THE FORMATION OF TYPE II CHONDRULES IN CM CHONDRITES: THE VIEW FROM PARIS.

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Introduction: Type II chondrules are less abundant in carbonaceous chondrites than in ordinary chondrites, but their olivines have a much wider composition range. Paris is a new CM with less alteration than usual [1], and abundant well-preserved Type II chondrules. Data for Paris and other CMs throw light on the origin of all Type II chondrules.

Results: Paris Type II chondrules have PO, BO, PP and RP textures, with IIA PO dominant. A significant minority of them have abundant relict grains (Fig. 1a). IIAB chondrules contain pyroxene phenocrysts and olivine microphenocrysts (white phase in Fig. 1b).

Olivine Fe-Mg. In Paris Type IIs, the range of olivine core compositions is Fa_{7-76} (Fig. 2), with most analyses Fa_{20-50}, whereas in Semarkona even including olivine rims the range is only from Fa_{7-42}. The most ferroan olivine in Paris and Murchison occurs in IIAB chondrules (Fig. 1b), along with pyroxene of intermediate composition.

Relict grains in Paris Type II chondrules include olivine, pyroxene ($Fs_3Wo_{0.6}$) and spinel (s.s.). Relict olivine ranges from Fa_{1-19}. Forsteritic olivine is dominant, but more ferroan relicts are found in the more ferroan chondrules. Some chondrules have a range of relict compositions. Chondrule Paris 2010-04-9 (Fig. 1a) contains ~10% relics, which differ from one another in BSE grey tones. Their compositions include $Fa_{1.6\pm0.15}$, Fo_4 and Fo_{11} while phenocryst cores are Fa_{31-39}. A similar chondrule (#1) in Cold Bokkeveld 2010-13 contains relics with compositions $Fa_{0.66\pm0.05}$ and $Fa_{6.3\pm0.7}$,with melt-grown cores mostly Fa_{17-21}.

Mn, Cr, Na. Paris and other CMs show an Fe-Mn correlation for Type II olivine similar to that for CO chondrites [2], with significantly higher Fe/Mn than chondrules from ordinary chondrites (Semarkona). However there exist distinct outliers from this distribution, as in [3], reflecting reservoirs different in Mn (and Cr). Ferroan relict grains connect the fields for Type II and Type I chondrules (Fig. 2), and only the most forsteritic relics plot in the field for Paris Type I olivine.

Cr is normally zoned in olivine in some chondrules, but more generally in Paris it decreases towards rims (Fig. 3), reflecting crystallization along with chromite. Partitioning of Fe and Mg between olivine and chromite (Fig. 4) indicates equilibration near or above 1400°C [3,4], i.e. no metamorphic resetting.

Olivine shows normal Fe-Na fractionation trends which differ from chondrule to chondrule (Fig. 5), reflecting different initial liquid compositions.

Discussion: Our olivine compositions show that CM and LL Type II chondrules come from different reservoirs. Villeneuve [5] proposed derivation of Type II from Type I chondrules. The abundance of forsteritic relics in CM Type IIs supports this, but the 'polymict' nature of the relict grains in many chondrules suggests dust-ball precursors. The range of relict compositions includes those of Type I chondrules but also a population intermediate between the Type I and II chondrules observed in the Paris CM. These relics are possibly related to chondrule recycling.

Possible processes involved in the addition of Fe to Type II chondrules include oxidation and condensation. Fe-Mn-Mg relationships here indicate at best a limited role for oxidation of Type I metal to ferroan silicate [5]. Such a process might explain the relict grains of composition intermediate between Type I and the most magnesian Type II olivine. For chondrules more ferroan than $\sim Fa_{10}$, the correlation lines show addition of Fe and Mn together to chondrule precursors, though with different Fe/Mn ratios in CM and LL chondrites.

[5,6] suggested condensation of Fe into molten Type II chondrules. Paris chondrules have FeO/MnO ratios close to twice those of Semarkona Type II chondrules. In that case, the the differences between LL and CM chondrules may be related to fO_2 and fS_2. The range of Fa contents found in Paris Type II olivine suggests a range of more than two log units in fO_2. The more oxidized chondrules found in the carbonaceous chondrites may be related to a higher fraction of water ice involved in the melting events, or a hydrogen-poor environment. Type II chondrules may have formed later than Type Is after extensive evolution of the disk. One possibility is impact plumes on early planetesimals as the environment producing an oxidizing environment in which ferroan silicate could be created [6]. Type II chondrules may thus post-date collisions of protoplanetary bodies containing Type I chondrules and low temperature condensates.

References:

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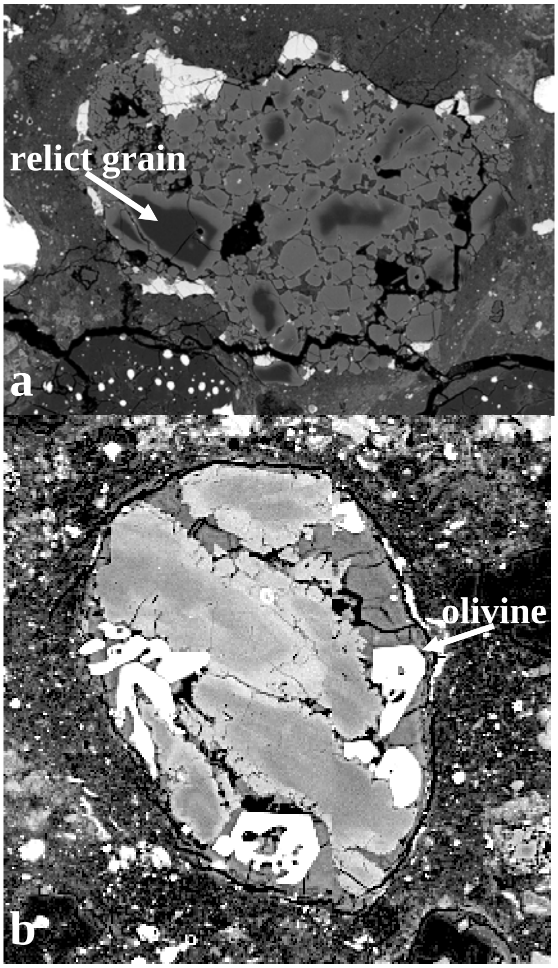

Fig. 1 Paris CM, BSE (a) Type IIA chondrule with relict grains $Fa_{1.6}$ – Fa_{11}. (b) Type IIAB chondrule with $Fs_{43\text{-}61}$ and white phase Fa_{74}.

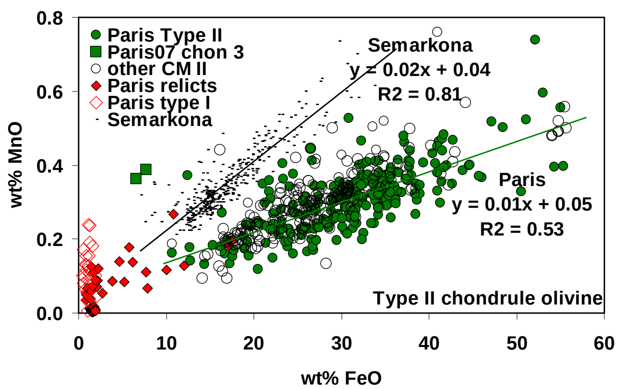

Fig. 2 Olivine in chondrules in the Paris (CM) and Semarkona (LL) chondrites.

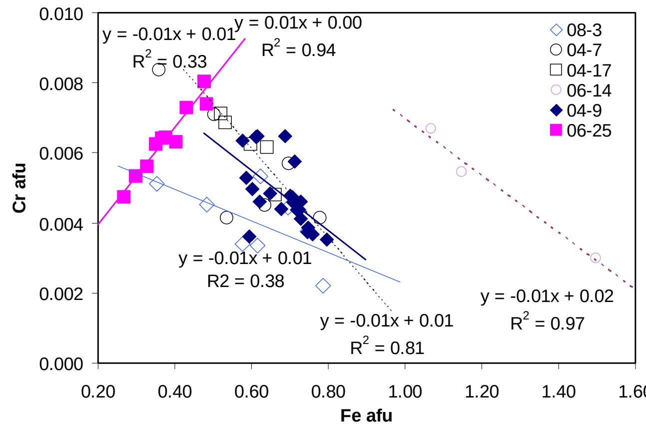

Fig. 3 Olivine Fe-Cr fractionation, 6 Paris chondrules.

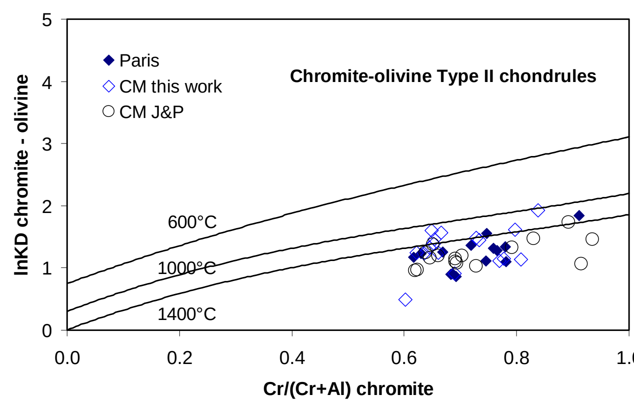

Fig. 4 Partitioning of Fe and Mg between chondrule olivine and chromite indicates no metamorphism.

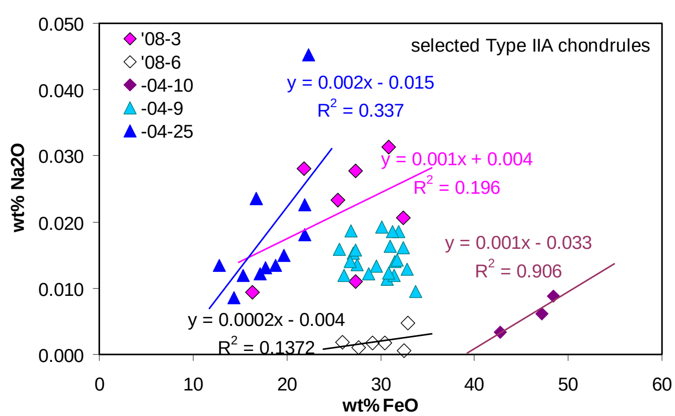

Fig. 5 Fractionation of Fe and Na in 5 Paris Type II chondrules.