Constraining the cooling rates of chondrules

Conference or Workshop Item

How to cite:

Stockdale, Shannon; Franchi, Ian; Anand, Mahesh; Grady, Monica and Morgan, Dan (2016). Constraining the cooling rates of chondrules. In: 13th Early Career Scientists Meeting UK Planetary Forum, 22/01/2016, University of Leicester, UK.

Version: Version of Record

Link(s) to article on publisher's website:
https://ukplanetaryforum.weebly.com/13th-early-career-planetary-scientists-meeting.html

Constraining the cooling rates of chondrules

S. C. Stockdale[1], I. A. Franchi[1], M. Anand[1, 2], M. M. Grady[1, 2] and D. Morgan[3]. [1]Department of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK. [2]Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK, [3]School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK. Email: Shannon.Stockdale@open.ac.uk

Introduction: Chondrules are millimetre sized, spherical melt droplets containing olivine, pyroxene, glass, metal and sulphides. They are the main components in chondritic meteorites, constituting up to 80 vol % in some chondrites [1]. The chondrules are products of widespread heating in the early solar system in a poorly understood event. Proposed models of chondrules formation vary from shockwaves in the solar nebula [2] to impact jetting on planetesimals [3]. Most chondrules have experienced extensive or complete melting, destroying much of what could be learned from the melting event. It is therefore the cooling event which could provide the best record of chondrule formation conditions.

Previous attempts to determine chondrule cooling rate have provided a reasonably conservative estimate of 10 to 1000 $\mathrm{Khr^{-1}}$ when compared with textures produced in dynamic crystallisation experiments [1]. Modelling of the compositional zoning within olivine phenocrysts within chondrules using electron probe micro analysis (EPMA) has yielded cooling rates of 0.7 to 2400 $\mathrm{Khr^{-1}}$ [4].

Many type II FeO-rich chondrules contain MgO-rich relict grains within olivine phenocrysts [5], that are ubiquitous in some carbonaceous chondrites [6]. These relicts are precursor grains which failed to melt. They likely originate from more MgO-rich type I chondrules; however, some could be nebular condensates [5]. Partial equilibration between the relict and the overgrown olivine during sub-solidus cooling creates diffusion profiles, the gradient of which can be used to determine the cooling rate. Using EPMA measurement of Fe-Mg diffusion profiles across the relict/crystal interfaces has yielded initial cooling rates of 300 to 400 $\mathrm{Khr^{-1}}$ for relict grains in a chondrule from Semarkona [7]. However, the cooling histories of chondrules can be complex, many experiencing multiple heating events. Also, the fastest cooling rates produce diffusion profiles that are a few microns across, which require better spatial resolution afforded by EMPA for determining accurate shapes of diffusion profiles

Using NanoSIMS it is possible to measure diffusion profiles across this crystal/relict interface with high spatial resolution of around 300 nm which is almost 10x better than that of EPMA. The sensitivity of the NanoSIMS also permits the measurement of multiple minor and trace elements beyond the detection limit of other conventional techniques. A Binary Element Diffusion Model (BEDM) [8] can then be used to identify complex heating events and determine the cooling rates of individual chondrules.

Methods: For our work we have selected samples that are of low petrographic grade and contain type II porphyritic olivine chondrules with relict grains. The olivine phenocrysts themselves appear relatively bright in back scatter electron imaging (BSE) and the relicts are identified as dark patches within the phenocrysts corresponding to a more MgO rich composition [6]. Many of these relicts have been identified in the CO3.0 carbonaceous chondrite ALHA77307, e.g. figure 1 which shows a small type II chondrule containing several relict grains.

Once enough suitable relicts have been identified and characterised, we will measure diffusion profiles for minor and trace elements (e.g. Mg, Fe, Mn, Ni, Ca and Cr) across the interface using the Cameca NanoSIMS 50L. The BEDM will be applied to create unique temperature-time paths and cooling rates for chondrules. The compatibility of current models for chondrule formation will be assessed and new possible models developed.

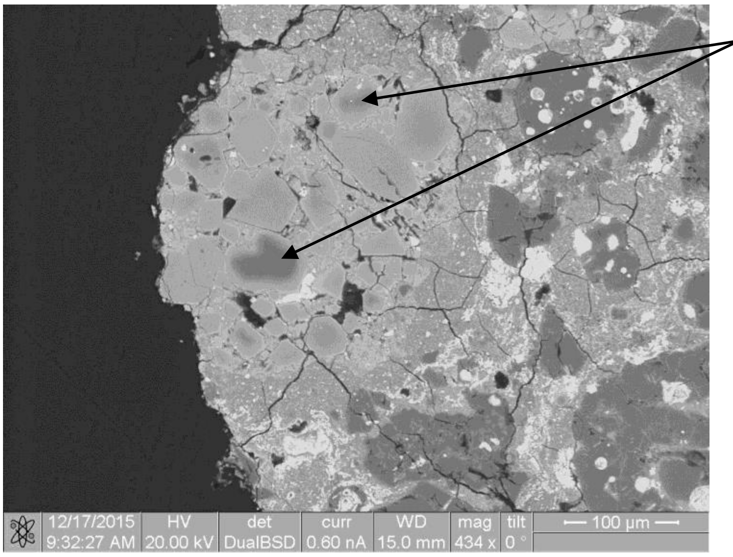

Figure 1: BSE image of a type II FeO-rich chondrule in ALHA77307. The olivine phenocrysts are relatively bright and the relict grains appear as dark patches in the centre of these phenocrysts.

References: [1] Hewins, R. et al., 2005. In *Chondrites and the Protoplanetary Disk,* 34:286-316. [2] Desch, S.J. and H.C.J. Connolly. 2002, *MAPS*. 37:183-207. [3] Johnson, B.C., et al. 2015. *Nature*. 517:339-341. [4] Miyamoto, M., et al. 2009. *MAPS*. 44:521-530. [5] Jones, R.H., jhhb9uyb97u0o1990. *GCA*. 54:1785-1802. [6] Wasson, J.T. and Rubin, A.E., 2003. *GCA*. 67:2239-2250. [7] Hewins, R. et al., 2009. Abstract #1513. 40th LPSC. [8] Morgan, D. and Blake, S., 2006. *CMAP*. 151:58-70.

Acknowledgements: This work is funded by an STFC PhD studentship (to SCS). We would also like to thank the MWG, NASA JSC for loan of the samples that make this work possible.