透過型電子顕微鏡によるラメラ磁性に関する研究

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Transmission electron microscopy of ”lamellar magnetism” in ilmenite-hematite

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http://www-hrem.msm.cam.ac.uk/index.shtml

Ilmenite-hematite solid solutions constitute some of the most abundant accessory minerals in igneous, metamorphic and sedimentary rocks, and can play an important role in the acquisition of rock magnetization.

Previous studies of the magnetic properties of hematite-ilmenite have focused on compositions in the range $Ilm_{50-85}Hem_{50-15}$, since solid solutions with these compositions have a Ti ordered R-3 structure that exhibits strong ferrimagnetism. However, McEnroe et al. (2002) found fine exsolution lamellae of hematite and ilmenite that had compositions close to their end members, high coercivities and stable natural remanent magnetization (NRM). The magnetization of these samples was too high to be accounted for solely by the spin-canted antiferromagnetic moment of hematite, suggesting that the presence of the fine exsolution lamellae may be related to the acquisition of NRM. Robinson et al. (2002) used Monte Carlo simulations to suggest that the ferrimagnetic moment of an intergrowth of hematite and ilmenite could be associated with the arrangement of cations and spins at the interface between hematite and ilmenite. They described this ’lamellar magnetism’ as being due to ’contact layers’, which are cation layers at the interface between hematite and ilmenite that do not correspond to the chemistry of either hematite or ilmenite.

As there are a few experimental results to support the lamellar magnetism hypothesis, a quantitative study of the relationships between exsolution lamellae and NRM is required. A high-resolution study of the crystallography, chemistry and defect structure of the interfaces between hematite and ilmenite is also necessary to investigate the lamellar magnetism hypothesis.

Transmission electron microscopy (TEM) is powerful tool for the examination of the crystallographic and chemical structure and microstructure of rock samples at the nanometer scale. Lorentz electron microscopy and electron holography can be used to observe magnetic microstructure in minerals directly at high spatial resolution. Here, we present the following results from a TEM investigation of the origin of high and stable NRM:

1) The microstructures and compositions of three mineral samples with different magnetic properties were examined. Fine ilmenite lamellae with a minimum thickness of 2 nm were observed between larger ilmenite lamellae with thicknesses of a few hundred nm. The magnetization of the samples appeared to correlate with the number of fine lamellae.

2) Fine hematite and ilmenite lamellae, less than 50 nm in length and parallel to the (001) basal planes of the host lattice, were found to be abundant in a hemo-ilmenite sample, with coherent and sharp structural and compositional interfaces.

3) Lorentz imaging suggested that the magnetic moments that carry stable NRM lie along the crystallographic a-axis in the (001) basal plane. The ratio of lamellae with opposite moments is close to 1:1, even after applying a large external field of 5T to the sample parallel to the a-axis.

Our results support the lamellar magnetism hypothesis. Since lower crustal rocks can contain hematite and ilmenite lamellae that exsolved during slow cooling, the formation of lamellae may be a predominant factor responsible for magnetism in the crust.