SCENARIOS FOR THE EVOLUTION OF LIFE ON MARS. D. Schulze-Makuch[1], L. N. Irwin[2], J. H. Lipps[3], D. LeMone[4], and J. Dohm[5], [1]Dept. of Geology, Washington State University, dirksm@wsu.edu, [2]Dept. of Biological Sciences, Univ. of Texas at El Paso, lirwin@utep.edu. [3]Dept. of Integrative Biology and Museum of Paleontology, Univ. of California at Berkeley, jlipps@berkeley.edu. [4]Dept. of Geological Sciences, Univ. of Texas at El Paso, lemone@geo.utep.edu. [5]Dept. of Hydrology and Water Resources, Univ. of Arizona, jmd@hwr.arizona.edu.

Introduction: Life as we know it has three basic requirements: an energy source, polymeric chemistry, and liquid water. These conditions were available on both Earth and Mars in their early histories. Since environmental conditions on both planets were similar initially, life may have originated separately on both planets. Alternatively, Martian and Earth organisms may have had a common origin, with interplanetary transfer of originating forms of life among the terrestrial inner planets [1,2]. Once established, however, life on Earth and Mars would necessarily have followed different trajectories, as the environmental history appears to have diverged drastically on the two planets after the first few hundred million years.

Martian Environmental History: Several lines of evidence (including geologic, topographic, geophysical, hydrologic) collectively point towards a dynamic, water-enriched planet, with somewhat Earth-like conditions during the embryonic stages of the development (estimated to be nearly the first 700 million years). The geologic, climatic, and paleohydrologic evolutional histories of Mars was portrayed by the overarching GEOMARS Theory [3], which describes 7 major evolutional phases (from oldest to youngest): (1) Mars differentiated shortly after accretion into a liquid metallic core, a mantle boundary layer (MBL) of high-pressure silicate mineral phases, upper mantle, magma ocean, thin komatiitic crust, and convecting steam atmosphere; (2) Mars cooled to condense its steam atmosphere and transformed its mode of mantle convection to initial stages of plate tectonics. Subduction of water-rich basaltic crust initiated arc volcanism and transferred water, carbonates, and sulfates to the mantle; (3) the core dynamo and associated magnetosphere lead to the formation and stability of liquid water on the Martian surface; (4) continental crust accreted and thickened, and hydrated basaltic crust subducted to the mantle boundary layer and lower mantle of Mars; (5) the core dynamo stopped during Noachian heavy bombardment while plate tectonics continued; (6) the Tharsis superplume arose with or shortly following the termination of plate tectonism, which included the focused subduction of hydrated crust in the Tharsis region; followed by (7) superplume/stagnant-lid phase of Martian planetary evolution with episodic phases of volcanism and water outflows. The 7th and latest stage may have persisted for probably more than the last 3.7 G.a. (Fig.1), with prevailing cold and dry conditions punctuated by episodic endogenic-driven activity that resulted in flooding, ponding in the northern plains, and short-lived hydrologic cycles [3-8].

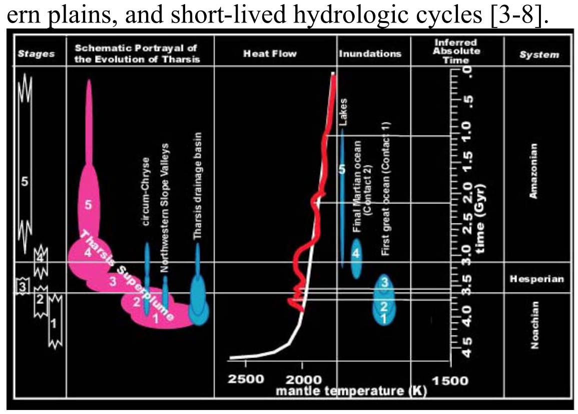

Fig. 1. Chart comparing the evolutional stages of geologic activity in the Tharsis Magmatic Complex [6], which includes circum-Chryse, Northwestern Slope Valleys [7], and Tharsis drainage basin/aquifer system [6]. Size of solid areas are roughly proportional to degree of exposed activity; loss of internal heat in Mars through time. Note the maximum effective heat flow to lithosphere in the Early into Middle Noachian and non-steady-state decline in subjective heat flow (red line) compared to proposed steady-state decline in mantle temperature with time (white line [9], following the Middle Noachian based on published geologic information [e.g. 3,6-8,10]

Evolutionary Scenarios: Early Mars would have possessed similar environments to those found on early Earth [11]. Thus, Mars would have at least in its early stages provided the same variety of environments as on Earth, including shallow water and littoral environments, and deep-water environments below the wave base in standing water [12]. Volcanic and hydrothermal activity would have been strong on early Mars, although by a factor of 100 less than on Earth [13]. An origin of life at sites of hydrothermal activity or episodic pools are thus also consistent with Martian conditions. However, the smaller size of Mars would imply that the planet would have cooled down more quickly and water would have condensed on the surface earlier than on Earth. This may not have inhibited life, because liquid water beneath an ice cap and heated from below by hydrothermal activity may in fact provide a suitable environment (e.g. Lake Vostok

(Earth), Europa; [14-16]. Also, if the first cells originated under hydrothermal conditions, they would shortly (~ million years) encounter their first evolutionary challenge. Thermophilic life would have to evolve adaptation to gradually colder and dryer conditions, culminating in a psychrophilic life style. However, once psychrophilic forms evolved, life on Mars could have remained with little change until today. Mineralogical energy sources may have been sufficient to support as much chemolithotrophic life on Mars in its first 10-50 million years as on early Earth [13].

The termination of plate tectonics during the superplume/stagnant-lid phase of Martian planetary evolution may not have inhibited life. From a microbial viewpoint, life occurs on temporal and spatial scales that are many orders of magnitude smaller than geological processes [11], thus microbial life could have become well-established on Mars before the climatic degradation made the surface inhospitable. However, a lack of plate tectonics would have limited available nutrients, and with it, biomass on Mars. Little diversity can be expected for contemporary life on Mars, if it exists. Due to the lack of an ozone shield, the Martian land surface may have always been sterile. Even life on Earth did not populate the surface before oxygen became abundant and the ozone shield sufficiently protective. The surface water environment, however, could have been habitable. Several centimeters of water provide efficient UV protection, along with other protective mechanisms [17].

Once life evolved on Earth, it proved to be extraordinarily tenacious. Despite numerous global catastrophes and recurrent environmental crises, several of which wiped out a large proportion of the species in existence, life has persisted to occupy every suitable habitat on the planet. Thus, if life on Mars could have spread from its origin to populate most of the planet and was abundant in liquid surface water pools or an early ocean, it may well have survived the environmental changes later in its history. At the microbial level, dormancy strategies, such as spores and the cryptogenic state of organisms found in cold environments on Earth, are of special relevance, because they allow organisms to exist through harsh conditions until the environment becomes suitable for active life again. This is directly relevant to Mars with its periodic conditions of liquid water on the surface and hostile conditions of long, cold dessication. If life evolved far enough on Mars to develop dormant states, it was likely hardy enough to survive any environmental stresses that followed in later Martian history.

Conclusions: Life adapts to optimally utilize its environmental resources; thus, a similar resource regime would in principle foster similarities in organismal strategies, even if they would had originated in separate geneses. As the environmental history on Earth and Mars appears to have diverged drastically after the first few hundred million years, so too would its life history. The most reasonable scenarios for the environmental history of Mars indicate long dry and cold periods interspersed with warmer and wetter environments. Life could be present today on Mars in liquid water in or beneath ice sheets, in ground waters, or in protected habitats such as lava tubes, cracks and fissures, or caves. The potential for life is enhanced in regions where elevated heat flow may occur, such as in parts of Tharsis and Elysium and the region that straddles the two volcanic provinces [18]. Possible organisms would be chemoautotrophic psychrophiles adapted to a nutrient poor environment, or photoautotrophc life in selected habitats such as in fringe areas of polar ice. Or, life may have evolved alternating cycles between dormant and active life forms, in which case microbes could be present in dormant forms close to the surface and in proliferative forms in protected environments. The periodic availability of liquid water on the Martian surface could have provided opportunities for biologic activity at the surface during the short-lived climatic perturbations, as well as to evolutionary progress driven by directional selection; not unlike the evolutionary innovations of organisms following Snowball Earth events.

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