DID MARS EVER HAVE A LIVELY UNDERGROUND SCENE? Joseph. R. Michalski, Natural History Museum, London, UK and Planetary Science Institute, Tucson, AZ, USA. michalski@psi.edu

Introduction: Prokaryotes comprise more than 50% of the Earth’s organic carbon, and the amount of prokaryote biomass in the deep subsurface is 10-15 times the combined mass of prokaryotes that inhabit the oceans and terrestrial surface combined [1]. We do not know when the first life occurred on Earth, but the first evidence is found in some of the oldest preserved rocks dating to 3.5 or, as much as 3.8 Ga [2]. While the concept of a “tree of life” breaks down in the Archean [3], it seems likely that the most primitive ancestors of all life on Earth correspond to thermophile chemoautotrophs. Perhaps these are the only life forms that survived intense heat flow during the Late Heavy Bombardment or perhaps they actually represent the first life forms, which may have developed to take advantage of existing chemical gradients within the crust [3-4].

The environments on early Mars and Earth may have been similar (Figure 1). But, Mars cooled quickly and since the Noachian, the surface has been cold, hyperarid, oxidizing, and probably inhospitable to life. On Earth, life never developed photosynthesis until ~3 Ga (which corresponds to the end of the Hesperian) [2], and probably didn’t colonize the land surface until the Proterozoic (Amazonian) [5]. It is entirely possible that even if life did form on Mars, it never colonized the surface. Ongoing efforts to characterize the habitability of Mars by studying sediments that formed at the surface might produce misleading results because they are investigating environments that might never have been inhabited on a planet that is very much habitable.

Spectroscopic results over the last 5-10 years have revealed significant diversity, abundance, and distribution of alteration minerals that formed from aqueous processes on ancient Mars (recently summarized by Ehlmann et al. [6]). The mineralogy and context of these altered deposits indicates that deep hydrothermal processes have operated on Mars, and might have persisted from the Noachian into the Hesperian or later. In this work, I consider the implications of recent results for the habitability of the subsurface, the occurrence of groundwater, and the possibility to access materials representing subsurface biological processes.

Results: I carried out a survey of deep craters with the intention of evaluating morphologic and mineralogical evidence for groundwater upwelling [7] in the deepest basins on Mars – where groundwater would have been most likely to emerge. A survey of deep, ancient craters in the northern hemisphere shows that most of the basins do not show any evidence for groundwater upwelling. But, several craters in the northwest Arabia Terra region do show such evidence, which could indicate that a regional event occurred in this area. The null results provide a way to constrain the minimum depth below the surface of a saturated groundwater zone, and craters that do show evidence for upwelling allow for constrains on the slope and absolute elevation of a past groundwater surface.

Figure 1: A concept diagram comparing the early histories of the Earth and Mars, with major events in the biological history of the Earth compared to epochs of alteration on Mars.
I propose a model of the subsurface geology of Mars which includes 4 zones involving groundwater [8]: 1) a surface cryosphere containing acidic ice deposits within which, sulfates might form and below which, clays may have formed [9]; 2) a shallow (1-2 km depth) unsaturated zone through which transient meltwater from surface ice (or episodic rain) could have passed, leaching the most mobile cations from basaltic materials and remerging after short traverse distances to deposit chloride salts; 3) a deep unsaturated zone containing disseminated clays and other hydrous silicates, through which strong brines may have passed and rarely or never reemerged at the surface; and 4) a very deep (>4-6 km) saturated zone with dense brines in limited pore space associated with highly altered crust. The combined total of all of these reservoirs could constitute a significant amount of Mars' global water budget, in subsurface fluid and structural water in minerals.

The subsurface was hydrothermally active early in Martian history [6]. Serpentinization in particular would have been an important process to consider with regard to the habitability of ancient Mars. The types of geologic processes that allowed life for form or survive on the early Earth were also occurring on early Mars. In order to truly characterize the habitability of Mars, it will ultimately be necessary to focus on the geology of the subsurface. Subsurface prokaryotes are not simply extremophiles that could survive in the deep crust of Earth or Mars. In fact, we are the extremophiles living at the surface looking at the largest category of simple life forms known, which occur at depth.


Figure 2: A conceptual diagram of the distribution and context of groundwater on Mars. At the left, a model of porosity as a function of depth (after [8]) shows that the deep crust could contain a significant amount of pore water. Two estimates of thermal gradients on Noachian Mars and in recent time show that the base of the cryosphere would have grown to significant depth since the Noachian. But earlier, hydrothermal processes could have occurred in the deep crust (zone 4) or possible in the unsaturated zone (zone 3). In zone 2, weak cryobrines could have traversed the crust only weakly altering basaltic material and becoming enriched in Na and K that would have been deposited as chlorides upon emergence during upwelling events. Sulfates correspond to ice-driven weathering processes in zone 1.