Linkage among Geology, Hydrology, Climate, and Life on Earth Point to Possible Life-containing Environments on Mars

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INTRODUCTION: On Earth, biology, hydrology, and geology are often interwoven such that certain types of life are often linked with specific geologic, hydrologic, and climatic conditions, which include rock type, pressure, temperature, and chemistry. Life has found a niche in diverse environments, and this presents the possibility that Mars, too, may record fossilized and/or extant life in diverse settings. Geologic, paleohydrologic, and climatic conditions through the evolution of Mars are similar in many respects to conditions occurring during the evolution of the Earth (e.g., geologic activity and water enrichment), and as such, point to environments on Mars with elevated life potential. Here, we discuss examples of environments on Mars that have elevated life potential. These are environments of which ought to be targeted by international robotic and/or manned missions to Mars.

ENVIRONMENTS ON MARS WITH ELEVATED POTENTIAL FOR LIFE ([1]):

Long-lived magmatic complexes. Similar to Earth, magmatic-driven processes, including plume-driven tectonism, dominate the dynamic geologic history of Mars such as exemplified at Tharsis [2]. Similar to Earth's Superplumes [3,4], that release significant internal heat energy and volatiles and ultimately have a significant influence on life [5], parts of the Tharsis Superplume [6] should be considered prime exobiologic targets.

Martian hydrothermal environments. Recorded geologic activity, coupled with extensive evidence of past and present-day water/ice, above and below the martian surface, indicate that hydrothermal environments certainly existed in the past and some may still even be active today [7]. Such environments should also be considered prime targets to determine whether life existed on Mars [8], as diverse life exists in such environments on Earth even at extreme temperature and pH conditions [7].

Subterranean caverns. Subterranean caverns are believed to exist in Mars' crust, especially in the Tharsis region [9,10]. Such underground environments are prime life-containing habitats, especially as their terrestrial counterparts host extensive and diverse life, with certain types in specific temperature and aqueous conditions [11].

Basins/aquifer systems. Geologic investigation has revealed two ancient (Noachian Period) large (Europe-size) basins, Tharsis [12] and Arabia Terra [13]. Both have potential long-term mixing of water and energy, and thus should be considered prime targets for future robotic and manned exobiologic missions.

Structurally-controlled conduits and basins. Tectonic structures can control the migration of fluids such as magma and water, as well as heat, in the subsurface, influencing volcanic and hydrogeologic activity. As energy plus water are often considered a prerequisites of life [14], such environments (e.g., Atacama Desert), are considered to be environments of elevated life potential [15].

Evaporite deposits such as salts. Widespread deposits with a chloride salt component have been identified and mapped, more noticeably in the Terra Sirenum region, but also across the entire planet at latitudes between -10º and -50º [16]. Many of the basins in the Terra Sirenum region are structurally controlled [17] similar to evaporite (salt)-containing basins of the Atacama Desert [18]. These deposits bear similarities to the life-containing evaporitic deposits found in the structurally-controlled basins of the Atacama Desert [18], and could also contain microorganisms that use salts for attracting water from the atmosphere hygroscopically [18,19].

Possible marine and lacustine sediments. There is evidence for lakes and oceans [20], resulting from endogenic-driven flooding such as from Tharsis [21]. In addition, impact craters often formed catchment basins for lakes identified through geomorphologic and topographic analyses [22] such as Eberswalde Delta [23]. Did such bodies harbor life on Mars?

Antarctic-like paleosols. Microbial life in Antarctic paleosols, with minor amounts of Fe available for physiological processes to function, argues for the potential of microbial life to exist in ice-enriched paleosols of Mars, particularly given its watery and dynamic geologic past and relatively high concentration of total and secondary Fe in subaerial paleosols [24].

Vent structures such as mud volcanoes. Large parts of the northern plains, particularly highlighted in the extensive deposits of the Vastitas Borealis Formation [25], are dotted with mounds, many of which display summit depressions. Among interpretations [26], venting related to mud volcanism is a possible mechanism for the formation for at least a percentage of the features [see Oehler and Allen, this conference]. Such environments on Earth have been shown to have elevated fossil life since the pipes involve water and often high energy conditions [27]. There are also vent structures in ancient provinces such as Arabia Terra [28].

Bodies of ice. Ice occurs in diverse geologic provinces and elevations on Mars, including the polar regions, northern plains, margin of the highland-lowland boundary, northwest flanks of the shield volcanoes of Tharsis Montes and Olympus Mons, and impact basins and rims. In addition, within distinct ancient mountain ranges such as Thaumasia highlands, ice-related features mark a complex history of multiple glacial/periglacial phases [29]. On Earth, microbes have been preserved for hundreds of thousands of years in ice [30], and some also have been found to be viable [31]. The extensive ice deposits on Mars should be sampled and analyzed.

Deep Mars. Life has found a niche kilometers below the Earth's surface [32], where water and other volatiles have been cycled to great depths. In fact, Earth's habitability at a global scale may rely on a vast underground reservoir of oxygen and other volatiles that are transferred to and from the surface and deep subsurface along plate tectonic-driven conveyor belts [33]. Deep within the martian crust, the putative life would be protected from radiation and challenging surface conditions. As Mars likely had a plate tectonic phase early in its history [34,35], such life would have benefited from similar cycling mechanisms as Earth [33].

SUMMARY. Mars has potential to contain life based in diverse environments similar to those of Earth. However, the martian surface differs from that on Earth in that it is subject to major UV and gamma ray exposure and lacks oxygen and other volatiles vital for the development of aerobic life. In addition, some martian geologic provinces are much more dynamic than others (e.g., Tharsis vs. Arabia Terra), and this may impact their habitability potential. As such, stable versus unstable environments also should be considered during the reconnaissance phase for choosing prime exbiologic targets. Ultimately, determining whether fossilized and extant life exists on Mars will take a sustained and targeted international effort.

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