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Terrestrial microfossils in Antarctic ordinary chondrites

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Abstract–Microfossils have been separated and identified in four high metamorphic grade chondrites from Allan Hills and Queen Alexandra Range, Antarctica. Diatoms and opal phytoliths representing both marine and terrestrial flora were recognized among the dust removed from cracks in all meteorites studied. It is likely that contamination of Antarctic meteorites with such biogenic material is ubiquitous. Standard clean room procedures to avoid laboratory introduction of microfossils into the meteorites were followed, and the genera and species identified so far are characteristic of marine, freshwater, and continental environments. The most probable mechanism for introduction of the microfossils into the meteorites is eolian transport to and on the polar ice cap. It is likely that wind-driven systems may sample atmospherically transported material from large portions of the southern hemisphere. Entrainment of terrestrial microfossils is probably a typical interaction of meteorites with the Antarctic environment and must be recognized and accounted for in any attempt to use Antarctic meteorites as sources of extraterrestrial life forms. Organic molecules derived from microfossils are likely to be pervasive throughout any crack network present in a meteorite at all scales from millimeter to submicron. Cracks are a ubiquitous consequence of weathering in and on the Antarctic ice and the probability that crack surfaces contain terrestrial organic materials is high.

INTRODUCTION

Recent searches for biogenic material in Antarctic meteorites have been remarkably successful and, with the suggestion that biological molecules from Mars were sampled by Allan Hills (ALH) 84001 (McKay *et al.*, 1996), have been a source of considerable controversy (Anders, 1996; Bradley *et al.*, 1997, Greenwood *et al.*, 1997; McKay *et al.*, 1997). The primary purpose of this study is to examine Antarctic meteorites as possible hosts for fossil material from the Antarctic environment—not to search for extraterrestrial microfossils. However, comments relevant to the search for extra-terrestrial life are made based on the observations.

Antarctic meteorites are typically fractured, cracked, and weathered and, therefore, plausible sites for trapping dust particles that have been transported into the proximity of the meteorites either within the ice or on the ice surface. We speculate that terrestrial dust particles may have lodged in cracks in the meteorites during their time in and on the Antarctic ice surface. That dust (including terrestrial microfossils) may be trapped in cracks in exposed rocks in Antarctica has already been demonstrated (Burckle, 1995; Burckle and Wasell, 1995; Burckle and Potter, 1996)

SAMPLING PROCEDURE

To test our speculation that meteorites act as traps for micro-fossils, we borrowed the "main masses" of four previously unprocessed meteorites that were still in their sealed bags used for storage after their initial classification at the Johnson Space Center (JSC). The meteorites are high metamorphic grade chondrites from Allan Hills (ALH 85130,0 and ALH 94018,0) and Queen Alexandra Range (QUE 93305,0 and QUE 94618,0; Fig. 1). Chip samples were taken from all four meteorites. No detailed petrographic work has been published on any of them.

Because the four meteorites are small, ordinary chondrites of high metamorphic grade (L5, H6), they are unlikely to have been handled much during curation and are therefore ideal candidates for our study. Further, they sample classes for which the suggestion that extraterrestrial life is present has never been made. Ordinary chondrites are the most abundant types collected in Antarctica and, therefore, represent the ideal test for determining whether the introduction of terrestrial microfossils is viable during a meteorites' residence time in and on the East Antarctic ice sheet.

Samples were selected by the curatorial staff in a clean room at the JSC Meteorite Processing Laboratory and hand carried (by J. S. D.) in sealed teflon bags to the Lamont-Doherty Earth Observatory (LDEO) where they were prepared in a clean room for microscopic analysis. Dust particles lodged in cracks were separated from the meteorites by immersion in double-distilled water in separate sealed containers followed by sonication. This technique is almost totally nondestructive and loosens and frees micrometer-scale particles from the crack substrate on which they were trapped. Less than one gram of dust (both meteoritic and terrestrial) was recovered from each meteorite. The Queen Alexandra Range meteorites were more friable, and most of the dust freed during sonication was meteoritic material with a minor terrestrial component. The Allan Hills

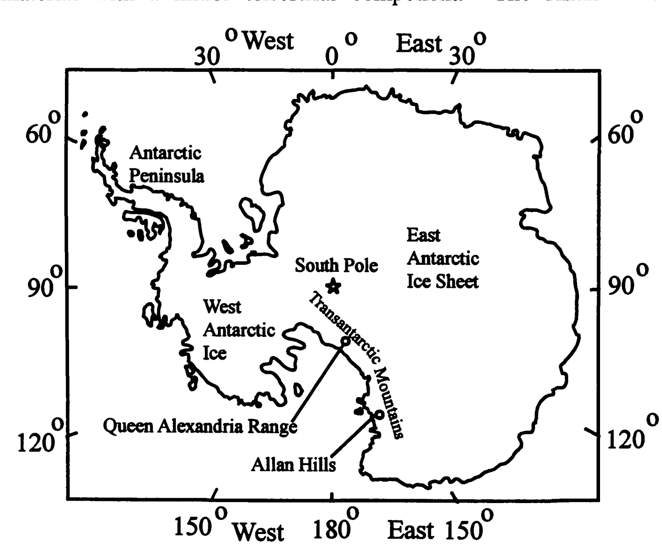

FIG. 1. Map of Antarctica showing location of Allan Hills and the Queen Alexandra range.

samples, on the other hand, were well indurated and most of the dust was of Earth origin.

RESULTS

Microfossils (diatoms and opal phytoliths) were found in dust samples from all meteorites (Fig. 2). Diatoms include the marine species *Coscinodiscus marginatus, Fragilariopsis kerguelensis, Thalassionema nitzschioides*, *Thalassiosira gracilis*, *T. lentiginosa,* and *T. lineata* as well as one small, freshwater species and unidentifiable fragments of presumed marine forms. In addition to these extant forms, two specimens of pre-Pleistocene species were also found: *Denticulopsis dimorpha* became extinct in the Southern Ocean during the early late Miocene (Gersonde and Burckle, 1990) and *Simonseniella barboi* became extinct during the early

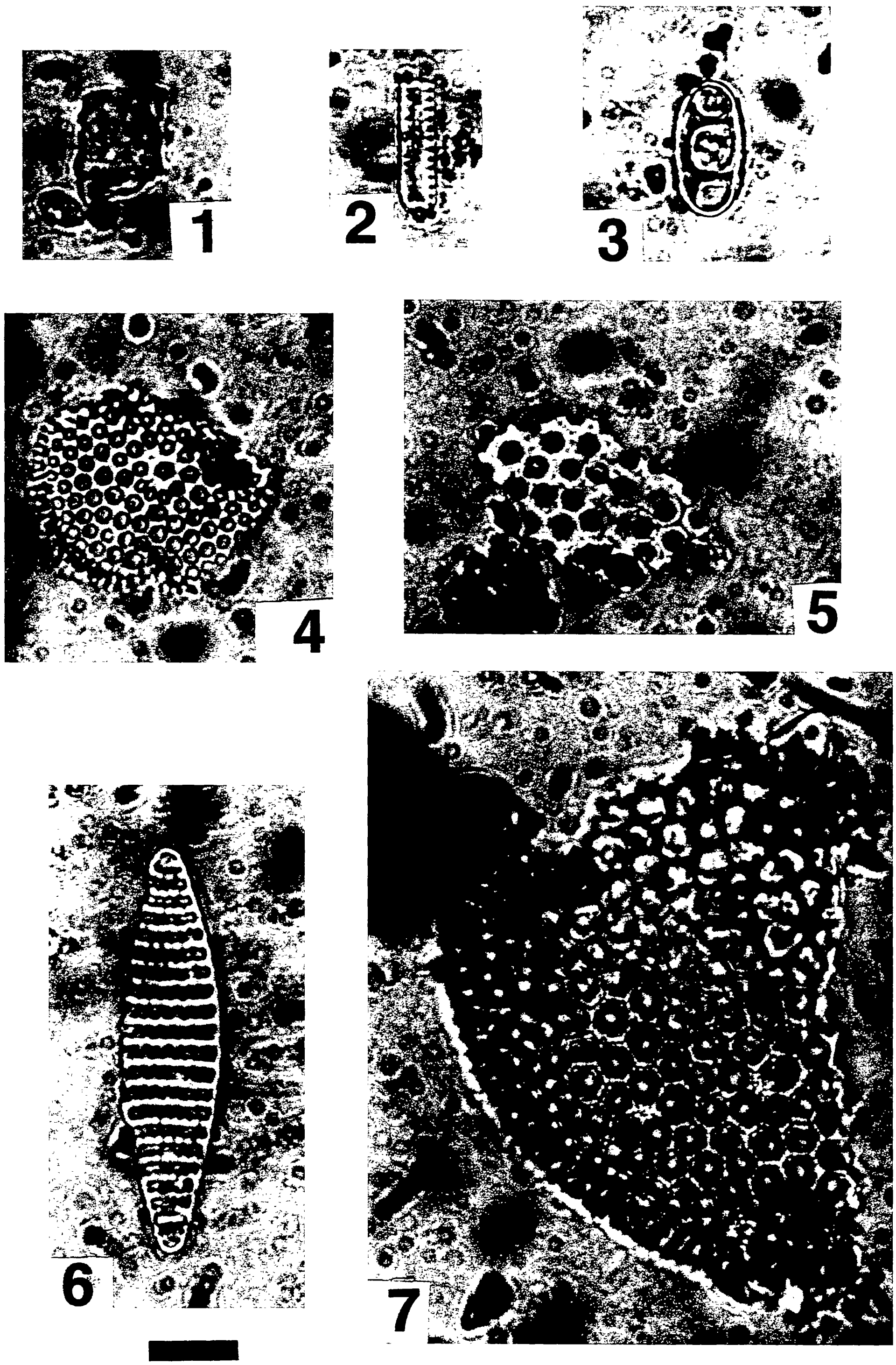

FIG. 2. Transmitted light photomicrographs showing representative microfossils from Antarctic meteorites: (1) opal phytolith, (2) *Thalassionema nitzschioides*, (3) *Denticulopsis dimorpha*, (4) *Thalassiosira gracilis*, (5) radiolarian fragment (?), (6) *Fragilariopsis kerguelensis*, (7) *Coscinodiscus marginatus*. Scale bar is 10 μm.

Pleistocene (Fenner, 1991). Such findings mirror those of Kellogg and Kellogg (1996) who reported the Miocene marine diatom *Denticulopsis hustedtii* in South Pole ice dated at 1449 B.P. Opal phytoliths are microscopic bodies of opaline silica secreted by plants. Their complete role is still not clear but they provide structural support to the plant and may play a role in cellular metabolism (Piperno, 1988). When plants decay or burn, the phytoliths are released to the soil or atmosphere. Modern forms have been reported in Antarctic terrestrial rocks of various ages (Bleakley, 1996) and in ice cores at South Pole, Siple Dome, and Taylor Dome (D. Kellogg, pers. comm.). With the exceptions noted, all species recognized are extant and almost certainly could yield organic molecules.

DISCUSSION

All meteorites studied by us contained microfossils characteristic of marine or terrestrial environments. Because of the precautions taken to isolate meteorites from the Antarctic environment and from one another after collection, it is extremely unlikely that the fossiliferous material extracted from these four chondrites could be a contaminant from either the JSC or LDEO. The microfossils observed are, therefore, considered to be material added to the meteorites after their arrival on Earth and prior to their collection in meteorites in Antarctica.

Organic molecules have been identified in Antarctic meteorites, both directly and indirectly (McKay *et al.*, 1996). Furthermore, detailed microscopic investigations of ALH 84001 suggest that it may also be contaminated by terrestrial organisms; in this case, Cryptoendoliths (Steele *et al.*, 1999). However, the presence of identifiable life forms that are unequivocally of terrestrial origin has not previously been recognized. The recognition of diatoms and opal phytoliths amongst dust particles in previously unopened cracks in meteorites demonstrates that marine and terrestrial microfossils may lodge in cracks in meteorites during their residence on the ice sheet surface or, less likely, while transiting through the ice sheet. Meteorites are almost always exposed on or near ice ablation zones (blue ice) that are being actively deflated by wind action. Diatoms and opal phytoliths are known to have been transported to the Antarctic ice surface by wind (Kellogg and Kellogg, 1996). Given this, an eolian transport mechanism for the diatoms and opal phytoliths found in the fractures is most plausible. However, although eolian transport is also indicated, we do not have a further explanation for the presence of the two fossil diatoms in our material (*Denticulopsis dimorpha* and *Simonsoniella barboi*).

Our findings do not bear directly upon the occurrence of the "nanofossils" in ALH 84001. However, the presence of microfossils of sizes between 5 and ~40 μm in four ordinary chondrites from Antarctica suggests that entrapment of micrometer-scale life forms by meteorites may be a ubiquitous process in Antarctica and suggests that these meteorites may be contaminated with organic molecules associated with these life forms. Obviously, more meteorites as well as dust bands from the various blue ice fields of Antarctica must be examined to confirm the ubiquity of this process. It is fortunate that there are many common types of meteorites available in the Antarctic collections that remain unprocessed because of their abundance and because they are not scientifically attractive to other investigators. Such meteorites that have been handled minimally are ideal candidates for expanding this study as the possibility of laboratory contamination is minimized.

Our finding of terrestrial microfossils in Antarctic meteorites has relevance to two additional points unrelated to meteorite contamination. Diatoms occurring in exposed glacial tills and in subglacial sediments on Antarctica have been used as evidence for very large ice volume changes on this continent. For example, a scenario of drawdown and subsequent renewal of the West Antarctic ice sheet within the last half million years (Scherer, 1991; Scherer *et al.*, 1998) has been proposed. However, the occurrence of diatoms on the Antarctic continent in both surface and deep ice layers (Kellogg and Kellogg, 1996; Abyzov *et al.*, 1998), in rocks of various types and ages (Burckle and Potter, 1996), exposed tills (Webb and Harwood, 1991), subglacial sediments (Scherer,1991; Scherer *et al.*, 1998), and now meteorites (this report) suggests that such microfossil occurrences be used with caution in detailing the past history of ice sheets. With respect to diatoms found beneath the West Antarctic ice sheet, equally viable but opposing mechanisms have been proposed for their emplacement, that is, removal of the West Antarctic ice sheet and subsequent deposition of diatoms in open water (Scherer, 1991; Scherer *et al.*, 1998), or eolian transport of diatoms onto the ice sheet and their subsequent deposition beneath the ice *via* basal melting (Burckle *et al.*, 1997). This does not mean that drawdown of the West Antarctic ice sheet did not occur during the late Quaternary but, rather, that it must be demonstrated by other lines of evidence.

Our second point deals with the opal phytoliths. If enough terrestrial material (*i.e.*, phytoliths; Wilding, 1967) is present in meteorite cracks, then it may be possible to obtain accelerator mass spectrometry (AMS) radiocarbon dates. Admittedly, the resulting dates will represent the average age of all phytoliths in the cracks. However, if one assumes that the rate of terrestrial influx into the cracks has been constant, then the average AMS age of the phytoliths should be dictated by the length of time the meteorites have lain exposed on the ice surface (*i.e.*, the longer the exposure the greater the average radiocarbon age).

CONCLUSIONS

The recognition of microfossils in typical Antarctic meteorites demonstrates that terrestrial life forms can be incorporated into meteorite fractures. Some of these microfossils are small enough to penetrate the rock through permeable pathways; open fractures may not always be necessary to record their occurrence in meteorites. Given the high winds on the East Antarctic ice sheet, one would expect the highest dust concentration and, thus, most of the terrestrial microfossils to accumulate in the interior of cracks where they cannot be dislodged by the wind. The presence of terrestrial microfossils in our samples indicates that Antarctic meteorites must not be assumed to be sources of pristine extraterrestrial organic material and claims for the presence of such material should be treated with extreme caution.

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