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STONE 6: Sedimentary meteors from Mars

F. Westall (1), R. Demets (2), F. Brandstetter (3), H.G.M. Edwards (4), C.S. Cockell (5), J. Parnell (6), F. Foucher (1), G. Kurat (3), A. Brack (1).

(1) Centre de Biophysique Molécualire-CNRS and Université d'Orléans, 45071 Orléans cedex 2, France (westall@cnrs-orleans.fr).
(2) European Space & Technology Centre (ESTEC), Keplerlaan 1, Postbus 299, 2200 AG Noordwijk, The Netherlands.
(3) Naturhistorisches Museum, Burgring 7, 1010 Vienna, Austria.
(4) Chemical and Forensic Sciences, University of Bradford, Richmond Road, Bradford, BD7 1DP, West Yorkshire, UK
(5) Planetary and Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.
(6) Department of Geology & Petroleum Geology, Meston Building, King's College, Aberdeen AB24 3UE, UK.

Abstract

STONE 6 is a space experiment to test the potential for survival of sedimentary meteors from Mars surviving entry into the Earth's atmosphere. Two sediments and a basalt (as the control) were embedded close to the ablation point of the heat shield of a FOTON M3 capsule for atmospheric entry from lower Earth orbit in September 2007. The sediments included (1) an ~3.5 billion year (Ga) old volcanic sand containing carbonaceous microfossils and (2) an ~370 million year (Ma) old lacustrine rock containing chemical biomarkers. The backs of the samples were smeared with a living endolithic microorganism, Chroococcidiopsis. The sediments survived reentry, as did some of the chemical biomarkers in the lacustrine sediment and the carbonaceous microfossils in the 3.5 Ga-old sediment survived (away from the fusion crust). An increase in the crystallinity of the carbon in both sediments was noted. The Chroococcidiopsis did not survive but their carbonised remains did. Thus sedimentary meteorites from Mars could reach the surface of the Earth and, if they contain traces of fossil life, these traces could be preserved. However, living organisms may need more than 2cm of rock protection.

Introduction

Although some 39 martian meteorites have so far been discovered, all are of basaltic composition and none are sedimentary, despite the large amount of evidence for sediments on the red planet. Why is this? Do the sediments not survive expulsion from the martian surface, the shock of entry into Earth's atmosphere and the impact of landing? Can martian sedimentary meteorites transport extant and extinct life to Earth? The STONE experiments, initiated in 1999 [1-3], address the survivability of Mars-analogue sediments, as well as the preservation of extant and extinct life, during atmospheric entry.

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 contained either organic biomarkers or the fossilised remnants of microorganisms that had been coated with living micro-organisms. The results help us to better understand (1) the mineralogical processing of sedimentary rocks during atmospheric entry, (2) the visual recognition of sedimentary Martian meteorites; (3) the survival of micro-organisms embedded in sedimentary rocks to access the feasibility of interplanetary transfer of life; (4) the survival of, and changes in, traces of past life in meteorites.

Materials and methods: The STONE 6 experiment used the following rocks as martian meteor analogues (Fig 1a): (1) an Early Archaean chert (3.446 Ga) from the Pilbara containing cryptic traces of fossil life (microfossils, C isotopes)[4], (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 [5-7].

A culture of a modern endolithic microorganism, *Chroococcidiopsis* sp. 0029 (CCMEE) (Fig. 1d), was smeared on the back side and on the flanges of each of the rocks before flight.

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 (a zircon based cement) and moulded into shape because it was too fractured to support milling.

Two different materials were used for the sample holders. The basalt sample holder was made of carbon-carbon material, whereas the sample holders for the laminate and the volcanic sand were made of silica phenolic material. In both cases, screws made of carbon-carbon material were used to fix the sample holders onto the heat shield.

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 and discussion

Entry speed of the FOTON capsule was 7.6 km/sec, slightly lower than the normal meteorite velocities of 12-15 km/sec. It was possible to determine the minimum temperature reached during entry through the thermal dissociation of one of the space cement that occurs at a temperature of ~1700°C. Although the basalt control sample was lost, comparison with the results of the STONE 5 experiment indicates that the temperatures upon entry are high enough to form a fusion crust.

Although the samples were supposed to be embedded around the ablation point of the capsule, it turned out that they were ~14° away from it. The Devonian laminate sample, being closest to the ablation point, probably underwent temperatures higher than the Early Archaean volcanic sand. Calculated pressures during entry are about 126kPa. The entry angle is calculated to have been steep rather than shallow, resulting in higher temperatures being reached over a relatively short period of time.

The two sedimentary rocks were severely ablated leaving only about 26% of the Devonian laminate and a thickness of 8mm from the originally 20 mm thick Early Archaean sediment. The Devonian laminate survived as a greenish, highly vesicular glass (Fig. 1a). The pre-flight rock was dominated by quartz, feldspar and calcite whereas the post-flight mineralogy includes CaO and $Ca(OH)_2$ due to thermal dissociation of calcite followed by rehydration in the atmosphere. Some of the organic carbon biomarker molecules in the rock survived the heat shock but, during the process, became thermally matured. Thus, at least some biological information was retained in this analogue meteor.

The Early Archaean volcanic sand formed an ~500 µm-thick fusion crust that was creamy white in colour. The lower 4 mm of remaining portion of the rock furthest away from the crust was characterised by a black/dark brown colour (Fig. 1c) in contrast to the creamy colour of the other half of the rock (more similar to the original, pre-flight rock, Fig. 1b). This was due to burning of the back side of this particular sample owing, apparently, to the entry of heat and flames behind the sample. This occurred because the difference in composition between the carbon-carbon screws and the silicon phenolic material of the sample holder resulted in a space appearing between the screws and the screw holes. Thus, the *Chroococcidiopsis* cells were completely carbonised (Fig. 1e), despite the 2 cm thickness of protective rock covering them.

Conclusion

The STONE 6 experiment has demonstrated, once again, that sedimentary meteors from Mars could potentially survive entry into the Earth's atmosphere. It underlines the fact that the sedimentary meteors are characterised by either no fusion crust or a cream/white fusion crust. Normally meteorites are identified because their black fusion crusts stand out against the white of the Antarctic ice sheet or the buff colour of the desert. Our results indicate that meteorite collectors should be looking for rocks with light-coloured rocks, with or without fusion crusts. Another important finding is that sedimentary martian meteorites could preserve important biochemical and morphological traces of past life (presupposing that life did actually arise on the planet). However, because of a technological flaw, no conclusions can be drawn regarding the thickness of rocky materials needed to protect extant life during atmospheric entry.

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