Global mapping and formation timescales of Martian fluvial systems

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Among all the planets of the Solar System except Earth, Mars is the one who has the greatest potential to host living organisms, extinct or current. In 1971 the mission Mariner 9 discovered fluvial systems on the surface of the planet. The images showed huge channels carved by catastrophic floods and valley networks of great extension. This discovery was one of the most important steps in the exploration of the Solar System because showed the signs of the presence of liquid water on the surface of a planet. However at present, the average atmospheric pressure on Mars is 7 mbar, the average temperature is 218 K. So ice typically sublimates to the water vapour without passing through the liquid phase [1]. The only possible precipitations are those of carbon dioxide in the solid state. The presence of valley networks on the Martian surface is the most compelling evidence that Mars was once capable of sustaining liquid water at the surface [2] [3]. These valleys, with their meandering trunks, densely dendritic form and tributaries resemble to the terrestrial one and seem to have formed by similar processes as terrestrial river valleys [3]: Martian valley networks show features resulting from a water surface flow likely due to rain or snow melting. This would suggest that early Mars could have been warmer and wetter than today with atmospheric pressure and surface temperature different from the present ones [4]. However, detailed geomorphic analysis of individual valley networks did not lead to a general consensus regarding their formation timescales. Therefore from a paleoclimatic point of view it is interesting to map Martian valley networks and to determine their formation timescales.

In this work we have used QuantumGIS (QGIS), a Geographic Information Software as a tool to create a map of Martian valleys and to calculate their geometric parameters (such as area and volume), based on MOLA (Mars Orbiter Laser Altimeter) and THEMIS (Thermal Emission Imaging System) data.

The MOLA experiment, aboard of the Mars Global Surveyor orbiter spacecraft, produced a global topographic grid with a 30 cm/pixel vertical resolution and ~460 m/pixel horizontal resolution at the equator [5], [6].

THEMIS went into orbit around Mars in 2001 aboard to the Mars Odyssey spacecraft. It is a camera which collects visible and infrared images with a resolution of ~ 19 m/pixel and ~ 100 m/pixel. A global mosaic of 100 m/pixel has been released to the public.

Combining THEMIS daytime IR and MOLA topographic data improves the identification of valley networks over THEMIS or MOLA alone, resulting in a superior data set for accurate mapping and analysis of the valley networks on Mars. The valleys have been mapped manually using same criteria followed by other authors [7],[8]. We searched for sublinear, erosional channels that form branching networks, slightly increasing in size downstream and dividing into smaller branches upslope. The mapped valleys have also been divided into different groups: valley networks (systems highly developed with many tributaries); single valleys (systems at most with one or two tributaries); longitudinal valleys (structures characterized by a long main branch and few tributaries); valleys on vulcanoes (valley networks and single valleys which are located on vulcanoes) and valleys on outflow channels or on rift systems (small tributaries of large canyons such as *Valles Marineris*).

We have used the map of Hynek and colleagues [8] as base map of our study. Respect to the previous manual maps [7], [8] data of higher image quality (new THEMIS mosaic) and topographic information allow us to identify more tributaries for a large number of systems. In order to be included in our catalog a feature has to: reflect the actual topography (as verified by a longitudinal profile); show V or U-shaped cross sections (as verified by a cross profile). We have mapped all the Martian valleys longer than 20 km obtaining: new tributaries for 919 valleys; 204 new valleys; 358 removed structures.

To understand the formation mechanisms of these fluvial systems and consequently make assumptions on the ancient climatic conditions of

the planet, we have determined the formation time of a sample of 63 Martian valleys, containing all the Martian fluvial systems with a total length greater than 600 km and a main branch longer than 160 km.
Our sample has been divided in two groups: 1) valleys with an interior channel (13 valleys); 2) valleys with no visible interior channel (50 valleys).
For the first group we estimated the formation time using a method based on the evaluation of water and sediment discharges. In particular, water discharges were obtained through morphometric (flow depth and width of the channel) and hydraulic parameters using a modified Manning's equation for steady, uniform flow taking into account the lower gravitational acceleration on Mars.[9] We obtained sediment discharges through the water discharge assuming a sediment load of about 10 kg/m^3.[9] Finally, the formation timescales have been calculated by the ratio between the eroded mass and the sediment discharge.

The formations timescales thus obtained are representative of a continuous flow. This is possible only in environments that invoke an essentially continuous source of supply for liquid water. Even on Earth channel forming conditions occurs rarely owing to the variability of the climatic phenomena. There is no reason to think this would be different for Martian valley networks [10]. So we assume 3 different possible values of intermittency: 5% if conditions on early Mars were humid or sub-humid [10], [11]; 1% if Martian environments were analogues to semiarid/arid terrestrial ones [10]; 0.1% for hyper-arid environments [12]. Once obtained the formation times for each valley we have evaluated the erosion rates, i.e. the eroded mass per unit of area and time. The mean erosion rates obtained for the 13 valleys with visible interior channel were used to calculate the formation times for the other 50 valleys considering the ratio between eroded mass and erosion rate. The formation times obtained in the four different cases (continuous flow, 5%, 1% and 0.1% of intermittency) are shown in Fig.1.

Since, owing to the variability in climatic phenomena, channel-forming flow conditions very rarely occurred on Mars[10], we have to exclude the first scenario. On the other hand, using an intermittency of 0.1% we obtained for twenty valleys values around 10^9 yr and these values are very unlikely if we consider that the age of Mars is 4,5 billion years. So there are two possible scenarios: Mars could have been humid and temperate or the valleys were formed in semiarid/arid environments. We think that the latter are more plausible according to the scenario proposed by several authors which suggest that, during the period of valleys formation, the climatic conditions on Mars were arid or semiarid [13],[14]. So in this scenario formation timescales of Martian valleys range from 6×10^4 to 5×10^8 yr. These results are in good agreement with those obtained by previous works and reported in literature [3].

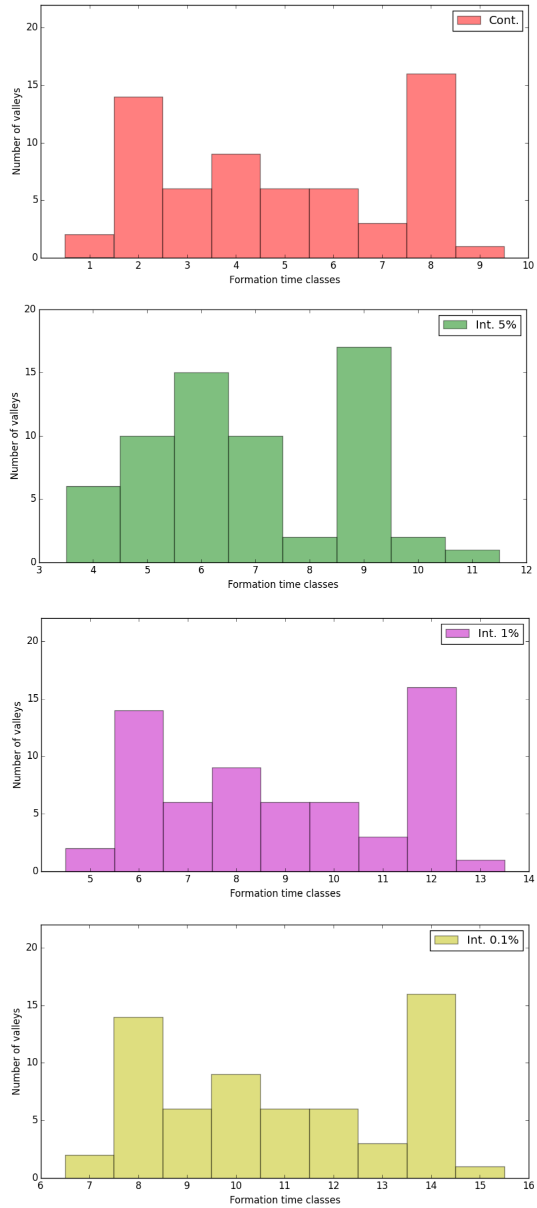

Figure 1. Histograms of the formation timescales obtained for the 63 valleys, here studied, in 4 different possible situations: continuous flow, intermittency of 5%, of 1% and of 0.1% . The timescales obtained were divided in 15 classes: class 1 - $5\times10^2 \leq t < 1\times10^3$, class 2 - $1\times10^3 \leq t < 5\times10^3$ and so on. The last class (15) has $5\times10^9 \leq t < 1\times10^{10}$.

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