Title: Nanopaleomagnetism: a multiscale approach to paleomagnetic analysis of geological materials

Supervisor: Dr. Richard Harrison

Importance of the research area:

Paleomagnetism has played a pivotal role in developing our modern understanding of the Earth, and remains one of the primary tools used to study the structure and dynamics of the Earth and other planets. Nevertheless, numerous factors can be detrimental to the fidelity of magnetic information recorded by a rock. The dominant source of uncertainty stems from the over reliance on bulk rock measurements. Rocks are chemically, mineralogically, texturally and magnetically heterogeneous materials, with heterogeneity occurring at all length scales – from metres to nanometres. There is a pressing need, therefore, to push the spatial resolution of paleomagnetic studies beyond their current limits and to extend the analysis into three dimensions. NanoPaleoMag is a major new research project, funded by a €2.3 million grant from the ERC, that aims to create an entirely new multiscale approach to paleomagnetic analysis, thereby opening up periods of Earth history that have hitherto defied conventional study.

The project:

Adopting cutting-edge techniques from physics and materials science, NanoPaleoMag will perform paleomagnetic measurements at submicron length scales, enabling primary magnetic signals to be extracted from ancient and severely altered geological materials. 3D measurements of the volume, shape and spacing of all magnetic particles within a microscale region of interest will be made using a 'dual beam' focussed ion beam workstation. Combined with high-resolution paleomagnetic measurements and nanometre/nanosecond electron/X-ray magnetic imaging, NanoPaleoMag will, for the very first time, be able to characterise the magnetic properties of geological materials at fundamental length scales and time scales. The nanoscale measurements will enable us to capture the essential physics of the remanence acquisition process and to explore magnetic behaviour 'in silico', allowing predictions to be made that can be tested directly against experimental observations at all length scales. Sample-return missions to asteroids, comets, moons and planets will soon provide unprecedented opportunities for extraterrestrial paleomagnetism. NanoPaleoMag will provide the methodology and instrumentation needed to analyse these precious materials.

What the student will do:

There are three PhD projects being offered within NanoPaleoMag. The first project will focus on the application of electron holography to study the nanoscale magnetic domain state and in-situ switching behaviour of magnetic particles at high temperatures. This information, which would represent the first ever in-situ observations of the temperature-dependence of magnetic properties in geological materials at this spatial resolution, will be combined with tomographic measurements of the particles' volume in order to model their thermal relaxation characteristics. The second project involves the application of emerging X-ray synchrotron methods for the imaging of magnetic particles at fundamental length scales and timescales. The student will use a variety X-ray magnetic imaging techniques, including X-ray photoemission electron microscopy (X- PEEM), magnetic transmission X-ray microscopy (MTXM) and X-ray holography to study magnetism at nanometre spatial scales and picosecond timescales. The third project will focus on macroscopic rock magnetic characterisation of bulk rock samples using first-order reversal curve (FORC) analysis. The student will be responsible for development of a set of integrated data analysis tools to enable the FORC signals from SP, SD, PSD and MD particles to be isolated from each other and quantified to yield coercivity and interaction-field distributions for each domain state separately.

Training:

Students will be given full training in experimental techniques, data analysis, programming skills and simulation methods, tailored to the specific project they are doing. The Cambridge Mineral Magnetism Group is a world leader in the field of nanomagnetic techniques applied to Earth and extraterrestrial materials. Students will be given to opportunity to collaborate with our partners across the world, including visits to labs in M.I.T., Jülich, Copenhagen, Berlin, and others.

References:

Harrison, R.J. and Feinberg, J.M. (2009) Mineral Magnetism: Providing New Insights Into Geoscience Processes. Elements, 5, 209-215

Harrison, R.J., Dunin-Borkowski, R.E., and Putnis, A. (2002) Direct imaging of nanoscale magnetic interactions in minerals. Proceedings of the National Academy of Sciences, 99, 16556-16561.

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