CM Carbonaceous Chondrite Lithologies and Their Space Exposure Ages. Michael Zolensky[1], Timothy Gregory[2], Atsushi Takenouchi[3], Kunihiko Nishiizumi[4], Alan Trieman[5], Eve Berger[1], Loan Le[1], Amy Fagan[5], Michael Velbel[6], Naoya Imae[7], Akira Yamaguchi[7], Marc Caffee[8]. [1]NASA Johnson Space Center, Houston, TX 77058, USA, [2]The University of Bristol, Bristol, BS8 1TH, UK, [3]University of Tokyo, Hongo, Tokyo, 113-0033, Japan, [4]UC Berkeley, Berkeley, CA 94720, USA, [5]Lunar and Planetary Institute, Houston, TX 77058, USA, [6]Michigan State University, East Lansing, MI 48824, USA, [7]National Institute of Polar Research, Tokyo, Japan, [8]Purdue University, West Lafayette, IN 47907, USA.

Introduction: The CMs are the most commonly falling C chondrites, and therefore may be a major component of C-class asteroids, the targets of several current and future space missions. Previous work [1] has concluded that CM chondrites fall into at least four distinct cosmic ray space exposure (CRE) age groups (0.1 Ma, 0.2 Ma, 0.6 Ma and >2.0 Ma), an unusually large number, but the meaning of these groupings is unclear. It is possible that these meteorites came from different parent bodies which broke up at different times, or instead came from the same parent body which underwent multiple break-up events, or a combination of these scenarios, or something else entirely.

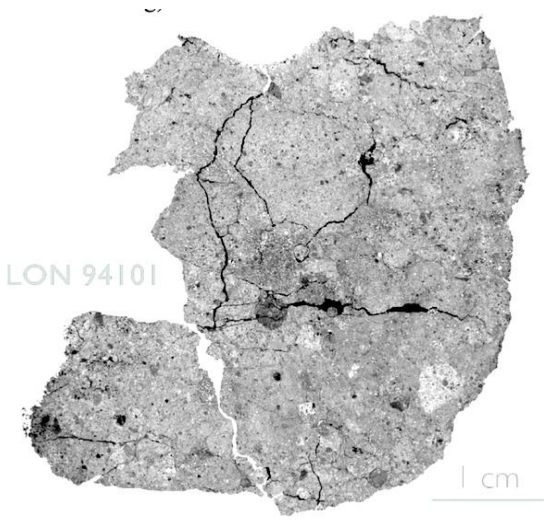
The objective of this study is to investigate the diversity of lithologies which make up CM chondrites, in order to determine whether the different exposure ages correspond to specific, different CM lithologies, which permit us to constrain the history of the CM parent body(ies). We have already reported significant petrographic differences among CM chondrites [2-4]. We report here our new results.

Techniques: We identified and described the lithologies making up CM chondrites using BSE mosaics and some X-ray element maps, collected using JSC's JEOL JSM-7600F Electron Microscope, collected some BSE mosaics using the SEM at Michigan State University, and made some light optical observations at the NIPR. In all we observed 129 different CM chondrites, 74 of which have well-defined CRE ages [1]. We described lithologies on the basis of these criteria:

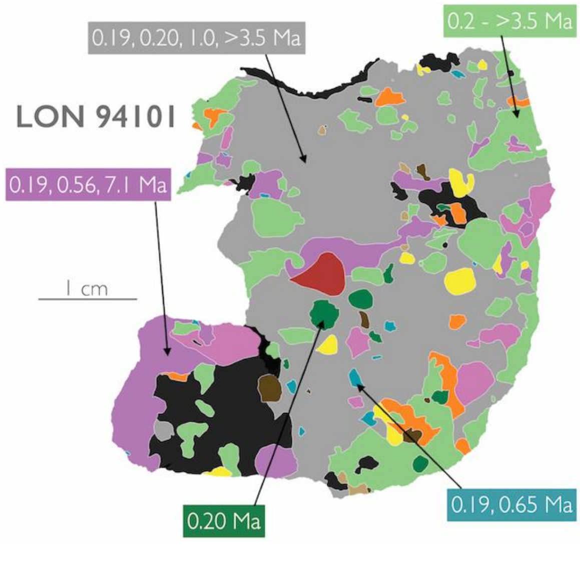
- Chondrule abundance, shape, size and sorting
- Chondrule dust mantle thickness and integrity
- Clast-matrix ratio
- Matrix mineralogy and texture
- Abundance and shape of sulfide minerals

Phyllosilicate composition is potentially an indicator of the degree of aqueous alteration a lithology has experienced [5], as it has been proposed that the ratio Mg/Fe in matrix phyllosilicates increases with increasing degree of aqueous alteration. Thus we collected compositional data for CMs to determine if there was a link between matrix phyllosilicate composition (Mg/Mg+Fe, Mg#) and exposure age. We used Cameca SX100 and JEOL 8530F electron microprobes at JSC, using a beam energy of 15 keV and a current of 20 nA.

A very large sample (~100 g) of the CM2 breccia LON 94101 was studied in detail to determine whether its diverse lithologies correspond to CM2 meteorites with different exposure ages. Lithologies identified in our suite of CM chondrites were used as a benchmark.



Above: A BSE mosaic of LON 94101, measuring 5 cm across. **Below**: Each color represents a different lithology within LON 94101. Lithologies were identified from 3 separate CRE age groups.



Results: We identified a total of twenty-three different CM lithologies from the BSE mosaics of 27 different CMs. That is a lot.

Some lithologies appeared repeatedly in different samples, while some only appeared once. Some CMs were composed entirely of only one lithology while some were composed of many (such as LON 94101, which contains at least 11 distinct lithologies).

Lithologies did not fall into one distinct exposure age group. For example, one of the lithologies appeared in meteorites from the 0.19, 0.20, 1.0 and >3.5 Ma exposure age groups. However, all of the samples containing only one lithology fell within the >3.5 Ma exposure age group.

Single samples were also found to contain lithologies of different degrees of aqueous alteration. For example, the phyllosilicate composition of lithologies making up ALH 85007 showed peaks at different Mg/(Mg+Fe) values. One lithology showed a single peak at Mg# = 60, while another showed a bimodal distribution with peaks at Mg# = 63 and 73. However, there was a general trend of CMs with younger exposure ages being more aqueously altered. We are currently further assessing matrix composition to determine whether this criteria is truly correlated with CRE age.

LON 94101 Within the CM2 chondrite LON 94101, we identified a total of eleven lithologies; of these, ten had been identified in the BSE mosaics of other CMs, while one was unique to LON 94101. The exposure ages of the CM2 meteorites composed of lithologies identified in LON 94101 ranged from 0.19 Ma to 7.1 Ma. The most common exposure ages were between 0.19 and 0.56 Ma; none had an exposure age of 2.5 Ma.

Discussion: The range of exposure ages found across a single type of lithology suggests that a CM lithology can be produced on multiple parent bodies, or that they are produced on the same parent body which underwent multiple impact events.

Different degrees of aqueous alteration in lithologies making up single CM breccias could suggest that different parts of a single CM parent body are sampled within the same meteorite, with each part of the parent body having undergone a different degree of alteration. The general trend of CMs of a younger exposure age being aqueously altered to a higher degree could reflect a parent body which is aqueously altered to a higher degree in the center, with sequential impacts exposing deeper and deeper regions in the parent body.

These data are also consistent with multiple CM parent bodies, with the most altered ones being most recently impacted.

References: [1] Nishiizumi and Caffee (2012) *43rd Lunar and Planetary Science Conference*. Abstract #2758; [2] Takenouchi et al. (2013) *Antarct. Meteorites XXXVI*, 69-70; [3] Takenouchi et al. (2014) *45th Lunar and Planetary Science Conference*, Abstract; [4] Gregory et al. (2015) *46th Lunar and Planetary Science Conference*. Abstract; [5] Brearley (2006) in *Meteorites and the early Solar System II*, p. 587-624.

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