K–Ar AGES OF YAMATO-74 METEORITES

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***Abstract*:** Measurements have been carried out on the isotopic compositions and contents of helium, neon and argon for three kinds of Yamato meteorites, which were petrologically classified into (a) L-chondrite (Yamato-74190–01), (b) H-chondrite (Yamato-74640–02) and (c) eucrite (Yamato-74159–01).

K–Ar age for each sample was calculated to be (a) ~2.1 b.y., (b) ~4.5 b.y. and (c) ~4.3 b.y.

From the isotopic correlation diagram for neon, it has been suggested that the neon of each sample consisted of a mixture of spallogenic neon and trapped one. ^{3}He exposure ages for the samples (a), (b) and (c) were calculated to be 25, 12 and 27 m.y. and ^{21}Ne exposure ages to be 25, 11 and 32 m.y., respectively.

1. Introduction

In December 1969, nine pieces of meteorites were discovered for the first time in the neighborhood of the southeastern foot of the Yamato Mountains in East Antarctica, by an oversnow traverse party of the 10th Japanese Antarctic Research Expedition 1968–1970 (JARE-10). The meteorites were named "Yamato meteorites" and designated later as "Yamato-691 to -699".

The glaciology party of JARE-14 found 12 meteorites in December 1973 (SHIRAISHI *et al.*, 1976), among which 8 samples were collected in the same bare ice area where the first meteorites were discovered by JARE-10.

Encouraged by these findings of meteorites in a very limited area in East Antarctica, the field party of JARE-15 sent out to the same region in 1974 made a special effort to find and collect 663 meteorite-like specimens in the same locality. These meteorites later were designated provisionally as "Yamato-74001 to -74663" (YANAI, 1976).

Petrographical studies have revealed that Yamato-74190–01 and Yamato-74640–02 are assigned to type L_{5-6} and type H_{6-5}, respectively (YANAI *et al.*, 1978) according to the classification by VAN SCHMUS and WOOD. Yamato-74159–01 was also petrologically identified to be an achondritic eucrite.

Very few investigations have been made hitherto on concentrations and isotopic compositions of rare gases in the Yamato meteorites except the reports by SHIMA *et al.* (1973), TAKAOKA and NAGAO (1978) and the present authors (1978).

This paper forms part of a further study of rare gases determinations and related discussions on three of Yamato-74 meteorites [(a) (Yamato-74190–01, (b) -74640–02 and (c) -74159–01].

2. Experimental

One half of each sample weighing *ca.* 0.5 g was ground into powder using an agate mortar and stored in a desiccator over silica gel. About 100–200 mg of the sample was loaded into a molybdenum crucible which was directly mounted on a tantalum heater. The extraction and purification system is connected in series with the ultra high vacuum mass spectrometer, which was reported previously (OKANO and NISHIMURA, 1973). Fig. 1 shows a schematic diagram of the analytical system used in this work (KAMAGUCHI and OKANO, 1978). The whole system was heated for degassing in an electric furnace at about 200°C, after which the retaining gas was extracted by resistive heating at the maximum temperature of 1800°C.

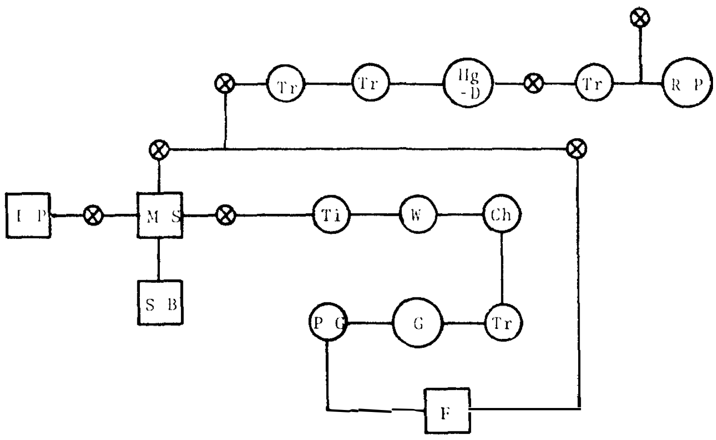

Fig. 1. A schematic diagram of the analytical system. IP: ion pump, MS: mass spectrometer, SB: sublimation pump, RP: rotary pump, Ti: titanium filament, W: tangsten filament, Ch: chacoal tube, G: getter (Ti–Zr alloy), F: extraction furnace, PG: pirani guage.

The volatile components in the extracted gas were removed with a cold trap cooled by liquid nitrogen and then the remaining gas was purified by a Ti–Zr alloy getter operated at about 550°C and subsequently by evaporated film of titanium. The gas thus purified was expanded to the mass spectrometer for the isotopic analyses of argon and helium.

Neon measurements were carried out after the interference of $^{40}Ar^{++}$ and CO_2^{++} became negligible by exposing the gas in the vacuum system to a charcoal trap held at $-195°C$. Sample runs were interspersed with air aliquots of precisely known amounts, which were used as standards for the isotopic ratios of argon and $^{20}Ne/^{22}Ne$. The relative sensitivities of He and Ne to Ar were estimated by using the known amounts of He- and Ne-spikes.

The absolute amount of each isotope of argon was determined by isotope dilution analysis with a ^{38}Ar spike, while those of He and Ne by comparing the each peak height with that of ^{40}Ar and taking account of the sensitivity described above.

Every measurement was carried out so quickly that the errors, which were due to the permeation of mainly ^{4}He (through the quartz tube operated at 550°C) and of ^{40}Ar from air, were estimated to be less than a few percent.

3. Results and Discussion

3.1. The analysis of rare gases in the meteorites

The results of the analysis are summarized in Table 1. On the assumption that air-contaminants are entirely removed on degassing at ~200°C, light rare

Table 1. Concentrations and isotopic ratios of rare gases in Yamato meteorites (concentration in ccSTP/g).

	(a) Yamato-74190-01 (2)*	(b) Yamato-74640-02 (3)*	(c) Yamato-74159-01 (3)*
^{3}He	6.27×10^{-7}	3.04×10^{-7}	7.47×10^{-7}
^{4}He	1.79×10^{-5}	3.62×10^{-5}	8.16×10^{-5}
^{20}Ne	1.34×10^{-6}	3.01×10^{-6}	2.94×10^{-6}
^{21}Ne	1.26×10^{-7}	5.81×10^{-8}	1.33×10^{-7}
^{22}Ne	2.32×10^{-7}	3.04×10^{-7}	3.75×10^{-7}
^{36}Ar	2.30×10^{-8}	6.93×10^{-8}	7.87×10^{-8}
^{38}Ar	$<1\times10^{-7}$	$<1\times10^{-7}$	$<1\times10^{-7}$
^{40}Ar	1.39×10^{-5}	6.88×10^{-5}	3.76×10^{-5}
$^{3}He/^{4}He$	3.50×10^{-2}	8.39×10^{-3}	9.15×10^{-3}
$^{20}Ne/^{22}Ne$	5.77	9.89	7.83
$^{21}Ne/^{22}Ne$	5.44×10^{-1}	1.91×10^{-1}	3.55×10^{-1}
$^{40}Ar/^{36}Ar$	6.05×10^{2}	9.92×10^{2}	4.78×10^{2}

* The numbers in the brackets indicate the numbers of analysis.

gases (He, Ne, Ar) contained in a meteorite are considered to consist of three components of different origins: 1) a cosmogenic component, 2) a radiogenic component, 3) a trapped component of primordial, ambient gases in the solar nebula. The isotopic ratios of meteoritic He, Ne and Ar are shown in Table 2.

Most of ^{3}He measured in this work can be attributed to the cosmogenic origin, provided that the $^{3}He/^{4}He$ ratio of primordial helium is *ca.* 10^{-4} as is shown in Table 2. On the contrary, the amount of cosmogenic ^{4}He is estimated by multiplying the amount of ^{3}He by 5. Hence the fraction of cosmogenic component of ^{4}He is found to be 18, 4 and 5 percent, for the samples (a), (b) and (c), respectively. The rest is considered to be a mixture of trapped and radiogenic components.

Table 2. Isotopic compositions of helium, neon and argon of different origins.

	Primordial component		Atmospheric component	Cosmogenic component*	Radiogenic component
	Solar-type	Planetary-type			
$^{3}He/^{4}He$	4.20×10^{-4} [1]	1.25×10^{-4} [1]	1.3×10^{-6} [4]	0.2	100% $^{4}He(U/Th)$
$^{20}Ne/^{22}Ne$	12.5 [1]	8.2 [1]	9.80 [5]	0.90	—
$^{21}Ne/^{22}Ne$	0.0345 [1]	0.024 [1]	0.0290 [5]	0.95	—
$^{36}Ar/^{38}Ar$	5.3 [2]	5.3 [2]	5.35 [6]	0.7	—
$^{40}Ar/^{38}Ar$	$\leqq10^{-4}$ [3]	$\leqq10^{-4}$ [3]	1580 [6]	0.1	100% $^{40}Ar(^{40}K)$

1) E. Anders *et al.*, Geochim. Cosmochim. Acta, **34**, 127, 1970.
2) D. Heymann, ed., Proc. 3rd Lunar Sci. Conf., **2**, 1821, 1972.
3) L.H. Ahrens, ed., Origin and Distribution of the Elements, Oxford, Pergamon Press, 125, 1968.
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* The isotopic composition of the product of spallogenic reaction has the dependence on the compositions of target nuclides and the depth of shielding. The values presented here are only rough estimates.

Fig. 2 shows the three-isotope correlation diagram for neon, which has been conveniently used for the analysis of components of meteoritic neon. In the figure, it is found that the points of samples (a), (b) and (c) lie on a line and that the line comes near the cosmogenic-solar line.

Therefore, it is suggested that neon in these three samples could be composed by mixing of a common solar-like primordial component (M in the figure) and a cosmogenic component. This figure also shows that the ^{22}Ne of samples (a), (b) and (c) consists of a mixture of cosmogenic neon and trapped one in the ratio of 1 : 1, 1 : 4 and 1 : 2, respectively.

The concentrations of cosmogenic ^{21}Ne was calculated from the following equation,

$$(^{21}Ne)_c = \frac{(^{21}Ne/^{22}Ne)_c[(^{21}Ne)_o - (^{21}Ne/^{22}Ne)_t(^{22}Ne)_o]}{(^{21}Ne/^{22}Ne)_c - (^{21}Ne/^{22}Ne)_t}$$

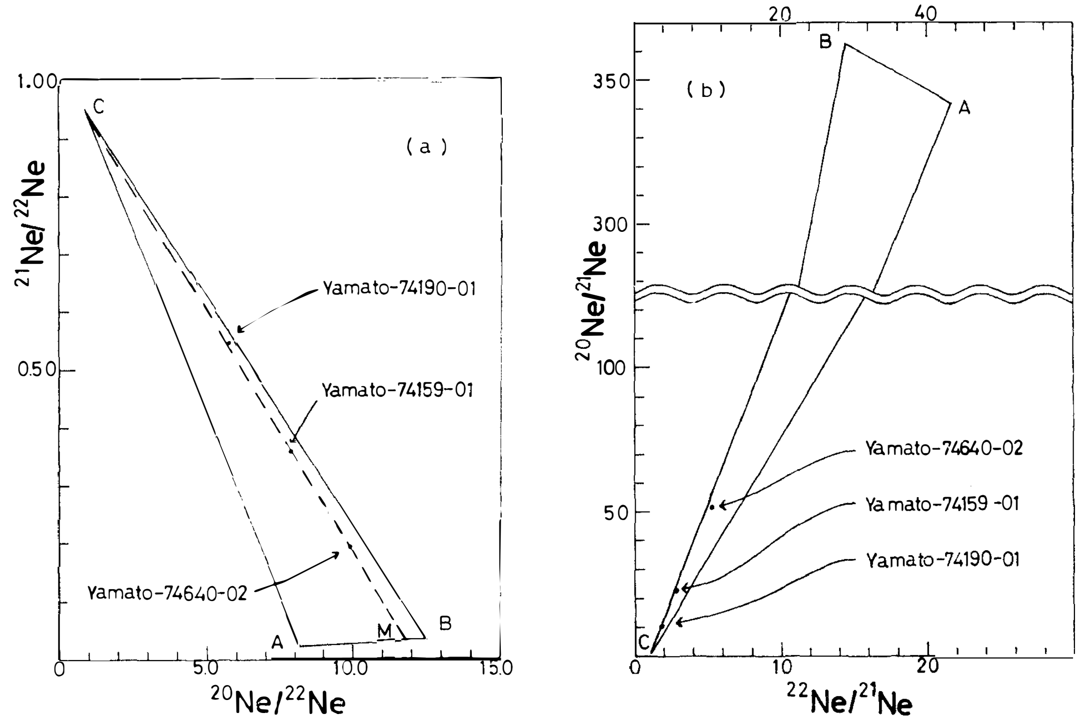

Fig. 2. Three-isotope correlation diagram for neon. Points A, B and C correspond to planetary-type neon, solar-type neon and cosmogenic neon, respectively.

where suffixes c, t and o represent cosmogenic, trapped and observed, respectively. The values of $(^{21}Ne/^{22}Ne)_c$ and $(^{21}Ne/^{22}Ne)_t$ can be read from Table 2 as 0.95 and 0.0345, respectively. The amounts of cosmogenic ^{21}Ne were estimated, from the above equation, to be 97 percent of ^{21}Ne for sample (a), 86 percent for sample (b) and 94 percent for sample (c). Most of ^{21}Ne was cosmogenic as calculated above and it is shown distinctly in Fig. 2b.

As was usual with the ordinary investigation of rare gases in meteorites, the measured ^{40}Ar was mostly a radiogenic component judging from the value of the $^{40}Ar/^{38}Ar$ ratio in Table 2.

For all runs, the mass peak of ^{40}Ar is so intensive compared with that of ^{38}Ar that the latter peak was covered by the tail of the former peak and no definite data are given here.

3.2. *Exposure ages*

As we see in the preceding section, the greater parts of ^{3}He and ^{21}Ne were the cosmogenic components. Provided the values of production rates for each species are available, one can easily calculate the exposure ages.

In order to estimate the production rate, empirical formulas as a function of the elemental composition in the meteorite were given by several authors (MAZAR *et al.*, 1970; HERZOG and ANDERS, 1971; BOGARD and CRESSEY, 1973). Since there were no available data on chemical compositions of meteorites used in this work, the average chemical compositions for L-chondrite, H-chondrite and eucrite (MASON, 1971) were employed for the calculations.

The production rates (P_3, P_{21}) of cosmogenic ^3He and ^{21}Ne calculated from the empirical formulas are listed in Table 3. In the table, the calculated ratios of P_3/P_{21}, observed cosmogenic values of $^3He/^{21}Ne$ and the exposure ages (t_3, t_{21}) are also listed.

Table 3. Production rates of cosmogenic ^3He and ^{21}Ne, and the exposure ages**.*

		Yamato-74190-01	Yamato-74640-02	Yamato-74159-01
P_3	(HERZOG and ANDERS)	2.48	2.48	2.73
	(HERZOG and ANDERS)	0.466	0.433	0.368
P_{21}	(MAZAR *et al.*)	0.53	0.51	0.43
	(BOGARD and CRESSEY)	0.466	0.435	0.224
P_3/P_{21}	(HERZOG and ANDERS)	5.32	5.73	7.42
$(^3He/^{21}Ne)_{c,obs.}$		5.14	6.15	5.98
t_3	(HERZOG and ANDERS)	25.3	12.2	27.4
	(HERZOG and ANDERS)	26.2	11.4	34.0
t_{21}	(MAZAR *et al.*)	23	9.7	29
	(BOGARD and CRESSEY)	26.2	11.4	55.8

* Production rates in 10^{-8} $cm^3/g/m.y.$
** Exposure ages in m.y.

The agreements between P_3/P_{21} and $(^3He/^{21}Ne)_{c,obs.}$ were pretty good except a little discrepancy in eucrite, where diffusive partial loss of helium may have been occurred through the exposure age.

Finally it is found in Table 3 that the agreements between the Ne- and He-exposure ages of each sample are reasonably good except the value of t_{21} estimated from the value of the production rate of BOGARD and CRESSEY for sample (c).

The average exposure ages of t_3 and t_{21} (HERZOG and ANDERS) are 25, 11 and 30 m.y. for samples (a), (b) and (c), respectively.

3.3. *K–Ar ages*

The K–Ar ages of these meteorites have been estimated and the results are listed in Table 4.

The potassium content was determined by atomic absorption spectrophotometry. The values for L- and H-chondrites are within the range of the distribution

Table 4. K–Ar ages of Yamato meteorites.

	Yamato-74190–01	Yamato-74640–02	Yamato-74159–01
K content (ppm)	1050	870	550
K–Ar age (b.y.)	2.1±0.5	4.5±0.3	4.3±0.5

* K–Ar ages were calculated on the basis of $\lambda=4.962\times10^{-10}\,y^{-1}$, $\lambda_e=5.81\times10^{-11}\,y^{-1}$ (STEIGER and JÄGER, 1977).

** The uncertainties in K concentrations were assumed to be 10%.

of the K content reported for each chondrite. However the value for eucrite may be deviated a little more than the upper limit of the value reported in literature (MASON, 1971).

Diogenites have very low K contents, as expected from their mineralogy, and an admixture of diogenitic fragment to eucritic material would markedly decrease the content of K in the resulting polymict mélanges compared to pure eucrite. Since extant eucrites vary largely in the K content, it is difficult to disentangle these effects.

Most of ^{40}Ar are considered to be radiogenic as already discussed. The K–Ar ages thus obtained are 2.1, 4.5 and 4.3 b.y. for L-chondrite, H-chondrite and eucrite, respectively.

Among the meteorites investigated in this work, only Yamato-74190–01 (L) has a younger age. It is considered that this meteorite may have been thermally denatured in its history and have lost some part of the radiogenic argon.

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