INCLUSION FOLIATION IN MURCHISON AS REVEALED BY HIGH RESOLUTION X-RAY CT.

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Introduction: Several classes of chondrites contain flattened chondrules with a preferred orientation [1-4]. Leoville, a CV3 chondrite, was found to have a strong foliation defined not only by chondrules, but also by inclusions and clasts [5]. However, one of the most extensively studied carbonaceous chondrites, the CM2 Murchison chondrite, has thus far not been reported to have any organized 3D fabric or foliation apart from a microscopic matrix foliation defined by the alignment of the basal plane (001) of serpentine [6]. One study did analyze Murchison chondrule shapes in situ but reported that the chondrules had a low mean aspect ratio (1.17) with no evidence of a preferred orientation [7]. We have acquired preliminary imaging of a Murchison sample using high-resolution X-ray computed tomography (HRXCT), which has revealed the apparent alignment of elongated inclusions. HRXCT is well suited to study macroscopic 3D textures in meteorites as it is able to non-destructively image the interior and produce a high-resolution 3D digital dataset that can be analyzed to quantify such fabrics. The purpose of our study is to quantify and fully characterize the 3D texture evident in Murchison using HRXCT and identify and describe the components that define it.

Data: A small portion (~ 3.5 cm^3) of Murchison sample USNM 5487 was scanned on the ultra-high-resolution ACTIS subsystem at University of Texas at Austin. Grayscales in each image (slice) represent X-ray attenuation, which is to first order dependent on the density of the material. The brightest pixels correspond to the densest material in the image. A representative slice from the Murchison sample is shown in Figure 1. Two components were defined based on their characteristics in the CT images. The first component is a set of inclusions that are brighter (denser) than the matrix and appear to have a wide variety of shapes, some quite irregular and angular. The second component is a group of inclusions that are darker (less dense) than the surrounding matrix and are commonly spherical or elliptical in cross-section.

Methods: We first extracted information for the bright inclusions using Blob3D [8,9]. Because these inclusions are readily distinguishable based on their brighter grayscale values, we opted for automatic extraction and separation of the inclusions. We then manually inspected the largest (by volume) 200 objects and selected 135 that represented single, well-defined inclusions that did not lie on the edge of the data volume. These objects were fit with an ellipsoid and the orientations of their long axes plotted, shown in Figure 2. Bright objects that were determined to be roughly spherical or ellipsoidal in shape (examined in 3D) and thus well-characterized with the ellipsoid function in Blob3D are highlighted in yellow. The remaining bright objects are currently interpreted to be fragments of inclusions or mineral crystals.

Because the dark inclusions commonly contain grayscale values that overlap with the surrounding matrix, we manually segmented a selection of 153 inclusions using Avizo by delineating one or more cross sections in each orthogonal plane. We selected inclusions that were well defined in the CT data permitting accurate segmentation, and made an effort to select inclusions with a range of sizes throughout the data volume. The segmented data were then imported into Blob3D and fit with ellipsoids to extract size and orientation information, shown in Figure 3.

Shape analysis was done by plotting the best-fit ellipsoids for each component on Sneed and Folk ternary diagrams using the TRI-PLOT software [10,11] (Figures 4 and 5).

Discussion: Our analysis to date suggests that the dark inclusions display a preferred orientation consistent with flattening while the bright inclusions do not. The bright inclusions are also more compact (roughly spherical) in shape than the dark inclusions, which have a higher median aspect ratio (1.60 compared to 1.49 for all bright inclusions and 1.24 for only the spherical/ellipsoidal bright inclusions).

Because the dark inclusions are the least dense phase in the meteorite and can also be quite large (> 2 mm diameter) it is unlikely that they represent true, unaltered chondrules (reported to be rare in Murchison [12,13]). It is more plausible that they are the friable, “white inclusion” aggregates noted by previous workers, although these are typically irregular rather than elliptical in shape [12,13]. More analysis will be done in the future to determine the compositional nature of the bright and dark inclusions.

Regardless, several questions remain to be answered. What process (impact, burial compaction, etc) could cause preferential alignment of the dark inclusions only? How is this related to the difference in shape that is evident between the dark and bright inclusions? Can a phyllosilicate orientation similar to that seen by [6] be seen in this sample and if so how does this relate to the orientation of the dark inclusions?

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References: [1] Dodd, R.T. (1965) *Icarus, 4,* 308-316. [2] Martin, P.M. and Mills, A.A. (1980) *EPSL,* 51, 18-25. [3] Sneyd, D.S. et al. (1988) *Meteoritics, 23*, 139-149. [4] Scott, E.R.D. et al. (1992) *GCA*, 56, 4281-4293. [5] Cain, P. M. et al. (1986) *EPSL,* 77, 165-175. [6] Fujimura, A. et al. (1983) *EPSL,* 66, 25-32. [7] Tomeoka K. et al. (1999), *GCA*, 63, 3683-3703. [8] Ketcham, R. A. (2005) *Geosphere, 1,* 32-41. [9] Ketcham, R. A. (2005) *J. Struct. Geol. 27,* 1217-1228. [10] Sneed, E.D. and Folk, R.L. *1958. J. of Geology, 66,* 114-150. [11] Graham, D.J. and Midgley, N.G. (2000) *Earth Surf. Process. Landforms,* 25, 1473-1477. [12] Fuchs, L.H. et al. (1973), *Smithson. Contrib. Earth Sci.*, 10, 1-39. [13] Olsen E. and Grossman L. (1978) *EPSL*, 41, 111-127.

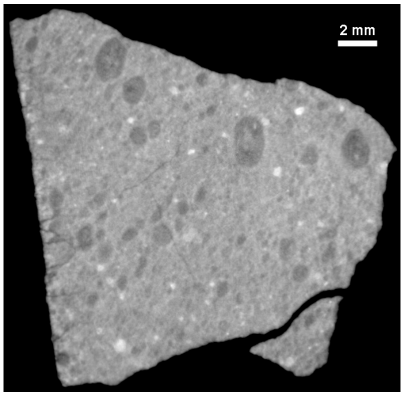

Figure 1. CT slice 211. Larger dark (less dense) objects are roughly elliptical in cross section and appear preferentially orientated.

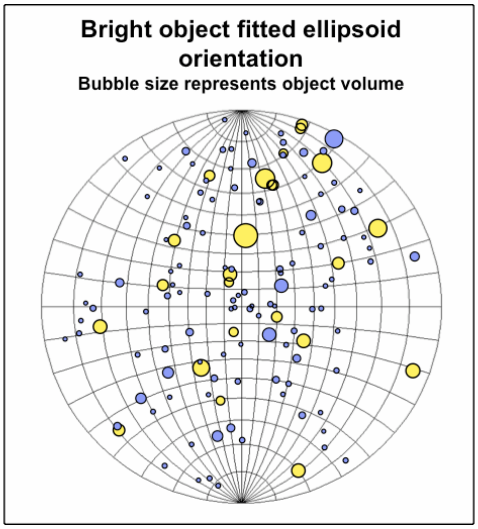

Figure 2. Orientation of fitted ellipsoid long axis for bright objects. Yellow bubbles represent inclusions which appear roughly spherical to elliptical in 3D. No orientation is apparent.

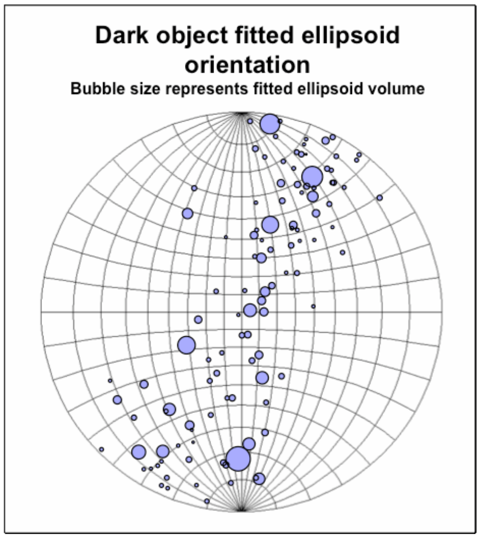

Figure 3. Orientation of fitted ellipsoid long axis for dark objects. A preferred orientation is suggested.

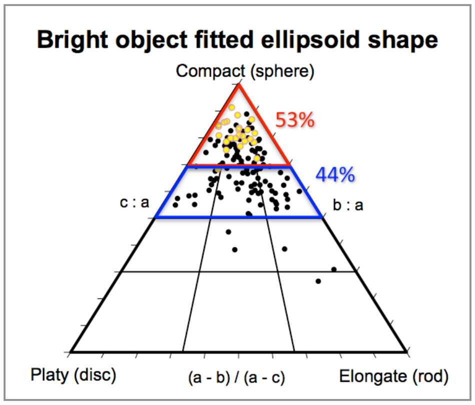

Figure 4. Shape of bright objects based on fitted ellipsoid. Yellow dots represent inclusions which appear roughly spherical to elliptical in 3D. A, B, and C refer to the long, intermediate, and short ellipsoid axes respectively.

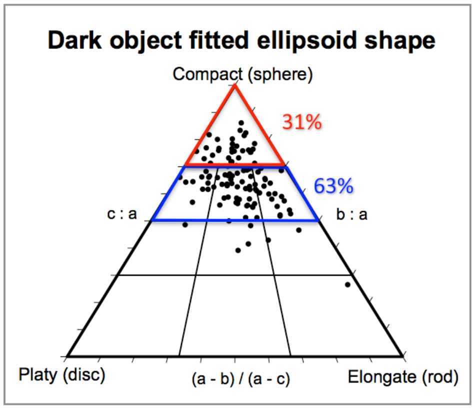

Figure 5. Shape of dark objects based on fitted ellipsoid. A, B, and C refer to the long, intermediate, and short ellipsoid axes respectively.