The Case for a Cold, Dry Early Mars from a Global Map of Valley Network Origin and Distribution. A. Grau Galofre[1] and A. M. Jellinek[1], [1] Department of Earth, Ocean and Atmsopheric Sciences, The University of British Columbia (agraugal@eos.ubc.ca).

Introduction: The southern highlands of Mars, and in particular the regions along the dichotomy line between 30ºN and 30ºS are covered in networks of fossil valleys that extend for hundreds of kilometers and present a striking variety of morphologies. These networks are one of the few keys to understand Mars' surface conditions and climate of a past dating back to 3.8Byr ago.

Based on their morphology and on their resemblance to terrestrial analogues, numerous hypothesis have been suggested for their origin: (1) extensive fluvial runoff incision, implying warm and wet climate conditions and the necessity for an active hydrological cycle [1], [2]; (2) groundwater sapping and episodic surface runoff, requiring a climate that allows for surface water stability for short periods of time [3]; (3) valleys incised by glacial and subglacial erosion, implying a cold and wet climate with no need for liquid precipitation [4], [5]; and (4) valleys as an ancient drainage system below ice sheets and ice caps, indicating a cold, dry climate with a surface hydrological cycle limited to snow precipitation and sublimation [6].

Methodology: We use a novel image analysis methodology to show that some channel networks result from surface water runoff, requiring a climate that met the conditions for surface water, at least sporadically. However, the majority of drainage areas and channel stream orders of the most mature Martian channels (e.g., higher number of sources, largest drainage area) are rigorously comparable to channels in extremely dry environments on Earth, suggesting that Mars was predominantly a dry, desert planet with little presence of surface water, concentrated in areas of steep topographic gradients [7] (figure1).

To build understanding, we compile a database of over 70 Martian channels in different locations following a map by [7] and measure length-width ratio and width of source valley networks as a measure of flow dynamics and erosional potential, mean junction angle of the branches as a measure of flow-topography interaction, and fractal dimension and stream order as proxys for valley complexity and branching density.

Using a Prinicpal Component Analysis (PCA), we show that Martian channels are similar to terrestrial examples, discarding the possibility that the landscape was carved by lava flows or by CO_2 ice. We then identify distinct valley types (systems carved by glaciers, rivers, subglacial channels and sapping valleys) through their position in the PCA space and compare individually each valley with theoretical models of each of the five parameters above mentioned. We also analyze the power law behavior relating length and width, and compare the scaling exponent to the literature for each of the valley types. We base our analysis on evidence from the location of each valley type in the PCA, the power law behavior and the individual geometry of each valley in comparison with the models to (1) characterize the channels on an individual basis (see figure1) and (2) produce a global map of Mars showing the probability of a particular type of valley to be present on each area.

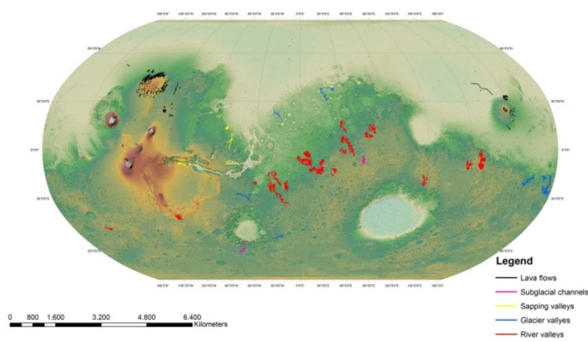

Figure1: Global map of Mars showing a classification of Martian valleys achieved using our methodology. Note the concentration of fluvial valleys along the large topographic gradients and the low complexity of the basins.

Results: We find at least 5 fluvial valleys along the strong topographic gradient following the entrance to the Noachian highlands from Arabia Terra (figure1, red stream lines), at least 4 glacier valleys following the Arabia dichotomy line (figure1, blue stream lines), extensive evidence for sapping valleys along the edges of Valles Marineris and in the younger terrains around the Tharsis bulge (figure1, yellow stream lines), and subglacial drainage channels in the Noachian highlands, 5 to 10º further south than their fluvial counterparts (figure1, pink stream lines).

Martian surface runoff valleys have a small number of order 1 channels (global number of 34653), 2 orders of magnitude below the number of order 1 channels in only the Australian continent (7380094 at 15s resolution [8]) and a maximum stream order of 7, compared to a maximum order of 11 in Australia. Similar results can be obtained considering other continents [8].

We also find evidence for groundwater erosion in the form of sapping valley development in much later stages of Martian history (late Noachian and Hesperian), along the edges of Valles Marineris. The formation of these valleys might not require climate conditions substantially different than the current ones.

Discussion: We find quantitative evidence for surface water runoff, implying that climate conditions had to meet the requirements for liquid water, at least locally and episodically. However, the low stream orders and low number of source channels compared to Australia and other sites on Earth suggest an extremely dry environment with scarce water to form source channels. Even in the cold and dry scenario we propose, liquid water can exist. For example, the paleolakes and delta fans mapped in Mars are possible in these climate conditions if they have a subglacial origin. We suggest that appropriate terrestrial analogues are lake Vostok (Antarctica), and other subglacial lakes and cavities in the Arctic and Antarctica.

Other pieces of evidence that support the cold and dry climate, on average, are (1) the localized presence of fluvial systems along steep topographic gradients, (2) the lack of substantial hydrous minerals and the abundant presence of pyroxenes and olivine, that degrade fast in the presence of abundant liquid water; (3) the lack of glacial valleys that would necessarily follow a warm and wet period with extensive presence of water; and (4) the climate models for Early Mars and the difficulty to justify warm temperatures under a faint young Sun [9].

Conclusions: Our results support the claim of climate models of a cold, dry Early Mars with episodes of liquid water runoff [5]. We show that fluvial runoff existed in the areas of steep slopes and strong topographic gradients delimiting Arabia Terra and the Noachian highlands. However, the small maximum stream orders on Mars, and the low number of channel sources suggest very scarce liquid water intake. Supporting other pieces of evidence, our study indicates that liquid water was existent, but significantly rare, on Early Mars.

References:

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