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Oxygen isotopic constraints on the geneses of the Late Cenozoic plutonic rocks of the Green Tuff Belt, Northeast Japan

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Abstract: Sixty-four samples from the late Cenozoic granitoids of the Green Tuff belt were analyzed for the whole-rock $\delta^{18}O$ values in northern Honshu and Hokkaido. The granitoids are widely exposed in the southern Fossa Magna region, where low-K magnetite-series of the Tanzawa pulton has the lowest $\delta^{18}O$ values, averaged to be 5.4‰. Similar low-K magnetite-series granitoids have low $\delta^{18}O$ values of 7.4‰ at Ashigawa type and 6.7‰ at Nii-jima. These low-K series rocks are considered generated from tholeiitic mafic rocks of oxidized type in the lower crust. Normal-K magnetite-series of the Kofu granodiorite has 7.4‰, but the ilmenite-series Tokuwa granodiorite has 9.4‰ and the Mitake granite has 11.2‰. These high values are due to igneous-source magmas mingled with ^{18}O-enriched sedimentary rocks from the basement accretionary complex. The complexity of the $\delta^{18}O$ values of the Kofu pluton reflects that of its tectonic setting straddling over the two major arcs. Many ^{18}O-depleted values were obtained from small granitic bodies distributed in the northern Fossa Magna and northward, suggesting meteoric water/ rock intraction that occurred at highest levels of the plutonic bodies in mountainous areas.

Keywords: Green Tuff, Fossa Magna, Miocene, granitoids, magnetite series, $\delta^{18}O$ values

1. Introduction

Late Cenozoic plutonism in Northeast Japan is typical plutonism occurring in active island arc environment, related to the westward subduction of the Pacific Plate along the Japan Trench. It is distributed generally to the west of the main Quaternary volcanic front. The plutonic rocks are emplaced mostly into Miocene submarine volcano-sedimentary rocks known as "Green Tuff", but partly basements of the pre-Paleogene sedimentary and metamorphic rocks, and granitic rocks. Their radiometric ages are largely Miocene, but vary up to 0.34 - 0.07 Ma (Doi *et al.*, 1995) on a still hot magnetite-series granodiorite at the Kakkonda geothermal field at the volcanic front of northern Honshu.

We have published a series of $\delta^{18}O$ (‰)$_{SMOW}$ data of the Japanese plutonic rocks (Ishihara and Matsuhisa, 1999, 2002, 2004). This paper is the fourth one describing the $\delta^{18}O$ values of the youngest plutonic rocks in the Japanese islands, and we intend to discuss their geneses from the O-isotopic aspects. The analytical methods are the same as those described in the previous papers (e.g., Ishihara and Matsuhisa, 2002).

2. Geological Outline of the Late Cenozoic Plutonic Rocks

The late Cenozoic plutonic rocks exhibit a variety of mode of occurrence. They are very large in the exposure in the southern Fossa Magna region, which belongs to the Outer Zone, i.e., south of the Median Tectonic Line; then middle sized in the northern Fossa Magna, but small to the north including Tohoku and Hokkaido Districts (Fig. 1), implying different erosion levels depending upon the tectonic background. The compositions vary widely from gabbroids to SiO_2 77 % rock, and the magnetic susceptibility ranges from 8 to over 3,000 x 10^{-6} emu/g (Table 1).

In the southern Fossa Magna, the ensimatic Ogasawara Arc collided into the ensialic Honshu Arc, then made the present bent structures. The Tanzawa pluton, the second-largest pluton (125 km^2) in the Fossa Magna, occurs within the ensimatic arc, while the largest Kofu pluton (ca. 600 km^2) is seen straddling over the two arcs.

The Tanzawa pluton intrudes into the thick (10,000 m) Miocene volcanic rocks of mafic to intermediate compositions of the Misaka Supergroup, whose metamorphic grades varying from zeolite facies to amphibolite facies. The pluton is composed of a small amount

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of gabbroids which tend to occur in the margin of the pluton (Takita, 1974), but the majority is tonalite in composition. Leucocratic tonalite occurs as small stocks or dikes. All of these rocks are characterized by low K_2O/Na_2O and Rb/K ratios and high values of magnetic susceptibility (Ishihara *et al.*, 1976; Ishihara and Terashima, 1992). The initial Sr isotopic ratio, 0.7036 (Shibata and Ishihara, 1979), is the lowest among the Japanese granitoids. Similar sodic tonalite with miarolitic cavities is found as fragments in volcanic ejecta in Nii-jima (Issiki, 1987).

The Kofu pluton is a composite Miocene intrusive body having wide variations in the composition and magnetic susceptibility. The southwestern margin (Fig. 2) is composed of sodic magnetite-series tonalite in the Ashigawa Village. This part of the pluton also intrudes into mafic to intermediate volcanic rocks of the upper part of the Misaka Supergroup. To the west of the Kofu pluton along the Fujigawa river, similar sodic magnetite-series tonalite-granodiorite occurs as a N-S trending small intrusion in the lower part of the Misaka Supergroup (e.g., Marui body, Yamanashi Pref., 1970).

The main part of the Kofu pluton intrudes discordantly into the Jurassic to Cretaceous sedimentary rocks of the Chichibu Terrane at north and Cretaceous to Paleogene sedimentary rocks of the Shimanto Terrane at east and possibly west, which is covered by Quaternary volcanics and sediments (Fig. 2).

The eastern part of the pluton is mostly granodiorite, which was called Tokuwa batholith by Shimizu (1986). This phase is essentially magnetite series, but converted to ilmenite series at margins where the granodiorite intruded into shale-dominant horizons of the Shimanto Supergroup (Ishihara *et al.*, 1976; Sato and Ishihara, 1983; Shimizu, 1986). The western part is generally ilmenite-series biotite granite in the Mitake-Shosenkyo area, whereas the central part is the youngest magnetite-series, Kogarasu granodiorite, intrusive to the Tokuwa granodiorite and coeval volcanic rocks in the middle (Mimura *et al.*, 1984).

The Chichibu mine stock, located in the southern belt of the Chichibu Terrane, intrudes into Jurassic shale and sandstone containing limestones, and formed many skarn-type base metal and iron deposits. The granitoids essentially belong to magnetite series, but the magnetite is generally absent in the southern, deepest horizon, which was interpreted as reduction by circulation of C- and H-bearing reducing gases from the wall rocks (Ishihara *et al.*, 1987).

The late Cenozoic plutonic rocks occur in the northern Fossa Magna, from the Lake Suwa to the north, Suzaka and Yuzawa-Tanigawadake areas, which are underlain by the basement rocks belonging to the Inner Zone of Southwest Japan (Fig. 1). Those of the Lake Suwa and Suzaka areas intrude Miocene Uchimura Group which is composed of basaltic to

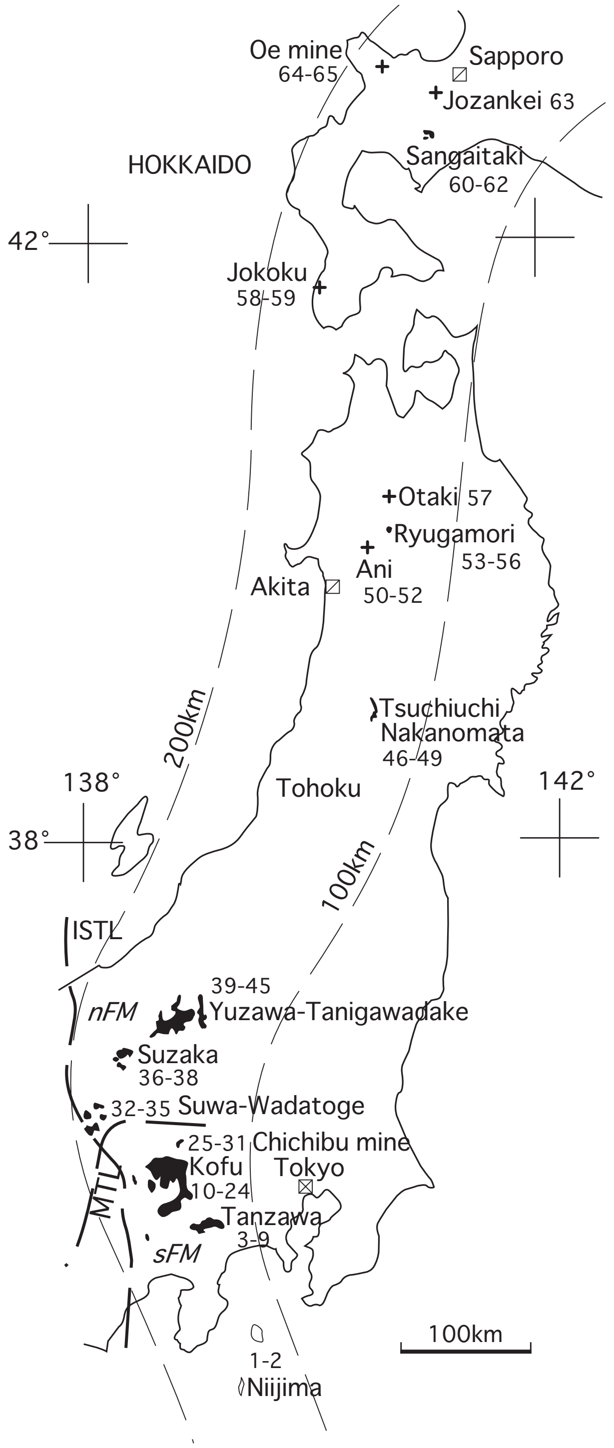

Fig. 1 Distribution of Late Cenozoic granitoids (solid and cross symbols) and studied localities (nos.1–65) in the NE Japan Arc. Simplified from Ishihara (1974). Numbers correspond to those of Table 1. MTL, Median Tectonic Line; ISTL, Itoigawa-Shizuoka Tectonic Line; *sFM*, southern Fossa Magna; *nFM*, northern Fossa Magna.

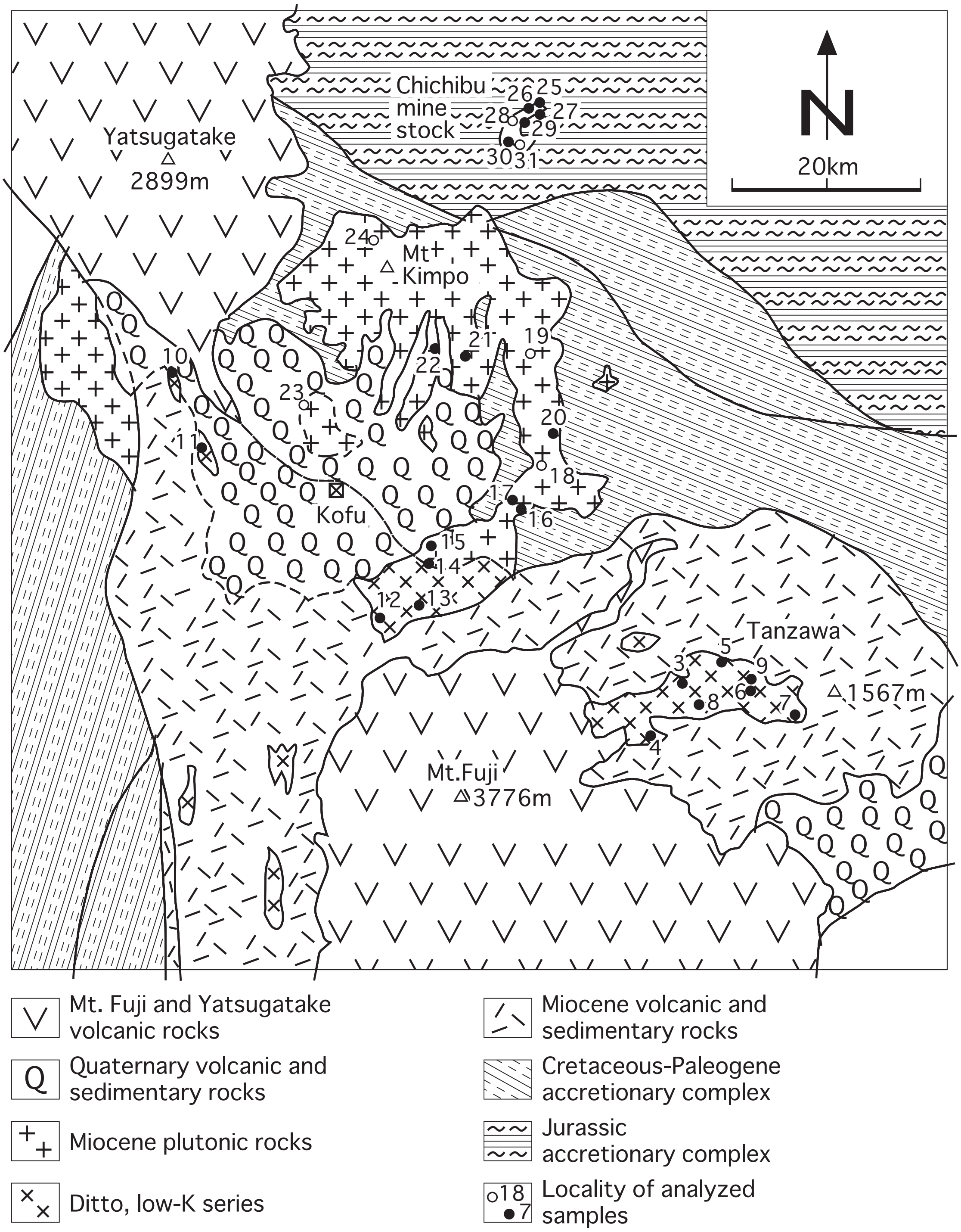

Fig. 2 Distribution of Late Cenozoic plutonic rocks in the southern Fossa Magna and localities of the studied samples, which correspond to those of Table 1. Solid circle, magnetite-series; open circle, ilmenite-series samples. The geology simplified from Geological Survey of Japan (1992).

rhyolitic volcanics and intercalated sediments, implying that they intruded into a depressed basins, and often covered by younger volcanic rocks.

The granitoids from the Lake Suwa and Wadatoge area are mostly granodiorite, whereas they are more mafic in the Suzaka area, being mostly hornblende quartz diorite, which may be porphyritic or aplitic at margins. Mafic enclaves are common. Relict of augite may be contained in the hornblende (Ota and Katada, 1955). The rocks are commonly altered, and epidote, chlorite and kaolinite are formed.

The late Cenozoic granitoids of the Yuzawa – Tanigawadake area (Chihara *et al.*, 1981) is quite different in the basement setting. They intrude commonly

Table 1 Oxygen isotopic data of the Late Cenozoic plutonic rocks of the Green Tuff Belt.

Sample nos.	Locality	Rock type	SiO_2 (%)	$\delta^{18}O$ (‰)	M.S.
Niijima					
1 GSJ R34174	West coast, Mamashitaura	Am-Bt tonalite	73.4	6.9 (CA)	479
2 AM2-1	do., SW part	Bt tonalite	77.0	6.4 (YM)	242
Tanzawa pluton					
3 75TA16	Sakase-zawa, Doushi	(Epd-)Hb diorite	44.2	5.3 (CA)	3077
4 75TA06	Mizunoki, Yotsukegawa, Yamakita	(Bt-)Hb qaurtz diorite	53.9	5.6 (CA)	1721
5 75TA17	Murokubogawa, Dosi	ditto	57.1	5.7 (CA)	1635
6 75TA09	Nakagawa, Yamakita	Bt-Hb tonalite	60.7	4.8 (YM)	1437
7 75TA03	Kurokuragawa, Yamakita	Hb-Bt tonalite	69.6	5.7 (YM)	625
8 75TA33	Komotsurizawa, Yamakita	Epd-Bt tonalite	70.4	5.2 (YM)	535
9 75TA25	Nakagawa, Museum site, Yamakita	Epd-Bt tonalite	73.2	5.7 (YM)	23
Kofu, Ashigawa type					
10 75KO36	Kobugawa, mouth, Narazaki	Hb tonalite	67.0	8.0 (CA)	622
11 75KO38	Tattani No.1 bridge, ditto	(Bt-)Hb tonalite	68.0	9.1 (CA)	631
12 75KO51	Kamiashigawa, Ashigawa	Hb tonalite	72.9	7.7 (CA)	463
13 80KO102	West of Naka-ashigawa, ditto	Green Bt granophyric granodiorite	74.7	7.1 (CA)	430
Kofu, Tokuwa-Kogarasu type					
14 80KO105	Kamikurokoma, Misaka	Bt-Hb granodiorite	67.3	7.3 (CA)	508
15 75KO48	Kanazawa, Ichinomiya	Hb tonalite	56.9	4.5 (CA)	334
16 80KO99	Quarry by Hatsukano JR-station	Hb-Bt tonalite (ilmenite series)	64.6	9.3 (YM)	14
17 80KO98	Mukaizawa, Mizunoda, Yamayo	Hb-Bt tonalite (ilmenite series)	65.4	8.8 (YM)	134
18 80KO93	Ryumonkyo, Yamato	Hb-Bt tonalite (ilmenite series)	64.3	10.5 (YM)	12
19 75KO84	Onyashiki, SW Enzan	Hb-Bt tonalite (ilmenite series)	65.0	9.0 (CA)	24
20 75KO89	Hikawa, Enzan	Bt-Hb granodiorite	64.1	8.1 (YM)	396
21 75KO32	Tokuwa, Mitomi	Bt-Hb tonalite	55.8	7.2 (CA)	3090
22 75KO19	Kogarasuyama, Makioka	Px-Hb tonalite	63.4	7.1 (CA)	999
Kofu, Mitake type					
23 74KO8	Kiyosawagawa, Shikishima	Hb-Bt monzogranite	74.9	11.2 (CA)	8
24 74KO6	Nishimatazawa, Kawakami	ditto (granophyric)	77.1	11.2 (CA)	29
Chichibu mine					
25 75CB93	Kanryugawa 1260m asl	Px-Hb quartz diorite	55.7	7.4 (YM)	1440
26 75CB84	ditto 1240 m asl	Hb tonalite	62.5	8.7 (CA)	1478
27 75CB82	ditto, 1070 m asl	(Tm-)Bt granodiorite	79.3	8.9 (CA)	715
28 75CB88	Hirogawarazawa 930 m asl	Bt-Hb tonalite (ilmenite series)	62.9	8.2 (CA)	108
29 75CB90	ditto, 830 m asl	(Px-)Bt-Hb quartz diorite	58.7	7.6 (CA)	1320
30 75CB73	Nakatsugawa 859 m asl	Hb-Bt tonalite	64.5	7.1 (CA)	866
31 75CB74	ditto, 830 m asl	Hb-Bt tonalite ((ilmenite series)	63.4	7.9 (CA)	50
Suwa-Wadatoge					
32 75WD03	Daimon 1 km N, Nagatocho	Px-Hb diorite (Epd>Ser)	55.2	3.8 (CA)	645
33 75WD11	Amari-toge 1 km N, Wada-mura	Bt-Hb granodiorite	65.1	6.1 (CA)	1099
34 76WD113	Daibutsu, Matsumoto	Hb-Bt granodiorite	66.6	8.5 (CA)	370
35 76WD103	Kuwabara, Suwa	Hb-Bt granodiorite	70.9	8.3 (CA)	505
Suzaka					
36 75SZ88	Yamauchi, 3 km S, Nagano	Hb qaurtz diorite	62.1	3.9 (CA)	1208
37 76SZ132	Suzurihara, Higashi-mura	Hb tonalite, porphyritic	64.0	2.7 (CA)	1569
38 76SZ127	Yamashinden, 2 km S, Nagano	Hb quartz diorite, albitized	73.9	2.7 (CA)	171

Table 1 continued.

Sample nos.	Locality	Rock type	SiO_2 (%)	$\delta^{18}O$ (‰)	M.S.
Yuzawa-Tanigawadake					
39 76TN147	Warabino, Muikamachi	Hb quartz diorite-diorite	54.0	7.8 (CA)	17
40 76TN165	Yusawa/Yubisogawa	Px-Hb tonalite	62.5	-1.7 (CA)	1654
41 76TN154	JR tunnel, Tsuchitaru <Kashima>	Bt-Hb granodiorite	64.3	6.3 (YM)	1061
42 76TN152	JR tunnel, below Mantarodani(<Taisei>	Px-Bt-Hb granodiorite	65.3	6.9 (CA)	866
43 76TN153	ditto <Taisei section>	Tit-Epd-Chl monzogranite	74.4	-1.2 (YM)	324
44 76TN158	Hiuchi-toge, Yuzawa	Hb-Bt-monzogranite, granophyric	71.8	1.5 (YM)	851
45 76TN166	Machigasawa/Yubisogawa	Bt monzogranite porphyry	73.4	3.3 (CA)	535
Tsuchiuchi					
46 70AN35	Tsuchinaigawa, dike	Hb Diorite	52.2	3.5 (CA)	1595
47 70AN34	ditto, water fall, main phase	ditto (Ser>Chl)	58.9	1.0 (CA)	1368
Nakanomata mine					
48 70AN29	Debris of the Ogiri adit	Hb quartz diorite, granophyre	58.9	-2.0 (CA)	2038
49 70AN28	300m N of the adit	ditto (Cc>Chl)	64.3	1.2 (CA)	1156
Ani mine					
50 70AN20	Itagizawa, Aniai	Bt-Hb diorite (Chl=Epd>Cc)	55.9	5.3 (YM)	1129
51 70AN03	Chuo Adit, 100 m vein	Bt granodiorite	67.2	5.5 (MK)	701
52 70AN07	Sanmai-Tsudo-ko, Irodate vein	Bt granodiorite, porphyritic	64.8	8.0 (MK)	614
Ryugamori					
53 B1-81	Kotsunagimori-Sendoishi	Hb Diorite (Ser>Chl>Epd)	51.5	6.7 (CA)	81
54 B1-68	ditto	(Px-)Bt-Hb diorite	57.0	6.8 (CA)	80
55 B2-1905	Kotsunagi-Osabe-zawa	Hb-Bt monzogranite (Chl>Ser>Cc)	71.7	6.6 (MK)	14
56 B2-191	ditto	(Hb-)Bt monzogranite	73.4	7.6 (CA)	15
Otaki					
57 77102706	Nakayamazawa、Odate	Bt granodiorite, granophyre	67.8	7.1 (CA)	n.d
Jokoku mine					
58 76701401	100m N,Hayakawa ridge	Hb-Bt quartz diorite	55.1	3.0 (CA)	1050
Sangaidaki					
59 MY Qd-91	Osaru River, Otaki	Bt-Hb quartz diorite (Chl>Eqd=Cc)	59.0	6.7 (CA)	1498
60 MY Gd1	Osaru River, Otaki	Bt-Hb-Px granodiorite (Cc>Ser)	68.2	8.4 (CA)	627
61 MY Adm 2B	Osaru rive, Otaki	(Hb-)Bt monzogranite	72.1	8.9 (CA)	135
Jozankei					
62 74HK01	Jozankei, Sapporo	Hb granodiorite porphyry (Cc>Ser)	65.4	8.6 (CA)	823
Oe mine					
63 74HK110	Oe mine	Bt-Hb granodiorite (Cc>Chl=Ser)	66.8	5.0 (MK)	2269
64 74HK111	ditto	ditto	67.7	4.7 (YM)	18

Analysts for $\delta^{18}O$: YM, Y. Matsuhisa; MK, M. Kusakabe ; CA, Chinese Academy of Geological Sciences. SiO_2 contents from Terashima and Ishihara (1986) and Ishihara *et al* . (1987), but those of the Ryugamori samples are from Hujimoto (1971). M.S., magnetic susceptibility from Kanaya and Ishihara (1973).

Abbreviations: Minerals: Am, Amphibole; Bt, biotite; Cc, calcite; Chl, chlorite; Epd, epidote; Hb, hornblende; Px, pyoxene; Ser, sericite; Tit, titanite, Tm, tourmaline. Others: asl, above sea level.

into Cretaceous granitoids, particularly in the eastern part. In the western part, they usually intrude Miocene volcano-sedimentary sequences. The volcanic rocks do not include basalts but rhyo-dacite. The late Cenozoic granitoids of the area are mostly quartz diorite and granodiorite, containing some gabbroids. Porphyritic phases are common, indicating shallow-levels of some intrusive bodies.

The late Cenozoic granitoids of the Tohoku-Hokkaido Districts are small in exposure. The largest one occurs to the west of Kamuroyama (1,326 m), having a dimension of E-W 4.2 km and N-S 20 km, which is called Tsuchiuchi body in this paper. The other late Cenozoic granitoids are usually smaller dikes or plugs with a few km or less in diameter.

The late Cenozoic granitoids have two modes of occurrence. One intrudes into basement rocks of Cretaceous granitoids, such as Tsuchiuchi and Ryugamori (Hujimoto, 1971), while the others intrude into Miocene volcano-sedimentary formations, such as Nakanomata mine (Orimoto, 1964b), Ani mine (Kamiyama *et al.*, 1958; Orimoto, 1964a), Otaki (Akita-ken, 1973), Jokoku mine (Ishihara and Morishita, 1983), Sangaitaki (Fujiwara, 1954), Hottari (Saito *et al.*, 1952; Ishihara *et al.*, 1998) and Oe mine (Shinoda *et al.*, 1974). The former may have intruded along the edge of Green Tuff basins, while the latter invaded within the Miocene basins. Some of these granitoids have a sudden change of texture; volcanic at the margin and plutonic in the center in the Tohoku district (Orimoto, 1965).

3. Analyzed Samples and Results

The analyzed samples are listed in Table 1 together with the sample localities, rock types, silica contents, $\delta^{18}O$ values and magnetic susceptibility (M.S.). The obtained $\delta^{18}O$ values are plotted against SiO_2 in Figs. 3 to 5.

3.1 Fossa Magna region

In the southernmost Fossa Magna region, there are many Miocene plutonic stocks and dikes having low-K, tonalitic compositions. From the largest Tanzawa pluton, seven samples were selected (Table 1). The $\delta^{18}O$ values vary from 4.8 to 5.7‰ and virtually no variation against the SiO_2 contents (Fig. 3). An average of the seven analyses is 5.4‰ at SiO_2 61.3% . These values are the lowest we have found on the Japanese granitoids, and the plots of the Tanzawa plutonic rocks are called here the Tanzawa trend (Fig. 3). This trend is ca. 1 permil lower than that of the Hachijo-jima tholeiites series of Matsuhisa (1979).

Similar leuco-tonalite occurring as fragments in Niijima has $\delta^{18}O$ values of 6.4 and 6.9‰, and the average

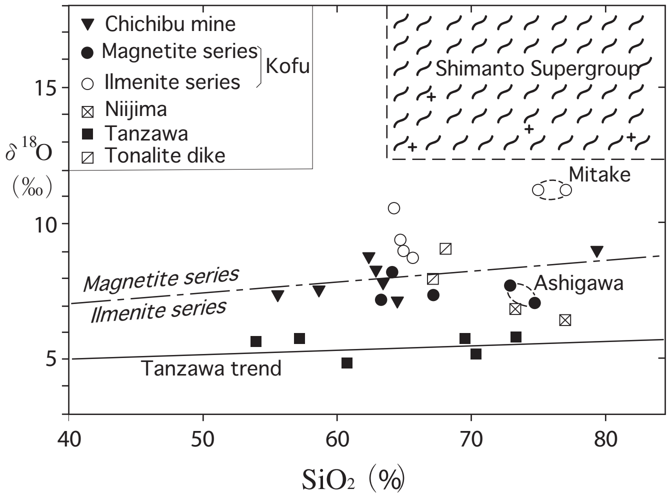

Fig. 3 Silica contents vs. $\delta^{18}O$ values of plutonic rocks from the southern Fossa Magna region. The magnetite- and ilmenite-series boundary line is taken from Ishihara and Matsuhisa (2002). Cross, Sandstone and shale of the Shimanto Supergroup by Shimizu (1986). The composition area for the Shimanto Supergroup was drawn in referring also to the data of Ishihara and Matsuhisa (1999).

of 6.7‰ at SiO_2 75.2% is 1.3‰ higher than that of the Tanzawa pluton at the same silica content. Another low-K series of the Ashigawa-type tonalite has an average $\delta^{18}O$ value of 8.0‰ at SiO_2 70.7%, and is 2.5‰ higher than the Tanzawa tonalite of the same SiO_2 content. Thus, three low K-series granitoids have own independent values reflecting their source materials.

In the Kofu pluton (Fig. 2), the major granodiorite has a wide range of $\delta^{18}O$ values, being low (7.1 - 8.1 ‰, average 7.4‰ at SiO_2 62.7%, n=4) on the magnetite series, but high (8.8 - 10.5‰, averaged as 9.4‰ at SiO_2 64.8%) on the local ilmenite-series Tokuwa type. The ilmenite-series granodiorite occurs at margins of the body and/or below the roof-pendant of the Shimanto Supergroup (Shimizu, 1986). One magnetite-series tonalite from the southern part has a $\delta^{18}O$ value as low as 4.5‰ (No. 15). The Mitake-type biotite granite of ilmenite series is the highest (11.2‰) among the Kofu granitoids.

In the Chichibu mine stock, the magnetite-series quartz diorite-granodiorite have $\delta^{18}O$ values of 7.1 - 8.9‰ . The ilmenite-series rocks have similar $\delta^{18}O$ values of 7.9 - 8.2‰. They are slightly higher and lower, respectively, than those of the magnetite and ilmenite-series of the main granodiorite of the Kofu pluton (Fig. 3).

The late Cenozoic granitoids of the Lake Suwa – Wadatoge area vary from 3.8 to 8.5‰. Two high values, 8.3 and 8.5‰, are plotted above the magnetite/ilmenite-series boundary line (Fig. 4). One low value

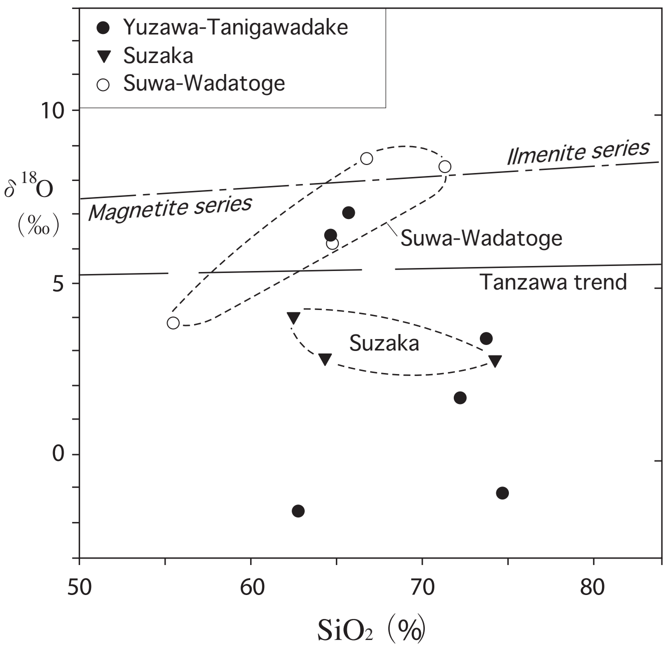

Fig. 4 Silica contents vs. $\delta^{18}O$ values of plutonic rocks from the northern Fossa Magna region.

(3.8‰, No. 32) has been severely altered to epidote> sericite. In the Suzaka area (Sawamura and Owa, 1953), the granitoids show low values between 2.7 and 3.9‰. All these rocks are hydrothermally altered to some degrees.

Similar rocks occur in the Yuzawa-Tanigawadake area. They reveal a wide range of 7.8 to -1.7‰ $\delta^{18}O$, but generally of low $\delta^{18}O$ values. The sample No. 41 (6.3‰ $\delta^{18}O$) was obtained from the Kashima excavating section of the Dai-Shimizu Shinkan-sen tunnel at 390 m above sea level, which is 300 meters below the surface. The sample No. 42 (6.9‰ $\delta^{18}O$) was collected from the Taisei excavating section of the Dai-Shimizu Shinkansen tunnel at 410 m above sea level, which is 600 meters below the rugged mountains at south of the Shigekura-dake (1,978 m). These samples are the freshest ones and the two values should represent the $\delta^{18}O$ values of the magmatic value of this pluton.The sample No. 43 was taken from the same Taisei excavating section and is irregular dike form intruding into the main phase. This rock contains secondary titanite, epidote and chlorite, and gives a very low value of -1.2‰. All the other rocks having low $\delta^{18}O$ values are more or less hydrothermally altered.

Among the late Cenozoic granitoids of the Tohoku-Hokkaido Districts, those intruding the basement complex have a wide range of $\delta^{18}O$ values (Fig. 5). The Tsuchiuchi body of magnetite series has low values of 3.5 and 1.0‰. The Ryugamori samples are those studied by Hujimoto (1971). The magnetic susceptibility measurement indicates that the body is exceptionally of ilmenite series in the Green Tuff belt. The granitoids have 6.6 to 7.6‰ $\delta^{18}O$, which are plotted below the magnetite/ ilmenite-series boundary line (Fig. 5); these rocks have been altered hydrothermally to some degrees (Table 1).

Small plutonic bodies occurring in Miocene basins have also a variety of $\delta^{18}O$ values. The samples 51 and 52 are taken from underground tunnels for Au-rich chalcopyrite veins at Ani mine, Akita Prefecture. Granitoids of the northern Tohoku disrict have the $\delta^{18}O$ values below the magnetite/ilmenite series boundary (Fig. 5). In the Hokkaido District, however, Jozankei granodiorite porphyry and some of Sangaitaki granitoids are plotted above the magnetite/ilmenite series boundary (Fig. 5), indicating that the granitoids here are slightly enriched in ^{18}O relative to those of the Tohoku district.

4. Discussion on Geneses

On the oxygen isotopic studies of the East Japan Island Arc, Matsuhisa (1979) found the lowest values on tholeiitic basalt to dacite (Group I) from an volcanic island of Hachijo-jima, and 0.5-1.7‰ $\delta^{18}O$ higher values on the calc-alkaline volcanic rocks (Group II) throughout the arc. He interpreted the Group I basalts are products of direct melting of fresh upper mantle, and the andesites and dacites are resulted from fractional crystallization of the tholeiitic basalt magmas. Felsic magmas could also be generated by dehydra-

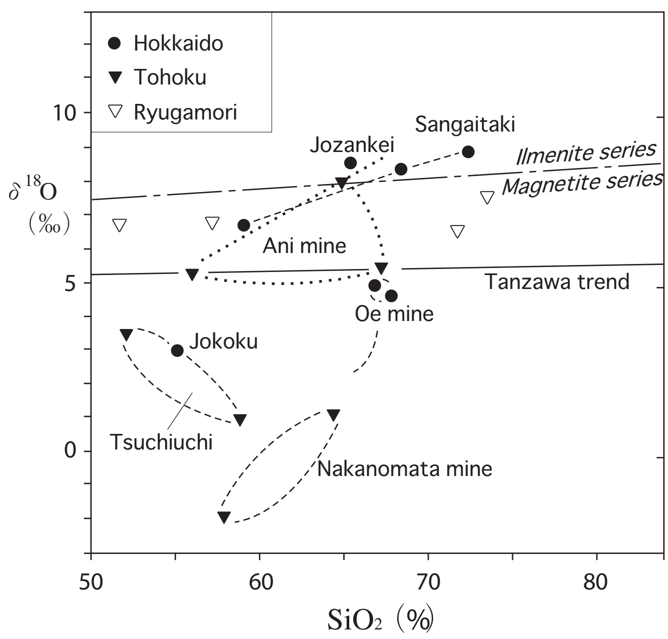

Fig. 5 Silica contents vs. $\delta^{18}O$ values of plutonic rocks from the Tohoku and Hokkaido Districts.

tion melting of pre-existed andesites by heat provided by basalt injection (Tamura and Tatsumi, 2002). The Group II volcanic rocks are considered to have formed from ^{18}O-enriched deep-source magmas and/or tholeiitic magmas contaminated with ^{18}O-rich crustal materials.

The mafic plutonic rocks of the Tanzawa pluton may represent original $\delta^{18}O$ composition of the underlying lower crust and upper mantle. Kawate and Arima (1998) postulated that the main part of the tonalites of this pluton was remelting portion of underplated gabbroic lower crust. Our data indicate that their source gabbroids must have had lower $\delta^{18}O$ values in the Tanzawa than that of the Hachijo-jima for some reasons. The tonalite breccias in the Nii-jima are, however, similar in the $\delta^{18}O$ values to the volcanic rocks of Hachijo-jima (Matsuhisa, 1979), and therefore they may be differentiates of the tholeiitic basalt. The Ashigawa-type tonalite of the Kofu pluton is slightly enriched in $\delta^{18}O$ than the Nii-jima tonalites, implying a higher $\delta^{18}O$ source rocks than the Hachijo-jima tholeiite. Thus, even within the low-K series, the source materials seem different in terms of $^{18}O/^{16}O$ ratio. The low-K series rocks contain usually magnetite, so that the source rocks must have been an oxidized type.

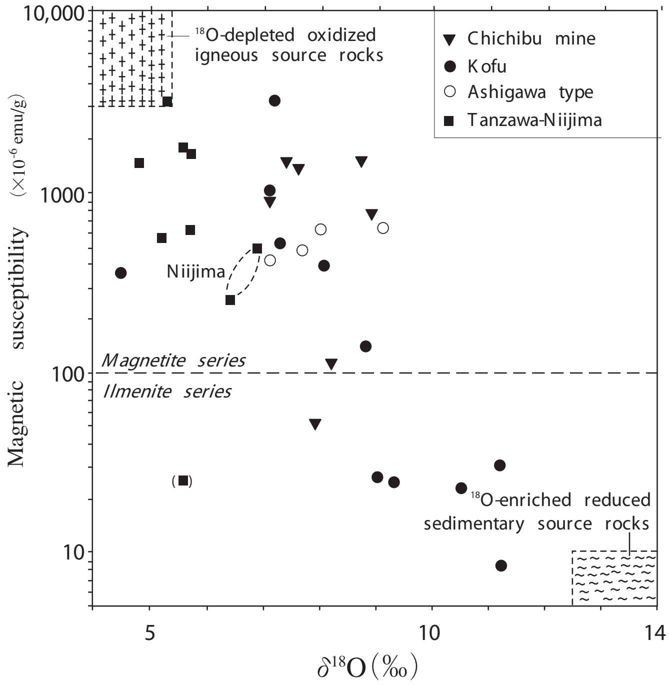

Fig. 6 Magnetic susceptibility vs $\delta^{18}O$ values of plutonic rocks from the southern Fossa Magna region.

The main part of the Kofu pluton having normal K_2O/Na_2O ratios, are plotted around the magnetite-series/ilmenite-series boundary (Fig. 3). The magnetite-series granodiorites are considered generated in ^{18}O-enriched igneous sources than the Hachijo-jima tholeiite. The ilmenite-series granitoids were reduced by dropping-off of the accretionary complex into the magma chamber in the middle-upper crust, which is visible in field around the Tokuwa Granodiorite, and also shown by a negative correlation between the $\delta^{18}O$ values and magnetic susceptibility (Fig. 6). The Mitake-type granites, on the other hand, contain no sedimentary enclaves but reduced. They may have been generated in C-bearing homogenized rocks in the middle crust, or a differentiated oxidized magma reduced by circulation of reduced gases (Takagi and Tsukimura, 1999).

Among 14 samples studied in the late Cenozoic granitoids of the northern Fossa Magna region, 8 samples showed $\delta^{18}O$ values lower than that of the Tanzawa trend (Fig. 4). These values are too low for the calc-alkaline granitoids, and considered ^{18}O-depletion by interaction with circulating heated meteoric water. This interpretation is supported by microscopic observation on the altered minerals and also by the fact that the depletion was most observed in the Yuzawa-Tanigawadake region, which is topographically high.

In the Tohoku and Hokkaido districts, the depleted values were found in very small stocks of the Nakanomata mine of Yamagata Prefecture, and of the Oe and Jokoku mines of Hokkaido. The freshest granitoids available on surface from these small stocks show a local heterogeneity being high in the southwestern Hokkaido (e.g., Sangaitaki, Jozankei) relative to the Tohoku district. The depleted values are considered caused by interaction with heated meteoric water at the time of mineralizations.

5. Conculusions

The whole rock $\delta^{18}O$ values of the late Cenozoic granitoids are most variable in those of the southern Fossa Magna region. Low-K magnetite-series tonalite of the Tanzawa pluton intruding into metavolcanics of the Green Tuff belt are the lowest in $\delta^{18}O$ values (5.4 ‰ at SiO_2 61%), implying that the source is ^{18}O-depleted tholeiitic gabbroids and/or mafic rocks of an oxidized type in the lower crust.

The largest Kofu composite pluton is found to consist of ^{18}O-depleted magnetite-series Ashigawa type (7.4‰ at SiO_2 73.8%) and ^{18}O-enriched ilmenite-series Tokuwa type (9.4‰ at SiO_2 64.8%) and Mitake type (11.2‰ at SiO_2 76.0%). This variation is considered to reflect the source rocks and lithology of the basements: the low $\delta^{18}O$ granitoids originated in mafic igneous source occurring in metavolcanic ensimatic basement, while the high $\delta^{18}O$ rocks generated in an igneous source intruding into thick piles of sediments in the accretionary terranes.

From the northern Fossa Magna northward, the late

Cenozoic granitoids have local heterogeneity, being high in the Wada-toge area and southwestern Hokkaido district. ^{18}O-depleted values have often been observed, suggesting pervasive interaction of the magmas with meteoric water at such high-level portions of these intrusive bodies.

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References

Akita-ken (1973) *Geological map series of Akita Prefecture, Ohdate. Scale 1:50,000*, 94 p. (in Japanese).

Chihara, K., Komatsu, M., Shimazu, M., Kubota, Y. and Shiokawa, S. (1981) Geology of the Echigo-Yuzawa District. *Quadrangle Series, Scale 1:50,000, Geol. Surv. Japan*, 108 p. (in Japanese with English abstract).

Doi, N., Kanisawa, S. and Ishikawa, K. (1995) Neo-tectonic fracturing after emplacement of Quaternary granitic pluton in the Kakkonda geothermal field, Japan. *Geotherm. Resources Council. Trans*. **19**, 297-303.

Fujiwara, T. (1954) Explanatory text of the geological map of Japan. *Sokeishu. Scale 1:50,000, Geol. Surv. Hokkaido*, 82 p. (in Japanese with English abstract).

Geological Survey of Japan (1992) *Geological map of Japan. 3rd ed., Scale 1:1,000,000*.

Hujimoto, Y. (1971) On the Ryugamori granite mass, northern Akita Prefecture. *Japan. Assoc. Miner. Petrol. Econ. Geol*., **65**, 16-33 (in Japanese with English abstract).

Ishihara, S. (1974) Magmatism of the Green Tuff tectonic belt, Northeast Japan. *Mining Geol. Spec. Issue*, **6**, 235-250.

Ishihara, S. and Matsuhisa, Y. (1999) Oxygen isotopic constraints on the geneses of the Miocene Outer Zone granitoids in Japan. *Lithos*, **46,** 523-534.

Ishihara, S. and Matsuhisa, Y. (2002) Oxygen isotopic constraints on the geneses of the Cretaceous-Paleogene granitoids in the Inner Zone of Southwest Japan. *Bull. Geol. Surv. Japan*, **53**, 421-438.

Ishihara, S. and Matsuhisa, Y. (2004) Oxygen isotopic constraints on the geneses of the Cretaceous granitoids in the Kitakami and Abukuma terrains, Northeast Japan. *Bull. Geol. Surv. Japan*, **55**, 57-66.

Ishihara, S. and Morishita, Y. (1983) Neogene molybdenite mineralization in the Jokoku mine area, Hokkaido. *Bull. Geol. Surv. Japan*, **34**, 81-87 (in Japanese with English abstract).

Ishihara, S. and Terashima, S. (1992) K/Rb ratio of two contrasting magma series of the Neogene plutonic belts in Japan. *Proc. 1987 Guangzhou Intern. Sym.* 23-22, Sci. House, Beijing.

Ishihara, S., Kanaya, H. and Terashima, S. (1976) Genesis of the Neogene granitoids in the Fossa Magna region in Japan. *Marine Sci. Monthly*, **8**, 523-528 (in Japanese).

Ishihara, S., Kasahara, Y. and Matsueda, H. (1998) Discovery of Neogene granitoids in the southwestern Hokkaido. *Bull. Geol. Surv. Japan*, **49**, 461-467 (in Japanese with English abstract).

Ishihara, S., Terashima, S. and Tsukimura, K. (1987) Spatial distribution of magnetic susceptibility and ore elements, and cause of local reduction on magnetite-series granitoids and related ore deposits at Chichibu, central Japan. *Mining Geol*., **37**, 15-28.

Isshiki, N. (1987) Geology of the Nii Jima district. *Quadrangle Series, Scale 1:50,000, Geol. Surv. Japan*, 85 p. (in Japanese with English abstract).

Kamiyama, T., Yonebayashi, S., Fukumoto, H., Honma, T. and Aoki, T. (1958) On the geology and ore deposit of the Ani mine, Akita Prefecture, Japan. *Mining Geol*., **8**, 193-209 (in Japanese with English abstract).

Kanaya, H. and Ishihara, S. (1973) Regional variation of magnetic susceptibility of the granitic rocks in Japan. *Jour. Japan. Assoc. Min. Pet. Econ. Geol*., **68**, 211-224 (in Japanese with English abstract).

Kawate, S. and Arima, M. (1998) Petrogenesis of the Tanzawa plutonic complex, central Japan: exposed felsic middle crust of the Izu-Bonin-Mariana Arc. *Island Arc*, **7**, 342-358.

Matsuhisa, Y. (1979) Oxygen isotopic compositions of volcanic rocks from the East Japan island arcs and their bearing on petrogenesis. *Jour. Volc. Geotherm. Res*. **5**, 271-296.

Mimura, K., Kato, Y., and Katada, M. (1984) Geology of the Mitake-Shosenkyo District. *Quadrangle series. Scale 1:50,000, Geol. Surv. Japan*, 61 p. (in Japanese with English abstract).

Orimoto, S. (1964a) On the Tertiary granitic rocks at Ani mine, Akita Prefecture. *Japan. Assoc. Miner. Petrol. Econ. Geol*., **51**, 200-209 (in Japanese with English abstract).

Orimoto, S. (1964b) Geology and ore deposits of Nakanomata mine, Yamagata Prefecture – Part I. *Japan. Assoc. Miner. Petrol. Econ. Geol*., **52**, 1-10 (in Japanese with English abstract).

Orimoto, S. (1965) Some characteristics of "Tertiary granites" in northeastern Japan.*Japan. Assoc. Miner. Petrol. Econ. Geol*., **53**, 55-66 (in Japanese with English abstract).

Ota, R. and Katada, M. (1955) Explanatory text of the geological map of Japan. *Suzaka. Scale 1:50,000, Geol. Surv. Japan*, 54 p. (in Japanese with English abstract).

Saito, M., Uemuira, F. and Ozawa, A. (1952) Explanatory text of the geological map of Japan. *Kayanuma. Scale 1:50,000, Geol. Surv. Japan*, 58 p. (in Japanese with

English abstract).

Sato, K. and Ishihara, S. (1983) Chemical composition and magneic susceptibility of the Kofu granitic complex. *Bull. Geol. Surv. Japan*, **34**, 413-427 (in Japanese with English abstract).

Sawamura, K. and Owa, E. (1953) Explanatory text of the geological map of Japan. *Scale 1:50,000. Suwa. Geol. Surv. Japan*, 45 p. (in Japanese with English abstract).

Shibata, K. and Ishihara, S. (1979) Initial $^{86}Sr/^{87}Sr$ ratios of plutonic rocks from Japan. *Contrib. Mineral. Petrol.*, **70**, 381-390.

Shimizu, M. (1986) The Tokuwa batholith, central Japan – An example of occurrence of ilmenite-series and magnetite-series granitoids in a batholith. *Univ. Museum, Univ. Tokyo, Bull.* **28**, 146 p.

Shinoda, M., Sakai, T., Koono, J. and Kikuchi, H. (1974) Geology of the Ooe-Inakuraishi mine, with special reference to the vein system. *Mining Geol.*, **24**, 119-128 (in Japanese with English abstract).

Takita, Y. (1974) Petrography and the plutonic history of the Tanzawa tonalite complex. *Jour. Geol. Soc. Japan*, **80**, 505-523 (in Japanese with English abstract).

Takagi, T. and Tsukimura, K. (1999) Genesis of oxidized and reduced type granites. *Econ. Geol.*, **92**, 81-86.

Tamura, Y. and Tatsumi, Y. (2002) Remelting of an andesitic crust as a possible origin for rhyolitic magma on oceanic arcs: an example from the Izu-Bonin Arc. *Jour. Petrol.*, **43**, 1,029-1,047.

Terashima, S. and Ishihara, S. (1986) Copper, lead, zinc, arsenic and sulfur of the Japanese granitoids (3): Green tuff belt of Northeast Japan and Outer Zone of the Southwest Japan. *Bull. Geol. Surv. Japan*, v. 37, 605-624.

Yamanashi Pref. (1970) *Geology of Yamanashi Prefecture with 1: 100,000 scale geological map. Yamanashi-ken*, 240 p. (in Japanese).

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東北日本，グリーンタフ帯の後期新生代深成岩類における酸素同位体比からの束縛条件

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要　旨

東北日本，グリーンタフ帯の後期新生代深成岩類の64試料の酸素同位体比($\delta^{18}O_{SMOW}$)を全岩法で求めた．深成岩類はフォッサマグナ南部で大規模に露出し，新鮮な岩石が得やすい．ここでは低カリウム系列の丹沢トナル岩類が極めて低い値，平均値で5.4‰を示す．低い$\delta^{18}O$値はソレアイト火山岩類で一般的である．酸化的な苦鉄質火成岩類がトナル岩類の出発物質と考えられる．しかし同じく低カリウム系列に属する甲府岩体の芦川型は平均7.4‰，新島の場合は6.7‰であり，それぞれが固有の出発物質を持つことを示す．甲府岩体で一般的な磁鉄鉱系の花崗閃緑岩類は平均して7.4‰であるのに対し，同じ岩体のチタン鉄鉱系徳和花崗閃緑岩類は9.4‰，御岳型黒雲母花崗岩は11.2‰を示し，共に高い値を持つ．その原因は火成岩起源マグマに^{18}Oに富む堆積岩類の混入があったためである．北部フォッサマグナ以北の後期新生代深成岩類は露出規模が小さい．低い$\delta^{18}O$値がしばしば認められ，固結時に地表水の混入が推察される．その原因は岩体頂部が露出していること及び地形的に高所にあることに求められる．