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

Conference or Workshop Item

IN-SITU NANOSIMS MEASUREMENTS OF ISOTOPIC HOTSPOTS IN THE CM2 METEORITE COLD BOKKEVELD.

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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 ^{15}N 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 an 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 µm^2 were extensively pre-sputtered with the ion beam. Within these areas, 25×25 µm^2 regions were mapped with two different analytical setups: (1) ^{12}C, ^{13}C, ^{16}O, ^{18}O, ^{12}C^{14}N, ^{12}C^{15}N (4 pA probe, MRP >9000); and (2) ^{1}H, ^{2}H, ^{12}C and ^{18}O (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

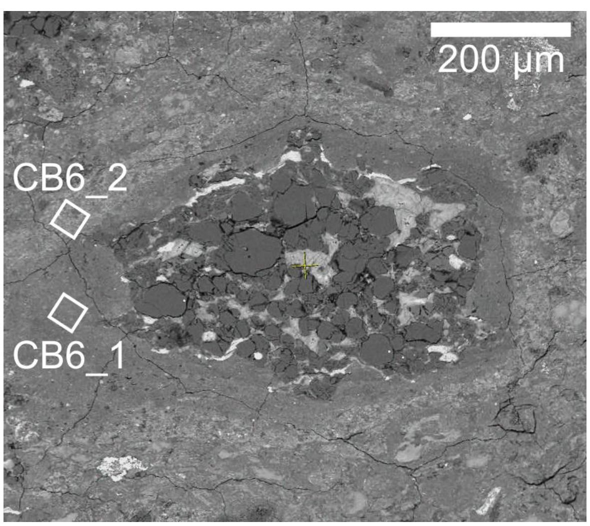

Figure 1. BSE image of a chondrule (CB6) in Cold Bokkeveld. Areas analysed by NanoSIMS have been indicated with white squares.

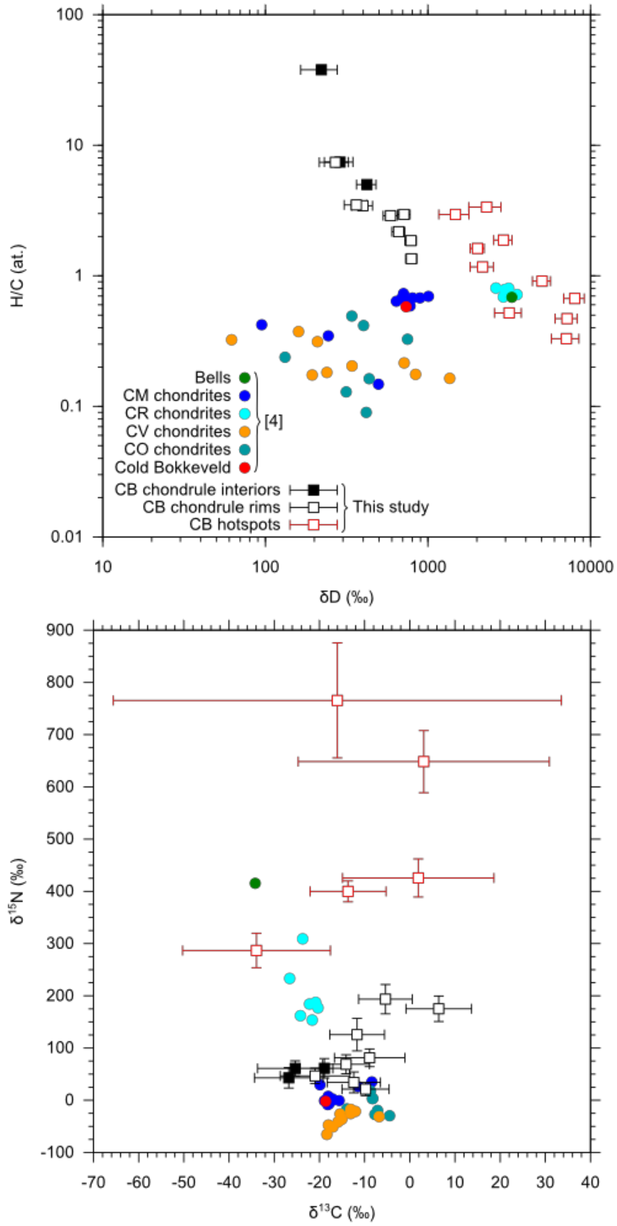

Figure 2. (a) δD vs. H/C and (b) δ^{13}C vs. δ^{15}N values for areas within Cold Bokkeveld. Data are compared with those of IOM from other carbonaceous chondrites [4]. Filled symbols represent analyses within chondrules, open symbols represent analyses of chondrule rim material.

analytical FEG SEM (Fig. 3a). All of the hotspots identified have sigma values of >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 δD, $\delta^{15}N$ 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 δD, $\delta^{15}N$ 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 ^{15}N 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 δD 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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References: [1] Busemann H. et al. (2006) *Science, 312,* 727–730. [2] Alexander C. M. O'D. et al. (2010) *GCA, 74,* 4417-4437. [3] Wirström E. S. et al. (2012) *ApJ, 757,* L11. [4] Alexander C. M. O'D. et al. (2007) *GCA, 71,* 4380-4403. [5] Remusat L. et al. (2010) *ApJ, 713,* 1048-1058. [6] Aleon J. (2010) *ApJ, 722,* 1342-1351.

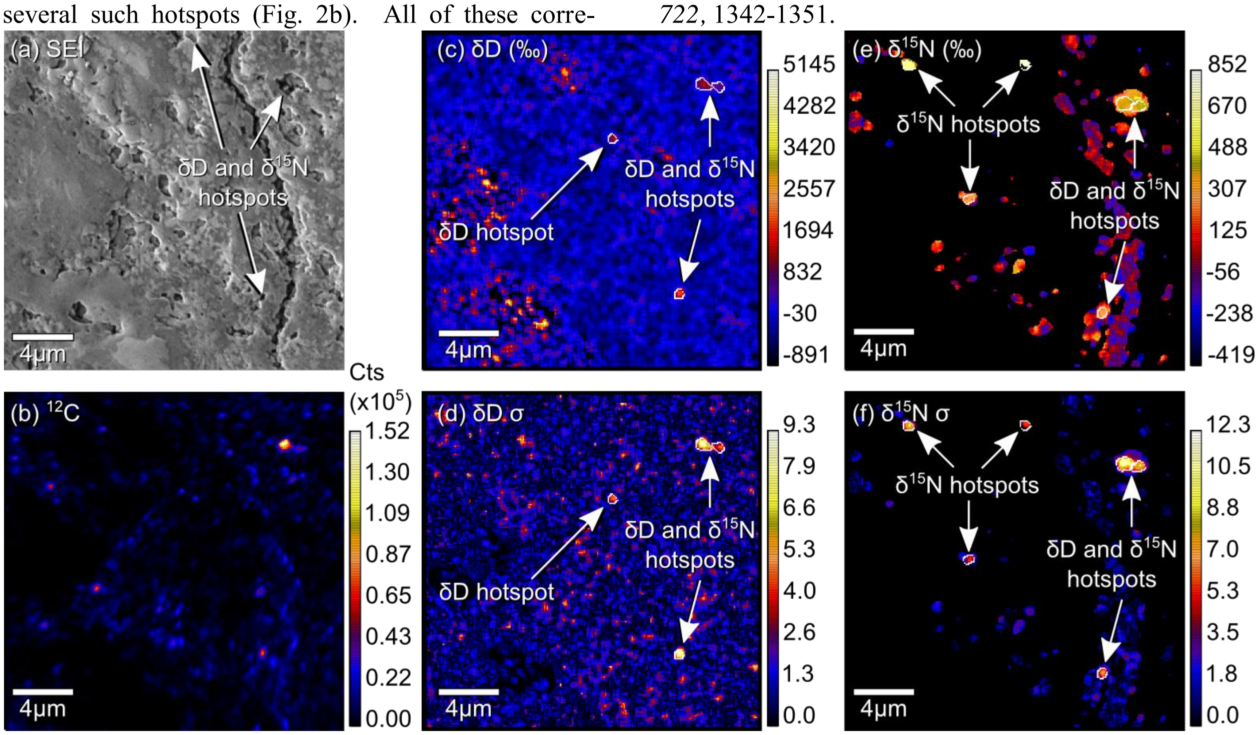

Figure 3. (a) SE image of analysed area CB6_2 with the locations of isotopic hotspots indicated. (b) NanoSIMS map illustrating ^{12}C concentration within CB6_2. (c) δD variations within CB6_2 and associated δD σ map (d). (e) $\delta^{15}N$ variations within CB6_2 and associated $\delta^{15}N$ σ map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