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Stratigraphy and K–Ar ages of Tertiary volcanic rocks in the Hamamasu area northwestern Hokkaido, Japan

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Abstract

Tertiary volcanic rocks in the Hamamasu area along the Japan Sea coast in northwestern Hokkaido are lithologically divided into three formations. These are, in ascending order, the Iwao, Horo and Hamamasu Formations. The Iwao Formation is composed mainly of lavas and pyroclastic rocks of basalt and andesite with subordinate amounts of debris flow deposits and fluvial deposits. The Formation is divided into six units, which are in ascending order, A, B, C, D, E and F units. K–Ar ages include 3.8±0.1 Ma for andesite from the A unit and basalts from the B and C units as well as an andesite dike intruding the B unit. The andesites of the D and F units are dated to be 3.7±0.1 Ma, and a basalt lava of the Hamamasu Formation to be 2.6±0.1 Ma.

These stratigraphical results and K–Ar age determinations show that volcanic rocks from the Iwao Formation, and the dike were derived from a volcano which has been erupted during a relatively short period of 3.7 to 3.8 Ma in the eastern part of this area, and the volcano seems to have collapsed, resulting in debris flow deposits and fluvial deposits. After completion of the volcano, the fluvial deposits accumulated on the southern part of this area. Thereafter, at 2.6 Ma the basaltic lavas overlay the volcanic products formed during the 3.7–3.8 Ma volcanic activity, mainly at the southern and northern parts of this area.

The geochemical characteristics of basalts from this area, different from those of the Pliocene to Quaternary basalts from the NE Japan arc and the Quaternary basalts from the Kurile arc, may suggest a different origin of the magma from those in the NE Japan and Kurile arcs.

Key words : Hamamasu area, northern Hokkaido, lava, debris flow deposits, fluvial deposits, volcano, sector collapse, K–Ar age, Pliocene, NE Japan arc, Kurile arc, basalt, andesite, Zr/Y ratio

Introduction

Northern Hokkaido is presently situated in the back arc region behind the junction of the Northeast Japan and Kurile arcs. Since 1980's, K–Ar and fission track ages for widely distributed Tertiary volcanic rocks in this region have been reported by many workers (e.g., Shibata et al., 1981 ; Koshimizu and Kim, 1986 ; Watanabe et al., 1991 ; Nakagawa et al., 1993 ; Goto et al., 1995). These age data have made it possible to discuss the evolution in time and space of the Tertiary volcanism in northern Hokkaido (e.g., Watanabe, 1994 ; Goto et al., 1995 ; Okamura et al., 1995).

Tertiary volcanic rocks also occur in the Hamamasu area located along the Japan Sea coast in northwestern Hokkaido (Fig. 1). Sato et al. (1963) divided the volcanic rocks in the area into lower andesitic lavas and breccia (Iwao lava and volcanic breccia bed), and upper basaltic lavas (Hamamasu basalts), which are unconformably overlain by the Shokambetsu volcanics. The Shokambetsu volcanics occupy topographically high areas, such as Mts. Shokambetsu-dake, Gunbetsu-dake and Hamamasu-dake, between 12 and 15 km inland from the Japan Sea coast. Although the Shokambetsu volcanics were considered to be Pleistocene by Sato et al. (1963), andesite from Mts. Shokambetsu-dake and Minamishokambetsu-dake gave Pliocene K–Ar ages of 2.07±0.20 Ma and 3.12±

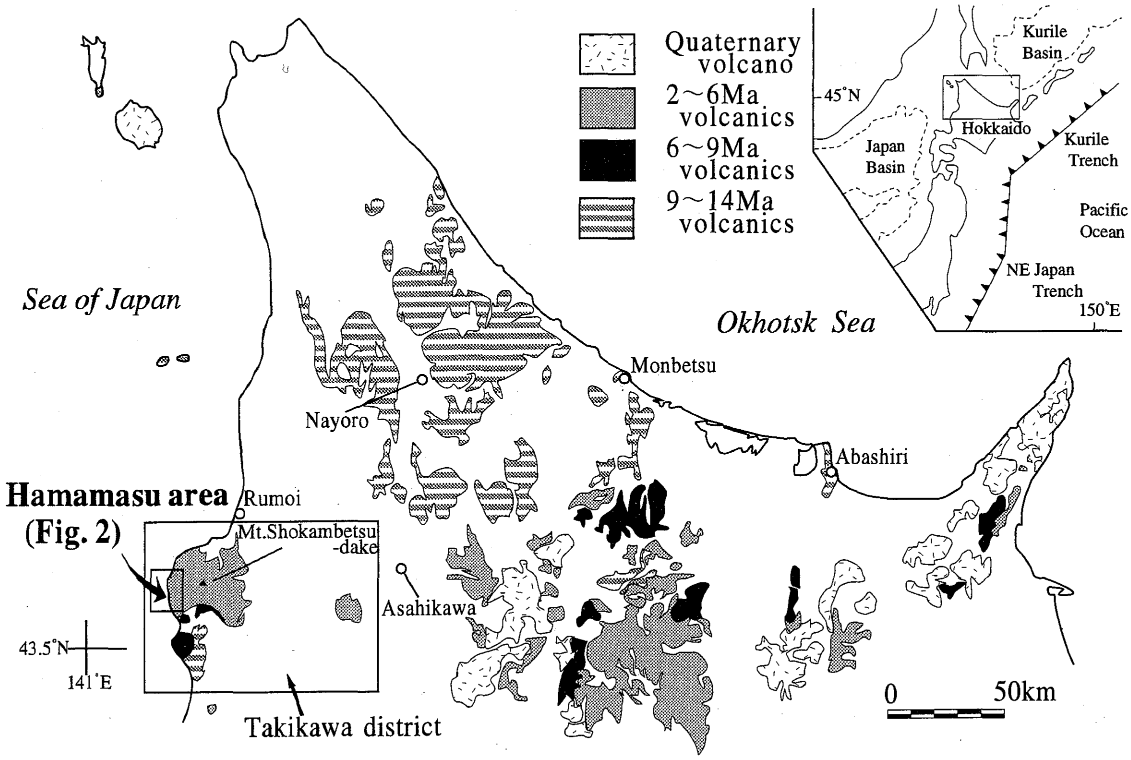

Fig. 1. Index map showing the study area and distribution of Cenozoic volcanic rocks in northern Hokkaido, Japan.

0.14 Ma, respectively (Yagi et al., 1987). However, the age of volcanic rocks constituting the basement to the Shokambetsu volcanics is still uncertain.

We carried out geological investigation for Tertiary volcanic rocks and determined K-Ar ages of these volcanic rocks in order to construct the volcanic history in the Hamamasu area. This paper uses the names "the Iwao Formation" instead of "Iwao lava and volcanic breccia" The Iwao Formation is exposed along the Japan Sea coast over a distance of about 20 km (Sato et al., 1963). The Hamamasu area corresponds to the southern half of the mapped area by Sato et al. (1963). In this paper, we also reported the major and trace element chemistry of these Tertiary volcanic rocks. Based on these results, the characteristics of Tertiary volcanic activity in the area are duscussed.

Stratigraphy

Tertiary volcanic rocks are exposed over an area of 15 km (N-S)by 6 km (E-W) in the Hamamasu area (Fig. 2). The Iwao Formation is lithologically divided into A, B, C, D, E and F units in ascending order, and the Hamamasu basalts are redefined and divided into two formations, the lower Horo Formation composed of conglomerate and the upper Hamamasu Formation composed of basaltic lavas (Fig. 3). The intrusive bodies composed of basalt and andesite are found as dikes, cutting either A, B, D or F units.

1. Iwao Formation

A unit

This unit is composed of andesitic lavas and pyroclastic rocks such as tuff breccia and volcanic breccia. Platy joints (a few cm to 10 cm intervals) are well developed in the lavas and reddish brown clinker is associated at the base of the lavas. The andesitic lavas include scatterd, subrounded accidental frag ments of granitic rocks and plagioclase-clinopyroxene-hornblende cumulates up to 20 cm in diameter. The total thickness of this unit exceeds 100 m. These lavas strike N 20° to 30° E or 15° to 20° W. The lavas consist of hornblende-orthopyroxene-clinopyroxene andesite with subordinate amounts of hornblende-clinopyroxene andesite and olivine-hornblende-orthopyroxene-clinopyroxene andesite. These andesites occasionally include phenocryst-size exotic corroded quartz grains.

B unit

This unit is composed of conglomerate (B-1 part) and basaltic lava (B-2 part), and exposes along the middle to upper reaches of the Chiyoshibetsu River (Fig. 2). The unit varies from 50 to 150 m in thickness and conformably overlies the A unit. The conglomerate of this unit is composed of poorly sorted, rounded or subrounded andesite gravel and boulder, with a maximum diameter of 3 m, which are often reversely gradded and stratified. The conglomerate has a relatively high content of matrix composed of gray tuff and tuffaceous silt, which supports andesitic

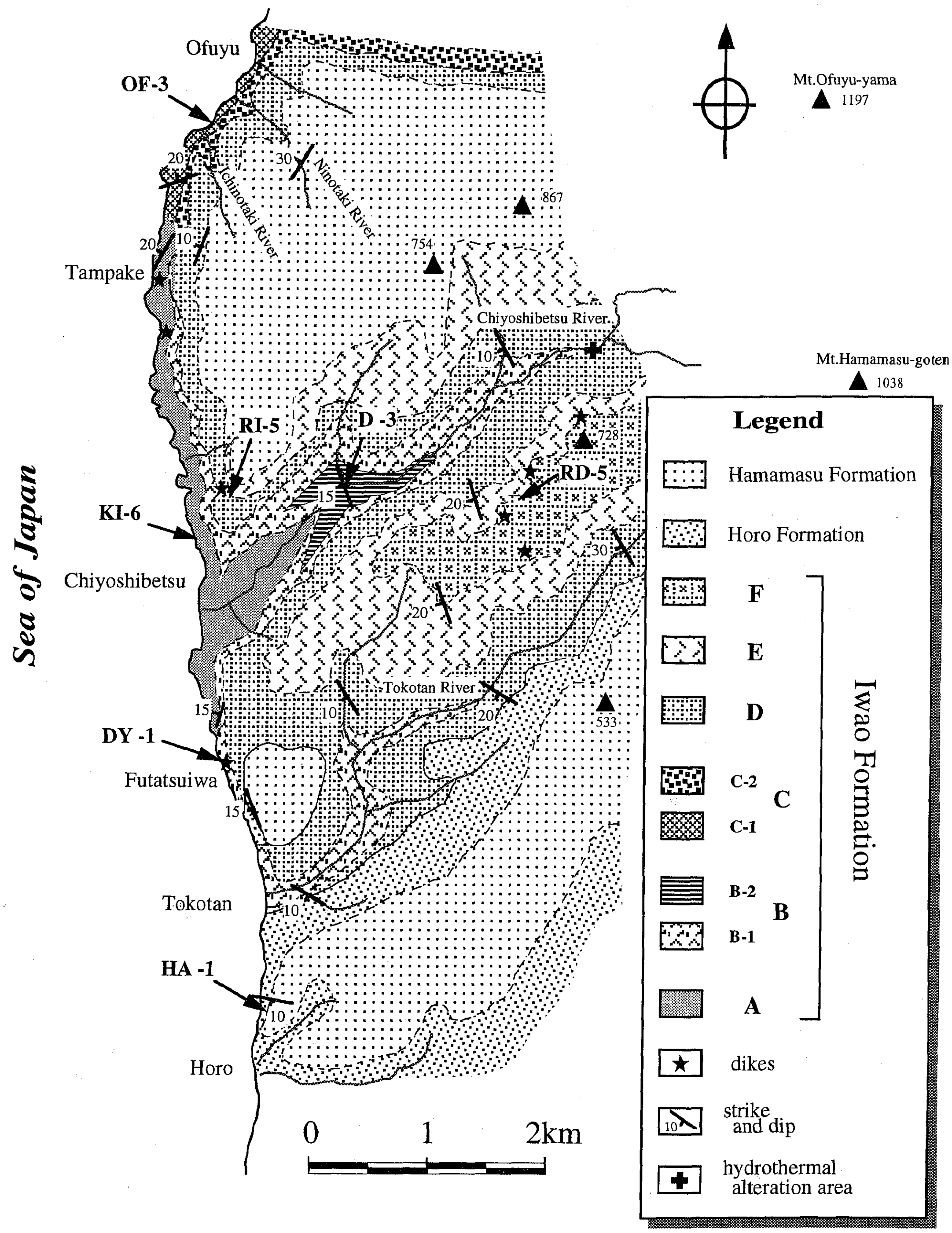

Fig. 2. Geologic map of the Hamamasu area. Arrows with KI-6, D-3, OF-3, RI-5, RD-5, HA-1 and DY-1 show localities of samples used for K–Ar age determination.

clasts. Weakly consolidated beds of gray tuffaceous silt and dark gray, fine-grained sand (from 10～30 cm thick) are often contained within this conglomerate. This suggests that the conglomerate has characteristics similar to those of debris flow deposits (e.g., Fisher and Schmincke, 1984).

The 10 m-thick basaltic lava within the conglomerate lies on a reddish brown scoriaceous fall deposit which contains a few volcanic bombs up to 30 cm diameter. Platy joints developed in the lava suggest northwest strike and 15° westward dip. These strike and dip are similar to those of the boundary between the lava and scoriaceous fall deposit. The basaltic lava consists of clinopyroxene-olivine basalt and olivine-clinopyroxene basalt with corroded quartz grains.

C unit

This unit is distributed only in the northern part of

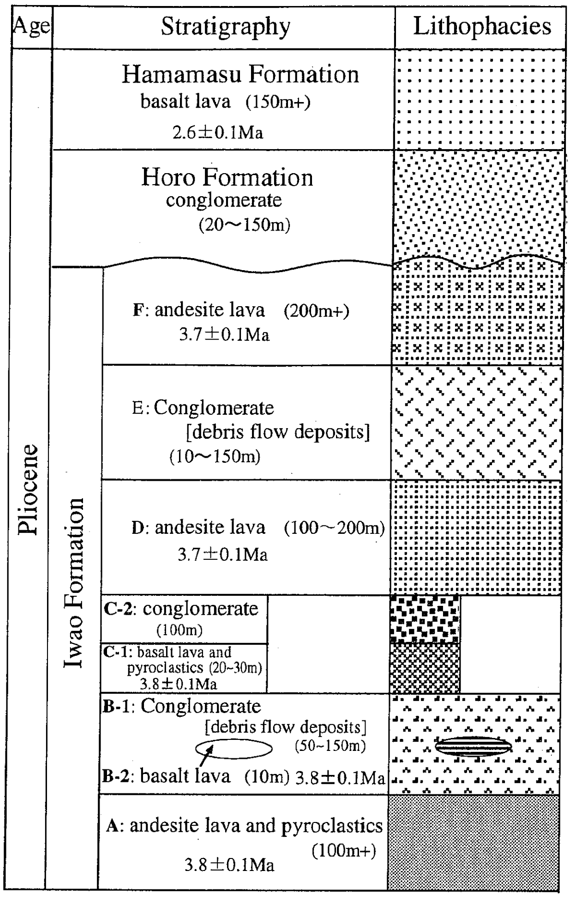

Fig. 3. Stratigraphic sequences of the Hamamasu area. K-Ar ages obtained in this study are shown.

the area (Fig. 2), and is divided into the lower C-1 and upper C-2 parts. The lower C-1 part consists of a basaltic lava and pyroclastic rocks, with a total thickness of 20 to 30 m. The lava consists of clinopyroxene-olivine basalt and olivine-clinopyroxene basalt, and contains embayed quartz grains rimmed with clinopyroxene. It is 5 to 10 m in thickness and rests conformably upon a reddish-brown well-sorted scoriaceous fall deposit. The fall deposit contains volcanic bombs up to 30 cm diameter. The boundary between the lava and fall deposit strikes N 50° to 60° W and dips 10 to 20° NE. These strike and dip are nearly consistent with those of platy joints in the lava. Pyroclastic rocks, which are common both above and below the lava, consist mainly of tuff breccia with fragments of basalt in a matrix of reddish-brown basaltic tuff.

The C-2 part corresponds to conglomerate and tuffaceous sandstone within the Iwao Formation (Sato et al., 1963) and conformably overlies the B unit. The part ranges in thickness from about 30 m along the lower reach of the Ichinotaki River to about 100 m along the lower reach of the Ninotaki River, and is composed of conglomerate. Several thin gray siltstone beds are intercalated with the conglomerate. The conglomerate is mainly composed of andesitic and less common basaltic clasts, which are well-sorted, rounded or subrounded, with an average size of about 20 cm. The limited exposure, drastic change in thickness and lithological characteristics of the conglomerate suggest that it represents fluvial deposits.

D unit

This unit consists of andesitic lavas with subordinate amounts of pyroclastic rocks, ranging in thickness from 100 to 200 m and conformably overlying both the B and C units. The lavas have well-developed platy joints with 5 cm intervals, and contain both corroded quartz grains and subrounded accidental fragments ranging in size from a few cm to 10 cm in diameter. These are similar features to the andesitic lava of the A unit. Platy joints in andesitic lavas indicates that these lavas strike N 60° W to N-S and dip 10° (at the Japan Sea coast side) to 30° west (at topographically high area). Strike and dip of the boundary between the lavas and B unit at Tokotan and Futatsuiwa are similar to those of platy joints in the lavas. The lavas exposed along the upper reaches of the Chiyoshibetsu River were subjected to hydrothermal alteration and have been changed into white colored argillaceous rocks. The andesite lavas are largely composed of hornblende-olivine-orthopyroxene-clinopyroxene andesite with less common olivine-clinopyroxene andesite.

E unit

This unit is composed of conglomerate which varies in thickness between 10 m and 150 m and conformably overlies the D unit. The conglomerate consists mainly of subangular and angular clasts of hornblende-orthopyroxene-clinopyroxene andesite (with a diameter of about 5 cm) in a matrix of gray tuff and tuffaceous silt. The conglomerate is frequently intercalated with approximately 10 cm-thick gray tuffaceous siltstone beds. This conglomerate may be debris flow deposits because it has a high matrix content and subangular to angular clasts are poorly sorted, well stratified and often reversely gradded.

F unit

This unit consists of andesitic lavas with subordinate amounts of tuff breccia, with a total thickness more than 200 m, and conformably overlies the E unit. The lavas have well-developed platy joints with a few cm intervals and generally strike N 30° to 40° E and dip 20° to 30° W. These strike and dip are nearly concordant with those of the boundary between the lavas and E unit. The andesite lavas are composed of hornblende-orthopyroxene-clinopyroxene andesite and orthopyroxene-clinopyroxene andesite which occasionally include phenocryst-size corroded quartz and plagioclase-clinopyroxene-hornblende cumulates up to 10 cm in diameter. This andesitic lavas were considered to be volcanic products of the Quaternay

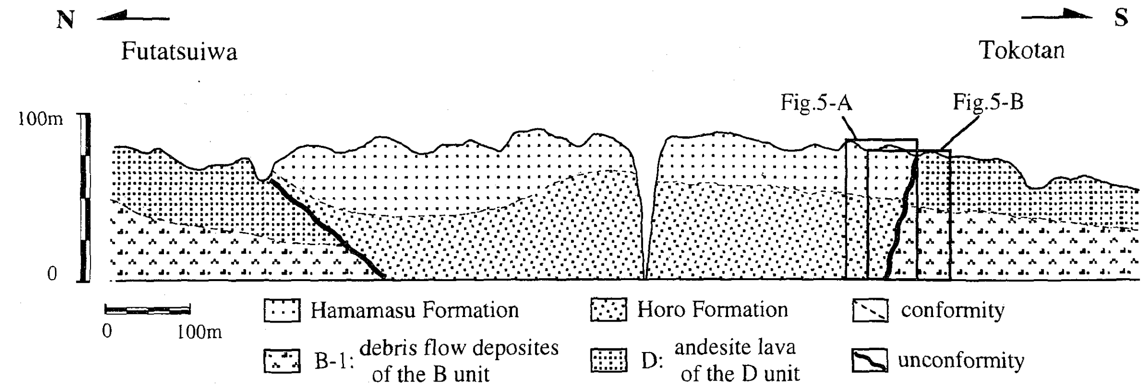

Fig. 4. N-S trending cross-section along the Japan Sea coast between Futatsuiwa and Tokotan.

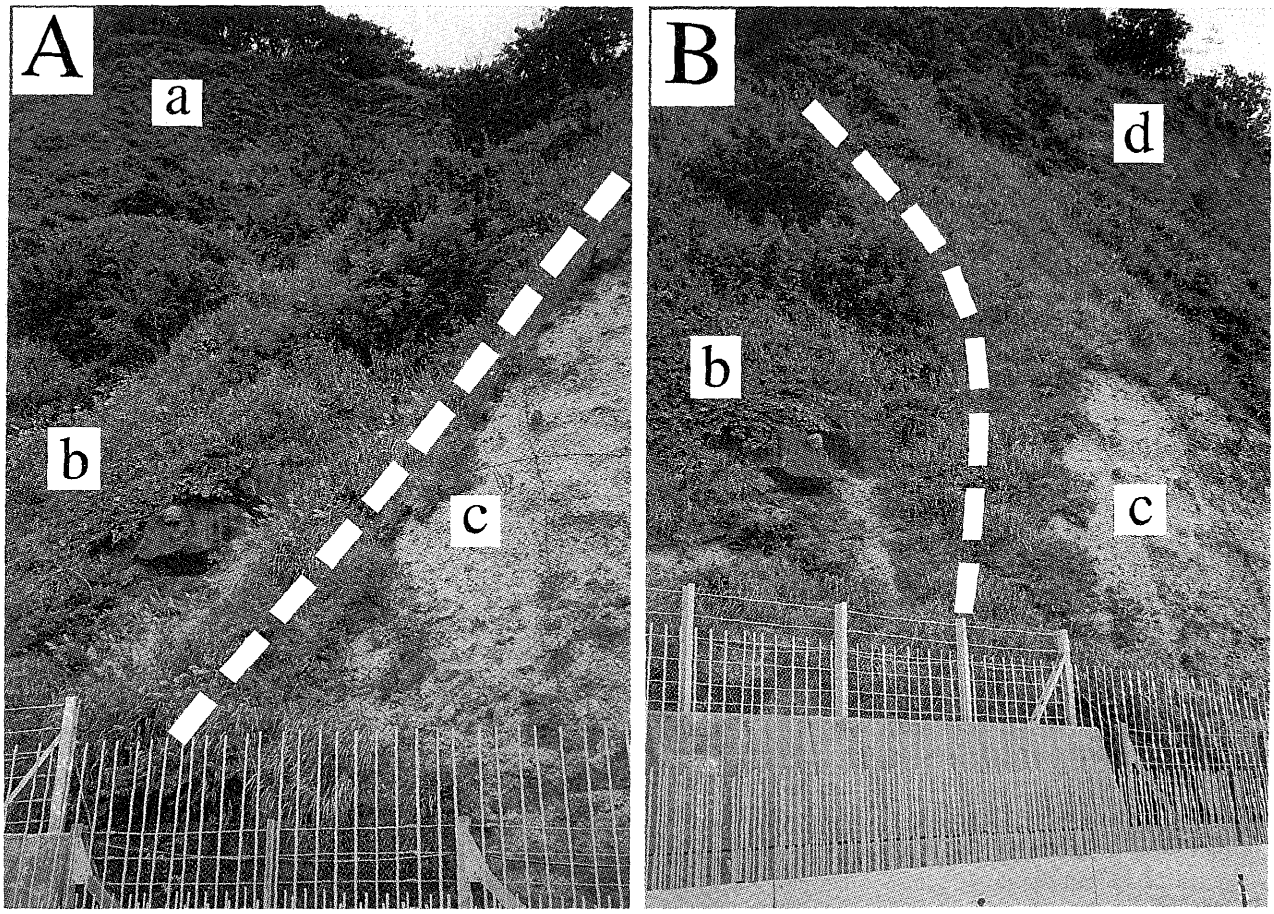

Fig. 5. Photographs of the outcrop near the boundary between the Horo Formation and the underlying B and D units. Locality is shown in Fig. 4. a : basalt lava of the Hamamasu basalts, b : Horo Formation, c : debris flow deposits of the B unit, d : andesite lava of the D unit. Broken line shows the boundary between the Horo Formation and the underlying units.

(Sato et al., 1963). However, we redefined the lavas as one unit in the Iwao Formation in this paper based on the results of stratigraphical works and K-Ar determination.

2. Horo Formation

This formation is composed of conglomerate which shows a wide range in thickness between 20 m and 150 m and unconformably overlies the B and D units. The conglomerate consists of well-sorted, rounded or subrounded andesitic and basaltic clasts, with a maximum diameter of 3 m in a matrix of brown fine-grained sand. The conglomerate is frequently intercalated with well-sorted, very coarse- and coarse-grained sands in which cross lamination is well developed. The formation may be regarded as fluvial deposits because of its lithological characters.

Continuous outcrops up to about 100 m thick along the Japan Sea coast between Futatsuiwa and Tokotan clearly show that the formation constructs channel structure and unconformably overlies the D unit and

Table 1. Brief description of samples used for K-Ar age determination.

Formation and Unit	Sample No.	Rock type	Phenocryst mineral	Groundmass	Exotic fragment
Hamamasu Formation	HA-1	basalt	ol+cpx+pl	intergranular, fresh	
Iwao Formation					
A unit	KI-6	andesite	cpx+opx+hbl+pl	hyalo-ophitic, fresh	quartz, granite
B-2 unit	D-3	basalt	ol+cpx+pl	intergranular, fresh	quartz
C-1 unit	OF-3	basalt	ol+cpx+pl	intergranular, fresh	quartz
D unit	RI-5	andesite	ol+cpx+opx+hbl+pl	hyalo-ophitic, fresh	quartz, granite
F unit	RD-5	andesite	cpx+opx+hbl+pl	hyalo-ophitic, fresh	quartz, granite
dike	DY-1	andesite	cpx+opx+hbl+pl	hyalo-ophitic, fresh	quartz, granite

ol;olivine, cpx;clinopyroxene, opx;orthopyroxene, hbl;hornblende, pl;plagioclase

Table 2. K-Ar age data of volcanic rocks from the Hamamasu area.

Sample No.	Location	K (wt%)	Rad.argon 40 (10^{-8}ccSTP/g)	K-Ar age (Ma)	Non Rad.Ar (%)
HA-1	N43° 39′ 22″ E141° 21′ 26″	0.61±0.01	6.12±0.1	2.6±0.1	43.2
KI-6	N43° 41′ 54″ E141° 20′ 52″	1.73±0.04	25.4±0.4	3.8±0.1	18.3
D-3	N43° 41′ 86″ E141° 21′ 44″	0.99±0.02	14.50±0.2	3.8±0.1	27.8
OF-3	N43° 43′ 58″ E141° 20′ 37″	1.03±0.02	15.15±0.3	3.8±0.1	34.4
RI-5	N43° 41′ 73″ E141° 20′ 74″	1.05±0.02	15.17±0.3	3.7±0.1	26.4
RD-5	N43° 41′ 96″. E141° 22′ 63″	0.83±0.02	11.86±0.2	3.7±0.1	32.1
DY-1	N43° 40′ 81″ N141° 20′ 74″	0.93±0.02	13.63±0.2	3.8±0.1	28

the B-1 part of the B unit (Figs. 4 and 5).

3. Hamamasu Formation

The Hamamasu Formation is composed of lavas more than 150 m and rest conformably on the Horo Formation. The scattered olivine phenocrysts of 1 cm diameter are seen in the lavas and spiracles are frequently found near the base of the lava above the contact with the underlying conglomerate of the Horo Formation. The boundary between the lava and the Horo Formation at the southern part of this area strikes N 60° W and dips 10° W. These strike and dip are nearly concordant with those of well-developed platy joints of the lava. The lavas at the northern part, on the other hand, strike N 30° to 40° E and dip 20° to 30° W, which were deduced from strike and dip of well-developed platy joints in the lavas. The lavas are represented by orthopyroxene-bearing clinopyroxene-olivine basalt with subordinate amounts of orthopyroxene-bearing olivine-clinopyroxene basalt which sometimes include corroded quartz grains.

4. Dikes

Basalt or andesite dikes are found along the Japan Sea coast between Tampake and Futatsuiwa and along a forestry road connecting both the upper reaches of the Tokotan and Chiyoshibetsu Rivers (Fig. 2). These dikes are vertical and strike E-W.

At the former area, at least two basalt dikes ranging in width from 2 to 3 m intrude the A unit, and one basalt dike with a similar width cuts the D unit. An andesite dike, about 10 m wide, intrudes the B-1 part of the B unit at Futatsuiwa.

At the latter area, more than four andesitic dikes intrude the F unit. They are 5 to 15 m in width and a 5 m-wide dike intruding tuff breccia of the F unit is regarded as feeder dike which grades outward into lava.

K-Ar age determination

1. Method

K-Ar age determination was made on seven whole rock samples whose locations are shown in Fig. 2. K was analyzed by flame photometry (Nagao et al., 1984 ; Doi and Itaya, 1992) and ^{40}Ar was analyzed by isotope dilution with ^{38}Ar as a tracer, using the mass spectrometer of Okayama University of Science (Nagao and Itaya, 1988 ; Itaya et al., 1991). The K-Ar age was calculated using the physical constant, $\lambda e = 0.581 \times 10^{-10}/y$, $\lambda\beta = 4.962 \times 10^{-10}/y$. $^{40}K/K = 0.0001167$ (Steiger and Jäger, 1977).

2. K-Ar ages of volcanic rocks in the Hamamasu area

The analyzed samples are briefly described in Table 1. Their phenocrystic minerals and groundmass are generally fresh and the exotic fragments including granitic rocks and corroded quartz in these rocks were removed by hand picking under microscope. Analytical results of K-Ar dating are given in Table 2.

The petrographic characteristics of the samples suggest that these K-Ar ages obtained in the present study indicate the ages of eruption and intrusion.

Table 3. Selected major and trace element compositions and normative compositions of volcanic rocks from the Hamamasu area.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sample	KI-4	F-7	KI-6	D-1	CSR-10	D-3	OF-2	TN-2	OF-3	RI-3	F-22	RI-5	RD-5	RD-3	RN-24	P-4	F-39	MT-8	HA-1	DY-1
SiO_2(%)	55.77	57.53	59.51	50.59	51.98	51.37	52.12	52.61	52.36	56.27	56.44	57.96	57.58	57.72	60.64	50.61	51.45	51.05	50.67	58.77
TiO_2	0.81	0.75	0.70	0.96	0.94	0.98	0.98	0.95	0.95	0.72	0.76	0.75	0.68	0.78	0.70	0.95	0.89	0.98	0.95	0.71
Al_2O_3	17.35	17.31	17.23	16.77	16.96	16.66	17.43	17.46	17.06	16.94	16.70	16.82	17.03	16.86	16.41	16.48	16.25	14.73	16.42	16.99
Fe_2O_3	4.81	3.79	4.09	4.84	4.34	4.09	4.89	4.18	4.20	3.56	3.41	3.80	3.44	3.10	2.73	3.82	3.36	3.61	3.56	3.41
FeO	2.02	2.75	1.60	3.62	4.02	4.44	3.40	3.80	4.08	2.83	2.91	2.75	2.57	2.99	2.95	4.85	4.90	4.85	5.20	2.83
MnO	0.15	0.13	0.11	0.15	0.15	0.15	0.14	0.14	0.16	0.12	0.12	0.13	0.12	0.12	0.12	0.16	0.16	0.15	0.16	0.12
MgO	4.96	4.42	2.94	8.59	7.25	8.48	6.35	6.57	6.11	4.99	5.51	4.56	4.20	4.24	3.48	8.39	8.67	11.19	8.00	4.04
CaO	8.52	7.89	6.85	9.74	9.39	9.53	9.29	9.38	9.79	7.54	7.74	7.51	7.24	7.22	6.38	10.01	9.81	9.47	10.31	7.31
Na_2O	3.00	3.26	3.38	2.81	2.92	2.75	2.97	2.97	2.88	3.09	3.16	3.12	3.36	3.40	3.43	2.61	2.67	2.66	2.59	3.13
K_2O	1.20	1.45	1.81	1.06	1.20	1.08	1.16	1.18	1.21	1.53	1.67	1.59	1.69	1.81	2.12	1.28	1.22	1.02	1.36	1.53
P_2O_5	0.18	0.19	0.18	0.21	0.21	0.20	0.22	0.21	0.20	0.19	0.19	0.20	0.20	0.20	0.19	0.23	0.20	0.23	0.22	0.18
$H_2O\pm$	0.39	-	0.53	0.17	0.18	0.09	0.27	0.37	0.09	0.65	0.30	0.60	0.72	0.78	0.09	0.37	-	0.33	-	0.27
total	99.16	99.47	98.94	99.52	99.53	99.82	99.22	99.83	99.10	98.43	98.91	99.77	98.83	99.20	99.25	99.76	99.57	100.26	99.44	99.29
FeO*/MgO	1.28	1.39	1.80	0.93	1.09	0.96	1.23	1.15	1.28	1.21	1.09	1.35	1.35	1.36	1.55	0.99	0.91	0.72	1.05	1.46
Qz	11.0	11.8	16.0	0.1	2.3	0.7	4.3	3.6	4.0	10.8	9.1	13.0	11.9	11.1	15.0	-	-	-	-	14.6
Or	7.1	8.6	10.9	6.3	7.1	6.4	6.9	7.0	7.2	9.2	10.0	9.5	10.2	10.8	12.6	7.6	7.2	6.0	8.0	9.1
Ab	25.7	27.6	29.0	23.9	24.7	23.2	25.3	25.1	24.5	26.7	27.0	26.6	28.9	29.3	29.2	22.1	22.7	22.4	21.9	26.6
An	30.6	28.4	26.9	30.1	29.7	29.9	31.0	30.9	30.2	28.4	26.7	27.4	26.9	25.8	23.3	29.5	28.9	25.1	29.2	28.0
Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Di	8.5	7.5	5.0	13.3	12.3	12.7	11.0	11.3	13.7	6.7	8.5	7.0	6.6	7.4	5.8	14.9	14.9	15.9	16.4	5.8
Hy	8.6	8.4	5.1	16.6	14.8	18.5	11.7	13.3	11.6	10.8	11.4	9.1	8.6	9.2	8.2	15.5	18.2	16.7	14.1	8.8
Ol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	1.1	5.8	2.4	-
Mt	4.7	5.5	3.5	7.0	6.3	5.9	7.1	6.1	6.1	5.3	5.0	5.6	5.1	4.6	4.0	5.5	4.9	5.2	5.2	5.0
Il	1.6	1.4	1.4	1.8	1.8	1.8	1.9	1.8	1.8	1.4	1.5	1.4	1.3	1.5	1.3	1.8	1.7	1.8	1.8	1.4
Ap	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4
Ba(ppm)	429	437	548	381	462	393	409	396	396	490	494	494	513	483	644	470	547	337	460	463
Cr	85	56	37	305	181	306	147	138	133	119	172	93	63	80	39	234	288	512	202	40
Nb	4.5	4.0	4.9	3.3	3.7	3.5	3.4	3.6	4.1	4.2	4.2	4.4	4.9	4.1	4.7	3.4	3.0	4.0	3.3	3.9
Ni	33	21	14	121	72	121	56	55	59	54	65	39	28	34	19	85	106	204	72	20
Rb	37.2	48.1	56.7	31.1	34.5	30.9	28.4	34.8	35.3	50.9	52.5	52.1	53.3	57.3	67.6	41.4	38.9	30.2	40.5	47.4
Sr	494	502	503	480	489	475	478	491	494	472	462	474	547	498	461	487	460	451	500	507
Y	18.3	18.2	17.4	21.3	21.3	21.1	20.8	20.5	21.3	17.1	17.4	19.1	17.8	18.5	18.6	21.6	20.1	18.9	22.9	18.2
Zr	115	110	117	96	99	99	100	100	103	111	104	116	115	121	122	89	83	93	91	113

1∼3 : A uint, 4∼6 : B unit, 7∼9 : C unit, 10∼12 : D unit, 13∼15 : F unit, 16∼19 : Hamamasu Formation, 20 : andesite dike.

Volcanic history before the Shokambetsu volcanic activity in the Hamamasu area

Although the Iwao Formation is lithologically divided into six stratigraphic units, basaltic and andesitic rocks from the A, B, C, D and F units and andesite from a dike intruding into the B unit yield similar K–Ar ages between 3.7 Ma and 3.8 Ma. This implies that these volcanic rocks were produced by the volcanic activity of a relatively short period in the Pliocene.

The stratigraphic relationship among the Iwao Formation, Horo Formation and Hamamasu Formation is consistent with the results of the K–Ar dating that the Hamamasu Formation (2.6 Ma) is younger than the Iwao Formation (3.7–3.8 Ma).

Differences in distribution as well as K–Ar ages between the Iwao Formation and Shokambetsu volcanics suggest that the former was derived from the volcanic center which is different from that producing the latter.

The center of the volcano producing the Iwao Formation may have been situated around the upper reaches of the Chiyoshibetsu River, between Mts. Ofuyu-yama and Hamamasu-goten. This is inferred by (1) the presence of many dikes including feeder dikes, striking E-W direction along a forestry road connecting both the upper reaches of the Tokotan and Chiyoshibetsu Rivers, (2) occurrence of acid

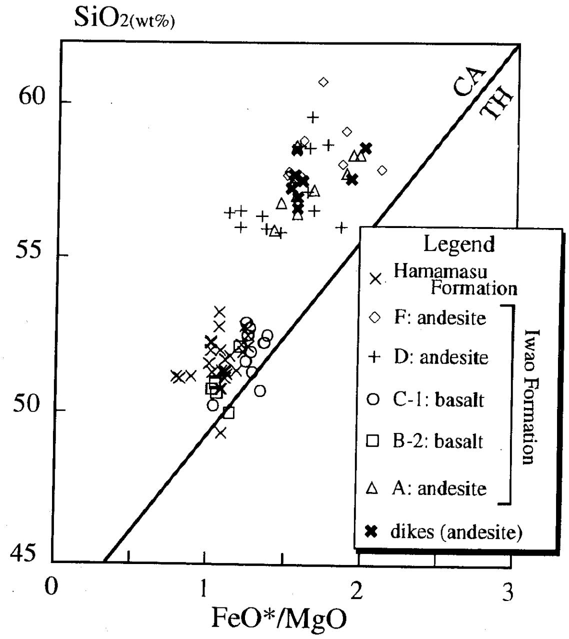

Fig. 6. FeO*/MgO versus SiO_2 diagram for the volcanic rocks from the study area. Line shows the boundary between the fields of calc-alkaline series (CA) and tholeiitic series (TH) (after Miyashiro, 1974).

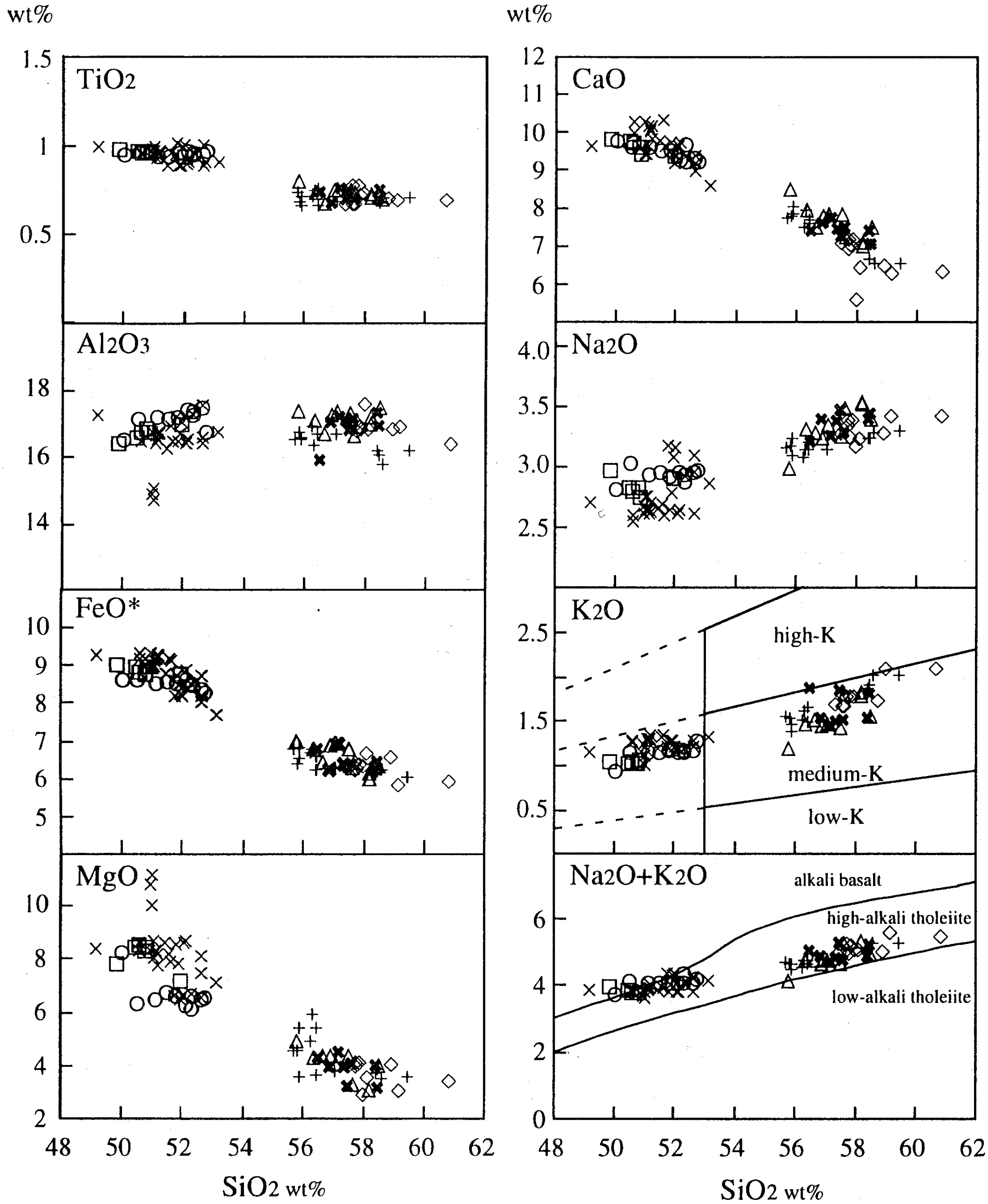

Fig. 7. SiO_2 versus major element variation diagram. The fields of low-, medium- and high-K andesites in SiO_2-K_2O diagram are from Gill (1981) and the fields of low-alkali tholeiite, high-alkali tholeiite and alkali basalt in SiO_2-(Na_2O+K_2O) diagram from Kuno (1966). Symbols are the same as in Fig. 7.

hydrothermal alteration (Sato et a., 1963) in andesitic lavas of the D unit along the upper reaches of the Chiyoshibetsu River, (3) a fan-shaped structure of the lavas striking northweat and dipping southwest in the south and striking northeast and dipping northwest in the north of the Chiyoshibetsu River, and (4) change in dip angle of the lavas that are more gentle near the coast (Fig. 2). The frequent existence of clinker at the base of these lavas indicates that the eruptions of this volcano took place mainly in teresstrial environment.

During the formation of the Iwao Formation at 3.7 to 3.8 Ma, the volcano may have collapsed, resulting in debris flow deposits and fluvial deposits which are found as constituents of the B, C and D units. The petrographic characteristics of basaltic and andesitic clasts in the debris flow deposits and fluvial deposits are similar to those of basaltic and andesitic lavas of

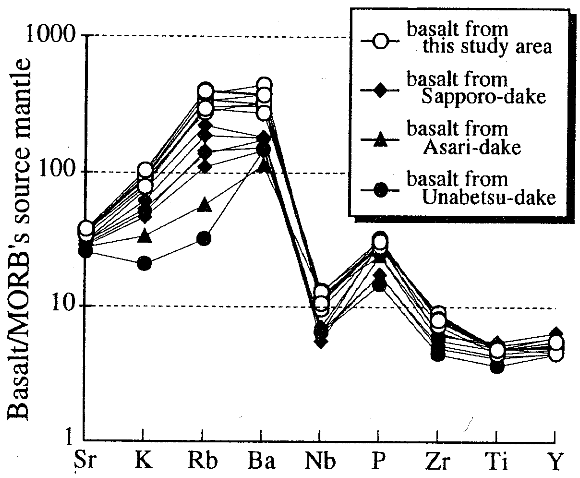

Fig. 8. Abundance pattern of incompatible elements of basaltic rocks normalized against N-type MORB's source mantle of Wood et al. (1979), compared with that of Sapporo-dake and Asari-dake in the western region of Sapporo by Nakagawa (1992) and Unabetsu-dake in the Kurile arc by Tsunoda and Shuto (1999).

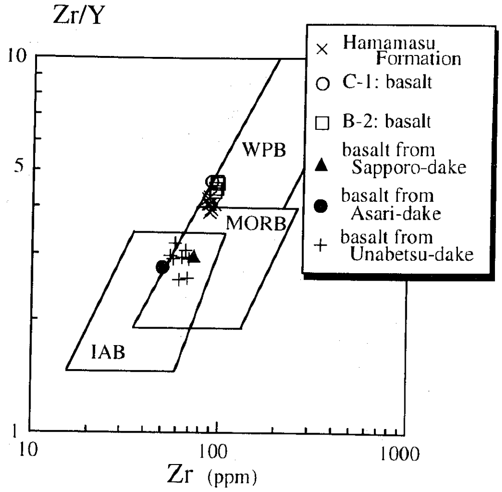

Fig. 9. Zr versus Zr/Y diagram. Data ; Sapporo-dake and Asari-dake are from Nakagawa (1992) and Unabetsu-dake is from Tsunoda and Shuto (1999) as in Fig. 8. The fields of WPB (within plate basalt), MORB (mid-ocean ridge basalt) and IAB (island arc basalt) are from Pearce and Norry (1979).

the Iwao Formation. This indicates that these deposits were not derived from the eruptive materials formed by the Shokambetsu volcanic activity.

After completion of the volcano, the south sector of the volcano seems to have collapsed, leaving fluvial deposits on the southern part of this area (formation of the Horo Formation). At 2.6 Ma, the Hamamasu Formation overlay the volcanic products formed during the 3.7–3.8 Ma activity mainly at the southern and northern parts of this area.

It is possible to consider that the 3.7–3.8 Ma volcanic centers were also located in the north of the Hamamasu area because of occurrence of the Iwao Formation associated with acid hydrothermal alteration in the northern half of the mapped area by Sato et al. (1963).

Geochemistry of volcanic rocks

Major and trace element compositions except FeO of volcanic rocks were determined by X-ray fluorescence spectrometry (RIX 3000) at Niigata University. Detailed procedures, precision and accuracy are discussed by Takahashi and Shuto (1997). Analysis of FeO was made by permanganate titration method. Eighty-four samples were analyzed from the five units of the Iwao Formation, the Hamamasu Formation and dike rocks. Analyses of twenty representative samples are listed in Table 3, which includes specimens selected for K–Ar age determination. FeO*/MgO versus SiO_2, and SiO_2 versus major element variation diagrams are shown in Figs. 6 and 7, respectively.

As shown in Figs. 6 and 7, volcanic rocks are classified into basaltic and andesitic groups. Basaltic rocks from the B and C units of the Iwao Formation and the Hamamasu Formation are included in the basalt group, with a SiO_2 range of 49.18% to 53.14%. These basaltic rocks are defined as olivine tholeiite and quartz tholeiite by Yoder and Tilley (1962) based on normative compositions (Table 3). Andesites from the A, D and F units and dikes have SiO_2 contents between 55.86% and 60.64%. There is a compositional gap of about 2.7% SiO_2 between the basalt and andesite groups.

All basalts and andesites plot in the calc-alkaline field in terms of FeO*/MgO-SiO_2 (Fig. 6), and within the medium-K andesite field and its extention in terms of SiO_2-K_2O (Fig. 7). On the SiO_2-(Na_2O+K_2O) diagram (Fig. 7), basaltic rocks mostly lie on or near the boundary between the alkali basalt and high-alkali tholeiite fields, whereas andesites plot close to the low-alkali tholeiite-high-alkali tholeiite boundary.

Incompatible trace element data of ten basalts (Table 3) are plotted on a conventional N-MORB's source mantle normalized spidergram (Fig. 8) together with data for the Pliocene and Pleistocene low-K tholeiitic basalts from Sapporo-dake and Asari-dake volcanoes in the western area of Sapporo, and the Pleistocene low-K tholeiitic basalts from Unabetsu-dake volcano in the Kurile arc. The incompatible element patterns characterized by the positive anomalies of large ion lithophile elements (LILE) such as Ba, Rb and K, and the negative anomalies of high field strength elements (HFSE) such as Nb and Zr (Fig. 8) show that these low-K tholeiitic basalts have trace element characteristics similar to those of the island arc type basalts (Nakagawa, 1992 ; Tsunoda and Shuto, 1999).

Basalts from the Hamamasu area are relatively enriched in LILE compared with the low-K island arc type basalts from Sapporo-dake, Asari-dake and Unabetsu-dake volcanoes (Fig. 8). Basalts from the area are also characterized by high Zr/Y ratios and plot in the field of within-plate basalt, whereas those from Sapporo-dake, Asari-dake and Unabetsu-dake volcanoes plot in the IAB or MORB fields (Fig. 9).

Nakagawa (1992) argued that the chemical zonation of the Pliocene and Quaternary volcanoes trending N-S direction in the central NE Japan arc may extend to the area west of Sapporo, based on the similarity in the major and trace element chemistry of basalts from the trench-side of NE Honshu and Sapporo-dake and Asari-dake volcanoes. The different geochemical characteristics of the Pliocene basalts from the two areas (the Hamamasu area and western area of Sapporo) suggest that the chemical zonation of the Pliocene to Quaternary volcanism in the NE Japan arc does not extend to the Hamamasu area.

The different geochemical characteristics between the Pliocene basalt from the Hamamasu area and the Quaternary basalt from Unabetsu-dake volcano also suggest that the origin of the Pliocene basaltic magma in the Hamamasu area is different from that of the Quaternary basaltic magma erupted in the Kurile arc.

Acknowledgements

The authors wish to express their sincere gratitude to Mrs. Y. Kakihara, M. Fukase and T. Takahashi of Niigata Univ. for many useful suggestions during geological field work. We are also grateful to Drs. N. Watanabe and N. Fujibayashi of Niigata Univ. for help during preparation of samples for K–Ar age determination. Thanks are also due to Dr. T. Okada of Okayama University of Science for K–Ar age determinations, and Dr. P.A. Morris of the Geological Survey of Western Australia for reading and improving the manuscript.

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* : in Japanese with English abstract
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Aoki, A., Shuto, K. and Itaya, T., 1999, Stratigraphy and K-Ar ages of Tertiary volcanic rocks in the Hamamasu area, northwestern Hokkaido, Japan. *Jour. Geol. Soc. Japan,* 105, 341-351.（青木　淳・周藤賢治・板谷徹丸，1999，北海道西北部，浜益地域に分布する第三紀火山岩の層序と K-Ar 年代．地質雑，**105**，341-351.）

北海道西北部，日本海沿岸の浜益地域には，鮮新世の署寒別火山噴出物に覆われて第三紀火山岩が広く分布しているが，それらは層序学的に下位から岩老層，幌層，浜益層に分けられ，さらに岩老層は，AからFの6ユニットに細分される．K-Ar 年代は下位の5ユニットの玄武岩と安山岩が 3.7±0.1 Ma と 3.8±0.1 Ma，Bユニット中の安山岩岩脈が 3.8±0.1 Ma，最上位の浜益層の玄武岩が 2.6±0.1 Ma を示す．岩老層の溶岩および火砕岩は，3.7～3.8 Ma に本地域東部に形成された火山から噴出し，土石流堆積物や河川性堆積物は，この火山の山体崩壊によって形成されたと推定される．2.6 Ma には浜益層の溶岩が噴出し，3.7～3.8 Ma の火山生成物を覆った．

本地域の玄武岩は，東北日本・千島弧の鮮新世～第四紀の玄武岩と異なる地球化学的性質をもっている．これは，本地域の鮮新世のマグマが，これらの鮮新世～第四紀のマグマとは異なる成因により形成されたことを示唆する．