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NOBLE GASES, CHEMICAL COMPOSITION, AND COSMIC-RAY EXPOSURE AGE OF THE YAMATO-74357 LODRANITE

Keisuke NAGAO[1], Otto EUGSTER[2], Andreas WEIGEL[2], Yayoi N. MIURA[3], Christian KOEBERL[4] and Nobuo TAKAOKA[5]

[1]*Institute for Study of the Earth's Interior, Okayama University, Misasa, Tottori 682–01*
[2]*Physikalisches Institut, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*
[3]*Department of Earth and Planetary Physics, University of Tokyo, Bunkyo-ku, Tokyo 113*
[4]*Institute of Geochemistry, University of Vienna, A-1010 Vienna, Austria*
[5]*Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, Hakozaki, Fukuoka 812*

Abstract: Cosmic-ray produced ^{3}He, ^{21}Ne, and ^{38}Ar concentrations and the chemical composition of the Yamato-74357 lodranite have been determined. Concordant concentrations of ^{3}He and ^{21}Ne have been obtained on both samples (Bern and Misasa). The concentration of cosmogenic ^{38}Ar is twice as high in the Bern as in the Misasa sample. The ^{3}He, ^{21}Ne and ^{38}Ar data for both samples yield an average cosmic-ray exposure age of 5.8±2.0 Ma. This age indicates that Yamato-74357 belongs to the lodranite group, which probably originates from a common break-up event about 5 Ma ago. Radiogenic ^{4}He and ^{40}Ar concentrations in the Bern sample are higher than those in the Misasa sample by more than a factor of two, suggesting that minerals enriched in U, Th and K are enriched in the finer grained fraction. The isotopic compositions of Kr and Xe are identical to those of the terrestrial atmosphere, except for the ^{129}Xe abundance. The small ^{129}Xe excess (^{129}Xe/^{132}Xe=1.15±0.04) is presumably due to the early formation of this meteorite.

1. Introduction

The Yamato-74357 lodranite was found in Antarctica as a small (13.8 g) piece with a fusion crust on one side (YANAI and KOJIMA, 1987). Its texture, mineralogy, chemical composition, and oxygen isotopic ratio were reported elsewhere (NAGAHARA *et al.*, 1990; CLAYTON *et al.*, 1992; TORIGOYE *et al.*, 1993). Noble gas compositions of this meteorite, determined by the stepwise heating method, have been reported previously (TAKAOKA *et al.*, 1993). Cosmic-ray exposure ages, based on the concentrations of cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar, showed some disagreement: 5.1±0.5, 10.1±1.3, and 3.0±0.3 Ma, respectively, were obtained. This may suggest heterogeneity of the target element concentrations, *e.g.*, high Mg and low Ca concentrations in the specimen studied by TAKAOKA *et al.* (1993). On the other hand, systematic noble gas studies of several lodranites indicated that the lodranites probably were ejected from their parent body by a single break-up event about 5 Ma ago (WEIGEL and EUGSTER, 1994; WEIGEL *et al.*, 1994). Hence, a reliable cosmic-ray

exposure age of the Y-74357 lodranite is necessary to show whether it belongs to the lodranite group, with a common exposure age, or not.

The objective of this paper is to report on our determination of the cosmic-ray exposure age of the Y-74357 lodranite. Here we discuss new noble gas data and an exposure age determined on a small sample prepared at the University of Bern from chips, which had remained from previous work in Misasa, Japan.

2. Experimental Procedures

2.1. Sample preparation

Two small chips with a total weight of 18.07 mg were gently crushed in a stainless steel mortar to obtain homogeneous material of ≤ 300 μm grain size for analyses of He, Ne, and Ar in Bern and of the chemical composition at the University of Vienna. (The samples are designated hereafter as "Bern" and "Vienna", respectively). In the early stage of crushing several coarser grains ≤ 500 μm were separated for noble gas analyses in Misasa (sample designation is "Misasa"). This sample was not further crushed, to avoid atmospheric contamination of the heavy noble gases Kr and Xe. Metal grains (1.96 mg) were separated from the crushed silicates. They were cut into 20 pieces and put into the three silicate samples according to their weight proportions so as to represent the original chemical compositions. Thus, we obtained three samples for noble gas and chemical analyses:

Bern	4.62 mg	(He, Ne and Ar),
Misasa	2.73 mg	(He, Ne, Ar, Kr, and Xe) and
Vienna	7.63 mg	(chemical composition).

A loss of 3.09 mg occurred during the procedure described above. Additional losses (10–15%) are due to loading the samples into the extraction line as indicated in Table 1a.

2.2. Analytical methods of noble gas and element concentrations

2.2.1. Bern sample (4.17 mg)

He, Ne, and Ar isotopic ratios and concentrations were analyzed in Bern, employing a radio-frequency extraction line and two metal-tube mass spectrometers equipped with secondary electron multipliers. Details of the experimental procedures have been given elsewhere (*e.g.*, EUGSTER, 1988; EUGSTER *et al.*, 1993). Blank levels at 1700°C for the Bern sample were ^{4}He=110, ^{20}Ne=3.7 and ^{40}Ar=7400 (10^{-12}cm^{3}STP). Isotopic ratios of the blank were atmospheric (Table 2a).

2.2.2. Misasa sample (2.39 mg)

All noble gases were analyzed using a modified VG5400 noble gas mass spectrometer, following a procedure that has been described elsewhere (*e.g.*, NAGAO and MIURA, 1993; NAGAO *et al.*, 1993; NAGAO, 1994). The sensitivity of the mass spectrometer, however, has recently been significantly improved by more than a factor of 10 by tuning of ion source parameters and flight tube geometry. With the higher sensitivity, ^{132}Xe of 1.5×10^{-16}cm^{3}STP can now be measured with a count rate of 1 cps, and the detection limit is less than 1×10^{-16}cm^{3}STP. Corrections for $^{40}Ar^{++}$ and CO_2^{++} at the ^{20}Ne and ^{22}Ne peaks were 7 and 2%, respectively.

2.2.3. Vienna sample (6.42 mg)

This coarse-grained sample (with some metal) was analyzed for major and trace element concentrations, using electron microprobe analyses and instrumental neutron activation analysis (INAA). First, the bulk sample was sealed into a polyethylene vial and then, together with a set of synthetic standards, irradiated for 8 hours at a flux of about 2×10^{12} n $cm^{-2}s^{-1}$, using the TRIGA Mark II reactor of the Atominstitut der Österreichischen Universitäten in Vienna. The accuracy of the data was evaluated by also analyzing international geological standard materials. For details of the analytical procedures, see KOEBERL (1993). After completion of the measurements and following an additional cooling period, the irradiated sample was fused under an Ar atmosphere to form a fused bead. This bead was then mounted and polished, and analyzed for major element composition with a Cameca Camebax electron microprobe, using standard Cameca data evaluation procedures. The bulk major element composition was obtained by averaging 15 individual analyses of 20×20 μm areas. Some elemental concentrations are reported in the footnote to Table 3; of those elements, Fe, K, Cr, and Ni were measured by INAA, and the others by fused bead electron microprobe analysis.

3. Noble Gas Isotopic Compositions and Cosmic-ray Exposure Age

Noble gas isotopic ratios and concentrations are listed in Tables 1a and 1b. The noble gas data from TAKAOKA *et al.* (1993) are also included for comparison. Because the samples used in this study were very small, we present abundances and isotopic ratios measured in blank runs in Tables 2a and 2b. The noble gas data in Tables 1a and 1b have been blank corrected. The blanks of ^{4}He, ^{20}Ne, and ^{40}Ar were 1.2, 3.6, and 21% of the measured amounts (*i.e.* of the amounts before blank subtraction) of the respective isotopes for the Bern sample, and 9, 13, and 6% for those of the Misasa sample. The blanks of ^{84}Kr and ^{132}Xe were 10 and 7% for the Misasa sample. The high ^{80}Kr/^{84}Kr ratio of 0.20 in the blank is presumably due to an interference of ^{40}Ar ions at the ^{80}Kr peak. The concentrations of ^{3}He, ^{21}Ne, and ^{36}Ar for the Bern and Misasa samples agree well, while the concentrations of radiogenic ^{4}He and ^{40}Ar, as well as the ratios ^{4}He/^{3}He and ^{40}Ar/^{36}Ar of the Bern sample, are two times higher than those of the Misasa sample. As the Bern sample consisted of crushed material $\leq$300 μm, while for the Misasa sample grain size was $\leq$500 μm, a possible explanation is that minerals enriched in U, Th and K, the parent nuclides of ^{4}He and ^{40}Ar, respectively, are concentrated in the finer grain size fractions. The ^{40}Ar/^{36}Ar ratio of the Misasa sample is identical to the atmospheric value (296), but this agreement clearly is fortuitous, because of the unambiguous detection of cosmogenic ^{38}Ar. There is also evidence for the presence of a small amount [*ca.* $(1.3\pm0.3)\times10^{-8}$ cm^3STP/g] of trapped ^{20}Ne in the Bern sample. The Kr and Xe isotopic ratios in the Misasa sample agree, within the respective errors, with those measured by TAKAOKA *et al.* (1993), and are indistinguishable from the terrestrial atmospheric ratios, except for an excess of ^{129}Xe, *i.e.*, ^{129}Xe/^{132}Xe=1.12–1.15. The presence of radiogenic ^{129}Xe from extinct ^{129}I indicates early formation of the Y-74357 lodranite. On the other hand, the K-Ar age calculated using the ^{40}Ar and K concentrations of

Table 1a. He, Ne and Ar abundances and isotopic compositions of Y-74357,73.

Sample	^{3}He	^{4}He	$\frac{^{3}He}{^{4}He}$	^{20}Ne	^{21}Ne	^{22}Ne	$\frac{^{20}Ne}{^{22}Ne}$	$\frac{^{21}Ne}{^{22}Ne}$	$\frac{^{22}Ne}{^{21}Ne}$	^{36}Ar	^{38}Ar	^{40}Ar	$\frac{^{38}Ar}{^{36}Ar}$	$\frac{^{40}Ar}{^{36}Ar}$
Bern	9.8	214	0.0459	2.38	0.977	1.515	1.573	0.645	1.551	0.837	0.334	668	0.398	798
(4.17 mg)	±.5	±11	±.0009	±.14	±.160	±.150	±.129	±.084	±.203	±.074	±.035	±36	±.024	±55
Misasa	10.9	122	0.0895	1.31	1.12	1.50	0.874	0.747	1.339	0.750	0.232	222	0.3087	295.9
(2.39 mg)	±1.1	±12	±.0038	±.13	±.11	±.15	±.044	±.014	±.026	±.075	±.023	±22	±.0024	±1.0
TAKAOKA *et al.*	8.29	239	0.0347	4.30	4.59	4.94	0.870	0.929	1.076	0.291	0.184	1027	0.632	3528
(38.7 mg)			±.0003				±.009	±.010	±.012				±.004	±54
(Step heating)														

Concentrations are given in units of 10^{-8} $cm^{3}STP/g$.

Table 1b. Kr and Xe abundances and isotopic compositions of Y-74357,73.

Sample	^{84}Kr	^{78}Kr	^{80}Kr	^{82}Kr	^{83}Kr	^{86}Kr	^{132}Xe	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
		$^{84}Kr=100$						$^{132}Xe=100$							
Misasa	202	0.598	3.75	20.05	20.02	30.51	48.1	n.d.	n.d.	7.45	114.5	15.7	79.4	39.1	32.7
	±20	±.088	±.29	±.42	±.63	±1.11	±4.8			±.57	±3.5	±.4	±3.6	±1.1	±1.4
TAKAOKA	95.1	0.71	4.45	20.2	20.7	30.4	53.3	(0.44)	(0.48)	7.32	112.2	15.8	79.7	39.3	32.7
et al.		±.16	±.35	±1.1	±.9	±1.0				±.63	±4.0	±1.1	±3.9	±2.1	±1.6
(1993)															

Concentrations are given in units of 10^{-12} $cm^{3}STP/g$.
n.g.: not determined.

Table 2a. He, Ne and Ar abundances and isotopic compositions of blank run.

	^{3}He	^{4}He	$\frac{^{3}He}{^{4}He}$	^{20}Ne	^{21}Ne	^{22}Ne	$\frac{^{20}Ne}{^{22}Ne}$	$\frac{^{21}Ne}{^{22}Ne}$	^{36}Ar	^{38}Ar	^{40}Ar	$\frac{^{38}Ar}{^{36}Ar}$	$\frac{^{40}Ar}{^{36}Ar}$
Bern 1700°C	n.d.	110	n.d.	3.7	a	a	a	a	a	a	7400	a	a
Misasa 1800°C	n.d.	290	<0.00003	4.8	0.050	0.55	8.7 ±.6	0.09 ±.03	1.17	0.257	337	0.2195 ±.0030	288.0 ±.4

Concentrations are given in units of 10^{-12} cm^3STP/g.
a: atmospheric isotopic compositions.
n.d.: not determined.

Table 2b. Kr and Xe abundances and isotopic compositions of blank run.

	^{84}Kr	^{78}Kr	^{80}Kr	^{82}Kr	^{83}Kr	^{86}Kr	^{132}Xe	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
	$^{84}Kr=100$							$^{132}Xe=100$							
Misasa 1800°C	52	0.94 ±.40	20.0 ±.9	20.9 ±1.3	20.2 ±1.7	30.7 ±2.2	8.6	n.d.	n.d.	8.3 ±3.3	98 ±11	15.7 ±3.9	80.4 ±6.3	42.3 ±3.2	35.8 ±3.7

Concentrations are given in units of 10^{-15} cm^3STP/g.
n.d.: not determined.

$668\times10^{-8}cm^3STP/g$ (Bern) and 150 ppm (Vienna) is 3.6 Ga, which is much younger than the age of the solar system. This may reflect a difference in retentivity for radiogenic ^{129}Xe and ^{40}Ar in the meteorite.

The concentrations of cosmogenic ^{3}He, ^{21}Ne, and ^{38}Ar (Table 3) were calculated based on the isotope ratios of cosmogenic and trapped components given by EUGSTER *et al.* (1993). Concentrations of ^{3}He and ^{21}Ne determined for the Bern and Misasa samples agree well, while the ^{38}Ar concentrations disagree, *i.e.*, $(0.20\pm0.03)\times10^{-8}cm^3STP/g$ for Bern and $(0.103\pm0.010)\times10^{-8}cm^3STP/g$ for Misasa. The disagreement is likely due to a low Ca concentration of the Misasa sample compared with that of the Bern sample. Cosmogenic $^{22}Ne/^{21}Ne$ ratios of 1.401 ± 0.187 and 1.326 ± 0.026 for the two samples indicate a small preatmospheric size of this meteorite, in accordance with the small recovered mass (13.8 g).

To determine the cosmic-ray exposure age for this meteorite, production rates, P, were calculated using the formulas presented by EUGSTER and MICHEL (1995). This procedure was particularly derived for achondritic compositions. The target element composition as measured for the Vienna sample (Table 3) was used in the calculation. The shielding of the sample within the meteoroid was taken into account for P_3 and P_{21}, using the formulas for diogenites (EUGSTER and MICHEL, 1995), as the chemical composition for the relevant elements of Y-74357 and diogenites is quite similar. The resulting production rates and exposure ages are given in Table 3. For the Bern and Misasa samples, a good agreement of the T_3 and T_{21} ages is observed. The T_{38} ages are significantly lower than the T_3 and T_{21} ages, perhaps due to inhomogeneities of

Table 3. Concentrations of cosmogenic ^{3}He, ^{21}Ne, and ^{38}Ar, cosmogenic $^{22}Ne/^{21}Ne$ ratio, production rates, and cosmic-ray exposure ages.

Sample	^{3}He	^{21}Ne	^{38}Ar	$(^{22}Ne/^{21}Ne)_c$	P_3	P_{21}	P_{38}	T_3	T_{21}	T_{38}	$T_{average}$
	10^{-10} cm^3 STP/g				10^{-10} cm^3 STP/gMa			Ma			
Bern	980± 60	97±16	20 ±3	1.401±0.187	145	13.0	4.51	6.8	7.5	4.4	6.2±1.6
Misasa	1090±110	112±11	10.3±1.0	1.326±0.026	150	16.9	4.51	7.3	6.6	2.3	5.4±2.7

Concentrations of target elements (wt%) used for the calculation of the production rates (see text): Si (22.8), Ti (0.12), Al (0.21), Fe (21.5), Mn (0.37), Mg (18.3), Ca (0.84), K(0.015), Cr (1.45), and Ni (0.96).

the distribution of the main target elements for the $^{38}Ar_c$ production among the different samples used for the noble gas and target element determinations.

In conclusion, we adopt as a cosmic-ray exposure age of the Yamato-74357 lodranite the average value of 5.8±2.0 Ma (1σ) for the Bern and Misasa samples. Consequently, this lodranite belongs to the lodranite group, which originated in a single break-up event that occurred 5±1 Ma ago (WEIGEL and EUGSTER, 1994; WEIGEL *et al.*, 1994).

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