POTASSIUM ISOTOPE COMPOSITIONS OF CARBONACEOUS AND ORDINARY CHONDRITES: IMPLICATIONS ON THE ORIGIN OF VOLATILE DEPLETION IN THE EARLY SOLAR SYSTEM

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Introduction: The differentiated planetary bodies of the solar system such as the Earth, Moon, Mars, and asteroid 4 Vesta are depleted in moderately volatile elements (*e.g.*, Na, Cl, K, Cu, Zn, and Rb) in various degrees compared with undifferentiated meteorites such as carbonaceous and ordinary chondrites [1]. The reason of such moderately volatile depletion in planetary materials is still under debate. Possible mechanisms include 1) incomplete condensation in the solar nebula; 2) partial evaporation during planetary accretion (*e.g.*, via high-energy impacts); 3) magma ocean degassing; and 4) local volcanic outgassing [2].

Here we focus on the solar nebula depletion scenario. If the volatile depletions occurred mainly in the nebular environments, and planetary materials simply inherited this depletion from their building-blocks (possibly some material akin to primitive meteorites), we should expect to observe at least some trends of volatile element depletions among undifferentiated, primitive meteorites. Indeed, such trends are seen for the different types of carbonaceous chondrites (CC) (see **Figure 1**). However, the degrees of depletion are much less than those observed in differentiated planetary materials. CI chondrites are the most volatile-rich materials in the solar system, and their compositions are similar to that of the Sun. The abundances of volatile elements in other CC decrease in the sequence of CI>CM>CO=CV>CR>CK [3-4]. Unlike the pattern of volatile depletion among planetary materials, this chemical pattern of volatile depletion exhibited among CC is most likely due to processes in nebular environment occurred in early solar system history.

For ordinary chondrites (OC), there is no clear trend in volatile element depletions (see **Figure 1**). Although their compositions are subject to various degrees of thermal alteration on their parent bodies which caused larger heterogeneities in the meteorite samples for highly volatile elements. However, abundances of moderately volatile elements should not vary dramatically among OC. Systematic studies of all chemical groups of CC and OC have helped distinguish the volatile depletion caused by nebular effects and by parent-body ones [5].

Potassium (K), is a moderately volatile element with a 50% condensation temperature of ~1006K [3]. The isotopes of K have been studied as a potential tracer of volatile depletion as early as 1995 [6]. At that time no variations between differentiated and undifferentiated meteorites were observed due to the large analytical uncertainties using Secondary Ion Mass Spectrometer (SIMS). Since 2016, high-precision K isotope analytical methods using Multi-Collector Inductively-Coupled-Plasma Mass-Spectrometers (MC-ICP-MS) [7-9] revealed small variations in K isotopes between different planetary materials (*i.e.*, Earth and Moon) which have been used to understand the accretion mechanism of different planetary bodies [10].
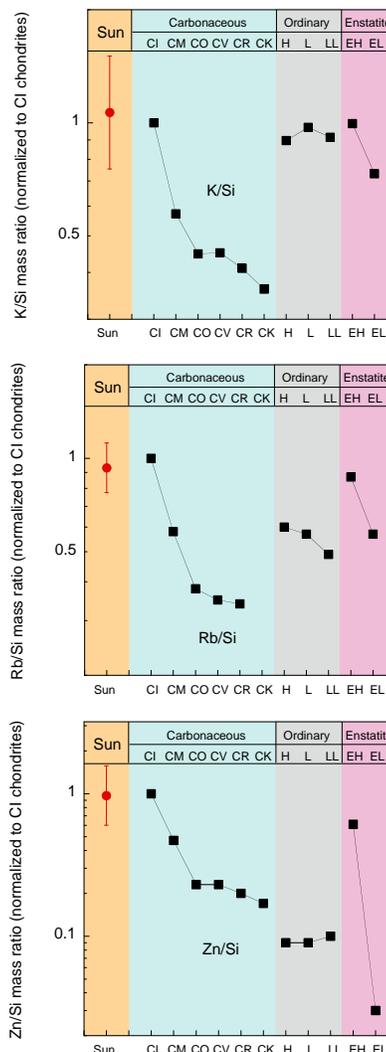
Figure 1. *The ratios of K/Si and Zn/Si in different chemical groups of chondrites normalized to the ratio of K/Si, Rb/Si and Zn/Si in CI chondrites. The ratios of the solar photosphere are also shown. All data are from ref. [3-4].*

High-precision K isotope data are limited for chondrites. Only 1 CC (Orgueil, CI1) and 3 equilibrated OC (Guareña, H6; Bruderheim and Peace River, L6) have been studied [10]. Previous isotope studies of other moderately volatile elements such as Zn and Rb [11-12] indicated large isotopic fractionations among different CC and OC groups. However, Zn, Rb, and K have different 50% condensation temperatures, and K is less volatile than Zn and Rb. The volatile depletion patterns of K and Zn are similar for CC, but not for OC (**Figure 1**).

Therefore in a new effort to better understand volatile depletion among chondrites and to distinguish different K isotopic effects occurred through nebular and parent-body processes by systematically studying different chemical and petrological types of chondrites, we analyzed K isotope compositions of 6 CC and 21 OC. The resulting measurements would also help constrain the mechanisms of volatile depletion among planetary bodies by exploring the ranges of K isotopic fractionation in the solar nebula and on parent-bodies.

Samples and Method: The names, chemical groups, and petrological types are all listed in **Table 1**. The samples covered all major chemical types of CC and OC. Of OC we included at least one sample of each petrological type in order to test for K isotopic fractionation during thermal metamorphism. All 27 samples but 1 are finds from Antarctica. Previous studies have shown the Antarctic meteorites are well-preserved and have little terrestrial contamination [13]. We also demonstrated that the K isotopes of Antarctic meteorites are indistinguishable from those in meteorite falls of the same type, in contrast to NWA (Northwest Africa) meteorites which are significantly contaminated by terrestrial K [14].

Details of our analytical method can be found in ref. [15]. All samples (~100 mg each) were digested using Parr high-pressure digestion vessels at 150°C in Quincy Lab Model 10 lab oven for two days through a two-step protocol (first in concentrated HF/HNO_3 mixture and then in aqua regia). Fully digested samples were dried and then loaded into chromatography columns (ID=1cm; filled with 17 mL Bio-Rad AG50W-X8 100-200 mesh cation exchange resin). Potassium was eluted with 0.7 N HNO3 and then collected. To further purify K from matrix elements, we repeated the same procedure with a smaller column.

Samples were then analyzed with a Thermo Scientific Neptune Plus MC-ICP-MS. The K isotopic compositions are reported in the delta notation, where $\delta^{41}K=([(^{41}K/^{39}K)_{sample}/(^{41}K/^{39}K)_{standard}-1]\times1000)$. The standard we used here is NIST SRM 3141a. The internal (within-run) reproducibility is typical ~0.05 ‰.

The long-term (~11 months) reproducibility of this method has been evaluated as 0.12‰.

Table 1. The chemical classification and petrological types of carbonaceous and ordinary chondrites in this study.

Classification	Name	Classification	Name
Carbonaceous		*Ordinary*	
CV3	Allende	L3.05	QUE97008
CK4	ALH85002	L3.6	GRO06054
CM2	ALH85013	L4	ALH85033
CO3	MIL11213	L5	GRO95530
CO3.5	ALH83108	L5	LAR06303
CR2	GRA06100	L6	ALH85017
		L6	ALHA76001
Ordinary		*Ordinary*	
H3.0	MET00526	LL3.2/3.4	ALHA76004
H3.7	ALHA77299	LL3.7	ALHA77278
H4	RKPA78004	LL4	GRO95552
H5	ALHA77279	LL5	LAP02207
H5	ALH84069	LL5	RBT04127
H5	PRE95400	LL6	PRA04405
H6	QUE90203	LL6	PRA04422

Results: Our new measurements of OC show no systematic variations in K isotopes as function of chemical classification or petrological types. Interestingly, different chemical groups of CC exhibit significant K isotopic fractionations which inversely correlate with their K/Si ratios. The detailed results will be presented during the conference. We will compare the data of chondrites with those of the Earth, Moon, Mars and 4 Vesta that will also be reported in this conference [14]. We will discuss the implication on the origin of volatile depletion in the early solar system.

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