Parting the Clouds: Machine learning guided microanalysis of the meteoritic cloudy zone

J.F. EINSLE[1], L. DALY[1], I. MACLAREN[2],A. EGGEMAN[3], R.J. HARRISON [4]

[1]School of Geographical and Earth Sciences, University of Glasgow

[2] School of Physics and Astronomy, University of Glasgow

[3] School of Materials, University of Manchester

[4] Department of Earth Sciences, University of Cambridge,

New nanopaleomagnetic methods to extract meaningful information from meteoritic materials have recently been developed, that are revealing new insights into the magnetic state of asteroids and other planetary bodies in the early history of the solar system [1], [2]. These new methods focus on the unique magnetic properties of a nanoscale intergrowth of Fe-rich and Ni-rich phases derived by spinodal decomposition during slow cooling over millions of years, called the 'cloudy zone'. Preliminary work shows evidence for chemically ordered structures within the cloudy zone [3].While Einsle et al provided perhaps the most comprehensive characterisation of the microstructure in the cloudy zone, there are outstanding questions related to the chemical ordering of the matrix phase of the cloudy zone and about the clustering of c-axis orientations for the tetrataenite islands. To answer these questions, we have conducted a scanning precession electron diffraction experiment using a direct electron detector to characterise the chemical ordering of the matrix phase. This crystallographic mapping technique collects a high resolution 2D diffraction pattern for each pixel of the map. Machine learning guides our analysis with a c-means clustering approach [4]. This data-driven method allows us to interrogate the high-dimensional large data set. Here we use these new correlations with cluster analysis to understand the Fe-Ni ordering behaviour in the cloudy zone matrix. This new insight will be used to further our understanding of how differentiated planetesimals cool. Additionally, this information will be key in advancing new methods for the synthesis of rare-earth-free permanent magnet materials [5].

[1] J. F. J. Bryson *et al.(* 2015*)*, *Nature*, **517**, 472–475.

[2] C. I. O. Nichols *et al*, (2016) *EPSL.*, **441**, 103–112.

[3] J. F. Einsle *et al.* (2018) *PNAS* **115,** 201809378.

[4] B. H. Martineau, *et al*. (2019), *ASCI*, **5**, 3,.

[5] S. Goto *et al.* (2017)," *Sci. Rep.*, **7**, 1–7.