STONE 6: Artificial Sedimentary Meteorites in Space

Conference or Workshop Item

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Introduction: The SNC meteorites are generally considered as originating from Mars however all are of ingneous origin [1-3]. There are no known sedimentary martian meteorites, despite the vast amount of evidence for aqueous, eolian and chemical sediments on the planet's surface [4,5]. Such material either does not survive the escape process, which requires an escape velocity of > 5 km/s, does not survive terrestrial atmospheric entry, or is not readily identifiable as being of extraterrestrial origin.

The STONE experiments*:* The STONE experiments aim at testing the survivability of different types of analogue martian sediments during entry into the Earth's atmosphere. The rocks are fixed into the heat shield of a FOTON re-entry vehicle around the ablation point and undergo entry speeds of about 8 km/s (meteoritc entry speeds are slightly higher, at 12-15 km/s). Previous STONE experiments have proven the survivability of dolomite and sandstone through atmospheric passage (STONE 1 and STONE 5) [6-8]. Interestingly, whereas a black fusion crust formed on the basalt control sample, the carbonate-rich sediments did not exhibit such fusion crusts. Their surfaces had simply been ablated. It was concluded that, unlike basaltic meteorites, it would be very difficult to distinguish potential sedimentary martian meteorites in the field at a casual glance.

STONE 6 objectives: The STONE 6 experiment was designed to test the effects of atmospheric entry on physical and (bio/geo)chemical modifications to sedimentary rocks that had been either coated with micro-organisms and/or contained the fossilised remnants of microorganisms. The results will help us to better understand (1) the mineralogical processing of sedimentary rocks to help visual recognition of sedimentary Martian meteorites; (2) possible isotope fractionation which may bias the analysis of "true" meteorites; (3) the survival of micro-organisms embedded in sedimentary rocks to access the feasibility of interplanetary transfer of life; (4) microbial contamination of meteorites when reaching the Earth's surface; (5) the survival of, and changes in, traces of past life in meteorites.

Materials and methods: The STONE 6 experiment used as meteorite analogues: (1) an Early Archaean chert (3.446 Ga) from the Pilbara containing cryptic traces of fossil life (microfossils, C isotopes) (Figs. 1a,c,d)[9], (2) a Devonian laminite (mudstone) from the Orkneys (Fig 1e), (3) and an Eocene basalt from Austria. The Early Archaean chert is a particularly relevant martian analogue, having formed (more or less) at a time when environmental conditions on early Mars were similar to those of the early Earth, i.e. when life could have existed on Mars [10,11].

A culture of a modern endolithic microorganism, *Chroococcidiopsis,* was smeared on the back side and on the flanges of each of the rocks before flight (Fig. 1g).

The "stones" were cut into a flanged dome shape, 2 cm thick at its apex, and were fixed around the ablation point of the heat shield of a FOTON-3 re-entry vehicle. The Early Archaean Chert had to be ground into ~3 mm-sized pieces then mixed with space cement and moulded into shape because it was too fractured to support milling.

The mission was launched from Baikonur on September 12th 2007 and, after 14 days in space, the re-entry vehicle returned to Earth. It was recovered about 30 min after landing in Kazakstan on the 26th September. One of the sample holders and its rock (the basalt) was lost during the violent re-entry but the other samples were recovered intact. They were immediately placed in a protective sample holder for transport to a clean room at ESTEC, Noordwijk where the sample holders were opened and the remains of the rocks extracted under a laminar flow hood on the 28th September.

Results: *(1) Early Archaean Chert* (reconstituted rock). More than half of this rock ablated away during re-entry (thickness 8 mm after the experiment) (Fig. 1b). The outer surface presented a fused, white vitreous appearance, whereas the back surface was blackened. The outer 2 mm of the rock (and the cement) have been melted and display a vesicular texture indicative of devolatilisation. There is a sharp but gradational contact between the devolatilisation zone and the unmelted zone. Thin section observations confirm the vitrification of the outer couple of mm of the rock surface. Although the components look "cooked" (brownish) in appearance, the sedimentary textures of the volcanic silts are pristine. There is, however, a marked increase in the transformation of the volcanic grains to muscovite, as well as a notable increase in the fragility of the rock fragments. In the original rock, the microfossils occur in colonies around the edges of the volcanic clasts and within the fine dust, as well as in biofilms on sediment surfaces [9]. SEM investigations to determine the fate of the 3.446 Ga-old microfossils are underway as are Raman spectroscopy of the carbonaceous component and isotopic C measurements.

(2) Most of the Devonian carbonaceous laminite sample was ablated away (Fig. 1f). Just 26% survived, including some greenish glass on the surface of unmelted rock. The rock is highly vesicular at the contact with the glass, indicating substantial devolatilization. This sample had an organic carbon content of 1.4 wt. %. The carbon survives in the flight sample, but has become more thermally mature. Nevertheless, some organic molecules have survived, albeit in substantially depleted quantities. These molecules retain some biological information. The glass also contains limited carbon (0.14 wt. %), due to the low oxygen fugacity during atmospheric entry.

X-ray diffraction traces show that the original sample was dominated by quartz, feldspar and calcite. The post-flight sample additionally contains calcium oxide and calcium hydroxide (portlandite), which represent the effects of thermal dissociation of calcite followed by rehydration from the atmosphere. The differential thermal analysis (DTA) traces show decrease in sample mass due to loss of water and carbon dioxide. More water is evident in the post-flight sample because of the rehydration of the calcium oxide.

(3) The dried biofilms of Chroococcidiopsis on the underside of the rocks did not retain viability but cells survived as carbonized forms "(pompeified") with only a little loss in cell volume (~10%) (Fig. 1h). This is incontrast to the STONE 5 experiment, which showed that endolithic organisms were complately destroyed [7]. Raman spectroscopy shows that the cells in the STONE 6 experiment still retain carbon, although they are partially graphitized.

Discussion and preliminary conclusions: Although the speed of entry of the artificial meteorites was not as high as that of natural meteorites (8 km/sec as opposed to 12-15 km/sec), it was close enough to provide useful information relating to potential martian sedimentary meteorites. It is clear that sedimentary martian rocks similar to those we used could survive atmospheric entry. The survival of the Early Archaean volcanic sands is important information since similar volcanic sands would have been common on Noachian Mars and could have hosted traces of life. We have demonstrated that biogenic molecules and actual cells can survive atmospheric entry (the latter, albeit in a carbonised form) and we hope to show the same for fossilised cells. Traces of life in martian sediments could therefore be found on Earth, if they can be recognized. Equally, traces of life in terrestrial meteorites, especially from the pre 3.5 Ga period for which we have no terrestrial record, could eventually be found on Mars.

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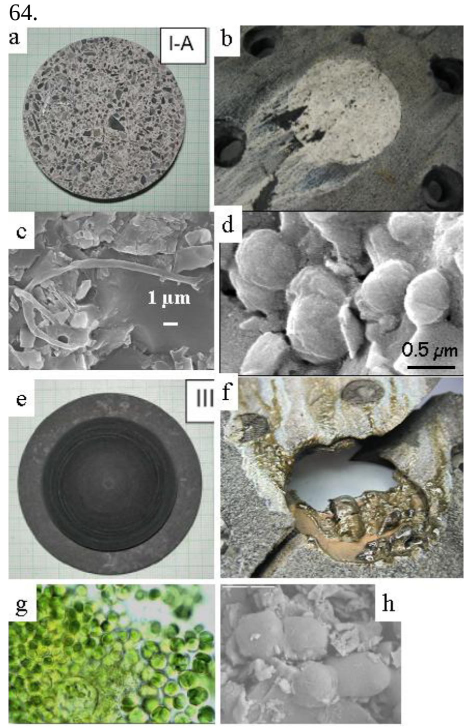

Figure 1. (a,b) Reconsituted rock of microfossiliferous Early Archaean Chert before and after flight. (c,d) Filamentous and coccoidal microofssils in the Early Archaean Chert sample (before flight). (e,f) Devonian carbonaceous laminate before and after flight. (g,h) *Chroococcidiopsis* before and after flight.