VERY RECENT HYDROCLIMATIC CHANGE ON MARS? V. R. Baker[1,2], J. M. Dohm[1], and J. C. Ferris[3], [1]Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, [3]U.S. Geological Survey, MS 412, Denver, CO 80225-0046.

Introduction: The geomorphology and geology of Mars, for at least the last 20 years [1], has presented a consistent, coherent picture of that planet as water-rich, such that aqueous activity has occurred, sporadically at least, on its surface throughout its history. The robustness of this conclusion is evidenced in its persistence, despite difficulties of reconciliation with geophysical and geochemical theory [2], and numerous nonaqueous hypotheses [e.g., 3] applied to restricted subsets of the interrelated evidence for aqueous activity on Mars. More recently, the role of water on the Martian landscape has been confirmed by striking discoveries of (a) exceptionally young, water-related landforms [4, 5] interpreted as part of a whole assemblage of very recent, water-related activity [6], and (b) neutron and gamma-ray signatures of a near-surface zone of high water-ice abundance at high Martian latitudes [7]. What do these discoveries mean for past hydroclimatic change on Mars?

Reconstructing the Past: There are two, somewhat conflicting strategies for specifying the boundary conditions necessary to explain the young aqueous landforms. Strategy U, a variant of uniformitarian principle, holds that present-day, exceedingly cold-dry Mars conditions are better (more simply, or parsimoniously) postulated as a basis for model simulations, rather than “speculations” about warmer, wetter past conditions. In terrestrial geology the uniformitarian principle has a long tradition of advocacy, and also one of scientifically counterproductive outcomes [8]. In contrast to Strategy U, Strategy C is less elegant in theory but more fruitful in historically demonstrable scientific success. It consists of colligation, coherence, and consilience. First one colligates all the evidence of the potential water-related landforms, as manifested in time and space. The most seasoned tool for this assembly, geological mapping, is used to demonstrate coherence of patterns. The fundamental questions to emerge from the revealed patterns are those of analogy and genesis [9]. If this entire assemblage of (apparently) water-related landforms, as manifested in time and spatial association (these being recognized by geological mapping), were to be observed on Earth, what would be the most productive hypotheses in regard to their origins? Finally, do the resulting hypotheses lead nowhere, or do subsequent discoveries line up in ways that make otherwise diverse theories converge in unified explanation, i.e., do we achieve consilience?

Very Young, Water-Related Landforms: The exceptionally young water-related features include gullies formed by debris-flow processes [4, 10], polygonally patterned ground [11], a thin ice-rich mantling layer at mid-to-high latitudes [12, 13], channels and related volcano-ice interaction features [14, 15, 16], lobate debris aprons [17] and lineated valley fills of possible glacial origin [6], and dark slope streaks on hillslopes [18] and sand dunes [10]. Varying degrees of controversy surround both the age estimates and the postulated origins of all these features. The young ages are implied by uncratered or very lightly cratered surfaces, implying an age within the last 10 million years [19]. While burial and exhumation may also generate such age relationships, this explanation creates the new problem of accounting for widespread exhumation in recent geological history.

Controversies over genesis are well illustrated by the putative very young glacial features. Resistance to the possibility of active glaciers in the Martian past [2] is most curious given that there is general scientific agreement on the huge assemblage of periglacial landforms on Mars [e.g. 20, 21]. These landforms are all well known to require active ground-ice processes, including freezing and thawing of water [22]. On Earth most of the equivalents to Mars periglacial landforms (ice-wedge polygons, thermokarst, frost mounds, rock glaciers, pingos) develop under climate conditions that are both warmer and wetter than those of cold-based glaciers [6]. What is critical for glaciers is that substantial atmospheric water vapor transport must occur to sustain the snow accumulation that generates the positive mass balance needed for glacial growth. There are no known Earth glaciers that persist for long time periods with water supplied from the melting of ground ice. Moreover, the mass and energy balances necessary to sustain glaciers on Mars are very similar to what is required for temporary ponding of water in lakes. Abundant evidence for relatively young (Amazonian) paleolakes on Mars [23] is consistent with the hypothesis of glacial landforms. It is also important that all the young water-related landforms are known from terrestrial experience to form very quickly (centuries to millennia).

A Recent Episode of Climate Change: Mars currently is experiencing ongoing climate change [24], and past climatic forcing by obliquity variations [25, 26] seems highly probable. Temporary ice-water phase changes and quasi-stability of liquid water [27, 28] are possible even under current conditions, at certain locations [29]. However, the immense volumes of water implied by precipitation of snow and sequestering in near-surface ground ice probably require a much more effective mechanism of water mobilization and recycling. The exceptionally young outflow channels and associated volcanism in both the Cerberus Plains [15] and Tharsis regions [16] most likely introduced large amounts of water and radiatively active gases into the atmosphere. This association of immense outflow channel discharges with contemporaneous water-related landforms is not unique in Martian geological history. Indeed, it is exactly this association that led to the MEGAOUTFLO hypothesis of episodic volcanism, outflow flooding, ponding of water, glaciation, and fluvial flow on Mars [30, 31]. This unanticipated discovery ties one explanation, that of the origin of very recent water-related landforms, to a larger explanatory scheme, MEGAOUTFLO (Mars Episodic Glacial Atmospheric Oceanic Upwelling by Thermotectonic Flood Outbursts), which was developed independent of and prior to the discovery. Not a logical confirmation, this is a consilience. It does not prove the truth of the explanation; instead, it shows the fruitfulness of the explanation as a guide to truth.

Conclusion: While arguments over the origins of individual landforms are interesting, and model simulations from simple assumptions are productive for theory representation, they should not displace the global study of landforms by colligation, coherence, and consilience. These methods have only begun to be applied to the newly recognized, exceptionally young, water-related landforms of Mars. The preliminary conclusion is that very recent hydroclimatic change, likely episodic, induced major hydrological activity of profound contrast to the current regime. While this conclusion is certainly problematic, its coherent plausibility and its immense importance for astrobiology and future human exploration merit more attention, including the theoretical modeling of its processes and consequences.

References: [1] Baker V. R. (1982) *The Channels of Mars,* (University Texas Press, Austin). [2] Carr M. H. (1996) *Water on Mars,* (Oxford, NY). [3] Hoffman N. (2000) *Icarus., 146,* 326–342. [4] Malin M. C. and Edgett K. S. (2000) *Science, 288,* 2330–2335. [5] Masson P. et al. (2001) *Space Science Reviews, 96,* 333–364. [6] Baker V. R. (2001) *Nature, 412,* 228–236. [7] Boynton W. V. et al. (2002) *Science, 297,* 81–85. [8] Baker V. R. (1998) In: *Lyell: The Past is the Key to the Present.,* (Geol. Soc. London Spec. Publ. 143, London), 171–182. [9] Gilbert G. K. (1886) *Amer. J. Sci., 31,* 284–299. [10] Costard F. et al. (2002) *Science, 295,* 110–113. [11] Siebert N. M. and Kargel J.S. (2001) *Geophys. Res. Letters, 28,* 899–903. [12] Mustard J.F. et al. (2001) *Nature, 412,* 411–414. [13] Kreslavsky M. A. and Head J. W. (2002) *Geophys. Res. Letters, 29,* doi: 10.1029/2002GLO15292. [14] Berman D. C. and Hartmann W. K. (2002) *Icarus., 159,* 1–17. [15] Burr D. M. et al. (2002) *Icarus., 159,* 53–73. [16] Mouginis-Mark P. J. (1990) *Icarus., 84,* 362–373. [17] Mangold N. and Allemand P. (2001) *Geophys. Res. Letters, 28,* 407–411. [18] Ferris J. C. et al. (2002) *Geophys Res. Letters, 29,* doi: 10.1029/2002GLO14936. [19] Hartmann W. K. and Berman D. C. (2000) *J. Geophys. Res., 105,* 15,011–15,025. [20] Lucchitta B. K. (1985) In: *Ices in the Solar System.,* (Reidel, NY), 563–604. [21] Squyres S. W. et al. (1992) In: *Mars,* (Univ. Arizona Press, Tucson) 493–522. [22] French H. M. (1996) *The Periglacial Environment,* (Longman, Harlow). [23] Cabrol N. A. and Grin E. A. (2001) *Icarus., 149,* 291–328. [24] Malin M. C. et al. (2001) *Science, 294,* 2146–2148. [25] Laskar J. and Robutel P. (1993) *Nature, 361,* 608–612. [26] Touma J. and Wisdom J. (1993) *Science, 259,* 1294–1297. [27] Hecht M. H. (2002) *Icarus., 156,* 373–387. [28] Kuznetz L. H. and Gan D. C. (2002) *Astrobiology, 2,* 183–195. [29] Haberle R. M. et al. (2001) *J. Geophys. Res., 106,* 23,317–23,326. [30] Baker V. R. et al. (1991) *Nature., 352,* 589–594. [31] Baker V. R. et al. (2000) *LPSC XXXI.,* Abstract #1863.