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NOBLE GASES IN THE UNIQUE METEORITES YAMATO-74063 AND -74357

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Abstract: Yamato-74063: The correlation in a three-isotope plot of Ne indicates Ne-A as the trapped component and a cosmogenic $^{22}Ne/^{21}Ne$ ratio as high as 1.31 ± 0.10. Considerable amounts of trapped gases are present in both metal and silicate separates. Trapped $^{36}Ar/^{132}Xe$ is different for metal and silicate, 72 and 17, respectively. The isotopic compositions of Kr and Xe are homogeneous and identical within errors for almost all temperature fractions of both separates. This observation includes even $^{129}Xe/^{132}Xe$. It is likely that the gases were acquired from a single gas-reservoir after most of radioactive ^{129}I had decayed to ^{129}Xe. There is a correlation between $^{36}Ar/^{132}Xe$ and $^{84}Kr/^{132}Xe$ for Y-74063, other unique meteorites and planetary Q-gas. The origin of trapped gas with low Ar/Xe is discussed. On laser ablation, most mineral grains released large amounts of trapped gases, suggesting that the trapped gases are not contained in specific carrier phases but in many major minerals.

Y-74357: The meteorite contains very little trapped gases. The cosmogenic $^{22}Ne/^{21}Ne$ ratio of 1.076 indicates that the stone was irradiated at an intermediate depth of a meteoroid. However, cosmogenic $^{3}He/^{21}Ne$ and $^{38}Ar/^{21}Ne$ are significantly lower than the ratios of production rates calculated for chondritic target chemistry, indicating that the stone is enriched in Mg and depleted in Ca. Correction for target chemistry (Mg) gives a tentative cosmic-ray exposure age of 10.1 Ma.

1. Introduction

Yamato(Y)-74063 contains large amounts of trapped heavy noble gases (TAKAOKA and YOSHIDA, 1991). The concentration of Xe is higher than that found in carbonaceous chondrites (*e.g.*, MAZOR *et al.*, 1970) and enstatite chondrites (*e.g.*, CRABB and ANDERS, 1981), and even ureilites (*e.g.*, GÖBEL *et al.*, 1978) with only a few exceptions. However, the host phase(s) of the trapped gases is unknown. YANAI and KOJIMA (1991) have classified it as a new type of chondrite with petrographic type 6 to 7. It is intermediate between E- and H-chondrite groups in mineral chemistry, but different in the low iron content from Acapulco-type meteorites and all known chondrite groups (YANAI and

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KOJIMA, 1991). The oxygen isotopic composition is almost identical with that of Acapulco, Lodran and their association (CLAYTON *et al.*, 1992). It is also similar in the isotopic composition of nitrogen to Acapulco (SUGIURA and HASHIZUME, 1991). The old ages obtained by K-Ar (TAKAOKA and YOSHIDA, 1991), Ar-Ar (KANEOKA *et al.*, 1992) and Rb-Sr (TORIGOYE *et al.*, 1993) dating reveal that this stone has not been subjected to any major metamorphic event during the last 4.5 Ga. The antiquity is identical with that for Acapulco (PALME *et al.*, 1981) and Acapulco-type meteorite ALHA77081 (SCHULTZ *et al.*, 1982).

Y-74357 is a small meteorite (13.8 g), which has affinities to Acapulco and Lodran in texture, mineralogy and chemistry (NAGAHARA *et al.*, 1991) and in the isotopic composition of oxygen (CLAYTON *et al.*, 1992). The REE fractionation pattern suggests that Y-74357 was subject to an enhanced degree of partial melting compared to Y-74063 and the fractionation was produced by extraction of plagioclase and orthopyroxene (TORIGOYE *et al.*, 1993).

2. Experimental

2.1. *Samples*

Chips (108 mg) of Y-74063 delivered from NIPR were divided into two parts for noble gas (65 mg) and nitrogen (43 mg; SUGIURA and HASHIZUME, 1991) analyses. From a part of the quota for noble gas analysis, magnetic (Fe-Ni metal, 1.2 mg) and non-magnetic (silicate, 10.0 mg) fractions were separated by means of a hand magnet. The silicate separate was etched in 0.05 M HCl for 3.5 hours at room temperature. These two fractions were analysed by stepwise heating. A chip was mounted in a metal base by means of an inorganic binding (Ceramabond™ 571, Aremco Products, Inc.) and planed gently for laser extraction. In addition, bulk noble gas analyses were performed on another part of Y-74063 (14.3 mg) and -74357 (38.7 mg).

2.2. *Mass spectrometry*

Samples were wrapped in Al-foil and mounted in a sample holder of an extraction line. They were heated in vacuum at 150°C for a night to desorb contaminating atmospheric gases. Both the mineral separates of Y-74063 and the bulk sample of Y-74357 were heated stepwise (30 minutes at each step), while the bulk sample of Y-74063 was heated at 1800°C for 30 minutes. Evolved gases were measured with a VG-5400 mass spectrometer at Okayama University. Typical blanks at 1800°C are: $^{4}\mathrm{He}=5\times10^{-10}$, $^{20}\mathrm{Ne}=4\times10^{-12}$, $^{36}\mathrm{Ar}=1\times10^{-12}$, $^{40}\mathrm{Ar}=3\times10^{-10}$, $^{84}\mathrm{Kr}=5\times10^{-14}$ and $^{132}\mathrm{Xe}=2\times10^{-14}\,\mathrm{cm}^3$ STP. Blanks at lower temperatures are lower. Doubly-charged ^{40}Ar and CO_2 corrections were, respectively, 7 and 0.3% for Y-74063 bulk, 12 to 14% and 5.8 to 8.4% for Y-74063 metal, 9 to 18% and 0.8 to 8.8% for Y-74063 silicate, and 0.7 to 3.6% and 0.05 to 0.4% for Y-74357. The mass spectrometer was calibrated for sensitivities and mass discrimination, using standard gases prepared from a mixture of known amounts of ^{3}He and ^{4}He, and from known amounts of air.

To examine noble gas compositions in mineral grains *in situ*, a 1064 nm beam from a pulsed Nd-YAG laser (pulse width = 1 ms) was focused on the sample to heat grains locally. The diameter of beam was approximately 50 to 100 μm, depending on pulse energy. The meteorite sample which was put on the metal base was placed in a vacuum chamber connected to the purification line of the mass spectrometer, while the laser beam was admitted through a glass window. A mineral grain to be heated was chosen using binoculars. For qualitative analyses of the grains molten by laser shots, the remaining glass melts were analysed with an electron probe microanalyser (EPMA) after noble gas analyses. Blanks of the mass spectrometer system in the laser ablation experiment are: $^4He=5\times10^{-12}$, $^{36}Ar=5\times10^{-13}$, $^{40}Ar=2\times10^{-10}$, $^{84}Kr=2\times10^{-14}$, $^{132}Xe=3\times10^{-15}$ in cm^3 STP.

For decomposition of He, Ne, and Ar into trapped and cosmogenic components, the following isotopic ratios were assumed: for the cosmogenic component, $^3He/^4He=0.2$, $^{20}Ne/^{22}Ne=0.85$, and $^{38}Ar/^{36}Ar=1.55$, and for the trapped component, $^4He/^{20}Ne=220$, $^{20}Ne/^{22}Ne=8.2$, $^{21}Ne/^{22}Ne=0.024$ and $^{38}Ar/^{36}Ar=0.188$.

3. Results

3.1. *Silicate and metal separates of Y-74063*

Concentrations and isotopic ratios of noble gases in the silicate and metal separates are listed in Tables 1, 2 and 3, together with the bulk sample of Y-74063. ^3He is almost completely cosmogenic, while ^4He is a mixture of trapped, cosmogenic and radiogenic gases. Trapped ^4He is estimated to be *ca.* 10 and 20% of the total ^4He, or less, for bulk and silicate, respectively. The ratio of cosmogenic ^3He in the silicate to that in the metal fraction (1.71) is slightly larger than the production ratio of cosmogenic ^3He between silicates and metal (1.54) given by BOGARD and CRESSY (1973).

Because of small sample size and low concentration of Ne, only upper limits are given for ^{20}Ne in the metal separate, while the ^{21}Ne concentration could be determined with large blank corrections (25 to 50%). Ne data at 750 and 1600°C for the silicate separate are unreliable because of the large blank correction more than 35%. Data for the 1000 and 1400°C extraction of the silicate sample, and the bulk samples (this work and TAKAOKA and YOSHIDA, 1991) fall on a correlation line, which indicates Ne-A as the trapped component and a high cosmogenic $^{22}Ne/^{21}Ne$ ratio of 1.31 ± 0.10 with cosmogenic $^{20}Ne/^{22}Ne=0.85$ (Fig. 1).

Argon is essentially a mixture of radiogenic and trapped gases. The low ^{40}Ar content for the metal separate can be assumed to be attributable to its low K content. Assuming 4.6 Ga as the gas retention age, the measured ^{40}Ar corresponds to 21, 380 and 600 ppm K for the metal, silicate and bulk samples, respectively. A K content of 580 ppm for a bulk sample of Y-74063 has been given by YANAI and KOJIMA (1991). Considerable amounts of trapped gases are present in the metal and silicate samples: *e.g.*, 24% and 34% of the trapped ^{36}Ar concentration measured for the bulk sample, respectively. Surprisingly, the trapped $^{36}Ar/^{132}Xe$ ratio is different for the metal and silicate, *i.e.*, 72 and 17, respectively (bulk: 22). This is an indication that both separates contain noble gas hosts, and that the dominant host phase in the metal is different from that in the silicate. Approximately 55% of trapped ^{36}Ar was released from the metal at $\leqq1100$°C, whereas only 32% was released from the silicate at $\leqq1200$°C. Hence the dominant host in the metal fraction has an Ar-retentivity lower than the corresponding phase in the silicate. This is true for Xe, too.

Table 1. Concentrations and isotopic ratios of He, Ne and Ar in Y-74063 and -74357.

Sample	$^{4}\mathrm{He}$[1]	$^{3}\mathrm{He}/^{4}\mathrm{He}$	$^{20}\mathrm{Ne}$[1]	$^{20}\mathrm{Ne}/^{22}\mathrm{Ne}$	$^{21}\mathrm{Ne}/^{22}\mathrm{Ne}$	$^{36}\mathrm{Ar}$[1]	$^{38}\mathrm{Ar}/^{36}\mathrm{Ar}$	$^{40}\mathrm{Ar}/^{36}\mathrm{Ar}$
Y-74063 bulk (14.3 mg)								
	27000	0.00475 ±0.00030	23.4	1.455 ±0.021	0.6768 ±0.0041	1455	0.1898 ±0.0009	33.91 ± 0.10
Y-74063 silicates (10.0 mg)								
750°C	8000	0.00848 ±0.00005	(0.4)[2]	(0.54)[2]	(0.74)[2]	5.7	0.2078 ±0.0058	4613 ±83
1000°C	6100	0.00889 ±0.00030	6.0	1.024 ±0.055	0.748 ±0.019	12	0.1990 ±0.0008	224.4 ± 0.6
1200°C	290	0.00910 ±0.00032	2.8	3.04 ±0.15	0.433 ±0.018	145	0.1889 ±0.0007	2.65 ± 0.03
1400°C	74	0.0087 ±0.0011	10.0	4.53 ±0.21	0.383 ±0.008	311	0.1886 ±0.0007	0.376 ± 0.013
1600°C	nd[3]	nd[3]	(1.3)[2]	(8.7)[2]	(0.19)[2]	35	0.1887 ±0.0007	2.17 ± 0.34
1700°C	nd	nd	nd[3]	nd[3]	nd[3]	0.2	0.1937 ±0.0017	nd[3]
Total	14460	0.00867 ±0.00017	18.8[2]	2.1[2] ±0.4	0.63[2] ±0.03	508.9	0.1892 ±0.0008	58.12[6] ± 0.98
Y-74063 metal (1.2 mg)								
750°C	2800	0.00993 ±0.00030	(<2)[4]	nd	[0.03][5]	33	0.1944 ±0.0022	38.8 ± 0.8
1100°C	2300	0.01785 ±0.00083	(<2)	nd	[0.06]	160	0.1959 ±0.0008	1.95 ± 0.15
1300°C	310	0.0125 ±0.0032	(<7)	nd	[0.09]	110	0.1907 ±0.0008	1.39 ± 0.26
1700°C	nd	nd	(<3)	nd	[0.04]	54	0.1888 ±0.0012	nd
Total	5410	0.01344 ±0.00069	(<14)	nd	[0.22]	357	0.1931 ±0.0010	5.76[6] ± 0.26
Y-74357 bulk (38.7 mg)								
700°C	1530	0.03212 ±0.00017	2.43	1.023 ±0.047	0.960 ±0.041	0.537	0.2388 ±0.0028	5934 ±45
900°C	487	0.03162 ±0.00017	4.79	0.893 ±0.006	0.952 ±0.008	0.160	0.542 ±0.011	26650 ±650
1100°C	221	0.03318 ±0.00033	10.3	0.846 ±0.007	0.928 ±0.008	0.301	0.727 ±0.009	2840 ±35
1300°C	99.2	0.06203 ±0.00099	8.27	0.868 ±0.016	0.919 ±0.012	0.484	0.7691 ±0.0056	4363 ±34
1800°C	50.9	0.0939 ±0.0025	17.2	0.861 ±0.002	0.924 ±0.008	1.43	0.7234 ±0.0023	347.3 ± 0.6
Total	2390	0.03468 ±0.00027	43.0	0.870 ±0.009	0.929 ±0.010	2.91	0.6320 ±0.0041	3528 ±54

[1] Noble gas concentrations are given in units of $10^{-9}\,\mathrm{cm^3}$ STP/g. Errors are less than 10%.

[2] Data with blank correction more than 35% are given in parentheses. Totals do not include these data.

[3] nd = not determined.

[4] Upper limits given in parentheses were calculated assuming 50% uncertainty in blank level.

[5] $^{21}\mathrm{Ne}$ concentrations are given in brackets. Blank correction is 25% (for 1300°C) to 50% (for 750°C).

[6] Total $^{40}\mathrm{Ar}/^{36}\mathrm{Ar}$ was calculated with data excluding 1700°C fraction.

Table 2. Concentrations and isotopic ratios of Kr in Y-74063 and -74357.

Sample	^{84}Kr1)	^{78}Kr	^{80}Kr	^{82}Kr	^{83}Kr	^{84}Kr	^{86}Kr
Y-74063 bulk (14.3 mg)							
	55.3	0.604	3.926	20.19	20.23	=100	31.02
		±0.011	±0.025	±0.06	±0.07		±0.08
Y-74063 silicate (10.0 mg)							
750°C	0.14	0.60	4.39	20.32	19.99	=100	30.40
		±0.47	±0.63	±0.33	±0.70		±0.91
1000°C	0.55	0.69	3.97	20.63	20.35	=100	30.60
		±0.10	±0.14	±0.28	±0.51		±0.45
1200°C	6.8	0.612	3.959	20.24	20.28	=100	30.82
		±0.017	±0.056	±0.15	±0.08		±0.11
1400°C	9.4	0.605	3.972	20.19	20.16	=100	30.87
		±0.021	±0.034	±0.11	±0.13		±0.12
1600°C	1.4	0.616	3.825	20.08	20.21	=100	30.95
		±0.073	±0.148	±0.39	±0.17		±0.42
1700°C	0.04	nd2)	4.11	20.0	21.2	=100	31.4
			±0.59	±1.6	±1.8		±2.5
Total	18.33	0.610	3.959	20.21	20.22	=100	30.85
		±0.029	±0.060	±0.16	±0.13		±0.16
Y-74063 metal (1.2 mg)							
750°C	0.19	nd	3.5	19.05	20.3	=100	31.8
			±1.2	±0.94	±2.2		±1.8
1100°C	0.96	0.85	4.96	20.85	20.05	=100	30.78
		±0.35	±0.90	±0.85	±0.61		±0.82
1300°C	1.4	0.78	4.26	20.70	21.01	=100	31.25
		±0.27	±0.39	±0.77	±0.79		±0.67
1700°C	1.1	1.03	4.33	20.4	20.48	=100	30.8
		±0.34	±0.34	±1.2	±0.37		±1.0
Total	6.35	0.88	4.43	20.56	20.56	=100	31.02
		±0.21	±0.55	±0.93	±0.69		±0.87
Y-74357 bulk (38.7 mg)							
700°C	0.0621	0.69	4.25	20.1	20.7	=100	30.34
		±0.12	±0.30	±0.9	±0.5		±0.63
900°C	0.00385	0.77	6.65	20.2	20.7	=100	29.0
		±0.42	±0.62	±1.5	±1.0		±2.2
1100°C	0.00235	0.73	5.4	21.9	22.5	=100	30.9
		±0.64	±1.2	±3.6	±4.4		±4.7
1300°C	0.00698	0.85	5.15	20.2	21.4	=100	28.8
		±0.30	±0.67	±1.6	±2.0		±2.0
1800°C	0.0198	0.71	4.28	20.3	20.0	=100	31.5
		±0.15	±0.22	±1.3	±1.2		±1.1
Total	0.0951	0.71	4.45	20.2	20.7	=100	30.4
		±0.16	±0.35	±1.1	±0.9		±1.0

1) Concentrations are given in unit of 10^{-9} cm^3 STP/g and errors are less than 10%.

2) nd = not determined.

Kr and Xe are mostly of trapped origin. A notable signature for Kr and Xe is their apparent isotopic homogeneity. In particular, the ^{129}Xe/^{132}Xe ratio is practically constant for all temperature fractions of both mineral separates, except for the 750°C fraction of metal that is affected by terrestrial contamination. There is no indication of

Table 3. Concentrations and isotopic ratios of Xe in Y-74063 and -74357.

Sample	$^{132}Xe^{1)}$	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
Y-74063 bulk (14.3 mg)										
	66.5	0.466	0.416	8.30	110.50	16.32	82.29	=100	37.60	31.29
		±0.009	±0.007	±0.03	±0.21	±0.04	±0.20		±0.08	±0.08
Y-74063 silicate (10.0 mg)										
750°C	0.20	0.65	0.42	7.99	109.1	15.85	82.03	=100	37.57	31.42
		±0.16	±0.11	±0.36	±1.2	±0.29	±0.74		±0.65	±0.67
1000°C	0.82	0.462	0.413	8.145	109.25	16.21	81.88	=100	37.99	31.98
		±0.023	±0.055	±0.086	±0.59	±0.11	±0.51		±0.37	±0.30
1200°C	6.20	0.4574	0.4080	8.113	109.33	16.159	81.738	=100	37.930	31.855
		±0.0096	±0.0092	±0.044	±0.21	±0.075	±0.055		±0.091	±0.055
1400°C	17.0	0.4532	0.4053	8.115	109.17	16.147	81.73	=100	37.965	31.885
		±0.0061	±0.0033	±0.020	±0.10	±0.028	±0.13		±0.075	±0.041
1600°C	5.80	0.4537	0.4039	8.121	109.59	16.18	81.95	=100	38.022	32.046
		±0.0041	±0.0061	±0.052	±0.28	±0.10	±0.17		±0.076	±0.082
1700°C	0.12	0.48	0.54	8.08	108.5	15.81	80.54	=100	37.86	31.81
		±0.17	±0.31	±0.47	±1.7	±0.31	±0.91		±0.93	±0.53
Total	30.14	0.4558	0.4064	8.116	109.28	16.154	81.78	=100	37.966	31.909
		±0.0086	±0.0084	±0.037	±0.18	±0.057	±0.14		±0.094	±0.065
Y-74063 metal (1.2 mg)										
750°C	0.13	nd[2]	nd[2]	8.0	103.9	15.8	81.4	=100	38.3	30.7
				±2.0	±6.5	±2.1	±8.3		±1.4	±2.8
1100°C	1.4	0.54	0.50	8.14	109.2	16.22	82.4	=100	37.9	31.4
		±0.29	±0.21	±0.47	±2.3	±0.65	±1.3		±1.0	±0.3
1300°C	1.6	0.51	0.47	8.12	110.0	16.2	81.4	=100	38.2	31.5
		±0.24	±0.22	±0.56	±1.6	±0.4	±0.5		±0.4	±0.4
1700°C	1.8	0.63	0.52	8.25	109.2	16.1	82.5	=100	38.2	32.2
		±0.15	±0.10	±0.26	±1.5	±0.3	±1.0		±0.9	±0.4
Total	4.93	0.56	0.55	8.17	109.3	16.16	82.1	=100	38.11	31.71
		±0.12	±0.17	±0.46	±1.9	±0.48	±1.1		±0.78	±0.43
Y-74357 bulk (38.7 mg)										
700°C	0.0352	0.44	0.48	7.44	98.8	15.9	79.9	=100	39.2	32.5
		±0.18	±0.10	±0.40	±2.2	±0.8	±2.8		±1.5	±0.9
900°C	0.00434	nd	nd	7.2	103.6	15.4	80.0	=100	40.6	32.9
				±1.1	±8.7	±1.4	±8.9		±4.7	±3.8
1100°C	0.00313	nd	nd	6.4	116.8	15.2	83.0	=100	42.3	32.9
				±0.9	±8.2	±1.8	±3.9		±3.2	±2.5
1300°C	0.00433	nd	nd	7.4	158.3	17.3	78.3	=100	39.5	33.5
				±1.4	±9.9	±2.1	±6.0		±2.6	±2.8
1800°C	0.00630	nd	nd	7.1	159.1	15.1	77.9	=100	37.7	32.8
				±0.9	±4.4	±1.9	±5.3		±2.8	±2.6
Total	0.0533	(0.44)	(0.48)	7.32	112.2	15.8	79.7	=100	39.3	32.7
				±0.63	±4.0	±1.1	±3.9		±2.1	±1.6

[1] Concentrations are given in unit of 10^{-9} cm^3 STP/g and errors are less than 10%.
[2] nd = not determined.

a contribution from *in situ* decay of ^{129}I. Rather the noble gas hosts in both silicate and metal separates are likely to have acquired their trapped gases from a single gas-reservoir, after most radioactive ^{129}I had decayed to ^{129}Xe. Except at ^{129}Xe, the isotopic ratios of Kr and Xe are identical with those for Q-gas (WIELER *et al.*, 1991,

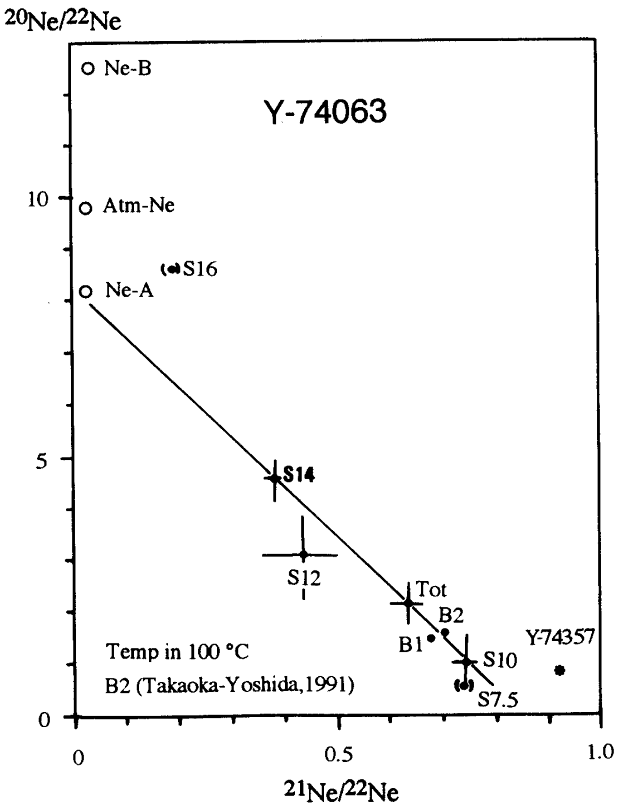

Fig. 1. Three-isotope plot for bulk samples, and temperature fractions of silicate separate of Y-74063. Data for 750 and 1600°C fractions shown in parentheses are unreliable because of blank correction exceeding 35%. Deviation of 1200°C point from the correlation line may be attributable to large blank correction (20 %). Least squares fitting to bulk samples, and 1000 and 1400°C fractions gives trapped $^{20}\mathrm{Ne}/^{22}\mathrm{Ne}=7.83\pm0.20$ *and cosmogenic* $^{22}\mathrm{Ne}/^{21}\mathrm{Ne}=1.31\pm0.10$ *with trapped* $^{21}\mathrm{Ne}/^{22}\mathrm{Ne}=0.024$ *and cosmogenic* $^{20}\mathrm{Ne}/^{22}\mathrm{Ne}=0.85$*, respectively.*

1992) found in carbonaceous and ordinary chondrites.

3.2. Noble gases released from Y-74063 by laser ablation

Result of the laser ablation experiment is given in Table 4, together with data of the bulk, silicate and metal samples for comparison. Full data are available on request. Pits 1 to 8 are the result of 10 to 21 shots of 0.3 J per pulse (typically 10 pulses/s). Pits 10 to 21 were shot by a single pulse of 0.075 J, whereas pit 9 was bored by 6 shots of 0.075 J/pulse. The amounts of ^{3}He evolved per pulse of a constant energy are constant within a factor of, for instance, 1.9 for 0.075 J/pulse, whereas ^{36}Ar and ^{132}Xe are variable up to a factor of 43. Since ^{3}He is cosmogenic, its distribution is supposed to be ubiquitous and homogeneous within the variance of the production rate among mineral grains. ^{4}He is much more variable up to a factor of 78, whereas ^{40}Ar is variable by a factor of 6.2, suggesting that U and Th are more concentrated in specific minerals than K.

In order to compare noble gas abundances released by laser ablation with one another and also with the noble gas concentrations for the bulk samples and mineral

Table 4. Normalized releases and elemental ratios of noble gases from Y-74063 by laser ablation method. Data for bulk, silicate and metal samples (totals) are given for comparison.

Pit No.	Weight[1] of melt (μg)	^{4}He[2]	^{36}Ar[3]	^{40}Ar[2]	^{132}Xe[3]	^{36}Ar/^{132}Xe	^{84}Kr/^{132}Xe	Comments
1	35	6.9	190	30	12	16	0.48	silicate (ol)
2	42	19	830	50	26	32	0.38	troilite
3	33	25	1400	43	76	19	0.60	silicate (ol/px)
4	39	4.0	440	30	9.0	49	0.54	metal
5	42	33	1400	82	55	26	0.48	troilite
6	26	8.9	580	41	20	29	1.4	silicate
7	79	6.4	710	12	5.2	140	1.0	metal
8	38	12	370	31	3.7	100	1.6	metal
9	11	4.9	740	25	35	21	0.17	silicate
10	1.8	12	56	nd[4]	1.5	37	nd[4]	silicate
11	1.3	11	1300	44	4.8	260	1.6	silicate
12	1.8	12	1100	86	32	33	0.33	troilite
13	2.1	150	160	92	32	5.2	0.14	silicate
14	1.2	9.2	1400	160	65	22	0.33	silicate
15	1.8	8.3	710	140	12	59	1.1	silicate
16	2.1	2.0	530	62	3.3	160	0.59	metal
17	1.9	17	2000	34	61	33	0.38	silic./tiny incl.
18	1.8	13	2100	26	28	76	0.35	silic./tiny incl.
19	2.3	4.7	380	67	39	15	0.21	troilite
20	1.4	11	290	90	19	15	0.44	silicate
21	1.3	108	600	54	26	23	1.8	silicate
Bulk (14.3 mg)		27.0	1460	49.3	66.5	22.0	0.832	this work
Silicate (10.0 mg)		14.5	509	29.3	30.1	16.9	0.608	this work
Metal (1.2 mg)		5.41	357	1.76	4.93	72.4	0.740	this work

[1] Weight of melt was calculated by dividing measured ^{3}He by cosmogenic ^{3}He determined for the silicate or metal separates (Table 1).

[2] Normalized releases for ^{4}He and ^{40}Ar are given in units of 10^{-6} cm^{3} STP/g.

[3] Normalized releases for ^{36}Ar and ^{132}Xe are given in units of 10^{-9} cm^{3} STP/g.

[4] nd = not determined.

separates, we estimate the weight ablated by laser shots, by dividing ^{3}He measured for each pit by the ^{3}He concentration determined for the silicate or metal separates. Concentrations of noble gas X in pit j can be given by,

$$C(X)_j = f_X C(^3\mathrm{He})[X]_j/[^3\mathrm{He}]_j,$$

where f_X is a fractionation coefficient for X that depends on degassing feasibility between He and X, and $C(^3\mathrm{He})$ is the concentration of ^{3}He determined for the silicate or metal separates. Since data are not available on fractionation of noble gases on instantaneous degassing by laser ablation, "normalized release" will be used for the concentration assuming $f_X = 1$: $NR(X) = C(^3\mathrm{He})[X]_j/[^3\mathrm{He}]_j$.

However, the laser beam did not always ablate a single mineral grain, and sometimes mineral grains adjacent to the target grain were also molten. Only when a large grain was shot by a single pulse, one pit corresponds to one mineral grain, because repetition of many shots with high energy (*e.g.*, 0.3 J/pulse) might bore a deep pit into adjacent grains.

In addition, the degassing process on laser ablation is controversial. For quantitative extraction of cosmogenic gases from a sizable sample of iron meteorite, melting is not sufficient. The iron has to be evaporated. On the other hand, noble gases can be quantitatively extracted from a sizable sample of stony meteorite with a prolonged heating time (*e.g.*, 10 min). In the present case of laser ablation, the heating time per pulse is 1 ms. When a sample grain was shot, some portion of it was evaporated and/or splashed to deposit on a cover glass that was placed at 5 mm above the sample, and the other portion, which was seemingly more than the deposits on the cover glass, remained as melt. The extraction yield and the elemental fractionation on laser ablation are important issues to be addressed in future works.

The most prominent observation is that most grains released large amounts of trapped gases with inferred concentrations similar to the one measured in the bulk analysis, suggesting that the trapped gases are not concentrated in specific mineral grains but dispersed in many grains. Among 21 pits, two and one pits give normalized releases higher than the concentrations of trapped Ar and Xe, respectively, in the bulk sample, whereas 10 pits have normalized releases higher than the concentration of radiogenic ^{40}Ar for the bulk. This may reflect partly a difference in the degassing feasibility between the noble gas components and partly a non-uniform distribution of noble gases among mineral grains.

The normalized amount of Xe released from metallic grains (pits 4, 7, 8 and 16) is low, and some silicates (pits 1, 10, 11 and 15) also have low Xe abundances. The mean Xe normalized release from pits 4, 7, 8 and 16 is 5.3×10^{-9} cm^3 STP/g, in agreement with the Xe content in the metal separate of 4.9×10^{-9} cm^3 STP/g. Pits 1 and 10 (silicates) are low in both ^{36}Ar and ^{132}Xe. Pit 11 with low Xe, however, is high in ^{36}Ar, the ^{36}Ar/^{132}Xe ratio being as high as 260. High concentrations of Xe are found in some silicate grains (pits 3, 14 and 17). Pit 17 is a silicate grain containing tiny inclusions of metal and troilite. Pits 3 and 14 may also be such silicates that contain dusty inclusions, although none were observed on the surface before laser ablation.

High normalized releases of ^{4}He and ^{40}Ar indicate that pits 5 and 13 are enriched in U/Th and K. Pit 21 that is enriched in ^{4}He includes phosphates, according to EPMA data. Pits 14 and 15 are highly enriched in ^{40}Ar. Metallic grains are not always depleted in ^{4}He (*e.g.*, pit 8) and ^{40}Ar (*e.g.*, pit 16). This may reflect the existence of phosphides in metal and degassing from grain boundaries and/or adjacent grains.

3.3. *Noble gases in Y-74357*

Concentrations and isotopic ratios of noble gases for the bulk sample of Y-74357 are given in Tables 1, 2 and 3. ^{3}He and Ne are mostly cosmogenic, and ^{4}He is a mixture mostly of cosmogenic and radiogenic gases. An upper limit of trapped ^{4}He is 2.3×10^{-7} cm^3 STP/g. However, considerable amounts of trapped Ar, Kr and Xe were released at 700°C. The ^{129}Xe/^{132}Xe ratio at 700°C is similar to the atmospheric ratio. Hence the trapped gases released at 700°C are likely due to terrestrial contamination. The large errors for isotopic ratios of Kr and Xe released above 700°C are due to low gas concentration and small sample size. With those large errors, the samll amounts of gases are indistinguishable from air in their composition except at ^{129}Xe, and a detailed comparison with gases obtained in other meteorites is precluded.

4. Discussion

4.1. *Trapped gases and their host in Y-74063*

The ^{36}Ar/^{132}Xe ratio for the silicate separate is 17. In the laser extraction, four pits gave ratios lower than 17, with pit 13 giving the lowest ratio of 5.2. This pit is low in Ar and intermediate in Xe abundance. Since it is rich in ^{4}He, the low ^{36}Ar is unlikely to be caused by preferential loss of Ar by diffusion. Pits 1 and 20 that have ^{36}Ar/^{132}Xe ratios lower than 17 also have low ^{36}Ar abundances. This suggests the existence in silicate grains of at least one trapped gas with ^{36}Ar/^{132}Xe less than 17; a ratio less than 5 is suggested by the result for pit 13.

As mentioned in the previous section, the ^{36}Ar/^{132}Xe ratio for the metal separate is 72. However, five pits on laser ablation give ^{36}Ar/^{132}Xe ratios higher than 72. Among them, pit 7, 8 and 16 that are metallic, give 100 to 160. These high ratios suggest that, if we take the face values, the metal separate may contain at least two trapped gases: one with ^{36}Ar/^{132}Xe $\geqq 72$ and another with a lower ratio.

On the other hand, pit 11, a silicate grain with low Ca and Al (probably olivine or Ca-poor pyroxene according to EPMA data) gives an even higher ratio of 260 for ^{36}Ar/^{132}Xe. Its low ^{40}Ar abundance indicates a low K abundance. This grain contains trapped gas of high ^{36}Ar/^{132}Xe with an average Ar concentration but very low Xe abundance. High Ar/Xe and low Xe abundance are also characteristic of metallic grains, as mentioned earlier.

It is informative to look at the data in a ^{36}Ar/^{132}Xe *vs.* ^{84}Kr/^{132}Xe diagram (Fig. 2), where a correlation seems to exist between Y-74063, Acapulco (PALME *et al.*, 1981), Acapulco-type ALHA77081 (SCHULTZ *et al.*, 1982), Q-gases (WIELER *et al.*, 1991, 1992), Kakangari (SRINIVASAN and ANDERS, 1977), Sharps (ZADNIK, 1985) and ALH-77015 (TAKAOKA *et al.*, 1981). In particular, the latter two are unique type-3 ordinary chondrites containing graphite-magnetite aggregates (MCKINLEY *et al.*, 1981). The correlation found between those unique meteorites and the planetary Q-gas suggests that trapped gas of low ^{36}Ar/^{132}Xe can be generated from planetary gas as a precursor, by first removing such gases of high ^{36}Ar/^{132}Xe as trapped in Sharps (Fig. 2). The noble gas hosts in those unique meteorites are possible candidates for host phases that removed light gases preferentially.

In summary, the trapped gases in Y-74063 can be distinguished into at least two groups: one has a high Ar/Xe ratio and is most prominent in metal, and the other has a low Ar/Xe ratio and dominates in silicates and in troilite. The high Ar/Xe ratios found for metal pits and silicate pit 11 indicate that gas of high Ar/Xe resides not only in metal but also in some silicate grains. If we take the currently prevailing view that trapped gases are carried by specific minerals, at least two major carrier phases are required as hosts of the two groups of trapped gases. However, almost all minerals released large amounts of trapped gases, as found in laser extraction. This suggests that the trapped gases are contained by the major minerals and not by trace carrier phases. Y-74063 was formed in a melt pocket by partial melting of a chondritic precursor

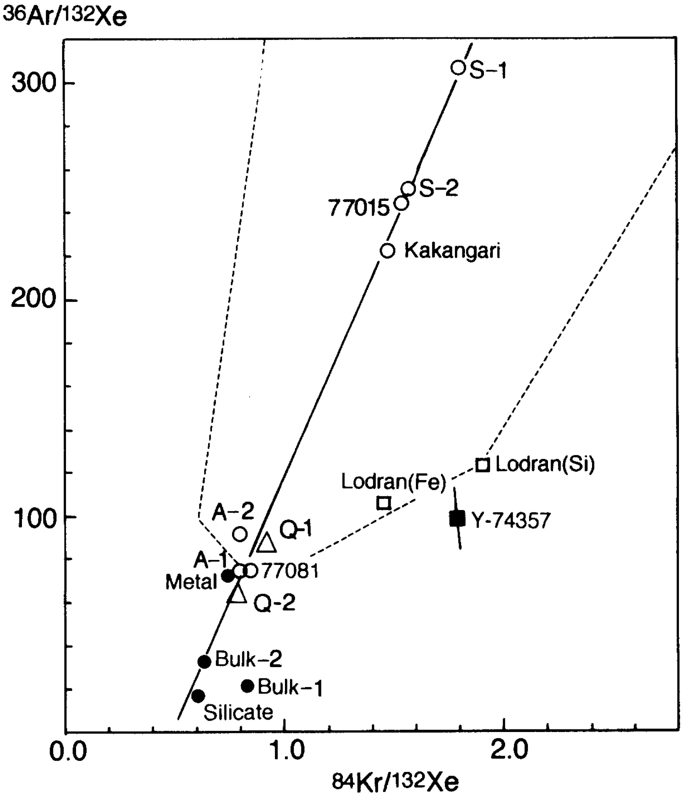

Fig. 2. Plot of $^{36}Ar/^{132}Xe$ *vs.* $^{84}Kr/^{132}Xe$. *Bulk sample, silicate and metal fractions of Y-74063, except Bulk-1, lie on a mixing line with the planetary Q-gas (Q-1 and -2), Acapulco (A-1 and -2), ALHA77081, Kakangari, ALH-77015 and Sharps (S-1 and -2). The latter two are unique type-3 chondrites containing graphite-magnetite aggregates. Y-74357 and Lodran are definitely off the correlation line. This correlation offers a suggestion for the origin of the gas with low Ar/Xe found in Y-74063. Data field of carbonaceous, enstatite and ordinary chondrites, and ureilites is shown by dotted lines.*

Data sources: Bulk-1, this work; Bulk-2, TAKAOKA and YOSHIDA, 1991;Silicate, this work; Metal, this work; Q-1, WIELER et al., 1991; Q-2, WIELER et al., 1992; A-1 (Acapulco C) and A-2 (Acapulco D), PALME et al., 1981; ALHA77081, SCHULTZ et al., 1982; Kakangari, SRINIVASAN and ANDERS, 1977; ALH-77015, TAKAOKA et al., 1981; S-1 (Sharps A) and S-2 (Sharps B), ZADNIK, 1985; Y-74357, this work; Lodran (Fe and Silicate), ZÄHRINGER, 1968.

(NAGAHARA *et al.*, 1990). In this case, the wide variation of the elemental ratio must be a reflection of the elemental fractionation during noble gas trapping in a melt pocket on the parent body. A possible scenario taking into account the noble gas and petrologic constraints is that in a melt pocket which was enriched in planetary gas, gas of high Ar/Xe was trapped by some minerals which grew according to chemical reactions in the pocket. After those minerals were separated from the melt pocket and thus gas of high Ar/Xe was removed from the planetary gas, a fraction of noble gas with low Ar/Xe remained to be trapped by other minerals.

In spite of the variable concentrations and elemental abundance ratios of the trapped gas, no isotopic variation, in particular at ^{129}Xe, has been detected except for isotopes (^{4}He and ^{40}Ar) affected by long-lived radioactive precursors. The homogeneity of the isotopic composition suggests that the trapped gas was acquired from a single gas reservoir, after most radioactive ^{129}I had decayed to ^{129}Xe.

4.2. *Trapped gases in Y-74357*

As mentioned earlier, trapped gases in the 700°C fraction are mostly of terrestrial origin due to atmospheric adsorption. Excluding this fraction, although the small amounts of Kr and Xe are indistinguishable from air in their isotopic composition except at ^{129}Xe, Y-74357 is similar to Lodran (Zähringer, 1968) in ^{36}Ar/^{132}Xe and ^{84}Kr/^{132}Xe ratios, but deviates significantly from the correlation line for Y-74063, Acapulco and ALHA77081 (Fig. 2). Y-74357 and Lodran, therefore, seem to have experienced a different history of elemental fractionation, possibly under different conditions in a parent body.

4.3. *Gas-retention and cosmic-ray exposure ages of Y-74063 and -74375*

Radiogenic ^{4}He and ^{40}Ar are summarized in Table 5. No data on the U content are available for Y-74063 and -74357. The K_2O content of 0.07 wt% (Yanai and Kojima, 1991) combined with our Ar analysis gives a K-Ar age of 4.6 Ga for Y-74063. If we accept for Y-74357 K contents of 35 and 50 ppm, as reported by Torigoye *et al.* (1993) and Fukuoka and Kimura (1990), respectively, nominal K-Ar ages are 6.8 and 6.1 Ga, which clearly exceed the age of the solar system. The K content of our sample appears to have been much higher, or otherwise, the meteorite may contain excess ^{40}Ar.

Cosmogenic ^{22}Ne/^{21}Ne, which is diagnostic for shielding depth, is calculated to be 1.31±0.10 for Y-74063. This high ratio indicates that Y-74063 was irradiated near the surface of a meteoroid or in a small meteoroid. The production rate for LL-chondrites, derived from Eugster (1988), was used because the meteorite is

Table 5. Gas-retention and cosmic-ray exposure ages for Y-74063 and -74357.

Meteorite	Radiogenic[1] ^{40}Ar	K (ppm)	T_{40} (Ga)	Cosmogenic[1]			Production rate[2]			T_3	T_{21}	T_{38}
				^{3}He	^{21}Ne	^{38}Ar	P_3	P_{21}	P_{38}	(Ma)		
Y-74063	49300	580[3]	4.6[4]	128	10.9	nd[5]	15.3[6]	1.75[6]	—	8.4	6.2	nd[5]
bulk	±4930		±0.4	±13	±1.1		±0.6	±0.42		±0.9	±1.3	
Y-74357	10110	nd[7]	nd[7]	82.8	45.9	1.47	16.3[6]	3.92[6]	0.49	5.1	11.7	3.0
bulk	±1010			±8.3	±4.6	±0.15	±0.5	±0.32	±0.02	±0.5	±1.5	±0.3
				(1.80	=1	0.032)	(4.2	=1	0.13)			
							—	4.5[8]	—	—	10.1[8]	—
								±0.4			±1.3	

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[1] Concentrations are given in units of 10^{-9} cm^3 STP/g.

[2] Production rates are given in units of 10^{-9} cm^3 STP/gMa.

[3] Yanai and Kojima (1991).

[4] Error was calculated assuming uncertainties of 10% for radiogenic ^{40}Ar and 20% for K.

[5] nd = not determined.

[6] Eugster (1988).

[7] Torigoye *et al.* (1993) and Fukuoka and Kimura (1990) have reported 35 and 50 ppm K, respectively. With these K contents, the K-Ar age exceeds the age of the solar system.

[8] Corrected for Mg content (×1.3; Torigoye *et al.*, 1993).

similar to LL-chondrites in Mg and Si contents (YANAI and KOJIMA, 1991). The cosmic-ray exposure age (6.2 Ma) obtained here agrees well with that reported by TAKAOKA and YOSHIDA (1991). The cosmic-ray age and cosmogenic ^{21}Ne in the metal separate (Table 1) can give a fractional production rate from Fe-Ni which is between 2.3 and 4.7×10^{-11} cm^3 STP/gFeNi/Ma.

The cosmogenic ^{22}Ne/^{21}Ne ratio of 1.076 for Y-74357 indicates that it was irradiated at an intermediate depth of a meteoroid. Cosmogenic ^{3}He/^{21}Ne and ^{38}Ar/^{21}Ne ratios are significantly lower than the ratios of production rates found for chondritic target chemistry, as given in Table 5. Y-74357 is enriched in Mg by a factor of 1.3 and depleted in Ca by a factor of 1.4, compared to L-chondrites (TORIGOYE *et al.*, 1993). Although the correction for target chemistry lessens the difference between the measured ratios and the calculated ones, the measured ^{38}Ar/^{21}Ne ratio is still significantly lower than the calculated one. Our sample appears, therefore, to be even more depleted in Ca than the one analyzed by TORIGOYE *et al.* (1993). Assuming enrichment of Mg by a factor of 1.3, the calculated ^{21}Ne cosmic-ray exposure age is 10.1 ± 1.3 Ma. This age is significantly longer than that for Y-74063 (6.2 Ma: this work), Acapulco (7.1 Ma: data given by PALME *et al.*, 1981, recalculated with the production rate given by EUGSTER, 1988) and ALHA77081 (5.6 Ma: SCHULTZ *et al.*, 1982).

5. Summary

Measurements of noble gas isotopes have been carried out for the unique meteorites Y-74063 and -74357 with affinities to Acapulco and Lodran. Results are:

(1) Y-74063 bulk contains large amounts of trapped Ar, Kr and Xe, whereas Y-74357 is highly depleted in trapped gases.

(2) A three-isotope plot of Ne for Y-74063 indicates that trapped Ne is Ne-A and cosmogenic ^{22}Ne/^{21}Ne is high (1.31), accordingly irradiated near the surface of a meteoroid or in a small meteoroid. The cosmic-ray exposure age for Y-74063 is 6.2 ± 1.3 Ma. The cosmic-ray age and cosmogenic ^{21}Ne in metal give the fractional production rate from Fe-Ni between 2.3 and 4.7×10^{-11} cm^3 STP/gFeNi per Ma.

(3) The isotopic compositions of Kr and Xe are homogeneous and identical with those of planetary Q-gases except at ^{129}Xe. ^{129}Xe/^{132}Xe is identical for almost all temperature fractions of silicate and metal separates of Y-74063.

(4) Both separates of Y-74063 retain considerable amounts of trapped gases. Trapped ^{36}Ar/^{132}Xe is 17 and 72 for silicate and metal, respectively. This may indicate that the noble gas hosts are different for both separates. The constancy of ^{129}Xe/^{132}Xe suggests that the trapped gases were acquired from a single gas-reservoir after most radioactive ^{129}I had decayed to ^{129}Xe, and that the elemental abundance ratios were fractionated during trapping. The origin of gas with low Ar/Xe is discussed, based on a correlation between ^{36}Ar/^{132}Xe and ^{84}Kr/^{132}Xe for Y-74063, other unique meteorites and the planetary Q-gas.

(5) Laser ablation of mineral grains revealed that trapped gases are not concentrated in specific mineral grains, but contained in almost all grains. Among them, such grains that contain tiny inclusions of metal and troilite are rich in trapped gases, especially in Ar, whereas some silicate grains are relatively depleted.

(6) Cosmogenic $^{22}Ne/^{21}Ne$ for Y-74357 indicates that the stone was irradiated at an intermediate depth of a meteoroid. The low $^{3}He/^{21}Ne$ and $^{38}Ar/^{21}Ne$ ratios suggest an excess of Mg and a deficit of Ca in Y-74357 compared to chondrites. Correction for target chemistry (Mg) gives a tentative age of 10.1 ± 1.3 Ma for its cosmic-ray exposure.

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