ON THE RELATIONSHIP BETWEEN COSMIC-RAY EXPOSURE AGES AND PETROGRAPHY OF CM CHONDRITES.

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Introduction: Carbonaceous (C) chondrites are potentially the most primitive among chondrites because they mostly escaped thermal metamorphism that affected the other chondrite groups. C chondrites are chemically distinguished 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 vary over a wide range, in contrast to those of ordinary and enstatite chondrites which are relatively uniform. It is critical to know how many separate bodies are represented by the C chondrites.

In this study we defined 4 distinct cosmic-ray exposure (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. We have reported the results of a preliminary grouping at the NIPR Symp. in 2013 [3], however, we revised the grouping and here report our new results.

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 compared the meteorites, focusing on the following five petrographic criteria:

1. Maximum size of chondrules
2. Maximum thickness of chondrule rims
3. Degrees of mafic silicate alteration in chondrules
4. Amount of tochilinite aggregates
5. Degree of brecciation

These criteria follow characterizations mentioned in Rubin et al. [1] and our earlier study [3]. Our observations were performed qualitatively to compare features with their CRE ages and textures. Some element maps are also made by SEM, and some quantitative analyses were made for the matrix serpentine by electron microprobe to compare compositions between each CRE age groups.

Result and Discussion: Fig. 2 is the CRE age distribution plot of CMs by Nishiizumi et al. [2]. 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 4 peaks at approximately 0.1 Myr, 0.2 Myr, 0.6 Myr and 2 Myr as group1, 2, 3 and 4, respectively. The plots around 4 Myr and 7 Myr are not distinct peaks because there are actually more samples around these ages which are not plotted in this graph because their CRE ages are not well-determined. Therefore, we consider only 4 distinct peaks at this time.

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 belong to the same group and some rare clasts (compressed tochilinite) similar to the texture in Y-793595 are found in the other meteorites (Fig. 3). This is consistent with the hypothesis that they were ejected by the same collisional event and that the peak in the CRE age distribution plot represents each collisional event [2].

Then, we compared each meteorite by the criteria and found some interesting trends. Although the average chondrule sizes, rim thicknesses and the amount of tochilinite of each group are similar, the degree of alteration of each group seems to be different. For example, meteorites in group 2 tend to be highly altered, while weakly altered meteorites are concentrated in group 4. 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 variations are truly significant. Therefore, we analyzed the iron content of tochilinite because its composition should change with the degree of aqueous alteration.

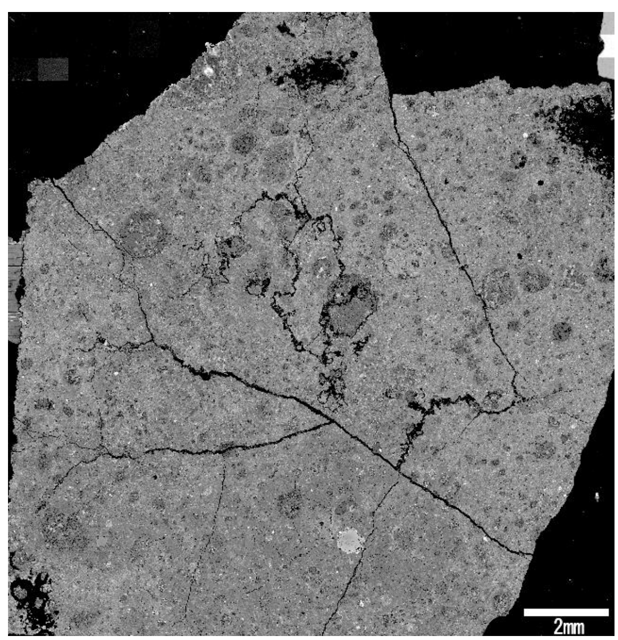

Fig. 1 BSE mosaic of Murchison (group 4)

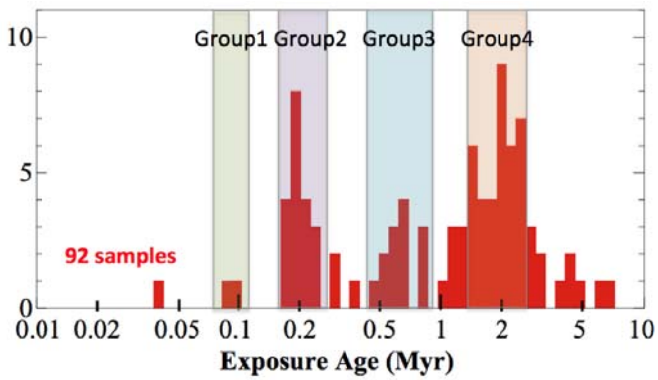

Fig. 2 Grouping of CMs by their CRE ages

Fig. 4 shows elemental maps of 3 meteorites having 3 different CRE ages. From these images we can find that Mg is abundant in Cold Bokkeveld, however it is low in Murray and LEW90500, and Al and Ca are more abundant than Mg in LEW90500. As mentioned above, we see compositional differences between each meteorite. Fig. 5 shows FeO contents of matrix serpentine in some meteorites from each group. Although it is believed that matrix FeO content changes with the degree of aqueous alteration, the relationship to the CRE ages is unclear probably because the amount of data is still small.

Conclusions: In this study, we sought correlations between the CRE ages and petrography of CMs, and we tentatively conclude that the degree of alteration seems to vary with the CRE ages.

We also found that CMs in each CRE age group have many different textures, some being similar and others not. This supports the idea that meteorites from each group were ejected by the same collisional event and the parent body(ies) of CMs is (are) complex and not uniform. However, at this time it is not clear that the differences in each group are significant and what they actually represent. Our preliminary analysis suggests that some CRE age groups are from separate parent bodies. However, further investigation is clearly required to better understand these relationships.

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. [3] Takenouchi A. et al. (2013) *Antarct. Meteorites XXXVI*, 69-70.

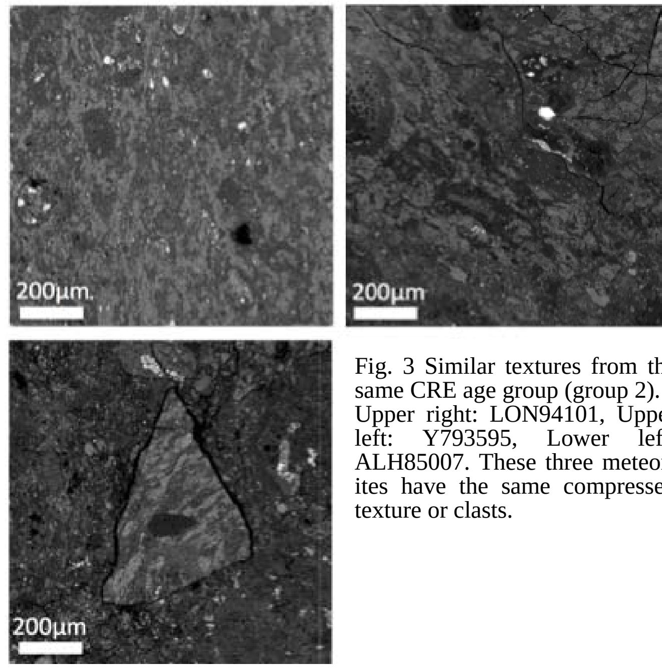

Fig. 3 Similar textures from the same CRE age group (group 2). Upper right: LON94101, Upper left: Y793595, Lower left: ALH85007. These three meteorites have the same compressed texture or clasts.

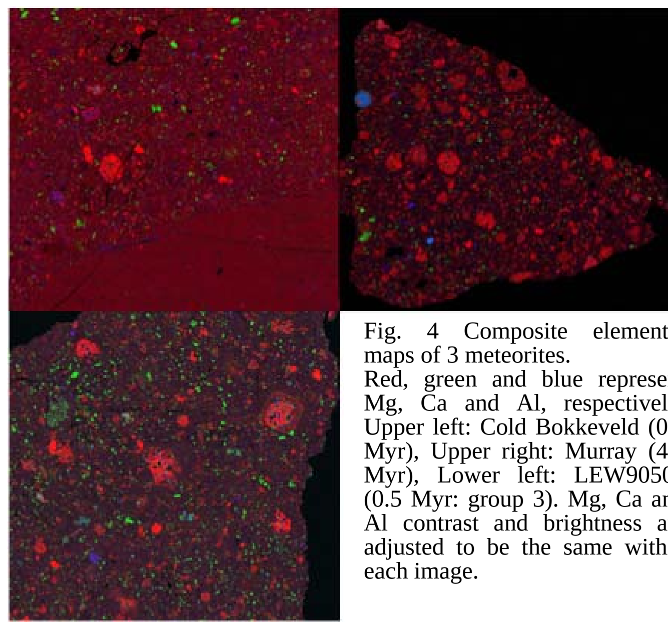

Fig. 4 Composite elemental maps of 3 meteorites.
Red, green and blue represent Mg, Ca and Al, respectively. Upper left: Cold Bokkeveld (0.3 Myr), Upper right: Murray (4.3 Myr), Lower left: LEW90500 (0.5 Myr: group 3). Mg, Ca and Al contrast and brightness are adjusted to be the same within each image.

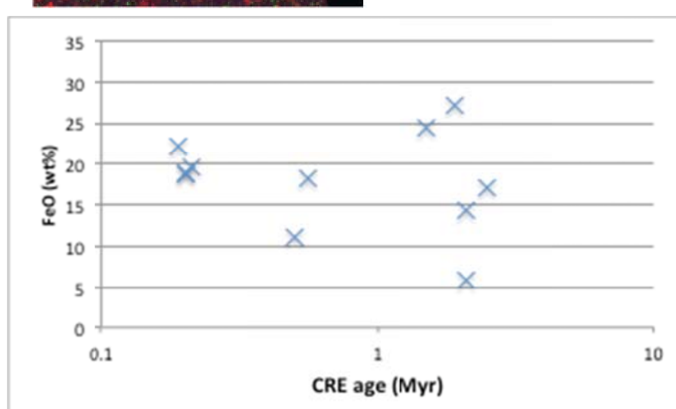

Fig. 5 FeO contents of matrix serpentine in some CM meteorites