MAGNETIC FORCE MICROSCOPY OF PRIMITIVE ACHONDRITES. I. Rauschenbach[1], I. Weber[1], T. Stephan[1], E. K. Jessberger[1] and C. Schröder[2], [1]Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany, irausch@uni-muenster.de, [2]Fachhochschule Bielefeld, Fachbereich Elektrotechnik und Informationstechnik, Wilhelm-Bertelsmann-Str. 10, 33602 Bielefeld, Germany.

Introduction: Scanning probe microcopy (SPM) techniques are currently very popular to examine surface morphologies down to nanometer scale by utilizing different types of interactions between a given surface and a probing sensor. This approach was first introduced by Binnig and Rohrer in 1982 as scanning tunneling microscopy (STM) [1]. In the following years, Binnig and Quate enhanced this technique and developed the scanning force microscopy (SFM) [2]. By measuring the force between tip and sample, instead of the current as in STM, SFM provides the opportunity to investigate insulating surfaces. Martin and Wickramasinghe introduced magnetic force microscopy (MFM) in 1987 as modification of SFM [3].

MFM has been designed to study magnetic materials on a nanometer scale by detecting magnetic forces or force gradients exerted on a probing tip that is moved over a sample surface. The magnetic forces between tip and surface result in a change of the magnitude (or the phase) of an oscillating cantilever, which eventually provides information about the spatial distribution of the local magnetic properties.

MFM is a well-known technique in material science to study magnetic properties. The primary goal of this study is to evaluate the possibilities of MFM in order to reveal information about processes in the early solar system, on meteorite parent bodies, and/or during terrestrial residence. Recently, some work on the CV chondrite Vigarano [4] and on selected CI and H chondrites [5] has already been performed. In the present study, MFM was applied for the first time to investigate primitive achondrites. In particular, preliminary results of the magnetic domain structure of meteoritic Fe-sulfide and Fe-hydroxide and their response to weathering are presented.

Samples and Methods: Standard polished thin sections were prepared from samples of the primitive achondrites Gibson and Winona. Polishing has no influence on the magnetic properties. This was demonstrated by thorough investigation of polished and unpolished terrestrial Fe-sulfides.

Gibson. In 1991, Gibson was found in Australia in a flat sandy area west of Highway #1. It belongs to the class of lodranites [6]. The total iron content is 10.7 % [7].

Winona. In 1928, Winona was found in Arizona. It is eponymous for the meteorites class of winonaites. The total iron concentration is 16.25 % [6].

All samples were studied with a Veeco Dimension 3100 scanning probe microscope. For both achondrites the analyses were restricted to Fe-sulfide and Fe-hydroxides, phases that show rich magnetic structures. Optical microscopy and scanning electron microscopy (SEM) were used to pre-select the relevant target areas and to determine their chemical composition.

Results: *Gibson.* In this sample, Fe-sulfide often occurs beneath Fe-hydroxide as shown in Fig. 1.

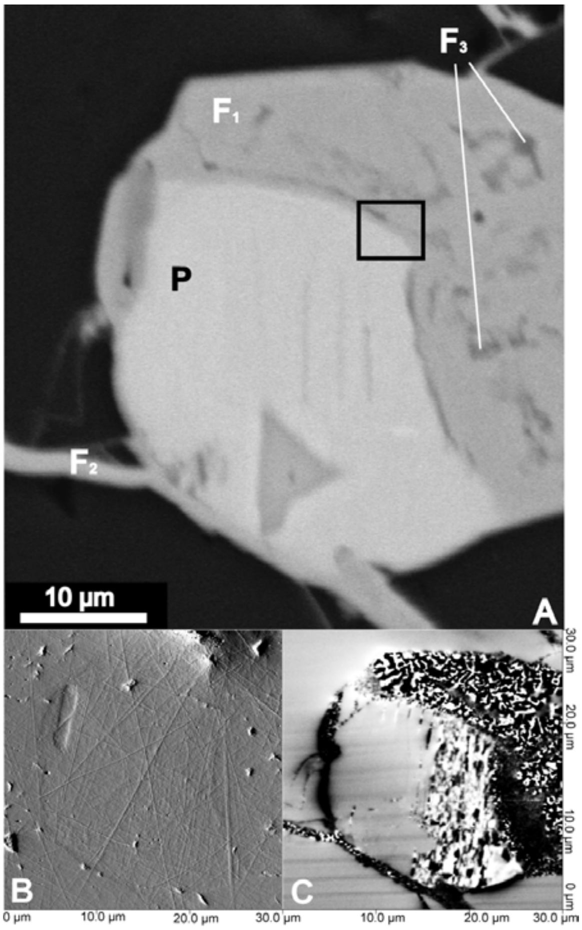

Fig. 1: Images of an Fe-sulfide (P) and Fe-hydroxides (F_{1-3}) in Gibson. A: backscattered electron (BSE) image, B: topographic image, C: magnetic force image.

In the topographic image (Fig. 1B) polishing traces are visible. The grain boundaries are faintly outlined. Figure 1C reveals the complex magnetic structure within the Fe-hydroxides F_1 and F_2. The gray value represents information about the direction of the magnetization of the sample with respect to the sensor: For black areas the magnetization of the sample is parallel to the tip, for white areas it is antiparallel.

The complex magnetic domain structure is shown in detail in Fig. 2. In contrast to Fe-hydroxides, Fe-sulfide does not show any magnetic response (Fig. 1C), apart from one area, which is possibly already in a weathering stage (Fig. 2, lower left). Here, the MFM image shows more diffuse structures indicating that magnetic domains are not yet well ordered.

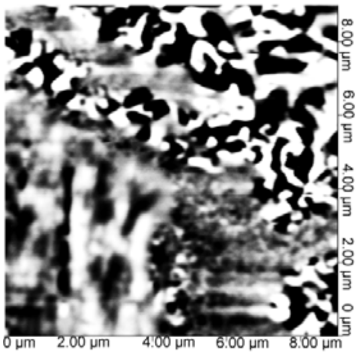

Fig. 2: Detailed magnetic force image of the black-framed area in Fig. 1.

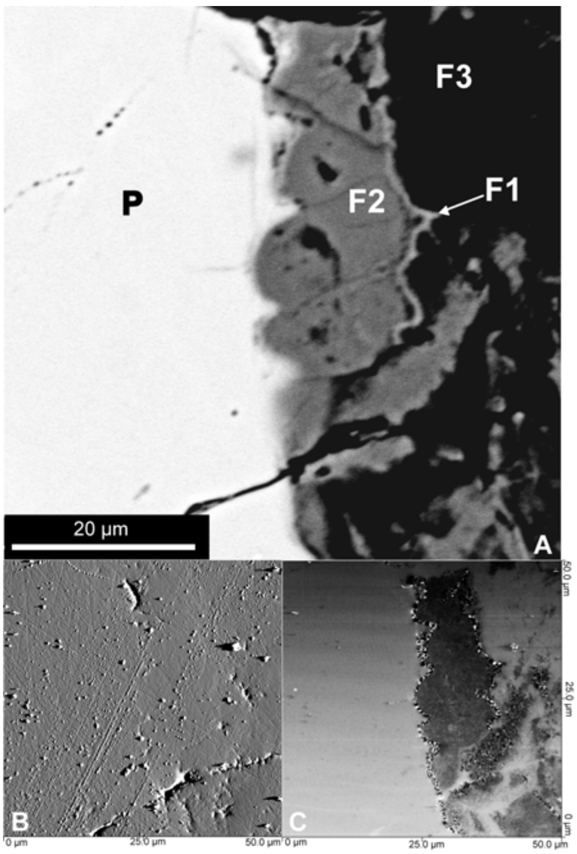

Fig. 3: Images of an Fe-sulfide (P) and Fe-hydroxides (F_{1-3}) with decreasing Fe content (from F_1 to F_3) in Winona. A: BSE image, B: topographic image, C: magnetic field image.

Winona. As with Gibson, Fe-sulfide often occurs beneath Fe-hydroxide. An example is shown in Fig. 3. Again, polishing traces are visible (Fig. 3B). Figure 3C contains the magnetic information. Strong magnetic domain structures with alternating parallel and antiparallel magnetized areas are found only in the Fe-hydroxide F_1, which forms a rim around F_2. The Fe-hydroxide F_2 shows a rectified magnetic response. Neither Fe-sulfide (P) nor the Fe-hydroxide F_3 shows any magnetic signal.

Conclusions: The discovered magnetic domain structures in the Fe-hydroxides are typical for ferromagnetic materials and are well known for synthetically produced surfaces [9, 10]. In this study we have shown that these structures are even observable in natural Fe-hydroxides.

In both samples, the quality of the magnetic signals differs between diverse Fe-containing phases. Strong magnetic domain structures were found only in single Fe-hydroxide phases. Fe-hydroxides are probably weathering products from former Fe,Ni-metal. Both meteorites were exposed to terrestrial weathering and the Fe-hydroxides contain different water contents. This leads to the assumption that these phases are possibly in different weathering stages. The quality and structure of magnetic domains in Fe-hydroxides may therefore depend on the weathering stage.

The present study on primitive achondrites show no defined magnetic response from Fe-sulfide in both samples. In contrast to this, MFM investigations of the CI chondrite Orgueil [5] showed significant magnetic structures in Fe-sulfide (pyrrhotite). We are currently investigating to what extend the thermal history, and hence differentiation processes might be responsible for these varying results.

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