COSMOGENIC RECORDS IN 18 ORDINARY CHONDRITES FROM THE DAR AL GANI REGION, LIBYA: II RADIONUCLIDES.

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Introduction: In the past decade more than 1000 meteorites have been recovered from the Dar al Gani (DaG) plateau in the Libyan part of the Sahara. The geological setting, meteorite pairings and density are described in [1].

So far, only a few terrestrial ages are known for DaG meteorites, e.g. 60±20 kyr for the DaG 476 shergottite shower and 80±20 kyr for the lunar meteorite DaG 262 [2]. However, from other desert areas, such as Oman, it is known [3] that achondrites may survive much longer than chondritic meteorites, so the ages of these two achondrites may not be representative of the majority of the DaG meteorite collection, of which more than 90% are ordinary chondrites.

In this work we report concentrations of the cosmogenic radionuclides, ^{14}C (half-life = 5,730 yr), ^{41}Ca (1.04×10^{5} yr), ^{36}Cl (3.01×10^{5} yr), ^{26}Al (7.05×10^{5} yr) and ^{10}Be (1.5×10^{6} yr) to determine the terrestrial ages of DaG meteorites and constrain their pre-atmospheric size and exposure history. The selection of the samples and their noble gas record are described in a separate paper [4].

Experimental procedures: Cosmogenic ^{14}C was extracted from bulk meteorite samples of 80-570 mg using techniques described in [5]. Measurements of ^{14}C by AMS were carried out at the Univ. of Arizona. For measurements of ^{10}Be, ^{26}Al, ^{36}Cl and ^{41}Ca we crushed ~1 g of sample and separated the metal (if any). The stone fraction was homogenized and an aliquot of 100-140 mg was used for radionuclide analyses, using chemical separation methods described previously [6]. Measurements of ^{10}Be, ^{26}Al, ^{36}Cl and ^{41}Ca were carried out at the LLNL-AMS facility.

Radionuclides. The measured radionuclide concentrations are given in Table 1.

^{14}C terrestrial ages. The ^{14}C concentrations range from 1-35 dpm/kg. Based on average production rates of 46.4 dpm/kg for H-, 51.1 dpm/kg for L- and 55.2 dpm/kg for LL-chondrites, these concentrations correspond to terrestrial ages of 2.5-31.0 kyr, similar to ^{14}C ages of many other Saharan meteorites [6]. For DaG meteorites in which ^{10}Be is saturated, based on the noble gas exposure age [4], we calculated a shielding-corrected terrestrial age using the ^{14}C-^{10}Be method [8]. The ^{14}C/^{10}Be ages (Table 1) show good agreement with the ^{14}C ages. Although the terrestrial ages do not show a clear correlation with the degree of weathering, the four oldest meteorites are also the most weathered (W3-W5).

^{36}Cl results. The ^{36}Cl concentrations range from 3-12 dpm/kg, although most (12) samples show values between 3-6 dpm/kg. The ^{36}Cl concentrations in these 12 samples show a negative correlation with the Fe+Ni concentration in the stone fraction. This trend suggests that most of the cosmogenic ^{36}Cl produced in the metal phase is lost upon weathering (oxidation) of the metal, upon which the oxidized metal dilutes the cosmogenic ^{36}Cl concentration in the stone fraction.

We normalized the measured ^{36}Cl concentration to a total Fe concentration of 13.5 wt% for H-, 16.0 wt% for L- and 17 wt% for LL-chondrites, i.e. the average values for the stone fraction of fresh falls [9]. We accounted for the production of ^{36}Cl from Ca and K, by assuming production rate ratios of $P(^{36}Cl)_{Ca}/P(^{36}Cl)_{Fe}=8$ and $P(^{36}Cl)_{K}/P(^{36}Cl)_{Ca}=1.8$ [7]. In addition, we corrected for the dilution with oxidized metal, which is up to 15% for H-chondrites, but less than 9% and <5% for L- and LL-chondrites, respectively.

The normalized ^{36}Cl concentrations (Table 1) show values of 20-26 dpm/kg(Fe+8Ca+15K) for most samples, which is consistent with the ^{14}C terrestrial ages <30 kyr. The normalized ^{36}Cl concentration of ~14 dpm/kg for DaG 343 corresponds to a terrestrial age of 150-200 kyr, but has a large uncertainty. The elevated ^{36}Cl values of 40-52 dpm/kg(Fe+8Ca+15K) in DaG 304, 308, 311, 904 and 908 are due to neutron-capture ^{36}Cl, indicating a large pre-atmospheric size.

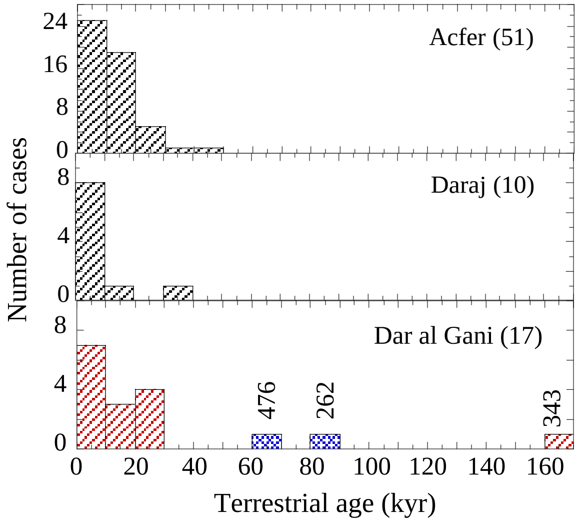

Fig. 1. Terrestrial ages of DaG chondrites (red bars, this work) compared to ages of chondrites from Acfer, Algeria and Daraj, W-Libya [6]. Terrestrial ages of the achondrites DaG 262 and 476 are from [2]

^{41}Ca results. The ^{41}Ca concentrations range from 1.6-18.5 dpm/kg, although most samples (13) show

values between 3–6 dpm/kg. The concentrations of ^{41}Ca in these samples show a similar trend as those of ^{36}Cl, indicating that ^{41}Ca in the metal phase is also lost upon oxidation. We therefore normalized the ^{41}Ca concentrations in the same way as the ^{36}Cl concentrations, assuming $P^{41}(Ca)/P^{41}(Fe)=6$ [10]. The normalized ^{41}Ca concentrations show a slight decrease with the ^{14}C terrestrial age, but the uncertainties in the ^{41}Ca values are too large to determine terrestrial ages on a timescale of <30 kyr. However, the normalized ^{41}Ca concentration of ~8 dpm/kg for DaG 343 corresponds to a terrestrial age of 160±40 kyr. This age is consistent with the ^{36}Cl terrestrial age, but much longer than the ^{14}C age of 31 kyr. The ^{14}C age of DaG 343 should therefore only be considered as a lower limit, because contamination with terrestrial CO_2 may be a problem at the level of ~1 dpm ^{14}C/kg.

The high ^{41}Ca values of 50-100 dpm/kg(Fe+6Ca) in four samples (DaG 304, 308, 311 and 904) are clearly due to neutron-capture ^{41}Ca. The presence of neutron-capture ^{36}Cl and ^{41}Ca in DaG 304, 308, 311 and 904 indicates that these four meteorites had large pre-atmospheric radii (R>50 cm), which is consistent with their low ^{22}Ne/^{21}Ne ratios. Surprisingly, DaG 908 contains significant n-capture ^{36}Cl, but no n-capture ^{41}Ca. This can be explained by a complex exposure history with a recent change in size. The break-up must have occurred 0.3-0.6 Myr ago, long enough for most n-capture ^{41}Ca to decay, but short enough to retain significant amounts of n-capture ^{36}Cl. It is possible that this break-up is responsible for the diffusive losses of cosmogenic ^{3}He (produced in the first stage) as well as radiogenic ^{4}He and ^{40}Ar [4].

^{10}Be and ^{26}Al results. The ^{10}Be and ^{26}Al concentrations range from 5-21 and 25-54 dpm/kg, respectively. The three samples with short ^{21}Ne ages of 0.9-1.1 Myr show low ^{10}Be concentrations (5.1-7.7 dpm/kg) and high ^{26}Al/^{10}Be ratios (4.8-5.2), consistent with a short exposure age. For samples with high shielding, i.e. with ^{22}Ne/^{21}Ne<1.1 and significant contributions of n-capture ^{36}Cl and ^{41}Ca, we applied the ^{10}Be/^{21}Ne and ^{26}Al/^{21}Ne exposure age methods [11]. The relatively low ^{10}Be and ^{26}Al concentrations in DaG 304, 308, 311 and 904 lead to ^{10}Be/^{21}Ne and ^{26}Al/^{21}Ne ages that are a factor of 2-4 higher than the ^{21}Ne ages.

Pairing. Based on the radionuclide data DaG 308/311 and DaG 330/341 are possible pairs. However, since the ^{21}Ne concentrations show 30-40% variations between the two members of each pair, pairing is not very likely.

Conclusions: The terrestrial ages of most DaG ordinary chondrite samples are <30 kyr, based on ^{14}C. The only exception is DaG 343 which has a terrestrial age of 160±40 kyr, based on ^{36}Cl and ^{41}Ca. This is the oldest for any ordinary chondrite found outside Antarctica. Four samples contain neutron-capture ^{36}Cl and ^{41}Ca, suggestive of a large pre-atmospheric size (R>50 cm). For these samples we used the ^{10}Be and ^{26}Al concentrations to determine ^{10}Be/^{21}Ne and ^{26}Al/^{21}Ne ages, which are more reliable for high shielding. One sample, DaG 908 shows significant neutron-capture ^{36}Cl, but no neutron-capture ^{41}Ca. We interpret the latter as evidence for a complex exposure history with a recent break-up event.

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Table 1. Cosmogenic radionuclide concentrations (dpm/kg) in 18 DaG meteorites.

DaG	Class	^{14}C	T(^{14}C)	T(^{14}C/^{10}Be)	^{10}Be	^{26}Al	^{36}Cl	^{36}Cl*	^{41}Ca	^{41}Ca**	^{22}Ne/^{21}Ne
304	H6,S3,W4	-	-	-	6.1±0.1	29.6±0.6	9.7±0.2	44±3	13.6±0.6	74±6	(1.11)
308	H6,S3,W2	-	-	-	13.7±0.3	43.9±0.9	9.9±0.2	42±3	10.5±0.5	53±5	1.041
311	H6,S3,W3	-	-	-	13.2±0.3	39.5±0.8	9.5±0.2	42±3	10.4±0.6	55±5	1.044
312	H6,S3,W2	2.8±0.2	23.1±1.5	22.0±0.9	14.9±0.3	37.2±0.7	4.1±0.1	19±1	3.7±0.2	20±2	1.121
321	H5,S3,W3	6.3±0.3	16.5±1.4	16.5±0.7	18.2±0.4	49.1±1.0	4.8±0.1	21±2	5.1±0.5	26±3	1.091
322	H4,S2,W2	34.4±0.9	2.5±1.3	1.0±0.6	15.5±0.3	43.6±1.1	4.9±0.1	21±2	5.5±0.3	28±3	1.221
336	H5/6,S2,W4	2.3±0.1	24.8±1.4	26.2±0.9	16.5±0.3	46.2±1.2	4.5±0.1	22±2	3.0±0.3	17±2	1.138
339	H5,S3,W3	15.2±0.2	9.2±1.3	8.4±0.6	15.8±0.3	45.3±0.9	4.9±0.1	22±2	4.5±0.2	24±2	(1.11)
343	H4,S2,W4	1.1±0.2	>31	>30	13.7±0.3	34.9±0.7	3.4±0.1	14±1	1.6±0.3	8±2	1.288
388	H5/6,S2,W5	2.3±0.2	24.9±1.5	24.9±0.9	17.5±0.4	47.2±1.0	5.0±0.1	22±2	3.6±0.3	19±2	1.077
904	H6,S2,W3	1.6±0.2	27.6±1.6	-	5.1±0.1	25.4±0.5	12.2±0.2	52±4	18.5±0.9	94±8	1.077
907	H6,S1,W3	30.4±0.2	3.5±1.3	4.1±0.7	21.0±0.4	53.6±1.1	5.8±0.1	23±2	4.1±0.4	19±2	1.090
908	H6,S4,W1	-	-	-	7.7±0.4	40.1±0.8	11.4±0.2	40±3	5.2±0.4	22±2	(1.08)
330	L5,S2,W3	25.9±0.2	5.6±1.3	4.6±0.6	17.2±0.3	49.2±1.0	5.4±0.1	20±2	4.1±0.3	18±2	1.154
341	L6,S3,W3	24.7±0.2	6.0±1.3	5.4±0.6	17.7±0.4	47.2±0.9	4.9±0.1	19±1	3.6±0.3	17±2	1.157
342	L5-6,S2,W3	14.6±0.2	10.3±1.3	10.4±0.6	20.1±0.4	53.5±1.1	5.6±0.1	20±2	4.5±0.7	19±3	1.069
906	L6,S3,W2	8.5±0.2	14.8±1.3	13.2±0.6	13.9±0.3	36.9±0.7	4.5±0.1	17±1	4.3±0.3	19±2	1.296
062	LL5-6,S3,W1	34.5±0.3	3.9±1.3	3.3±0.6	19.7±0.4	52.9±1.1	7.5±0.2	26±2	5.7±0.3	22±2	1.134

S1-S4 = shock stage [1]; W1-W5=weathering grade; *dpm/kg[Fe+8Ca+15K] **dpm/kg[Fe+6*Ca] (see text).