

**ICP-MS ANALYSIS OF A SUITE OF CARBONACEOUS CHONDRITES.** S. J. Hammond<sup>1</sup>, P. A. Bland<sup>1</sup>, S. H. Gordon<sup>1</sup> and N. W. Rogers<sup>2</sup>, <sup>1</sup>Impacts and Astromaterials Research Centre (IARC), Department of Earth Science and Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ, UK. E-mail: s.hammond@imperial.ac.uk, <sup>2</sup>Department of Earth and Environmental Sciences, Centre for Earth, Planetary, Space and Astronomical Research (CEPSAR), The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.

**Introduction:** Carbonaceous chondrites are amongst the most primitive materials from the solar system, and provide insights into early solar system formation processes, an area of considerable scientific debate. Whilst several recent studies have focused on the analysis of the various components which make up carbonaceous chondrites (e.g. [1, 2]), there still remains a relative paucity of bulk analyses, which individual component measurements are often compared to. This study aims to expand on the current data set, using inductively coupled plasma mass spectrometry (ICP-MS) techniques, and provides an internally consistent data set with which data from milled separate components can be compared. We present data for 52 elements from 26 carbonaceous chondrites (CH, CR, CV, CM, CO, CK, CI and ungrouped samples). This study offers an insight into volatile element depletion patterns in the carbonaceous chondrite groups, and a comparison between meteorite fall and find samples.

Quadrupole ICP-MS is a common analytical tool within the geological sciences, but is scarcely used in the analysis of extra-terrestrial materials. Previous studies [3, 4, 5] have illustrated that ICP-MS analytical techniques provide both a precise and accurate way of measuring trace element abundances on small sample populations of meteoritic samples, and therefore reduce the time and difficulty in sample analysis compared to RNAA analytical techniques.

#### **Methods:**

*Sample Dissolution.* Between 3 and 12 mg of each sample was weighed into pre-cleaned PFA screw capped beakers (from a larger aliquot of homogenized powder). Sample dissolution was achieved using an HF: HNO<sub>3</sub> dissolution procedure, with an additional HCl stage, using only small volumes of ultra pure reagents. Following complete dissolution, residues were taken up in sufficient 2% HNO<sub>3</sub> (UpA Grade), to give a  $2 \times 10^3$  fold dilution of the original sample.

*Trace element analysis.* Trace element abundances were determined by ICP-MS at the Open University, using an Agilent 7500s instrument. Elements with atomic masses greater than Rb were measured using a PFA concentric nebuliser, which gives a greater sensitivity than more traditional nebulisers. Elements with atomic masses lower than Rb were measured using a Babington nebuliser. Whilst this nebuliser is less sensitive than the PFA nebuliser, it is also less susceptible to residual drift within the experimental run, which can

often be an important factor in determining the accuracy of the lower mass elements. Oxide interferences (for both nebulisers) were kept low, at <0.5% CeO<sup>+</sup>/Ce<sup>+</sup>, and doubly charged species interference levels were <1% (Ce<sup>++</sup>/Ce<sup>+</sup>) for the PFA nebuliser, and <1.2% for the Babington nebuliser.

Analyses were standardised against a set of synthetic multi-element reference standards, made from single element plasma standard solutions and 2 % UpA HNO<sub>3</sub>. Differences in ionization behaviour between these synthetic standards and natural samples were corrected by doping each of the solutions with a concentrated Be-Re solution (2 ppm Be, 1 ppm Re, of which 200 µl was added to 5 ml of sample solution), thus allowing for the correction of matrix effects on ionisation within the plasma. Residual drift was monitored and corrected for, using repeat analyses of a sample with “unknown” composition. Detection limits for elements with atomic masses greater than Rb are estimated to be < 5 ppt in solution (equivalent to < 10 ppb in the sample), and a little higher (< 25 ppt in solution, < 50 ppb in the sample) for lighter elements, with the exception of the major elements P, K and Ca.

#### **Results and discussion:**

*Accuracy and Precision.* To assess the precision and accuracy of our method (particularly the calibration with synthetic standards and the doping of solutions to correct for matrix problems) compared to more traditional RNAA analyses, and previous ICP-MS analyses, we dissolved five aliquots each of four USGS rock reference standards (BIR-1, BHVO-1, W-2 and DNC-1), and six aliquots of the CI meteorite Orgueil, and analysed them as “unknown” samples.

The precision of our analyses is perhaps best assessed from variations within the USGS rock standards. These data show that precision is routinely better than  $\pm 3$  % (relative standard deviation (RSD)) for elements heavier than Rb (with the exception of Pt, Ta, Tl, Pb and U) and between 0.5 % and 5 % for elements lighter than Rb.

The accuracy of our method can be assessed by comparing our data from the homogeneous USGS standards to published values (from [6]). Where concentrations are comparable to those of the synthetic standards (i.e. within the range of meteoritic values) our results are within 10 % of preferred values [6], with the

exception of Ga and Sr (<15 % difference) and Zn (<20 % difference).

Our data from Orgueil (CI) have been compared to published values measured by NAA [7] and ICP-MS [4] (Fig. 1). 23 of the elements analysed lie within 5% of the values of Anders and Grevesse [7], with a further six elements within 10 %. Six elements lie within 10 – 15 %, and five more are within 25 % of the RNAA values. Only four elements lie outside of 25 % (Nb, Mo, Ru and Tl).

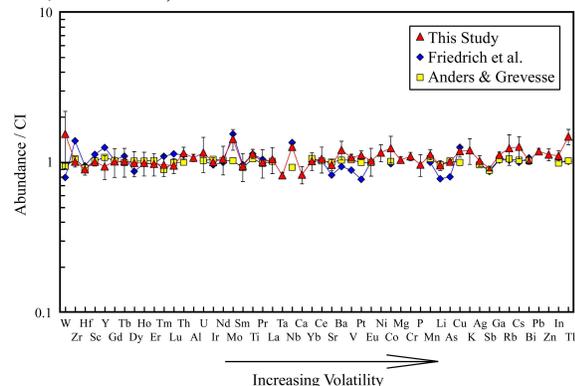


Fig. 1. Comparison of our data from Orgueil compared to published values [4, 7].

Variation between different aliquots of Orgueil is much greater than variation observed in the USGS standards, due to sample heterogeneity. This variation is recorded as error bars in Fig. 1 (2 s.d. from the mean).

With the exception of Alais and Orgueil, all samples show a depletion in the most volatile elements, and are enriched in the refractory elements compared to CI chondrite. The trends in volatile element depletion replicate those observed by others – data from this study for Vigarano and Ornans differ by <15% from published values [8] for the majority of elements analysed. The sequence of volatile element depletion for meteorite fall samples is CV>CO>CM, and whilst our CH group sample is a find (see implications of this below) it is more depleted in the most volatile elements than CV chondrites.

*Weathering of find versus fall samples.* Most refractory element abundances of CV find meteorites are similar to CV fall meteorites, and show a similar degree of depletion in the more volatile elements compared to CI. However, we observe several key differences between samples from the Acfer region and a CV fall (in this case we compare to Allende) for a number of elements. We observe strong enrichments in U, Sr, Ba and Li (Fig. 2) in Acfer 086, and Acfer 272 (Ba concentrations are 130 times CI in Acfer 086), which we suggest occurs as a result of terrestrial weathering –

these elements are highly mobile in fluid phases. Enrichment in Sr and Ba has been observed in H chondrites from the Acfer region [9] and enrichments in Sr, Ba and U in the L chondrite Castenazo is attributed to weathering in a hot desert environment [10]. We also observe a depletion in both Ni and Co, which is suggested by [9] to occur as a result of partially flushing these elements through the system as metal oxidation proceeds during weathering.

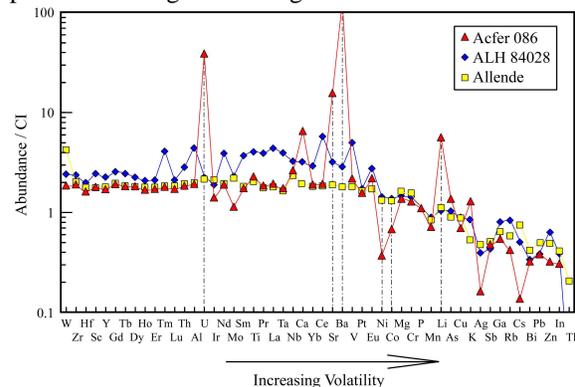


Fig. 2. Chondrite normalised multi element diagram for Acfer 086, ALH 84028 and Allende illustrating effects of terrestrial weathering.

The CV find sample ALH 84028 does not show the pronounced U, Sr, Ba or Li enrichment, or depletion in Ni and Co relative to Allende, suggesting that find samples from cold environments are much less susceptible to alteration by terrestrial weathering than their counterparts found in hot desert environments. These trends are also replicated in CO find samples, where Acfer 243 shows pronounced U, Sr, Ba and Li enrichments, but ALH 77307 does not. We therefore urge caution when analyzing meteorite find samples, particularly when commenting on the elements outlined above, which are substantially modified as a result of terrestrial processes.

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