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

A. Takenouchi[1], M. E. Zolensky[2], K. Nishiizumi[3], M. Caffee[4], M. A. Velbel[5], K. Ross[6], A. Zolensky[7], L. Le[6], N. Imae[8], A. Yamaguchi[8], T. Mikouchi[1], [1]University of Tokyo, Hongo, Tokyo 113-0033, Japan. a.takenouchi@eps.s.u-tokyo.ac.jp, [2]ARES, NASA Johnson Space Center, Houston, TX 77058, USA, [3]Space Sciences Lab., UC Berkeley, CA 94720, USA, [4]Dept of Physics, Purdue University, W. Lafayett, IN 47907, USA, [5]Michigan State University, East Lansing, MI 48824, USA [6]Jacobs Technology, Houston, TX 77058, USA, [7]Nashville, TN, USA, [8]National Inst. of Polar Res., Tachikawa ,Tokyo 190-8518, Japan.

Introduction: Carbonaceous (C) chondrites may be the most primitive chondrites group; they mostly escaped thermal processing that affected the other chondrite groups. C chondrites are chemically distinguishable from other chondrites by their high Mg/Si ratios and refractory elements. C chondrites also exhibit varying degrees of aqueous alteration. Based on major element and oxygen isotopic ratios they are subdivided into eight subgroups (CI, CM, CO, CV, CK, CR, CB and CH). Across these eight subgroups the elemental ratios vary over a wide range, in contrast to those of ordinary and enstatite chondrites, which are relatively uniform. The varying chemical compositions and degree of aqueous alterations makes it difficult to know just how many parent bodies the C chondrites comprise. Cosmic ray exposure (CRE) ages can identify groupings based on their exposure as small bodies to cosmic rays.

We have defined, in this work, four distinct CRE age groups of CMs. To determine whether the groups show significant petrographic differences that might reflect different parent body (asteroid) geological processing, or multiple original bodies, we systematically characterized the petrography characteristics for each of the four CRE age groups. Preliminary results were reported at the NIPR Symp. in 2013 [1]. In this report we report new measurements which in turn are used to revise the grouping data.

Samples and Method: We examined thin sections of 125 CM and CM-related chondrites by optical microscopy and scanning electron microscopy (SEM). We made whole mosaics of each thin section by reflected light and backscattered electron (BSE) imaging (Figure 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

The qualitative observations of these five criteria were supplemented by a few SEM element images, and selected quantitative analyses of the matrix serpentine by electron microprobe.

Result and Discussion: Figure 2 shows the CRE age distribution plot of CMs [3]. There are four distinguishable peaks. Three of these peaks have enough members to allow statistically significant studies of the properties of each CRE age group. The four peaks have CRE ages of approximately 0.1 Myr, 0.2 Myr, 0.6 Myr and 2 Myr. The apparent peaks around 4 Myr and 7 Myr may not be distinct peaks. There are more samples having about these ages that are not plotted in this graph because their CRE ages are not well determined by ^{10}Be (half-life = 1.36 Myr) exposure age method. For now we consider only four distinct peaks at this time.

We found that some meteorites within the same CRE age group have the same texture (or the same clasts). For example, LON94101, Y-793595 and ALH85007 belong to the same CRE age group and all contain unusual clasts (compressed tochilinite) (Figure 3). This observation is consistent with the hypothesis that they were ejected by the same collisional event from the same parent body [3].

Figure 4 shows elemental maps of three meteorites having three different CRE ages. In this image, 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.

Additional comparisons of each meteorite using the criteria show some interesting trends. The average chondrule size, rim thickness, and amount of tochilinite of each group are similar. The degree of mafic silicate alteration of each group seems different. For example, meteorites in the 0.2 Myr peak tend to be highly altered, while weakly altered meteorites are concentrated in the 2 Myr peak. It seems that there are some systematic variations between the CRE ages and the textures, however this correlation is at best qualitative and needs further measurements to confirm whether they are significant.

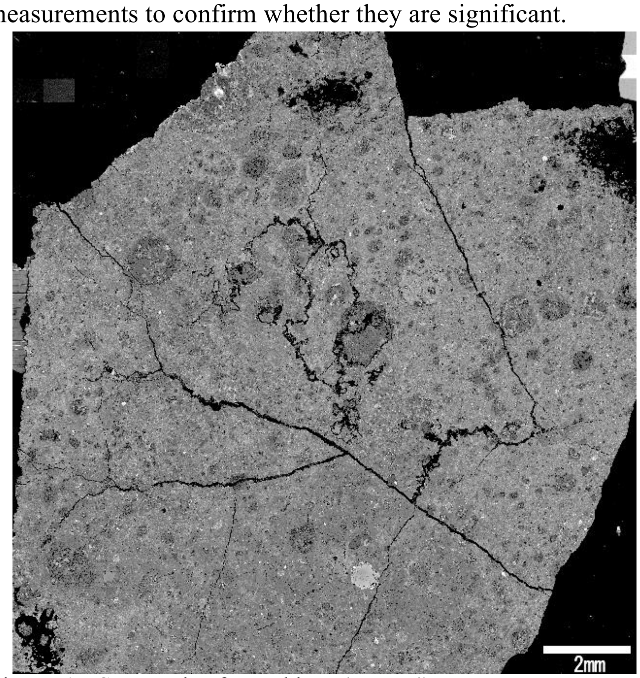

Figure. 1 BSE mosaic of Murchison (group 4)

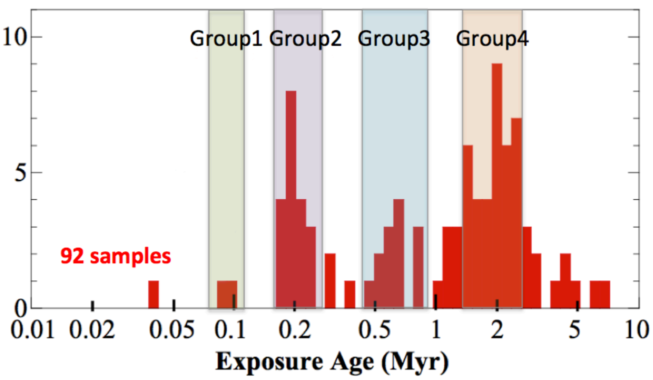

Figure 2 Grouping of CMs by their CRE ages [2]

Further confirmation is potentially found in the iron content of tochilinite because its composition should change with the degree of aqueous alteration.

Figure 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 work, we sought correlations between the CRE ages and the petrography of CMs. We tentatively conclude that there are differences in the petrographic characteristics of the CRE age groups. We also found that CMs in each CRE age group have many different textures, and that in some instances there are similarities, but in others there are not. The variations in petrographic characteristics in many instances are correlated with distinct CRE age groups. This supports the hypothesis that CM meteorites from each group were ejected by the same collisional event, and that 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 may be from separate parent bodies. Further investigation is clearly required to better understand these relationships.

References: [1] Takenouchi A. et al. (2013) *Antarct. Meteorites XXXVI*, 69-70. [2] Rubin A. E. et al. (2007) *Geochim. Cosmochim. Acta 71. 2361-2382*. [3] Nishiizumi K. and Caffee M. C. (2012) *LPSC XLIII*, abst #2758.

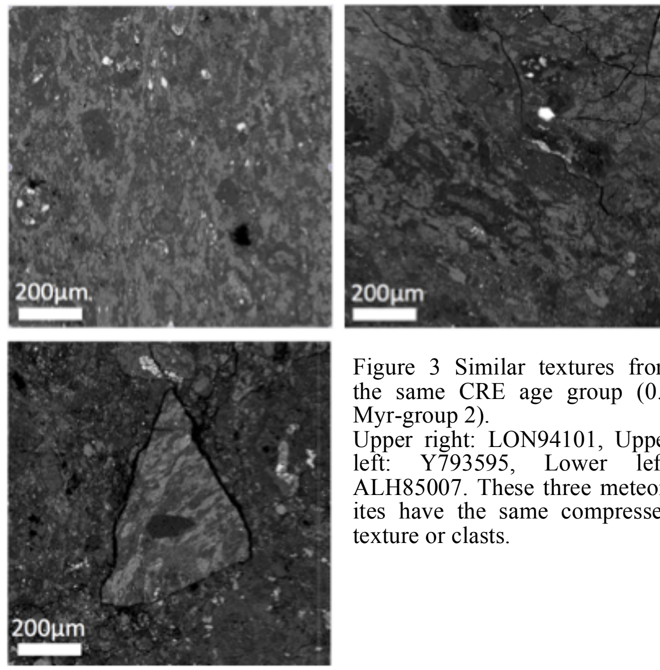

Figure 3 Similar textures from the same CRE age group (0.2 Myr-group 2).
Upper right: LON94101, Upper left: Y793595, Lower left: ALH85007. These three meteorites have the same compressed texture or clasts.

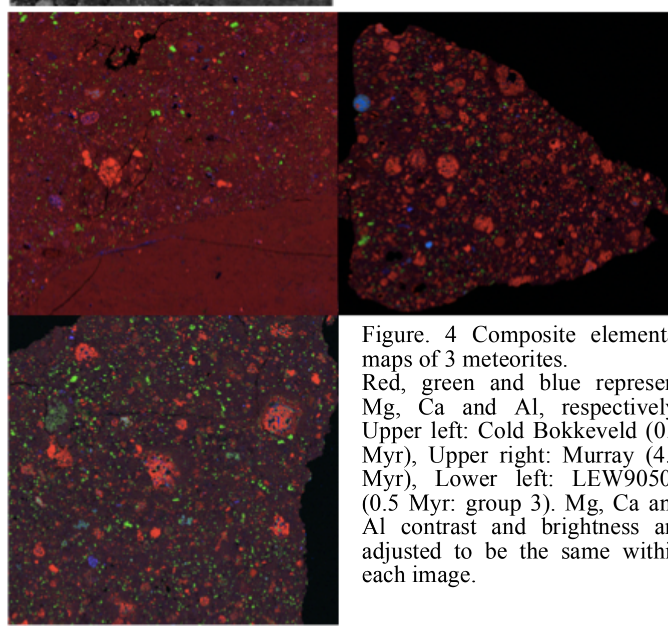

Figure. 4 Composite elemental maps of 3 meteorites.
Red, green and blue represent Mg, Ca and Al, respectively. Upper left: Cold Bokkeveld (0.3 Myr), Upper right: Murray (4.3 Myr), Lower left: LEW90500 (0.5 Myr: group 3). Mg, Ca and Al contrast and brightness are adjusted to be the same within each image.

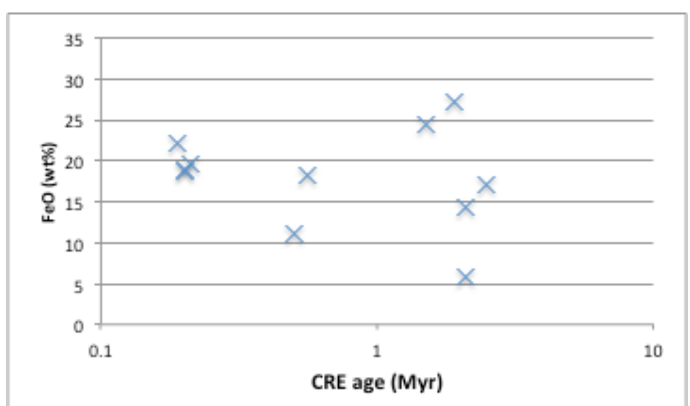

Figure. 5 FeO contents of matrix serpentine in some CM meteorites