THE END OF THE BEGINNING: THE HESPERIAN-AMAZONIAN TRANSITION CLIMATE OPTIMA

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Introduction: Recently the inventory of fluvial features that have been dated to the late Hesperian to early Amazonian epoch (A-H) has increased dramatically, including a reassessment of the ages of the large alluvial fans [1] and deltas (such as in Eberswalde crater) to this time period [2]. The well preserved fluvial landforms of the Hesperian-Amazonian transition are of particular interest because they may represent the last widespread episode of aqueous activity. Activity that took place during a time widely believed to be characterized by a relatively thin atmosphere and global cryosphere. Deciphering the climatic environment in this epoch capable of forming such fluvial features is challenging but is significant in terms of furthering our understanding of the potential late-stage habitability of Mars. The effects of water (both fluid and ice) on a paleo-landscape are the most unambiguous marker of past climate. No other process leaves a more exquisite signal of general weather.

Geological Observations:

Mid latitude Valleys: Since large alluvial fans and deltas have been discussed fairly widely, we will focus here on mid-latitude valleys (MLVs). The mid-latitudes of Mars feature distinctive landforms, including mantling deposits, possibly glacial and periglacial landforms, young gullies on steep slopes, and sparse, shallowly-incised, fresh-appearing valleys (e.g., [3-4]. MLVs are distinct from the older, more integrated Noachian-Hesperian (N-H) valley systems which are deeply dissected, are generally of much larger spatial extent, and are more degraded [5-8]. Although some MLVs involve rejuvenation of older valley networks, many MLVs are carved into smooth or rolling slopes and intercrater terrain (Fig. 1). The MLVs range from a few meters to more than 300 m in width, with nearly parallel valley walls and planforms that are locally sinuous. Although the MLVs in Newton and Gorgonum basins extend from the basin rims up to 75 km into the basin interior [9], most MLVs are shorter and often discontinuous.

We operationally define MLVs into two classes (Fig. 2). 'Mode 1' valleys are narrow, sinuous, entrenched valleys typically with sharp upper edges at CTX image scales. They are generally "v-" or "u"-shaped with widths 20-50+ m and may range from a few hundred meters in length to several kilometers (also see Fig. 2 in [9]). Mode 1 valleys are often unbranched, start and terminate abruptly by narrowing and shallowing, may lack obvious fluvial features upstream or downstream, or they may connect to Mode 2 valleys (Fig. 2). Several Mode 1 valleys may chain together with intervening Mode 2 valleys or with no apparent connecting fluvial features. 'Mode 2' valleys are wider generally with near-parallel borders and nearly flat floors (Fig. 2). The lateral borders may be indistinct, but are sometimes steep slopes of varying height. They often exhibit low longitudinal lineations which appear to be bedforms such as fluvial bars or low banks. These bedforms suggest that Mode 2 contained flows over their width, and are thus channels incised to varying degrees relative to their surroundings. Mode 2 valleys often connect to or are interspersed with Mode 1 valleys.

The MLVs are distinguished from the N-H valley networks by having a restricted latitudinal range, a less-degraded morphology, a shallower incision, and dimensions suggesting considerably lower formative discharges (up to a few tens of cumecs [9]). Although a wide variety of evidence suggests that the N-H valley networks formed by widely distributed precipitation as rain or snow and subsequent runoff (see summaries in [7, 10-18]), features of MLVs are more enigmatic and have been hypothesized to have resulted from more than one mode of origin and multiple episodes of formation.

Infernces for H-A Climate: The sourcing of most MLVs at the upper basin interior rims and regional highs indicates water was primarily derived from precipitation limited to these localities. We suggest that this pattern is most consistent with precipitation as snow or frosts rather than convective rainstorms. As in terrestrial mountain ranges, snow or frost could accumulate seasonally or possibly over multi-year periods during obliquities favorable for ice accumulation in the mid-latitudes (e.g., [19-20]) with seasonal or episodic melting of the snow or ice deposits feeding the MLVs. The absence of obvious glacial features associated with these source regions suggests either that the inferred ice deposits were only tens of meters thick or were cold-based but subject to episodic melting.

A variety of mechanisms have been suggested for producing runoff that formed post-Noachian Martian valleys, including hydrothermal circulation for the volcanic channels [21-22], accumulation of snowpack with melting due to volcanic heating [23-24], melting of ice-rich deposits due to a favorable climate at low relative elevations [3], melting of glacial ice [4] and the direct influence of an impact cratering event [25-26]. The dendritic MLV networks and those in Newton and Gorgonum basins [9] appear to require at least regionally extensive precipitation, either producing direct runoff or melting of accumulated snow and ice [27-29]. Explanations for the post-Noachian fluvial features that require precipitation or ice melting raise the possibility that fluvial activity during the later Hesperian and Amazonian may have may have been the consequence of one or more global episodes of enhanced precipitation.

The occurrence of widespread MLVs suggest the possibility of their formation during one or more regional to global climatic episodes, perhaps due to melting of seasonal to long-term accumulations of snow and ice. Temperatures warm enough to cause extensive melting may have occurred during optimal orbital and obliquity configurations, perhaps in conjunction with intensive volcanism releasing moisture and greenhouse gasses, or as a result of a brief episode of warming from a large impact somewhere on Mars. The location of most MLVs to the northern and western basin slopes of Newton and Gorgonum basins suggests a possible aspect control to ice accumulation or melting [9]. MLV activity occurred about at the same time as formation of the major outflow channels (e.g. [30]). A possible scenario is that delivery of water to the northern lowlands provided, through evaporation and sublimation, water that temporarily accumulated in the mid-southern latitudes as widespread ice deposits whose partial melting formed the MLVs and small, dominantly ice-covered lakes such as occurred in Gorgonum basin (e.g., [31]).

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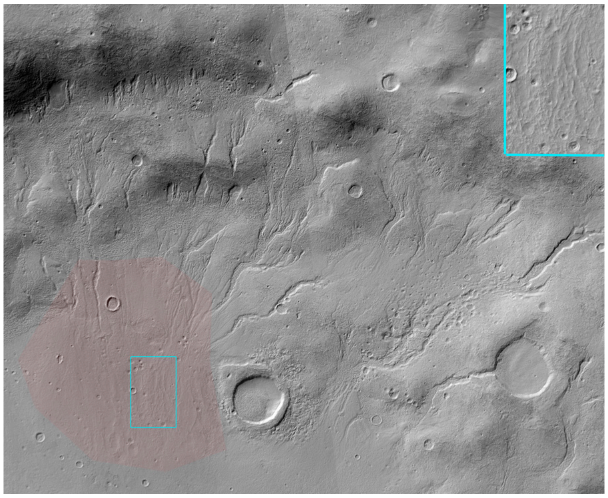

Figure 1. Portion of the interior slope of an 77 km diameter mid-latitude crater (39.3ºS 19.3ºE), showing muted (softened) topography incised by MLV channels, alluvial fan deposits at terminus of MLVs (pink coloration), and variable widening and valley wall undercutting by ice-related processes. Upper right of image shows detail of inverted-relief distributaries on fan surface (blue box on fan). Image width 28.8 km, from CTX images P16_007255_1411 and B17_016340_1402.

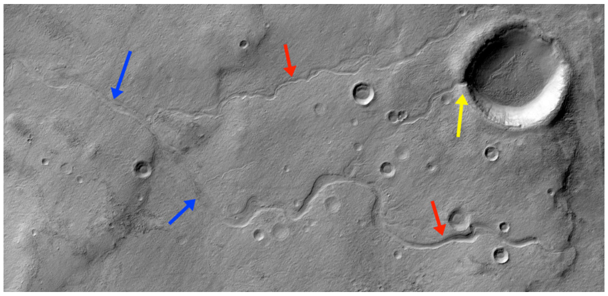

Figure 2. Mid-latitude valleys near 41.4°S 162.6°E showing changes from narrow incised (Mode 1, red arrows) to wide valleys that are unincised or shallowly incised (Mode 2, blue arrows). Mode 1 channels generally occur where MLVs are incised into broad ridges. Yellow arrow points to an exit breach located high on the rim of a 3.1 km crater. This suggests the crater was nearly full of water or ice at the time of breaching. Image width 17.4 km, from CTX image P14_006696_1369.