

## EXPLORING THERMAL SIGNATURES IN THE EXPERIMENTALLY HEATED CM CARBONACEOUS CHONDRITE ALLAN HILLS 83100

P. Lindgren<sup>1,2</sup>, A. M. Andreassen<sup>1</sup>, M. R. Lee<sup>1</sup>, R. Sparkes<sup>3</sup>, R. C. Greenwood<sup>4</sup> and I. A. Franchi<sup>4</sup>, <sup>1</sup>School of Geographical and Earth Sciences, University of Glasgow, UK [paula.lindgren@glasgow.ac.uk](mailto:paula.lindgren@glasgow.ac.uk) <sup>2</sup>Scottish Universities Environmental Research Centre (SUERC), UK, <sup>3</sup>School of Science and the Environment, Manchester Metropolitan University, UK, <sup>4</sup>Planetary and Space Sciences, The Open University, UK

**Introduction:** CM carbonaceous chondrites were aqueously altered in their parent body(ies) within 4 Ma of formation [1] to produce secondary minerals including carbonates and phyllosilicates [e.g. 2]. Several CMs were also heated and dehydrated at some time after aqueous alteration. The cause of this later thermal processing is poorly known, although impacts and solar radiation are possible heat sources [3]. We have sought to better understand the changes that occur upon heating of highly aqueously altered CMs, and to identify the best tools to record the effects of thermal metamorphism. We have examined the effect of heating on water/hydroxyl content, carbon structure, O-isotope signature, and sulphide and carbonate microstructure in the highly aqueously altered meteorite Allan Hills (ALH) 83100 (CM2.1 according to the classification of [4]).

**Methods:** Chips and powders of ALH 83100 were placed in platinum crucibles and heated in a tube furnace under vacuum for 24 hours. Two chips (244 mg) and a powder (43 mg) were heated to 400°C, and two chips (234 mg) and a powder (34 mg) were heated to 800°C. BSE imaging of carbonates and sulphides, and quantitative elemental ED X-ray analyses of matrix were carried out on polished thin sections of unheated, 400°C and 800°C chips, using a field emission Zeiss Sigma SEM operated at 20 kV. Carbon in unheated, 400°C and 800°C powders was analysed using a Renishaw inVia Raman microscope operated with a 514 nm laser, and the collected Raman spectra were processed using automated fitting procedures [5]. O-isotope compositions of the unheated, 400°C and 800°C samples were determined using a modified version of an infrared laser fluorination system [6].

**Results and discussion:** Experimental heating led to dehydration of both the 400°C and 800°C samples, reflected in weight loss post heating (~9% at 400°C, ~19% at 800°C). Dehydration was also indicated by an increase in totals of matrix analyses: 78.7% in unheated (n=10, 1σ=2.8), 82.3% in 400°C (n=10, 1σ=2.6), and 91.7% in 800°C (n=10, 1σ=2.2). The increase of analytical totals due to loss of water and OH has been observed in both naturally and experimentally heated CMs [e.g. 3, 7]. The  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O}$  values increased after heating:  $\delta^{17}\text{O} = -0.024$  and  $\delta^{18}\text{O} = 4.48$  for an unheated sample, and  $\delta^{17}\text{O} = 5.87$  and  $\delta^{18}\text{O} = 16.17$  for a 800°C chip. This trend is consistent with results from experimental heating of the Murchison and Mighei CM carbonaceous chondrites [8]. The Raman data of unheated, 400°C and 800°C powders fall into three groups in a carbon D (FWHM) vs. D/G (intensity) diagram. The 800°C sample has the highest D/G (intensity); an increase of ~0.48 from unheated, and the lowest D (FWHM); ca 11  $\text{cm}^{-1}$  lower than unheated. This is consistent with it being the most thermally altered [9]. Contrary to expectations, the 400°C sample has the highest D (FWHM); ca 65  $\text{cm}^{-1}$  lower than unheated, although similar effects have been noticed in previous experiments [10] and may be explained if the first stage of carbonization does not result in structural ordering. Further signatures of heating were found in the carbonate and sulphide microstructure. Sulphides did not show any obvious textural changes at 400°C, but at 800°C striking changes had occurred. Here, irregular veins of Ni-Fe metal with thicknesses of ~1-5  $\mu\text{m}$  dissect the Ni-Fe sulphide grains. These metal veins are enriched in Ni compared to the host sulphide and could represent melt veins. Melt veins related to sulphides have previously been observed in the naturally heated CM Belgica 7904 [3]. Some carbonates at 400°C showed porosity and shrinkage rims, but most appeared unaffected by heating. However, at 800°C the carbonates were almost completely lost.

**Conclusions:** Dehydration is a key signature of heating in the aqueously altered CM carbonaceous chondrites, evident in ALH 83100 at both 400°C and 800°C. More experiments are needed to understand the Raman signature of carbon during mild heating (400°C), but at higher temperatures (800°C) the structural order of carbon in CMs is a good indicator of heating. O-isotopes move towards heavier compositions with increased thermal alteration, but can be difficult to interpret in naturally heated samples when the initial degree of aqueous alteration is unknown. The carbonate and sulphide microstructures are more obvious as indicators of heating at 800°C, than at 400°C. Further work is needed to find robust thermal signatures in CMs also at lower temperatures.

**Acknowledgements:** NASA Antarctic meteorite collection, Terry Donnelly (SUERC), UK-STFC.

**References:** [1] Fujiya W. 2012. *Nature Communications* 3:627. [2] McSween H.Y. 1979. *Geochimica et Cosmochimica Acta* 43:1761-1770. [3] Nakato A. et al. 2008. *Earth Planets Space* 60:855-864. [4] Rubin A.E. 2007. *Geochimica et Cosmochimica Acta* 71:2361-2382. [5] Sparkes R. et al. 2013. *Applied Spectroscopy* 67:779-788. [6] Miller M.F. et al. 1999. *Rapid Communications in Mass Spectrometry* 13:1211-1217. [7] Lee M.R. et al. 2016. *Geochimica et Cosmochimica Acta* (doi:10.1016/j.gca.2016.05.008). [8] Ivanova et al. 2010. *Meteoritics and Planetary Science* 45:1108-1123. [9] Quirico et al. 2014. *Geochimica et Cosmochimica Acta* 136:80-99. [10] Bonnet J.-Y. et al. 2015. *Icarus* 250:53-63.