SNOWMELT AND THE FORMATION OF VALLEY NETWORKS ON MARTIAN VOLCANOES. C. I. Fassett and J. W. Head III, Dept. of Geological Sciences, Brown University, Providence, RI 02906 (Caleb_Fassett@brown.edu and James_Head_III@brown.edu).

Introduction: The formation mechanism for valley networks on the surface of Mars remains an open question despite the vast amount of new information that has been obtained about the planet in recent years. Distinguishing between the various models is difficult due to (1) ongoing uncertainty in the morphological differences between Martian valleys and drainage systems on Earth [e.g. 1,.2] (2) the unknown relative importance of groundwater sapping and surface runoff, and (3) difficulty reconciling the observations which suggest minimal interaction of water with the Martian near-surface (e.g. unweathered olivine) with the widespread geomorphologic evidence for water erosion (such as the valley networks themselves) [3,4].

There are prominent systems of valley networks on several volcanoes which are especially useful to examine when trying to understand Martian hydrological history [5]. They are simpler cases to model in several respects than the more typical highland valley networks on Mars, since they are found on (relatively) simple topographic surfaces (at least in several cases) with (relatively) clear substrate properties. Also, these systems are found on volcanoes that date from much of Martian history (from the Noachian to the Amazonian, and we can determine these ages with greater certainty than is possible for most valley networks in the highlands. This range of ages suggests that either the Noachian-aged valley networks may not require a warmer, wetter climate to form, or that episodes of similarly warm and wet conditions may have reoccurred (perhaps only locally) at several points in Martian history. Here, the previous work of Gulick and Baker [5] and Gulick [6] is reconsidered in the light of new data and new modeling of how basal melting of snow may occur on Mars [7]. We focus our efforts on the volcanoes Ceraunius Tholus, Hecates Tholus, and Alba Patera.

Valley Network Observations: The valleys found on these Martian volcanoes are typically hundreds of meters wide and tens of meters deep [8]. On Ceraunius Tholus and Hecates Tholus, there is a clear radial distribution of valleys (e.g., Fig 1). These networks have higher drainage densities than those found in other dissected regions of the Martian surface [5], but appear to be poorly integrated, with the exception of valleys on Alba Patera.

Gulick and Baker classify these valley networks based on whether they showed evidence for formation by runoff, groundwater sapping, or both [5]. They propose an evolutionary sequence of processes, where valleys are initiated by runoff, but later formation is dominated by sapping. Although we agree with Gulick and Baker's conclusion that individual valleys on Ceraunius Tholus and Hecates Tholus show evidence for having undergone both processes, we believe this may have occurred simultaneously (or perhaps not in a simple sequence) [8]. Alba Patera's valleys appear to be formed only by surface runoff [5]. This may reflect local conditions that made groundwater sapping more unlikely to occur on Alba, especially the shallower slopes which are found there compared to Ceraunius and Hecates. On the basis of these observations, we concluded that a scenario invoking snow accumulation and melting could possibly account for the features we observe. Thus, we have attempted to assess this model.

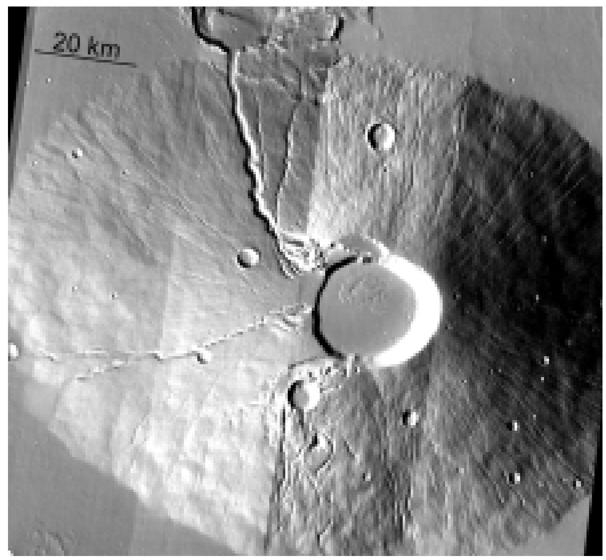

Figure 1. THEMIS Daytime IR mosaic of Ceraunius Tholus. The three large, unusual valleys on the north flank may have formed by volcanic processes [11] or collapse [12] rather than having been eroded by water.

Modeling: If the Martian atmosphere was not significantly warmer and thicker when the valleys found on these volcanoes formed than it is today, rainfall would necessarily be precluded as the cause of these valleys. Melting of ground or surface reservoirs of frozen water seems the most plausible source mechanism for valley formation on the Martian volcanoes.

Gulick [6] modeled the hydrothermal system developed around a magmatic intrusion/magma chamber, and suggested that this may be the mechanism for outflow of water that carved valley networks on the volcanoes (and potentially in more ancient regions of the Martian surface). However, two aspects of this model appear unrealistic for the situation we are considering here: (1) the entire volcanic edifice is treated as saturated with water (also connected to aquifers beyond its flanks), and (2) the atmospheric pressure was set arbitrarily to 1 bar to prevent boiling. Both of these assumptions serve to diminish the need for a recharge mechanism for the hydrothermal system, because they remove the continuous loss of water to the atmosphere (through sublimation of ice formed after water was brought to the surface and boiling of near-surface groundwater).

Periodic deposition and melting of snow provides a possible mechanism for forming the valleys on the volcanoes as well as to recharge the hydrothermal systems active in their subsurface. Recent work by Carr and Head [7] models the depth of snowpack that must exist for melting to form for a given basal heat flow and surface temperature. Numerical modeling of diffusive heat flow away from a cooling magma reservoir suggests that more than enough heat would be conducted to the surface to melt snow. This neglects advection of heat by water, which probably is the dominant cooling process given the range of permeability that is probably appropriate for these volcanoes [6]. However, advection would likely enhance snowmelt, since cooling (and heat transport) would be accelerated. Although advective effects would result in increased heating away from the summit, both this case and the purely conductive case would largely concentrate melt formation near the summit (in the region above the magma source).

The concentration of melt formation in a region at the summit or near-summit is a potentially testable aspect of this model. Summit snowmelt is also consistent with the observed radial symmetry of valley networks seen on several of the Martian volcanoes, and seems intuitively consistent with the poor integration of individual valleys. Further testing of this and other aspects of this model is underway.

Conclusions: We find that under atmospheric conditions similar to those today, significant snow accumulation on the summits of active volcanoes would create an environment conducive to valley network formation. Given a thick enough accumulation of snow, conductive and advective heat loss from magma reservoirs are a sufficient source of heat to melt ice at the base of the snowpack. This model is consistent with the observed radial distribution of valleys, their poor integration, and the evidence that both sapping and runoff played a role in valley development.

Questions and Future Work: Several aspects of this model will be explored more in future work. First, it is important to understand how, why, and where snow might have been deposited on the Martian surface. Ideas about how this might occur (probably during periods of high obliquity) are still being developed [e.g., 9]. Second, it is unclear whether snowmelt could account for or is consistent with special cases such as the largest of the valley systems on Ceraunius Tholus's north flank (Fig 1). Third, we are outlining models of the actual amount of snow that would need to be deposited for melting to occur, as well as for melt volumes and melt production rates, given various assumptions about heat flow.

Finally, if the snowpack melting model for valley formation is viable for the observed volcanoes, how applicable is it for more typical valley networks in the Martian highlands? Invoking the existence of abnormal local heat sources is clearly more plausible for the volcanoes than in the highlands. Given the difficulties that remain for this and alternative hypotheses, melting of snow (perhaps in earlier period of higher heat flux) remains a possibility that needs be examined as a formation mechanism for highland valley networks [12].

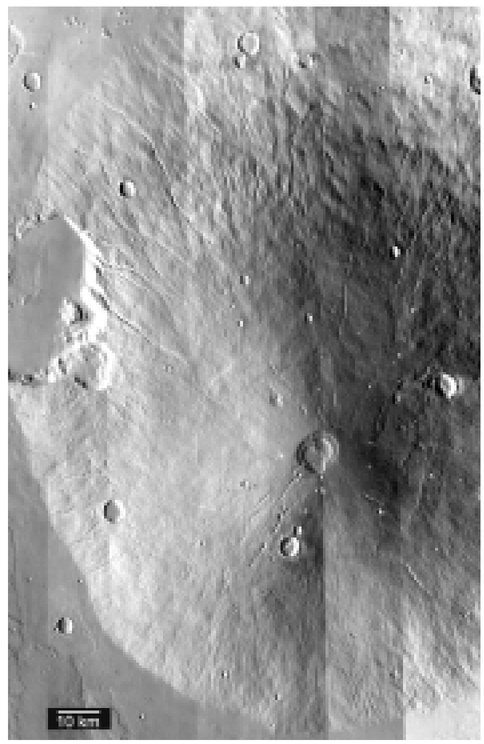

Figure 2. THEMIS IR mosaic of Hecates Tholus.

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