EARLY MARS GLOBAL HYDROLOGY: WAS THE MARTIAN HYDROLOGIC CYCLE AND SYSTEM GLOBALLY VERTICALLY INTEGRATED DURING THE LATE NOACHIAN? James W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912 USA (james_head@brown.edu).

Introduction: The concept of a global hydrological cycle and system provides an important framework for the understanding and analysis of the distribution of water on a planet, the nature of the individual reservoirs, the rates of exchange among the reservoirs, how these vary as a function of latitude and under different planet-scale environmental conditions, and how these vary with geological time. How has the hydrological cycle on Mars [1] changed with time and how can knowledge of major trends in atmospheric/climatic evolution and geothermal flux help to clarify its early history? Here we investigate the current view [1-3], assess alternate scenarios [4-5], and propose tests to distinguish among these models.

The Current Hydrological Cycle on Mars: The major themes and reservoirs of the martian hydrological system were first outlined by Clifford [1, 6]. These concepts are built on a foundation of the nature of the early crust of Mars and its ability to act as an aquifer (Fig. 1). To a first order, the current hydrological cycle is one characterized by a global cryosphere, and a subsurface groundwater system whose size is determined by estimates of the amount of groundwater assumed under various models to remain there [7]. This system is currently *horizontally stratified* (Fig. 1) [8], with the global cryosphere isolating the groundwater system from the surface (except by very slow diffusive processes). On the surface, water is latitudinally exchanged between the three main reservoirs (the polar caps, the regolith and the atmosphere) due to seasonal and longer-term climate effects [9]. Key to the long-term stability of this is a low geothermal flux and a cold hyperarid climate. Analysis of ice-related surface geological features shows that these conditions, and a horizontally stratified hydrological cycle, are liikely to have prevailed throughout the Amazonian [10].

The Noachian Hydrological Cycle on Mars: Many hypothesize that the Noachian of Mars was a warm, wet period of pluvial activity [11] with a higher global geothermal gradient (Fig. 2). In this case, the hydrological system would be *vertically integrated*, at least in low to mid-latitudes [2,3,12] (Fig. 2). Surface runoff would be important, the water table would be close to the surface, vertical exchange would be very important, and vertical recharge would maintain an episodically high water table over time intersecting the surafce [2,3,12]. An implication of this scenario is the presence of a Noachian ocean in the northern lowlands (Fig. 2).

The Hesperian Transition in the Hydrological Cycle on Mars: A traditional view [see review in 13] is that as the Noachian geothermal flux decreased, and the climate became more like today, the cryosphere began to grow in area and thickness until a global cryosphere developed (Fig. 3). By the late Hesperian, Mars was likely to have been a cold hyperarid desert, but dike emplacement and other local perturbations of the global cryosphere caused the catastrophic release of groundwater sequestered below the cryosphere (Fig. 3). This may have led to standing bodies of water in the northern lowlands (the "second ocean"), which then froze and sublimed [14], adding to the surface water inventory.

Was Noachian Mars Warm and Wet?: This traditional view [e.g., 11] has recently been challenged by several developments: 1) The growing evidence that mineralogic indicators for early phyllosilicates (interpreted to support warm and wet surface conditions [15]) could also be explained by subsurface hydrothermal effects in an early period of high thermal flux [16]; 2) The difficulty of producing and maintaining an atmosphere that could lead to a warm and wet early Mars with pluvial activity [17]; 3) Evidence that south circumpolar ice deposits are consitent with cold lower latitude surface temperatures [18]; 4) The poor integration of the surface hydrologic system (valley networks, open-basin lakes [19-20]), suggesting short-term activity, rather than long-term integrated pluvial systems; 5) Emerging evidence in the Antarctic Dry Valleys that Mars-like fluvial and lacustrine activity can occur under surafce climate conditions with mean annual temperatures (MAT) well below 0°C [22]; 6) The possibility that surface drainage features could be explained by top-down transient atmospheric effects caused by punctuated volcanism during the late Noachian-early Hesperian (LN-EH) [5]. Here we outline three alternate scenarios for a "non-warm and wet" early Mars that appear to be consistent with the six new developments outlined above [4]. We address the question: Could Mars have been cold and dry (Figs. 4, 6) or cold and wet (Fig. 5), instead of the pluvial warm and wet early Mars envisioned by some (Fig. 2) [e.g., 11]?

Scenario 1: Some have argued that aqueous activity on early Mars may be cold and dry, analogous to the Antarctic Dry Valleys on Earth [21]. In this case, snowfall (nivial activity) may have been dominant and spin axis and orbit changes may have driven snow and ice latitudinally across the surface, with periods of high obliquity depositing snow in the equatorial regions (Fig. 4) and periods of lower obliquity causing transient equatorial melting of snowpack to form valley networks and other aqueous features.

Scenario 2: In this scenario, a cold and wet early Mars (Fig. 5), the cryosphere and surface snowpack is melted by an elevated Noachian geothermal flux [22], forming many of the valley networks and related features seen in the Noachian record. Long periods of warm and wet conditions are not required and the hydrological system is locally to regionally vertically integrated.

Scenario 3: In this case, early Mars is cold and relatively dry, but the early CO_2 atmosphere [17] supports large south polar ice deposits [18] and permits surface ice at lower latitudes (Fig. 6). Enhanced atmospheric heating is caused by punctuated phases of late Noachian-early Hesperian volcanism [4,5,23], leading to at least decadal-scale melting of snow and ice, and formaton of valley networks, open-basin lakes and surface sulfate deposits [24], but insufficient top-down heating to thaw the cryosphere.

In Scenarios 1 and 3, vertical integration of the late Noachian-early Hesperian hydrological system is not required. Although the cryosphere may have been thinner due to an elevated geothermal flux at this time, it is unlikely to have been high enough globally [18] to have maintained bottom up surface melting with currently understood atmospheric conditions [17].

Summary: Each of these scenarios carries a series of predictions that can be tested with observations. We are currently analyzing the surface features that formed in the vicinity of the possible transition from the traditional view of a *vertically integrated* hydrological system [2,3] that would be typical of an early "warm and wet" Mars (Fig. 2), to one that is characterized by the current *horizontally stratified* hydrological system (Fig. 1). Our current data and analyses favor Scenario 3 (Fig. 6) and suggest that Mars was more likly to have been characterized by a "cold and dry" early history and a horizontally stratified hydrologic system throughout most of its history. In this scenario, the Hesperian represents a *perturbation* on the historically horizontally integrated hydrological system, rather than a *transition* from vertical integration to horizontal stratification. We continue to test these scenarios.

References: 1) S. Clifford (1993) *JGR 98*, 10973; 2) J. Andrews-Hanna et al. (2007) *Nature 446*, 163; 3) J. Andrews -Hanna et al. (2007) JGR 1122, E08001; 4) J. Head (2012) *LPS 43*, this mtg; 5) I. Halevy and J. Head, (2012) *LPS 43*, this mtg; 6) S. Clifford and T. Parker (2001) *Icarus 154*, 44; 7) M. Carr (1996) *Water on Mars*, Princeton; 8) J. Head (2003) *Brown/Vernadsky 44*; 9) F. Forget and R. Pierrehumbert (1997) *Science 278*, 1273; 10) J. Head and D. Marchant (2008) *LPS 39*, 1295; 11) R. Craddock and A. Howard (2002) *JGR 107*, 5111; 12) J. Andrews-Hanna and K. Lewis (2011) *JGR 116*, E02007; 13) M. Carr and J. Head (2010) *EPSL 294*, 185; 14) M. Kreslavsky and J. Head (2002) *JGR 107*, 5121; 15) J.-P. Bibring et al. (2006) *Science 312* 400; 16) B. Ehlman et al. (2011) *Nature 479*, 53; 17) R. Wordsworth et al. (2011) *4th Mars Atmosphere Workshop*; 18) J. Fastook et al. (2012) *Icarus*, in press; 19) C. Fassett and J. Head (2008) *Icarus 195,* 61; 20) C. Fassett and J. Head (2008) *Icarus 198,* 37; 21) M. Carr and J. Head (2003) *GRL* 30, 2245; 22) D. Marchant and J. Head (2007) *Icarus 192*, 187; 23) J. Head J. and L. Wilson (2011) *LPS 42* #1214; 24) A. Gendrin et al. (2005) *Science 307*, 1587.

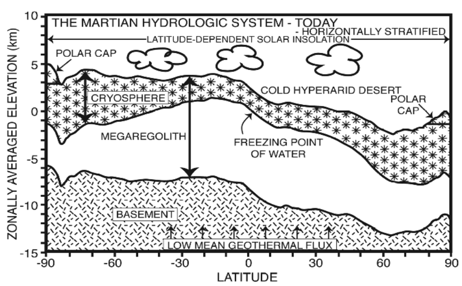


Fig. 1

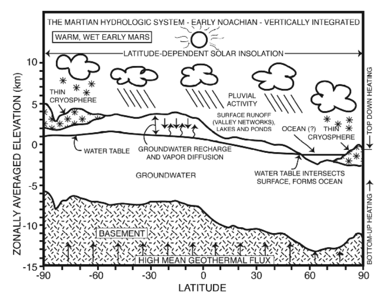


Fig. 2

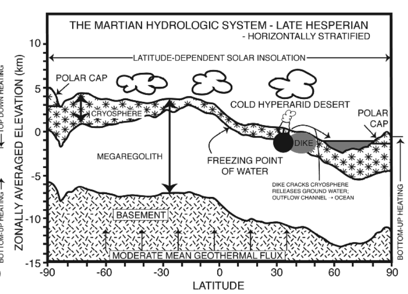
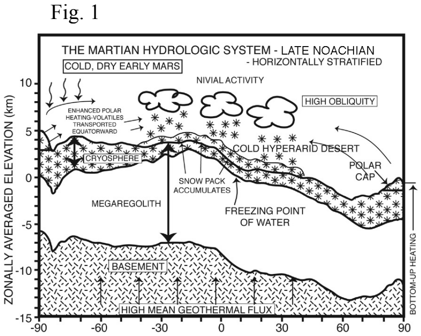


Fig. 3



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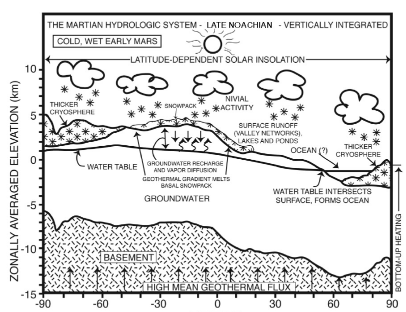

Fig. 5

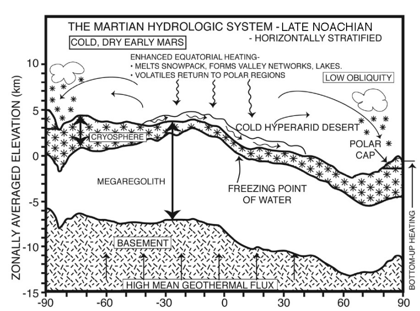

Fig. 6