A Micromagnetic Perspective on the Vortex State in Earth and Planetary Materials

IOAN LASCU[1*] RICHARD HARRISON[2], JOSHUA EINSLE[2], MATTHEW BALL[2]

[1] National Museum of Natural History, Smithsonian Institution, Washington, DC, 20560, United States
[2] Department of Earth Sciences, University of Cambridge, Cambridge, CB2 3EQ, United Kingdom
[*] Lascui@si.edu

A wide variety of Earth and planetary materials are very good recorders of paleomagnetic information. However, most magnetic grains in these materials are not in the stable single (SD) domain grain size range, but are in non-uniform, vortex magnetization states. We provide a detailed account of vortex phenomena in rocks and meteorites by simulating first-order reversal curves (FORCs) via finite-element micromagnetic modeling of magnetite nanoparticles with realistic morphologies. The particles have been reconstructed from focused ion beam nanotomography, and accommodate single and multiple vortex structures. Single vortex (SV) grains have fingerprints with contributions to both transient and transient-free zones of FORC diagrams. Non-interacting SV grains contribute positive peaks to the central ridge of the FORC diagram, which are accompanied by negative peaks below the ridge. SV central ridges are distributions of vortex reversal fields, and usually have higher median coercivities than SD central ridges. SV irreversible events at multiple field values along different FORC branches determine the asymmetry in the upper and lower lobes of generic bulk FORC diagrams of natural vortex state materials. We also modeled multi vortex (MV) FORC signatures for the first time. Due to their larger size, multiple micromagnetic states they can be in, and intraparticle interactions, MV grains contribute positive and negative peaks that are spread vertically in the transient-free zone of a FORC diagram. Large populations of grains create a broad central peak in the FORC diagram. The intensity of the central peak is higher than that of the lobes, implying that MV particles are more abundant than SV particles in natural materials with vortex state fingerprints. Based on the similarities between the FORC fingerprints of MV particles and those of strongly interacting SD ensembles, we propose that widely documented SD-like moments in vortex state samples are due to MV, not SD grains. The abundance of MV particles, and their SD-like properties point to MV grains being the main natural remanent magnetization carries in Earth and planetary materials.