Geophysical Research Abstracts, Vol. 9, 07221, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-07221

1 Title of Abstract

Environmental conditions on early Mars and the possibility of Martian life

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The same habitable conditions existed on both early Mars and early Earth: liquid water, a source of carbon and nutrients, and a source of energy. Mars probably had habitable environments before the Earth because it was smaller, cooled down faster and did not suffer a moon-forming impact. Given the necessary ingredients for an origin of life (the same as those for habitability, but with the addition of water-rock interactions), and an estimation of about 10 - 100 My necessary for the appearance of life, any martian environment that could have retained liquid water for that period of time could potentially have seen the birth of new life forms, despite the lack of a global ocean. In this scenario, life may have originated at numerous, isolated points on the surface of Mars. Before the deterioration in the surface conditions of the planet (between $\sim$4.0 and 3.5 Ga), there were three main potential habitable environments: subsurface (including sediment pore space and endolithic niches), open water (planktonic), and open surfaces (sediment and rock surfaces). Once life had appeared, from a microbial point of view, the nature of large-scale environments is, however, basically irrelevant. Given the small size ($\sim$1 μm) and weight 1 x 10^{12} g) of bacteria, they can live on extremely low nutrient contents. Thus, a 10-20 μm sized colony of chemolithotrophs

in a subsurface environment could live in a microenvironment of some 50-100s μm.

In which ever habitable location life appeared on Mars, it would have been ubiquitous within the confines of the habitable zone, as demonstrated by the traces of early life on Earth (Westall and Southam, 2006). Since there was no global ocean there would have been substantial heterogeneity in terms of distribution and possibly evolutionary roads for isolated habitats. During and after climatic deterioration life would have retreated into subsurface habitats. However, any biogenic signature left in the early martian sediments would be fossilised and encased in the mineral matrix that solidified the rock. In early Earth analogues the mineralising matrix was mainly chert. The consolidating mineral matrix in Noachian sediments is likely to have been similar, given the availability of water, the volcanic nature of the sediments and the supposed hydrothermal activity. Chert is relatively inert. The change-over period during environmental deterioration was characterised by sulphate deposition, whereas the subsequent Hesperion-Amazonian periods saw dry weathering and Fe oxide deposition. Sulphates and Fe-oxides are more easily altered than chert. However, impact ejected boulders of Noachian age could be found anywhere on the Martian surface.

Based on comparison with the early Earth analogues, in terms of quantity of carbon per gram of sediment, the biomass developed by the early anaerobic organisms was very small. Fossilised, subsurface chemolithotrophic colonies (10-50 μm in diameter) distributed heterogeneously on volcanic particle surfaces in shallow water sediments produce 0.01-0.05 wt.% C (Westall et al., 2006a). In a 1 x 3 cm core this equates to 0.002-0.01 g C in a sediment layer 2 mm thick. Early Earth anaerobic photosynthetic colonies developed on sediment surfaces in the photic zone have higher concentrations of $>$0.05 wt % C because of the greater efficiency of the photosynthetic metabolism (Walsh and Lowe, 1999; Westall et al., 2006b). Sediments hosting layers of the remains of these organisms may contain between 0.025-0.25 g C in a 2 mm thick layer in the core (could such relatively advanced organisms have evolved on Mars before climatic deterioration?). It is to be expected that potential martian life, whether extinct or extant, would be equally subtle in physical and chemical expression, making *in situ* organic analysis challenging. On the other hand, whereas it may not be possible to directly observe individual colonies trapped in an inert mineral matrix (unless fortuitously exposed by weathering on an exposed rock surface), biofilm layers may be visible by *in situ* microscopic observations in the rock and in a core.

In conclusion, study of Early Earth analogue habitats and their traces of life is an important aid in understanding Noachian habitability and potential life forms. Noachian terrain should be prime targets for future Mars missions and The eventuality should be envisaged that it may not be possible to find definitive traces of life with an *in situ* robotic mission and sample return missions will be necessary..