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

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1. 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.

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]. 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.

2. Methods

Back scattered electron (BSE) images were acquired with an FEI Quanta 200 3D microscope. Secondary electron (SE) images were acquired using a Zeiss Supra 55V analytical FEG SEM.

25 μm^2 regions were mapped for ^{1}H, ^{2}H, ^{12}C, ^{13}C, ^{16}O, ^{18}O, $^{12}C^{14}N$, $^{12}C^{15}N$ using a Cameca NanoSIMS 50L. NanoSIMS data were reduced using the L'Image software (L. Nittler, Carnegie Institution of Washington). All of the hotspots identified have sigma values of >4 (as calculated in L'Image and illustrated in δD σ and $\delta^{15}N$ σ maps below).

3. Results and discussion

The bulk δD, $\delta^{15}N$ and $\delta^{13}C$ isotopic compositions of the analysed areas span the range reported for IOM in other CM chondrites [4].

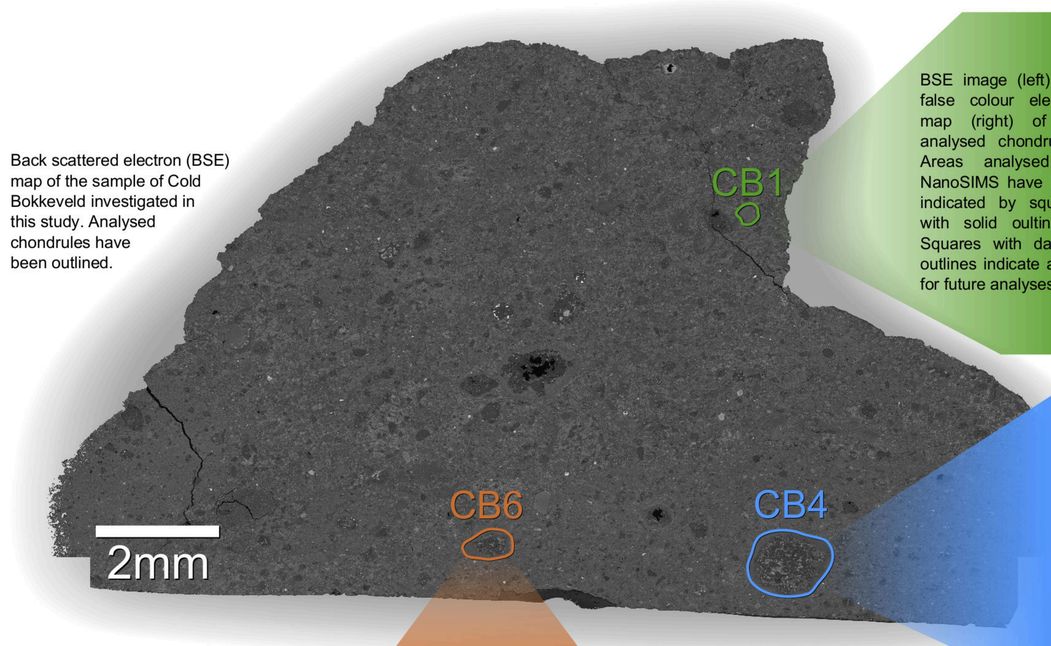
The highest bulk δD, $\delta^{15}N$ and $\delta^{13}C$ values are observed within the rims of chondrules while the highest H/C ratios are observed in the chondrule interiors.

D-enrichments are identified in the rims of several chondrules. ^{15}N-enrichments are less common than the D-enrichments (found in only 2 analysed areas - CB4_5 and CB6_2). Two correspond to D-enrichments, however, ^{15}N and D hotspots are not always spatially correlated [1,3]. Isotopic hotspots correlate to relatively C-rich areas of the sample and depressions in the surface of the sample.

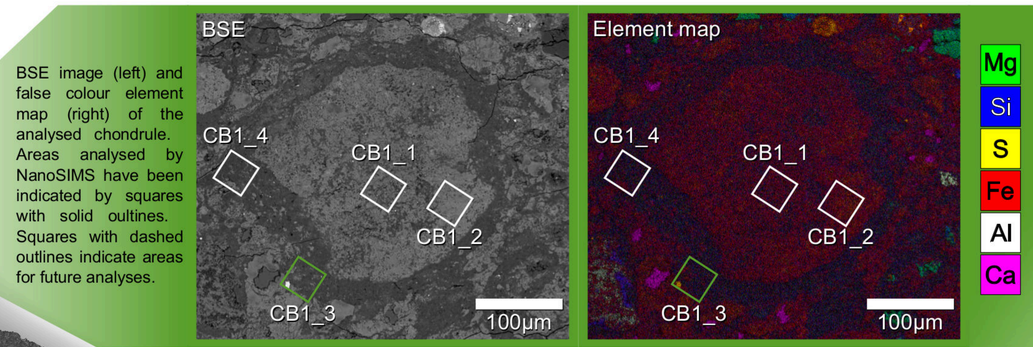
Based on the models of [3], the combined ^{15}N- and D-enrichments are most likely to be carried by amines. Nitriles are the most likely source of the ^{15}N-enrichments that do not appear to be correlated with D hotspots.

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].

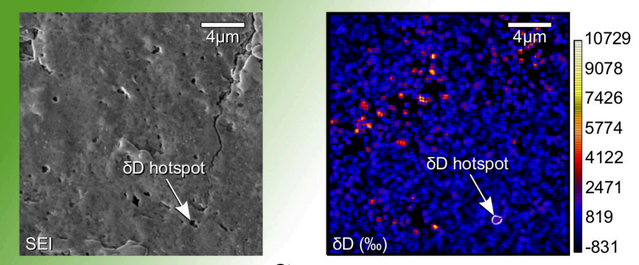
Additional areas have been identified for future analyses. SE imaging of several of these indicates the presence of rounded particles (~0.1-1.0 μm) resembling nanoglobules identified in previous studies of meteoritic organics [e.g. 7].



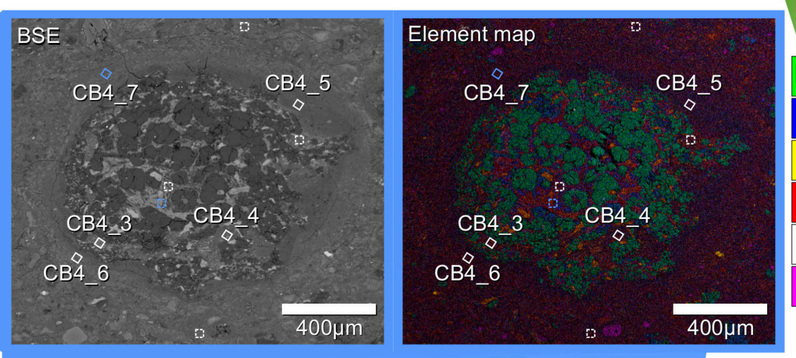
Back scattered electron (BSE) map of the sample of Cold Bokkeveld investigated in this study. Analysed chondrules have been outlined.

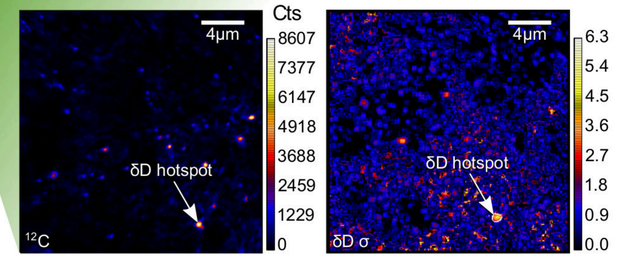


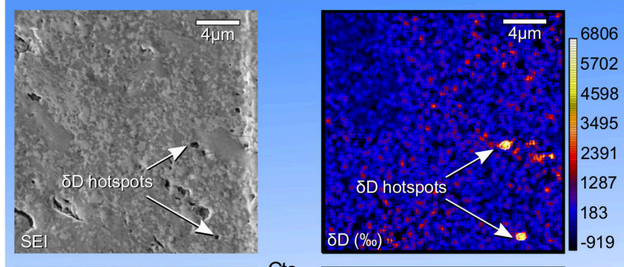
BSE image (left) and false colour element map (right) of the analysed chondrule. Areas analysed by NanoSIMS have been indicated by squares with solid oultines. Squares with dashed outlines indicate areas for future analyses.

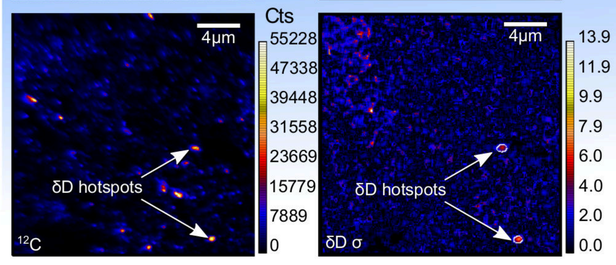


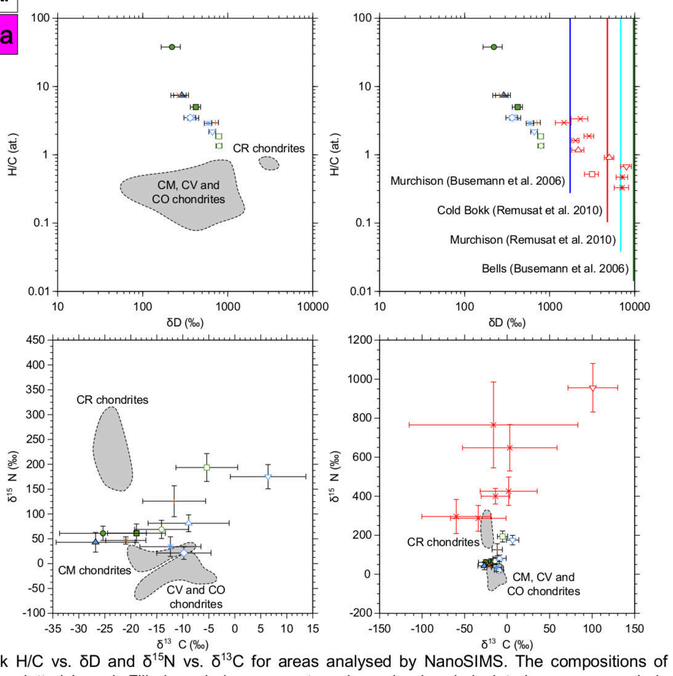
Secondary electron image (SEI) and corresponding isotopic maps of selected area of interest (outlined in colour in the BSE chondrule images). The locations of isotopic hotspots have been indicated.

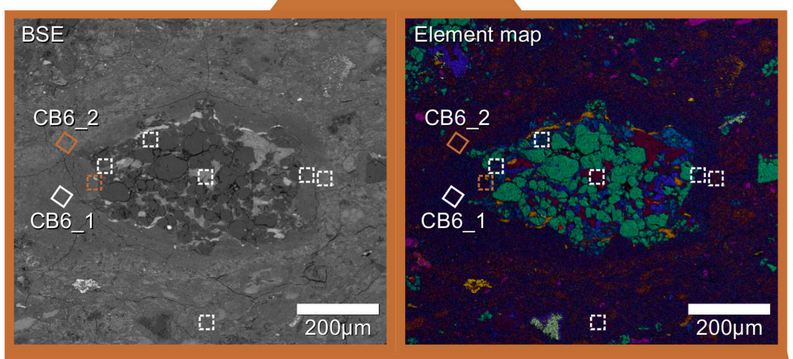


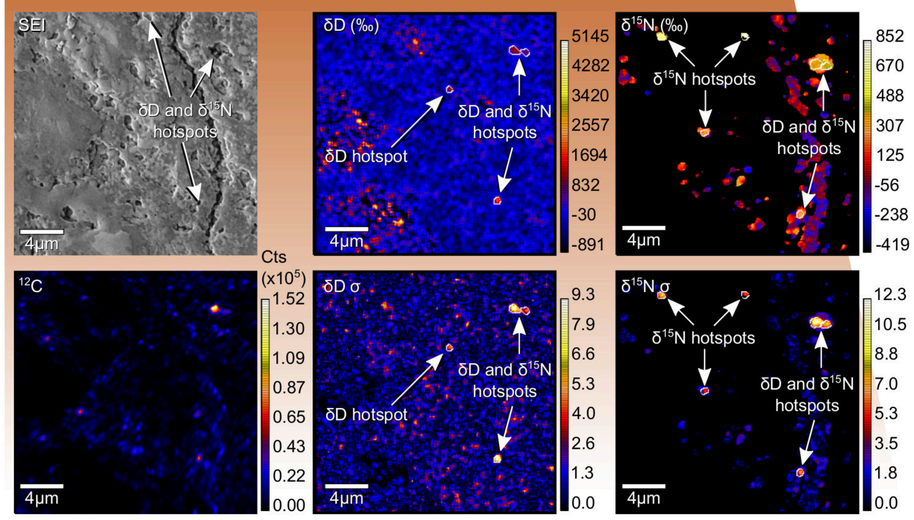


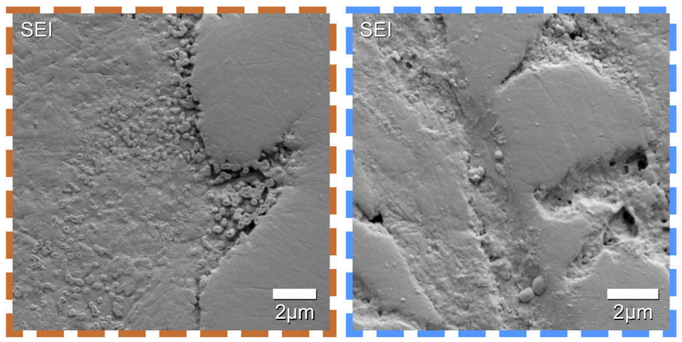












(above) Plots of bulk H/C vs. δD and $\delta^{15}N$ vs. $\delta^{13}C$ for areas analysed by NanoSIMS. The compositions of isotopic hotspots are plotted in red. Filled symbols represent analyses in chondrule interiors, open symbols represent analyses in chondrule rim material. Error bars represent 2σ errors. Data are compared with IOM compositions reported by [4] and maximum isotopic hotspot compositions reported by [1] and [5].

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 putative association observed between isotopically anomalous IOM and chondrule rims and altered matrix may indicate the remobilisation of D-rich IOM post accretion.

(left) Secondary electron images (SEI) of areas proposed for future NanoSIMS analyses.

References: [1] Busemann H. et al. (2006) Sci-ence, 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. [7] Garvie L. A. J. et al. (2008) MAPS, 43, 899-903.