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XIV. PETROGRAPHY AND ISOTOPIC AGE OF VOLCANIC ROCKS DREDGED FROM THE BACK-ARC RIDGES AND KNOLLS AT THE NORTH END OF THE IZU-OGASAWARA ARC

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Introduction

Northern back-arc region of the Izu-Ogasawara arc is characterized by echelon ridges and small knolls. Formation process and age of the back-arc echelon ridges are still not clear (e.g. Karig and Moore, 1975; Bandy and Hilde, 1983; Chamot-Rooke and Le Pichon, 1989). Furthermore, among small knolls dispersed behind the volcanic front, only Higashi-Izu-oki submarine volcanoes were studied in detail (Hamuro *et al.,* 1983), and age and chemical characteristics of volcanism of other knolls remained unclear. Rock sampling by chain-bag type dredge was conducted to investigate acoustic basement and submarine volcanoes in the northern Izu-Ogasawara arc (34° 10′ N-34° 40′ N) during GH97 cruise (Table XIV-1 and Fig. XIV-1). Dredge sites were located on the slopes of ridges extending from Quaternary volcanic front to the Shikoku Basin in NE-SW direction (Taka-se Bank, Hyotan-se Bank, Zenisu Ridge, Izu Spur), small knolls, and caldera behind the front (Mikomoto Knoll, Toshima Hole, and a small knoll northeast of the Otoyama-dashi Bank). In this study, description of volcanic rocks including chemistry and ages are reported.

Description of volcanic rocks

Taka-se Bank

Taka-se bank is one of the small highs on a ridge extending in southwest direction from the Oshima Island through the Toshima Island (Fig. XIV-1). Dredge sampling was done on the southern slope of the Taka-se bank (D1182). Huge amount of samples were recovered, most of which are calcareous rocks mainly composed of calcareous algae and coral remains (Fig. XIV-2). Some calcareous rocks exhibit layered structure on cross sections and contain rock fragment (mainly calcareous rocks and pumice) at the core.

Only two volcanic rocks were collected, both of which were clinopyroxene-olivine basalt specimens. These basalts contain plagioclase (5%, <3 mm), clinopyroxene (2%, <3 mm), olivine (<1%) and rare orthopyroxene as phenocrysts. Groundmass is extensively altered and mainly composed of plagioclase, pyroxene and small amount of glass. No Mn-oxides coating is observed on the collected rocks.

Keywords: Izu-Ogasawara arc, back-arc ridges, dating, chemistry, volcanic rock, Izu Peninsula

Table XIV-1 Dredge sites and sample list of GH97 cruise.

Station No.	Local. No.	Dredge No.	Latitude N	Longitude E	Water depth (m)	Location	Number of samples	Dredge haul with sample numbers in parentheses.
8544	A	D1180	34°20.003' 34°20.186	139°04.624 139°04.270	345 257	Hyotan-se Bank	3	Calcareous sandstone, conglomerate (including dacitic clast (1, 2)) and scoria (3).
8546	B	D1181	34°23.098 34°22.765	139°05.923 139°05.885	360 230	Hyotan-se Bank	22<	Cpx-opx andesitic volcanic breccia. cpx-opx andesite(1-13), crystalline tuff(14-16), volcanic breccia(17-19, 22), sandstone(20,21)
8547	C	D1182	34°25.583 34°25.821	139°09.891 139°09.919	270 180	Taka-se Bank	4<	Several cobbles of cpx andesite (1, 2) and limestone (3, 4).
8548	D	D1183	34°28.144 34°28.271	139°03.679 139°03.487	540 460	Mikomoto Knoll	8	Several blocks of volcanic rock with thick ferromanganese oxide crust. Rock types are ol-cpx basalt (1, 2, 4-7), dolerite (3), hyaloclastic breccia (8). Hydrothermal Mn and/or qz fragments are also found.
8550	E	D1184	34°12.802 34°12.706	138°50.755 138°50.119	1339 1000	NW off Zenisu	52<	A large amount of volcanic rocks and two rounded cobble. Volcanic rocks are cpx-opx andesite (2-6, 11-26, 30, 32, 40-43), cpx andesite (1, 10, 27), volcanic breccia (31), rounded microdiorite (50), rounded sandstone (51), pumiceous breccia (55), conglomerate (60, 67-69, 73,74), pumiceous lapilli tuff (61-65), coarse-grained sandstone (70, 72, 75), tuffaceous sandstone (71), Mn-coated cpx-opx andesite (80-82).
8553	F	D1185	34°18.334 34°18.381	138°58.731 138°58.865	395 308	Hyotan-se Bank	10<	Volcanic breccia (1,3,4,10), dacite (2,6,8,9), tuff breccia (5) and limestone(7)
8575	G	D1186	34°21.140 34°21.534	138°45.487 138°44.961	987 685	Eastern flank of Izu Spur	19<	Cpx-opx andesite (2, 5, 7-9, 11, 14), extensively altered andesite (3, 4, 6, 10, 12, 13, 15-17), Mn-crust (18), sandstone (19), (volcanic breccia (5)).
8591	I	D1187	34°41.929 34°42.117	138°31.940 138°31.895	570 440	Senoumi-kita Bank	13<	Mudstone (1-5, 10, 12), sandstone (6, 8-9), conglomerate (7), tuff breccia (11)
8707	L	D1188	34°38.540 34°38.652	139°14.065 139°14.303	361 332	A small knoll, NE of Otoyama-dashi Bank	21<	Altered and fragile lapilli tuff (1, 2, 11, 16, 17) and basalt (3-10, 12-15, 18-21, subaqueous volcanic bomb mantled with reddish brown palagonite rind).
8708	M	D1189	34°34.341 34°34.423	139°15.324 139°15.419	332 280	Toshima Hole (Toshima-oki Caldera)	20<	Porphyritic dacite blocks (boulder to cobble size) (1-13, 16-18) with less aphyric basalt cobble (14, 15, 20).

Positions mean "hit bottom" (upper) and "left bottom" (lower).

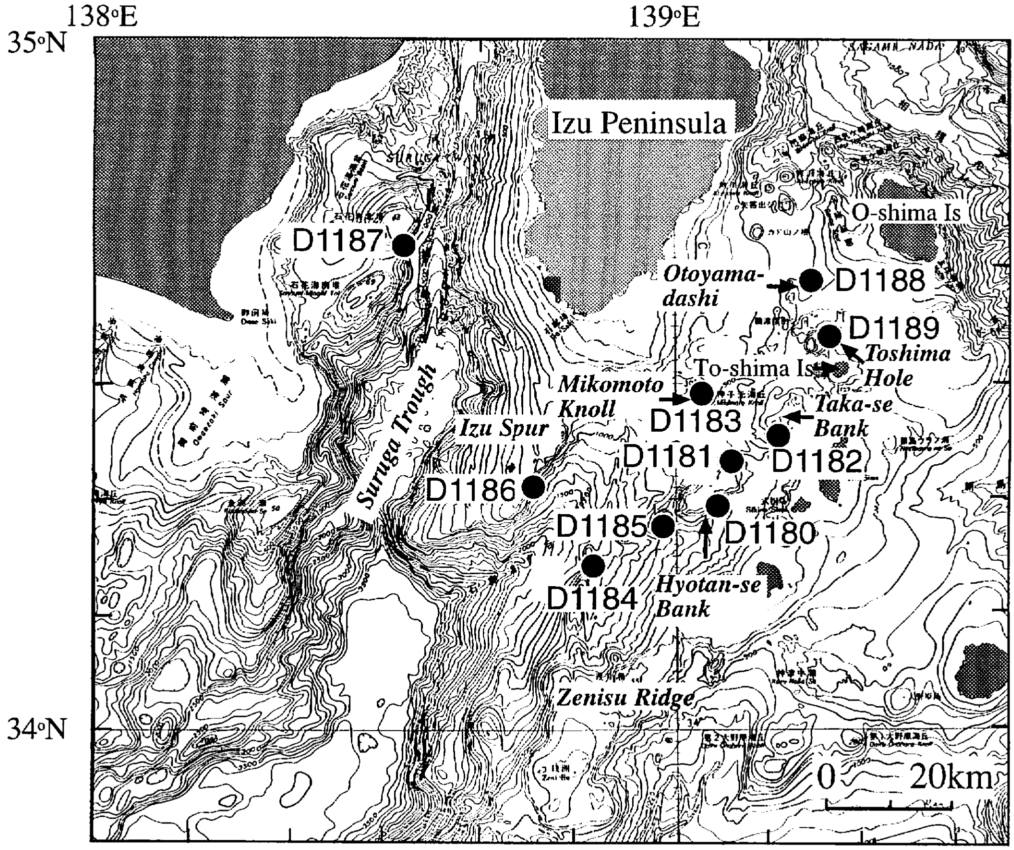

Fig. XIV-1 Locality map of dredge sites (original map: Hydrographic Department, M.S. A., Japan). Contour interval is 100 m.

Hyotan-se Bank

Hyotan-se bank is northeast-southwest elongating high located southwest of the Taka-se bank (Fig. XIV-1). Relative height of this bank is around 300m. Around the Hyotan-se Bank, dredge sampling was conducted at 3 sites, southern slope (D1180), northeastern slope (D1181) and a knoll located southwest of the Hyotan-se Bank (D 1185).

On the southern slope (D1180), only three pieces of rocks were collected, one was scoria and the others were conglomerates (Fig. XIV-2). The conglomerates are mainly composed of sub-angular granule of dacite and andesite. They are cemented with calcareous material and stained with Mn-oxides. Andesite granules are crystalline and contain plagioclase (<0.4 mm) and minor clinopyroxene (0.2 mm) as phenocrysts. Glassy dacitic fragments are also observed.

On the northeastern slope (D1181), huge amount of andesite lava and subordinate amount of crystalline tuff, volcanic breccia and sandstone were recovered (Fig. XIV-2). The andesite lavas are glassy and porous. The lavas are very fresh apart from partial oxidation. No Mn-oxides coating is observed. The andesite contains plagioclase (6

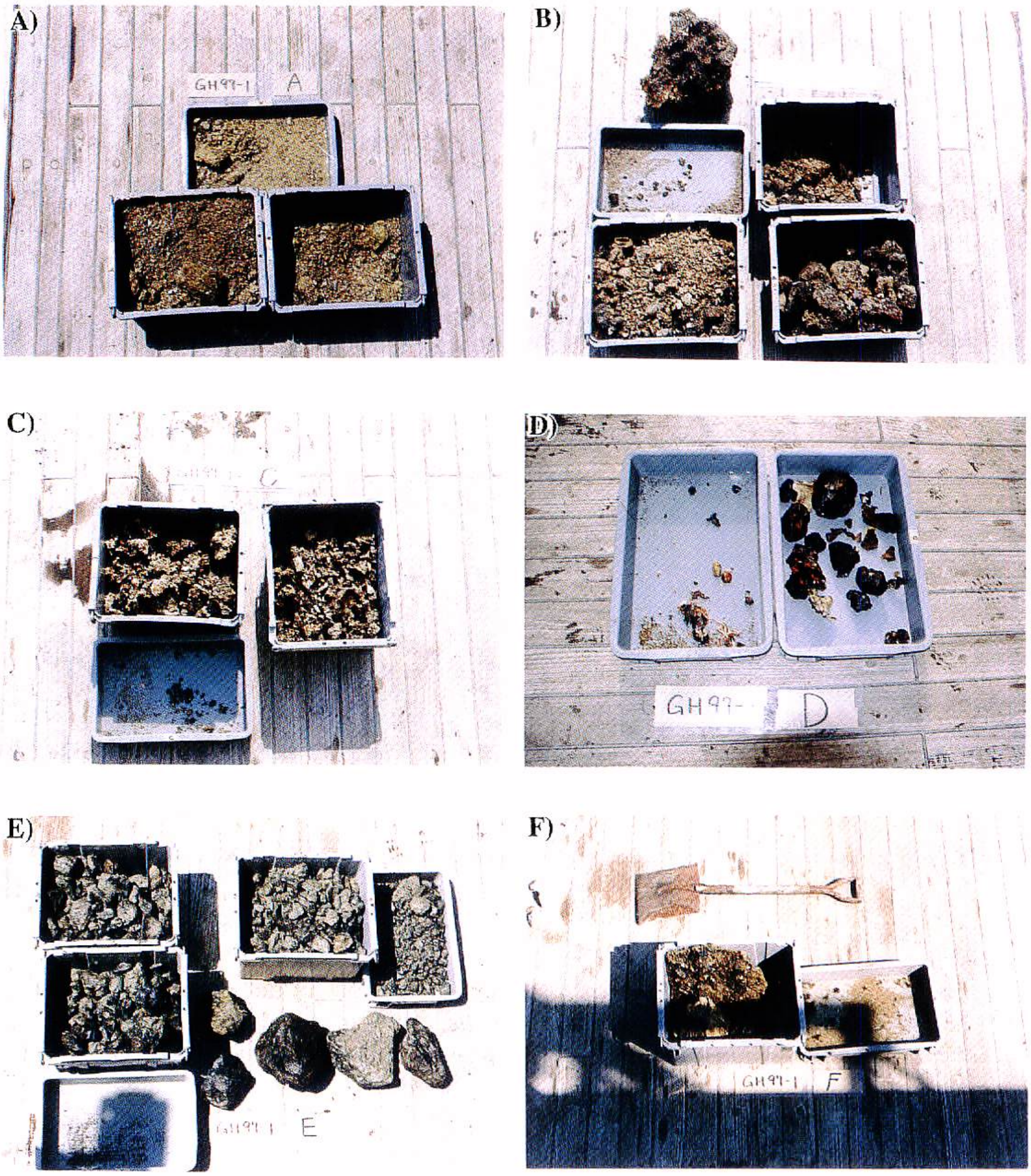

Fig. XIV-2 Photograph of dredged samples at each station.
A): D1180, B): D1181, C): D1182, D): D1183, E): D1184, F): D1185, G): D1186, H): D1187, I): D1188, J): D1189.

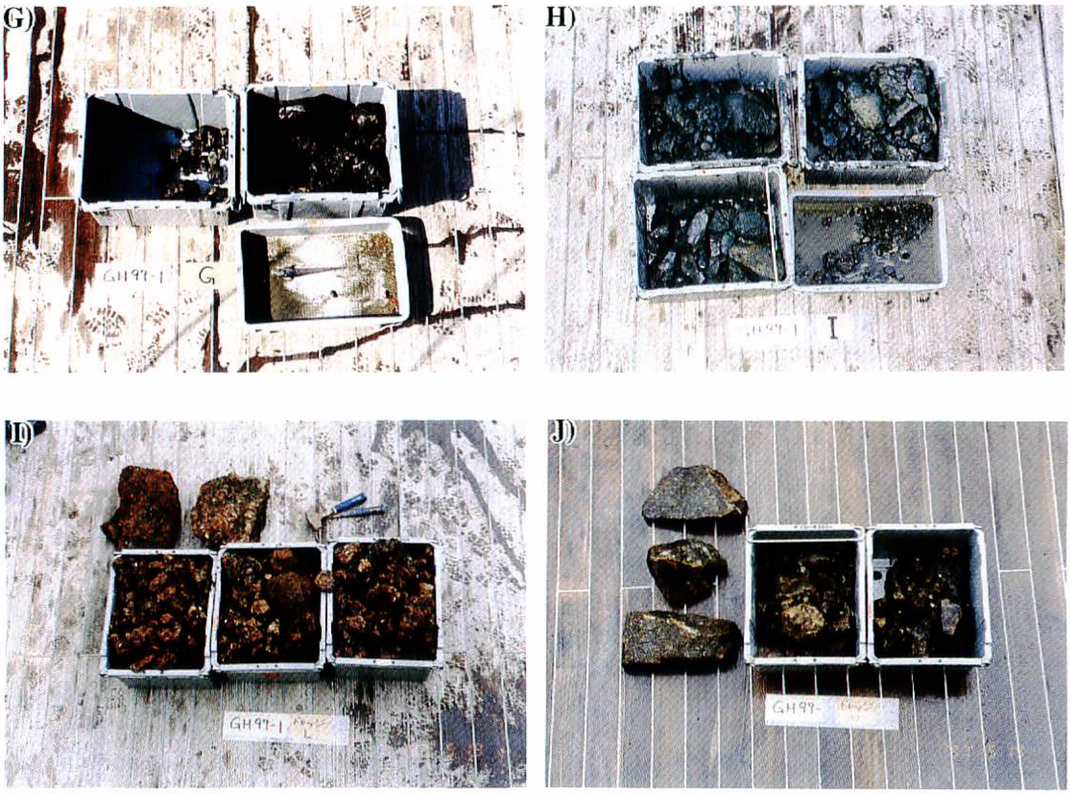

Fig. XIV-2 (continued)

%), clinopyroxene (1.5%) and orthopyroxene (0.5%) as phenocrysts. Groundmass is mainly composed of brown glass and plagioclase laths. Crystal tuff is mainly composed of pumiceous fragments and crystals of plagioclase, orthopyroxene, clinopyroxene and hornblende. Sandstone is mainly composed of pumiceous grains, but also contains andesite fragments up to several percent. Graded bedding and cross stratification are clearly observed.

At a small knoll southwest of the Hyotan-se bank (D1185), volcanic breccia, dacite lava and calcareous rocks were collected (Fig. XIV-2). Volcanic breccia are poorly sorted and mainly composed of dacite fragments. Matrix of the breccia is also composed of fine fragments of dacite. Dacite lava is poorly vesiculated ($<8\%$) and fresh except for the rim. The dacite contains plagioclase ($<4\%$), clinopyroxene (0.5 %) and trace amount of orthopyroxene ($<0.5\%$) as phenocrysts. Groundmass is mainly composed of plagioclase laths and small amount of transparent glass ($<3\%$). Some plagioclases show swallowtail texture. Mn-oxides coating is hardly observed.

Zenisu Ridge

Basalt and andesite lavas and volcaniclastics were recovered from the Zenisu Ridge during the GH80-3 cruise (D433: Nakamura *et al.*, 1984). Nakamura *et al.* (1987) reported whole rock chemistry and K-Ar ages of the lavas (2.9 ± 0.3 and 3.3 ± 0.7

Ma). In this study, dredging was performed on a ridge extending north from the Zenisu (D1184: Fig. XIV-1). Huge amount of samples were recovered. Andesite lava, conglomerate, tuff, and sandstone were collected (Fig. XIV-2). Andesite lava is most abundant and exhibits several types of appearance due to the difference in vesicularity and abundance of phenocrysts. Vesicularity is usually less than 5% , but reaches up to 10% in some samples. Most lava blocks are fresh. Andesite lava usually contains phenocrysts of plagioclase (up to 10%), clinopyroxene, orthopyroxene and minor amount of olivine. Groundmass is composed of plagioclase, pyroxene and brown-colored glass. Amount of glass varies widely from less than 1% to 8% . Pumiceous breccia is mainly composed of pumice fragments (70-80%) with minor andesite. Conglomerate is poorly sorted. Main constituent of the conglomerate is andesite and pumice fragment, and abundance ratio between the two varies widely. Sandstone is moderately to well sorted and composed of subangular to subrounded fragments of andesite and pumice. Thickness of Mn-oxides crust covering the rocks from this dredge site is less than 5 mm.

Izu Spur

The Izu Spur is a ridge extending from the southernmost part of the Izu Peninsula in south-southwest direction and constitutes a part of the eastern border of the Suruga Trough. Dredging was performed on the eastern scarp of the Izu Spur to get the basement rocks of the Izu Peninsula (D1186: Fig. XIV-1). More than 20 pieces of rock were recovered, and most of them were clinopyroxene-orthopyroxene andesite (Fig. XIV-2). Minor amount of Mn-oxides and sandstone were also collected. The andesite lavas are surrounded by palagonitized rim whose thickness reaches up to 30 mm. Clinopyroxene-orthopyroxene andesite contains plagioclase ($<10\%$), clinopyroxene (4%) and orthopyroxene ($<1\%$) as phenocrysts. Groundmass is mainly composed of plagioclase, pyroxene, opaque mineral, and brown transparent glass ($<3\%$). The andesite lavas are coated with thick Mn-oxides crust, and its thickness reaches up to 40 mm.

Mikomoto Knoll

The Mikomoto Knoll, one of the small knolls dispersed between the Izu Peninsula (and its southward extension) and the volcanic front, is located northwest of the Takase Bank and southeast off the Izu Peninsula. Dredging was performed on the southern flank of the Mikomoto Knoll (D1183: Fig. XIV-1). Eight pieces of rock were recovered composed of basalt and hyaloclastite (Fig. XIV-2). The basalt is highly vesiculated and is composed of phenocrysts of plagioclase (1%), olivine (1%) and clinopyroxene ($<0.5\%$). Some clinopyroxene crystals show hourglass structure. Groundmass is mainly composed of plagioclase and minor amount of pyroxene and olivine. Many pyroxenes exhibit dendritic growth, and plagioclases show swallowtail texture. Some of the basalt are doleritic. The basalt has hydrogenetic Mn-oxides crust up to 40 mm in thickness. Mn-oxides thought to have hydrothermal origin are disseminated in the matrix of hyaloclastite. Quartz veinlets are also observed in the hyaloclastite and imply the existence of ancient low temperature hydrothermal activity at the Mikomoto Knoll.

Toshima Hole

The Toshima Hole is a submarine caldera located at 5 km northwest of the Toshima Island. Somma of this caldera exhibits ellipsoidal shape of 5 km x 3 km in size, and its relative height is about 250 m (Iwabuchi *et al.*, 1989). This caldera has two central cones. Dredge site (D1189) was located on the caldera wall (Fig. XIV-1). Large amount of boulder- to cobble-sized volcanic rocks up to 44 cm in diameter were recovered (Fig. XIV-2). The volcanic rocks are composed of two rock types, i.e., dacite and clinopyroxene-olivine basalt. The dacite contains megacrysts of quartz and plagioclase in addition to clinopyroxene and orthopyroxene as phenocrysts. Trace amount of olivine phenocryst and pseudomorph of hornblende are also observed. Some dacite blocks contain dark inclusions. clinopyroxene-olivine basalt is slightly vesiculated. Groundmass is composed of plagioclase, olivine, clinopyroxene and opaque mineral. Some clinopyroxenes show dendritic habit.

A knoll northeast of the Otoyama-dashi Bank

West of the Niijima Island occur many small knolls which are similar in size to the monogenetic volcanoes. They scatter between the Oshima Island and Izu Peninsula. Among these knolls, a knoll northeast of the Otoyama-dashi Bank was dredged (D 1188 : Fig. XIV-1). Collected rocks are four large blocks of lapilli tuff up to 45 cm in size, seven boulders (around 20 cm in diameter), and many smaller fragments of basalt (Fig. XIV-2). Rubble and matrix are both oxidized to reddish brown color. The basalt is moderately vesiculated, and contains plagioclase, clinopyroxene and olivine as phenocrysts.

Whole rock chemistry and age of volcanic rock

Bulk chemical analysis and dating of volcanic rocks from 7 dredge stations were conducted to characterize each topographic feature surveyed in this study.

Analytical method

Whole rock chemistry

Fresh samples were selected for bulk chemical analysis from 7 dredge stations. About 50 g of slabs were cut out from the freshest part of each sample. These slabs were soaked in distilled water at about 70°C for 4 to 5 days to remove sea water contamination. After drying in the air, the slabs were pulverized using crusher and agate mortar. Major and trace element composition except for rare earth elements (REE) were determined by XRF. For major element analysis, glass beads were prepared by fusion of mixture of 0.6 g of subsamples and lithium tetraborate in a ratio of 1:10 (Togashi and Terashima, 1997). For trace element analysis, pressed powder disks were prepared. Three g subsamples were held with boric acid and pressed under 7 ton pressure (Togashi and Terashima, 1997). Analytical error is <2% for major elements, <5% for trace elements except for Rb, and <30% for Rb. Selected REE and Sc, Co, Cs, Hf, Ta and Th were analyzed by instrumental neutron activation analysis (Tanaka *et al.*, 1988). About 200 mg each of samples were sealed in quartz tube and irradiated for 24 minutes in HR-2 position of JRR3 reactor of Japan Atomic Energy Research Institute ($1.0 \times 10^{14} n/cm^2S$). g-ray spectra of the samples were analyzed using a hyperpure germanium detector and a multi-channel analyzer (Tanaka *et al.*, 1988).

K-Ar dating

Some samples have Mn-oxides crusts or palagonitized rims or both. To prevent the inclusion of these portions, slabs about 1 cm thick and 30-100 g weight were taken from the freshest and well-crystallized parts of the samples with a water-cooled saw. The slabs were crushed to 250-500 μ m using iron pestle. In order to remove sea water contamination (NaCl etc.), crushed samples were rinsed in an ultrasonic bath and soaked in distilled water at about 70°C for 4 to 5 days until the water remained clear after the addition of $AgNO_3$. To avoid excess ^{40}Ar, large phenocryst (>0.5 mm) were removed by hand-picking and with an isodynamic magnetic separator. For potassium analysis, the 3-5 g sub-samples for argon isotope analysis were further pulverized using an agate mortar.

Argon isotopic ratios were determined by unspiked sensitivity method. In case of dating of low-K_2O Quaternary volcanic rocks having small accumulations of radiogenic ^{40}Ar, the conventional assumption that rocks have atmospheric initial $^{40}Ar/^{36}Ar$ may not be appropriate. Matsumoto *et al.* (1989) and Matsumoto and Kobayashi (1995) demonstrated that the measurements of stable $^{38}Ar/^{36}Ar$ ratios in young volcanic rocks are useful in calculating the mass fractionated initial $^{40}Ar/^{36}Ar$ ratios, thus getting a more accurate age. In this study, age of dacite from the Toshima Hole was determined using mass fractionation procedure. For other samples, since uncertainty for $^{38}Ar/^{36}Ar$ ratio was large due to the bad condition of mass spectrometer, ages were calculated based on the assumption that initially trapped argon possessed atmospheric isotope ratio. Most of the samples excluding a basalt from the knoll northeast of the Otoyama-dashi Bank have low atmospheric contamination. and mass fraction of initially trapped argon should not affect obtained ages significantly.

Argon extraction from the samples was done using stainless-steel made ultra-high vacuum extraction line. Samples of 1.0-1.2 g wrapped in 10 μ m copper foil were fused at 1500°C using a double-vacuum tantalum resistance furnace following the bakeout at 130°C for 48 hours. Purification of sample gas was achieved with two SAES Getters NP-10 Sorb-Ac pumps and one zirconium and titanium plate getter. Argon isotopes were measured on a VG Isotopes 1200C mass spectrometer equipped with Nier-type ion source and a single Faraday collector. Argon isotopes of air standard was analyzed once or twice a day for determination of sensitivity of the mass spectrometer and mass discrimination correction. The sensitivity for argon isotopes was kept at $(4.36 \pm 0.04) \times 10^{-8}$ ml STP Ar V^{-1} during this study. The total ^{40}Ar contents of sample gas were determined by the comparison of ^{40}Ar peak intensities with the air standard. Total hot blanks were about 5×10^{-9} ml STP for ^{40}Ar, 3.5×10^{-12} ml STP for ^{38}Ar and 1.8×10^{-11} ml STP for ^{36}Ar.

Potassium contents were determined on about 200 mg each of samples by flame emission spectrometry, using peak integration and lithium internal standard method (Matsumoto, 1989). Error for potassium analysis was estimated to be 0.5% based on the replicate analyses of reference material (Matsumoto, 1989). Calculation of age and error estimation were done following the equation described in Matsumoto *et al.* (1989).

Laser-heating $^{40}Ar/^{39}Ar$ dating

Slabs 1 mm-thick were taken out from the freshest part of the samples with water-cooled saw. The slabs were gently crushed into small pieces of about 7 mg weight and then ultrasonically cleaned in distilled water. The pieces were further treated ultrasonically in 3N HCl for 15 minutes to remove alteration products. After this treatment, the samples were soaked in distilled water at 70°C for 3 days.

The samples were wrapped in aluminum foil packets each about 8 mm × 8 mm in size. The packets were piled up in a pure aluminum (99.5% Al) irradiation capsule with flux monitor minerals. Sanidine separated from the Fish Canyon Tuff (FC3) from Colorado, U.S.A. (Hurford and Hammerschmidt, 1985; Naeser and Cebula, 1985; Lanphere *et al.*, 1992) was used for the flux monitor. We adopted 27.5 Ma as the age of FC3 sanidine (Uto *et al*, unpublished data). Correction for interfering isotopes was achieved by analyses of CaF_2 and $KFeSiO_4$ glass irradiated together with samples.

The irradiation capsule was wrapped with a 0.8 mm-thick cadmium foil to minimize the unwanted reaction by the thermal neutron. Samples were irradiated for 24 hours in a hydraulic rabbit irradiation facility (HR1 position situated in the core part) of the JMTR reactor. The average neutron flux in this facility is about 6.7×10^{12} n/cm^2s for fast neutron and $8.1 \times 10^{13} n/cm^2s$ for thermal neutron (JMTR handbook, 1995).

Argon isotope analysis was carried out using the laser-heating $^{40}Ar/^{39}Ar$ dating system at the Geological Survey of Japan (Uto *et al.*, 1997). Each grain was placed in a hole drilled on a copper sample holder. Samples were baked at 250°C for about 72 hours before analysis. Continuous Ar ion laser was used for sample heating. All analyses of the flux monitor minerals were done on a single grain of FC3 sanidine. D 1186-2 sample was dated in stepwise heating analysis. The sample was heated for 3 minutes in each step keeping laser power constant. Laser beam diameter was adjusted to 2 mm to ensure uniform heating of the sample. Extracted gas was purified for 10 minutes with three Zr-Al getters (SAES AP-10) and one Zr-Fe-V getter (SAES GP-50). Two Zr-Al getters were kept at 400°C and other getters were at room temperature. Argon isotopes were measured on a VG Isotech VG3600 noble gas mass spectrometer equipped with a Nier-type ion source and two collectors (a Faraday collector and a Daly collector). In this study, all the analyses were done using the Daly collector. The sensitivity of the collector was about 5×10^{-10} mlSTP/V. Mass discrimination was monitored using diluted air. The blank of the system including the mass spectrometer and the extraction line was 4.5×10^{-14} mlSTP for ^{36}Ar, 2.8×10^{-13} mlSTP for ^{37}Ar, 2.0×10^{-14} mlSTP for ^{38}Ar, 4.0×10^{-14} mlSTP for ^{39}Ar and 1.5×10^{-12} mlSTP for ^{40}Ar. The blank analysis was done every 2 or 3 step analyses.

Results

Whole rock chemistry

Analytical results are shown in Table XIV-2 and Fig. XIV-3. Range of chemical compositions of the volcanic rocks from the volcanic front and back-arc seamount chains located between 30°N and 32°N are shown (Morita *et al.*, unpublished data; Hochstaedter *et al.*, in prep, and Ishizuka *et al.*, 1998) in Fig. XIV-3 for comparison. Rocks from the Toshima Hole, a knoll northeast of the Otoyama-dashi Bank and

Table XIV 2 Major and trace element compositions of dredged volcanic rocks.

Sample No.	1181-1	1183-2	1184-11	1184-30	1185-1	1186-2	1188-3	1189-9	1189-15	1189-17
Major element (wt.%)										
SiO_2	59.96	44.58	56.71	54.19	66.09	59.43	49.63	66.14	50.44	55.43
TiO_2	0.70	0.99	0.80	0.93	0.66	0.83	0.98	0.52	0.94	0.77
Al_2O_3	17.57	19.47	17.89	18.22	15.24	15.86	17.53	15.25	17.58	17.12
Fe_2O_3	7.28	12.37	8.35	9.53	5.15	7.71	10.98	4.97	10.22	8.60
MnO	0.15	0.69	0.19	0.19	0.16	0.16	0.17	0.12	0.19	0.16
MgO	2.41	4.33	2.96	3.52	1.42	3.06	6.95	2.25	7.10	5.17
CaO	7.45	11.64	7.85	8.08	4.40	6.62	11.21	4.98	10.96	9.05
Na_2O	3.27	2.59	3.34	3.46	4.12	3.14	2.51	3.85	2.41	2.77
K_2O	0.58	0.43	1.03	1.24	1.05	1.80	0.43	1.26	0.36	0.65
P_2O_5	0.11	0.53	0.18	0.23	0.18	0.16	0.19	0.14	0.18	0.23
L.O.I.	0.55	3.57	0.72	0.00	1.27	1.19	-0.15	0.31	0.19	0.31
Total	100.04	101.19	100.01	99.58	99.74	99.96	100.44	99.79	100.57	100.27
Trace element (ppm)										
V	164	404	205	217	44	190	318	90	296	211
Cr	8	529	12	9	5	12	133	29	262	108
Ni	2	159	6	2	6	7	52	10	78	38
Cu	27	126	32	33	11	49	77	14	65	20
Zn	67	131	70	76	86	64	82	43	82	66
Rb	6	3	18	19	13	39	8	23	5	9
Sr	235	312	284	310	263	239	408	275	388	416
Ba	111	62	88	90	163	144	73	227	64	111
Y	31	63	31	35	38	39	19	23	21	21
Zr	100	57	93	95	154	154	67	125	67	91
Nb	2	2	4	4	5	5	2	5	5	2

L.O.I. = Loss on ignition

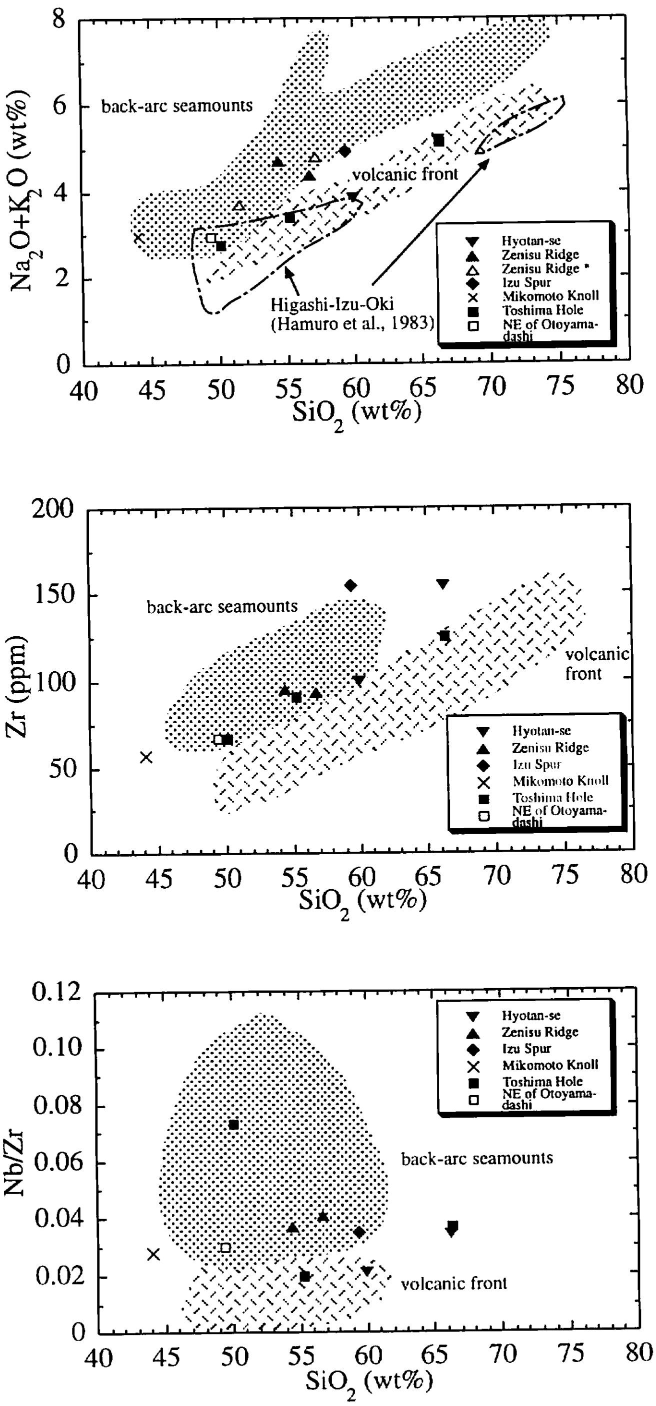

Fig. XIV-3 Chemical compositions of dredged rocks.
Compositional ranges of volcanic rocks from back-arc seamounts and volcanic front of the Izu-Ogasawara Arc (compilation from Morita *et al.* (unpublished data), Hochstaedter *et al.* (in prep.), and Ishizuka *et al.* (1998)) are also shown.

Table XIV-3 Selected instrumental neutron activation analyses of dredged volcanic rocks collected in GH97 cruise.

	1181-1	1183-2	1184-11	1184-30	1185-1	1186-2	1188-3	1189-9	1189-15	1189-17
Sc	21.4	40.6	21.1	24.3	13.5	14.9	30.9	11.1	29.6	21.0
Co	13.5	55.7	16.1	16.6	4.95	14.9	30.9	9.74	30.8	21.1
Cs	0.47	n.d.	0.34	n.d.	0.36	0.87	n.d.	0.81	0.29	0.26
La	4.19	8.62	6.00	6.64	8.73	9.36	4.98	8.95	4.35	6.86
Ce	11.1	9.12	14.6	15.9	24.0	21.6	12.1	20.2	11.0	15.8
Sm	2.82	3.85	3.17	3.46	4.58	3.76	2.16	2.63	2.17	2.74
Eu	0.93	1.25	1.05	1.15	1.44	0.97	0.80	0.79	0.82	0.89
Tb	0.83	0.70	0.77	0.73	1.00	0.80	0.45	0.54	0.47	0.50
Yb	2.69	3.52	2.66	2.88	3.61	3.19	1.53	2.08	1.77	1.88
Lu	0.35	0.50	0.32	0.40	0.44	0.42	0.22	0.26	0.27	0.28
Hf	2.23	1.13	1.99	2.01	3.68	3.24	1.16	2.50	1.21	1.65
Ta	n.d.	n.d.	n.d.	0.14	0.25	0.30	0.17	0.21	n.d.	0.20
Th	0.44	0.21	0.86	0.90	1.18	2.05	0.54	1.48	0.39	0.53

n.d. = not detected (ppm)

Table XIV-4 K-Ar ages of volcanic rocks obtained by the unspiked sensitivity method.

ages calculated by conventional procedure ($^{40}Ar/^{36}Ar$ ratio of initial trapped argon = 295.5)

Sample No.	Rock type	K_2O	$^{40}Ar/^{36}Ar$	$^{40}Ar_{rad}$	Atm.Ar	Age
		(wt%)	(±1σ)	(10^{-7} mlSTP/g)	(%)	(Ma; ±1σ)
Hyotan-se Bank						
D1181-1	cpx-opx andesite	0.774	382.8±0.5	0.4207	78.1	**1.68±0.02**
D1185-1	cpx-opx dacite	1.214	825.1±2.5	0.8556	37.3	**2.18±0.02**
Zenisu Ridge						
D1184-11	cpx-opx andesite	1.334	1355±3	2.306	24.3	**5.35±0.05**
Izu Spur						
D1186-2	cpx-opx andesite	2.241	1367±4	3.371	20.0	**4.66±0.05**
Knoll northeast of the Otoyama-dashi Bank						
D1188-3	cpx-ol basalt	0.442	291.9±1.0	<0.0076		**<0.055**

age calculated by mass fractionation correction procedure

Sample No.	Rock type	K_2O	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$	$^{40}Ar_{rad}$	Atm.Ar	Age
		(wt%)	(±1σ)	(±1σ)	(10^{-6} mlSTP/g)	(%)	(Ma; ±1σ)
Toshima Hole							
D1189-17	cpx-opx dacite	0.571	0.1841±0.0024	317.5±1.2	0.02220	90.4	**0.12±0.03**

$\lambda_\beta=4.962\times10^{-10}y^{-1}$, $\lambda_e=0.581\times10^{-10}y^{-1}$, $^{40}K/K=0.01167\%$ (Steiger and Jaeger, 1977).

Reported ratios of $^{40}Ar/^{36}Ar$ are normalized to the atmospheric ratio using the data of air standard analysis.

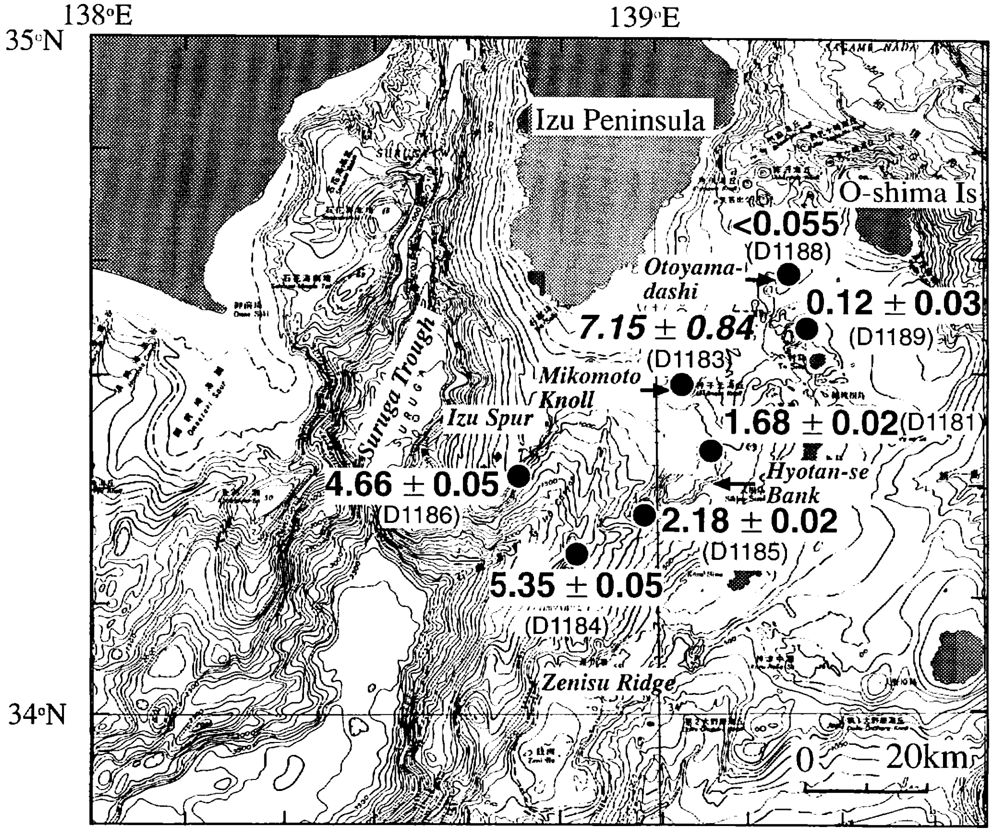

Fig. XIV-4 K-Ar ages and $^{40}Ar/^{39}Ar$ age obtained in this study from the northern part of the Izu-Ogasawara arc.

Hyotan-se shows similar chemical characteristics to that of volcanic front or intermediate between the front and back-arc seamounts. These rocks are depleted in alkalis and incompatible elements. On the other hand, basaltic to andesitic rocks from the Zenisu Ridge, Izu Spur, and Mikomoto Knoll are relatively enriched in alkalis and incompatible elements and similar to the rocks from the back-arc seamounts. These Hyotan-se shows similar chemical characteristics to that of volcanic front or intermediate between the front and back-arc seamounts. These rocks are depleted in alkalis and incompatible elements. On the other hand, basaltic to andesitic rocks from the Zenisu Ridge, Izu Spur, and Mikomoto Knoll are relatively enriched in alkalis and incompatible elements and similar to the rocks from the back-arc seamounts. These rocks are within a compositional range of calc-alkaline rocks from the back-arc seamounts. The across-arc variation of chemical characteristics observed in this study is consistent with the trend reported for the southern part of the Izu-Ogasawara arc (Ikeda and Yuasa, 1989; Tatsumi *et al.*, 1992; Hochstaedter *et al.*, in prep).

K-Ar and $^{40}Ar/^{39}Ar$ age

Lavas from a small knoll northeast of the Otoyama-dashi Bank and Toshima Hole

Table XIV-5 Analytical data for stepwise heating analysis of a basalt (D1183 2) from the Mikomoto Knoll.

Laser ouput	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$ ($x10^{-3}$)	$^{36}Ar/^{39}Ar$ ($x10^{-3}$)	$^{40}Ar^*$ (%)	$^{39}Ar_K$ fraction (%)	$^{40}Ar^*/^{39}Ar_K$	Age (Ma)
J=0.003901±0.000020							
0.1W	13.35±1.36	2.007±0.608	196.7±68.7	58.0	0.2	7.760±20.334	53.8±138.9
0.16W	7.293±0.401	2.107±0.208	8.689±24.267	67.9	0.7	4.956±7.187	34.5±49.6
0.3W	1.974±0.017	2.965±0.030	2.938±2.225	72.0	9.2	1.422±0.659	9.98±4.61
0.5W	0.7331±0.0081	6.112±0.051	2.485±1.327	88.6	19.4	0.6502±0.3943	4.57±2.77
0.8W	0.8861±0.0045	16.14±0.07	5.949±0.751	95.6	22.8	0.8556±0.2257	6.01±1.58
1.2W	1.090±0.005	28.50±0.11	10.83±1.01	85.0	21.9	0.9458±0.3060	6.64±2.15
1.9W	1.427±0.015	42.40±0.42	15.99±0.59	85.2	15.7	1.257±0.187	8.83±1.31
3W	3.445±0.027	69.65±0.55	36.38±2.41	3.3	6.4	0.1190±0.7577	0.84±5.33
fusion	53.53±7.03	195.6±19.5	28.80±2.91	0.0	3.7	<6	<39

Corrected for decay and blank. All errors listed at the 1σ level excluding the error of J value.

$(^{40}Ar/^{39}Ar)_K$=0.002765±0.002468, $(^{38}Ar/^{39}Ar)_K$ =0.05086±0.00004

$(^{39}Ar/^{37}Ar)_{Ca}$=0.0008136±0.0000142, $(^{36}Ar/^{37}Ar)_{Ca}$=0.0003605±0.0000041

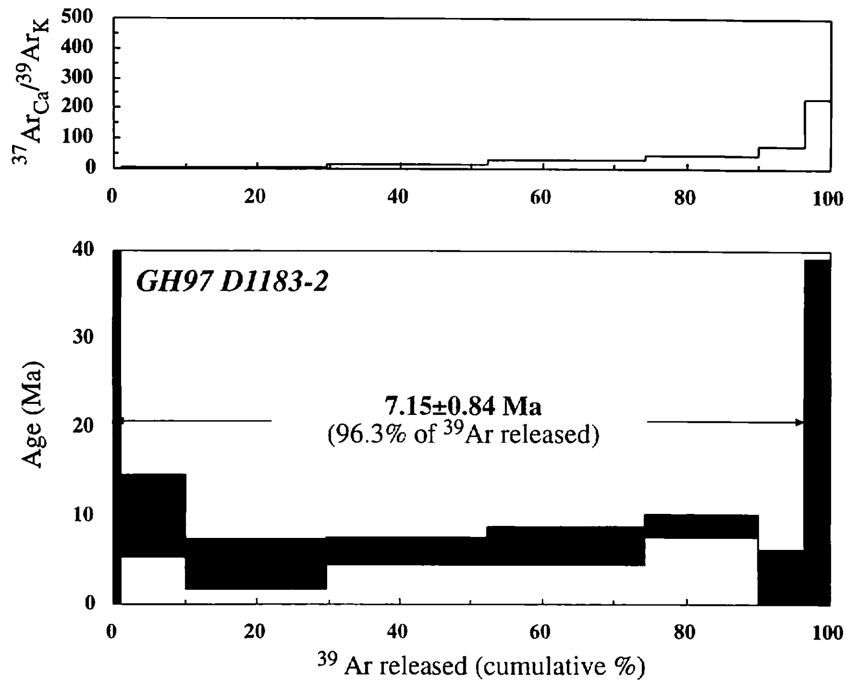

Fig. XIV-5 $^{40}Ar/^{39}Ar$ age spectrum for a basalt from the Mikomoto Knoll (D1183-2).

close to the Quaternary volcanic front exhibited late Quaternary age (Table XIV-4 and Fig. XIV-4). Clinopyroxene-olivine basalt (D1188-3) from the knoll east to the Otoyama-dashi Bank gave an age younger than 0.055 Ma. Clinopyroxene-orthopyroxene dacite from the Toshima hole was 0.12 ± 0.03 Ma.

On the other hand, volcanic rocks from the ridges extending from volcanic front to back-arc region exhibit older ages of late Miocene (Table XIV-4 and Fig. XIV-4). Clinopyroxene-orthopyroxene andesite from northeastern slope of the Hyotan-se Bank gave an age of 1.68 ± 0.02 Ma and Clinopyroxene-orthopyroxene dacite from the southwestern slope of the Hyotan-se Bank was dated to be 2.18 ± 0.02 Ma. Lavas from the Zenisu ridge and the Izu Spur gave older ages. Clinopyroxene-orthopyroxene andesite from the Zenisu Ridge gave an age of 5.35 ± 0.05 Ma and clinopyroxene-orthopyroxene andesite from the Izu spur was dated to be 4.66 ± 0.05 Ma. The age for andesite lava from the Zenisu Ridge obtained in this study is about 2 m.y. older than that reported by Nakamura *et al.* (1987).

Olivine-clinopyroxene basalt from the Mikomoto Knoll was dated by laser-heating $^{40}Ar/^{39}Ar$ dating method due to the paucity of the fresh sample. Well crystallized doleritic part was used for the analysis. Analytical result is shown in Table XIV-5 and Fig. XIV-5. Stepwise heating analysis comprised of 9 steps was performed on this sample. Ages from the first two steps have large uncertainties. This is because the amount of degassing in these two steps were extremely small. Large errors for the last two steps are due to the large contribution of Ca-derived interference isotope and low yield of radiogenic ^{40}Ar. Consecutive 8 steps excluding the last step yielded consistent ages within 2σ error and gave a plateau age of 7.15 ± 0.84 Ma. This plateau age is supposed to give a reliable eruption age for the basalt from the Mikomoto Knoll.

Discussion

Zenisu Ridge, Izu Spur, Mikomoto Knoll

Andesitic lavas collected in this study from the Zenisu Ridge show similar chemical characteristics to those reported by Nakamura *et al.* (1987), i.e., relative enrichment of alkaline elements compared to the lavas from the volcanic front. On the Zenisu Ridge, basaltic to andesitic volcanism was active from late Miocene to Pliocene.

The Izu Spur is supposed to be a part of basement of the Izu Peninsula. However, the age of a andesite lava from this spur is younger than Miocene formation exposed at the Izu Peninsula. This implies that the Izu Spur is not a part of basement of the Izu Peninsula. The lavas from this spur show strong similarities in chemical characteristics to the Zenisu Ridge.

The ages obtained for the Zenisu Ridge and Izu Spur fall within range of volcanic activity (12.5-2.9 Ma: Ishizuka *et al.*, 1998) of back-arc seamount chains of the Izu-Ogasawara arc distributed south of the study area. Chemical characteristics of lavas from the Zenisu Ridge and Izu Spur are also quite similar to those of the back-arc seamount chains.

Age and chemical characteristics of volcanism on the Zenisu Ridge and Izu Spur suggest that these back-arc ridges were formed by volcanism behind the volcanic front, as is suggested for the back-arc seamount chains of the Izu-Ogasawara arc (Hochstaedter *et al.* in prep, Ishizuka *et al.*, 1998) and not formed solely by tectonic uplift due to the subduction of the Philippine Sea plate to the Nankai Trough (e.g. Chamot-Rooke and Le Pichon, 1989).

The obtained age and chemical characteristics (enrichment of alkaline elements and incompatible elements) of basalt from the Mikomoto Knoll are also similar to those of the lavas from the back-arc ridges (Zenisu Ridge and Izu Spur) and seamount chains of the Izu-Ogasawara arc. This suggests that the Mikomoto Knoll is the site of Miocene volcanism behind the volcanic front, though it does not form a ridge-like topographic feature.

Hyotan-se Bank

Ages of lavas from the Hyotan-se Bank indicate that active volcanism took place at least until late Pliocene to early Pleistocene on this bank. Since no evidence for younger volcanic activity is obtained, volcanism on this bank is supposed to have ceased after early Pleistocene.

Ages of andesitic to dacitic lavas from the Hyotan-se Bank are within an age range (2.8-1 Ma: Ishizuka *et al.*, 1998) of volcanic rocks from the extension of the back-arc seamount chain into the back-arc knolls zone (Honza and Tamaki, 1985) in the southern part of the Izu-Ogasawara arc. Location of the Hyotan-se Bank, ridges and knolls between the volcanic front and steep westward slope down to the Shikoku Basin, is similar to that of the back-arc knolls zone. However, evidence of rifting is not found in the northern area of the Izu arc including the Hyotan-se Bank. Cessation of volcanism on the Hyotan-se Bank and other back-arc ridges might be a result of eastward movement of the western margin of the active volcanic zone of the Izu arc.

Toshima Hole and a knoll northeast of the Otoyama-dashi Bank

Basaltic volcanism on a knoll northeast of the Otoyama-dashi Bank and basaltic to dacitic volcanism on the Toshima Hole are late Quaternary in age. Chemical characteristic of the lavas are intermediate between those of the volcanic front and back-arc seamounts. The Toshima Hole and the knoll northeast of the Otoyama-dashi Bank are supposed to be Quaternary submarine volcanoes just behind the volcanic front.

Summary

1. Volcanism was active in late Quaternary on the Toshima Hole and a small knoll northeast of the Otoyama-dashi Bank, located just behind the Quaternary volcanic front of the Izu-Ogasawara arc. Chemical characteristics of lavas from these submarine volcanoes are intermediate between those of the volcanic front and the back-arc ridges and seamount chains of the Izu-Ogasawara arc.

2. Volcanism on the Hyotan-se Bank forming a northeast-southwest extending ridge is late Pliocene to early Pleistocene in age. Chemical characteristics of andesite to dacite lavas from this bank are intermediate between those of the volcanic front and the back-arc ridges and seamount chains of the Izu-Ogasawara arc.

3. On the Zenisu Ridge and Izu Spur, Miocene to Pliocene volcanism erupted basaltic to andesitic lavas. Chemical characteristics of lavas from these back-arc ridges are similar to those of the back-arc seamount chains of the Izu-Ogasawara arc, i.e., relative enrichment in alkaline elements and incompatible elements compared to the volcanic front.

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