

**K ISOTOPE VARIATIONS IN CHONDRULES, CAIs, MATRIX AND BULK CHONDRITES.** Y. Ku<sup>1</sup>, M. I. Petaev<sup>1</sup>, A. Ya. Skripnik<sup>2</sup>, M. A. Ivanova<sup>2</sup>, and S. B. Jacobsen<sup>1</sup>, <sup>1</sup>Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, MA02138, USA. <sup>2</sup>Vernadsky Institute, Russian Academy of Sciences, 19 Kosygin Street, Moscow 119991, Russia. (yku@g.harvard.edu)

**Introduction:** The lack of correlation between the K isotopic composition and K depletion in bulk chondrite samples implies that thermal processing in the solar nebula is not the main mechanism to explain the observed K isotope variations [1-2]. We [1] suggested that variations are inherited from pre-solar materials. Recently K isotopic compositions of chondrules and matrices were reported for ordinary (Hamlet LL4 [3]) and carbonaceous (Allende CV3 [4]) chondrites. In both studies, matrix  $\delta^{41}\text{K}$  values in general agree with the bulk sample average while chondrules show a wider range of  $\delta^{41}\text{K}$ . The wider range was explained by parent body alteration due to interaction of chondrules with an *ad hoc* K-bearing fluid. No petrographic or chemical evidence in support of such an interaction was provided. Also, many chondrule  $\delta^{41}\text{K}$  values [3-4] are only based on a single measurement. Thus, the observed wide range of  $\delta^{41}\text{K}$  variations in chondrules may simply reflect inadequate reproducibility of the analyses. To verify whether the observed variations in  $\delta^{41}\text{K}$  result from aqueous alteration, it is necessary (1) to identify whether the K in a sample is primitive or associated with altered mineral phases, and (2) to make repeat K isotope analyses of the same materials. Here we report K isotope data for major chondrite components – chondrules and matrices – to check if there are K isotopic fractionations between components, and if so, whether they correlate with elemental fractionations caused by thermal processing during their formation.

**Sample description and analytical methods:** We analyzed 5 matrix samples and 13 chondrules separated from three ordinary chondrites: 2 matrix samples, with and without tiny chondrules, and 7 chondrules from Elenovka (L5); a homogeneous matrix sample and 2 chondrules from Saratov (L4); and 2 matrix samples (dark and light lithologies) and 4 chondrules from a highly heterogeneous Ochansk (H4). We also analyzed 9 chondrules, 2 CAIs and five matrix samples with different grain sizes from the CV3 chondrite Allende. All major textural and chemical types of chondrules are represented in our sample set. Before dissolution, all chondrules were studied by SEM/EPMA techniques. Large (>20 mg) chondrules were mounted in epoxy and sliced off-center - the smaller chips were used for SEM/EPMA work while the larger portions were extracted, cleaned and dissolved. We also dissolved a piece of epoxy to verify that its K content is

negligible. In the case of small chondrules, we imaged and analyzed by SEM EDS either broken surfaces or chips of gently crushed intact chondrules mounted in carbon paint and carbon-coated. After the analysis, they were thoroughly cleaned and dissolved.

Each sample was gently powdered, dissolved and analyzed with our Thermo iCAP TQ ICP-MS in order to establish their bulk compositions and volatile element depletion patterns. Then the solutions were passed through the ion exchange columns to separate K, and the purified K-cuts were analyzed using the Nu Sapphire ICP-MC-MS, with the results expressed relative the *Suprapur* standard (see [1] for details).

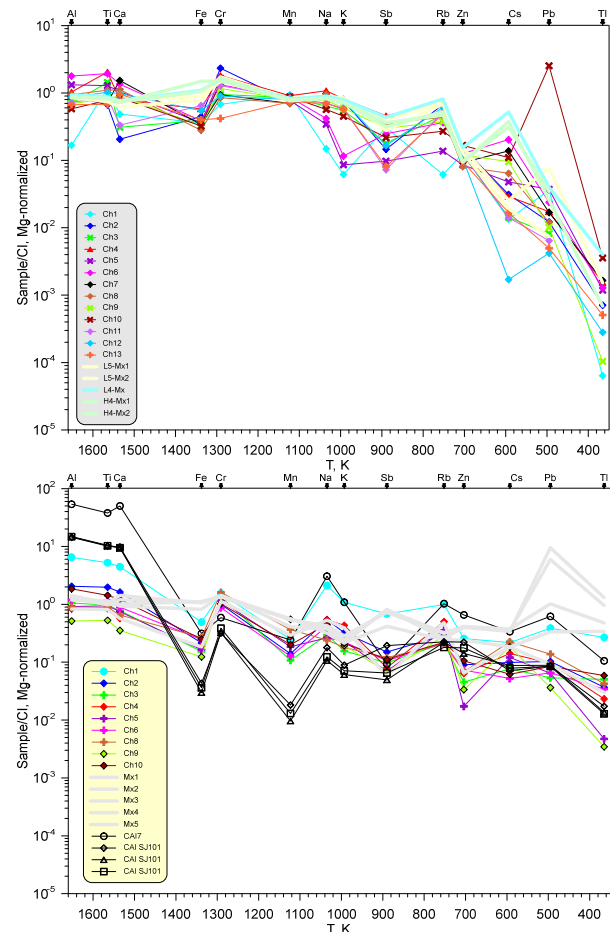


Fig. 1. Element depletion patterns of samples from ordinary chondrites (upper panel) and Allende (lower panel). Colored filled symbols denote textural chondrule types: circle - PL-rich, diamond - OP & OPP, cross - RP, triangle - GO, and plus - BO.

**Results and Discussion:** Concentrations of selected elements in the samples studied, normalized to CI chondrites and Mg, are plotted in Fig. 1 versus condensation temperatures and showing the increasing degree of depletion for elements with low condensation temperatures. The element depletion patterns of chondrules from ordinary chondrites and Allende are somewhat different and, in general, similar to the matrix depletion patterns in each group, but there are no systematic variations among different chondrule types. Currently it is unclear whether the similar depletion patterns of the matrices and chondrules result from a similar thermal history during formation, or whether parent body processing has partially homogenized their compositions.

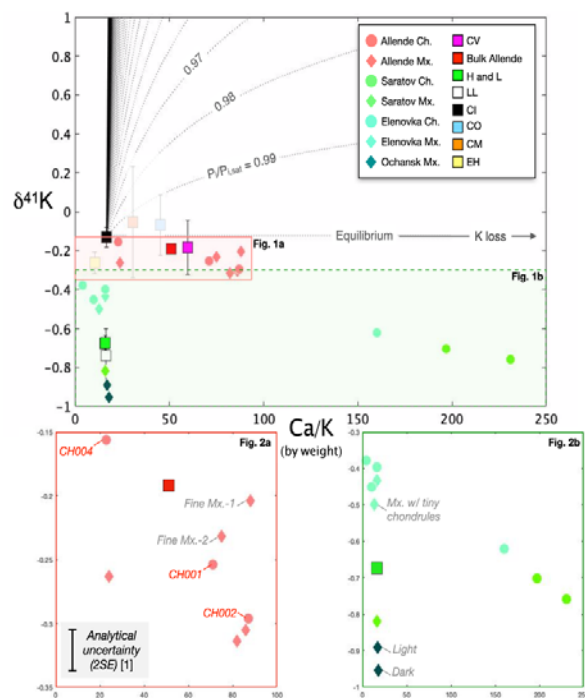


Fig. 2. K isotopic compositions of chondrites and their components (modified from [1]). The figure shows the K depletion in bulk meteorites as well as in each component are not correlated with their K isotopic composition (details in [1]). Fig. 2a is the zoomed view for Allende meteorite. Fig. 2b presents the matrix and chondrule  $\delta^{41}\text{K}$  values from three ordinary chondrites.

No significant K isotopic fractionation was found between ordinary chondrites' matrix and chondrule components, as well as among various types of chondrules. In Elenovka, matrix with and without chondrules yield identical  $\delta^{41}\text{K}$  values that are similar to the values in three chondrules. One Elenovka chondrule (#1) has lighter  $\delta^{41}\text{K}$  than other samples. Two Saratov

chondrules show  $\delta^{41}\text{K}$  values similar to the matrix, all being slightly lighter than the average ordinary chondrites [1]. The samples of dark and light matrix from Ochansk show identical  $\delta^{41}\text{K}$  values, which are the lightest among all ordinary chondrite components analyzed here (Fig. 2).

The five Allende matrix samples have similar  $\delta^{41}\text{K}$  values. The finer-grained matrix has slightly lighter  $\delta^{41}\text{K}$  than the coarser-grained matrix, but the average of all five samples agrees with the bulk Allende-1 value of  $-0.192$  [1]. Two chondrules (CH001 and CH002) with clear evidence of secondary alteration have  $\delta^{41}\text{K}$  values similar to the fine-grained matrix, slightly lighter than the bulk, while relatively fresh CH004 chondrule has the  $\delta^{41}\text{K}$  value similar to the coarse-grained matrix, slightly heavier than the bulk. More repeat measurements are needed, but considering the analytical uncertainty of 30 ppm [1], there is no significant K isotope fractionation between Allende components.

Both chondrules and matrices of ordinary and carbonaceous chondrites have different K isotopic compositions implying that neither of them can be approximated by a common nebular component. Therefore, mixing a CI-like matrix and other major chondritic components to reproduce K isotopic compositions of the bulk meteorites [2] is incorrect. The similar  $\delta^{41}\text{K}$  values for matrices and chondrules mean that the process which has depleted volatile elements in the solar system bodies did not significantly fractionate K isotopes. This further supports the idea that the K isotope variations in chondritic meteorites are inherited from pre-solar isotopic heterogeneity [1].

All five Allende matrix samples have relatively flat depletion patterns (Fig.1), and such a lack of fractionation agrees with a consistent  $\delta^{41}\text{K}$  value. The altered Allende chondrules CH001 and CH002 show depletion patterns similar to CH004. Interestingly, most chondrules studied here have slightly lower K concentrations than the matrix samples despite very similar depletion patterns. So far Allende samples show no correlation between the volatile element depletion and the K isotopic composition.

**References:** [1] Ku Y. and Jacobsen S. B. (2020) *Sci. Adv.*, 6. [2] Bloom H. et al. (2020) *CGA*, 277, 111-131. [3] Koefoed P. et al. (2020) *Meteoritics & Planet. Sci.*, 55, Nr 8. [4] Jiang Y. et al. (2020) *Meteoritics & Planet. Sci.*