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磁気光学イメージング（MOI）の岩石磁気学への応用と開発
Development and application of magneto-optical imaging (MOI) for rock magnetism

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Magneto-optical imaging (MOI) technique measures the magnetic flux threading a magneto-optically (MO) active film, which rotates the polarization direction of transmitted light (Faraday rotation), directly placed on the sample. Through the analyzer of a reflected light microscope, the vertical component of surface magnetic field of the sample is observed. Owing to the thin MO film (5 um) and the small sample-to-film distance (~100 nm), internal structures within metallic grains in meteorites carrying saturation isothermal remanent magnetization is successfully imaged with a spatial resolution better than 10 um. In addition to its high spatial resolution, this technique offers a direct comparison of magnetic and reflected light images, making it a very powerful tool to map and identify the carriers of magnetic remanence in rock samples.

We present results of an integrated study of metallic grains in meteorites, combining MOI, petrography, FE-SEM, TEM, microprobe analyses, and DC demagnetization. Metallic Fe-Ni grains in meteorites have microscopic structures due to Ni diffusion during slow cooling subsequent to metamorphism on their parent body. Previous magnetic studies suggested that tetrataenite (ordered FeNi) is the stable magnetic carriers in these meteorites. On the other hand, mineralogical studies showed that tetrataenite is intimately mixed with other Fe-Ni phases (kamacite and taenite, that contain less than 10 wt% and around 30 wt% Ni, respectively), and forms complex microstructures (see below). However, due to the typical spatial resolution of classical bulk magnetic measurements (~1 mm), it has been so far difficult to isolate the contribution of these different Fe-Ni minerals.

We studied equilibrated ordinary chondrites. Optical and electron microscopies showed two types of micron- to submicron-scaled tetrataenite-bearing microstructures: (1) Zoned taenite particles that consist of a taenite core, surrounded by a "cloudy zone" (20-150 nm large tetrataenite granules embedded in taenite matrix), and a 1-10 um thick tetrataenite rim. (2) Zoneless plessite particles that consist of $<$ 10 um large tetrataenite grains embedded in a kamacite matrix. MOI of saturation remanence showed that only the nm-sized tetrataenite granules in cloudy zone carry very strong remanence. Micron-scale mapping of coercivity of remanence (B_{cr}), by means of DC demagnetization coupled with MOI, combined with FE-SEM and TEM study showed that this cloudy zone has zoning in Ni composition, tetrataenite grain size, and B_{cr}. The center part has finer tetrataenite (20 nm), lower bulk Ni composition (30 wt %) and higher B_{cr} values (up to 1 T) than the outer part (150 nm, 55 wt %, and 400 mT respectively). This result shows good agreement with B_{cr} distribution of bulk ordinary chondrite. Therefore, tetrataenite in the cloudy zone is a potential very stable carrier of extraterrestrial remanence. Moreover, even in weathered meteorites, we can observe natural remanence of metals separated from magnetic signature from oxides. This result demonstrates that MOI is a hopeful technique to discriminate the primary magnetization from altered samples.

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