THE EVOLUTION OF SURFACE TOPOGRAPHY AND ENVIRONMENT OF MARS FROM CHANNEL NETWORKS.

R. Bahia[1], M. Jones[1], N. Mitchell[1], S. Covey-Crump[1], [1]University of Manchester, School of Earth and Environmental Sciences, The University of Manchester, Oxford Road, Manchester, M13 9PL (rickbir.bahia@manchester.ac.uk).

Introduction: Valley networks on the Martian surface have been noted as evidence for past water cycles and surface run-off on Mars for many years [e.g. 1–3]. Their orientation and distribution has also been used to understand Mars' ancient climate [e.g. 3, 4]. Responses to loading of the lithosphere 4.1-3.7 Ga, during the Noachian period, have been suggested to explain the positioning and orientation of these valley networks. New analysis of high spatial resolution images (e.g. Mars Orbiter Laster Altimeter (MOLA) and Mars Express High Resolution Stereo Camera (HRSC)) have, however, revealed valley networks orientated in many different directions relative to the Noachian slope [5–7].

The current explanation for this variation in valley orientation relative to Noachian slope, is that there was modification of the local topography (e.g. impact cratering) during the period between establishment of the regional slopes, and development of the channels [5, 6]. There are flaws in this hypothesis as the flows which produced the channels would still follow the regional slope as the channel developed, thereby preserving this change in slope. Other more plausible hypothesizes as a cause for channel reorientation are either distortion of the Martian surface post-channel formation due to impacts; or tectonic activity driven by lower crustal flow due to lateral crustal thickness variations or lithospheric flexure as a result of material deposition and/or erosion [7–10]. There are, however, no large scale studies at present which have analytically examined the effect that surface topographic changes, post-valley network formation, may have had on establishing this discordance.

The aim of this investigation is to examine the surface record provided by flows, such as water drainage channels (but also flows associated with glacial activity), to investigate the nature of both surface elevation and environmental changes on Mars. It involved the large scale identification of fluvial and glacial valleys across the Martian surface to determine their geological and age distribution. The relationship between valley density and morphology with age can be used to further our understanding of the past Martian climate; and help us discern whether Mars had sustained periods of a warm and wet climate, or whether these periods were more episodic and localized.

Since fluids flow down the slope of steepest descent, river channels are excellent geomorphological indicators of slope at the time of channel formation. We aim to identify the areas which show discordance between palaeoflow direction and current regional slope and determine the possible cause/s.

Martian Valley Maps: Three global maps of Martian valley networks have been produced at present [2, 3 and 11]. The most up-to-date global valley map was produced by Hynek et al. (2010) using THEMIS (Thermal Emission Imaging System) daytime IR (Infrared) (231 m/pixel), MOC (Mars Orbital Camera) wide angle (231 m/pixel) and MOLA (Mars Orbital Laser Altimeter) (~500 m/pixel) topographic data. Localized/regional studies using higher resolution images, e.g. CTX (Context Camera - ~ 5 m/pixel) have furthered our understanding of the timing, duration and the amount of liquid water required to produce valley networks, as well as identifying additional morphologies, e.g. inverted channels which cannot be distinguished in lower resolution images [e.g. 4, 12, 13, 14]. This investigation produces a valley map of Martian valley networks from -20° - 20° longitude and -90° – 90° latitude using high resolution images (~20 – 25 m per pixel), and categorizes channels with regards to their substrate and morphology. The selected study area covers 31 geological units, spanning all 3 geological periods; Noachian, Hesperian and Amazonian.

Data and Methods: The valleys were identified in ESA Mars Express Orbiter – High/Super Resolution Stereo Colour Imager (HRSC) images (~ 25 m per pixel) and manually mapped using the polyline function within ArcMap 10.2.1, defined under analogous characteristics as those of previous studies e.g. Carr [1995] and Hynek et al. [2010]; i.e., sublinear features dividing into small branches upslope and become singular downstream whilst slightly increasing in size. These polylines were subsequently converted into vectors, representative of the slope direction at the time of valley formation. This slope direction was then compared to the aspect (current regional slope direction) and the difference used to determine slope discrepancy.

Images were map projected using a combination of ISIS 3 (Integrated Software for Imagers and Spectrometers) and the United States Geological Survey (USGS) Map Projection Web Service (POW) image processing cloud to generate ArcMap 10.2.1 readable .cub file formats. Due to the large area covered by this investigation, we used the digital elevation model, MGS MOLA Elevation Model 463 m (MEGDR), created using information from the Mars Orbiter Laser Altimeter (MOLA; [Smith et al., 2001]), with horizontal resolution of ~ 100 m per pixel at the equator and 3 m vertical accuracy [Lemoine et al., 2001]. The identification and assessment of the morphological characteristics of valleys were carried out using ArcMap 10.2.1.

A secondary procedure used to determine the morphology of these sublinear features was the ArcMap 10.2.1 interpolate line feature, which allows for cross-section production whilst analyzing the images. Topographic troughs that were visually indicative of valleys formed by fluvial processes were traced.

In order to attain the relative ages and geological settings of the mapped valleys/channels, the Atlas of Mars 1:15,000,000-Scale Global Geologic Series Map was used [Skinner et al., 2006]. The ages for these surfaces are determined from crater density counts.

We created a new classification scheme that is based on objective criteria, allowing us to relate valley morphology to paleohydraulics and, therefore, the environment in which they were formed. By viewing the distribution of these channels, we can determine whether there is a relationship between the valley types and the environment/age of surface in which they form and what is controlling this distribution.

Channel Catalogue: The valleys were initially subdivided according to the substrate on which they were produced, i.e. bedrock or alluvial. This is due to the mechanisms which produced them being different; hence their morphology is indicative of differing production conditions. Gullies were not mapped in this study, due to the ambiguity in their formation mechanisms. Bedrock valleys were subsequently subdivided into V and U shaped. Alluvial channels were all identified as inverted channels and subdivided into: Single Channel – Low Sinuosity/Straight, Single Channel – Sinuous, Multithread – Anastomosing and Multithread – Braided.

Initial Results: A total of ~ 219.39 x 10^6 m of V-Shaped valleys were mapped out within the area of investigation, 44.63 percent more valley length than that mapped by Hynek et al.,. Similarly to previous studies these valleys were largely situated between -50° – 2° Lat., -20° – 20° Long. U- Shaped valleys are also present, however on a lesser scale (~18 x 10^6 m), with the majority situated in the lower latitudes (-83 - -62 Lat., -2.5 – 20 Long.). .). Valleys with both V and U shaped profiles are present throughout the study area. Bedrock incised valley networks were found on surfaces of all ages, however only short immature networks were found within Amazonian aged surfaces too.

Very few alluvial channels were identified, sparsely distributed between -45.0 – 33.2 Lat. The majority are sinuous (~1.19 x 10^6 m) in morphology, with low sinuosity/straight being second most common (~0.54 x 10^6 m), and braided least common (~0.41 x 10^6 m). Straight/low sinuosity channels and sinuous channels are situated in surfaces of all ages apart from the Hesperian-Noachian boundary, with most in Noachian aged surfaces. Braided channels are found only in Noachian aged surfaces.

Identified valley networks show a varying level of discordance with current regional slope (from following the current regional slope to complete inversion); however, more work needs to be done on these before any quantitative information can be revealed.

Discussion: The majority of channels/valleys are situated in Noachian aged surfaces, so this is likely to have been the period that saw most fluvial activity - consistent with previous studies [e.g. 2, 3]. Additionally, exclusively U-shaped valleys, indicative of glacial activity, are present predominately in Noachian surfaces, implying that this period saw most glacial activity too. The presence of these valleys conforms to the hypothesis that the global erosion rate was at its peak during the Noachian period, and that valley network production during this time was at its peak [14].

Many more valleys have been identified in our study than found by Hynek et al. (2010), further supporting the theory of extensive precipitation and surface runoff on ancient Mars. Denser concentrations of valleys are seen almost everywhere other than the northern most latitudes (> 50 Latitude), where no valleys have been identified. In addition, we have identified valleys in areas where they have not been noted previously (e.g. -30 – -60 lat., 0 – 20 long). We predict that images with greater resolution (e.g. CTX) will allow even more channels to be identified – Davis et al. (2016) using CTX images of an area also examined by this study identified many channels not seen in the HRSC images.

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