ANCIENT BIOSIGNATURES IN ROCKS AND THEIR RELEVANCE IN THE SEARCH FOR EXTRATERRESTRIAL LIFE. F. Westall[1], B. Cavalazzi[1,2], F. Foucher[1], A. Hubert[1,4], [1]Centre de Biophysique moléculaire-CNRS-OSUC, Orléans, France (frances.westall@cnrs-orleans.fr), [2]Univ. Johannesburg, South Africa, [3]ENS-Lyon, France, [4]ISTE-Grenoble, France, [5]ISTO-CNRS-Orléans, France.

Introduction: The search for biosignatures in rocks, including extraterrestrial materials, requires solid understanding of the nature of biosignatures, their preservation, and their identification. The most ancient traces of life on Earth, which formed at a time when life may still have existed at the surface of Mars (if it ever appeared, *i.e.* ~3.5 Ga [1,2]), is therefore of enormous benefit in the search for ancient traces of life, for example on Mars. The significance of these ancient life forms in terms of environment of formation (= local habitability), early stage of evolution, mode of biosignature preservation, as well as the methods used for biosignature identification, is extremely important in helping to plan strategies for *in situ* analysis on another planet, choice of sample for return to Earth, and analysis of returned samples in terrestrial laboratories.

Ancient biosignatures: The most immediately evident biosignatures in rocks ~3.5 Ga-old are macroscopic to microscopic vestiges of photosynthetic microbial mats (mats and stromatolites, [3]). Photosynthesis is, however, a very evolved metabolic strategy. Given the limited habitability conditions on early Mars, when life could possibly have flourished, it is unlikely that such an evolved form of energy transfer could have developed independently on Mars [2]. Nor is it likely that such organisms could have been transported from the Earth to Mars in meteorites [4]. On the other hand, the abundant volcanic and organic primary materials on Mars could have supported primitive metabolisms, such as chemotrophy. Note that the environmental conditions on the early Earth were very different to those of the present day planet [1,5]: basically anoxic, warmer ocean water temperatures, slightly acidic pH, silica-staurated seawater, etc.

Chemotrophic signatures in the ancient terrestrial rocks are subtle and relatively difficult to identify because of the nature of the microorganisms that produced them and their modes of preservation. The microorganisms were small (Fig. 1), heterogeneously distributed, and contributed little carbon biomass. They formed colonies on the surfaces of volcanic rocks and particles, leaving corrosion patterns in the vitreous surfaces of pillow basalts [6] and volcanic shards (Fig. 2 [7]). Preservation of the morphological, chemical and isotopic signatures was by silicification (some biostructures were calcified before silicification, [8]) which, while very effectively preserving microbial morphologies and chemical and isotopic signatures (silica, for example, being less "leaky" than carbonate), at the same time, significantly diluted these signatures [8,9]. The mode of preservation of the biosignatures therefore places additional constraints on their detectability.

For effective interpretation, any study of ancient biosignatures needs to be placed in different levels of environmental context [5]: from the regional to local environment of deposition, e.g. deep basin, littoral, hydrothermal; to the microbial scale environment, e.g. rock/mineral surface, sediment surface. The former must necessarily be evaluated on Mars but the microenvironment will be analysed in the returned sample since it is the immediate environment of the potential biosignature that is of importance.

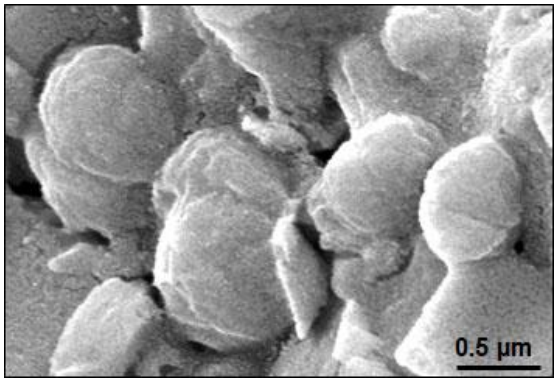

Fig. 1. ~3.5 Ga-old silicified chemolithotrophs in volcanic sediments from the Pilbara [5].

Analytical implications: Methods used today to study the structure and composition of the organic molecules, the isotopic signatures and the morphology of the fossil microbial traces are wide ranging and highly sophisticated. Given the small size of the microbial structures and their chemical traces, *in situ* observation/analysis on the micron to nanometer scale is desirable in order to better evaluate the biogenicity of the features. This induces constraints on instrument detection levels and resolution.

Morphological biosignatures: Fossilised chemolithotrophic microorganisms in ~3.5 Ga-old rocks from the Pilbara in Australia are ~0.5-1 µm in size (Fig. 1 [5]). They may leave corrosion features in the surfaces of rocks/minerals of the order of a few microns in size. Possible confusion of morphological signatures with

similar structures formed abiogenically means that nm-scale structural details as well as other lines of biogenic evidence are needed for support [5].

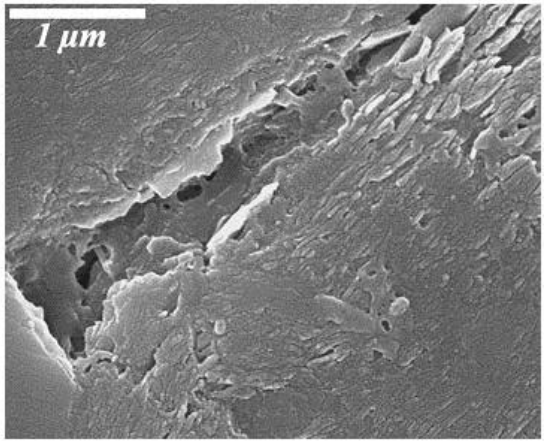

Fig. 2. Corrosion tunnel in a 3.5 Ga-old volcanic shard from the Pilbara [5].

The fossil chemolithotrophs are large compared to hypothesised primitive cells, perhaps similar to viruses in size. Martian life may have been very small and may not have reached the size of present day (or even Early Archaean) chemotrophic life forms. Viruses contribute hugely to the present microbial but, biomass until recently, have generally been analytically "invisible". Although they can be fossilised (Fig. 3 [10]), the resulting structures (of the order of 50-100 nm) would be very difficult to identify.

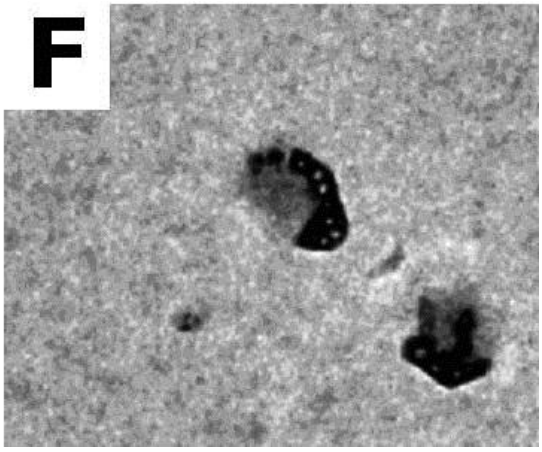

Fig. 3. Silicified viruses [10].

Organic molecules: The TOC in early Archaean sediments is generally low (0.01-0.05%) but can be up to 0.1-0.5% in particularly rich sediments. Apart from dilution due to fossilisation and the fact that they have undergone burial metamorphism (prehnite-pumpellyite to lowermost greenschist facies), these very old molecules are significantly degraded. Most are aromatic fragments of the original macromolecules |8,11]. Although they have many similarities with abiogenic PAHs, they also exhibit more complexity than the latter.

Microbial organic matter typically contains either structurally important metals and/or "opportunistically"-chelated metals. Excess concentrations of certain metals compared to the background levels may also contribute to interpretations of biogenicity.

Metabolic signatures: Isotopic fractionation of certain bio-essential elements, such as C, N, Fe etc., is the most commonly used signature of past microbial metabolism but other signatures include biominerals and corrosion or leaching effects in adjacent rocks and minerals.

Conclusions: The search for biosignatures in returned martian materials will really be like searching for a needle in a haystack. In the first place, there is a strong likelihood that the life forms may be even more primitive and smaller than the oldest forms of life on Earth. This means that microbial TOC in the sediments/rocks will be limited and also that the biosignatures are likely to be heterogeneously distributed. The technological challenges for their identification are therefore strong but continued advances in the level of instrumental resolution are promising. The conclusion is that it will probably only be in samples returned from Mars that we will be able to definitively identify *bona fide* biosignatures (if they exist!).

References: [1] . Westall, F., 2005, in T. Tokano (Ed.) Water on Mars and Life, pp. 45–64. [2] Westall, F., et al. 2011. Planet. Space Science, 59, 1093–1106 [3] Westall, F. 2011. in Gargaud, M. et al. (Cambridge University Press), 391-413. [4] Cockell, Charles S. (2008). Origins of Life and Evolution of Biospheres, 38(1), pp. 87–104. [5] Westall, F., et al. 2011. Planet. Space Science, 59, 1093–1106. [6] Furnes, H., et al. 2004. Science, 304: 578-581. [7] Foucher, F., et al. 2010. Icarus, 207, 616-630. [8] Westall, F., et al. 2011. Earth. Planet. Sci. Lett., 310, 468-479. [9] Westall, F., Cavalazzi, B., 2011. *in* Encyclopedia of Geobiology (Eds.) V. Thiel, J. Reitner, Springer, Berlin, 189-201. [10] Orange, F., et al. 2011. Biogeosciences, 8, 1465–1475. [11] Derenne, S. et al., 2008. Earth Planet. Sci. Lett., 272 (2008) 476–480.