**HIGH RESOLUTION VISUALIZATION OF CARBONACEOUS CHONDRITE FABRIC BY X-RAY COMPUTED TOMOGRAPHY.** Zacchary N.P. Hoskins[1], Phil A. Bland[1], Gretchen K. Benedix[1], Belinda Godel[2], Alex W.R. Bevan[1,3] & Jon M. Friedrich[4]
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**Introduction:** The compactional process responsible for transforming primitive asteroids into planetary embryos (and the conditions under which this compaction took place) remain poorly understood [1,2,3]. Modelling of primitive parent bodies suggests that the first parent bodies should have accreted with porosity in excess of 70%, yet observations of meteorites derived from these primitive parent bodies show no sign of such high porosities [1,2]. In addition, although matrix provides a unique window into disk composition and process, the abundance and size frequency distribution of phases within it are poorly constrained or unknown. Through looking at the geometries and distributions of the various sub-micron components, such as the pores and porosity in primitive meteorites, we can determine the dynamics of the environment that the compaction took place, e.g. revealing foliations or lineations that could be the product of impact induced compaction,. The size distribution of these components may be related to the intensity of compaction (and/or rate of cooling in the case of metals) [4,5,6]. Resolving matrix and chondrule metals – for example – might allow us to test whether matrix has a condensation-related size frequency distribution. Finally, it may be possible to combine both the morphology and size frequency distributions for porosity and separate primary (pore space) porosity from secondary (fracture) porosity in a given sample, allowing us to reconstruct both its primordial (pre-compaction) porosity, and its impact history. To date, there is no published 3-D observations of metal or pore geometries within primitive carbonaceous meteorites below the micron scale with the highest resolution performed on an actual chondrite being a voxel size of 7.2μm on Mokoia by Hezel et al. 2013 [7]. Sub-micron resolution is necessary for accurate quantification of pores and metal particles found in meteorites

**Method:** High resolution (sub-micron) x-ray microtomography has never before been performed on a meteoritical sample, and is an order of magnitude higher than any previous studies using computed tomography. For the purposes of this research, four millimeter scale carbonaceous chondrite samples (Vigarano CV3, Bali CV3, Kaba CV3 and Lancé CO3.5) were scanned using the Zeiss™ Versa XRM-500 high resolution 3-D x-ray microscope installed at the Australian Resources Research Centre (CSIRO Mineral Resources, Kensington, Western-Australia). The instrument was set-up to image porosity at a voxel size of 700nm (see Figure 1), a voxel size that is 10 times greater than the resolution used in Hezel et al. 2013 [7]. The reconstructed volumes were then processed using the AVIZO™ (version 9.3) software to segment pore spaces within each of the samples (using grey scale thresholding) and compute individual pore characteristics (shape, size and orientation) (see Figure 2). These numerical data was then analyzed to identify pore size distributions and total porosity for each sample and assess elongation and/or shortening of individual pores. After the pore size distributions were analyzed, the reconstructed volumes were re-investigated using a weighted size distribution to determine a semi-quantitative value for primary vs secondary porosity. The elongation/shortening axes of individual pores were then plotted as a stereonet to test whether any kind of foliation or lineation are present and that could be attributed to shock processing (see Figure 3). The total porosity obtained was then compared against the literature for consistency [8,9,10,11].

**Results & Discussion:** A priority was to establish a method for separating primary from secondary porosity. Initial analysis of the pore size distribution (based on number of pores) in all 4 carbonaceous chondrites showed a skewed distribution centered on the significant quantity of micro pores (pores < $2\mu m^3$). However, when weighted against their contribution to the total porosity it was observed in all cases to show a distinct bimodal distribution, often consisting of a normal distribution curve representing natural porosity while a large peak starting at $10^5\ \mu m^3$ tended to be the influence of fractures. This approach allows us to quantify primary porosity. Calculated primary porosities using the size distributions, rendered geometries and x-ray images was determined at 5.0% ± 1.7% for Vigarano, 6.4% ± 0.7% for Bali, 14.3% ± 4.6% for Kaba and 13.9% ± 2.5% for Lancé.

Orientations of long axes and short axes for pores generated by the AVIZO software showed a preferred orientation in both Vigarano and Bali, while Kaba and Lancé showed no preferred alignment. This alignment however, did not extend to the metal grains in both aligned samples. Further investigation into the geometries of these shapes revealed a foliation of pore spaces in Vigarano, and a minor lineation of pore spaces in Bali.

Metal grain abundances were found to correlate with the abundance and size of chondrules. Work is ongoing to separate matrix from chondrule metal, allowing for a comparison of their size frequency distributions.

**Conclusion:** In this research we describe the highest resolution X-ray computed tomography analysis of meteorites thus far. We outline a method to separate primary from secondary porosity in primitive meteorites, and provide the first quantification of primary and secondary porosity in these meteorites. Geometrical analysis of carbonaceous chondrite samples has allowed for the identification of sub-micron foliations and lineations that allow us to interrogate the shock history of these samples. A combination of the two will let us determine the primordial (pre-compaction) porosity of our samples. Results of our analysis of the geometry and distribution of metal phases in meteorites at high resolution are ongoing and will be presented at the conference.

**References:** [1] Davison et al. (2016) *Astrophysical Journal, 821, 68-85* [2] Bland P. et al. (2014) *Nature Comms, 5, 5451.* [3] Bland P. et al. (2011) *Nature Geoscience, 4, 244-247* [4] Meibom A. et al. (1999) *Geophys. Res, 104, 22053-22059* [5] Hutchison R. et al. (1980) *Nature, 287, 787-790.* [6] Willis J. & Goldstein J.I. (1981) 12th *Lunar and Planetary Science Conference* Proceedings, *Section 2, 1135-1143.* [7] Hezel et al. (2013) *Geochimica et Cosmochimica Acta, 116, 33-40.* [8] Consolmagno G., Britt D. & Macke R. (2008) *Chemie Der Erde - Geochemistry, 68, 1-29*. [9] Consolmagno G., & Britt, D. (1998) *Meteoritics & Planetary Science, 33, 1231-1241.* [10] Corrigan C. et al. *Meteoritics & Planetary Science, 32, 509-515*. [11] Macke R. J. (2010) *Survey of Meteorite Physical Properties: Density, Porosity and Magnetic Susceptibility.* PhD Dissertation.

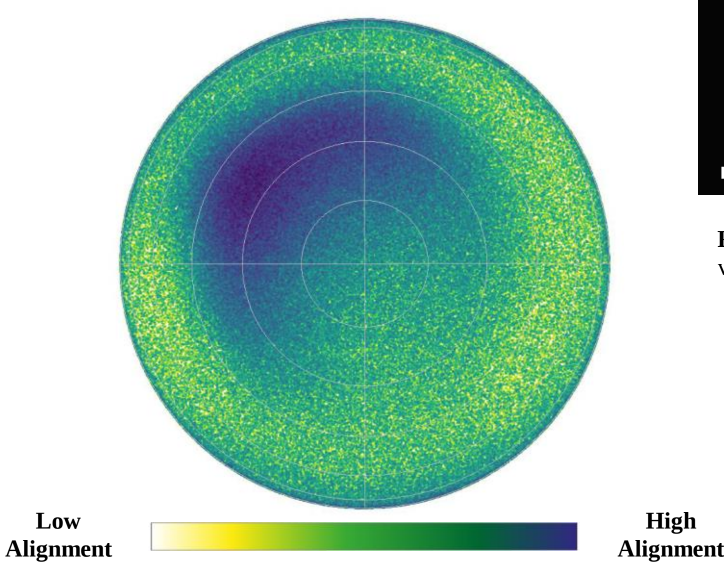


**Figure 3:** Orientations of long axes in pore spaces (Vigarano Sample).

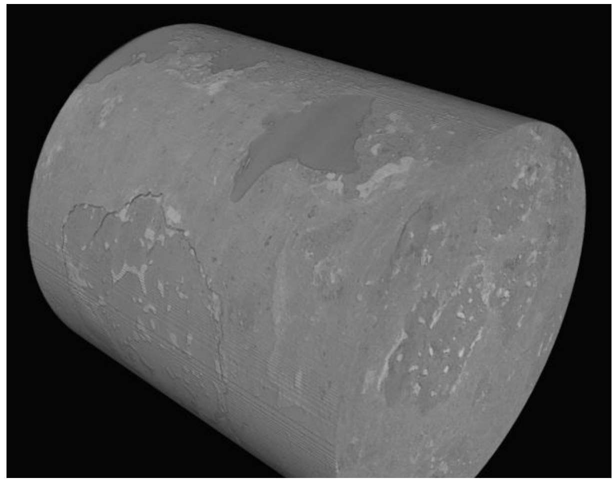

**Figure 1:** 3D volume rendering showing details of Kaba Sample.

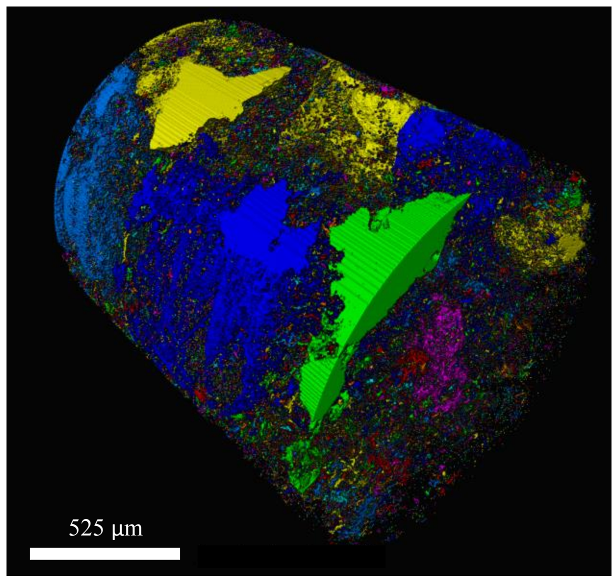


**Figure 2:** Pore spaces after isolation from surrounding voxels (Kaba). Colours used to identify individual pores.