COMBINED FE- AND SI-ISOTOPE MEASUREMENTS OF CV CHONDRITE CHONDRULES AND CAIs.

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Introduction: Chondrules have highly variable chemical compositions [e.g. 1]. One of the major questions is how chondrules obtained this large variability. The answer to this will potentially reveal important details of chondrule evolution. Popular explanations for the chemical variations of chondrules comprise (i) heterogeneities among chondrule precursor grains, (ii) elemental exchange between chondrule and surrounding gas during chondrule formation and (iii) elemental exchange on the meteorite parent body.

Knowledge of the chondrule isotopic composition help to discriminate between these possibilities. However, different elements and hence, isotope systems have different cosmochemical and geochemical properties and are therefore affected to different degrees by the above mentioned processes to produce chemical variations among chondrules. The elements Fe and Si have similar condensation temperatures, but the diffusion and mobility of Fe is much higher than that of Si. In addition, Fe occurs in three different valence states: Fe⁰, Fe²⁺ and Fe³⁺. It has been shown that redox reactions fractionate Fe isotopes [2]. The presence of metal and/or sulfide in many chondrules also raises the question of which chondrule phase governs the bulk Fe isotopic composition of the chondrule. In order to answer this, the modal abundance of metal/sulfide in chondrules must be known. There is so far only one recent study of 8 chondrules in CR chondrites showing that modal abundances of metal in these have an extremely large range between 1 and 37 vol% [3].

We recently measured Fe-isotopic compositions and studied the petrology of a large set of chondrules and CAIs in CV chondrites [4]. We now measured the Si-isotopic composition of some of these chondrules and CAIs. There are so far only few studies of Si-isotopic compositions of chondrules [5-7], but no systematic study. In addition we measured the modal abundance of opaque phases (combined sulfides and metal) in Allende, in order to get an idea of the spread of opaque abundances in CV chondrites.

Techniques: The Si-isotopes have been measured using the Nu Plasma MC-ICP-MS at the University of Oxford. The column chemistry was done using the procedure of [8].

The modal abundances of opaques have been determined using an X-Tek HMX-ST CT 3D scanner. The edge length of each voxel was 8.1 µm.

Results: We measured Si-isotopic compositions of 7 chondrules and 3 CAIs from the CV chondrites Mokoia and Grosnaja. The results of the Fe-isotope measurements and the petrologic studies are published in [4]. Figure 1 compares the Si- and Fe-isotopic compositions of the 7 chondrules and 3 CAIs.

Fig. 1: Si- and Fe-isotopic composition of chondrules and CAIs in CV chondrites.

The Si-isotopic composition of bulk chondrules is very constant at around δ²⁹Si = -0.12±0.04(1σ)%o, except for one chondrule (+0.58‰). The latter is an otherwise unremarkable porphyritic chondrule comprising
olivine (ol), clinopyroxene (cpx), feldspar (fsp) and sulfide (sul; Fig. 2). Two CAIs have the lightest and the third CAI has the heaviest Si-isotopic composition of all measured objects. In contrast, the Fe-isotopic composition of these chondrules is much more variable and the CAIs have the lightest compositions of all measured objects.

Fig. 2: BSE image of the chondrule having an 0.7‰ heavier $\delta^{29}$Si composition than the others.

The modal abundances of opaque phases measured in 7 other Allende chondrules have a large total range from 0.0 to 6.5 vol% (Fig. 3).

Fig. 3: Modal abundances of opaque phases in 7 different Allende chondrules (chd).

Discussion: Of the 7 chondrules measured, 6 have the same Si-isotopic composition within error. It is unclear why one chondrule has a highly different value. Further measurements will reveal whether this is an outlier or the indication of a real variability of bulk chondrule Si-isotopic compositions. [7] report Si-isotopic compositions for 5 Chainpur chondrules that have only minor variations ($\delta^{28}$Si = -0.26±0.11(1σ)%). Therefore, we assume for the moment that Si-isotopic compositions of CV-chondrules are all the same and the one chondrule is an outlier. The result that all chondrules have the same Si-isotopic composition is then in conflict with the explanation that chemical or isotopic variability (e.g. Fe-isotopes) of chondrules can be explained by chondrule precursor heterogeneities. If this were the correct process, an explanation must be found as to why the Si-isotopes are not variable.

In a typical type 1 chondrule, the Fe-concentration of silicates is so low (<5 wt%) that less than 5 vol% sulfide or less than 2 vol% metal is required until the opaque phase contributes more Fe to the bulk chondrule than the silicates. We determined up to 6.5 vol% opaque phases in a set of 7 Allende chondrules. Therefore, in some chondrules opaque are the major carrier phases of Fe. We found that the chondrule Fe-isotopic compositions are independent of their sulfide modal abundance. If the Fe in the silicates were responsible for the bulk Fe-isotopic composition, it would need to be highly fractionated, as the sulfide and/or metal acts like an isotopic buffer. [9] measured the Fe-isotopic composition of Chainpur (LL3.4) chondrule olivines and found $\delta^{56}$Fe fractionations <0.7-1.4‰. Such small fractionations of the silicates are insufficient to change the bulk chondrule Fe-isotopic composition. If CV chondrule olivines have similar Fe-isotopic compositions to Chainpur chondrule olivines, it is impossible that fluid assisted processes on the parent body produced the bulk chondrule Fe-isotopic signature. These processes redistribute Fe in and out of chondrule silicates, while the opaque in the chondrites studied remain largely unaffected. And as described above, the Fe-isotopic compositions of the silicates are insufficiently fractionated in order to change the bulk chondrule Fe-isotopic composition, thereby explaining their Fe-isotopic variation.

Unfortunately the Fe-isotopic composition of individual CV chondrite chondrule components are unknown. It is planned to measure them in the near future to confirm the latter argument.

Conclusion: The results of our study exclude chondrule precursor grains and parent body processes as explanations for chemical and isotopic variabilities observed among chondrules. We conclude that nebula processes must be responsible for this variation. This conclusion sets constraints for nebula conditions and requires e.g. high solid densities as suggested by [10].