X-RAY MICRO-COMPUTED TOMOGRAPHY IMAGING OF THE BUZZARD COULEE CHONDRITE.

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Introduction: On the evening of November 20, 2008 the Buzzard Coulee H4 Chondrite fell to Earth in a witnessed fireball near Lloydminster, Alberta and Saskatchewan, Canada[1]. Before winter, hundreds of pristine samples were recovered, 18 of which were later obtained by the National Meteorite Collection of Canada (Natural Resources Canada); these individuals range over an order of magnitude in mass and exhibit many shapes, and are an appropriate set to characterize the meteorite. In 2010-2011 bulk density and magnetic susceptibility were determined non-destructively by multiple methods to gain as much knowledge as possible while preserving the integrity of the samples[2]. Surface features were digitally photographed (Figure 1 - Left) and then imaged with a high-precision Konica-Minolta Vivid 9i laser camera, allowing 3D models of all fragments to be built (Figure 1 - Middle).

X-ray Micro-Computed Tomography: Seventeen Buzzard Coulee fragments ranging in mass from 67.32 to 8.80g were imaged by non-destructive X-ray Micro-Computed Tomography (Micro-CT) at the Robarts Imaging Institute, UWO, using a GEHC eXplore speCZT Micro-CT scanner operating at 110 kV (peak). Each five-minute scan consists of 900 separate radiographs taken over one full 360° rotation about the sample. The radiographs were used to reconstruct a 3D image of the sample's radio-density displayed in greyscale Hounsfield units (HU)[3]. Each voxel in the image is a cubic element with a 50µm edge length. An artifact of the Micro-CT process is that X-ray beams are more attenuated as they propagate through the thicker center of an object than when they pass through its thinner edges. This effect complicates quantitative analysis of Micro-CT data. The Micro-CT results were processed at UWO and provided to Carleton University for further analysis.

Bulk Volume / Density Results: Using GEHC's Microview software package, each 3D Micro-CT image can be draped by an external surface using the Isosurface tool, based on a threshold HU value (T=2900 HU based on surface model comparisons, Figure 1). Microview is then able to calculate the volume of this model to be compared to previous volume measurements using other methods. Using volumes determined using Micro-CT, the average density of the Buzzard Coulee suite is 3.44±0.03 g/cm^3. This value is consistent with densities from 3D Laser Imaging (Figure 2), Archimedean beads and with typical values for H Chondrites[4]. This demonstrates that Micro-CT is a valid approach to obtain non-destructive bulk density measurements.

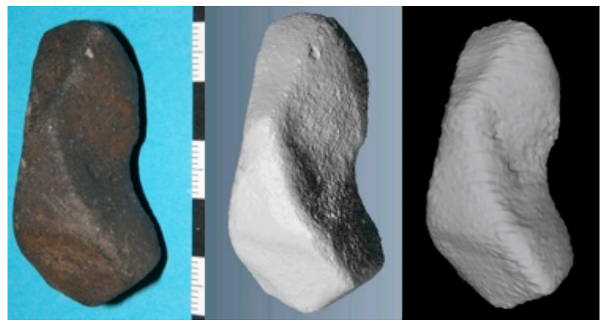

Figure 1 - Buzzard Coulee Fragment A6. Left: Digital photo with 1cm scale bar; Middle: 3D Laser model[2]; Right: Micro-CT Isosurface model.

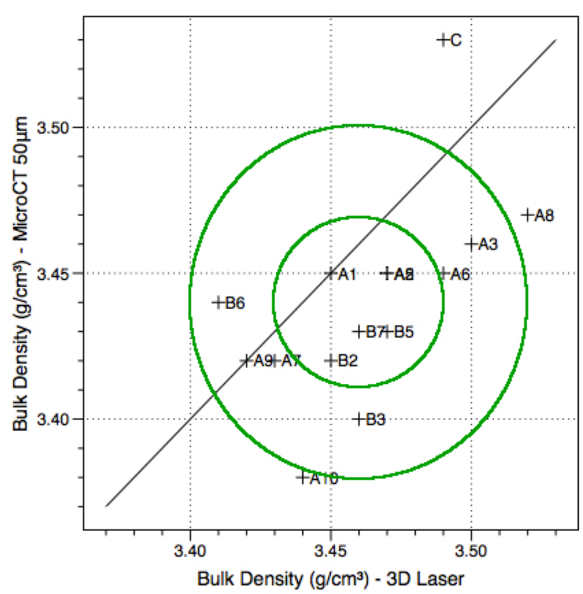

Figure 2 - Buzzard Coulee bulk density obtained by 3D Laser and Micro-CT methods; 1 and 2 standard deviations from the mean density of each method plotted as green circles.

Radio-Density Profile Analysis - Attenuation Curves and Corrections: Using GEHC Microview or open-source ImageJ software, lines through each 3D Micro-CT image can be selected (Figure 3 - Top) and profiles of line length vs. attenuation can be exported for analysis. These profiles typically exhibit a concave curve with its minimum coinciding with the fragment's center (Figure 3 - Middle). For each fragment, 10 profiles at various orientations were taken through consecutive planes near the center of a fixed axis, and average quadratic best-fit lines were generated (Figure 4). Each quadratic best-fit line can be subtracted from it's profile in an attempt to compensate for the attenuation effect (Figure 3 - Bottom).

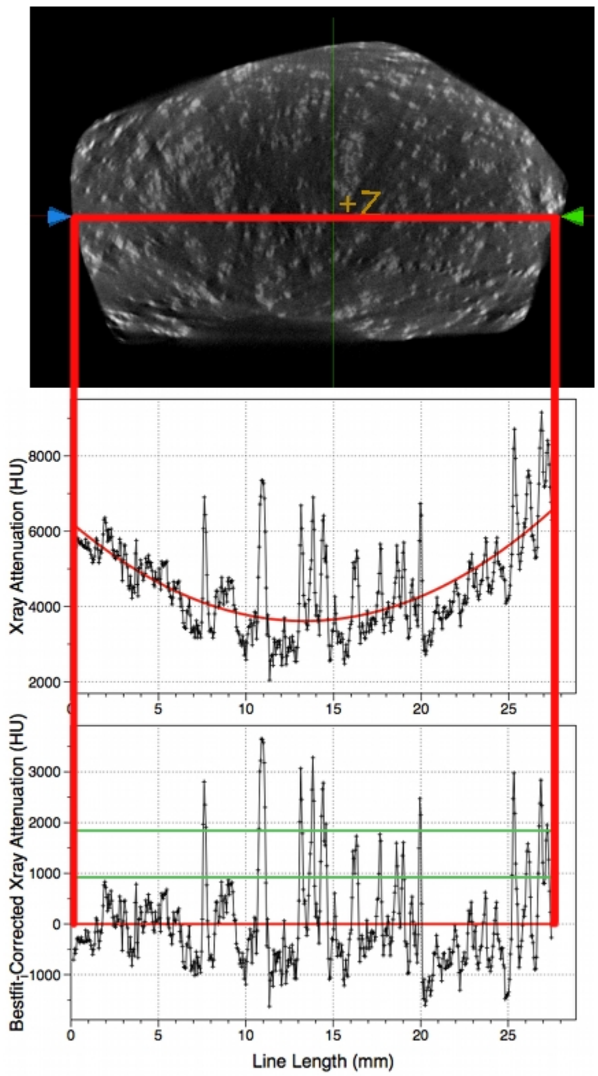

Figure 3 - Buzzard Coulee Fragment A8: Selection and correction of line length vs. attenuation profiles. Top: Micro-CT planar cross-section with selected line; Middle: raw attenuation profile with quadratic best-fit; Bottom: corrected attenuation profile with best-fit line subtracted (1 and 2 positive standard deviations are plotted in green).

After correction (Figure 3 - Bottom), the various low and high radio-density regions within each profile can be easily identified by visual inspection. Positive 'spikes' can be seen to match bright high radio-density regions in the cross-sections. They perhaps represent metallic minerals with significantly higher radio-density than the silicate-dominated background[3]. The attenuation correction represents a first step towards generating a usable data set for further attempts at quantitative results, particularly to establish metrics to assess metallic mineral quantities in each fragment. Expanding this process to cover the entire volume of a Micro-CT image may provide a powerful new non-destructive method for the determination of metal content in meteorites and terrestrial rocks.

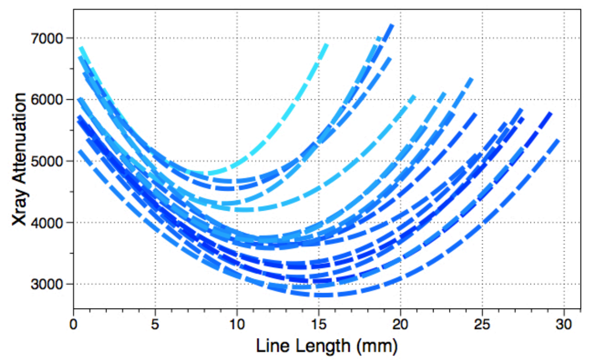

Figure 4 - Average quadratic best-fit lines for each fragment. Colour is a function of the volume, with darker shades representing the larger fragments. This trend confirms that attenuation is related to the size of the fragment.

Future Work: Based on interesting features identified and located in the Micro-CT images, several polished thin sections of Buzzard Coulee are currently being made. They will be analyzed by optical and scanning electron microscopy for comparison with the original Micro-CT images. The thin sections themselves might be further examined by Micro-CT. Additional investigations involving Raman spectroscopy and electron microprobe work are also planned.

References: [1] Hildebrand, A.R. et al. (2009) *LPS XL,* Abstract #2505. [2] Fry, C., Samson, C., McCausland, P.J.A. and Herd, R.K. (2011) *LPS XLII,* Abstract #1427. [3] McCausland, P.J.A., Brown, P.G. and Holdsworth, D.W. (2010) *LPS XLI,* Abstract #2584. [4] Consolmagno G.J. and Britt, D.T. (1998) *Meteoritics & Planet. Sci. 33*, 1231-1241.