

DEUTERIUM ENRICHMENTS – PARENT BODY PRODUCTS OR A QUESTION OF PRESERVATION?

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Introduction: It has long been recognized that both the soluble (SOM) and insoluble (IOM) organic matter in primitive chondrites and IDPs contain organic material with large D and ¹⁵N enrichments [1]. In the SOM there are considerable isotopic variations amongst individual compounds within and between meteorites. Similarly, the IOM varies dramatically in isotopic composition on small spatial scales, and from meteorite to meteorite [2, 3]. The most striking variations within the IOM are to be found in so-called hotspots, many but not all of which appear to be associated with nanoglobules.

It is almost universally accepted that the large D and ¹⁵N enrichments in the organics are the products of low temperature chemistry in the interstellar medium (ISM) or the early Solar System. If this is the case, all chondrites would have accreted a common organic component and the variations between meteorites, particularly between meteorites from the same chondrite group, must be due to parent body processes [3].

At first glance, it seems quite plausible that the variations in isotopic composition between meteorites are the products of parent body alteration of a common suite of precursors. For instance, amino acids are most abundant and most isotopically anomalous in the least aqueously altered CM and CR chondrites [4, 5]. On the other hand, there is no strong correlation in the isotopic composition of IOM with degree of aqueous alteration within and between CI, CM and CR chondrites [3]. The most isotopically anomalous CM, Bells, is not the least altered. Even more puzzling is that in the ordinary chondrites, but not the COs and CVs, D enrichments in IOM increase dramatically with increasing metamorphic grade [3]. Is this due to preferential preservation of hotspots/globules, or a novel isotopic fractionation process? In addition, in the CH and CB meteorites there are very large ¹⁵N, but not D, enrichments. Some of this heavy N is in IOM that is much more enriched ($\delta^{15}\text{N} \approx 900\text{‰}$) than in any typical chondrite [6], but much of the N is in inorganic materials.

The CH/CB group may be the products of an impact and, therefore, the N isotopic fractionations may be associated with shock. Isotopically heavy N ($\delta^{15}\text{N}$ up to 500-1000 ‰) is also found in brecciated urelites and type 3 OCs [7, 8].

Finally, there is the intriguing discovery of very D-rich water in mica and amphibole ($\delta\text{D} = 3660\text{‰}$) in the R4 LAP 04840 [9]. The D enrichment is much higher than in any bulk chondrite or estimates of the water in them. It is comparable to the most enriched IOM. Consequently, the water could have been derived by oxidation of IOM, but there is no evidence for the CO₂ that would have accompanied the water. Alternatively, it is possible that an unknown fractionation processes in the R chondrite parent body fractionated the H.

Given the possibility of heretofore unrecognized fractionation processes operating on parent bodies, here we further explore the relationship between IOM composition and parent body processes. To this end, we have prepared residues for several new meteorites that extend the range of parent body processes in CMs and OCs, as well as re-analyzed residues with low H/C ratios to check whether adsorbed water was producing some of the observed scatter in our previous H isotope data.

Methods: The new residues prepared included: QUE 97990, one of the least altered CMs, Essebie an anomalous CM with some petrologic similarities to Bells, and WSG 95300 (H3.3). New IOM residues were prepared and analyzed, along with old ones, as described in [3]. The only difference is that for the H and O analyses, the samples were stored in a He-flushed autosampler to reduce the amount of water they can adsorb from the atmosphere.

Results: QUE 97990 IOM has a H isotopic composition ($\delta\text{D} = 1,220 \pm 5\text{‰}$) that is significantly higher than all CMs (700-900 ‰) except Bells (3,285 ‰). Essebie has an even more D-rich bulk IOM composition (1,540‰). However, none of these meteorites have as D-rich IOM as WSG 95300 (11,850 ‰). Several of the remeasured residues gave lower H contents and higher δD values than previously reported [3], resulting in a clear correlation between δD or $\delta^{13}\text{C}$ and H/C in the OCs (Figs. 1 and 2).

Discussion: With increasing thermal metamorphism, the H/C ratio of the IOM decreases [3]. Thus the correlations seen in the OC data in Figs. 1 and 2 clearly point to a metamorphic control on the H isotopic composition. Similar correlations are not seen for the COs and CVs although they have seen a similar range of metamorphic temperatures [10-12]. [3] attributed to differential preservation of a D-rich component

under different chemical conditions in the different parent bodies. They did not consider isotopic fractionation during metamorphism because the OC data would require a Rayleigh fractionation factor that was much larger than predicted even assuming loss of atomic H. However, fractionations associated with radiolysis are very large and could produce large D-enrichments provided the H generated is lost before it can exchange [13]. It is intriguing therefore that the OCs, but not the COs and CVs, appear to have behaved as partially open systems during metamorphism [14].

[3] suggested that Bells was so much more isotopically anomalous than other CMs because the different conditions of alteration it experienced resulted in less exchange or destruction of the D and ^{15}N carriers. However, Bells is also highly brecciated, possibly enabling it to behave as a more open system than other chondrites. Loss of H_2 and other reduced gases produced during serpentinization would explain the more oxidized nature of its alteration. It is interesting that Essebie, which is also heavily brecciated and more oxidized than other CMs, has the next most D-rich IOM composition of the CMs that have been measured. It is also slightly offset in Fig. 2 from the main CM group in the direction of Bells. On the other hand, the relatively unaltered QUE 97990 is not brecciated and its IOM is also more D-rich than typical CMs.

Nanoglobules are often very D- and ^{15}N -rich and have been suggested to be interstellar [15]. Bells appears to be richer in nanoglobules than most CMs. If so, it cannot be ruled out at this stage that nanoglobules are less susceptible to destruction during alteration under more oxidizing conditions. However, it should not be completely ruled out that they formed on parent bodies. Certainly, objects with similar spherical morphologies can be produced by polymerization of formaldehyde from solution [16].

Conclusions: Very large variations in H and N isotopic compositions are seen in IOM from primitive meteorites. In the OCs the D enrichments increase with increasing degree of metamorphism, either reflecting preferential preservation of a D-rich component or the influence as an as yet unidentified fractionation mechanism. In the CMs the isotopic composition of the IOM also seems to be a function of the parent body alteration conditions – meteorites with low degrees of alteration and high degrees of brecciation have the highest D (and ^{15}N enrichments)

References:

[1] Gilmour I., in *Meteorites, Comets and Planets*, A. M. Davis, Ed. (Elsevier-Pergamon, Oxford, 2003), vol. 1, pp. 269-290. [2] Busemann H. *et al.*, (2006) *Science* **314**, 727. [3] Alexander C. M. O. D. *et al.*, (2007) *GCA* **71**, 4380. [4] Martins Z. *et al.*, (2007) *M&PS* **42**,

2125. [5] Pizzarello S. *et al.*, (2008) *Proc. Nat. Acad. Sci.* **105**, 3700. [6] Grady M. M., Pillinger C. T., (1990) *EPSL* **97**, 29. [7] Grady M. M., Pillinger C. T., (1988) *Nature* **331**, 321. [8] Mostefaoui S. *et al.*, (2005) *M&PS* **40**, 721. [9] McCanta M. C. *et al.*, (2008) *GCA* **72**, 5757. [10] Bonal L. *et al.*, (2007) *GCA* **71**, 1605. [11] Bonal L. *et al.*, (2006) *GCA* **70**, 1849. [12] Cody G. D. *et al.*, (2008) *EPSL* **272**, 446. [13] Lin L.-H. *et al.*, (2005) *GCA* **69**, 893. [14] Wombacher F. *et al.*, (2008) *GCA* **72**, 646. [15] Nakamura-Messenger K. *et al.*, (2006) *Science* **314**, 1439. [16] Cody G. D. *et al.*, (2009) *LPS XXXX*.

