Life on Mars? Microbes in Mars-like Antarctic Environments

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Abstract

Cold mountain environments on Earth range from cold tropical and cold middle-latitude to cold polar with the latter bearing properties nearly equivalent to those of Mars. Antarctic cold desert soils, present-day environmental conditions, and geologic and hydrologic records of a dynamic past are similar in many respects to those of the Red Planet, including similar lithologies, variable salt/Fe ratios, and quasi-permanent dry frozen state with infrequent melting and wetting with liquid water, all of which are prerequisites for life. Similar to Mars, Antarctica also records changing environmental conditions through time related to both endogenic (e.g., magmatic)- and exogenic (e.g., impact cratering events and changes in orbital parameter-related activity. Surface conditions, however, differ significantly among the two terrestrial planets. Whereas Earth is protected from intense UV and Gamma Ray exposure due to its oxygen-and nitrogen-enriched atmosphere and active magnetosphere, the oxygen-depleted, thin atmosphere and an inert magnetosphere of Mars, and thus heavy bombardment of UV and Gamma Rays, coupled with wind-driven resurfacing (i.e. sand blasting), would seemingly make surface conditions hostile to life. But if not at the surface, is it possible that life resides in the near-surface environment similar to bacteria and fungi identified in salty paleosols at centimeter depths located near the Antarctic inland ice? Future international missions to test whether fossilized and/or extant life exists on Mars will include the exploration of widely-distributed, Antarctic-like paleosol environments.

1. Introduction

Extremophiles are known to inhabit some of the most severe environments on Earth, including the tropical alpine of the East African mountains (Mahaney, 1990), the Andean summits of Venezuela (Mahaney et al., 2008, 2009a), the alpine of the Rocky Mountains (Mahaney et al., 1983), and the Dry
The presence of extant or fossil microorganisms on Mars may date to the embryonic stages of its evolution (i.e. the early and middle Noachian epochs, and possibly pre-Noachian (Nimmo and Tanaka, 2005), at a time in which the conditions may have been more suitable for life when compared to present-day. This includes the possible presence of oxygen, both active magnetosphere and possible plate tectonism, abundant liquid water available at and near the surface, warmer temperatures, and a thicker atmosphere, conditions approximating the Archaen Earth (Fairén and Dohm, 2004; Baker et al., 2007). Other pre-requisites for life to exist include relatively high concentrations of Fe necessary for respiration.

If extremophiles exist today in Antarctic paleosols with dry frozen microenvironments, containing high concentrations of salt that lower the freezing temperature to below minus 50°C, scant snowfall with minimum melting, low concentrations of secondary Fe ($\text{Fe}^{+3}$), nitrogen obtained from the atmosphere, and almost nil clay mineral concentrations, then parallels with Martian environments suggest life may have been seeded on early Mars (cf Joseph, 2009) and may well exist there today either in extant or fossil form (cf Levin, 2010).

The physiologically-advanced eukaryotes identified in Antarctic paleosols are probably more biologically advanced compared with fungi to be expected on Mars and most probably would not survive radiation bombardment existing there today. Alternatively, convergent evolution posits that unrelated organisms might achieve similar evolutionary status responding to similar environmental stresses during the early history of these planets, and divergent evolutionary development in response to different environmental stresses (Earth vs. Mars). However, if microflora exist on Mars, individual species may well rely on C, O, N and Fe, similar to that of Earth, and the presence of these chemical elements bodes well for the hunt for exobiological signatures.

Since Mars may have had an oxygen-rich environment much earlier than Earth, perhaps a billion or more years earlier, it is possible life evolved on Mars much earlier than on Earth. If life did evolve earlier on Mars, in the midst of high meteorite bombardment, adding heat/energy to the evolutionary mix, it is possible life was delivered to Earth in martian ejecta. The trans-planet evolutionary connection cannot be discounted (Milekowsky et al., 2000; Menor-Salván, 2009; Sharov, 2010); particularly in that it has been demonstrated that bacteria can survive journeys through space including the ejection from and reentry through the atmosphere to a planet’s surface (Burchella et al., 2001; Burchell et al. 2004; Horneck et al. 1994, 1995, 2001; Mastrapaa et al. 2001; Nicholson et al. 2000).

2. Earth and Mars Settings

Earth. Tropical and middle latitude alpine environments, while extreme in terms of temperature fluctuations on an annual or daily basis, are endowed with plentiful C, N and O, plus reasonable concentrations of Fe to sustain life. Even young Holocene soils in these locales provide microenvironments in which both bacteria and fungi can live and proliferate (Mahaney, 1990; Mahaney et al., 1983, 2009a). In the Andean alpine, colliform bacteria have been identified in rock materials hypothesized to correlate with ‘Black Mat’ (Mahaney et al., 2009a) deposits, which are related to the Younger Dryas advance of alpine ice (Mahaney, 2008). Indeed, fungal filaments are known to occur infrequently in deposits adjacent to the Humboldt Glacier at 4300 m a.s.l. in the Mérida Andes of Venezuela, and well-formed colonies of both bacteria and fungi are known from deposits on Mt. Kenya, East Africa (Mahaney, 1990), at similar altitudes. Unlike the Antarctic, water in liquid form is available.
East Africa (Mahaney, 1990), at similar altitudes. Unlike the Antarctic, water in liquid form is available through part of the year in these environments with liquid water available almost on a daily basis in the tropical alpine and for months at a time in the middle latitudes.

In Antarctic cold desert soils, liquid water is available mostly subsequent to infrequent snowfall during the short summer months (Mahaney et al., 2001, 2009b). The representative paleosols in the Antarctic Dry Valleys range in age from 15-20 Ma and exist as thin “pedons,” each pedostratigraphic section having variable depths not exceeding 150 cm. Individual soil profiles or pedons within a section have depths of 10-20 cm, each representing perhaps a million years of weathering in what is ostensibly the driest polar desert on Earth. These till stacks comprise mainly sandy materials, with or without a pebble layer of ventifacted sediment, underlain by a Fe-rich horizon, which in turn is underlain by a salt-rich horizon (Claridge, 1977; Claridge & Campbell, 1968). Contrary to expectations, both the microfauna and microbes described below were found in the salt-rich horizons where liquid water may exist if the temperature were to exceed minus 50°C and relatively high concentrations of Fe, necessary for respiration, occur in an overlying layer.

Fig. 1. Location of sites adjacent to the Taylor Glacier and the Inland Ice, Antarctica

Mars. The ancient terrains such as Terra Sirenum and Terra Cimmeria (Fig. 1) are marked by magnetic signatures and spatially associated structurally-controlled basins (Dohm et al., 2002, 2005) that have been recently identified to contain salt, similar to the salt-containing, plate-tectonic-related basins of the extremely arid Atacama Desert (Chong et al., 1999; Warren-Rhodes et al., 2007a,b). Similar to the Atacama Desert, the structurally-controlled basins of ancient terrains of Mars may mark an ancient phase of plate tectonism at a time when internal and external conditions were exceedingly different than those of today (Fairén and Dohm 2004; Baker et al., 2007). Such conditions, coupled with hydrological cycling (Dohm et al., 2008b), such as floods and associated inundations to form water bodies ranging from lakes to oceans in the northern plains, and including associated snowfall and glacier and rock glacier development in the south polar region, would approximate those of the Antarctic (Baker, 2001).

With possible ancient plate cycling, there may have been sufficient oxygen in the atmosphere to promote the sustainability of life. In addition, the interaction of heat energy related to the Tharsis Superplume (Dohm et al., 2007), pulsating since at least 3.5 Ga until present-day, and water of the Tharsis basin (Dohm et al., 2001), would have been conducive to the sustainability of life, at least in the subsurface, as water plus energy is the prerequisite of life (e.g., Furfaro et al., 2008).

Most importantly, Fe abundance appears to be elevated in parts of the northern plains and highland-lowland boundary regions of Mars (including below the putative Noachian shoreline demarcation, as shown by Dohm et al., 2009a), occasionally in association with other chemical elements (e.g.,...
shown by Dohm et al. 2008a), occasionally in association with other chemical elements (e.g., Karunatillake et al., 2009). The Fe-enriched deposits are particularly interesting from the perspective of past aqueous activity because they have been identified as sites of long-lived, magma-water interactions such as Apollinaris Patera (Scott et al. 1993) and the Cerberus plains (Burr et al., 2002), as well as paleolakes, particularly in the case of Amazonis, Elysium, Utopia, Acidalia, Chryse, and Arcadia Planitiae (Scott et al., 1995; Scott & Chapman, 1995). Activity may include periglacial and glacial resurfacing; for instance, ice mantles enriched with fine-gained materials (Head and Pratt, 2001; Head et al., 2006a,b; Kargel, 2004; Kostama et al., 2006; Soare et al., 2007) that could subdue the GRS signatures. Significantly, the Fe-enriched regions, visible from the GRS-based Fe map, correspond with rock materials, which have been mapped, characterized, and interpreted to include a sedimentary origin (Tanaka et al., 2005).

Moreover, to orbital-based perspectives, Fe-based, in situ investigations have been performed at three locations on Mars through the Sojourner (e.g., Bertka and Fei, 1998) and Spirit and Opportunity Rovers (e.g., Squyres et al., 2004) of the Pathfinder and Mars Exploration Rover (MER) missions, respectively. Though both orbital- and rover (field)-based missions have yielded significant information concerning the Fe concentrations on Mars, which include elevated concentrations for parts of Mars (Boynton et al., 2007; Dohm et al., 2008a), greater constraints on bulk composition of Fe at local to global averages will be necessarily refined through future tier-scalable robotic reconnaissance missions (e.g., Fink et al., 2005). Nevertheless, terrains containing paleosols enriched in liquid water/water-ice, Fe, and salt, could contain life similar to Earth, and thus should be considered as prime targets of future exobiologic missions.

Fig. 2. Pedostratigraphic sections at Aztec and New Mountain areas, Antarctica. Fungi have been identified in horizons marked with an arrow; skeletons of Coleopteran species identified in the Cz2 horizon of profile 831.

3. Results and Discussion

The profiles shown in Fig 2 are typical of the cold polar soils described by Campbell and Claridge (1987) and Mahaney et al. (2001, 2009b). The field work in 1998, which focused partly on the microbial content of the weathered regolith, resulted in sampling of both the Fe and salt-rich horizons in profiles 828 and 829 where colonies of the fungi *Beauveria bassiana* and *Penicillium brevicompactum* were identified. *Penicillium* species are known in a wide variety of environments from Arctic to tropical, but were previously unknown in the cold polar soils of the Antarctic Dry Valleys.

The fungus *Beauveria* is reported associated with insects, the particular microfauna unknown at the time the fungi was identified. Later, recovery of skeletons of Coleoptera (beetle fragments of Scarabaeidae, subfamily Aphodiinae, tribe Eupariini, possibly *Ataenius* spp); taxonomic notes from P. Skelley, personal communication, 2009) in the Cz2 horizon of profile 831 (Fig. 2) suggest the Beauveria lives in...
While we do not suggest that advanced microfauna exist on Mars, there is the distinct possibility that various species of bacteria and fungi are prevalent on the Red Planet (Levin, 2010; Mahaney et al., 2001), though microbial populations are likely to be sparse and/or spatially patchy (Cockell and Stokes, 2004; Warren-Rhodes et al., 2007a-c). It has been suggested that terrestrial microbes might have made the journey to Mars in ejecta generated from Earth impacts (Folk, 1998; Melosh, 1988; Mileikowsky et al., 2000) or vice versa, from Mars to Earth. If Martian life forms originated on Earth, they will contain ferrichromes, compounds important in respiration processes, and they will have released organic compounds capable of chelation, a process important in mineral weathering. On the other hand, if microbes such as those types identified in Antarctic profiles 828 and 829 originated on Mars, they would have ended their interplanetary journey finding near-permanent residence in soil.

The presence of microbial life in Antarctic paleosols, with minor amounts of Fe available for physiological processes to function, argues for the potential existence of microbial life 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 (Mahaney et al., 2000, 2001, 2009b). The distribution of Fe over a large part of the northern plains of Mars as determined by the GRS instrument (Boynton et al., 2007; Fig. 3) is invoked as a comparison with the Antarctic. Because Mars is considered to have had a potentially warmer/wetter paleoclimate during the Noachian Period, paleosols are likely to have developed during this ancient period of Mars evolution, leading to the production of secondary Fe-rich beds/horizons at a much earlier stage when compared with the Earth.

Using approximate time lines for Fe production, advanced Fe production necessary for respiration in microbes probably started during the first $10^9$ yr of the history of Mars; on Earth, the production of secondary Fe in large quantity began at the Archean/Proterozoic boundary, or nearly 2.5 Ga (Ogg et al., 2008).

But could life forms have managed to survive the intensive exposure to solar and Gamma Rays and mechanical weathering processes such as induced by wind at the surface/near surface environments, which includes fractures and joints in the rock materials? Such potential should be tested through future smart robotic reconnaissance to the red planet, especially in the subsurface through drilling that may yield fresh samples. Furthermore, the distribution of Fe over a large part of the northern plains of Mars, as determined by the GRS instrument, is invoked as a comparison with the Antarctic and could be readily sampled with current robotic technologies.

4. Conclusions

Paleosols in the Antarctic Dry Valleys are excellent terrestrial analogues for paleosols of Mars, including weathered regolith located close to the Martian polar caps. Proglacial and periglacial zones on Mars are crucial in making the connection to the Antarctic. The distribution of Fe over a large part of the northern plains of Mars as determined by the GRS instrument (Boynton et al., 2007; Fig. 3) is invoked as a comparison with the Antarctic. Because Mars is considered to have had a potentially warmer/wetter paleoclimate during the Noachian Period, paleosols are likely to have developed during this ancient period of Mars evolution, leading to the production of secondary Fe-rich beds/horizons at a much earlier stage when compared with the Earth.
weathered regolith located close to the Martian polar caps. Proglacial and periglacial zones on Mars are considered to undergo partial thaw (Baker, 2001; Kargel, 2004), perhaps on an annual basis which would provide more meltwater than in the Antarctic which is dry frozen most of the time. The possibility of finding complex weathering sequences archived in the Martian cryosphere is great given the monoplate stable crust that is thought to have been in place since Noachian time (~3.5 Ga). The complex of deposits in the canyon walls of Valles Marineris (Dohm et al., 2009) might well contain paleosols dating far back into the geological history of Mars. Microbes described in Antarctic paleosols are specialized eukaryotes that most likely could not survive on Mars today, but they do indicate that life can exist in extreme environments and suggest it is highly probable that life on Mars may have found a "best solution" to extreme environmental stress. Convergent evolution on Mars may well have led to the genesis of microbes that rely on C, CO$_2$, N and Fe as they do on Earth. However, life may have developed on Mars and may exist there as fossil or extant extremophiles.

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Ancient microbes on Mars? A living lake?: More than 3 billion years ago, a massive meteor hit Mars, creating an approximately 155-km-wide crater in the planet’s surface. A much more serious concern about living on Mars is radiation. Without a protective magnetic field like that surrounding the Earth, the surface of the Red Planet is constantly bombarded with galactic cosmic rays—high-energy particles from space that can lead to a variety of health problems. At the doses of cosmic radiation that humans would receive on a trip to the Red Planet, one of the primary problems they will face is cancer. The possibility of life on Mars is a subject of huge interest in astrobiology due to its proximity and similarities to Earth. To date, no proof has been found of past or present life on Mars. Cumulative evidence shows that during the ancient Noachian time period, the surface environment of Mars had liquid water and may have been habitable for microorganisms. The existence of habitable conditions does not necessarily indicate the presence of life. Lab experiments with primitive microbes taken from an Antarctic lake have shown that the hardy single-celled organisms can tolerate at least the warmest of the frigid temperatures found on Mars. And they found that these species of microorganisms "huddled" together in colder temperatures to form a chemically linked unit called a biofilm. The finding marks the first time this phenomenon has been detected in the Antarctic
species of so-called extremophiles. The findings provide more evidence for the ideas that liquid found beneath Mars' surface could harbor microbial life and that life Life on Mars: from microbes to monuments. David Pratt. December 2011. Contents. Introduction Lunar or terrestrial? Water on Mars The search for life The Face on Mars The Cydonia complex Other possible anomalies Sources. Introduction. Mars “named after the Roman god of war” lies 1.5 times further from the sun than the earth does. Its year is about 1.9 times as long as an earth year, while a day is only 37 minutes longer than on earth. Like dry ice, water ice on Mars that is heated by the sun usually sublimes directly into vapour. However, when temperature rises above 0°C and atmospheric pressure exceeds 6.1 millibars (conditions known as the triple point of water), ice, liquid water and water vapour can coexist, and melting ice becomes liquid water.