Antarct. Meteorite Res., **12**, 81–93, 1999

NOBLE GASES AND K-Ar AGES OF FIVE RUMURUTI CHONDRITES YAMATO(Y)-75302, Y-791827, Y-793575, Y-82002, AND ASUKA-881988

Keisuke NAGAO[1], Ryuji OKAZAKI[1,2], Shinobu SAWADA[3] and Noboru NAKAMURA[3,4]

[1] *Laboratory for Earthquake Chemistry, Graduate School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033*

[2] *Department of Earth Science, Faculty of Science, Kyushu University, 33, Hakozaki, Fukuoka 812-8581*

[3] *Graduate School of Science and Technology, Kobe University, Nada, Kobe 657-8501*

[4] *Department of Earth and Planetary Sciences, Faculty of Science, Kobe University, Nada, Kobe 657-8501*

Abstract: Noble gases and K concentrations have been determined for aliquot samples prepared from the five Antarctic R-chondrites Yamato (Y)-75302, Y-791827, Y-793575, Y-82002, and Asuka (A)-881988. K-Ar ages of about 4.2 Ga were obtained for Y-75302, Y-791827, Y-793575 and A-881988, while Y-82002 showed a slightly younger age of 3.9 Ga. The Y-75302, Y-791827 and Y-82002 are enriched in solar light noble gases. Four meteorites Y-75302, Y-791827, Y-82002 and A-881988 have cosmic-ray exposure ages of about 20 Ma, while the age of Y-793575 is about 7 Ma. Based on the noble gas compositions and K-Ar ages, Y-75302 and Y-791827 are probably paired and Y-82002 may belong to this pair. Relatively high and variable ^{129}Xe/^{132}Xe ratios between 2–3.7 as well as enrichments of heavier Xe isotopes were observed in all R-chondrites.

1. Introduction

Rumuruti chondrites (R-chondrites) comprises of more than 10 specimens (KALLEMEYN *et al.*, 1996) and the number is increasing by the discovery in hot deserts. A summary is given in Table 1. R-chondrites are characterized by a high degree of oxidation and ^{17}O/^{16}O ratios which are distinctly higher than ordinary chondrites (*e.g.*, KALLEMEYN *et al.*, 1996). Full noble gas data including Kr and Xe isotopes for all R-chondrites are not available; only a part of data has been reported. According to the reported noble gas data, most R-chondrites are regolith breccia and about half of them contain high concentrations of light noble gases of solar origin. Cosmic-ray exposure ages measured for these meteorites are in a wide range from 2.6 Ma (Hammadah al Hamra: WEBER and SCHULTZ, 1998a) to 50 Ma (Hughes 030: BISCHOFF *et al.*, 1998). The ^{129}Xe/^{132}Xe ratios are generally high and variable (1.3–3.3: WEBER and SCHULTZ, 1998a) among R-chondrites. K-Ar ages reported for Acfer 217 and Carlisle Lakes are 3.9 and 3.4 Ga, respectively (BISCHOFF *et al.*, 1994).

Table 1. List of R-chondrites.

R-chondrites	Weight (g)	Matrix	Shock	Weathering	Country/Place	Year	Fall/Find	Ref.
Acfer 217	174	R3.8	S2	W5-6	Sahara desert, Algeria	1991	Find	b) c) e)
ALH85151	13.9	R3.6	S2	W2-3	Allan Hills, Antarctica	1985	Find	e)
A-881988	171.9				Asuka, Antarctica	1988	Find	f)
Carlisle Lakes	49.5	R3.8	S3	W3-4	Australia	1977	Find	e)
DaG 013	205	R3.5	S1	W4	Dar al Gani, Libya	1995	Find	e)
HaH 119	352	R4	S3	W4	Hammadah al Hamra, Libya	1995	Find	e)
Hughes 030	~100	R3.6			South Australia	1991	Find	d)
PCA 91002 #	210.2	R3.8	S3-4	W2-3	Pecora Escarpment, Antarctica	1991	Find	e) g)
PCA 91241 #	75	R3.8	S3-4	W2-3	Pecora Escarpment, Antarctica	1991	Find	e) g)
PRE 95410 $	42				Mt. Prestrud, Antarctica	1995	Find	e)
PRE 95411 $	44				Mt. Prestrud, Antarctica	1995	Find	e)
PRE 95412 $	15				Mt. Prestrud, Antarctica	1995	Find	e)
Rumuruti	67	R3.8	S2	W0-1	Rift Valley, Kenya	1934	Fall	a) e) h)
Y-75302	3.62	R3.8	S4	W3-4	Yamato, Antarctica	1975	Find	e) f)
Y-791827	9.02				Yamato, Antarctica	1979	Find	f)
Y-793575	25	R3.8	S2	W3-4	Yamato, Antarctica	1979	Find	e) f)
Y-82002	6.99	R3.8	S2	W4-5	Yamato, Antarctica	1982	Find	e) f)

paired, $ paired.

a) SCHULZE and OTTO (1993); b) WLOTZKA (1992); c) BISCHOFF *et al.* (1994) ; d) GROSSMAN (1998) ; e) WEBER and SCHULTZ (1998a); f) YANAI and KOJIMA (1995); g) RUBIN and KALLEMEYN (1994); h) SCHULZE *et al.* (1994).

As a part of a consortium study on R-group chondrites (KOJIMA *et al.*, 1998), five R-group chondrite specimens (sample weights: 0.22–3.0 g) were allocated to us for analyses of trace elements, Rb-Sr isotopes and noble gases. We have measured noble gas isotopic compositions of aliquot samples prepared for K analysis to determine K-Ar ages. We present noble gas abundances, cosmic-ray exposure ages, and K-Ar ages for these specimens and discuss the relationship with other known R-chondrites. Some noble gas data for Yamato (Y)-793575 have been reported by WEBER and SCHULTZ (1996). Preliminary results of this work have been published in abstracts (KOJIMA *et al.*, 1998; NAGAO *et al.*, 1998; OZAKI *et al.*, 1998).

2. Experimental Procedures

Sample preparations and K analyses were carried out at Kobe University. All samples were first examined with binocular microscopes. The samples appeared fresh and no obvious contaminants nor weathering products were observed. They were subjected to our normal cleaning procedures: two times 0.1 NHCl wash, repeated rinse with distilled water and acetone wash. Several small chips (weighing about 150 mg) were collected, crushed and ground to powder with an agate mortar. The coarse-grained ($100<\phi<260\,\mu$m) fractions (weighing about 100 mg) were prepared as "bulk samples" for analyses of trace elements including K and noble gases to avoid terrestrial noble gas contamination. Fine-grained ($\phi<100\,\mu$m) fractions (about 50 mg) were set aside for later use. About two-thirds (63 mg) of the coarse-grained fraction of each R-chondrite was used for noble gas analyses and one-third aliquot (about 20 mg) was analyzed for trace elements including K.

The abundances of K in the coarse-grained "bulk samples" were determined by Direct-Loading Isotope Dilution Mass Spectrometry (DL-IDMS) (NAKAMURA *et al.*, 1989). The procedural blanks of K were about 450 pg which is negligibly small. The accuracy of K concentrations are considered to be 1–3%.

Noble gas analyses were performed on a modified-VG5400 mass spectrometer at the Institute for Study of the Earth's Interior, Okayama University. Samples weighing 61–66 mg (Table 2) were loaded in a glass sample holder connected to an extraction furnace and purification system. Then, the samples were heated at 150°C in ultra-high vacuum for about 24 hours to remove atmospheric noble gas contamination. Noble gases were extracted by melting the samples at 1800°C in a molybdenum crucible, purified with Ti-Zr getters as well as separated by a cryogenic-trap into four fractions He-Ne, Ar, Kr and Xe. He, Ne and Ar were measured by a Daly-multiplier collector, while Kr and Xe by an ion counting collector. Sensitivities and mass discrimination effects for each noble gas were calibrated by measuring atmospheric noble gases. For the correction of mass discrimination effects on ^{3}He/^{4}He ratio, a laboratory He standard with $^{3}\mathrm{He}/^{4}\mathrm{He}=1.71\times10^{-4}$ was used. Typical blank values were $^{4}\mathrm{He}=5\times10^{-10}$, $^{20}\mathrm{Ne}=2.6\times10^{-12}$, $^{36}\mathrm{Ar}=2.5\times10^{-12}$, $^{40}\mathrm{Ar}=7.5\times10^{-10}$, $^{84}\mathrm{Kr}=5\times10^{-14}$ and $^{132}\mathrm{Xe}=5\times10^{-14}$ cm^{3} STP, and were almost negligible. Statistical 1σ errors are given for the isotopic ratios in Tables 2 and 3. Uncertainties for the gas concentrations are estimated to be about 10%. Cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar were calculated with the following assumptions (*e.g.*, BISCHOFF *et al.*, 1994) for trapped (t) and cosmogenic (c) components:

$(^3He/^4He)_t = 3.3 \times 10^{-4}$, $(^{21}Ne/^{22}Ne)_t = 0.030$, $(^{21}Ne/^{22}Ne)_c = 0.90$, $(^{38}Ar/^{36}Ar)_t = 0.188$ and $(^{38}Ar/^{36}Ar)_c = 1.55$.

3. Results and Discussion

Isotopic ratios and concentrations of He, Ne and Ar are presented in Table 2, those for Kr and Xe in Table 3. He, Ne and Ar data for Y-793575 reported by WEBER and SCHULTZ (1996) are in good agreement with our data.

3.1. Solar noble gases

Concentrations of trapped noble gases are presented in Table 4. The trapped ^4He and ^{20}Ne concentrations in Y-793575 and Asuka (A)-881988 are not given in Table 4, because ^4He concentrations of $(1.2–1.3) \times 10^{-5}$ cm^3 STP/g corrected for cosmogenic ^4He can be produced from U (*ca.* 10 ppb) and Th decay during the K-Ar age of about 4 Ga (Table 5) and also the Ne isotopic compositions suggest only a cosmogenic origin. Measured concentrations of ^{84}Kr and ^{132}Xe are assumed to be of trapped. Assuming elemental composition of solar gas, solar Kr and Xe concentrations in the meteorites with abundant solar He and Ne are estimated as about 20% and < 1% of observed ones, respectively.

Solar-type He and Ne is dominant in three meteorites Y-75302, Y-791827 and Y-82002 as indicated by the high concentrations of ^4He and Ne isotopic ratios. But they are still lower than reported concentrations for other gas-rich R-chondrites ALHA 85151 (WEBER and SCHULTZ, 1998a) and PRE 95411/412 (WEBER and SCHULTZ, 1998b). However, the lower concentrations of light noble gases could be due to a coarse-grained specimen as mentioned before. Solar gases are implanted into surface layer of grains and might be enriched in finer grains. Noble gas elemental ratios, normalized to ^{36}Ar, are presented in Fig. 1 with those for solar and planetary noble gas compositions for comparison. Light noble gas compositions in Y-75302, Y-791827 and Y-82002 are similar to solar gases, indicating solar gas implantation for these meteorites on their parent body. Heavier noble gases in Y-793575 and A-881988 are plotted along the planetary composition. Solar noble gas implantation is negligible in the two meteorites.

Heavier noble gas elemental ratios, $^{36}Ar/^{132}Xe$ and $^{84}Kr/^{132}Xe$, are plotted in Fig. 2. Y-75302, Y-791827 and Y-82002 plot above the area representing chondritic composition, showing enrichment in trapped solar Ar. On the other hand, Y-793575 and A-881988 without solar gases plot in the area of chondritic composition. Generally, high measured $^{84}Kr/^{132}Xe$ ratio in chondritic meteorites indicates terrestrial weathering because the terrestrial atmospheric $^{84}Kr/^{132}Xe$ ratio (=28) is higher than the chondritic composition (*e.g.*, SCHERER *et al.*, 1994; BISCHOFF *et al.*, 1994). The $^{84}Kr/^{132}Xe$ ratios for five meteorites studied in this work are 0.875–1.63, which are in the range of chondritic composition, may indicate negligible weathering effect.

Ne isotopic ratios are plotted in Fig. 3 with reported data for R-chondrites (BISCHOFF *et al.*, 1994; WEBER and SCHULTZ, 1996, 1998b). Neon isotopic compositions of Y-75302, Y-791827 and Y-82002 are a mixture of cosmic-ray produced Ne and trapped Ne of solar origin. Trapped $^{20}Ne/^{22}Ne$ ratio estimated by extrapolation of a line passing through the data points for these samples is 11.7 ± 0.3 at $^{21}Ne/^{22}Ne = 0.030$.

Table 2. Isotopic ratios and concentrations of He, Ne and Ar.

Meteorite	Weight (mg)	^{3}He	^{4}He	^{3}He/^{4}He	^{20}Ne	^{21}Ne	^{22}Ne	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{36}Ar	^{38}Ar	^{40}Ar	^{38}Ar/^{36}Ar	^{40}Ar/^{36}Ar
Y-75302	66	496	520000	0.000954±.000014	1267	66.9	178	7.116 ±.021	0.3761±.0022	93.7	26.1	56200	0.2781±.0005	599.8±1.5
Y-791827	63	457	399000	0.001144±.000006	1260	73.7	184	6.865 ±.010	0.4005±.0010	84.2	24.2	43700	0.2872±.0012	519.4±1.5
Y-793575	61	103	12100	0.008509±.000067	16.7	16.6	20.5	0.8131±.0020	0.8089±.0013	13.7	4.58	46700	0.3341±.0022	3412 ±26
Y-82002	64	436	343000	0.001271±.000009	656	53.0	112	5.856 ±.011	0.4732±.0011	58.1	18.4	45800	0.3160±.0011	788.6±2.2
A-881988	65	272	13900	0.019663±.000094	45.5	46.9	57.4	0.7935±.0015	0.8178±.0012	29.4	10.5	59300	0.3562±.0011	2018.6±6.8

Concentrations of He, Ne and Ar in 10^{-9} cm^3 STP/g.

Table 3. Isotopic ratios and concentrations of Kr and Xe.

Meteorite	^{84}Kr	^{78}Kr	^{80}Kr	^{82}Kr	^{83}Kr	^{86}Kr	^{132}Xe	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
		^{84}Kr=100						^{132}Xe=100							
Y-75302	264	0.823 ±.015	4.893 ±.031	21.22 ±.14	21.46 ±.08	31.09 ±.14	272	0.522 ±.013	0.500 ±.009	8.32 ±.08	206.5 ±0.6	16.23 ±.07	81.75 ±.24	38.41 ±.08	32.42 ±.14
Y-791827	222	0.853 ±.014	4.937 ±.037	21.22 ±.12	21.52 ±.07	31.09 ±.19	217	0.523 ±.006	0.510 ±.014	8.37 ±.07	224.7 ±1.1	16.29 ±.07	81.85 ±.19	39.03 ±.16	33.05 ±.16
Y-793575	168	0.698 ±.014	5.388 ±.056	20.93 ±.15	20.61 ±.07	31.23 ±.08	192	0.491 ±.014	0.448 ±.007	8.35 ±.06	374.2 ±2.2	16.17 ±.08	81.93 ±.17	39.28 ±.19	33.43 ±.22
Y-82002	231	0.825 ±.012	4.732 ±.045	21.14 ±.07	21.31 ±.14	30.99 ±.17	218	0.489 ±.009	0.480 ±.007	7.95 ±.06	196.7 ±0.8	15.85 ±.05	80.88 ±.26	39.04 ±.17	33.31 ±.18
A-881988	495	0.681 ±.015	4.743 ±.032	20.62 ±.06	20.44 ±.04	30.59 ±.08	303	0.440 ±.021	0.409 ±.015	7.66 ±.05	199.1 ±0.6	15.59 ±.06	79.98 ±.15	38.77 ±.16	32.88 ±.09

Concentrations of ^{84}Kr and ^{132}Xe in 10^{-12} cm^3 STP/g.

Table 4. Concentrations of trapped noble gases.

Meteorite	^{4}He	^{20}Ne	^{36}Ar	^{84}Kr	^{132}Xe	^{36}Ar/^{132}Xe	^{84}Kr/^{132}Xe
	10^{-9} cm^{3}STP/g			10^{-12} cm^{3}STP/g			
Y-75302	520000	1190	87.8	264	272	323	0.971
Y-791827	399000	1190	78.2	222	217	360	1.02
Y-793575	—	—	12.3	168	192	64.1	0.875
Y-82002	343000	605	52.8	231	218	242	1.06
A-881988	—	—	25.8	495	303	85.1	1.63

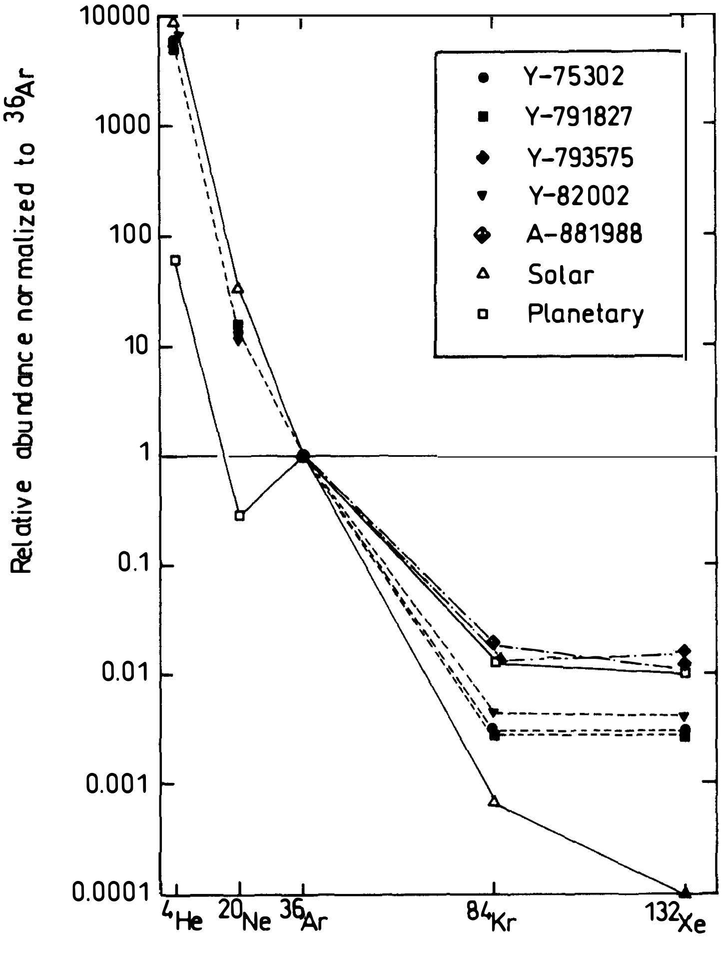

Fig. 1. Noble gas abundance ratios normalized to ^{36}Ar are plotted. Those of solar and planetary gases (e.g., OZIMA and PODOSEK, 1983) are also shown for comparison. ^{4}He and ^{20}Ne for Y-793575 and A-881988 are not plotted, because they do not contain significant amounts of trapped ^{4}He and ^{20}Ne. Heavy noble gas abundance ratios for these meteorites agree well with the planetary ones. Y-75302, Y-791827 and Y-82002 with high concentrations of light noble gases show abundance ratios similar to that of solar gases. Heavy noble gases in the three meteorites are plotted between those of solar and planetary ones. Because measured Xe isotopic ratios (Fig. 5) do not indicate significant contribution of solar Xe (as well as Kr) to trapped Q-Xe, the lower abundance ratios of heavy noble gases for the three meteorites are probably due to addition of solar ^{36}Ar to primordial Ar.

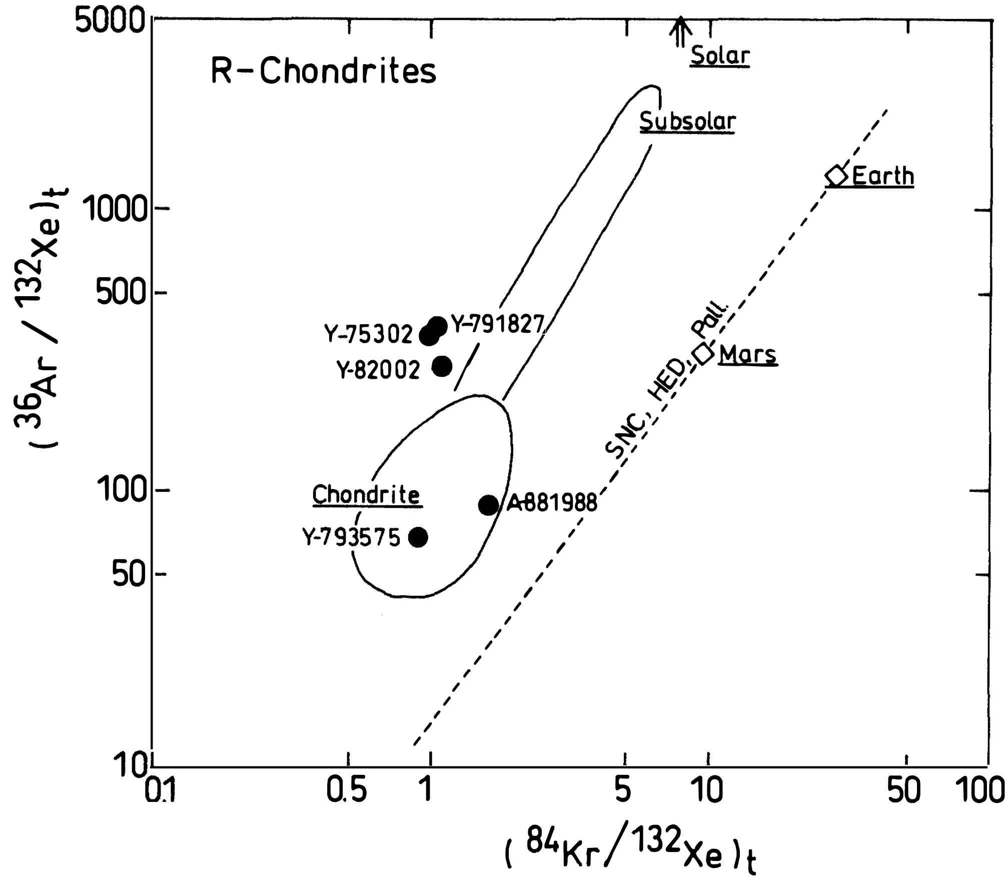

Fig. 2. Plot of $^{36}Ar/^{132}Xe$ versus $^{84}Kr/^{132}Xe$. Y-793575 and A-881988 without solar noble gases show chondritic composition. On the other hand, Y-75302, Y-791827 and Y-82002 with abundant light solar gases are plotted above the area for chondrites due to the enrichments in ^{36}Ar of solar origin. Atmospheric heavier gas contamination is not implied by the relatively low $^{84}Kr/^{132}Xe$ ratios (see text).

The $^{20}Ne/^{22}Ne$ is lower than the ratio of 13.0±0.2 determined for ALHA 85151 (WEBER and SCHULTZ, 1995). Mount Prestrud (PRE) 95410 and 95412 (WEBER and SCHULTZ, 1998b) show also higher $^{20}Ne/^{22}Ne$ ratios than our samples. Nevertheless, $^{20}Ne/^{22}Ne$ ratios of trapped Ne of solar gas origin in R-chondrites are between solar wind Ne and SEP Ne. Low energy particles such as solar wind Ne would have been partially lost and particles with higher energy such as SEP ($^{20}Ne/^{22}Ne$=11.2: BENKERT *et al.*, 1993) might have been retained preferentially. Another possible cause for our low $^{20}Ne/^{22}Ne$ ratio is that we measured coarser grained materials separated from crushed sample. This procedure might have reduced low energy solar component enriched in fine grained materials.

In contrast to these meteorites, Ne isotopic ratios for Y-793575 and A-881988 are plotted in the area for cosmogenic Ne, and do not show a signature of solar Ne as shown in Fig. 3. The Ne isotopic ratios of Y-793575 measured in this work are in very good agreement with those reported by WEBER and SCHULTZ (1996). This meteorite is light/dark-structured regolith breccia (KALLEMEYN *et al.*, 1996). Since meteorites with a

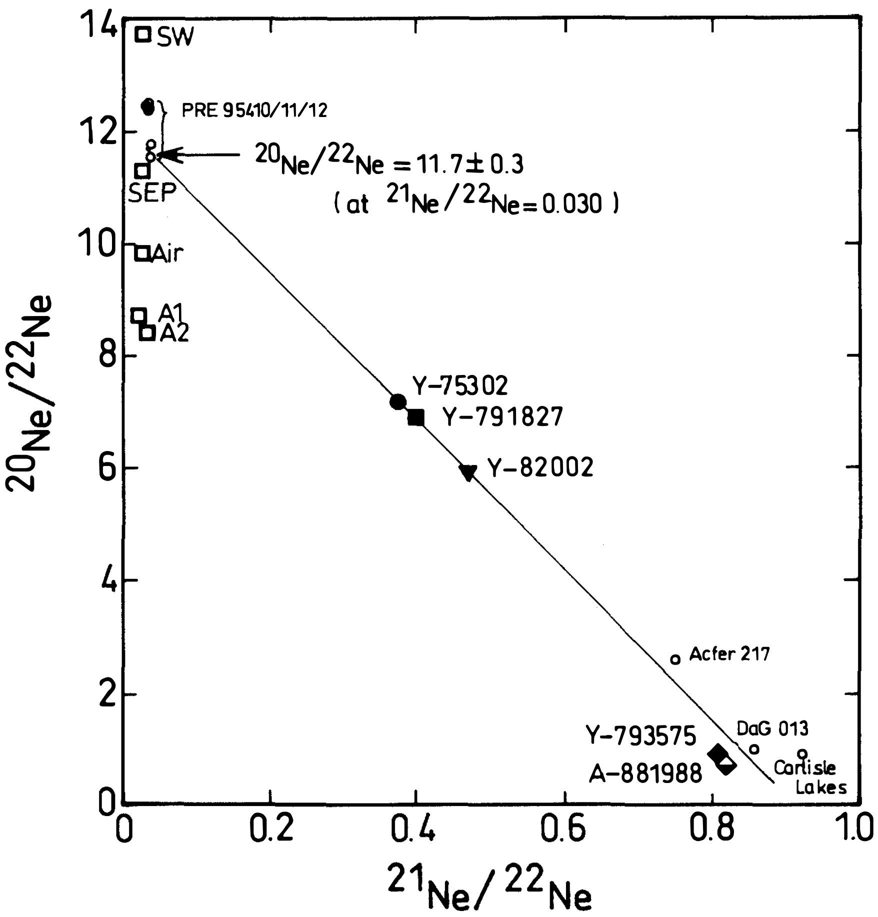

Fig. 3. Three isotope plot of Ne. Y-75302, Y-791827 and Y-82002 are plotted along a straight line, showing that Ne in these samples are a mixture of cosmogenic Ne and solar Ne. $^{20}Ne/^{22}Ne$ ratio of solar Ne in these meteorites is estimated as 11.7 ± 0.3 assuming $^{21}Ne/^{22}Ne=0.030$, which is close to SEP-Ne. Similar ratios are reported for PRE95411 (WEBER and SCHULTZ, 1998b). However, PRE95410/12 (WEBER and SCHULTZ, 1998b) and ALHA85151 (WEBER and SCHULTZ, 1995, 1998a) have higher $^{20}Ne/^{22}Ne$ ratios. The Ne isotopic composition of Y-793575 and A-881988 is cosmogenic. The high $^{22}Ne/^{21}Ne$ ratios suggest smaller preatmospheric bodies. Data source for other meteorites: Acfer 217 and Carlisle Lakes (BISCHOFF et al., 1994); DaG 013 (WEBER and SCHULTZ, 1996).

light/dark structure often contain implanted solar noble gases, reason of the absence of solar gases in this meteorite is not clear. High values of cosmogenic $^{22}Ne/^{21}Ne$ ratios, 1.22–1.23, suggest small preatmospheric masses for the two meteorites. This is consistent with the small recovered masses for these meteorites: 25 g and 171.9 g for Y-793575 and A-881988, respectively. In contrast to these meteorites, lower $^{22}Ne/^{21}Ne$ ratio for Carlisle Lake (BISCHOFF *et al.,* 1994) indicates larger preatmospheric size, radius$>$20 cm (WEBER and SCHULTZ, 1998a), though its recovered mass is as small as 49.5 g (*e.g.,* KALLEMEYN *et al.,* 1996).

3.2. *K-Ar ages*

Potassium and radiogenic ^{40}Ar concentrations, and calculated K-Ar ages are

Table 5. Potassium concentrations and K-Ar ages.

Meteorite	K (ppm)	^{40}Ar-rad. (10^{-9}cm^{3}STP/g)	K-Ar age (Ga)
Y-75302	878	56200	4.18 ± 0.16
Y-791827	695	43700	4.15 ± 0.16
Y-793575	738	46900	4.17 ± 0.16
Y-82002	869	45800	3.87 ± 0.16
A-881988	912	59400	4.21 ± 0.16

Decay constants of $\lambda_e=0.581\times10^{-10}$/y and $\lambda_\beta=4.962\times10^{-10}$/y, and atomic ratio of ^{40}K/K$=0.0001167$ (STEIGER and JÄGER, 1977) were used for the K-Ar age calculation.

Table 6. Concentrations of cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar, cosmogenic ^{22}Ne/^{21}Ne ratios and cosmic-ray exposure ages.

Meteorite	^{3}He	^{21}Ne	^{38}Ar	^{22}Ne/^{21}Ne	P_3	P_{21}	P_{38}	T_3	T_{21}	T_{38}	T_{average}
	(10^{-9}cm^{3}STP/g)				(10^{-9}cm^{3}STP/g·Ma)			(Ma)			
Y-75302	326	63.7	9.66	(1.11)	16.0	3.01	0.458	20.4	21.2	21.1	20.9 ± 0.4
Y-791827	325	70.5	9.55	(1.11)	16.0	3.01	0.458	20.3	23.4	20.9	21.5 ± 1.6
Y-793575	103	16.5	2.30	1.236	15.4	1.92	0.369	6.7	8.6	6.2	7.2 ± 1.3
											7.7 ± 0.5#
Y-82002	323	51.3	8.51	(1.11)	16.0	3.01	0.458	20.2	17.0	18.6	18.6 ± 1.6
A-881988	272	46.8	5.64	1.223	15.5	2.00	0.379	17.5	23.4	14.9	18.6 ± 4.4

WEBER and SCHULTZ (1996).

presented in Table 5. The K concentrations are in the range of ordinary chondrites (*e.g.*, KALLEMEYN, 1989). ^{40}Ar is assumed to be totally radiogenic with a 10% uncertainty. In the calculation of K-Ar ages, 10% and 2% errors were considered for radiogenic ^{40}Ar and K concentrations, respectively. Four meteorites, Y-75302, Y-79187, Y-793575 and A-881988, have an almost identical age of 4.2 Ga. The exception is Y-82002 which has a slightly younger age of 3.9 Ga. These data are compatible to the previously reported K-Ar ages for other R-chondrites reported; 3.9 and 3.4 Ga for Acfer 217 and Carlisle Lakes, respectively (BISCHOFF *et al.*, 1994).

3.3. *Cosmic-ray exposure ages*

Concentrations of cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar, cosmogenic ^{22}Ne/^{21}Ne ratios, production rates, and cosmic-ray exposure ages are summarized in Table 6. Because the (^{22}Ne/^{21}Ne)$_c$ ratios for Y-75302, Y-791827 and Y-82002 are not determined due to the high concentrations of solar Ne, an average value of 1.11 for chondrites is adopted for these samples. The assumption would be reasonable because the calculated exposure ages T_{21} are in good agreement with the ages based on ^{3}He$_c$ and ^{38}Ar$_c$. Production rates of ^{3}He, ^{21}Ne and ^{38}Ar are calculated by the formula presented in EUGSTER (1988) with target element compositions for R-chondrites reported by PALME *et al.* (1996). Average of T_3, T_{21} and T_{38} exposure ages for each meteorite is adopted in the following discussion. The age of 7.2 ± 1.3 Ma for Y-793575 agrees with the age of 7.7 ± 0.5 Ma

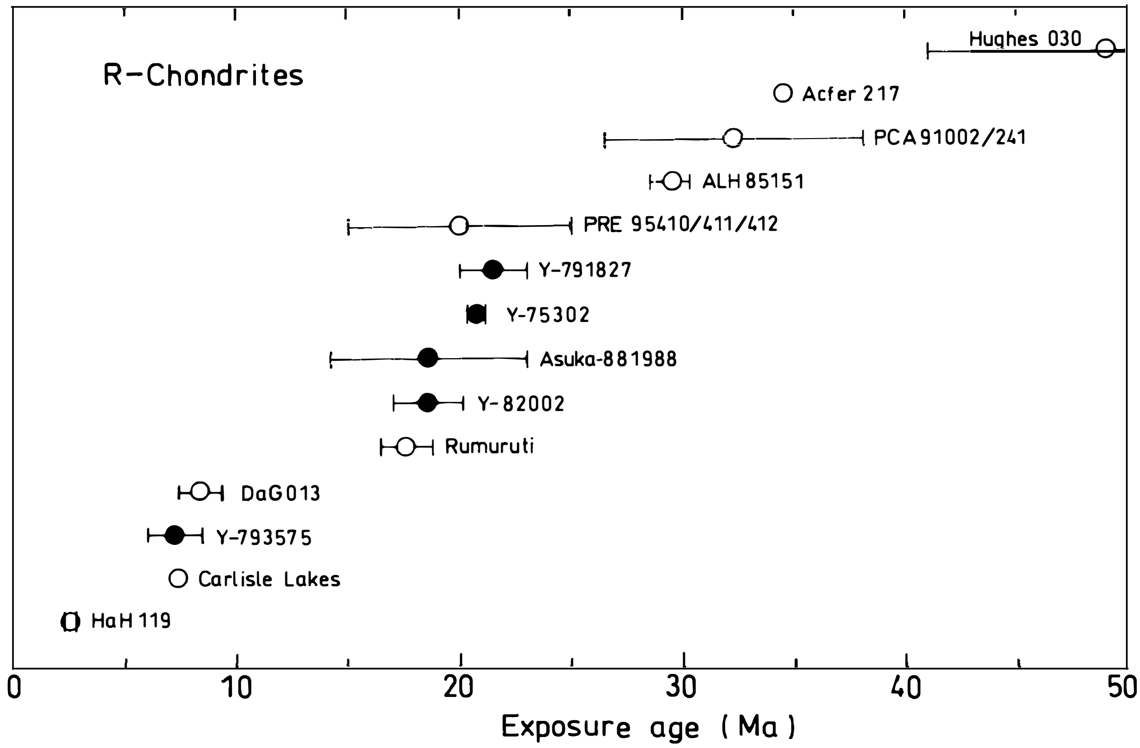

Fig. 4. Cosmic-ray exposure ages for R-chondrites. The ages obtained in this work and the ages reported for PRE 95410/411/412 (Weber and Schultz, 1998b) and Hughes 030 (Bischoff et al., 1998) are added to Fig. 1 of Weber and Schultz (1998a). The exposure ages for Y-793575 obtained in this work agree well with that by Weber and Schultz (1996).

reported by WEBER and SCHULTZ (1996). In Fig. 4 we add our new data to the figure showing exposure age distribution summarized by WEBER and SCHULTZ (1998a). The exposure age of Y-793575 is similar to those of DaG 013 and Carlisle Lakes. The exposure ages of Y-75302, Y-791827, Y-82002 and A-881988 are around 20 Ma, and agree with those of Rumuruti and PRE-95410/411/412 (PRE data are from WEBER and SCHULTZ, 1998b).

Figure 4 implies that exposure ages of R-chondrites vary between 3 Ma and 50 Ma: 3 Ma - HaH 119; 7 Ma - Carlisle Lakes, Y-793575 and DaG 013; 20 Ma - Rumuruti, Y-75302, Y-791827, Y-82002, A-881988 and PRE 95410/411/412; 33 Ma - ALHA 85151, PCA 91002/241 and Acfer 217; 50 Ma - Hughes 030 (WEBER and SCHULTZ, 1998a; BISCHOFF *et al.*, 1998).

3.4. *Pairing*

KALLEMEYN *et al.* (1996) discussed paring of three Yamato R-chondrites Y-75302, Y-82002 and Y-793575 based on mineralogical observations, and concluded that Y-793575 does not appear to be paired with either Y-75302 or Y-82002. They also tentatively concluded that Y-75302 and Y-82002 are not paired because of their different shock stage. Our noble gas data support the former conclusion, because Y-793575 does not contain solar noble gases and its cosmic-ray exposure age of about 7 Ma which are clearly different from those of Y-75302 and Y-82002 (Tables 2 and 6).

Based on our noble gas data and K-Ar ages, Y-75302 and Y-791827 are probably paired. Noble gas compositions and exposure age of Y-82002 are very similar to those of Y-75302 and Y-791827, which may suggest that Y-82002 belongs to the above mentioned pair of Y-75302 and Y-791827. However, this pairing is still ambiguous because Y-82002 shows a slightly shorter exposure age (Table 6) and a younger K-Ar age (Table 5) compared to other two Yamato meteorites. Concentrations of solar noble gases in Y-82002 are also slightly lower than those in the two Yamato meteorites. Because of their regolith breccia structure, heterogeneous noble gas distributions might be a cause for the slight disagreements.

A-881988 can be excluded from the paring with the four Yamato R-chondrites because 1) both A-881988 and Y-793575 have no solar gases but the exposure age is different with each other, 2) the exposure ages for A-881988, Y-75302, Y-791827 and Y-82002 are similar but the three Yamato meteorites are enriched in solar gases, and 3) long distance between the sampling sites for Asuka and Yamato.

3.5. Xe isotopes

One significant aspect characterizing R-chondrites compared to the case of ordinary chondrites is a variable and high $^{129}Xe/^{132}Xe$ ratio unrelated to concentrations of

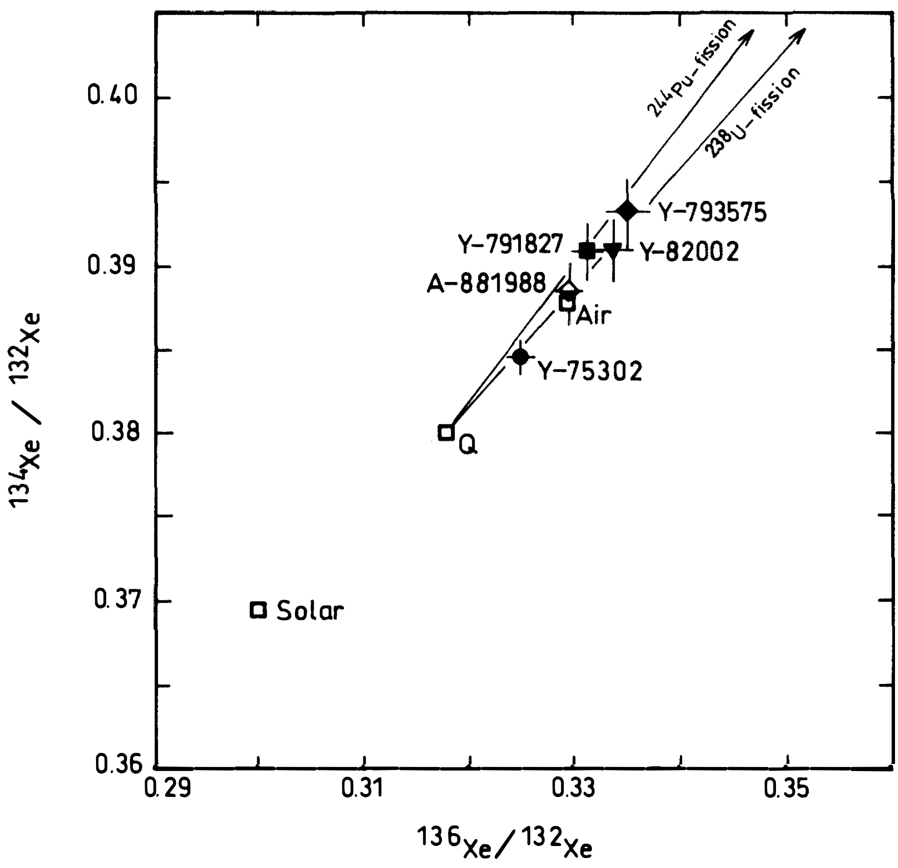

Fig. 5. A plot of $^{134}Xe/^{132}Xe$ versus $^{136}Xe/^{132}Xe$. Data points would be explained by addition of fissiogenic Xe from ^{238}U or ^{244}Pu to Q-Xe (WIELER et al., 1992).

trapped Xe (*e.g.*, WEBER and SCHULTZ, 1998a). Our $^{129}Xe/^{132}Xe$ data for five Antarctic R-chondrites are 1.97 to 3.74. Although the excess ^{129}Xe would have been derived from in situ decay of extinct ^{129}I, iodine concentration data for R-chondrites are still unavailable.

Light isotopes are basically resemble Q-Xe with a small contribution of cosmogenic ^{124}Xe and ^{126}Xe. A-881988 is clearly affected by a small contribution of atmospheric Xe as shown by the lower $^{124}Xe/^{132}Xe$ and $^{126}Xe/^{132}Xe$ ratios than Q-Xe. The plot of $^{134}Xe/^{132}Xe$ *versus* $^{136}Xe/^{132}Xe$ (Fig. 5) indicates excesses in heavier Xe isotopes compared with Q or solar Xe, which is probably due to fission products from ^{244}Pu or ^{238}U. Because of the experimental uncertainty of data, however, we can not resolve the fission products from these two nuclides added to the Q-Xe composition. Additional experiments are required to clarify the heavy noble gas isotopic compositions trapped in this interesting new chondrite group.

Acknowledgments

Authors wish to thank the NIPR for providing R-group chondrites. Constructive comments by reviewers, Drs. L. SCHULTZ and anonymous, were greatly appreciated.

References

BENKERT, J.-P., BAUR, H., SIGNER, P. and WIELER, R. (1993): He, Ne, and Ar from the solar wind and solar energetic particles in lunar ilmenites and pyroxenes. J. Geophys. Res., **98**, 13147–13162.

BISCHOFF, A., GEIGER, T., PALME, H., SPETTEL, B., SCHULTZ, L., SCHERER, P., LOEKEN, T., BLAND, P., CLAYTON, R.N., MAYEDA, T.K., HERPERS, U., MELTZOW, B., MICHEL, R. and DITTRICH-HANNEN, B. (1994): Acfer 217—A new member of the Rumuruti chondrite group (R). Meteoritics, **29**, 264–274.

BISCHOFF, A., WEBER, D., BARTOSCHEWIT, Z. R., CLAYTON, R.N., MAYEDA, T.K., SCHULTZ, L., SPETTEL, B. and WEBER, H.W. (1998): Characterization of the Rumuruti chondrite regolith breccia Hughes 030 (R3-6) and implications for the occurrence of unequilibrated lithologies on the R-chondrite parent body. Meteorit. Planet. Sci., **33**, A15–A16.

EUGSTER, O. (1988): Cosmic-ray production rates for ^{3}He, ^{21}Ne, ^{38}Ar, ^{83}Kr, and ^{126}Xe in chondrites based on ^{81}Kr-Kr exposure ages. Geochim. Cosmochim. Acta, **52**, 1649–1662.

GROSSMAN, J.N. (1998): The meteoritical bulletin, No. 82, 1998 July. Meteorit. Planet. Sci., **33**, A221–A239.

KALLEMEYN, G.W., RUBIN, A.E., WANG, D. and WASSON, J.T. (1989): Ordinary chondrites: Bulk compositions, classification, lithophile-element fractionations, and composition-petrographic type relationships. Geochim. Cosmochim. Acta, **53**, 2747–2767.

KALLEMEYN, G.W., RUBIN, A.E. and WASSON, J.T. (1996): The compositional classification of chondrites: VII. The R chondrite group. Geochim. Cosmochim. Acta, **60**, 2243–2256.

KOJIMA, H., IMAE, N., SAWADA., S. NAKAMURA, N., CLAYTON, R.N., MAYEDA, T.K., YANAI, K. and MORIKAWA, N. (1998): Consortium studies of five Antarctic Rumuruti chondrites. Antarctic Meteorites XXIII. Tokyo, Natl Inst. Polar Res., 54–57.

NAGAO, K., OKAZAKI, R., SAWADA, S. and NAKAMURA, N. (1998): Noble gas study of the five Yamato Rumuruti-group chondrites. Antarctic Meteorites XXIII. Tokyo, Natl Inst. Polar Res., 101–103.

NAKAMURA, N., YAMAMOTO, K., NODA, S., NISHIKAWA, Y., KOMI, H., NAKAYAMA, T. and MISAWA, K. (1989): Determination of picogram quantities of rare earth elements in meteoritic materials by direct-loading thermal ionization mass spectrometry. Analyt. Chem., **61**, 755–762.

OZAKI, H., SHINOTSUKA, K., KALLYMEYN, G.W. and EBIHARA, M. (1998): Chemical composition of Asuka-881988, Yamato-75302 and Yamato-791827, Antarctic R chondrites. Antarctic Meteorites XXIII.

Tokyo, Natl Inst. Polar Res., 123–125.

OZIMA, M. and PODOSEK, F.A. (1983): Noble Gas Geochemistry. Cambridge, Cambridge Univ. Press.

PALME, H., WECKWERTH, G. and WOLF, D. (1996): Composition of a new R-chondrite and the classification of chondritic meteorites. Lunar and Planetary SCIENCE XXVII. Houston, Lunar and Planet. Inst., 991–992.

RUBIN, A. and KALLEMEYN, G.W. (1994): Pecora Escarpment 91002: A member of the new Rumuruti (R) chondrite group. Meteoritics, **29**, 255–264.

SCHERER, P., SCHULTZ, L. and LOEKEN, T. (1994): Weathering and atmospheric noble gases in chondrites. Noble Gas Geochemistry and Cosmochemistry, ed. By J. MATSUDA. Tokyo, Terra Sci. Publ., 43–53.

SCHULZE, H. and OTTO, J. (1993): Rumuruti: A new Carlisle Lakes-type chondrite. Meteoritics, **28**, 433.

SCHULZE, H., BISCHOFF, A., PALME, H., SPETTEL, B., DREIBUS, G. and OTTO, J. (1994): Mineralogy and chemistry of Rumuruti: The first meteorite fall of the new Rchondrite group. Meteoritics, **29**, 275–286.

STEIGER, R.H. and JÄER, E. (1977): Subcommision on geochronology: Convention on the use of decay constants in geo- and cosmo-chronology. Earth Planet. Sci. Lett., **36**, 359–362.

WEBER, H.W. and SCHULTZ, L. (1995): Noble gases in Rumuruti-group chondrites. Meteoritics, **30**, 596.

WEBER, H.W. and SCHULTZ, L. (1996): Noble gases in two R chondrites. Meteorit. Planet. Sci., **31**, A148.

WEBER, H.W. and SCHULTZ, L. (1998a): The noble gas record of Rumuruti-chondrites. Lunar and Planetary SCIENCE XXIX. Houston, Lunar Planet. Inst., 1122.

WEBER, H.W. and SCHULTZ, L. (1998b): Noble gases in the Antarctic R-chondrites Mount Prestrud 95410, 95411, and 95412. Meteorit. Planet. Sci., **33**, A164–A165.

WIELER, R., ANDERS, E., BAUR, H., LEWIS, R.S. and SIGNER, P. (1992): Characterization of Q-gases and other noble gas compositions in the Murchison meteorite. Geochim. Cosmochim. Acta, **56**, 2907–2921.

WLOTZKA, F. (1992): The meteoritical bulletin, No. 73. Meteoritics, **27**, 477–483.

YANAI, K. and KOJIMA, H. (1995): Catalog of the Antarctic Meteorites. Tokyo, Natl Inst. Polar Res., 230 p.

(Received October 12, 1998; Revised manuscript accepted January 7, 1999)