Coordinated petrography and oxygen isotopic compositions of Al-rich chondrules from CV3 chondrites

Mingming Zhang [1,2], Yangting Lin[1,2], Guoqiang Tang [1] and Xianhua Li[1,2]
[1]Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), 19 Beituchengxi Rd, Chaoyang District, Beijing100029, mmzhang@mail.iggcas.ac.cn
[2]University of Chinese Academy of Sciences, 19 Yuquan Rd, Shijingshan District, Beijing100049.

Introduction: Aluminum-rich chondrules (ARCs) display more affinities with ferromagnesian chondrules (FMCs) than Ca-Al-rich inclusions (CAIs) in terms of petrologic features, oxygen isotopes and the Al-Mg system. Al-rich inclusions can be subdivided into plagioclase-rich, olivine-rich and glassy, with their mineral assemblages and textural relationships consistent with the crystallization of melts [1,2,3]. Recently, FMCs from a diverse suite of carbonaceous chondrites (CCs) revealed two distinct oxygen isotope reservoirs with $\Delta^{17}O$ values of ~ -5‰ and ~ -2‰ [4,5]. In this study, we coordinated the petrology, bulk compositions and oxygen isotope compositions of ARCs in the CV chondrites Allende and Leoville and the ungrouped CC Ningqiang in order to elucidate any potential genetic relationships between ARCs, CAIs and FMCs.

Results and Discussion: Six ARCs were found from Allende, 5 from Leoville and 1 from Ningqiang. These ARCs were classified as plagioclase-olivine-rich (POIs, 3), plagioclase-enstatite-rich (PEIs, 5), spinel-bearing barred olivine (Sp-BO, 1), compound chondrules (2) and a fassaite-spinel-bearing fragment (1). Enstatite shows two types of occurrences: a. coarse grains in the rims of ARCs and b. anhedral crystals intergrown with diopside. This implies two episodes of crystallization during the cooling of ARC melts. Plagioclase and most of the olivine appear as euhedral crystals. However, rounded olivine grains (15-75 μm) with slightly higher Fa content (Fa_{3-5} vs. $Fa_{<1}$) in POIs may be relict. Spinel occurs in two forms: a. euhedral grains intergrown with barred olivine in Sp-BO, and b. rounded inclusions inside plagioclase in both POIs and compound chondrules. Spinel in the POIs and compound chondrules is interpreted as relict [6]. The fassaite-spinel-bearing fragment containing oval-shaped fassaite (40×20 μm, TiO_2: 2.98~ 6.52 wt.%) with two spinel inclusions could also be relict.

Bulk compositions of 8 ARCs (3 POIs, 4 PEIs, 1 Sp-BO) were calculated from their mean and modal mineral compositions. On the plane of forsterite-projected tridymite-diopside-spinel system [2,3], 3 PEIs and 1 POI plot within the protoenstatite field, 2 POIs and 1 PEI plot in the anorthite field, implying crystallization sequences of protoenstatite + forsterite—anorthite—orthoenstatite + diopside and anorthite + forsterite—protoenstatite—orthoenstatite + diopside, respectively. Moreover, 1 Sp-BO ARC plots within the spinel field, indicating the simultaneous crystallization of spinel + forsterite. These crystallization sequences in the ARCs are consistent with their textural relationships suggesting the crystallization of melts.

$\delta^{18}O$, $\delta^{17}O$ and $\Delta^{17}O$ of co-crystallized olivine, spinel and pyroxene range from -7.44‰ to -1.78‰, -10.6‰ to -5.06‰, and -6.9‰ to -4.1‰, respectively. The average $\Delta^{17}O$ of -5.68 ± 1.24‰ (2SD) is consistent with the widespread oxygen isotope reservoir ($\Delta^{17}O$~ -5‰) in CC chondrule-forming regions [4,5]. In contrast, plagioclase displays a broader range of O isotopic compositions as well as higher $^{17,18}O$-enrichments with $\delta^{18}O$ from -0.5‰ to 14.63‰ and $\delta^{17}O$ from -4.62‰ to 6.51‰. The $\Delta^{17}O$ changes continuously from -4.4‰ to -1.47‰ and shows no correlation with either location or An content. Thus, the ^{16}O-depletion could have originated from oxygen isotopes exchanging with the surrounding ^{16}O-poor reservoir, probably the oxygen isotope reservoir with $\Delta^{17}O$ of ~-2‰. Relict olivine and spinel have $\delta^{18}O$ ranging from -35‰ to -19‰, directly relating to ^{16}O-rich olivine from AOAs and spinel from CAIs. Relict fassaites have $\Delta^{17}O$ values from -5.7‰ to -6.4‰, close to the values of euhedral grains in ARCs and are distinct from those in CAIs. This suggests that the oxygen isotopes in fassaite have highly exchanged with the melts of ARCs.

Conclusions: (1) Mineral assemblages and textural relationships of ARCs are consistent with the crystallization of melts, except for a few relict grains. (2) The ARC melts record a oxygen isotope reservoir with $\Delta^{17}O$~ -5‰ that is most consistent with the oxygen isotopic reservoir of FMCs in CCs. (3) Plagioclase may have experienced a post-crystallization oxygen isotope exchange with in an oxygen isotope reservoir with $\Delta^{17}O$ of -2‰. (4) CAIs and AOAs may have served as precursors to ARCs in various ratios.

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