Deciphering Extraterrestrial Magentism Using Magnetite Framboids

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Research theme:	• Planetary Evolution and Materials
Eligible courses:	• DPhil in Earth Sciences

Overview

Within just ~5 Myr following the ignition of the Sun, our solar system transformed from a chaotic disk of dust and gas into an organised system of planetary bodies. This period therefore marks the birth of the solar system and is the pivotal interval when the evolutionary pathway of each planet was set. Despite its importance, the nature of the protoplanetary disk and its role in planet building are incompletely understood.

We can fill this knowledge gap by measuring the properties of meteorites, which are fragments of dozens of different planetary bodies from throughout the solar system. Despite carrying vital information, one property of these extraterrestrial rocks that is comparatively poorly understood is their magnetism. This is in large part due to their magnetic mineralogies and thermal histories, which mean existing magnetic measurements of meteorites are often unreliable/challenging to access and interpret.

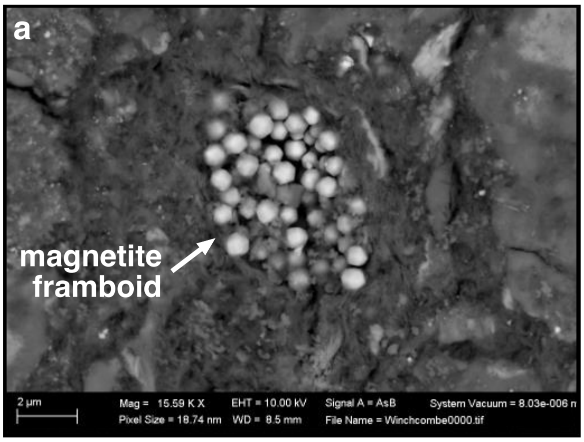

Figure 1: magnetite framboids in the Winchcombe meteorite (modified by Bryson et

In 2021, the Winchcombe meteorite fell in the UK and was collected within hours, making it the freshest meteorite on Earth. The magnetism of this chondrite indicates that a rare morphology of magnetite known as framboids – packed particles of magnetite that form via precipitation and are each ~100-200 nm (Figure 1) – is a particularly reliable magnetic recorder. As such, measuring the magnetisation carried solely by framboids would overcome the difficulties that have hindered previous studies of the magnetic records carried by meteorites. However, the magnetic mineralogy of very few meteorites consists solely of magnetite framboids, meaning bulk paleomagnetic measurements of most meteorites are complicated by the signals from other recorders (e.g., Maurel et al., 2024).

Over the last decade, a new magnetometer – known as a geo-quantum diamond microscope (geo-QDM) – has been pioneered that can measure the magnetisation of sub-millimetre scale samples. Petrographic studies of meteorites demonstrate that millimetre-sized pockets of chondrites can contain magnetite framboids as their sole magnetic mineral. As such, by extracting these framboid-rich regions and measuring their magnetisation in isolation using the geo-QDM, we are now finally able to obtain reliable magnetic records from the early solar system. The aim of this PhD project is to pioneer this workflow and apply it to several chondrite groups to recover the most reliable paleointensities yet from the early solar system.

Methodology

First, optical and electron microscopy will be used to identify pockets of chondrites that consist solely of magnetite framboids (and associated morphologies). Next, these pockets will be drilled out and subsampled using a micromill to produce ~10-20 mutually oriented pieces, each ~200-400 µm large. Each of these will then be stepwise demagnetised using alternating fields and/or thermal techniques, and imaged at each step using the geo-QDM in the Oxford paleomagnetism lab. The student will then apply a laboratory remanence using a field with a known intensity, which they will demagnetise using the same procedure. This will allow the intensity of the ancient field that imparted the natural remanence to be calculated. This workflow will be optimised and applied to up to six meteorite groups, to glean a complete and reliable picture of the magnetic field that threaded the protoplanetary disk.

Timeline

Year 1: Training on the wire saw, electron microscope, micromill, and geo-QDM. Acquisition of relevant meteorites from museums, collections, and dealers. Optimisation of workflow. Training in scientific reading, writing, and presentation.

Year 2: Application of workflow to several meteorite groups to acquire majority of the data.

Years 3 & 4: Application of workflow to final meteorite groups. Compile complete dataset and interpretation of these data. Presentation of results at international conferences. Writing results into papers/chapters. Thesis completion and submission.

Training & Skills

The student would gain valuable skills in performing scientific measurements and quantitative data analysis. They will also gain key skills in understanding and presenting (both written and oral) scientific findings. The student would gain first-hand experience in people, time, and financial management, as well as working in a multi-faceted team. There would also be the opportunity to learn coding skills to complement existing data analysis packages. Finally, all the relevant training courses offered by the University would be open to the student.

References & Further Reading

J. F. J. Bryson, C. I. O. Nichols, & C. Mac Niocaill (2023) A unified intensity of the magnetic field in the protoplanetary disk from the Winchcombe meteorite. *Meteoritics & Planetary Science*, **59**, 1194-1215.

C. Maurel, J. Gattacceca, & M. Uehara (2024), Hayabusa 2 returned samples reveal a weak to null magnetic field during aqueous alteration of Ryugu's parent body. *Earth and Planetary Science Letters*, **627**, 118559.

Further Information

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