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Geochemical evidence for ternary mixing of back-arc rift lava from the Izu-Ogasawara (Bonin) Arc

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IKEDA Yasuo, YUASA Makoto and TANAKA Tsuyoshi (1992) Geochemical evidence for ternary mixing of back-arc rift lava from the Izu-Ogasawara (Bonin) Arc. *Bull. Geol. Surv. Japan,* vol. 43 (7), p. 413-420, 5fig., 1tab.

Abstract: Nd- and Sr-isotopic evidence of back-arc rift and arc lavas from the Izu -Ogasawara Arc are described with published isotope and trace element data. The rift lavas have geochemical features similar to back-arc basin basalt. Constraints imposed by the isotopic and trace element data require ternary mixing involving depleted MORB, IAT (island-arc tholeiite), and DUPAL components for the generation of the rift lavas. In the rifting stage, mixing of N-MORB and DUPAL materials results in the production of an E-MORB-like material. The E-MORB-like material intruded into the IAT material. This process results in the source material mixings and therefore must ultimately produce the rift magma.

1. Introduction

In general, geochemical evidence of back -arc basin basalt (BABB) in intra-oceanic setting such as Mariana Trough shows intermediate features between N-MORB and island-arc basalt (e.g. Hawkins and Melchior, 1985; Volpe *et al.,* 1987). The geochemical variability of BABB has been explained by mixing between N-MORB and arc magmas (Volpe *et al.,* 1987).

The Sumisu and Myojin rifts are an excellent example of nascent back-arc basin behind the Izu-Ogasawara (Bonin) Arc which is located along the boundary between of the Pacific and Philippine Sea plates parallel to the Izu-Ogasawara trench (Ikeda and Yuasa, 1989) (Fig. 1). Chemical compositions of the rift basalts are similar to BABB (Ikeda and Yuasa, 1989; Hochstaedter *et al.,* 1990a, b; Ikeda, 1990) (Fig. 2). In this case, a model of mixing between E-MORB and island-arc tholeiite magmas to produce the rift basalts has been proposed by Ikeda and Yuasa (1989). The magmatic evolution model for the rift lavas indicates that the general model of BABB established in the Mariana Trough (Volpe *et al.,* 1987) is not globally applicable. Consequently studies on the origin of the E -MORB-like source, in back-arc basin environments are yet insufficient.

The purpose of this paper is to describe Nd isotope ratios of the rift lavas with published isotope and trace element data of Ikeda and Yuasa (1989) and Hochstaedter *et al.* (1990b) and to investigate further constraints on characteristics of the E-MORB-like end -member component more accurately including the formation process of the rift magma.

2. Samples and analysis

The samples for Nd isotopic analyses were chosen from those previously analysed for

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Keywords: Izu-Ogasawara Arc, back-arc rift, DUPAL component, IAT component, E-MORB, N-MORB

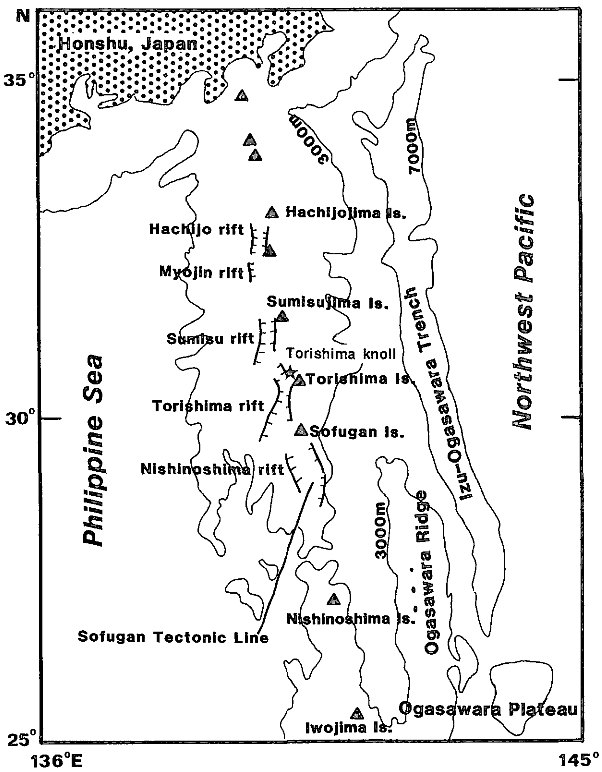

Fig. 1 Location map of the Izu-Ogasawara Arc.

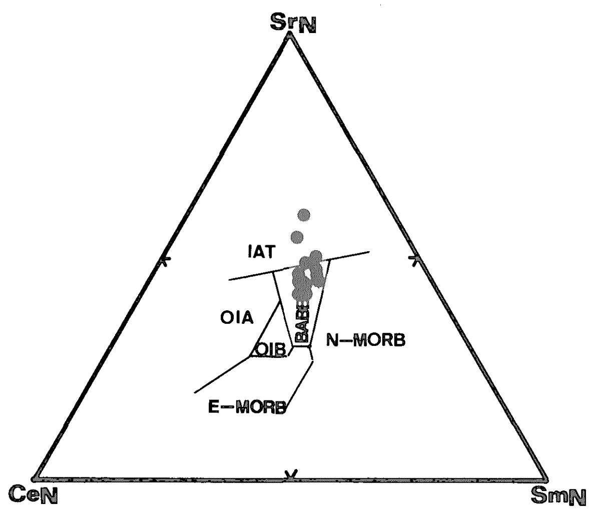

Fig. 2 $Ce_N/Sr_N/Sm_N$ discriminant diagram (Ikeda, 1990) for the back-arc rift basalts from the Izu-Ogasawara Arc (data from Ikeda and Yuasa, 1989; Hochstaedter *et al.,* 1990b). N-MORB (N type mid-ocean ridge basalt), E-MORB (E type mid-ocean ridge basalt), OIT (ocean island tholeiite), OIA (ocean island alkaline basalt), BABB (back-arc basin basalt), IAT (island-arc tholeiite).

major and trace elements, and Sr isotope ratios by Ikeda and Yuasa (1989).

Nd isotope ratios for the samples were determined by VG micromass spectrometer (30-54R) at the Geological Survey of Japan. Nd isotope ratios were analysed as NdO^+ using Re single filament and were normalized to $^{146}Nd/^{144}Nd = 0.7219$. The measurements of the La Jolla Nd standard during the experiment is 0.51183 ± 0.00002. As the value is lower by three in the last digit than the actual value of La Jolla (0.51186), we added three to the last digit of our data.

3. Results

Nd isotope ratios of lavas from the Sumisu and Myojin rifts and island-arc tholeiite from the Torishima knoll (Fig. 1) are presented in Table 1 with contents of SiO_2 and trace element ratios, and Sr isotope ratios in Ikeda and Yuasa (1989). $^{87}Sr/^{86}Sr$ ratios of the rift lavas are higher than for Pacific N-MORB (0.70242-0.70283 : Ito *et al.*, 1987 ; White *et al.*, 1987) and E-MORB (FAMOUS area, 0.70276-0.70296 : Dupré *et al.*, 1981) and lower than those of island arc tholeiites (IAT) of the Torishima knoll. $^{143}Nd/^{144}Nd$ ratios for the rift lavas range from 0.51301 to 0.51308 and are lower than or equal to those of Pacific N-MORB, E-MORB (Allègre *et al.*, 1983 ; Ito *et al.*, 1987 ; White *et al.*, 1987) and IAT of the Torishima knoll. As shown in Hochstaedter *et al.* (1990b), the Nd-Sr isotope ratios of the rift lavas are in the range of the most enriched MORB and BABB from an intra-oceanic back-arc basin such as the Mariana Trough and Lau Basin. A plot of $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ (Fig. 3) shows the transitional nature of the rift lavas which plot between the defined fields for N- & E-MORB and Izu-Ogasawara arc lavas. Also note that the data distribution of the rift lavas extends toward DUPAL OIB (Dupal anomaly ocean island basalt) and are apparently affected by arc components.

4. Discussion

Ikeda and Yuasa (1989) suggest the principal component in the mantle source region beneath the rift is similar to an E-MORB source and a mixing model between E-MORB and island-arc magmas to produce the rift lavas. Hochstaedter *et al.* (1990a, b) also propose similar generation model for the rift lavas: enriched blobs or mantle entrained in a more depleted matrix. High $^{208}Pb/$

Table 1 SiO_2 (wt. %) compositions and Sr-, Nd-isotope and trace element ratios of volcanic rocks from back-arc rift and volcanic front of the Izu-Ogasawara Arc.

Sample	SiO_2#	Rb/Sr#	Nd/Sr#	Sm/Nd#	Ba/Ce#	$(Ce/Yb)_N$#	$^{87}Sr/^{86}Sr \pm 2\sigma$#	$^{143}Nd/^{144}Nd \pm 2\sigma$
Myojin rift								
D609-1	49.74	0.017	0.033	0.31	5.31	1.30	0.70332±6	0.51303±2
Sumisu rift								
D643-2	48.08	0.027	0.039	0.28	3.05	1.44	0.70302±9	0.51301±4
D462	47.50	0.013	0.029	0.34	4.49	1.16	0.70307±2	0.51308±3
D460-2	48.17	0.022	0.037	0.32	2.83	1.34	0.70323±10	0.51308±2
D460-1	57.94	0.069	0.079	0.26	4.91	1.72	0.70305±3	0.51306±1
D462-1	49.61	0.017	0.037	0.34	4.68	1.12	0.70320±4	0.51308±3
D894-2	50.00	0.043	0.040	0.31	3.71	1.85	0.70315±30	0.51303±2
Torishima knoll								
D648	50.91	0.017	0.030	0.36	9.40	0.71	0.70343±4	0.51309±3

data from Ikeda and Yuasa (1989)

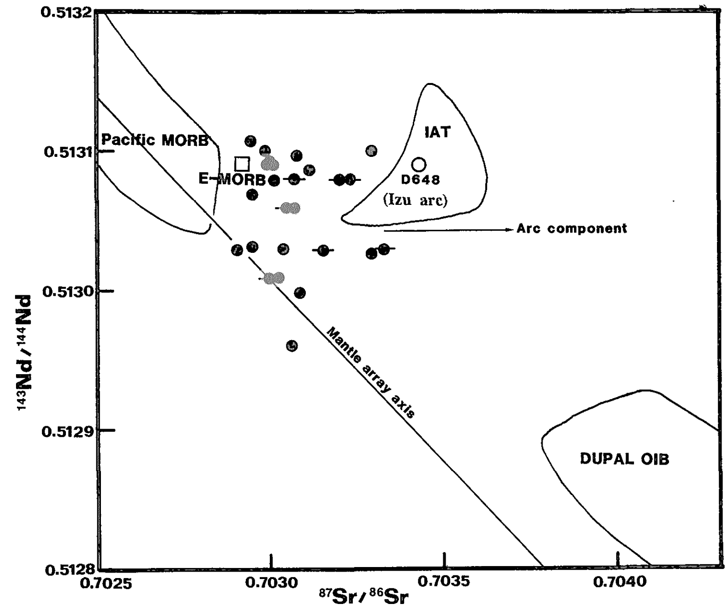

Fig. 3 Plot of $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ for samples from the back-arc rifts and volcanic front of the Izu-Ogasawara Arc (solid circle; Hochstaedter *et al.*, 1990b, solid circle with bar; this report). Pacific MORB (Ito *et al.*, 1987, White *et al.*, 1987), E-MORB (FAMOUS area, open square; Allègre *et al.*, 1983), IAT (Izu-Ogasawara arc: Torishima knoll-D648; Kaitoku & Nishinoshima, Lin *et al.*, 1990, this report), DUPAL OIB (Dupuy *et al.*, 1987).

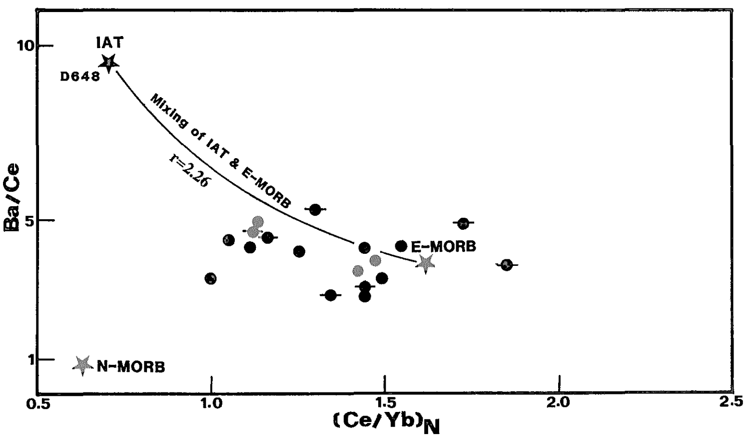

Fig. 4 Ba/Ce versus $(Ce/Yb)_N$ diagram for samples from the back-arc rifts and volcanic front of the Izu-Ogasawara Arc (solid circle; Hochstaedter *et al.*, 1990b; solid circle with bar; this report). The mixing line using equation of Vollmer(1976) between island-arc tholeiite (Torishima knoll: D648; Ce=5.79 ppm, Yb=2.07 ppm, Ba/Ce=9.40) - E-MORB (Sun and McDonough, 1989; Ce=15.0 ppm, Yb=2.37 ppm, Ba/Ce=3.8) is shown as solid line. r: function of extent of the curvature between the two end-members and of the overall curvature of the hyperbolic curve.

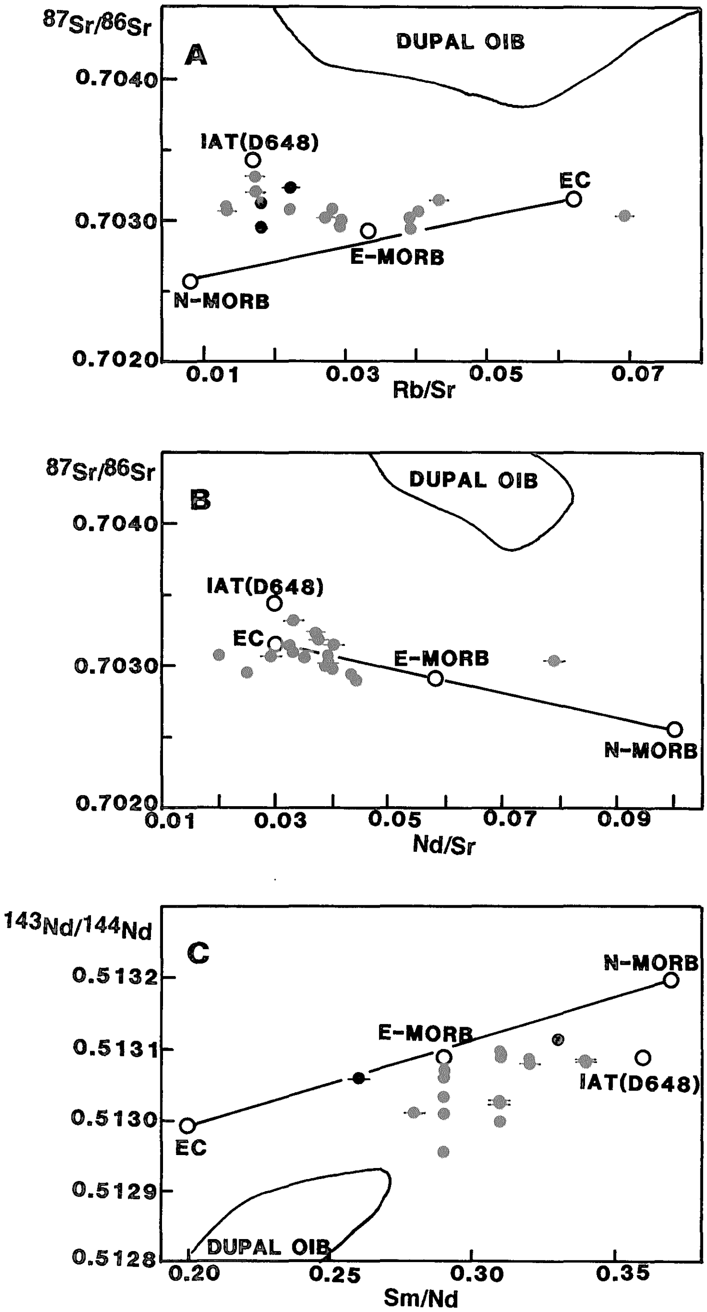

Fig. 5 Source mixing model on $^{87}Sr/^{86}Sr$ vs. Rb/Sr (A), $^{87}Sr/^{86}Sr$ vs. Nd/Sr (B) and $^{143}Nd/^{144}Nd$ vs. Sm/Nd (C). Linear trend on the plot is mixing line between N-MORB and EC (DUPAL source material = old oceanic lithosphere). The back-arc rift data are from Hochstaedter et al. (1990b) (solid circle) and this report (solid circle with bar). Data source of hypothesized end member source components: N-MORB & EC (Volpe *et al.*, 1990), E-MORB (Allègre *et al.*, 1983; Sun and McDonough, 1989), DUPAL OIB (Dupuy *et al.*, 1987), IAT (D648 of this report).

^{204}Pb and moderate $^{207}Pb/^{204}Pb$ of the rift lavas compared with Pacific N-MORB and Izu-Ogasawara Arc lavas suggest that the source of the rift lava reflects an ancient enriched mantle component and a DUPAL component (Dupré and Allègre, 1983; Hart, 1984) exist beneath the Philippine plate (Hochstaedter *et al.*, 1990b) as a cause for similar unusual values from the Philippine Sea and eastern Philippine arc (Mukasa *et al.* 1987).

In the following section, taking the above geochemical informations into consideration, we evaluate and modify the two-component mixing model for the rift lavas of Ikeda and Yuasa (1989) using Nd- and Sr-isotopic and available trace element data.

Constraints on the nature of the rift lava source regions can be obtained from Ba-Ce-Yb systematics (Fig. 4). The rift lava compositions are more similar to E-MORB than to N-MORB. The data distribution of the rift lavas suggests that two-component mixing melts in the source region can account for the observed correlations. End-member values are constraints by asymtotes and intercepts for hyperbolic and linear mixing curves calculated from the data (Vollmer, 1976). One component has a composition similar to E-MORB, while the other end-member resembles IAT from the Torishima knoll. As shown by Vollmer (1976), the mixing curvature ($r=2.26$) in Fig. 4 is determined by the ratio, where in the present case: $r=Ce(E\text{-}MORB)\cdot Yb_N(IAT)/Ce(IAT)\cdot Yb_N(E\text{-}MORB)$. The results support the earlier conclusion of Ikeda and Yuasa (1989). The IAT magma has a signature similar to depleted mantle that has been metasomatized by Ba-rich and REE-poor fluids from a subducted slab (Lin *et al.*, 1989) (Fig. 4).

There is also correlation on plots of Nd and Sr isotopic ratios versus Rb/Sr, Nd/Sr and Sm/Nd elemental ratios, which interpret as due to recent mixing rather than closed system evolution of a common homogeneous source (Fig. 5). The fit of the data to a linear trend suggests that the isotopic variation of the rift lavas can be explained by two-component mixing of IAT and E-MORB. The disperse of data may be reflect source heterogeneity.

As shown by Hochstaedter *et al.* (1990b), if the rift lavas reflect the effect of a DUPAL component, the position of E-MORB in Fig. 5 should be expressed by binary mixing of N-MORB and DUPAL components. The DUPAL component, however, reflects fragment of old oceanic lithosphere, EC (enriched component) as shown by Volpe *et al.* (1990), rather than DUPAL OIB source material such as Marquesas (Dupuy *et al.*, 1987) (Fig. 5).

From the above arguments, it is concluded that the generation process for the rift lavas results in ternary mixing involving depleted MORB component, IAT component and EC with DUPAL component. A plausible generation model is summarized as follows: In the rifting stage, N-MORB and EC can be expected to mix. The mixed material produces an E-MORB-like material. The E-MORB-like material intrudes into a IAT material. The process results in mixing and must ultimately produce the rift magma.

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References

Allègre, C.J., Hart, S.R. and Minster, J.F. (1983) Chemical structure and evolution of the mantle and continents determined by inversion of Nd and Sr isotopic data, II. Numerical experiments and discussion. *Earth Planet. Sci. Lett.*, vol. 66, p. 191-213.

Dupré, B. and Allègre, C.J. (1983) Pb-Sr isotope variation in Indian Ocean basalts and mixing phenomena. *Nature*, vol. 303, p. 142-146.

———, Lambret, B., Rousseau, D. and Allègre, C.J. (1981) Limitations on the scale of mantle heterogeneities under oceanic ridges. *Nature,* vol. 294, p. 552-554.

Dupuy, C., Vidal, P., Barsczus, H.G. and Chauvel, C. (1987) Origin of basalts from the Marquesas Archipelago (south central Pacific Ocean): isotope and trace element constraints. *Earth Planet. Sci. Lett.,* vol. 82, p. 145-152.

Hart, S.R. (1984) A large-scale isotope anomaly in the Southern Hemisphere mantle. *Nature,* vol. 309, p. 753-757.

Ikeda, Y. (1990) $Ce_N/Sr_N/Sm_N$: A trace element discriminant for basaltic rocks from different tectonomagmatic environments. *N. Jb. Miner. Mh.,* H4, p. 145-158.

——— and Yuasa, M. (1989) Volcanism in nascent back-arc basins behind the Shichito ridge and adjacent areas in the Izu-Ogasawara arc, northwest Pacific: evidence for mixing between E-type MORB and island arc magmas at the initiation of back-arc rifting. *Contrib. Mineral. Petr.,* vol. 101, p. 377-393.

Ito, E., White, W. and Gopel, C. (1987) The O, Sr, Nd and Pb isotope geochemistry of MORB. *Chem. Geol.,* vol. 62, p. 157-176.

Hawkins, J.W. and Melchior, J.T. (1985) Petrology of Mariana Trough and Lau Basin basalts. *J. Geophs. Res.,* vol. 90, p. 11431-11468.

Hochstaedter, A.G., Gill, J.B., Kusakabe, M., Newman, S., Pringle, M., Taylor, B. and Fryer, P. (1990a) Volcanism in the Sumisu Rift, I. Major element, volatile, and stable isotope geochemistry. *Earth Planet. Sci. Lett.,* vol. 100, p. 179-194.

———, Gill, J.B. and Morris, J.D. (1990b) Volcanism in the Sumisu Rift, II. Subduction and non-subduction related components. *Earth Planet. Sci. Lett.,* vol. 100, p.195-209.

Lin, P-N, Stern, R. and Bloomer, S.H. (1989) Shoshonitic volcanism in the northern Mariana arc 2. Large-ion lithophile and rare earth element abundances: evidence for the source of incompatible element enrichments in intraoceanic arcs. *J. Geophys. Res.,* vol. 94, p. 4497-4514.

———, Stern, R.J., Morris, J. and Bloomer, S. H. (1990) Nd- and Sr-isotopic compositions of lavas from the northern Mariana and southern Volcano arcs: implications for the origin of island arc melts. *Contrib. Mineral. Petrol.,* vol. 105, p. 381-392.

Mukasa, S.B., McCabe, R. and Gill, J.B. (1987) Pb-isotopic compositions of volcanic rocks in the West and East Philippine island arcs: presence of the Dupal isotopic anomaly. *Earth Planet. Sci. Lett.,* vol. 84, p. 153-164.

Sun, S. and McDonough, W.F. (1989) Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In *Magmatism in the Ocean Basins* (Saunders, A.D. and Norry, M.J. Eds.), Geol. Soc. Spec. Pub., vol. 42, p. 313-345.

Vollmer, R. (1976) Rb-Sr and U-Th-Pb systematics of alkaline rocks: the alkaline rocks from Italy. *Geochim. Cosmochim. Acta,* vol. 40, p. 283-295.

Volpe, A.M., Macdougall, J.D. and Hawkins, J.W. (1987) Mariana Trough basalts (MTB): trace element and Sr-Nd isotopic evidence for mixing between MORB-like and arc-like melts. *Earth Planet. Sci. Lett.,* vòl. 82, p. 241-254.

———, ———, Lugmair, G.W., Hawkins, J. W. and Lonsdale, P. (1990) Fine-scale isotopic variation in Mariana Trough basalts: evidence for heterogeneity and a recycled component in backarc basin mantle. *Earth Planet. Sci. Lett.,* vol. 100, p. 251-264.

White, W. and Bryan, W.B. (1977) Sr-isotope, K, Rb, Cs, Sr, Ba, and rare-earth geochemistry of basalts from the FAMOUS area. *Geol. Soc. Am. Bull.,* vol. 88, p. 571-576.

———, Hofmann, A.W. and Puchelt, H. (1987) Isotope geochemistry of Pacific Mid-Ocean Ridge basalt. *J. Geophys. Res.,* vol. 92, p. 4881-4893.

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伊豆-小笠原弧の背弧リフト溶岩の三元混合の岩石化学的証拠

池田保夫・湯浅真人・田中　剛

要　旨

背弧海盆玄武岩の岩石学的特徴を備えた伊豆-小笠原弧の背弧リフト溶岩の Nd, Sr 同位体比とこれまで公表されている Pb 同位体比および微量元素の岩石化学的情報は三つの混合物が関与していることを示した．まずリフティングの段階で，N-MORB 源物質（マントル又はマグマ）と DUPAL 組成（古い海洋リソスフェア）源物質との混合がおこって，E-MORB 様源物質が生じた．この E-MORB 様源物質が上昇して枯渇した島弧源物質に突入し，これら両物質が混合し，この混合した物質から背弧リフト溶岩が導かれた．

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