COSMOGENIC RADIONUCLIDES IN FOUR PAIRED ANTARCTIC L/LL CHONDRITES INDICATE SIMILAR COSMIC-RAY EXPOSURE AGE AS CHELYABINSK LL CHONDRITE. K. C. Welten[1], K. Nishiizumi[1] and M. W. Caffee[2], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA (kcwelten@berkeley.edu), [2]Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA.

Introduction: Cosmic-ray exposure (CRE) ages of meteorites provide information on ejection events on their parent body and the subsequent delivery of meteorite fragments from the asteroid belt to Earth [1,2]. CRE ages of ordinary chondrites (OC) generally range from 3-100 Ma, although a small fraction shows shorter ages [3]. Meteorites with short CRE ages, which can be derived from low concentrations of cosmogenic radionuclides or noble gases, may represent material ejected from near-Earth objects [4]. In this work, we report on the short CRE age of four paired fragments of an L/LL chondrite find from the Wisconsin Range (WIS) ice fields in Antarctica.

A total of 33 meteorites were found on several small ice fields near the WIS range during two short searches in the early 1990s. The WIS meteorite collection includes 1 iron, two CM chondrites and 30 OC, (9 H, 17 L, 4 LL). We selected 10 chondrites (3 H, 5 L and 2 LL) from the WIS collection for our ^{36}Cl terrestrial age survey. The separation of the metal fraction showed that five of the ten chondrites have metal contents of <5 wt%, typical for LL chondrites. Since L/LL and LL chondrites represent only ~10% of the OC flux to Earth, the high abundance of metal-poor OC in the WIS collection could indicate that several of these OC are paired fragments of a single meteorite with affinities to both L and LL chondrites, similar to the QUE 90201 L/LL chondrite pairing group [5].

To investigate pairing relationships among the WIS chondrites, we measured concentrations of the cosmogenic radionuclides, ^{10}Be ($t_{1/2}$ = 1.36x10^{6} yr), ^{26}Al (7.05 x 10^{5} yr), ^{36}Cl (3.01 x 10^{5} yr), and ^{41}Ca (1.04 x 10^{5} yr) in the metal and stone fraction of 10 chondrites. We first discuss identification of the L/LL chondrite pairing group among the WIS chondrites, and then focus on the CRE history of this pairing group.

Experimental: We crushed 2-3 g of each sample in an agate mortar and separated the metallic fraction with a magnet. The magnetic fraction is cleaned in two ultrasonic agitation steps, with 0.2N HCl and concentrated HF, to remove attached troilite and silicates, respectively. We dissolved 20-100 mg of purirfied metal in 1.5N HNO_3, along with a carrier solution containing a few mg of Be, Al, Cl and Ca. After dissolution, a small aliquot of each sample was taken for chemical analysis. We also dissolved 100-120 mg of the stone fraction of four samples, along with Be and Cl carrier, in concentrated HF/HNO_3. We separated Cl by precipitation as AgCl, and used ion exchange and acetyl-acetone extraction techniques to separate the Be, Al and Ca fractions. The chemical composition of the metal fraction was measured by Atomic Absorption Spectroscopy, while those of the stone fractions were measured by ICP-OES.

The AMS measurements of ^{10}Be, ^{26}Al, ^{36}Cl, and ^{41}Ca in the metal fractions of WIS 90301, 90302 and 91601, and of ^{10}Be, ^{26}Al, ^{36}Cl in the stone fraction of WIS 91601 were performed at Lawrence Livermore National Laboratory [6]. The AMS measurements of the other samples were performed at PRIME Lab, Purdue University [7]. The measured isotopic ratios were normalized to AMS standards [8-11] and converted to concentrations in disintegrations per minute per kg (dpm/kg). The results for the four paired WIS samples are shown in Table 1.

Results and Discussion: The ^{36}Cl concentrations in six of the ten WIS chondrites are within the range of typical saturation values of 20-25 dpm/kg[metal], indicating terrestrial ages <50 kyr. The four remaining chondrites, WIS 90300 (L/LL5), 91601 (LL5), 91602 (L5) and 91603 (L4), have lower ^{36}Cl concentrations of 15.5-18.2 dpm/kg[metal]. Although these low ^{36}Cl concentrations could indicate terrestrial ages of 100-200 kyr, the low ^{10}Be concentrations in the metal phase of these four meteorites, ranging from 1.7 to 2.7 dpm/kg, indicate that the radionuclides never reached their saturation levels. The low ^{10}Be concentrations combined with the elevated ^{36}Cl/^{10}Be ratios of 7-9 in the metal phase either indicate a short CRE age (1.5-2.2 Ma) in an object of 50-100 cm radius, or a complex CRE history with a first stage in a large object, followed by a recent CRE of ~0.5 Ma in a smaller object (Fig. 1). The elevated ^{26}Al/^{10}Be ratio of 1.07 in the metal phase of WIS 91601 (relative to saturation value of 0.71) seems to favor a short CRE age of ~1.2 Ma. Since the four WIS chondrites with low ^{10}Be and high ^{36}Cl/^{10}Be ratios have low metal contents combined with high metal-Co concentrations, we conclude that they are paired fragments of a single pre-atmospheric object which probably should be classified as an L/LL chondrite. Since the olivine-Fa contents of 26 mole% in three fragments are on the border of L and LL, and one (29 mole%) is in the middle of LL range, classification of the group as LL is also possible. The remaining metal-poor chondrite (WIS 91618, LL4) has much higher ^{10}Be and ^{36}Cl concentrations of 5.7 and 20.7 dpm/kg, respectively, indicating that it came from a different (smaller) object than the four WIS chondrites with LL affinity.

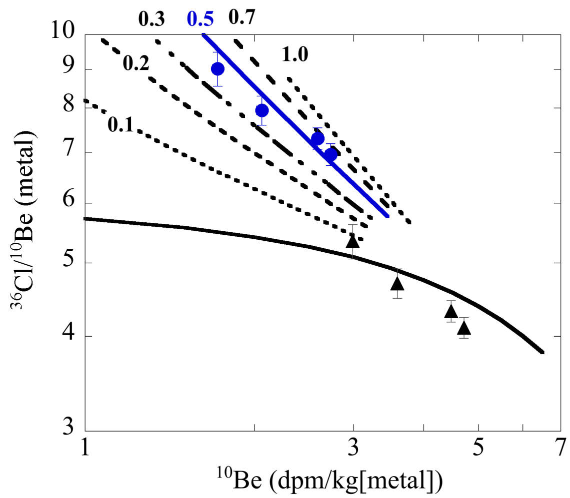

Figure 1. Relationship between measured $^{36}Cl/^{10}Be$ ratio and ^{10}Be in the metal phase of four paired WIS chondrites (blue circles) in comparison with values for meteorites with CRE ages >10 Ma (black curve) and meteorites with two-stage exposure with second stage of 0.1-1.0 Ma (dashed and semi-dashed lines). The black triangles correspond to corrected values for a simple CRE age of 1.7 Ma.

The measured ^{10}Be concentrations in the stone fraction of three members of the WIS 90/91 pairing group are relatively constant at 12.9-14.0 dpm/kg, while the measured ^{26}Al concentrations in the stone fraction vary from 46-59 dpm/kg. The ^{10}Be concentrations are about 30-50% lower than typical saturation values of 20-25 dpm/kg, while the ^{26}Al concentrations are much closer to typical saturation values of 60-70 dpm/kg in medium sized objects. The ^{10}Be and ^{26}Al concentratios in the stone fraction are more consistent with a short CRE age in an object with a radius of ~60 cm than with a complex exposure history. In the first scenario with a CRE age of 1.5-2 Ma, WIS 91601/603 come from the near-surface of the meteoroid, while WIS 91602 comes from the center, and 90300 from intermediate depth. The ^{36}Cl concentrations of 8.5-18.1 dpm kg^{-1} in the stone phase of the four paired WIS meteorites are significantly higher than estimated ^{36}Cl contributions of 6-7 dpm/kg from spallation reactions on K, Ca and Fe [12]. The elevated ^{36}Cl concentrations in the stone fraction indicate that these samples contain significant contributions of ^{36}Cl from neutron-capture reactions on ^{35}Cl [13]. The neutron-capture ^{36}Cl contribution increases from ~1.5 dpm/kg in WIS 91601 to ~11 dpm/kg in WIS 91603. While these high neutron-capture ^{36}Cl contributions indicate a pre-atmospheric radius of >45 cm, no correlation is found between neutron-capture ^{36}Cl and the depth-sensitive ^{10}Be in the metal phase. This could indicate that the concentration of Cl, the target element for neutron capture ^{36}Cl, ranges from ~40 ppm in 91601/02 to >200 ppm in 91603. Future measurements of ^{41}Ca in the stone fraction may provide more reliable information on the recent thermal neutron flux and thus on the pre-atmospheric size and depth of the paired WIS chondrites.

Conclusions: The cosmogenic radionuclide concentrations and the metal composition of three L chondrites and one LL chondrite from the WIS ice fields indicate these meteorites are paired fragments of an object that has affinities to both L and LL chondrites. The radionuclide concentrations in the metal and stone fraction of these meteorites are best explained by a CRE age of 1.2-2.2 Ma in an object with a radius of ~60 cm. With a CRE age of ~1.7 Ma, the WIS 90/91 pairing group overlaps with CRE ages of 1.2 Ma for Appley Bridge LL6 [14] and 1.2-1.5 Ma for the large Chelyabinsk LL5 chondrite [15,16], suggesting they could have been ejected during the same breakup event of an LL-chondrite parent body ~1.5 Ma ago.

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Table 1. Cosmogenic radionuclides (in dpm/kg) in metal (m) and stone (s) phase of WIS chondrites.

Meteorite	Class	Metal	^{10}Be (m)	^{26}Al (m)	^{36}Cl (m)	^{41}Ca (m)	^{10}Be (s)	^{26}Al (s)	^{36}Cl (s)
WIS 90300	L/LL5	2.9%	2.07±0.04	-	15.9±0.3	-	14.0±0.3	54.4±1.7	13.4±0.3
WIS 91601	LL5	4.2%	2.59±0.08	2.78±0.08	18.2±0.2	22.5±1.0	12.9±0.2	46.4±1.1	8.5±0.3
WIS 91602	L5	3.4%	1.73±0.08	-	15.5±0.4	-	13.2±0.1	58.9±1.7	16.4±0.4
WIS 91603	L4	2.6%	2.73±0.04	-	18.2±0.5	-	-	-	18.1±0.2