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NOBLE GASES IN HOSTS AND INCLUSIONS FROM YAMATO-75097 (L6), -793241 (L6) AND -794046 (H5)

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Abstract: Noble gas analyses for the inclusions and hosts from Yamato(Y)-75097, Y-793241 and Y-794046 have been performed. The concordant exposure ages as well as gas retention ages are observed between the host and the inclusion of each meteorite. These indicate that both experienced the same heating event and exposure history. High ^{129}Xe/^{132}Xe ratios ($\cong$50) and neutron induced ^{80}Kr, ^{82}Kr and ^{128}Xe are due to very low concentrations of trapped noble gases in the inclusions from Y-75097 and Y-793241. This indicates a close genetic relationship and an early crystallization when ^{129}I was still alive. The inclusion of Y-794046, however, has a noble gas signature which is quite different from the other ones, suggesting a different origin. Negligible amounts of radiogenic ^{129}Xe and fissiogenic ^{136}Xe suggest a late formation.

1. Introduction

As a part of the consortium studies on Yamato(Y)-75097, -793241 and -794046, noble gas isotopic ratios and concentrations were measured in these three meteorites, which have large igneous inclusions. Descriptions of petrology, mineralogy and chronology of these meteorites are reviewed by YANAI and KOJIMA (1993) and NAKAMURA *et al.* (1993). Photographic displays are presented in the photographic catalog (YANAI and KOJIMA, 1987). The Y-75097 (L6) and Y-793241 (L6) chondrites contain dunitic inclusions, and a harzburgitic inclusion is found in the Y-794046 (H5) chondrite. The inclusion of Y-75097 is similar to the Brachina meteorite in mineral assemblage and texture (YANAI *et al.*, 1983; YANAI and KOJIMA, 1993). As a preliminary investigation of noble gases, total melt extractions were performed for both the inclusions and the hosts of these meteorites (NAGAO, 1993). Because noble gas data are informative for genetic relationships between host and inclusion of the meteorite, they are presented here as a progress report. More detailed studies will be carried out in the future.

2. Experimental Procedures and Results

Samples allocated for noble gas studies were as follows:

Y-75097,106 host (291 mg),
Y-75097,109 inclusion (97 mg),
Y-793241,88 host (272 mg),

Y-793241,63 inclusion (189 mg),
Y-794046,63 host (311 mg), and
Y-794046,99 inclusion (361 mg).

For the noble gas analysis, the samples were crushed to coarse grains, *ca.* ≅2 mm. About half of the allocated material was used for this work. The noble gas mass spectrometry applied for these meteorites is described in detail elsewhere (*e.g.*, NAGAO and MIURA, 1993; NAGAO *et al.*, 1993). Only a brief description is given here.

The samples were wrapped in Al-foil and put in a sample holder connected to the gas extraction line and heated to about 180°C for 24 hours in vacuum to reduce adsorbed atmospheric noble gas contamination. Noble gases of the meteorite samples were extracted by heating at 1700°C for 30 min in a Mo crucible and then purified with Ti-Zr getters. Separation into four fractions, He-Ne, Ar, Kr and Xe was carried out by a charcoal trap before introducing the individual fraction into the mass spectrometer (modified VG5400). Hot blank levels were 2×10^{-9}, 2×10^{-12}, 5×10^{-9}, 4×10^{-13} and $4\times10^{-14}\,cm^3STP$ for ^4He, ^{20}Ne, ^{40}Ar, ^{84}Kr and ^{132}Xe, respectively. Correction for $^{40}Ar^{++}$ at ^{20}Ne was smaller than 0.7% and that of CO_2^{++} at ^{22}Ne was negligible. Calibrated amounts of atmospheric gas were used as a standard to determine the sensitivities and mass discrimination of the mass spectrometer. Isotopic ratios and concentrations obtained in this work are presented in Tables 1–3. The errors for the isotopic ratios are statistical one (1σ) and the analytical uncertainties for gas concentrations are estimated to be about 10% for He and Kr, and about 5% for Ne, Ar and Xe. Decomposition of noble gases into trapped, cosmogenic and fissiogenic components was carried out following EUGSTER *et al.* (1993).

Table 1. Concentrations and isotopic ratios of He, Ne and Ar.

Meteorite	^4He	^{20}Ne	^{36}Ar	^{40}Ar	$^3He/^4He$	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$
	($10^{-8}cm^3STP/g$)								
Y-75097									
Host (L6)	338	8.01	2.32	240	0.1083	0.843	0.931	0.503	103.5
(113.1 mg)					±0.0009	±0.002	±0.003	±0.001	±0.1
Inclusion	271	9.43	0.645	205	0.1407	0.844	0.943	1.018	317.7
(56.5 mg)					±0.0014	±0.002	±0.003	±0.002	±0.3
Y-793241									
Host (L6)	1750	5.99	1.30	6110	0.0227	0.816	0.837	0.716	4711
(86.3 mg)					±0.0002	±0.002	±0.003	±0.001	±10
Inclusion	268	7.06	0.390	3550	0.1457	0.825	0.835	1.326	9105
(113.2 mg)					±0.0012	±0.002	±0.003	±0.005	±60
Y-794046									
Host (H5)	33.1	0.891	0.500	577	0.0529	0.858	0.921	0.372	1154
(133.0 mg)					±0.0005	±0.002	±0.004	±0.001	±1
Inclusion	18.3	1.48	0.220	2280	0.0953	1.016	0.904	0.727	10350
(185.9 mg)					±0.0008	±0.003	±0.003	±0.005	±100

Table 2. Concentration and isotopic composition of Kr.

Meteorite	^{84}Kr (10^{-12}cm^{3}STP/g)	^{78}Kr	^{80}Kr	^{81}Kr	^{82}Kr	^{83}Kr	^{86}Kr
		^{84}Kr = 100					
Y-75097							
Host (L6)	61.4	1.35	7.22	0.05	23.8	25.2	30.1
(113.1 mg)		±0.04	±0.17	±0.03	±0.6	±0.5	±0.4
Inclusion	16.2	4.00	37.8	0.14	44.1	40.7	28.3
(56.5 mg)		±0.17	±1.2	±0.12	±2.5	±1.2	±1.7
Y-793241							
Host (L6)	62.9	1.95	13.8	0.05	25.0	28.3	30.0
(86.3 mg)		±0.15	±0.4	±0.09	±0.5	±1.1	±0.7
Inclusion	36.6	3.14	27.9	0.08	33.7	31.7	29.0
(113.2 mg)		±0.27	±0.6	±0.09	±1.0	±0.6	±1.2
Y-794046							
Host (H5)	57.6	0.70	4.94	0.06	20.6	20.7	31.4
(133.0 mg)		±0.05	±0.16	±0.05	±0.5	±0.9	±1.1
Inclusion	73.1	0.71	5.88	0.04	20.8	20.8	30.2
(185.9 mg)		±0.05	±0.23	±0.02	±0.3	±0.4	±0.5

Table 3. Concentration and isotopic composition of Xe.

Meteorite	^{132}Xe (10^{-12}cm^{3}STP/g)	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
		^{132}Xe = 100							
Y-75097									
Host (L6)	56.0	0.64	0.78	8.68	119.0	16.4	82.3	38.8	32.4
(113.1 mg)		±0.06	±0.10	±0.11	±1.6	±0.4	±1.6	±0.8	±0.5
Inclusion	7.5	2.7	4.1	34.7	4970	14.0	75.0	58.1	56.7
(56.5 mg)		±0.3	±0.6	±3.3	±130	±1.1	±4.6	±3.0	±3.9
Y-793241									
Host (L6)	50.2	0.67	0.81	8,73	114.1	16.5	82.2	39.5	33.6
(86.3 mg)		±0.03	±0.04	±0.34	±1.6	±0.4	±0.8	±1.1	±0.6
Inclusion	14.3	0.88	1.25	14.2	4720	16.4	81.5	38.5	32.6
(113.2 mg)		±0.19	±0.18	±0.6	±70	±0.6	±1.1	±1.2	±0.9
Y-794046									
Host (H5)	87.9	0.50	0.45	8.35	134.1	16.4	81.9	38.3	32.2
(133.0 mg)		±0.04	±0.03	±0.13	±1.2	±0.2	±1.1	±0.3	±0.3
Inclusion	22.5	0.42	0.47	7.57	99.3	15.6	78.9	38.9	33.0
(185.9 mg)		±0.03	±0.07	±0.31	±1.7	±0.6	±1.4	±0.7	±0.5

3. Trapped Noble Gases

Trapped ^{36}Ar, ^{84}Kr and ^{132}Xe concentrations in the hosts and the inclusions of Y-75097, Y-793241 and Y-794046 are given in Table 4. Trapped He and Ne isotopes could not be identified due to overwhelming cosmogenic He and Ne and radiogenic ^{4}He. The Y-794046 inclusion is an exception; a small amount of trapped ^{20}Ne, $\cong 0.2 \times 10^{-8}$ cm^{3}STP/g is observed. The trapped heavy noble gas concentrations in the

Table 4. Trapped ^{36}Ar, ^{84}Kr and ^{132}Xe concentrations.

Meteorite	^{36}Ar	^{84}Kr	^{132}Xe	^{36}Ar/^{132}Xe	^{84}Kr/^{132}Xe
	(10^{-12}cm^{3}STP/g)				
Y-75097					
Host (L6)	17800	60	55.7	320	1.1
Inclusion	2520	15	5.05	499	2.9
Y-793241					
Host (L6)	7950	61	49.1	162	1.2
Inclusion	640	34	14.1	45.4	2.4
Y-794046					
Host (H5)	4320	58	87.8	49.2	0.67
Inclusion	1330	72	22.5	59.1	3.2

hosts of these meteorites are in the range for type 6 ordinary chondrites (MARTI, 1967), consistent with the classification for Y-75097 (L6) and Y-793241 (L6), but discordant with the petrologic type 5 for the Y-794046 host. The concentrations in the inclusions are very low which might be the result of intensive degassing during their formation in the parent bodies.

The trapped noble gas compositions for these meteorites are investigated in Fig. 1. Several noble gas components and meteorites are plotted for comparison (see caption of Fig. 1). Y-793241 host and Y-794046 host fall in the range of chondrites. Y-75097 host is enriched in Ar compared to the hosts of Y-793241 and Y-794046. The high ^{36}Ar/^{132}Xe ratio of 320, however, is confirmed by TAKAOKA *et al.* (1981) [^{36}Ar/^{132}Xe$=240$]. The inclusion of Y-75097 indicates enrichments in Ar and Kr compared to its host and is plotted in the field for E-chondrites with a subsolar or Ar-rich noble gas component (CRABB and ANDERS, 1981; WACKER and MARTI, 1983). The Ar/Xe ratios higher than that for the typical planetary gases are found in other meteorites such as CO3, some ureilites, aubrites and unequilibrated ordinary chondrites (SWINDLE, 1988). These results mean that the Y-75097 inclusion contains a trapped noble gas component similar to that of E-chondrites. This is confirmed by the noble gas data of the Y-75097 inclusion given by OTT *et al.* (1993).

Two inclusions from Y-793241 and Y-794046 are plotted on a lower part of the array (dotted line in Fig. 1) for the SNC meteorites Shergotty, Nakhla and Chassigny (OTT, 1988), the Martian atmosphere (OWEN *et al.*, 1977) and the Earth's atmosphere. The linear array is distinct from that of chondrites as pointed out by OTT and BEGEMANN (1985), though the reason for the linear trend is still unexplained (*e.g.*, OWEN *et al.*, 1992; OZIMA and WADA, 1993). Some non-chondritic meteorites with low concentrations of trapped noble gases also lie along the trend. Furthermore, some terrestrial volcanic rocks derived from the earth's mantle overlap the field for SNCs. They argued that the noble gas composition for the terrestrial volcanic rocks is controlled by some elemental fractionation processes such as adsorption, absorption, partial melting and bubbling, which produce a linear trend on the logarithmic scale (OZIMA and WADA, 1993; WADA and OZIMA, 1993). Though the Y-793241 inclusion is similar to that of Y-75097 (PRINZ *et al.*, 1984),

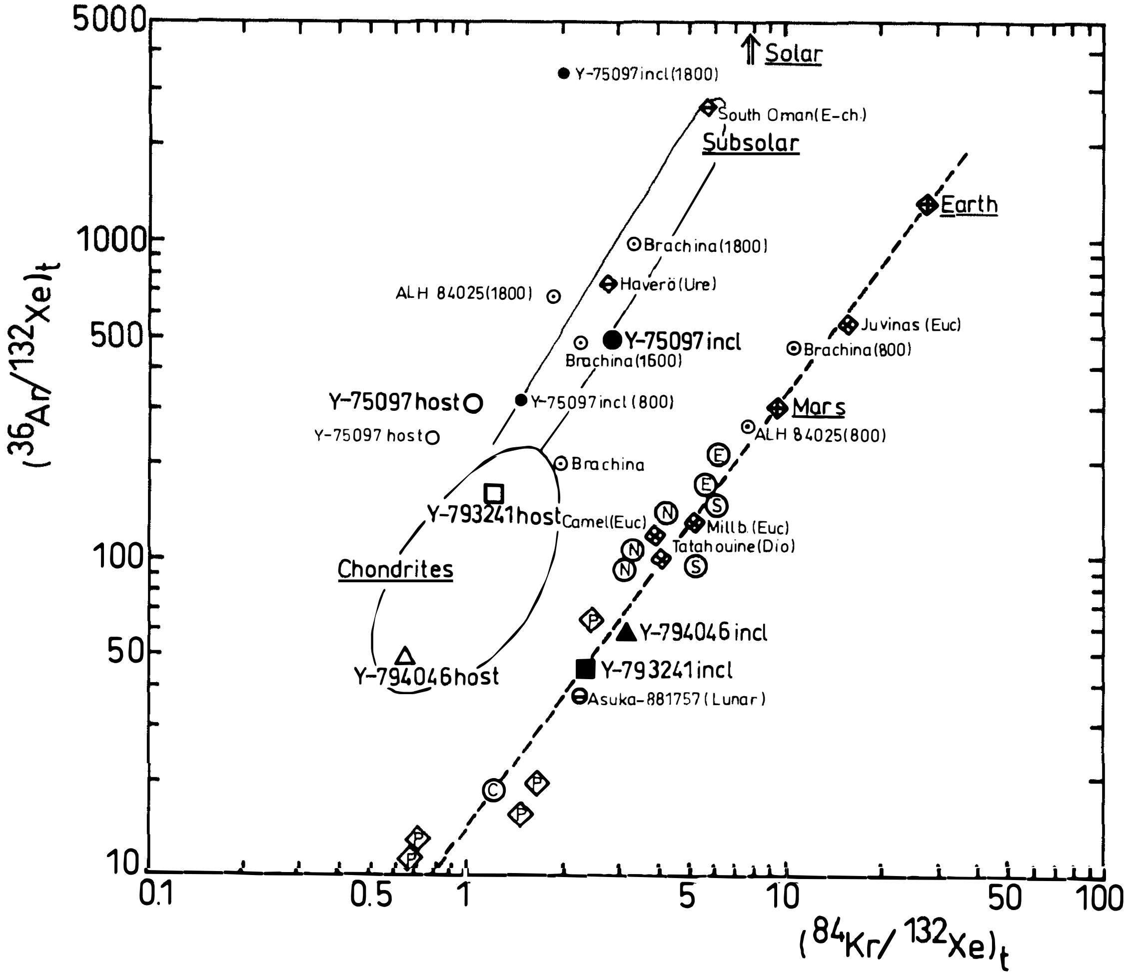

Fig. 1. Plot of trapped ^{36}Ar/^{132}Xe versus ^{84}Kr/^{132}Xe ratios. References: Stepped heating on Y-75097 inclusion, Brachina and ALH 84025 brachinite (Ott et al., 1985, 1993); Brachina (Bogard et al., 1983); Y-75097 host (Takaoka et al., 1981); South Oman enstatite chondrite (Crabb and Anders, 1981); Haverö ureilite (Weber et al., 1976); S-Shergotty, N-Nakhla and C-Chassigny (Ott, 1988); E-EETA 79001 shergottite lithology A (Bogard et al., 1984); Millbillillie, Camel Donga and Juvinas eucrites (Miura et al., 1993); Tatahouine diogenite (Michel and Eugster, 1994); Asuka-881757 lunar meteorite (Nagao and Miura, 1993); P-silicate in a pallasite (Nagao, unpublished); Mars-Martian atmosphere (Owen et al., 1977).

the different composition of trapped noble gases between them suggests that they are not paired. While two inclusions of Y-793241 and Y-794046 are similar in respect to the trapped Ar, Kr and Xe compositions, their isotopic compositions of Xe are quite different from each other (Fig. 2), suggesting different origins of these inclusions as will be discussed later. It is not clear at present why the noble gases from various materials of different origins show a common linear trend in Fig. 1. Since the noble gas concentrations for these meteorites are very low, some degassing and/or adsorbing processes might be responsible for these elemental compositions.

4. Cosmic-Ray Produced Noble Gases

4.1. Cosmic-ray exposure ages

Concentrations of cosmogenic noble gases, ^{3}He, ^{21}Ne, ^{38}Ar, ^{81}Kr, ^{83}Kr and ^{126}Xe, and some isotopic ratios of cosmogenic Ne, Kr and Xe are presented in Table 5. Because the host meteorites are chondritic (L6 and H5), AVCC-Xe (EUGSTER *et al.*, 1967) was assumed to be trapped Xe to calculate isotopic ratios of cosmogenic and fissiogenic Xe. AVCC-Xe was also assumed for the inclusions of Y-75097 and Y-793241. For the inclusion of Y-794046 atmospheric Xe was used because of its similarity to the atmospheric Xe composition (Fig. 2). The high δ-values of light isotopes are due to the cosmic-ray products.

Cosmic-ray exposure ages are calculated using the cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar concentrations. The calculation was not applied for ^{83}Kr and ^{126}Xe because of relatively large uncertainties of their concentrations and unavailability of data for their target elements. The production rates calculated are given in Table 6. For the correction for shielding depths cosmogenic ^{22}Ne/^{21}Ne ratios (Table 5) are used (P_3 and P_{21}: EUGSTER (1988); P_{38}: SCHULTZ *et al.* (1991)). Because chemical compositions of inclusions are different from the chondritic ones (YANAI *et al.*, 1983; WARREN and KALLEMEYN, 1989; YANAI and KOJIMA, 1993; FUKUOKA, 1993; NAKAMURA *et al.*, 1993, 1994), the production rates were corrected for their chemical compositions with the methods of EUGSTER (1988) using the available data on chemical compositions which are summarized in Table A1 (Appendix). The correction for P_3 from L chondrites is small ($<4\%$), while the production rates of P_{21} of inclusions are 22–30% larger than that for L-chondrites, due to the high concentration of Mg. On the other hand, low concentrations of Ca in inclusions of Y-75097 and Y-793241 reduce their production rates of P_{38} to 52–67% of that for L-chondrites.

Calculated cosmic-ray exposure ages, T_3, T_{21} and T_{38}, are also given in Table 6. The ages based on ^{3}He, ^{21}Ne and ^{38}Ar for each sample are generally in good agreement. The only exception is T_3 of Y-794046, which is much lower than T_{21} and T_{38}, suggesting He loss from both the host and the inclusion. For Y-75097 and Y-793241 the ages obtained for host and inclusion agree very well (21.1 ± 0.9 and 21.1 ± 1.8 Ma for Y-75097 and 24.2 ± 1.5 and 23.8 ± 0.5 Ma for Y-793241) indicating the same exposure history for both host and inclusion. The age for Y-793241 is about 3 Ma longer than that for Y-75097. Because the agreement among the ages based on cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar is excellent for each meteorite, the difference between the two meteorites seems to be real, which means that they are not paired.

Y-794046 (H5) has an exposure age of about 3 Ma, much shorter than both other L6 chondrites. Though the exposure age (3.3 Ma) of its inclusion is slightly longer than that of the host (2.7 Ma), it is not clear at present whether the difference of about 0.5 Ma is real.

An apparent exposure age calculated by ^{81}Kr-Kr method can give a terrestrial age in combination with a real exposure age (FREUNDEL *et al.*, 1986). Our data of

Table 5. *Cosmogenic noble gas concentrations and isotopic ratios.*

Meteorite	^{3}He	^{21}Ne	^{38}Ar	^{81}Kr	^{83}Kr	^{126}Xe	^{22}Ne/^{21}Ne	^{78}Kr/^{83}Kr	^{80}Kr/^{83}Kr	^{82}Kr/^{83}Kr	^{124}Xe/^{126}Xe	^{128}Xe/^{126}Xe	^{130}Xe/^{126}Xe
	(10^{-8}cm^{3}STP/g)			(10^{-12}cm^{3}STP/g)									
Y-75097													
Host	36.6	8.84	0.834	0.029	3.48	0.208	1.0743	0.136	0.61	0.75	0.50	1.4	1.1
	±3.7	±0.44	±0.042	±0.018	±0.46	±0.056	±0.0035	±0.014	±0.07	±0.17	±0.22	±0.5	±1.2
Inclusion	38.1	10.55	0.610	0.023	3.65	0.283	1.0601	0.154	1.52	1.15	0.64	7.7	0.8
	±3.8	±0.53	±0.031	±0.020	±0.43	±0.048	±0.0037	±0.013	±0.11	±0.15	±0.13	±1.5	±0.4
Y-793241													
Host	39.8	6.15	0.782	0.031	5.57	0.203	1.1945	0.155	1.13	0.63	0.55	1.7	1.9
	±4.0	±0.31	±0.039	±0.054	±0.82	±0.024	±0.0043	±0.025	±0.14	±0.17	±0.10	±0.9	±1.1
Inclusion	39.1	7.15	0.506	0.028	4.74	0.121	1.1972	0.200	1.87	1.16	0.50	7.3	0.6
	±3.9	±0.36	±0.025	±0.031	±0.58	±0.026	±0.0043	±0.025	±0.14	±0.14	±0.24	±1.7	±0.8
Y-794046													
Host	1.75	0.957	0.105	0.037	0.15	0.038	1.0853	0.4	4	0.7	0.9	3.8	7.8
	±0.18	±0.048	±0.005	±0.032	±0.66	±0.030	±0.0047	±1.6	±16	±6.6	±1.1	±4.4	±7.3
Inclusion	1.75	1.32	0.135	0.026	0.64	0.030	1.1064	0.12	2.2	0.9	0.46	3.3	3.1
	±0.18	±0.07	±0.007	±0.015	±0.38	±0.016	±0.0039	±0.09	±1.3	±1.0	±0.36	±2.9	±4.5
Spallation (Marti *et al.*, 1966)								0.179	0.495	0.765	0.59	1.45	0.97

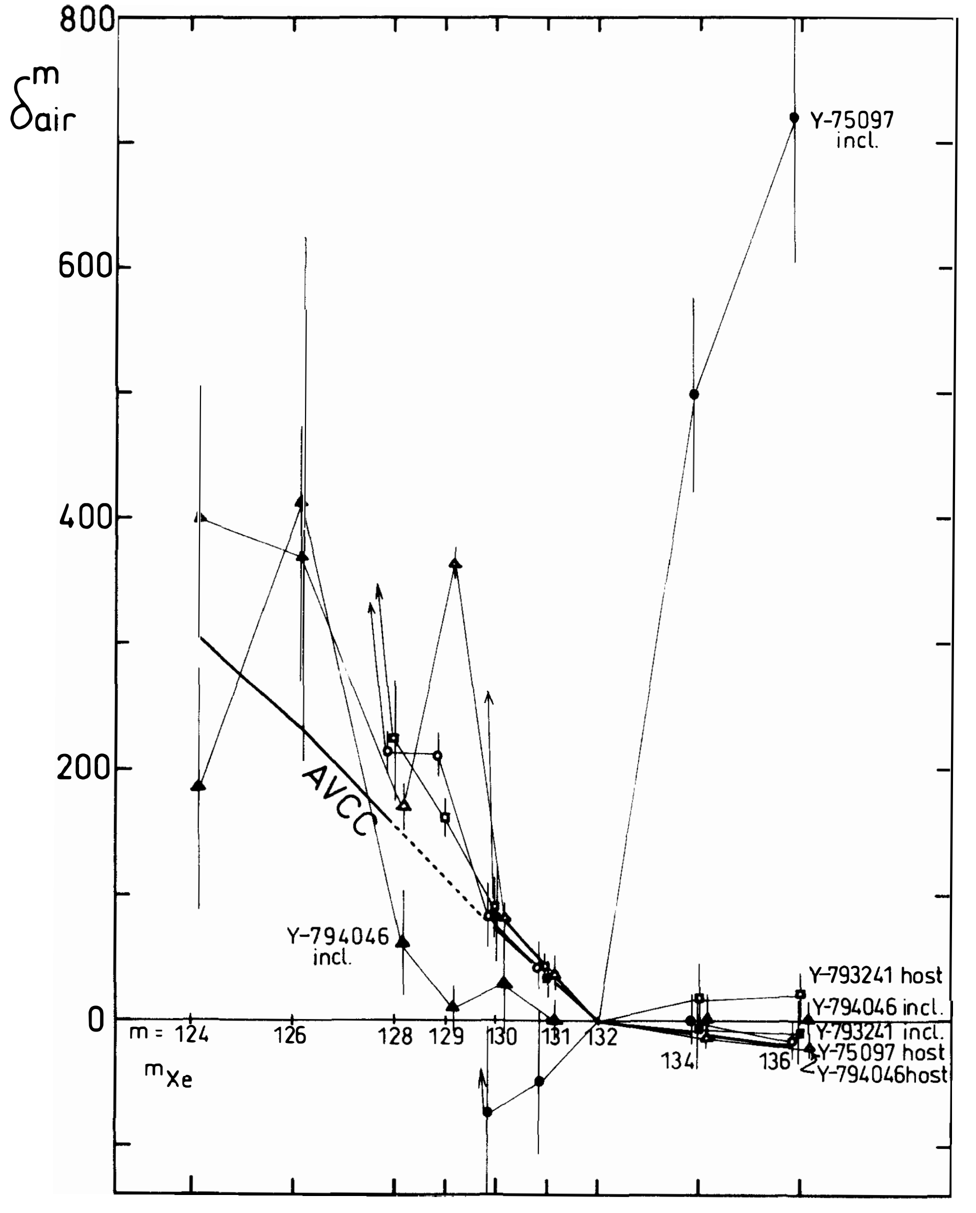

Fig. 2. Plot of δ-values defined by, $\delta^m_{air}=[(^mXe/^{132}Xe)_{sample}/(^mXe/^{132}Xe)_{air}-1]\times 1000$. *Large δ-values for* ^{134}Xe *and* ^{136}Xe *of Y-75097 are due to fission Xe. Trapped Xe isotopic compositions in Y-794046 inclusion are likely atmospheric. Large δ-values for light isotopes are due to cosmogenic and radiogenic* ^{129}Xe*, some of which are beyond the scale.*

^{81}Kr have large experimental uncertainties due to low concentrations of ^{81}Kr ($\leq 3\times 10^{-14}$ cm^{3}STP/g) and small sample sizes used, thus, only upper limits of terrestrial ages can be given (<0.14, <0.33 and <0.21 Ma for Y-75097, Y-793241 and Y-794046, respectively).

4.2. Neutron induced ^{80}Kr, ^{82}Kr and ^{128}Xe

Cosmogenic Kr and Xe isotopic ratios in Y-75097 and Y-793241 (Table 5) show excesses in ^{80}Kr, ^{82}Kr and ^{128}Xe compared to pure spallogenic Kr and Xe

Table 6. Production rates of cosmogenic nuclides and cosmic-ray exposure ages (Ma).

	$P_3$$^{1)}$	$P_{21}$$^{1)}$	$P_{38}$$^{2)}$	T_3	T_{21}	T_{38}	$T_{average}$$^{3)}$
Y-75097							
Host (L6)	1.64$^{A)}$	0.417$^{A)}$	0.0400$^{A)}$	22.3±2.2	21.2±1.1	20.9±1.1	21.1±0.9
			0.0414$^{C)}$			20.1±1.0	
Inclusion	1.68$^{A)}$	0.553$^{A)}$	0.0236$^{A)}$	22.7±2.3	19.1±1.0	(25.8±1.3)	21.1±1.8
			0.0285$^{C)}$			21.4±1.1	
Y-793241							
Host (L6)	1.58$^{A)}$	0.250$^{A)}$	0.0351$^{A)}$	25.2±2.5	24.6±1.2	22.3±1.1	24.2±1.5
	1.57$^{B)}$	0.244$^{B)}$	0.0351$^{B)}$	25.4±2.5	25.2±1.3	22.3±1.1	
Inclusion	1.62$^{A)}$	0.311$^{A)}$	0.0176$^{A)}$	24.1±2.4	23.0±1.2	(28.8±1.4)	23.8±0.5
	1.62$^{B)}$	0.297$^{B)}$	0.0213$^{B)}$	24.2±2.4	24.1±1.2	23.8±1.2	
Y-794046							
Host (H5)	1.60$^{B)}$	0.356$^{B)}$	0.0381$^{B)}$	(1.09±0.11)	2.69±0.13	2.76±0.13	2.73±0.05
Inclusion	1.69$^{A)}$	0.426$^{A)}$	0.0375$^{A)}$	(1.04±0.11)	3.10±0.16	3.60±0.19	3.26±0.23
	1.69$^{B)}$	0.412$^{B)}$	0.0428$^{B)}$	(1.04±0.11)	3.20±0.17	3.15±0.16	

$^{1)}$ and $^{2)}$ Production rates (10^{-8}cm^{3}STP/gMa) calculated using the formulas by EUGSTER (1988) and SCHULTZ *et al.* (1991), respectively.

$^{3)}$ Exposure ages in parentheses were not used in the calculation of averages.

$^{A)}$ and $^{B)}$ Chemical compositions by YANAI and KOJIMA (1993) and FUKUOKA (1993), respectively, were used for the correction of target element compositions.

$^{C)}$ K concentrations by NAKAMURA *et al.* (1994) were used for the correction.

Table 7. ^{80}Kr, ^{82}Kr and ^{128}Xe produced from neutron capture on Br and I, radiogenic ^{129}Xe, and fissiogenic Xe.

Meteorite	^{80}Kr$_n$	^{82}Kr$_n$	^{128}Xe$_n$	(^{80}Kr/^{82}Kr)$_n$	^{129}Xe$_{rad}$	^{136}Xe$_{fiss}$	(^{134}Xe/^{136}Xe)$_{fiss}$
	(10^{-12}cm^{3}STP/g)				(10^{-12}cm^{3}STP/g)		
Y-75097							
Host (L6)	0.38±0.24	<0.54	<0.10	—	8.6±1.5	0.28±0.39	—
Inclusion	3.7 ±0.6	1.4±0.6	1.8 ±0.5	2.6±1.2	367±22	2.63±0.43	0.92±0.18
Y-793241							
Host (L6)	3.6 ±0.9	<0.20	<0.24	—	6.1±1.4	1.09±0.42	0.96±0.64
Inclusion	6.5 ±1.0	1.9±0.7	0.70±0.25	3.4±1.4	661±34	0.12±0.18	—
Y-794046							
Host (H5)	<3.8	<0.97	<0.27	—	26.7±1.9	0.13±0.37	—
Inclusion	1.09±1.05	<0.73	<0.15	—	<0.73	0.00±0.14	—

(MARTI *et al.*, 1966). Such excesses in ^{82}Kr and ^{128}Xe cannot be observed in the host phases of either meteorite. Because the ^{80}Kr/^{82}Kr excess ratios, 2.6±1.2 and 3.4±1.4 of Y-75097 and Y-793241, respectively (Table 7), agree with the theoretical production ratio by neutron capture on ^{79}Br and ^{81}Br (MARTI *et al.*, 1966), the excesses are attributed to isotopes produced by the neutron capture on Br and I. The neutron induced ^{80}Kr concentrations are in the range for ordinary chondrites reported by EUGSTER *et al.* (1993). The enhanced isotopic anomalies are observed because of the low concentrations of trapped Kr and Xe in the meteorites. Br concentrations for these meteorites have not been measured yet; therefore, an estimation of their preatmospheric sizes in space based on the slowing down density for epithermal neutrons is not possible.

5. Gas Retention Ages

5.1. *K-Ar ages*

Concentrations of radiogenic ^{40}Ar, determined in this work, and K concentrations reported by NAKAMURA *et al.* (1994) and FUKUOKA (1993), give the K-Ar ages listed in Table 8. The ^{40}Ar concentrations of 220×10^{-8} cm^{3}STP/g in the host of Y-75097 reported by TAKAOKA *et al.* (1981) and KANEOKA *et al.* (1988) agree with the value given in Table 8, if 5% uncertainty is assumed for these concentrations.

Low K-Ar ages of 599±36 and 485±30 Ma are obtained for the host and the inclusion of Y-75097, respectively. This meteorite is heavily shocked with shock veins running also through the inclusion (YANAI *et al.*, 1983; YANAI and KOJIMA, 1993; NAKAMURA *et al.*, 1993). ^{40}Ar-^{39}Ar dating of Y-75097 host has given the plateau age of 490 Ma (KANEOKA *et al.*, 1988). The K-Ar age (485±30 Ma) for the inclusion agrees well with the plateau age. These results indicate that this L6 chondrite suffered a well known impact event for the L chondrite group ≅0.5 Ga ago (ANDERS, 1964; BOGARD *et al.*, 1976; WASSON and WANG, 1991). Rb-Sr model age of 3.91 Ga for whole rock of Y-75097 (NAKAMURA *et al.*, 1984) indicates incomplete resetting of the Rb-Sr system in spite of almost perfect resetting of K-Ar one.

Table 8. Concentrations of radiogenic ^{40}Ar and ^{4}He, and K-Ar and U, Th-He ages.

Meteorite	^{40}Ar (10^{-8} cm^{3}STP/g)	K (ppm)	K-Ar age (Ma)	^{4}He (10^{-8} cm^{3}STP/g)	U (ppb)	U, Th-He age (Ma)
Y-75097						
Host (L6)	240± 12	870± 44[1]	599± 36	148± 34	13±10%[3]	490±160
Inclusion	205± 10	950± 48[1]	485± 30	73± 27	6.4±3.3[4]	
Y-793241						
Host (L6)	6110±310	756± 38[1] 870±130[2]	4560±120 4330±260	1540±175	13±10%[3]	3710±490
Inclusion	3550±180	526± 26[1] 490± 70[2]	4270±120 4380±250	65± 27	0.55±0.26[4]	
Y-794046						
Host (H5)	577± 29	691± 35[1] 400± 60[2]	1420± 70 2020±190	24± 3	12±10%[3]	90± 20
Inclusion	2280±110	1780± 89[1] 1760±110[2]	1880± 80 1890± 90	9± 2	4.5±1.5[4]	

[1] Isotope dilution mass spectrometry by NAKAMURA *et al.* (1994). Though experimental errors given by them are less than 2%, 5% error was assigned considering heterogeneity of K concentration in the sample.

[2] INAA by FUKUOKA (1993) and 15% error was assumed except for Y-794046 inclusion for which 6% error was assumed (see Table 1 by FUKUOKA, 1993).

[3] Average values for L and H chondrites (WASSON and KALLEMEYN, 1988).

[4] Calculated from the ^{4}He concentrations of inclusions and the U, Th-He ages of their hosts.

Yamato-793241 yields K-Ar ages of 4.56±0.12 Ga (756 ppm K: NAKAMURA *et al.*, 1994) and 4.33±0.26 Ga (870 ppm K: FUKUOKA, 1993) for the host and 4.27 ±0.12 Ga (526 ppm K: NAKAMURA *et al.*, 1994) and 4.38±0.25 Ga (490 ppm K: FUKUOKA, 1993) for the inclusion, which are concordant for both phases. Rb-Sr model ages for the inclusion and the host are 4.45 Ga (NAKAMURA *et al.*, 1984) and 4.4 Ga (NAKAMURA *et al.*, 1993), respectively. Almost concordant K-Ar and Rb-Sr ages for both the host and the inclusion of Y-793241 are compatible with the unshocked petrographic features (NAKAMURA *et al.*, 1993).

Yamato-794046 yields K-Ar ages of 1.42±0.07 Ga (691 ppm K: NAKAMURA *et al.*, 1994) and 2.02±0.19 Ga (400 ppm K: FUKUOKA, 1993) for the host and 1.88 ±0.08 Ga (1780 ppm K: NAKAMURA *et al.*, 1994) and 1.89±0.09 Ga (1760 ppm K: FUKUOKA, 1993) for the inclusion. This agreement of ages indicates that one heating event thoroughly reset the K-Ar system for both phases. Rb-Sr isochron ages of 3.6 and 3.8 Ga for the host and the inclusion of this meteorite (FUJIMAKI *et al.*, 1993) are substantially older than the K-Ar ages. This suggests at least two major thermal events, one reset the Rb-Sr clock 3.8–3.6 Ga ago and another reset only K-Ar system without disturbance for Rb-Sr one about 1.9 Ga ago.

The K-Ar ages obtained for three meteorites show that the inclusions were emplaced in the host meteorites before or at the heating events resetting K-Ar systems for both host and inclusion of each meteorite.

5.2. *U, Th-He ages*

Since the retention of radiogenic and cosmogenic He gives information concerning the heating event(s) which occurred on the parent body or during cosmic-ray exposure age (EUGSTER *et al.*, 1993), U, Th-He ages based on the average U and Th concentrations (WASSON and KALLEMEYN, 1988) are given in Table 8. The U, Th-He age of 490±160 Ma for the Y-75097 host agrees with the K-Ar age (599± 36 Ma) within errors. He loss from this meteorite is not serious, which is supported by the concordant exposure ages based on the cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar. Somewhat lower U, Th-He age of 3710±490 Ma compared to the K-Ar age is obtained for the host of Y-793241. The He loss must have occurred before or at separation of the meteoroid from the parent body, because the cosmogenic He has been retained perfectly in this meteorite (Table 6). Substantial loss of both radiogenic ^{4}He and cosmogenic ^{3}He from Y-794046 is indicated by the very short U, Th-He age of 90±20 Ma (Table 8) and the short exposure age (T_3) compared to T_{21} and T_{38} (Table 6). This meteorite might have passed near the sun and been affected by solar radiation as suggested by EUGSTER *et al.* (1993) for the meteorites showing loss of both cosmogenic and radiogenic He.

U concentrations of the inclusions calculated based on the K-Ar ages, the concentrations of radiogenic ^{4}He and Th/U=3.6 are given in Table 8. Though the low concentrations of U and Th should be partly due to a He loss from the inclusions, they seem to have resulted from intensive elemental fractionation (NAKAMURA *et al.*, 1993; FUKUOKA, 1993).

6. Radiogenic ^{129}Xe and Fissiogenic Xe

6.1. *Unusually high ^{129}Xe/^{132}Xe in the inclusions of Y-75097 and Y-793241*

The most characteristic isotopic ratio observed in this work is the very high ^{129}Xe/^{132}Xe for the inclusions of Y-75097 and Y-793241, which are 49.7±1.3 and 47.2±0.7, respectively. An even more enhanced ratio, 84.9±5.0, was observed in a high temperature fraction by a stepped heating experiment on the inclusion of Y-75097 (OTT *et al.*, 1993). The concentrations of radiogenic ^{129}Xe are calculated to be 367±22 and 661±34×10^{-12}cm^{3}STP/g for Y-75097 and Y-793241 inclusions, respectively (Table 7), which show a clear contrast to the low concentrations in their hosts. The ^{129}Xe$_{\mathrm{rad}}$ concentration of Y-75097 inclusion is in good agreement with the value 3.4×10^{-10}cm^{3}STP/g presented by OTT *et al.* (1993). Since the radiogenic ^{129}Xe concentrations are rather high but in the range for ordinary chondrites (*e.g.*, EUGSTER *et al.*, 1993), these high ratios are mainly due to the low concentrations of trapped Xe. If both inclusions originally contained similar concentrations of radiogenic ^{129}Xe and trapped Xe, the low concentrations in the Y-75097 inclusion might be caused by partial degassing by the impact event which occurred 490 Ma ago, which reset the K-Ar system of Y-75097.

Because the Y-75097 and Y-793241 have similar exposure ages, the concentrations of both radiogenic ^{129}Xe and neutron induced ^{128}Xe, which are produced from I, should depend roughly on I concentration and ^{129}I/^{127}I ratio at the beginning of Xe retention. The concentration of neutron induced ^{128}Xe in the Y-75097 inclusion is 2.5 times higher than that in the Y-793241 inclusion (Table 7). This requires 2.5 times larger concentration of ^{129}Xe$_{\mathrm{rad}}$ in the Y-75097 inclusion compared to that in the Y-793241, if we assume common (^{129}I/^{127}I)$_{\mathrm{i}}$ for these inclusions. The observed ^{129}Xe$_{\mathrm{rad}}$ concentrations, however, are higher in Y-793241 than in Y-75097. This may suggest either a loss of ^{129}Xe$_{\mathrm{rad}}$ from the Y-75097 inclusion ($\cong$80% of total ^{129}Xe) or an earlier retention of ^{129}Xe$_{\mathrm{rad}}$ (>2x half-life of ^{129}I) in the Y-793241 inclusion than in the Y-75097 inclusion. Both cases are unlikely because most ^{244}Pu-fission Xe is retained in the Y-75097 inclusion and it presumably started to retain the fission Xe not later than the Y-793241 inclusion (Table 9). Therefore it is difficult at present to give a concordant scenario for these inclusions based on the available data.

The radiogenic ^{129}Xe concentration of the Y-794046 host is 27×10^{-12}cm^3 STP/g, 3–4 times those of the hosts from Y-75097 and Y-793241. On the other hand, the ^{129}Xe/^{132}Xe ratio in its inclusion is 0.993±0.017, which is not in the range for ordinary chondrites (*e.g.*, EUGSTER *et al.*, 1993; NAGAO *et al.*, 1993) but is identical with that for diogenites (MICHEL and EUGSTER, 1994) and with the atmospheric value. Accordingly, the concentration of radiogenic ^{129}Xe is negligible if atmospheric Xe is adopted as trapped Xe and, thus, only an upper limit is given in Table 7. This inclusion is quite different from the two inclusions of Y-75097 and Y-793241 in respect to the Xe isotopic composition.

6.2. ^{244}Pu fission Xe and ^{244}Pu-Xe retention ages

Relative enrichments in heavy Xe isotopes of Y-75097 inclusion are demonstrated in Fig. 2. Fissiogenic ^{136}Xe concentrations are presented in Table 7. The $^{136}Xe_{fiss}$ concentration in the Y-75097 inclusion, 2.6×10^{-12} cm^{3}STP/g, is about 4 times higher than the value of $\cong 0.7\times10^{-12}$ cm^{3}STP/g given by OTT *et al.* (1993). This indicates a heterogeneous concentration of fissiogenic Xe and, accordingly, heterogeneity of their parent nuclides within the inclusion. $(^{134}Xe/^{136}Xe)_{fiss}$ ratios are 0.92 ± 0.18 and 0.96 ± 0.64 (Table 7) for the Y-75097 inclusion and the Y-793241 host, respectively, which agree with those of ^{244}Pu fission (ALEXANDER *et al.*, 1971) (Fig. 3).

According to the method developed by EUGSTER *et al.* (1991, 1993) and MICHEL and EUGSTER (1994), $^{244}Pu\text{-}^{136}Xe_{fiss}$ ages are estimated in Table 9. The initial ratio $(^{244}Pu/^{150}Nd)_i$ at the time when fission Xe retention began was calculated from equation (2) of MICHEL and EUGSTER (1994). ΔT is the time difference between Xe retention of a meteorite and that of Angra dos Reis (ADOR) for which $(^{244}Pu/^{150}Nd)_{i,ADOR}=1.6\times10^{-3}$ and a crystallization age of 4550 Ma have been

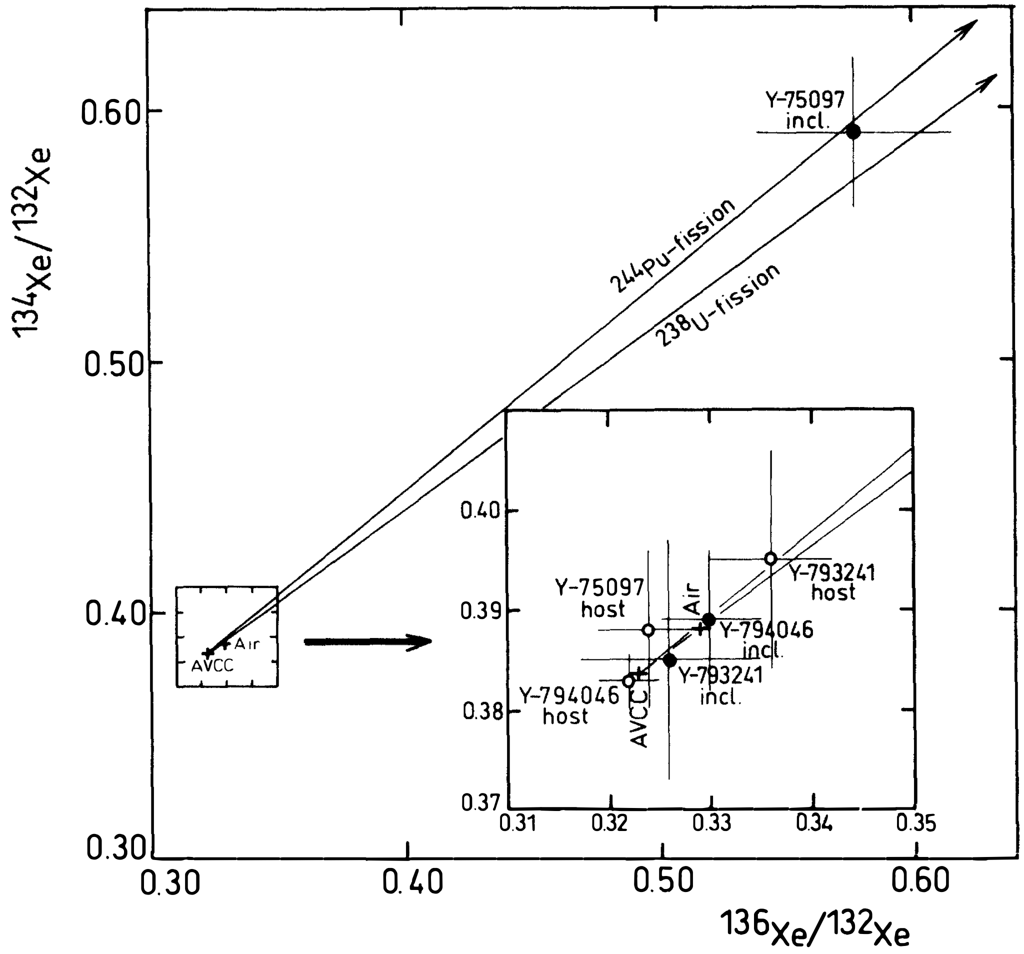

Fig. 3. *Plot of ^{134}Xe/^{132}Xe versus ^{136}Xe/^{132}Xe. Excesses in heavy Xe isotopes found in the Y-75097 inclusion and Y-793241 host appear to be ^{244}Pu-fission Xe though the experimental uncertainty is large.*

determined (LUGMAIR and MARTI, 1977).

The time difference ΔT and the retention age T_{136} are presented in Table 9. The Y-793241 host shows somewhat older age than ADOR and is in the range for ordinary chondrites (EUGSTER *et al.*, 1993). In contrast to this, the very large positive ΔT age, 568±19 Ma, of the Y-75097 inclusion is difficult to understand, even if the lower $^{136}\mathrm{Xe}_{\mathrm{fiss}}$ concentration by OTT *et al.* (1993) is used in the calculation (Table 9). The large ΔT may be caused by the low Nd concentration used for the calculation. A strong compositional variation within the inclusion of Y-75097 has been reported by YANAI *et al.* (1983) and WANG *et al.* (1993). Middle REE abundances reported for the inclusion (NAKAMURA *et al.*, 1984; WARREN and KALLEMEYN, 1989) indicate heavily heterogeneous distribution of Nd within the inclusion. This may also be the case for the Y-793241 inclusion (NAKAMURA *et al.*, 1984, 1993). However, even if we use the Nd concentration of 0.68 ppm for unfractionated L chondrites (WASSON and KALLEMEYN, 1988), the time difference becomes 155 Ma which is still somewhat older than for the ADOR and ordinary chondrites (EUGSTER *et al.*, 1993). Therefore the Y-75097 inclusion might have

Table 9. Fission Xe retention ages estimated from ^{244}Pu-fission Xe.

Meteorite	$^{136}\mathrm{Xe_f}$[1]	$^{136}\mathrm{Xe_f(U)}$[2]	$^{136}\mathrm{Xe_f(Pu)}$[3]	Nd[4]	$(^{244}\mathrm{Pu}/^{150}\mathrm{Nd})_i$[5]	ΔT[6]	T_{136}[7]
	(10^{-12} cm^{3}STP/g)			(ppm)		(Ma)	
Y-75097							
Host (L6)	0.28	0.043	0.24	0.825	0.00045	−150	4400
	±0.39	(13 ppbU)	±0.39	±0.003	±0.00073	±190	±190
Inclusion	2.63	0.021	2.61	0.0205	0.196	568	5118
	±0.43	(6.4 ppbU)	±0.43	±0.0002	±0.032	±19	±19
Inclusion[8]	0.68				0.048	400	4950
Y-793241							
Host (L6)	1.09	0.043	1.05	0.679	0.00238	47	4597
	±0.42	(13 ppbU)	±0.42	±0.004	±0.00095	±47	±47
Inclusion	0.12	0.0018	0.12	0.0297	0.0062	160	4710
	±0.18	(0.55 ppbU)	±0.18	±0.0002	±0.0093	±180	±180
Y-794046							
Host (H5)	0.13	0.039	0.09	0.526	0.00026	−210	4340
	±0.37	(12 ppbU)	±0.37	±0.002	±0.00107	±490	±490
Inclusion[9]	0.003	0.015	−0.01	0.779	<0.00026	<−210	<4340
	±0.143	(4.5 ppbU)	±0.14	±0.004			
Inclusion[10]	0.28		0.26		0.00051	−135	4415
	±0.14		±0.14		±0.00027	±63	±63

[1] Total fission ^{136}Xe; [2] fission ^{136}Xe from ^{238}U spontaneous fission accumulates in 4500 Ma calculated using U concentrations in Table 8; [3] fission ^{136}Xe from ^{244}Pu; [4] isotope dilution mass spectrometry by NAKAMURA *et al.* (1994); [5] initial ratio at the time when fission Xe retention began, calculated using the equation, $(^{244}\mathrm{Pu}/^{150}\mathrm{Nd})_i = 0.00154[^{136}\mathrm{Xe}_{\mathrm{f(Pu)}}]/[\mathrm{Nd}]$, given by MICHEL and EUGSTER (1994); [6] time difference between Xe retention of meteorite and that of Angra dos Reis (ADOR) calculated based on the $(^{244}\mathrm{Pu}/^{150}\mathrm{Nd})_i = 0.0016$ for ADOR (LUGMAIR and MARTI, 1977): [7] absolute fission Xe retention age based on $T_{136} = 4550$ Ma for ADOR (LUGMAIR and MARTI, 1977); [8] fission Xe concentration by OTT *et al.* (1993); [9] Atmospheric Xe was assumed to be trapped Xe (see text); [10] AVCC-Xe was assumed to be trapped Xe.

been formed earlier than the ADOR. The Y-793241 inclusion also may be older than the ADOR though the experimental uncertainty is large. To confirm the ages, both Nd concentration and Xe isotopic composition should be determined on an aliquot sample of these inclusions. It should be kept in mind, however, that there is a possibility that chemical coherence between Pu and Nd is not maintained during the extensive igneous process involving heavy chemical fractionation.

The Y-794046 inclusion did not show any excess in ^{136}Xe when atmospheric Xe was assumed to be trapped Xe. Even though we assume AVCC-Xe to be trapped, which will give an upper limit for the time of Xe retention, the resulting ΔT value (-135 ± 63 Ma) is still negative. Because the degree of REE fractionation is small (NAKAMURA *et al.*, 1993; FUKUOKA, 1993), Nd concentration in our sample may not differ appreciably from the value given by NAKAMURA *et al.* (1994). The Y-794046 inclusion likely began to retain Xe after most ^{244}Pu had decayed, which is consistent with the absence of radiogenic ^{129}Xe in the inclusion (Table 7).

7. Noble Gas Resemblances Between the Inclusions of Y-75097 and Y-793241, and Brachinites: Suggesting Common Origin?

Noble gas data for both inclusions of Y-75097 and Y-793241 are quite similar in some respects: 1) high concentrations of radiogenic ^{129}Xe (370–660×10^{-12} cm^{3}STP/g), 2) old Xe$_{\text{fiss}}$ retention age, 3) presence of neutron induced ^{80}Kr, ^{82}Kr and ^{128}Xe, and 4) very low concentrations of trapped noble gases (*e.g.*, 5–14×10^{-12} cm^{3}STP/g ^{132}Xe). These results indicate that they were well degassed at the time when ^{129}I was still alive and began to retain radiogenic and fissiogenic Xe. The similarities in their major element chemical compositions (Table A-1) and trace element abundance patterns (NAKAMURA *et al.*, 1993) are also excellent. On the other hand, the different compositions of trapped noble gases between these inclusions (Fig. 1) may suggest a different origin. Neutron induced ^{128}Xe and radiogenic ^{129}Xe concentrations in both inclusions (Table 7) are difficult to explain if we assume a simple and common history of Xe retention and cosmic-ray irradiation for both inclusions as discussed before. K-Ar and cosmic-ray exposure ages show that these two meteorites cannot be paired. Differences also remain in their mineral compositions (*e.g.* SACK and LIPSCHUTZ, 1993). Though many data suggest that both inclusions are closely related genetically to each other and might have derived from a common parent body as described by SACK and LIPSCHUTZ (1993), there still remains a possibility of independent products.

The resemblance between the igneous inclusion of Y-75097 and Brachina with respect to their texture, mineralogy and bulk chemistry has been pointed out for the first time by YANAI *et al.* (1983). This is also emphasized by YANAI and KOJIMA (1993) and SACK and LIPSCHUTZ (1993), though marked difference in chemical compositions is found between them (NAKAMURA *et al.*, 1984; WARREN and KALLEMEYN, 1989). OTT *et al.* (1993) showed a compositional similarity of noble gases between the Y-75097 inclusion and the brachinites Brachina and ALH84025.

The characteristic noble gas signatures for the inclusions of Y-75097 and Y-

793241 resemble those of Brachina (BOGARD *et al.*, 1983; OTT *et al.*, 1985, 1993) and ALH84025 brachinite (OTT *et al.*, 1993). Heterogeneous distribution of ^{244}Pu in brachinites is suggested by the disagreement of ^{136}Xe$_{\text{fiss}}$ concentrations obtained by duplicate analyses on Brachina and by single analysis on ALH84025 (OTT *et al.*, 1985, 1993). This is the case for the inclusions of Y-75097 and Y-793241, *i.e.*, the fission ^{136}Xe is significant in the former but not in the latter. Retention of ^{244}Pu-derived fission Xe in Brachina is confirmed by the presence of ^{244}Pu fission tracks (CROZAZ and PELLAS, 1984). They also suggested a rapid cooling based on the density distribution and retention temperatures of fission tracks in apatite and olivine. If we use the fission ^{136}Xe of $0.62 \pm 0.14 \times 10^{-12}$ cm^{3}STP/g for the Brachina given by OTT *et al.* (1985) and 0.45 ppm Nd (BOGARD *et al.*, 1983), the time difference ΔT is calculated to be 33 ± 27 Ma, indicating older retention than ADOR. This does not contradict the estimate for the Brachina by CROZAZ and PELLAS (1984) and for the inclusions of Y-75097 and Y-793241 (Table 9). Hence there is a possibility that they originated in a rather small parent body in the early solar system.

To the contrary, oxygen isotopic compositions for these inclusions show that the inclusion of the Y-75097 plot near the field of H chondrites and that of Y-793241 below the H-chondrite field are different from Brachina as well as any known achondrites (MAYEDA *et al.*, 1987; CLAYTON *et al.*, 1991). The oxygen isotopic composition of Brachina is similar to those of eucrites, plotted below the terrestrial fractionation line (CLAYTON and MAYEDA, 1983). Hence, the oxygen isotopes seem to rule out the hypothesis of common origin for these materials. WARREN and KALLEMEYN (1989) noted that Y-75097 and the brachinites might have formed by analogous processes even though oxygen isotopes rule out kinship between them. The oxygen isotopic compositions in chondrules of ordinary chondrites plot in a wide range covering the fields for the chondrite groups H, L and LL, suggesting two-component mixing for their formation (CLAYTON *et al.*, 1991). Since the Y-793241 inclusion lies between the Y-75097 inclusion and the Brachina in the δ^{17}O vs. δ^{18}O plot, an analogous mixing process may be considered for the formation of the above mentioned brachina-like materials. An alternative scenario for the origin of these brachina-like materials is that similar evolutional processes caused by impact or igneous heating occurred on individual small asteroids or in localized portions of a single body in the early solar system. This might produce the brachina-like igneous rocks, similar to but not identical to each other.

8. Conclusions

1) Noble gas compositions of the inclusions of Y-75097 and Y-793241 L6 chondrites indicate that they are closely related genetically. Affinity with the brachinites, Brachina and ALH84025, are also suggested based on the similarity in their noble gas compositions, though their oxygen isotopic compositions disagree with each other.

2) The ^{244}Pu-fission derived ^{136}Xe and the abundant ^{129}Xe from extinct ^{129}I in

the inclusions of Y-75097 and Y-793241 show that the heating event which produced the Brachina-like igneous materials must have occurred in the early solar system, *ca.* ≥4550 Ma. On the other hand, the inclusion of Y794046 H5 chondrite seems to have started Xe retention >210 Ma later than ADOR.

3) Concordant K-Ar ages between the host and the inclusion of each meteorite indicate that a heating event resetting the K-Ar system occurred on the host meteorite parent body after emplacement of the inclusion. The average K-Ar ages for Y-75097, Y-793241 and Y-794046 are 0.54, 4.4 and 1.8 Ga, respectively. Accordingly, the parent body of the inclusions from Y-75097 and Y-793241 must have broken up and ejected fragments in space before 4.4 Ga, or the parent body impacted on L6 asteroid at that time if both inclusions derived from a common parent body. The Y-75097 meteorite suffered again from an impact heating at about 0.5 Ga ago, which involved many L chondrites.

4) Concordant cosmic-ray exposure ages between the host and the inclusion of each meteorite are also obtained, *i.e.*, 21.1±0.9, 21.1±1.8, 24.2±1.5, 23.8±0.5, 2.73±0.05 and 3.26±0.23 Ma for host and inclusion of Y-75097, Y-793241 and Y-794046, respectively. The different exposure ages as well as the different K-Ar ages between Y-75097 and Y-793241 suggest unpaired fall.

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Appendix

Table A1. Major element concentrations in hosts and inclusions from Y-75097, Y-793241 and Y-794046.

Element (wt%)	Y-75097		Y-793241		Y-794046		References
	Host (L6)	Inclusion	Host (L6)	Inclusion	Host (H5)	Inclusion	
Si	18.55	18.27	18.04	18.18	—	21.55	a)
	—	18.6	—	—	—	—	d)
Ti	0.13	0.05	0.04	0.05	—	0.07	a)
	—	—	0.06	0.07	0.08	0.06	b)
	—	<0.2	—	—	—	—	d)
Al	1.38	1.32	1.29	1.43	—	1.59	a)
	—	—	1.02	1.61	0.93	1.33	b)
	—	1.7	—	—	—	—	d)
Fe (total)	20.90	15.96	22.77	16.11	—	10.81	a)
	—	—	23.2	15.2	25.3	11.4	b)
	—	16.0	—	—	—	—	d)
Mn	0.26	0.29	0.26	0.30	0.233	0.29	a)
	—	—	0.267	0.312	0.233	0.304	b)
Mg	15.70	20.48	15.47	20.71	—	19.19	a)
	—	—	15.1	19.5	14.1	18.5	b)
	15.1	17.4	15.0	18.1	15.7	21.3	c)
	—	21.0	—	—	—	—	d)
Ca	1.30	0.47	1.33	0.32	—	1.44	a)
	—	—	1.29	0.74	1.18	1.55	b)
	1.32	0.42	1.29	0.46	1.28	1.71	c)
	—	0.36	—	—	—	—	d)
Na	0.71	0.74	0.69	0.79	—	0.86	a)
	—	—	0.745	0.852	0.615	0.920	b)
	—	0.88	—	—	—	—	d)
K	0.07	0.04	0.09	0.05	—	0.13	a)
	—	—	0.087	0.049	0.040	0.176	b)
	0.0870	0.0950	0.0756	0.0526	0.0691	0.1780	c)
	—	0.070	—	—	—	—	d)
P	0.11	0.16	0.09	0.07	—	0.03	a)
Cr	0.40	0.66	0.37	0.40	—	0.45	a)
	—	—	0.278	0.303	0.269	0.366	b)
	—	0.71	—	—	—	—	d)
Ni (total)	1.19	0.0236	0.81	0.0296	—	0.06	a)
	—	—	1.64	0.0718	1.81	0.0550	b)
	—	0.0302	—	—	—	—	d)
Co	0.008	<0.003	0.053	<0.003	—	<0.003	a)
	—	—	0.0651	0.00475	0.0781	0.0033	b)
	—	0.0024	—	—	—	—	d)

a) YANAI and KOJIMA, 1993; b) FUKUOKA, 1993; c) NAKAMURA *et al.*, 1994; d) WARREN and KALLEMEYN, 1989.