STONE-6 experiment: testing the survival of microfossils in martian analogues rocks during entry into the Earth's atmosphere

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The oldest traces of life on Earth occur in cherts (silicified volcanic silts and sands) that were deposited in coastal environments ∼3.5 billion years ago [1, 2, 3, 4, 5, 6]. These microfossils are the remains of relatively evolved organisms, implying that life had to have appeared much earlier [6]. However, studies related to the origin of life are hampered by the fact that suitable rocks dating from the first billion years are lacking on Earth, since older materials are too heavily metamorphosed or have been destroyed by plate tectonics. Investigations are now focussed on the search for older microfossils on other planets and, in particular, on Mars. Mars does not appear to have undergone plate tectonic activity as on Earth and, if life appeared on that planet, its fossilised traces could be found embedded in rocks from the Noachian period (4.5 to ∼3.5 billion years ago), *i.e.* the period that is missing on Earth.

One means of studying Noachian martian rocks would be to analyse sedimentary meteorites from Mars. This solution has the advantage of being cheaper than the explorations of martian rocks by rovers and allowing high resolution analyses in laboratory. However, the 49 meteorites of presumed martian origin found to date are all composed of basaltic volcanic minerals [7]. The aim of this study was thus to determine if martian sedimentary rocks, and the hypothetical microfossils they could contain, can survive the Earth's atmospheric entry.

Experiments

The STONE experiments were designed in 1996 by R. Demets and A. Brack in order to simulate closely as possible the conditions undergone by natural meteorites and to test the survivability of various samples during entry into the Earth's atmosphere [8]. The last mission, STONE-6 (September 2007, ESA), tested the survival of martian analogue sedimentary rocks that included one containing microfossils. The sample was composed of silicified volcanic sand that had been deposited in a littoral environment from the ∼3.5 Ga-old "Kitty's Gap Chert", in the Pilbara region, NW Australia. This rock is considered to be a good analogue for lithified Noachian volcanic sediment and contains small colonies of fossilised prokaryote-like microorganisms corresponding to the oldest preserved organisms [5].

Results

After landing of the capsule, several types of analyses were made to observe and study both the survival of the microfossils and the modification of the rock composition. The first optical observations show that a white fusion crust formed during entry due to the devolatilisation and vitrification of the quartz (see Fig. 1). This contrasts with the black crust of basaltic meteorites and may explain why sedimentary stony meteorites have not been yet found (meteorite hunters look for black fusion crusts).

Figure 1: The STONE 6 artificial meteorites after landing in Kazakhstan. The samples are embedded at the apex of the heat shield, around the ablation point. A micrograph of the sedimentary rocks sample after landing is shown in insert.

Although colonies of bacteria can be observed by optical microscopy in thin section, the individual microorganisms are too small (<1μm) to be visible. Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) were thus used to observe the microfossils. A protocol has been developed to re-localize the areas of interest with a great accuracy on the different apparatus. Raman spectrometry was also used to demonstrate the carbonaceous composition of the colonies of fossil microbes, as well as to study the evolution of the mineralogy through the sample thickness. An analytical model is used to estimate the temperature evolution in the sample in well accordance with the modification of the mineralogy as shown in Fig. 2. Although the kerogenous material near the fusion crust is graphitized, we demonstrate that the microfossils located deeper in the sample are well preserved. Filamentous and coccoidal microfossils plus microbial polymer (EPS) in this sample are shown in Fig. 3. We conclude that, if sedimentary Martian meteorites were found on Earth, they could contain eventual traces of extraterrestrial life and maybe of the first living martian organisms.

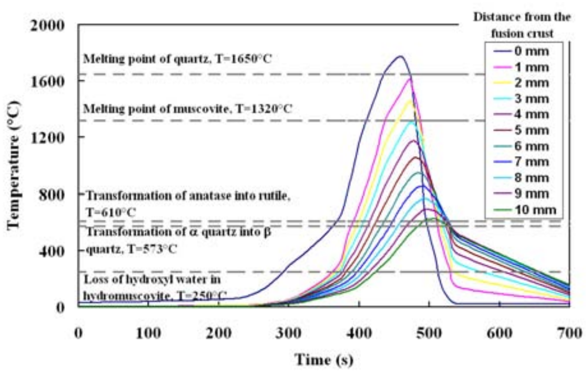

Figure 2: Analytical model of the temperature evolution through the sample thickness. The transition temperatures of the minerals have been reported.

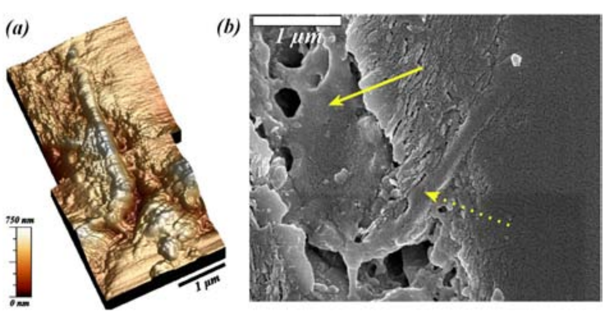

Figure 3: (a) AFM image of a filamentous microfossil and (b) the corresponding SEM image showing the EPS (solid arrow) surrounding the structure (dash arrow).

References

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