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Martian "microfossils" in lunar meteorites?

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Abstract–One of the five lines of evidence used by McKay *et al.* (1996) for relic life in the Martian meteorite Allan Hills (ALH) 84001 was the presence of objects thought to be microfossils. These ovoid and elongated forms are similar to structures found in terrestrial rocks and described as "nanobacteria" (Folk, 1993; McBride *et al.*, 1994). Using the same procedures and apparatus as McKay *et al.* (1996), we have found structures on internal fracture surfaces of lunar meteorites that cannot be distinguished from the objects described on similar surfaces in ALH 84001. The lunar surface is currently a sterile environment and probably always has been. However, the lunar and Martian meteorites share a common terrestrial history, which includes many thousands of years of exposure to Antarctic weathering. Although we do not know the origin of these ovoid and elongated forms, we suggest that their presence on lunar meteorites indicates that the objects described by McKay *et al.* (1996) are not of Martian biological origin.

INTRODUCTION

Terrestrial "nanobacteria" are controversial objects that have been observed in and on the surfaces of carbonate rocks from various countries (Folk, 1993; McBride *et al.*, 1994). When viewed at high magnification using a scanning electron microscope (SEM), they resemble bacteria; although they are an order of magnitude smaller. The Martian meteorite in which McKay *et al.* (1996) reported what appeared to be microfossils of nanobacteria is a find with a very large terrestrial age. A long duration on Earth results in considerable weathering, so that a large number of poorly understood artifacts are produced and the samples are badly contaminated with terrestrial biological and nonbiological materials. In addition, the microstructures described by McKay *et al.* (1996) could be laboratory artifacts, perhaps a product of the conductive coating placed on the samples for examination in the electron microscope. Alternatively, they could be unfamiliar mineral structures on surfaces that have not been examined previously at these magnifications and with this thoroughness.

We examined fresh fracture surfaces of several lunar meteorites and ALH 84001. Our argument is that the Moon, with its lack of water, lack of an atmosphere, extreme temperature ranges and hostile radiation, is currently a sterile environment. There is no evidence that it was ever different from its present state and suitable for life. If the lunar meteorites contain objects like those observed in ALH 84001, then it is highly unlikely that the objects seen in the Martian meteorite were biological in origin. On the other hand, the lunar and Martian meteorites have experienced virtually identical terrestrial histories, both in the Antarctic and in the laboratory.

EXPERIMENTAL

We examined internal fracture surfaces of the ALH 84001 Martian meteorite and four lunar meteorites. The lunar meteorites ALH 81005, MacAlpine Hills (MAC) 88104 and 88105 (these two might actually be pieces of the same original meteorite), and Queen Alexandra Range (QUE) 93069 are anorthositic breccias originally from the lunar highlands (Benoit *et al.*, 1996). As its name suggests, ALH 81005 was found on the same ice sheet as Martian meteorite ALH 84001. Lunar meteorite QUE 94281 is basalt-rich breccia, probably from a lunar mare region (Benoit *et al.*, 1996). All of these meteorites are fairly weathered, and are category A/B on a scale where A is least weathered and C is highly weathered as judged from visual inspection of the hand specimen (Grossman, 1994). This scheme may underestimate the degree of weathering of these samples because it was designed for metal-bearing meteorites that readily rust. Lunar meteorite QUE 94281 has evaporites on its surface, where water-soluble salts have been leached out of the sample by the weathering process (Velbel *et al.*, 1991). The terrestrial residence times of our lunar meteorites are very large, 18 ± 3 ka for ALH 81005 (Jull, 1992); 42.3 ka for the two MAC meteorites (Jull and Donohue, 1991); and 5–11 ka for QUE 93069 (Nishiizumi *et al.*, 1996). This compares with 13 ka for ALH 84001 (Jull *et al.*, 1995). We are aware of no terrestrial age data for QUE 94281.

We used the same equipment and procedures for our samples as McKay *et al.* (1996) used to image microstructures on ALH 84001. Samples were coated with an Au–Pd alloy using a sputter coating unit to avoid charging in the electron microscope, and then placed in JEOL 35CF or Philips 40XL field emission scanning electron microscopes at the Johnson Space Center. Images were taken of any microstructures resembling those described by McKay *et al.* (1996) and Folk and co-workers (Folk, 1993; McBride *et al.*, 1994). About 60 images of the lunar meteorites and 60 of ALH 84001 were obtained.

RESULTS

We identified the following classes of SEM images based on the morphological characteristics of submicrometer objects on the internal fracture surfaces of our meteorites: areas containing elongated objects, areas containing spheres or approximately spherical objects, and areas containing both of these objects. Some objects were clearly lying on the surface of the meteorite, some apparently grew out of the surface, whereas some were located on highly textured surfaces and their relationship to the surface was unclear.

The Martian meteorite contained many ~100 nm elongated forms of the sort illustrated by McKay *et al.* (1996) in their Fig. 6B.; whereas most of the objects on the lunar samples were ~20 nm spherical or ovoid forms. However, both forms were found on both types of meteorite. Figure 1 compares elongated and ovoid forms from the lunar meteorites QUE 93069 and QUE 94281 with the

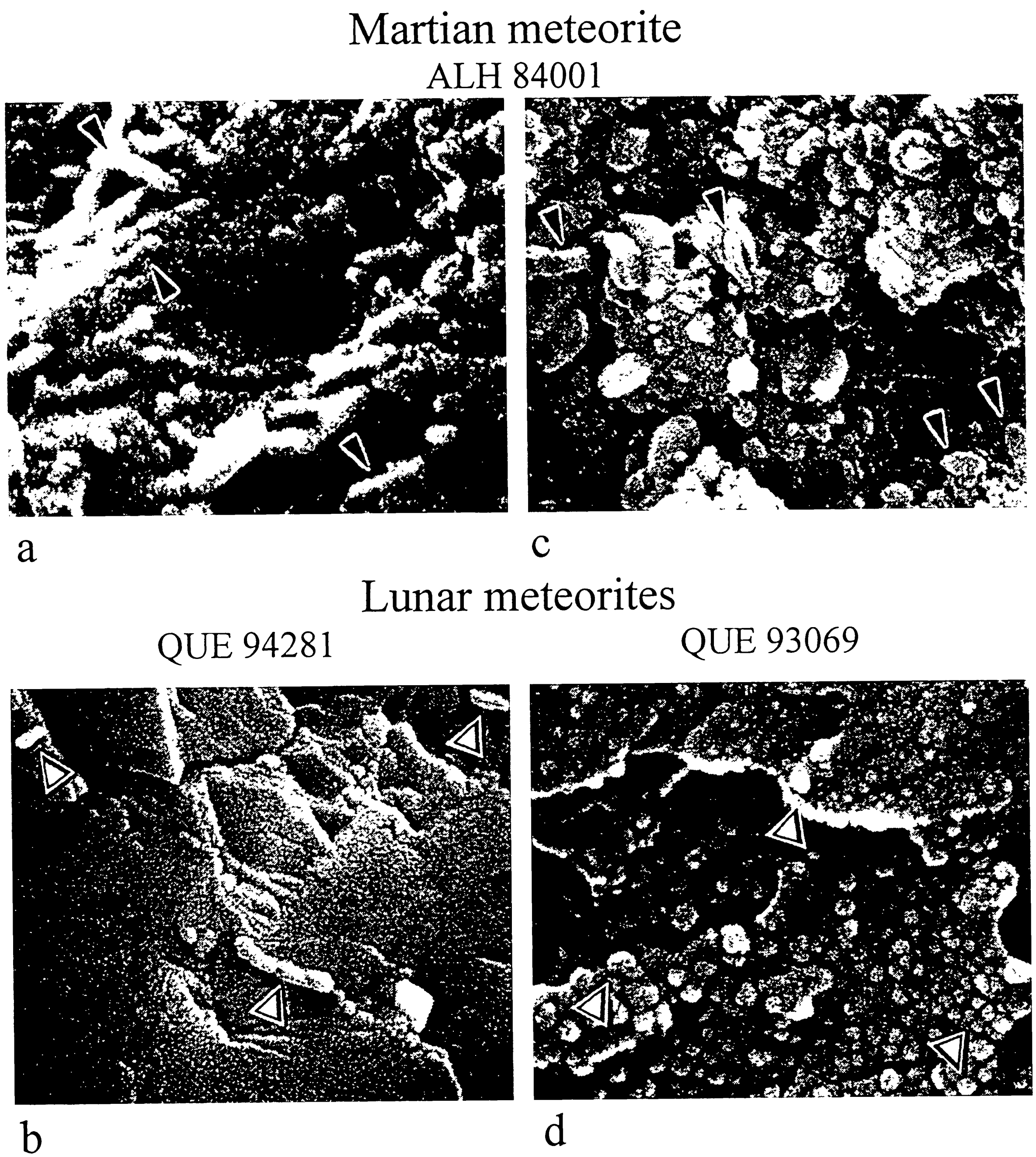

FIG. 1. Submicrometer objects on the surfaces of lunar meteorites and Martian meteorite Allan Hills 84001. Figure 1a and c are images from Martian meteorite ALH 84001 (reproduced from Fig. 6 of McKay *et al.*, 1996); whereas, Fig. 1b and d are images from lunar meteorites QUE 94281 and QUE 93069 (from the present work). Figure 1a–c shows elongated objects, whereas Fig. 1c and d shows ovoid objects of the sort thought by McKay *et al.* (1996) to be microfossils of ancient life on Mars. Field emission-scanning electron microscope images were taken at the Johnson Space Center. The horizontal fields of view are 1 μm.

images produced by McKay *et al.* (1996) of ovoid and elongated objects on the internal fracture surfaces of ALH 84001. The objects appear to be identical. Figure 1 shows a field containing elongated objects 80–200 nm long and ~20 nm in diameter in Martian meteorite ALH 84001 (Fig. 1a) and lunar meteorite QUE 94281 (Fig. 1b); three objects in both fields of view are indicated with arrowheads. In both cases, the elongated objects are not perfect cylinders but are irregular, perhaps because the objects are segmented. Also, the elongated objects are not perfectly straight but are slightly curved. The only difference in the two images is that the lunar objects are lying on a smoother surface. There appears to be no morphological differences between the objects themselves.

We did not note the mineralogy of the surfaces on which our objects were found. Many of the structures on our samples of ALH 84001 were identical to the structures found by McKay *et al.* (1996). According to D. McKay (pers. comm.), they were actually "better" examples. However, some of these faces clearly graded into regions where the structures were undoubtedly crystal edges and clearly growing out of the crystal (Bradley *et al.*, 1997). Some of our objects were on crystalline substrates, probably feldspar. It seems reasonable to us that most crystalline fracture surfaces will produce edge effects of the sort described by Bradley *et al.* (1997), but we doubt that this is the only mechanism operating here. Some of our lunar structures are clearly located on glass, where they appeared to be corrosion effects.

The longest object in Fig. 1b is lying along the edge of a crystal plane. This suggests that these objects are spalling off of crystal edges. Such a suggestion is similar to that of Bradley *et al.* (1997) who discussed the elongated forms in ALH 84001. The two smaller objects in Fig. 1b are randomly oriented. Clearly, once dislocated from the crystal, the elongated forms could adopt any orientation; therefore, lack of orientation cannot be used as an argument against an origin by spalling off from crystal faces. In both the lunar and the Martian meteorites, fields can be found in which the elongated forms are aligned, and fields can be found in which the grains are randomly oriented.

The ovoid structures in the lunar meteorite QUE 93069 (Fig. 1d) can be compared with those in Martian meteorite ALH 84001 (Fig. 1c). Again, the image for the ALH 84001 Martian meteorite is from the McKay *et al.* (1996) paper. As before, we can see no difference between the objects featured by McKay *et al.* and those readily found on the lunar meteorites. In this case, the underlying substrates for the lunar and Martian meteorites appear identical. It would be possible to splice the two images together and not be able to tell that the images came from separate samples. The substrate in these two fields of view is sufficiently textured that it is impossible to tell whether the ovoids were originally part of the surface or are independent objects lying on the surface.

DISCUSSION

McKay *et al.* (1996) suggested that these forms were of Martian biological origin but these objects could also be: (1) original mineralogical features of the meteorites, (2) secondary mineralogical features due to terrestrial weathering (3) terrestrial biogenic contaminants, either from the natural environment or the laboratory, or (4) sample preparation artifacts or artifacts of the viewing method.

Based on a small subset of the present images, Benoit and Taunton (1997) found only a few, generally isolated objects on the lunar samples that had sizes and shapes like those reported by McKay *et al.* (1996). As Fig. 1 shows, the objects on the two types of meteorite are identical. Of the areas photographed, six fields of view on ALH 84001 contained elongated objects, compared with four on the lunar meteorites QUE 93069 and QUE 94281, whereas eighteen fields of view on lunar meteorites contained ovoids, compared to only four on ALH 84001. The statistics are very poor and reflect observer interests, but it is clear that both types of meteorite contain both forms of microstructures. A difference in the proportions of the two morphologies is of interest because it might reflect how the formation of these objects varies with the mineralogy and petrology of the meteorites.

On the basis of our studies, we are unsure as to the origin of these submicrometer objects, but several possibilities are suggested by our images. It seems very likely that some are spalling off the mineral grains, but it seems equally likely that some are independent objects lying on the surface. Some are probably coating artifacts, and some may be terrestrial contaminants, either biological or mineralogical. Whichever process occurred, or combination of processes, it seems clear that since identical forms are found on the lunar and Martian meteorites that the objects cannot be of Martian biological origin.

It seems impossible to avoid the conclusion that much about these meteorites reflects terrestrial contamination. During their thousands of years in the Antarctic, the meteorites have spent time buried in the ice, lying on the surface, exposed to the Sun and winds, and blown in and out of puddles of water, some clean and some muddy. Thus, even momentary heating to 500 °C during the thermoluminescence survey of Antarctic meteorites, for instance, causes a thick, greasy translucent fluid to condense on the windows of the apparatus after only one or two samples. Any attempts to discuss weathering and contamination in terms of simple gradients of alteration through the meteorites, or generalizations based on a few individual meteorites, are grossly oversimplistic. McKay *et al.* (1996) suggested that the lack of organic compounds in the outer regions of the meteorite indicated that the compounds were indigenous. However, it could also indicate that the last soaking the meteorite received was in relatively clean water. The literature is rife with studies of the effects of terrestrial weathering on the physical, mineralogical, elemental, isotopic properties and organic compound inventory of Antarctic meteorites (Benoit *et al.*, 1991; Stelzner and Heide, 1996; Mittlefehldt and Lindstrom, 1991; Wright *et al.*, 1989; Jull *et al.*, 1998; Bada *et al.*, 1998).

However, these issues are secondary to our present purpose. Our main point is that internal fracture faces of lunar meteorites, when examined in the same manner as ALH 84001, contain objects with the same dimensions and structures as those reported by McKay *et al.* (1996). Because the lunar meteorites came from a sterile environment and contain identical forms as the Martian meteorite ALH 84001, the objects described by McKay *et al.* are not due to ancient biological activity on Mars.

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