

THE K ISOTOPES IN SEMARKONA CHONDRULES ¹C.M.O'D. Alexander and ²J.N. Grossman. ¹Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd. N.W., Washington D.C. 20015, USA. ²U.S. Geological Survey, 954 National Center, Reston, VA 20192, USA.

Introduction: Volatile elements can provide some of the best constraints on the nature of the chondrule formation process and of chondrule precursors. For instance, volatile-poor chondrules may have formed either from volatile-poor material, or by partial evaporation of volatile-rich material during melting.

At the liquidus temperatures of most porphyritic chondrules, Na and K should be lost very rapidly. Alkali abundances in OC porphyritic chondrules do vary by almost three orders of magnitude and tend to be lower in the more refractory Type 1s. Rayleigh-type evaporative loss of K from synthetic chondrules produces rapid increases in $\delta^{41}\text{K}$, even at modest levels of evaporation [1]. Thus, if the range of alkali abundances in chondrules were produced by evaporation under Rayleigh conditions, K should exhibit large heavy isotope enrichments in chondrules with low K abundances.

However, to date no resolvable K isotopic fractionations have been found in chondrules [2, 3]. There are several possible explanations for this lack of isotopic fractionation. Two of them are: (1) that volatile loss was suppressed by high nebula $f\text{O}_2$, and (2) that evaporation of K, enhanced by H_2 , occurred under non-Rayleigh conditions. Experiments have shown that neither explanation is able to sufficiently suppress K evaporation and isotopic fractionation under realistic nebular conditions [4].

A third explanation which is explored here is that the alkalis in chondrules have been affected by secondary processes, such as parent-body metamorphism or aqueous alteration. Previous measurements of K isotopes were conducted on Bishunpur chondrules. Bishunpur is a very robust meteorite, suggesting it has experienced some sintering (metamorphism). The alkalis are very mobile even at modest temperatures and it is possible that exchange with the matrix has erased the isotopic signature of evaporation. Semarkona is the least metamorphosed ordinary chondrite. Here we present measurements of K isotopes in 29 Semarkona chondrules.

Experimental Methods: The Semarkona chondrules selected exhibit a wide range of compositions and textures. They included approximately equal numbers of type I and II chondrules. In the Sears classification, the proportions of classified chondrules are: A1 25%, A2 5%, A3 5%, A5 35%, B2 30%. One dark-zoned chondrule was

measured, as were two matrix areas and a melt inclusion in a chondrule olivine.

The isotope analyses were performed using the Carnegie Cameca IMS 6f ion probe at a mass resolution of 5500. Operating conditions were: 12.5kV O^- primary beam and +10 kV secondary accelerating voltage with a 50 eV energy window. Repeated analyses of a basaltic glass and NBS-610 glass give a standard deviation of about 1‰ for $\delta^{41}\text{K}$. However, in some Bishunpur chondrules multiple analyses produced a much larger range in $\delta^{41}\text{K}$ (5-10‰). We do not think this is due to indigenous isotopic variations in the chondrules. It is more likely to be an instrumental artifact, probably reflecting the influence of surface roughness, fractures and dendrites in the sputtered areas. Sodium, Al and Si count rates were monitored during the isotopic analyses. From these, using the basaltic glass as a standard, Na/Al and K/Al ratios were determined at each spot. Where comparisons were possible, the ratios determined by ion probe are generally very close to those determined by electron probe.

At low K abundances, contamination may become important. To gauge the level of contamination, a chondrule olivine was analyzed by ion microprobe under the same conditions as the glasses. Since olivine probably contains some K, it provides an upper bound on the level of contamination. Potassium count rates from the olivine were 3 times lower than for even the most K depleted glass ($\delta^{41}\text{K}=30\pm 11\%$).

Results: Figures 1 and 2 summarize our results. As can be seen, the alkali/Al ratios vary by more than two orders of magnitude in the chondrules analyzed. This is comparable to the range seen in Bishunpur chondrules [3]. However, in the population of Bishunpur chondrules analyzed, none had super-chondritic alkali/Al ratios and proportionally more of them had low alkali/Al ratios ($\text{Na,K/Al/L}<0.1$). The reasons for these differences are unclear but may reflect sampling biases and/or different parent body processing.

Most chondrules have K isotopic compositions within the range $\pm 3\%$. This is about the range we would expect from the reproducibility of our standard analyses. However, analyses from six chondrules fall significantly outside of this range. Multiple analyses from two of these chondrules have ranges of 0-18‰ and 1-10‰. Similar ranges have been seen in some Bishunpur chondrules and, as discussed above, we believe the range of compositions are artifacts. Two chondrules, $\delta^{41}\text{K}= 9\%$ and -9% have only one

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analysis each, so their compositions must remain questionable. The last two chondrules have two analyses each. In both chondrules, the analyses are consistently heavy ($K/Al/L=0.06$ and $\delta^{41}K=10, 15\%$; $K/Al/L=0.37$ and $\delta^{41}K=5, 6\%$). Therefore, it seems possible that these two chondrules have indeed experienced some K isotopic fractionation.

Discussion: Assuming that all chondrules initially had roughly chondritic K/Al ratios, the L-chondrite normalized K/Al ratio provides a measure of the fraction of K that was lost during chondrule formation. In this case, Rayleigh fractionation predicts a simple relationship between K/Al/L ratio and $\delta^{41}K$. Although, we have tentatively identified at least two chondrules with modest enrichments in ^{41}K , the enrichments are much smaller than would be expected for Rayleigh distillation from chondrules with initially chondritic K/Al ratios.

The absence of a Rayleigh-like relationship between K isotopic composition and elemental abundance in chondrules exhibiting such a wide range of alkali abundances is problematic. Experimentally measured evaporation rates suggest that one cannot simply appeal to heterogeneous precursors to explain the range of alkali abundances. The measured rates suggest that under currently accepted conditions and timescales for chondrule formation, K should have experienced significant evaporation and isotopic fractionation whatever its starting abundance. The more refractory the chondrule, the greater the degree of K loss and isotopic fractionation that is expected.

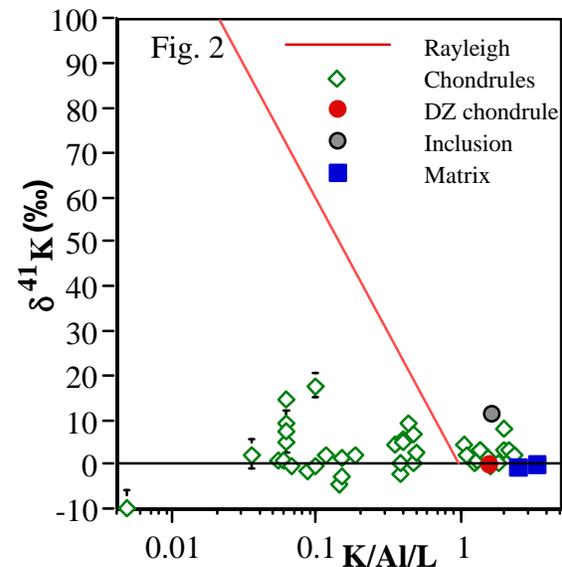
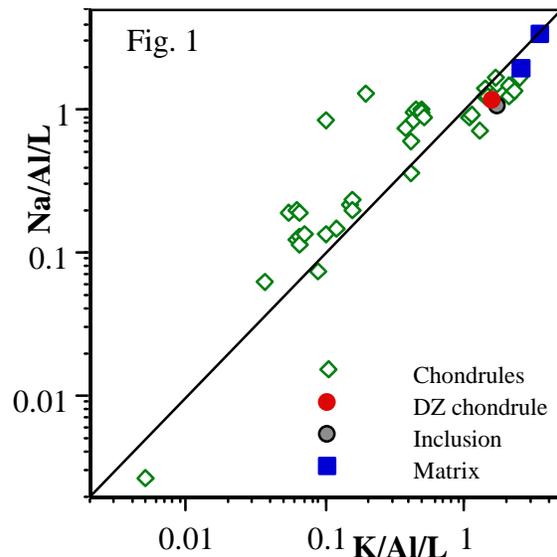
Although Semarkona has not experienced metamorphism, parent body modification of alkali abundances and isotopic compositions in chondrules may still be a factor. There is radial alkali, halogen and water zonation in some Semarkona chondrules [5]. This is clear evidence of exchange between chondrules and matrix during the aqueous alteration Semarkona has experienced. Using previously acquired elemental maps, care was taken to only analyze interior, depleted glass areas in zoned chondrules. These areas almost certainly represent the pre-accretionary compositions of the chondrule glasses. However, in those chondrules with uniformly superchondritic alkali abundances, which includes some type I chondrules, secondary exchange with the matrix may have gone to completion.

From our analyses, it seems likely that most chondrules in Semarkona and Bishunpur lacked any K isotopic fractionation even before parent body alteration occurred. This is consistent with direct condensation models of chondrule liquids, although we doubt that such models can explain many of the properties of real chondrules (e.g., relict grains, fast cooling rates).

Type I chondrules in particular could have formed from volatile-poor material such as high-temperature condensates, which would not be expected to show K isotopic fractionation. Nevertheless, because they are

so refractory they should have experienced significant volatile loss of their alkalis during chondrule formation, enough to have produced large isotopic fractions.

Since we believe K evaporation must have occurred, at present our favored explanation for the scarcity of K isotopic fractionation is that chondrules exchanged with the surrounding gas while molten. What is now certain, however, is that OC chondrules did not experience simple Rayleigh-type loss of K.



References: [1]Yu Y.*et al.* (1998) *Lunar Planet Sci.* **XXIX**, #1642. [2]Grossman J. N.*et al.* (1998) *Meteoritics Planet. Sci.* **33 Suppl.**, A64-A65. [3]Alexander C. M., O'D.*et al.* (1999) *Meteoritics Planet. Sci.* Submitted. [4]Wang J.*et al.* (1999) *Lunar Planet. Sci.* **XXX**, #1778. [5]Grossman J. N.*et al.* (1997) *Lunar Planet. Sci. Conf.* **XXVIII**, 481-482.