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The timing and geneses of ilmenite-series and magnetite-series granitic magmatism in the north-central Hokkaido, Japan

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Abstract: K-Ar age determination was made on twelve rocks and minerals of the Cenozoic granitoids in north-central Hokkaido where the plutonic rocks are most widely seen in the east-west direction, and petrological studies were done on representative Eocene and Miocene granitoids at Uttsudake, Nisshotoge and Kamishiyubetsu intrusive bodies. Eocene granitoids were found in two additional bodies, and the whole distribution trend is a northeast. The Eocene granitoid and gabbroid are the first magmas generated since the change of subduction direction of the Pacific Plate. Tonalitic rocks along the Kamishiyubetsu tectonic zone are ilmenite series or intermediate series until 11 Ma, the plutonism was then converted to magnetite series at 9 Ma of Pliocene.

The ilmenite-series granitoids are least potassic in the Eocene granitoids and are most potassic in the middle Miocene ones. These granitoids have negative $\delta^{34}S$ values and are high in the $\delta^{18}O$ values, indicating some contribution of the basement sedimentary rocks to the granitic magmas. A highest degree of 40 percent of the sediments contribution was calculated on the $\delta^{18}O$ values of middle Miocene granitoids. Late Cenozoic volcanic rocks were also started with ilmenite-series magmatism, and converted to magnetite series at 13-11 Ma, then up to the Quaternary magnetite-series andesitic volcanoes. It is suggested that C-bearing sedimentary and igneous continental crust was first heated up to generate felsic ilmenite-series magmas by intrusion of gabbroic magmas and volatiles from the upper mantle, and later with increasing heat, C-free mafic materials became to be melt to form magnetite-series tonalitic intrusion or andesitic eruption.

1. Introduction

In the central Hokkaido, Cenozoic granitoids occur along the Hidaka sedimentary and metamorphic belt. They are mostly fine-grained massive granitoids of I-type ilmenite series (Ishihara and Terashima, 1985). These granitoids are spatially associated with gabbroids, especially in the westernmost zone; thus bimodal in composition. The southwestern zone of the Hidaka belt is composed of highly metamorphosed rocks, including interlayered granitic rocks, which have been altogether described as migmatites till 1960s. Both S-type and I-type granitoids are recognized recently in these migmatite zone (Owada, 1989; Shimura *et al.*, 1992; Takahashi, 1992).

The Cenozoic granitoids had been considered to have late Cretaceous age until 1960s, and K-Ar dating on biotite in the late 1960s revealed Oligocene and Miocene ages (Kawano and Ueda, 1967; Shibata, 1968). Later, Eocene ages (42, 43 Ma) were discovered in the Monbetsu and Uttsudake bodies of the northern part (Shibata and Ishihara, 1981). Rb-Sr whole-rock isochron ages are available in the southern part. The largest body of Nisshotoge pluton gives 18.7 Ma (Shibata and Ishihara, 1979), which is very close to K-Ar mineral

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Keywords: Hokkaido, Uttsudake, Granitoids, Gabbroids, K-Ar age, Tertiary, Magnetic susceptibility, Kamishiyubetsu tectonic zone

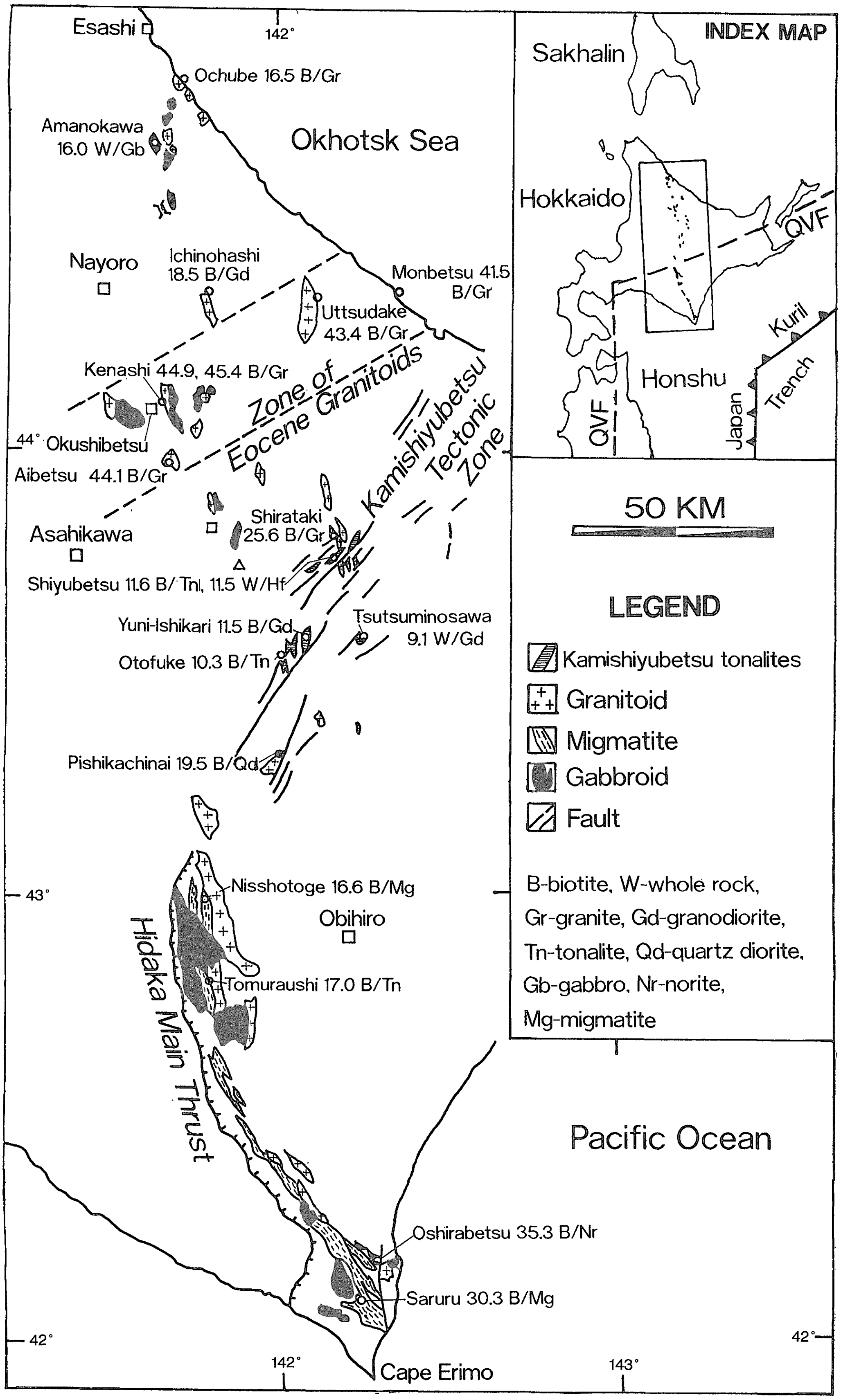

Fig. 1 Distribution and radiometric ages of plutonic rocks of central Hokkaido. QVF in the index map, Quaternary volcanic front. The geological elements extracted from Takahashi *et al.* (1980 a), Ishihara and Terashima (1985) and Maeda *et al.* (1990). Migmatite in the legend is now called heterogeneous and homogeneous tonalites (Komatsu *et al.*, 1986) or anatexite (Maeda *et al.*, 1990).

age of 16.0 and 16.6 Ma of the same pluton (Shibata, 1968; Ishihara and Terashima, 1985). Within the high-grade metamorphic rocks of the axial zone, however, the heterogeneous and homogeneous anatectic granitoids give older ages of 56–51 Ma (Owada *et al.*, 1991; 1997).

The southern part of the Hidaka belt was considered to have formed by upthrusting of the eastern main block toward the western block due to oblique subduction of the Pacific Plate along the Kuril Trench since Miocene (Kimura, 1986). Thus, the zone along the Hidaka Main Thrust (Fig. 1) is a distinct suture between the western block (i.e., Eurasian Plate) and eastern block (North American Plate) of Hokkaido, and a whole sequence from the upper mantle (west) to the upper crust (east) of the Hidaka belt of the eastern block is exposed in the southern part. SAEKI et al. (1995) tried to draw out timing of the upthrusting by K-Ar dating and obtained hornblende ages of 25.2–41.0 Ma and biotite ages of 17.0–35.2 Ma on migmatites and metamorphic rocks in the southernmost part of the Hidaka belt, and interpreted that intrusion age of the anatectic granitoids was ca.40 Ma and the stage of the upthrusting occurred in 36–17 Ma.

The Cenozoic granitoids of the northern part of the Hidaka belt, on the other hand, occur as small bodies elongating in a north-south direction, often associated with gabbroids along the suture zone (Fig. 1), and Miocene volcanic rocks are exposed in the surrounding areas to the east. These volcanic rocks have never been thought to be related to the granitoids, and considered to belong to the Green Tuff igneous activities (Yahata and Nishido, 1990), which are basaltic and intermediate to felsic magnetite-series magmatism in the main part of northern Honshu. Discovery of 17 Ma ilmenite-series volcanic rocks at Pinneshiri, however, led Ishihara *et al.* (1995) to reconsider the relationship between the so-called Outer Zone granitoids and Inner Zone volcanic rocks,

Table 1 Exposed area of plutonic rocks in north-central Hokkaido.

Locality and body	Area (km^2)	Total
Ochube-Bifukatoge area		
	Gabbroid: 20.8(Amanokawa), 20.1, 9.7, 7.1, 1.2, 0.4, 0.4, 0.2	59.9
	Granitoid: 8.3(Furrepu), 3.8(Ochube), 1.2, 0.4, 0.2, 0.2, 0.2, 0.1	14.4
Ichinohashi body		
	Granitoid: 10.6	10.6
Okushibetsu area		
	Gabbroid: 33.6, 11.2(Towari-Penkenukananpu), 1.8, 0.8, 0.3, 0.3	48.0
	Granitoid: 13.2, 12.1(Kanashi), 1.9, 0.3	27.5
Aibetsu body		
	Granitoid: 6.9	6.9
Shirataki Granite		
	Granitoid: North body 7.5, Middle body 3.4(1.7+1.2+0.3+0.2)	
	South body 4.5 (1.7+1.7+1.1)	15.4
Kamikawa-Taisetsusan		
	Gabbroid: 11.2 (Taisetsusan), 0.6 (Kamikawa)	11.8
	Granitoid: 3.5(Ukishima), 1.4 (Kamikawa)	4.9
Pishikachinai area		
	Granitoid: 29.3 (pishikachinai), 0.8	30.1
Total	Gabbroids	119.7
	Granitoids	109.8
Kamishiyubetsu tectonic Zone		
Ishikaridake area		
	Yuni Ishikari 4.2, Otofukeyama 3.5, Others 0.8, 0.4, 0.2	9.1
	Tsutsuminosawa 1.0	1.0
Shiyubetsu area		
	3.2, 2.9, 0.8	6.9
Total		17.0

and the Outer Zone granitoids may have had an effusive equivalent.

In this paper, additional age determinations were made on eight granitoids, one gabbroid and one hornfels. Our previous data (Shibata and Ishihara, 1981) are also included (see Table 2), because they were published originally in an abstract form. Eocene ages were discovered in two additional plutons. One Pliocene body was discovered at Tsutsuminosawa, besides common middle Miocene granitoids. Representative Eocene, middle and late Miocene granitoids were studied modally and chemically at Uttsudake, Nishotoge and Kamishiyubetsu intrusive bodies. Oxygen isotopic ratios were determined on representative 29 samples from the whole region.

This paper summarizes all the available age and magnetic susceptibility and petrochemical data of our studies on the granitoids of the north-central Hokkaido, where the granitic activities are most widely seen in the east-west direction, and concerns mainly temporal change of the magnetite/ilmenite-series magmatism and the alkali ratios, and finally geneses of the north-south and northeast-trending granitoids. The studied plutonic bodies are shown in Figure 1 and their exposed areas are given in Table 1.

2. K-Ar Age Determination

2. 1 Eocene Granitoids

The Eocene granitoids were previously known in the Uttsudake and Monbetsu bodies (Shibata and Ishihara, 1981), which are composed mainly of rocks with granitic composition. Two additional bodies discovered are the Kenashi body in Okushibetsu and the Aibetsu body in Aibetsu, which are located to the southwest of the Uttsudake and Monbetsu bodies.

In the Okushibetsu area, small plutonic bodies ranging in composition from troctolite gabbro to granite occur in north-south and northeast directions (Yoneyama, 1990). The gabbroid and granitoid occur closely related together (Fig. 1) and their exposure ratio is roughly 2 (Table 1).

2.1. 1 Kenashi granite, Okushibetsu plutonic complex
95092703: Biotite granite, Kenashi body of Yoneyama (1990); Latitude 43° 58′ 09″ N, Longitude 142° 39′ 20″ E; Tokusei, Okushibetsu, Asahi township (1/50,000, Okushibetsu).

The granite of the Kenashi body is slightly porphyritic biotite granite of ilmenite series, which has been strongly chloritized. Magnetic susceptibility of this granite, as measured by a portable device of KT-5 and WSL-A meters, ranges from 0.16 to 0.21×10^{-3} SI unit. The analyzed minerals were separated from the freshest looking part of the medium-grained biotite granite. Two different biotite separates from the same hand specimen were dated at 45.4±0.9 Ma and 44.2±1.2 Ma by two different laboratories (Table 2), thus indicating an Eocene age.

2.1. 2 Iwanaiko gabbro, Okushibetsu plutonic complex
95092702: Layered gabbro, fine-grained chilled phase of Yoneyama (1990); Lat. 44° 05′ 52″, Long. 142° 44′ 43″, 8 km SE of the previous sample, Nisama, Iwanai lake, Asahi township (1/50,000, Okushibetsu).

This gabbro is distinctly layered striking N 20° E and dipping 60° SE. It is an olivine-pyroxene-amphibole gabbro with the color index more than 50 percent. The magnetic susceptibility, 0.53 to 1.34×10^{-3} SI unit, is fairly high as ilmenite series rock for the high color index. The age determined was 23.0±0.5 Ma. However, we may need further study on better samples, because the analyzed sample contained only 0.19 % K_2O and the air contamination was very high as 91.0 percent (Table 1).

2.1. 3 Aibetsu granite, Okushibetsu plutonic complex
95092701: Biotite granite, Aibetsu body; Lat. 33° 07′ 45″ N, Long. 142° 39′ 16″E; Shimokawa north, Okushibetsu, Asahi township (1/50,000, Aibetsu).

On the contrary to the above-mentioned area, the Aibetsu body consists of no gabbroid but soly biotite granite of ilmenite series. Its location is so close to the Kenashi body that the Aibetsu body could be a part of the Okushibetsu plutonic complex. Biotite, partly chloritized, of the medium-grained biotite granite which has magnetic susceptibility of 0.16–0.18×10^{-3} SI unit, gives also an Eocene age of 44.1± 0.9 Ma (Table 2).

Eocene granitoids so far identified are exposed abundantly as many small plutons from the Okushibetsu-Aibetsu area to Monbetsu. This is the widest plutonic area across the central zone of Hokkaido (Fig. 1), and is the oldest plutonism showing northeast alignment before the Kamishiyubetsu plutonic rocks.

2. 2 Oligocene-middle Miocene Granitoid and Gabbroid

In the northern part of central Hokkaido, small plutonic bodies of this age are scattered (Fig. 1). They are Ochube-Amanokawa plutonic complex, Ichinohashi granitoid, Shirataki granite, and others. The following three rocks were newly dated.

2.2. 1 Ochube-Amanokawa plutonic complex

In the Ochube-Amanokawa area, small bodies of both granitoids and gabbroid are present together (Fig. 1). They are magnetite free, ilmenite series (Ishihara and Terashima, 1985). Biotite age of the Ochube body gives 16.5±1.0 Ma (74 HK 09).
95092904: Pyroxene-amphibole gabbro; Lat. 44° 40′ 39″ N, Long. 142° 36′ 21″ E; Amanokawa, Utanobori township (1/50,000, Ochube).

Table 2 K-Ar ages of plutonic rocks and related hornfels in the Hidaka belt.

No.	Field no.	Locality	Pluton	Material analyzed	K_2O (wt %)	^{40}Ar Rad (10^{-6} cc/g)	Air cont. (%)	K-Ar age (Ma)	Analyst
Eocene granitoids									
1)	74HK24	Monbetsu	Monbetsu, fGr	Biotite	7.55	10.2	10.8	41.5 ± 1.3	KS*
2)	74HK21	Rorochi River	Uttsudake, fGr	ditto	4.67, 4.77	6.70	11.1	43.4 ± 1.4	KS*
3)	95092702	Okushibetsu	Layered gabbro	Whole rock	0.193	0.14	91.0	23.0 ± 0.5	NZ
4)	95092703A	Okushibetsu	Kenoshi, mGr	ditto	2.49	3.70	23.0	45.4 ± 0.9	NZ
5)	95092703B	ditto	ditto	ditto	3.25	4.75	55.9	44.9 ± 1.2	GC
6)	95092701	Aibetsu dum	Aibetsu, mGr	ditto	4.87	7.01	7.0	44.1 ± 0.9	NZ
Oligocene-Miocene granitoids and gabbroids									
7)	74HK09	Berauchinai	Ochube, fGd	Biotite	7.41	3.96	67.0	16.5 ± 1.0	KS*
8)	95092904	Amanokawa	f gabbro	Whole rock	1.71	0.890	87.0	16.0 ± 0.3	NZ
9)	74HK26	Shikaribetsu River	Ichinohashi, mGd	Biotite	7.55, 7.36	4.45	36.2	18.4 ± 0.6	KS*
						4.49	21.3	18.6 ± 0.6	KS*
10)	94070209	Pankeshubetsu River	Shirataki, cGr	Chloritized biotite	0.39	0.31 ± 0.01 0.33 ± 0.01	69.2 66.7	25.0 ± 2.7 26.2 ± 2.8	MB
11)	94070103	Ishikaribetsu River	Pishikachinai, fTn	Biotite	3.62	2.28 ± 0.03 2.27 ± 0.03	18.5 19.0	19.5 ± 0.5 19.4 ± 0.5	MB
Late Miocene granitoids									
12)	15-25A	Akibasawa	Yuni-Ishikari, fGd	Biotite	2.62	0.98 ± 0.02 0.95 ± 0.02	49.8 50.4	11.6 ± 0.4 11.3 ± 0.4	MB
13)	OTS1	Otofukeno-sawa	Dike, West of Otofuke, fTn	ditto	2.78	0.92 ± 0.02 0.91 ± 0.02	47.0 46.8	10.3 ± 0.3 10.2 ± 0.3	MB
14)	CUN9a	Shikanosawa, East	Shiyubetsu, fTn	ditto	3.76	1.42 ± 0.02 1.40 ± 0.02	25.7 27.2	11.7 ± 0.3 11.5 ± 0.5	MB
15)	CUN17	ditto. West	Hornfels	Whole rock	2.29	0.86 ± 0.01 0.84 ± 0.01	30.7 32.1	11.6 ± 0.4 11.3 ± 0.4	MB
16)	94070205	Tsutsuminosawa	fGd	ditto	2.55	0.753	86.9	9.1 ± 0.3	GC
Eocene-Miocene granitoids in the south									
17)	74HK76	Nisshotoge	Migmatite	Biotite	8.49	4.57	49.6	16.6 ± 0.7	KS*
18)	74HK59	Tomuraushi	Tonalite	ditto	9.09	5.02	14.1	17.0 ± 0.5	KS*
19)	2104	Oshirabetsu	Norite	ditto	8.18	9.42	10.9	35.3 ± 1.1	KS*
20)	74HK90	Saruru	Migmatite	ditto	7.19	7.10	53.0	30.3 ± 1.3	KS*

Decayconstants: $\lambda e=0.581\times10^{-10}$/y and $\lambda\beta=4.962\times10^{-10}$/y , Isotopic abundance: $^{40}K/K=0.01167$atom%. Errors: two standard deviations, but data of KS*, one standard deviation. Data of SHIBATA and ISHIHARA (1981), those with KS*, are also included.
Locality of these samples are listed in ISHIHARA and TERASHIMA (1985). 15-25A, collected by J. MAEDA.
Abbreviation : f, fine; m, medium; c, coarse-grained. Qd, quartz diorite; Tn, tonelite; Gd, granodiorite; Gr, monzogranite.
Analysts : KS, K.Shibata; GC, Geochron Lab.; NZ, Geological & Nuclear Sciences Ltd.; MB, Central Lab., Mitsubishi Material Co. Ltd.

This very fresh gabbro having magnetic susceptibility of $0.39-0.62\times10^{-3}$ SI unit, was obtained by the construction of the Amanokawa Tunnel, and has a high content of K_2O (1.71 %). This was dated at 16.0 ±0.3 Ma (Table 1). Thus, these gabbroid and granitoid were formed around the same time.

2.2. 2 Shirataki granite

94070209 : Sheared biotite granite, Shirataki body ; Lat. 43° 48′ 40″N, Long. 143° 10′ 38″E ; Pankeshiyubetsu Gulch, Shirataki Village (1/50,000, Shiyubetsu).

The Shirataki granite is a north-south trending, sheared biotite granite of ilmenite series, and its biotite is strongly altered to chlorite (Hasegawa *et al.*, 1961). Two fission track dates of 32.0 and 33.0 Ma have been reported on the zircon (Koshimizu and Kim, 1986). Our results on chloritized biotite, though its K_2O content is only 0.39 %, is much younger, as 25.6±2.8 Ma, which may indicate the final stage of the shearing and the related hydrothermal alteration.

2.2. 3 Pishikachinai granitoid

The Pishikachinai granitic pluton occurs as somewhat NE-elongated circular body (Fig. 1). It is zoned having gabbro and quartz diorite-tonalite rim of less than 1 km wide in the northern margin. Our magnetic studies indicate that the mafic phases show the magnetic susceptibility of magnetite-series values, ranging up to 11.5×10^{-3} SI unit in the gabbro and 7.0×10^{-3} SI unit in the quartz diorite. However, the major part of biotite granite which is partly porphyritic showed magnetite-free, ilmenite-series values. Leucogranite in the southern part belongs also to ilmenite series.

Chemical analyses of Tomura (1983) indicate that averaged FeO/Fe_2O_3 ratios of 12 gabbroids (SiO_2 50−59 %) and 19 granitoids (SiO_2 59−77 %) are 8.1 and 5.9, respectively. Since magnetite-series/ilmenite-series granitoids are separated at 2.0 of the same ratio at a granodiorite composition, the ferric/ferrous ratios imply that the pluton is essentially composed of ilmenite series.

94070103: Hornblende-biotite tonalite, weakly chloritized, Pishikachinai body ; Lat. 43° 20′ 13″ N, Long. 143° 01′ 50″E ; Ishikaribetsu-gawa, Shikaoi township (1/50,000, Nukabira).

The studied sample was collected from the northern mafic margin. Our sample of chloritized biotite from the tonalite gives 19.5±0.5 Ma, which is slightly older than whole rock K-Ar age of 15.0±0.8 Ma given by Maeda *et al.* (1990) for biotite-hornblende norite of the northern margin. We need further detailed study here for the disagreement.

2. 3 Late Miocene Granitoids

Quartz diorite, tonalite and granodiorite, more or less dike-like in form and often altered to some extent, are exposed along the Kamishiyubetsu tectonic zone (Hasegawa *et al.*, 1961 ; Hashimoto, 1978), which is a set of right-lateral faults with a total displacement of 50 km (Kimura, 1981), and was formed by the collision of the forearc sliver of the Kuril Arc, due to the oblique subduction of the Pacific Plate (Kimura *et al.*, 1983). These rocks are called the Kamishiyubetsu intrusive rocks.

Characteristics of the Kamisiyubetsu intrusive rocks have not been well known and only one whole rock dating of 9.5 Ma (Maeda *et al.*, 1990) was available in these rocks. Thus, additional studies were made in this study.

2.3. 1 Kamishiyubetsu intrusive rocks

The Kamishiyubetsu intrusive rocks occur not always in the northeast-southwest directions but locally in north-south direction around the Ishikari-dake (1,967 m) and Shiyubetsu-dake (1,688 m), which are shown in an aeromagnetic map (Fig. 2). These rocks are generally tonalite containing modal quartz more than 20 percent in the salic components (Fig. 3). The mafic minerals are mostly hornblende and biotite, sometimes with trace amounts of clinopyroxene and rarely orthpyroxene, but these minerals are often altered (Ihara, 1995). These rocks are considered as the products of one group of granitic activity for the similarlity of the bulk composition.

In the Ishikari-dake area, the major bodies are the Yuni-Ishikari body of 4.2 km² and the Otofukeyama of 3.5 km² in exposure. Much smaller dikes of NE trend occur around the Shiyubetsu-dake. These tonalitic rocks and associated hornfels were studied at the following localities :

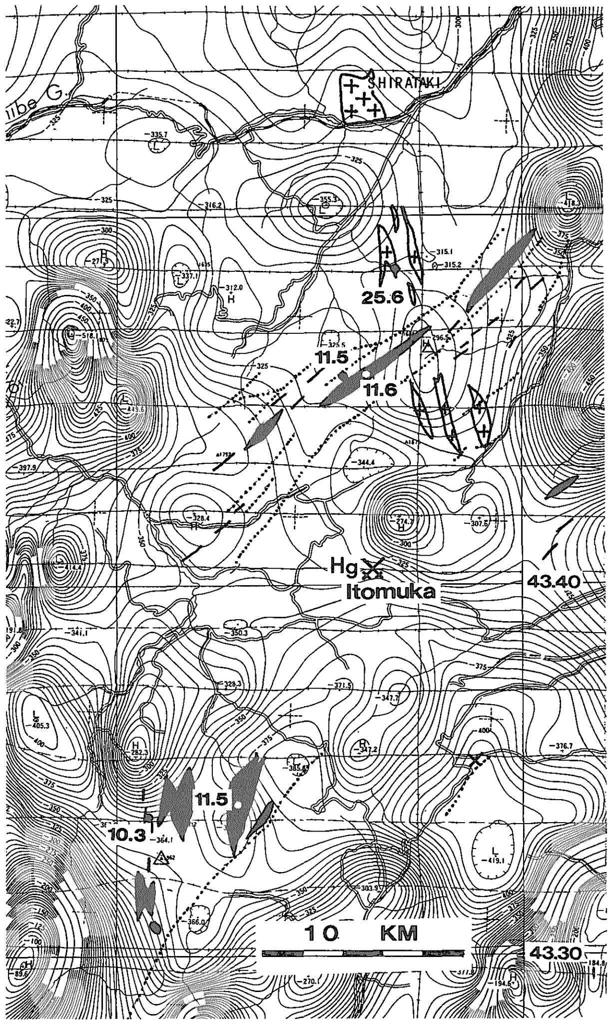

Fig. 2 Magnetic anomalies, K-Ar ages and intrusive bodies in the Ishikaridake-Shiyubetsudake area, central Hokkaido. Contours are total intensity of aeromagnetism (Nakatsuka *et al.*, 1978). Open mark with cross is Shirataki granite ; solid mark is tonalites of Ishikaridake-Shiyubetsu group. Note that none of these intrusive bodies is related to high magnetic anomalies. Mercury deposits and prospects are shown. Circle with numerals, localities of the dated samples and the results (in Ma).

15-25A: Biotite-hornblende granodiorite, Yuni-Ishikari body (collected by J. Maeda) ; Lat. 43° 33′ 31″ N, Long. 143° 04′ 22″ E ; 4.6 km NE of the peak Ishikari-dake, Akiba Gulch, Kamikawa township (1/50,000, Ishikaridake).

This is a hollocrystalline, fine-grained granodiorite taken from a middle part of the Yuni-Ishikari body of E-W 1.5 and N-S 4 km. Biotite separated from this rock gives 11.5±0.4 Ma.

OTS1 : Hornblende-biotite tonalite dike; Lat. 43° 33′ 29″ N, Long. 143° 01′ 20″ E ; 2 km north of the peak Ishikari-dake, Otofuke Gulch, Kamikawa township (1/50,000, Ishikaridake).

This small dike (3 m wide), cropping out 5 km west

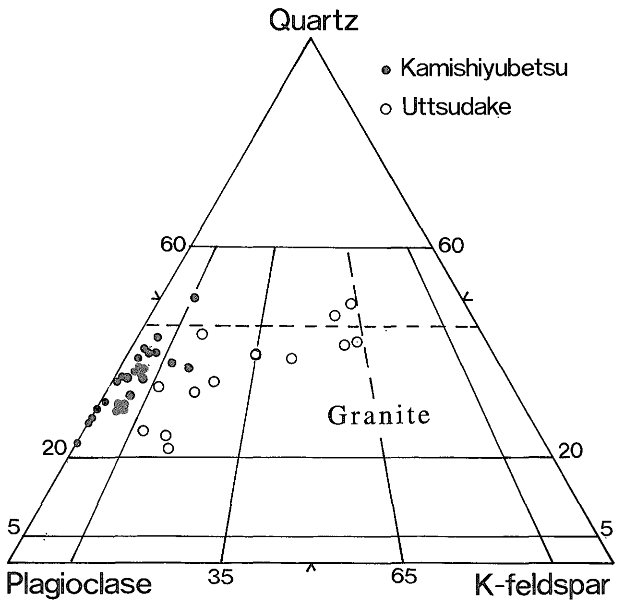

Fig. 3 Modal plagioclase-K-feldspar-quartz ratios of the Uttsudake and Kamishiyubetsu granitoids. The original data are taken from Ihara (1995) and Nagasaka (1997).

of the Yuni-Ishikari body, gives a biotite age of 10.3± 0.3 Ma. These two ages determined are slightly older than the age (9.5 Ma) given by Maeda *et al.* (1986).

CUN 9 a : Hornblende-biotite tonalite, Shiyubetsu body; Lat. 43° 45′ 46″N, Long. 143° 08′ 43″E ; Eastern branch of uppermost stream of Shikanosawa, Shirataki Village (1/50,000, Shiyubetsu).

This sample is taken from a middle part of 0.8 by 5 km intrusive body (Fig. 2). Biotite separated from this tonalite gives 11.6±0.4 Ma (Table 1).

CUN17 : Biotite hornfels Shiyubetsu ; Lat. 43° 45′ 27″N, Long. 143° 08′ 08″ E ; Western tributary of the uppermost stream of Shikanosawa, Shirataki Village (1/ 50,000, Shiyubetsu).

This is biotite hornfels of the Hidaka Group attached to the northwestern margin of the dike (Fig. 2). The hornfels gives a whole rock age of 11.6±0.4 Ma, which is not older than but identical to the age of the tonalite.

The age determinations above-mentioned indicate that the Kamishiyubetsu tonalitic rocks have intrusive ages of 10-12 Ma; thus fractures of the Kamishiyubetsu tectonic zone were formed prior to this period. The results of this study also indicate that whole rock age of pelitic hornfels could be useful for age determination of nearby intrusion.

2.3. 2 Tsutsuminosawa granitoid

About 18 km east of the Otofuke body, there occurs a tonalitic body having dimensions of E-W 1 km and N-S 1.5 km. This body is heterogeneous in texture and composition (Watanabe and Hasegawa, 1981) ; their magnetic susceptibility ranges from 26.0×10^{-3} in the mafic facies to 4.0×10^{-3} SI units in the felsic facies. Thus, this body belongs to magnetite series, and are magnetically different from the Kamishiyubetsu tonalites.

94070205 : Hornblende-biotite granodiorite ; Lat. 43° 35′ 00″ N, Long. 143° 15′ 72″ E ; Near the mouth of Tsutsuminosawa, a tributary of Tokoro river, Oketo township (1/50,000, Tsunemoto).

The studied rock is very fine-grained granodiorite with magnetic susceptibility of 4.0×10^{-3} SI unit, thus belonging to magnetite series. This gives a whole rock age of 9.1±0.3 Ma, which is the youngest among the rocks examined in and around the Kamishiyubetsu tectonic zone.

3. Magnetic Susceptibility

The previous study of Ishihara and Terashima (1985) indicates that Tertiary granitoids of Hokkaido belong generally to ilmenite series, but in the Uttsudake body 2 out of 6 samples showed magnetic susceptibility higher than 100×10^{-6} emu/g (3×10^{-3} SI), implying that the body could be composed of 75 % ilmenite series and 25 % magnetite series. These samples were obtained from river float, so that the Uttsudake pluton was studied in detail (Nagasaka, 1997).

Magnetic susceptibility was measured by KT-3 device on sawed specimens of 9 granodiorites, 38 granites and 7 microgranites. The result indicates that all but one granophyric biotite granite (3.68×10^{-3} SI) show the magnetic susceptibility of ilmenite series, which is below 3.0×10^{-3} SI. Thus, the Uttsudake granitoid belongs to ilmenite series similarly to the other granitic bodies in Hokkaido.

Maeda *et al.* (1986) considered that the tonalitic rocks intruded along the Kamishiyubetsu tectonic zone could be one of the earliest arc-andesitic activities related to the Kuril Arc-Trench system. This interpretation may imply that all the tonalitic rocks belong to magnetite series, because the late Miocene to Quaternary andesitic volcanoes of the Kuril-Akan volcanic belt are generally composed of magnetite-series andesitic rocks (Ishihara *et al.*, 1995).

Figure 4 illustrates histograms of magnetic susceptibility of the intrusive bodies measured by a portable magnetic susceptibility meter, WSL-A, on the sawed samples. The Shiyubetsu body gives all ilmenite-series values. Only two out of 25 measurements are magnetite-series values in the Otofukeyama body. In the Yuni-Ishikari body, on the other hand, magnetite series values exceeds the ilmenite-series values with 14 : 8 ratio ; thus it belongs to magnetite-series granitoids, according to the original definition (Ishihara, 1981). But these magnetite-bearing values are not as high as typical quartz diorite values in the Sanin and Kitakami districts, and are similar to those of the intermediate series (Ishihara *et al.*, 1984). Moreover,

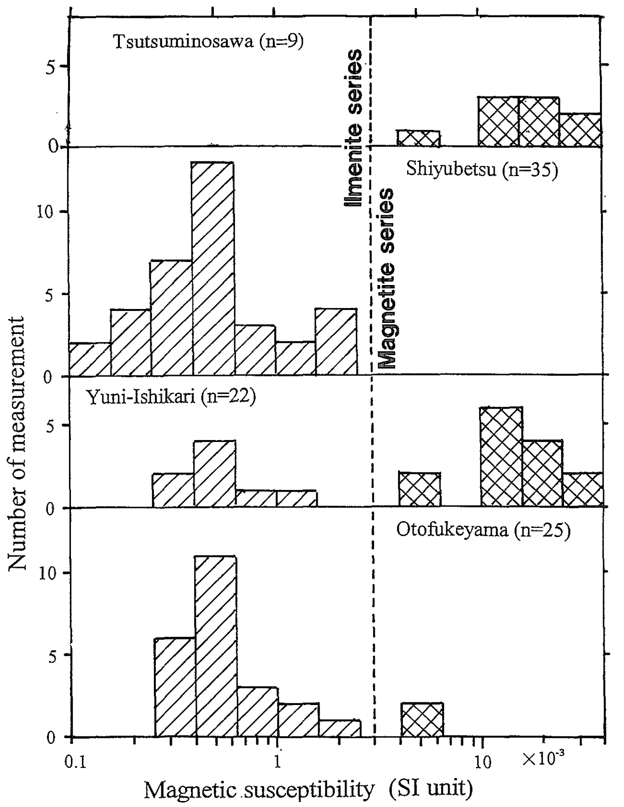

Fig. 4 Histograms of magnetic susceptibility of tonalitic rocks from the Ishikaridake-Shiyubetsudake area. Broken line is separation line of the magnetite-series and ilmenite-series granitoids.

these intrusive bodies show no magnetic anomaly on the aeromagnetic map (see Fig. 2), implying there is no magnetic intrusive bodies underneath. Thus, the Kamisiyubetsu intrusive rocks have generally ilmenite-series character. The magnetite-bearing character of the Yuni-Ishikari body may be due to local increasing of the oxygen fugacity by dissociation of the contained water (Czamanske and Mihalik, 1972) near the top of the intrusive body. The Kamisiyubetsu tonalites could not be the vents for magnetite-series andesites-dacites.

4. The Temporal Change of Granitoid Series

The Eocene granitoids so far identified in the north-central Hokkaido show presently a northeast trend, which is parallel to the present volcanic front of the Akan-Shiretoko-Kuril volcanoes that are subduction-related to the Kuril Trench. Yet they are magnetically quite different, being magnetite-free in the former but strongly magnetite-bearing in the latter. The determined ages of the Eocene granitoids to the change of direction of the Pacific Plate motion (41.7 Ma, Jackson *et al.*, 1976) are similar, the sodic granitoids must have been the first product of the subduction-related magmatism with the new plate motion. Thus, the granitic magmatism was ilmenite series from the beginning up to middle Miocene.

Late Miocene tonalitic rocks of the Kamishiyubetsu tectonic zone are essentially of ilmenite series with apparent magnetite-series of the Yuni-Ishikari body. However, the tonalitic rocks at the mouth of Tsutsuminosawa are of typical magnetite-series in judging from their magnetic susceptibility values (Fig. 4). This rock is about 2 m.y. younger than similar tonalites in the Kamisiyubetsu tectonic zone mentioned above. Between 12-10 Ma and 9 Ma, the granitic magmatism was thus converted from ilmenite series to magnetite series.

Similar change from ilmenite series to magnetite series is also observed on late Cenozoic volcanic rocks of the north-central Hokkaido (Ishihara *et al.*, 1995), which is summarized in Figure 5. The Pinneshiri lava (17.1 Ma, Goto *et al.*, 1995) has the lowest value of magnetic susceptibility and would be most reduced. Somewhat intermediate values were observed on lavas of Koitoi-Nakaporonai, Otoifuji, Hakodake, Piyashiri and Fureppu, which have K-Ar ages of 13-11 Ma. The other lavas younger in age are all magnetite series (Fig. 5).

The Pinneshiri rhyolitic lava is the oldest among the volcanic rocks and is considered as an effusive facies of ilmenite-series granitoid (Ishihara *et al.*, 1995). Recently, two types of inclusions are reported in the rhyolite: (i) sedimentary type having cordierite-biotite-garnet-plagioclase mineral assemblage which could be restite of the source rocks, and (ii) magmatic type with andesitic composition (Kakihara, 1996). Thus, contribution of the pelitic crustal materials to generation of the Pinneshiri magma is obvious, and the following volcanic rocks with low magnetic susceptibility, such as those of the Koitoi-Nakaporonai, Otoifuji and others (Fig. 5), may have been also affected by C-bearing continental materials (Ishihara *et al.*, 1997). On the contrary, all the Quaternary volcanoes are strongly magnetite bearing (Ishihara *et al.*, 1995).

5. Alkali and Oxygen Isotopic Ratios

5. 1 Alkali Ratio

Na_2O and K_2O contents have important bearing on the granitoid geneses. Miocene tonalites of Tanzawa type intruded into meta-volcanic rocks formed in oceanic island environment are sodic (Ishihara *et al.*, 1976) and the initial Sr ratio is 0.7036 (Shibata and Ishihara, 1979). These granitoids could have originated in tholeiitic amphibolite in the lower crust (Arima *et al.*, 1996) ; thus Na_2O represents a deep igneous source of basaltic composition. On the other hand, K_2O/Na_2O ratio increases greatly during weathering and sedimentation of igneous rocks; K_2O is finally fixed as illite in pelitic sedimentary rocks, and thus K_2O indicates a sedimentary source of upper contimental crust.

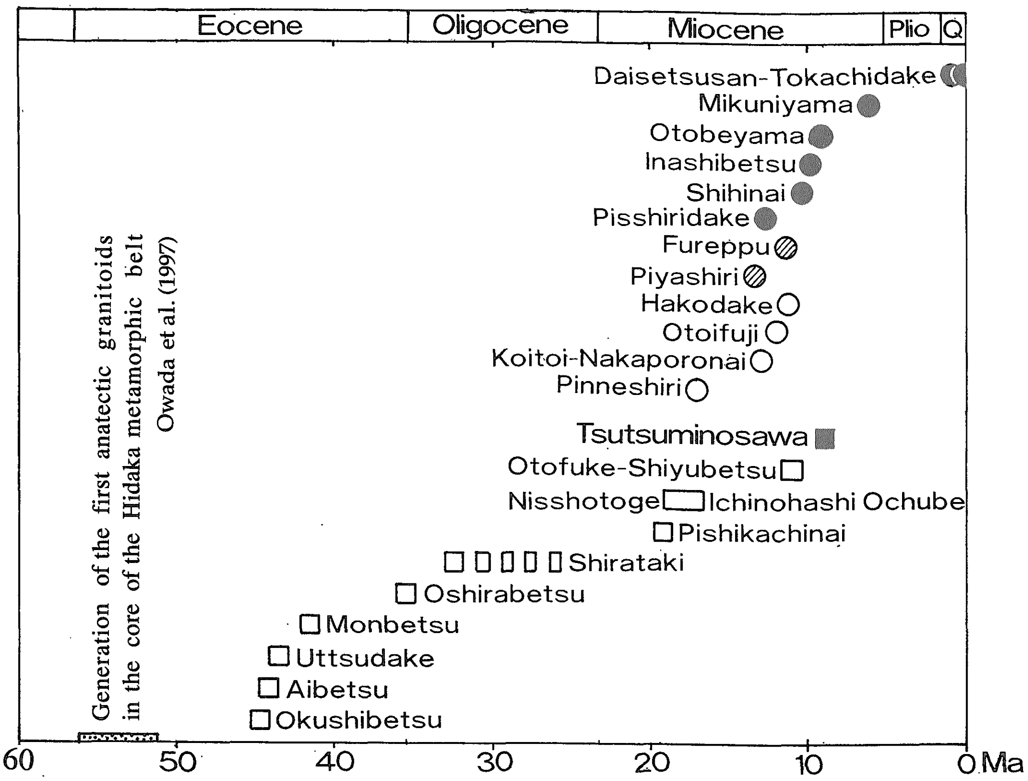

Fig. 5 Summary of the igneous history of central Hokkaido in terms of magnetite-series/ilmenitite-series classification. Box is granitoids; circle is volcanic rocks, data of which are taken from Ishihara *et al.* (1995). Magnetite-series rocks are filled, ilmenite-series rocks are open marks, and an intermediate one is shaded. Abbreviations: Plio, Pliocene; Q, Quaternary.

The Na_2O and K_2O contents are important criteria for S and I type granitoids classification (Chappell and White, 1974). In their reconnaissance study, Ishihara and Terashima (1985) found that Eocene Uttsudake and Monbetsu granitoids are most sodic and least potassic and low in Rb among the Tertiary granitoids of north-central Hokkaido. Thus, additional chemical analyses were performed on the Kamishiyubetsu intrusive rocks (Ihara, 1995), the Nisshotoge pluton (Koike, 1997) and the Uttsudake body (Nagasaka, 1997) using an XRF spectrometer of Hokkaido University by the methods described in Tsuchiya *et al.* (1989) and Tanaka and Orihashi (1997).

Figure 6 is CaO-Na_2O-K_2O diagrams of these granitoids. Eocene granitoids of the Uttsudake pluton are plotted between the Tanzawa tonalite trend and average compositional trend of the Outer Zone granitoids of Southwest Japan, which are potassic, being composed of both S and I types (Takahashi *et al.*, 1980 b). The Okushibetsu granitoids are plotted more or less in the same field, but strictly speaking, granodioritic rocks are plotted in more sodic but granitic rocks are plotted in more potassic side (Fig. 6 A). If the Monbetsu granites of Eocene age whose chemical data are given in Ishihara and Terashima (1985) are plotted in the diagram, they are submerged into the plots of the Uttsudake granites.

The middle Miocene granitoids of the Nisshotoge pluton are plotted generally parallel to the CaO-K_2O side line and the felsic rocks are quite potassic; those of the Kamishiyubetsu Tectonic Zone are divided into three categories based on Na_2O contents, being least sodic in the Otofukeyama body but most sodic in the Shiyubetsu body. Thus, the Eocene granitiods are most sodic among the three groups of the granitic activities, and the compositions become less sodic with time.

Table 3 is the averaged Na_2O contents normalized to the SiO_2 65 %, using the average compositional trend of the Japanese granitoids, which slightly increases in Na_2O with silica contents. Eocene granitoids are again as high as 4.74–3.95 % in the content, while the Oligocene granitoids are 3.82–3.65 %, the middle Miocene granitoids are 3.86–3.49 %, and the late Miocene granitoids are 3.71–3.37 %. I-type tonalites (3.37 %) of the Shiyubetsu intrusive rocks and S-type tonalite (3.38 %) of the Niikappu river (Shimura *et al.*, 1992) are more or less the same as the average composition of the Japanese granitoids, and are least sodic (Table 3). Thus, the Eocene granitoids, particularly of Uttsudake and Okushibetsu bodies, can be said to be most sodic among the granitoids studied.

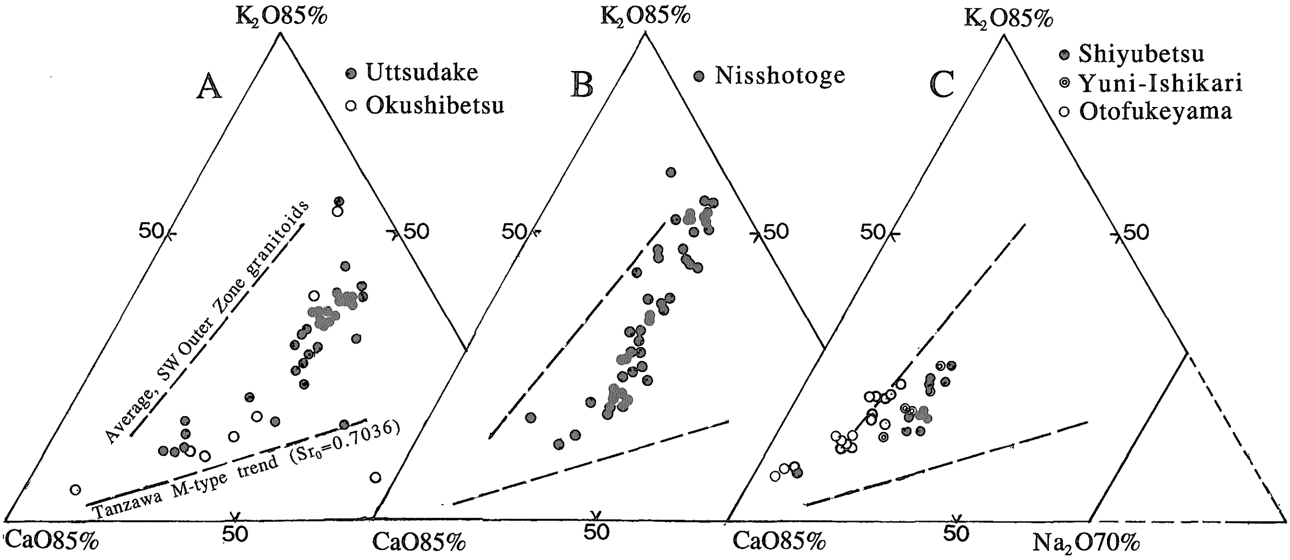

Fig. 6 CaO-Na_2O-K_2O diagrams for selected granitoids in the north-central Hokkaido. The original data are taken from Yoneyama (1990), Ihara (1995), Koike (1997) and Nagasaka (1997).

Table 3 Averaged Na_2O contents of Cenozoic granitoids of central Hokkaido.

Plutons	K-Ar age	Na_2O	(n)	Reference
Upper Miocene				
Shiyubetsu	11.6 Ma	3.37 %	(13)	This study
Yuni-Ishikari	11.5	3.52	(5)	This study
Otofukeyama	10.3	3.71	(17)	This study
Middle Miocene				
Ochube	16.5	3.49	(3)	Ishihara and Terashima (1985)
Ichinohashi	18.5	3.58	(2)	Ishihara and Terashima (1985)
Pishikachinai	17.3	3.86	(25)	Tomura (1983)
Nisshotoge	17.3(Rb-Sr)	3.81	(19)	Ishihara and Terashima (1985),
	16.6			Koike (1997)
Oligocene				
Shirataki	>32.5	3.65	(2)	Watanabe and Hasegawa (1981)
Oshirabetsu	36-28	3.82	(2)	This study
Eocene				
Okushibetsu	44.8	4.74	(9)	Yoneyama (1990)
Uttsudake	43.4	4.36	(35)	Nagasaka (1997)
Monbetsu	41.5	3.95	(2)	Ishihara and Terashima (1985)
Migmatite zone				
Niikappu river	50-40(Rb-Sr)	3.38	(6)	Shimura *et al.* (1992)
Saruru river	30.3	3.15	(3)	Ishihara and Terashima (1985)
		3.63	(10)	Owada (1989)

5. 2 $^{18}O/^{16}O$ ratio

Oxygen isotopic ratio, $\delta^{18}O_{SMOW}$ value, is also a good indicator of crustal contamination (Taylor, 1968; Matsuhisa *et al.*, 1982), because ^{18}O is enriched in such low temperature precipitates as illite and chert in sedimentary environment. The $\delta^{18}O_{SMOW}$ values were determined on whole rock powders of 21 granitoids, 2 gabbroids, 4 metamorphic rocks and 2 sedimentary rocks by the analytical procedures described in Ishihara and Matsuhisa (1998). The results are listed in Table 4 and additional analyses of major chemistry for the Uttsudake granitoids are listed in Table 5.

The highest values obtained are 11.6 and 11.4 permil of siltstone and sandstone hornfels (average 11.5 ‰) and 10.7-9.8 permil of biotite gneisses (average 10.0 ‰) from the Hidaka metamorphic zone. Sandstone

Table 4 $\delta^{18}O$ of intrusive rocks in central Hokkaido.

Sample nos. and locality	Rock type	SiO_2 (%)	δ ^{18}O (‰)	Analysts
Upper Miocene granitoids				
OTS 2, Otofukeyama	Bt-hb qz diorite	55.7	6.7	CA
AKB 2, ditto	Hb-bt tonalite	62.1	9.6	CA
AKB 1, ditto	Bt-hb qz diorite	64.9	9.2	CA
UN 7, Yuni-Ishikari	Bt-cpx-hb qz diorite	61.5	6.7	CA
UN 2, ditto	Bt-act qz diorite porph	61.9	1.0	CA
CUN12, Shiyubetsu	Bt-hb qz diorite	63.2	8.5	CA
CUN 3, ditto	Bt bg hb qz diorite	63.7	7.3	CA
Middle Miocene granitoids				
74HK09, Ochube	Hb-bt granodiorite	61.0	9.5	NZ
74HK07, ditto	Bt granite	67.1	11.2	NZ
74HK08, ditto	Bt granite	73.0	10.1	NZ
74HK27, Ichinohashi	Cpx-hb-bt qz diorite	54.9	9.2	NZ
74HK41, Nisshotoge	Cpx-hb-bt tonalite	61.8	8.5	YM
74HK44, ditto	Hb-bt granodiorite	66.6	8.5	YM
74HK71, ditto	Bt granite	69.2	9.6	YM
74HK39, ditto	Bt granite	75.0	9.4	YM
74HK42, ditto	Gt-bt gneiss	64.7	10.7	YM
74HK46, ditto	Bt hornfels	64.9	11.6	YM
Oligocene granitoids				
Shirataki I	Weakly sheared granite	70.7	5.0	CA
Shirataki II	Strongly sheared granite	70.3	0.0	CA
75HK95, Saruru	Bt tonalite	64.0	9.7	YM
74HK91A, ditto	Bt gneiss, fine grained	63.6	10.1	YM
74HK91B, ditto,	Bt gneiss, medium-grained	65.0	9.5	YM
74HK87, ditto,	Bt gneiss	66.4	9.8	YM
74SHK51, ditto	Bt hornfels (sand-size)	65.1	11.4	YM
Eocene granitoids				
74HK22 Uttsudake	Fine, opx qz diorite porph.	63.9	4.8	NZ
74HK21 ditto	Very fine, hb-bt granite	72.6	8.7	NZ
74HK23 ditto	Very fine, sph-hb granophyre	74.4	9.3	NZ
Gabbroids				
74HK64 Tomuraushi	Fine, cpx-hb gabbro	50.8	7.3	NZ
74HK65 ditto	Coarse, hb diorite	51.7	5.4	NZ

Abbreviations: cpx-clinopyroxene, opx-orthopyroxene, hb-hornblende, bt-biotite, porph-porphyry. Shirataki I and II, donated by J. WATANABE; their SiO_2 described in WATANABE and HASEGAWA (1981). The other SiO_2 contents are given in ISHIHARA and TERASHIMA (1985), IHARA (1995) and Table 5. Analysts: NZ, M. Burgen and P. Blattner, Inst. Geological & Nuclear Sci., New Zealand; CA, B.F. Wan, Inst. Ore Geology, CAGS, China; YM, Y. Matsuhisa, Geol. Surv. Japan.

Table 5 Chemical composition of the Uttsudake granitoids.

	74HK22	74HK26	74HK23
SiO_2	63.87	73.68	74.35
TiO_2	0.70	0.30	0.29
Al_2O_3	15.31	13.77	13.57
Fe_2O_3	6.51	2.35	1.80
MnO	0.11	0.04	0.01
MgO	2.81	0.35	0.26
CaO	5.71	1.41	1.02
Na_2O	3.08	4.38	4.67
K_2O	1.83	3.53	3.70
P_2O_5	0.11	0.05	0.04
Total	100.04	99.86	99.71

Analyzed by XRF method described in Tanaka and Orihashi (1997)

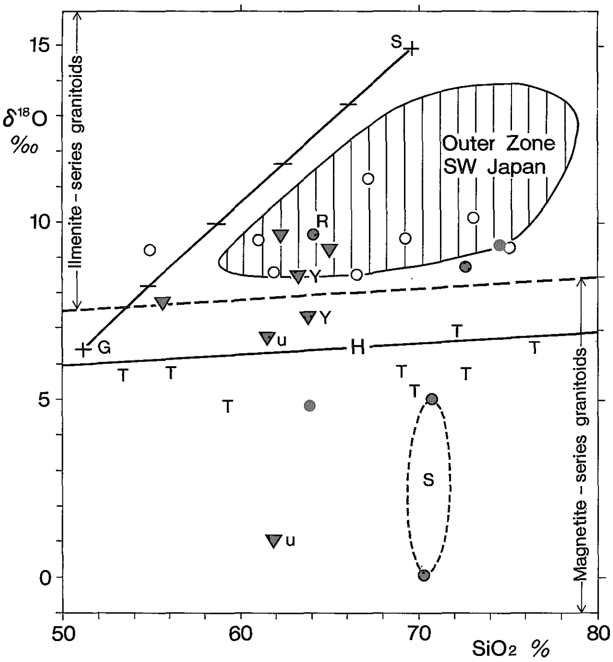

Fig. 7 Oxygen isotope ($\delta^{18}O$) vs. silica plots of the studied granitoids. Solid circle, Eocene and Oligocene (R, tonalite from the migmatite zone; S, Shirataki granite); open circle, Middle Miocene; triangle, upper Miocene (U, Yuni-Ishikari; Y, Shiyubetsu). T is Tanzawa tonalites of Matsuhisa *et al*. (1982). Straight solid line with H, Hachijojima tholeiite trend of Matsuhisa (1979). Shaded, area for the Outer Zone granitoids of Southwest Japan from Ishihara and Matsuhisa (1998). For the curved line with G and S, see text.

and shale of the whole Hidaka belt in north-central Hokkaido, however, give an average of 15 permil at SiO_2 69.7 percent (n=18, Ishihara *et al.*, in prep.). Thus, the $\delta^{18}O$ values decrease from unmetamorphosed rocks to high grade metamorphic rocks. The granitoids are usually lower than 10.0 permil; partial melting of sediments alone cannot be considered on the granitoid genesis by the $\delta^{18}O$ data. An average of two gabbroids is 6.4 permil at SiO_2 51.3 %, which is 1.6 permil higher than tholeiitic basalt of the Hachijojima volcanic rocks (Matsuhisa, 1979).

In the $\delta^{18}O$-SiO_2 diagram (Fig. 7), almost all the granitoids are plotted in the area between the two distinct trends; the mixing line of gabbroid and sedimentary rocks of the Hidaka Supergroup (G-S), which is calculated by assuming $\%O_2 = 0.194 \times \%SiO_2 + 35.0$ (Eugster, 1969), and the Hachijojima tholeiitic magma trend (H), which is thought to be fractionation trend of island-arc tholeiitic magmas (Matsuhisa, 1979). The broad distribution of the granitoids in the diagram indicates that they were formed from the two end-components; mafic source magmas and sedimentary rocks, with various degrees of mixing and differentiation.

It is worth noticing that the Tanzawa tonalites (Matsuhisa *et al.*, 1982) come close to the Hachijojima trend in the diagram. If we can assume the differentiation trends of intrusive magmas being parallel to that of the Hachijojima magma, the intersections of the trends with the mixing line in Figure 7 give the mixing ratios of sedimentary components to the magmas. The attached ticks to the mixing line G-S imply 20 percent intervals of the mixing ratio.

Using average $\delta^{18}O$ values and SiO_2 contents of individual intrusions, mixing ratios are estimated as follows. The highest mixing ratio was obtained on middle Miocene granitoids of the Ochube pluton, whose average of 10.3 permil (n=3) gives ca.40 percent mixing of the sedimentary component. Similar middle Miocene granitoids of the Nisshotoge pluton (averaged 9.0, n=4) reveal 22 percent mixing. About the sodic Eocene granitoids of the Uttsudake pluton, all the three analyses (7.6‰$\delta^{18}O$, 70.3 % SiO_2) give the mixing ratio of 6 percent. If one low value of 4.8 permil (74 HK 22) is excluded, because of its subvolcanic texture, the average becomes 9.0 permil at SiO_2 73.5 percent and gives the mixing ratio of 20 percent.

Similarly, quartz diorites of the Otofukeyama bodies (averaged as 8.5‰, 60.9 %) and Shiyubetsu (7.9‰, 63.5 %), reveal the mixing ratio of 20 and 12 percent, respectively. In the Yuni-Ishikari bodies, one low value (6.7‰) may be related to its general magnetite-series character, but much lower value of 1.0 permil on the porphyry could have been caused by hydrothermal circulation of meteoric water at a high level of the intrusion. Similarly, two low values, 5.0 and 0.0 permil of the Shirataki granites are considered also due to ^{18}O-depletion by isotope exchange with circulating meteoric thermal water during shearing of the granites, judging from the mode of occurrence of the granites.

6. Characteritics and Petrogeneses

6. 1 Gabbroids vs. Granitoids

One of the characteristics of the late Cenozoic plutonism in the north-central Hokkaido is granitoids and gabbroids occurring together in an equal amount (120 km^2 vs. 110 km^2 in the exposed areas , Table 1). The granitoids tend to occur in the whole region, but the gabbroids are exposed only along the western edge of the Hidaka Belt; the gabbroids may have occurred along a structural discontinuity. Wherever the gabbroids are abundant, the granitoids are also abundantly distributed in general. They are spatially very closely related in the Ochube-Amanokawa area and Okushibetsu area. They are temporally identical in the Ochube-Amanokawa area. (16.5 vs. 16.0 Ma). Thus, the plutonism of the north-central Hokkaido is bimodal in character.

The bimodal magmatism is generally known to occur in volcanic regions with an extensional tectonic setting, such as in the Basin and Range province of the western United States (Christiansen and Lipman, 1972; Christiansen and McKee, 1978). In the back-arc basins of the Japanese Island Arc, Konda (1974) recognized coastal basaltic and interior felsic volcanism in the middle Miocene of the Tohoku district. In the north-central Hokkaido, basalts occur in a small amount but andesites and rhyolites are majority (Goto *et al.*, 1995). Instead, the bimodal plutonism is at least seen in the middle Miocene in the Ochube-Amanokawa area and possibly in the Eocene Period in the Okushibetsu area.

Tectonic setting of central Hokkaido in 37-0 Ma appears to be generally compressional, because the maximum compression must have occurred when the eastern block of Hokkaido collided on the western block. This collision made thrusting up of the high-grade metamorphic zone in the southern Hidaka Belt and formation of NE shearing in the Kamishiyubetsu Tectonic Zone (Kimura *et al.*, 1983). However, extensional tectonic setting appears to have occurred intermittently. In central Hokkaido, Maeda *et al.* (1990) inferred an extensional stress regime in the middle Miocene by the presence of A-type volcanism and development of sedimentary basins. The bimodal plutonism of the Ochube-Amanokawa area may be another example to indicate extensional setting in the middle Miocene (16 Ma).

The gabbroids tend to occur in a north-south direction along the western fringe of the Hidaka metamorphic belt (Fig. 1). Individual granitic bodies of central Hokkaido have generally north-south elongation, and partly sheared in the same direction. The N-S direction is alignment of the basement constituents, too. Thus, the gabbroic magmas brought up mostly along the structural discontinuity (suture zone) and provided heat to generate granitic magmas.

Coexisting gabbroids and granitoids are best seen in the Tottabetsu area of the southern Hidaka Belt where these rocks intrude into high-grade metamorphic zone with a maximum pressure and temperature of 7.2 kb and 870℃ (Osanai *et al.*, 1992). Here, two distict affinities, i.e., normal mid-ocean ridge basalt (N-MORB) and high Mg andesite, are geochemically recognized in the gabbroids, and explained by a ridge-trench collision model : N-MORB originated in upwelling asthenospheric mantle and high-Mg andesite generated in the mantle wedge (Maeda and Saito, 1997).

6. 2 Geneses of Granitic Magmas

The granitoids in central Hokkaido are ilmenite-series with a very small amount of intermediate series from Eocene to late Miocene (11 Ma) ; then became magnetite-series tonalites after 9 Ma. These Tertiary granitoids are similar to the Miocene Outer Zone granitoids of Southwest Japan, in the sense that both consisting of ilmenite series intrude into accretionary complex of outer zones of the Japanese Island Arc. Both the granitoids have negative $\delta^{34}S$ values on their rock sulfur, namely -3 to -16 permil in the Outer Zone of Southwest Japan, while in Hokkaido around -11 permil in those of the migmatite zone and -8 to -5 permil in the Nisshotoge and Ichinohashi plutons of non-metamorphic zone (Sasaki and Ishihara, 1979 ; Ishihara *et al.*, 1988).

These negative values were considered resulted from mixing of ^{32}S-enriched sedimentary sulfur from the accretionary complex to the parental granitic magmas from depth. Further, based on the $\delta^{18}O$ values, contribution of sedimentary rocks was calculated to be 65-45 percent for the S-type ilmenite-series and 43-30 percent for I-type ilmenite series granitoids (Ishihara and Matsuhisa, 1998). In Hokkaido, $\delta^{18}O$ values are lower than those of the Outer Zone of Southwest Japan (Fig. 7), thus suggest low mixing ratios, lower than 40 percent. Some reach to the values of magnetite series, but these can be caused by meteoric water circulation during the subsolidus stage. We need further detailed studies on their mineral separates.

Sodic granitoids of Eocene age have the lowest value on the initial Sr isotopic ratio (0.70407, Ishihara and Terashima, 1985) among the granitoids in north-central Hokkaido. This value is still higher than that of Tanzawa tonalites (0.7036, Shibata and Ishihara, 1979). The Tanzawa tonalites could have been generated by dehydration melting of amphibolites, chemically similar to low-K tholeiitic basalt (Arima *et al.*, 1996) or by direct partial melting of the subducted oceanic slab (Drummond and Defant, 1990). The Eocene granitoids could be generated in mafic igneous rocks in the lower crust.

The Tanzawa tonalites contain abundant magnetite as typical magnetite series, while the Eocene granitoids are magnetite-free, ilmenite series. The $\delta^{18}O$ values are higher in the Eocene granitoids than in the Tanzawa tonalites (Fig. 7). This fact implies that the Eocene granitoids also have contribution of the basement metamorphic rocks of sedimentary in origin. The alkali ratios and $\delta^{18}O$ values indicate that the contribution of crustal materials became highest in a middle Miocene and decreased to the late Miocene, then further to the Quaternary volcanic rocks.

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北海道中央北部におけるチタン鉄鉱系と磁鉄鉱系花崗岩活動の変遷と成因

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要　旨

北海道中央部のトナル岩類を中心とする12個の岩石・鉱物試料についてK-Ar年代と帯磁率とを測定し，既発表資料と合わせてチタン鉄鉱系と磁鉄鉱系花崗岩活動の時間的変遷を追及した．始新世花崗岩が新たに2岩体で発見され，既知の岩体を含め，その分布方向は東北系である．始新世花崗岩は，西進太平洋プレートに伴う最初のマグマ活動と考えられる．上支湧別構造帯に沿うトナル岩類は，11 Maまではチタン鉄鉱系と少量の中間系であり，9 Ma以降に磁鉄鉱系に移行する．

新たに実施した花崗岩類の主成分分析と酸素同位体分析によれば、始新世花崗岩類が最もナトリウム質であり、中新世中期花崗岩類が最もカリウム質である。全岩 $\delta^{18}O$ 値も同様に始新世花崗岩類で低く、中新世中期花崗岩類で高い。斑れい岩類と日高層群の砂岩・頁岩類の平均値を端成分とする単純混合を仮定すると、実測 $\delta^{18}O$ 値は堆積岩類40-0%の混入率を示す。

後期新生代の火山岩類もチタン鉄鉱系で始まり，中間系を経て磁鉄鉱系に変わる．この様な大局的な規則性は，新しく火成弧が発生する際に，マントルからの斑れい岩質マグマ・熱・揮発性成分によって含有機炭素を含む大陸地殻が溶融してチタン鉄鉱系が生じ，さらなる温度の上昇によって有機炭素を含まない、より難溶性の苦鉄質物質が部分溶融して苦鉄質マグマが発生・上昇したことを物語っている．