CALCIUM-ALUMINIUM-RICH INCLUSION ABUNDANCE AND MINERALOGY WITHIN CM CARBONACEOUS CHONDRITES.

P-E. M. C. Martin[1], and M. R. Lee[1], [1]School of Geographical and Earth Sciences, University of Glasgow, Glasgow, UK. (p.martin.2@research.gla.ac.uk).

Introduction: Calcium-Aluminium-rich Inclusions (CAIs) record some of the solar system's earliest events that are available for study in meteorites.

Whilst the mineralogy of CAIs has been documented thoroughly, their abundance within carbonaceous groups is still poorly constrained. Studies such as **[1]** show the difficulty in reporting accurate CAI modal abundances without sufficient material. CM (Mighei-like) chondrites are amongst the most common carbonaceous meteorite samples and should provide abundant material for study, however, the problem becomes more complex as samples display varying degrees of aqueous alteration. Therefore, it is of utmost importance to appreciate the diversity of alteration histories these inclusions might have been subjected to in order to properly measure, analyse, and evaluate the different populations of CAIs within CM chondrites.

The focus of our work is on reporting CAI abundances and mineralogical descriptions of these objects from across a diverse array of CM lithologies. Results will enable us to investigate the potential link between CAI abundance and to the degree of aqueous alteration of their host CM lithologies.

Materials and Methods: This study comprises data from a polished section of *D'Angelo Bluff* (DNG) 06004 (CM2), as well as from 12 polished blocks of Winchcombe (CM2.0-2.6, **[2, 3]**) and a polished block of *LaPaz Icefield* (LAP) 02239 (CM2.4-2.5, **[4]**).

CAIs were identified using large area Energy Dispersive X-ray Spectroscopy (EDS) maps, alongside Backscattered Electron (BSE) images, produced using a Zeiss Sigma Variable Pressure Analytical Scanning Electron Microscope (SEM; accelerating voltage of 20 keV/1-2 nA; carbon coating ~10 nm thickness) at the University of Glasgow. All data were collected and processed using the AZtec v6 software from Oxford Instruments.

CAI areas, (cf. **Table 1**) and other geometric dimensions (e.g. perimeter, roundness, and solidity) were acquired as per the method in **[6, 9]**. The Fine-Grained Rims (FGR) of such objects were excluded during size measurements as they require a further dedicated study, although their presence (or absence) and their integrity were recorded during data collection. The CAI abundances in **Table 1** were calculated as the sum of all the surface areas of the CAIs divided by the total area of each CM sample, as indicated in **[1]**.

CAIs were classified according to the morphological and mineralogical criteria presented in **[7]**. Only objects containing spinel or diverse assemblages of spinel, hibonite, perovskite, and pyroxene were considered. Pyroxene and pyroxene-olivine inclusions were not included in this study.

	Petrologic subtype	***n* CAIs**	**Investigated area (mm^2)**	**CAIs/mm^2**	**Size range (µm)**	**Average (µm)**	**CAI abundance (area%)**
Winchcombe [3]	2.0-2.6 [2]	21	154.7	0.14 ±0.17	25-199	82 ±43	0.14 ±0.19
DNG 06004	2.4 [5]	98	47.21	2.08	12-317	52 ±44	0.84
LAP 02239 [4]	2.4-2.5 [6]	70	75.53	0.93	14-352	72 ±59	0.72
Mighei [7]	2.3 [6]	35	-	-	25-1150	181 ±206	-
QUE 97900 [8]	2.6 [6, 8]	32	50	0.64	33-525	122 ±97	1.43
Paris [9]	2.7 [9]	18	108	0.17	33-172	111 ±39	0.21
Murchison [1]	2.5 [6]	201	34	5.91	6-180	23	0.97
Nogoya [1]	2.2 [6]	6	6	1.00	5-13	7	0.02
Murray [10]	2.4-2.5 [6]	-	115.2	-	-	-	1.6 ±1.3

Table 1. *Abundance and size of CAIs within the studied CM lithologies compared to the prototypical CM, Mighei, other CMs from the literature. CAI count comprises whole inclusions, fragments, and single crystals. ± represents standard deviation.*

Results: CAI abundances in the studied samples range from 0.14 ±0.19 to 0.84 area% (average: 0.74 ±0.59 area%, cf. **Table 1**) with a total CAI count of 189, throughout 277.44 mm^2 of various aqueously altered CM lithologies (2.0-2.6, **[2, 3, 4]**).

All observed CAIs follow a similar distribution pattern ~60%/~30%/~10% across the three distinct major texturally- and mineralogically-dependant categories described by **[7]**:

Simple inclusions: These are the most abundant type of CAI observed across the investigated CMs (57.1 ±4.65%, cf. **Table 2**). Specimens are mainly composed of spinel and comprise inclusion fragments and/or single crystals **[7]**. These inclusions can be in direct contact with the matrix (no reaction has been observed at the boundaries) or seldom enclosed within a relatively well-preserved pyroxene rim (generally diopside) or mantled by Fe-rich phyllosilicates. Perovskite and hibonite can occur as mineral accessories alongside and seldom within the spinel.

Simple aggregates: They are diverse objects that can be identified as loosely connected and porous clusters of spinel (seldom with hibonite as an accessory) or as distended chain-like structures mostly consisting of spinel within a rim of pyroxene (mostly diopside) or phyllosilicates **[7]**. In LAP 02239, many of these objects display a pyroxene rim with 120° triple-junctions. These are the second most abundant type of CAI observed within CMs (average: 33.2 ±6.53%, cf. **Table 2**).

Complex aggregates: Apart from a single CAI within Winchcombe, which contains a core region composed of sparse micrometric clusters of perovskite and grossmanite (Ti-rich pyroxene, **[11]**), all objects within this category contain spinel clusters that appear as disjointed regions of irregularly shaped groups of spinel with varying textures, enclosed within a common rim or mantle generally composed of pyroxene or phyllosilicates **[7]**. They are the least abundant type of CAI among the studied CM lithologies (average: 9.0 ±2.73%, cf. **Table 2**).

	Winchcombe [3]		**DNG 06004**		**LAP 02239 [4]**		**Mighei [7]**	
	CAIs	**%**	CAIs	%	CAIs	**%**	CAIs	**%**
Simple inclusion	13	61.9	51	52.0	42	60	19	54.3
Simple aggregate	6	28.6	42	42.9	21	30	11	31.4
Complex aggregate	2	9.5	5	5.1	7	10	4	11.4
Aggregate	0	0	0	0	0	0	1	2.9
Total CAIs	21		98		70		35	

Table 2. *Types of CAI encountered within various CM lithologies according to the classification defined by* **[7]**.

Discussion: From Winchcombe's most aqueously altered lithology (lithology F: CM2.0, **[2]**) to Paris, one of the most pristine CMs (CM2.7, **[9]**), this study can provide a broad perspective on a potential correlation between CAIs and the degree of aqueous alteration of the CM parent body. However, no link between degree of aqueous alteration and CAI abundance were found in this investigation. The CAI abundances recorded in this study are also considerably lower than the average CAI abundance of 1.21 area% reported by **[1]**. This difference may be due to sample size, as CAIs follow a Poisson distribution and so data can only be representative if large areas are studied (1000-2000 mm^2, **[1]**).

Some simple aggregates found within LAP 02339 show signs of recrystallisation (120° triple-junction pyroxene), contrary to complex aggregates which do not display any signs of destabilisation and melting. The absence of re-equilibration suggests that the heterogeneity of these objects from their altered regions (e.g. replacement by phyllosilicates, textural variance, absence of primitive refractory phases) might have occurred at a later stage of CAI incorporation within the CM parent bodies.

Future work will focus on increasing the area of investigation of CM lithologies in order to obtain a more representative CAI abundance across the different degrees of aqueously altered CM lithologies.

Acknowledgements: We thank ANSMET and the NHM for loan of the samples studied.

References: **[1]** Hezel D. C. et al. (2008) *M&PS*, 43 (11), 1879–1894. **[2]** Suttle M. D. et al. (2022) *M&PS*, 1–25. **[3]** Martin P-E. M. C. et al. (in preparation). **[4]** Lee et al. (2023) *M&PS* (in review). **[5]** Hanna R. D. Et al. (2020) *Icarus*, 346, 113760. **[6]** Rubin A. et al. (2007) *GCA*, 71 (9), 2361–2382. **[7]** MacPherson G. R. & Davis A. M. (1994) *GCA*, 58 (24), 5599–5625. **[8]** Rubin A. (2007) *M&PS*, 42 (10), 1711–1726. **[9]** Rubin A. (2015) *M&PS*, 50 (9), 1595–1612. **[10]** Norton M. B. & McSween H. Y. Jr. (2007) *LPSC XXXVIII*, Abstract #1807. **[11]** Martin P-E. M. C. et al. (this meeting) *LPSC MMXXIII*.