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On low noble gas concentrations in Antarctic micrometeorites collected from Kuwagata Nunatak in the Yamato Meteorite Ice Field

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Abstract: Noble gas concentrations and isotopic compositions were determined on Antarctic Micrometeorites (AMMs) collected in Kuwagata Nunatak in the Yamato Meteorite Ice Field around the Yamato Mountains in 1998. Noble gas concentrations in Kuwagata AMMs are lower than those of previously measured Dome Fuji AMMs. The heavy noble gas composition is chondritic and shows no atmospheric contamination. In order to clarify the differences of noble gas concentrations between Kuwagata and Dome Fuji AMMs, statistic calculations were done. The differences in ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe concentrations between the two types of AMMs are significant in both F-test and T-test. On the other hand, ^{36}Ar is not significant in the F-test, and ^{20}Ne is not significant in both tests. These results revealed a systematic decrease of noble gas concentrations in Kuwagata AMMs compared to those of the Dome Fuji AMMs. Since jarosite—a by-product mineral from aqueous alteration of sulfide minerals—was detected in Kuwagata samples, He loss may be due to aqueous alteration in Antarctic glacial ice. A contamination by atmospheric noble gases might be avoided by sample preparation using acetone to detach AMMs from stainless steal filters.

1. Introduction

Since Nishibori Eizaburo collected cosmic dust in Antarctica in 1957–1958 (Nishibori and Ishizaki, 1959), many dust collecting projects were carried out and numerous extraterrestrial particles were recovered from Antarctic snow or blue ice (Thiel and Schmidt, 1961; Shima and Yabuki, 1968; Shima *et al*., 1969; Tazawa and Fujii, 1987; Koeberl *et al*., 1988; Koeberl and Hagen, 1989; Maurette *et al*., 1991; Taylor *et al*., 1998, 2000). Recently, Japanese Antarctic Research Expedition (JARE) collected numerous AMMs in the Dome Fuji Station in 1996 and 1997 (Nakamura *et al*., 1999a), in the Yamato Meteorite Ice Field in 1998 (Yada and Kojima, 2000), and at a bear ice region near the Tottuki Point in 2000 (Iwata and Imae, 2001).

In our previous studies, noble gas compositions in individual AMMs collected from the Dome Fuji Station in 1996 and 1997 were determined and information on their source material was obtained (Osawa *et al*., 2000; Osawa and Nagao, 2002). Most Dome Fuji AMMs had plenty of solar helium and neon, and negligible amounts of cosmogenic nuclides, showing their extraterrestrial origin and short cosmic-ray exposure ages. In this paper, we show the result on noble gas analyses for AMMs collected from Kuwagata

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Nunatak in the Yamato Meteorite Ice Field in 1998 by JARE-39 and compare the result with the previous data on Dome Fuji AMMs. This work was performed as a part of consortium study of JARE AMMs (Terada *et al.*, 2001).

2. Samples

AMM samples were collected in the Kuwagata Nunatak at 2200 m altitude in the Yamato Meteorite Ice Field around the Yamato Mountains in December 3 to 9, 1998 (Yada and Kojima, 2000). This area is located on the side flow of the ice sheet avoiding the Nunatak. The $\delta^{18}O$ variation in air bubbles trapped inside the ice core samples close to the Kuwagata Nunataks indicates that the age of the ice core close to the surface is 31000–32000 years (Terada *et al.*, 2001). Of eleven sampling points in the Kuwagata area, #2 and #11 were selected in this study. Ten relatively large AMMs with irregular shape—five Kuwagata#2 and five Kuwagata#11 samples—were selected for noble gas analyses. No spherule was selected in this work. Their size, type, chemical composition, SEM back-scattered image, and EDS spectrum are published in the World Wide Web via Internet as an AMM database (URL: http: //dust.cc.gakushuin.ac.jp/dust/). These AMMs fell on Earth about 30000 years ago and have been preserved in ice. They differ from the Dome Fuji AMMs that were recovered from recent snow.

3. Analytical method

A tantalum sample holder was used. The experimental procedure was similar to that of the previous work (Osawa *et al.*, 2000). Samples were preheated at 150°C for one day. A Nd-YAG continuous wave (CW) laser with an output power of 2.5–3.5 W was used to heat the AMMs and extract noble gases from individual AMMs. Released gas was purified in a purification line with two Ti-Zr getters, and Ne, Ar, Kr, and Xe were trapped in a cryogenically cooled trap at 15 K. First, He was measured by a modified VG-5400 mass spectrometer (MS-III). Then, Ne, Ar, Kr, and Xe were released at 45, 100, 135, and 200 K, respectively and were separately measured. Sensitivities for all noble gases and mass discrimination effects were calibrated by measurements of atmospheric noble gases and a helium standard gas with $^3He/^4He=1.71\times10^{-4}$ that had been prepared by mixing pure ^3He and ^4He in our laboratory. Interferences of Ar^{++} and CO_2^{++} at masses 20 and 22, respectively were corrected. Blank corrections were carried out for all samples. The averaged value of blank measurements was taken as a blank value for the blank correction.

4. Results

Sizes, weights, noble gas contents and concentrations of the AMMs are shown in Table 1 and noble gas isotopic compositions are shown in Table 2. Sizes were determined by SEM observation. The most remarkable characteristics of Kuwagata AMMs are that noble gas concentrations, especially helium, fall within a narrow range in contrast to the Dome Fuji AMMs including the F96 and F97 series presented by Osawa and Nagao (2002). The He concentrations of the Dome Fuji samples ranged from

Table 1. Noble gas contents and concentrations for Kuwagata AMMs.

sample	size	weight (μg)	contents (10^{-12} cm^3 STP)*						concentrations (10^{-6} cm^3 STP/g)†					
			^{4}He	^{20}Ne	^{36}Ar	^{40}Ar	^{84}Kr	^{132}Xe	^{4}He	^{20}Ne	^{36}Ar	^{40}Ar	^{84}Kr	^{132}Xe
Y98K02KS048	128×109	0.8	59.7	5.0	1.4	169	0.0028	0.0026	66.9	5.7	0.9	n.d.#	0.0035	0.0032
Y98K02KS261	164×161	0.9	27.4	46.8	3.6	227	0.0043	0.0010	23.6	51.5	3.2	29	0.0048	0.0011
Y98K02KS267	271×242	1.3	12.3	2.5	1.3	220	0.0044	0.0015	4.9	1.7	0.5	15	0.0036	0.0012
Y98K02KS268	219×169	1.1	27.3	1.1	1.0	206	0.0044	0.0019	19.2	0.6	0.2	4.9	0.0040	0.0017
Y98K02KS275	230×167	1.2	48.9	3.8	1.9	235	0.0042	0.0007	37.2	2.9	1.0	30	0.0037	0.0007
Y98K11KS015	133×16	0.8	35.0	1.0	0.6	142	0.0040	0.0018	28.8	0.7	0.2	7.6	0.0031	0.0015
Y98K11KS029	86×12	0.7	47.4	5.7	0.6	134	0.0038	0.0021	50.7	7.4	0.2	n.d.#	0.0033	0.0022
Y98K11KS049	95×19	0.7	70.2	9.4	0.7	136	0.0012	0.0010	83.2	12.7	0.3	0.2	n.d.	0.0006
Y98K11KS062	91×21	0.7	26.0	0.9	1.0	232	0.0056	0.0039	20.0	0.5	0.7	137	0.0057	0.0048
Y98K11KS066	146×35	0.9	57.7	56.7	1.0	103	0.0042	0.0020	50.8	62.4	0.6	n.d.#	0.0029	0.0015
Blank1‡			6.2	0.4	0.7	201	n.d.	n.d.						
Blank2§			12.0	0.5	0.5	133	0.0015	0.0006						

* not corrected for blank

† corrected for blank

‡ Average of 4 measurements utilized to blank correction for Kuwagata#2 samples.

§ Average of 6 measurements utilized to blank correction for Kuwagata#11 samples.

cannot determined due to low content of ^{40}Ar compared to the blank content.

Table 2. Noble gas isotopic compositions for Kuwagata AMMs.

sample	$^{3}He/^{4}He$	$^{20}Ne/^{22}Ne$	$^{21}Ne/^{22}Ne$	$^{40}Ar/^{36}Ar$	$^{38}Ar/^{36}Ar$	$^{84}Kr=1$*			$^{132}Xe=1$*				
						^{82}Kr	^{83}Kr	^{86}Kr	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
Y98K02KS048	2.46×10^{-4}	11.9	0.031	<8.2	0.199	0.24	0.19	0.40	1.04	0.14	0.92	0.46	0.29
	$\pm0.90\times10^{-4}$	±1.0	±0.010		±0.025	±0.10	±0.11	±0.15	±0.53	±0.07	±0.41	±0.21	±0.13
Y98K02KS261	3.04×10^{-4}	10.5	0.034	8.7	0.203	0.27	0.18	0.35	1.02	0.18	1.11	0.61	0.28
	$\pm0.92\times10^{-4}$	±0.3	±0.007	±11.2	±0.013	±0.09	±0.08	±0.18	±0.38	±0.11	±0.74	±0.42	±0.16
Y98K02KS267	3.23×10^{-4}	12.0	0.072	<75.9	0.193	0.27	0.24	0.25	1.53	0.20	1.28	0.49	0.17
	$\pm2.59\times10^{-4}$	±1.6	±0.037		±0.034	±0.14	±0.16	±0.08	±0.47	±0.12	±0.54	±0.17	±0.07
Y98K02KS268	2.65×10^{-4}	15.4	0.016	<134.5	0.163	0.24	0.22	0.27	0.95	0.19	0.90	0.37	0.32
	$\pm0.35\times10^{-4}$	±3.7	±0.023		±0.061	±0.52	±0.09	±0.10	±0.17	±0.05	±0.51	±0.18	±0.14
Y98K02KS275	2.69×10^{-4}	11.1	0.033	28.1	0.202	0.19	0.20	0.34	1.12	0.20	0.80	0.37	0.35
	$\pm0.75\times10^{-4}$	±1.4	±0.023	±25.6	±0.022	±0.04	±0.11	±0.09	±0.12	±0.11	±0.19	±0.12	±0.14
Y98K11KS015	2.06×10^{-4}	10.9	0.160	88.2	0.197	0.22	0.14	0.27	0.85	0.2	0.97	0.36	0.34
	$\pm1.02\times10^{-4}$	±2.9	±0.075	±52.6	±0.047	±0.13	±0.07	±0.11	±0.29	±0.16	±0.57	±0.19	±0.20
Y98K11KS029	2.54×10^{-4}	12.1	0.034	35.5	0.194	0.31	0.24	0.28	0.830	0.13	0.63	0.36	0.32
	$\pm0.76\times10^{-4}$	±0.5	±0.020	±62.1	±0.043	±0.23	±0.11	±0.14	±0.39	±0.12	±0.25	±0.11	±0.18
Y98K11KS049	3.45×10^{-4}	10.8	0.027	39.2	0.198	n.d.	n.d.	n.d.	0.96	0.11	0.73	0.34	0.27
	$\pm0.54\times10^{-4}$	±0.7	±0.009	±50.4	±0.031				±0.68	0.20	±0.28	±0.41	±0.25
Y98K11KS062	3.60×10^{-4}	10.6	0.007	222	0.210	0.17	0.35	0.36	1.11	0.17	0.86	0.39	0.35
	$\pm1.57\times10^{-4}$	±2.9	±0.067	±8.9	±0.013	±0.08	±0.40	±0.19	±0.37	±0.09	±0.25	±0.18	±0.12
Y98K11KS066	3.49×10^{-4}	11.3	0.033	<1	0.200	0.25	0.14	0.26	1.04	0.18	1.11	0.40	0.35
	$\pm1.29\times10^{-4}$	±0.8	±0.008		±0.017	±0.10	±0.08	±0.12	±0.66	±0.13	±0.59	±0.24	±0.29

* not corrected for blank

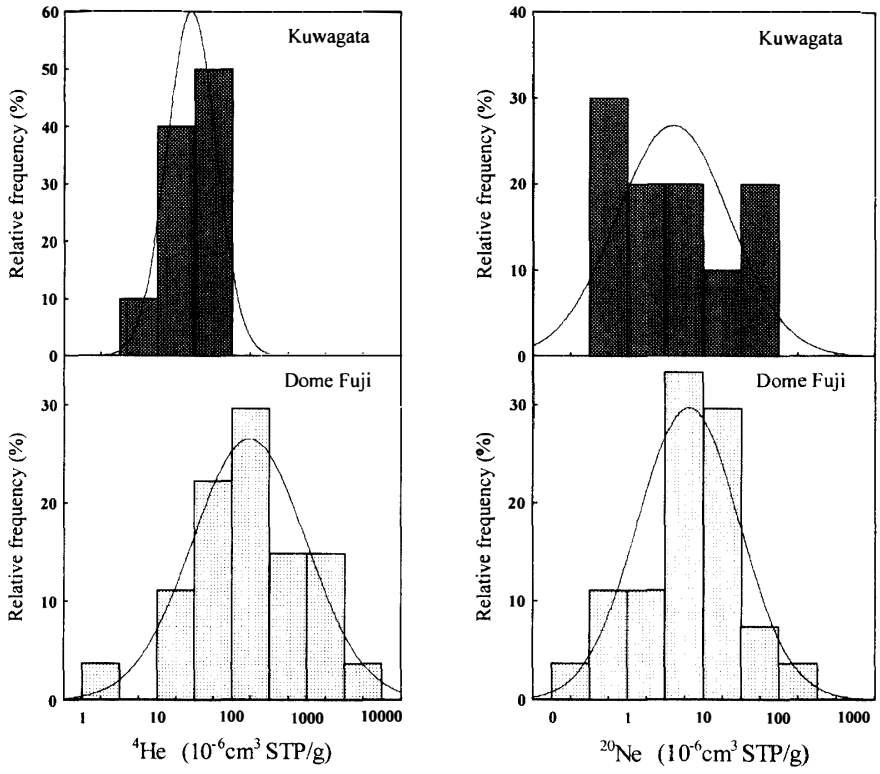

Fig. 1. Histograms of helium and neon concentrations. Ordinates show relative frequency (%), and abscissas show ^{4}He and ^{20}Ne concentration in logarithm scale. Solid lines denote normal distribution curves. Dome Fuji data are after Osawa and Nagao (2002). Ancient comic dusts, Kuwagata AMMs, have narrow range of He concentration and lower concentration than that of Dome Fuji AMMs. While Ne do not have such a clear difference between Kuwagata and Dome Fuji AMMs.

1–9700 $\times 10^{-6}$ cm^3 STP/g. Whereas the Kuwagata samples are in a narrow range of 10–100 $\times 10^{-6}$ cm^3 STP/g. Histograms of the He and Ne concentrations are displayed in Fig. 1. Data of Dome Fuji AMMs are after Osawa and Nagao (2002). Helium concentrations of Kuwagata AMMs are evidently lower than the Dome Fuji AMMs. Since solar He is dominant in AMMs (Table 2), their concentrations reflect the amounts of implanted solar components rather than primordial trapped components or atmospheric contamination. On the other hand, as for Ne, such a large difference is not found. Histograms for ^{36}Ar and ^{40}Ar concentrations are shown in Fig. 2. As in the case of He, Kuwagata AMMs apparently have lower Ar concentration than those of Dome Fuji AMMs. The low concentrations of Ar indicate low atmospheric contamination because pristine trapped ^{36}Ar is observed to be predominant in the micrometeorites and ^{40}Ar is consistent with atmospheric contamination (Osawa and Nagao, 2002). Radiogenic ^{40}Ar is not dominant in AMMs.

Figure 3 shows histograms for Kr and Xe concentrations. Among the noble gases, Kr is the most sensitive indicator for atmospheric contamination (Scherer *et al.*, 1994). It is evident that Kuwagata AMMs have lower ^{84}Kr concentrations than those of Dome Fuji samples, indicating lower atmospheric contamination. The same conclusion is

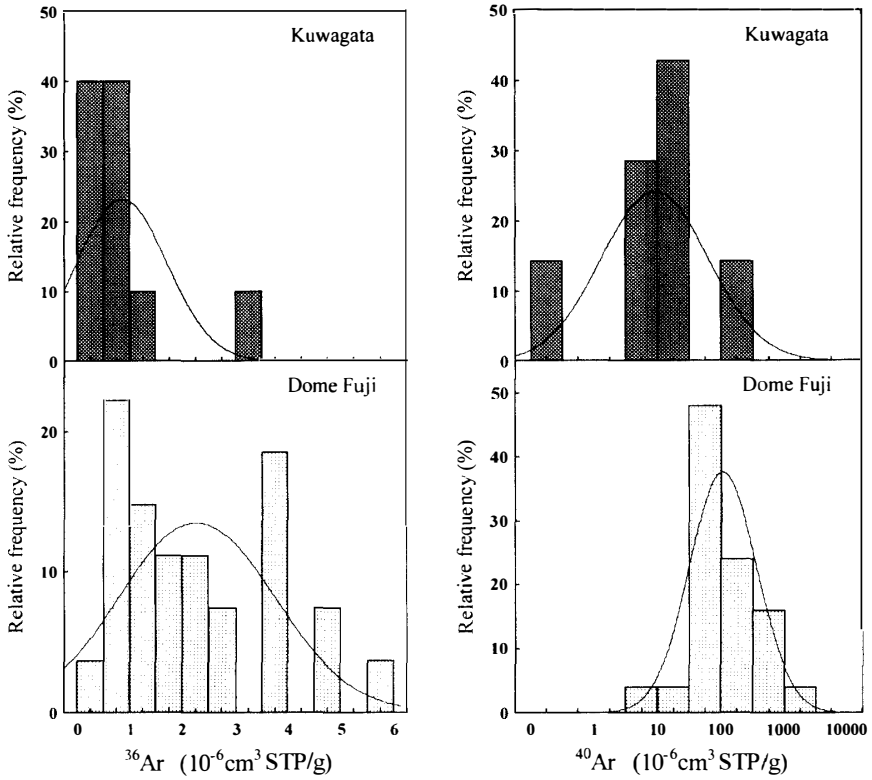

Fig. 2. Histograms of ^{36}Ar and ^{40}Ar concentrations. Solid lines represent normal distribution curves. Dome Fuji data are after Osawa and Nagao (2002). A distinct difference of Ar concentrations can be confirmed both in the cases of ^{36}Ar and ^{40}Ar.

obtained from the Xe data. Y98K02KS267 has excess ^{129}Xe (Table 2) and low heavy noble gas concentrations, also indicates lack of atmospheric contamination. Heavy noble gas compositions are displayed in Fig. 4. Kuwagata samples preserved the pattern of the chondritic heavy noble gases better than the Dome Fuji samples. All Kuwagata samples plot in the hatched areas that show the range for carbonaceous chondrites. An exceptional grain, Y98K02KS261, shows a slightly higher ^{36}Ar concentration than carbonaceous chondrites, perhaps originating from SEP-Ar suggested from the highest ^{36}Ar/^{132}Xe ratio of ~2900. The solar ^{36}Ar/^{132}Xe ratio is ~10000, compared to the chondritic value of ~100.

Table 3 is a summary of the noble gas concentrations in AMMs and gives the result of statistic calculations. Average concentrations of Kuwagata samples are lower than those of Dome Fuji samples in all noble gas elements and Dome Fuji AMMs have larger standard deviations than those of Kuwagata AMMs. In order to compare noble gas concentrations of Kuwagata AMMs to those of Dome Fuji AMMs statistically, F-test and T-test were done. A significant difference of variance in ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe concentrations is found in F-tests between Kuwagata and Dome Fuji samples. On the other hand, ^{20}Ne and ^{36}Ar are not significant in the F-tests. Especially, the F-value of ^{20}Ne is 1.0, showing that it is almost completely homoscedastic. Calculated probabilities in one-tailed tests (tests for the probability that the variance of ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe concentrations of Dome Fuji AMMs are larger than those of Kuwagata AMMs) show a

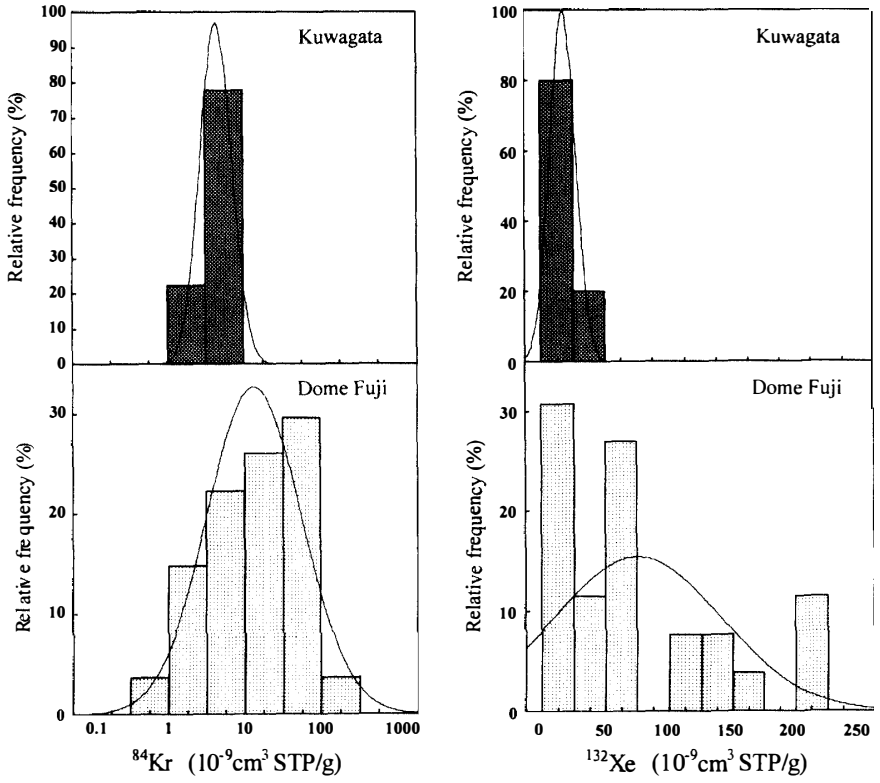

Fig. 3. Histograms of ^{84}Kr and ^{132}Xe concentrations. Solid lines represent normal distribution curves. Dome Fuji data are after Osawa and Nagao (2002). Kuwagata AMMs clearly have lower ^{84}Kr and ^{132}Xe concentrations than those of Dome Fuji AMMs, reflecting low Earth's atmospheric contamination.

high significance for the difference between Kuwagata and Dome Fuji AMMs. However, this is not the case for ^{20}Ne and ^{36}Ar. Extremely low probabilities are found for ^{4}He and ^{84}Kr, proving a clear difference of variance between these AMMs.

T-tests were done to compare the mean values. Since variances of ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe were not homoscedastic, degrees of freedom (ϕ) were calculated as follows:

$$\phi = \frac{1}{\sqrt{\frac{c^2}{n_A - 1} + \frac{(1-c)^2}{n_B - 1}}},$$

n_A and n_B are numbers of samples. c is separately calculated as follows:

$$c = \frac{\frac{\hat{\sigma}_A^{\,2}}{n_A}}{\frac{\hat{\sigma}_A^{\,2}}{n_A} + \frac{\hat{\sigma}_B^{\,2}}{n_B}}.$$

$\hat{\sigma}_A$ and $\hat{\sigma}_B$ are standard deviations. Degrees of freedom for ^{20}Ne and ^{36}Ar were calculated from n_A+n_B-2, because the results of the F-tests were not significant. Differences of the mean values of the ^{20}Ne concentrations are not significant in the T-tests

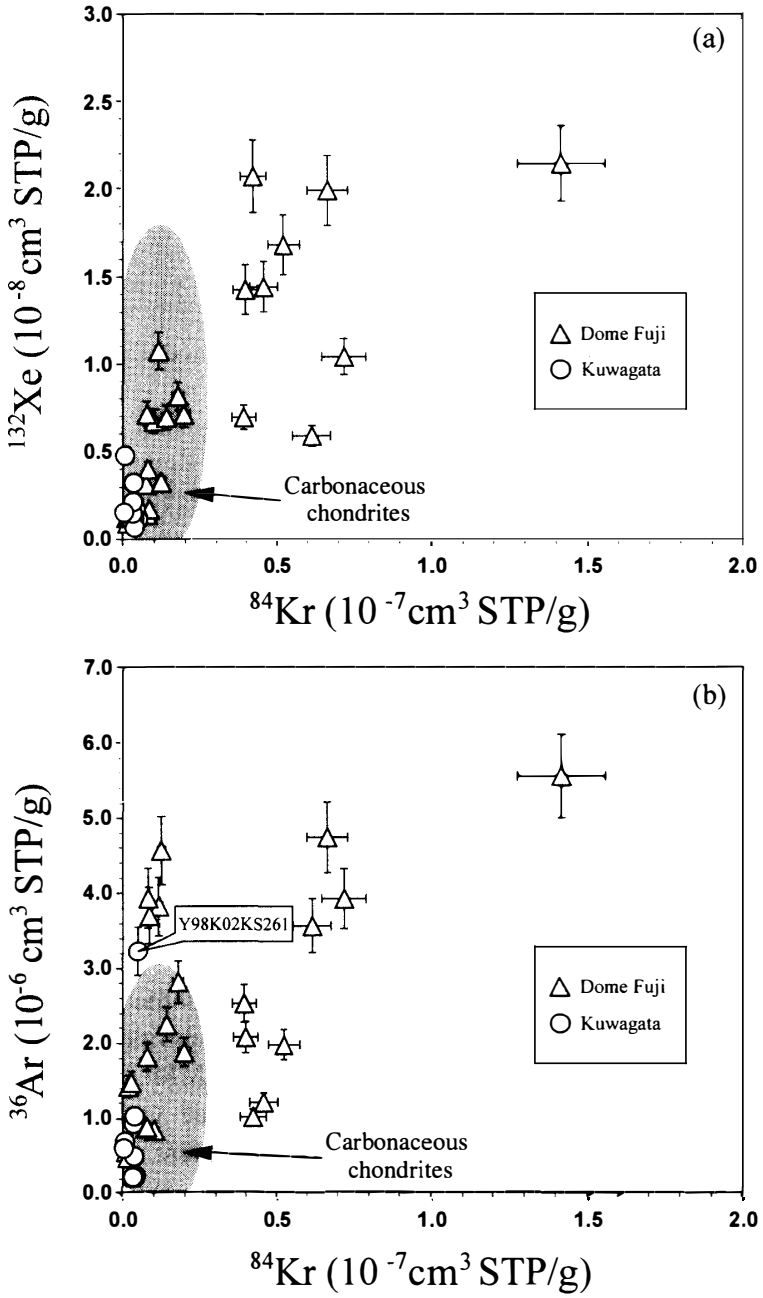

Fig. 4. Concentrations of ^{84}Kr versus ^{132}Xe and ^{36}Ar. 10% errors are shown. Dome Fuji AMMs are shown in triangles and Kuwagata AMMs are shown in circles. Shaded area means the range of carbonaceous chondrites. Most Kuwagata samples are plotted within the shaded area, indicating preservation of primordial trapped heavy noble gas component.

as well as in the F-tests, showing that there are no differences in mean values of the concentrations. The result of the T-test on ^{36}Ar is significant in contrast to the result of the F-test. The results of the T-tests for ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe are significant as well as the results of the F-tests. These statistic calculations clearly show the systematic decrease of the noble gases concentrations in Kuwagata AMMs compared to those of the

Table 3. Comparison of noble gas concentrations in AMMs.

	^{4}He	^{20}Ne	^{36}Ar	^{40}Ar	^{84}Kr	^{132}Xe
	$10^{-6}cm^3$ STP/g					
Kuwagata						
average	38.5	14.6	0.80	31.9	0.0038	0.0018
standard deviation	24.2	22.8	0.91	47.9	0.0009	0.0013
Dome Fuji						
average	769	16.6	2.22	195	0.026	0.0077
standard deviation	1883	23.1	1.50	272	0.032	0.0065
F-test						
F-value	6065	1.0	2.8	32	1265	26.2
Probability in one-tail test	5.5×10^{-16} sig.	0.97 not sig.	0.11 not sig.	0.00031 sig.	1.3×10^{-11} sig.	2.0×10^{-5} sig.
T-test*						
T-value	2.02	0.23	2.73	2.85	3.66	4.33
Probability in one-tail test	0.027 sig.	0.41 not sig.	0.0042 sig.	0.0040 sig.	5.6×10^{-4} sig.	7.9×10^{-5} sig.

* As for ^{20}Ne and ^{36}Ar, heteroscedastic tests were done.
sig. = significant

Dome Fuji AMMs.

There are clear differences between the results of ^{4}He and ^{20}Ne calculations in both F- and T-tests as shown in Table 3, although these two elements were mainly derived from implantation of solar ionized particles in interplanetary space simultaneously. Indeed, solar He and Ne isotopic compositions were detected in Kuwagata AMMs as shown in Table 2. The causes for the difference are discussed in the next section. Differences of ^{40}Ar concentrations between Kuwagata and Dome Fuji samples are larger than those of ^{36}Ar, reflecting the degree of atmospheric contamination. Since the terrestrial atmosphere has a higher $^{40}Ar/^{36}Ar$ ratio (296) than the primordial Ar component trapped in AMMs (<1), the ^{40}Ar concentration is enhanced relative to that of ^{36}Ar by the adsorption of atmospheric Ar.

Probably, the Kuwagata AMMs originally had the same light noble gas composition as the Dome Fuji AMMs, the difference may have been caused by a secondary effect, which occurred on Earth, as will be discussed in the next section.

5. Discussion

The results of the present work show that noble gas concentrations in Kuwagata AMMs are systematically lower than those in the Dome Fuji AMMs instead of the same grain size range (50–250 μm in mean diameter). These AMMs were measured under the same experimental conditions, such as the same preheating temperature, the same preheating duration, using the same mass spectrometer, and the same laser power. Thus

significant difference of noble gas concentrations should arise from the difference of AMMs themselves. Statistic tests clearly show that the two groups of AMMs do not belong to the same population. The observed differences originate from their history on Earth rather than from experimental conditions or from irradiation condition in interplanetary space.

In order to explain the low concentrations of He in the Kuwagata samples, some chemical reactions between the surface of AMMs and Antarctic ice can be considered. It is difficult to assume that the Kuwagata AMMs originally had lower contents of solar He than the Dome Fuji AMMs because the solar wind becomes saturated in the surface layer of a small particle within a few decades (*e.g.,* Hudson *et al.*, 1981). Even if 30000 years ago the solar wind flux were weaker than the present flux, solar He would be easily saturated during the orbital evolution of micrometeorites. Although cosmic dust particles can reach Earth from their parent body within 0.5 Ma due to Poynting-Robertson drag forces, there is enough time for solar He to become saturated. It is thus reasonable to assume that solar He trapped in AMMs was lost during storage in Antarctic ice.

Aqueous alteration of the surface of AMMs might cause solar He depletion. Nakamura *et al.* (1999b) showed the loss of the solar wind particles from minerals comprising the clastic matrix material of CM chondrites due to aqueous alteration in the parent body. Indeed, jarosite [$KFe_3(SO_4)_2(OH)_6$], which is a by-product mineral from aqueous alteration of sulfide minerals in the ice, was observed in ~43% of Kuwagata#11 samples by the X-ray diffraction analysis using a Gandolfi camera with a monochromated synchrotron X-ray microbeam, although this mineral is not significantly found in the Dome Fuji AMMs (Terada *et al.*, 2001). Electron probe micro analyzer (EPMA) analysis also shows that bulk chemical composition for Kuwagata#2 AMMs have lower Mg concentrations than Dome Fuji AMMs, indicating extraction of Mg in glacier ice (Yada *et al.*, 2001). These reports support the idea that the aqueous alteration process has weakened the light noble gas retentivity in AMM surface. Since low energy solar wind exists only at <500 Å depth in the surface layer of AMM, it is easily lost by the jarosite forming reaction in the Antarctic ice. On the other hand, solar energetic particles (SEP), which are high-energy ion particles, remain in AMM because SEP is implanted into AMM deeper than low energy solar wind. Indeed, there is no significant difference for Ne concentration between Kuwagata and Dome Fuji AMMs, since SEP-Ne is predominant in AMMs. Systematic decrease of He concentration for Kuwagata AMMs may be explained by the escape of solar-wind-He. SEP-He and cosmogenic ^{3}He presumably remain in AMM.

Meanwhile, it is difficult to explain the lack of atmospheric contamination by the same mechanism of alteration. It is natural that aqueous alteration increases concentrations of Ar, Kr, and Xe due to the atmosphere, which solved in natural water and adsorbed on the surface of by-product minerals. If the adsorbed atmosphere can be removed in glacial ice by the aqueous alteration as an exceptional case, the influence of atmospheric contamination would consequentially become small. However, it cannot be confirmed whether such an exceptional phenomenon has actually happened.

A procedure of sample preparation can be another possible cause. Dome Fuji AMMs were washed and removed from filters by distilled water. On the other hand, acetone was used instead of water in the preparation of Kuwagata samples. By this

procedure, terrestrial organic matters with atmospheric noble gases might be removed from the surface of Kuwagata AMMs. However, infrared microscopic analysis showed that there is no significant organic material in most Dome Fuji AMMs, and only one sample had intense C-H stretching vibration (Osawa *et al.*, 2001), showing the dearth of contamination of terrestrial organic matter. Small amount of organic matters might possibly have a large amount of atmospheric noble gases.

Another possibility is glycol phthalate used in X-ray diffraction analysis. Since noble gas measurements were done after X-ray diffraction analysis in the case of F96 samples of Dome Fuji AMMs, terrestrial contamination might be significant due to residue of the adhesive that was not completely removed. However, we cannot explain the case of F97 samples for which X-ray diffraction analysis was not done.

Whatever the cause is, it is important that Kuwagata AMMs preserved chondritic heavy noble gas composition as presented in Fig. 4, showing their original noble gas composition trapped in their parent bodies. Although Dome Fuji AMMs contain chondritic heavy noble gases, they are masked by the atmospheric contamination. This result supports the conclusion that AMMs originally have chondritic heavy noble gas composition, supposed in the previous work (Osawa and Nagao, 2002).

6. Conclusion

He and Kr concentrations in Kuwagata AMMs were distinctively lower than those of Dome Fuji AMMs measured in the previous work. Ar and Xe concentrations in Kuwagata AMMs also show lower concentrations than those of Dome Fuji samples. However, there is no clear difference in Ne. Kuwagata AMMs preserved primordial chondritic heavy noble gas composition, showing lack of atmospheric contamination.

Statistic calculations, F-test and T-test were done for noble gas concentrations in order to compare Kuwagata AMMs to Dome Fuji AMMs. Variances of ^{4}He, ^{40}Ar, ^{84}Kr, and ^{132}Xe concentrations were significant in F-test, while ^{20}Ne and ^{36}Ar were not significant. Mean values for all noble gas elements other than ^{20}Ne were significant in T-test. These results show evident differences of noble gas concentrations between Kuwagata and Dome Fuji samples.

He loss may have occurred by aqueous alteration in Antarctic glacial ice, forming jarosite in the surface layer of AMMs. Lack of atmospheric contamination may reflect sample preparation using acetone. Atmospheric noble gases in Dome Fuji samples might be derived from terrestrial organic matters, although no positive proof exist in the present stage. To clarify the possibility, it is necessary to do the experiment in which Dome Fuji AMMs are washed by acetone in the future work.

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