IMPACT-INDUCED HESPERIAN VALLEY NETWORKS AND THEIR IMPLICATIONS FOR THE HESPERIAN CLIMATIC REGIME. Gareth. A. Morgan and James. W. Head, Dept. Geol. Sci., Brown University., Providence, RI 02912 (gareth_morgan@brown.edu).

Introduction: Noachian valley networks have been identified and studied on Mars since their initial discovery in the early Mariner missions [1], and their origin has been a source of debate ever since. Due to the implied involvement of surface water runoff, their presence has been heralded as important morphological indices of the martian paleoclimate, suggesting that early warm and wet conditions once dominated the climatic regime of the planet [2]. However, the discovery of later Hesperian-aged valleys has called into question the traditional views of martian climatic history [3, 4]. Mangold et al (2004) [5] documented examples of such valleys that exhibit morphologies consistent with terrestrial precipitation-fed (pluvial) networks. Such findings have been used to infer that rather than an abrupt end to a warm-wet climate on Mars at the Late Noachian-Early Hesperian boundary, such atmospheric conditions and water cycle persisted well into the Hesperian.

Here we present the results of research into an area along the northern extent of the Dichotomy Boundary of Mars (centered at: 32ºE, 40ºW) (Fig. 1), a region that exhibits abundant evidence for glacial activity within the Amazonian [e.g. 6, 7]. The study area also displays valley networks formed in the Hesperian, dated on the basis of crater counting techniques [8-9]. However, there are other mechanisms by which valley networks can be formed that do not rely on the prevalence of conditions warmer and wetter than the current climate. These include: groundwater sapping, water lubricated debris flows and hydrothermal activity.

Our analysis revealed that an internal source of water, such as groundwater from an underground aquifer forming sapping features, was not consistent with the geological evidence. Instead our research supports an origin through surface runoff from the interaction of impact-induced hydrothermal activity and ice/snow deposits.

Morphology of the Region: The valley networks are located on the flanks of a ~60 km crater situated within an isolated plateau that is separated from the global escarpment by a system of fretted valleys. Integrated systems of Lineated Valley Fill (LVF) [7-8] are found to occupy the fretted terrain, similar to terrestrial debris-covered glacial systems. LVF has also been found within the main crater and across the plateau surface, and crater counts of portions of the LVF in the fretted valley to the south of the main plateau indicate a Late Amazonian (~100-200 Ma) age [9].

The Valley Networks: The networks are found both within the crater itself and along its flanks, but it is the external networks that are most abundant and hence of significance. Although valley networks are found across the plateau as far as 75 km from the crater rim, the majority of them are located to the south and southeast of the crater (Fig. 1). The valleys exhibit a range of scales consisting of widths from 500 m down to 30 m. In several sections some valleys are also observed to widen to the point that they are no longer clearly defined; in other sections braiding is apparent (Fig. 2). The valleys are generally steep-sided and have flat floors. No channels are observed to be present within any of the valleys at any of the available resolution scales, although this could be the result of material, such as LVF (which is found in craters across the plateau) being deposited within them subsequent to the valley formation. Tributary systems are a common occurrence for valleys of all scales and in some instances valleys diverge into several branches which reemerge down slope producing anastomosing patterns (Fig. 2).

Evidence for potential 'ponding' sites is also seen; channels are sometimes observed to disappear into hollows and reemerge from the down-slope side (Fig. 2). The depressions have a range of scales (of the order of several kilometers) and shapes and topographic relationships; comparison to fresh impact crater deposits suggests that their origin may be related to the impact event itself. Whether water pooled for any significant length of time is unclear. Evidence for lacustrian environments such as paleoshorelines and relic deltas have been found in other locations across Mars [e.g. 10]. However, no such features have been observed within the THEMIS and HRSC images and the small number of MOC high-resolution images. In many circumstances the depressions have flat, smooth floors at 20 m resolution, which may represent some form of deposited material.

Complex drainage systems make it difficult to interpret individual valley systems from the images. Nevertheless many of the valleys have an apparent orientation in a direction perpendicular to the crater rim. This is especially evident in the smaller networks but is also observed in the large valleys to the southeast of the plateau (Fig. 2). These are aligned in a northeast direction for almost their entire length apart from short sharp deflections consisting of 90º meanders, revealing interactions between crater ejecta and valley formation. Valley networks sources are not always clear. Many seem to originate from depressions within the outer reaches of the crater rim material, but the networks to the west of the crater have no apparent source; their upslope regions simply terminate on the plateau slopes. A large number of valleys are also found to originate close to the drainage divide formed by the summit of the escarpment that runs in a northeastern direction from the main crater rim.

Valley Formation: Underground aquifers have been suggested to exist on Mars to explain other water-eroded features [11], although in the absence of a significant means of recharge, such aquifers would simply be insufficient to supply such large scale valleys. The fact that valleys form on an isolated plateau that stands over one kilometer above the surrounding terrain, suggests that it is unlikely that this surface could be internally supplied by a significant enough source of groundwater to create the channels. The occurrence of valley heads at the crest of steep ridges running along the plateau is also not consistent with a subsurface aquifer water source eroding the valleys. Theater-shaped valley heads, which are typical of sapping valleys [12], are also absent. On the basis of these observations, groundwater sapping from a subsurface aquifer is not favored. This suggests that an external source of water may be responsible, for example, runoff supplied by direct precipitation or from melting of snow and ice.

The occurrence of anastomosing drainage patterns and braided valleys in the study region shares some similarities with terrestrial subglacial and proglacial drainage configurations [13]. The close spatial association between the crater and valleys implies that the impact event may have been linked to the subsequent formation of the valleys. The formation of impact induced hydrothermal systems on Earth is well documented [e.g. 14] and the generation of melt sheets within and around craters provide significant thermal anomalies. Computer models have revealed that even for small martian craters (D = 7 km) ground temperatures around the crater can be raised above 273 K for tens of thousands of years [15], a period sufficient for the erosion of the valley networks we have studied [e.g. 16]. Thus we suggest that an interaction between the thermal anomaly associated with the impact and the deposition of snow and ice was responsible for the generation of the valleys. This may have taken the form of hot impact ejecta landing on extensive snow and ice deposits similar to those that formed later in the Amazonian, or the deposition of snow shortly after the formation of the crater and its melting from the vestigial heat of the impact.

Conclusion: Significant evidence exists for the occurrence of glacial activity or 'ice ages' associated with orbital parameter oscillations during the Amazonian. Our analysis suggests that ice may have been deposited within the region during the Hesperian and melted by the hot ejecta to form the valley networks. Snowfall immediately after the event could have been melted by residual impact heat, further contributing to Hesperian valley network formation. When considered in the context of the other Hesperian valleys [such as those presented in [17], the Hesperian may have been characterized by a more complex climatic regime than initially thought. In relation to the recent documentation of apparently active gullies [18], water may well have been an important agent of erosion throughout the history of Mars, further supporting the possibility of life on the planet.

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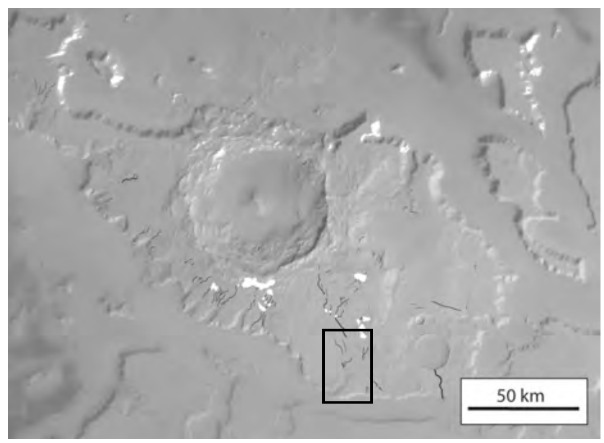

Fig. 1. HRSC image of the study region showing the distribution of the valley networks.

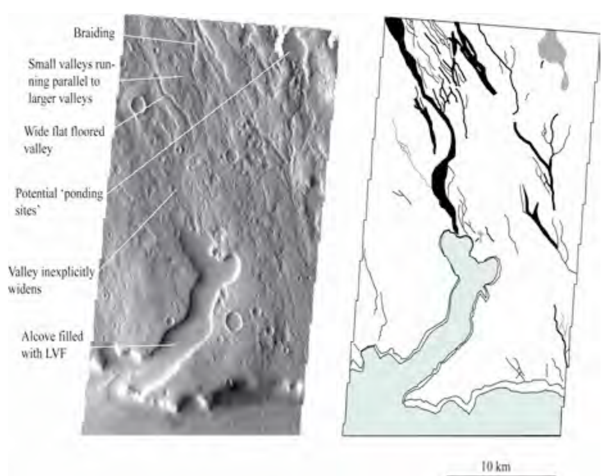

Fig 2. Themis visible image and Sketch map highlighting the morphology of the valley networks.