A MORPHOLOGIC & CRYSTALLOGRAPHIC COMPARISON OF CV CHONDRITE MATRICES.
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Introduction: The matrices of chondritic meteorites hold key information regarding thermal and metamorphic processing on the parent body [e.g. 1, 2]. It is therefore imperative to quantitatively characterize physical properties, such as grain shape, size and orientation, to identify correlations or patterns between and within meteorite classes, and identify the controlling processes for these variations. Such information is not routinely obtained for meteoritic materials, but studies to date have shown the great value of documenting grain size [3-6], texture [7] and morphologic and crystallographic properties [8-10]. Grain shape, size and crystallographic orientation are commonly used to ascertain the cooling rate, temperature and pressure conditions during crystallisation [11] and the presence and direction of flow or magma chamber settling [e.g. 12] for igneous rocks, and the conditions of the depositional environment, amount of grain transportation, and direction and form of fluvial and aeolian processes for sedimentary rocks [e.g. 13]. Such information can be obtained from whole samples, compared between and across rock types, and classifications can then created to facilitate the interpretation of processes that contributed to the history of the rock.

Here, we propose that quantitative characterization of chondrite matrices become routine when describing chondritic samples. A large range of information can be obtained using the described approach, such as grain size, shape, lattice deformation, mineralogy, crystallographic alignment, and crystal size distributions, making this an efficient and high-value method for analyzing fine-grained material. CV chondrites are the focus of this initial study, as a large body of research has been performed on the parent body processing of this group and the origins of chemical and mineralogical variations amongst the class [e.g. 2]. We therefore can consider our high-resolution quantitative morphologic and crystallographic results within the context of prior research.

Methods: Three CV chondrite samples (Allende-WAM, Kaba- NHM and Vigarano- NHM) were compared within this study. Four regions of interest were chosen for each sample; 2 situated in close proximity to chondrules (proximal), and 2 situated far from chondrules (distal) to identify any differences between distal and proximal sites. Electron backscatter diffraction (EBSD) analyses were employed to obtain full area, high resolution crystallographic maps of each region at an accelerating voltage of 16 KeV, a beam intensity of 16, and a working distance of 20.5 mm. Maps were collected at a consistent step size of 0.12 µm, using high gain, 4 x 4 binning, and 1.0 mean angular deviation threshold for all samples. Data were noise reduced as per established protocols [8-10], and individual grains were defined based on crystallographic orientation using the ‘grain detect’ algorithm within the Oxford Instruments’ Channel5 software, using a 10 degree misorientation threshold for adjacent pixels.

Grain parameters were quantified using the Tango module of the Channel 5.12 software. The circle-equivalent diameter, aspect ratio, crystal lattice deformation, and crystallographic alignments of all forsterite grains within each region were averaged, to quantify the ‘typical’ interstitial forsterite matrix characteristics in each sample. Crystallographic alignments were assessed using both the mean uniform density (M.U.D.) values and the misorientation index values [14]. As the method of data collection was consistent across all meteorites, direct comparisons can be made between them using this information, therefore this approach is suitable for comparisons across all chondrites.

	Allende	Kaba	Vigarano
Mean grain circle-equivalent diameter (µ)	0.83	0.47	0.48
Standard Deviation	*0.89*	*0.35*	*0.34*
Mean Grain Aspect Ratio	1.89	1.88	1.84
Standard Deviation	*0.70*	*0.67*	*0.60*
Mean Grain Misorientation (GOS) (°)	0.78	0.56	0.63
Standard Deviation	*0.71*	*0.34*	*0.39*
Forsterite Proportion (%)	91	74	77

Table 1: Matrix forsterite statistics of three CV chondrites

Results: High-resolution secondary electron imaging demonstrated the quality of the crystal facets of the forsterite grains at each site; Allende contains primarily euhedral-subhedral laths, Kaba contains subhedral laths, and Vigarano contains subhedral-anhedral grains that appear more rounded in shape.

Grain statistics: Allende contains the largest and most elongate grains (Table 1), Kaba and Vigarano contain the smallest grains, and Vigarano contains the least elongate grains. Crystal size frequency distributions were also generated; the majority of grains are small and at the lower limits of detection, and the abundance gradually decreases with increasing grain diameter. Allende has the greatest spread of data as expected due to the larger mean grain diameter. GOS is the grain orientation spread, used here as a measure of crystal-plastic deformation within the forsterite grains. Allende has the largest amount of GOS, and Kaba has the smallest amount. The EBSD approach allows for mineral abundance to be quantified, and therefore the amount of forsterite present in each sample can be calculated as a percentage of all minerals present in the studied regions. Allende contains the most forsterite (91%), whereas Kaba and Vigarano on average contain ~15% less forsterite. The matrix of Kaba and Vigarano therefore contain more minor phases when compared to the matrix of Allende.

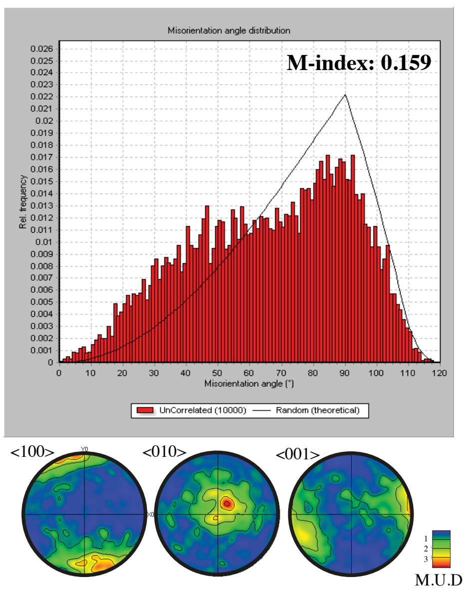

Figure 1: Crystallographic preferred orientation analyses for Allende distal site 2. Top shows the misorientation index with the measured values in red (histogram) and the theoretical random distribution shown as black line. Bottom shows the contoured data on a lower-hemisphere, equal-area plot.

Crystallographic preferred orientations: Most sites contain little to no crystallographic orientation, as demonstrated by the low M.U.D. values, and low M-Index values. The exception is distal Site 2 in Allende, as shown in Fig. 1. Here, the misorientation histogram shows a non-random distribution, with more low- to mid-angle misorientations between grains, demonstrating a weak alignment. The lower-hemisphere plot demonstrates that there is a weak alignment in all crystallographic axes. There is no clear distinction between grain properties at distal or proximal sites in any sample.

Discussion: The maximum temperatures experienced by each sample can be described as Allende>> Kaba=Vigarano [15], which positively correlates to the mean grain size statistics. This does not necessarily imply that thermal alteration controls grain size, but it demonstrates the need to document grain morphology across all CV chondrites for comparison. Aqueous alteration on the parent body is less easily defined given the varied products we see in these samples, but elongate olivine laths have been noted to be a product of alteration [e.g. 2], and these are present in both Kaba and Allende. This may indicate that Kaba and Allende originate from the same general region on the parent body, and that Vigarano originates from a different region, for example. In terms of intragrain misorientation, Allende has the highest bulk matrix strain, whereas Kaba has the lowest bulk matrix strain, potentially indicating that the strain-inducing event occurred closest to Allende, or that other factors control the amount of bulk matrix strain, such as temperature, post-deformation annealing and grain shape/size. The regions chosen in these samples do not show any substantial crystallographic alignment (aside from 1 site out of 12). The heterogeneous strength and orientation of CPOs within each sample are best explained by locally heterogeneous compaction caused by impacts on the parent body rather than global compaction due to burial on the parent body, as found in [9]. Further parameters and the potential controlling planetary processes will be discussed at the meeting.

Conclusions: EBSD mapping and analyses provide a rapid means to quantify the matrix microstructure of chondrites, including grain morphologic parameters, across a specified region. Consistent documentation across multiple samples would allow for a deeper understanding of the parent body processes controlling grain size, shape, and crystallographic alignment. We recommend that this be used in the characterization of fine-grained meteoritic media so that the community can identify patterns and correlations between physical and chemical properties of the grains.

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