MAGNETIC SIGNATURE OF LHERZOLITIC SHERGOTTITES ALH 77005 AND YAMATO 000097: "BROWN" COLOR OLIVINES AND DETECTION OF FE METAL PARTICLES BY MAGNETOTACTIC BACTERIA: V. Hoffmann[1,2], M. Funaki[3], M. Torii[4], T. Kurihara[5] and T. Mikouchi[5]. [1] Inst. for Geosciences and ZAG, University of Tübingen, Sigwartstrasse 10, 72076 Tübingen, Germany. [2] Dep. of Geo- and Environ. Sci., Faculty of Geosciences, University of München, Germany. [3] National Inst. Pol. Res., 9-10 Kaga 1 Chome, Itabashi-Ku, Tokyo 173, Japan. [4] Dep. of Geosphere-Biosphere System Science, Okayama University of Science, Okayama, Japan.[5] Dep. of Earth and Planet. Sci., University of Tokyo, Japan. (Email: viktor.hoffmann@uni-tuebingen.de)

Introduction: In recent years, the systematic investigation of the magnetic signature of Martian meteorites (SNC) received increasing interest [1, 2, 3, 4, 5 and references herein]. Presently ca. 45 unpaired SNC meteorites are known which represent the only samples from the red planet available for laboratory analyses. Exploring the magnetic signature of SNC meteorites will help to unreveal the planetary development of Mars and the potential existence of a strong dynamo field during the first 0.5-1Gy. Since some time, the dark brown-blackish olivine color gave rise for speculations concerning an impact-related background. In 2005 the first finding of Fe metal phases in olivine grains of the lherzolitic shergottite NWA 1950 was reported by [6]. Recently nano-sized Fe or Fe-Ni metal grains could be also detected in NWA 2737, a shocked dunite [7, 8]. Fe or Fe-Ni metal nano phases were not observed in terrestrial olivines so far.

In 1977 ALH 77005 was found in Antarctica and it was the first SNC ever investigated by magnetic means [9]. Interestingly, an average abundance of 0.042 wt% of Fe metal was reported as quantitatively estimated by a magnetic analysis. At that time ALH 77005 was classified as "a eucritic unique achondrite", by ordinary petrographic means no metal could be observed [9].

The paired lherzolitic shergottites Yamato 000027/47/97 are investigated within a consortium study organized NIPR [10]. First data concerning mineralogy, petrology and magnetic signature were published in Antarctic Meteorites XXXI (2007) [e.g. 5, 11]. In the case of lherzolitic shergottites an obvious relation between the magnetic signature (magnetic susceptibility (MS), NRM/IRM intensity) and the mass – or size - of the respective Mars rocks was found [5]: the smaller the mass-size the lower MS or IRM intensity values. Preliminarily, we interpreted this behavior as likely due to terrestrial alteration.

Results and interpretation: Newly taken chips (both interior and exterior samples) and PTS of ALH 77005 and Yamato 000097 provided by NIPR and NASA, respectively, were investigated systematically by magnetic means. In addition, low-temperature experiments using MPMS and thermomagnetic curves were obtained. Bitter technique and magnetic force microscopy (MFM) allowed us to observe the magnetic remanence carriers in high resolution. Magnetotactic bacteria (MTB) were used to search for submicron-sized ferro(i)magnetic particles. The application of the MTB technique was first described on the iron meteorite Nova Petropolis [12]. The main advantages of the MTB method can be summarized as follows: (1) MTB are very sensitive magnetic sensors to detect magnetic S (N) poles. (2) The direction of the dipole moment of magnetic grains may be identified using both North seeking (NSB) and South seeking (SSB) MTB. (3) The directions of lines of the magnetic force radiating from the grains can be observed. (4) MTB allow to identify the magnetic south (S) pole distribution within a PTS of any rock or mineral, even of very tiny particles with sizes below optical resolution.

Generally speaking, in the case of lherzolitic shergottites the magnetic signature is quite variable, sometimes even within one and the same specimen (Fig. 1). This contrasts with the more homogeneous distribution of the magnetic data of other shergottite groups or nakhlites. Low temperature experiments (MPMS) revealed the presence of Ti-, Al-, Mg- substituted magnetite, chromite and a phase-transition below 20 K.

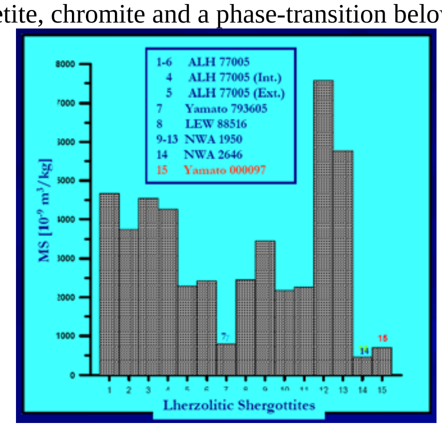

Fig. 1: Magnetic susceptibility values of lherzolitic shergottites. New original values and literature data [1, 2, 5].

We also conducted similar experiments on terrestrial equivalents (rocks/mineral phases), for example on iron metal from Disco/Greenland, or awaruite (Ni_3Fe) from California and Switzerland. MS values of terrestrial dunites, peridotites or lherzolites are significantly lower than those of lherzolitic shergottites or chassignites (MS_{terr} below 300 10^{-9} m^3/kg) which clearly indicates different magneto-mineralogy. Awaruite has a T_c of around 610°C and a transition near 110-120K, resembling (masking) magnetite. The T_c of iron metal is near 760°C, another transition was found around 10-20 K in low-T IRM data. Most likely, the transition below 20K which was found in several lherzolites can be attributed to a Fe metal phase.

The magneto-mineralogy of ALH 77005 was studied already by Nagata and co-operators from 1979 on [9]. Fig. 2 shows an example of a thermomagnetic curve obtained in UHV: the curve is nearly reversible, revealing only two Curie points between 750 and 770°C indicating iron-metal like phases.

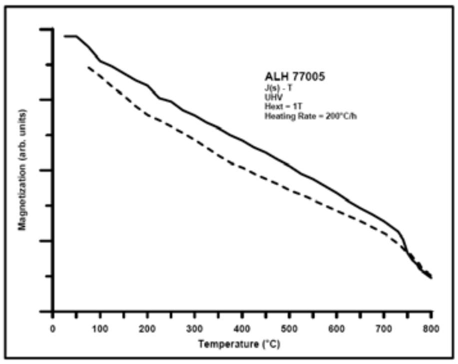

Fig. 2: Thermomagnetic curve (magnetization) obtained on ALH 77005 from 1983 with T_c of around 760°C, indicating Fe metal as the dominating magnetic mineral (dashed: cooling curve).

A first test using MTB was performed on a PTS of Yamato 000097. Conventional optical microscopy, Bitter technique and MFM did not provide positive results in terms of magnetic remanence carriers. Therefore we decided to apply the MTB technique because of its higher sensitivity and the chance to quickly observe large areas. Fig. 3 shows a ferrimagnetic Fe-sulphide grain, most probably monoclinic pyrrhotite, with clear clusters of MTB (whitish) indicating the position of magnetic S-poles.

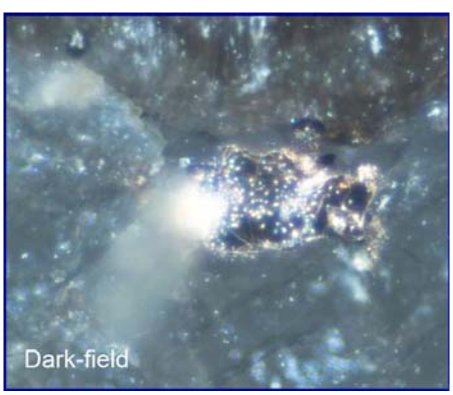

Fig. 3: Magnetic S-pole distribution on a ferrimagnetic Fe-sulfide grain (ca. 25µm) in Yamato 000097 as observed with MTB.

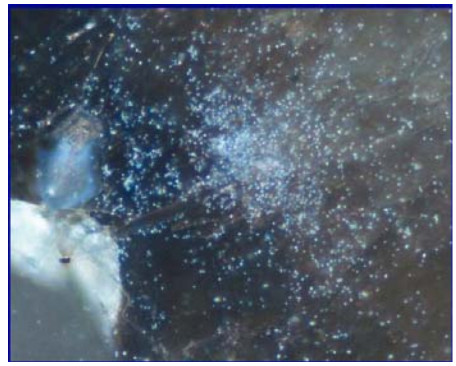

Fig. 4: A dense cluster of MTB (whitish) on brown olivine indicating an area with high concentration of submicron ferro(i) magnetic grains is seen (S-poles) (dark field). (area ca. 100x100µm).

Surprisingly, several brown olivine grains also revealed dense clusters of MTB (fig. 4, whitish). We interpret this result as an indication for the likely presence of submicron sized ferro(i)magnetic grains, probably Fe metal or magnetite.

Summarizing, we could demonstrate by magnetic means that the lherzolitic shergottites ALH77005 and Yamato 000097 contain Fe metal phases as carriers of magnetic remanences. For the first time MTB were successfully applied in searching and localizing Fe metal particles in a silicate matrix (brown olivines).

In a parallel contribution, Kurihara et al. [13] could prove the existence of Fe metal phases (sizes up to 50nm) in the lherzolitic shergottites ALH 77005, Yamato 000097 and others, by TEM analysis.

In conclusion, the large scatter of the lherzolites magnetic signature could find its explanation in terrestrial alteration processes of the Fe metal particles which most likely could result in the formation of weakly magnetic Fe-oxides/-hydroxides. More over, the role of iron metal grains in interpreting Mars crustal magnetic anomalies and hydroalteration processes ("red planet") needs to be studied in more detail.

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