Update on terrestrial ages and pairing studies of Antarctic meteorites. K. C. Welten[1], M. W. Caffee[2] and K. Nishiizumi[1], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA. [2]Department of Physics, Purdue University, West Lafayette, IN 47907-1396, USA.

Introduction:

Terrestrial ages of Antarctic meteorites provide information on meteorite accumulation mechanisms, pairing, mean survival lifetimes and meteorite influx rates. Previous surveys of Antarctic meteorites included ^{26}Al and TL measurements. Although these techniques have the advantage of being non-destructive, they do not provide absolute terrestrial ages. The determination of terrestrial ages using cosmogenic ^{36}Cl (half-life = 3.01x10^5 yr) is a long-term on-going project [1]. Carbon-14 has also been used to determine terrestrial ages [e.g., 2] but can be detected in only 30-50% of the Antarctic meteorites. The detection limit of ^{14}C in meteorites corresponds to a terrestrial age of ~35 kyr, so the longer half-life of ^{36}Cl makes it a superb analytical tool for meteorites having terrestrial ages of 30 kyr to ~3 Myr. In 2004, we initiated a systematic ^{36}Cl terrestrial age survey of Antarctic ordinary chondrites. The amount of material required for the ^{36}Cl measurement by accelerator mass spectrometry (AMS) is small and the chemical preparation is relatively easy. We will present the ^{36}Cl terrestrial ages of 490 ordinary chondrites that were collected by the US Antarctic Search for Meteorites (ANSMET) program.

Methodology.

The terrestrial age of a meteorite is calculated from the measured ^{36}Cl concentration by assuming (1) an average saturation value of 22.1 ± 2.8 dpm kg^{-1} in the metal phase [3], which is valid for chondrites with radii of <45 cm, and (2) a minimum cosmic-ray exposure (CRE) age of 1.5 Myr, which is valid for the majority of ordinary chondrites. For more than 90% of the ordinary chondrites, the measurement of ^{36}Cl in the metal phase thus suffices to ascertain terrestrial ages, but for meteorites which experienced high shielding (R>50 cm) or a short CRE age, the ^{36}Cl concentration either overestimates or understimates the terrestrial age. with ^{36}Cl concentrations of <15 dpm kg^{-1} we also measure ^{10}Be in the metal phase to determine shielding-corrected terrestrial ages using the observed correlation between ^{10}Be and the ^{36}Cl/^{10}Be ratio [4]. In addition to providing more reliable terrestrial ages, the combined ^{10}Be and ^{36}Cl measurements also provide valuable clues for identifying large pairing groups, as was shown for FRO 90174, a large H3-6 pairing group from the Frontier Mountain stranding area [5]. We will calculate shielding corrected terrestrial ages and will discuss several interesting pairing groups that were identified based on the cosmogenic radionuclide analyses.

Experimental Procedures:

We crushed chondrite samples of 2-3 g and separated the metal with a hand magnet. We purified the metal by ultrasonic agitation with 0.2N HCl and concentrated HF to dissolve attached troilite and silicates, respectively. The purified metal is dissolved in 1.5 N HNO_3 along with 1-2 mg of Be, Al, Ca, and 3-5 mg of Cl carrier. After dissolution of the metal, small aliquots were taken for chemical analysis (Mg, Fe, Co, Ni) by atomic absorption spectrometry. From the remaining solution we separated the Be, Al and Cl fractions for analysis by accelerator mass spectrometry (AMS) at Purdue University [6]. The measured ^{10}Be/Be and ^{36}Cl/Cl ratios were corrected for background and normalized to ^{10}Be and ^{36}Cl AMS standards [7,8].

Results and discussion.

Terrestrial ages. The measured ^{36}Cl concentrations in the metal phase of 490 ordinary chondrites range from 1.0 to 26 dpm kg^{-1} (Fig. 1). More than half of the samples show ^{36}Cl concentrations >20 dpm kg^{-1}, i.e., they overlap with the saturation activity measured in recent ordinary chondrite falls. This indicates that more than 50% of the Antarctic chondrites have relatively young terrestrial ages of <50 kyr.

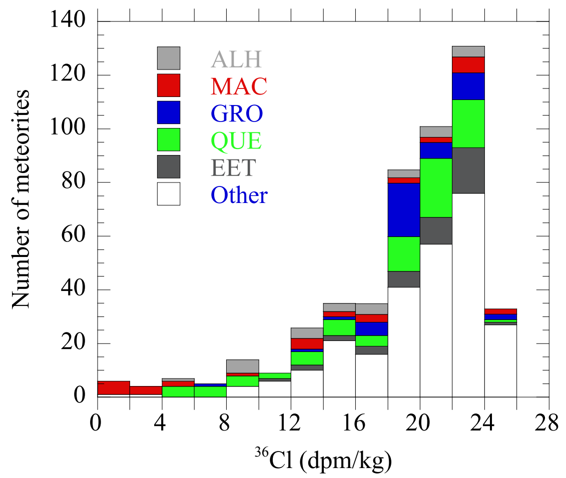

Figure 1. Histogram of ^{36}Cl concentrations in the metal fraction of Antarctic ordinary chondrites.

For samples with ^{36}Cl concentrations of <15 dpm kg^{-1}, we used the ^{10}Be-^{36}Cl/^{10}Be method [4], which yields terrestrial ages up to ~650 kyr. Several meteorites with terrestrial ages older than 300 kyr are from the Allan Hills Main Ice field, which is known to be one of the oldest stranding surfaces [1], but old meteorites were also identified in several other stranding areas, such as Grosvenor Mountain (GRO), Lewis Cliff (LEW) and MacAlpine Hills (MAC).

This suggests that many of the Antarctic stranding areas started accumulating meteorites several hundred kyr ago, but that only a small number of these old meteorites have been preserved since then. Possible mechanisms that may explain the loss or removal of meteorites from the stranding areas include: (1) terrestrial weathering, (2) ice flow out of the stranding area, and/or (3) aeolian transport of small meteorites (<100 g). Since none of the Antarctic chondrites show evidence of severe weathering effects that are often observed in old chondrites from hot desert environments, the loss of meteorites by terrestrial weathering seems unlikely. We thus conclude that removal of old meteorites by ice flow and/or aeolian transport is the most plausible explanation for the relatively short mean lifetime of Antarctic meteorites found on meteorite stranding surfaces.

Pairing studies. Some of the Antarctic meteorite stranding areas are dominated by one or two large meteorite showers which may include several hundred to thousands of individual fragments that formed during atmospheric disruption of a single large meteoroid. Since it is difficult to identify paired ordinary chondrites based on petrologic or mineralogic features alone, the cosmogenic radionuclide concentrations often provide the only evidence for identifying paired meteorites fragments. An excellent example is the pairing of 19 H-chondrites from the Frontier Mountain stranding area, which belong to a large, heterogeneous H3-6 chondrite shower. This single H-chondrite shower accounts for the high H/L-chondrite ratio at Frontier Mountain [5].

The QUE 90201 pairing group. The low ^{36}Cl concentrations of 4-15 dpm kg^{-1} in fifteen L5 and LL5 chondrites from the Queen Alexandra Range (QUE) yield shielding-corrected ages of 100-150 kyr, much younger than the ages based on ^{36}Cl only. Most of these meteorites belong to a single large L/LL5 chondrite shower, QUE 90201, which is believed to include as many as 2000 fragments. The radionuclide concentrations indicate that the fragments belong to a single object with a pre-atmospheric diameter of ~3 m, corresponding to an estimated mass of 50,000 kg, which experienced a catastrophic disruption upon atmospheric entry ~120 kyr ago [9].

The MAC 02630 pairing group. The lowest ^{36}Cl concentrations of 1.0-2.5 dpm kg^{-1} were found in eight H-chondrites from the MacAlpine Hills stranding area. Assuming an average saturation value of 22 dpm kg^{-1}, these ^{36}Cl concentrations correspond to terrestrial ages of 0.9-1.3 Myr. However, the low ^{10}Be concentrations of 0.05-0.16 dpm kg^{-1} in the metal fraction indicate that the low ^{36}Cl concentrations are not due to a long terrestrial age, but to a very short CRE age (<0.1 Myr). Based on the unusually low radionuclide concentrations we conclude that these eight H-chondrites are part of a single shower, which represents an object with a pre-atmospheric radius of 1-2 m. The samples range in petrologic type from H3 to H6, indicating the object was a heterogenous breccia. Noble gas studies show high solar gas contents, indicating the object was a regolith breccia [10].

The GRO 03001 pairing group. In the 2003/04 season, the ANSMET team recovered 83 meteorites with a total mass of 105 kg in an elliptical area of 1.6 x 0.2 km^2 from a blue ice field near Otway Massif in the Grosvenor Mountains. The size distribution of the meteorites within this area suggested they represent a well preserved strewnfield, with the largest masses (GRO 03001, 29 kg, and GRO 03002, 28 kg) on the East end and the smallest masses (~100 g) on the West end of the field, but the classification of the meteorites ranging from LL5 to H5 lends considerable doubt to this interpretation [11]. Concentrations of cosmogenic ^{10}Be and ^{36}Cl in the metal fraction of 14 H-chondrites from the Otway Massif indicate that ten H5 chondrites (including GRO 03001) are paired fragments that belong to a single meteoroid. The elevated ^{36}Cl/^{10}Be ratios in these meteorites indicate that they experienced a complex exposure history with a long first stage exposure on the H-chondrite parent body and a recent breakup event ~1 Myr ago, which ejected the meteoroid and sent it into an Earth crossing orbit, resulting in rapid delivery to Earth [11].

Conclusions:

The ^{36}Cl concentrations in the metal phase of 490 Antarctic chondrites range from 1-26 dpm/kg. After appropriate shielding corrections based on the ^{10}Be-^{36}Cl/^{10}Be correlations, we determine terrestrial ages up to ~650 kyr, although the majority of the meteorites have ages of less than 50 kyr. However, the combined ^{10}Be and ^{36}Cl concentrations indicate that not all low ^{36}Cl concentrations are due to long terrestrial ages. A significant fraction of the low ^{36}Cl concentrations are either due to high shielding conditions (in paired fragments of a few large meteorite showers) or to short CRE ages in paired H-chondrites from the MacAlpine Hills stranding area.

References:

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