

## TRACE AND MINOR ELEMENT COMPOSITION FOR INDIVIDUAL SEMARKONA CHONDRULES.

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**Introduction:** Excepting CIs, all chondrites contain chondrules and exhibit a level of volatile element depletion with respect to the solar photosphere (excluding O, H, and the noble gases). Through obtaining trace and minor element absolute bulk chemical compositions for chondrules and matrix we can : 1) investigate the genetic relationships between components, 2) assess their role in establishing chemical fractionation between chondrite groups, and 3) search for possible redistribution of elements in the course of parent-body alteration.

Chondrules are divided into two main chemical groups known to exhibit significant differences in terms of their volatile element abundances: type Is (FeO-poor, reduced) are depleted in volatile elements, whereas type IIs (FeO-rich, oxidised) are closer to CI abundances [e.g. 1].

Semarkona (LL3.0), almost certainly the most pristine ordinary chondrite available for scientific investigation [eg. 2], is composed of ~25% type I and ~58% type II chondrules [3]. The bulk rock composition is well known [4-5] whilst major element compositions for individual chondrules have been measured via INAA and broad beam EMPA [1]. The trace and minor element absolute abundances (ppm) for individual chondrules have not been studied in a systematic manner until now. Here, we combine micromill extraction with solution inductively coupled mass spectrometry (ICP-MS) to obtain these data from a set of well characterized chondrules.

**Method:** 12 chondrules were selected from within a Semarkona polished resin mount. High resolution SEM images were collected and EPMA used to determine major element abundances within olivine, pyroxene and glass. The images were used to measure the nominal grain sizes (NGS) of the chondrules after [6], to serve as a quantitative indicator of textures. ~100µg was then extracted from each chondrule using a New Wave micromill, as described in [7]. Each sample was accurately weighed and digested via typical HNO<sub>3</sub>:HF dissolution. Solution ICP-MS was then employed to measure the absolute abundances for ~52 elements within each sample.

**Data:** Results are shown in Fig. 1-2, in which data are normalised to CI values. Each chondrule is unique

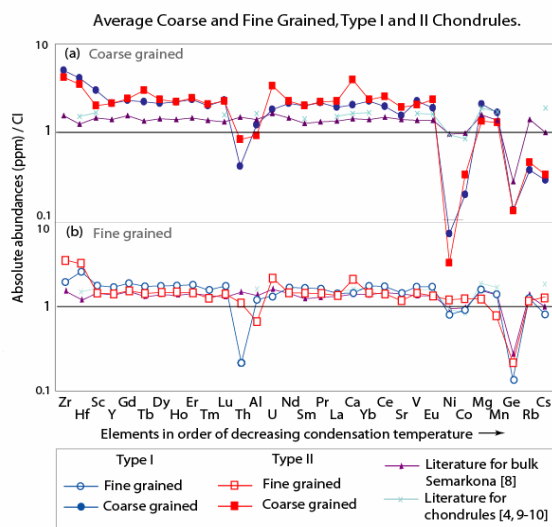


Fig. 1. The upper section (a) illustrates the average composition for type I and II coarser grained (NGC>20: microporphyrines, porphyries and non porphyritic) chondrules. The lower section (b) shows the average composition for type I and II finer grained (NGS<20) chondrules. Literature values for Semarkona bulk rock and chondrules are also displayed. All data are normalised to CI values.

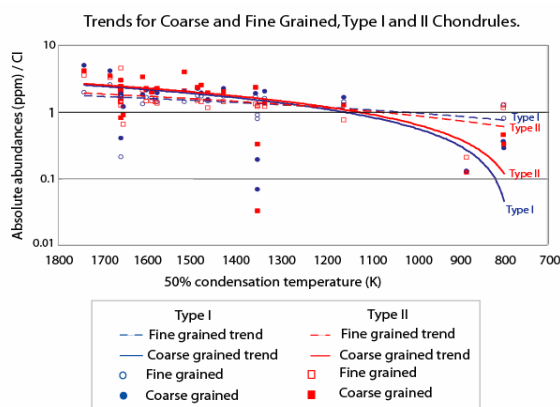


Fig. 2: A log. plot displaying the absolute element abundance (normalised to CI) for all coarse and fine grained chondrules from both types I and II varieties against the elements' corresponding condensation temperature [after 11]. Linear trend lines are drawn to illustrate the variation in depletion of the more volatile elements relative to CI values.

in its trace and minor element composition. Elements were sorted into order of volatility (the temperature at which the element condenses from a gas) [after 11] so that the level of volatile element depletion with relative to CI value could be easily discerned.

Fig. 1 illustrates the similarity (with the exception of several elements) between our ICP-MS determined chondrule compositions and published values for bulk rock [4] and chondrules [8-10]. This is unsurprising given that Semarkona is primarily composed of chondrules. Both types of chondrules are, however, somewhat enriched in refractory elements and depleted in volatile elements. Despite our rather small sample set, it is interesting that, in contrast to published major element data [eg 1], the extent of volatile element depletion is only slightly more pronounced in type Is than type IIs.

The variance between the fine and coarse grained chondrules is displayed in fig. 1. The type of chondrule appears to have very little influence over the chemical composition when divided into fine and coarse grained. Fine grained chondrules appear to have a composition very similar to CI values, whereas the coarse grained chondrules display an enrichment in refractory and depletion in volatile elements below CI.

**Discussion:** All typical chondrules are depleted in volatile elements with respect to solar composition, the depletion being marginally less pronounced in type IIs than type Is [1]. The origin of this depletion has been long debated. Loss during the chondrule forming event and inheritance of the signature from precursors have both been suggested. [12]

Trends in the compositions for finer-grained chondrules (fig. 1(b)) help better understand this depletion. Scarce and often small, these chondrules contribute little to the bulk composition of the chondrite, yet can potentially explain the effect of the chondrule melting event. The high resolution SEM pictures and NGS countings show that there are no discontinuities between fine-grained and coarse-grained chondrules. Hewins et al. [6] interpreted fine-grained chondrules as having been less extensively melted than coarse-grained chondrules (to lower peak temperatures and/or shorter durations) as heating destroys the crystallisation nuclei. Glassy or barred olivine chondrules therefore represent the most extensively melted objects in which all the nuclei were destroyed during the melting event, whilst the finer-grained chondrules maintained enough crystal nuclei so that coarsening was inhibited. In terms of major elements, the less melted, finer-grained type I chondrules were significantly less depleted than the more extensively melted, coarse chondrules [6]. It could therefore be inferred that the latter lost their volatiles in the course of the melting event.

Our results confirm the above findings for type I chondrules and show that a similar pattern is true for type II chondrules. The difference between fine and coarse-grained chondrules is slightly less pronounced in type IIs than in type Is, despite the larger range in grainsizes analysed for type IIs (the finest-grained type I chondrules did not contain enough mass on which to perform the chemistry). An explanation for this disparity is for the type IIs to have melted at a higher pressure, thus potentially limiting the level of element evaporation as suggested by [13]. Alternatively, the relative oxidation state of the precursor may have played a role, causing the internal  $fO_2$  of the object to alter during melting, potentially favouring evaporation from the more reduced (type I) chondrules. More chondrules need to be analysed via this method in order that a more conclusive decision be made.

**Conclusion:** We have developed a powerful analytical method capable of determining absolute abundances for a wide range of minor and trace elements from well characterised, in-situ chondrules. Data presented here span a broader range of elements than any previous study. Nonetheless, our results do not confirm the accepted thinking that type Is are significantly more depleted in volatile elements than type IIs. Instead, the divergence is relatively minor, with both types of chondrule exhibiting approximately the same level of volatile element depletion relative to CI. There is a difference in composition with regards grain size however, with the finer-grained chondrules being less depleted in volatile elements than coarser-grained chondrules. We interpret this as the result of volatile loss during chondrule formation, and suggest that chemical differences between the precursors of type I and type II chondrules may have been minor. If the precursors were indeed similar then we ask the question: what created the characteristic differences displayed by type I and type II chondrules?

**References:** [1] Jones R. H. et al. (2005) Chond & Prot Plan Disk, *ASP Conf Series*, 341, 251-285. [2] Sears D. W. et al. (1980) *Nature*, 287, 791-795. [3] Zanda B. et al. (2006) *EPSL*, 248, 650-660. [4] Kallemeyn G. W. et al. (1989) *GCA*, 53, 2747-2767. [5] Jaroswich E. (1990) *MAPS*, 25, 323-337. [6] Hewins R. H. et al. (1997) *Ant. Met. Res.*, 10, 275-298. [7] Gordon S. H. et al. (2007) LPSXXXVIII, Abs#1819. [8] Wasson J. T and Kallemeyn G. W. (1988) *Roy Soc Phil Trans*, 325, 525-544. [9] Grossman J. N. et al. (1983) *GCA*, 47, 759-771. [10] Grossman J. N. et al. (1985) *GCA*, 49, 925-939. [11] Lodders K. (2003) *ApJ*, 591, 1220-1247. [12] Scott E. R. D. and Krott A. N. (2005) in *Treatise on Geochem* 1, 143-200. [13] Lewis R. D. et al. (1993) *Meteoritics*, 28, 622-628.