Geochemistry of Miocene back-arc basin basalts from northeast Hokkaido, Japan

Abstract

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Received March 18, 1997.

Accepted November 25, 1997.

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Volcanic activity took place from 14 to 4 Ma in northeast Hokkaido. Newly determined compositions of major and trace elements reveal that the basaltic rocks of 4-6 Ma and 10-12 Ma are characterized by an island-arc type, whereas 7-9 Ma basaltic rocks which are distributed in a graben and adjacent areas have a non-island arc type composition. The geochemical characteristics of the 7-9 Ma basaltic rocks are similar to those of back-arc basin basalts. These geological and geochemical features suggest that the basalts of 7-9 Ma of NE Hokkaido were generated in an extensional tectonic setting due to injection of hot plume-like asthenosphere related to back-arc spreading of the Kurile basin.

Key words : northeast Hokkaido, back-arc basin basalt, Kurile basin, Kurile arc, island-arc, non-island arc, Miocene

Introduction

Northeast (NE) Hokkaido is situated in a back-arc region of the present Kurile arc between Kurile and Japan Sea basins (Fig. 1). Neogene volcanic rocks (basalt~rhyolite; 4-14 Ma) are widely distributed in this area (Watanabe et al., 1991; Goto et al., 1995; Okamura et al., 1995). The volcanic rocks of 9-14 Ma include non-island arc types (icelandite and high-Ti andesite-dacite) associated with calc-alkaline arc lavas (Kokubu et al., 1994; Goto et al., 1995; Okamura et al., 1995).

Goto et al. (1995) interpreted that these volcanic activities have no relation with the spreading of the Japan Sea, because the volume of volcanic products decrease from east (Sea of Okhotsk side) to west (Japan Sea side) and the age of the volcanism is younger than the spreading age of the Japan Sea (15-20 Ma; Otofujii et al., 1985).

Previous tectonic models for the Neogene volcanism in NE Hokkaido are summarized as follows: The volcanic activity was not caused by subduction of the Pacific plate but was due to back-arc spreading related to the Kurile basin formation (Goto et al., 1995), steepening of the subducting Pacific plate with hot asthenosphere injection (Watanabe, 1995), or collision tectonics related to the Eurasian, Okhotsk and Pacific plates (Okamura et al., 1995).

The age of the Kurile basin formation is still controversial. Kimura and Tamaki (1986) presumed it to be during Oligocene to middle Miocene. Recently, Takeuchi (1997) inferred that back-arc spreading of the Kurile basin ceased at the late Miocene (~9 Ma) on

the basis of K-Ar age data of the Tertiary volcanic rocks in South Sakhalin.

New major and trace element data for a limited period 4-12 Ma basaltic rocks (basalt~basaltic andesite) from NE Hokkaido are presented in this paper, because these may contain more information on the composition of the source mantle as compared to felsic rocks that are affected by fractionation and crustal contamination. Based on the data, this paper infers the mantle source of the basaltic rocks and tectonic evolution of this region.

Geological and tectonic setting

Based on age and petrological characteristics, volcanic activity between 4 and 14 Ma in north-northeast Hokkaido is divided into five north-south volcanic zones: Nakagawa, Utanobori, Omu, Kitami, and Abashiri zones, from the Japan Sea side (west) to Okhotsk Sea side (east) (Watanabe and Yamaguchi, 1988; Kokubu et al., 1994; Okamura et al., 1995). In the Kitami volcanic zone, the N-S trending Monbetsu-Rubesibe or Monbetsu-Kamishihoro graben extends about 60 km within a 10 km-wide on land (Yahata and Nishido, 1995; Watanabe, 1995; Okamura et al., 1995, Yahata, 1997) (Fig. 1). The graben began to form at about 11.5 Ma (Yahata, 1997) and is confirmed to be deeper than 700 m by vertical drilling of MITI (1991).

The volcanic rocks are mainly composed of calc-alkaline andesite and show no systematic across-arc variation in K content (Goto et al., 1995; Okamura et al., 1995). Volcanism began about 14 Ma throughout the five volcanic zones and finished at about 11 Ma in

Fig. 1. Distribution of Neogene basaltic rocks and locations of analyzed samples in the northeast Hokkaido.

Table 1. Summary of geological characteristics of the analyzed volcanic rocks from the northeast Hokkaido.

No.	Sample No.	Latitude	Longitude	Formation	Rock Type	Phenocryst	Volcanic Zone	Age
1	Mo1	44°37'39"N	142°47'51"E	Nakahoronai lava	Basaltic andesite	(pl)	Omu	12.9Ma*
2	R1	43°32'56"N	143°40'29"E	Kunnebetsu lava	Basaltic andesite	pl>cpx>opa	Kitami	3.93Ma**
3	Ya1	43°40'24"N	143°23'46"E	Maruyama lava	Basalt	pl>ol>cpx>opa	Kitami	Pliocene***
4	Ya2	43°44'23"N	143°21'08"E	Keshomappu lava	Basaltic andesite	pl>cpx	Kitami	4.3Ma*
5	Sa951	44°03'03"N	143°49'26"E	Saroma lava	Basaltic andesite	pl>cpx	Kitami	Pliocene****
6	Ma1	44°00'21"N	143°28'07"E	Shanafuchi F. (Nirinpangawa lava)	Basalt	ol>pl>opa	Kitami(graben)	8.2Ma*****
7	Ma2	44°00'04"N	143°28'17"E	Shanafuchi F. (Nirinpangawa lava)	Basalt	ol>pl>opa	Kitami(graben)	8.2Ma*****
8	Ma3	44°00'42"N	143°26'27"E	Shanafuchi F. (Sakaeno lava)	Andesite	pl>cpx>opx>opa	Kitami(graben)	Miocene
9	Ma954	44°01'37"N	143°27'19"E	Shanafuchi F. (Kakurezawa lava)	Basalt	ol>pl>opa>(cpx),(opx)	Kitami(graben)	7.3Ma*****
10	Ma5	44°03'35"N	143°28'41"E	Tomeoka F. (lava)	Basalt	ol>pl>opa	Kitami(graben)	8.7Ma*****
11	Ma6	44°05'11"N	143°21'57"E	Shanafuchi F. (lava)	Basalt	pl>ol>opa	Kitami(graben)	Miocene
12	Ma7	44°04'50"N	143°23'11"E	Shanafuchi F. (Chiyoda lava)	Basalt	pl>ol>(opa)	Kitami(graben)	Miocene
13	Ma8	44°05'31"N	143°33'32"E	Shanafuchi F. (Minaminosawa lava)	Basalt	ol>pl>(opa)	Kitami	Miocene
14	Ma9	44°06'44"N	143°29'42"E	Shanafuchi F. (Minaminosawa lava)	Basalt	pl>ol>(opa),(cpx)	Kitami(graben)	Miocene
15	Mo3	44°26'17"N	143°13'32"E	Saruru dyke	Basaltic andesite	ol>pl>vcpx	Kitami	9.1, 8.8Ma*
16	Mo4	44°21'45"N	143°21'29"E	Monbetsu lava	Basalt	ol>cpx>(pl),(opa)	Kitami	Miocene
17	Mo5	44°20'28"N	143°19'07"E	Monbetsu lava (Monbetsu-yama)	Basalt	ol>pl	Kitami	8.82Ma#
18	Ab951	44°06'36"N	144°14'38"E	Abashiri F. (hyaloclastite)	Basalt	pl>cpx>ol>opx	Abashiri	10.62Ma##
19	Ab953-1	44°00'53"N	144°17'16"E	Ponmoi dyke	Basalt	pl>cpx>opa	Abashiri	4.49Ma##
20	Ab955	44°00'38"N	144°17'05"E	Ponmoi dyke	Andesite	pl>hor>opa	Abashiri	Pliocene
21	Ab956	44°00'57"N	144°17'16"E	Ponmoi dyke	Basalt	pl>cpx>opa	Abashiri	Pliocene

Abbreviation of phenocryst: pl=plagioclase, ol=olivine, cpx=clinopyroxene, opx=orthopyroxene, hor=common hornblende and opa=opaque minerals. Phenocryst in parenthesis: rare.

Data source of age: * = Watanabe et al. (1991), ** = Kokubu et al. (1994), *** = Sako et al. (1964), **** = Kuroda and Teraoka (1964), ***** = Yahata and Nishido (1995), # = MITI (1990), ## = Yahata et al. (1995).

the Nakagawa volcanic zone and about 9 Ma in the Utanobori and Omu volcanic zones (Watanabe, 1995). The volcanism continued until about 6–4 Ma in the Kitami and Abashiri volcanic zones (Kokubu et al., 1994; Goto et al., 1995; Watanabe, 1995; Okamura et al., 1995; Yahata and Nishido, 1995; Yahata et al., 1995). Furthermore, volcanic activity in the Omu and Kitami volcanic zones including the graben is characterized by rhyolite-dominant bimodal suites (Oba, 1975; Kokubu et al., 1994; Goto et al., 1995;

Watanabe, 1995; Okamura et al., 1995; Yahata and Nishido, 1995).

At about 6 Ma, the N–S volcanic trend changed to NE–SW direction of the present Kurile arc, and was succeeded by Pliocene to Quaternary volcanism (Watanabe, 1994, 1995).

Samples and analytical methods

Basalt, basaltic andesite and andesite from the three eastern volcanic zones (Omu, Kitami, and Abashiri)

Table 2. Major (oxides : wt. %) and trace (in ppm) element compositions of the volcanic rocks from the northeast Hokkaido.

	R-1	Ya-1	Ya-2	Ma1	Ma2	Ma3	Ma954	Ma5	Ma6	Ma7	Ma8	Ma9	Mo1	Mo3
SiO ₂	57.07	52.04	56.97	49.63	49.80	63.19	51.88	51.88	49.57	49.77	49.20	49.41	55.23	53.12
TiO ₂	1.23	1.04	1.18	1.22	1.13	0.96	1.09	1.27	1.45	1.18	0.99	1.29	0.95	1.14
Al ₂ O ₃	16.37	18.79	17.06	17.68	17.65	16.39	16.58	17.59	17.67	18.16	16.58	17.65	18.63	17.84
Fe ₂ O ₃ *	9.80	9.05	8.56	10.28	9.67	6.01	9.41	9.42	11.47	9.74	9.59	9.43	8.17	7.86
MnO	0.17	0.15	0.13	0.18	0.16	0.13	0.16	0.15	0.20	0.17	0.15	0.19	0.12	0.13
MgO	2.57	5.19	2.59	7.38	8.06	1.37	7.75	7.02	5.68	6.97	9.34	7.04	4.36	6.63
CaO	6.42	9.75	6.47	9.85	9.71	4.68	8.57	9.07	9.55	10.15	9.84	10.83	8.14	8.06
Na ₂ O	3.64	2.95	4.10	3.06	2.92	4.01	2.88	3.41	3.07	3.00	2.56	3.05	3.45	3.74
K ₂ O	1.37	0.73	1.29	0.51	0.70	2.37	0.81	0.74	0.42	0.32	0.52	0.33	1.05	0.80
P ₂ O ₅	0.25	0.19	0.34	0.27	0.23	0.30	0.21	0.34	0.23	0.19	0.16	0.14	0.14	0.29
Total	98.89	99.88	98.69	100.06	100.03	99.41	99.34	100.89	99.31	99.65	98.93	99.36	100.24	99.61
Ba	450	263	344	143	163	367	151	169	119	96	113	56	162	148
Cr		135	12	251	284		376	210	26	45	351	221	21	193
Nb	3.7	3.8	7.3	1.7	3.6	6.3	4.4	5.5	4.3	3.0	3.6	2.8	4.4	7.6
Ni	3.1	43.1	7.7	98	121	6.5	129	78	11	14	132	39	15	91
Rb	39	17	34	12	17	46	20	17	4.7	6.2	5.7	4.4	31	15
Sr	297	321	295	350	352	276	294	358	344	372	321	314	197	329
V	165	225	206	227	241	67	194	197	299	199	227	233	187	174
Y	47	24	33	26	23	39	23	25	26	24	19	23	25	24
Zn	94	65	79	67	60	78	65	73	88	63	61	56	65	58
Zr	117	102	209	126	101	175	121	161	120	122	86	105	121	148
La	19.24	10.47	20.20	11.58	11.92	18.44	10.34	13.75	8.81	8.78	7.57	5.72	9.15	12.08
Ce	31.38	19.96	40.15	23.90	20.37	39.81	23.80	30.42	20.26	20.09	16.74	13.17	18.75	26.07
Sm	7.14	3.58	5.84	4.74	4.15	6.24	3.87	4.77	4.55	3.72	3.07	3.09	3.45	3.83
Eu	2.20	1.07	1.64	1.60	1.53	1.65	1.08	1.55	1.41	1.41	1.07	1.07	1.09	1.28
Tb	1.47	0.47	1.11	1.03	0.78	1.01	0.72	1.04	0.90	0.90	0.62	0.76	0.72	0.60
Yb	5.64	2.58	3.72	3.83	3.21	5.14	3.29	3.23	3.93	3.14	2.57	2.60	3.55	2.86
Lu	0.62	0.35	0.51	0.43	0.36	0.62	0.40	0.45	0.52	0.38	0.29	0.31	0.40	0.39
Hf	2.98	2.05	4.30	3.08	2.25	3.62	2.85	3.14	2.70	2.85	1.94	1.96	2.96	2.86
Ta	0.17	0.16	0.35	0.14	0.26	0.38	0.25	0.38	0.27	0.17	0.14	0.10	0.23	0.50
Th	4.15	2.02	2.74	0.97	1.22	3.88	1.86	1.73	0.71	0.82	1.29	0.60	2.33	1.46
U	1.35	0.67	0.85	0.29	0.47	1.62	0.88	0.51	0.27	0.48	0.24	0.29	1.10	0.68

Note: Major elements and trace elements (Ba, Cr, Nb, Ni, Rb, Sr, V, Y, Zn, Zr) were determined by XRF. Other trace elements were determined by INAA. Fe reported as total Fe₂O₃.

Table 2. (continued)

	Mo4	Mo5	Sa951	Ab951	Ab953-1	Ab955	Ab956
SiO ₂	52.22	52.06	56.39	51.92	51.50	58.01	52.11
TiO ₂	1.09	1.25	0.95	1.02	0.68	0.44	0.69
Al ₂ O ₃	17.98	18.06	16.53	19.17	18.39	18.91	18.65
Fe ₂ O ₃ *	8.12	9.10	7.41	9.55	10.04	7.12	9.96
MnO	0.13	0.15	0.13	0.16	0.18	0.10	0.16
MgO	6.49	6.05	5.11	3.91	4.83	2.60	4.88
CaO	8.13	8.22	8.03	10.37	10.25	7.14	10.26
Na ₂ O	3.77	3.69	3.37	3.04	2.47	3.43	2.66
K ₂ O	0.96	0.99	1.29	1.07	1.15	1.43	1.07
P ₂ O ₅	0.28	0.34	0.12	0.18	0.19	0.20	0.16
Total	99.17	99.91	99.33	100.39	99.68	99.38	100.60
Ba	190	169	269	371	225	301	239
Cr	192	158	107		9.5		4.2
Nb	5.8	8.4	2.5	3.9	2.5	1.9	1.0
Ni	94	85	22	12	13	6.7	16.1
Rb	18	22	32	29	19	27	19
Sr	332	357	248	412	382	421	383
V	194	201	182	340	270	114	291
Y	24	32	26	23	19	18	17
Zn	61	69	53	76	72	63	66
Zr	143	166	90	91	71	95	70
La	12.73	16.55	11.24	12.40	9.55	12.80	8.77
Ce	28.21	30.17	21.40	24.80	18.54	27.22	17.40
Sm	4.10	5.58	3.39	4.08	3.41	3.59	3.08
Eu	1.48	1.80	0.94	1.04	0.95	1.06	1.08
Tb	0.67	0.70	0.81	0.75	0.47	0.63	0.52
Yb	3.22	4.08	3.09	2.90	2.20	2.00	2.07
Lu	0.39	0.54	0.36	0.30	0.41	0.32	0.31
Hf	2.97	3.34	2.12	1.98	1.92	1.95	1.77
Ta	0.42	0.38	0.25	0.21	0.07	0.09	0.08
Th	1.56	1.50	3.37	2.71	1.96	2.90	2.02
U	0.68	0.34	0.91	1.05	3.13	1.54	1.03

Fig. 2. K_2O vs. SiO_2 plot for the volcanic rocks from the northeast Hokkaido. Boundaries among the rock suite fields are after B. V.S.P. (1981). Open circle: volcanic rock of 4-6 Ma, Solid circle: volcanic rock of 7-9 Ma, Cross: volcanic rock of 10-12 Ma.

were selected for analysis. Sample localities, formation, age, rock type and phenocryst assemblages of the analyzed rocks are summarized in Fig. 1 and Table 1. All samples are fresh and were pulverized in an agate mill.

Concentrations of major elements and Sr, Rb, Ba, Zr, Y, Nb, V, Zn, Ni and Cr were determined by XRF (Rigaku RIX 3000) at National Institute of Polar Research (Tokyo), following analytical procedures of Motoyoshi and Shiraishi (1995). Other trace elements were analyzed by INAA at Rikkyo University (Yokosuka).

Geochemical characteristics

Major and trace element compositions of the volcanic rocks are given in Table 2.

Most of the volcanic rocks (basalt~andesite) plot in the calc-alkaline field (medium-K field) on the K_2O vs. SiO_2 diagram (B. V.S.P., 1981) (Fig. 2). The FeO^*/MgO ratios of the basaltic rocks (basalt~basaltic andesite) show approximately 1 (Tables 1-2, Fig. 3). This suggests that the basaltic rocks have less evolved compositions. The TiO_2 vs. FeO^*/MgO diagram (Fig. 3) shows that 7-9 Ma basaltic rocks from the graben and adjacent areas in the Kitami volcanic zone (Fig. 1, Table 1) have higher TiO_2 contents than those of the other basalts at similar FeO^*/MgO . The 7-9 Ma basaltic rocks are similar to MORB in this regard, whereas the 10-12 Ma and 4-6 Ma volcanic rocks from the study area are poor in Ti compared with MORB and similar to island-arc rocks (island-arc tholeiite: IAT). The Ti vs. Cr diagram (Pearce, 1975) also shows that most of the 7-9 Ma basaltic rocks are plotted in the field of the ocean-floor basalt, whereas 10-12 Ma and 4-6 Ma lavas plot in the island-arc tholeiite field (Fig. 4).

Mantle-normalized incompatible-element variation diagrams (Holm, 1985) for the volcanic rocks from NE

Fig. 3. TiO_2 vs. FeO^*/MgO diagram for the volcanic rocks from the northeast Hokkaido. MORB and IAT (island-arc tholeiite) fields are after compiled data of Ikeda and Yuasa (1989). Symbols are same as in Fig. 2.

Hokkaido are compiled in Fig. 5. Overall, the mantle-normalized trace element patterns of 4-6 Ma, 7-9 Ma, and 10-12 Ma volcanic rocks in NE Hokkaido do not show a significant difference to each other. They have a negative slope and several major anomalies (negative Nb anomaly and positive Sr anomaly), which are common in island-arc rocks. The patterns for some 7-9 Ma volcanic rocks slightly differ from 10-12 Ma and 4-6 Ma lavas by having a positive gradient for the segments of Rb-Ba and Th-U, and a rather flat slope for the segment La-Ce-P-Zr-Sm. These patterns for some volcanic rocks of 7-9 Ma are similar to that of the back-arc basin basalt

Fig. 4. Ti vs. Cr diagram (Pearce, 1975) for the volcanic rocks from the northeast Hokkaido. Symbols are same as in Fig. 2.

Fig. 5. Mantle-normalized trace element variation diagram for the volcanic rocks of 4-6 Ma, 7-9 Ma and 10-12 Ma from the northeast Hokkaido. The data are normalized to estimated primitive mantle abundance by compiled data of Holm (1985).

(Holm, 1985).

On the Th/Yb vs. Ta/Yb diagram (Pearce, 1982, 1983) (Fig. 6), most of the basaltic rocks of 7-9 Ma from the NE Hokkaido plot in the oceanic arc region, but the effect of subduction-related components is less than the other basaltic rocks of 4-6 Ma and 10-12 Ma. Ta/Yb ratios of the 7-9 Ma basaltic rocks range from 0.03 to 0.2, suggesting the involvement of depleted mantle (MORB source)~enriched mantle (OIB~within plate source) sources in their petrogenesis.

On the K/Rb vs. Zr/Rb diagram (Fig. 7), the data for 7-9 Ma basaltic rocks fall close to a trend passing through MORB~back-arc basin basalt (BABB)~within plate basalt (OIB), whereas the other basaltic rocks plot in a region of island-arc rock suites.

On the $Ce_N/Sr_N/Sm_N$ diagram (Ikeda, 1990; Fig. 8), the 7-9 Ma basaltic rocks are plotted in the field of within plate basalt (OIT and OIA) and BABB.

Origin of 7-9 Ma basaltic rocks and tectonic evolution

Geochemical characteristics of the basaltic rocks of 7-9 Ma have a non-island arc type composition and are clearly distinct from the other island arc basaltic rocks of 10-12 Ma and 4-6 Ma (Figs. 3-4). Considering geochemical information of Figs. 5, 7 and 8, the 7-9 Ma non-island arc type basaltic rocks are similar to BABB-like characteristics. The geochemical features of the 7-9 Ma basaltic rocks in Fig. 6 suggest that enriched~depleted mantle (MORB source) appear to play a part in the genesis of the basaltic rocks, aided by a subduction-derived component such as Th.

If the formation of the graben in the Kitami volcanic zone is ascribed to buoyant rising of hot asthenosphere as discussed by Watanabe (1995), this injection of hot plume-like asthenosphere should cause the basaltic magmatisms of 7-9 Ma associated with the development of the graben in regional extension.

Fig. 6. Th/Yb vs. Ta/Yb diagram (Pearce, 1982, 1983) for the basaltic rocks from the northeast Hokkaido. Symbols are same as in Fig. 2. The "mantle array", vectors (s=subduction zone enrichment, c=crustal contamination, w=within plate enrichment), and tholeiite (TH), calc-alkaline (CA) and shoshonitic (SHO) boundaries are taken from Pearce (1982, 1983).

Fig. 7. K/Rb vs. Zr/Rb diagram for the basaltic rocks from the northeast Hokkaido. Symbols are same as in Fig. 2. The values of N-MORB, back-arc basin, within plate tholeiitic, within plate alkalic, island-arc tholeiitic, and island-arc calc-alkaline are compiled from Wilson (1989).

The injection of hot plume-like asthenosphere (depleted~enriched mantle) into the subduction-modified mantle wedge may be contaminated by a subduction component. The plume could partially melt as a consequence of adiabatic decompression to produce BABB-like magma. These processes are essentially similar to those of Crawford et al. (1981), Volpe et al. (1987) and Ikeda and Yuasa (1989) for the Izu-Mariana back-arc basin regions.

Goto et al. (1995) inferred that the non-island arc volcanism such as icelandite and high Ti andesite-dacite related to spreading of the Kurile basin. On

the other hand, Watanabe (1995) and Okamura et al. (1995) considered that the volcanism is not related to spreading of the Kurile basin, because the ages of the volcanism are younger than those of the inferred spreading age of the Kuril basin (Oligocene to middle Miocene; Kimura and Tamaki, 1986; Gnibidenko et al., 1995). However, recently Takeuchi (1997) suggested that the 9-23 Ma volcanism in Sakhalin and Hokkaido was caused by southward migration of the Kurile arc with back-arc spreading of the Kurile basin.

Considering geochemical characteristics of the 7-9

Fig. 8. $Ce_N/Sr_N/Sm_N$ diagram (Ikeda, 1990) for the basaltic rocks from the northeast Hokkaido. The subscript N means concentrations are normalized to primordial mantle composition ($Ce=1.9$ ppm, $Sm=0.385$ ppm, and $Sr=23$ ppm). IAT: island-arc tholeiite, N-MORB: normal MORB, E-MORB: enriched MORB, BABB: back-arc basin basalt, OIT: ocean island tholeiite, OIA: ocean island alkaline.

Ma basalts, it seems likely that the graben is the south end of the rift responsible for spreading of the Kurile basin. If this model is accepted, the volcanic activity in the Kurile basin should continue on into 7 Ma. At present, owing to a lack of data of precise volcanic ages and ocean drilling in the Kurile basin, the definite conclusion including the origin of the back-arc basin basalt (7–9 Ma) which are derived from the hot asthenosphere must be reserved.

Acknowledgements

I thank Prof. R.J. Stern of Texas University at Dallas and H. Kagami of Institute for study of the Earth's Interior Okayama University for his critical review of early version of the manuscript. I wish to thank Dr. Y. Motoyoshi and Prof. K. Shiraishi of National Institute of Polar Research for help with XRF analyses, and Dr. J. Maeda of Hokkaido University and Prof. K. Tomura of Rikkyo University for help with NAA work. A part of this study was supported by a Grant in Aid for Scientific Research of the Ministry of Education, Japan to H. Kagami (No. 07304041).

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(要 旨)

Ikeda, Y., 1998, Geochemistry of Miocene back-arc basin basalts from northeast Hokkaido, Japan. *Jour. Geol. Soc. Japan*, **104, 99-106, (池田保夫, 1998, 北海道北東部の中新世背弧海盆玄武岩の地球化学. 地質雑, **104**, 99-106.)**

北海道北東部には4-14 Maに活発な火山活動が起きた。この時期のマグマの組成は玄武岩～流紋岩の広い組成範囲にわたり、島弧的なものと非島弧的なものが存在している。今回、新たに、4-12 Maの玄武岩質岩の主成分元素と微量元素を検討した結果、4-6 Maと10-12 Maの玄武岩は島弧タイプ、地溝帯に分布する7-9 Maの玄武岩は非島弧タイプで、その岩石化学的特徴は背弧海盆玄武岩に類似していることが判明した。この7-9 Maの非島弧タイプの玄武岩は地質学的・地球化学的特徴から、千島海盆の形成に関連した熱いアセノスフェアの注入によって地溝帯が形成されるとともに、背弧海盆型玄武岩マグマが生成されることによって形成されたことが示唆された。