THE SHORT COSMIC RAY EXPOSURE AGES OF TWO H CHONDRITES: EVIDENCE OF A COMMON EJECTION EVENT 0.1 MILLION YEARS AGO. K. C. Welten[1], M. W. Caffee[2], M. M. M. Meier[3], M. Riebe[3], K. Nishiizumi[1], and R. Wieler[3]; [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA, [2]Department of Physics, Purdue University, West Lafayette, IN 47907, USA, [3]Department of Earth Sciences, ETH Zürich, CH-8092 Zürich, Switzerland.

Introduction: Cosmic-ray exposure (CRE) ages of fossil L-chondrites from Ordovician limestone have shown that large asteroid breakup events can rapidly deliver meteorites from the asteroid belt to Earth within 10^5-10^6 yr [1]. The identification of several asteroid clusters suggest that up to four smaller breakup events occurred in the last 1 Myr [2,3]. Spectroscopic data indicates that these asteroids are ordinary chondrite type bodies [4]. No clear evidence of these events has been found in the CRE record of ordinary chondrites, since most CRE ages are 1-50 Myr. A few ordichondrites, on the other hand, have CRE ages <1 Myr [5-8]. Until now it has been assumed that these meteorites were either ejected from asteroids that are already in Earth-crossing orbits or were ejected from asteroids that were close enough to one of the orbital resonances to allow rapid evolution to an Earth-crossing orbit, but they could also be linked to (one of) the recent asteroid breakup events [2,3].

The youngest CRE ages reported for ordinary chondrites are 0.03 Myr for Farmington (L5), 0.033 Myr for Galim(a) (LL6) and 0.068 Myr for the Antarctic H5 chondrite, Grove Mountains (GRV) 98004 [5-8]. A preliminary CRE age of ~0.025 Myr was reported for two paired Antarctic H-chondrites, MacAlpine Hills (MAC) 02630 and 02740, both with low radionuclide concentrations [9]. Among more than 300 H-chondrites only a handful show CRE ages <1 Myr, and most of these are between 0.5-1 Myr [10]. In this work we present new cosmogenic nuclide data on the Antarctic H-chondrites GRV 98004 and a group of MAC meteorites we will commonly refer to as “MAC 02”, to determine if their CRE ages represent a common ejection (or asteroid breakup) event.

Meteorite samples: Noble gas analyses of GRV 98004 (H5, 155 g) yielded a CRE age of 0.078 ± 0.010 Myr, based on cosmogenic ^{21}Ne [8]. We separated metal and stone fractions for cosmogenic radionuclide analysis from a sample of ~1.3 g taken within 1 cm from the sample that was previously analyzed for noble gases [7,8].

Since our initial report on the CRE age of MAC 02630 and 02740 [9], we identified six additional chondrites, MAC 02623, 02806, 02812, 02833, 02924 and 02953, with similarly low ^{36}Cl concentrations in the metal fraction (1.0-2.5 dpm/kg). Although some were classified as L-chondrites, the bulk metal content and metal composition indicate all six meteorites are H-chondrites. We measured the cosmogenic radionuclides ^{10}Be, ^{26}Al and ^{36}Cl in both the metal and stone fraction of these samples to verify pairing and constrain their pre-atmospheric size. These analyses will allow more reliable production rate estimates for the MAC 02 samples and thus a more accurate CRE age. We also measured noble gases in six of the eight MAC 02 H chondrites to further constrain the CRE age.

Experimental methods: We dissolved 50-100 mg of purified metal along with a carrier solution containing Be, Al and Cl. For each sample we also dissolved 100-200 mg the non-magnetic (stone) fraction, along with Be and Cl carrier. After dissolution, a small aliquot was taken for chemical analysis. Be, Al and Cl were separated using procedures described previously [11] and concentrations of ^{10}Be, ^{26}Al and ^{36}Cl were measured by accelerator mass spectrometry (AMS) at Purdue University [12]. The noble gas concentrations and isotopic composition were analyzed in 6 MAC 02 chondrites using procedures described previously [13]. Concentrations of cosmogenic radionuclides and ^{21}Ne, as well as trapped ^{20}Ne are shown in Table 1.

Results and discussion: The low concentrations of ^{10}Be, ^{26}Al and ^{36}Cl in the stone and metal phase of GRV 98004 are consistent with a short CRE age. Assuming ^{10}Be and ^{36}Cl production rates of 5.5 and 22 dpm/kg in the metal, respectively, the measured concentrations of 0.215 and 3.85 dpm/kg yield a CRE age of 0.080 ± 0.010 Myr. The radionuclide concentrations in the stone fraction are also consistent with an age of ~0.08 Myr. The relatively low ^{10}Be(stone)/^{10}Be(metal) ratio of 3.6 indicates that GRV 98004 was a small object in space, consistent with the ^{22}Ne/^{21}Ne ratio of 1.15 [8]. We thus conclude that the CRE age of GRV derived from radionuclides is consistent with the ^{21}Ne age of 0.078 ± 0.010 Myr [8].

Measured concentrations of cosmogenic ^{10}Be, ^{26}Al and ^{36}Cl in the metal fraction of eight MAC 02 H-chondrites range from 0.05-0.16 dpm/kg (^{10}Be), 0.08-0.25 dpm/kg (^{26}Al), and 1.0-2.5 dpm/kg ^{36}Cl, respectively. While the ^{36}Cl concentrations in MAC 02 are 10-20 times lower than typical concentrations of 20-25 dpm/kg observed in recent chondrite falls, the ^{10}Be concentrations are 30-100 times lower than typical saturation values of 4-6 dpm/kg. These low ^{10}Be and ^{36}Cl concentrations have not been observed in any other Antarctic chondrites, with the exception of GRV 98004, and indicate CRE ages <0.1 Myr. The large variations in radionuclide concentrations (up to a factor of ~3) indicate irradiation in a large meteoroid with a radius of 100-150 cm. The radionuclide record of all eight MAC 02 chondrites confirm that they are paired fragments of a single large object, that broke up during atmospheric passage. The large size implies that we can not use average production rates to calculate the CRE age, while the shielding independent ^{21}Ne/^{26}Al and ^{21}Ne/^{10}Be do not change significantly in the first ~0.1 Myr of CRE. We therefore derived the CRE age from the cosmogenic ^{10}Be and ^{26}Al concentrations in the stone fraction of the least shielded sample, MAC 02924, assuming production rates for a depth of ~10 cm in an object with R~120 cm [14]. This approach yields ages of 0.06-0.09 Myr, so we adopt an average CRE age of 0.075 Myr.

Noble gases. Most MAC 02 samples contain large amounts of solar He, Ne and Ar, that were implanted during regolith exposure. The cosmogenic ^{21}Ne component – after correction for trapped Ne – varies by a factor of 50, at least an order of magnitude more than the radionuclides. The large variations in cosmogenic ^{21}Ne – which correlate with trapped Ne - indicate that most MAC 02 samples contain cosmogenic ^{21}Ne from a previous CRE in the regolith, which makes it difficult to calculate the 4π CRE age in space. Fortunately, the least shielded member, MAC 02924, also has the lowest trapped noble gas content. Assuming a ^{21}Ne production rate of 0.28 x 10^{-8} cm^3 STP/g Ma^{-1} for near surface production in an object with R=120 cm [14] we calculate a CRE age of 0.064 Myr for MAC 02924. This age overlaps with the radionuclide exposure ages and suggests that MAC 02924 contains virtually no cosmogenic Ne contribution from CRE in the regolith.

Conclusions. The CRE ages of GRV 98004 and the MAC 02630 pairing group overlap within experimental error at ~0.08 Myr. Given that these are the only two H-chondrites with such short exposure ages, this may indicate that the two meteorites originated from the same ejection (or breakup) event. However, since these two meteorites are not observed falls, but fell some time ago on the Antarctic ice, their ejection ages are the sum of CRE age plus terrestrial age. Based on the high ^{36}Cl/^{10}Be ratios in the metal phase of both H chondrites, we can constrain their terrestrial ages to <30 kyr, so we conclude that their ejection ages are 0.09 ± 0.02 Myr. This age overlaps with the formation age of 0.05-0.25 Myr for the youngest asteroid cluster centered on 1992 YC2 [3]. However, this asteroid cluster is at least 0.1 AU from the nearest resonance zone, which implies that a very small fraction of the ejecta will undergo fast meteorite delivery to Earth. We thus conclude that the timing of ejection of two H-chondrites is consistent with the breakup of the parent body of 1992 YC2, but that the direct link between these two events is far from proven. Interestingly, the CRE ages of the GRV and MAC 02 H-chondrites also overlap with the CRE age of 0.082 Myr of the Sutter's Mill CM chondrite [15], although this may just be coincidence and does probably not imply a genetic connection.

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Table 1. Concentrations of cosmogenic radionuclides (in dpm/kg) in the metal and stone fractions of GRV 98004 (H5) and in MAC 02 H-chondrites, as well as cosmogenic ^{21}Ne and trapped ^{20}Ne (in 10^{-8} cm^3 STP/g) in bulk samples.

Meteorite	Type	^{10}Be(m)	^{10}Be(s)	^{26}Al(m)	^{26}Al(s)	^{36}Cl (m)	^{36}Cl (s)	$^{21}Ne_c$	$^{20}Ne_{tr}$
GRV 98004	H5	0.215±0.009	0.770±0.019	-	3.27±0.16	3.85±0.08	1.35±0.04	-	-
MAC 02740	H4	0.051±0.003	0.326±0.016	-	2.55±0.11	1.00±0.09	2.02±0.05	0.32	100
MAC 02630	H5	0.072±0.006	0.504±0.022	0.082±0.015	3.41±0.13	1.25±0.06	2.49±0.05	0.89	967
MAC 02953	H6	0.112±0.005	0.466±0.019	0.137±0.021	2.84±0.12	1.42±0.03	2.26±0.07	-	-
MAC 02833	H3.7	0.065±0.006	0.564±0.014	0.120±0.020	3.38±0.13	1.56±0.03	2.48±0.07	0.087	142
MAC 02623	H5	0.067±0.006	0.590±0.024	0.142±0.020	3.33±0.10	1.69±0.06	2.31±0.07	0.179	212
MAC 02812	H4	0.119±0.006	0.604±0.025	0.223±0.020	3.89±0.17	2.37±0.09	1.15±0.03	0.102	96
MAC 02806	H5	0.138±0.008	0.643±0.025	0.212±0.038	3.49±0.11	2.43±0.06	1.00±0.02	-	-
MAC 02924	H5	0.163±0.009	0.711±0.018	0.250±0.022	3.35±0.12	2.53±0.06	0.99±0.03	0.018	5.6