MARS= OCEANUS BOREALIS, ANCIENT GLACIERS, AND THE MEGAOUTFLO HYPOTHESIS. V.R. Baker[1, 2], R.G. Strom[2], J.M. Dohm[1], V.C. Gulick[3], J.S. Kargel[4], G. Komatsu[5], G.G. Ori[5], and J.W. Rice, Jr.[2]; [1]Dept. Of Hydrology and Water Res., Univ. of Arizona, Tucson, AZ 85721-0011, [2]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ 85721-0092, [3]NASA-Ames Research Center, MS 245-3, Moffett Field, CA 94035, [4]U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001; [5]Dipartimento di Scienze, Universitad d=Annunzio, Viale Pindaro 42, 65127 Pescara, Italy. (baker@hwr.arizona.edu)

Introduction: Recent results from the Mars Orbiter Laser Altimeter (MOLA) instrument of Mars Global Surveyor [1, 2] corroborate the existence of a vast ocean on the northern plains of Mars. Named Oceanus Borealis [3], this great ponding of water, documented by several investigators over the past 15 years [4, 5, 6, 7, 8], formed and reformed episodically during later Mars history, after cessation of the late heavy bombardment [3]. Among the many geological indicators of this ocean, several interpreted shoreline features [7, 9] are disputed by one study of a small number of Mars Orbiter Camera (MOC) images [10]. Many other lines of geological evidence consistently point to relatively recent episodes of ponded water. As in terrestrial proglacial lakes associated with cataclysmic flooding [11, 12], it may be that shoreline features are not well-developed for such transient pondings of water.

MEGAOUTFLO Hypothesis: A genetic model, first presented in 1991 [3], ascribes the episodic formation of Oceanus Borealis to cataclysmic outburst flooding of the outflow channels. Peak outflow discharges of 10^8 to 10^9 m^3s^{-1} [13, 14] imply total released reservoir volumes of 10^5 to 10^7 km^3 of water, using scaling relationships for terrestrial floods [12]. The higher volumes match the volume of Oceanus Borealis estimated by Head et al. [2]. The immense peak discharges implied by the size and morphology of the outflow channels [15, 16] have heretofore not been adequately explained by any previous models. We suggest a mechanism whereby CO_2 clathrate in the Martian permafrost zone [17] is destabilized by episodes of very high heat flow, such that released CO_2 from the lower permafrost zone (2 - 3 km depth) and dissolved CO_2 from the underlying groundwater explosively forces out pressurized slurries of water and fractured rock fragments in massive outbursts [18]. The huge floods form Oceanus Borealis as the atmosphere is being transformed by released CO_2 to a transient greenhouse condition [3, 19]. Subsequent sediment-charged water enters the ocean as hyperpycnal flows, generating density flows that extend deposits across the northern plains.

We name this explanatory hypothesis for Oceanus Borealis and its consequences the MEGAOUTFLO hypothesis for AMars **E**pisodic **G**lacial **A**tmospheric **O**ceanic **U**pwelling by **T**hermotectonic **FL**ood **O**utbursts@ [20]. This hypothesis explains the long epochs ($\sim10^8+$ years), during which the Mars surface had extremely cold, dry conditions similar to those prevailing today, terminated by short-duration ($\sim10^4$ to 10^5 years) episodes of much warmer, wetter conditions associated with a transient greenhouse climate. These quasi-stable episodes resulted in glaciation [21, 22] and valley network formation [8, 23] late in Martian history, coincident with the great outflow channel discharges that formed Oceanus Borealis. The processes are cyclic with the long epochs of cold-dry conditions alternating with very short episodes of cool-wet conditions associated with ponding on the northern plains. Only a few such cycles are indicated in the geological evidence.

Episodic Thermal Fluctuations: Internal planetary heat provided the trigger for the massive outflows that transformed Martian climate during the geologically short epochs of ocean formation. Superimposed on the long-term monotonic decline in mantle heat flux for Mars [24], we envision short-duration episodes of higher heat flux to the surface, perhaps of a type modeled by Herrick and Parmentier for terrestrial planetary histories [25]. These episodes of higher heat flow are consistent with the magmatic and tectonic history of Mars [26]. The higher heat flow is directly evidenced in the warm-based glacial processes responsible for the character of the glacial land forms [21, 22], which could not have occurred for permafrost conditions like those prevailing today.

During the short-duration thermal episodes of cataclysmic outflow, a temporary cool-wet climate prevailed. Water that evaporated off Oceanus Borealis was transferred to uplands, including the Tharsis volcanoes and portions of the southern highlands, where precipitation as snow promoted the growth of glaciers. Extensive periglacial landform development at high latitudes [27, 28] is also readily explained by this moisture influx. The Olympus Mons volcanic construct developed in Oceanus Borealis, and its aureole represents immense submarine landslides [29], similar to those characterizing the Hawaiian Islands [30].

Climatic Change: The cool-wet climate was inherently unstable. Water from the evaporating ocean was lost to storage (1) in highland glaciers, and (2) via infiltration into the highly porous lithologies of the Martian surface. The latter, not a lack of precipitation [31], explains the observed low density [32, 33] and lack of upland dissection for Martian valley networks. Moreover, many of the networks [34], or parts of them [32] were active in later Mars history, after the end of late heavy bombardment. The sapping origin of the valleys [35] implies continually recharged water to maintain flow; only precipitation can achieve this condition, though local spring flow may also be fed by hydrothermal processes [36].

The transient Martian greenhouse also progressively lost CO_2 via (1) dissolved gas in the infiltrating acidic water, and (2) silicate weathering carrying bicarbonate into the subsurface by infiltration. Subsequent underground carbonate deposition then released CO_2 to the groundwater, which became trapped beneath an ice-cemented permafrost zone. The latter developed as the greenhouse effect declined because of atmospheric loss of water and CO_2 over a time scale of 10^3 to 10^5 years. Concurrent planetary heat flow decline, following the triggering peak episode, produced a downward extending permafrost that progressively incorporated the recharging water and groundwater. As the permafrost extended downward into the stability field for CO_2 clathrate [17], this gas hydrate accumulated above the gas-charged groundwater. Thus, the long-term reservoir for carbon on Mars is a sequestering underground in the forms of (1) clathrate, (2) gas-charged groundwater, and (3) carbonate cements. Only occasionally, and for relatively short duration, does carbon get transferred to the atmosphere, as greenhouse-promoting CO_2, during the cataclysmic ocean-forming episodes. Oceanus Borealis does not last long enough in any individual episode for appreciable carbonate deposition, thereby explaining the lack of observed carbonates in spectra from the Thermal Emission Spectrometer of Mars Global Surveyor [37]. The short duration of the ocean-forming phases also explains the very low degradation rates for much of the Martian surface during the long period after heavy bombardment. Degradation was highly localized in time and space.

Conclusion: The MEGAOUTFLO hypothesis explains many otherwise enigmatic aspects of Mars geology and atmospheric history. The cyclic character of the triggering heat flow events, cataclysmic outburst flooding, ocean formation, transient greenhouse atmosphere, and subsequent sequestering of water and CO_2 in the subsurface all combine into a single coherent conceptual model, binding together the numerous diverse components of paleoenviromental history for Mars.

References: [1] Head J.W. et al. (1998) *GRL*, *24*, 4401-4404. [2] Head J.W. et al. (1999) *Science*, *286*, 2134-2137. [3] Baker V.R. et al. (1991) *Nature*, *352*, 589-594. [4] Jöns H.P. (1985) *LPSC XVII*, 404-405. [5] Lucchitta B.K. et al. (1985) *NASA Tech. Memo 88383*, 450-453. [6] Parker T.J. et al. (1987) Lunar and Planet. Inst. *Tech. Rept. 87-01*, 96-98. [7] Parker T.J. et al. (1989) *Icarus*, *82*, 111-145. [8] Gulick V.C. and Baker V.R. (1990) *JGR*, *95*, 14,325-14,344. [9] Parker T.J. et al. (1993) *JGR*, *98*, 11,061-11,078. [10] Malin M.C. and Edgett K.S. (1999) *GRL*, *26*, 3049-3052. [11] Rudoy A.N. and Baker V.R. (1993) *Sediment Geology*, *85*, 53-62. [12] Baker V.R. et al. (1993) *Science*, *259*, 348-350. [13] Robinson M.S. and Tanaka K.L. (1990) *Geology*, *18*, 902-905. [14] Komatsu G. and Baker V.R. (1997) *JGR*, *102*, 4151-4160. [15] Baker V.R. (1982) *The Channels of Mars*, Univ. Texas Press, Austin. [16] Baker V.R. et al. (1992) in *Mars*, Kieffer H.H. et al. eds., Univ. Arizona Press, Tucson. [17] Kargel J.S. et al. (2000) *LPSC XXXI*, this volume. [18] Komatsu G. et al. (2000) *LPSC XXXI*, this volume. [19] Gulick V.C. et al. (1997) *Icarus*, *130*, 68-86. [20] Baker V.R. (1999) *Bull. Amer. Astron. Soc.*, *31*, 1133. [21] Kargel J.S. and Strom R.G. (1992) *Geology*, *20*, 3-7. [22] Kargel J.S. et al. (1995) *JGR*, *100*, 5351-5368. [23] Gulick V.C. and Baker V.R. (1989) *Nature*, *341*, 514-516. [24] Schubert G. et al. (1992) in *Mars*, Kieffer H.H. et al. eds., Univ. Arizona Press, Tucson. [25] Herrick D.L. and Parmentier E.M. (1994) *JGR*, *99*, 2053-2062. [26] Dohm J.M. et al. (2000) *LPSC XXXI*, this volume. [27] Rossbacher L.A. and Judson S. (1981) *Icarus*, *45*, 39-59. [28] Lucchitta B.K. (1985) in *Ices in the Solar System*, Klinger J. et al., eds., D. Reidel, Boston. [29] Mouginis-Mark P.J. (1993) *LPSC XXIV*, 1021-1022. [30] Moore J.G. et al. (1989) *JGR*, *94*, 17,465-17,484. [31] Malin M.C. and Carr M.H. (1999) *Nature*, *397*, 589-591. [32] Baker V.R. and Partridge J.R. (1986) *JGR*, *91*, 3561-3572. [33] Carr M.H. (1995) *JGR*, *100*, 7479-7507. [34] Scott D.H. and Dohm J.M. (1992) *LPSC XXIII*, 1251-1252. [35] Baker V.R. et al. (1990) in *Ground-water Geomorphology*, Higgins C.G. and Coates D.R., eds. Geol. Soc. Amer. Spec. Paper *252*, Boulder. [36] Gulick V.C. (1998) *JGR*, *103*, 19,365-19,387. [37] Christensen P. (1999) *Eos*, *80*, F 601.