INVENTORY OF POTENTIALLY HABITABLE ENVIRONMENTS ON MARS

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On Earth, biology, hydrology, and geology are interlinked such that certain types of organisms are often associated with specific geologic, hydrologic, and/or climatic conditions, including rock type, pressure (both atmospheric and lithostatic), humidity, temperature, and chemistry. The amazing diversity of life on Earth, which includes some of the extremophiles, has been realized in part through the hypothesis that Mars may record fossilized and/or extant life [1].

Mars has had an active and varied geologic history similar in many respects to that of Earth, especially highlighted by post-Viking-era missions [2]. Though present-day Mars is characterized by a thin atmosphere, a cold and dry climate, and pervasive eolian modification, numerous features have terrestrial counterparts that indicate an Earth-like dynamically active planet. These include: ancient mountain ranges, such as Thaumasia highlands and Coprates rise, and other large ancient tectonic structures [3,4], extensional, contractional, and strike-slip faults [5], wrinkle ridges [6], structurally controlled basins among distinct magnetic signatures and highly degraded promontories [4,7], gigantic collapse features indicative of subterranean crustal voids such as the chaotic terrains that source the circum-Chryse outflow channels [8], volcanic constructs of wide-ranging geometric shapes [9], lava flows [10], vent structures such as mud volcanoes [11-13], and magmatic-tectonic-water-interrelated landforms (e.g., structurally controlled release of volatiles in volcanic terrains) [14]. In addition, Mars has had long-term water-enrichment, as evidenced by large outflow channels [15], valley networks of varying ages [16], gullies and debris aprons [17], polygonal-patterned ground [18], glaciers [19], rock glaciers [20], deltas [21,22], impact crater lakes [23,24], impact cratering events and related hydrothermal activity such as at Toro Crater [25,26], and possible water bodies ranging from lakes to oceans [16,27-29].

Recent missions are also revealing Mars to be a geochemically diverse planet when compared to Viking-based assessment. For example, the idea of a basaltic and basaltic-andesite Mars with patches of hematite, based on spectroscopy, has evolved into a more mature understanding where Mars is seen to exhibit greater lithologic diversity including quartz, serpentine, sulfates, salts, chloride, and clays [30-37]. Often, these lithologies are linked directly to the interaction among aqueous geochemical reactions, as well as geologic activity, consistent with the previously listed examples.

Inspired by a geologically dynamic and water-enriched planet throughout most of its history, we investigate prime examples of Earth-like environments on Mars with elevated habitability potential, environments that ought to be targeted by robotic and manned missions to Mars. These include long-lived magmatic complexes, hydrothermal environments, possible subterranean caverns, basins/aquifer systems, structurally controlled conduits and basins, evaporite deposits such as salts, possible marine and lacustrine sediments, Antarctic-like paleosols, vent structures such as mud volcanoes and piping structures, and ice bodies such as ice lenses (**Table 1**). Please see [38] for greater detail.

TABLE 1. Habitable environments on Mars based on the direct linkage among life on Earth and specific environmental conditions.

Env.	Earth E.g.	Earth – Life E.g.	Mars. E.g.
Magmatic complexes	Superplumes [39,40]	Methogens, thermophiles, and chemoautotrophs	Tharsis [41]
Impact- and magmatic-induced hydrothermal	Solfatara Crater [42]; Ries impact structure [43]	Solfatara—thermoacidophilic sulfur oxidizing Archaea, thermophilic or thermotolerant bacteria	Apollinaris Patera [44-46], Toro [25,26]
Caverns	Numerous and diverse	Primarily chemoautotrophs	Tharsis [47]
Basin/aquifer systems	Numerous and diverse	Microbial mats with photosynthetic, chemoautotrophic, and heteroptrophic communities near surface; methanogens and other anaeropic prokaryotes in the deeper subsurface	Tharsis [41,48]
Structurally controlled conduits and basins.	Atacama Desert [49] and World Deserts [50]	Cytophaga–Flavobacterium–Bacteroides; Proteobacteria; Acidobacteria; Actinobacteria and Haloarchaea	Tharsis [40] and on the margin of Hellas [51]
Evaporite deposits such as salts	Atacama Desert [52]	Endolithic phototrophs, heterotrophic bacteria, and archea.	Chloride-bearing deposits in the southern highlands [36]
Possible marine and lacustrine deposits.	Numerous and diverse	Enormous diversity of micro- and macro-organisms, Prtokaryotae and Eukaryotae.	Northern plains [53] and Eberswalde crater [54]

Antarctic-like paleosols	Dry valleys [55]	Fungi and soil bacteria, including Alphaproteobacteria, Gammaproteobacteria (Pseudomonas), Flavobacterium, and Actinobacteridae (Micrococcus)	Possible areally extensive and diverse localities [55]
Vent structures	Parts of the Grand Canyon [56]	Archaea, Bacteria, Algae, and Fungi, and even macroorganisms	Mounds with summit pits in the parts of the northern plains such as within the Vastitas Borealis Formation [12-13,56]
Ice bodies	Antarctic [57]	Bacillus, Mycobacteria, Micrococcus, Brevibacterium, Arthrobacter, Clavibacter etc.; these bacteria are also found in permafrost and tundra soil, Dry Valley rock materials, and sea ice; Acidovorax, Actinomyces, Afipia, Comamonas, and Aquabacterium are found in ice cores above Vostok Lake, Antarctica**.**	North and South Poles

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