IDENTIFICATION OF FEO-RICH RELICT OLIVINES IN TYPE IIA CHONDRULES USING FE-MN SYSTEMATICS.
J. Berlin, R. H. Jones and A. J. Brearley, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, U.S.A., e-mail: jberlin@unm.edu

Introduction: Relict grains (i.e., grains that did not crystallize *in situ* from the host chondrule melt) provide a real physical record of chondrule precursor grains. Most relicts appear to be derived from previous generations of chondrules and hence represent evidence for recycling of material in the chondrule forming region(s). [1] estimated that at least 15% of chondrules contain material that experienced at least two chondrule-forming events. Two types of relict grains are frequently encountered in chondrules: relict forsterite or enstatite grains in FeO-rich (type II) chondrules and "dusty" olivine grains in FeO-poor (type I) chondrules [e.g., 1-3]. Moreover, [4] showed evidence that FeO-poor relicts exist in type I chondrules and [5] suggested that type II chondrules might contain ubiquitous FeO-rich relict grains. Below, we show how the latter can easily be identified via Fe-Mn systematics.

Samples and method: As part of a detailed EPMA study of chondrules from pristine chondrites [6,7], we obtained random (3-10) olivine analyses of 5 type IIA chondrules in Kainsaz (CO3.2), 2 type IIA chondrules in MET00426 (CR3.0) and 6 type IIA chondrules each in MET00526 (L/LL3.05) and QUE97008 (L3.05). Additional analyses were collected on relict grains. Quantitative analyses were obtained on a JEOL 8200 electron microprobe with a focused beam, an accelerating voltage of 15 keV and a beam current of 20 nA. We also included previously published data in our study ([8], also see references in [6,7]).

Results: Olivines from type IIA chondrules in CO and unequilibrated ordinary chondrites (UOC) have significantly different slopes in a Mn vs. Fe diagram [6,7], as indicated in Figs. 1d and 2b. Our recent assessment of previously published data of olivine zoning profiles in Semarkona type IIA chondrules [8] indicates that olivine grains which crystallized from the same chondrule melt typically fall on a single trendline in the Mn vs. Fe diagram [7]. Each chondrule may show a slightly different slope, but when a relict grain is encountered it plots in a significantly different region of the diagram. Most of the olivines we analyzed have compositions consistent with crystallization from the host chondrule when it was molten. However, based on their aberrant compositions, we recognized five FeO-rich olivine grains that we consider to be relicts, as well as several relict forsterites. Three of the FeO-rich relict grains are discussed below.

In a Kainsaz type IIA chondrule (Fig. 1a), we found that the relict core of Grain 1 (Fig. 1a,b) has an unusually high Mn content (0.89 wt% MnO at Fa_{20}), while the host olivines have much lower Mn contents (0.09–0.37 wt% MnO, with the lowest MnO contents found in the cores) and plot along the CO trendline in the Mn (afu) vs. Fe (afu) diagram (Fig. 1d). The relict core of another grain in the same chondrule (Grain 2, Fig. 1a,c) has a slightly higher Mn content than typical CO type IIA chondrule olivines (Fig. 1d). Close-up images of the relict grains (Fig. 1b,c) reveal the presence of tiny, aligned metal blebs (<1 μm).

We also identified a relict grain in a Semarkona type IIA chondrule (Fig. 2a) based on previously published data by [8]. The elongated olivine grain in the center of this chondrule has unusually low Mn contents (0.10–0.25 wt% MnO at $Fa_{18–24}$) compared to UOC data (Fig. 2b), with a composition that lies close to and even below the CO trendline.

Discussion: We have observed several FeO-rich grains in type IIA chondrules that we consider to be relicts, because they do not plot on the host olivine trendlines in a Mn vs. Fe diagram (Figs. 1d and 2b). The composition of the relict core of Grain 1 in the Kainsaz chondrule (Fig. 1) is very unusual in comparison with the typical range observed in chondrites [6,7]. However, it is actually very similar to the composition of olivines (Fa_{20-21} and 0.8 MnO wt%) in a chondrule-like object ("Torajiro") found in samples collected by the Stardust mission from comet 81P/Wild 2 [9]. Because other olivines with even higher Mn contents were also found in such chondrule-like objects in Wild 2 samples, [9] associated them with LIME olivines [10]. In our case, the presence of small metal blebs (Fig. 1b,c) might indicate that both relict grains in the Kainsaz chondrule were initially more FeO-rich and underwent reduction before the formation of the host chondrule. Grain 1 in the Kainsaz chondrule may have been derived from a previous generation of UOC type IIA chondrules (initial Fa_{42}) rather than from another CO type IIA chondrule (projected Fa_{95} would clearly be unreasonable). The low Mn content of the relict grain in the Semarkona chondrule suggests that it could potentially be a grain that originally formed in the CO type IIA chondrule formation region (Fig. 1b).

Because we only analyzed 3-10 grains per chondrule, it is fairly possible that we missed other relict grains. The prospect of finding more relict grains using Fe-Mn systematics might result in a greater population of relicts in chondrules than what has previously been estimated (e.g., [1]).

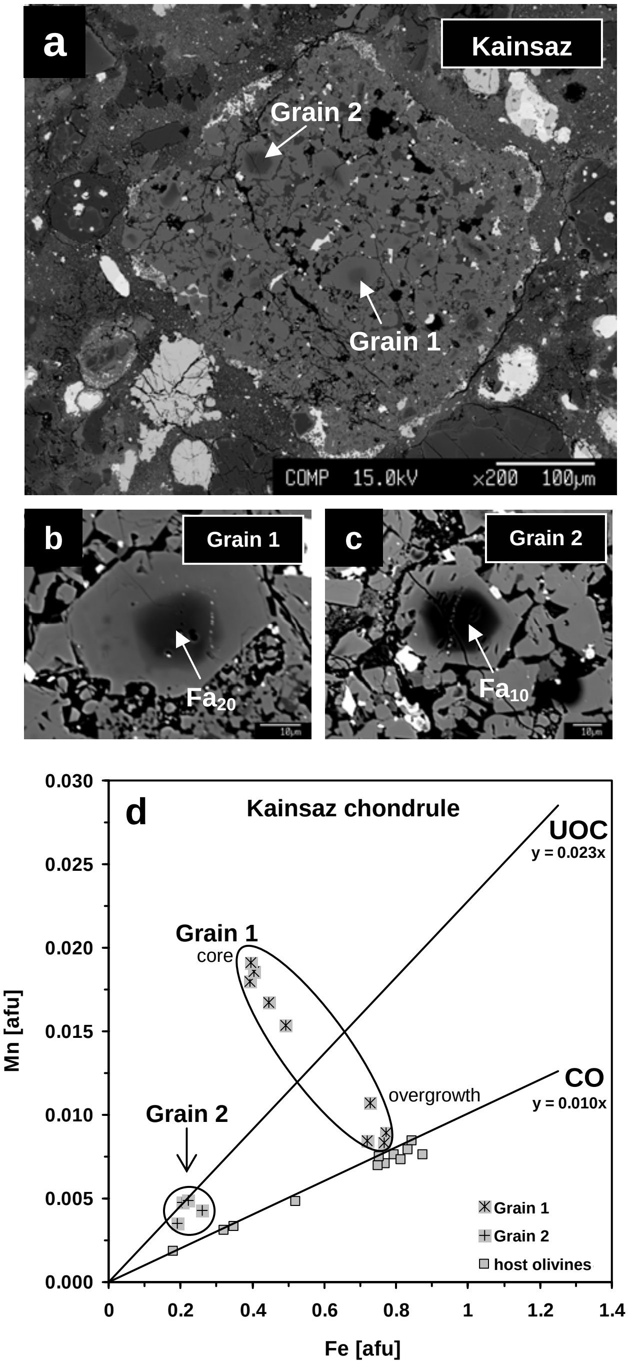

Fig. 1. a) Type IIA chondrule in Kainsaz (CO3.2). Close-up images of the indicated relict grains are shown in (b) and (c). d) Mn (afu) vs. Fe (afu = atomic formula units) of individual olivine analyses of the chondrule shown in (a). The trendlines for UOC and CO type IIA chondrule olivines are from [6,7]. Host chondrule olivines of the Kainsaz chondrule shown in (a) plot along the CO trendline, while the relict grains have higher Mn contents.

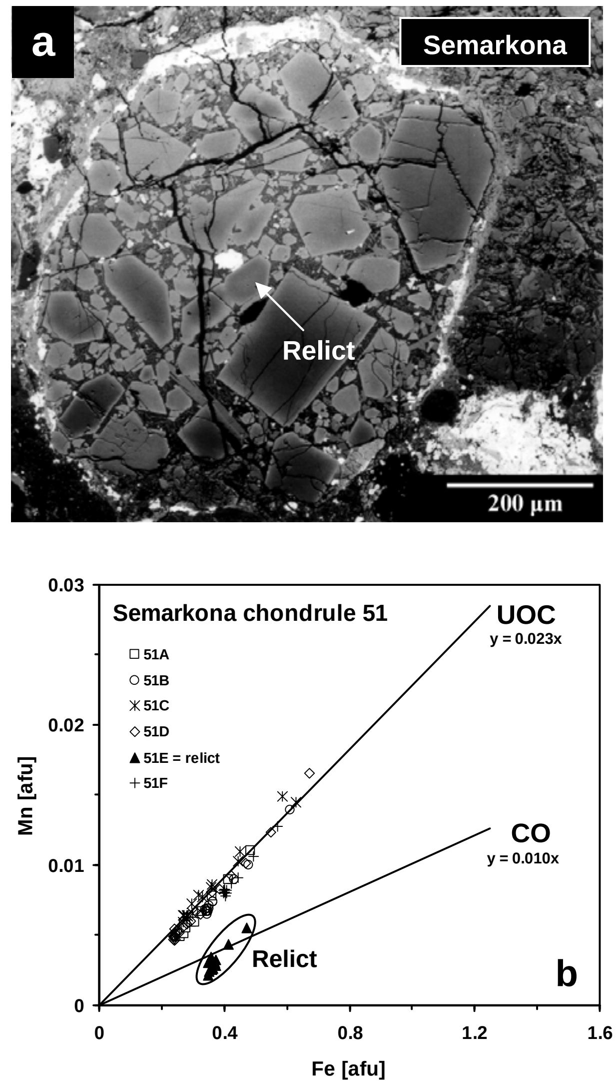

Fig. 2. a) Type IIA chondrule (#51 in [8]) in Semarkona (LL3.0). b) Mn (afu) vs. Fe (afu) of individual olivine analyses (zoning profiles) from [8] of the chondrule shown in (a). The trendlines for UOC and CO type IIA chondrule olivines are from [6,7]. Host chondrule olivines of the Semarkona chondrule shown in (a) plot along the UOC trendline, while the relict grain has a much lower Mn content.

Acknowledgements: This work was funded by NASA grant NNG06GG37G to A.J.B. and NNG06GF73G to R.H.J

References: [1] Jones R. H. (1996) In *Chondrules and the protoplanetary disk*. 163-172. [2] Jones R. H. and Danielson L. R. (1997) *Meteoritics & Planet. Sci., 32,* 753-760. [3] Pack A. et al. (2004) *GCA, 68,* 1135-1157. [4] Jones R. H. and Carey E. R. (2006) *LPS XXXVII,* Abstract #1783. [5] Wasson J. T. and Rubin A. E. (2003) *GCA, 67,* 2239-2250. [6] Berlin J. et al. (2008) *LPS XXXIX,* Abstract #2490. [7] Berlin J. (2009) *Ph.D. thesis*, University of New Mexico. [8] Jones R. H. (1990) *GCA, 54,* 1785-1802. [9] Nakamura T. et al. (2008) *Science, 321,* 1664-1667. [10] Klöck W. et al. (1989) *Nature, 339,* 126-128.