In-situ nanoSIMS measurements of isotopic hotspots in the CM2 meteorite Cold Bokkeveld

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IN-SITU NANOSIMS MEASUREMENTS OF ISOTOPIC HOTSPOTS IN THE CM2 METEORITE COLD BOKKEVELD. J. F. Snape¹, A. Morlok¹,², N. A. Starkey¹, I. A. Franchi¹ and I. Gilmour¹, ¹Planetary and Space Sciences, The Open University, Milton Keynes, MK7 6AA, U.K. (joshua.snape@open.ac.uk), ²Institut für Planetologie, Wilhelm-Klem-Str. 10, Münster, Germany.

Introduction: Previous studies have identified isotopic hotspots in insoluble organic matter (IOM) from carbonaceous chondrites [e.g. 1,2]. The origins and formation mechanisms of these hotspots and the host IOM are a matter of ongoing debate. For example, it is not clear whether D and ¹⁵N enrichments in IOM formed within a common organic precursor in cold interstellar environments [3,4] or due to irradiation of organic material in the early Solar System [5,6]. It is also unclear what effect parent body processes would have had with regard to the alteration of meteoritic IOM [2]. In order to address these issues, more recent studies have attempted to make in-situ measurements of isotopic anomalies in IOM [e.g. 5]. In this study we present in-situ NanoSIMS isotopic analyses of material within a sample of the CM2 meteorite Cold Bokkeveld, comparing the distribution of hotspots and bulk H, C and N isotopic composition in the rims and interiors of altered chondrules.

Analytical Techniques: Back scattered electron (BSE) images were acquired with a FEI Quanta 200 3D microscope. These were then used to identify regions of interest within the sample (Fig. 1). C, N and H isotopic ratios were determined using a Cameca NanoSIMS 50L. Areas of 30×30 μm² were extensively pre-sputtered with the ion beam. Within these areas, 25×25 μm² regions were mapped with two different analytical setups: (1) ¹²C, ¹³C, ¹⁶O, ¹⁸O, ¹²C¹⁴N, ¹²C¹⁵N (4 pA probe, MRP >9000); and (2) ¹H, ²H, ¹²C and ¹⁸O (10pA, MRP ≈ 4000). Data were reduced using the L’Image software (L. Nittler, Carnegie Institution of Washington). Post-NanoSIMS secondary electron (SE) images were acquired using a Zeiss Supra 55V.

Figure 1. BSE image of a chondrule (CB6) in Cold Bokkeveld. Areas analysed by NanoSIMS have been indicated with white squares.

Figure 2. (a) δD vs. H/C and (b) δ¹³C vs. δ¹⁵N values for areas within Cold Bokkeveld. Data are compared with those of IOM from other carbonaceous chondrites [4]. Filled symbols represent analyses within chondrules, open symbols represent analyses of chondrule rim material.

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analytical FEG SEM (Fig. 3a). All of the hotspots identified have sigma values of \( \geq 4 \) (as calculated in L’Image).

**Results:** A total of thirteen areas were analysed within three separate chondrules and their rims. An example of one such chondrule (CB6) is presented in Fig. 1. The bulk \( \delta D, \delta^{15}N \) and \( \delta^{13}C \) isotopic compositions of these areas are within the range reported for IOM in other carbonaceous chondrites (Fig. 2; [4]). H/C ratios within the Cold Bokkeveld areas are significantly higher than those of carbonaceous chondrite IOM, however, this is almost certainly due to the fact that these areas also include non-organic phyllosilicate material. The highest bulk \( \delta D, \delta^{15}N \) and \( \delta^{13}C \) values are observed within the rims of chondrules while the highest H/C ratios are observed in the chondrule interiors (Fig. 2).

**D-enrichments.** D-enrichments are identified in the rims of several chondrules (Fig. 2a). CB6_2 is an example of one area within which multiple D-enrichments were observed (Fig. 3c-d). These appear to correspond to depressions in the surface of the sample, as indicated in the SE image of CB6_2 (Fig. 3a). The D-enrichments also correlate to relatively C-rich areas of the sample (Fig. 3b).

**\( ^{15}N \)-enrichments.** Less common than the D-enrichments are \( ^{12}C \) hotspots. However, one area within the rim of a chondrule (CB6_2) was found to contain several such hotspots (Fig. 2b). All of these correspond to relatively C-rich areas and two correspond to D-enrichments (Fig. 3c-f).

**Discussion:** The variation of bulk \( \delta D \) values might reflect the incorporation of multiple materials into the chondrules [5], or could be due to post-accretionary remobilisation of D-rich IOM [2]. As with previous studies, our results indicate that \( ^{15}N \) and D hotspots are not always spatially correlated [1,3]. Based on the models of [3], nitriles are the most likely source of the \( ^{15}N \)-enrichments that do not appear to be correlated with D hotspots. The combined \( ^{15}N \)- and D-enrichments are most likely carried by amines. The putative association observed between isotopically anomalous IOM and chondrule rims and altered matrix may indicate the remobilisation of D-rich IOM post-accretion. More detailed characterisation of the mineralogical environment of D-rich grains may assist in establishing the extent to which equilibration of D has, or has not, occurred on parent bodies.

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Figure 3. (a) SE image of analysed area CB6_2 with the locations of isotopic hotspots indicated. (b) NanoSIMS map illustrating \( ^{12}C \) concentration within CB6_2. (c) \( \delta D \) variations within CB6_2 and associated \( \delta D \) \( \sigma \) map (d). (e) \( ^{15}N \) variations within CB6_2 and associated \( ^{15}N \) \( \sigma \) map (f).