MATRIX-CHONDRULE RELATIONSHIP AND THE ORIGIN OF CHONDRULES. H. Palme[1], and D. C. Hezel[2] [1]Forschungsinstitut und Naturmuseum Senckenberg, Senckenberganlage 25, D-60325 Frankfurt am Main, Germany (herbert.palme@uni-koeln.de), [2]Institut für Geologie und Mineralogie, Universität zu Köln, Zülpicherstrasse 55, Germany.

Bulk compositions of carbonaceous chondrites (CC) are well defined. The mean Si/Mg (wt) ratio of CC is 1.11±0.02: 01.12±0.03 (22 samples) [1], 1.10±0.03 (18 samples) [2] and 1.11±0.02 (22 samples) [3]. There is a slight, barely resolvable decrease of 2 % from CI to CV. Meteorites of the Renazzo group (CR) have CI-chondritic Si/Mg and Al/Mg ratios, the latter is unique among CC. The solar photospheric Si/Mg ratio is 1.10±0.2 .The mean Fe/Mg ratio of CC decreases somewhat with increasing petrologic type, from 1.91 in CI (solar ratio 1.87±0.45) to 1.75 in CO and in CR and 1.59 in CV [3], reflecting incomplete sampling of metal [4], formed above 1200 K (10^{-4} bar). The major non-refractory elements are uniformly distributed in CC. In the Allende meteorite Si/Mg and Fe/Mg ratios are constant within analytical uncertainties in samples larger than 600 mg and avoiding large chondrules, dark inclusins and CAI [5].

The chemical composition of the matrix of carbonaceous chondrites is different from bulk meteorites and from CI-chondrites. In Fig. 1 we have plotted data on bulk CC indicating a small spread in Fe/Mg and very constant Si/Mg ratios. The solar values are within error bars indistinguishable from CC.

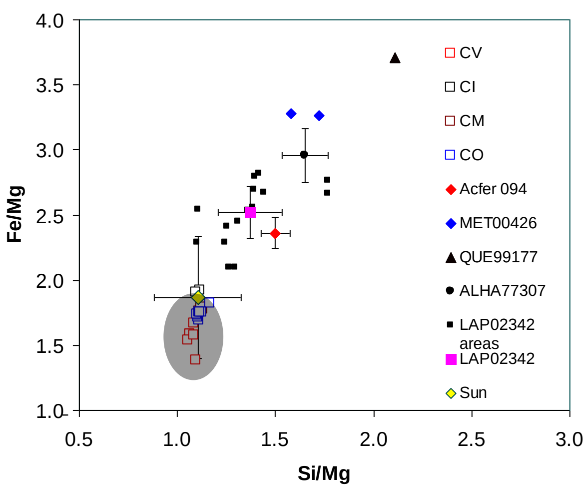

Fig. 1: Matrices of the most primitive carbonaceous chondrites have higher Fe/Mg and Si/Mg ratios than bulk carbonaceous chondrites and the Sun (see text for details). Sources of data: [3,6,7,8,9].

We have also plotted recent carefully selected matrix data from some of the most primitive CC. The most unaltered carbonaceous chondrites such as Acfer 094 (unclassified), LAP 02342 (CR), ALHA77307 (CO), MET 00426 (CR) and QUE 99177 (CR) have Fe/Mg and Si/Mg ratios in their matrix significantly above all CC and the CI or solar values. The error bars indicated in Fig. 1 are from [6]. The individual area analyses of LAP 02342 reflect some heterogeneity of matrix on a scale of 50 µm, which are ascribed by [7] to nebular not parent body processes. It is however important to note that all data plot above the CC ratios in Si/Mg as well as in Fe/Mg. There is furthermore no compositional difference between fine grained rims surrounding chondrules and interchondrule matrix [6,7,8].

Although the precise fraction of matrix in these meteorites is not well known, matrix is abundant in all of them (e.g. 35-60 % in CR chondrites [10]; 63% in Acfer 094 [11]). As the bulk composition of these meteorites is within the range of CC analyses, chondrules must have on average significantly lower Fe/Mg and Si/Mg ratios than bulk meteorites.

The elevated Si/Mg ratio of matrix is characteristic of most, if not all, carbonaceous chondrites. In ordinary chondrites (OC) the effect is even more pronounced (see [12]). But since the matrix fraction is very low conclusions regarding chondrule compositions are not justified. The Si/Mg fractionation is particularly prominent in Renazzo [13], where a heavily altered fine grained matrix encloses chondrules with a high modal content of forsteritic olivine. Hezel and Palme [14] have shown that the Si-Mg fractionation between chondrules and matrix is a general property of all groups of carbonaceous chondrites. Because this fractionation is present in most chondritic meteorites and because it is so prominent in the most primitive carbonaceous chondrites (Fig.1), it cannot result from parent body metamorphism.

The Fe-Mg fractionation between chondrules and matrix is even more pronounced than the Si-Mg fractionation. In Fig. 2 we show a Fe-Mg plot for the CV chondrite Mokoia. The chondrule data are from more than 90 chondrules analysed by INAA [15]. The bulk CC show some spread in Fe as described above, but this is a minor effect compared to the large variations of FeO in individual chondrules. The complementarity of chondrules and matrix is evident. It is impossible to produce refractory, Mg-rich chondrules by parent body metamorphism. Heating of Mokoia would rather equilibrate Fe between chondrules and matrix.

In summary, the matrix of the most primitive carbonaceous chondrites is fractionated relative to the bulk meteorites which have approximately the CI-composition. The direction of fractionation is the same in all CC and in OC, independent of the extent of alteration of the matrix. It is impossible that this fractionation is produced on the parent body. Chondrules have, on average, the complimentary pattern, although this may be difficult to see, as the composition of individual chondrules is extremely variable. Wasson and Rubin [6,7] invoke ejection of liquid metal droplets and mesostasis glass during crystallization of liquid chondrules causing the observed fractionations.

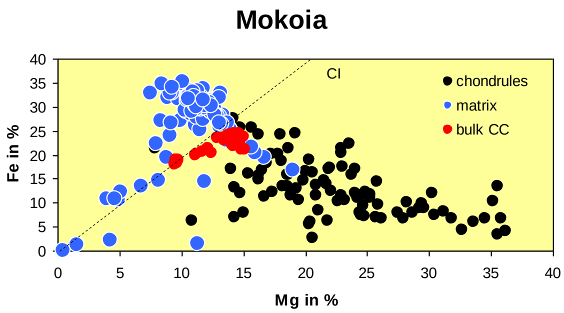

Fig. 2: Chondrules and matrix in the CV-chondrite Mokoia. Chondrules [15], matrix (this work), bulk [3].

Fractionation of refractory elements between matrix and chondrules has been found in some carbonaceous chondrites. Hezel and Palme [16]) showed that the two CV chondrites Allende and Y-86751 with almost identical bulk chemical composition have the opposite distribution of Ca and Al in matrix and chondrules. Allende has lower than bulk Ca/Al-ratios in chondrules and a complimentary elevated Ca/Al ratios in matrix. The Y-86751 CV-chondrite has high Ca/Al ratios in chondrules and low ratios in matrix. The exceptionally high Al in matrix and a correspondingly low Ca of Y-86751 matrix are shown in Fig. 3, which is from [17] (see also [18]). The reason for the high Al in matrix is an unusual high population of tiny spinel grains, which were not incorporated in chondrules [18, 14]. The excess Al in the matrix is missing from chondrules. This indicates a very strong relationship between matrix and chondrules.

A similar strong matrix-chondrule relationship is apparent from the superchondritic Ti/Al ratios in chondrules of Renazzo, Mokoia and other CC [13, 19]. In these meteorites Ti is preferentially incorporated in chondrules, which leads to a deficit in the matrix, perhaps involving perovskite.

All these complementary relationships were established before parent body formation and require the formation of both, matrix and chondrules from a single reservoir as discussed in detail by [14, 16]**.**

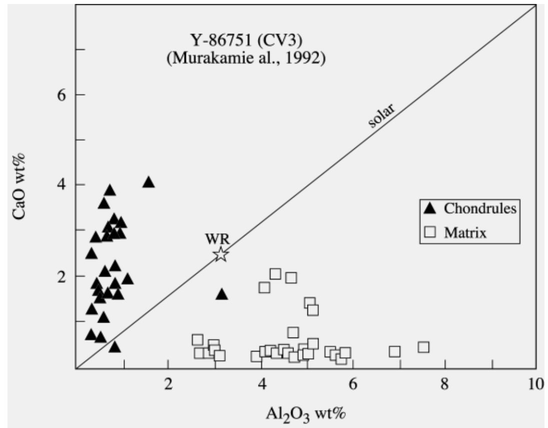

Fig. 3: High Ca, low Al in chondrules and low Ca, high Al in matrix of Y-86751 (CV), a meteorite in bulk composition very similar to Allende. Fig. from [16].

Summary. Models of chondrule formation require a close spatial relationship of chondrules and matrix. Elements that are not incorporated in chondrules remain in matrix. Fractionations occurred at high temperatures (preferred incorporation of forsterite, fractionation of spinel and perovskite) and in very local environments. Large scale chondrule formation models are difficult to reconcile with these findings.

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