**EXPOSURE HISTORIES OF CI1 AND CM1 CARBONACEOUS CHONDRITES.** K. Nishiizumi[1] and M. W. Caffee[2], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [2]Department of Physics, Purdue University, West Lafayette, IN 47907-1396, USA (mcaffee@purdue.edu).

**Introduction:** The cosmic ray exposure (CRE) age is the time interval between a meteoroid's (<several m diameter) ejection from the parent body and its collision with Earth. The distribution of meteorite CRE ages constrains the collisional and orbital dynamics of these objects. Numerical simulations predict that most of meteorite's accumulated exposure to cosmic rays as a relatively small object occurs in main belt, before its deliverer to a resonance [1, 2]. The CRE ages of most ordinary chondrites range from several Myr to tens of Myr [3], as measured by cosmogenic noble gases. The CM2 chondrites, on the other hand, have much shorter CRE ages (< 1 Myr). These ages are based on cosmogenic radionuclide measurements [e.g., 4]. In this work our goal is to determine whether additional classes of carbonaceous chondrites, specifically the CI1, CM1, and CM1/2 meteorites, have similar short CRE ages.

**Exposure Ages of CM2 Chondrites:** Mazor et al. [5] investigated noble gases in carbonaceous chondrites. . They observed that both the CRE ages and the gas retention ages of CI and CM carbonaceous chondrites differed from those of other meteorites types. Since carbonaceous chondrites generally contain considerable trapped Ne, it is sometimes difficult to accurately resolve short CRE ages; for meteorites with CRE ages less than 1 Myr radionuclides are a more sensitive indicator. We measured the CRE ages of CM2 chondrites using $^{10}$Be (half-life = 1.36 Myr) and $^{26}$Al (0.705 Myr) [e.g., 4]. We have now meaured radionuclides in over 120 CM2 meteorites (excluding pairs). The noble gases have been measured in some of these as well [e.g. 6]. For those meteorites that have apparent CRE $^{10}$Be ages > 3 Myr, our ages are lower limits (the mean-life of $^{10}$Be is 2 Myr). Based on our measurements our findings are: (1) about one-third of the CM2s have CRE ages less than 1 Myr; (2) nearly one-half of the CM2s have CRE ages less than 2 Myr; and (3) no CM2 chondrites have CREs age longer than 7 Myr. For those CM2s that have exposure ages < 1 Myr, there are two discernable clusters; ~20% of the CM2 meteorites are in a cluster corresponding to 0.2 Myr and ~15% are in a cluster that is 0.5-0.7 Myr in age. These clusters most likely represent collisional events. All these features are observable in both Antarctic and non-Antarctic CM2 meteorites, although our study is heavily biased toward Antarctic CM2 meteorites, which represent ~85% of our samples ( Table 2).

**Exposure Ages of CI1 and CM1 Chondrites:** We have also extended our investigation of the CRE age distribution to those CI1 and CM1 meteorites that have a high degree of aqueous alternation. Nine CI1, 18 CM1, 13 CM1/2 meteorites, and 1 C1/2-ungrouped carbonaceous chondrite were recognized. With the exception of 5 CI1 meteorites (Alais, Ivuna, Orgueil, Revelstoke, and Tonk) and 2 CM1 meteorites (Moapa Valley and NWA 4765), the remaining meteorites (34 in total) were recovered from Antarctica. All non-Antarctic type 1 carbonaceous chondrites (with the exceptions of Moapa Valley and NWA 4765) were falls. The bias toward falls probably indicates that the fragile nature of these classes of meteorites make them difficult to identify after a long terrestrial residence, unless they are preserved in the ice in Antarctica. We measured $^{10}$Be, $^{26}$Al, and $^{36}$Cl (half-life = 0.30 Myr) in 3 CI1, 6 CM1, 6 CM1/2 meteorites and one C1/2 ungrouped carbonaceous chondrite by AMS. The preliminary results are shown in Table 1.

Table 1. Cosmogenic radionuclide concentration (dpm/kg) in CI1, CM1, CM1/2, and C1/2-ungrouped carbonaceous chondrites.

| | $^{10}$Be | $^{26}$Al | $^{36}$Cl |
|---|---|---|---|
| ***CI1*** | | | |
| Ivuna | 1.60±0.04 | 6.51±0.36 | 5.57±0.17 |
| Orgueil | 21.2±0.4 | 40.5±0.8 | 160±1 |
| Y-86029 | 1.21±0.05 | 5.31±0.25 | 1.95±0.09 |
| ***CM1*** | | | |
| GRO 95645 | 18.4±0.5 | 32.9±1.3 | 6.20±0.16 |
| LAP 02277 | 2.01±0.11 | 9.76±0.41 | 3.10±0.12 |
| LAP 031079 | 9.24±0.23 | 23.1±0.8 | 5.25±0.16 |
| MET 01070 | 2.18±0.09 | 7.30±0.31 | 2.79±0.11 |
| MIL 05137 | 2.24±0.05 | 6.92±0.32 | 2.62±0.11 |
| Moapa Valley | 1.75±0.03 | 12.6±0.5 | 2.35±0.09 |
| ***CM1/2*** | | | |
| ALH 83100 | 2.80±0.05 | 10.8±0.2 | |
| LAP 031166 | 2.00±0.04 | 7.96±0.42 | 2.13±0.06 |
| LAP 031214 | 2.09±0.10 | 6.58±0.34 | 2.21±0.13 |
| MCY 05231 | 7.23±0.09 | 23.6±1.0 | 20.8±0.6 |
| MIL 07677 | 2.01±0.07 | 7.28±0.44 | 2.81±0.10 |
| Y-82042 | 16.8±0.3 | 37.8±0.9 | 15.5±0.2 |
| ***C1/2-Ung*** | | | |
| Y-82162 | 1.41±0.04 | 6.24±0.29 | 2.13±0.08 |

*CI1.* The CRE age of Alais (7.2 Myr [5]) is the longest exposure age among all CI1 and CM chondrites. The CRE age of Orgueil is similar, based on noble gas (many measurements) and our $^{53}$Mn measurement. Tonk has a CRE age of 1.5 Myr [5]. Ivuna has a complex cosmic ray exposure history [4, 5]. The distribution of CRE ages of CI1 is very similar to that of CM2 (Table 2).

*CM1.* All the CRE ages for CM1 are based on our radionuclide data, except ALH 88045, which has a noble gas exposure age of 0.2 Myr [7]. Except for GRO 95645 (~3 Myr) and LAP 031079 (0.9±0.1 Myr), the CRE ages of all other CM1 meteorites are ~0.2 Myr, in agreement with the noble gas age of ALH 88045.

*CM1/2.* Excepting Yamato 82042 (~2.6 Myr) and MCY 05231 (0.8±0.1 Myr), the 4 other CM1/2 have CRE ages of 0.2 Myr.

Table 2 summarizes the CRE age distributions of CI1, CM1, CM1/2 meteorites, as well as the C1/2-ungrouped carbonaceous chondrites. A comparison of both Antarctic and non-Antarctic CM2 meteorites is also given. Even though this data set is still limited in number, we can make some inferences about the CRE histories of these meteorites. There is a clear 0.2 Myr (0.20±0.05 Myr) exposure age peak that extends across all classes of carbonaceous chondrites measured by us to date (Table 2). With the caveat that we have only a limited number of measurements, the fraction of CI1 meteorites in the 0.2 Myr peak is about the same as that of the CM2 meteorites. Most of the CM1 and CM1/2 meteorites are in the 0.2 Myr exposure age peak. If a carbonaceous chondrite has a CRE age < 1 Myr, it is either in the 0.2 Myr or ~0.5 Myr peak. Based on our measurements there is not an even distribution of CRE ages < 1 Myr.

Our measurements indicate two significant findings: a 0.2 Myr peak in the CRE age distribution that cuts across different chemical and petrologic meteorites types; and many carbonaceous chondrites have extremely short CRE ages. Evidently, both CI1 and CM1-CM2 chondrites were liberated from their respective parent bodies at the same time, 0.2 Myr ago. This similarity in age leads us to conclude that the breakup of these parent bodies was not coincidental. Two possibilities are that they all derived from the same parent body, or the CM parent body cullieded with the CI1 parent body, thus exposing all fragments at the same time. The short CRE exposure ages is also surprising given our expectations of meteorite transport processes. These short CRE ages are much shorter than the time anticipated between a fragmentation event and placement of the fragments into an orbital residence, from which it is delivered to Earth. There are several possible explanations: the fragmentation event could have occurred while the objects were in Earth-crossing orbits already; the fragmentation event could have occurred in a location from which the fragments were immediately put into an orbital residence; the friable nature of these meteorites has biased our sampling and we only see those with short exposure ages. Our expectation is that the first scenario would produce discrete peaks in the CRE age distribution, the other two would still produce a range of exposure ages, which we do not observe. At this time though we cannot be overly dogmatic about any or these since our data set is limited in size. A significant contribution would be the determination of terrestrial ages, which would then allow us to determine ejection ages. We typically employ $^{36}$Cl and $^{41}$Ca for this purpose but, unfortunately, the high abundance of $H_2O$ in many of these meteorites enhances the thermal neutron flux in the pre-atmospheric body, leading to significant production of neutron capture $^{36}$Cl and $^{41}$Ca.

Table 2. Cosmic ray exposure age distributions of CI1 and CM carbonaceous chondrites.

| Class | Exposure age (Myr) | | | |
|---|---|---|---|---|
| | 0.1-0.2 | 0.5-0.7 | >1 | Total |
| CI1 | 2 | | 3 | 5 |
| CM1 | 5 | | 2 | 7 |
| CM1/2 | 4 | 1 | 1 | 6 |
| C1/2 Ung. | 1 | | | 1 |
| CM2 Antarctic | 23 | 16 | 89 | 128 |
| CM2 Non-Ant. | 5 | 3 | 14 | 22 |

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