SEARCHING FOR THE LITHOLOGY RESPONSIBLE FOR LARGE CRUSTAL MAGNETIZATION ON MARS : A CHANGING PERSPECTIVE FROM NWA 7034.

P. Rochette[1] J. Gattacceca[1,5], R. B. Scorzelli[2], P. Munayco[2], C. Agee[3], C. Cournède[1] and J. Geissman[4]. [1]CEREGE Aix Marseille Université, France (rochette@cerege.fr), [2]CBPF Rio de Janeiro, Brazil, [3] University of New Mexico, USA [4]University of Dallas, USA, [5]Department of Earth, Atmospheric, and Planetary Sciences MIT, Cambridge, USA.

Introduction: Significant magnetic fields over part of the Noachian crust at satellite altitude have been documented by the Mars Global Surveyor mission [1]. Present models for these anomalies require remanent magnetization up to 15–30 A/m over a crustal thickness of 20–50 km [2]. Other inversion studies (see review in [3]) set the minimum magnetization over the strongest anomalies in the 20-60 A/m range. Based on a synthesis of the magnetic properties of 26 martian meteorites, Rochette et al. [4] attempted to identify which lithologies, among the about six different known, could account for such magnetization. As natural magnetization (NRM) of martian meteorites is strongly affected by 1) impacts at the surface of Mars, 2) weathering at the surface of the Earth and 3) use of strong magnets by meteorite hunters, it was concluded that saturation isothermal remanence (IRM) would be a more reliable proxy for in situ NRM within the martian crust. Using scaling of NRM/IRM it was concluded that a minor fraction of martian meteorites (either nakhlites or a few shergottites) had enough magnetic minerals, either magnetite or pyrrhotite, to account for a 5 A/m NRM. We revisit these conclusions, using data on 4 new unpaired meteorites of special interest: the lherzolitic shergottite NWA 1950 and chassignite NWA 2737, that have been shown to have their magnetization party or totally carried by impact generated metallic iron nanoparticles [5], the recent shergottite fall Tissint [6] and the new lithology represented by NWA 7034. NWA 7034 has several characteristics at odds with any other martian meteorite, including a very large amount of magnetite *sensu lato* [7]. Of particular importance for the search of the source of crustal magnetization is the fact that this new lithology is the only one to have a chemical and mineralogical composition matching what is assumed to be the main crustal lithology on Mars [8]. Its age (at 2.1 Ga) is also significantly older than all other martian meteorites, apart from ALH 84001 (at 4.2 Ga).

Sample and methods: samples of weight in the 200-500 mg range, selected away from the fusion crust in the fresher zones, were obtained directly from the researchers who classified these meteorites. Their magnetic properties were measured in CEREGE using the following instruments: MFK1 bridge from Agico for the low field magnetic susceptibility and its variation with temperature, 2G superconducting magnetometer for remanent magnetization, Micromag VSM for hysteresis properties. Sensitivity of these instrument is several orders of magnitude lower than the observed signal and the main instrumental problem is to avoid saturating the instruments (in particular for NWA 7034). Mössbauer spectroscopy, in transmission geometry, was performed at room (RT) and liquid helum temperature (4.2K), using a 512 channel Halder spectrometer. The drive velocity was calibrated using a ^{57}Co/Rh matrix source and an iron foil both at RT. All measurements were performed at high velocity (±12 mm/s), with an average recording time of 24h, absorber and source at same temperature. NORMOS code was used for spectral analysis based on a least-square fitting routine.

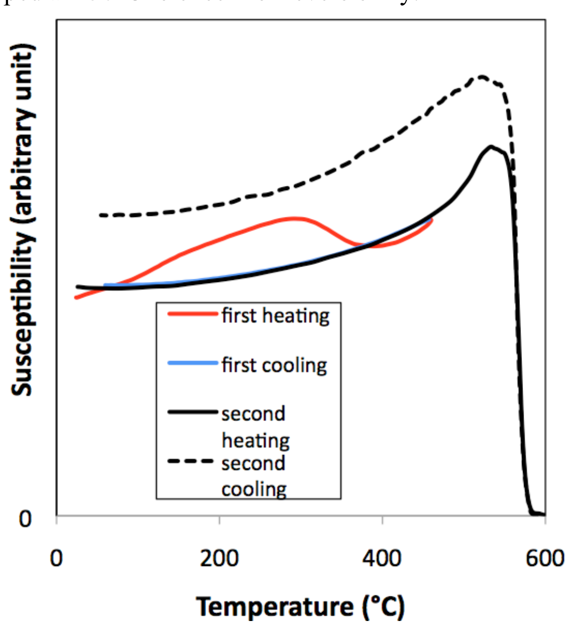
Magnetic mineralogy of NWA 7034: Two fragments showed very consistent hysteresis loops, with saturation magnetization (M_s) of 6.4 to 7.1 Am^2/kg. Saturation at 0.3 T, coercivity B_c of 35 mT, and hysteresis parameters (M_{rs}/M_s=0.3, B_{cr}/B_c=1.6), are typical of micron-sized magnetite *s.l.*, with no detectable trace of other magnetic minerals. Paired meteorite NWA7533 yields essentially identical parameters. M_s values, equivalent to 7-8 wt. % of pure magnetite, further exclude other minerals (like pyrrhotite or hematite) as the main magnetic mineral. This computed amount is half the amount of cubic iron oxides determined by XRD (15%), in agreement with microprobe data showing a large range of substitution (by Cr, Ti, etc.) in the oxides. High temperature susceptibility cycles exhibit an irreversible decrease around 300-350°C range (Fig.1), typical of the transformation of maghemite into hematite. Maghemite is confirmed by refined XRD spectra and EPMA totals significantly lower than the M_3O_4 formula. At higher temperature, reversible Curie point appear spreaded in the 540-570°C range. Thermal demagnetization of IRM under argon atmosphere do confirm the main unblocking ranges around 300°C and 520-560°C. All evidences, including Mössbauer sextets observed from room to low temperature, point toward the presence of a range of Fe rich spinel with variable oxydation state (from magnetite to maghemite) and substitution. Mössbauer spectroscopy also indicates that about 8% of total iron is nanophase Fe^{3+}, paramagnetic at room temperature and ordered below 25 K, with hyperfine parameters typical of goethite (Fig.2). Unfortunately the NRM of the samples examined is likely reset by the use of rare earth magnets by meteorite hunters, as shown by a NRM/IRM ratio above 0.3 up to 170 mT alternating field demagnetization.

Discussion: NWA 7034 appears to bear a very large IRM, an order of magnitude higher than the strongest values observed so far on martian meteorites ([4] and Fig.3). The addition of new data with respect to the ones from [4] does not change this conclusion, in particular the metal-bearing samples [5] have high susceptibility but limited IRM. Using the minimum crustal magnetization at 15 A/m, one gets a threshold of 260 Am^2/kg for required IRM [4]. At this level, no pyrrhotite-bearing shergottites, like Tissint, have the necessary remanence. A single magnetite-bearing shergottite, Los Angeles, is suitable, but its low unblocking temperature (<150°C) and impact-melt characteristics, disqualify such a lithology as being able to retain a high magnetization down to 20-50 km depth. The other candidate, MIL 03346, is a nakhlite and this lithology is not considered to be significantly representative of the magnetized martian crust [8].

NWA 7034 shows nine times higher IRM than the above threshold; only a few km thick layer of such lithology could thus account for the observed magnetic fields. Thus, if such lithology is restricted to the impact reworked upper few kilometers of the martian crust, or distributed in hydrothermally transformed upper crustal material, it can still provide an elegant answer to the puzzle of why parts of the Martian crust produce such large magnetic fields at satellite altitude. However, this hypothesis requires that this lithology is not a welded regolith, which would limit its thickness to much less than 1 km.

Evidence for two purely ferric phases, goethite and maghemite, makes NWA7034 the most oxidized martian meteorite ever studied.

Fig.1: high temperature magnetic susceptibility cycles on NWA 7034. First heating cycle has been stopped at 450°C to check for reversibility.



References [1] Acuña M. H. *et al.* (1999). *Science* 284:790– 793. [2] Langlais B. *et al.* (2004). *JGR* 109, doi: 10.1029/2003JE002048. [3] Quesnel Y. *et al.* (2007). *Planet. Space Sci.*, 55, 258-269 [4] Rochette P. et al. (2005). *MAPS* 40, 529-540. [5] Van de Moortèle B. *et al.* (2007). *EPSL* 262, 37-49. [6] Gattacceca J. et al. (2012). Met.Soc. Meeting abstract . MAPS [7] Agee C.B. et al. (2013). *Science*, in press. [8] McSween H. Y. et al. (2009). *Science* 324, 736.

Fig.2: Mössbauer spectra of NWA 7034 at room and liquid helium temperature. In pink and green appear the magnetite s.l. sextets, in yellow and light blue the Fe^{2+} in silicate doublets, and in dark blue the goethite signal (sextet at 4.2 K and doublet at 300K).

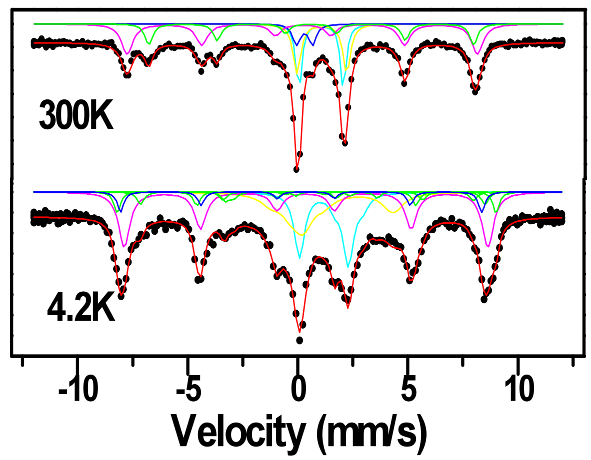


Fig.3: Saturation remanence (IRM) versus low-field susceptibility of martian meteorites (after [4-6] and this study). Dashed line corresponds to the threshold for 15 A/m NRM.