Proc. NIPR Symp. Antarct. Meteorites, 5, 36-48, 1992

NOBLE GASES IN YAMATO-793274 AND -86032 LUNAR METEORITES

Nobuo TAKAOKA[1] and Yo-ichi YOSHIDA[2]

Department of Earth Sciences, Faculty of Science, Yamagata University, Yamagata 990

Abstract: Isotopic abundances of noble gases are reported for whole rock samples, mineral and grain size separates prepared from lunar meteorites Yamato-793274 and -86032. Y-793274 is rich in trapped solar gases, whereas Y-86032 is depleted in them, resembling the Y-82192 and -82193 lunar meteorites. From measurements of radiogenic Ar, the K-Ar age of Y-86032 is calculated to be 3940±240 Ma, in agreement with the K-Ar and Ar-Ar ages for Y-82192 and -82193. From measurements of cosmogenic noble gases, the total duration of cosmic-ray exposure is calculated to be 510±140 and 11±1 Ma for Y-793274 and -86032, respectively. The exposure age of Y-86032 is in good agreement with that for Y-82192/3. The agreement in the K-Ar and exposure ages as well as in the trapped gas abundances supports the earlier result that Y-86032 is paired with Y-82192 and -82193. Y-793274 experienced most of exposures to cosmic-rays in the lunar regolith because the transit time from the moon to the earth has been reported to be very short, whereas it is supposed that Y-86032 experienced a large part of cosmic-ray exposure in the interplanetary space during the flight from the moon to the earth.

1. Introduction

Y-793274 is a small lunar meteorite which weighs only 8.66 g and is classified as a basaltic-anorthositic breccia (YANAI and KOJIMA, 1991) consisting of 2/3 mare material of very low Ti and 1/3 highland material (WARREN and KALLEMEYN, 1991; KOEBERL *et al.*, 1991). It is similar to EET87521 in many ways with some distinctions such as the chemical composition of the dominant basaltic component (LINDSTROM *et al.*, 1991).

Y-86032 is a large lunar meteorite weighing 648.4 g and classified as an anorthositic regolith breccia. It is similar to the Y-82192 and -82193 lunar meteorites which were recovered from the same area as Y-86032 was recovered (*e.g.*, TAKEDA *et al.*, 1989). These three lunar meteorites have been reported to be paired meteorites from the same fall (EUGSTER *et al.*, 1989).

Sample splits Y-793274,63 and Y-86032,63, ,66 and ,108 were allocated to us for noble gas analyses in the consortium studies of lunar meteorites (TAKEDA

Present address:

[1] *Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, Hakozaki, Fukuoka 812.*

[2] *Publication Division 2, Ascii Co. Ltd., 11-1, Minami-Aoyama 6-chome, Minato-ku, Tokyo 107-24.*

et al., 1989, 1991). Preliminary results of noble gas analyses of these sample splits have been reported by TAKAOKA and YOSHIDA (1990).

2. Sample and Experiment

The delivered specimen of Y-793274,63, weighing 58 mg, is composed of glassy grains and gray matrix. In order to examine gas loss and elemental fractionation upon melting by shock heating, glassy grains were separated by hand-picking. Subsample Y-793274,63A is the fraction composed of such grains. One grain in this fraction was used for EPMA analysis of the elemental composition. After the separation of glass grains, two grain-size separates of <25 μm (,63B) and >25 μm (,63C) were prepared by sieving. Subsample 63C was further divided into two parts, one for Ar to Xe analyses and another for He to Ar analyses.

Sample Y-86032,63 is a fragment of grayish breccia matrix which was chipped for noble gas analysis. Y-86032,66 was chipped from a far-side of the samples listed in Table 2 of TAKEDA *et al.* (1989) to check homogeneity of noble gas distribution (KOJIMA, private communication). Y-86032,108 is one of two specimens prepared from a large fragment of a light clast which is feldspathic fragmental breccia. Another of these specimens was allocated for Ar-Ar dating (TAKEDA *et al.*, 1989). For noble gas analyses, mineral and grain-size separates as well as bulk samples were prepared. Black (probably ilmenite) grains (as Y-86032,63A and ,66A) and white feldspathic grains (as Y-86032,63B and ,108B) were separated by hand-picking. After that, two grain-size fractions of <25 μm (as ,63C and ,66C) and >25 μm (as ,63D and ,66D) were separated from Y-86032,63 and ,66. Because of small sample size, the residues of Y-86032,108 were not

Table 1. Samples of lunar meteorites used in this work.

Meteorite	Sample	Weight (mg)	Description
Y-793274	Y-793274,63A	8.71	Glass separates
	Y-793274,63B	5.96	Grain size fraction: <25 μm
	Y-793274,63Ca	16.35	Grain size fraction: >25 μm used for Ar, Kr and Xe measurements
	Y-793274,63Cb	4.17	Grain size fraction: >25 μm used for He, Ne and Ar measurements
Y-86032	Y-86032,63WR	62.7	Bulk of anorthositic breccia
	Y-86032,63A	9.39	Black, ilmenite-like separates
	Y-86032,63B	6.96	White, feldspathic separates
	Y-86032,63C	25.85	Grain size fraction: <25 μm
	Y-86032,63D	50.90	Grain size fraction: >25 μm
	Y-86032,66WR	55.4	Bulk of anorthositic breccia
	Y-86032,66A	8.22	Black, ilmenite-like separates
	Y-86032,66C	32.88	Grain size fraction: <25 μm
	Y-86032,66D	74.71	Grain size fraction: >25 μm
	Y-86032,108WR	42.7	Bulk of feldspathic clast
	Y-86032,108B	7.09	White, feldspathic separates
	Y-86032,108C	1.59	Residues after separation of Y-86032,108B

Table 2. Isotopic abundances of noble gases in lunar meteorites Y-793274 and -86032

Sample	^{4}He 1)	$^{3}He/^{4}He$	^{20}Ne 1)	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$	^{36}Ar 1)	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$	^{84}Kr 1)	^{132}Xe 1)
Y-793274,63A	189	0.000961 (39) 2)	23.3	10.42 (6) 2)	0.164 (1) 2)	23.1	0.2046 (11) 2)	2.156 (11) 2)	19.1	2.56
Y-793274,63B	616	0.000627 (26)	76.8	11.64 (7)	0.0794 (7)	77.9	0.1927 (11)	2.396 (10)	54.0	6.73
Y-793274,63Ca	—	—	not analyzed	—	—	95.3	0.1905 (17)	2.367 (24)	62.8	8.19
Y-793274,63Cb	548	0.000517 (72)	107	11.95 (5)	0.0649 (8)	79.7	0.1889 (18)	2.293 (52)	—	n. a. —
Y-86032,63WR	0.443	0.181 (7)	0.155	3.622 (21)	0.601 (6)	0.258	0.2854 (21)	44.34 (27)	0.28	0.050
Y-86032,63A	0.567	0.1288 (63)	0.284	5.26 (21)	0.479 (21)	0.289	0.2701 (22)	49.39 (61)	0.30	0.060
Y-86032,63B	0.341	0.104 (6)	0.0582	[1.47 (12)] 3)	[0.587 (64)] 3)	0.115	0.395 (8)	98.5 (2.6)	0.35	0.12
Y-86032,63C	0.383	0.122 (5)	0.101	2.738 (38)	0.661 (15)	0.168	0.313 (3)	61.1 (1.0)	0.74	0.23
Y-86032,63D	0.324	0.129 (5)	0.137	3.422 (47)	0.605 (11)	0.208	0.2868 (40)	52.96 (65)	0.55	0.12
Y-86032,66WR	0.380	0.133 (5)	0.127	3.285 (20)	0.606 (3)	0.296	0.2724 (23)	46.32 (20)	0.44	—
Y-86032,66A	0.600	0.138 (6)	0.307	5.85 (14)	0.442 (15)	0.320	0.237 (2)	34.5 (4)	0.29	0.039
Y-86032,66C	0.338	0.133 (6)	0.0940	2.805 (41)	0.685 (10)	0.121	0.298 (3)	63.3 (5)	0.86	0.27
Y-86032,66D	0.364	0.144 (6)	0.152	3.623 (32)	0.5985 (81)	0.201	0.2881 (33)	46.44 (55)	0.56	0.16
Y-86032,108WR	0.0674	0.213 (11)	0.0200	0.820 (10)	0.794 (7)	0.0285	1.132 (17)	121.5 (8)	0.073	0.014
Y-86032,108B	0.260	0.0798 (59)	0.0604	[1.95 (17)]	[0.671 (64)]	0.0543	0.605 (13)	78.4 (2.3)	0.14	0.03
Y-86032,108C	0.828	0.0831 (73)	0.303	[3.89 (67)]	[0.440 (78)]	0.282	0.2939 (36)	47.9 (2.0)	1.1	0.7

1) Noble gas concentrations are given in units of 10^{-6} and 10^{-9} cm^3 STP/g for He, Ne and Ar, and Kr and Xe, respectively.

2) Errors are given in last one or two digits in parentheses.

3) Ne isotopic ratios for which correction for doubly-charged CO_2 exceeds 20% are given in square brackets.

separated to grain sizes. They were analyzed as subsample Y-86032,108C. Names of subsamples used for noble gas analyses are listed in Table 1.

Samples wrapped in Al-foil were heated in vacuum in side-arms of a sample holder to outgas adsorbed atmosphere at about 100°C for one night. The noble gases released at 1750°C were measured by conventional mass spectrometry (TAKAOKA, 1976; TAKAOKA and NAGAO, 1978). Blanks at 1750°C are 1×10^{-9} for ^{4}He, 6×10^{-12} for ^{20}Ne, 1×10^{-11} for ^{36}Ar, and $<1\times10^{-13}$ for ^{84}Kr and ^{132}Xe in unit of cm^3 STP. Because of small sample size, correction for doubly-charged CO_2 exceeds 20% for three Y-86032 subsamples for which the Ne isotopic ratios are given in square brackets in Table 2. For other Y-86032 subsamples, the correction is typically between 1.6 and 10%, and it is less than 0.3% for Y-793274 which contains large amounts of solar noble gases. The correction for doubly-charged ^{40}Ar is less than 1% for all samples.

3. Results and Discussion

The results of noble gas analyses are given in Table 2. Errors cited for isotopic ratios correspond to 95% confidence level. Errors for noble gas concentrations are about 10%. The result on the elemental composition of Y-793274,63A (glass), which was measured with EPMA, is given in Table 3.

For decomposition of noble gases into trapped (t), radiogenic (r) and cosmogenic (c) components, the following isotopic ratios are assumed: $(^3\mathrm{He}/^4\mathrm{He})_c=0.2$, $(^{20}\mathrm{Ne}/^{22}\mathrm{Ne})_c=0.8$, $(^{21}\mathrm{Ne}/^{22}\mathrm{Ne})_t=0.032$, $(^{38}\mathrm{Ar}/^{36}\mathrm{Ar})_t=0.188$, $(^{38}\mathrm{Ar}/^{36}\mathrm{Ar})_c=1.54$, $(^{40}\mathrm{Ar}/^{38}\mathrm{Ar})_c=0.2$. In spite of these assumptions, the isotopic ratios of trapped Ne estimated in Fig. 2 are used for Y-793274. Although $(^{40}\mathrm{Ar}/^{36}\mathrm{Ar})_t$ for Y-86032 could be determined to be 7 ± 13 from a ^{40}Ar/^{36}Ar *vs.* 1/^{36}Ar plot, we use a literature value of 12.1 ± 3.0 reported by EUGSTER *et al.* (1989), since our result includes large errors. For the isotopic ratios of trapped Xe, surface-correlated Xe (SUCOR-Xe, PODOSEK *et al.*, 1971) is used.

Table 3. Elemental compositions of Y-793274 and -86032 used for discussion in this work.

Sample	Si	Ti	Al	Fe (wt%)	Mg	Ca	Na	K	References
Y-793274,63A (glass)	22.83	0.40	6.86	12.86	4.53	9.02	0.26	n.d.	This work
Y-793274 (whole rock; mean)	22.0	0.36	8.54	11.0	5.58	8.73	0.30	0.072	1, 2, 3, 4, 5
Y-86032 (whole rock; mean)	20.6	0.09	15.3	3.40	3.20	11.7	0.31	0.017	1, 5, 6

Ref.: 1) LINDSTROM *et al.* (1991), 2) KOEBERL *et al.* (1991), 3) FUKUOKA (1990), 4) WARREN and KELLEMEYN (1991), 5) YANAI and KOJIMA (1991), 6) KOEBERL *et al.* (1989).

3.1. *Trapped gases*

The result on trapped gases is given in Table 4. Figure 1 shows comparison of trapped gas abundances. The trapped gas abundances of Y-793274,63 are lower

Table 4. Trapped noble gases in Y-793274 and -86032.

Sample	^{4}He	^{20}Ne	^{36}Ar	^{4}He/^{3}He	^{20}Ne/^{22}Ne	^{22}Ne/^{21}Ne	^{38}Ar/^{36}Ar	^{40}Ar/^{36}Ar
	(10^{-6} cm^{3}STP/g)							
Y-793274,63A	n.d.	23.0	22.8					
Y-793274,63B	206–615	76.5	77.6					
Y-793274,63Ca	n.d.	n.d.	95.1					
Y-793274,63Cb	140–548	107	79.6					
Y-793274,63	—	—	—	2570(610)	12.37(19)	29.9(1.6)	0.1854(37)	n.d.
Y-86032,63WR	n.d.	0.130	0.239					
Y-86032,63A	n.d.	0.259	0.271					
Y-86032,63B	n.d.	0.0285	0.0974					
Y-86032,63C	n.d.	0.0768	0.152					
Y-86032,63D	n.d.	0.113	0.193					
Y-86032,66WR	n.d.	0.103	0.277					
Y-86032,66A	n.d.	0.285	0.308					
Y-86032,66C	n.d.	0.0722	0.111					
Y-86032,66D	n.d.	0.127	0.186					
Y-86032,108WR	n.d.	0.0005	0.0086					
Y-86032,108B	n.d.	0.0383	0.0375					
Y-86032,108C	n.d.	0.258	0.260					
Y-86032	—	—	—	n.d.	11.61(20)	=31.3	n.d.	7(13)

n.d. = not determined, and errors of isotopic ratios are given in last two or three digits in parentheses.

than those of Y-791197 (TAKAOKA, 1986) and ALHA81005 (BOGARD and JOHNSON, 1983; EUGSTER *et al.*, 1986), but the abundance pattern is very similar to each other except for Ne. The depletion in Ne for Y-793274,63A, ,63B, and ,63C can be attributed to fractional gas losses by shock and/or shock-heating. Compared with the other fractions (,63B and ,63C), the abundances of trapped gases in glass (,63A) are significantly lower. However, the abundance pattern for glass is the same as that for the other fractions which did not melt by impact-shock; that is, the glass sample (,63A) retains reduced amounts of heavy noble gases with the unfractionated proportion. If the original materials of glass contained the same amounts of heavy noble gases as the other fractions did, this suggests that at least the heavy gases were lost by shock without significant elemental fractionation, although any data on the elemental fractionation at the shock release of noble gases are not available.

No anticorrelation between the trapped gas abundance and the grain size is found in both Y-793274 and -86032. Large grains are more abundant in the trapped gases than small grains. The same trend has been reported for ALHA81005 (EUGSTER *et al.*, 1986). The similarity in the abundance pattern between Y-793274 and the <15 μm fraction of ALHA81005 indicates that the preferential loss of light trapped gases is common from fine grains of lunar meteorites which experienced heavy shock.

In spite of absence of the anticorrelation between grain-size and trapped gas abundances, ^{20}Ne/^{22}Ne, ^{22}Ne/^{21}Ne, and ^{38}Ar/^{36}Ar correlate well with 1/^{22}Ne, 1/^{21}Ne, and 1/^{36}Ar, respectively, in Y-793274 (Fig. 2). This indicates that both the isotopic

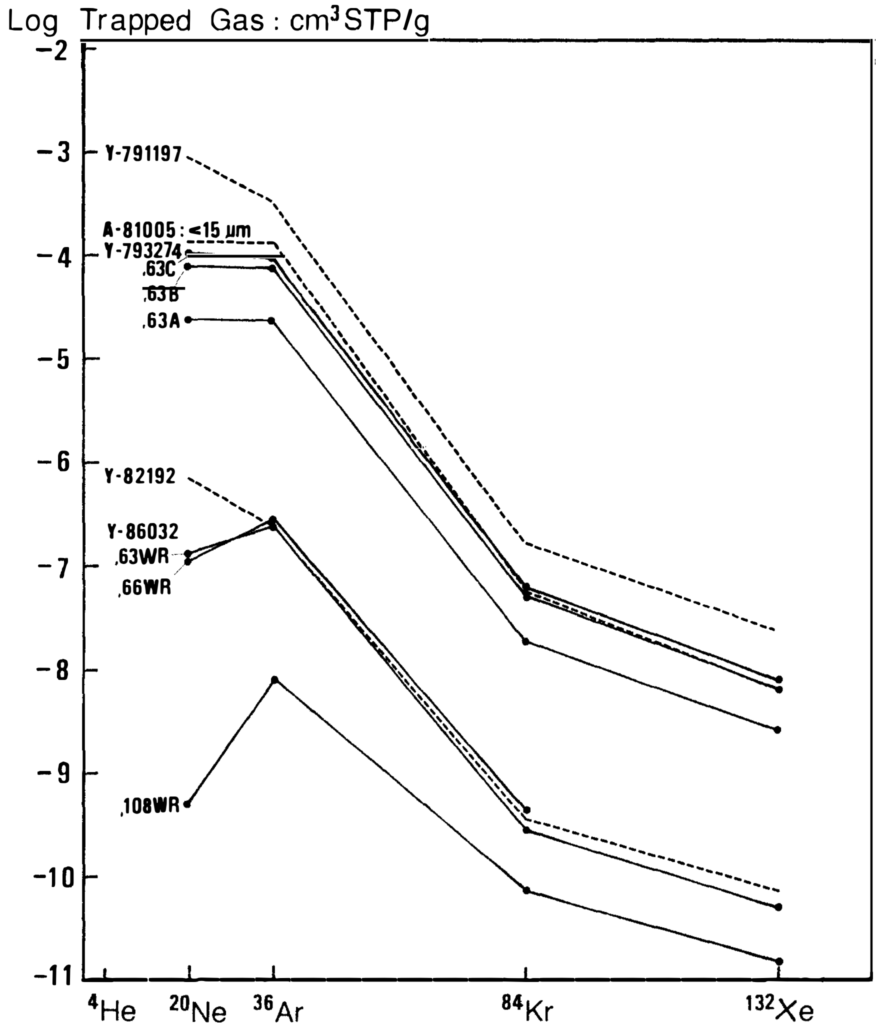

Fig. 1. Comparison of abundances of trapped noble gases. Compared with Y-793274,63B and ,63C, the abundances for Y-793274,63A are significantly lower. However, the abundance pattern for 63A (glass) is the same as that for the other fractions (63B and 63C) which did not melt by impact-shock and for the <15 µm fraction of ALHA 81005 (EUGSTER et al., 1986). This suggests that at least loss of heavy gases by shock-melting was not accompanied by significant elemental fractionation. These samples lost light gases preferentially, but the abundance pattern of Ar, Kr and Xe is identical with that of Y-791197.

The abundances of trapped noble gases for Y-86032,63 and ,66 are in good agreement with those for Y-82192 (TAKAOKA, 1987) except for Ne, whereas those for Y-86032,108 are significantly low. All samples from Y-86032 are greatly depleted in ^{20}Ne. The lower abundances of trapped gases are accompanied by the larger fractionation of $^{20}Ne/^{36}Ar$.

ratios of trapped and cosmogenic gases and the concentration of cosmogenic gas were kept uniform after the significant losses of trapped Ne and Ar. The correlation between $^{3}He/^{4}He$ and $1/^{4}He$ in Y-793274 gives trapped $^{3}He/^{4}He=(3.9\pm0.9)\times10^{-4}$, although it contains large errors. The poor correlation may be due to the inhomogeneity of the U distribution and the different retentivities of radiogenic and

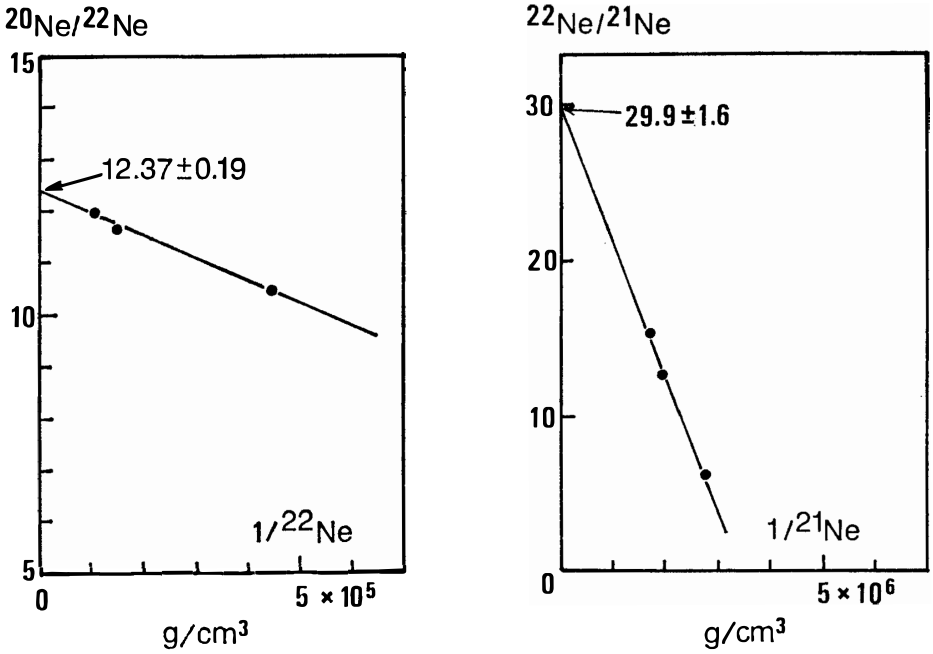

Fig. 2. Determination of trapped $^{20}Ne/^{22}Ne$ and $^{22}Ne/^{21}Ne$ for Y-793274,63. Both ratios agree with those for solar wind within uncertainties, although they are very slightly lower than the solar value (EBERHARDT et al., 1972).

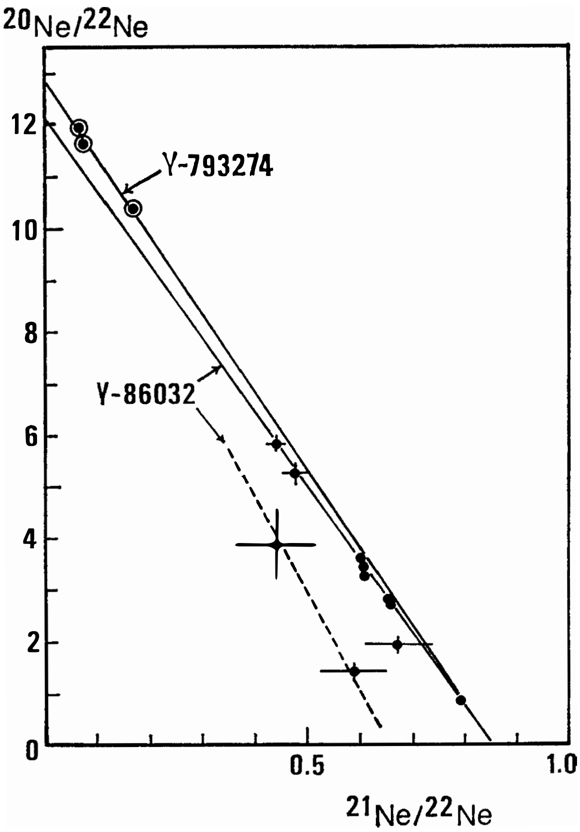

Fig. 3. Three isotope plots of Ne for Y-793274 and -86032. Correlation lines for Y-793274 and -86032 yield 12.41±0.19 and 11.61 ±0.20 for trapped $^{20}Ne/^{22}Ne$, respectively, from intersections of the correlation lines at $^{21}Ne/^{22}Ne=0.032$. Intersections at $^{20}Ne/^{22}Ne=0.80$ yield 1.25±0.16 and 1.257±0.060 for cosmogenic $^{22}Ne/^{21}Ne$ ratios for Y-793274 and -86032, respectively. The trapped $^{20}Ne/^{22}Ne$ ratio for Y-793274 is in good agreement with that determined in Fig. 2. Two data points for Y-86032,63B and ,108C, which are greatly off from the correlation line, yield very low $(^{21}Ne/^{22}Ne)_c$ which are consistent with the Ne ratio produced in Na-rich minerals.

cosmogenic He. The lack of correlation between $^{40}Ar/^{36}Ar$ and $1/^{36}Ar$ is also attributable to the inhomogeneity of K contents. The isotopic ratios of trapped gases determined by the correlation plots are given in Table 4.

Figure 3 is a three-isotopic plot of Ne for both meteorites. The $(^{20}Ne/^{22}Ne)_t$ ratio for Y-793274 is determined to be 12.41 ± 0.19, which agrees well with the ratio derived from the $^{20}Ne/^{22}Ne$ *vs.* $1/^{22}Ne$ plot (Fig. 2). This ratio, although very slightly low, agrees with that of solar Ne found in lunar soils (EBERHARDT *et al.*, 1972). The $(^{20}Ne/^{22}Ne)_t$ ratio of 11.61 ± 0.20 obtained for Y-86032 is significantly lower than that for the lunar soils. Since Y-86032 has lost most of trapped and radiogenic He (Table 2) and large part of trapped Ne (Fig. 1), the low $(^{20}Ne/^{22}Ne)_t$ ratio may be attributable to the preferential loss of light isotopes.

3.2. *Radiogenic gas and K-Ar age*

Estimation of radiogenic ^4He is impossible because of large amounts of trapped He in Y-793274, and most of radiogenic ^4He has been lost from Y-86032. For these reasons, we do not discuss radiogenic ^4He. The concentrations of radiogenic ^{40}Ar were calculated by correcting for trapped Ar. The concentrations of radiogenic ^{40}Ar for the subsamples of Y-86032 are given in Table 5. For calculation of the

Table 5. Cosmogenic and radiogenic noble gases in Y-793274 and -86032.

Sample	Cosmogenic				Radiogenic
	^3He	^{21}Ne 10^{-9} cm^{3}STP/g	^{38}Ar	$^{22}Ne/^{21}Ne$	^{40}Ar 10^{-6} cm^{3}STP/g
Y-793274,63A	n.d.[1)]	305	504		n.d.
Y-793274,63B	n.d.	317	647		n.d.
Y-793274,63Ca	n.d.	n.d.	553		n.d.
Y-793274,63Cb	n.d.	293	317		n.d.
Y-793274	—	—	—	1.25(16)[2)]	—
Y-86032,63WR	80.2	25.4	28.6		8.5(7)[3)]
Y-86032,63A	73.0	25.2	27.0		10.0(8)
Y-86032,63B	35.4	23.2	27.1	1.60(7)[4)]	10.1(3)
Y-86032,63C	46.7	24.2	23.9		8.4(5)
Y-86032,63D	41.8	23.9	23.4		8.7(6)
Y-86032,66WR	50.5	23.1	28.5		10.3(9)
Y-86032,66A	82.8	22.4	17.9		7.3(9)
Y-86032,66C	44.9	21.9	15.2		6.3(3)
Y-86032,66D	52.4	24.8	22.9		7.1(6)
Y-86032,108WR	14.4	19.4	30.7		3.35(3)
Y-86032,108B	20.7	20.7	25.8		3.8(1)
Y-86032,108C	68.8	33.6	34.0	1.66(12)[4)]	10.4(8)
Y-86032	—	—	—	1.257(60)[5)]	—

1) Not determined. 2) Cosmogenic $^{22}Ne/^{21}Ne$ was calculated from Ne data for Y-793274,63A, 63B and 63C. Errors in last two digits are given in parentheses.
3) Estimated errors for radiogenic ^{40}Ar are given in parentheses.
4) Cosmogenic $^{22}Ne/^{21}Ne$ was calculated from trapped $^{20}Ne/^{22}Ne$ for Y-86032 (Table 4) and measured values.
5) Cosmogenic $^{22}Ne/^{21}Ne$ was calculated from Ne data for all samples of Y-86032 except Y-86032,63B and ,108C.

K-Ar age, we use the Ar data for Y-86032,63WR and ,66WR which are both whole rock samples, because the K content is available only for the whole rock samples, whereas other subsamples are mineral separates and residues, or grain-size separates prepared from the residues after the mineral separation, for which the K contents are not available.

The K-Ar age is calculated to be 3940±240 Ma for Y-86032, assuming K= 0.017 wt% which is an average of values in KOEBERL *et al.* (1989) and YANAI and KOJIMA (1991). The attached error should be larger because it does not contain the uncertainty of K content. The K content ranging from 0.011 to 0.021 wt% has been listed in KOEBERL *et al.* (1989). The present result agrees with the K-Ar age (3680±300 and 3819±400 Ma) given by EUGSTER *et al.* (1989), and also with the Ar-Ar age of Y-82192 which is 4240±340 Ma (KANEOKA and TAKAOKA, 1987). This is an addition of evidence supporting the earlier result that Y-86032 is paired with Y-82192 and -82193 (EUGSTER *et al.*, 1989).

3.3. Cosmogenic gas and cosmic-ray exposure age

From Fig. 3, $(^{22}Ne/^{21}Ne)_c$ can be estimated to be 1.25±0.16 and 1.257±0.060 for Y-793274 and -86032, respectively. The large $(^{22}Ne/^{21}Ne)_c$ ratios indicate shallow shielding to cosmic-ray exposure. The exposure at a shallow depth is compatible with the abundant trapped solar gases for Y-793274. Y-86032,63B and ,108C are distinctly off the correlation line. Because cosmogenic $^{22}Ne/^{21}Ne$ is approximately 1.6 for both samples (Table 5), they seem to be enriched in Na-rich minerals for which $(^{22}Ne/^{21}Ne)_c$ is as high as 1.5 (SMITH and HUNEKE, 1975). ^{3}He determined for Y-86032 is assumed to be cosmogenic because most of trapped He is lost from this stone. Cosmogenic ^{21}Ne and ^{38}Ar are calculated in a usual way assuming two component mixing. The result on the cosmogenic gases is summarized in Table 5. Production rates of cosmogenic ^{21}Ne and ^{38}Ar for Y-793274, which experienced exposure to cosmic-rays in the lunar regolith as will be discussed later, are calculated according to HOHENBERG *et al.* (1978). The production rates by SCHULTZ (1990) and FREUNDEL *et al.* (1986) as well as by HOHENBERG *et al.* (1978) are used to calculate those for Y-86032, which experienced the cosmic-ray exposure in both the interplanetary space and the lunar regolith.

As given in Table 6, Y-793274 yields high concentrations of cosmogenic gases. Since the transit time from the moon to the earth has been reported to be 0.04± 0.01 Ma by NISHIIZUMI *et al.* (1991), this indicates a long irradiation of Y-793274 in the lunar regolith. The production rates of cosmogenic nuclides consequently depend on the shielding depth. The $(^{131}Xe/^{126}Xe)_c$ ratio is a well-known indicator of the shielding depth (HOHENBERG *et al.*, 1978). Our Xe data, which contain large errors and are not listed, cannot define the shielding depth. As mentioned above, the large $(^{22}Ne/^{21}Ne)_c$ ratio indicates a shallow shielding. Although the shielding depth of 150–190 g/cm^2 has been reported by NISHIIZUMI *et al.* (1991), the radio-activities of ^{26}Al, ^{36}Cl and ^{41}Ca reflect the cosmic-ray exposures in a few Ma before the ejection from the moon because the half-lives of these nuclides are less than 0.8 Ma, and thus the radio-activities of these nuclides do not give useful constraints on early cosmic-ray exposures which the Y-793274 material

Table 6. Cosmic-ray exposure and K-Ar ages of Y-793274 and -86032.

Meteorite	Cosmogenic		Production rate		Exposure age		Radiogenic	K-Ar age
	^{21}Ne 1)	^{38}Ar 1)	P_{21} 2)	P_{38} 2)	T_{21}(Ma)	T_{38}(Ma)	^{40}Ar 1)	T_{40}(Ma)
Y-793274	305 3)	510 3)	1.1 4)	1.0 4)	280	510	n.d.	n.d.
	±12	±140			±11	±140		
Y-86032	24.0 3)	25.4 3)	2.18 5)	2.29 5)	11.0	11.1	9400 6)	3940 7)
	±2.0	±2.3			±0.9	±1.0	±140	±240

1) Concentrations are given in units of 10^{-9} cm^3STP/g.
2) Production rates are given in units of 10^{-9} cm^3STP/g Ma.
3) Cosmogenic gases are averages of 63B and 63C for Y-793274, and all subsamples of Y-86032,63 and ,66.
4) Production rates in the lunar regolith (2π geometry) were calculated according to HOHENBERG *et al.* (1978) and elemental compositions given in Table 3.
5) Production rates in space (4π geometry) were calculated using averages between those calculated by HOHENBERG *et al.* (1978) and SCHULTZ (1990) for ^{21}Ne, and between those by HOHENBERG *et al.* (1978) and FREUNDEL *et al.* (1986) for ^{38}Ar.
6) Radiogenic ^{40}Ar is an average of Y-86032,63WR and ,66WR.
7) K=0.017 wt% was assumed. See Table 3 and text.

experienced in prolonged periods. We assume 40 g/cm^2 for Y-793274, taking the shielding depths for Y-791197 (<65 g/cm^2, TAKAOKA, 1986) and ALHA81005 (<50 g/cm^2, EUGSTER *et al.*, 1986) into consideration. The $(^{21}Ne)_c$ and $(^{38}Ar)_c$ production rates calculated between 2 and 100 g/cm^2 vary within ±20% of the rates calculated at 40 g/cm^2. Accordingly, the production rates do not depend critically on the shielding depth between 2 and 100 g/cm^2. The production rates at 170 g/cm^2 are lower by 35% than those at 40 g/cm^2. A factor of two is used to convert 2π irradiation geometry in the lunar regolith into 4π irradiation geometry in the interplanetary space.

The cosmic-ray exposure age for Y-793274 is calculated to be 280 Ma from $(^{21}Ne)_c$ and 510 Ma from $(^{38}Ar)_c$ in 2π geometry. The short Ne age can be attributed to the loss of cosmogenic Ne, induced probably by the impact shock, since Y-793274 has lost the great portion of trapped Ne, as found earlier. We adopt 510±140 Ma for the total cosmic-ray exposure age for the Y-793274 material. Because the transit time from the moon to the earth is very short, the Y-793274 material experienced cosmic-ray irradiation totally during 510±140 Ma in the lunar regolith.

The age of 11 Ma is obtained for the cosmic-ray irradiation of Y-86032 in 4π geometry. Since Y-82192 and -82193, the paired meteorites with Y-86032, yield high ^{53}Mn activities which indicate that they experienced cosmic-ray irradiations mainly in the space, we suppose that Y-86032 also experienced great part of irradiation to cosmic-rays during the transit time from the moon to the earth.

4. Conclusion

Y-793274,63 contains large amounts of trapped solar gases. Compared with other lunar meteorites, the abundances of trapped gases in Y-793274,63 are lower

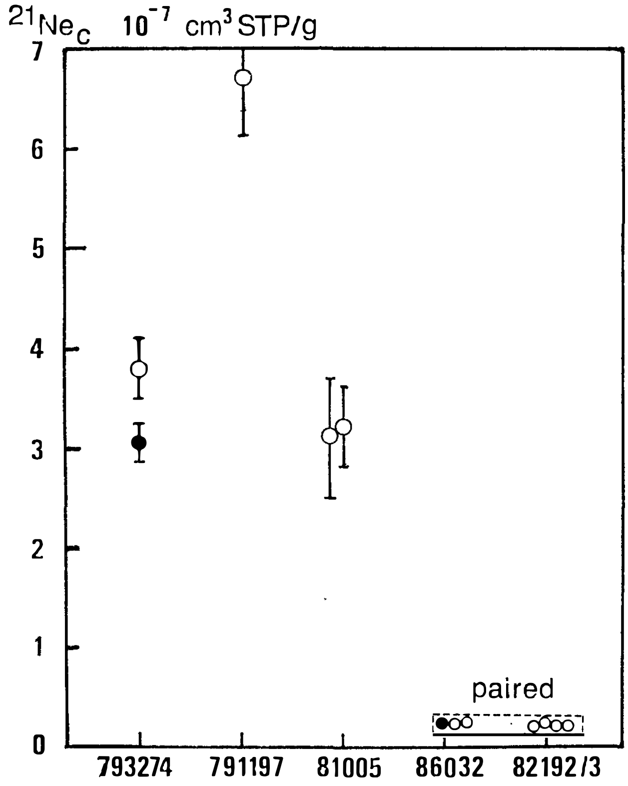

Fig. 4. Comparison of cosmic-ray produced ^{21}Ne in lunar meteorites. Cosmogenic ^{21}Ne in Y-793274,63 (this work: solid circle; EUGSTER, 1990: open circle) is in agreement with that in ALHA 81005 (BOGARD and JOHNSON, 1983) within experimental errors, whereas it is lower by a factor of two than that for Y-791197 (TAKAOKA, 1986). Cosmogenic ^{21}Ne for Y-86032 (this work: solid circle; EUGSTER et al., 1989: open circle) agrees well with each other and with that for Y-82192/3 (TAKAOKA, 1987; EUGSTER and NIEDERMANN, 1988).

than those for Y-791197 and ALHA81005. However, the trapped gas abundances are not uniform in Y-793274, because EUGSTER (1990) has reported higher abundances for the other sample Y-793274,66, for example 3 to 13 times $(^{20}Ne)_t$ compared with our result.

The concentration of cosmogenic ^{21}Ne is compared with that for the other lunar meteorites in Fig. 4. Cosmogenic ^{21}Ne in our sample is 25% lower than that in Y-793274,66 (EUGSTER, 1990). The discrepancy can be ascribed to the difference in cosmogenic ^{21}Ne loss. Data for Y-793274 are in agreement with those for ALHA81005 within 15%. However, there is a large discrepancy by a factor of 2 from Y-791197. Agreement in $(^{21}Ne)_c$ is excellent between Y-86032 and Y-82192/3 which are paired. The total duration of cosmic-rays exposure was calculated to be 510±140 and 11±1 Ma for Y-793274 and -86032, respectively. The exposure are of Y-86032 is in good agreement with that of Y-82192/3.

Since we failed to determine the trapped $^{40}Ar/^{36}Ar$ ratio for Y-793274,63, no K-Ar age can be given for this stone. For Y-86032, we have 3.94±0.24 Ga. This agrees with the age for Y-82192 and supports the earlier result that Y-86032 is paired with Y-82192 and -82193.

Acknowledgments

The authors thank Drs. K. YANAI and H. KOJIMA for the samples and Prof. H. TAKEDA for organizing the consortium studies of Y-86032 and -793274. They also thank Prof. M. HONDA, Dr. K. NISHIIZUMI and an anonymous reviewer for constructive comments. One of the authors (Y. Y.) is grateful to Prof. K. SAITO for discussion and encouragement.

References

BOGARD, D.D. and JOHNSON, P. (1983): Trapped noble gases indicate lunar origin for Antarctic meteorite. Geophys. Res. Lett., **10**, 801–803.

EBERHARDT, P., GEISS, J., GRAF, H., GRÖGLER, N., MENDIA, M. D., MÖRGELI, M., SCHWALLER, H., STETTLER, A., KRÄHENBÜHL, U. and VON GUNTEN, H. R. (1972): Trapped solar wind noble gases in Apollo 12 lunar fines 12001 and Apollo 11 braccia 10046. Proc. Lunar Sci. Conf., 3rd, 1821–1856.

EUGSTER, O. (1990): Lunar meteorite Yamato-793274: Cosmic-ray produced and solar wind noble gases. Relation with Allan Hills A 81005? Paper Presented to 15th Symposium Antarctic Meteorites, May 30–June 1, 1990. Tokyo, Natl Inst. Polar Res., 188–190.

EUGSTER, O. and NIEDERMANN, S. (1988): Noble gases in lunar meteorites Yamato-82192 and -82193 and history of meteorites from the moon. Earth Planet. Sci. Lett., **89**, 15–27.

EUGSTER, O., GEISS, J., KRÄHENBÜHL, U. and NIEDERMANN, S. (1986): Noble gas isotopic composition, cosmic ray exposure history, and terrestrial age of the meteorite Allan Hills A81005 from the moon. Earth Planet. Sci. Lett., **78**, 139–147.

EUGSTER, O., NIEDERMANN, S., BURGER, M., KRÄHENBÜHL, U., WEBER, H., CLAYTON, R.N. and MAYEDA, T.K. (1989): Preliminary report on the Yamato-86032 lunar meteorite: III. Age, noble gas isotopes, oxygen isotopes and chemical abundances. Proc. NIPR Symp. Antarct. Meteorites, **2**, 25–35.

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

FUKUOKA, T. (1990): Chemistry of Yamato-793274 lunar meteorite. Paper Presented to 15th Symposium Antarctic Meteorites, May 30–June 1, 1990. Tokyo, Natl Inst. Polar Res., 122–123.

HOHENBERG, C. M., MARTI, K., PODOSEK, F. A., REEDY, R. C. and SHIRCK, J. R. (1978): Comparison between observed and predicted cosmogenic noble gases in lunar samples. Proc. Lunar Planet. Sci. Conf., 9th, 2311–2344.

KANEOKA, I. and TAKAOKA, N. (1987): ^{40}Ar-^{39}Ar analyses of lunar anorthositic breccia, Yamato-82192, from Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **46**, 105–112.

KOEBERL, C., WARREN, P.H., LINDSTROM, M. M., SPETTEL, B. and FUKUOKA, T. (1989): Preliminary examination of the Yamato-86032 lunar meteorite: II. Major and trace element chemistry. Proc. NIPR Symp. Antarct. Meteorites, **2**, 15–24.

KOEBERL, C., KURAT, G. and BRANDSTÄTTER, F. (1991): Lunar meteorite Yamato-793274: Mixture of mare and highland components, and barringerite from the moon. Proc. NIPR Symp. Antarct. Meteorites, **4**, 33–55.

LINDSTROM, M.M., WITTLEFEHLDT, D.W., MARTINEZ, R.R., LIPSCHUTZ, M.E. and WANG, S.-S. (1991): Geochemistry of Yamato-82192, -86032 and -793274 lunar meteorites. Proc. NIPR Symp. Antarct. Meteorites, **4**, 12–32.

NISHIIZUMI, K., ARNOLD, J.R., KLEIN, J., FINK, D., MIDDLETON, R., SHARMA, P. and KUBIK, P.W. (1991): Cosmic ray exposure history of lunar meteorite Yamato-793274. Paper Presented to 16th Symposium Antactic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 188–190.

PODOSEK, F.A., HUNEKE, J.C., BURNETT, D.S. and WASSERBURG, G.J. (1971): Isotopic composition of xenon and krypton in the lunar soil and in the solar wind. Earth Planet. Sci. Lett., **10**, 199–216.

SCHULTZ, L. (1990): Production rates of noble gases in meteorites—A review. Paper Presented to Workshop on Cosmogenic Nuclide Production Rates, ed By P.A.J. ENGLERT *et al.* Houston, Lunar Planet. Inst., 109–110 (LPI Tech. Rept. 90–05).

SMITH, S.P. and HUNEKE, J.C. (1975): Cosmogenic neon produced from sodium in meteoritic minerals. Earth Planet. Sci. Lett., **27**, 191–199.

TAKAOKA, N. (1976): A low-blank metal system for rare gas analysis. Mass Spectros., **24**, 73–86.
TAKAOKA, N. (1986): Noble gases in Yamato-791197: Evidence for lunar highland origin. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 124–132.
TAKAOKA, N. (1987): Noble gas study of Yamato-82192 lunar meteorites. Mem. Natl Inst. Polar Res., Spec. Issue, **46**, 96–104.
TAKAOKA, N. and NAGAO, K. (1978): Rare gas studies of Yamato-7301(j), -7304(m) and -7305(k). Mem. Natl Inst. Polar Res., Spec. Issue, **8**, 209–219.
TAKAOKA, N. and YOSHIDA, Y. (1990): Noble gases in lunar meteorites. Paper Presented to 15th Symp. Antarct. Meteorites, May 30–June 1, 1990. Tokyo, Natl Inst. Polar Res., 126–128.
TAKEDA, H., KOJIMA, H., NISHIO, F., YANAI, K., LINDSTROM, M.M. and YAMATO LUNAR METEORITE CONSORTIUM GROUP (1989): Preliminary report on the Yamato-86032 lunar meteorite: I. Recovery, sample descriptions, mineralogy and petrology. Proc. NIPR Symp. Antarct. Meteorites, **2**, 3–14.
TAKEDA, H., SAITO, J., YANAI, K. and KOJIMA, H. (1991): Consortium report of lunar meteorite Yamato-793274. Proc. NIPR Symp. Antarct. Meteorites, **4**, 3–11.
WARREN, P.H. and KALLEMEYN, G.W. (1991): Geochemical investigation of five lunar meteorites for the composition, origin and evolution of the lunar crust. Proc. NIPR Symp. Antarct. Meteorites, **4**, 91–117.
YANAI, K. and KOJIMA, H. (1991): Varieties of lunar meteorites recovered from Antarctica. Proc. NIPR Symp. Antarct. Meteorites, **4**, 70–90.

(Received September 27, 1991; Revised manuscript received January 9, 1992)