RELICT FORSTERITE IN UNEQUILIBRATED ENSTATITE CHONDRITES. L. C. Zenie[1], N. V. Almeida[1], A. J. King[1], I. A. Franchi[2], P. F. Schofield[1] and S. S. Russell[1], [1] Department of Earth Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK, [2] Planetary and Space Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.

Introduction: Enstatite chondrites (ECs) are thought to represent the material present in the accretion regions of the terrestrial planets [1]. However, ECs contain unique mineral assemblages which indicate that they formed under much more reduced conditions than the Earth. Their major silicate phase is near-endmember enstatite [2, 3] of which two types have been identified [4]: primary enstatite which crystallised directly from chondrule melts and secondary enstatite which formed by reduction of ferroan olivine. Olivine in unequilibrated ECs (<8 vol.%) is almost pure forsterite ($Fa_{<1}$) [5], and found almost exclusively inside chondrules.

Forsterite grains which experienced low degrees of melting and/or short heating durations above solidus temperatures have been found to survive as relict grains [6]; relicts are grains that did not crystallise *in situ* with their host chondrules. It is hypothesized that most forsterite grains within type I chondrules are relicts [7]. The detection and abundance of relict grains in porphyritic chondrules is important for determining the nature of their precursors and their mode of formation [8]; they preserve the imprint of processes that occurred in the solar nebula [9].

High resolution cathodoluminescence (CL) imaging increases significantly the probability of finding relict grains [10, 11]. Two types of low-FeO (<3 wt.% FeO) silicates have been described in the literature [12] and can be identified with CL imaging; pure, Fe-free, endmember minerals with below detectable (<0.04 wt.%) levels of trace elements exhibit blue luminescence, whereas if trace minerals are present (>0.04 wt.%) they may appear red [13].

It has long been assumed that ECs formed from material condensed at supersolar C/O ratios, however, recent trace element work suggests that ECs may have instead formed from precursors that formed in a more oxidising environment [14]. Later processing of these precursors in an unusually S (and other volatile)-rich and O-poor environment may then explain the highly reduced nature of ECs [14, 15]. Exposure to such environments could explain the reduction of olivine to Mg-rich pyroxenes. ECs may, therefore, record an evolving nebular composition from oxidising to reducing conditions. Following on from an earlier study [16], we have analysed several relict olivines in primitive unequilibrated ECs to explore this hypothesis.

Method: A polished section of Kota Kota (EH3; BM.1905, 355; P22811) was studied. Element mapping by EDS (Zeiss EVO 15LS SEM) was used to locate olivine grains, followed by high-resolution CL imaging (512×512 pixels). Mosaics were collected with a Gatan ChromaCL imaging system, at an accelerating voltage of 10kV, beam current of 3nA and a distance of ~1 mm from the CL detector.

Findings: Forsterite grains were identified in 24 chondrules in the Kota Kota sample (~25% of all chondrules in the sample). They occur either as anhedral to subhedral grains in the centre of chondrules surrounded by enstatite or as mottled grains within larger enstatite phenocrysts. Olivine abundance in the chondrules ranged from $\leq$ 1% to $>$ 30% with the largest grain measuring ~ 1.2 mm × 1.2 mm. Based on the size and morphology of the forsterite grains, ten porphyritic olivine-pyroxene (POP) chondrules were prioritized for CL imaging; two of which are shown in Figs. 1 and 2.

The analysed chondrules are type IB and, therefore, it is likely that all forsterite grains located within them are relicts. The chondrules were found to exhibit different CL properties that can be divided into six groups: (i) bright red CL throughout the grain, often with varying intensity; (ii) bright red CL interiors rimmed by blue CL; (iii) bright red CL containing areas of enstatite showing blue CL; (iv) dark red CL around the edges of the chondrules; (v) mixed CL appearing purple; and (vi) consistently blue CL throughout.

Red and blue CL observed in the chondrules indicate the presence of forsterite and enstatite with varying concentrations of trace minerals. Many of the red luminescing forsterite grains exhibit intensity differences. These likely represent the heterogeneity and complex zoning of trace element distributions in individual grains [10], however, they may also be the result of shock. The enstatite showing dark red luminescence around the edges of the chondrules likely represents a later generation of chondrule growth (Figs. 1 and 2).

Implications: The existence of silicates exhibiting different CL indicates these grains may have different precursors, evolutionary paths or may have formed at different times in the same evolving region of the nebula. It is possible that blue luminescing enstatite formed by reduction of olivine. This supports the hypothesis of an evolving solar nebula and the suggestion that the precursors of EC chondrules may have formed in a more oxidized environment.

EC chondrule precursors, therefore, may have been more similar to other chondrite groups and terrestrial planets than previously thought. Indeed, the relict olivine grains of our study may give us insight into the composition and nature of the building blocks of Earth.

Our work will advance to analysis on the electron microprobe to confirm the CL intensity variations are due to complex zoning of trace elements in these grains as opposed to being shock induced. This analysis should aid in providing further understanding of the origin and history of relict grains.

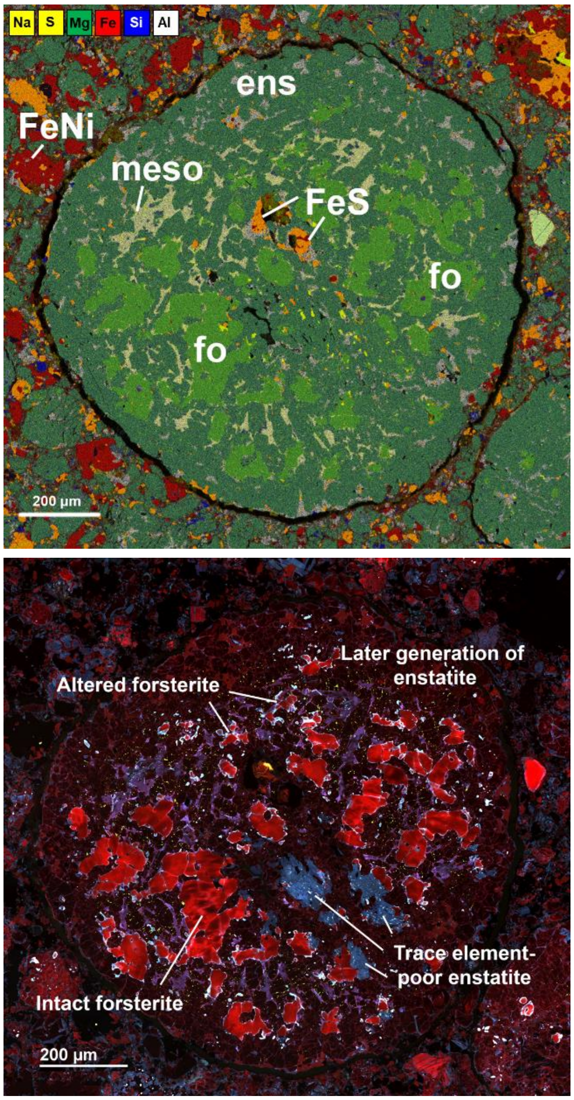

Figure 1 – Composite element map (top) and CL image (bottom) of chondrule C1 (Olivine < 20%; $Fa_{0.42}$).

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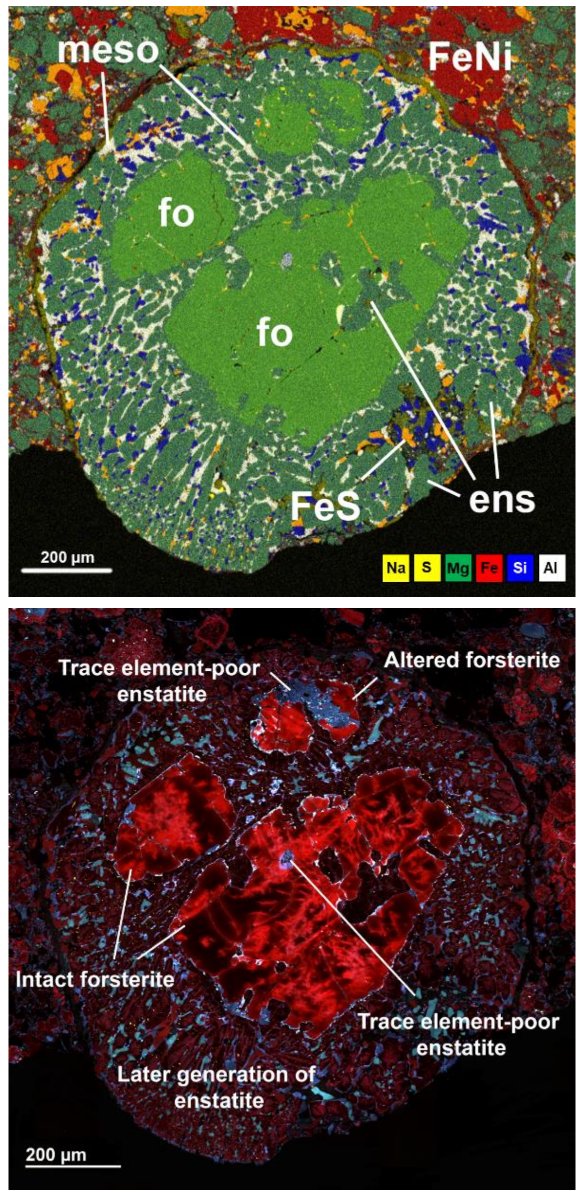

Figure 2 – Composite element map (top) and CL image (bottom) of chondrule C2 (Olivine ~ 30%; $Fa_{1.17}$).