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REFRACTORY PRECURSOR COMPONENTS IN AN ALLENDE FERROMAGNESIAN CHONDRULE;

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Chemical and petrological studies of chondrules revealed that they were formed through melting of pre-existing solid precursor materials [1], and that one of the refractory lithophile precursors was a high temperature condensate from the nebular gas and related to Ca, Al-rich inclusions (CAIs) [2,3]. Sheng et al. [4] found relict spinel grains with isotopically fractionated Mg in plagioclase-olivine inclusions from CV chondrites and suggested that the major fractionation processes were common to CAIs and chondrules. We have determined the Mg isotopic composition of five barred olivine chondrules and one coarse-grained rim from the Allende (CV3) meteorite. A reproducibility of instrumental isotope fractionation is ± 2 ‰ per amu. The precision of the $^{26}Mg/^{24}Mg$ data after normalization for mass fractionation can be as good of 0.5 ‰ ($2\sigma_{mean}$). The Mg analytical results are given in Table 1 and indicate that $\Delta^{25}Mg/^{24}Mg$ and $\delta^{26}Mg$ of the chondrules are normal within errors.

Chondrule R-11 mainly consists of olivine (Fa_{10-32}), low-Ca pyroxene ($En_{93}Fs_1Wo_6$), plagioclase (An_{89}), and glass (Na_2O=14 wt %, K_2O=1.8 wt %) with minor amounts of Fe sulfides, and can be assigned to a ferromagnesian type. The most characteristic feature is that a large, unhedral Mg-spinel grain (~ 250 μm in size: Fig. 1) is existed in a central portion of the chondrule. The host chondrule (excluding a spinel grain) shows a fractionated (4.6-7.8 x CI-chondrite), HREE-depleted abundance pattern with a positive Yb anomaly. The REE abundances are hump-shaped functions of elemental volatility (i.e., moderately refractory REE-enriched), suggesting that the precursor component of R-11 host is related to Group II CAIs and could be a condensate from the nebular gas. SEM-EDX analysis reveals that an interior portion of spinel is almost Fe-free but in an outer zone (~ 20-40 μm width), FeO contents increase steeply (Fig. 2). Spinel also contains minor amounts (< 0.75 wt %) of Ti_2O, Cr_2O_3, and V_2O_5. On the basis of the abundances of K and Rb in the host chondrule (2.39 x and 2.13 x CI-chondrite, respectively), vaporization loss of moderately volatiles was not so large during melting event of chondrule formation, which in turn strongly suggests that spinel could not be produced as distillation residues [5] of precursor material during chondrule formation. This is consistent with chondrule texture. According to the experiments, barred olivine chondrules were reproduced by melting temperatures of 1400-1600°C and cooling rates of 100-2000°C/hr [6]. The Fe-Mg zoning of spinel may have been generated by diffusional emplacement of Mg and Fe during melting event of chondrule formation.

The spinel crystal contains tiny metallic grains and a 15 μm-sized silicate inclusion. The submicron-sized grains are composed of refractory (Mo, W) Pt-group (Pt, Ir, Os, Ru, Rh) metals with minor amounts of Fe (0.3 wt %) and Ni (5.4 wt %). The silicate inclusion is composed of Al, Ti-rich pyroxene (Al_2O_3=19 wt %, TiO_2=2.6 wt %, CaO=26 wt %) and an Al, Si, Ca-rich phase (Al_2O_3=21 wt %, SiO_2=38 wt %, CaO=38 wt %). This is the first occurrence of refractory Pt-group metal nuggets (RPMNs) in a ferromagnesian chondrule from Allende. In Fig. 3, CI-chondrite normalized elemental abundances for one of the nuggets (RPMN-1) are compared with the data of a RPMN in a Type A Allende CAI [7]. In RPMN-1, W, Os, Ir, Mo, and Ru are uniformly enriched ($2\text{-}6 \times 10^5$ x CI-chondrite) and abundances of Pt and Rh decrease ($2\text{-}10 \times 10^4$ x CI-chondrite) with increasing volatility. Moreover, abundances of Fe and Ni in the nugget are equal to or less than CI-chondrite level. The elemental abundance patterns of both RPMNs are identical. Precursor components of refractory siderophiles are suggested for Allende chondrules [8]. However, their chemical features have not been well understood yet. It is generally accepted that RPMNs in CAIs were produced during high temperature events at least 1300°C and before 100 % condensation of Fe in the early solar nebula [9-13]. Thus, we suggest that one of the refractory siderophile precursor components of Allende chondrules is a high temperature condensate from the nebular gas and associate with refractory lithophiles. Since RPMNs in R-11 were surrounded by Mg-spinel, they may have been separated from the common siderophiles (Fe, Ni, Co) during early stage of condensation and were not affected by low temperature sulfidization [14].

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Table 1: Mg Analytical Results.

Sample	$\Delta^{25}Mg/^{24}Mg$ (‰)‡	$\delta^{26}Mg$ (‰)£
R-1	1.9 ± 1.7¶	-0.1 ± 0.4§
R-11†	2.5 ± 1.5	-0.1 ± 0.2
	2.5 ± 0.6	-0.1 ± 0.3
R-13	0.7 ± 0.8	-0.3 ± 0.3
G-2	2.1 ± 1.1	-0.2 ± 0.4
G-3	1.5 ± 0.7	-0.3 ± 0.2
G-2 CGR*	1.8 ± 1.3	0.3 ± 0.3

‡ $\Delta^{25}Mg/^{24}Mg = [(^{25}Mg/^{24}Mg)_m/(^{25}Mg/^{24}Mg)_s - 1] \times 1000$, where 'm' denotes the measured raw $^{25}Mg/^{24}Mg$ ratios, 's' is grand mean value: $^{25}Mg/^{24}Mg = 0.12464$ for raw data determined from standards.

£ $\delta^{26}Mg = [(^{26}Mg/^{24}Mg)_c/0.139813 - 1] \times 1000$, where 'c' is the value corrected for fractionation according to $(^{26}Mg/^{24}Mg)_c = (^{26}Mg/^{24}Mg)_{meas}/\alpha^2$, where $\alpha = (^{25}Mg/^{24}Mg)_{meas}/(^{25}Mg/^{24}Mg)_c$, and $(^{25}Mg/^{24}Mg)_c = 0.12663$ reported by [15], and 0.139813 is the grand mean value for all standards normalized using power law.

† Exculuding a spinel grain.

* Coarse-grained rim.

¶ Errors are 2 σ.

§ Errors are 2 σ_m.

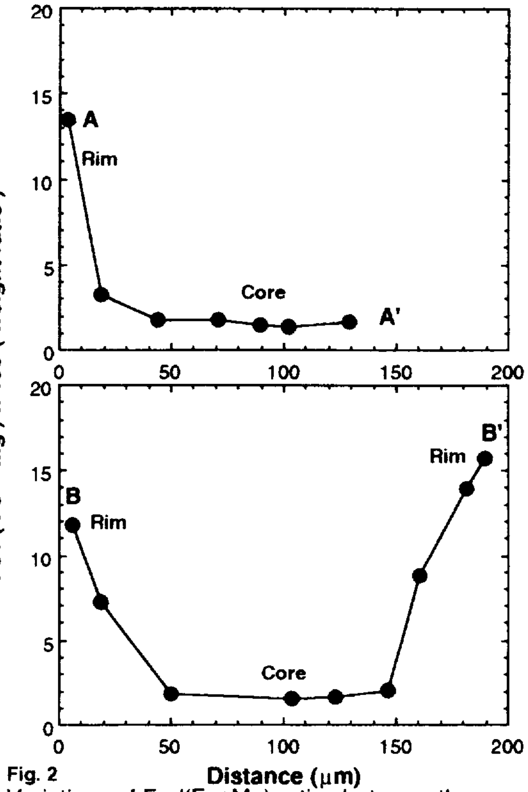

Fig. 2
Variations of Fe /(Fe+Mg) ratios between the Fe-rich rim and the Fe-poor core of spinel in R-11.

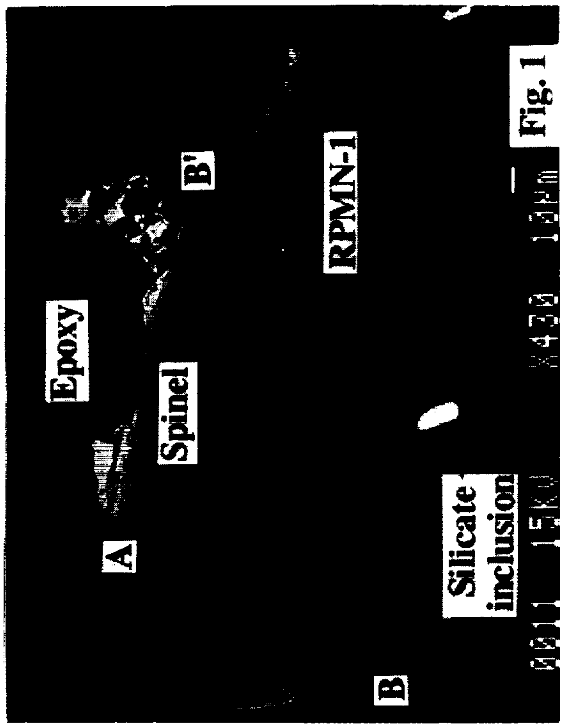

Fig. 1

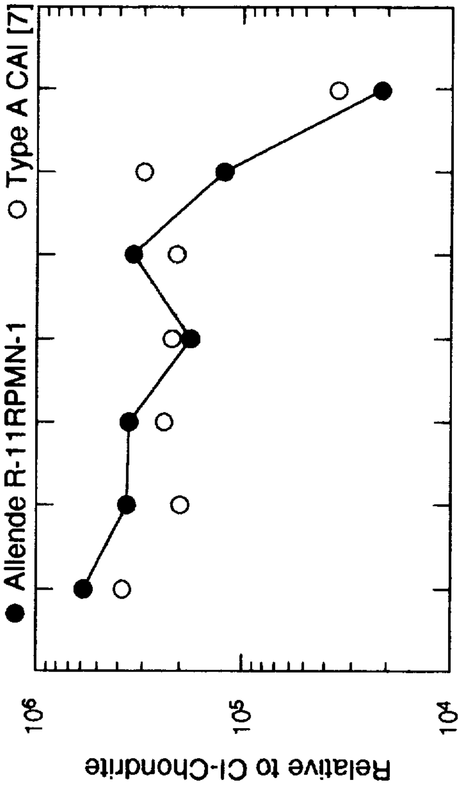

Fig. 3
CI-chondrite normalized refractory Pt-group metal abundances for RPMNs in Allende R-11 and Type A CAI [7].