Constraining the Cooling Rates of Chondrules

Conference or Workshop Item

CONSTRAINING THE COOLING RATES OF CHONDRULES. S. C. Stockdale[1], I. A. Franchi[1], M. Anand[1,2] and M. M. Grady[1,2], [1]School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK. [2]Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK. Email: Shannon.Stockdale@open.ac.uk

Introduction: The cooling rate of chondrules is one of the important constraints on chondrule formation and can be used to distinguish between competing chondrule formation mechanisms. These mechanisms range from shockwaves in the solar nebula[1] to collisions between planetesimals[2]. Dynamic crystallisation experiments are the most widely cited methods of determining chondrule cooling rates and have provided cooling rates from 1 to 3000 Kh^{-1}[3,4]. This is a very large range and in order to assess whether this is a true representation of chondrule cooling rates in the early solar system, it should be validated or constrained by using a more direct method.

Many type II, FeO-rich chondrules contain MgO-rich relict olivine grains inherited from the precursor assemblage. Minor element concentrations of these grains bear a strong relationship to type I chondrules and therefore they likely originate from previous generations of these chondrules[5]. These are important features as they can allow us to determine the cooling rate of their hosts[6].

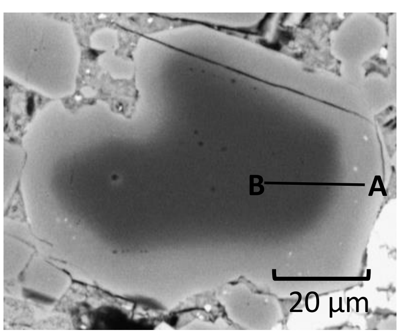
During sub-solidus cooling, partial equilibration occurs between the relict grain and overgrowth crystal which creates diffusion profiles for a range of major, minor and trace elements. The amount of re-equilibration is dependent upon the cooling rate of the chondrule. Relatively broad diffusion profiles could indicate slower cooling rates as more equilibration has occurred. Narrow diffusion profiles should indicate faster cooling rates as there was less time for equilibration.

Methods and results: Relict grains have been identified and characterised using Back Scattered Electron (BSE) imaging, Energy Dispersive X-ray Spectroscopy (EDS) mapping and EDS point analyses on an FEI Quanta 200 3D FIB-SEM. In BSE images, relict grains appear as dark patches within relatively bright phenocrysts. Preliminary diffusion profiles have also been measured for Fe and Mg using EDS point analyses with a spacing of 2 µm, a counting time of 240 s and an accelerating voltage of 10 kV. Measured diffusion profiles (e.g. Fig. 1) are narrow, several micrometres across, indicating rapid cooling took place.

Discussion and future work: The cooling histories of chondrules are likely to be complex and may not be resolvable with the relatively large excitation volume of the EDS point analyses. In order to see this complexity and unravel possible multiple heating events, a technique with high spatial resolution must be employed. NanoSIMS combines high spatial resolution (~300 nm) with high sensitivity which will allow us to measure accurate diffusion profiles for a range of major, minor and trace elements. Therefore, we will use the Cameca NanoSIMS 50L at The Open University to measure diffusion profiles for a range of elements (e.g. Mg, Fe, Ca, Cr, Mn, Ti, Al, Ni, and V) between relict grain and overgrowth. A binary element diffusion model will be developed[7], and used in conjunction with these diffusion profiles to obtain temperature-time paths from which cooling rates can be extracted. These cooling rates can then be used to evaluate the current models of chondrule formation.

References: [1] Morris M. and Desch S. (2010), *The Astrophysical Journal, 722(2),* 1474-1494 [2] Johnson B.C. et al. (2015) *Nature, 517(7534),* 339-341 [3] Desch S. J. and Connolly H. C. J. (2002) *Meteoritics & Planet. Sci., 37,* 183-207 [4] Hewins R. et al. (2005) In *Chondrites and the protoplanetary disk, 341*, 286-316 [5] Jones R. H. (1990) *GCA, 54*, 1785-1802 [6] Hewins R. et al. (2009) *LPS XL*, 1513 [7] Morgan D. and Blake S. (2006) *Contrib. Min. Pet., 151(1)*, 58-70

a)



b)

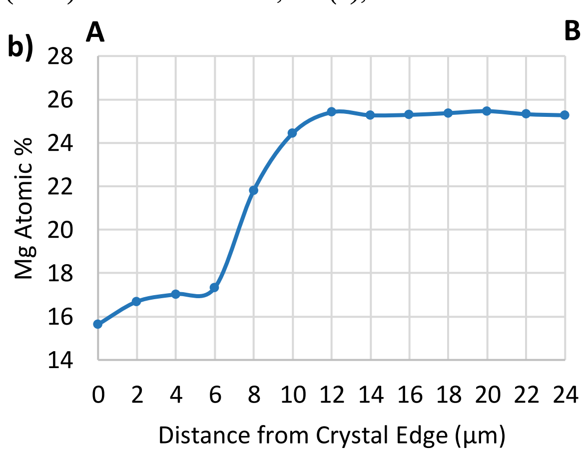


Figure 1 – a) BSE image of an olivine phenocryst containing a relict grain from a chondrule in ALHA 77307 showing the location of **b)** Mg diffusion profile AB measured using EDS point analyses.