Abstracts

EVOLUTION OF THE GLOBAL WATER CYCLE ON MARS: THE GEOLOGICAL EVIDENCE.

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The geological evidence for active water cycling early in the history of Mars (Noachian geological system or heavy bombardment) consists almost exclusively of fluvial valley networks in the heavily cratered uplands of the planet [1–3]. It is commonly assumed that these landforms require explanation by atmospheric processes operating above the freezing point of water and at high pressure to allow rainfall and liquid surface runoff [4–6]. However, it has also been documented that nearly all valley networks probably formed by subsurface outflow and sapping erosion, involving groundwater outflow prior to surface-water flow [7–10]. The prolonged groundwater flow also requires extensive water cycling to maintain hydraulic gradients, but need this be via rainfall recharge, as in terrestrial environments [11,12]?

It is important to contrast the Noachian-age evidence of water cycling with that proposed for later epochs of martian history (postheavy bombardment or Hesperian and Amazonian geological systems). Valleys formed at these times [13,14] coincident with glaciation [15], periglacial mass movement [16,17], and ponded water on the northern plains [18,19]. The latter may have constituted transient oceans, fed by outflow channel discharges [20,21], that temporarily induced short-term phases of warm, wet atmospheric conditions [22]. Extensive glaciation in middle Amazonian time [23] required a short-term epoch of precipitation. Unequivocal geological evidence for precipitation does not occur for Noachian time.

The argument for a Noachian ocean on Mars is theoretical [24]; confirming geological landforms are not present. Moreover, there are strong arguments against the possibility of a CO_2 greenhouse warming of the atmosphere to temperatures above freezing [e.g., 25] during the heavy bombardment epoch coinciding with the faint young Sun [26]. Theoretical resolutions of this "paradox" include modified solar theory [27] or the development of a reducing atmosphere greenhouse [28,29].

The theoretical arguments for the early Mars warm, wet scenario (EMWS) is predicated upon far less compelling geological evidence than that for the episodic late Mars climatic change hypothesis [22], since only valley networks create the rationale. Crater degradation by pluvial action [30] is alternatively explained by backwasting and downwasting through mass movement [31,32], indicating a need for resolution of the conflicting interpretations. Without unequivocal evidence of glaciers, oceans, or other indicators of global pluvial processes, there is the possibility of an alternative case of nonpluvial water cycling to explain the valley networks.

Large quantities of groundwater can by cycled in the vicinity of subsurface thermal anomalies through hydrothermal circulation [33,34]. Possible thermal anomaly sources include igneous sills [35,36], volcanos [37], and impacts [38]. During the Noachian, planetary heat flow was much greater [39], yielding high near-surface temperatures [40]. However, these do not, by themselves, account for the prolonged circulation necessary to form valleys. Ratios of water volume circulated to excavated valley volume are estimated as low as 4 [41,42], but terrestrial analogs suggest values more on the order of 10^3 [43]. Localized hydrothermal circulation seems the only possibility for yielding the higher ratio.

Noachian valley formation by hydrothermal processes does not require the EMWS, but snowfall would certainly enhance the process of valley formation with recharge into hydrothermal warm spots. The distributed volcanism of the late Noachian intercrater plains is consistent with the formation of valleys by hydrothermal circulation, explaining the low drainage densities [44] and clustered distributions of valleys.

Mars erosional episodes are clustered in time [45]. The Noachian epoch was followed by Hesperian and Amazonian periods of valley formation [22]. Volcanism also became localized over the same period, eventually clustering at Elysium and Tharsis. Massive Hesperian and Amazonian outflows probably explain the depositional mantles of the northern plains [46,47]. The Hesperian/Amazonian ages of plains materials [48–50] are in accord with this model of post-Noachian change. The EMWS may well have been endogenetically induced by more uniform volcanism in space and time, while the cataclysmic episodic phases of later epochs of warmth on Mars reflect a subsequent localization of volcanism in time and space [22].

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ANCIENT MARTIAN VALLEY GENESIS AND PALEOCLIMATIC INFERENCE: THE PRESENT AS A KEY TO THE PAST. G. R. Brakenridge, Surficial Processes Laboratory, Department of Geography, Dartmouth College, Hanover NH 03755, USA.

Understanding the origin of the relict fluvial landforms that dissect heavily cratered terrains on Mars is one of the clearest challenges to geomorphology to emerge in this century. The challenge is not being successfully met. Twenty years after the discovery of these landscapes we still do not know how the valleys formed or what they imply regarding paleoclimate. Geomorphology has not, to date, provided robust, remote-sensing-related analytical tools that are appropriate to the problem. It cannot because, despite the truism that "form follows function," landform genesis on Earth is not studied today by matching landform morphometries to genetic processes. Instead, the lithology, structure, and stratigraphy of the material underlying the landform is sought, and the local geological history may be investigated in order to understand the stage on which modern surficial processes are playing. Unfortunately, not much information other than morphometry has been assembled for the ancient martian valleys.

The problem is complicated by the relict nature of the landforms and the apparent need to infer genetic processes that are no longer occurring; the past must be reconstructed. To this end, geoscientists commonly use the principle of "uniformitarianism," wherein inferences regarding the past are based on the reality of the present. Consider the limitations that a comparative planetology approach presents, e.g., to a geologist from Mars attempting to understand the genesis of the now-relict Appalachian Mountains. Mars-Earth comparisons could not yield much insight. Understanding the passive margin Appalachians is critically dependent on a chain of insights regarding processes that derive from Earth's present. Terrestrial crustal plates move, and sea floor spreading, subduction, continental collision, and subsequent rifting occur. Inferring such processes would seem wildly speculative from a Mars perspective, and the genetic chain for creating relict mountains is indeed complex. However, we know that the Appalachians were in fact so created, and we gained such knowledge by extrapolation from the present (e.g., the Himalayas). When investigating the genesis of relict fluvial valleys on Mars, we could do the same.

For example, immediately inside the rim of the 120-km-diameter crater Cerruli (located at ~ +30°, 340°), 1-km-wide, flat-floored and (narrower) v-shaped valleys debouch from apparent 5–10-km-wide collapse depressions and extend for distances of a few tens of kilometers downslope and toward the center of the crater [1]. None of the valley landforms examined are cratered; they may have formed quite recently or may still be active. Intervening preserved highland remnants may be composed of ice-rich sedimentary material [1], and the large collapse depressions exhibit margin-proximal parallel lineations suggestive of margin-derived sediment input.

The terrain bears little resemblance to fluvial landscapes on Earth, but is similar to ancient, fluvially dissected terrain in Aeolis Quadrangle [2]. The flat-floored valleys do crudely resemble terrestrial glaciated valleys, and parabolic viscous drag-flow lineation is expressed locally on their smooth-surfaced floors, suggesting wall-to-wall longitudinal transport of debris and/or ice. However, these valleys exhibit scalloped margins and no snowfields feed their headwaters. Instead, and at varying distances upslope from the abrupt amphitheater headwalls, shallow closed depressions are visible in Viking Orbiter stereopairs (204S18-21), and these may indicate embryonic collapse and possible future headward growth of the valleys.

Viking-based stereoscopy also demonstrates that low-gradient or flat plains separate steep-gradient, incised, v-shaped valley reaches. At the limit of resolution, narrow channels on these plains appear to connect the valley reaches, but the incised reaches are perhaps more akin to avalanche chutes than to terrestrial fluvial valleys.

There is evidence for at least two different valley genesis pathways on sloping terrain inside Cerruli's complex crater rim: (1) collapse, linking of collapsed areas by growing flat-floored valleys, and transport of valley floor material in the downvalley direction even as valley widths grow, at least slightly, by mass-wasting; and (2) carving of much narrower, sometimes en echelon valleys along steep hillsides, coupled with suggestive evidence of intervening flow in channels on relatively flat terrain.

I offer here the speculative genetic hypothesis that the flat-floored landforms represent episodically active, sediment-laden valley glaciers formed by localized geothermal melting of abundant interstitial ice (permafrost) in a fine-grained sedimentary terrain. Geothermal melting may also localize spring heads for the narrow, deep, high-gradient valleys, or the collapse process itself may result in the generation of decanted, relatively sediment-poor overland water flows (some local evidence of fluid overtopping of the localized depressions exists). Whatever the genetic mechanisms for the suite of valley landforms, perhaps the most interesting observation is simply their youth. In aggregate, the morphologies are similar to the ancient valley systems cited as evidence for a previously much denser atmosphere on Mars.

If even very local valley genesis occurs today and the landforms are similar to those dating from ca. 3.8 Ga, then global climatic cooling may not be the most appropriate shut-off mechanism for the ancient valleys. Other mechanisms include (1) a change in planetary volcanism style from mainly effusive plains volcanism to plumate eruptions [2], (2) changes in orbital parameters destabilizing ground ice at low latitudes but permitting stability at higher latitudes [3], or