EXPOSURE AGES OF CARBONACEOUS CHONDRITES - I ; K. Nishiizumi*, J. R. Arnold, Dept. of Chemistry, Univ. of Calif., San Diego, La Jolla, CA 92093-0317, M. W. Caffee, R. C. Finkel, J. R. Southon, CAMS, Lawrence Livermore National Lab, Livermore, CA 94551, H. Nagai, M. Honda, Dept. of Chemistry, Nihon Univ., Tokyo, M. Imamura, INS, Univ. of Tokyo, Tokyo, K. Kobayashi, RCNST, Univ. of Tokyo, Tokyo, P. Sharma, NSRL, Univ. of Rochester, Rochester, NY 14627

The recent exposure histories of carbonaceous chondrites have been investigated using cosmogenic radionuclides. Our results may indicate a clustering of exposure ages of C1 and C2 chondrites into two peaks, 0.2 My and 0.6 My, perhaps implying two collisional events of Earth-crossing parent bodies.

Among carbonaceous chondrites are some having short exposure ages [1, 2] which Mazor et al. hypothesized cluster into a small number of families. This hypothesis is based on spallogenic ^{21}Ne exposure ages, which in some instances are difficult to determine owing to the large amounts of trapped noble gases in carbonaceous chondrites. Also, since ^{21}Ne is stable it integrates a sample's entire exposure history, so meteorites with complex exposure histories are difficult to understand using exclusively ^{21}Ne. Cosmogenic radionuclides provide an alternative means of determining the recent cosmic ray exposure duration. To test the hypothesis of Mazor et al. [2] we have begun a systematic investigation of exposure histories of Antarctic and non-Antarctic carbonaceous chondrites, especially C2s.

Measurements of ^{10}Be ($t_{1/2}$=1.5 My), ^{26}Al (0.71 My), and ^{36}Cl (0.30 My) were obtained by AMS at Lawrence Livermore National Lab, the University of Tokyo, and the University of Rochester. ^{53}Mn (3.7 My) was measured by NAA. Only new results are shown in Table 1. ^{10}Be and ^{26}Al in some of these meteorites have been reported previously [1, 3-6]. Our ^{10}Be results are in good agreement with those of Moniot et al. [5]. The experimental errors have been significantly improved by this work.

The exposure ages of 70 carbonaceous chondrites were calculated using both cosmogenic radionuclides and noble gases [7]. With the exception of Ivuna (0.18 My by radionuclides vs. 2.3 My by ^{21}Ne), Mighei (2.0 vs. 2.7 My), ALH 77307 (0.7 vs. 16 My), and Orgueil (>10 vs. 4 My), there is reasonable general agreement. For the four noteworthy differences all but one, Orgueil, have ^{21}Ne ages older than radionuclide ages and can be plausibly explained by complex or early irradiation [3]. The situation with Orgueil is more complicated. The ^{53}Mn exposure age, which is based on bulk material, is >10 My, which is considerably longer than the ^{21}Ne exposure age from bulk material (4 My). However, Nichols et al. obtained an exposure age of 16 My, which agrees with our ^{53}Mn result, based on ^{21}Ne from olivine separates [8]. We cannot explain the apparent deficit of ^{21}Ne in bulk material at this time. Several paired falls are suggested among Antarctic carbonaceous chondrites. The concentrations of cosmogenic nuclides support the proposed pairing of ALH 83100, 83102, 84029, 84042, and 84044, although ^{26}Al in ALH 84029 [6] is somewhat lower than in the others. On the other hand, ALH 81002 and 82100 are not paired based on cosmogenic radionuclide concentrations. ALH 82100 has only a 40,000 year exposure age which is one of the shortest known meteorite ages.

The histogram of exposure ages of C1 and C2 chondrites is shown in Fig. 1. The possible paired Antarctic meteorites are plotted as an average of the ages. Exposure ages are plotted at an interval of 0.1 My to better reveal exposure age peaks which may be sharper than 0.5 My. The actual uncertainties of the ages for over a few My exposure ages are much wider than the histogram interval. Only two meteorites, Al Rais (14 My, CR2) and Orgueil (16 My, CI1) lie outside the figure. It is known that the majority of C1 and C2 chondrites have shorter exposure ages than type 3-6 carbonaceous chondrites or ordinary chondrites. About 50% of C2 chondrites have exposure ages less than 0.8 My. The ^{36}Cl concentrations indicate that Antarctic C2 chondrites reported here have terrestrial ages shorter than 0.07 My. For terrestrial ages this short no corrections are required before comparison to non-Antarctic meteorites. The distribution of exposure ages indicates that there is no significant difference between Antarctic and non-Antarctic C2s. Both Antarctic and non-Antarctic C2s have distinct groups of exposure ages at 0.2 My and around 0.6 My. The most likely explanation for this distribution is that a single breakup event of an Earth-crossing parent body is responsible for each of the two clusters. While such events undoubtedly could also occur in the asteroid belt it seems unlikely that two events occurring there would produce peaks with such short exposure ages since it is difficult to reach the earth in < 1 My [9]. The range of exposure ages observed in C1 chondrites overlaps with that of C2s, indicating no significant difference in exposure ages between C1 and C2 chondrites. The common breakup of Ivuna (CI1) and Cold Bokkeveld (CM2) was previously suggested [1].

The saturation activity of ^{36}Cl in C-chondrites (bulk) is 7.5 to 10 dpm/kg. ^{36}Cl in some C2s is higher than saturation, especially in ALH 85007 and LEW 88001. The excess ^{36}Cl in ALH 85007 and LEW 88001 was presumably produced by thermal neutron capture on ^{35}Cl. The contribution was calculated to be 50 dpm ^{36}Cl/g Cl and 165 dpm ^{36}Cl/g Cl respectively assuming 300 ppm Cl in the meteorites. The high neutron fluence in LEW

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88001 is similar to that found in Allende whose preatmospheric radius was 55-65 cm, although the recovered mass of LEW 88001 was only 45 g. Many meteorites paired with LEW 88001 would therefore be expected.

Table 1. Concentrations of cosmogenic radionuclides in carbonaceous chondrites

Name	Class	^{53}Mn dpm/kg Fe	^{10}Be dpm/kg	^{26}Al dpm/kg	^{36}Cl dpm/kg	Source
Ivuna	CI1	17.3 ± 2.5	1.76 ± 0.08*			USNM 2478
Orgueil	CI1	419 ± 20	20.48 ± 0.89*			Paris 221
Banten	CM2	237 ± 10	16.84 ± 0.59*			MTF 816
Cold Bokkeveld	CM2	25.8 ± 2.3	2.95 ± 0.14*			Me 1736,7,8
Mighei	CM2	144 ± 6	13.70 ± 0.38*			Me 1456
Murchison	CM2	131 ± 7	11.07 ± 0.31*			Me 2644
Murray	CM2	271 ± 13	17.10 ± 0.49*			ASU 635.2
Nogoya	CM2	16.4 ± 2.7	2.22 ± 0.10*			Me 1680
ALH 81002	C2		19.93 ± 0.21	31.76 ± 0.69	7.84 ± 0.17	,26
ALH 82100	C2		0.43 ± 0.02	1.79 ± 0.05	0.98 ± 0.03	,19
ALH 83102	C2		3.05 ± 0.05			,30
ALH 84033	C2		24.13 ± 0.21	40.9 ± 1.1	11.65 ± 0.19	,19
ALH 85007	C2		2.23 ± 0.04	7.25 ± 0.23	8.34 ± 0.17	,14
Belgica 7904	CM2		13.74 ± 0.17	51.0 ± 1.5	14.04 ± 0.46#	,76
EET 90021	C2		11.31 ± 0.21	24.24 ± 0.86	8.82 ± 0.32	,6
EET 90043	C2		17.35 ± 0.18	32.43 ± 0.87	5.96 ± 0.14	,5
GRO 85202	C2		2.14 ± 0.04	7.76 ± 0.18	2.92 ± 0.05	,12
LEW 88001	C2		18.82 ± 0.21	45.2 ± 1.2	57.2 ± 1.2#	,8
LEW 90500	CM2		5.24 ± 0.13	15.05 ± 0.57	5.28 ± 0.12	,16
MAC 88100	C2		20.94 ± 0.18	40.79 ± 0.76		,23
MAC 88107	C2		2.12 ± 0.03	7.63 ± 0.19		,27
MAC 88176	C2		5.67 ± 0.07	16.16 ± 0.50		,13
Y-74662	CM2	265 ± 11				
Y-86720	C2		4.47 ± 0.05	22.57 ± 0.67	6.03 ± 0.15#	,93
EET 87770	CR2		18.95 ± 0.18	51.2 ± 1.4	8.69 ± 0.21#	,8
MAC 87320	CR2		18.35 ± 0.35%	43.8 ± 1.3%		,15
Grosnaja	CV3	183 ± 10				Me 1732
EET 90007	C4		21.33 ± 0.27	47.82 ± 0.91	10.82 ± 0.25	,7
Karoonda	CK4		21.16 ± 0.34	40.01 ± 0.69	10.29 ± 0.10	offG5997
Maralinga	C5		20.31 ± 0.64	46.03 ± 0.85	8.87 ± 0.19	
Mulga (West)	C5/6		18.60 ± 0.48	31.09 ± 0.86	6.07 ± 0.07	
LEW 87009	C6		20.12 ± 0.19%	46.66 ± 0.90%		,21

* University of Tokyo, # University of Rochester; others by LLNL; % Non-magnetic phase

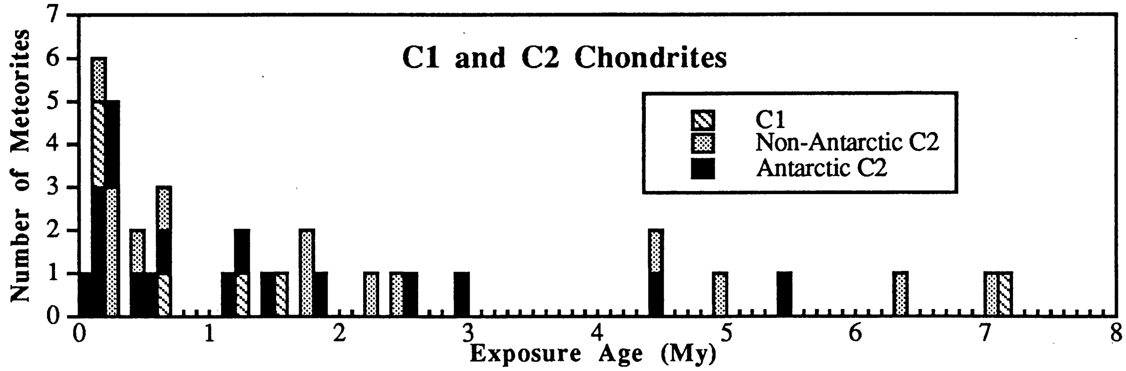

Fig. 1. Exposure ages of C1 and C2 chondrites

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