The quest for primary magnetisation in Earth's oldest materials

R.J. HARRISON[1], R.J.M. TAYLOR[1], F. TANG[1], V.S.C. KUPPILI[1], M.R. BALL[1], J.F. EINSLE[2], C.S. BORLINA[3], R.R. FU[4], B.P. WEISS[3], W.D.A. RICKARD[5], D.W. SAXEY[5], S.M. REDDY[5]

[1]Department of Earth Sciences, University of Cambridge, Cambridge, U.K.
[2]School of Geographical and Earth Sciences, University of Glasgow, U.K.
[3]Department of Earth, Atmospheric, and Planetary Sciences, M.I.T., Cambridge, Massachusetts, U.S.A.
[4]Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts, U.S.A.
[5]School of Earth and Planetary Sciences, Curtin University, Perth, WA, Australia.

Grains of zircon ($ZrSiO_4$) from Jack Hills (Australia) yield ages up to 4.4 Ga and record a palaeomagnetic signal linked to the presence of magnetite inclusions. Whether these signatures record the magnetic field at the time of zircon growth, or are younger, remains intensely debated[1,2]. We apply a correlative, multi-scale approach to characterising the magnetism of 3.9 Ga Jack Hills zircons across mm-μm-nm-Å scales. Quantum Diamond Microscopy locates remanence carriers using high-sensitivity magnetic maps with sub-grain spatial resolution. Transmission electron microscopy reveals secondary magnetite formed as iron diffuses into radiation-damaged zircon along the cores of dislocations and is precipitated inside nanopores, as well as during low-temperature recrystallization of radiation-damaged zircon in the presence of an aqueous fluid. Atom probe tomography of a magnetic region shows the presence of two geochemically-distinct sets of ~10 nm clusters: one containing Y and Pb, the other containing Fe and Pb. The Y-rich clusters yield $^{207}Pb/^{206}Pb$ data that indicate mobility of Pb, and associated Y, at c. 3.4 Ga[3] and then again during the late Archean, possibly associated with the intrusion of c. 2.65 Ga granites. The Fe-rich clusters have significantly lower $^{207}Pb/^{206}Pb$ ratios indicating that ingress of Fe occurred during Proterozoic events younger than c. 2 Ga. The ability to date the formation of secondary magnetite would open up new possibilities to acquire interpretable chemical remanent magnetisation from the Archean period, raising the prospect of new ways to increase the quality and quantity of paleomagnetic data from this period.

[1] Tang et al. (2019) *PNAS*, 116, 407-412. [2] Tarduno et al. (2020) *PNAS*, 117, 2309-2318. [3] Valley et al. (2014) Nat Geosci 7, 219–223.