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NITROGEN ISOTOPIC COMPOSITIONS IN THREE ANTARCTIC AND TWO NON-ANTARCTIC EUCRITES

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Abstract: Nitrogen isotopic compositions were determined with stepped combustion method for three Antarctic eucrites (Allan Hills-76005, Yamato (Y)-792510 and -82066) and two non-Antarctic eucrites (Juvinas and Camel Donga). The abundances of indigenous nitrogen in these eucrites are from 0.05 to 1.3 ppm, much lower than that in ordinary chondrites. The less abundance of nitrogen for eucrites is due to thermal events on the parent body. Isotopic ratios of the trapped nitrogen are also considered. Contribution of terrestrial nitrogen (δ^{15}N from 0‰ to +20‰) and cosmogenic nitrogen (δ^{15}N > +100‰) is significant in the case of eucrites at low temperature (<600°C) and high temperature (>1000°C) fractions, respectively. Hence, nitrogen released at medium temperature fractions is considered. The observed minimum δ^{15}N values released in medium temperature fractions of Y-792510 and Camel Donga are −54‰ and −18‰, respectively. The low δ^{15}N values cannot be explained by contribution of the terrestrial and cosmogenic components. This is strong evidence for existence of trapped components in eucrites which have ^{15}N/^{14}N ratios different from the atmospheric value. Since there may be some contribution of terrestrial or cosmogenic nitrogen even at medium temperature fractions, the minimum values observed in the present work should be considered as upper limits for the trapped components.

1. Introduction

Eucrites are well known as differentiated meteorites produced by igneous processes on the HED (Howardite-Eucrite-Diogenite) parent body (*e.g.*, CONGSOLMAGNO and DRAKE, 1977; TAKEDA, 1979; TAKEDA *et al.*, 1983). Due to degassing during igneous processes, abundances of primordial noble gases and the other volatile elements in HED meteorites are lower than those in chondrites. Although noble gases in many HED meteorites have been measured (*e.g.*, NAGAO and MATSUDA, 1986; MICHEL *et al.*, 1991; MIURA *et al.*, 1993), the primordial noble gases have not been detected. In fact, MICHEL *et al.* (1991) have suggested that trapped xenon in diogenite is mostly adsorbed air xenon in origin. On the other hand, precise nitrogen measurements have not been done for HED meteorites. The only previous work for Pasamonte eucrite (KUNG and CLAYTON, 1978) showed that bulk nitrogen content was 8 ppm and its δ^{15}N was +5.4‰ (nitrogen isotopic composition is expressed by convention as δ^{15}N (‰) $= [(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{sample}}/(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{air}} - 1] \times 1000$). Since nitrogen has only two isotopes (^{14}N and ^{15}N) and since the extracted nitrogen from meteorites is a mixture of different origins, it is difficult to interpret the nitrogen isotopic variation if all nitrogen is extracted at once, as was done for Pasamonte. However, stepwise extraction technique can be used for separating the nitrogen of different origin (BOYD *et al.*, 1988). If we can get abundances and isotopic compositions of trapped nitrogen, it will provide us information concerning the formation of HED parent body. Petrological studies suggest that eucrites are classified according to the depth in the parent body; ordinary, lava-like and cumulate eucrites (*e.g.*, TAKEDA, 1979) have experienced different melting and cooling histories. Moreover, two different crystal fractionation trends, which are Nuevo Laredo trend and Stannern trend, were recognized for eucrites (IKEDA and TAKEDA, 1985). These igneous and metamorphic processes may have caused elemental and isotopic fractionation. If nitrogen abundances and isotopic compositions reflect these processes on the parent body, then sub-classification of eucrites using nitrogen isotopes may be possible.

In this study, we measured the abundances and isotopic compositions of nitrogen in eucrites using a stepped combustion method (BOYD *et al.*, 1988). Nitrogen isotopic compositions of five eucrites have been determined, and isotopic compositions and abundances of cosmogenic and trapped nitrogen were considered.

2. Samples

Three Antarctic eucrites Allan Hills (ALH)-76005, Yamato (Y)-792510 and Y-

Table 1. Recovered masses, petrogical features, cosmogenic ^{21}Ne and ^{38}Ar, radiogenic ^{40}Ar and cosmic-ray exposure ages for five eucrites.

	Recovered mass (g)	Note	Petrological feature&	(^{21}Ne)$_c$#	(^{38}Ar)$_c$	^{40}Ar	Exposure age (Ma)	Ref.$
				(10^{-8} cm^3 STP/g)				
ALH-76005	698.2	Find 1976,	Polymict	2.16	1.77*	930	14**	1)
		Antarctica		1.49	1.29	1010	9.8**	2)
Y-792510	608.73	Find 1979,	Monomict	2.89	1.55	1030	11.7±1.1	3)
		Antarctica	(Ordinary)	3.39	2.34	1450	18**	4)
Y-82066	191.40	Find 1982,		1.62	1.21*	1650	10.6±1.1***	5)
		Antarctica						
Camel Donga	> 6000	Find 1984,	Monomict	4.86	5.02	1450	37**	4)
		Australia	(Ordinary)	5.16	6.00*	1840	46**	6)
Juvinas	>91000	Fell 1821,	Monomict		1.35*	1410	9.5±0.8	7)
		France	(Ordinary)	1.73	1.47	1570	11**	8)

Measured ^{21}Ne was assumed as almost cosmogenic.

* Concentration of cosmogenic ^{38}Ar was calculated with assumptions of (^{38}Ar/^{36}Ar)c = 1.55 and (^{38}Ar/^{36}Ar)t = 0.188 for cosmogenic and trapped ratios, respectively.

** Cosmic-ray exposure age was calculated using ^{38}Ar production rate of 0.131×10^{-8} cm^3 STP/g/Ma.

*** Cosmic-ray exposure age was re-calculated using new ^{38}Ar production rate, which was determined using a function of chemical compositions (MIURA *et al.*, in preparation).

& TAKEDA and GRAHAM (1991) and YANAI *et al.* (1987).

$ References for cosmic-ray exposure age and noble gas data: 1) VOGT *et al.* (1986). 2) NAGAO and MATSUDA (1989). 3) NAGAO and OGATA (1989). 4) MIURA *et al.* (in preparation). 5) MIURA *et al.* (1991). 6) PALME *et al.* (1988). 7) FREUNDEL *et al.* (1986). 8) data by WEBER (1989) taken from SCHULTZ and KRUSE (1989).

82066, and two non-Antarctic eucrites Juvinas and Camel Donga were measured. Noble gas and petrological features reported for these five eucrites (FREUNDEL *et al.*, 1986; NAGAO and MATSUDA, 1986; VOGT *et al.*, 1986; YANAI *et al.*, 1987; PALME *et al.*, 1988; SCHULTZ and KRUSE, 1989; NAGAO and OGATA, 1989; MIURA *et al.*, 1991; TAKEDA and GRAHAM, 1991) are summarized in Table 1. Among five eucrites only ALH-76005 is a polymict eucrite, and Y-792510, Juvinas and Camel Donga are monomict eucrites. The terrestrial ages for two Antarctic eucrites, Y-792510 and Y-82066 have been determined by ^{81}Kr method to be 0.14 Ma and 0.09 Ma, respectively (MIURA *et al.*, in preparation). The terrestrial age of ALH-76005 is estimated to be about 0.1 Ma because meteorites ALH-79017 and ALH-81009 which are paired with ALH-76005 have terrestrial ages of about 0.1 Ma (FREUNDEL *et al.*, 1986). The five eucrites we measured are not paired with each other.

3. Sample Preparation and Experimental Procedure

Before a sample was introduced into an ultra-high vacuum line, it was crushed to small chips of a few tens of mg in weight and washed with acetone. About 200 mg of samples were wrapped in platinum foil of 10 μm in thickness and put into a quartz glass sample chamber connected to a gas extraction/purification system and a quadrupole mass spectrometer. Nitrogen was extracted by heating the sample in an oxygen atmosphere with the pressure from 1×10^2 Pa to 2×10^3 Pa. Extraction temperatures are from 200°C up to 1200°C in 100°C step and heating duration for each step was 25 minutes. The highest temperature steps (1200°C) were repeated several times to promote complete extraction of nitrogen. After gases were extracted from the sample, oxygen gas was absorbed by Cu-CuO heated at 630°C. Extracted gases were split into two fractions, one is for nitrogen analysis and the other for neon and argon. Neon was also separated from argon. Neon, argon and nitrogen isotopes were measured separately with a quadrupole mass spectrometer in a static mode. Molecular nitrogen was measured at masses 28, 29, and 30. The details for mass spectrometrical procedure are described in HASHIZUME and SUGIURA (1990, 1992a).

Standard air nitrogen, cold blanks and hot blanks were measured using the same procedure as for a sample. Typical hot blanks are 1 ng, 1×10^{-12} cm^3, 1×10^{-8} cm^3 for N_2, ^{21}Ne and ^{40}Ar, respectively, and cold blanks are 1 ng, 1×10^{-14} cm^3, 1×10^{-8} cm^3, respectively.

In some fractions above 1000°C, where cosmogenic nitrogen was released, large changes in the relative intensities of masses 28, 29, and 30 were observed during mass spectrometry. This is most likely caused by isotopic disequilibrium effect of trapped nitrogen and cosmogenic nitrogen pointed out by HASHIZUME and SUGIURA (1992a). Isotopic ratios of ^{15}N/^{14}N for such fractions were calculated assuming isotopic non-equilibration of nitrogen (HASHIZUME and SUGIURA, 1992a).

All samples were measured twice except for Juvinas, which was measured three times. For seven analyses out of eleven, samples treated with H_2O_2 were used to minimize organic contaminations. The H_2O_2 treatment was performed at 80°C for 1 hour after washing the sample with acetone.

4. Results

The abundances and isotopic ratios of nitrogen and abundances of cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and measured ^{40}Ar are presented in Table 2. For Juvinas #3 only nitrogen isotopes were measured. Uncertainties of abundances are estimated to be about 10%, and error for δ^{15}N is 1σ. In calculating concentrations of cosmogenic ^{38}Ar, the following isotopic ratios were assumed: $(^{38}\mathrm{Ar}/^{36}\mathrm{Ar})_t = 0.188$ and

Table 2a. Nitrogen abundance and $\delta^{15}N$ value, and concentrations of cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and measured ^{40}Ar.

ALH-76005 #1 (217.5mg)

Temperature °C	N_2 ppm	δ^{15}N ‰	$(^{21}\mathrm{Ne})_c$ 10^{-8}cm^3 STP/g	$(^{38}\mathrm{Ar})_c$ 10^{-8}cm^3 STP/g	^{40}Ar 10^{-6}cm^3 STP/g
200	4.815	−25.7±2.3	0.015	0.002	0.10
300	39.14	−3.3±3.0	0.034	0.007	0.11
400	0.527	25.5±2.8	0.054	0.052	0.19
500	0.243	24.9±1.8	0.080	0.164	0.46
600	1.020	21.8±2.1	0.165	0.202	1.37
700	0.100	11.9±2.7	0.240	0.157	2.62
800	0.098	14.3±2.8	0.453	0.168	3.64
900	0.098	24.4±2.8	0.603	0.191	2.81
1000	0.076	63.6±3.0	0.383	0.264	1.67
1100	0.032	131.3±13.1	0.177	0.234	1.23
1200	0.151	227.9±6.6	0.124	0.357	1.40
1200	0.003	965.4±1500	n.d.	0.064	0.19
200-1200°C	46.18	−3.5±2.5	2.31	1.86	15.8
700-1200°C	0.558	91.1±3.0			

ALH-76005 #2 (207.5 mg, H_2O_2 treated)

Temperature °C	N_2 ppm	δ^{15}N ‰	$(^{21}\mathrm{Ne})_c$ 10^{-8}cm^3 STP/g	$(^{38}\mathrm{Ar})_c$ 10^{-8}cm^3 STP/g	^{40}Ar 10^{-6}cm^3 STP/g
200	0.093	−19.9±2.2	0.204	0.003	n.d.
300	0.867	−10.1±1.4	0.037	0.005	0.09
400	0.919	9.2±1.4	0.056	0.053	0.17
500	0.038	−2.1±3.8	0.079	0.158	0.40
600	0.048	−7.2±2.5	0.199	0.255	1.77
700	0.014	−9.9±5.3	0.330	0.211	3.81
800	0.020	2.1±4.3	0.581	0.215	4.29
900	0.016	51.3±7.6	0.561	0.226	2.59
1000	0.013	178.6±23.2	0.394	0.359	1.98
1100	0.011	209.5±33.0	0.182	0.171	0.87
1200	0.035	230.9±11.6	0.080	0.387	1.32
1200	$0.030^{\$}$	8.6±3.0	0.007	n.d.	0.10
1200	$0.026^{\$}$	−7.0±3.2	n.d.	n.d.	0.08
200-1200°C	2.130	5.1±0.8	2.71	2.04	17.4
700-1200°C	0.165	82.1±6.5			

Table 2b.

Y-792510 #1 (80.10 mg)

Temperature °C	N_2 ppm	δ^{15}N ‰	$(^{21}\text{Ne})_c$ 10^{-8} cm^3 STP/g	$(^{38}\text{Ar})_c$ 10^{-8} cm^3 STP/g	^{40}Ar 10^{-6} cm^3 STP/g
200	0.008	−20.4±9.4	0.094	n.d.	n.d.
300	0.126	−8.1±3.3	0.674	0.024	0.22
400	0.034	−8.0±4.4	0.249	0.121	1.08
500	0.057	−15.5±3.5	0.251	0.209	2.52
600	0.031	−18.1±4.7	0.293	0.266	4.52
700	0.010	−54.2±14.1	0.521	0.190	3.19
800	0.015	−38.4±4.8	0.853	0.192	2.01
900	0.021	−15.12±3.9	0.881	0.193	1.30
1000	0.020	44.5±4.6	0.389	0.252	0.94
1100	0.019	39.5±4.7	0.142	0.214	0.77
1200	0.078	73.9±4.2	0.072	0.952	2.29
1200	0.095$^{\$}$	8.7±2.9	n.d.	0.107	0.39
1200	0.063$^{\$}$	−9.2±3.3	n.d.	0.022	0.15
200–1200°C	0.577	5.7±1.3	4.42	2.74	19.4
700–1200°C	0.321	19.2±1.7			

Y-792510 #2 (201.0 mg, H_2O_2 treated)

Temperature °C	N_2 ppm	δ^{15}N ‰	$(^{21}\text{Ne})_c$ 10^{-8} cm^3 STP/g	$(^{38}\text{Ar})_c$ 10^{-8} cm^3 STP/g	^{40}Ar 10^{-6} cm^3 STP/g
200	0.032	−19.0±3.8	0.312	0.005	0.04
300	0.064	−0.6±2.7	0.530	0.017	0.10
400	0.156	−9.6±1.7	0.262	0.107	0.78
500	0.056	−12.0±2.2	0.157	0.296	2.95
600	0.069	−33.8±1.9	0.186	0.249	3.16
700	0.194	−36.2±1.5	0.415	0.174	2.65
800	0.036	−27.0±2.7	0.724	0.202	2.10
900	0.081	−20.2±1.8	0.683	0.182	1.02
1000	0.049	15.5±2.3	0.339	0.223	0.61
1100	0.178	16.9±1.7	0.158	0.203	0.56
1200	0.628	19.0±1.7	0.072	0.830	1.20
1200	0.617$^{\$}$	−13.0±2.2	n.d.	0.009	0.04
1200	0.764$^{\$}$	−6.1±1.5	0.013	n.d.	0.03
1200	0.134$^{\$}$	−1.3±1.9	0.017	n.d.	0.03
1200	0.126$^{\$}$	2.0±2.0	0.009	n.d.	0.02
1200	0.025$^{\$}$	−1.1±3.5	0.004	n.d.	0.03
200–1200°C	3.209	−3.64±0.68	3.88	2.49	15.3
700–1200°C	2.832	−2.31±0.76			

$(^{38}\text{Ar}/^{36}\text{Ar})_c = 1.5$ for trapped and cosmogenic argon, respectively.

Nitrogen abundances obtained by duplicate analyses agree well with each other for Y-82066 and Camel Donga. However, those for ALH-76005, Y-792510 and Juvinas are different. This may be due to a large amount of terrestrial contamination for

Table 2c.

Y-82066 #1 (300.4 mg, H_2O_2 treated)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ $10^{-8}cm^3$ STP/g	$(^{38}Ar)_c$ $10^{-8}cm^3$ STP/g	^{40}Ar $10^{-6}cm^3$ STP/g
200	0.011	−20.6±3.9	0.141	0.002	0.02
300	0.073	−7.8±2.2	0.469	0.013	0.16
400	0.154	−12.0±1.7	0.103	0.064	0.96
500	0.099	6.7±1.9	0.038	0.162	2.54
600	0.123	31.2±2.1	0.061	0.166	3.79
700	0.091	35.6±1.9	0.136	0.110	4.13
800	0.075	29.2±2.9	0.306	0.106	3.70
900	0.072	34.2±2.3	0.333	0.077	1.40
1000	0.067	25.9±2.3	0.292	0.120	0.99
1100	0.019	76.6±4.2	0.156	0.128	0.77
1200	0.036	212.1±6.4	0.127	0.305	0.88
1200	0.021	68.8±4.2	0.013	0.032	0.22
1200	0.009	62.1±7.2	0.006	0.017	0.16
200–1200°C	0.850	26.5±0.8	2.18	1.30	19.7
700–1200°C	0.390	53.1±1.2			

Y-82066 #2 (222.7 mg, H_2O_2 treated)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ $10^{-8}cm^3$ STP/g	$(^{38}Ar)_c$ $10^{-8}cm^3$ STP/g	^{40}Ar $10^{-6}cm^3$ STP/g
200	0.043	−15.0±2.3	0.038	n.d.	0.01
300	0.075	−2.3±1.7	0.293	0.011	0.10
400	0.007	7.1±5.9	0.093	0.053	0.63
500	0.058	6.9±2.0	0.045	0.184	2.45
600	0.094	36.1±2.0	0.076	0.132	2.49
700	0.059	54.0±2.1	0.189	0.079	2.45
800	0.057	59.2±2.1	0.352	0.098	2.66
900	0.104	43.9±2.1	0.444	0.079	1.95
1000	0.041	82.8±2.8	0.321	0.171	0.74
1100	0.014	100.3±8.3	0.089	0.113	0.56
1200	0.023	139.6±7.2	0.070	0.196	0.60
1200	0.007	161.4±22.1	0.002	0.050	0.13
1200	0.008	85.5±11.1	n.d.	0.029	0.08
200–1200°C	0.590	40.6±1.0	2.01	1.20	14.9
700–1200°C	0.313	66.9±1.8			

ALH-76005 #1, Y-792510 #2 and Juvinas #3 possibly caused by insufficient washing with acetone. The total nitrogen abundances taken from all temperature fractions range from 0.2 ppm to 2.7 ppm except for ALH-76005 #1, Y-792510 #2 and Juvinas #3. The bulk isotopic compositions (weighted mean for all temperature fractions) range from −4‰ to +70‰. However, since nitrogen abundances in eucrites are very low, the contribution of terrestrial nitrogen is not negligible. Although H_2O_2 treatment was

Table 2d.

Camel Donga #1 (227.6 mg)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ $10^{-8}cm^3$ STP/g	$(^{38}Ar)_c$ $10^{-8}cm^3$ STP/g	^{40}Ar $10^{-6}cm^3$ STP/g
200	0.273	38.4±2.3	0.006	0.004	0.55
300	0.308	11.2±3.7	0.016	0.010	0.20
400	0.156	15.1±2.4	0.047	0.077	0.23
500	0.173	6.4±2.4	0.213	0.282	0.89
600	0.683	18.7±2.4	0.393	0.326	1.46
600	0.081	3.0±2.9	0.141	0.106	0.61
700	0.144	−7.1±2.5	0.489	0.260	1.50
800	0.138	−17.1±2.6	0.769	0.295	1.49
900	0.161	−15.2±2.5	1.230	0.391	1.55
1000	0.206	0.1±2.2	1.179	0.663	1.49
1100	0.164	5.4±2.4	0.416	0.688	1.33
1200	0.186	41.5±2.3	0.211	0.914	1.78
1200	0.018	156.0±19.5	0.018	0.219	0.34
200–1200°C	2.691	13.4±0.9	5.13	4.24	13.4
700–1200°C	1.017	5.4±1.0			

Camel Donga #2 (194.5 mg, H_2O_2 treated)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ $10^{-8}cm^3$ STP/g	$(^{38}Ar)_c$ $10^{-8}cm^3$ STP/g	^{40}Ar $10^{-6}cm^3$ STP/g
200	0.200	11.0±2.7	0.009	0.006	0.46
300	0.112	4.4±3.1	0.020	0.008	0.10
400	0.149	6.6±2.7	0.101	0.133	0.30
500	0.171	5.2±2.5	0.304	0.334	1.08
600	0.181	−2.7±2.2	0.528	0.327	1.48
700	0.162	−18.7±2.5	0.682	0.226	1.19
800	0.181	−17.8±2.1	1.086	0.268	1.15
900	0.246	−10.4±2.2	1.337	0.418	1.27
1000	0.226	5.9±2.1	0.894	0.606	1.12
1100	0.203	7.5±2.0	0.337	0.536	1.03
1200	0.297	87.9±2.0	0.118	1.291	1.98
200–1200°C	2.128	11.4±0.7	5.42	4.15	11.2
700–1200°C	1.315	15.3±0.9			

done for some samples to minimize organic contamination, differences between H_2O_2-treated samples and untreated samples are not clear. The terrestrial contaminants which are probably organic materials are chiefly released at temperature fractions below 600°C.

Release profiles of nitrogen and their isotopic ratios for the measured five eucrites are shown in Fig. 1. Four eucrites, ALH-76005, Y-792510, Juvinas and Camel Donga melted at 1200°C. Among them, ALH-76005, Y-792510 and Juvinas released large amounts of nitrogen at 1200°C. However, nitrogen isotopic ratios obtained for some

Table 2e.

Juvinas #1 (103.7mg, H_2O_2 treated)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ 10^{-8} cm^3 STP/g	$(^{38}Ar)_c^{\#}$ 10^{-8} cm^3 STP/g	$^{40}Ar^{\#}$ 10^{-6} cm^3 STP/g
200	0.120	−6.0±1.9	not measured	not measured	not measured
300	0.041	−6.5±2.6			
400	0.038	−4.0±2.6			
500	0.067	0.3±2.7			
600	0.059	0.2±2.7			
700	0.011	6.7±6.0			
800	0.005	10.5±14.5			
900	0.006	21.9±17.9			
1000	0.004	109.1±99.4			
1100	0.006	221.5±168.0			
1200	0.044	306.5±41.9			
1200	0.011	726.2±381.8			
1200	0.033$^{\$}$	−1.3±5.2			
1200	0.040$^{\$}$	−0.5±4.5			
200–1200°C	0.485	45.8±4.6			
700–1200°C	0.160	157.0±37.6			

Only nitrogen isotopes were measured for this sample.

Juvinas #2 (240.5, H_2O_2 treated)

Temperature °C	N_2 ppm	$\delta^{15}N$ ‰	$(^{21}Ne)_c$ 10^{-8} cm^3 STP/g	$(^{38}Ar)_c$ 10^{-8} cm^3 STP/g	^{40}Ar 10^{-6} cm^3 STP/g
200	0.094	4.1±1.5	0.114	n.d.	0.01
300	0.023	−4.8±3.1	0.309	0.01	0.02
400	0.020	−0.2±3.2	0.262	0.007	0.08
500	0.018	−2.4±3.5	0.069	0.047	0.46
600	0.019	−3.2±3.4	0.051	0.116	1.34
700	0.010	6.1±4.6	0.070	0.076	1.16
800	0.011	6.8±4.3	lost	lost	lost
900	0.010	8.1±4.6	0.512	0.142	2.75
1000	0.006	30.3±6.4	0.329	0.154	1.98
1100	0.006	116.5±11.1	0.184	0.120	1.16
1200	0.015	909.0±40.5	0.517	0.756	5.26
1200	0.006	289.5±33.9	0.005	0.057	0.99
200–1200°C	0.228	67.9±1.5	2.42	1.48	15.2
700–1200°C	0.054	269.6±14.6			

of the repeated steps at 1200°C are close to 0‰ (noted by "\$" in Table 2), obviously different from the ratios for the first 1200°C steps. We speculate that nitrogen with $\delta^{15}N$ of about 0‰ obtained for the second and the third extractions was derived from organic material; some organic nitrogen released from the samples at lower temperatures might be adsorbed at the upper part of the sample chamber, and released again when the temperature of the chamber became high during repeated heating at 1200°C. Hence,

Table 2e (Continued).

Juvinas #3 (222.4 mg)

Temperature °C	N_2 ppm	δ^{15}N ‰	(^{21}Ne)$_c$ 10^{-8} cm^3 STP/g	(^{38}Ar)$_c$ 10^{-8} cm^3 STP/g	^{40}Ar 10^{-6} cm^3 STP/g
200	0.815	15.6±2.5	0.06	0.001	0.15
300	0.436	19.0±2.9	0.33	0.0004	0.07
400	0.575	10.7±2.2	0.30	0.005	0.11
500	0.323	16.4±3.0	0.11	0.03	0.36
600	0.303	15.5±2.0	0.076	0.08	1.1
700	0.277	14.3±3.2	0.097	0.09	1.5
800	0.076	18.2±3.5	0.23	0.10	2.3
900	0.055	21.3±3.5	0.39	0.1	2.3
1000	0.051	23.5±3.5	0.37	0.14	2.3
1100	0.027	42.9±5.7	0.17	0.10	1.3
1200	0.053	157.7±7.3	0.56	0.54	3.8
1200	0.061$	35.4±2.9	0.013	0.049	0.63
1200	n.d.		0.004	0.017	0.20
200–1200°C	3.052	18.5±1.0	2.71	1.25	16.1
700–1200°C	0.600	32.3±2.0			

$: For some of the repeated fractions at 1200°C, δ^{15}N values are significantly low compared with that for the first fraction. These fractions are excluded from the calculation of the bulk nitrogen content listed in Table 3.

we exclude these data (noted by "$" in Table 2) when calculating nitrogen abundance in eucrites. Y-82066 (which is the only sample not totally melted) and Camel Donga (totally melted) do not show release of a large amount of nitrogen at 1200°C.

Since nitrogen extracted below 600°C is considered to be mostly terrestrial contaminants, we assumed nitrogen extracted above 700°C (data for some of the 1200°C fractions noted by "$" in Table 2 were excluded) as indigenous nitrogen in eucrites; the calculated nitrogen abundances range from 0.05 ppm to 1.3 ppm (Table 2). These concentrations are much lower than those for ordinary chondrites (*e.g.*, Kung and Clayton, 1978; Hashizume and Sugiura, 1992b). Hashizume and Sugiura (1992c) reported that nitrogen is concentrated in the metal portion in the case of H-chondrites. In considering the fact that metal content in eucrite is much lower than those in H-chondrites, it would be better to compare nitrogen abundances in eucrite with those in the silicate portion of chondrites. Unfortunately, nitrogen abundance in the silicate portion of chondrites has not been determined yet. Camel Donga has the highest nitrogen concentration (1.0–1.3 ppm) among the measured eucrites. Since Camel Donga contains 2 wt% of metal (Palme *et al.*, 1988), which is higher than the other four eucrites, the abundant nitrogen of Camel Donga may have come from nitrogen in the metal.

The results of duplicate measurements for neon and argon in each sample are in good agreement with each other. Neon and argon in lower temperature fractions are not dominant and the adsorption of neon and argon is not a serious problem. Hence, neon and argon taken from all temperature fractions are considered as noble gas abundances in the meteorites. The concentrations of ^{40}Ar for ALH-76005 in our result

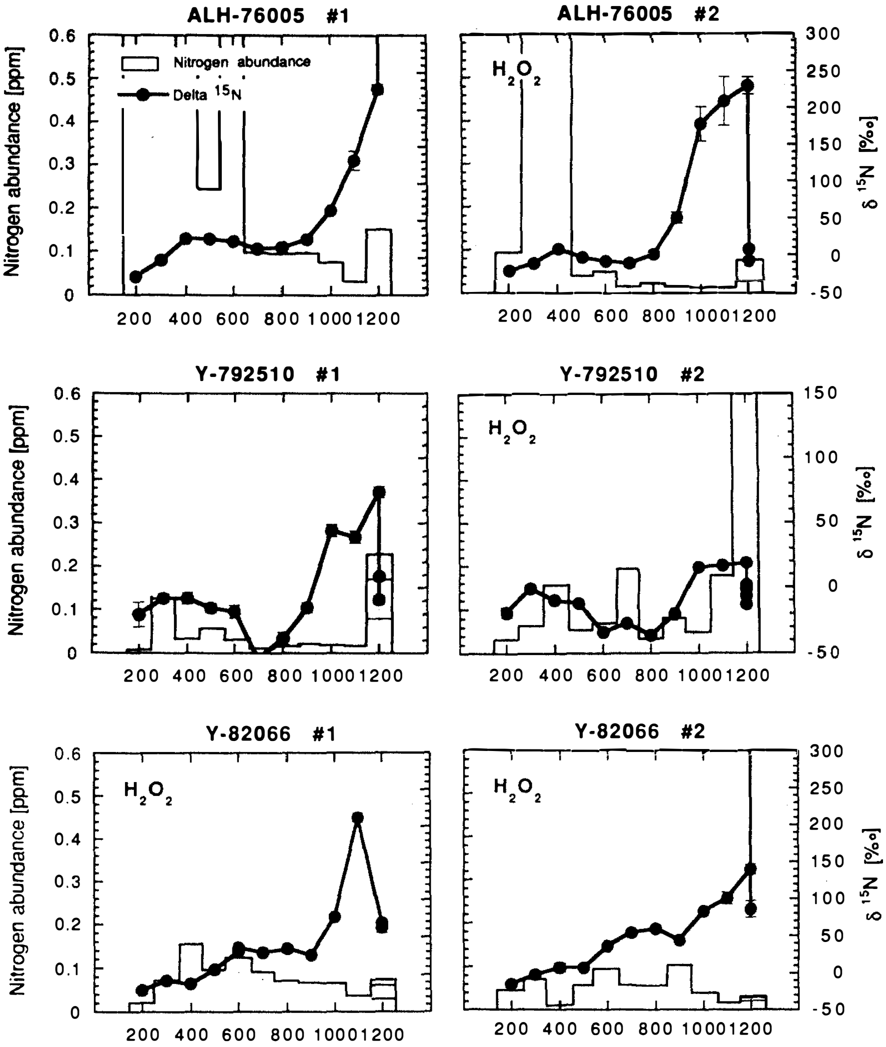


Fig. 1. Release profiles of nitrogen and $\delta^{15}N$ *value, which is defined by* $\delta^{15}N = ((^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{air} - 1) \times 1000$. *For seven analyses out of eleven, the sample was treated with* H_2O_2 *before the measurement. The total amounts of nitrogen in most eucrites are less than about 1 ppm. The terrestrial nitrogen which is probably due to organic material was observed at the low temperature fractions below 600°C, and the cosmogenic nitrogen at the high temperature fractions. Therefore, nitrogen released around 700–900°C fractions is considered as trapped nitrogen. The lowest* $\delta^{15}N$ *values observed in medium temperature fractions for two eucrites Y-792510 and Camel Donga are about −40‰ and −20‰, respectively, and they cannot be explained by the contribution of the terrestrial and cosmogenic nitrogen. The observed* $\delta^{15}N$ *may be upper limits of* $\delta^{15}N$ *of the trapped nitrogen for these eucrites. For the other eucrites,* $\delta^{15}N$ *in medium temperature fractions ranges in the terrestrial and cosmogenic nitrogen.*

(Table 2) are two times higher than that reported by others (Table 1). It must be that the samples measured by us contain more abundant potassium than that measured by others. The other results for noble gases in this study, cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and measured ^{40}Ar, are consistent with the reported values listed in Table 1.

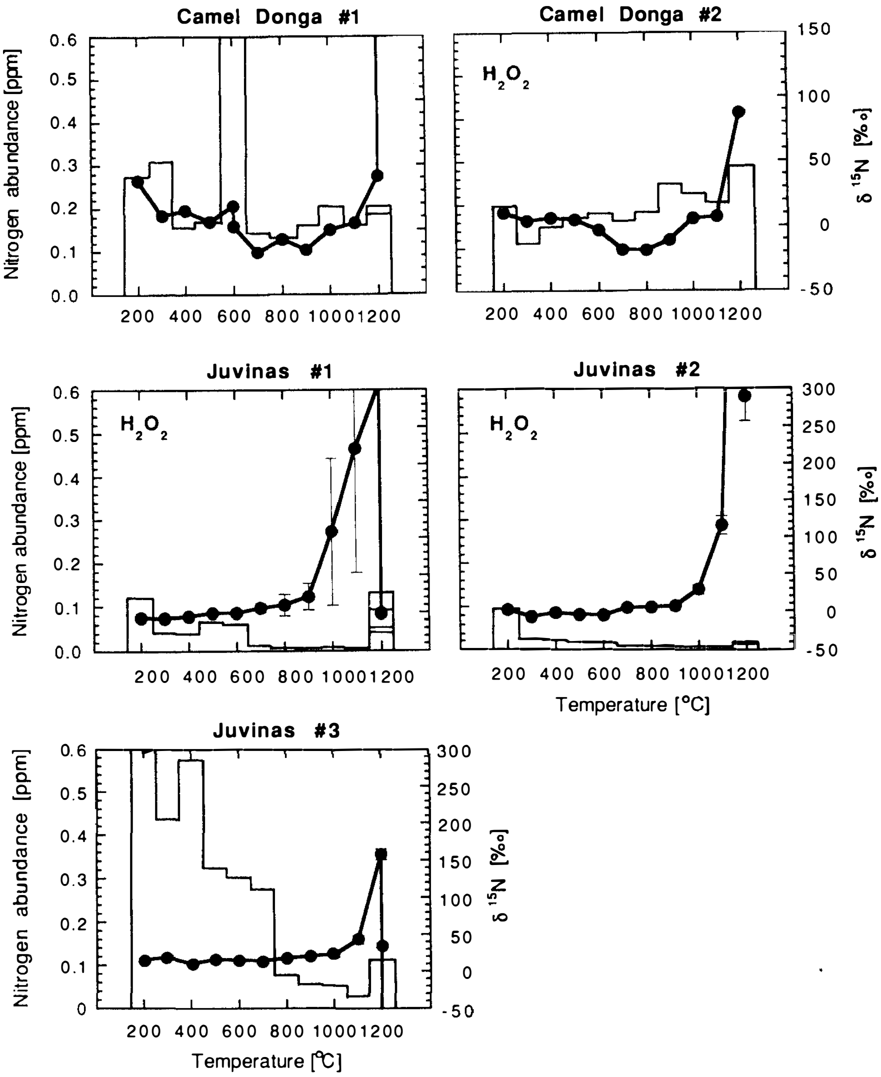


Fig. 1 (Continued).

5. Discussion

5.1. Nitrogen isotopic compositions in eucrites

As described above, we assumed that nitrogen obtained above 700°C is indigenous nitrogen, in which trapped nitrogen as well as cosmogenic nitrogen (*e.g.*, BECKER *et al.*, 1976) are included. Higher $^{15}N/^{14}N$ ratios observed at high temperature fractions ($>1000°C$) are due to contribution of cosmogenic nitrogen. First, we assume trapped nitrogen has an atmospheric $^{15}N/^{14}N$ ratio ($\delta^{15}N=0‰$). Then we can obtain concentrations of cosmogenic ^{15}N as excess ^{15}N defined by the following equation; Excess $^{15}N=((^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{air}-1)\times[^{14}N]$, where $(^{15}N/^{14}N)_{air}$ is 3.67×10^{-3} and $[^{14}N]$ is concentration of measured ^{14}N. If the assumption that excess $^{15}N=$ the amount of cosmogenic ^{15}N is correct, excess ^{15}N should be correlated with other cosmogenic nuclides such as ^{38}Ar. In Fig. 2a, the calculated excess ^{15}N are plotted against cosmogenic ^{38}Ar. The line in Fig. 2 shows the expected correlation line for eucrite: $P_{15}=5.5\times P_{38}$, where P_{15} and P_{38} are production rates of cosmogenic ^{15}N and

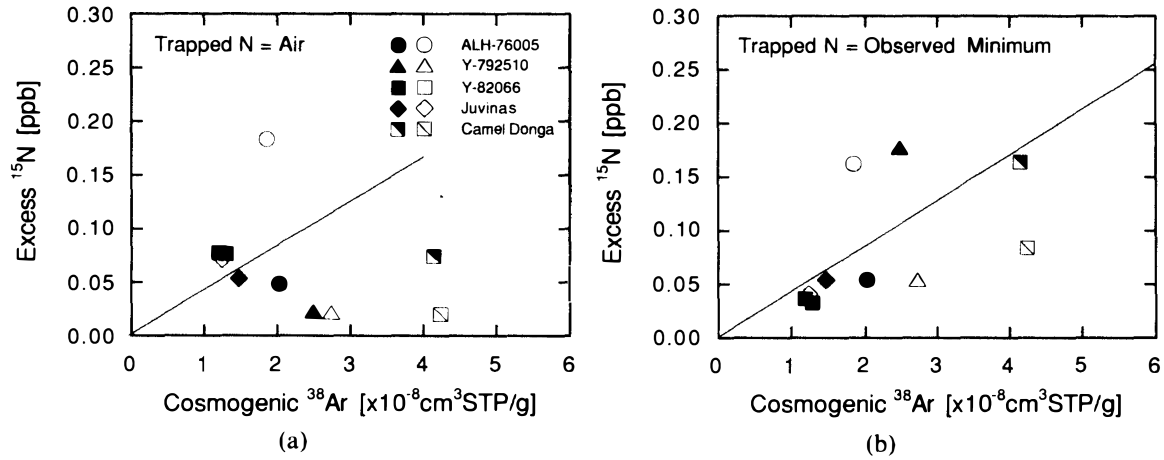


Fig. 2. *Plots between excess* ^{15}N *versus cosmogenic* ^{38}Ar. *Excess* ^{15}N *is calculated by; excess* $^{15}N=((^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{trap}-1)\times[^{14}N]$, *where* $[^{14}N]$ *is a concentration of measured* ^{14}N. *Solid and open symbols show the samples treated with* H_2O_2 *and untreated, respectively. A correlation line of* $P_{15}=5.5\times P_{38}$ *for eucrite is calculated using the equation* $P_{15}=15.2\times P_{38}$ *proposed for L-chondrite (HASHIZUME and SUGIURA, 1992c). (a) The isotopic composition of atmospheric nitrogen is assumed as that of trapped nitrogen. (b) The observed minimum* $\delta^{15}N$ *value among 700°C–900°C fractions is assumed as* $\delta^{15}N$ *of trapped nitrogen for each sample.*

^{38}Ar (in unit of atom/g/Ma), respectively. This is calculated using the correlation for L-chondrites, $P_{15}=15.2\times P_{38}$ (HASHIZUME and SUGIURA, 1992b) and considering differences in chemical compositions between eucrite and L-chondrites; P_{15}(Eucrite)/P_{15}(L-chondrite) = 1.2 and P_{38}(Eucrite)/P_{38}(L-chondrite) = 3.3 are adopted. It is apparent in Fig. 2a that no correlation exists between ^{15}N and ^{38}Ar. This suggests that the calculated excess ^{15}N cannot be regarded as the amount of cosmogenic ^{15}N. In other words, the assumption that the trapped nitrogen has an atmospheric ^{15}N/^{14}N ratio must be incorrect.

As mentioned earlier, contribution of terrestrial contamination in lower temperature fractions (<600°C) and that of cosmogenic nitrogen in higher temperature fractions (>1000°C) are significant. Hence, trapped components may be most noticeable in the medium temperature fractions (700–900°C). One of the most remarkable features in nitrogen isotopic compositions in eucrites (Fig. 1) is that Y-792510 and Camel Donga show negative δ^{15}N values in medium temperature fractions. The lowest δ^{15}N values observed are -54‰ for Y-792510 and -18‰ for Camel Donga (both at 700°C fractions). These low values cannot be explained by contribution of terrestrial nitrogen (typical range of δ^{15}N is 0 to 20‰; *e.g.*, FAURE, 1977) or cosmogenic nitrogen (δ^{15}N$>$100‰; *e.g.*, BECKER *et al.*, 1976). This is strong evidence for existence of trapped components in eucrites which have ^{15}N/^{14}N ratios different from the atmospheric value. Since there may be some contribution of terrestrial or cosmogenic nitrogen even in 700°C fractions, the minimum values observed in the present work should be considered as upper limits for the trapped components.

The δ^{15}N values in the medium temperature range are close to the atmospheric value for ALH-76005 and Juvinas, and slightly higher for Y-82066. Two of them, ALH-76005 and Y-82066, also show minimum $\delta^{15}N$ values in this temperature range. In these cases, the observed $\delta^{15}N$ values may be attributed to terrestrial nitrogen and/or cosmogenic nitrogen. Although we do not know exactly the real $\delta^{15}N$ values for the trapped nitrogen, we tentatively assume here that the observed minimum $\delta^{15}N$ values are not very different from the real values.

We calculate excess ^{15}N assuming the minimum $\delta^{15}N$ values as trapped values and examine if there is any correlation between the calculated excess ^{15}N and cosmogenic ^{38}Ar. The results are shown in Fig. 2b. The correlation seems to be better in Fig. 2b than in Fig. 2a, but there are still rather large discrepancies between the expected correlation line and the data points. This suggests that the minimum $\delta^{15}N$ values cannot be treated as the real $\delta^{15}N$ values for the trapped components.

Now we try to estimate isotopic composition of the trapped nitrogen using another calculation. We assume that the observed nitrogen above 700°C is a mixture of cosmogenic and trapped nitrogen. Since we can calculate the abundance of cosmogenic nitrogen using the production rate (P_{15}) and the exposure age, we can estimate the $\delta^{15}N$ values for the trapped nitrogen by subtracting cosmogenic nitrogen from the observed total nitrogen above 700°C. The production rate of nitrogen for eucrites has not been investigated in detail. So, we calculate production rate of ^{15}N (P_{15}) for eucrite based on P_{15} reported for ordinary chondrites. P_{15} of 4.7×10^{-12} g/g/Ma (HASHIZUME and SUGIURA, 1992b) proposed for L-chondrite is used. Since production rate of nitrogen is sensitive to the concentration of oxygen which is a main target element of nitrogen, we calculated P_{15} for eucrite assuming oxygen abundances of 41% and 37.5% for eucrite (based on the data in NAGAO and OGATA, 1989 and MIURA *et al.*, 1993) and L-chondrite (KERRIDGE, 1988), respectively. P_{15} for eucrite is calculated to be

Table 3. Bulk nitrogen abundance and $\delta^{15}N$, observed minimum $\delta^{15}N$, and calculated $\delta^{15}N$ corrected for cosmogenic.

Sample name		N_2 (>700°C) ppm	Bulk $\delta^{15}N$ (>700°C)[1] ‰	Minimum $\delta^{15}N$ (700°–900°C)[2] ‰	Calculated cosmogenic ^{15}N[3] ppb	$\delta^{15}N$ corrected for cosmogenic ^{15}N[4] ‰
ALH-76005	#1	0.502	99.7±1.2	11.9±2.7	0.06	63±7
	#2	0.138	95.0±1.3	−9.9±5.3		−38±26
Y-792510	#1	0.160	37.0±2.5	−54.2±14.1	0.084	−106±29
	#2	1.17	5.2±1.0	−36.2±1.5		−14±4
Y-82066	#1	0.390	53.1±1.2	29.2±2.9	0.059	12±8
	#2	0.313	66.9±1.8	43.9±2.1		16±10
Camel Donga	#1	1.02	5.4±1.0	−17.1±2.6	0.24	−57±13
	#2	1.32	15.3±0.9	−18.7±2.5		−33±10
Juvinas	#1	0.087	270±54	6.7±6.0	0.058	88±38
	#2	0.054	270±15	6.1±4.6		−21±61
	#3	0.539	32.0±1.9	14.3±3.2		2.5±6.1

[1] $\delta^{15}N$ of weighted mean for 700°C–1200°C fractions (1200°C fractions labeled "$" in Table 2 are excluded).

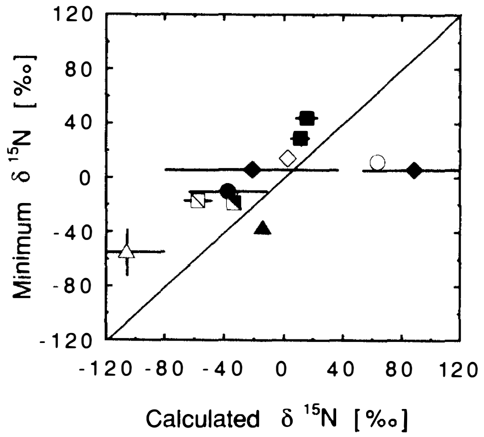
[2] Observed minimum $\delta^{15}N$ among 700°C–900°C fractions (see text).

[3] Cosmogenic ^{15}N is calculated using P_{15} of 5.6×10^{-9} g/g and exposure age reported for each eucrite.

[4] Estimation of $\delta^{15}N$ for a trapped component. Bulk $\delta^{15}N$ (>700°C) is corrected for cosmogenic ^{15}N. Error of 20% is adopted for the concentration of cosmogenic ^{15}N.

5.6×10^{-12} g/g/Ma. Using this value with assuming 20% error and the cosmic-ray exposure ages listed in Table 1 (mean values were used for ALH-76005, Y-792510, Juvinas and Camel Donga), the concentrations of the cosmogenic ^{15}N are calculated.

Fig. 3. Plot of observed minimum δ^{15}N versus calculated bulk δ^{15}N above 700°C fractions after cosmogenic correction. The symbols of five eucrites are the same as those in Fig. 2. If observed minimum δ^{15}N is consistent with bulk δ^{15}N corrected for cosmogenic nitrogen, the plot should fall on a line. Y-792510 and Camel Donga show lower δ^{15}N values.



The concentrations of cosmogenic ^{15}N for five eucrites are given in Table 3. They are calculated to be (0.067–0.24) × 10^{-9} g/g. The cosmogenic ^{15}N calculated for each eucrite is subtracted from measured nitrogen taken from the fractions higher than 700°C. The cosmogenic ^{15}N contributions to measured ^{15}N (>700°C) range from 8% up to 20%. The δ^{15}N after correcting cosmogenic ^{15}N of two eucrites Y-792510 and Camel Donga, for which low minimum δ^{15}N values are observed as mentioned above, are also significantly low (Table 3). However, calculated values of duplicate measurement for Y-792510 are not consistent with each other. Since the amount of nitrogen above 700°C of Y-792510 # 2 is much larger than that of # 1, contaminated nitrogen such as terrestrial organic nitrogen may be larger for # 2 than for # 1. Figure 3 is a plot of observed minimum δ^{15}N *vs.* calculated bulk δ^{15}N corrected for cosmogenic nitrogen. If the terrestrial and cosmogenic nitrogen does not contribute to the fraction above 700°C and if P_{15} we used are correct, observed minimum δ^{15}N values should be identical with calculated bulk δ^{15}N corrected for cosmogenic nitrogen. In this case the plot should fall on a line shown in Fig. 3. A positive correlation can be seen in the figure, though the data points show rather large scattering. It is also clear in this figure that the calculated δ^{15}N values for Y-792510 and Camel Donga are significantly lower than the atmospheric value.

5.2. *Release profile of cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and ^{40}Ar*

The release profiles of cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and ^{40}Ar are plotted in Fig. 4. For Y-792510, Y-82066 and Juvinas, cosmogenic ^{21}Ne are released at two different temperature steps at 300°C and around 800°C. This pattern having two release temperatures is different from the patterns for ALH-76005, Camel Donga and also many chondrites. The amounts of released cosmogenic ^{21}Ne around 300°C fractions are larger than 10% of the total ^{21}Ne for Y-792510, Y-82066 and Camel Donga. Such a high abundance of cosmogenic ^{21}Ne cannot be explained by the release from accessory minerals; it must be released from major minerals in eucrite containing target elements for Ne (*e.g.*, Mg, Al and Si). In the previous work concerning release profile of noble gases by combustion method, the release of ^{21}Ne from ilmenite and lunar regolith at

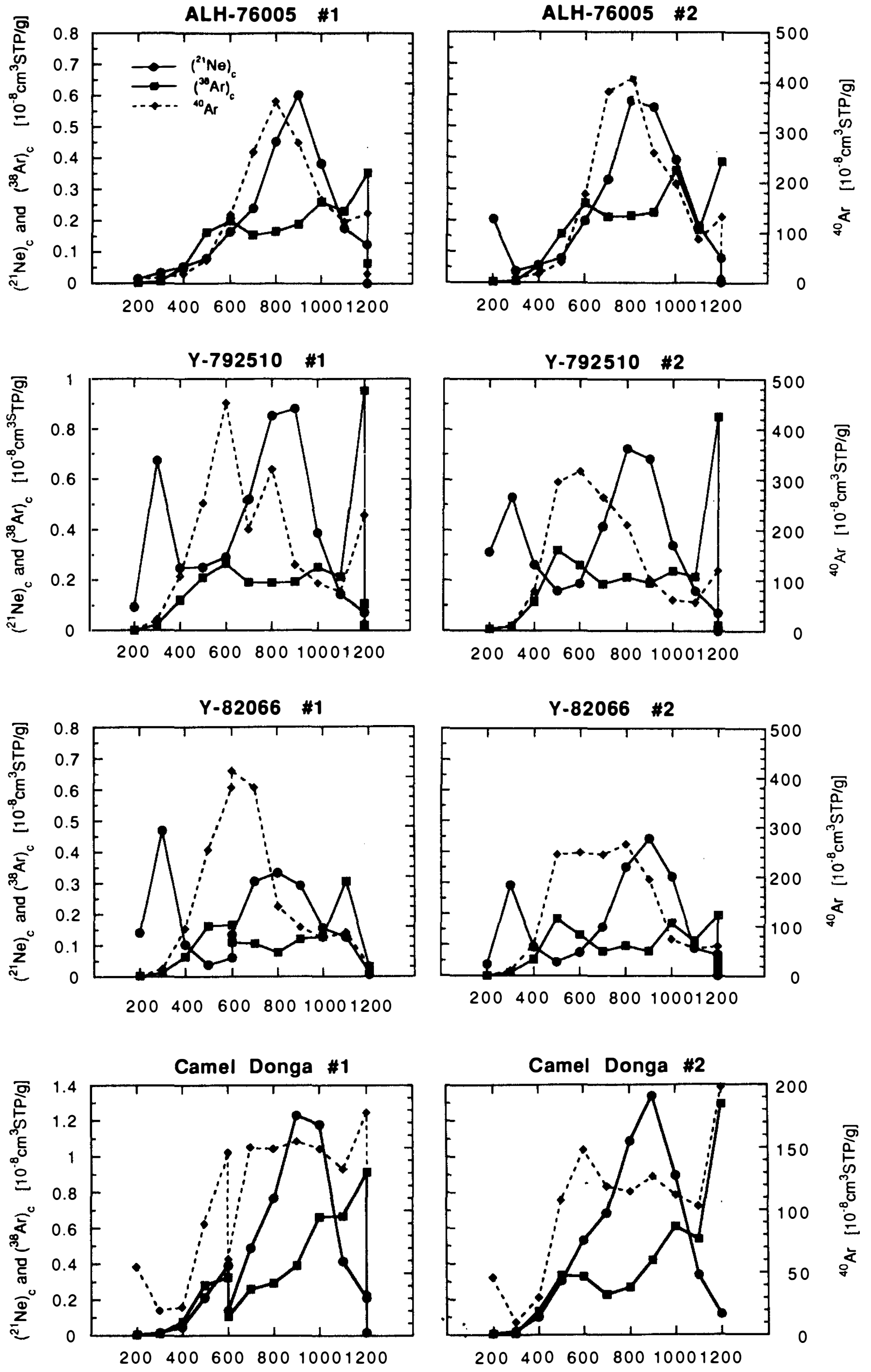


Fig. 4. Release profiles of cosmogenic ^{21}Ne, cosmogenic ^{38}Ar and measured ^{40}Ar. The measured ^{40}Ar is mostly radiogenic ^{40}Ar produced by potassium decay. The release of ^{40}Ar rises to the peak at 600°C– 800°C. Cosmogenic ^{21}Ne is released at two different temperatures of about 300°C and 800°C for Y-792510, Y-82066 and Juvinas. For the other eucrites, cosmogenic ^{21}Ne is released only at the higher temperatures of around 800°C. Cosmogenic ^{38}Ar is continuously released from 500°C up to 1200°C steps.

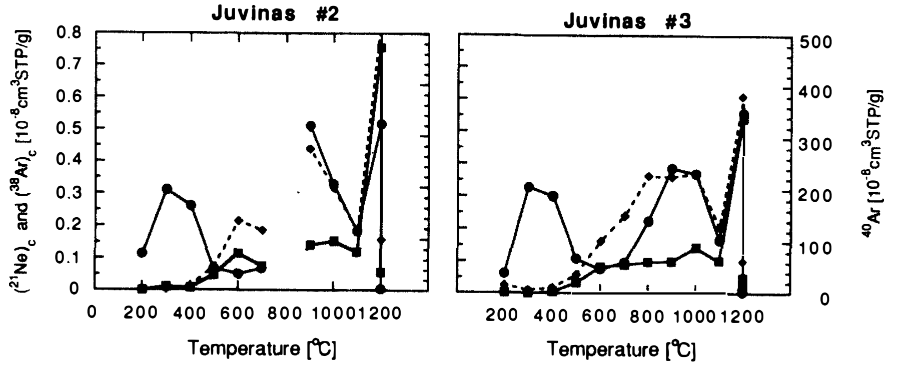


Fig. 4 (Continued).

the temperature around 400°C has been reported (Frick *et al.*, 1988). Although we have no evidence to identify the mineral which released ^{21}Ne at the low temperature, it is possible to consider pyroxene and plagioclase as candidates. In contrast, the cosmogenic ^{38}Ar is continuously released from 500°C up to 1200°C, and the release pattern shows bimodal peak around 600°C and 1000°C. Release profile of cosmogenic ^{38}Ar is compared with that of excess ^{15}N in Fig. 5. The excess ^{15}N is calculated assuming the observed minimum δ^{15}N values for the trapped nitrogen. Release pattern of cosmogenic ^{38}Ar is partly correlated with that of ^{15}N above 700°C as shown in the figure. This may indicate that the origin of excess ^{15}N is cosmogenic. At low temperatures,

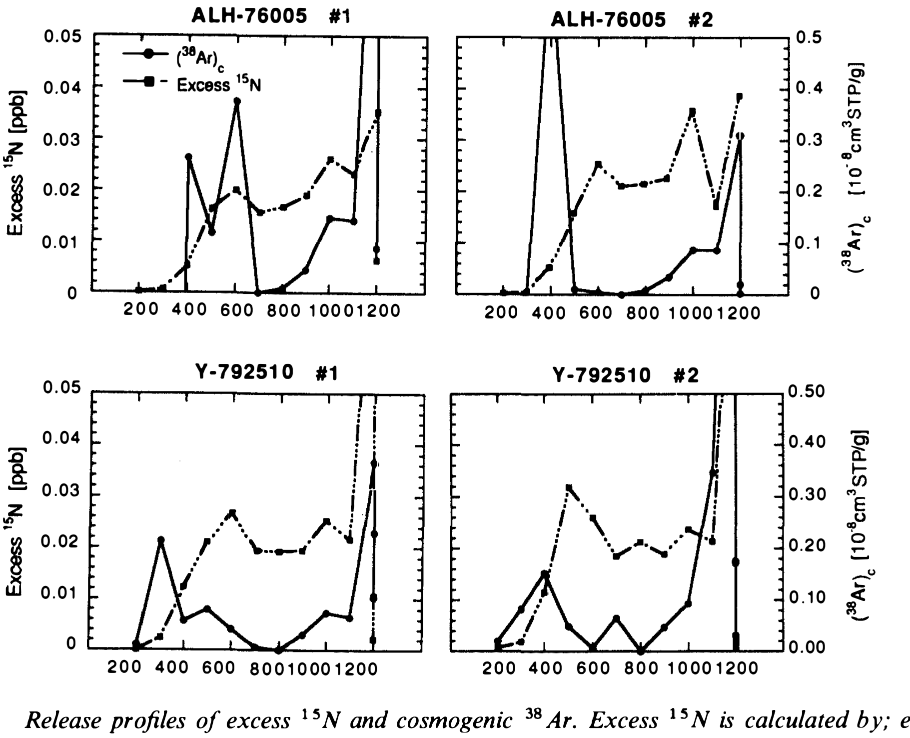


Fig. 5. Release profiles of excess ^{15}N and cosmogenic ^{38}Ar. Excess ^{15}N is calculated by; excess $^{15}N = ((^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{minimum} - 1) \times [^{14}N]$, where $(^{15}N/^{14}N)_{minimum}$ is observed minimum $^{15}N/^{14}N$ and $[^{14}N]$ is a concentration of measured ^{14}N. The release pattern for ^{15}N is correlated with that for ^{38}Ar in some higher temperature fractions.

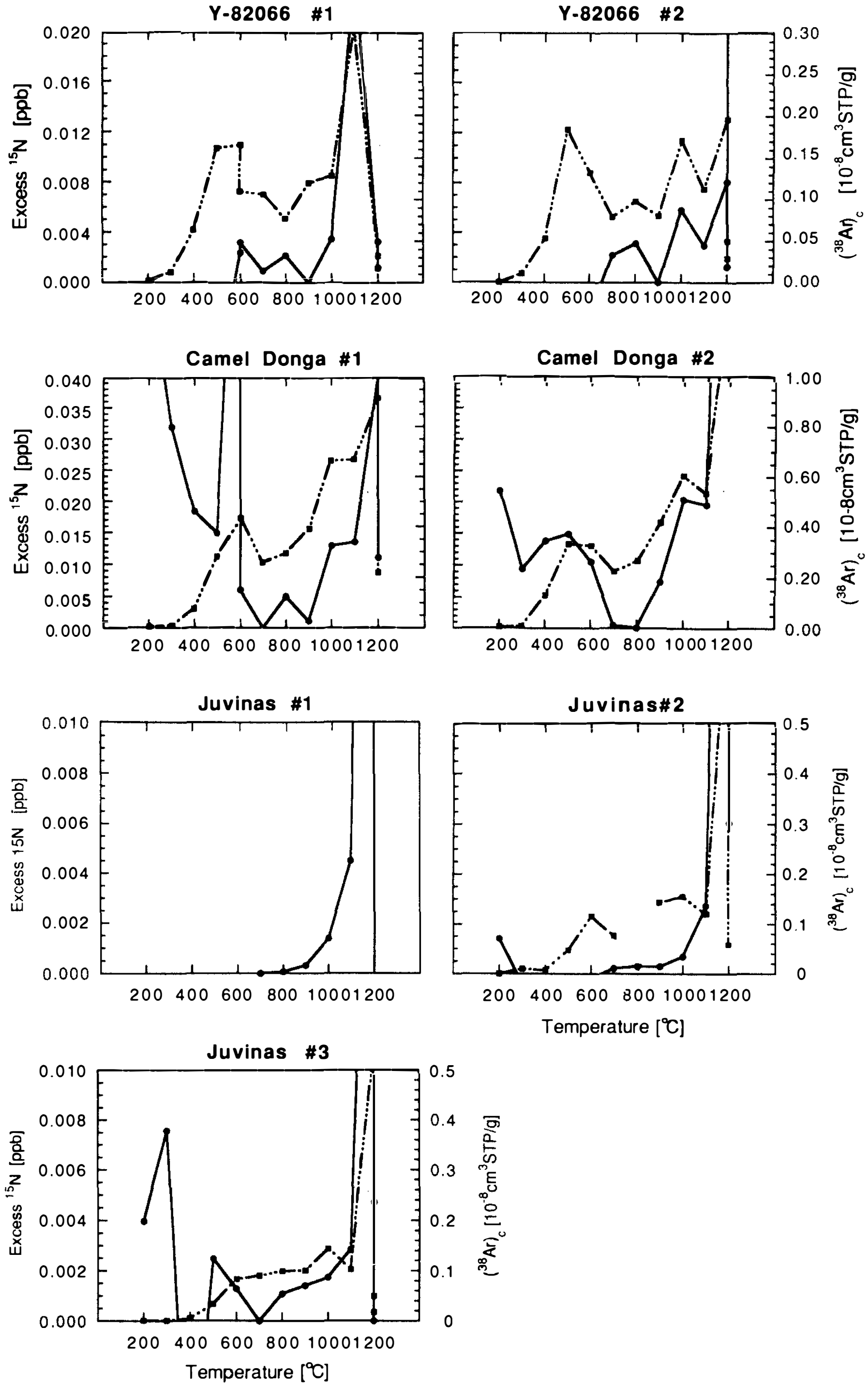


Fig. 5 (Continued).

since the origin of excess ^{15}N may be terrestrial organic material, ^{15}N and ^{38}Ar are not correlated with each other. ^{40}Ar is released around temperatures of 600°C–800°C. The release temperature of radiogenic ^{40}Ar is lower than that of cosmogenic ^{38}Ar.

6. Summary

(1) Since nitrogen of the terrestrial contaminants is not negligible, nitrogen released above 700°C is considered as indigenous nitrogen of eucrites. Nitrogen abundances thus calculated (0.05–1.3 ppm) are lower than those in ordinary chondrites (0.6–25 ppm; KUNG and CLAYTON, 1978; HASHIZUME and SUGIURA, 1992b).

(2) Two eucrites Y-792510 and Camel Donga released nitrogen with negative $\delta^{15}N$ values around 700°C fractions. The observed minimum $\delta^{15}N$ values of $-54‰$ and $-18‰$ for Y-792510 and Camel Donga, respectively, cannot be explained by the contribution of the terrestrial and cosmogenic nitrogen. Since the abundances of the trapped nitrogen are very low, the terrestrial contaminant is not negligible. Hence, the observed $\delta^{15}N$ values may be upper limit of the trapped nitrogen for these eucrites.

(3) Nitrogen isotopic compositions observed in the medium temperature fractions for the other three eucrites ALH-76005, Y-82066 and Juvinas are within the range of the terrestrial and cosmogenic nitrogen isotopic compositions.

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References

BECKER, R. H., CLAYTON, R. N. and MAYEDA, T. K. (1976): Characterization of lunar nitrogen components. Proc. 7th Lunar Sci. Conf., 441–458.

BOYD, S. R., WRIGHT, I. P., FRANCHI, I. A. and PILLINGER, C. T. (1988): Preparation of subnanomole quantities of nitrogen gas for stable isotopic analysis. J. Phys. E: Sci. Instrum., **21**, 876–885.

CONSOLMAGNO, G. J. and DRAKE, M. J. (1977): Composition and evolution of the eucrite parent body. Evidence from rare earth elements. Geochim. Cosmochim. Acta, **41**, 1271–1282.

FAURE, G. (1977): Nitrogen. Principles of Isotope Geology, ed. by G. FAURE, 2nd ed. New York, Wiley, 513–521.

FREUNDEL, M., SCHULTZ, L. and REEDY, C. (1986): Terrestrial ^{81}Kr-Kr ages of Antarctic meteorites. Geochim. Cosmochim. Acta, **50**, 2663–2673.

FRICK, U., BECKER, R. H. and PEPIN, R. O. (1988): Solar wind record in the lunar regolith: Nitrogen and noble gases. Proc. Lunar Planet. Sci. Conf., 18th, 87–120.

HASHIZUME, K. and SUGIURA, N. (1990): Precise measurement of nitrogen isotopic composition using quadrupole mass-spectrometer. Mass Spectrosc., **38**, 269–286.

HASHIZUME, K. and SUGIURA, N. (1992a): Measurement of cosmogenic nitrogen using a static mass-spectrometry system and its implication. Geochim. Cosmochim. Acta, **56**, 1625-1631.

HASHIZUME, K. and SUGIURA, N. (1992b): Nitrogen isotopic compositions in bulk ordinary chondrites. submitted to Geochim. Cosmochim. Acta.

HASHIZUME, K. and SUGIURA, N. (1992c): Various nitrogen compositions in H-chondrite metal. Meteoritics, **27**, 232.

IKEDA, Y. and TAKEDA, H. (1985): A model for the origin of basaltic achondrite based on the Yamato 7308 howardite. Proc. Lunar Planet. Sci. Conf., 15th, Pt. 2, C649–C663 (J. Geophys. Res., **89** Suppl.).

KERRIDGE, J. F. (1988): Meteorites and the Early Solar System. Tucson, Univ. Arizona Press, 1269 p.

KUNG, C. and CLAYTON, R. N. (1978): Nitrogen abundances and isotopic compositions in stony meteorites. Earth Planet. Sci. Lett., **38**, 421–432.

MICHEL, Th., EUGSTER, O., LEHMANN, B., THONNARD, N. and WILLIS, R. D. (1991): ^{81}Kr ages and trapped Xe of diogenites, an eucrite, and a howardite: Measurement of Kr isotopes using resonance ionization mass spectrometry (abstract). Meteoritics, **25**, 387.

MIURA, Y., NAGAO, K. and FUJITANI, T. (1991): ^{81}Kr terrestrial ages and grouping of Yamato eucrites. Papers Presented to the 16th Symposium on Antarctic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 129–130.

MIURA, Y., NAGAO, K. and FUJITANI, T. (1993): ^{81}Kr terrestrial ages and grouping of Yamato eucrites based on noble gas and chemical compositions. Geochim. Cosmochim. Acta (in press).

NAGAO, K. and MATSUDA, J. (1986): Rare gas studies of Antarctic meteorites. Papers Presented to the 11th Symposium on Antarctic Meteorites, March 25–27, 1986. Tokyo, Natl Inst. Polar Res., 131–132.

NAGAO, K. and OGATA, A. (1989): Noble gases and ^{81}Kr terrestrial ages of Antarctic eucrites. Mass Spectrosc., **37**, 313–324.

PALME, H., WLOTZKA, F., SPETTEL, B., DREIBUS, G. and WEBER, H. (1988): Camel Donga: A eucrite with high metal content. Meteoritics, **23**, 49–57.

SCHULTZ, L. and KRUSE, H. (1989): Helium, neon and argon in meteorites—A data compilation. Meteoritics, **24**, 155–172.

TAKEDA, H. (1979): A layer crust model of a howardite parent body. Icarus, **40**, 455–470.

TAKEDA, H. and GRAHAM, A. L. (1991): Degree of equilibration of eucritic pyroxenes and thermal metamorphism of the earliest planetary crust. Meteoritics, **26**, 129–134.

TAKEDA, H., MORI, H., DELANEY, J. S., PRINZ, M., HARLOW, G. E. and ISHII, T. (1983): Mineralogical comparison of Antarctic and non-Antarctic HED (Howardites-Eucrites-Diogenites) achondrites. Mem. Natl Inst. Polar Res., Spec. Issue, **31**, 181–205.

VOGT, S., HERPERS, U., SARAFIN, R, SIGNER, P., WIELER, R., SUTER, M. and WOELFLI, W. (1986): Cosmic ray records in Antarctic meteorites—A data compilation of the Cologne-Zuerich Collaboration. LPI Tech. Rep., **86-01**, 55–57.

YANAI, K and KOJIMA, H., comp. (1987): Photographic Catalog of the Antarctic Meteorites. Tokyo, Natl Inst. Polar Res., 298 p.

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