

Thematic Article

Noble gases in pillow basalt glasses from the northern Mariana Trough back-arc basin

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Abstract Noble gas concentrations and isotopic compositions have been measured in eight samples of pillow basalt glasses collected from seven different localities along 250 km of the Mariana Trough spreading and rifting axis. The samples have uniform and mid-ocean ridge basalt (MORB)-like $^3\text{He}/^4\text{He}$ values of $9\text{--}12 \times 10^{-6}$ (6.4–8.6 times atmospheric) despite large variations in ^4He . Concentrations of the noble gases Ne, Ar, Kr, and Xe show much smaller variations between samples, but larger variations in isotopic compositions of Ne, Ar, and Xe. Excess radiogenic ^{21}Ne is observed in some samples. $^{40}\text{Ar}/^{36}\text{Ar}$ varies widely (atmospheric to 1880). Kr is atmospheric in composition for all samples. Some samples show a clear excess ^{129}Xe , which is a well-known MORB signature. Isotopic compositions of the heavier noble gases (Ar, Kr, and Xe) in some samples, however, show more atmospheric components. These data reflect the interaction of a MORB-like magma with an atmospheric component such as seawater or of a depleted mantle source with a water-rich component that was probably derived from the subducting slab.

Key words: atmosphere, back-arc basin basalt, basalt glass, Mariana Trough, mixing, MORB, noble gas.

INTRODUCTION

Many compositional aspects of back-arc basin basalts (BABB) such as basalts of the Mariana Trough, are similar to mid-ocean ridge basalt (MORB; Hart *et al.* 1972; Saunders & Tarney 1979; Wood *et al.* 1981; Gribble *et al.* 1996). However, a water-rich subduction component (derived from subducted lithosphere and sediments) is involved in the generation of BABB. This subduction component is typically identified because of elevated contents of water (typically $>1.5\%$ H_2O for BABB versus $<0.3\%$ H_2O for MORB) and fluid-mobile elements such as K, Rb, and other large ion lithophiles (LIL) (Hawkins &

Melchior 1985; Hawkins *et al.* 1990; Stolper & Newman 1994; Gribble *et al.* 1996).

Noble gases in BABB provide important information for understanding the roles played by primitive mantle on the one hand and subducted materials on the other (Poreda 1985; Sano *et al.* 1986; Poreda & Craig 1989; Honda *et al.* 1993; Gasparon *et al.* 1994). For example, $^3\text{He}/^4\text{He}$ and $^{40}\text{Ar}/^{36}\text{Ar}$ data in Mariana Trough basalt glasses indicate that the noble gases in these basalts are a mixture of gases derived from unmodified depleted mantle and a component that recently was in equilibrium with the atmosphere, presumably originating in the subducted slab (Poreda 1985; Sano *et al.* 1986).

In order to examine the sources responsible for generating Mariana Trough BABB, we have

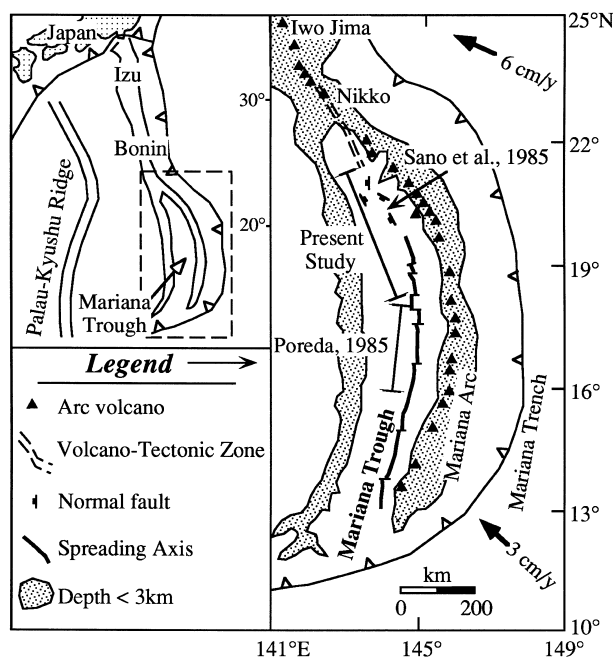


Fig. 1 Location map of the Mariana arc system showing the extension axis of the Mariana Trough and region sampled for the present study. Also shown are regions studied by Poreda (1985), and Sano *et al.* (1986).

analysed both isotopic and elemental compositions of all noble gases from He to Xe in pillow basalt glasses from seven different localities along a 250-km-long section of the extension axis in the northern Mariana Trough (Fig. 1). We also present water and CO₂ concentration data, and consider the significance of the noble gas data in this context. The present study is intended to present these data for the purpose of further constraining models for the generation of BABB.

METHODS

SAMPLES

Pillow basalts with fresh glass were recovered from the northern Mariana Trough on the GH88-1 cruise of the research vessel (R/V) *Hakurei-maru* during 1988 and the Tunes 7 cruise of the R/V *Thomas Washington* in 1991. Approximate locations of the glasses are listed in Table 1. All samples were collected from along the extension axis of the Mariana Trough, and this indicates that most samples are 'zero age'. However, samples D46:1-6 and D47:1-5 may be as old as 1.8 ± 0.6 Ma (Stern *et al.* 1996). Geochemical and radiogenic isotopic (Sr, Nd, and Pb) compositions of the Tunes 7 suite are reported and discussed

elsewhere (Gribble *et al.* 1998), while major element data are presented for the GH88-1 suite for the first time here. The sampled region (Fig. 1) extends north from that studied by Poreda (1985), and encompasses the area studied by Sano *et al.* (1986).

SAMPLE PREPARATION AND ANALYSIS

All analyses were conducted on clean glass separates, isolated from pillow rinds. Major element compositions are from Gribble *et al.* (1996) except for D1009 and D1010 which were determined at University of Texas at Dallas. The H₂O (as total water) and CO₂ (as carbonate) contents of glasses were determined by Fourier transform infra-red spectroscopy (Stolper & Newman 1994). Uncertainties are estimated at no more than 15% for CO₂ and 5% for H₂O.

For noble gas studies, glassy pillow rinds were crushed to ~2-5 mm and cleaned ultrasonically in water, ethanol, and acetone. Sample sizes were typically from 1 to 2 g; this was wrapped with 10- μ m-thick Al foil. Wrapped samples were placed inside the sample holder and connected to an ultra-high vacuum line for noble gas extraction and purification. While the extraction line was baked, the sample was heated to ~150 °C for more than 1 day in an effort to remove atmospheric contamination. Noble gases were extracted by melting the sample in a Mo crucible at 1800 °C, then purified by exposing the gases to hot Ti-Zr getters. Before He and Ne analysis, Ar, Kr and Xe were separated using a charcoal trap at temperatures of liquid nitrogen temperature. Ne was trapped on another trap at temperature of 13-14 °K, and then He isotopic ratios were analysed. After evacuation of He, the Ne released from the trap at a temperature of 35 °K was analysed. Ar, Kr and Xe were separated into two fractions, Ar and Kr + Xe, by the charcoal trap at a temperature of -60 °C. Abundances and isotopic compositions were measured on a modified VG 5400 mass spectrometer (VG Isotech) at the Institute for Study of the Earth's Interior, Okayama University (Miura & Nagao 1991; Nagao & Takahashi 1993). Pipetted atmospheric noble gases and a standard ³He/⁴He gas prepared in the laboratory were used to determine the sensitivities and mass discriminations for all noble gas isotopes. Blank levels of the system during the analyses were ⁴He = 2.7×10^{-10} , ²⁰Ne = 1.3×10^{-11} , ⁴⁰Ar = 4.2×10^{-9} , ⁸⁴Kr = 3.7×10^{-13} , and ¹³²Xe = 4.5×10^{-14} cm³ STP.

Table 1 Compositional data and locations of Mariana Trough basalts

	68:1-2	47:1-5	46:1-6	72:2	75:1-2	80:1-3	D1009	D1010
SiO ₂	52.48	51.22	51.46	51.57	52.30	49.56	51.24	51.41
TiO ₂	1.01	0.96	1.12	1.27	1.61	0.84	1.21	1.26
Al ₂ O ₃	16.53	16.60	16.95	16.92	16.38	17.93	16.65	16.58
FeO*	7.51	7.53	7.81	7.34	8.38	8.61	7.49	7.58
MgO	6.26	7.33	7.07	6.55	7.33	8.60	7.44	7.57
CaO	11.07	12.12	11.56	10.57	10.60	11.55	10.92	10.98
Na ₂ O	2.86	2.49	2.70	3.09	3.27	2.40	2.97	3.01
K ₂ O	0.43	0.24	0.22	0.48	0.35	0.35	0.37	0.37
P ₂ O ₅	0.18	0.13	0.15	0.18	0.18	0.14	0.10	0.18
Sum	98.33	98.62	99.04	97.97	100.40	99.98	98.37	98.93
Mg#	64	67	66	65	65	67	68	68
Q/OL [†]	Q2.5	Q0.8	Q0.8	Q0.5	OL1.3	OL9.8	OL1.8	OL2.2
H ₂ O (%)	1.87	1.76	1.41	2.23	0.72	0.57	1.20	1.13
CO ₂ (p.p.m.)	100	81.3	137	81	282	362	171	172
Saturation Depth* (m)	5400	4700	4700	6400	6200	7600	4900	4700
Location:								
N latitude	21°24'	21°00'	20°45'	19°59'	19°38'	19°12'	18°09'	18°09'
E longitude	143°16'	143°27'	143°36'	143°48'	144°39'	144°48'	144°44'	144°44'
Collection depth (m)	3850 ± 50	4390 ± 710	3700	4415 ± 35	4415 ± 35	4045 ± 5	3735 ± 35	3740 ± 60

All analyses use glass separates.

*Depth for vapor saturation in the mixed H₂O–CO₂ volatile system at 1150 °C.

[†]Q/OL = % normative quartz or olivine.

Errors for isotope ratios are given as one standard deviation. Uncertainties for concentrations are estimated to be $\sim \pm 10\%$.

RESULTS

Major element, water, and CO₂ compositions are presented in Table 1. Results for elemental and isotopic compositions of noble gases are presented in Tables 2 and 3.

Combined H₂O and CO₂ contents of these basalt glasses tend to be somewhat higher than those of the Mariana Trough basalts from further south. The depth of collection indicated by the volatile compositions, assuming saturation with respect to a mixed H₂O–CO₂ fluid at eruption and temperature of 1150 °C, range from 4.7 to 7.6 km (cf. Stolper & Newman 1994). All of the samples are saturated or significantly supersaturated in mixed phase volatiles, and the extent of supersaturation approximates He and Ar abundances.

The ³He/⁴He ratios in the samples are remarkably uniform at $9.0\text{--}12.0 \times 10^{-6}$ ($R/R_A = 6.4\text{--}8.6$ times atmospheric) and have MORB-like compositions (average 1.2×10^{-5} ; Kurz 1991). Only sample D46:1–6 has an isotopic composition ($R/R_A = 6.4$) that is distinct from the average

MORB He isotopic composition of $R/R_A = 8.2 \pm 0.7$ (Hilton *et al.* 1993). This constancy of helium isotopic composition is remarkable because it is maintained over a 500-fold range in helium concentrations (Fig. 2). These observations are similar to those of Lau Basin basalts (Honda *et al.* 1993). As discussed by Honda *et al.* (1993), this trend cannot result from the ingrowth of radiogenic ⁴He in differentiating magma, post-eruptive contamination with atmospheric helium from seawater, or diffusive loss of magmatic helium, but is likely to reflect the helium isotopic signatures of magma sources.

In contrast to the large concentration range shown by He, ²⁰Ne varies only from 1.3 to 15.6×10^{-10} cc/g. The ratio ⁴He/²⁰Ne is thought to reflect the degree of air contamination (Craig *et al.* 1978). The measured ⁴He/²⁰Ne ratios in the present study range from 45 to almost 60 000. There is a strong inverse relationship between ⁴He/²⁰Ne and ²⁰Ne, which can be explained by mixing of mantle-derived noble gases (high ⁴He/²⁰Ne) with atmospheric noble gases (⁴He/²⁰Ne = 0.318). Atmospheric contamination for ⁴He is thus limited to <0.1%.

Neon isotopic compositions are shown on a three-isotope plot (²⁰Ne/²²Ne vs ²¹Ne/²²Ne) in Fig. 3. The Ne isotopic data for Mariana Trough

Table 2 Isotopic compositions and concentrations of He, Ne and Ar in Mariana Trough basalts

Sample	Weight (g)	³ He	⁴ He	³ He/ ⁴ He	²⁰ Ne	²⁰ Ne/ ²² Ne	²¹ Ne/ ²² Ne	³⁶ Ar	³⁸ Ar	⁴⁰ Ar	³⁸ Ar/ ³⁶ Ar	⁴⁰ Ar/ ³⁶ Ar
D46:1-6	1.5826	0.279	311	8.96 ± 0.15	6.83	9.716 ± 0.014	0.02896 ± 0.00069	4.23	0.794	1900	0.1877 ± 0.0004	333.91 ± 0.86
D47:1-5	1.3589	6.27	5720	10.97 ± 0.12	7.57	9.858 ± 0.019	0.0296 ± 0.0005	6.80	1.28	2160	0.1879 ± 0.0004	317.77 ± 0.83
D68:1-2	1.8315	2.32	2010	11.55 ± 0.12	4.55	9.767 ± 0.016	0.02852 ± 0.00063	8.75	1.65	2650	0.1880 ± 0.0004	303.07 ± 0.78
D72:2	1.7331	6.04	5700	10.59 ± 0.08	1.33	9.853 ± 0.025	0.0309 ± 0.0022	4.38	0.824	1310	0.1881 ± 0.0004	299.44 ± 0.85
D75:1-2	1.5650	163	146 000	11.19 ± 0.04	2.44	9.997 ± 0.060	0.0355 ± 0.0017	5.05	0.949	2460	0.1879 ± 0.0005	487.4 ± 1.8
D80:1-3	1.1137	106	90 900	11.61 ± 0.15	2.21	9.942 ± 0.016	0.0324 ± 0.0028	4.23	0.794	7960	0.1877 ± 0.0008	1883.9 ± 5.7
D1009	1.8102	74.2	66 400	11.17 ± 0.08	15.6	9.686 ± 0.015	0.02992 ± 0.00024	15.4	2.90	8150	0.1880 ± 0.0005	529.9 ± 1.6
D1010	1.8574	99.6	83 200	11.97 ± 0.09	3.67	9.952 ± 0.018	0.03254 ± 0.00074	6.37	1.20	5790	0.1883 ± 0.0005	908.3 ± 2.5

Unit: ³He/⁴He = (10⁻⁶), concentrations of ⁴He, Ne and Ar = 10⁻¹⁰ cc/g, and concentrations of ³He = 10⁻¹² cc/g.

Table 3 Isotopic compositions and concentrations of Kr and Xe in Mariana Trough basalts

Sample	⁸⁴ Kr	⁷⁸ Kr	⁹⁰ Kr	⁸² Kr ⁸⁴ Kr = 100	⁸³ Kr	⁸⁶ Kr	¹³² Xe	¹²⁴ Xe	¹²⁶ Xe	¹²⁸ Xe	¹²⁹ Xe ¹³² Xe = 100	¹³⁰ Xe	¹³¹ Xe	¹³⁴ Xe	¹³⁶ Xe
D46:1-6	9.42	0.640 ± 0.025	4.05 ± 0.04	20.50 ± 0.20	20.31 ± 0.10	30.57 ± 0.17	1.41			7.08 ± 0.52	99.2 ± 3.4	15.38 ± 0.83	80.6 ± 3.2	39.5 ± 1.6	33.44 ± 0.93
D47:1-5	17.6	0.636 ± 0.036	4.06 ± 0.04	20.43 ± 0.14	20.28 ± 0.12	30.58 ± 0.12	4.05	0.319 ± 0.115	0.293 ± 0.081	7.22 ± 0.35	98.28 ± 0.56	15.30 ± 0.37	78.78 ± 0.51	38.83 ± 0.30	33.08 ± 0.49
D68:1-2	20.3	0.616 ± 0.023	4.06 ± 0.04	20.38 ± 0.11	20.27 ± 0.11	30.58 ± 0.09	1.15			7.33 ± 0.24	100.5 ± 1.2	15.17 ± 0.19	78.89 ± 0.66	39.03 ± 0.21	32.95 ± 0.29
D72:2	8.70	0.77 ± 0.28	4.30 ± 0.75	20.40 ± 0.14	20.17 ± 0.16	30.70 ± 0.24	1.74			7.02 ± 0.20	98.51 ± 0.77	15.06 ± 0.25	78.62 ± 0.56	38.61 ± 0.30	33.08 ± 0.18
D75:1-2	11.9	0.619 ± 0.055	4.07 ± 0.07	20.54 ± 0.11	20.30 ± 0.14	30.52 ± 0.15	0.930			7.04 ± 0.47	99.50 ± 0.94	15.04 ± 0.12	78.95 ± 0.85	39.10 ± 0.95	32.94 ± 0.87
D80:1-3	12.6	0.63 ± 0.11	4.05 ± 0.07	20.49 ± 0.15	20.35 ± 0.21	30.60 ± 0.23	0.754			7.12 ± 0.33	101.63 ± 0.66	14.91 ± 0.40	78.99 ± 0.60	39.04 ± 0.32	33.09 ± 0.72
D1009	36.3	0.620 ± 0.021	4.03 ± 0.04	20.37 ± 0.09	20.32 ± 0.07	30.56 ± 0.08	2.64	0.420 ± 0.076	0.371 ± 0.130	7.17 ± 0.14	99.05 ± 0.48	15.12 ± 0.21	78.80 ± 0.41	38.55 ± 0.28	32.85 ± 0.26
D1010	13.9	0.670 ± 0.048	3.99 ± 0.08	20.33 ± 0.11	20.26 ± 0.18	30.55 ± 0.15	2.23	0.392 ± 0.035	0.323 ± 0.032	7.101 ± 0.078	98.54 ± 0.36	15.18 ± 0.14	79.05 ± 0.61	38.76 ± 0.19	32.94 ± 0.23
Air		0.609	3.960	20.22	20.14	30.52		0.354	0.330	7.136	98.32	15.136	78.90	38.79	32.94

Concentrations of ⁸⁴Kr and ¹³²Xe are given in the unit of 10⁻¹² cc/g.

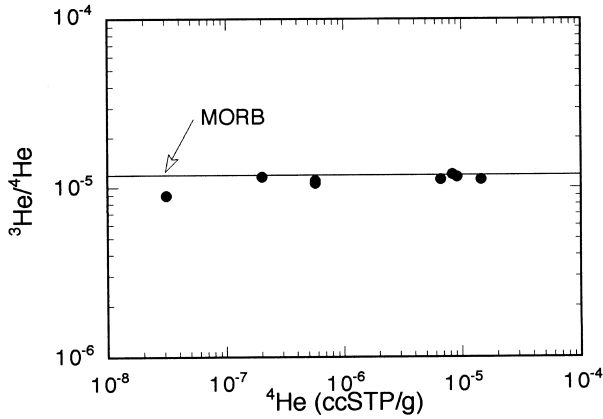


Fig. 2 $^3\text{He}/^4\text{He}$ ratios plotted against ^4He concentrations for the Mariana Trough basalts. Average $^3\text{He}/^4\text{He}$ ratio of mid-ocean ridge basalt (MORB) ($= 1.2 \times 10^{-5}$; $8.5R/R_A$) from Kurz (1991).

samples differ from correlation lines defined by MORB, Loihi-Kilauea (L-K) and Lau Basin basalts as given by Sarda *et al.* (1988) and Honda *et al.* (1991, 1993). Although only a fraction of the range of $^{20}\text{Ne}/^{22}\text{Ne}$ shown in MORB and OIB (up to 13.7; Porcelli & Wasserburg 1995) is seen in the data, Mariana Trough BABB appear to define a trend that is not seen in other basalts. The $^{21}\text{Ne}/^{22}\text{Ne}$ shows the presence of radiogenic ^{21}Ne produced from U and Th by the reactions $^{18}\text{O}(\alpha, n)^{21}\text{Ne}$ and $^{24}\text{Mg}(n, \alpha)^{21}\text{Ne}$. Neon in Mariana Trough basalts lies on a mixing line between atmospheric Ne and mantle-derived Ne that is more radiogenic than that found in MORB or Lau Basin basalts (Fig. 3).

The $^{40}\text{Ar}/^{36}\text{Ar}$ of the Mariana Trough samples varies from 299 (close to the atmospheric ratio of 295.5) to as high as 1884. These ratios are similar

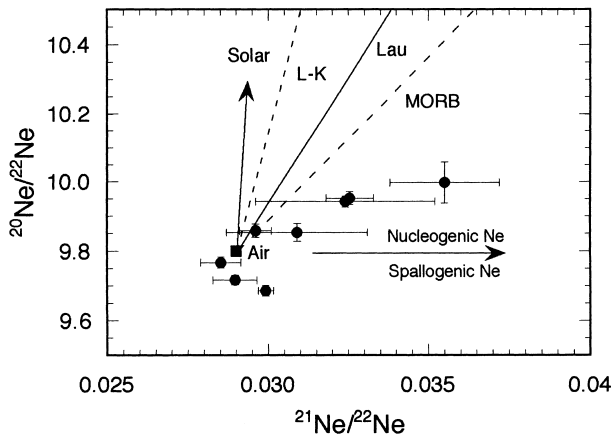


Fig. 3 Neon isotope plots for Mariana Trough basalts. Atmospheric neon is shown as Air. Mid-ocean ridge basalt (MORB), Loihi-Kilauea (L-K) and Lau Basin correlation lines are as given by Sarda *et al.* (1988), Honda *et al.* (1991) and Honda *et al.* (1993).

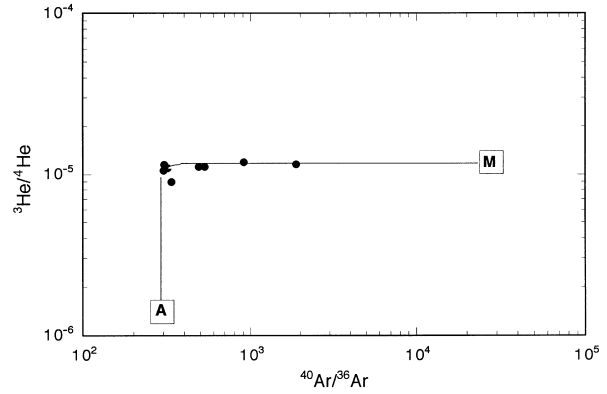


Fig. 4 Helium and argon isotopic composition of Mariana Trough basalts. The line connecting M–A represents the two-component mixing between mid-ocean ridge basalt (MORB) (M) and atmosphere (A) (Kaneoka & Takaoka 1985).

to other data for the Mariana Trough ($^{40}\text{Ar}/^{36}\text{Ar} = 360\text{--}3869$; Sano *et al.* 1986), as well as back-arc basin basalts from the Lau Basin (300–2430; Honda *et al.* 1993), but are much lower than the maximum ratio found for MORB ($^{40}\text{Ar}/^{36}\text{Ar} = 28000$; Staudacher *et al.* 1989). The $^3\text{He}/^4\text{He}$ and $^{40}\text{Ar}/^{36}\text{Ar}$ data are most simply explained as resulting from mixing between MORB and atmospheric components (Fig. 4). There is a negative correlation between the $^{40}\text{Ar}/^{36}\text{Ar}$ ratios and H_2O contents of the samples (Fig. 5). As shown in Lau Basin basalts (Honda *et al.* 1993), this is also consistent with addition of atmosphere-derived argon.

Abundances of krypton in the samples ($^{84}\text{Kr} = 0.87\text{--}3.6 \times 10^{-11}$ cc STP/g) are higher than the range found for Lau Basin basalts ($0.2\text{--}0.9 \times 10^{-11}$ cc STP/g), but fall at the lower end of the

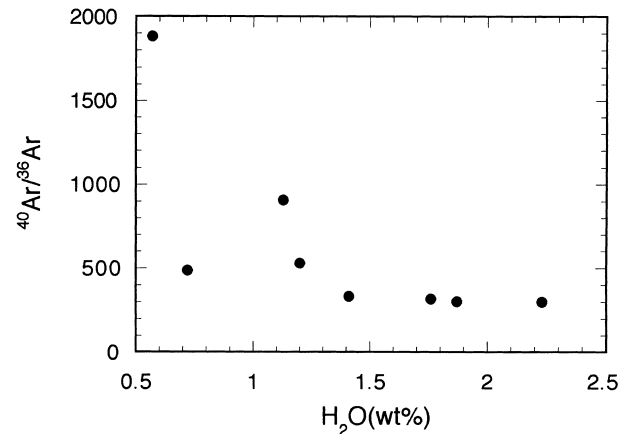


Fig. 5 $^{40}\text{Ar}/^{36}\text{Ar}$ ratios vs H_2O contents for the Mariana Trough basalts.

range found for MORB ($0.1\text{--}100 \times 10^{-11}$ cc STP/g; Honda *et al.* 1993). As shown for other terrestrial materials, isotopic ratios of krypton in Mariana trough glasses have approximately atmospheric compositions indicating that the mass fractionation effects are very minimal.

Correlated excesses in ^{129}Xe are found in some Mariana Trough samples, such as those found for MORB by Staudacher and Allègre (1982). A plot of the data on a $^{134}\text{Xe}/^{130}\text{Xe}$ versus $^{129}\text{Xe}/^{130}\text{Xe}$ diagram (Fig. 6) shows a clear linear correlation that is similar to that defined for MORB data. These are the first data for Xe in back-arc basin basalts that differ from atmospheric isotopic compositions. Staudacher and Allègre (1982) argued that the excess ^{129}Xe is a decay product of extinct nuclide ^{129}I (half-life = 17 Ma) that was present only very early in the Earth's history. Excess $^{131\text{--}136}\text{Xe}$ may result from spontaneous fission of ^{238}U and/or another extinct nuclide ^{244}Pu (half-life = 82 Ma). The linear correlation shown on Fig. 6 can be explained as a simple mixture of atmospheric and MORB components.

We note that D80:1–3, the sample with the highest $^{129}\text{Xe}/^{130}\text{Xe}$ value, also has the highest $^{40}\text{Ar}/^{36}\text{Ar}$ value (1884) of the sample suite, and also has a very high $^4\text{He}/^{20}\text{Ne}$ value ($> 40\,000$). Moreover, it has the lowest H_2O content (0.57%) of the suite; the other seven samples contain 0.7–2.2% H_2O .

NOBLE GASES IN THE MANTLE SOURCE OF MARIANA TROUGH BASALTS

The isotopic compositions of noble gases in Mariana Trough basalts are consistent with a

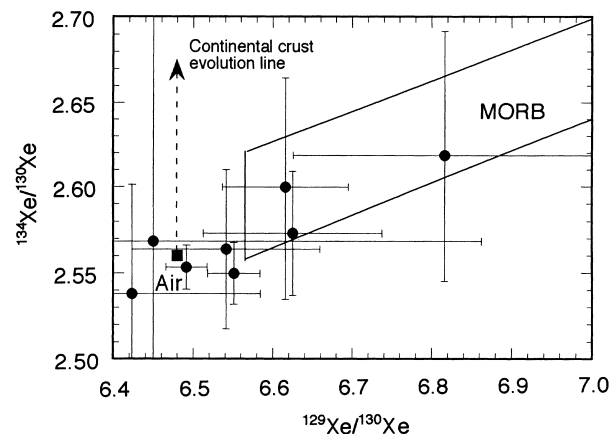


Fig. 6 $^{134}\text{Xe}/^{130}\text{Xe}$ vs $^{129}\text{Xe}/^{130}\text{Xe}$ for Mariana Trough basalts. The mid-ocean ridge basalt (MORB) field is compiled from Staudacher & Allègre (1982).

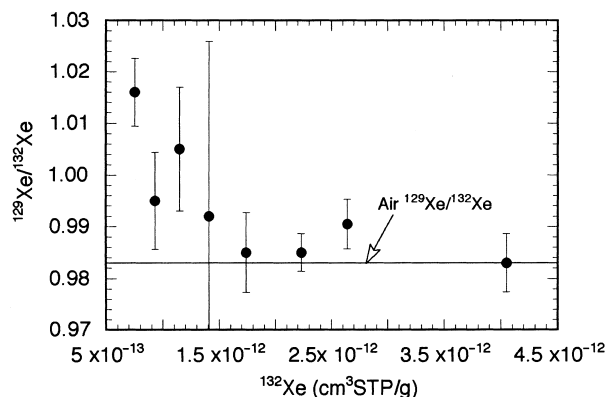


Fig. 7 $^{129}\text{Xe}/^{132}\text{Xe}$ ratios vs ^{132}Xe contents for Mariana Trough basalts.

two-component mixture of gases from atmospheric and MORB sources. The question arises as to where this mixing occurs. The two main possibilities are shallow mixing (in the lab, during eruption, or accompanying storage and interaction of magma with altered crust or with seawater) and deep mixing (in the mantle above the subduction zone). The $^3\text{He}/^4\text{He}$ versus ^4He and $^4\text{He}/^{20}\text{Ne}$ preclude significant direct mixing of atmosphere or atmospheric components dissolved in seawater. The sample with the lowest $^4\text{He}/^{20}\text{Ne}$ is D46:1–6, with a ratio of 45.5, and thus the largest possible direct atmospheric component allowed by this is less than 1%. All other samples have up to three orders of magnitude lower direct atmospheric component.

Some investigators have suggested that the most atmospheric heavy noble gas components in oceanic basalts result from interactions with seawater (Fisher 1989; Patterson *et al.* 1990; Honda *et al.* 1993). In order to further understand the significance of atmospheric and radiogenic components, we studied variations of isotopic compositions of the heavy noble gases. Figure 7 shows a negative correlation between $^{129}\text{Xe}/^{132}\text{Xe}$ and ^{132}Xe abundances for Mariana Trough samples. Interestingly, there is a weak positive correlation between the abundances of xenon and water (Fig. 8). Consideration of Fig. 7 and Fig. 8 together suggests that the source for the atmospheric heavy noble gas component in the Mariana Trough samples result from interaction with seawater, because seawater has heavy noble gas abundances a few orders of magnitude higher than oceanic basalt glasses (Honda *et al.* 1993). Similar positive correlations between ^{132}Xe and H_2O are shown in Lau Basin

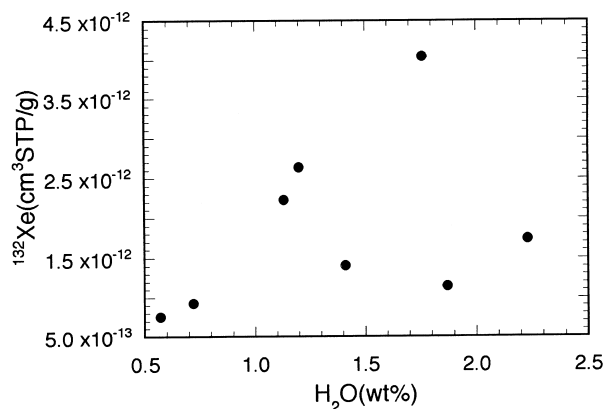


Fig. 8 ¹³²Xe concentrations vs H₂O contents for Mariana Trough basalts.

basalt (Honda *et al.* 1993). They suggest that the noble gases indicate interaction of magmas with a water-rich, recycled component derived from the subducted slab or atmospheric contamination of the magmas just prior to eruption in the back-arc environment.

On the basis of their major and trace elements and Sr–Nd–Pb, He–Sr and D/H–He isotope systematics, Mariana Trough basalts petrogenesis is explained by melting a mixture of a MORB mantle source and an H₂O-rich subduction component (Poreda 1985; Sano *et al.* 1986; Stolper & Newman 1994; Gribble *et al.* 1996). It seems that the noble gas data observed for Mariana Trough basalts support the mixing model for the generation of Mariana Trough back-arc basin basalt.

There is an interesting correlation between the samples' gas inventory and tectonic setting. Martinez *et al.* (1995) concluded that extension in the Mariana Trough is propagating northward, so that the northern part of the Trough is rifting and erupting arc-like magmas, while sea floor spreading occurs south of 19°45'N. The composition of noble gases reflects the observed change in tectonic style from south to north. Although helium isotopic compositions are apparently not sensitive to the variation in tectonic style, largely because of the similarity of ³He/⁴He between arc lavas (R/R_A ~ 7.5; Poreda & Craig 1989) and back-arc basin basalts (R/R_A ~ 8), other noble gas isotopic ratios reflect this transition. The ⁴He/²⁰Ne value varies from 46 to 756 for the three samples collected where rifting occurs (D46:1–6, D47:1–5, and D68:1–2) and is much higher (4256–60 000) for the other five samples from regions of sea floor spreading. Similarly, atmospheric ⁴⁰Ar/³⁶Ar ratios are observed from rifting regions, whereas much more radiogenic isotopic compositions are

found to the south. Similar relationships found for the Lau Basin by Hilton *et al.* (1993) were interpreted to reflect assimilation of old crust in the rifting zone. Alternatively, these relationships may indicate a larger role for arc sources compared to MORB sources farther north in the Mariana Trough.

ACKNOWLEDGEMENTS

We would like thank Dr Yayoi Miura of Earthquake Research Institute, University of Tokyo for help with analytical work. Thanks also to Dr Jongman Lee for analysing the major element composition of D1009 and D1010. Samples collected during the Tunes 7 expedition were done with the support of the US National Science Foundation.

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