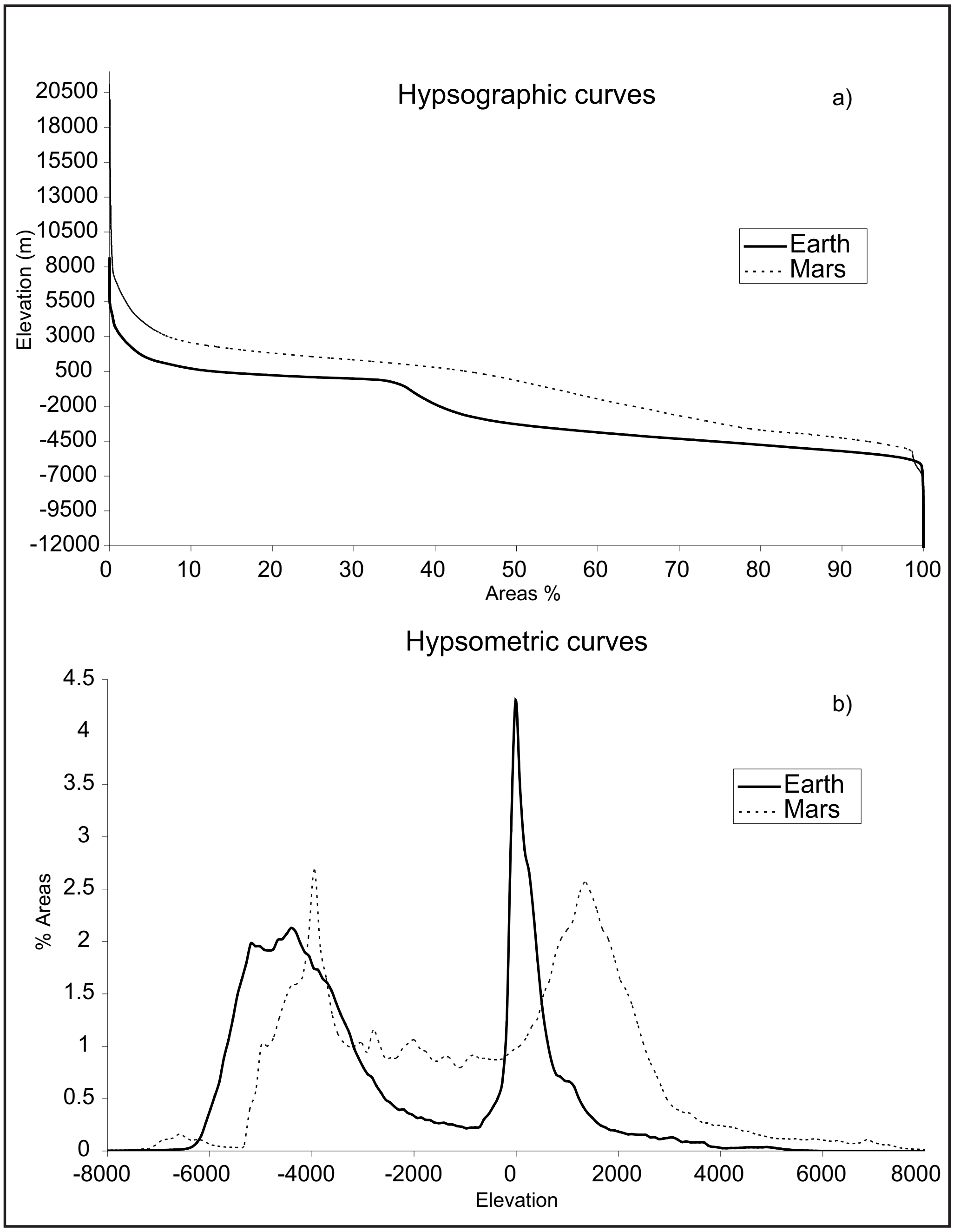

Fig. 2. Comparison between the terrestrial and Martian Hypsographic (a) and Hypsometric (b) curves.

the curves suggests similar geodynamic processes of crustal differentiation on Earth and Mars. Also Mars is characterized by two different crusts, such as the continental and oceanic

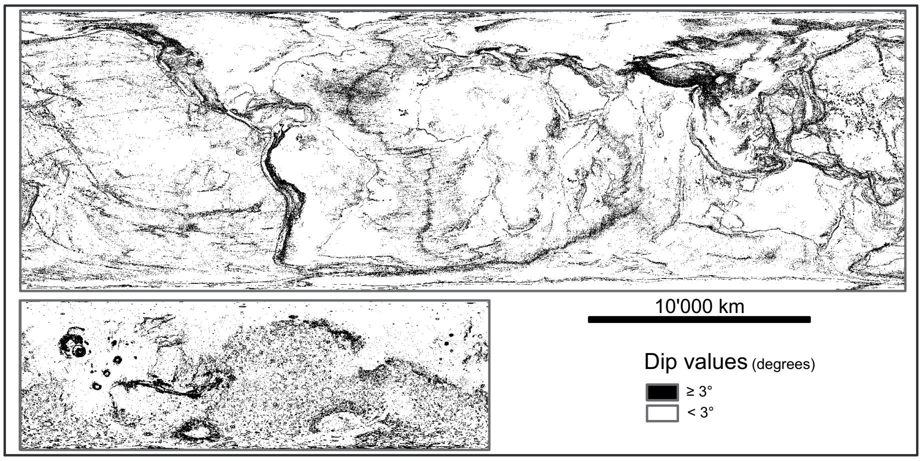

Fig. 3. Dip distribution of the terrestrial and Martian surfaces (equal area projection).

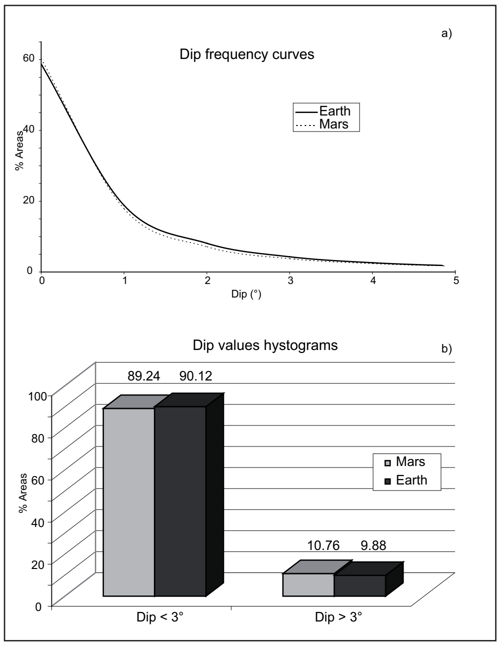

Fig. 4. Comparison between the dip distribution curves (a) and histograms (b) of the terrestrial and Martian surfaces.

crusts on Earth (Zhong & Zuber 2001). Two different kinds of crust could explain the Mars dichotomy (Smith & Zuber 1996), represented by the presence in the northern hemisphere of a wide (about 20% of the total surface), lightly cratered and younger depressed area (lowlands) and an elevated, rugged, heavily cratered and ancient terrain in the southern hemisphere (highlands). The lowlands have an average elevation of 5 km below the highlands and are rich in dune fields, rift valleys, dry riverbeds and water flow patterns.

The main differences between the two hypsometric curves are represented by their peaks and the trend between them (Fig. 2b). Not considering the zero value points of the two curves, which were produced using different criteria, it can be seen that the height difference between the two peaks on Mars (~5300m) is greater than that on Earth (~4500m), and the trend between the two main peaks shows differences in terms of elevation value frequency. The minimum between the two peaks has a difference of less than 0.2% in the Earth curve, while the corresponding value of the Mars curve is just less than 1%. This difference could indicate the long-term inactivity of tectonic processes on Mars with subsequent isostatic readjustment of the surface, and/or an early interruption of the crustal differentiation. The same features are visible comparing the two hypsographic curves, where the less marked differentiation of the two different kinds of crust is more evident (Fig. 2a).

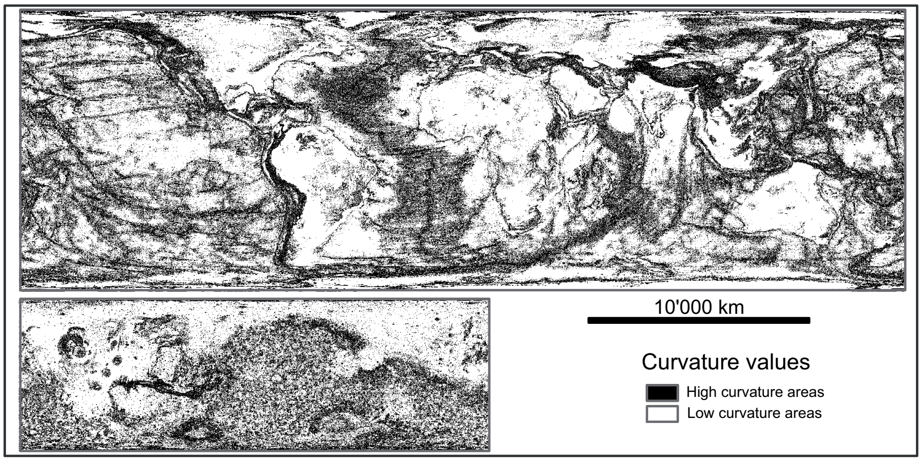

Fig. 5. Curvature distribution of the terrestrial and Martian surfaces (equal area projection).

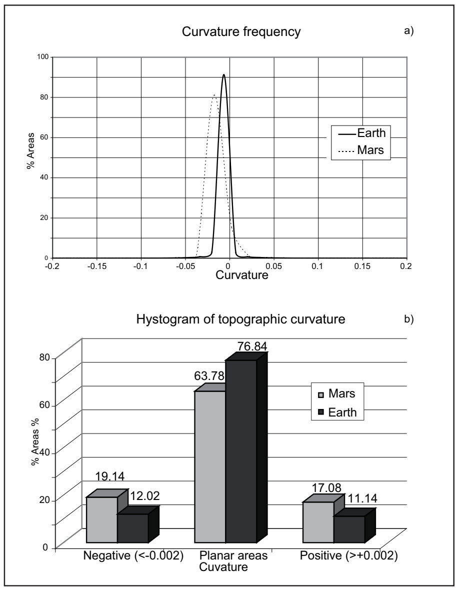

Fig. 6. Comparative analysis of the curvature distribution curves (a) and histograms (b) of the terrestrial and Martian surfaces.

The comparison between the dip distribution curves of Mars and Earth shows an essential similarity, with the same trend and the same percentage of the surface (about 10%) characterized by a dip of more than 3° (Fig. 4). Conversely, the curvature comparative analysis outlines significant differences (Fig. 6). The surface of Mars is clearly more irregular and abrupt; arbitrarily considering as regular the areas with a curvature of less than 0,0002 , then 77% of the Earth's surface is regular, while only 64% of Mars is similarly regular. The comparison between the two maps representing the distribution of the curvature (Fig. 5) shows that the widespread topographic irregularities of Mars are essentially due to the presence of numerous impact craters, and subordinately volcanic edifices, while the topographic irregularities of the Earth coincide with plate margins and especially with collisional margins characterized by mountain belts. This difference is evident observing the general pattern of the curved areas: circular, sub-circular or irregular on Mars, but elongated and linear on the Earth. The only exception is the Valles Marineris, generally considered to be an extensional rift valley.

Clearly the different erosion rates on the two planets plays a fundamental role: the greater part of the topographic accidents on Mars date back to the Noachian period (more than 3.5 billion years ago), when craterization of the surface was very intense and the succes-

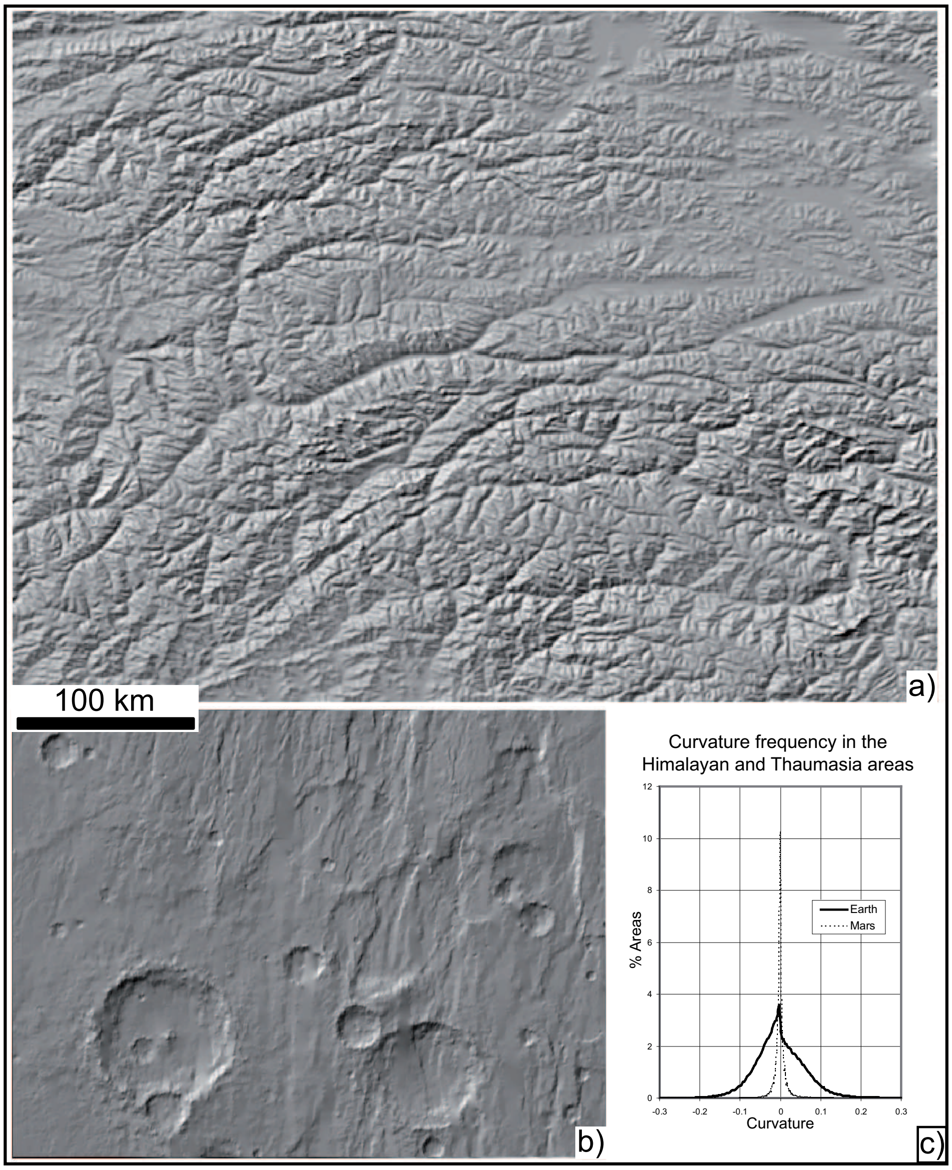

Fig. 7. Shaded relief maps of two typical rugged areas on Earth (Himalaya) (a) and Mars (Thaumasia Region) (b). Comparison between the curvature distribution of the Himalaya and Thaumasia surfaces (c).

sive erosion and morphological evolution was a trivial process; conversely the topographic relief on Earth is the expression of recent processes because it is subjected to intense and diffuse erosion and obliteration. In fact, the impact craters on Earth, probably as widespread in the past as on Mars, are now insignificant morphological features.

Moreover, if we compare two typical rugged areas on Earth (e.g. Himalaya) and Mars (e.g. Thaumasia Region) the results show that a collisional belt on Earth has a much greater curvature (Fig. 7) than any other kind of irregular surface on Mars. This observation confirms, moreover, that the topography on Mars is the product of the past, caused by currently inactive processes essentially linked to craterization and volcanism, and that now there are no visible topographic features related to plate tectonics or similar processes.

4. Conclusions

The analogies and differences between the topographic features of Mars and Earth indicate that the two planets have been subjected to a different geological evolution, especially during the last 2 or 3 billion years. In fact, since the two frequency distribution curves of elevation show an analogous bimodal nature that suggests an oceanic and continental crustal differentiation, producing the Mars dichotomy, the differences in the pattern of the curves, especially between the two peaks, probably indicate a premature end to geodynamic processes on Mars, with an early interruption of the crustal differentiation and consequent isostatic crustal adjustment. The comparative analysis of the dip and curvature of the surfaces confirms the long-lasting geodynamic and morphological inactivity of Mars, where craterization and volcanism were the more significant processes that modelled the surface of Mars.

References

Baker V. R. 2005, Nature 434, 280

Golombek M. P. & Bridges N. T. 2000, J. Geophys. Res., 105, 1841

Neumann, G. A., D. D. Rowlands, F. G. Lemoine, D. E. Smith & M. T. Zuber, 2001, J. Geophys. Res., 106, 23723

Roberts A. 2001, First Break 19, 85

Smith D.E. & Zuber M.T. 1996, Science, 271, 184

Smith D.E., Zuber M.T., Frey H.V,. Garvin J.B., Head J.W., Muhleman D.O., Pettengill G.H., Phillips R.J., Solomon S.C., Zwally H.J., Banerdt W.B., Duxbury T.C., Golombek M.P., Lemoine F.G., Neumann G.A., Rowlands D.D., Aharonson O., Ford P.G., Ivanov A.B., Johnson C.L., McGovern P.J., Abshire J.B., Afzal R.S. & Sun X.L. 2001, J. Geophys. Res. 106, 23689

Watters, T., McGovern, P. & Irwin Iii, R. 2007, Ann. Rev. Earth Planet. Sci., 35, 621

Zhong & Zuber 2001, Earth Plannet. Sci. Lett., 189, 75