FORMATION OF MARTIAN VALLEY NETWORKS: MELTING OF LOW TO MID-LATITUDE SNOWPACKS DURING PERIODS OF HIGH OBLIQUITY? M. H. Carr[1] and J. W. Head III[2], [1]U. S. Geological Survey, Menlo Park, CA, 94025, carr@usgs.gov, [2] Department of Geological Sciences, Brown University Box 1846, Providence, RI, 02906, james_head_III@brown.edu

Introduction. Martian valley networks appear to be cut by liquid water and have characteristics suggestive of both groundwater sapping and surface runoff. Irrespective of which process dominated, precipitation is required either to provide runoff directly or to recharge the groundwater system. While most valleys are ancient, the less common young valleys indicate that valley formation continued, at least episodically, throughout martian history. Because of their likely formation by liquid water, the valleys have been taken as evidence that early Mars was warm and wet and possibly experienced warm episodes subsequently. This perception is being increasingly questioned because of failure to detect weathering products from orbit [1], the widespread presence of the easily weathered mineral olivine [1], the vulnerability of the early atmosphere to losses by impact erosion [2], the likely rapid scavenging of CO_2 from the atmosphere under warm conditions [3] and climate modeling studies that show that Mars cannot be warmed sufficiently by a H_2O-CO_2 atmosphere to allow rainfall [4]. On the other hand, evidence for widespread water erosion has been strengthened by recent MGS and Odyssey data, particularly identification of unambiguous delta deposits and cut-off meanders [5]. The possibility explored here is that the valley networks formed as a result of melting of snow precipitated at low latitudes during periods of high obliquity.

Dissection by valley networks. While the evidence for formation of valley networks by water erosion is compelling, the pattern of dissection is very different from the Earth s. Although new data show more mature and integrated drainage systems [6], further analysis of the patterns show distinctive variations from Earth [7]. From MOLA topography, the planet can be divided into six drainage basins (Chryse, Amazonis, Hellas, Isidis, Argyre, Utopia). However, no valleys (except for the Ladon-Uzboi outflow system) extend all the way from the basin divides to the basin lows, as is the usual case on Earth. Large integrated drainage systems did not develop. Despite the 3-5 km elevation drop across the plains-upland boundary, few valleys extend more than 1000 km into the uplands. Similarly, no major valleys formed on the eastern wall of Hellas despite 9 km of relief. Only one valley network (Evros Vallis) can be traced for over 2000 km, although there are, of course longer outflow channels. For comparison, the Earth, with a land area one and a half times the area of the cratered uplands, has 46 rivers longer than 2000 km. In addition, in the cratered uplands, most drainage is into local closed depressions. Most of these are impact craters, but a significant fraction are not. Many valleys enter a closed depression and another valley emerges from the pour point of the depression, suggesting that lakes were formerly present in many of the depressions.

On Earth, lakes tend to be eliminated as the lake outlet is lowered by erosion. Lakes are common only in places such as the Canadian shield where non-fluvial processes such as glaciation have recently sculpted the landscape. In the martian uplands closed depressions are common at all scales. Erosion has not been sufficiently sustained to develop large drainage basins and eliminate local depressions despite a topographic record that probably extends well into the Noachian. If the valleys were cut by liquid water then water would have likely pooled in these local depressions and then subsequently seeped into the ground or sublimated. One possibility is that during the Noachian conditions amenable for water erosion occurred only sporadically, such as during periods of high obliquity, so that development of large drainage systems, comparable to such systems as the Mississippi and Amazon on Earth, could not keep pace with the regeneration of the topography by impact and tectonic activity.

Melting of a snowpack during periods of high obliquity. During periods of high obliquity water is driven off the polar caps and deposited as snow at low to mid latitudes [8,9]. Such snowpacks could be melted either by solar heat from above or by internal heat from below or from a combination of the two [10]. Clow [11] concluded that small amounts of snowmelt could be generated by solar melting even with surface temperatures well below freezing. The melt is produced within a few tens of centimeters of the surface as a result of a solid state greenhouse. Only small amounts of water can be generated in this way because melting is restricted to the within the annual skin depth of a few tens of centimeters and the meltwater refreezes as it trickles down through the snow pack into the underlying cold snow or ground. In addition to this near-surface melting, the snow pack could melt at its base if it was thick enough and if the heat flow was high enough [12].

The depth at which a snow pack will melt as a result of internal heating depends on thermal conductivity of the snow, the internal heat flow and the surface temperature. The thermal conductivity of snow depends on its density. Density increases with depth as a result of pressure sintering. Thermal conductivities were estimated for martian snowpacks using experimental data on snow conductivity and assuming that the pressure-density relations for martian snow are the same as for terrestrial snow. Thermal conductivies are low near the surface and increase to values close to solid ice at depths of a few hundred meters. Estimates of the heat flows on Mars at the end of heavy bombardment have been recently revised downward from the range of 0.1-0.15 W m^{-2} to 0.05 to 0.1 W m^{-2} [13], but there is considerable uncertainty, and it is likely that at this time the heat flow was rapidly declining and locally variable. Estimates of surface temperature are even more uncertain, in part because of not knowing how thick the atmosphere was and what the effects of clouds were [14]. Figure 1 shows the estimated depths to melting as a function of surface temperature and heat flow. The results suggest that for heat flows of around 0.1 W m^{-2} [8] and surface temperatures in the 230-240K range [14] snow packs greater than 200-300 m thick would melt at their base.

The present on-the-surface inventory of water is only about the global equivalent of 20-25 m, almost all of which is in the polar caps. An unknown, and possibly large amount of water may, however, be in the upper few kilometers of the ground. On early Mars, when the heat flows were higher and the cryosphere thinner, a much larger fraction of the total near surface inventory would have been on the surface. Thick ice/snow deposits are, therefore more likely for this time. Melting of extensive, thick ice deposits on early Mars may thus have provided runoff to cut the valley networks and locally recharge the groundwater system. Subsequently, as more water became incorporated in the cryosphere and the heat flow declined, ice deposits thick enough for basal melting became rare, and restricted mostly to volcanoes where heat flows were anomalously high (e.g. [15]).

The rate of supply of water by the mechanism would be modest. With a heat flow of 0.1 W m^{-2} only the equivalent of 1 cm depth of water would be generated in a year over the area of the snow pack. However, the liquid water could accumulate at the base of the snowpack over periods of many years and be released episodically to cut the valleys.

References: [1] Christensen, P. R., et al, *JGR, 106*, 23,823-23,971, 2001. [2] Melosh, H. J. and Vickery, A. N., *Nature, 338*, 487-489, 1989. [3] Pollack, J. B., et al., *Icarus, 71*, 203-224, 1987. [4] Kasting, J. F., *Icarus, 94*, 1-13, 1991. [5] Malin, M. C. and Edgett, K. S., *Sciencexpress*, Nov.13, 2003. [6] Hynek, B. and Phillips, R. J., *Geology, 31*, 757-760, 2003. [7] Stepenski, T. F. and Coradetti, S., *EOS Trans. AGU*, 84 (46), abstract #P11B-1033, 2003. [8] Jakosky, B. M. and Carr, M. H., *Nature, 315*, 559-561, 1985. [9] Mischna, M. A. et al., *JGR, 108*, E6, 2003. [10] Carr, M. H. and Head, J. W. III, *GRL, 30*, 10.1029/2003GL018575, 2003. [11] Clow, G. D., *Icarus, 72,* 95-127, 1987. [12] Zent, A. P., *LPSC 30,* 1803, 1999. [13] Spohn, T., et al., Chronology and Evolution of Mars, Kluwer, 2001, 231-262. [14] Colaprete A., and Toon, O. B., *JGR, 108*, E4, 2003. [15] Fassett, C. and Head, J. W., *LPSC 35*, 2004, this volume.

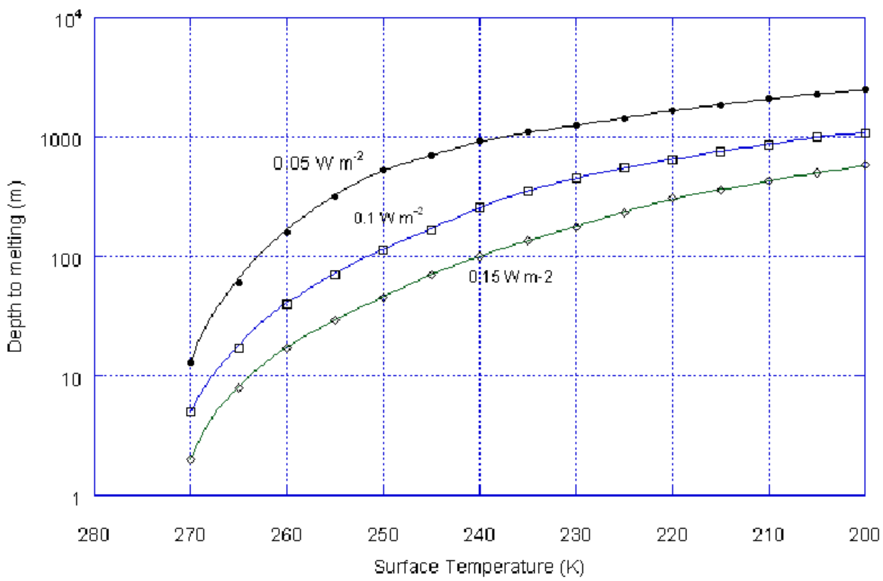

Figure 1. Depth at which a martian snowpack will melt at its base as a function of the heat flow and the surface temperature.