What Are Space Exposure Histories Telling Us about CM Carbonaceous Chondrites?

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Introduction: Chondrites are chemically primitive and carbonaceous (C) chondrites are potentially the most primitive among them because they mostly escaped thermal metamorphism that affected the other chondrite groups and ratios of their major, non-volatile and most of the volatile elements are similar to those of the Sun. Therefore, C chondrites are expected to retain a good record of the origin and early history of the solar system.

Carbonaceous chondrites are chemically differentiated from other chondrites by their high Mg/Si ratios and refractory elements, and have experienced various degrees of aqueous alteration. They are subdivided into eight subgroups (CI, CM, CO, CV, CK, CR, CB and CH) based on major element and oxygen isotopic ratios. Their elemental ratios spread over a wide range though those of ordinary and enstatite chondrites are relatively uniform. It is critical to know how many separate bodies are represented by the C chondrites.

In this study, CM chondrites, the most abundant carbonaceous chondrites, are examined. They are water-rich, chondrule- and CAI-bearing meteorites and most of them are breccias. High-temperature components such as chondrules, isolated olivine and CAIs in CMs are frequently altered and some of them are replaced by clay minerals and surrounded by sulfides whose Fe was derived from mafic silicates. On the basis of degrees of aqueous alteration, CMs have been classified into subtypes from 1 to 2, although Rubin et al. [1] assigned subtype 1 to subtype 2 and subtype 2 to subtype 2.6 using various petrologic properties. The classification is based on petrographic and mineralogic properties. For example, though tochilinite (2[(Fe, Mg, Cu, Ni[])S] 1.57-1.85 [(Mg, Fe, Ni, Al, Ca)$(HH)_2$]) clumps are produced during aqueous alteration, they disappear and sulfide appears with increasing degrees of aqueous alteration.

Cosmic-ray exposure (CRE) age measurements of CM chondrites reveal an unusual feature. Though CRE ages of other chondrite groups range from several Myr to tens of Myr, CMs exposure ages are not longer than 7 Myr with one-third of the CM having less than 1 Myr CRE age. For those CM chondrites that have CRE ages <1 Myr, there are two discernable CRE peaks. Because a CRE age reflects how long a meteorite is present as a separate body in space, the peaks presumably represent collisional events on the parent body (ies) [2].

In this study we defined 4 distinct CRE age groups of CMs and systematically characterized the petrography in each of the 4 CRE age groups to determine whether the groups have significant petrographic differences, with such differences probably reflecting different parent body (asteroid) geological processing, or multiple original bodies.

Samples and Method: We observed thin sections of 125 CM and CM-related chondrites by optical microscopy and scanning electron microscopy (SEM). Moreover, we made whole mosaics of each thin section by reflected light and backscattered electron imaging (Fig. 1). We then grouped the meteorites into several groups based on the following nine petrographic criteria:

1. Abundance of chondrules
2. Abundance and thickness of chondrule rims
3. Chondrule sizes
4. Degrees of chondrule fracturing
5. Degrees of mafic silicate alteration in chondrules
6. Amount of metal iron
7. Amount of CAIs
8. Amount of tochilinite clamps
9. Brecciation

These criteria follow characterizations mentioned in Rubin et al. [1]. Our resultant groupings are performed qualitatively because this is the first attempt to group them with their CRE ages and textures.

Some element maps are also made by SEM and some quantitative analyses were made of matrix by electron microprobe to compare compositions between each CRE age groups.

Result and Discussion: Figure 2 is the CRE age distribution plot of CMs observed in this study [2]. In this plot, the 73 well determined CMs are shown. According to this plot, there are several distinct peaks and the large number of samples permits investigation of each CRE age group. We label the perceptible 3 peaks approximately around 0.2 Myr, 0.6 Myr

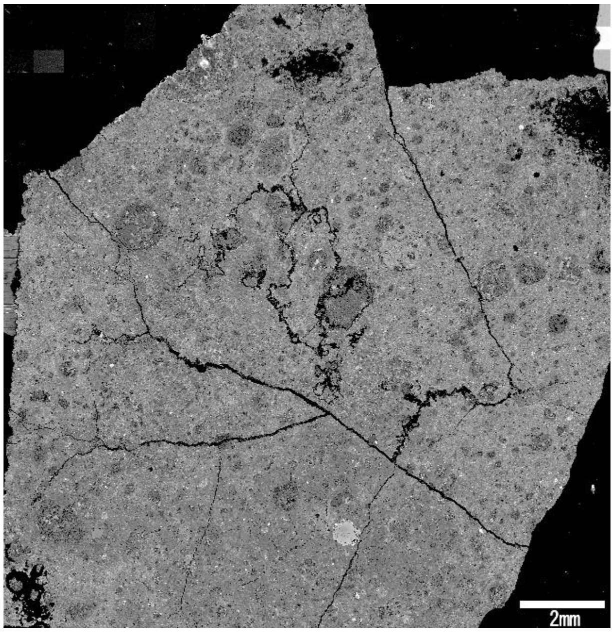

Fig. 1 BSE mosaic of Murchison

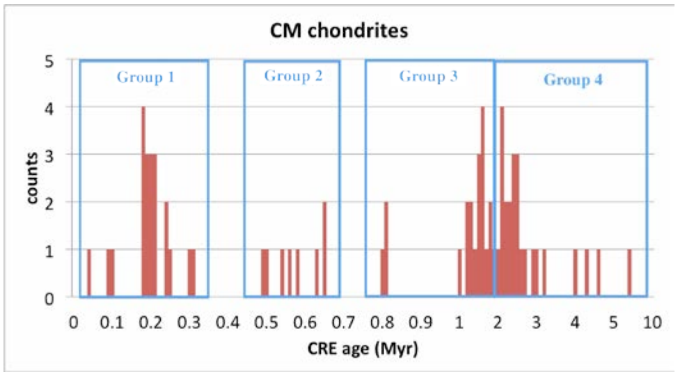

Fig. 2 CRE age distribution plot of observed CMs

and 1.5 Myr as group1, 2 and 3, respectively. Although meteorites whose CRE age is over 2.5 Myr are plotted, their CRE ages are still uncertain because of limitation on measurement, therefore they all are grouped as group 4.

According to our observations, we find that some meteorites in the same CRE age group have the same texture (or the same clast). For example, LON94101, Y-793595 and ALH85007 are belonging to the same group and some rare clasts (compressed tochilinite) similar to the texture in Y-793595 are found in the other meteorites. This is consistent with the hypothesis that they are ejected by the same collisional event and the peak in the CRE age distribution plot represents each collisional event [2].

Then, we compare each meteorite by the criteria and find some trends. Although the average chondrule sizes and rim thicknesses of each group are similar, the degree of alteration and the amount of tochilinite is different. Meteorites in group 1 to 3 tend to be more altered than meteorites in group 4 and the amount of tochilinite tend to decrease from group 1 to group 3 and be constant from group 3 to 4. Therefore, it seems that there are some correlations between the CRE ages and the textures, however this observation is still qualitative and we need to confirm whether these changes are significant.

Figure 3 shows elemental maps of 4 meteorites selected from 3 different CRE age groups and not-measured group. From these images we can find that Mg is rich in ALH88045 and Cold Bokkeveld, however it is low in Murray and LEW90500, and Al and Ca are more abundant than Mg in LEW90500. As above, we see compositional differences between each meteorite. However, we have only a small amount of compositional data, and it is therefore unclear whether the compositions of meteorites with similar textures are alike or not.

Conclusions: In this study, we sought correlations between the CRE age and textures of CMs for the first time and we found the degree of alteration and the amount of tochilinite change with the CRE ages. However, this observation is still qualitative, therefore, quantitative observation, for example the compositional analysis by electron microprobe to quantify the degree of alteration is needed.

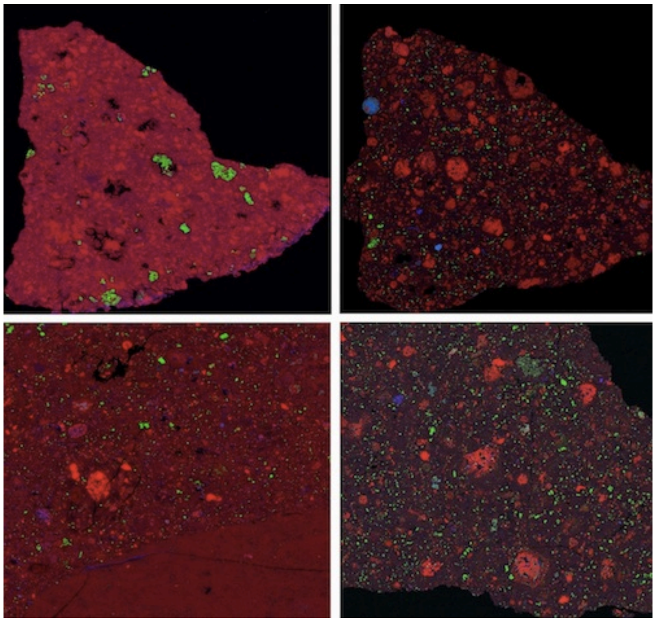

Fig. 3 Composite elemental maps of 4 meteorites
Red, green and blue represent Mg, Ca and Al, respectively. Upper left: ALH88045, Upper right: Murray, Lower left: Cold Bokkeveld, Lower right: LEW90500. Mg, Ca and Al contrast and brightness are adjusted to be the same within each image.

We also found CMs in each CRE age group have many different kinds of textures, some are similar and others are different. This means that meteorites from each group was ejected by the same collisional event and the parent body(ies) of CMs is (are) complex and not uniform.

At this time, although it is not clear that the differences in each group are significant and what they represent. Our preliminary analysis suggests that some CRE age groups are from separate parent bodies. Further investigation is required to permit selection of the correct situation.

References: [1] Rubin A. E. et al. (2007) *Geochim. Cosmochim. Acta 71. 2361-2382*. [2] Nishiizumi K. and Caffee M. C. (2012) *LPSC XLIII*, abst #2758.