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Hydrological investigation of Mars Durius Vallis watershed

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Abstract. We present the preliminary results of a geo/hydrological investigation we have performed on the Mars Durius Vallis region, a specific equatorial transition region located between 168° and 177° East Longitude and 15° to 22° South Latitude, where we identified dense drainage networks and patterns. Most of the riverbeds we present do not show morphologies attributable to catastrophic mega-floods. They show, instead, erosional morphologies requiring long time formation, hence needing an extended rain-cycle and/or sapping processes acting for extended periods of time.

Key words. Mars – Hydrology – Riverbeds – Drainage Density – Durius – MOLA DEM

1. Introduction

The study of superficial fluvial morphologies on Mars may provide us with a complete new picture of the past hydrological history of the red planet. Mars appears to be characterized, in an era yet to be determined, by large quantities of liquid water sustained by an Earth-like water cycle. Superficial liquid water may also imply that environmental conditions appropriate to sustain organic and prebiotic chemistry were present on Mars. These conditions could eventually lead to the development of life, if they were maintained for a sufficient amount of time.

Drainage networks mainly characterize the heavily cratered southern plateau of the planet (Pieri 1980), while the ancient northern lowlands of Mars have been resurfaced since the time planet-wide valley development ceased

(Parker et al. 1993). In particular, the transition region between the southern highlands and the northern plains, characterized by a planet-wide fretted escarpment, shows noticeable valleys patterns and drainage networks (Pieri 1980; Parker et al. 1993).

We have identified Mars equatorial drainage basins on the basis of topographic and hydrologic evidences. These basins are characterized by slopes and riverbeds. Focusing on the riverbeds networks we have determined and analyzed hydrological parameters trying to unveil the origin and complex evolution of Martian drainage systems.

2. Hydrology parameters

A stream network is defined trough several hydrological parameters derivable from a digital elevation model:

- 3D length of all detectable riverbeds, computed from the source to the mouth, belonging to the entire drainage area,
- 3D area of the whole drainage basin,
- Drainage density, derived from the ratio between the total sum of the 3D lengths of all detectable riverbeds and the 3D drainage area of the basin,
- Mean slope of each riverbed and mean slope of the drainage network area,
- Strahler order and Shreve magnitude which classify all segments of the riverbed.

The drainage density expresses the degree of basin dissection by surface stream. Given a valley network, the closer the riverbed heads are to the drainage divides, the greater the total length of the network, and hence the drainage density, is. This parameter reflects the interaction between the channelization processes, the ground water resistance and the diffusive infilling processes. It influences the water discharge efficiency from a given area during individual rainfall or water production events.

Two objective criteria used to define a riverbed on Earth are the Strahler order and the Shreve magnitude (Horton 1945; Schumm 1956) . Assuming no triple junction, the first parameter attributes order one to the fingertip tributary which originates from a source. When a junction between two streams of order u happens, a new stream segment of order $u+1$ is formed. If a junction of two streams of unequal order u and v happens, being v greater than u, the downstream segment is considered by Strahler methodology having an order equal to that of the higher order stream v. On the other hand the Shreve methodology attributes order one to the fingertip tributaries originating at a source and when a junction of two streams of order u and v takes place, the order $u+v$ is given to the new riverbed segment.

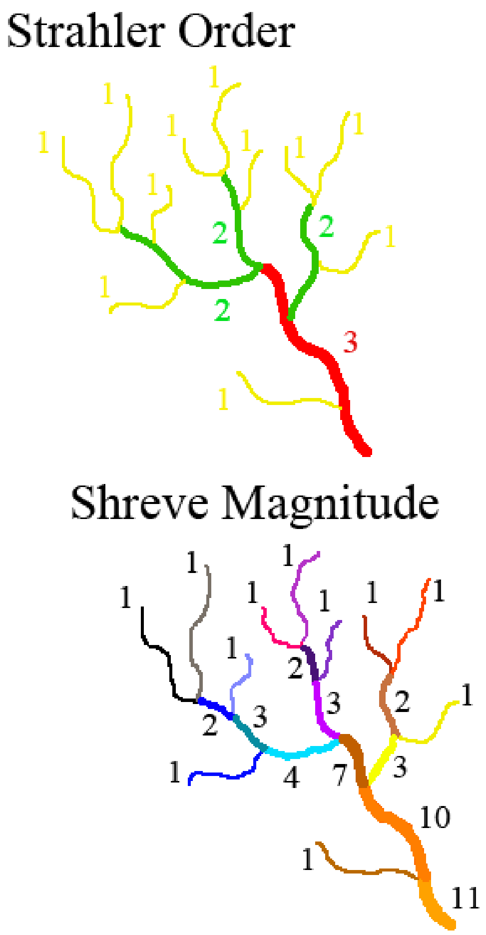

Fig. 1. The difference between Strahler and Shreve methods in attributing the riverbeds stream order.

A graphic representation of the difference between Strahler and Shreve methods is presented in Fig. 1.

3. Analysis and discussion's results

This study is based on a digital elevation model (DEM) which presents a scale of 460 m/px, derived from the Mars Orbiter Laser Altimeter instrument MOLA (Zuber et al. 1992) onboard NASA *Mars Global Surveyor* spacecraft. We focused on the region called Durius Vallis. This area is situated across the equatorial transition region of the Martian hemispherical dichotomy, located between 168° E and 177° E Longitude and between 15° S and 22° S Latitude. This region is surrounded on the North side by the de Vaucouleurs crater, on the East and South side by the huge watershed related to the Ma'adim Vallis, on the West side by the Al Qahira Vallis watershed. The Durius region presents a difference of elevation of roughly 4 800 meters, the highest peak being 3 052 m located South of the Durius Vallis and the lowest point being North, at -1 770 m inside the Durius Vallis itself.

Through the use of the ESRI Software ArcGIS10 and Python routines, we extracted the Durius's drainage networks from the MOLA DEM. We identified a total of 34 riverbeds scattered over the entire Durius Vallis surface. An example of the resulting map is showed in Fig. 2.

Once the drainage networks are identified, we computed the Strahler order and the Shreve magnitude, the 3D stream length of the riverbeds and the 3D area of the watersheds. The drainage density, the highest and the lowest elevation value and the mean slope of each riverbed were also computed.

In Fig. 3 we present the plot area versus mean slope derived from our data. Som et al. (2009) state that on a typical active terrestrial orogens the slope can be related to the drainage area as an inverse power law of exponent θ, being this exponent the river profile concavity. On terrestrial terrains Som et al. (2009) claim this value to be 0.5. We fitted our points with a linear law, a power law, an exponential law and a logarithmic law. Our best fit is the power law equation overwritten in the plot:

$$y = 8.462x^{-0.504}. \quad (1)$$

The last value presented at the end of each fitting equation is our computed best mutual fit index (ζ), derived with the equation:

$$\zeta = \sqrt{\frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n-1}},$$

where n is the total number of riverbeds, y_i is the measured value and $\hat{y}_i$ is the expected value from the fitting equation. As it is derivable from the best mutual fit index definition, the best fitting equation will be the one with the lowest value of ζ. The derived global riverbeds profiles concavity, θ, we obtained is consequently 0.5. This value implies that the typical active terrestrial processes cited in Som et al. (2009) were possibly active also on Mars at the time the Durius Vallis riverbed network was carved.

We followed the same approach with the length-slope plot, fitting multiple functions and finding out that the power law fit is still the best fit for our data:

$$y = 3.938x^{-0.580}.$$

What the plots in Fig. 3 and in Fig. 4 are showing is that the greater the slope of the terrain, where the river has carved its bed, is, the smaller the drainage area of the basin and the length of the river itself is. More inclined terrain do not easily give the possibility to the river to carve a more sinuous, and hence longer path, as it happens on Earth. On Earth meandering riverbeds happen when they cross flat or softly-sloping terrains.

In Fig. 5 we show the relationship between the 3D length of the riverbeds and their 3D drainage area. Som et al. (2009) state that the scaling relationship between channel length and drainage area is a robust empiricism for perennial and ephemeral channel through the full range of drainage area size on Earth. This relation, called Hack's law, is commonly expressed as a power law relationship relating the length of the main riverbed of a network and its

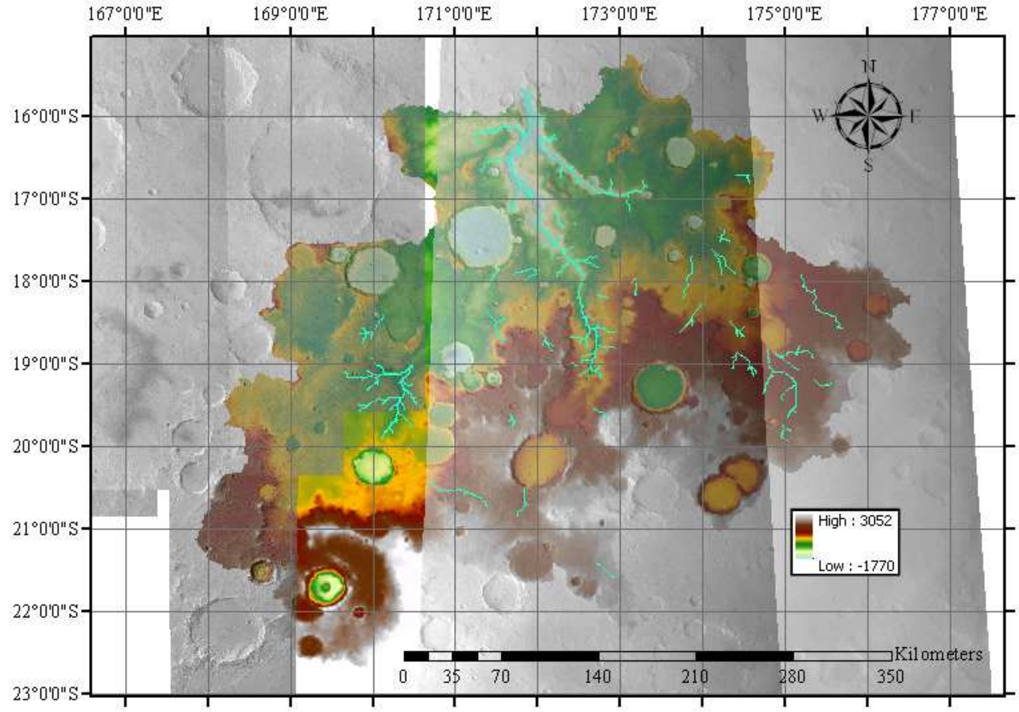

Fig. 2. Map of the Durius Vallis with the 34 polylines identifying all riverbeds found in this watershed. The scale in kilometers is showed on the map together with the elevation values which are indicated in meters. The images presented are those from the High Resolution Stereo Camera, HRSC, onboard ESA *Mars Express* spacecraft (Neukum et al. 2004).

global drainage area to the exponent n. This exponent n is expected to be of 0.5-0.6 on Earth.

In our method we have decided to consider the total length of each single network belonging to one drainage basin and not only the length of the main river belonging to the network, as in Hack's approach. As shown in Fig. 5, the derived best fit is not a power law relationship as in the case of the Hack's law, but rather a linear law showing that bigger the length of the network is, bigger its correspondent drainage area will be. The derived equation is:

$$y = 8.28x - 17.14,$$

and it also presented on the plot.

For sake of completeness we analyzed the behavior of the Strahler order and Shreve magnitude with respect to the average surface slope. We also observed, as expected, that the greater the slope of the area is, the smaller the Strahler order of the network is (the same behavior happens on Earth on the mountains sides). For smaller slopes the riverbed network becomes bigger arriving up to order number 4. The same behavior happens when the Shreve magnitude is plotted against the slope.

4. Summary and conclusions

We presented the preliminary results of a geo/hydrological investigation we have performed on the Mars Durius Vallis region, an area situated across the equatorial transition region of the martian dichotomy, located between 168° E and 177° E Longitude and between 15° S and 22° S Latitude.

This is a specific equatorial transition region where we identified 34 riverbeds, some of them presenting dendritic patterns. The morphologies we pointed out throughout our pre-

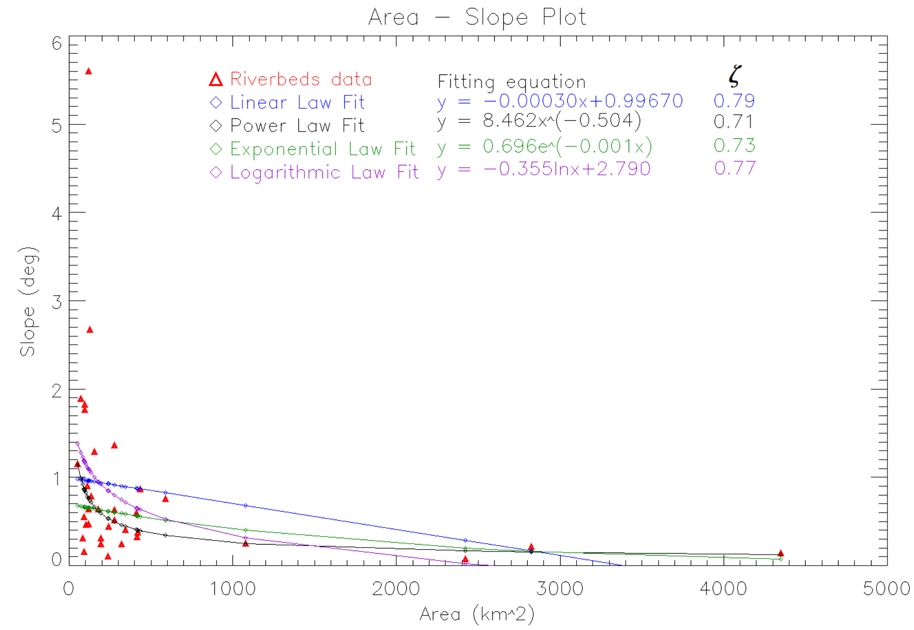

Fig. 3. The Area - Slope relationship. The riverbeds data and the four different fits are presented together with their fitting equation and the best mutual fit index ζ.

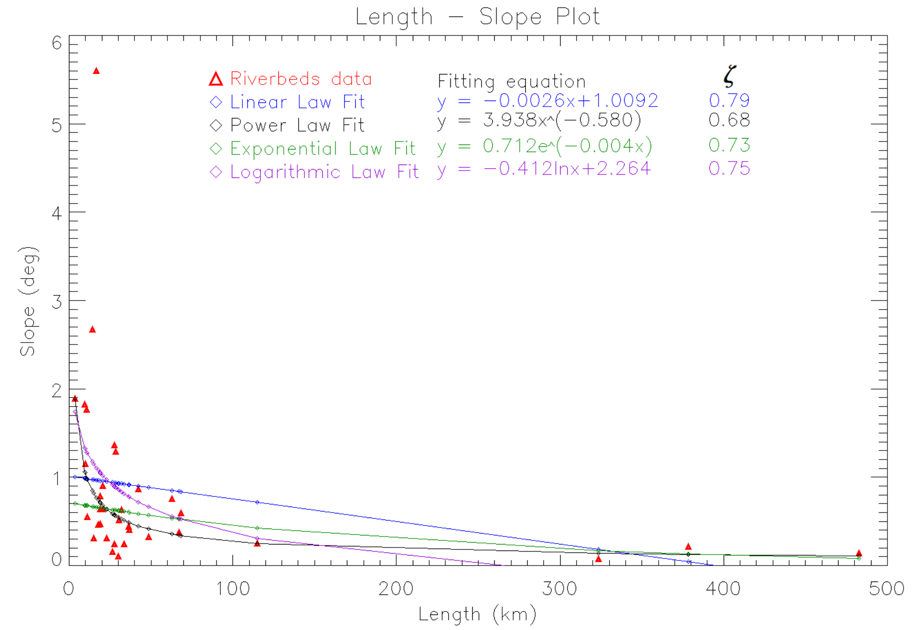

Fig. 4. The Length - Slope relationship. The riverbeds data and the four different fits are presented together with their fitting equation and the best mutual fit index ζ.

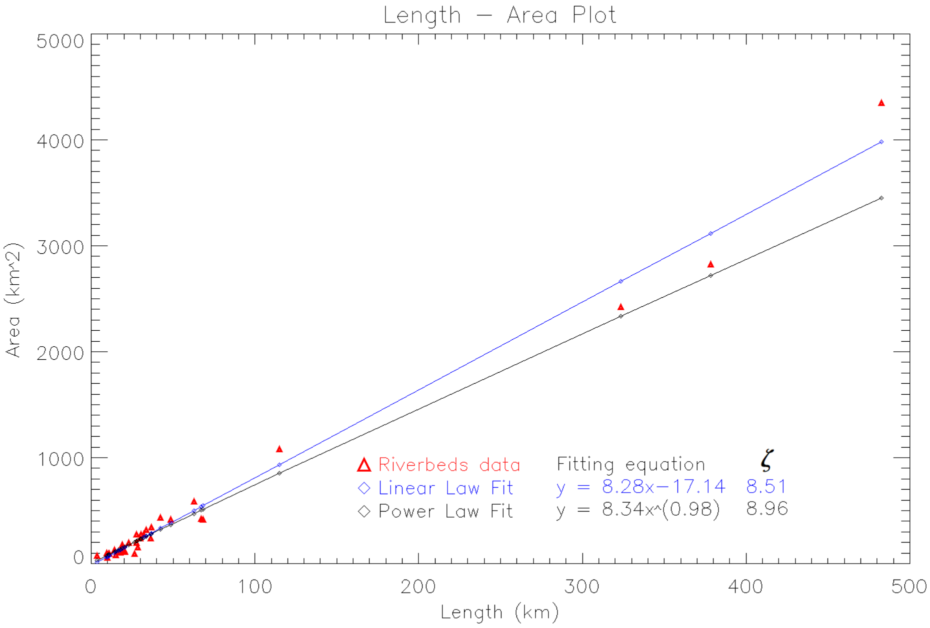

Fig. 5. The Length - Area relationship. The riverbeds data, the linear law and the power law fitting equations are presented together with the best mutual fit index ζ.

liminary results are not attributable to catastrophic mega-floods, instead they show erosional morphologies requiring an abundant and long-lasting presence of water on the surface. The analysis of area-slope and length-slope plots shows that the typical processes active on Earth cited in Som et al. (2009) were possibly active also on Mars at the time the Durius Vallis riverbed network was carved.

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