MAGNETIC PHASES OF ALMAHATA SITTA: NEW RESULTS. Hoffmann V.H.*, Torii M., Funaki M., Hochleitner R., Kaliwoda M., Mikouchi T., Zolensky M., *Department of Geosciences, University of Tuebingen, Sigwartstraße 10, 72076 Tuebingen, hoffmann.viktor@gmx.net

Introduction

Almahata Sitta (AS) meteorite fall happened in October 2008 and since that numerous fragments and individuals could be recovered [1]. AS was classified as a polymict Ureilite, however, recently it was found to be a complex breccia consisting of many different meteoritic lithologies including various E- and ordinary chondrite types [2,3]. Here we report new results obtained on a number of fragments of ureilitic (#22/27/36/44/49/138) and chondritic lithology (EL 5/6, H 5/6 and others) [see also [2] for details]. In the ureilitic lithologies Ni/Si-poor kamacites were identified as the dominating magnetic phases. Additionally suessite $(Fe,Ni)_3Si$, schreibersite $(Fe,Ni)_3P$, cohenite $(Fe,Ni,Co)_3C$, (Cr-)troilite (FeS), daubreelite ($FeCr_2S_4$) and chromium bearing spinel ($\sim FeCr_2O_4$) could be detected in various amounts [4,5].

The multitude of magnetic phases identified in the ureilite lithology requires investigating in more detail their individual role in terms of (1) (paleo-) magnetic record, origin and meaning, (2) the physical and mineralogical background of the magnetization processes, as well as (3) their petrogenesis and petrofabric.

Methods and instrumentation

MPMS

Low temperature experiments were done with an MPMS XL5 at Okayama University of Science applying the following experimental setup (ZFC zero field cooling, FC field cooling) on small fragments: the sample is first cooled from 300 K to 5 K in zero-field, then 1 T field was imparted to give IRM at 5K. From 5K to 300K, IRM was measured in steps of 1.5 K (ZFC). Next, sample was cooled under 1 T field again to 5 K. After switching off the field, IRM was measured up to 300 K in steps of 1.5 K (FC). IRM acquisition was done at 300 K from 1mT to 5T in 100 steps with logarithmically equal spacing. IRMunmix version 2.2 by [6] was used for the IRM evaluation. All investigations were done on small fragments.

Thermomagnetic experiments

High field thermomagnetic runs (magnetization (H_{ext} = 0.4 T) were done in a vacuum of about 1 Pa, temperature range was 40-800°C and heating rate 12°C/min.

Vibrating Sample Magnetometer (VSM)

Temperature dependence of magnetic hysteresis properties has been studied using a Vibrating Sample Magnetometer (VSM). Hysteresis loops were measured in steps of 30 °C from room temperature to 800 °C in a vacuum of 3 10^{-3} Pa. Applied external magnetic fields varied between –1 and +1 T. Fragments of AS4 and 39 as well as of NWA 1241 were used for the experiments.

EMPA data

Quantitative chemical data were obtained by electron microprobe analysis (EMPA) using a CAMECA SX100 operated at 15keV acceleration voltage and 20nA beam current (further details in [4]).

Results and Interpretation

Presently the poor knowledge of the magnetic properties of many extraterrestrial ferro(i)magnetic phases (specifically at low temperature) prevents a detailed interpretation and understanding of the AS magnetic signature. Therefore we decided to include a series of well defined (extra-) terrestrial samples in our investigations to be used as standard material. For mineralogical and Raman-spectroscopy data we refer to our parallel contribution [7]. In the following, new and original magnetic data as obtained on selected magnetic phases are summarized (see also [8,9]:

(i) Troilite FeS (cm-sized nodules from Nantan (IIICD octaedrite): $T_{LT} \sim$ 60-70K.

(ii) Schreibersite $(Fe,Ni)_3P$ (cm sized inclusions in Shikote Alin (IIAB octahaedrite): $T_c \sim$ 300-310°C; low-T: no transition (see fig.1).

(iii) Cohenite $(Fe,Ni,Co)_3C$ (in native iron from Disco/Greenland and Taimyr / Siberia): $T_c \sim$ 215-220°C; low-T: no transition.

(iv) Daubreelite $FeCr_2S_4$ (Neuschwanstein EL6): $T_c \sim$ 160-165K [10]

(v) Suessite $(Fe,Ni)_3Si$ (NWA1241 monomict ureilite): $T_c \sim$ 550-560°C; low-T: no transition (see fig. 2).

The elemental composition of the standard samples is as follows (main elements only, weight %), table 1:

	Ni	Fe	P	S	Si	Cr	Σ
Troilite		63.7		36.0			99.7
Schreibersite	14.5	70.4	12.6				97.5
Daubreelite		16.4		43.4		35.4	97.2
Suessite	4.3	80.5			14.3		99.1

Fig. 1: Thermomagnetic run (saturation magnetization in vacuum) for schreibersite (sample (ii)) is fully reversible and gives a T_c of 300-310°C.

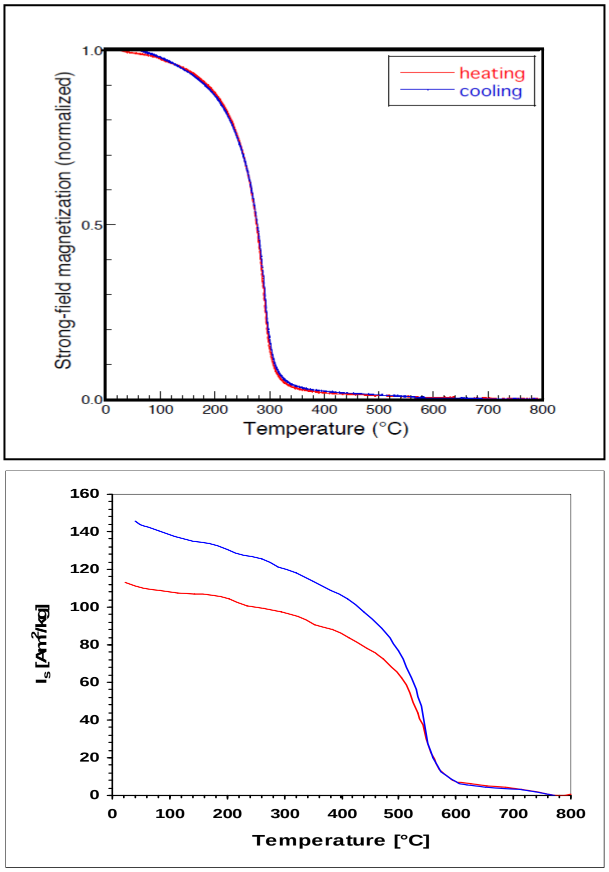

Fig. 2: Saturation magnetization versus temperature run for NWA 1241 is dominated by a T_c of 550-560°C (suessite) and a minor transition above 700°C (kamacite) (red: heating). The increase in intensity during cooling (blue) is likely due a conversion of non-stoichiometric to stoichiometric suessite (see [11]).

The use of the quasi standard or calibration samples helped us to obtain a more sophisticated view of the magnetic record of Almahata Sitta (based on the ureilitic lithology). The VSM experiments can provide data of the temperature dependence of

- initial / paramagnetic magnetic susceptibility (X_i, X_p)
- saturation magnetization (I_s) and saturation remanence (I_{rs})
- Coercivity (H_c) and remanence coercivity (H_{cr}),

and in this way some hints concerning the magnetic particle size / magnetic domain state of the acting magnetic remanence carriers.

The results can be summarized as follows, NWA 1241 was included to study the role of suessite:

NWA 1241 (monomict ureilite)

General trend: cooling curve intensities are higher than heating ones (all parameters): probably due to neo-formation of suessite (most likely transformation of non-stoichiometric to stoichiometric suessite [11], and fig.2.

Main features: the in-field parameters X_i, X_p and I_s /H_c are dominated by coarse grained suessite while the remanence parameters I_{rs} and H_{cr} propose fine grained (SD/PSD) suessite, cohenite and schreibersite as carriers of the magnetic record.

AS4

General trend: heating/cooling curves are similar in intensity, significant mineralogical alterations can be excluded.

Main features: coarse grained kamacite dominates the induced magnetization while other phases (cohenite, suessite?) might contribute to the magnetic record.

AS39

General trend: Heating/cooling curve intensities are similar for all parameters except H_c.

Main features: induced magnetisation is dominated by coarse grained kamacite while I_{rs} and H_{cr} and the (paleo-)magnetic record are characterized by fine grained kamacite as well as some contribution from fine-grained suessite, cohenite and schreibersite in SD/PSD size.

Acknowledgements:

This study was performed partly under the cooperative research program of Center for Advanced Marine Core Research (CMCR), Kochi University (10B033).

References

[1] Jenniskens P. et al (2009), Nature 458: 485-488. [2] Bischoff A. et al., (2010), MAPS, in press. [3] http://asima.seti.org/2008TC3. [4] Hoffmann V. et al. (2010), MAPS, under revision. [5] Hochleitner et al., (2010), Antarct. Meteor. XXXIII, 22-23. [6] Heslop D. et al. (2002), Geophys. J. Int., 148: 58-64. [7] Kaliwoda M. et al. (2011). 42nd LPSC, #xxx. [8] Sugiura N., Strangway D.W., 1988. In: Kerridge J.F., Matthews M.S., Meteorites and the early Solar System. Univ. Arizona Press, Tucson, 595-615. [9] Kohout T. et al., (2010), 41st LPSC, #1048. [10] Hochleitner et al. (2004), MAPS 39/10: 1643-1648. [11] Ikeda Y. (2007), Polar Sci., 1: 45-53.