A 750μm-WIDE SUB-HEXAGONAL CLAST IN THE MATRIX OF ORGUEIL. Y. LE GAC[1], G. K. BENEDIX[1], P. A. BLAND[2], I. LYON[3], T. HENKEL[3], D. ROST[3] and S. S. RUSSELL[1]. [1]Impacts & Astromaterials Research Centre (IARC), Department of Mineralogy, The Natural History Museum, Cromwell Road, London SW7 5BD, UK, [2]IARC, Department of Earth Science and Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK, and [3]School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Oxford Road, Manchester, M13 9PL, UK. (e-mail: y.legac@nhm.ac.uk).

Introduction: CI carbonaceous chondrites remain enigmatic rocks, even two centuries after the fall of the first sample (Alais, in 1806) [1]. There are only five CI1 meteorite falls. They have a similar bulk elemental composition to the solar photosphere [2, 3], and as such, CI chondrites are believed to be the most chemically primitive materials available for study in the laboratory [4]. A long recognized -but recently reviewed- paradox in CI chondrites is that despite their primitive composition, these are also the most aqueously altered meteorites [5, 6, 7]. There still remains uncertainties about the origin and formation of the parent bodies for such meteorites. One hypothesis, based on evidence from textural and mineralogical arguments [8] and historical descriptions of the orbital parameters [9], is that CI chondrites derive from cometary nuclei.

In this work we focus on an interesting feature recently observed in the matrix of the most studied CI sample Orgueil (CI1) (BM1985 M16062). The brecciation level and the different lithologies encountered in CI chondrites have been studied in the past [10]. Orgueil is known to be the most brecciated sample, and this is presumed to relate to a multi-stage history of parent-body processing. We have detected an unusual regular-sided clast around 750μm in diameter. Finding such a feature in Orgueil is intriguing as it does not fit well with the effects of the presumed brecciation and aqueous alteration of the meteorite. We are investigating the chemical composition of this clast and are comparing it with the reference bulk CI chondrite composition, through a variety of electron- and ion-based analytical techniques

Analytical Techniques: We mapped a number of CI chondrite sections, using a JEOL 5900LV SEM fitted with an Oxford Instruments X-sight energy dispersive X-ray detector, running the Montage and SmartMap routines of INCA software. The operating conditions were 10 kV and 2nA. We used a CAMECA SX100 electron microprobe to make more precise maps of the clast, imaging its edges, at 10 kV and 20 nA. SEM and electron micropobe were performed at the Natural History Museum in London. The last step was made with the IDLE 3 ToF-SIMS [11] at the University of Manchester: we ran elemental maps on regions comprising both the clast and the matrix. This was a preliminary study with the ToF-SIMS.

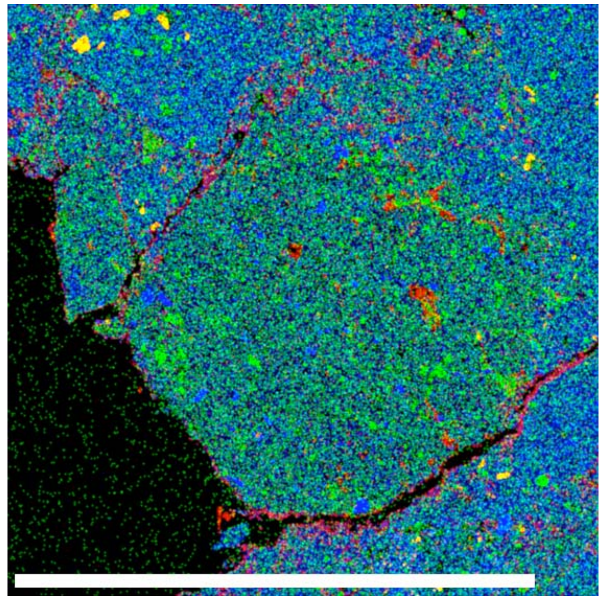

Fig. 1: Elemental map montage of Orgueil (CI1), showing the 750μm-wide sub-hexagonal clast. Mg is in blue, Fe is in green and S is in red. The scalebar is 1mm across.

Results: The clast only appears obvious in elemental maps (Fig. 1). The texture is very similar to the surrounding material, so is invisible on the BSE image.

SEM elemental montage: The Mg/Fe ratio appears to be discriminant, and reveals that the clast is slightly depleted in Mg compared to the surrounding matrix. The depletion is not great (~1.40 at%) but is consistent throughout the clast.

Electron Microprobe: Element mapping reveals sharp edges, making the clast a well defined regular-sided feature (Fig. 2). Ni and Co are not abundant, but are slightly enriched in the clast relative to the surrounding matrix. Si is slightly more abundant in the surrounding CI.

Olivine composition: We have found a number of olivine phenocrysts in the clast. The distribution and abundance of these phenocrysts does not appear significantly different from the rest of the sample.

ToF-SIMS: The ToF-SIMS data confirms the elemental variations observed with the electron microprobe. In addition to elemental mapping we can extract quantitative data to compare the composition of the clast and matrix (Fig. 3). Na and K are very sensitive to surface contamination and caution should be used in comparing the abundance of these elements. Mg and Ti appear to be slightly enriched in the matrix, whereas the clast is relatively enriched in Cr, Mn, Fe, Co, and Ni.

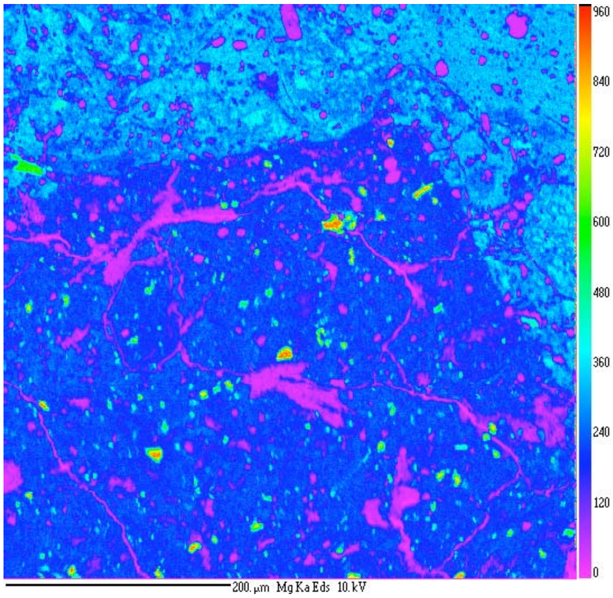

Fig. 2: Electron microprobe Mg map between the clast (depleted) and the surrounding matrix (enriched). The sharp edges of the clast are obvious. The scalebar is 200µm across.

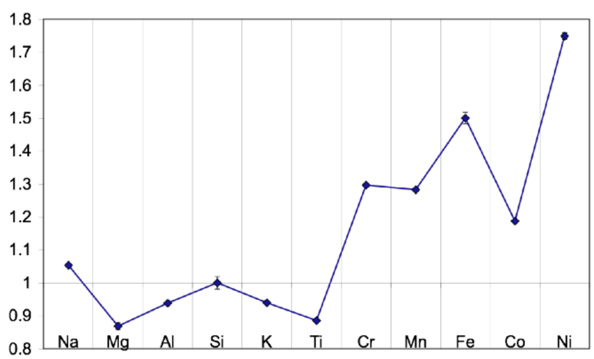

Fig. 3: Elemental ratios *clast/matrix*. The clast is depleted in Mg, Al and Ti, and enriched in Cr, Mn, Fe, Co and Ni relative to the matrix.

Discussion and Conclusion: The clast has features that require explanation as it may have important implications for understanding the origin of Orgueil. To summarise relevant observations: it is as fine-grained as the surrounding matrix; Mg is depleted; Cr, Mn, Co, Ni and Fe are enriched; sharp edges are preserved at contact with the matrix. These features all suggest that the clast represents a distinct lithologic type [10]. The composition of olivine phenocrysts in the clast does not differ from those in the bulk sample, suggesting that olivine phenocrysts in clast and matrix share a common origin. Other than olivines there are no other phenocrysts observable in the clast. The Mg depletion resides in the fine-grained components of the clast. Aqueous alteration is usually associated with grain size reduction of the chondrite components. Our clast clearly did not escape hydration but it is difficult to explain the sharp contact of the clast edges with matrix. If the clast had been included in the parent-body at the beginning of the alteration process, the mobility of the elements would have blurred its edges (due to a chemical gradient or a fluid flow). The clast thus seems to be a late-stage accretional component to the CI parent-body perhaps implying CI chondrites sourced already hydrated components from multiple sources that produce lithological variations in addition to in situ brecciation. The clast shape recalls the shape of a sectioned olivine grain. The main constraints on this clast are: its size, its regular-sided shape and its chemistry (after having experienced intense aqueous alteration). Considering a single mineral to be the precursor of this clast may account for its shape, however this is difficult to reconcile with its large size (~750µm). The size of the clast is also difficult to relate to any hypothetical chondrule precursor. Suggesting that the clast is a remnant of another type of chondrite may be consistent with its size and its chemistry (the processes experienced thus become more difficult to assess) but explaining its pseudo-euhedral shape becomes more difficult.

To improve our understanding of how this clast agglomerated to the CI parent-body, and what its precursor may have been, we are acquiring more ToF-SIMS data with higher spatial resolution and sensitivity. We are also determining the bulk modal mineralogy of multiple Orgueil sub-samples by PSD-XRD in order to compare the abundances of olivine in matrix with that determind in the clast by X-ray mapping. We also plan to use LA-ICP-MS to contrain the abundance of trace elements in the clast. This should give us an improved insight into compositional heterogeneity of CI chondrites. It is very difficult to learn about the "primordial" CI because they have experienced such complete aqueous alteration. Clasts such as these are important as they provide clues about the original texture and heterogeneity of the parent body of these enigmatic meteorites.

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