Hydrothermal chemotrophic biosignatures on Mars.

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Introduction: Our approach to the search for biosignatures on Mars is based on the hypothesis that habitable conditions on Mars, even early in its history, were never very clement and not of long term duration [1,2], although present understanding of the early habitability of the planet may change [3]. In view of what we term a "punctuated" habitability scenario, we consider that the most likely life forms to have appeared on Mars are chemotrophic organisms.

Fossilisation of hydrothermal chemotrophs: Experiments have shown that different species of chemotrophs react in different ways to exposure to mineral solutions, some becoming fossilised (mineral-coated) and others not [4]. However, the most common biosignatures are probably those produced by degraded organic molecules either disseminated within a mineral matrix (either detrital and/or primary/secondary), while morphologically preserved biosignatures (microfossils) may be rarer.

Examples of fossil chemotrophs and their hydrothermal environment: The most relevant analogue for early Mars is the early Archaean Earth, where anaerobic environmental conditions from the local to microscopic scale were very similar to those on the early Mars [1,2,5]. This is the only more or less completely O_2-free period that the Earth has experienced.

We have documented the very profound influence of hydrothermal activity on the early Earth and the influence of hydrothermalism on the distribution and biomass of chemotrophic life forms [6]. Basaltic volcanic sediments deposited in shallow to intertidal water depths at around 3.33 Ga (Josefsdal Chert, Barberton Greenstone Belt, South Africa) were influenced to varying degrees by seawater/hydrothermal mixtures. Macroscopic to microscopic sediment deformation features document the influx of hydrothermal fluids during sediment deposition while trace element compositions (Fe, Ni, Co, Mn, As, Ba, Mo etc.) track the hydrothermal influence on the micron scale in primary and secondary precipitated minerals, as well as the carbonaceous remains of the presumed chemotrophic colonies.

We identify relatively high density colonisation of volcanic particles in the vicinity of hydrothermal conduits, as well as the formation of "floating" colonies in silica-rich hydrothermal fluids [2] Fig. 1. In the former case, the volcanic particles are coated with irregular (spiky) layers of carbon up to several tens of µm in thickness whose structure is incompatible with an abiotic origin. *In situ* carbon isotope compositions (-21 to -28‰ $\delta^{13}C$) are compatible with microbial fractionation. As a result of the high carbon content and its mineral-bound distribution, the sediment has a characteristic clotted appearance. Primary deposits of hydrothermal silica without volcanic particles formed next to major fluid-conducting faults also present a clotted appearance. The clots have an irregular, spiky morphology incompatible with transported, detrital carbon and must have formed *in situ*. The biomass produced is at times high enough to form mm-cm thick carbon-rich layers. With *in situ* instrumentation, both layers and clotted textures could be microscopically identifiable. Spectral (Raman and IR) signatures of carbon associated with such structures, together with MS analyses of carbon molecules, isotopes and chirality, could confirm the carbonaceous composition and potentially determine the biogenicity of the organic carbon.

Conclusions: Early life was chemotrophic and, although it was apparently widely but tenuously distributed, significant biomass development was controlled by access to nutrient-rich hydrothermal fluids. Thus, it is in such environments that we should be searching for Martian biosignatures.

References: [1] Westall et al., (2011) *PSS* 59, 1093. [2] Westall et al., (2015) *Astrobiology*, 15, 998. [3] Bouley et al. (2016) *Nature* in press. [4] Orange et al., (2009) *Geobiology*, 7, 403. [5] Westall et al., (2013) *Astrobiology*, 13, 887. [6] Westall et al. (2015) *Geology*, 43, 615

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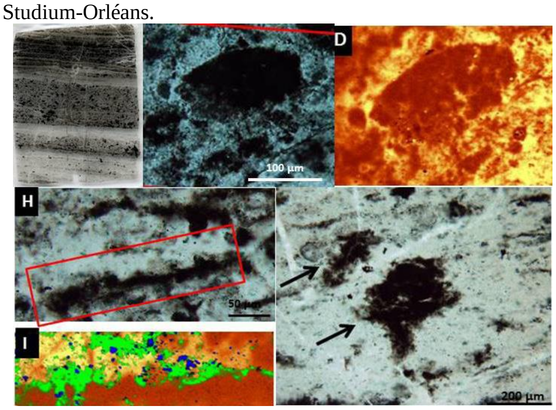

Figure 1. Clotted textures, chemotrophic coated volcanic grains and "floating colonies in 3.33 Ga old sediments [2].