RARE GAS STUDIES OF SIXTEEN STONY METEORITES FROM ANTARCTICA

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Abstract: The concentrations of rare gases and isotopic compositions of He, Ne and Ar were determined for fourteen chondrites and two achondrites from Antarctica. The Xe isotopic ratios were also determined for seven meteorites. Cosmic-ray exposure and gas retention ages are given. Exposure age of 55 Ma determined for Y-75015 eucrite is longer than those for most eucrites so far reported. Xe contained in chondrites is a mixture of cosmogenic and trapped components. ^{129}Xe excess from extinct ^{129}I was found for these chondrites. In Y-75015 eucrite, trapped and cosmogenic Xe's were dominant and an appreciable amount of fissiogenic Xe was detected. Five groups of paired meteorites are suggested on the basis of rare gas data.

1. Introduction

The concentrations and isotopic compositions of rare gases in meteorites give us useful information about the ages of meteorites, the cosmic-ray irradiation history and paired meteorites which are fragments of one meteorite. Moreover, combined measurements of rare gases and radioactive nuclides show more detailed history and mechanisms on the exposure of cosmic-ray. For antarctic meteorites we have reported several significant results on cosmic-ray exposure and gas-retention ages, neutron capture effects, gas-rich meteorites and some paired meteorites (TAKAOKA and NAGAO, 1978, 1980a, b; NAGAO and TAKAOKA, 1979; TAKAOKA *et al.*, 1981; TAKAOKA, 1982).

2. Experimental Procedures and Samples

The experimental technique employed for rare gas analysis is a standard one already reported (*e.g.* TAKAOKA, 1976). Bulk samples between 50 and 300 mg were used for the rare gas mass spectrometry. Seven meteorites Y-74015, -74073, -74115, -74192, -75015, -75258 and -75289 were analyzed by a mass spectrometer recently constructed at Okayama University of Science. For these seven meteorites the Xe isotopic ratios were also determined. The other meteorites were analyzed at Yamagata University.

Samples used in this work are six H chondrites, seven L chondrites, one LL chon-

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Table 1. Samples used in this work.

Meteorite	Classification 1)	Recovered mass 2) (g)	Degree of weathering 1)	Description 2)
Y-74073 3)	H5	29.9	B	Fragment with a fusion crust.
Y-74107 3)	H5	114.0	B	About one-fifth missing, well rounded mass with a crust.
Y-74115 6)	H5	1045.1	B	Complete individual with a fusion crust.
Y-74192	H5 or 6	420.3	C	Approximately half of the original mass with a crust.
Y-74234 4)	H5	25.9	C	Fragment with a fusion crust.
Y-74364 6)	H4	757.8	B	Almost complete individual with a smooth surface.
Y-74015	L6 or LL	88.0		Nearly complete individual with a fusion crust.
Y-74165	L4	203.4	C	Part of larger mass with a fusion crust.
Y-74455	L6	114.1	A	Nearly complete, partially abraded.
Y-74650	L6	163.2	A/B	Complete individual except one corner.
Y-74663	L6	213.9	B	Almost complete individual.
Y-75289	L5	50.9		Almost complete individual with a fusion crust. Weathered.
ALH-77214	L3	2097.4		
Y-75258 6)	LL6	971.0		Heavily abraded flat specimen with patches of fusion crust.
Y-74011 5)	Di	206.0	A	Broken mass with a fusion crust partially. Similar to Y-74013.
Y-75015	Eu	166.6		Complete individual. Very similar to Y-75011 and to Y-74159 (polymict breccia).

1) Mason and Yanai (1983). 2) Yanai (1979).

3) Y-74070–075 and Y-74104–108 are fragments of a single fall (Mason and Yanai, 1983).

4) Y-74194–342 are paired (Mason and Yanai, 1983).

5) 22 diogenites of Y-74 meteorites are all paired (Mason and Yanai, 1983).

6) Isotopic compositions of light rare gases have been reported by Takaoka and Nagao (1980) and Takaoka *et al.* (1981).

drite, one diogenite and one eucrite. They are listed in Table 1 with classification, recovered mass, degree of weathering and description. Y-74073(H5) and Y-74107 (H5) have been reported to belong probably to a group of Y-74070–Y-74075 and Y-74104–Y-74108 which may be fragments of a meteorite, and Y-74234 (H5) and Y-74011 (Di) to other groups of Y-74194–Y-74342 chondrites and of 22 diogenites of the Y-74 meteorite collection, respectively (Mason and Yanai, 1983). Y-75015 eucrite is a polymict breccia and is very similar to Y-75011 and Y-74159 eucrites (Yanai, 1979).

3. Results

Isotopic compositions of He, Ne and Ar and rare gas concentrations are listed in Table 2. Errors cited for the isotopic ratios are statistical errors (1σ) calculated from sample and calibration measurements. Uncertainties for the rare gas concentrations are estimated to be about 10% except for Kr concentrations for Y-74015, -74073,

Table 2. Concentrations of rare gases and isotopic compositions of He, Ne and Ar.

Meteorite	^{3}He*	^{4}He*	^{3}He/^{4}He#	^{21}Ne*	^{22}Ne/^{21}Ne#	^{20}Ne/^{22}Ne#	^{36}Ar*	^{40}Ar*	^{38}Ar/^{36}Ar#	^{40}Ar/^{36}Ar	^{84}Kr**	^{132}Xe**
H chondrite												
Y-74073 (H5)	8.97	365	24.1±0.5	1.31	1205±3	851±3	0.679	2370	497±3	3496±8		1.1
Y-74107 (H5)	4.94	408	12.1±0.8	2.32	1082±9	838±7	0.778	2367	507±9	3043±40	0.71	1.3
Y-74115 (H5)	16.0	1570	10.2±0.2	2.67	1142±7	818±4	0.790	5640	675±6	7140±43		1.2
Y-74192 (H5-6)	79.7	3260	24.4±0.1	14.1	1086±4	836±1	2.02	5440	927±12	2694±13		1.7
Y-74234 (H5)	1.38	14.2	95.0±6.2	0.662	1136±13	1213±12	1.66	444	239±3	268±3	3.1	0.71
Y-74364 (H4)	12.6	1345	9.4±0.6	1.61	1272±11	821±8	1.13	4434	402±5	3920±80	2.0	2.2
L chondrite												
Y-74015 (L6)	14.8	157	94.4±1.9	3.90	1095±6	864±5	0.510	128	811±4	251±1		0.73
Y-74165 (L4)	36.5	291	125±8	10.0	1062±9	863±8	2.35	255	480±5	108±1	0.76	1.1
Y-74455 (L6)	37.8	923	41.0±2.7	5.35	1276±20	817±8	0.683	4040	1076±19	5920±240	0.66	0.57
Y-74650 (L6)	19.0	1333	14.3±0.9	3.55	1126±9	836±8	0.618	4138	579±20	6700±350	0.83	0.89
Y-74663 (L6)	25.9	986	26.3±1.7	3.29	1256±9	819±8	0.696	4406	665±15	6330±200	0.96	1.1
Y-75289 (L5)	21.3	1620	13.1±0.1	4.52	1104±4	850±2	1.22	5440	567±9	4460±170		1.7
ALH-77214 (L3)	4.16	1005	4.1±0.3	0.896	1385±15	2467±25	91.8	3075	187±2	33.5±0.3	63	47
LL chondrite												
Y-75258 (LL6)	42.5	1730	24.6±0.5	6.75	1109±2	851±2	1.21	4890	763±4	4057±7		0.78
Diogenite												
Y-74011	89.1	623	143±9	23.3	1085±8	843±8	0.870	46.3	1421±16	53.3±0.8	0.28	0.046
Eucrite												
Y-75015	101	10100	9.98±0.01	15.3	1161±2	816±2	6.71	2530	1493±2	376.6±1.2		0.89

* Concentrations of He, Ne and Ar are given in unit of 10^{-8} cm^{3}STP/g.

** Concentrations of Kr and Xe are given in unit of 10^{-10} cm^{3}STP/g.

\# Isotopic ratios except ^{40}Ar/^{36}Ar are given in unit of 10^{-3}.

-74115, -74192, -75015, -75258 and -75289. Because of a memory effect from the previous analyses of a large amount of atmospheric Kr, the concentrations and isotopic ratios of Kr contain large uncertainties and any results for Kr are not given for these seven meteorites.

ALH-77214 (L3) chondrite contains a small amount of trapped Ne. In other meteorites cosmogenic He and Ne, and radiogenic ^{4}He are predominant. Ar is a mixture of trapped, cosmogenic and radiogenic components. To distinguish the individual component, the following isotopic ratios of end members were assumed: for cosmogenic gases $(^{3}\mathrm{He}/^{4}\mathrm{He})_c = 0.2$, $(^{20}\mathrm{Ne}/^{22}\mathrm{Ne})_c = 0.85$ and $(^{21}\mathrm{Ne}/^{22}\mathrm{Ne})_c = 0.92$, and for trapped gases $(^{4}\mathrm{He}/^{20}\mathrm{Ne})_t = 330$, $(^{20}\mathrm{Ne}/^{22}\mathrm{Ne})_t = 8.2$ and $(^{21}\mathrm{Ne}/^{22}\mathrm{Ne})_t = 0.03$ (*e.g.* Takaoka *et al.*, 1981). Because the amount of trapped Ne is very small compared with cosmogenic Ne content in ALH-77214, other trapped Ne components such as atmospheric and solar Ne do not change an estimation of cosmogenic ^{21}Ne content. Though the $^{20}\mathrm{Ne}/^{22}\mathrm{Ne}$ ratio of Y-74234 is slightly higher than cosmogenic $^{20}\mathrm{Ne}/^{22}\mathrm{Ne}$ ratio, trapped Ne may not be contained because of low concentrations of other rare gases in this meteorite.

Cosmogenic ^{3}He and ^{21}Ne, and radiogenic ^{4}He and ^{40}Ar are listed in Table 3. All ^{40}Ar was assumed to be radiogenic. Y-74234, Y-74015 and Y-74165 chondrites have very low concentrations of radiogenic ^{4}He and ^{40}Ar, which implies a recent out-gassing caused by collisional or metamorphic events. The low concentration of radiogenic ^{4}He and ^{40}Ar for Y-74011 diogenite can be attributed to low U, Th and K contents.

The Xe isotopic compositions for six chondrites and an eucrite are listed in Table 4. For six chondrites Xe is a mixture of cosmogenic, radiogenic and trapped components. ^{129}Xe excess from extinct ^{129}I was found in all chondrites. In Y-75015 eucrite, trapped and cosmogenic Xe's were dominant and an appreciable amount of fission component was detected.

4. Discussion

4.1. *Cosmic-ray exposure age*

Cosmogenic ^{3}He and ^{21}Ne, and cosmic-ray exposure ages are listed in Table 3. Production rates, shielding corrections and chemical correction factors by Cressy and Bogard (1976) were used in the calculation. Cosmic-ray exposure ages determined by cosmogenic ^{21}Ne for H, L and LL chondrites are distributed between 1.5 and 28 Ma as shown in Fig. 1. The age distribution is similar to the distributions for antarctic and non-antarctic chondrites previously reported. The similarity supports the previous conclusion that the cosmic-ray irradiation history of the antarctic chondrites is not significantly different from that of the non-antarctic ones (Takaoka *et al.*, 1981).

Y-74011 diogenite, which seems to be one of fragments of a diogenite shower (Honda, 1981), shows concentrations of cosmogenic ^{3}He and ^{21}Ne higher by a factor of about 1.3 than those for Y-74013 and Y-74097 diogenites (Nagao and Takaoka, 1979). The cosmic-ray exposure age T_{21} for Y-74011 is 38 Ma, which is 6 and 3 Ma longer than those for Y-74013 and Y-74097, respectively. Since the concentrations of cosmogenic ^{21}Ne for the diogenites are correlated with ^{53}Mn contents (Honda, 1981), the differences between the cosmogenic He and Ne concentrations are due to different

Table 3. Cosmic-ray exposure and gas retention ages.

Meteorite	^3He_c 1)	$^{21}Ne_c$ 1)	T_3 3)	T_{21} 3)	T_{21} 4)	^4He_r 2)	$^{40}Ar_r$ 2)	T_4 5)	T_{40} 5)
	(10^{-8} cm^{3}STP/g)		(Ma)			(10^{-8} cm^{3}STP/g)		(Ga)	
Y-74073 (H5)	8.79	1.31	4.2	3.6	6.5	321	2370	1.1	2.9
Y-74107 (H5)	4.94	2.32	2.0	4.5	7.0	383	2370	1.3	2.9
Y-74115 (H5)	16.0	2.67	6.9	6.7	11	1490	5640	3.8	4.4 6)
Y-74192 (H5 or 6)	79.7	14.1	32	28	44	2860	5440	5.2	4.2
Y-74234 (H5)	1.38	0.662	0.59	1.6	2.6	—	444	—	1.0
Y-74364 (H4)	12.6	1.61	6.6	4.5	9.6	1280	4430	3.5	3.9
Y-74015 (L6 or LL)	14.8	3.90	5.9	7.6	12	83	128	0.24	0.35
Y-74165 (L4)	36.5	10.0	14	18	25	109	255	0.32	0.64
Y-74455 (L6)	37.8	5.35	19	14	30	734	4040	1.9	3.7
Y-74650 (L6)	19.0	3.55	7.9	7.9	12	1240	4140	2.9	3.7
Y-74663 (L6)	25.9	3.29	13	8.6	18	860	4410	2.2	3.8
Y-75289 (L5)	21.3	4.52	8.6	9.2	14	1510	5440	3.3	4.2
ALH-77214 (L3)	4.16	0.888	1.7	1.9	2.9	248	3080	0.7	3.3
Y-75258 (LL6)	42.5	6.75	17	14	22	1520	4890	3.7	4.0
Y-74011 (Di)	89.1	23.3	33	38		178	46.3	1.1	
Y-75015 (Eu)	101	15.3	38	55		9600	2530	2.7	3.6

1) Cosmogenic ^{3}He and ^{21}Ne. 2) Radiogenic ^{4}He and ^{40}Ar.

3) Cosmic-ray exposure ages calculated according to CRESSY and BOGARD (1976). Production rates (in 10^{-8} cm^{3}STP/g·Ma) of ^{3}He are 2.44, 2.39, 2.46, 2.53 and 2.52 and those of ^{21}Ne are 0.470, 0.441, 0.483, 0.513 and 0.234 for L, H, LL, Di and Eu, respectively. Shielding factors are follows; $F(^3He)=2.385-1.244(^{22}Ne/^{21}Ne)_c$ for P_3, and $F(^{21}Ne)=38.27-62.53(^{22}Ne/^{21}Ne)_c+26.1(^{22}Ne/^{21}Ne)_c^2$ for $1.08<(^{22}Ne/^{21}Ne)_c<1.20$, $F=1.181$ for $(^{22}Ne/^{21}Ne)_c\leq 1.08$, $F=0.818$ for $(^{22}Ne/^{21}Ne)_c\geq 1.20$. Correction factors for elemental compositions of achondrites were calculated with Si and Mg contents of Y-74013 (Di) and Y-75015 (Eu) (YANAI, 1979). Elemental composition of Y-74011 (Di) was assumed to be similar to that of Y-74013 (Di).

4) Cosmic-ray exposure ages calculated according to NISHIIZUMI *et al.* (1980). Production rates (in 10^{-8} cm^{3}STP/g·Ma) of ^{21}Ne, P°_{21}, are 0.31, 0.31 and 0.29 for L, LL and H chondrites, respectively. Shielding correction was calculated by $P_{21}=4.845\,P^{\circ}_{21}[21.77(^{22}Ne/^{21}Ne)-1]^{-1}$.

5) Gas retention ages.

6) K concentration is 770 ppm (measured by NISHIDO).

degree of shielding effect and the disagreement in exposure ages is due to insufficient shielding correction.

For Y-75015 eucrite the exposure age obtained from cosmogenic ^{3}He is much shorter than the age from cosmogenic ^{21}Ne. The difference between the ages may be accounted for by a preferential loss of cosmogenic ^{3}He. MEGRUE (1966) has shown that the feldspar loses nearly all its cosmogenic ^{3}He. A correction for diffusional loss of He from feldspar was proposed by HEYMANN *et al.* (1968). The exposure age corrected for diffusional loss of cosmogenic ^{3}He is 54 Ma. In this calculation a weight fraction of feldspar of about 28% in Y-75015 eucrite was obtained from cosmogenic ^{3}He/^{38}Ar ratio. The age of 54 is in good agreement with the age of 55 Ma from cosmogenic ^{21}Ne. The exposure age for Y-75015 eucrite is longer than those for eucrites including non-antarctic ones except for Luotolax, of which the age is 62 Ma (HEYMANN *et al.*, 1968).

The production rates of cosmogenic ^{3}He and ^{21}Ne used in the calculation of

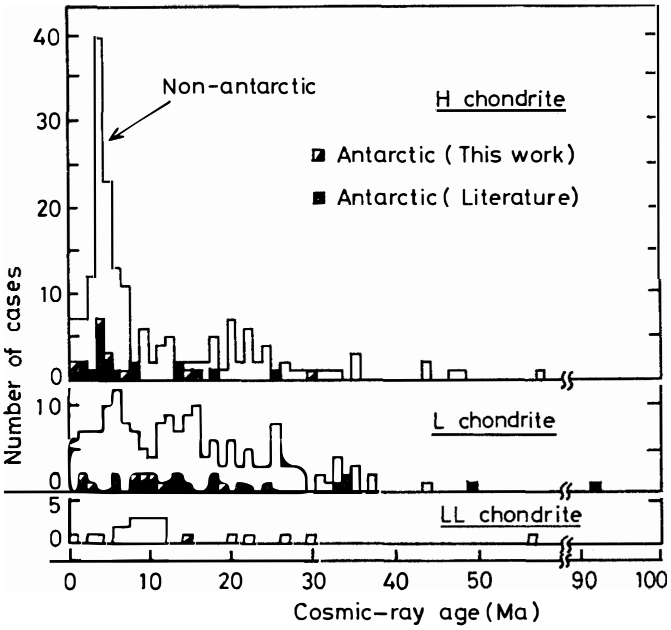

Fig. 1. Distribution of comsic-ray exposure ages of antarctic H, L and LL chondrites. Published data on antarctic chondrites are also plotted. Data: TAKAOKA and NAGAO (1978, 1980b), NAGAO and TAKAOKA (1979), TAKAOKA et al. (1981) and TAKAOKA (1982).

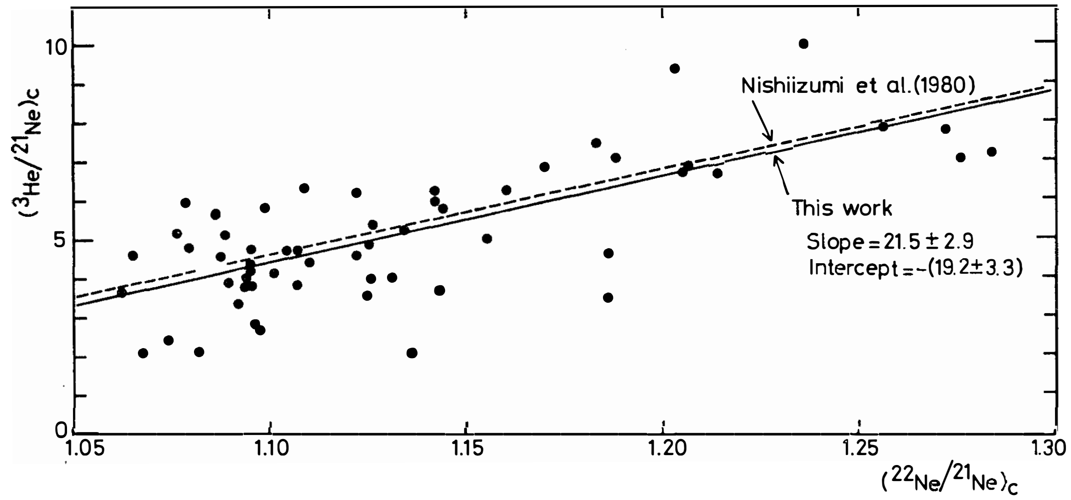

Fig. 2. A correlation plot between the ^{3}He/^{21}Ne and ^{22}Ne/^{21}Ne ratios of cosmogenic He and Ne in antarctic chondrites. The solid line was determined by a least squares fit for all data plotted. The line is practically the same as the correlation line (slope=21.77 and intercept=−19.32) determined by NISHIIZUMI et al. (1980) from 138 non-antarctic chondrites. Data sources are given in Fig. 1. Unpublished data are also plotted.

exposure age noted above are obtained from cosmogenic ^{26}Al content. However, NISHIIZUMI *et al.* (1980) proposed the production rates of ^{21}Ne based on ^{53}Mn, ^{81}Kr-^{83}Kr, and ^{22}Na-^{22}Ne methods, and recommended a production rate of 0.31×10^{-8} cm^{3}STP/g·

Ma for L chondrite. The production rates based on the three methods are in good agreement, but they are small by a factor of about 0.7 compared with the production rate of 0.470×10^{-8}cm^{3}STP/g·Ma based on ^{26}Al method (CRESSY and BOGARD, 1976).

We also calculated the exposure ages for chondrites with the production rates and the shielding correction by NISHIIZUMI *et al.* (1980). The ages are listed in Table 3. The shielding correction by them is based on the correlation between the ^{3}He/^{21}Ne and ^{22}Ne/^{21}Ne ratios of cosmogenic He and Ne. As shown in Fig. 2 the correlation line determined for antarctic chondrites is practically the same as the correlation line obtained by NISHIIZUMI *et al.* (1980) based on 138 selected data for non-antarctic chondrites. The agreement between the correlation lines for both the antarctic and the non-antarctic chondrites indicates that the shielding correction by NISHIIZUMI *et al.* (1980) is also applicable to antarctic chondrites. Because of the low production rate, the exposure ages obtained are systematically longer than those calculated with the production rate by CRESSY and BOGARD (1976). The disagreement between production rates based on ^{26}Al-age and other methods is a problem to be solved and we do not conclude at present which age is proper.

4.2. U/Th and K-Ar ages

The concentrations of radiogenic ^{4}He and ^{40}Ar, and the gas retention ages are listed in Table 3. Radiogenic ^{4}He was corrected for cosmogenic and trapped components by the following equation;

$$^4\mathrm{He}_\mathrm{r}={}^4\mathrm{He}_\mathrm{m}-5\cdot{}^3\mathrm{He}_\mathrm{c}-330\cdot{}^{20}\mathrm{Ne}_\mathrm{t},$$

where r, m, c and t mean radiogenic, measured, cosmogenic and trapped components, respectively. Since the radiogenic ^{4}He for Y-74234 is negative value after a correction, radiogenic ^{4}He is not given in Table 3. This reflects a preferential loss of He from this chondrite. ^{40}Ar determined was assumed to be mostly radiogenic. In calculation of U/Th-He and K-Ar ages, mean concentrations of U (12, 15, 13, 7 and 130 ppb for H, L, LL, Di and Eu, respectively) and K (850 ppm for H, L and LL) and Th/U$=$3.6 were assumed (MORGAN, 1971; GOLES, 1971). For Y-74115 (H5) chondrite, the K content was measured to be 700 ± 10 ppm. For Y-75015 eucrite, the K$_2$O content of 0.07 wt% by fused bead analysis (YANAI, 1979) was used in calculation of K-Ar age.

K-Ar ages for H and L chondrites show distribution characteristic in each group. The age for Y-74234 is 1.0 Ga which is a young age in H-group chondrites. Y-74015 and Y-74165 L chondrites have young K-Ar ages of 0.35 and 0.64 Ga. The ages belong to a cluster of young ages around 0.5 Ga for shocked L-group chondrites.

Most of the K-Ar ages reported for eucrites are appreciably lower than 4.5 Ga, and U/Th-He ages are systematically lower than K-Ar ages which suggests He loss (HEYMANN *et al.*, 1968). U/Th-He and K-Ar ages for Y-75015 eucrite are typical ones for the eucrites.

4.3. Xe isotopic composition

The Xe isotopic compositions are listed in Table 4. Isotopic variations compared with atmospheric Xe are shown in Fig. 3, by using δ_{132} (atm) values defined as

$$\delta_{132}\,(\mathrm{atm})=\left[\frac{(^{m}\mathrm{Xe}/^{132}\mathrm{Xe})}{(^{m}\mathrm{Xe}/^{132}\mathrm{Xe})_{\mathrm{atm}}}-1\right]\times 10^{3},$$

Table 4. Isotopic compositions of Xe.

Meteorite	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe
Y-74073	0.464±0.026	0.416±0.021	7.77±0.07	134.3±0.9
Y-74115	0.487±0.041	0.498±0.010	8.85±0.25	143.2±1.5
Y-74192	0.574±0.008	0.573±0.010	8.40±0.10	125.0±0.7
Y-74015	0.509±0.042	0.472±0.017	8.27±0.26	105.6±2.3
Y-75289	0.481±0.027	0.423±0.025	8.15±0.16	113.8±1.0
Y-75258	0.603±0.048	0.559±0.024	8.51±0.10	138.2±2.3
Y-75015	3.65 ±0.11	6.11 ±0.25	14.72±0.09	94.0±1.0

Meteorite	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
Y-74073	15.65±0.21	79.8±0.9	=100	40.26±0.30	34.31±0.29
Y-74115	16.70±0.17	80.9±0.6	=100	37.17±0.18	30.53±0.16
Y-74192	16.25±0.07	82.1±0.3	=100	37.99±0.22	32.21±0.44
Y-74015	15.60±0.21	80.0±0.9	=100	37.90±0.41	30.70±0.33
Y-75289	16.05±0.04	79.4±0.4	=100	38.62±0.38	32.14±0.22
Y-75258	16.33±0.07	81.4±0.4	=100	37.69±0.33	30.73±0.36
Y-75015	19.26±0.22	95.2±1.4	=100	42.68±0.37	37.79±0.31

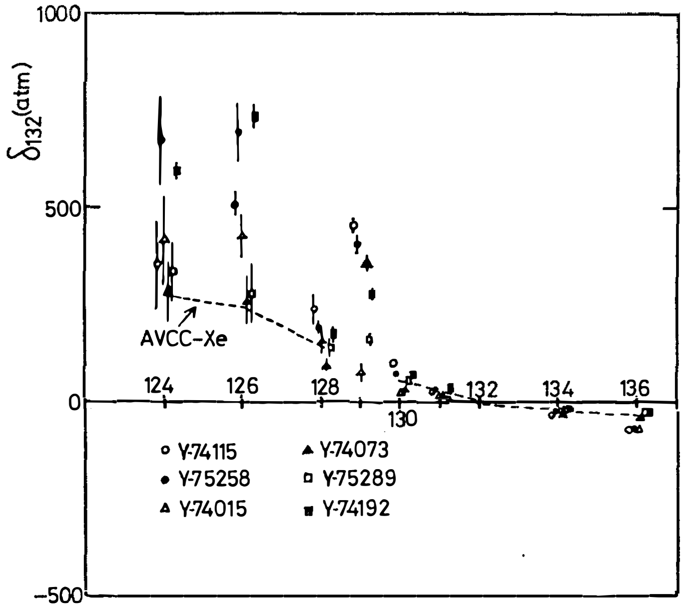

Fig. 3. The Xe isotopic compositions for six chondrites. δ_{132} (atm) is defined as

$$\delta_{132}\,(atm)=\left[\frac{(^{m}Xe/^{132}Xe)}{(^{m}Xe/^{132}Xe)_{\mathrm{atm}}}-1\right]\times 10^{3},$$

where atm means atmospheric.

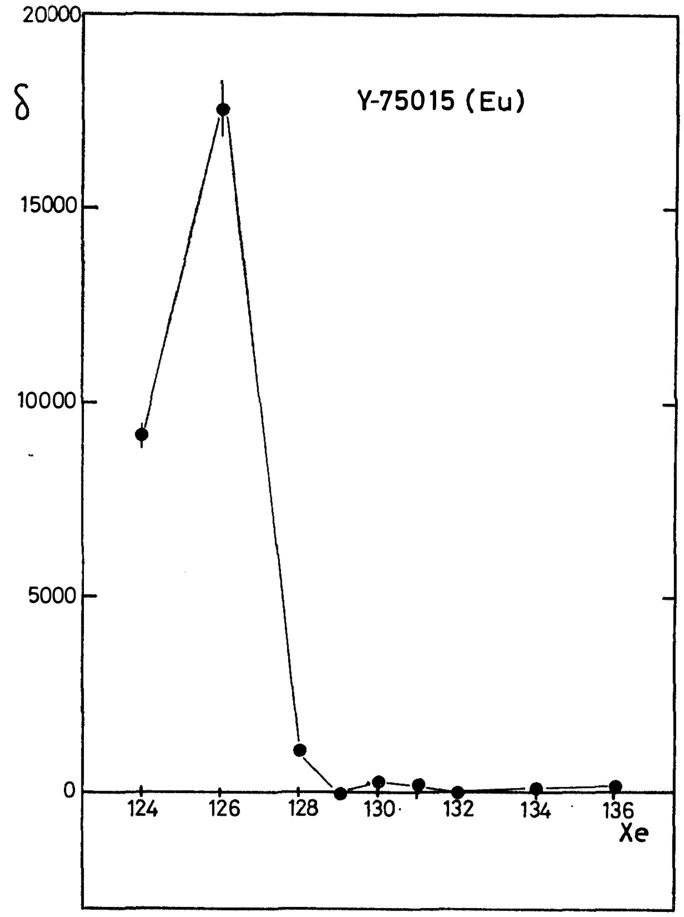

Fig. 4. The Xe isotopic composition for Y-75015 eucrite. δ_{132} *(atm) is defined in Fig. 3. Large excesses in light Xe isotopes are due to cosmogenic Xe. Fissiogenic* ^{134}Xe *and* ^{136}Xe *are seen as positive* δ*-values.*

where subscript "atm" means atmospheric. AVCC-Xe (Eugster *et al.*, 1967) is also shown for comparison. The isotopic compositions of Xe in Y-74073 (H5) and Y-75289 (L5) chondrites are identical with that of AVCC-Xe within experimental errors. Xe in other chondrites is a mixture between cosmogenic and AVCC-Xe. Excess ^{129}Xe from extinct ^{129}I was observed in all chondrites studied.

Figure 4 shows an isotopic composition of Xe in Y-75015 eucrite. Large enrichment in light Xe isotopes is evidently due to cosmogenic Xe. Concentration of observed cosmogenic ^{126}Xe is 5.4×10^{-12} cm^3 STP/g. The concentration is consistent with cosmogenic ^{126}Xe of 4.5×10^{-12} cm^3 STP/g calculated with the production rate deduced by Marti *et al.* (1966) using Ba and REE concentrations of 43 and 31 ppm, respectively, and the exposure age of 55 Ma listed in Table 3. The Ba and REE concentrations used in the calculation were assumed to be similar to those for other Ca-rich achondrites (Eberhardt and Geiss, 1966).

Positive excesses of ^{134}Xe and ^{136}Xe in Fig. 4 and the high concentration of radiogenic ^{4}He in this eucrite indicate the existence of fissiogenic component. In calculation of the isotopic composition of fission Xe, the following were assumed; 1) all ^{126}Xe

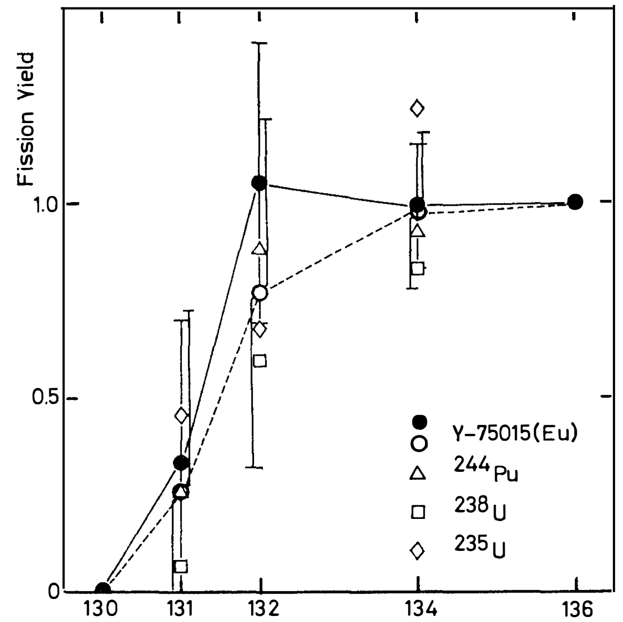

Fig. 5. Mass spectrum of fissiogenic Xe in Y-75015 eucrite normarized to ^{136}Xe. Closed and open circles correspond to spectra calculated on assumption that trapped Xe is AVCC and atmospheric, respectively.

was cosmogenic, 2) ^{130}Xe is not produced by fission, 3) mass spectrum of spallation Xe is the same as that in Stannern eucrite (Marti *et al.*, 1966) and 4) trapped Xe is similar to AVCC-Xe or to atmospheric Xe. Fissiogenic ^{136}Xe is calculated to be 1.0 and 0.8 in unit of 10^{-11}cm^{3}STP/g on the assumption that trapped component is AVCC-Xe and atmospheric Xe, respectively. Mass spectra of fissiogenic Xe normalized to ^{136}Xe are illustrated in Fig. 5. Mass spectra of fission Xe from ^{244}Pu, ^{238}U and ^{235}U are also plotted for comparison. ^{244}Pu is the most promising, though the large error bars in the present result make it obscure to identify the parent nuclide.

4.4. Paired meteorites

Five groups of meteorites with similar rare gas compositions are listed in Table 5.

Y-74650 and Y-74454 are both L6 chondrites and are in very good agreement with respect to both rare gas composition and ^{53}Mn activity which is an unsaturated level. These two chondrites seem to be paired. Though Y-74663 (L6) shows a similar rare gas composition, the ^{53}Mn content is lower than that for other members of the group. The ^{3}He/^{4}He ratio also differs from the ratio for the group by a factor of two. This meteorite may not be included in the group.

According to Takaoka *et al.* (1981), Y-75097, -75102, -75108 and -75271 are paired. The paired meteorites are classified as L6 chondrites and are characterized by low contents of radiogenic ^{4}He and ^{40}Ar, which indicates the thermal history of shock metamorphism caused by collision about 0.5 Ga ago (Heymann, 1967). These chondrites are regarded to be members of a group consisting of 150 fragments from

Table 5. Meteorites with similar rare gas compositions.

Meteorite	^{3}He/^{4}He	^{21}Ne1)	^{36}Ar1)	^{40}Ar/^{36}Ar	^{53}Mn2)	Remarks
Y-74650 (L6)	0.014	3.6	0.62	6700	380	This work
Y-74454 (L6)	0.012	3.2	0.98	8490	387	T1981
Y-74165 (L4)3)	0.125	10	2.4	108	311	This work
Y-74190 (L6)		12			441	K1979
Y-75097 (L6)	0.123	9.4	1.8	122	424	T1981
Y-75102 (L6)	0.158	9.4	1.8	126	452	T1981
Y-75108 (L6)	0.102	9.8	2.9	84	407	T1981
Y-75271 (L6)	0.115	10	2.3	104	424	T1981
ALH-77214 (L3)	0.0041	0.90	92	34	152	This work
ALH-77015 (L3)	0.0036	0.96	87	43	162	T1981
ALH-77167 (L3)	0.0038	0.81	96	34	137	T1981
ALH-77260 (L3)	0.0039	0.55	90	34	130	T1981
Y-74072 (H5)	0.0042	1.6	2.0	1800		T1982
Y-74073 (H5)	0.024	1.3	0.68	3500	253	This work
Y-74074 (H5)	0.0043	1.8	0.76	4200		T1982
Y-74104 (H5)	0.0035	1.7	1.7	1300		T1982
Y-74106 (H5)					340	
Y-74107 (H5)	0.012	2.3	0.78	3000	370	This work
Y-74108 (H5)					360	
Y-74011 (Di)	0.143	23	0.87	53	525	This work
Y-692 (Di)	0.107	19	1.12	89	442	S1973
Y-74013 (Di)	0.130	16	0.90	36	401	N1979
Y-74097 (Di)	0.151	17	0.83	32	421	N1979

1) Concentration unit in 10^{-8} cm^{3}STP/g.

2) ^{53}Mn contents were from HONDA (1981). Unit in dpm/kgFe+Ni/3.

3) We can not conclude at present whether Y-74165 is included in the group or not. Though rare gas composition is in agreement with those of the group, ^{53}Mn content is about three-fourth of the activity level of the group.

References; S1973: SHIMA *et al.* (1973), K1979: KAMAGUCHI and OKANO (1979), N1979: NAGAO and TAKAOKA (1979), T1981: TAKAOKA *et al.* (1981), T1982: TAKAOKA (1982).

Y-75108 to -75257 (YANAI, 1979). The total weight is estimated to be more than 20 kg and they are inferred to have fallen as a shower (HONDA, 1981). Y-74190 was added to the group by HONDA (1981) because of the similar ^{53}Mn and cosmogenic ^{21}Ne contents.

Both cosmogenic and radiogenic rare gas contents of Y-74165 agree with those of the group. Though Y-74165 is classified as L4 chondrite (MASON and YANAI, 1983) whcih differs from the petrologic type of this group, the chondrite is well equilibrated according to the low concentration of trapped Xe measured in this work. The ^{53}Mn content, however, is about three-fourth of the activity level of the group. The difference in ^{53}Mn contents may be due to a depth effect in a large preatmospheric object of this group or due to a long terrestrial age compared with others. We reserve at present a possibility that this meteorite is included in the group.

A group of six ALH-77 L3 chondrites is characterized by very high concentrations of trapped gases, and the unsaturated low ^{53}Mn and ^{26}Al contents (HONDA, 1981). Four meteorites, for which rare gas data are available, are listed in Table 5. The similar rare gas compositions among them confirm the grouping.

MASON and YANAI (1983) have reported that Y-74070–Y-74075 and Y-74104–Y-74108 H chondrites are paired. Meteorites in this group are also listed in Table 5. The unsaturared low ^{53}Mn contents are accounted for by the short exposure ages of about 4 Ma. A variation of ^{53}Mn contents between Y-74073 and Y-74107 meteorites is positively correlated with that of cosmogenic ^{21}Ne contents. The variation seems to be caused by a shielding effect because the ^{22}Ne/^{21}Ne ratios, 1.205 and 1.082 for Y-74073 and Y-74107 respectively, are consistent with a depth effect. Y-74073 meteorite might be irradiated in a shallow site or in a small size of meteoroid. Though cosmogenic ^{21}Ne contents support this grouping, the ^{3}He/^{4}He and ^{40}Ar/^{36}Ar ratios show large variations by more than a factor of three. The disagreement in rare gas composition for this group is a clear contrast to the good agreements for the groups consisting of L chondrites noted above. The variation of the ^{40}Ar/^{36}Ar ratios is due mainly to the variation of trapped ^{36}Ar contents. Although the reason is not clear at present, it may be due to a sample heterogeneity caused by weathering with respect to trapped component.

As discussed previously, H-group chondrites make a cluster of exposure age at about 4 Ma. At that time breakup of a parent body might have released H-group meteorites into space. Since 4 Ma is not sufficient for ^{53}Mn to reach a saturation level, many H chondrites are unsaturated in ^{53}Mn contents and low in cosmogenic ^{21}Ne contents. This makes it difficult to distinguish the paired H-group meteorites from other groups or single fall with a short exposure age. In the Y-74 meteorite collection there are many H chondrites with a low ^{53}Mn activity level from 200 to 400 dpm/kgFe, of which eleven chondrites including the five samples listed in Table 5 show similar cosmogenic ^{21}Ne concentrations of about 2×10^{-8} cm^3 STP/g. Other rare gas compositions for these meteorites do not show clear differences among them. The rare gas compositions and ^{53}Mn contents are not enough to identify pairing of such meteorites.

Four diogenites are listed in Table 5. They seem to be fragments of a diogenite shower (HONDA, 1981). HONDA (1981) included Y-692 diogenite into a member of the group of Y-74 diogenites. Although their cosmic-ray exposure ages are different from each other as discussed in Section 4.1, cosmogenic ^{21}Ne for four diogenites in Table 5 are correlated with ^{53}Mn contents. The ^{53}Mn contents were summarized by HONDA (1981). The positive correlation between cosmogenic ^{21}Ne and ^{53}Mn contents indicates that the discordance among the exposure ages is due to different degree of shielding effect. If this is the case, however, the fact that the ^{22}Ne/^{21}Ne ratios for these diogenites show no variation expected from a shielding effect as shown in Fig. 2 is left unexplained.

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