Hyperfine Interact (2008) 186:105–111
DOI 10.1007/s10751-008-9839-x

Characterization of Maghsail meteorite from Oman by Mössbauer spectroscopy, X-ray diffraction and petrographic microscopy

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Abstract The meteorite found at Maghsail (16 55 70 N–53 46 69 E) west of Salalah Oman, has been studied by ^{57}Fe Mössbauer spectroscopy, X-diffractometry and petrographic microscopy. In the polished section the meteorite exhibits a porphyritic texture consisting of pyroxene and olivine phenocrysts in a fine to medium grained ground mass in addition to minor phases possibly skeletal chromite, troilite and minute amount of iron oxides. X-ray diffraction supports the existence of these compounds. The Mössbauer spectra of powdered material from the core of the rock at 298 K and 78 K exhibit a mixture of magnetic and paramagnetic components. The paramagnetic components are assigned to the silicate minerals olivine and pyroxene. On the other hand, the magnetic spectra reveal the presence of troilite and iron oxides. The petrographic analyses indicate that the iron oxides are terrestrial alteration products.

Keywords Maghsail meteorite · Mössbauer spectroscopy · XRD · Petrographic microscopy

1 Introduction

In recent years large numbers of meteorites have been found in the deserts of Oman. The range of petrological types and locations has opened up a potentially important field of research. When meteorites approach the surface of the Earth,

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they are exposed to reactions due to surrounding environment. Due to meteorites accumulations over long periods of time, hot and cold desert environments are most suitable for weathering studies [1–3]. Initial fast oxidations of iron metal followed by more gradual oxidation of troilite were observed in the omani desert meteorites [4]. A meteorite of approx. 300 g was found close to a limestone quarry in the hilly area 5 km N of the coastal village of Al Maghsail (16 55.47 N–53 47.10 E) west of Salalah, Oman. The importance of this find is attributed to two factors: firstly its proximity to the sea (~5 km from the coast) leading to exposure to high humidity levels; and secondly the find is within the area affected by the summer Monson drizzles and mist which means receiving larger and regular amounts of rain.

In this work we investigate this meteorite in terms of its weathering product and classification using optical microscopy, X-ray diffraction (XRD) and Mössbauer spectroscopy.

2 Experimental

A polished thin section, prepared to standard petrographic thickness, was made to be used for the petrographic analysis of this meteorite.

A small piece of the meteorite was taken from a layer below the exposed fusion crust. The sample was then ground and the resulting powder was used for XRD and Mössbauer spectroscopy.

The powder X-ray diffraction (XRD) was done using a Philips PW1710 diffractometer in the 2θ range of 10°–70°. The sample has been prepared for XRD by pressing the powder into the middle of the well of the aluminum sample holder using a glass slide. The phases were identified by performing multiple searches on a database using PW 1876 PC-identify and PW 1877 APD (Automatic Powder Diffraction) software programs.

Mössbauer measurements were performed at 298 K and 78 K in transition mode geometry on a powdered sample using a constant acceleration Mössbauer spectrometer with 50 mCi ^{57}Co in Rh source. The spectrometer was calibrated using the spectrum of α-Fe foil at room temperature. The measured data were fitted using a non-linear least-square fitting program assuming Lorentzian lines.

3 Result and discussion

Polished thin section analysis of the cross-polarized transmitted light exhibits a porphyritic texture consisting of pyroxene and olivine phenocrysts in a fine to medium grained ground mass in addition to minor phases possibly skeletal chromite, troilite, eliminite, plagiglass and minute amount of iron oxides (hematite, magnetite goethite). Petrographic observations using reflected light microscopy indicate that the Fe-Ni metal alloy (Taenite) is moderately weathered resembling terrestrial alteration of W2 grade [5]. Thin section studies using transmitted light microscopy showed that the meteorite is moderately shocked (S4) and is classified as L6 [6]. The observations show cryptocrystalline, zoned cryptocrystalline and barred olivine chondrules. The zoned cryptocrystalline and barred olivine chondrules show darker and finer grains in the center and lighter at the rims while the barred olivine chondrule shows several sets of parallel olivine bars Fig. 1. Further analysis shows

Fig. 1 Images of chondrules taken under cross-polarized transmitted light. **a** cryptocrystalline chondrule; **b** barred olivine chondrule showing several sets of parallel olivine bars; **c** zoned cryptocrystalline chondrule with darker and finer grains in the center and lighter at the rims

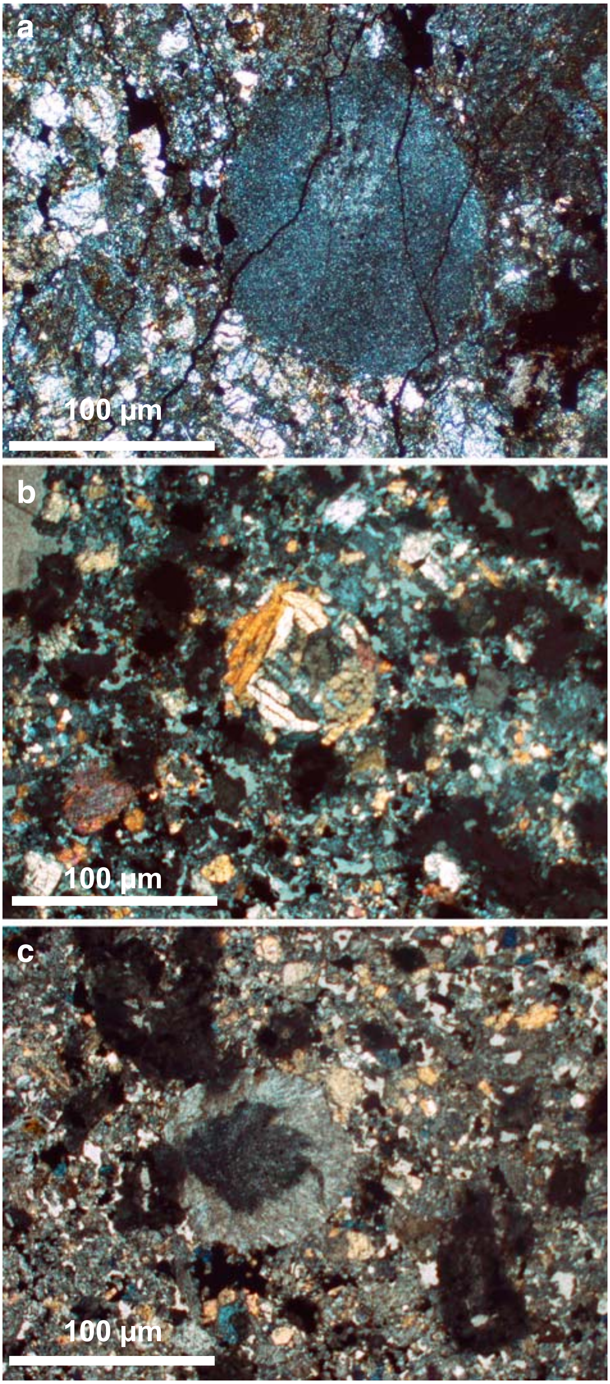

Fig. 2 Images taken under reflected microscope showing fractures filled with calcite as a result of terrestrial weathering

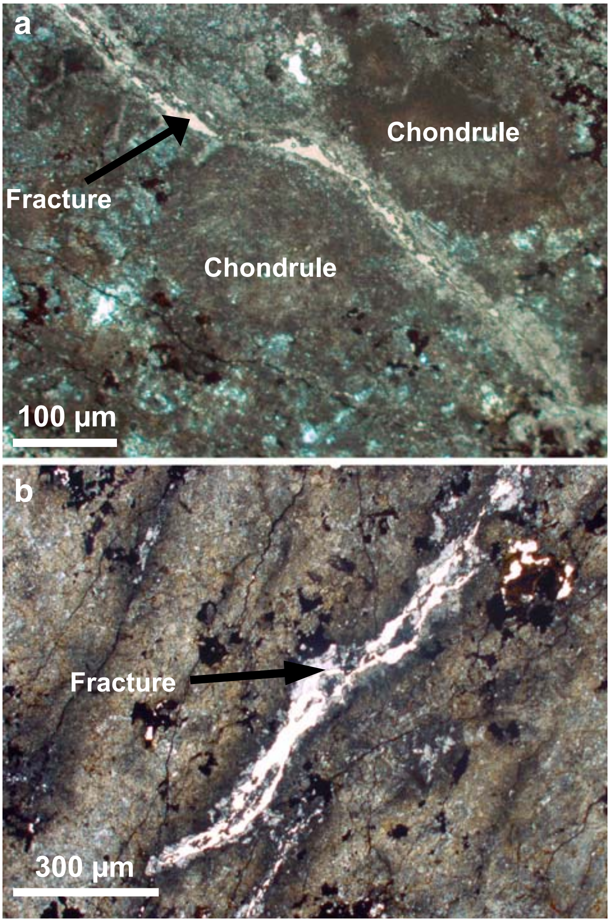

Fig. 3 Images taken under reflected microscope showing possible chromites grain

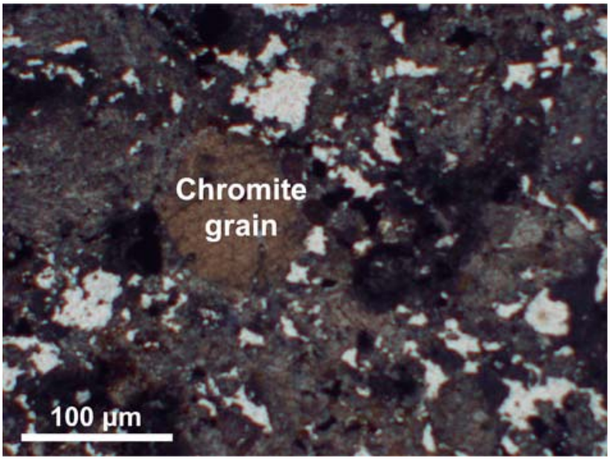

Fig. 4 Powder XRD spectrum of Maghsail meteorite. Component spectra are identified in the legend

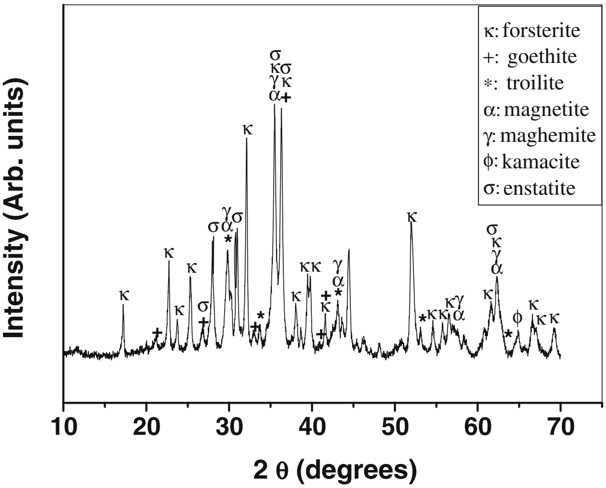

Fig. 5 Least squares fit of **a** 298 K and **b** 78 K spectra of Maghsail meteorite

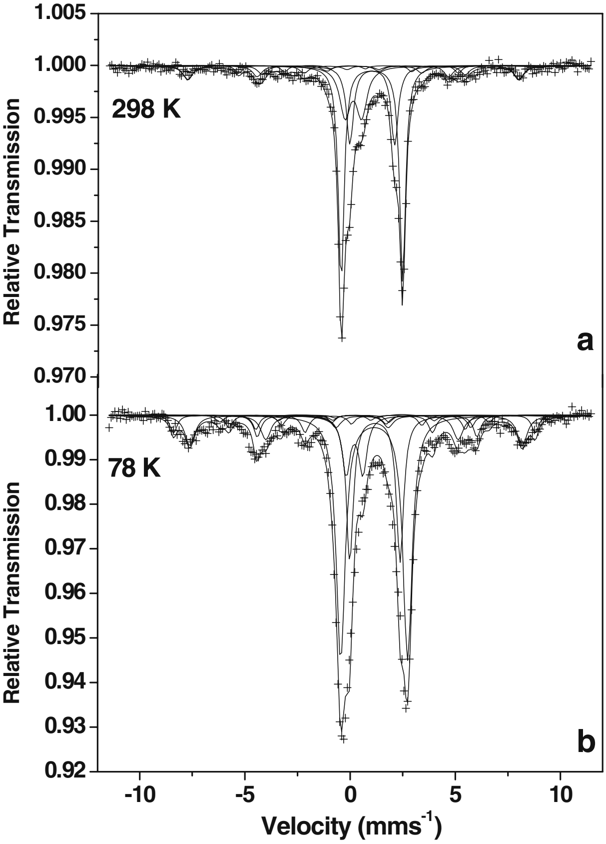

Table 1 The Mössbauer parameters obtained at 298 K and 78 K from the fits of Maghsail meteorite

	δ (±0.02) $\mathrm{mms^{-1}}$		ΔE_Q (±0.01) $\mathrm{mms^{-1}}$		B (±0.1) (T)		A (±1) (%)	
	298 K	78 K	298 K	78 K	298 K	78 K	298 K	78 K
Olivine	1.16	1.28	2.93	3.18	–	–	43	41
Pyroxene	1.17	1.32	2.13	2.39	–	–	19	20
Troilite	0.75	0.98	0.05	−0.07	30.0	32.4	6	7
Kamacite	0.03	0.17	0.02	−0.09	32.5	35.7	4	4
Fe^{3+}/Goethite	0.27	0.72	0.80	0.40	–	–	18	9
Oxides	0.27	0.55	0.02	−0.29	49.0	54.2	10	5
Oxides	–	0.52	–	−0.29	–	49.2	–	12
Oxides	–	0.53	–	−0.09	–	42.0	–	2

The parameters are: δ, the isomer shift; ΔE_Q, the quadrupole splitting; B, the magnetic field splitting in Tesla; and A, the relative absorption area

fractures filled with calcite which is a result of terrestrial weathering and possible minor amounts of chromite (Figs. 2 and 3). As expected, the ferric iron content is particularly clear on spots along the calcite veins.

The X-ray powder diffraction patterns obtained from the Maghsail meteorite is shown in Fig. 4, indicating the existence of olivine, pyroxene, troilite, kamacite, taenite and iron oxides (magnetite, maghemite, and goethite). The results agree with those obtained from the petrographic study. Clear identification of chromite existence in the Maghsail meteorite was difficult due to complexity of the patterns.

The Mössbauer spectra of the 298 K and 78 K of Maghsail sample are shown in Fig. 5a and b respectively. The spectrum at 298 K illustrates the main contributions of olivine, pyroxene, troilite, kamacite, goethite, and magnetite. The spectrum recorded at 78 K was fitted with the same components at room temperature. In addition to those two sextets were added to obtain a good fit. The sextets are attributed to oxides of 42 T and 49.2 T. Values of the fitted hyperfine field parameters are presented in Table 1. The Mössbauer parameters of the identified components are comparable with our previously studied meteorites and others [7–10].

Even by comparing large number of sub spectra obtained at 298 K and 78 K temperatures, it is difficult to form a picture of the oxide minerals in this meteorite. This is attributed to the minor amounts of oxides in this meteorite comparable to the many Omani meteorites found in the desert environment. The main paramagnetic doublets of olivine and pyroxene are justified at both temperatures.

To classify the meteorite we note that the intensity of the absorption in Mössbauer spectrum is related to the proportion of the total Fe in the individual phases. Such advantage of Mössbauer spectroscopy supports the characterization of several meteorites. Verma and coworkers [10] developed a one-dimensional plot of the olivine/pyroxene in addition to a two-dimensional plot of area of metallic phases versus area of silicate phases. The former chart gives a better zone separation for the three groups, H, L and LL of the ordinary chondrites. The studied meteorite can be characterized as an ordinary chondrite meteorite [10, 11]. Further, from the olivine/pyroxene ratio of 2.32, the maghsail meteorite is classified as L.

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