

TRACE ELEMENT VARIATION IN CARBONACEOUS CHONDRITE MATRIX. P. A. Bland¹, O. Alard², M. Gounelle³ and N. W. Rogers², ¹Department of Earth Science and Engineering, Royal School of Mines, Exhibition Road, Imperial College London, South Kensington Campus, London SW7 2AZ, U.K., p.a.bland@imperial.ac.uk; ²Department of Earth Sciences, The Open University, Milton Keynes MK7 6AA, U.K.; ³CSNSM - Université Paris 11, Bâtiment 104, 91 405 Orsay Campus, Paris, France

Introduction: Chondrite matrix is defined as ‘the fine-grained, predominantly silicate, material interstitial to macroscopic, whole or fragmented, entities such as chondrules, inclusions and large isolated mineral (i.e., silicate, metal, sulphide and oxide) grains’ [1]. Matrix materials are derived from a wide variety of sources: presolar grains, solar-nebular condensates, and finely ground lithic material from chondrules and inclusions. These fine-grained components were subsequently lithified following accretion with varying amounts of inclusions (chondrules, CAIs, DIs, AOs etc) on asteroid parent bodies, where they experienced variable aqueous, thermal, and impact processing. The fine-grained nature of chondrite matrix, and the often substantial secondary processing that it has experienced, has made unraveling the origins and abundances of specific matrix components extremely difficult. There remains little consensus on the origin of matrix materials, even within one chondrite group.

Any discussion of matrix chemistry must also be concerned with the origins of volatile and moderately volatile element depletions in chondrites. Although variable secondary processing has meant that matrix mineralogy differs substantially from meteorite to meteorite and group to group, it was long considered that matrix chemistry in unequilibrated chondrites (UCs) should be essentially the same. This was an assumption of the 2-component model proposed by Anders [2], in which a volatile-rich component (matrix, of CI composition) accretes with volatile-depleted chondrules. Wasson and Chou [3], observing a monotonic decrease in volatile abundance with decreasing condensation temperature, proposed the incomplete condensation model, in which a solar gas is dissipated during condensation. Subsequent studies, in particular experiments by Palme and co-workers which showed that volatile fractionation patterns cannot be reproduced by heating chondritic materials (e.g. [4]), and modeling of nebula conditions by Cassen (e.g. [5]), have supported the incomplete condensation model, and it is now broadly favoured.

Although both models were based on measurements of trace element abundance in bulk chondrites, they make specific predictions about the composition of matrix. More recently, the x-wind model [6] has also made predictions about matrix composition. In the x-wind model, high-temperature processing of CAIs

and chondrules occurs close to the Sun, and these components are then carried out to fall onto a ‘cold’ accretion disk, composed of essentially unaltered fine-grained interstellar material i.e. in this formulation matrix should be of approximately similar composition in different UCs (although it may entrain variable proportions of chondrule fragments), and non-fragmental matrix should not be compositionally related to chondrules in a given meteorite.

It is clear that knowledge of the trace element chemistry of chondrite matrix is of value in understanding nebula conditions. However, problems of small sample size and contamination in analysing matrix separates, and sensitivity in *in situ* studies, make acquiring trace element data for matrix analytically challenging. Previous workers have used a range of techniques [7-13], typically applied to individual meteorites or small groups of samples. Here we employ both laser ablation ICP-MS and solution ICP-MS to analyse the trace element composition of matrix in a range of carbonaceous chondrites.

Experimental methodology: Laser ablation ICP-MS analysis were performed with a UP213 laser (Quintupled Nd:YAG delivering a 213 nm UV beam) coupled to a HP7500a ICP-MS (Open University). Ablations were performed in He atmosphere and the ICP-MS was operated in shield torch mode. Analyses were initially normalised to both an external and an internal standard, NIST612 and Ca content, respectively, in order to correct for drift and fractionation effects. Yet because of the small scale variation of major element content in matrix, precise quantitative analysis remained difficult to achieve, therefore we chose to process data ratioed relative to Yb and normalised to CI. Given the focus of this study, a major concern was that volatile fractionation could be an analytical artifact arising from heating at the point where the laser interacts with the sample. We investigated this possibility by comparing analyses of Alais matrix performed with various spot sizes (40-200 μ m) and energy output, thus drastically changing the energy density of the ablation area. We also performed raster sampling on a large area of this same sample at low energy. From this analysis it appears unlikely that the fractionation we observe in some samples is related to a thermal effect of the ablation system. Furthermore, we separated samples of matrix (2-5mg) from Allende,

Vigarano, Murchison, Cold Bokkeveld, Mighei and Al Rais, for solution analysis by ICP-MS after acid digestion (performed at Montpellier University on a VG PQ2 ICP-MS). The extremely good agreement between solution analysis and laser analysis indicate that our LA-ICP-MS data do not suffer from an analytical artifact.

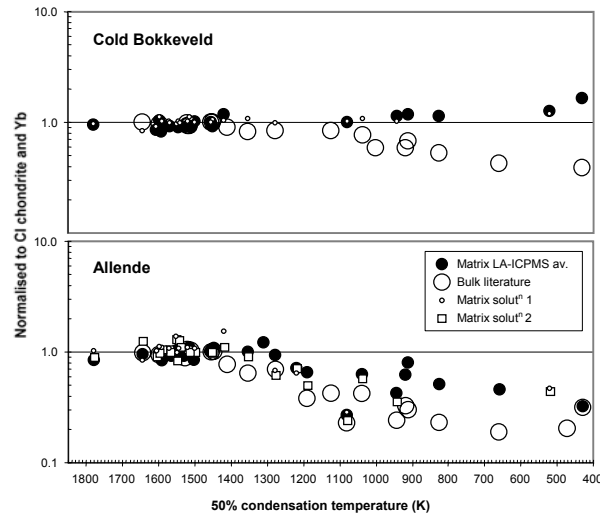


Figure 1. A comparison of trace element data from laser ablation and solution ICP-MS for Cold Bokkeveld and Allende matrix, with literature data for the bulk meteorite. Elements are ordered based on condensation temperature.

Results and Discussion: Matrix is variable in composition on the micrometer scale, with the degree of variability increasing from CO<CV<CR<CM<CI. The chemical heterogeneity of CI chondrites has previously been recognised [13]. In Orgueil and Alais our LA-ICP-MS analysis reveal an order of magnitude variation in the abundance of volatile and moderately volatile trace elements over distances of a few hundred micrometers. Importantly, although their overall abundance varies, the ratio of volatiles with differing chemical affinities remains approximately constant, suggesting that the heterogeneity did not arise through secondary processing.

Average matrix composition is significantly different between different groups, and in some cases even between meteorites within the same group. Thus, in its simplest form, the 2-component model cannot be valid.

CV chondrite matrix shows a marked decrease in moderately volatile trace element abundances with decreasing condensation temperature, consistent with the incomplete condensation model. CO matrix shows a similar fractionation pattern, although it is slightly

less developed, and CR matrix shows only a minor fractionation. In the case of the CMs the picture is complex: Murchison matrix shows some fractionation, but matrix in Cold Bokkeveld and Mighei shows no discernible depletion in volatile or moderately volatile elements. Cassen [5] observed a similar feature: although a model based on incomplete condensation in a cooling nebula readily and quantitatively reproduced the fractionation of moderately volatile elements found in CO and CV meteorites, no model accurately matched CM abundances. Cassen [5] offered the possibility that CMs contain an unfractionated CI-like component. Our data support that suggestion.

Finally, matrix is enriched in volatile and moderately volatile elements compared to the bulk meteorite, and the degree of enrichment tends to increase with volatility.

Conclusions: LA-ICP-MS analysis appears to be an effective means of investigating matrix trace element abundance *in situ* in chondrites. For the CO and CV chondrites our data support an incomplete condensation explanation for trace element fractionation, which also had the effect of homogenising matrix chemistry in meteorites with the largest fractionations. In contrast, CR matrix shows only a minor depletion, and CM matrix (Murchison excepted) is barely distinguishable from CI, suggesting the presence of a significant unfractionated component in CM matrix, reminiscent of Anders 2-component model. We are currently comparing our dataset to bulk trace element data for these meteorites, as well as chondrule and CAI trace element data, in an effort to contribute to the discussion on chondrule/matrix complementarity.

References: [1] Scott E. R. D., Barber D. J., Alexander C. M. O'D., Hutchison R. and Peck J. A. (1988) In *'Meteorites and the Early Solar System'* (J. F. Kerridge and M. S. Matthews, eds.) pp 718-745, Univ. Arizona, Tucson. [2] Anders E. (1964) *Space Sci. Rev.*, 3, 583-714. [3] Wasson J. T. and Chou C.-L. (1974) *Meteoritics*, 9, 69-84. [4] Wulf A. V., Palme H. and Jochum P. (1995) *Planet. Space Sci.*, 43, 451-468. [5] Cassen P. (1996) *MAPS*, 31, 793-806. [6] Shu F. H., Shang H. and Lee T. (1996) *Science*, 271, 1545-1552. [7] Rubin A. E. and Wasson J. T. (1987) *GCA*, 51, 1923-1937. [8] Rubin A. E. and Wasson J. T. (1988) *GCA*, 52, 425-432. [9] Alexander C. M. O'D. (1995) *GCA*, 59, 3247-3266. [10] Brearley A. J., Bajt S. and Sutton S. R. (1995) *GCA*, 59, 4307-4316. [11] Inoue M., Nakamura N. and Kimura M. (1996) *LPSC XXVII*, 581-582. [12] Hua X., Zinner E. K. and Buseck P. R. (1996) *GCA*, 60, 4265-4274. [13] Morlok A., Bischoff A., Henkel T., Rost D. Stephan T and Jessberger E. K. (2001) *LPSC XXXII*, #1530.