MAGNETIC SIGNATURE OF EXPERIMENTALLY SHOCKED SAN CARLOS OLIVINES: SIMULATION OF THE NEOFORMATION PROCESSES OF NANO-SIZED FE-Ni AND MAGNETITE PARTICLES IN BROWN COLORED OLIVINES OF SOME MARTIAN METEORITES (SNC). V.H. Hoffmann[1,2], T. Mikouchi[3], T. Kurihara[3], M. Funaki[4], M. Torii[5], [1] Institute for Geosciences and ZAG, University of Tübingen, Sigwartstrasse 10, 72076 Tübingen, and [2] Department of Geo- and Environmental Sciences, University of München, Theresienstrasse 41, 80333 München, Germany, [3] Dep. of Earth and Planet. Sci., University of Tokyo, Japan, [4] National Inst. Polar Res., 9-10 Kaga 1 Chome, Itabashi-Ku, Tokyo 173, Japan. [5] Dep. of Geosphere-Biosphere System Science, Okayama University of Science, Okayama, Japan.

Introduction: Recently the brown-colored olivines of some highly shocked Martian meteorites (SNC) became the focus of a set of research projects. NWA 2737, a shocked dunite, was the first SNC meteorite which was found to contain nano sized Fe-Ni metal particles [1]. [2] attributed the formation of such nano phases in olivine matrix to shock metamorphism in a degree of at least 40GPa. In the meantime, native Fe-Ni or magnetite nano particles in brown/black Fe-bearing olivines could be detected in several more SNC meteorites: ALH 77005 (Fe-Ni), YM 000097 (Fe-Ni), LEW 88516 (Fe_3O_4), NWA 1950 (Fe-Ni), LAR 06319 (Fe-Ni) [2,3,4,5,6,7] and DaG 476 (in olivine and pyroxene [this study]). [2] reported the results of laboratory shock experiments on natural San Carlos olivines: depending on the sample properties (olivines with/without graphite) and the degree of shock (20 – 46 GPa) magnetite (Ni free) or Ni bearing Fe nano phases were found in the olivine matrix by TEM and EDS analyses. The idea of this part of the study is to better understand the magnetic signature and record of the highly shocked olivine bearing SNC meteorites which are known to contain nano sized Fe-Ni metal or magnetite particles.

Samples and experiments: The magnetic properties of a series of laboratory-shocked olivines were investigated in detail. We used selected samples of the set as described by [2]. The following magnetic parameters were measured, (i) on natural San Carlos olivines (several mm in size) and olivine powder as prepared for the shock experiments, and (ii) on the shocked olivines (with and without graphite, and after shock experiments at 20 and 40GPa, respectively): IRM (1T and -0.3T in z direction, pulse magnetizer) followed by stepwise AF demagnetization (max. field 100mT, z direction, IRM measured in x/y/z direction), magnetic susceptibility (χ), low-temperature experiments (FC and ZFC curves, 1T IRM @ 1.9K), thermomagnetic analyses (χ-T, in air, T_{max} 700°C or 800°C, respectively), and hysteresis curve – IRM acquisition – DC backfield curve (H_{max} 500mT). All data are compared with the results of a systematic search on the magnetic signature of the forsterite-fayalite series (synthetic material) as reported by [8] and additional systematic low-temperature investigations [this study]. For a detailed description of the samples and their preparation as well as of the shock experiments we refer to [2].

Results: According to magnetic susceptibility (χ) (mean value 17.8 10^{-8} m^3/kg), the used natural San Carlos olivines are quite low in Fe, their Fayalite content is slightly below Fa10. Thermomagnetic curves indicate minor amounts of a ferrimagnetic phase with a Curie temperature (T_c) of about 580°C, likely magnetite. After grinding (producing the olivine powder for the shock experiments) χ decreased by more than 10%, T_c of ≈ 650 and 700°C are attributed to maghemite/ hematite. Some influence of the sample preparation process can be also seen in the IRM data and the S factor, respectively (introduction of stress and some oxidation of the original ferrimagnetic phase(s) in the olivines due to grinding).

The effects of the shock experiments on the magnetic signature and the phase composition can be summarized as follows:

(1) Olivines without graphite: IRM at -0.3 and 1T are strongly increased already at 20GPa (to 35.9 and 51.4 10^{-4} Am^2/kg, respectively), followed by some decrease at 40GPa shock; the S value (which is a measure of the content of soft/hard magnetic phases) is nearly constant; χ shows a strong maximum at 20GPa (149 10^{-8} m^3/kg), at 40GPa χ is similar to the starting value; thermomagnetic curves reveal (i) at 20GPa 2 T_c around 250-300°C (Mg-ferrite?) and 590°C (magnetite), and (ii) at 40GPa a T_c around 590°C (magnetite).

(2) Olivines with graphite: IRM at -0.3 and 1T, both parameters show some increase at 20 GPa (28.8 and 36.7 10^{-4} Am^2/kg, respectively) and a jump at 40GPa to 264 and 288 10^{-4} Am^2/kg, respectively; the S value is nearly constant up to 20GPa, followed by an increase to 0.96 at 40GPa (new soft magnetic phases dominating); χ revealed a strong increase to 212 and 310 10-8 m^3/kg at 20 and 40GPa; the 20GPa sample has a Tc of 590°C (magnetite) and likely at 650°C (maghemite?), the behavior of the

40GPa sample is different from all others with some transitions around 240°C (unknown phase?), 600-650°C (magnetite-maghemite?) and 750°C (Iron).

(3) Hysteresis curves, IRM acquisition and DC backfield data were obtained on the unshocked powdered sample (i) and the 40GPa shocked sample (ii): (i) showed nearly paramagnetic behavior, typical for olivines of the San Carlos chemical composition [8], however a minor ferrimagnetic component was detected; the 40 GPa sample is clearly dominated by strongly ferri(o) magnetic components, and a only minor paramagnetic contribution. H_c is 22.3 mT, the relations M_{rs}/M_s and H_{cr}/H_c are 0.23 and 2.81, respectively, pointing to PSD/MD behavior.

(4) Low temperature IRM experiments were performed on all samples, untreated powder and shocked samples with/without graphite. The un-shocked olivine is characterized by the typical low-T behavior of a fayalite with a low Fe content (below Fa10) and does not show any transitions; amongst a more or less significant increase of the IRM intensities for all shocked samples, only the 20GPa sample curves (with graphite) indicated a very weak transition around 110-120K, pointing to magnetite. According to our experiments, native Iron (natural) does not have any transition at low temperatures, (except eventually at very low T below 10K which needs to be confirmed).

Conclusions

Basically, the results which were obtained by [2] could be confirmed by our detailed studies of the magnetic signature, record and phase composition. However, the very high sensitivity of our magnetic methods allow are much more detailed view to the effects of shock, especially dynamics and kinetics of this process, on the magnetic properties of olivines and consequently the shock-induced neoformation of nano sized ferri(o)magnetic phases. The 40GPa sample (with graphite) behaves differently from all others because it contains quite a significant amount of native Fe (only neglectible Ni according to our results) while both the 20GPa and the 40GPa sample without graphite are mainly dominated by magnetite like phases (eventually also maghemite or Mg-ferrite). Our data clearly indicate that already at 20GPa the magnetic signature and phase composition is significantly modified. We assume that the concentration of the newly formed ferri(o)magnetic phases is too low to be easily detectable with TEM/EDX.

The shock induced neoformation of nano Fe (Ni bearing) under reducing conditions in the presence of carbon phases such as graphite can be confirmed in the laboratory. Graphite was also found in Martian meteorites by Raman spectroscopy in YM 000593 (nakhlite) and SaU 060 (olivine phyric shergottite) [9]. Therefore we believe that this model can be regarded as a real and has to be taken into account in order to understand the magnetic signature of the Martian meteorites and the Mars crust. However, no systematic studies are reported concerning the likely presence and concentration of graphite (or other C phases) in SNC meteorites and no findings have been made so far in situ on Mars (e.g. by the rovers or the Phoenix lander) to our best knowledge.

As a next step, new sets of laboratory shock experiments are performed on well defined synthetic olivines of varying fayalite content (polycrystalline, about 0.5µm in size, see [8]). In this way, we are able to control the preconditions concerning sample material (natural San Carlos olivines contain traces of ferrimagnetic phases, likely magnetite) and much more important, Martian olivines are known to be more Fe rich than terrestrial ones (Fa30 and Fa50 will be in the main focus). Additionally, a better knowledge of the presence and concentration of Carbon phases such as graphite in Martian meteorites and Martian rocks/soils in general (in situ data) is required.

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