ORIGIN OF THE REFRACTORY COMPONENT IN FERROMAGNESIAN CHONDRULES AND CONSTRAINTS ON THEIR THERMAL HISTORIES: CLUES FROM GLASS INCLUSIONS IN OLIVINE FROM CARBONACEOUS CHONDRITES.

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Introduction: In a broad sense, the refractory components in ferromagnesian chondrules were derived from Ca-, Al-rich materials [1,2] but the specific carriers and possible relationships to known CAIs are uncertain. The rare relict CAIs in chondrules [3] may not be typical, and aluminous spinels [4], although more common, are not definitive because they are present in many kinds of refractory and ultrarefractory inclusions. In this study, we examine the compositions of glass inclusions (GI) in olivine from CM, CR, and CV chondrites [this study, [5-7], and references therein] for clues into (1) the nature of precursor materials that contributed to the refractory signatures of ferromagnesian chondrules, and (2) the interactions between GI and surrounding olivine that could help to constrain thermal histories. In order to reduce possible complications due to alteration, we restricted our study to Na-poor GI (≤ 0.2 wt % Na_2O).

Samples: Glass compositions were obtained from two GI in each of two isolated olivines in Murchison. Both olivine grains contain murchisite [8-9], one grain of which is in contact with glass, and one GI contains an alloy ($Fe_{93}Ni_6P_1$) + schreibersite spherule. These olivine grains may have come from broken-up chondrules. We also collected 70 GI analyses from the literature [[5-7], and references therein]: these include inclusions from isolated grains, from small aggregates of olivine crystals (suggestive
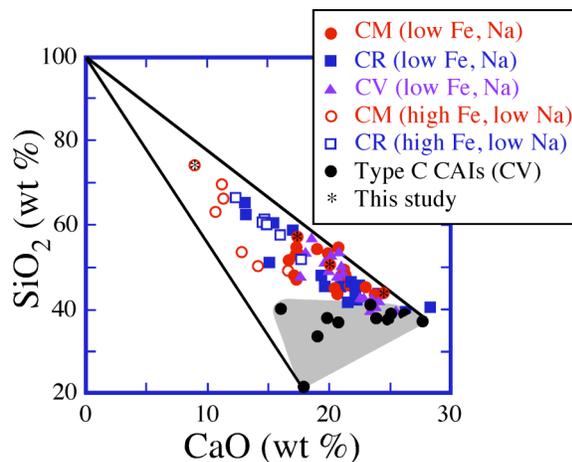
of chondrule fragments), and enclosed within well-defined chondrules.

Results: Fig. 1 shows CaO vs. SiO_2 for bulk Type C CAIs [10-11; all from CVs] and GI. The data are consistent with compositions of GI as mixtures of Type C-like material and SiO_2–rich material. High-Fe (1-9 wt% FeO) GI tend to be more Si-rich than low Fe-glass, but there is considerable overlap. Plots for other oxides with SiO_2 are also generally consistent with GI as mixtures of Type Cs with SiO_2.

Fig. 2 is a projection of GI from $MgAl_2O_4$ spinel (Sp) and FeO onto the gehlenite (Ge), anorthite (An), and forsterite (Fo) plane. Also shown are projections of boundary curves from the spinel-saturated liquidus phase diagram with the second crystalline phase in equilibrium with spinel (Sp) and liquid identified within fields bounded by multiply saturated phase boundaries (Mel: melilite; Mon: monticellite; Ol: olivine; Gro: grossite; Cpx: clinopyroxene; An: anorthite; Hib: hibonite; Cor: corundum). GI and Type Cs lie close to the plane Ge-SiO_2-Sp. [13] suggested the plane Ak17-SiO_2-Sp for Type Cs and

Fig. 1. CaO vs. SiO_2 for CM, CR, and CV chondrites and Type C CAIs (note for Type Cs, we accepted up to 0.7 wt % Na_2O, although most have <0.2 wt %).
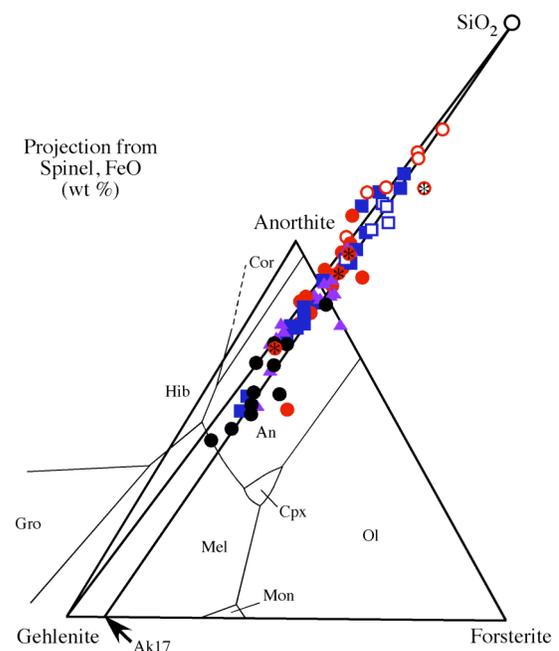

Fig. 2. GAFS projection of olivine-hosted GI and bulk Type Cs. Data and symbols as in Fig. 1.

this is also plausible for the GI. Regardless of the details, the trend of silica enrichment appears to be a robust signature for both Type Cs and GI. This trend is unaffected by the presence of multiple saturation boundaries in Fig. 2 or of the Fo-An-(Sp) plane (a thermal divide for spinel-saturated liquids [12]).

We projected GI and Type Cs in Fig. 2 to the line between Ge and silica and then plotted the amount of Sp component as a function of the fractional distance for each composition between Ge and silica (Fig. 3). As in Fig. 1, the GI can be described as a mixture of Type C material and SiO_2.
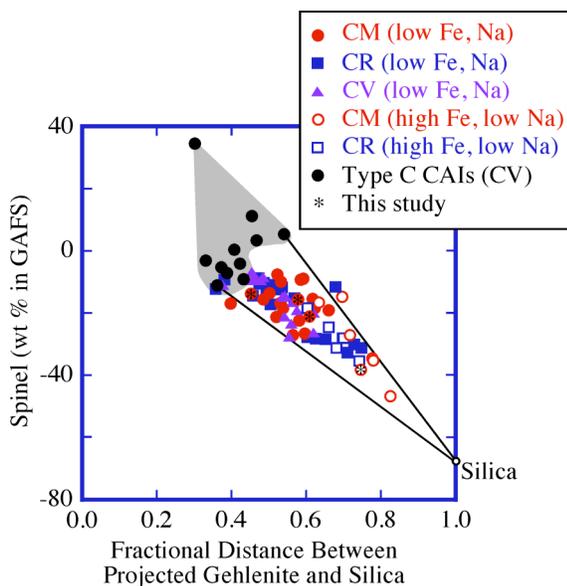

Fig. 3. Amount of Sp component in Ge-An-Fo-Sp (FeO) for GI and bulk Type Cs as a function of the fractional distance between Ge and Silica in the Ge-Silica-Sp plane

Fig. 4 is a projection like Fig. 2 but for anorthite-saturated liquids. This phase diagram is applicable to low-FeO GI (<1 wt % FeO). Also plotted are GI compositions for CMs. All of these GI plot above and generally well above the saturation surface and, therefore, have plagioclase on the liquidus, even though all of them are inclusions in olivine. The points plotting closest to the olivine field also have the lowest An contents, possibly due to dissolution of olivine but in no case was sufficient olivine dissolved to bring the GI to olivine saturation (i.e., considerable olivine would need to be dissolved into these GI to make them saturated with respect to olivine and this did not happen). Moreover, the data clearly show that the dominant compositional trend exhibited by GI is towards silica, not forsterite.

Discussion: Three key features are apparent in the GI data: First is the strong trend of silica enrichment. This could in part reflect the reduction of fayalite component in olivine to Fe metal plus silica
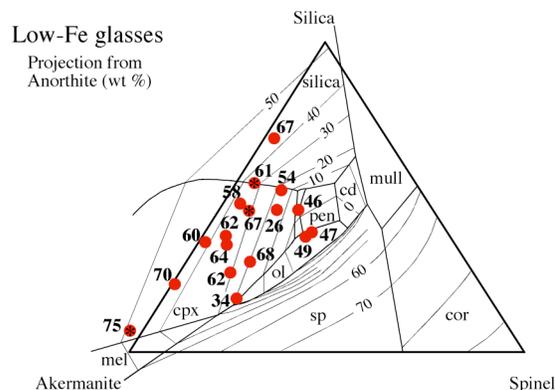

Fig. 4. Anorthite-saturated liquid compositions projected from An onto the plane formed by the compositions of Sp, silica, and åkermanite (Åk). Low-FeO GI from CM chondrites are also shown. Numbers adjacent to the points are wt % An component. Mull: mullite; pen: protoenstatite; cd: cordierite. Symbols as in Fig. 1.

(dissolved into GI) but this does not explain why the GI are not olivine-saturated. The second is an absence of evidence for significant dissolution of olivine into GI (i.e., GI are far removed from the olivine field in Figs. 2 and 4). The small size of GI make this particularly difficult to understand as rates of dissolution of olivine and diffusion coefficients for olivine components in the melt at high temperatures are such that GI should rapidly reach olivine saturation. Third, the absence of plagioclase crystals in the melt inclusions given the fact that anorthite is the liquidus phase for all the GI (Figs. 2 and 4). The absence of anorthite could reflect the well-known difficulty this phase has in nucleating, especially in small melt inclusions. We do not currently have a satisfactory explanation for all of these observations, but they appear to rule out exposure of GI to liquidus temperatures within their olivine hosts for more than at most a few seconds. This places severe constraints on thermal histories for these glass inclusions and their olivine hosts, and may indeed rule out high temperatures in these histories.

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