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^{40}Ar-^{39}Ar ANALYSES OF Y-74063 AND ALH-78230: CONSORTIUM STUDY ON UNIQUE METEORITES FROM ANTARCTICA

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Abstract: As part of a consortium study on unique meteorites from Antarctica, ^{40}Ar-^{39}Ar analyses were performed for two meteorites Y-74063 and ALH-78230, which are related to lodranite and the Acapulco meteorite. Y-74063,93 shows an ^{40}Ar-^{39}Ar plateau age of 4556±53 Ma, containing about 10^{-6}cm^{3}STP/g trapped ^{36}Ar. ALH-78230,55 also indicates an ^{40}Ar-^{39}Ar plateau age of 4531±23 Ma in the higher temperature fractions, but the lower temperature fractions suggest the occurrence of a later degassing event around 400–500 Ma. Trapped ^{36}Ar is about 10^{-8} cm^{3}STP/g. These results indicate that the two meteorites Y-74063 and ALH-78230 experienced different thermal histories.

1. Introduction

Among a number of meteorites collected from Antarctica, some meteorites have been classified as unique ones, because their bulk compositions are different from those of known chondrite groups (YANAI and KOJIMA, 1991). They are characterized by roughly chondritic compositions and non-chondritic textures (NAGAHARA *et al.*, 1990). As part of a consortium study on such unique meteorites from Antarctica, ^{40}Ar-^{39}Ar analyses were performed for Yamato-74063 (Y-74063) and Allan Hills-78230 (ALH-78230).

Y-74063 has been classified as a new type of chondrite between E and H chondrites (YANAI and KOJIMA, 1991). Both Y-74063 and ALH-78230 are texturally, mineralogically, and chemically related to each other including some other unique meteorites and also related to Lodran and/or Acapulco (NAGAHARA *et al.*, 1990). Oxygen isotope studies of these meteorites also suggest that they have oxygen isotopes similar to those of Lodran and Acapulco, which are clearly different from those in E and H chondrites (MAYEDA *et al.*, 1987; MAYEDA and CLAYTON, 1989). For Y-74063, petrological and chemical studies (FUKUOKA and KIMURA, 1990; YAMAMOTO *et al.*, 1990, 1991; IKEDA *et al.*, 1991; YANAI and KOJIMA, 1991) and noble gas studies (TAKAOKA and YOSHIDA, 1991; TAKAOKA *et al.*, 1991) have been reported. Petrological and chemical investigation for ALH-78230 were published by FUKUOKA and KIMURA (1990) and YAMAMOTO *et al.* (1991).

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2. Samples

Y-74063 was found on the bare ice field at the south end of the Yamato Mountains, Antarctica by the 15th Japanese Antarctic Research Expedition (JARE-15), 1974. It is an almost completely smoothly rounded stone covered with brownish-black fusion crust. In a thin section, chondrules are generally poorly traced and merge into the recrystallized matrix (YANAI and KOJIMA, 1991). The texture and chemical homogeneity of olivine (Fa 10.9%) and low-Ca pyroxene (Fs 10.7%) indicate that Y-74063 is an equilibrated chondrite and belongs to petrologic type 6 of VAN SCHMUS and WOOD (1967) or type 7 (YANAI and KOJIMA, 1991). The total iron content of this meteorite is lower than that of the ordinary chondrite groups and the abundance of troilite is much higher than that of all ordinary chondrites (YANAI and KOJIMA, 1991). Furthermore, texture, mineralogical and chemical compositions of this meteorite indicate that Y-74063 is a new type of chondrite between E and H chondrites (YANAI and KOJIMA, 1991) and classified as Lodran-Acapulco type (NAGAHARA *et al.*, 1990).

ALH-78230 is also classified into this new type of chondrite group (NAGAHARA *et al.*, 1990). This meteorite was collected from the Allan Hills area, 1978. It shows a medium-grained equigranular texture of olivine and pyroxene with minor nickel-iron metal, trolite, and plagioclase. Metal amounts to about 25 vol.% modally (YANAI and KOJIMA, 1987). The composition of minerals is very uniform: olivine, Fa 10.3%; pyroxene, Fs 9.8%. However, no evidence for the occurrence of chondrules has been found in spite of the chondritic texture, mineral assemblage and composition of ALH-78230 (YANAI and KOJIMA, 1991).

We obtained samples Y-74063,93 and ALH-78230,55 for our ^{40}Ar-^{39}Ar analyses.

3. Experimental

The experimental procedures were almost the same as those reported before (KANEOKA and TAKAOKA, 1986). The sample chips with grain sizes of 1–5 mm were wrapped in aluminium foil and stacked together with the hornblende age standard sample MMhb-I (K-Ar age$=519.5\pm2.5$ Ma) (ALEXANDER *et al.*, 1978), as well as CaF_2 and K_2SO_4 in a vacuum-sealed quartz vial.

The samples were irradiated in the JMTR of Tohoku University with a total fast neutron flux of about 1×10^{19}nvt/cm^2. Ar gas was extracted at the Radioisotope Center, University of Tokyo. The Ar isotopes were measured at Yamagata University on a Nier-type mass spectrometer with a multiplier and a resolving power of about 600 (TAKAOKA, 1976). Thus, each Ar peak could be separated sufficiently from hydrocarbon peaks.

Blanks and the effects of interfering Ar isotopes produced from neutron-irradiated Ca and K were corrected to calculate an ^{40}Ar-^{39}Ar age, using the correction factors determined based on the measurements of Ar isotopes for neutron-irradiated CaF_2 and K_2SO_4. The following values were assumed to calculate an ^{40}Ar-^{39}Ar age: for trapped Ar, $^{40}Ar/^{36}Ar=1.0$ and $^{38}Ar/^{36}Ar=0.187$; for cosmogenic

Ar, $^{40}Ar/^{36}Ar=0.15$ and $^{38}Ar/^{36}Ar=1.5$. The amounts of ^{40}Ar were estimated by the peak height method using the calibrated air standard; about 20% uncertainty is assigned for the concentrations based on the reproducibility of the mass spectrometer sensitivity. Since no monitor was included to infer the production rate of ^{38}Ar from ^{37}Cl through the neutron irradiation and the separation of ^{38}Ar in each component is not precise, we did not try to give an exposure age from the present data.

4. Results and Discussion

The observed Ar isotopic ratios and the amount of ^{40}Ar for Y-74063,93 and ALH-78230,55 are summarized in Table 1. The calculated ^{40}Ar-^{39}Ar ages are also

Table 1. Ar isotopes in neutron-irradiated unique meteorites from Antarctica.
Y-74063,93 0.0947g $J=0.05152\pm0.00035$

T(°C)	[^{40}Ar] ($\times10^{-8}cm^3$ STP/g)	$^{36}Ar/^{40}Ar$ ($\times10^{-3}$)	$^{37}Ar/^{40}Ar$ ($\times10^{-3}$)	$^{38}Ar/^{40}Ar$ ($\times10^{-3}$)	$^{39}Ar/^{40}Ar$ ($\times10^{-3}$)	$^{40}Ar^*/^{39}Ar^*$	Age (Ma)
600	14.3	91.26 ±1.36	32.65 ±0.65	980.6 ±18.7	3.348 ±0.123	286.9 ±46.7	4977 ±275
700	—	Lost before Ar analysis					
800	177	38.41 ±0.18	7.586 ±0.021	11.94 ±0.05	5.221 ±0.027	193.2 ±25.7	4318 ±218
900	172	5.373 ±0.028	8.470 ±0.061	2.231 ±0.007	5.113 ±0.005	199.3 ±11.1	4369 ±92
1000	941	0.6752 ±0.0154	8.008 ±0.070	0.9287 ±0.0089	4.575 ±0.051	223.2 ±2.6	4556 ±22
1100	912	9.532 ±0.073	14.64 ±0.04	4.434 ±0.031	4.605 ±0.011	225.1 ±0.8	4570 ±13
1200	94.1	6.985 ±0.054	33.16 ±0.06	7.650 ±0.027	4.865 ±0.011	223.5 ±23.6	4559 ±176
1300	206	27.18 ±0.10	64.03 ±0.20	15.63 ±0.07	5.308 ±0.037	218.4 ±28.6	4520 ±217
1400	121	70.82 ±0.16	190.4 ±1.7	36.62 ±0.11	6.780 ±0.034	217.1 ±34.6	4510 ±264
1600	708	87.62 ±0.26	91.47 ±0.39	5.296 ±0.016	2.475 ±0.056	702.2 ±134.3	6523 ±336
Total	(3345.4)	28.47	38.37	10.03	4.300	256.8	4791

N.B. 1) All tabulated data have been corrected for the blanks, but do not include other corrections.
2) $^{40}Ar^*/^{39}Ar^*$ indicates a ratio of the radiogenic ^{40}Ar from the decay of ^{40}K ($^{40}Ar^*$) to the K-derived ^{39}Ar by a reaction of ^{39}K (n, p)^{39}Ar ($^{39}Ar^*$).
3) To calculate an age, the following correction factors were used for K- and Ca-derived interference Ar isotopes.
$(^{39}Ar/^{37}Ar)_{Ca}=(2.34\pm0.06)\times10^{-3}$, $(^{38}Ar/^{37}Ar)_{Ca}=(3.54\pm0.02)\times10^{-3}$, $(^{36}Ar/^{37}Ar)_{Ca}$

included in Table 1 and shown in Figs. 1 and 2 as age spectra. Release patterns of each Ar isotope are shown in Figs. 3 and 4 for Y-74063,93 and ALH-78230,55, respectively. Unfortunately, the 700°C fraction was lost for Y-74063,93 due to the breakup of a glass ampoule before Ar analysis. The loss of ^{39}Ar in this fraction was assumed to be 10% of the total amount of ^{39}Ar for calculating the integrated fraction rate of ^{39}Ar in Fig. 1.

Both Y-74063,93 and ALH-78230,55 show relatively good ^{40}Ar-^{39}Ar plateau ages of 4556±53 Ma and 4531±23 Ma in the higher temperature fractions, respectively. This implies that these meteorites might have kept the records of a relatively early stage of their parent body evolution. Although both Y-74063 and ALH-78230 have been regarded to belong to the same meteorite group of the Lodran-Acapulco type (NAGAHARA *et al.*, 1990), their ^{40}Ar-^{39}Ar age spectra show different patterns.

ALH-78230,55 0.0943g J=0.04975±0.00036

T(°C)	[^{40}Ar] (×10^{-8}cm^3 STP/g)	^{36}Ar/^{40}Ar (×10^{-3})	^{37}Ar/^{40}Ar (×10^{-3})	^{38}Ar/^{40}Ar (×10^{-3})	^{39}Ar/^{40}Ar (×10^{-3})	^{40}Ar*/^{39}Ar*	Age (Ma)
600	6.60	5.266 ±0.316	10.63 ±0.97	118.8 ±1.3	2.387 ±0.083	441.4 ±53.0	5653 ±208
700	10.0	14.68 ±0.26	18.19 ±0.47	103.3 ±1.2	150.9 ±1.4	6.695 ±1.361	518.7 ±91.7
800	14.0	1.003 ±0.012	17.88 ±0.10	17.04 ±0.10	231.8 ±1.0	4.351 ±0.632	353.5 ±45.7
900	158	1.962 ±0.093	4.728 ±0.030	1.753 ±0.027	6.911 ±0.080	145.8 ±2.5	3808 ±30
1000	420	0.1641 ±0.0066	6.836 ±0.109	1.578 ±0.013	4.401 ±0.043	231.5 ±2.6	4559 ±22
1100	1264	0.8074 ±0.0051	6.816 ±0.024	2.463 ±0.005	3.402 ±0.009	301.1 ±2.5	4999 ±19
1200	569	0.1354 ±0.0029	15.20 ±0.09	7.916 ±0.018	4.706 ±0.019	220.9 ±1.3	4481 ±15
1300	554	0.3924 ±0.0055	19.79 ±0.10	14.03 ±0.02	4.537 ±0.011	232.3 ±1.0	4565 ±14
1400	219	0.5832 ±0.0130	77.15 ±0.18	107.7 ±0.3	5.299 ±0.021	227.8 ±11.3	4532 ±83
1600	36.9	6.466 ±0.069	1543 ±3	468.5 ±2.3	24.13 ±0.15	168.6 ±29.9	4040 ±286
Total	3251.5	0.6948	32.67	18.22	5.926	180.6	4151

=(3.27±0.03)×10^{-4}, (^{40}Ar/^{39}Ar)$_K$=(1.62±0.10)×10^{-1}, (^{38}Ar/^{39}Ar)$_K$=(3.65±0.05)×10^{-2}.

4) J= (exp (λt_s)−1)/(^{40}Ar*/^{39}Ar*)$_s$; t_s: K-Ar age of a standard sample; subscript "s" refers to a standard sample; λ =5.543×10^{-10}/y.

5) Uncertainties in the measured ratio represent those of the mass spectrometric analyses. For the ^{40}Ar*/^{39}Ar* ratios and calculated ages, however, 20% of blank correction and other uncertainties are included.

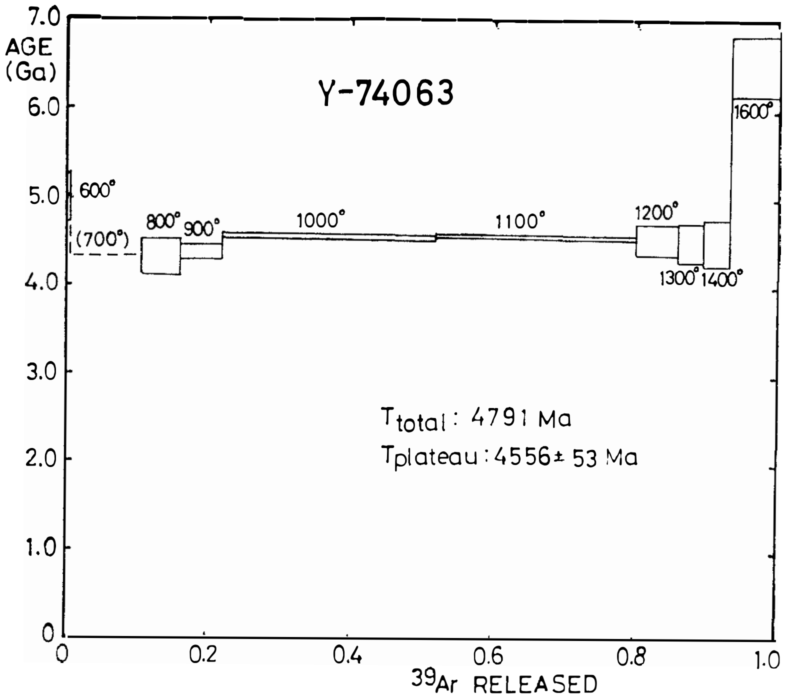

Fig. 1. *^{40}Ar-^{39}Ar age diagram for the unique meteorite Y-74063,93. The number at each column indicates the degassing temperature in degree Celsius. The uncertainty is indicated by 1σ. T_{total} represents a total ^{40}Ar-^{39}Ar age and $T_{plateau}$ indicates an ^{40}Ar-^{39}Ar plateau age, respectively.*

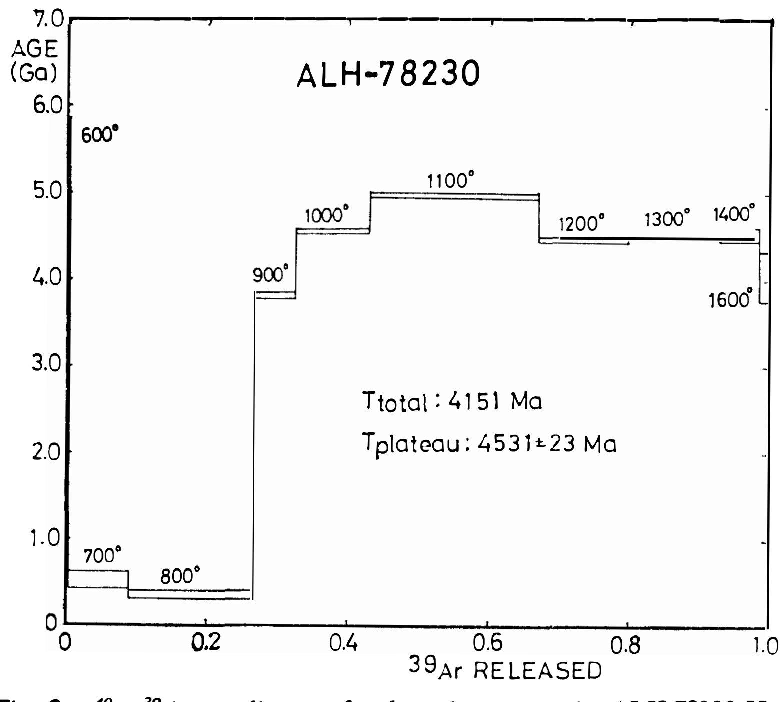

Fig. 2. *^{40}ar-^{39}Ar age diagram for the unique meteorite ALH-78230,55. The 1100°C fraction was excluded in calculating a plateau age ($T_{plateau}$).*

Y-74063,93 shows a relatively flat ^{40}Ar-^{39}Ar age spectrum except for the lowest (600°C) and the highest (1600°C) temperature fractions. The apparently too high ^{40}Ar-^{39}Ar ages which exceed 4900 Ma in these temperature fractions were probably caused by the addition of atmospheric components. In the case of the 600°C fraction, the atmospheric Ar was probably adsorbed on the sample surface, while that observed in the 1600°C fraction might be due to an insufficient blank correction. Although the datum for the 700°C fraction in the ^{40}Ar-^{39}Ar age spectrum is missing, there are no signs of serious secondary thermal effects which occurred later than 4000 Ma.

The 700° and 800°C fractions of ALH-78230,55 show relatively young ages of 350–500 Ma, suggesting a later degassing event. Such young ages are similar to those which have often been reported for L chondrites (*e.g.*, HEYMANN, 1967). Furthermore, the 1100°C fraction of ALH-78230 shows an ^{40}Ar-^{39}Ar age of 4999±19 Ma, which is too high to be accepted as a meaningful event. However, as shown in the release pattern of Ar for this meteorite (Fig. 4), the degassing rates of ^{40}Ar and ^{36}Ar at 1100°C are very high. Such a high degassing rate of ^{36}Ar in this temperature fraction is not common to ordinary meteorites and it suggests the incorporation of an atmospheric component in this fraction. Such phenomena have

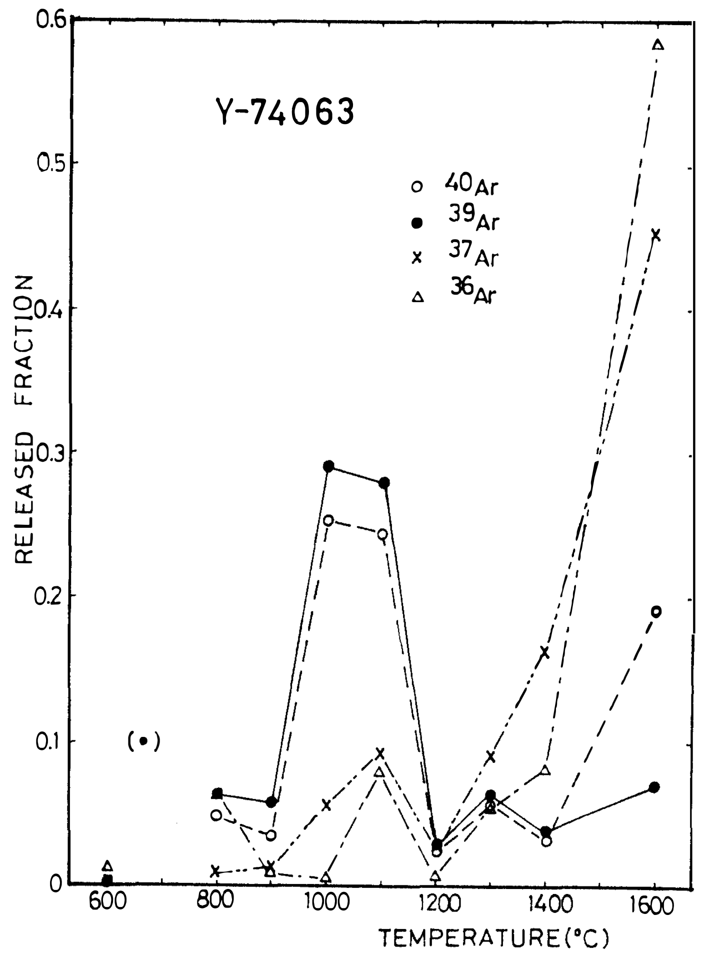

Fig. 3. Release patterns of Ar isotopes for Y-74063,93.

been observed for some Antarctic meteorites before and were interpreted to be due to the redistribution of the atmospheric Ar trapped in a weathered meteorite through the decomposition of goethite to hematite during neutron irradiation (KANEOKA, 1983a, b). Hence we cannot deny the possibility thta ALH-78230 might have been affected by weathering to some extent.

In Figs. 3 and 4, release patterns of Ar for Y-74063,93 and ALH-78230,55 are shown. For Y-74063,93, ^{40}Ar is correlated with ^{39}Ar except for the 1600°C fraction. This corresponds to a relatively good ^{40}Ar-^{39}Ar plateau age for this sample. In the 1600°C fraction, the degassing rate of ^{37}Ar, which is a product of ^{40}Ca by neutron irradiation, is high. This is common to ordinary meteorites, because such components mostly originate from Ca-bearing pyroxene. On the other hand, more than half of ^{36}Ar is observed in the 1600°C fraction. Such high degassing rates of ^{36}Ar are rarely observed in the highest temperature fraction. In fact, the degassing rate at 1600°C of ^{36}Ar for ALH-78230,55 is only about 10% of total ^{36}Ar as shown in Fig. 4. Because the ^{40}Ar/^{36}Ar ratio for the 1600°C fraction of Y-74063,93 is only about 11 as shown in Table 1, the high abundance of ^{36}Ar cannot be due to atmospheric contamination. Thus the observed ^{36}Ar most likely represents a primordial component. TAKAOKA and YOSHIDA (1991) also reported large amounts

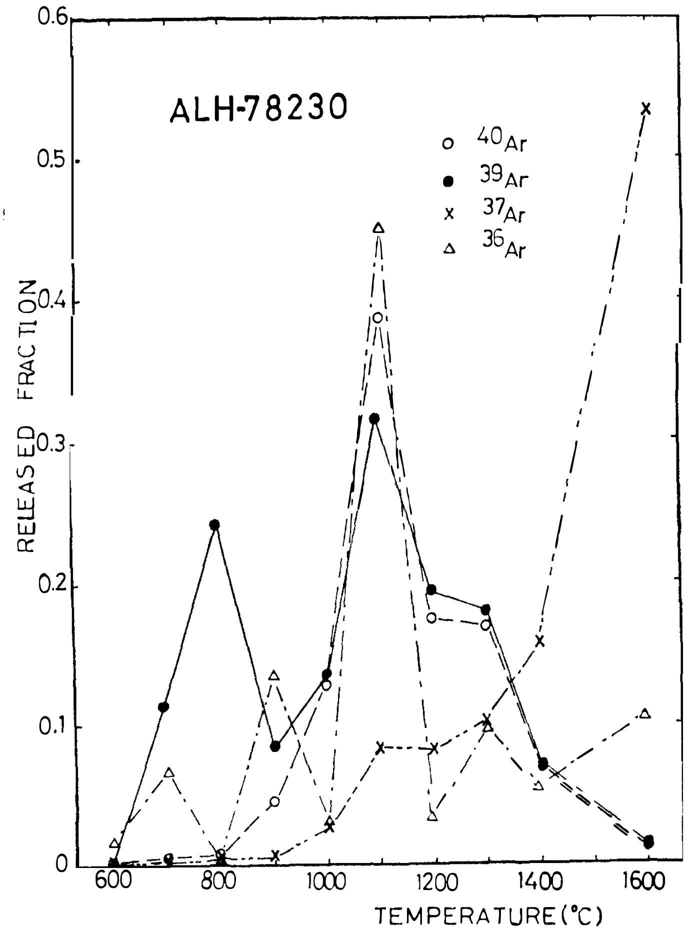

Fig. 4. Release patterns of Ar isotopes for ALH-78230,55.

of trapped heavy noble gases for Y-74063: they observed 1.56×10^{-6} cm^{3}STP/g ^{36}Ar. In the present study, although the 700°C fraction is missing, the total amount of ^{36}Ar is more than 1×10^{-6} cm^{3}STP/g for Y-74063,93. Hence, our result supports the inference that Y-74063 contains large amounts of trapped heavy noble gases.

The release patterns for ALH-78230 in Fig. 4 indicate that ^{40}Ar roughly correlates with ^{39}Ar above 1000°C. However, below 900°C the amounts of ^{40}Ar are quite low compared with those of ^{39}Ar. This clearly indicates a later degassing event for this meteorite as mentioned before. The large degassing rate of ^{36}Ar at 1100°C is probably due to the addition of an atmospheric component as discussed before. Even including this fraction, the total amount of ^{36}Ar for ALH-78230 is only 2.3×10^{-8} cm^{3}STP/g, which is much lower than that of Y-74063.

Accordingly, although both Y-74063 and ALH-78230 have been classified on the basis of petrochemical data (NAGAHARA *et al.*, 1990) to be in the Lodran-Acapulco type, ^{40}Ar-^{39}Ar analyses suggest that they have experienced different thermal histories and reflect different trapping characteristics for noble gases. In particular, Y-74063 appears to have retained most noble gases which it trapped during its crystallization. YANAI and KOJIMA (1991) have reported that this meteorite seems to have suffered thermal effects on the basis of granular textures suggesting recrystallization of the matrix. If such a thermal event had affected the meteorite, the result of ^{40}Ar-^{39}Ar analyses suggests that the event must have occurred in a very early stage of the evolution of the meteorite parent body. Furthermore, the high abundances of the trapped noble gases in this meteorite also imply that the thermal effect was not intensive enough to degass the heavy primordial noble gases or that the event occurred in an environment where the primordial noble gases were abundant. On the other hand, ALH-78230 was formed in an environment where the primordial noble gases were not abundant. Old ^{40}Ar-^{39}Ar plateau ages in the higher temperature fractions and a relatively small degassing rate of ^{36}Ar in the highest temperature fraction imply that the low abundances of the trapped component should not be attributed to the secondary effects such as a later degassing from the meteorite, but should rather be attributed to a particular environment where the meteorite material formed.

Thus, as judged from the noble gas abundances, Y-74063 and ALH-78230 have formed in different environments and their thermal histories are also different. Hence, although petrochemical features are similar for these two meteorites, they reflect different phases for the evolution of their parent body(ies). These results should also be taken into account in the discussion of the relationship and evolution of unique meteorites.

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