**ABUNDANCE, SPATIAL VARIABILITY, AND GEOCHEMISTRY OF TRANSITION METALS IN CARBONACEOUS CHONDRITE MATRICES.**

K. A. Dyl[1,2], J. S. Cleverley[2], P. A. Bland[1], and C.G. Ryan[2]. [1]Department of Applied Geology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia. Email: katie.dyl@curtin.edu.au. [2]CSIRO Earth Sciences and Resource Engineering, 26 Dick Perry Avenue, Kensington, Perth, WA 6151, Australia.

**Introduction:** Our understanding of the early Solar System stems primarily from carbonaceous chondrites (CCs), undifferentiated meteorites that have experienced varying degrees of aqueous alteration (see [1]). Paradoxically, the most altered CCs (CIs) also have elemental abundances within error of the solar photosphere, suggesting they are the most pristine materials preserved in our collections [2]. In situ measurements of trace elements in the matrices of CV and CM meteorites, however, suggests that this is not the case. These data are consistent with matrix formation from a nebular reservoir depleted in volatile elements; aqueous alteration would not, therefore, contribute to trace element mobility on planetesimals [3].

While this is a high-precision technique, the spot size (~100 μm) is still orders of magnitude larger than matrix grain sizes (~100s nm). While electron microscopes can achieve the high resolution required, low count rates and large uncertainities associated with such measurements make this solution impractical. Recently, the MAIA detector [4], in concert with the Australian Synchrotron X-Ray Fluorescence Microscopy (XFM) beamline, was devolped to enable these sorts of experiments. It results in high-resolution (~2 μm) datasets of entire thin sections (~cms) on the timescale of hours. We have demonstrated its potential to provide novel insights into the geochemistry of meteorites and evolution of planetesimals (e.g. [5-8]).

Here we present quantified trace element data from a broad range of CCs: Vigarano, a reduced CV3, and 3 CM meteorites (Murchison, Bells, and Cold Bokkeveld-CB). While Murchison is thought to be one of the less altered CMs, Bells and CB both have unusual chemistry and evidence for more prevasive water-rock interaction [9]. The Vigarano data complements the maps previously obtained on the oxidized CV3 Allende ([6-8]). All objects reveal that trace elements, particularly transition metals, are heterogeneous at the micron scale and have relationships to rock textures on the scale of a thin section.

**Methods:** We analazyed thin sections of the 3 different CM meteorites and a Vigarano thick section mounted in epoxy. Samples were polished using colloidal silica for 30 minutes to provide a clean surface to analyze. The data were collected using the XFM beamline at the Australian Synchrotron, Victoria, Australia. The unique MAIA detector, comprised of 384 Si-diode detectors, allowed for rapid data acquisition across a wide energy range (4-18 keV) [4]. This range includes Kα emission lines for elements ranging from Ca to Zr (i.e., first row transition metals).

Quantification of the data is possible via GeoPIXE, a program utilizing a dynamic analysis matrix method to deconvolve the various emission lines [10]. We assume an olivine matrix and take into account the high Fe-content of the meteorite samples. Despite this, we still see pile-up of Fe-electrons at ~13 keV. This results in spuriously low Fe-values and complicates spectral decovolution in that region. Foils run prior were used to calibrate the x-ray spectra.

**Vigarano (CV3):** A region of fine-grained matrix in Vigarno is presented in Fig. 1. We observe two lithologies of "matrix." One is more coarse- grained,

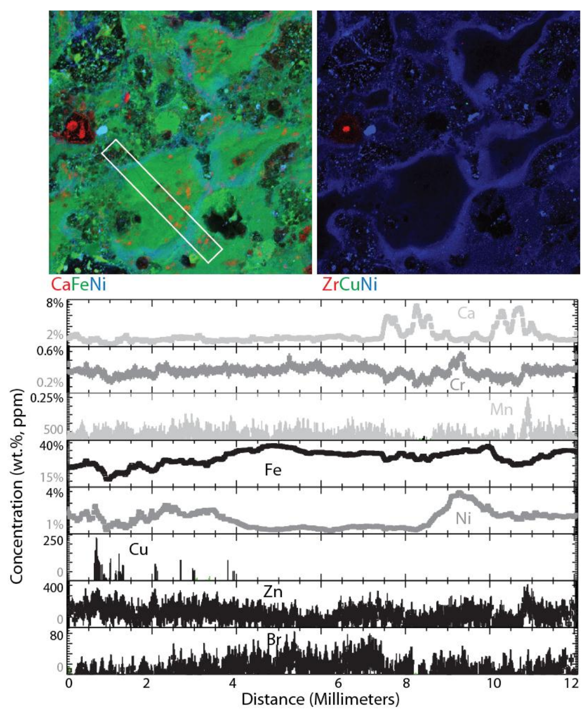


**Figure 1:** X-ray maps of a matrix-rich area in Vigarano. RGB maps show relationships between the various elements, specifically Ca-Fe-Ni and Zr-Cu-Ni. The white box is the traverse (12 mm) quantified below. The average Fe in matrix is ~35%; literature data ranges from 40-44% [11].

has a significant fraction of Mg-rich silicate, and contains Ni as discrete phases throughout. In addition to a Cu "hotspot" of 250 ppm across the traverse, we see another in the x-ray map on the right (bright-green feature). The second type is more fine-grained and homogeneous, higher in Fe, and appears to be enriched in Co and Br. At the edges of these matrix regions, Ni and Cr contents increase (1% to 4% and 0.2% to 0.6% respectively). Associated with these Ni-rich edges are Ca-rich minerals.

**CM meteorites:** The element distributions for the 3 CM meteorites studied are shown in Figure 2. In all 3 images, the RGB settings are consistent, as were the experimental conditions. Red represents different trace elements in each image. In CB, we observe Cr is isolated into very Cr-rich phases associated with chondrules. In Murchison, we observe that spherical Fe-sulfide is commonly surrounded by a halo of Zn; zinc enrichment also occurs in Ni-rich veins and rims. Finally, the Ca distribution in Bells likely indicates carbonate distribution.

The differences in the texture and distribution of Fe and Ni within matrix is dramatically different in all 3 CM meteorites. While CB and Murchison preserve heterogeneity and textures throughout their matrices, Bells appears to be homogeneous. In addition, while Ni-rich chondrule rims and veins are thin and strongly aligned with the rock fabric in CB, Murchison has much larger, more randomly distributed features.

**Conclusions and Implications:** In all 3 CM2 meteorites studied, as well as the reduced CV3 Vigarano, we see subtle yet convincing evidence for the redistribution of transition metals during parent body metamorphism. In Vigarano, the lengthscale of Fe, Ni, Cr (as well as Ca) variability appears to be millimeters. This is in contrast with our previous Allende datasets, which showed little variation in these elements outside of chondrule rims and other rock fragments [7,8].

In the CM meteorites, however, we see variations in Fe and Ni, as well as elements like Zn, Cr, and Ca, that are associated with textures at the centimeter-scale. A likely explanation is that aqueous alteration is accompanied by a transition to oxidizing conditions in these samples. For many transition metals, this results in a change to siderophilic, lithophilic, or chalcophilic behavior. The transition would facilitate the breakdown of phases and mass transfer of the effected elements.

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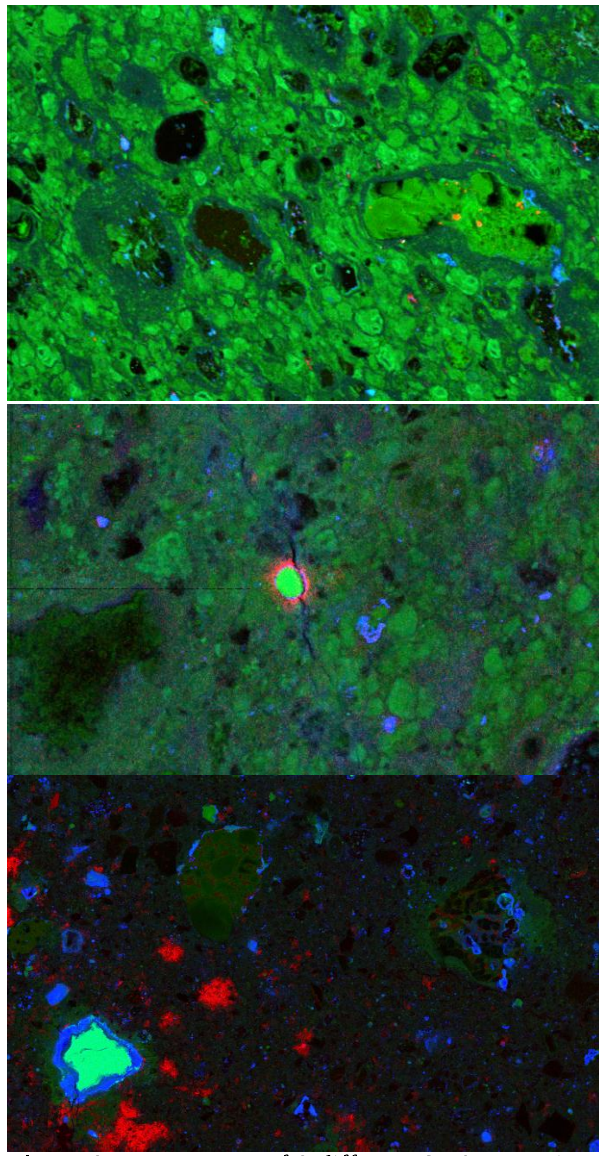

**Figure 2:** X-ray maps of 3 different CM2 meteorites. *Top*: Cold Bokkeveld, Cr(R)Fe(G)-Ni(B). *Middle:* Murchison, Zn(R)-Fe(G)-Ni(B). *Bottom:* Bells, Ca(R)-Fe(G)-Ni(B). The width in all cases corresponds to ~1.7mm. We see distinct differences, particularly in Fe-Ni abundances and micron-scale textures of matrix.