CHONDRULE FORMATION IN ORDINARY CHONDRITES: INSIGHT FROM OXYGEN ISOTOPES.

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Introduction: Irrespective of their primitive or differentiated nature, meteorites exhibit a fundamental isotopic dichotomy (e.g., O, Cr, Ti) between a carbonaceous (CC) and a non-carbonaceous (NC) group, which might represent the outer and inner solar system, respectively [1–2]. The bulk chondrite isotopic dichotomy is now observed at the scale of individual chondrules [3], which are ubiquitous submillimeter-size igneous silicate spheroids formed during the evolution of the protoplanetary disk. This suggests NC and CC chondrules formed from different precursors and/or under different conditions, thus calling into question the conditions of dust formation in both reservoirs.

Material & method: We acquired high-resolution element X-ray maps, and high-precision EPMA elemental and O isotopic compositions of olivine grains in 11 PO type 1 chondrules from three ordinary chondrites belonging to the NC group (OC; Bishunpur (3.15), Piancaldoli (3.10), Semarkona (3.00)).

Results: OC olivine-rich chondrules show similar features compared to CC chondrules with (i) chemical zonings of trace and minor elements (e.g., Al_2O_3, TiO_2, CaO, MnO, and Cr_2O_3), and (ii) asymmetric growth of outer crystals [4–8]. However, some hopper-textured crystals in porphyritic OC chondrules are observed whereas it has only been reported in CC barred olivine chondrules so far [7]. Four chondrules show relict olivine grains, having distinct O isotopic compositions from host grains ($\Delta^{17}O_{Host} \sim 0.9 \pm 1.3$ ‰), without any specific spatial distributions within chondrules. Relict grains plot roughly along the PCM (Primitive Chondrule Minerals) line while the host grains are systematically displaced toward its left.

Discussion: From these data [9], we draw three constraints on chondrule formation. Firstly, the similar features observed within OC and CC chondrules [4–8] indicate that the processes that control chondrule formation were similar at different heliocentric distances in the disk. These processes are the partial melting of precursor aggregates with gas-melt interactions. This allows external gaseous matter to condensate [4–8] and buffers the O isotopic composition of the melt to that of the local reservoir composition [4–5, 10–12]. $SiO_{(g)}$ and $Mg_{(g)}$ would have a predominant role in explaining observed textures [4–8] but H_2O vapor might have also significantly contributed to the O isotopic budget as a major component of the gas phase [12].

Secondly, the mass-dependent variability in O isotopic compositions (i.e., variations of $\delta^{18}O$ and $\delta^{17}O$ at a constant $\Delta^{17}O$) observed for host olivine grains within each single chondrule can be explained by kinetic fractionation, either by diffusion during the crystal growth or by condensation/evaporation. However, the extreme conditions required for crystal growth fractionation give preference for the later.

Finally, we identified several generations of relicts within each chondrule. Relict grains derived from refractory inclusions ($\Delta^{17}O \sim -25$ ‰) are rare but still observable, as in CC chondrules [4–5]. We also highlighted a second generation of relicts having a $\Delta^{17}O \sim -5$ ‰ and variable chemical compositions as observed for host grains in CC chondrules. However, O isotopic compositions, expressed as $\Delta^{18}O$ (= $\delta^{18}O - \delta^{17}O$), is lower for OC chondrules compared to CC, indicating this second generation cannot result from recycling of host grains from the CC reservoir. Such an interval between the two groups is bigger than intra-chondrule variations and seems to reflect bulk chondrite features. This might reveal the OC and CC reservoir separation was already established before the final chondrule formation event. This supports the well-isolated NC and CC reservoir conclusions and argue against disk-wide transport of chondrules across and between these two reservoirs. Primary causes of chondrule forming event might have been different between NC and CC reservoirs [13], although having resulted from the same major processes for explaining chondrule textural and isotopic features. These differences in disk dynamic might have resulted in variation of dust production efficiency and/or recycling, that can be as much as twice efficient/frequent in inner solar system compared to outer solar system, as infer from relict grain abundances within each chondrule and chondrule abundances within chondrites.

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