Observing the Interaction Between Magnetic and Chemical Microstructures at the Nanometer Scale Using Electron Holography

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Off-axis electron holography in the transmission electron microscope has been used to image the spatial distribution of magnetic fields in a natural intergrowth of magnetite and ulvospinel with nanometer resolution. The morphology of these intergrowths consists of cuboidal blocks of magnetite with average size 100 nm within a matrix of ulvospinel. Since ulvospinel is paramagnetic at ambient conditions, the initial MD grain is subdivided by the non-magnetic lamellae to yield an approximately cubic array of interacting SD or PSD magnetite particles. The technique allows both single-domain and vortex states within individual blocks to be imaged, and provides detailed information about the magnetostatic interaction fields between neighbouring blocks. Combined with high-resolution chemical maps obtained using electron spectroscopic imaging, we are able to present a comprehensive analysis of the relationship between the magnetic and chemical microstructures of the intergrowth. The observations provide new insight into the question of whether such intergrowths are a potential source of strong and stable remanent magnetization on the Earth and other planets. The high spatial resolution of the technique makes it ideal for the study of nanoscale particles at the boundary between SD and PSD behaviour, and provides the opportunity to study the crystallographic, chemical, and defect microstructures of the sample simultaneously with the holographic measurements. This is the first study to apply electron holography to one of the central problems of rock magnetism, and paves the way for a new era of magnetic microscopy in this field.