GLOBAL HISTORY OF WATER AND CLIMATE.

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Introduction: Despite acquisition of superb new altimetry and imagery by Mars Global Surveyor, most aspects of the water and climate story are likely to remain controversial. The relative roles of surface runoff and groundwater seepage in the formation of valley networks are yet to be resolved as are the climatic conditions required for their formation. Similarly, the fate of the floodwaters involved in formation of the outflow channels remains unresolved. While the MOC images provide little supporting evidence for proposed shorelines around an extensive global ocean [1], the altimetry suggests the presence of a bench at constant altitude around the lowest parts of the northern plains [2]. Here I describe some of the attributes of the channels and valleys as seen in the early MOC images, summarize the evidence for climate change on Mars, and discuss some processes that might have affected the climate on early Mars. MOC images are referred to by a 5-digit number, the first three being the orbit, the last two being the sequence in that orbit. Individual images are available for viewing at ida.wr.usgs.gov

Outflow Channels: Outflow channels are so large that they had already been well characterized before the MGS mission. MOC images (e.g. 45603, 47405) of deep scour on the floors of many channels reinforce the previous interpretation of origin of most outflow channels by large floods. More puzzling are channels that start at the base of the Olympus Mons scarp (43004), and Marte Vallis (40703), which appears to be partly filled with lava and drains from what appears to have been a large lava lake [3]. Could lava erosion have played a role in the formation of these channels? In addition, some channels, such as Hephaestus Vallis (51001) , being partly chains of disconnected depressions, provide clear evidence of sub-surface erosion and/or solution.

Valley Networks: The significantly higher resolution of the MOC images compared with all previous imaging of Mars has led to a significantly improved understanding of the characteristics of the valley netorks, which are typically much smaller than the outflow channels. A somewhat surprising finding is that even the Noachian terrains are only sparsely dissected at the MOC scale [4]. The areas between valleys visible in the Viking images are typically not dissected with a hierarchy of tributaries that bridge the gap in scale between the 1-2 km wide valleys seen previously and 10 meter scale objects visible in the MOC images.(05803,08205, 51304). In addition, areas that appear densely dissected in Viking images commonly have poorly organized drainage patterns when viewed at the MOC scale (04304, 08905, 09306). Throughgoing valleys and an ordered set of tributaries are difficult to discern. These areas more resemble terrestrial thermokarst terrains than areas where fluvial processes dominate. A few areas do, have more typical fluvial erosion patterns. At 26S, 84W numerous closely spaced tributaries feed larger valleys to form a dense, well integrated valley system (07705). Such examples, are however, rare.

Debates about the origin of valley networks have focused mainly on (1) the role of fluvial erosion versus other processes, (2) the relative roles of groundwaer sapping and surface runoff, and (3) the climatic conditions required for valley formation. MOC images of the 800-km long Nanedi Vallis (8794, 8705) strongly support an origin of this valley by slow erosion of running water. Its highly sinuous shape indicates that it is unlikely to be a flood channel, and, indeed, a river channel is visible at places within the valley The sinuous shape also suggests that the valley became incised as a result of sustained erosion by a river that .originally meandered across the Xanthe plains into which the valley is cut. Although 800 km in length, Nanedi Vallis has only a few short tributaries. This suggests that the river that cut the valley was fed largely by groundwater. (It does not rule out precipitatation, but implies that if precipitation occurred locally, then infiltration dominated over surface runoff). The climatic conditions needed to sustain river flow and cut Nanedi are uncertain, and depend on how stable ice covered rivers could be under cold climatic conditions [5,6]. Valleys that start on the upper part of the wall of the crater Gruithuysen (10605) provide another example of formation of valleys by groundwater seepage. Seepage is implied since no valleys are found outside the crater rim.

While Nanedi and Gruithuysen can plausibly be explained as a result of groundwater seepage, other processes are likely to have been involved in valley formation. The well integrated network at 26S, 84W is consistent with surface runoff, and the thermokarst like patterns in several areas suggest ground ice played a role. Moreover precipitation is needed to maintain a groundwater table particularly in the high-standing southern highlands where most of the valley networks occur.

Erosion Rates: In view of the many ambiguities involved in interpreting the valley networks, the change in crater obliteration rates at the end of heavy bombardment may provide the best evidence for climate change on early Mars. Noachiuan craters several tens of km across are observed in all states of preservation. Erosion rates in the Noachian have been estmated to be about 10 μm/yr [7]. In contrast post Noachian craters are mostly well prerved and indicate erosion rates of no more than 10^{-2} μm/yr [7,8,9]. The simplest explanation, and one consistent with presence of groundwater in the southern highlands at the end of heavy bombardment is that is that for most of heavy bombardment Mars was warm and wet and had a thick atmosphere and that toward the end of heavy bombardment the atmosphere, thinned considerably and the surface cooled.

Climate Change: A thick atmosphere is difficult to maintain on early Mars because the atmosphere is vulnerable to being eroded away by impacts [10] and to being eliminated by weathering [11]. The fainter Sun also makes it difficult to maintain warm conditions at the surface[11]. Modeling [12] suggests that high weathering rates on early Mars could lead to rapid sequestration of a large fraction of the orignal CO_2 in the ground. While in the ground it is protected from elimination by impact erosion. High, but rapidly declining, heat flows will results in burial of the carbonates. Ultimately the carbonates reach depths where they dissociate and the CO_2 is returned to the atmosphere. Meanwhile the impact rate has declined and impact erosion has become less efficient. The modeling suggests that 0.5 to 1 bar of CO_2 can be retained in the atmosphere at the end of heavy bombardment despite the effects of weathering and impact erosion. This is true, however, only if the early atmosphere can provide significant greenhouse warming such as by infrared scattering by CO_2 clouds [13].

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