THE WATERY ORIGIN AND EVOLUTION OF MARS: A GEOLOGICAL PERSPECTIVE. Victor R. Baker¹, Shigenori Maruyama², James M. Dohm³, ¹Dept. of Hydrology & Atmospheric Sciences and Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721-0011 (baker@email.arizona.edu); ²Dept. of Earth & Planetary Sciences, Tokyo Inst. of Technology, Meguro 152-8551, Japan; ³Dept. of Space Exploration & Discovery, Univ. Museum, Univ. Tokyo, Tokyo, Japan, 113-0033

Introduction: Mars has had a long geological history of watery activity. Though this fact has been geologically obvious for at least the past 35 years [e.g., 1, 2, 3], there has also been considerable skepticism about the role of water in the planetary evolution of Mars [4]. In this paper we update our continuing development of a working hypothesis [5-10] for explaining the watery geological evolution Mars. Named GEOMARS (Geological Evolution Of Mars and Related Syntheses), this hypothesis was motivated by (1) the need to provide a unified explanation for the many otherwise, puzzling, anomalous discoveries made by exploratory Mars spacecraft, especially since the late 1990s (see below), (2) the physical insight that terrestrial planets, depending on their first-order geophysical parameters, should evolve through various modes of mantle convection, including magma-ocean, plate tectonic, and stagnant lid convective processes [11], and (3) analogical geological reasoning [12]

Anomalies in Need of Explanation: Mars presents us with numerous water-related anomalies in its planetary evolution that either can be explained piecemeal by ad hoc hypotheses, or, alternatively, might be viewed as part of something to be explained by a unifying, working hypothesis. Examples of these anomalies include the following: (A) a Martian crust extensively layered to the depth of several kilometers [13,14], probably indicating an early history of extensive fluvial denudation [15] and sedimentation, contemporaneous with and immediately subsequent to the late heavy bombardment cratering episode; (B) many geological indicators pointed to the role of an episodically present, ancient ocean on the northern plains that played a critical role in Mars’ long-term hydrological cycle [2], (C) areas of hematite mineralization indicated an ancient phase of aqueous activity [16], (D) a globally bimodal Mars hypsometry with discrete highlands in the south, associated with much thicker crust (~60 km), and low-lying plains in the north, underlain by relatively thin crust (~30 km), thereby comprising a dichotomy analogous to that of Earth, but explained differently by the conventional theory [17]; (E) striking linear crustal magnetization anomalies of remarkable intensity that occur in the southern highlands [18]; (F) persistence of water-related activity on Mars to the present day, with extensive evidence of very recent hillslope gullies [19], glaciers [3], outflow channels [20, 21], and related phenomena; (F) episodic volcanism and related tectonic processes persisting through later Martian history to the present time despite physical theory predicting greatly reduced heat flow through time for the planet, (G) progressive concentration of volcanism and tectonic activity at Tharsis and Elysium, episodically operating through most of Martian history, extending from the late Noachian to the present [22].

Early Mars: Our earlier versions of GEOMARS were described in several full papers [23, 24, 25]. These proposed that Mars: (> 4.0 Ga) rapidly accreted, differentiated and formed a magma ocean, developed a powerful dynamo and associated magnetosphere, and then experienced some kind of proto-plate tectonics. At ~4.0 Ga, the dynamo/magnetosphere terminated, and subduction associated with the early phase of proto-plate tectonics shut down tens of millions of years later. At < ~3.93 Ga, Mars then became a one-plate planet dominated by the Tharsis superplume, the influence of which has continued until recent geological time. Apparently quite independent of our work, this same general sequence was recently numerically modeled by Zhang and O’Neill [26].

Our recent work [27] suggests that the Martian upper mantle would have been entirely molten when Mars formed, and with the solidification of the Martian surface there may have been an anorthositic primordial continent. In other words, like the Moon at 4.53 Ga, Mars would have likely had anorthosite, KREEP basalt, and KREEP gabbro. The recent discovery of anorthosite on Mars indicates the possibility of a felsic Hadean-aged equivalent continental crust.

Our current view envisions a rapid, relatively dry initial accretion of Mars at 4.56 Ga that was without atmospheric and oceanic components. This was followed by a magma ocean phase during which the anorthosite crust formed. This was then followed by a heavy bombardment involving the
Proto-Plate Tectonics and Tharsis: We have recently documented considerable geological evidence for the phase of early Proto-Plate Tectonics on Mars [29, 30]. This process would have been associated with a remarkably intense core dynamo and consequent magnetic field. This, in turn, led to the formation of intensely magnetized oceanic plateau that accreted to proto-continental terrains now in evidence as the linear anomalies of remnant magnetism in the Martian southern highlands.

The early phase of plate tectonics, would, via subduction, convey water, carbon dioxide, and other volatiles to the core-mantle boundary zone, thereby depleting the reservoir of these materials from the surface and transferring them to the deep mantle. This whole-mantle subduction processes also cooled the evolving core, thereby terminating the dynamo by the time of the late heavy bombardment. Thus, this early phase of plate tectonics, could have generated the Martian highland crust by continental accretion. Moreover, by concentrating volatiles in a local region of the Martian mantle, the early plate-tectonic phase of Mars would have led to the superplume at Tharsis. The immense concentration of volcanism at Tharsis in later Mars history would have a great influence on climate change and the generation of megafloods, in analogous fashion to Earth superplume centers. The persistence of this volcanism episodically through later Martian history would provide a mechanism for the episodic, short duration aqueous phases that generated transient “oceans” and fluvial landforms. 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 were short-duration episodes of higher heat flow to the surface. Such episodes of higher heat flow seem consistent with both the magmatic and tectonic history of Mars.