REE+Y SYSTEMATICS IN CC AND UOC CHONDRULES. A. Pack[1], J. M. G. Shelley[2] and H. Palme[3], [1]CRPG/CNRS 15 Rue Notre Dames des Pauvres, 54501 Vandoeuvre-lés-Nancy, France, apack@crpg.cnrs-nancy.fr. [2]RSES, Australian National University, Mills Road, Canberra ACT 0200, Australia, mike.shelley@anu.edu.au. [3]Institute of Mineralogy and Geochemistry, University of Cologne, Zülpicher Strasse 49b, D-50674 Köln, Germany, palme@min.uni-koeln.de.

Introduction: Some Ca,Al-rich inclusions (CAIs) or their precursors formed by condensation after removal of an early condensed highly refractory component. The evidence is based on their uniquely fractionated rare earth element (REE) patterns. These Group-II REE patterns are the best evidence for condensation processes [1]. They cannot be produced by evaporation of chondritic material. Chondrules are richer in SiO_2 and MgO and less refractory as CAIs and have sampled material that formed at lower temperatures at which all REEs were fully condensed. Misawa and Nakamura [2] were the first to report gas/solid fractionated REEs in chondrules from carbonaceous chondrites (CCs). They attributed the unusual REE patterns to incorporation of CAI-like components into chondrule precursor material [3,4,5]. Chondrules from unequilibrated ordinary chondrites (UOCs) have, in most cases, largely unfractionated REEs [6]. The lack of non-igneous fractionation in REEs of UOC chondrules may indicate thus indicate that chondrule recycling was more effective in UOCs than in CCs.

We have used high-precision LA-ICPMS techniques (RSES, ANU Canberra) to analyze chondrules and chondrule mesostases from CCs (Allende: CV3; Vigarano: CV3) and UOCs (Dar al Gani 369: L/H3; Dar al Gani 378: H/L3, Chainpur LL3.4). REEs are highly incompatible with respect to the major chondrule phases (olivine, pyroxene). Hence, mesostasis is the major REE carrier and mesostasis analyses will give informations about REE fractionation of bulk chondrules [6].

Results: Amongst 12 chondrules studied, we have identified five chondrules with positive and negative anomalies in Sm, Eu, Tm and Yb (Fig. 1a–e). The chondrules come from CV3 chondrite Vigarano, UOCs DaG369 (L/H3) and DaG378 (H/L3). Four objects are type-I porphyric olivine chondrules and one is a barred olivine chondrule. The patterns with anomalous Sm resemble those known from ultra refractory as well as those from Group-II CAIs [7]. Two chondrules (DaG369-RF02 and DaG378-RF03) with extreme negative anomalies in Sm, Eu and Yb and a pattern resembling that of ultra refractory CAI patterns have been previously described [8]. These two chondrules are unusually rich in alkalis and poor in Ca with olivine being more Ca-rich than the surrounding mesostasis glass. Within analytical uncertainty, Y/Ho is unfractionated in the mesostases.

Discussion: We present two types of REE patterns. The first type (Fig. 1d,e) includes large negative anomalies in Sm, Eu and Yb accompanied by a slight LREE < HREE fractionation. This pattern is suggestive of incorporation of an ultra refractory condensate that formed under highly reducing conditions at high C/O ratios [8]. Thermodynamic calculations indicate that Sm becomes considerably more volatile with decreasing C/O ratio [9]. It was suggested by [8] that ultra refractory oldhamite (CaS) was the high-REE carrier phase in the precursor material of the two chondrules DaG369-RF02 and DaG378-RF03. Oldhamite occurs in the highly reduced enstatite chondrites (ECs). The presence of oldhamite in UOC chondrule precursor material would indicate mixing of UOC and EC material [8].

The second new REE pattern is characterized by positive Sm, Eu, Tm and Yb anomalies and a slight LREE < HREE fractionation (Fig. 1a–c). A very similar pattern has been observed in perovskite from ALH85085 (CH2) [10] and hibonite from the CM2 chondrite Murchison [11] (Fig. 1f). These patterns can be explained in terms of removal of the "reduced" ultra refractory component followed by condensation of the remaining gas with enrichments of the more volatile REEs.

The presence of Sm anomalies in chondrules indicates that a certain fraction of both, CC and UOC chondrule precursor materials formed by fractional condensation at non-canonical high C/O ratios [8]. An elevated C/O ratio can be the result of evaporation of C-rich material from the ISM. The data from [10,11] indicate that anomalous Sm may not be restricted to highly reduced material as CaS. None of the chondrules from CCs and UOCs contained CaS or any other exotic reduced phase. Either the reduced phases in the precursor had been oxidized during the chondrule forming event or oxides and silicates such as shown in Fig. 1f were the high-REE carriers with anomalous Sm.

The presence of gas/solid fractionated REEs in chondrules excludes extensive recycling of chondrules which would ultimately lead to largely unfractionated REEs. We suggest that chondrule recycling in the CC and OC formation region was not effective enough to erase all nebular REE signatures in chondrules.

The number of chondrules with unusual REE patterns in a given meteorite is not well known. This would require REE analyses of hundreds of chondrules. A better knowledge of the fraction of unusual chondrules would allow to develop a stochastic model that predicts the maximum number of chondrule recycling steps.

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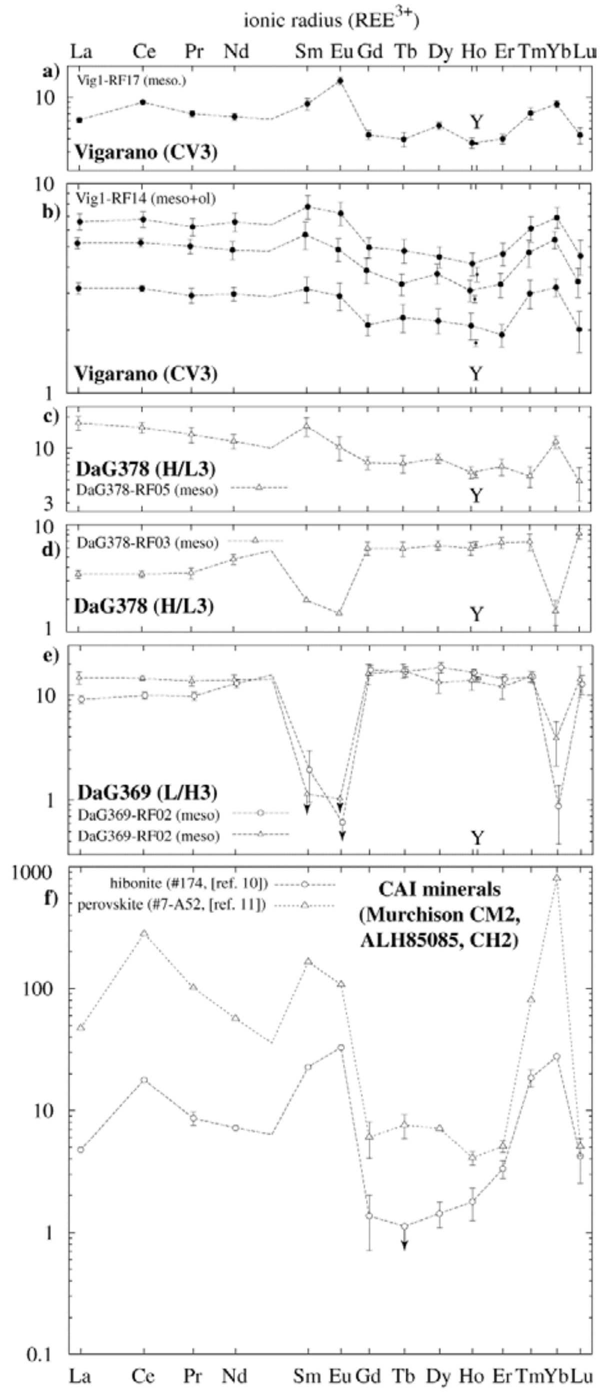

Fig. 1: C1-normalized REE concentrations in mesostases from (a,b) Vigarano, (c,d) DaG378 and (e) DaG369. (f) shows data from CAI hibonite and perovskite with distinct positive Sm anomalies (data from [10,11]).