

LITHIUM ISOTOPE COMPOSITION OF ORDINARY AND CARBONACEOUS CHONDRITES, AND DIFFERENTIATED PLANETARY BODIES: BULK SOLAR SYSTEM AND SOLAR RESERVOIRS.

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Introduction: Li isotope compositions of meteorites are presently available for the C1 chondrite Orgueil ($\delta^7\text{Li} = +3.9\%$, [1]), for carbonaceous chondrites ($\delta^7\text{Li} = +3.0\%$ to -3.5% , [2]), a few chondrules and CAI's [3, 4], 2 bulk Nakhilite samples and their constituent olivines and clinopyroxenes ($+5.1\%$ and $+3.7\%$, [5]). Additional data from SIMS studies exist for a pyroxene from a shergottite (core to rim variation from -17 to $+10\%$, [6]) and for melt inclusions in a lunar meteorite (low-Ti mare basalt: $\delta^7\text{Li} = +15\%$, [7]).

Seitz et al. [8-10] measured the Li isotope composition in lunar samples and SNC meteorites. The majority of their samples have an isotope signature close to $+4\%$, similar to bulk silicate Earth [11]. It was concluded that this value may represent the isotopic composition of the inner solar system [10] in agreement with the Li isotope composition of Orgueil (C1) [1].

In contrast, McDounough et al. [2] proposed a bulk solar system value of around 0% for $\delta^7\text{Li}$ based on the average of 6 carbonaceous and one ordinary chondrite. Additionally, the chondrites investigated by [2] display a large range in Li-isotopes from $+3.9$ for Orgueil (CI) to -3.5 for Felix (CO). Based on their results, McDounough et al. [2] suggested that Li isotopes are fractionated on the chondrite parent bodies and correlated with the degree of alteration and metamorphic grade. This differs from the observations for terrestrial planets [11], which show that the diverse processes of planetary accretion and differentiation have not led to a differentiation of Li isotope composition. However, this may be different for parent body processes operating on the more primitive and less differentiated bodies of the solar system.

In order to tighten constraints on the Li isotope composition of the bulk solar system and Li isotope fractionation during accretion and parent body processes, we determined Li isotope compositions and concentrations on a number of meteorite falls comprising samples from H-, L-, LL-chondrites, carbonaceous chondrites (CI, CV3, CV3ox CV3red, CM CM2, CK and CO3), and on several achondrites, including dio-

genites, a eucrite, silicate inclusion in a IAB and a pallasitic olivine.

Methods: Rock digestion and column chemistry followed the procedure of [11], where small 1.4 ml exchange columns with a resin height of 6 cm filled with BioRad AG50W-X8 were used for Li separation. The Multi-Collector Inductively Coupled Plasma Mass Spectrometer (Neptune) allows simultaneous measurement of both ^6Li and ^7Li . Measurements were performed at dry plasma conditions using a Cetac Aridus[®] nebuliser fitted with a PFA spray chamber and an ESI microconcentric-nebuliser with an uptake rate of $20\mu\text{l}/\text{min}$. The sample gas is dried at 160°C before being introduced into the plasma. With the Finnigan standard cones (H-Cones) an intensity of 40-50 pA ($=4-5\text{ V}$ using $10^{11}\ \Omega$ resistor) for ^7Li at a 10 ppb concentration level is achieved. Sample analysis is carried out sequentially by 'bracketing' the sample with the L-SVEC standard [12]. Isotope compositions are expressed as per mil deviations from the NIST L-SVEC standard: $\delta^7\text{Li} = \left[\frac{(^7\text{Li}/^6\text{Li})_{\text{sample}}}{(^7\text{Li}/^6\text{Li})_{\text{L-SVECstandard}}} - 1 \right] * 1000$. Internal precision is typically between $0.2-0.6\%$ (2SE) and the long term reproducibility, determined on replicate measurements of the geological standard JB-2, is about 1.2% (2SD). Lithium concentrations of samples were determined along with the isotope measurements by comparing the ion beam intensities with those of the 10 ppb NIST L-SVEC standard solution. The daily precision of these concentration measurements is typically 10% (2 SD). The long term reproducibility is about 15% (2 SD) [10, 11].

Results: Carbonaceous chondrites have Li isotope compositions ranging from $\delta^7\text{Li} +3.0\%$ (for Allende CV3 and Ornans CO3) to $+4.9\%$ (for Karoonda CK) and Li concentrations from 2.3 to $1.0\ \mu\text{g}/\text{g}$, respectively. Our data for C1 Orgueil ($\delta^7\text{Li} +3.4\% \pm 0.7$, and $1.6 \pm 0.25\ \mu\text{g}/\text{g}$ Li) are in good agreement with those from the literature [1] (Fig 1.). Those for Murchison ($\delta^7\text{Li} +4.3\%$, $1.5\ \mu\text{g}/\text{g}$) and Allende ($\delta^7\text{Li} +3.0\%$, $2.5\ \mu\text{g}/\text{g}$) agree (within 2σ uncertainties) with the data of McDounough et al. [2]. Compared to their data, sig-

nificant heavier isotope compositions are obtained for Efremovka (CVred, $\delta^7\text{Li}$ +4.3‰, 1.7 $\mu\text{g/g}$) and Karoonda (CK, $\delta^7\text{Li}$ +4.9‰, 1.0 $\mu\text{g/g}$). Ordinary chondrites are slightly lighter in $\delta^7\text{Li}$ than carbonaceous chondrites, ranging from $\delta^7\text{Li}$ +0.9‰ at 1.3 $\mu\text{g/g}$ (Bremervörde, H3) to $\delta^7\text{Li}$ +3.7‰ at 2.3 $\mu\text{g/g}$ (Tuxtuac, LL5). Average $\delta^7\text{Li}$ increases from H-chondrites to L-chondrites to LL-chondrites, however, the groups can not be distinguished in their Li isotope composition outside uncertainties. There is no overall correlation between $\delta^7\text{Li}$ and the petrological types as observed by [2]. Amongst the achondrites, the HEDs show a large range in Li concentrations from about 3 $\mu\text{g/g}$ for the diogenites to 11.7 $\mu\text{g/g}$ for one basaltic eucrite. However, the range for $\delta^7\text{Li}$ is rather restricted to values between +3.5 to +4.7‰ [Bereba: 3.9‰ \pm 0.5; Bilanga: 3.7‰ \pm 0.2; Johnstown (whole rock) 3.5‰ \pm 0.5; Johnstown (orthopyroxene separate): 4.7‰ \pm 0.3]. A silicate inclusion from IAB El Taco has $\delta^7\text{Li}$ = 3.6‰ \pm 0.7 and thus falls in the $\delta^7\text{Li}$ range of the eucrites with, however, a lower Li concentration of only 2.8 $\mu\text{g/g}$ Li. The olivine from the pallasite Admire has a $\delta^7\text{Li}$ of +2.5‰ \pm 0.3, isotopically similar to L-chondrites however, with a very low Li concentration of only 0.8 $\mu\text{g/g}$.

Our new data set for carbonaceous chondrites does not show a systematic variation in $\delta^7\text{Li}$ with petrological types. Instead, there might be a negative correlation of $\delta^7\text{Li}$ with Li concentrations which remains to be verified in further investigations. The $\delta^7\text{Li}$ range of carbonaceous chondrites entirely overlaps with that for the basaltic shergottites, low-Ti mare basalts, HED, MORB and the value for bulk silicate Earth.

Discussion and conclusions: Oxygen isotopes proved to be the most powerful tool to discriminate chondrite reservoirs. In particular ordinary (H-, L- and LL-) chondrites, which plot above the terrestrial fractionation line (TF) in the $\delta^{17}\text{O}$ - $\delta^{18}\text{O}$ -diagram, are separated from carbonaceous chondrites, which all lie below the TF. Here, we present the first study that demonstrates that chondrite reservoirs are also heterogeneous in their Li isotope compositions (Fig 1). The carbonaceous chondrites have a mean isotope composition of $\delta^7\text{Li}$ = 3.8‰ \pm 0.7 (2SE = student-t, 95% confidence level) that agrees with the mean isotope composition of achondrites from small asteroidal bodies ($\delta^7\text{Li}$ 3.5‰ \pm 0.8; 2SE for HED, one pallasite and one IAB silicate inclusion), and also with the mean $\delta^7\text{Li}$ of terrestrial planets [9, 11]. In contrast, Li isotope compositions of ordinary chondrites are systematically lighter, with a mean $\delta^7\text{Li}$ -value of 2.2‰ \pm 0.4 (2SE). Although, the exact cause for this isotopic heterogene-

ity is unclear yet, it could indicate the existence of distinct Li isotope reservoirs in the early solar system at the time of chondrite parent body formation (Fig.1).

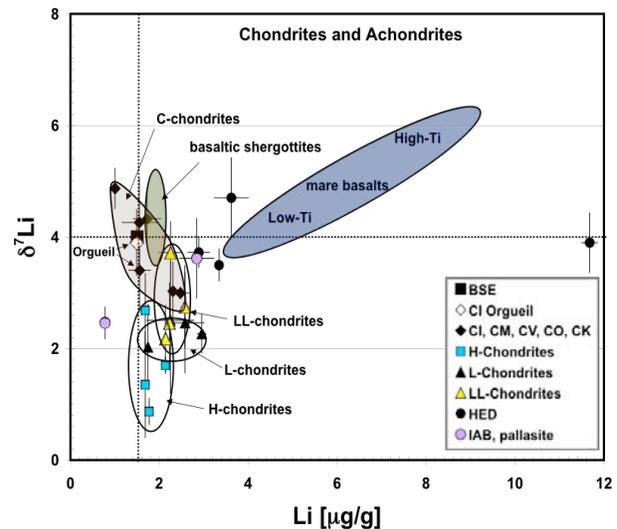


Fig 1: $\delta^7\text{Li}$ values of carbonaceous and ordinary chondrites and achondrites as a function of Li abundances. Data for lunar and martian basalts are taken from [10], for Orgueil from [1] and for BSE from [11].

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