HARVESTING METEORITES IN THE OMANI DESERT: IMPLICATIONS FOR ASTROBIOLOGY

Beda A. Hofmann[1], Edwin Gnos[2], Ali Al-Kathriri[2,3]
[1]Natural History Museum, Bernastrasse 15, CH-3005 Bern, Switzerland
[2]Institute für Geological Sciences, Baltzerstrasse 1, CH-3012 Bern, Switzerland
[3]Directorate General of Commerce and Industry, Salalah, Sultanate of Oman

Abstract

Meteorites will remain the most accessible, most diverse and most abundant source of extraterrestrial materials for many years to come. New sources of large numbers of meteorites allow the recovery of rare types particularly relevant for astrobiology, including Martian and Lunar samples. Oman has become an important source of meteorites only since 1999. Conditions for search and recovery are particularly favourable in many areas here because of an abundance of flat, light-colored, sand- and and vegetation-free surfaces. During search expeditions carried out in the central deserts of Oman in 2001-2003 large numbers of meteorites, including a Martian and a Lunar sample, were recovered. The mass of recovered meteorites is 1334 kg, corresponding to approximately 150 to 200 fall events. We aim to classify all recovered specimens and study pairing and weathering effects. Our expeditions demonstrate the possibility to recover meteorite samples with astrobiological relevance with modest investments of finances and manpower.

1. Introduction

Meteorites are an important and still near-unique source of solid-state information from extraterrestrial bodies, mainly the asteroids, but also Moon and Mars. Traditionally, the recovery of new meteorites was mainly a matter of chance until systematic, but very cost-intensive searches were started in Antarctica in 1966. With the recognition of meteorite accumulations in hot deserts, mainly in the western U.S., north Africa, Australia and most recently on the Arabian pensinsula, systematic searches for meteorites in these areas provide a new and important source of meteorites. Contrary to meteorite searches in Antarctica, most searches in hot deserts (with the notable exception of Australia) were carried out by private meteorite hunters. Starting with Meteoritical Bulletin 84 (2000), large numbers of meteorites from Oman have been reported in recent years. Since 1999, this country has become an important source of meteorites and has yielded several Martian and Lunar samples. In January 2001 we started, in close collaboration with the Ministry of Commerce and Industry in Muscat, the first of three meteorite search campaigns in the central deserts of Oman. These were conducted during the winters 2001-2003. The aim of our project is the recovery of a statistically relevant number of meteorites over a large area to understand processes that lead to the concentration and destruction of meteorites on desert surfaces, as well as a detailed investigation of the rare meteorite types recovered.

2. Methods

Searches for meteorites were carried out visually from 4WD vehicles, in parties of 2-4 persons. We completed a total of 11‘645 search km. All meteorites appear dark compared with the bright limestone desert soil. Typically, meteorites were visually recognized over a distance of less than 30 m, in rare cases over up to 200 m. Masses of individual meteorites ranged from <1 g to >100 kg. Test searches by foot were conducted to investigate a possible under-estimation of small meteorites during searches from cars, but proved to be much less effective than searches using vehicles. A total of 339 man days were invested in pure search activity. GPS coordinates were recorded for every find. Samples were collected without touching and wrapped in aluminium foil and polypropylene bags for transport. In addition to meteorites, soil samples were collected at numerous localities, usually as pairs consisting of soil collected directly below meteorites and of a reference sample taken at 10 m distance.

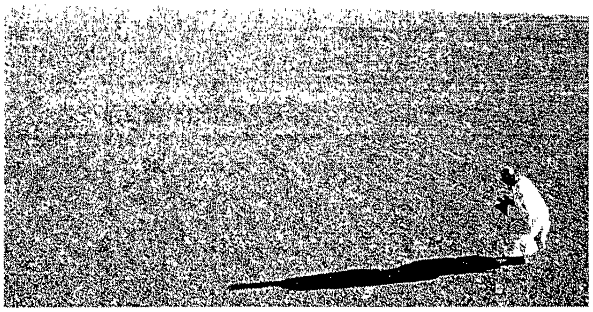
Polished thin sections are prepared from all meteorites (exluding large numbers of obviously paired samples) followed by classification using optical microscopy and electron microprobe analysis of pyroxene and olivine, and additional methods where needed.

3. Geological background

The central Oman desert is an area extending for approximately 200 by 600 km between the Arabian sea and the Rub Al-Khali sandy desert. In the north, toward the Oman Mountains, flat limestone desert plains grade into alluvial fans not favourable for meteorite search due to an abundance of dark rocks. The desert plains are underlain by a thick sedimentary sequence ranging in age from the Precambrian to the late Tertiary. The youngest sediments are horizontally bedded Tertiary shallow marine (locally lacustrine) carbonates (1, 2). Areas least affected by erosion are made up of Miocene limestones, in other areas strata of Eocene age are exposed, indicating stronger erosion. The most favourable areas for meteorite search appear to be on Miocene rocks, where erosion over the last 5 to 10 Ma was only in the order of a few tens of meters. Evidence of ferruginization in common. Typically, the desert soil on carbonates is made up of cm-sized limestone fragments mixed with silty material

Proc. of the III European Workshop on Exo-Astrobiology. Mars: The search for Life, Madrid, Spain, 18-20 November 2003.
(ESA SP-545, March 2004)

representing dissolution residues and wind-blown material. Preliminary geochemical data indicate a very homogeneous composition of soils over large areas, providing a rather uniform geochemical environment for meteorite weathering. The area is arid desert, but occasional rains and fog provide some humidity for weathering processes. Palaeoclimatic studies indicate that conditions were more humid during the last glacial due to a stronger influence of the monsoon (3).



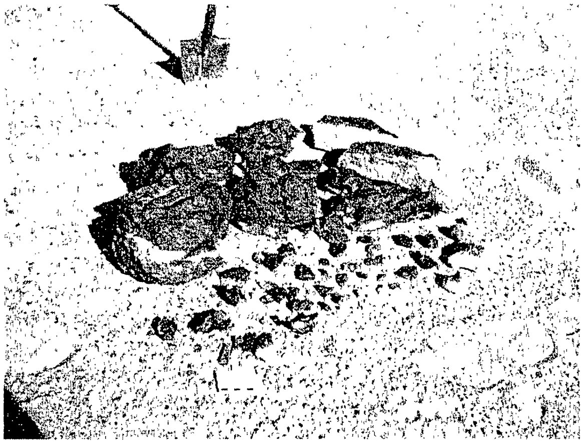
Typical meteorite recovery area in central Oman, near the find site of the SaU 094 Mars meteorite.

4. Results of search campaigns 2001-2003

Based on our field experience it appears that meteorites are not evenly distributed in the Omani desert. Certain surfaces appear to yield higher find rates, but this will have to be refined when all pairings are searched out. Factors such as wind ablation and fragmentation due to oxidation/hydra-tion-related volume increase, as well as burial in the soil, influence the long-term survival and visibility of meteorites. Based on our searches, we estimate a typical find rate of one meteorite per km^2.

Our search resulted in the recovery of approx. 3700 meteorite specimens with a total weight of 1334 kg. Many of these meteorites are paired and several strewnfields were found, the largest, Jiddat al Harasis 073 (4), a fall of an ordinary chondrite (L6), yielded >2500 stones over an area of 4x20 km. Excluding such strewnfields, the recovered number of individual meteorites (fall events) is in the order of 150-200. Most finds are ordinary chondrites, typically showing a significant degree of weathering (most are W3-4). Special meteorites found include SaU 094 (5), a Martian meteorite (paired with SaU 005, forming a group of at least eight paired stones); SaU 169 (6), a very unusual KREEP-rich Lunar impact melt breccia with adhering regolith; an octaedrite (the first iron from Oman); a mesosiderite (forming a strewnfield) and several rare chondrites (2CV, 1CR, 1CO, 1EH, 1EL, 1R).

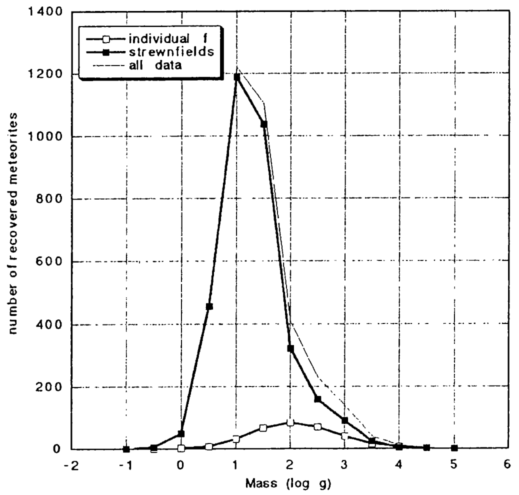
Studies of weathering (7) show that, similar to studies conducted on meteorites from the Sahara, H_2O, barium and strontium appear to be the most sensitive indicators of terrestrial alteration. In the field, weathering effects are fragmentation and dispersal of fragments over up to 20m, and burial in the soil. Field evidence indicates that both burial and exhumation occur over large periods of time. We found evidence for a high concentrations of salts in many meteorites, likely due to weathering-related effects of concentration and water-meteorite reactions.



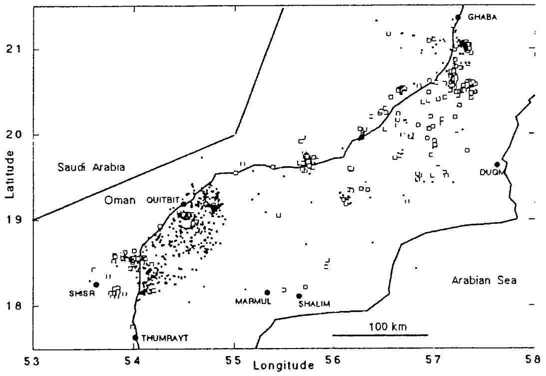
Fragments of a single meteorite (ordinary chondrite), total weight 44 kg, originally dispersed over several tens of meters. Fragmentation is mostly due to weathering. Note adhering soil marking burial depths. Scale in cm in foreground.

The median mass of recovered meteorites outside strewnfields is 226g (n=331). In strewnfields, the median mass is significantly lower at 31g (n=3349). The median mass of 226g is significantly higher than in Antarctica, where typical sizes are in the order of 10g (8). Since strewnfields are easily recognized in the desert, this bias may indicate the presence of large numbers of paired (meteorite shower) samples in the Antarctic collection.

We also investigated the circular, 6 km diameter Habhab structure at 19.9°N, 57.0°E. This structure has been interpreted as a possible impact crater based on satellite images. Combined field evidence and seismic profiles indicate, however, that the structure is caused by a near-surface salt plug (9).



Histogram showing the size distribution of meteorites from strewnfields (filled symbols) compared with single finds (open symbols).



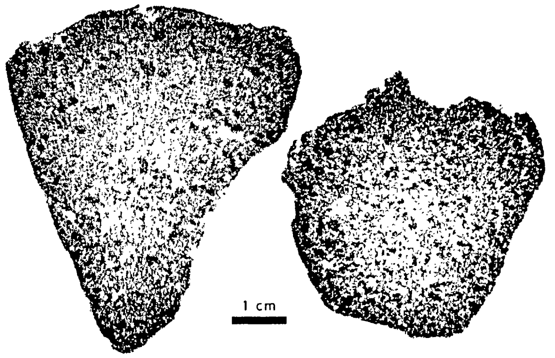
Map showing the distribution of meteorite finds in central Oman. Open symbols: finds during our searches; dots: published finds.

5. Implications for astrobiology

The recovery of meteorites is of obvious relevance for astrobiology. Meteorites are the most important solid extraterrestrial samples, providing background information on the solar nebula, asteroids, Mars and Moon. In addition, scientifically motivated meteorite searches in hot deserts can provide information on meteorite fall dynamics and weathering.

Based on presently available information, Martian and Lunar meteorites appear to be overrepresented in Oman. Within just four years, this country has yielded 3 of currently 30 known Mars meteorites and 9 of ~29 Lunar meteorites. On the other hand, only one iron meteorite has been found. By combining all available data on meteorite finds we aim to provide pairing-corrected find statistics and search for possible geological causes for the apparent over/underrepresentation of certain meteorite types. This approach may help to develop search strategies with enhanced chances of finding planetary meteorites.

Mars meteorite SaU 094 on desert soil. The surface is sand-blasted and nearly completely lacks fusion crust. Maximum size is 6 cm.



X-ray tomographs of Mars meteorite SaU 094. White areas are vesicles in shock melt, dark spots are olivine crystals.

Mars meteorite SaU 094 is part of the first well-documented Mars meteorite strewnfield. It provides insights into the ejection shock problem, atmospheric breakup behaviour and weathering of Mars rocks under terrestrial conditions. SaU 094 is heavily shocked, with abundant shock melts, and shows signs of significant terrestrial weathering (carbonate veining, secondary gypsum in melt glass vescicles, shock melt alteration). This meteorite appears not very suitable for the search for evidence of hydrous alteration on Mars, or even traces of life.

Lunar meteorite SaU 169 samples a large impact event in the early Lunar history. Based on it's KREEP-rich composition it is likely related to the Imbrium-forming impact. This and similar samples are likely to provide insight into the history of impacts on the Moon-Earth system during a time critical for the development of life.

The detailed study of meteorite weathering is relevant to the interpretation of meteorites on Earth, and provides information on weathering of meteoritic material possibly present on planetary surfaces (Mars). The experience gained with meteorites in terrestrial hot deserts may further help to recognize meteorites on the surface of Mars where, based on the high age of certain surfaces, they should be much more abundant than on earth.

6. Acknowledgements

We thank Dr. Hilal Al-Azri, Director General of Minerals, Ministry of Commerce and Industry, Muscat, for the permission to conduct this project. The following persons helped with searching meteorites in Oman: Manuel Eggimann, Otto Eugster, Marc Hauser, Urs Krähenbühl, Silvio Lorenzetti, Lorenz Moser. This project is supported by the Swiss National Science Foundation (grant 2100-064929).

7. References

1. Le Métour, J., Michel, J.C., Béchennec, F., Platel, J.-P., Roger, J. Geology and mineral wealth of the Sultanate of Oman. Ministry of Petroleum and Minerals, Sultanate of Oman, Muscat, 285pp, 1995.

2. Le Métour, J., Platel, J.-P. Geological map of Oman, 1:1000'000. Ministry of Petroleum and Minerals, Sultanate of Oman, Muscat, 1993.

3. Fleitmann, D., Burns, S.J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A., Matter, A. Holocene forcing of the Indian Monsoon recorded in a stalagmite from southern Oman. Science 300, 1737-1739, 2003.

4. Gnos, E., Hofmann, B.A., Al-Kathiri, A., Lorenzetti, S., Eugster, O., Jull, A.J.T. The newly discovered Jiddat al Harasis strewnfield in Oman. Meteoritics and Planetary Science 38 (suppl.), A31, 2003.

5. Gnos, E., Hofmann, B.A., Franchi, I.A., Al-Kathiri, A., Hauser, M., Moser, L. Sayh al Uhaymir 094: A new Martian meteorite from the Oman desert. Meteoritic and Planetary Science 37, 835-854, 2002.

6. Gnos, E., Hofmann, B.A., Al-Kathiri, A., Lorenzetti, S., Villa, I., Eugster, O., Jull, A.J.T., Eikenberg, J., Spettel, B., Krähenbühl, U., Franchi, I.A., Greenwood, G.C. Lunar meteorite SaU 169: An extremely KREEP-rich rock. Meteoritics and Planetary Science 38 (suppl.), A40, 2003.

7. Al-Kathiri, A., Hofmann, B.A., Gnos, E., Jull, A.J.T. Weathering of meteorites from Oman: The influence of soil chemistry and correlation of chemical/mineralogical weathering proxies with ^{14}C terrestrial ages. Meteoritics and Planetary Science 38 (suppl.), A55, 2003.

8. Huss, G. Meteorite mass distribution and differences between Antarctic and non-Antarctic meteorites. Geochim. Cosmochim. Acta 55, 105-111, 1991.

9. Hofmann, B.A., Gnos, E., Al-Kathiri, A., Al-Busaidi, S.A., Al-Rajhi, A., Al-Batashi, M., Terken, J. The Habhab structure of central Oman: not an impact crater. Meteoritics and Planetary Science 38 (suppl.), A55, 2003.