CHEMICAL VARIATION OF THE CRETACEOUS GRANITOIDS ACROSS SOUTHWESTERN JAPAN

—Shirakawa-Toki-Okazaki Transection—

SHUNSO ISHIHARA* and SHIGERU TERASHIMA*

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Introduction

Unilateral chemical variation is known on the ore metals from high-temperature type mineral deposits related to the Cretaceous to Paleogene granitoids in southwestern Japan (ISHIHARA, 1971b). This is suggestive for a regional variation on chemistry of the granitoids. Thus a systematic study to examine chemical variation of the major granitic masses was commenced by the senior author in the late 1960s. A part of the results was already included in the previous papers (*e.g.*, ISHIHARA, 1973) but the details were not published except for the radioactive elements (ISHIHARA *et al.*, 1969). This paper describes the original analytical data and regional variation along the western part of the Chubu district. Some genetic discussion is given in later sections.

The analyzed granitoids are the so-called fresh rocks available on surface and underground. The number of analyzed samples are approximately proportional to the exposed area of various granitoids, so that an arithmetic mean of all the analyses is believed to give an average composition of the Cretaceous granitoids along this transection. The total number of the analyses is 48 and the localities are plotted in Fig. 1. The analyses were made by conventional wet chemical method and atomic absorption spectrometry. The first author is responsible for field and mineralogical examination and the second author for chemical analyses in this joint paper.

Nomenclature of the granitic rocks adopted

in this paper is that recommended by the IUGS subcommission on the systematics of igneous rocks (STRECKEISEN *et al.*, 1973), a part of which is shown in Fig. 2. All the rocks examined fall within the category of granitoids. Gabbro and diorite are very rare along this transection.

General remarks

The granitoids in the Shirakawa-Toki-Okazaki transection constitute a part of the Cretaceous to Paleogene batholith distributed in the inner side of southwestern Japan. The K-Ar mineral age and the Rb-Sr whole rock age of the granitoids from the studied region give a narrow range between 55 and 80 m.y. (see Fig. 6).

Exposure of the granitoids in the north of the studied region have small dimensions (Fig. 1). They consist of fine-grained rocks. The IC number by CHAYES (1956) for example is more than 70 (ISHIHARA, 1971a). The southern region, on the other hand, is occupied almost entirely by medium- to coarse-grained granitoids. The IC number is less than 70 (SUZUKI & ISHIHARA, 1969).

The granitoids in the northern region consist of hornblende-biotite quartz monzodiorite and biotite monzogranite, and generally belong to the magnetite-series granitoids (ISHIHARA, 1975). The Shirakawa and Kadohara granitoids represent the northern region. This part belongs to the Sanin-Shirakawa belt or Molybdenum province in the previous papers (ISHIHARA, 1971b; KANAYA & ISHIHARA, 1973; TSUSUE & ISHIHARA, 1974).

The rocks in the southern region are largely composed of hornblende-biotite granodiorite

* Geological Survey of Japan, Kawasaki, Japan

Fig. 1. Distribution of the studied granitoids and localities of the analyzed samples.

Numerals 1 through 48 are the analysis numbers listed in Tables 1 and 2. Shaded area, magnetite-bearing granitoids; blank area, magnetite-free granitoids. The area of the Ryoke granitoids I, II and III nearly corresponds respectively to the zones classified by metamorphic grade of the intruded Paleozoic rocks by YAMADA *et al.* (1974): I, non-metamorphic and biotite zones; II, cordierite zone; and III, sillimanite zone. The broken line in the Ryoke III granitoids illustrates the outline of the Shimoyama tonalite.

and tonalite, and biotite or muscovite-biotite monzogranite. They have magnetite-free nature. The granitoids are divided into the Toki-Naegi pluton, which belongs to the Sanyo-Naegi belt or Tungstern province in the previous papers, and the Ryoke granitoids of the Ryoke belt or Barren province, although no sharp boundary can be drawn between these two belts. The Ryoke granitoid terrain is further subdivided geographically into the Areas I, II, and III, as illustrated in Fig. 1. Typical Ryoke granitoids, i.e., those in the Areas II and III, are foliated and relatively heterogeneous as compared with massive granitoids distributed to the north.

YAMADA *et al.* (1974) considered the Cretaceous granitoids of the entire Chubu District to belong to ten intrusion phases based on the cross-cutting relationship in field, and grouped these into the "older" and the "younger" granitoids. The majority of the granitoids in the studied region, except the Shimoyama tonalite, belongs to their younger granitoids.

Analyzed samples

Localities of the analyzed samples are shown in Fig. 1. Their modal compositions are given in Table 1 and Fig. 2.

Shirakawa granitoids

The Shirakawa granitoids consist of the Hatogaya, Hirase, Mihoro, Awara-dani, and some other small plutons. The Hatogaya pluton in its northern half is composed of xenolithic block of quartz monzodiorite (Analysis No. 1) and the surrounding monzogranite (No. 2), both intruded by aplitic monzogranite (No. 3). The southern half consists of monzogranite.

The Hirase pluton is most salic as a whole among the Shirakawa granitoids, and consists of monzogranite (Nos. 4, 5), which contains aplitic phase (No. 6) and small bodies of pegmatites. Molybdenite-quartz vein mineralization is known in the margin of the pluton. Both the Mihoro (No. 7) and the Awara-dani (No. 8) plutons consist of quartz monzodiorite. The Awara-dani pluton has generally magnetite-free nature unlike those other plutons in the Shirakawa area.

Fig. 2. Modal plagioclase-potassium feldspar-quartz of the Shirakawa, Toki, Naegi and Ryoike granitoids.

The original data on the Shirakawa granitoids and the Naegi monzogranite are given in ISHIHARA (1971a) and ISHIHARA (1971b), respectively. The rest are listed in Table 1 of the present paper. Solid circle, Shirakawa granitoids; open circle with bar, Toki and Ryoike I granitoids; open circle, Ryoike II and III granitoids.

The Kadohara pluton exposed to the west of the Awara-dani pluton may be Cretaceous in age (KAWAI *et al.*, 1957), although no chronological evidence is so far available. This is composed of quartz monzodiorite, which is partly granophyric in texture. Secondary epidote is fairly common. Two analyses (Nos. 9,10) from this pluton are supplemented.

Toki and Naegi plutons

The Toki pluton showing a circular exposure of 139 km² has granodiorite at the northwestern corner (Nos. 11,12) but the majority is monzogranite (Nos. 13—17).

The Naegi pluton, located to the east of the Toki pluton, is entirely monzogranite (Nos. 18,19). A fine-grained marginal phase (No. 20) can be seen along the western rim. Many small bodies of pegmatite that contain various heavy metal oxides are known in the monzogranite, and greisen-type tungsten (and tin) deposits surround the pegmatite zone around the northwestern margin of

Table 1. Modal analyses of the Toki and Ryoike granitoids.

Analysis No.	Pl	Kf	Qz	Hb	Bt	Mus	Others	Total Points	
TOKI Granitoids	11	45.4	17.1	26.8	0.2	9.2	-	1.3	3676
	12	35.6	17.8	40.1	0.2	6.0	-	0.3	6659
	13	32.3	30.7	32.3	-	4.1	-	0.6	3608
	14	33.3	30.3	33.6	-	2.6	tr	0.2	3153
	15	37.7	29.5	28.6	-	3.9	0.1	0.2	3054
	16	38.3	26.3	33.6	-	1.2	0.2	0.4	3287
	17	27.3	27.0	43.8	-	1.3	-	0.6	3439
RYOKE I Granitoids	21	45.3	22.9	23.9	1.6	6.0	-	0.3	5743
	22	42.6	16.7	27.0	4.1	9.4	-	0.2	2811
	23	51.4	12.0	28.1	1.1	7.2	-	0.2	2727
	24	40.7	25.8	28.2	1.4	3.7	-	0.2	5418
	25	31.0	29.6	37.5	-	1.7	0.1	0.1	3208
	26	37.2	29.0	30.1	-	3.6	-	0.1	5482
	27	45.7	26.6	20.0	0.5	7.0	-	0.2	2582
	28	23.4	39.1	34.4	-	2.6	0.1	0.4	5001
	29	37.2	27.8	33.0	-	1.9	-	0.1	2844
	30	28.0	34.2	36.2	-	1.3	-	0.2	5600
RYOKE II Granitoids	31	48.3	6.1	22.7	8.0	14.3	-	0.6 (px 0.3)	2689
	32	57.9	8.8	20.2	2.0	10.5	-	0.6	5820
	33	49.9	19.6	24.6	1.6	4.1	-	0.2	6331
	34	45.5	10.3	34.8	1.8	7.2	-	0.4	6156
	35	36.7	31.3	27.6	1.4	2.7	-	0.3	6506
	36	45.2	-	9.9	29.0	13.5	-	2.4	2441
	37	39.8	14.1	33.3	4.4	8.1	-	0.3	4794
	38	35.3	19.7	38.0	4.5	2.3	-	0.2	4784
RYOKE III Granitoids	39	46.7	2.0	21.8	7.8	21.3	-	0.4	3041
	40	48.9	2.9	19.7	8.3	19.6	-	0.6	2710
	41	44.4	6.7	37.1	-	11.2	0.2	0.4 (gt 0.1)	2849
	42	46.3	14.5	31.5	-	6.8	0.6	0.3	2766
	43	37.3	20.0	33.5	-	6.1	2.8	0.3 (gt 0.2)	5536
	44	46.8	8.4	34.1	-	8.3	2.0	0.4 (gt 0.2)	2991
	45	26.1	33.6	32.7	-	3.6	3.7	0.4 (gt 0.3)	2545
	46	32.3	25.6	33.8	-	3.9	4.1	0.3	2539
	47	31.7	23.5	37.6	-	3.7	3.1	0.4	2988
	48	33.8	26.1	33.1	-	2.6	4.0	0.4 (gt 0.1)	3197

Point counter method was applied for one to three thin sections, 0.5 by 0.5 mm interval, potassium feldspar stained. Those of Nos. 11, 13, 16, 17, 28, 30, 39, 42 and 47 are taken from SUZUKI & ISHIHARA (1969). Abbreviations: Pl, plagioclase; Kf, potassium feldspar; Qz, quartz; Hb, amphiboles; Bt, biotite; Mus, muscovite; px, pyroxene; gt, garnet.

the Naegi pluton.

Ryoike granitoids

The Ryoike granitoids in this paper are defined as those having i) an areal scale of foliation, ii) microscopically observed stress effect such as kink and bent on biotite, wavy extinction on quartz, and a protoclastic texture in some occasions, and iii) those intruding into the Ryoike metamorphic rocks.

The Ryoke granitoids in the north, Ryoke I granitoids, are complex because the area is close to the northern end of the Ryoke belt. Analysis No. 21 for example is a strongly foliated granodiorite (see photograph in Fig. 9 of ISHIHARA & SUZUKI, 1969), which is common in the Ryoke II granitoids, and stress effect during the solidifying process is very distinct. Yet, Nos. 25 and 28 are stress-free monzogranite. The foliated granodiorite is a large xenolithic block floating in the monzogranite.

The Ryoke I granitoids consist of granodiorite (Nos. 21—23) and monzogranite (Nos. 24—28). Another monzogranite (Nos. 29, 30), distributed to the east of Seto, was correlated to the Toki and Naegi monzogranite by YAMADA *et al.* (1974). Petrochemically, the monzogranite has an intermediate nature between the Toki-Naegi monzogranite and the Ryoke I monzogranite.

The Ryoke II granitoids are mainly composed of granodiorite (Nos. 31—34) and partly monzogranite (No. 35), and are foliated northeast in general. The southwestern part is occupied by a porphyritic rock due to huge microcline crystals up to 15 by 60 mm. Analysis Nos. 36, 37, and 38 were taken from a road-cut to the south of Asuke township. Quartz diorite of No. 36 is irregularly shaped xenolith of 0.7 by 1 meters in the host granodiorite (No. 37) and monzogranite of No. 38 is slightly pegmatitic and salic portion next to the xenolith. These unusual rocks of Nos. 36 and 38 are not included in the discussion of the regional variation of chemistry.

The Ryoke III granitoids are characterized by a wide extent of muscovite-biotite monzogranite, which contains trace amount of garnet up to 0.3 volume%. Strongly foliated tonalite (Nos. 39–40), which may be called Shimoyama tonalite, occurs in the middle of the monzogranite (see Fig. 1). The foliation is generally parallel to the strike of the Median Tectonic Line.

The muscovite-biotite monzogranite is clastic in the marginal parts, being muscovite-bearing biotite granodiorite (Nos. 41, 42). A compositional banding may be seen in

Fig. 3. An example of heterogeneity of the Ryoke granitoids at Loc. 43.

A, biotite-rich band; B, biotite-poor band in the muscovite-biotite monzogranite.

the main part of the monzogranite. Analysis Nos. 44 and 55 demonstrate such banding of 7 to 10 cm in width (Table 1, Fig. 3). No. 43 is an average of the two analyses and this is used in the following discussion. The rest (Nos. 46—48) were taken from relatively homogeneous parts. Direction of the banding and faintly observed foliation vary from one place to another, although the longitudinal axis of exposure follows the structural trend of the Ryoke belt.

Major elements

The results of chemical analyses are listed in Table 2. The major elements are plotted against the differentiation index (abbreviated as DI) of THORNTON & TUTTLE (1960) in Fig. 4, with three categories of symbol, namely the Shirakawa and Kadohara granitoids (abbreviated as Shirakawa), the Toki and Naegi granitoids (abbreviated as Toki) and the Ryoke I granitoids, and the Ryoke II and III granitoids. The Toki granitoids and the Ryoke I granitoids are plotted with the same symbol, because i) the essential purpose of this study is to examine geographical chemical variation, ii) definition of the Ryoke granitoids is tectonics rather than chemistry, and iii) an intermediate nature is observed in some of the Ryoke I granitoids, as described previously.

SiO₂ is low in the Shirakawa granitoids and high in the Ryoke II and III granitoids (Fig. 4). This tendency is consistent with

the result of the modal analyses (Fig. 2). Regional variation of Al_2O_3 and CaO is not clear in Fig. 4, but Al_2O_3 is slightly high at DI 65—90 of the Ryoke II and III granitoids. An excess Al_2O_3 clearly increases to the south (see Fig. 6). Na_2O is definitely high in the Shirakawa granitoids. K_2O is high in the salic phases (DI above 80) of the Toki and Ryoke I granitoids. For these reasons the total alkalis are lowest in the Ryoke II and III granitoids.

There is no clear difference on the total Fe content in the three regions, but the Shirakawa granitoids have ferric and those of other regions have ferrous nature, which are consistent with their magnetite-bearing and free character observed under the ore-microscope. FeO content of the Toki and Ryoke I granitoids is slightly higher than that of the Ryoke II and III granitoids. Both MgO and TiO_2 are high in the Shirakawa granitoids and are low in the Ryoke II and III granitoids.

P_2O_5 is high at DI 60—80 of the Shirakawa granitoids. This is due to relatively high content of apatite in these rocks. The same tendency is observed at DI 80—90 of the Ryoke II and III granitoids. Microscopic and X-ray studies indicate that this is due to both apatite and monazite contained in the muscovite-biotite monzogranite.

Minor elements

The same diagram as Fig. 4 is prepared

for minor elements and illustrated in Fig. 5. Two informations can be taken from this diagram. One is the variation of lithophile elements in different DI percentage. F, Rb, and Pb for example are generally considered to be concentrated at a late stage of magmatic evolution. This is true in the Toki and Ryoke granitoids. The Shirakawa granitoids, however, do not show such variation. These two phenomena are tentatively called "increase type" and "constant type", respectively. The second information is regional variation of the minor elements, which is closely related to the above-mentioned two types.

F, Rb, Pb, Sn, Be, and even Li, which is considered to substitute Mg in rock-forming minerals, increase with the increase of DI in the Toki and Ryoke I granitoids. In the Shirakawa granitoids, no change (Li, Pb, and Be), slight decrease (F and Sn), or very slight increase (Rb) can be observed. Cl, Sr, Zn, and Cu decrease with the increase of DI in all the granitoids.

Regionally speaking, F is high in the Toki and Ryoke I granitoids, and is low in the other granitoids. Cl shows somewhat similar regional distribution. Sr is lowest but Rb is highest in the Toki granitoids. The Naegi monzogranite is extremely low in Sr. Li is high in both the Toki and Ryoke granitoids, especially in the muscovite-biotite monzogranite. No regional variation can be seen on Zn and Cu, but the Kadohara quartz monzodiorite has high Cu content.

Table 2. Chemical analyses of the studied granitoids (on pages 6—9).

Major elements were analyzed by conventional wet chemical method used at the Geological Survey of Japan. Analyst, Tokyo Analytical Laboratory for Coal & Minerals. Alkalis were re-examined by atomic absorption method (TERASHIMA, 1970), F and Cl by spectrophotometric method (TERASHIMA, 1974), and the others by atomic absorption methods (TERASHIMA, 1971, 1973, 1975). All analyzed by S. TERASHIMA. Analysis Nos. 4 and 5 contain 0.07 and 0.04% S, respectively. For rock names refer the modal compositions. Localities and sample numbers are given in the appendix.

Nos. 36–38 were sampled from the same outcrop. No. 36, center of 0.7 by 1 m mafic xenolith; No. 37, host granodiorite; No. 38, pegmatitic salic rim, 7 cm in width, around the xenolith. No. 43, arithmetic mean of Nos. 44 and 45. No. 44, biotite-rich band of 10 cm in width; No. 45, biotite-poor band of 7 cm in width. The banding strikes $\text{N}50^\circ\text{W}$ and dips 70°S .

Table 2-1.

SHIRAKAWA GRANITOIDS												
Analysis No.	HATOGAYA			HIRASE			OTHERS		KADOHARA		TOKI	
	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	59.10	72.86	76.28	71.46	75.48	76.20	69.34	65.46	61.32	62.32	68.10	70.57
TiO ₂	0.87	0.25	0.10	0.24	0.14	0.08	0.37	0.43	0.63	0.62	0.46	0.39
Al ₂ O ₃	17.56	13.94	12.84	15.35	13.47	13.60	15.46	17.12	16.86	15.78	16.52	14.78
Fe ₂ O ₃	1.86	1.20	0.68	0.40	0.36	0.48	1.12	0.72	1.44	2.28	0.64	0.40
FeO	3.92	0.93	0.18	1.36	0.68	0.14	1.58	2.66	3.81	3.05	2.95	2.30
MnO	0.27	0.04	0.04	0.06	0.05	0.02	0.10	0.06	0.06	0.09	0.06	0.09
MgO	2.42	0.40	0.15	0.68	0.47	0.04	0.78	1.55	2.98	2.64	0.96	0.77
CaO	5.34	1.77	0.69	1.80	0.45	0.67	2.63	3.67	5.36	4.57	3.05	2.60
Na ₂ O	4.42	3.63	3.62	4.29	3.65	3.60	4.35	4.00	3.72	3.79	3.34	3.41
K ₂ O	2.03	3.77	4.63	2.97	3.95	4.45	2.86	2.93	2.47	2.93	2.92	3.47
P ₂ O ₅	0.33	0.12	0.09	0.01	<0.01	0.07	0.19	0.23	0.19	0.19	0.14	0.11
H ₂ O(+)	1.14	0.54	0.14	0.68	0.53	0.22	0.76	0.47	0.57	1.05	0.54	0.70
H ₂ O(-)	0.38	0.18	0.16	0.34	0.36	0.24	0.22	0.40	0.32	0.30	0.22	0.20
Total	99.64	99.63	99.60	99.64	99.60	99.81	99.76	99.70	99.73	99.61	99.90	99.79
F	860	260	270	790	340	140	440	520	470	440	820	770
Cl	165	55	85	80	30	55	145	165	300	250	250	140
Sr	452	249	30	234	77	21	259	492	559	411	358	257
Rb	70	110	162	131	137	149	95	117	79	99	132	151
Li	13	9	8	32	31	8	12	36	12	8	47	37
Zn	105	33	28	34	17	17	75	63	38	53	66	61
Cu	4	2	1	3	4	2	4	5	46	41	4	2
Pb	9	9	15	10	11	13	13	12	9	13	14	20
Sn	2.0	0.2	0.6	1.0	0.6	0.6	1.4	2.2	1.8	1.8	4.2	3.2
Be	2.6	1.2	2.1	2.9	1.5	2.1	2.1	2.7	1.2	1.3	3.0	2.8
Q	9.84	33.10	36.06	29.44	37.13	36.93	26.12	19.77	13.34	15.44	27.99	29.49
C	-	0.96	0.83	1.83	2.40	1.81	0.88	1.25	-	-	2.65	0.95
or	12.00	22.28	27.36	17.55	23.34	26.30	16.90	17.31	14.60	17.31	17.26	20.51
ab	37.40	30.72	30.63	36.30	30.89	30.46	36.81	33.85	31.48	32.07	28.26	28.85
an	22.08	8.00	2.84	8.86	2.17	2.87	11.81	16.70	22.01	17.39	14.22	12.18
wo	0.94	-	-	-	-	-	-	-	1.39	1.69	-	-
en	0.51	-	-	-	-	-	-	-	0.80	1.09	-	-
fs	0.40	-	-	-	-	-	-	-	0.53	0.48	-	-
en	5.52	1.00	0.37	1.69	1.17	0.10	1.94	3.86	6.62	5.48	2.39	1.92
fs	4.33	0.38	-	1.88	0.81	-	1.55	3.69	4.35	2.38	4.24	3.42
mt	2.70	1.74	0.42	0.58	0.52	0.28	1.62	1.04	2.09	3.31	0.93	0.58
hm	-	-	0.39	-	-	0.28	-	-	-	-	-	-
il	1.65	0.47	0.19	0.46	0.27	0.15	0.70	0.82	1.20	1.18	0.87	0.74
ap	0.76	0.28	0.21	0.02	0.02	0.16	0.44	0.53	0.44	0.44	0.32	0.25
Total	98.13	98.93	99.30	98.61	98.72	99.34	98.77	98.82	98.85	98.26	99.13	98.89
D. I.	60.4	87.0	94.7	84.5	92.6	94.3	80.8	71.8	60.1	66.0	74.2	79.7

Table 2-2.

T O K I G R A N I T O I D S								R Y O K E I G R A N I T O I D S				Analysis No.
T O K I					N A E G I			21	22	23	24	
13	14	15	16	17	18	19	20					
72.72	74.44	74.29	75.18	75.54	76.73	76.12	77.48	65.53	68.06	70.03	72.10	SiO ₂
0.11	0.10	0.07	0.07	0.12	0.09	0.09	0.09	0.55	0.52	0.29	0.24	TiO ₂
14.67	14.07	14.04	13.68	13.32	12.88	13.04	12.57	16.60	14.96	14.83	14.36	Al ₂ O ₃
0.56	0.40	0.24	0.16	0.32	0.32	0.12	0.20	0.60	0.60	0.40	0.48	Fe ₂ O ₃
1.35	1.14	0.93	0.93	0.86	0.79	0.75	0.61	3.84	3.20	2.14	1.58	FeO
0.07	0.05	0.05	0.04	0.04	0.02	0.03	0.02	0.07	0.11	0.07	0.04	MnO
0.21	0.24	0.11	0.08	0.14	0.13	0.02	0.02	1.30	1.45	0.70	0.47	MgO
1.20	1.24	1.11	0.95	0.87	0.90	0.71	0.66	4.03	3.71	2.29	2.20	CaO
3.63	3.40	3.49	3.51	3.46	3.27	3.71	3.61	3.15	2.84	3.05	3.46	Na ₂ O
4.35	4.07	4.68	4.63	4.29	4.27	4.50	4.13	2.78	3.10	5.10	3.82	K ₂ O
0.06	0.06	0.05	0.02	0.05	0.02	0.03	0.08	0.13	0.12	0.09	0.07	P ₂ O ₅
0.63	0.21	0.38	0.50	0.31	0.22	0.19	0.27	0.82	0.67	0.48	0.57	H ₂ O(+)
0.26	0.38	0.28	0.14	0.32	0.08	0.54	0.22	0.32	0.38	0.36	0.32	H ₂ O(-)
99.82	99.80	99.72	99.89	99.64	99.72	99.85	99.96	99.72	99.72	99.83	99.71	Total
1330	1060	1150	1420	900	1270	1420	1300	530	500	530	580	F
90	160	110	80	60	150	80	65	95	120	90	135	Cl
115	88	69	54	46	15	14	4	158	229	193	189	Sr
236	213	243	289	271	330	333	346	143	112	202	135	Rb
44	43	60	44	40	80	91	60	48	47	35	28	Li
80	34	25	23	31	13	30	21	46	59	44	34	Zn
10	1	1	2	3	1	1	2	1	2	3	1	Cu
44	27	30	30	33	25	28	25	18	20	28	20	Pb
11.2	3.3	2.6	1.8	5.2	2.6	5.5	5.0	4.0	3.7	3.0	1.2	Sn
5.5	3.3	3.3	3.0	4.5	4.2	4.4	5.0	2.5	1.9	1.8	2.3	Be
31.35	35.47	33.00	34.25	36.52	38.81	35.31	39.07	23.73	27.75	25.59	31.14	Q
1.95	1.96	1.33	1.22	1.52	1.29	0.85	1.15	1.39	0.47	0.34	0.70	C
25.71	24.05	27.66	27.36	25.35	25.23	26.59	24.41	16.43	18.32	30.14	22.57	or
30.72	28.77	29.53	29.70	29.28	27.67	31.39	30.55	26.65	24.03	25.81	29.28	ab
5.56	5.76	5.18	4.58	3.99	4.33	3.33	2.75	19.14	17.62	10.77	10.46	an
-	-	-	-	-	-	-	-	-	-	-	-	wo
-	-	-	-	-	-	-	-	-	-	-	-	en
-	-	-	-	-	-	-	-	-	-	-	-	fs
0.52	0.60	0.27	0.20	0.35	0.32	0.05	0.05	3.24	3.61	1.74	1.17	en
1.96	1.69	1.49	1.53	1.19	1.07	1.19	0.84	5.78	4.73	3.25	2.18	fs
0.81	0.58	0.35	0.23	0.46	0.46	0.17	0.29	0.87	0.87	0.58	0.70	mt
-	-	-	-	-	-	-	-	-	-	-	-	hm
0.21	0.19	0.13	0.13	0.23	0.17	0.17	0.17	1.04	0.99	0.55	0.46	il
0.14	0.14	0.12	0.05	0.12	0.05	0.07	0.19	0.30	0.28	0.21	0.16	ap
98.93	99.21	99.06	99.25	99.01	99.40	99.12	99.47	98.57	98.67	98.98	98.82	Total
88.7	89.0	91.0	92.0	92.1	92.3	94.1	94.5	67.8	71.1	82.4	84.0	D. I.

Table 2-3.

Analysis No.	R Y O K E I G R A N I T O I D S						R Y O K E II G R A N I T O I D S					
	MIZUNAMI-SANAGE				SETO		AKECHI-TOYOTA					ASUKE
	25	26	27	28	29	30	31	32	33	34	35	36
SiO ₂	73.04	72.67	73.42	76.17	74.54	74.96	63.92	66.16	67.09	68.24	71.26	51.46
TiO ₂	0.15	0.14	0.26	0.10	0.14	0.12	0.66	0.59	0.31	0.38	0.28	2.07
Al ₂ O ₃	15.28	14.94	13.66	13.06	14.06	13.92	16.58	16.96	17.79	16.18	15.30	16.90
Fe ₂ O ₃	0.32	0.40	0.60	0.16	0.28	0.36	0.82	0.80	0.40	0.72	0.56	2.28
FeO	1.15	1.15	1.62	0.86	1.04	0.83	4.42	3.59	2.01	2.59	1.65	9.59
MnO	0.06	0.04	0.07	0.02	0.08	0.07	0.11	0.08	0.06	0.06	0.04	0.26
MgO	0.26	0.19	0.51	0.06	0.29	0.27	2.28	1.19	0.58	0.89	0.37	3.49
CaO	1.93	1.82	1.53	1.09	1.12	1.22	4.90	4.31	4.76	3.56	2.69	8.32
Na ₂ O	3.01	3.05	3.14	3.29	3.29	2.93	2.79	3.07	3.05	3.27	3.63	2.60
K ₂ O	4.02	4.35	4.22	4.49	4.16	4.50	2.20	2.05	2.63	2.69	3.19	1.41
P ₂ O ₅	0.04	0.03	0.09	0.02	0.04	0.03	0.15	0.16	0.08	0.11	0.07	0.32
H ₂ O(+)	0.27	0.57	0.52	0.32	0.45	0.38	0.66	0.66	0.68	0.60	0.26	0.62
H ₂ O(-)	0.26	0.42	0.16	0.20	0.34	0.24	0.38	0.32	0.22	0.24	0.40	0.52
Total	99.79	99.77	99.80	99.84	99.83	99.83	99.87	99.94	99.66	99.53	99.70	99.84
F	600	290	630	1000	370	360	480	700	380	480	420	540
Cl	80	70	110	90	65	80	60	160	100	60	145	290
Sr	72	152	143	51	72	56	251	283	356	293	257	336
Rb	168	120	180	206	234	260	99	78	72	76	71	44
Li	20	21	39	37	72	51	34	25	18	16	17	25
Zn	17	26	44	26	27	28	63	68	37	50	37	142
Cu	1	3	2	2	1	2	4	6	2	9	2	23
Pb	24	21	26	25	31	42	19	11	17	15	16	13
Sn	1.6	1.2	4.6	1.4	5.8	4.1	2.8	0.6	1.1	2.2	0.6	0.4
Be	1.7	1.0	3.0	2.5	3.0	2.5	1.6	2.0	1.9	1.7	2.0	1.5
Q	34.96	33.44	34.23	36.88	36.04	37.24	22.81	27.57	27.10	28.62	30.83	4.91
C	2.56	1.98	1.36	0.85	2.20	2.08	1.06	2.24	1.46	1.68	1.15	-
or	23.76	25.71	24.94	26.53	24.58	26.59	13.00	12.11	15.54	15.90	18.85	8.33
ab	25.47	25.81	26.57	27.84	27.84	24.79	23.61	25.98	25.81	27.67	30.72	22.00
an	9.31	8.83	7.00	5.28	5.30	5.86	23.33	20.34	23.09	16.94	12.89	30.28
wo	-	-	-	-	-	-	-	-	-	-	-	3.72
en	-	-	-	-	-	-	-	-	-	-	-	1.52
fs	-	-	-	-	-	-	-	-	-	-	-	2.23
en	0.65	0.47	1.27	0.15	0.72	0.67	5.68	2.96	1.44	2.22	0.92	7.18
fs	1.71	1.62	2.18	1.32	1.60	1.16	6.55	5.11	2.96	3.65	2.18	10.56
mt	0.46	0.58	0.87	0.23	0.41	0.52	1.19	1.16	0.58	1.04	0.81	3.31
hm	-	-	-	-	-	-	-	-	-	-	-	-
il	0.28	0.27	0.49	0.19	0.27	0.23	1.25	1.12	0.59	0.72	0.53	3.93
ap	0.09	0.07	0.21	0.05	0.09	0.07	0.35	0.37	0.19	0.25	0.16	0.74
Total	99.25	98.78	99.12	99.32	99.05	99.21	98.83	98.96	98.76	98.69	99.04	98.71
D. I.	84.8	86.0	86.5	91.9	89.3	89.3	60.1	66.4	69.3	73.2	81.2	35.7

Table 2-4.

RYOKE II GRANITOID		R Y O K E III				G R A N I T O I D S			OKAZAKI			Analysis No.
37	38	SHIMOYAMA		41	42	NUKATA			46	47	48	
		39	40			43	44	45				
68.54	72.52	60.24	61.08	69.68	72.78	72.49	72.49	72.49	73.30	73.57	72.99	SiO ₂
0.42	0.26	0.78	0.76	0.30	0.23	0.21	0.25	0.17	0.16	0.16	0.13	TiO ₂
15.26	14.14	16.73	17.34	16.50	14.93	14.98	14.94	15.01	15.16	15.18	15.15	Al ₂ O ₃
0.68	0.56	0.80	0.68	0.48	0.36	0.40	0.44	0.36	0.28	0.36	0.24	Fe ₂ O ₃
3.13	2.01	5.14	4.92	2.44	1.90	1.55	1.90	1.19	1.19	1.04	0.86	FeO
0.08	0.06	0.11	0.11	0.09	0.04	0.05	0.06	0.04	0.06	0.05	0.06	MnO
1.25	0.87	4.01	3.58	0.74	0.62	0.57	0.59	0.55	0.46	0.28	0.26	MgO
3.59	2.83	5.57	5.10	2.97	2.58	1.93	2.46	1.40	1.60	1.23	1.40	CaO
2.45	2.17	2.84	2.99	3.44	3.37	2.95	3.49	2.40	3.21	2.97	3.43	Na ₂ O
3.81	4.11	2.03	2.06	1.90	2.14	3.85	2.38	5.32	3.32	4.01	4.58	K ₂ O
0.09	0.06	0.20	0.19	0.15	0.09	0.14	0.15	0.13	0.13	0.11	0.15	P ₂ O ₅
0.16	0.08	0.95	0.84	0.74	0.49	0.30	0.46	0.14	0.63	0.57	0.49	H ₂ O(+)
0.46	0.24	0.26	0.16	0.30	0.14	0.38	0.26	0.50	0.34	0.32	0.20	H ₂ O(-)
99.92	99.91	99.66	99.81	99.73	99.67	99.80	99.87	99.70	99.84	99.85	99.94	Total
530	250	480	390	630	230	515	550	480	700	400	480	F
60	85	260	335	55	70	40	40	40	60	60	60	Cl
255	252	331	308	388	439	359	387	330	216	201	97	Sr
110	105	71	81	60	70	103	83	123	116	134	210	Rb
22	14	42	41	61	29	37	42	31	57	43	105	Li
59	38	80	90	70	61	63	80	46	43	46	37	Zn
2	2	20	20	2	2	3	3	2	3	2	2	Cu
22	23	15	15	19	20	25	19	30	20	27	27	Pb
2.0	2.0	1.6	1.8	1.6	0.4	1.2	1.7	0.7	1.6	1.2	3.5	Sn
1.6	1.4	2.0	2.2	2.2	0.6	1.5	2.1	0.9	2.5	1.5	2.4	Be
28.29	35.65	15.10	16.70	33.64	37.48	35.01	36.07	33.95	37.36	37.55	31.97	Q
0.79	1.12	0.21	1.37	3.74	2.59	2.79	2.51	3.07	3.69	3.98	2.36	C
22.51	24.29	12.00	12.17	11.23	12.65	22.75	14.06	31.44	19.62	23.70	27.06	or
20.73	18.36	24.03	25.30	29.11	28.52	24.97	29.53	20.31	27.16	25.13	29.02	ab
17.22	13.65	26.33	24.06	13.75	12.21	8.70	11.22	6.10	7.09	5.38	5.97	an
-	-	-	-	-	-	-	-	-	-	-	-	wo
-	-	-	-	-	-	-	-	-	-	-	-	en
-	-	-	-	-	-	-	-	-	-	-	-	fs
3.11	2.17	9.99	8.92	1.84	1.54	1.42	1.47	1.37	1.15	0.70	0.65	en
4.64	2.91	7.69	7.42	3.76	2.89	2.25	2.82	1.68	1.80	1.44	1.28	fs
0.99	0.81	1.16	0.99	0.70	0.52	0.58	0.64	0.52	0.41	0.52	0.35	mt
-	-	-	-	-	-	-	-	-	-	-	-	hm
0.80	0.49	1.48	1.44	0.57	0.44	0.40	0.47	0.32	0.30	0.30	0.25	il
0.21	0.14	0.46	0.44	0.35	0.21	0.33	0.35	0.30	0.30	0.25	0.35	ap
99.29	99.59	98.45	98.81	98.69	99.05	99.20	99.14	99.06	98.88	98.95	99.26	Total
72.0	78.6	51.9	54.8	75.0	79.4	83.5	80.4	86.5	85.1	87.3	88.7	D. I.

Fig. 4. Major elements (wt. %) plotted against the differentiation index (wt. %).

Symbols same as in Fig. 2. Straight line, average compositions of the Japanese granitoids by ARAMAKI *et al.* (1972).

Fig. 5. Minor elements (ppm) plotted against the differentiation index (wt. %)

Symbols same as in Fig. 2.

Pb is very low in the Shirakawa granitoids, although the K_2O contents are more or less the same as those of the Toki and Ryoke granitoids. Both Sn and Be are high in the Toki and Ryoke granitoids.

Fig. 6.

Geographical distribution

Among the elements described above, some components are selected and geographically presented in Figs. 6 and 7. Although the DI percentage is ignored on these plots, the regional characteristics afore-mentioned are still seen in the diagrams. The following three points may be worth mentioning on Fig. 6.

An excess alumina, here normative corundum, increases definitely to the south. The corundum is highest in the muscovite-biotite monzogranite of the Ryoke III granitoids. Tonalite of the same group having such low DI values as 52 and 55, yields normative corundum. At second, normative or+ab decreases obviously to the south in contrast to the slight increase of normative Q.

Finally, both normative en/en+fs and mt+hm are high in the Shirakawa granitoids. This is consistent with the originally high contents of MgO in these rocks (Fig. 4) and the fact that iron is distributed to both Fe-Ti oxide phase and Mg-Fe silicate phase in these magnetite-bearing rocks. A clear increase of the en/en+fs ratio to the south is seen in the hornblende-biotite or biotite assemblage rocks of the Toki and Ryoke granitoids, which means a systematic change of Mg/Fe ratio in these silicates, because the granitoids are of the ilmenite series and contain no other ferromagnesian minerals.

In Fig. 7, minor elements are plotted onto the same transection. F, Rb, Li, Pb, Sn and

Fig. 6. Geographical variation of selected components as projected onto the N30°W line.

Open circle, the most differentiated pluton in Toki-Okazaki area. Naegi monzogranite (Nos. 18-20) for the Toki area, monzogranite (Nos. 29, 30) for the Ryoke I area, and muscovite-biotite monzogranite (Nos. 41-43, 46-48) for the Ryoke III area. Solid circle, all the others. Circle in the radiometric age data shows K-Ar mineral age and square Rb-Sr whole rock age. K-Ar age after KAWANO & UEDA (1966) and SHIBATA & ISHIHARA (1974); Rb-Sr age from SHIBATA & ISHIHARA (unpublished).

Fig. 7. Geographical variation of selected minor components as projected onto the N30°W line.

Symbols same as in Fig. 6.

Be increase from south to the Toki granitoids. They are low in the Shirakawa granitoids.

Discussion

Regional variation

There are many papers discussing regional variation of chemistry of volcanic rocks but a few on granitic rocks in the Japanese Islands. TANEDA (1962) discussed the subject on the Cretaceous granitoids in terms of the alkali-lime index, and found low values in the inner side and high values in the outer side in southwestern Japan. He emphasized the presence of a regional specificity in chemical characteristics of a given area regardless of its petrography and ages (TANEDA, 1965).

KIKUCHI (1974) adopted KUNO's alkali-silica diagram for plotting about 700 analyses of granitoids and reached to the same conclusion as in TANEDA (1962), i. e., $\text{Na}_2\text{O} + \text{K}_2\text{O}$ increase continentward but the increase is less distinct than that seen on the Quaternary volcanic rocks.

The results of the present study and the author's unpublished data of the Chugoku District indicate that the continentward increase of the total alkalis is much less distinct than that of Fe_2O_3 , and the $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio is the only parameter showing prominent regional variation across southwestern Japan. Very slight increase can be seen on the total alkalis, Na_2O (not K_2O), MgO and TiO_2 .

Regional chemical variation is well studied in the central part of the Sierra Nevada batholith. BATEMAN & DODGE (1970) reported continentward increase of the K_2O index, $\text{K}_2\text{O}/(\text{SiO}_2 - 45) \times 1000$. If this index is calculated and plotted on Fig. 6, the pattern is similar to that of normative or/or+ab. The continentward increase of the oxidation ratio of DODGE (1972) is consistent with our results.

In Sierra Nevada, K/Rb ratio is rather constant (DODGE *et al.*, 1970), and U and Th increase continentward (WOLLENBERG & SMITH, 1970). Here in southwestern Japan, in addition to U and Th (ISHIHARA *et al.*, 1969), F, Rb, Li, Pb, Sn and Be increase continentward from the Ryoke III granitoids to the Toki granitoids, but they are low in

the Shirakawa granitoids.

The enrichment of the lithophile elements in the Toki granitoids is best shown by that of Rb (Fig. 7). The enrichment is more than that of K_2O , so that the K/Rb ratio is lowest in the granitoids. F/Rb ratio, on the other hand, is rather constant throughout the granitoids along the transection. These two contrasting variations in these ratios imply that Rb, as well as Li, Pb, Sn and Be, may be concentrated by both magmatic differentiation and F-rich volatile transport. The extreme concentration of some of these elements is well exemplified by greisen-type W(-Sn) mineralization around the Naegi granite.

The greisen-type mineralization is absent in and around the Sierra Nevada batholith (HOBBS & ELLIOTT, 1973). Sn contents of the batholith are low ranging generally from 1 to 2 ppm. These characters are similar to those of the Cretaceous granitoids in the Kitakami belt, which are poor in the lithophile elements. The different chemical variations across the southwestern Japan and Sierra Nevada batholith are considered due to different concentration of the lithophile elements, particularly of F, in the original magmas of the two areas.

Genesis of the chemical variation

Cause for the chemical variation may be a matter of provenance of the granitic magmas, because of its regional character. In their interpretation of Sr (and Pb) isotope data, GORAI and his students hold strongly an opinion of mantle-derived source for general granitic rocks (GORAI, 1960, 1967; GORAI *et al.*, 1972). They claim that the granitic magmas derived from the upper mantle and/or eclogitic material which have slightly higher Rb/Sr ratio than the source material for oceanic tholeiite, and consider that the contribution of sialic materials within the earth crust is not significant.

KIKUCHI (1974) followed the KUNO's (1966) model for generation of the granitic magmas, and claimed a small inclination of the generation belt in order to explain the absence of alkaline rocks along the Sea of Japan, and proposed a thick generation belt because

the rocks of his low alkali and high alkali tholeiite series occur together.

In Sierra Nevada and its vicinity, crustal origins are favored by many geologists (e.g., MOORE, 1959; BATEMAN & EATON, 1967) and much deeper materials by isotope geochemists, and proposed hypotheses are summarized by KISTLER & PETERMAN (1973) as follows: i) Melted crustal material in a thickened prism of rocks in a geosyncline marginal to the continent, ii) Partially melted fractions of lower crust and upper mantle with varying proportions of assimilated uppercrustal material, and iii) Palingenically derived magma from oceanic basalts and sediments in the context of plate tectonics.

The Cretaceous granitoids in the inner side of southwestern Japan have been conventionally divided into two units, the Ryoke granitoids and the rest distributed to the north (e.g., 1/2,000,000 scale geological map of Japan by the GEOLOGICAL SURVEY OF JAPAN). We prefer to group, however, the Ryoke and Toki granitoids as one unit and the Shirakawa granitoids as a separate unit because of the following reasons.

i) Consistent nature observed on their major elements on both the Toki and Ryoke granitoids, like Fe_2O_3/FeO .

ii) Different variation patterns observed on minor elements: the increase type for the Toki and Ryoke granitoids and the constant type for the Shirakawa granitoids.

iii) Geographical affinity between the Toki and Ryoke granitoids and gradual change in petrochemistry at their border, while the Shirakawa granitoids are isolated.

The Toki and Ryoke granitoids have low Fe_2O_3/FeO ratio; hence low normative magnetite contents and low en/en+fs ratio. This is due to assemblage of Fe-Ti oxide minerals (TSUSUE & ISHIHARA, 1974). Since genesis of the magnetite-free and bearing granitoids is given in a separate paper, conclusions are given here in brief. Available information including isotope studies indicates that the role of carbonaceous materials is most essential to form the magnetite-free granitoids. The intruded rocks for the Toki and Ryoke granitoids are composed of such rocks favorable

Table 3. Average chemical compositions of selected granitoids at silica 73%

	SHIRAKAWA (n=4)	TOKI (n=5)	RYOKE I (n=5)	RYOKE III (n=4)
SiO ₂	74.02	73.44	73.48	73.09
TiO ₂	0.18	0.15	0.18	0.17
Al ₂ O ₃	13.90	14.25	14.26	15.12
Fe ₂ O ₃	0.66	0.35	0.39	0.32
FeO	0.79	1.33	1.27	1.16
MnO	0.05	0.06	0.05	0.06
MgO	0.43	0.28	0.30	0.39
CaO	1.18	1.42	1.71	1.54
Na ₂ O	3.80	3.49	3.19	3.14
K ₂ O	3.83	4.24	4.18	3.94
P ₂ O ₅	0.06	0.06	0.05	0.13
H ₂ O(+)	0.47	0.48	0.45	0.50
H ₂ O(-)	0.26	0.25	0.27	0.31
Total	99.63	99.80	99.78	99.87
F	415	1146	620	524
Cl	63	116	97	55
Sr	148	117	121	218
Rb	135	226	162	141
Li	20	46	29	61
Zn	28	45	29	47
Cu	3	3	2	3
Pb	11	30	23	25
Sn	0.8	4.4	2.0	1.9
Be	1.9	3.6	2.1	2.0
D. I.	89.7	88.1	86.6	86.2

Selected original data are Nos. 2-5 for the Shirakawa granitoids, Nos. 12-16 for the Toki granitoids, Nos. 24-28 for the Ryoike I granitoids, and Nos. 43, 46-48 for the Ryoike III granitoids.

to yield reducing environment as shale and sandstone and their metamorphic equivalents, which contain nearly 1% C, and well mixing phenomena between the granitoids and the Ryoike metamorphic rocks are observed.

Contents of F, Rb, Li, Pb, Sn and Be are higher in the Toki and Ryoike granitoids than in the Shirakawa granitoids (Table 3). These minor components are generally enriched in the earth crust than in the upper mantle, particularly in shale and crust-originated granitoids like some of the Paleozoic and Mesozoic granitoids in continental regions (ISHIHARA, 1974). We assume that the Toki and Ryoike granitoids have had a close genetic relationship with the crustal materials and possibly derived from them.

Amount of F in the Ryoike II and III granitoids is not so high as that of the Toki granitoids. A deep facies may be exposed in this part of the Ryoike belt, as evidenced by Cretaceous sedimentation of the Izumi sandstone on these granitoids. F tends to be concentrated in a shallow level in the

granitoids batholith. The different F contents may have been resulted from different erosion levels at the present surface.

The excess alumina increases from north to south and is highest in the muscovite-biotite monzogranite. The monzogranite contains garnet, and sillimanite may be present together with muscovite. Mafic xenoliths are generally absent. The monzogranite occurs to follow the thermal axis of the Ryoike belt and is closely associated with high grade metamorphic rocks. The monzogranite may be melted fraction of nearby metamorphic rocks or of similar pelitic and psammitic rocks that constitute the basement for the metamorphic rocks. The melting in such a shallow environment is possible in assuming that the Ryoike belt is unusual tectonic zone with a high rate of heat flow, which has been recorded in the metamorphic rocks.

The other large unit of the Ryoike belt, hornblende-biotite granodiorite of the Ryoike II granitoids, for example, are more mafic in composition than the monzogranite, and wherever mafic xenolith is dominant, the host granodiorite becomes mafic. The granodiorite may have been generated in somewhat deeper horizon as in the lower crust.

Either a crustal origin of igneous source materials or the upper mantle origin is possible for the Shirakawa granitoids. The most widespread older rock unit in the Shirakawa region is the Hida metamorphic rocks and Funatsu granite. They are calcic in nature having a low K₂O/Na₂O in general (SUZUKI, 1975). Yet very potassic and high Rb content rocks are known in limited places (SHIBATA *et al.*, 1970; SUZUKI, *op. cit.*). Precambrian metamorphic and granitic rocks in the Kamiaso conglomerate, which was found in the studied region, are known to be rich in K₂O and Rb (ADACHI, 1973; SHIBATA & ADACHI, 1974). The source outcrop may be hidden in the Shirakawa region.

Chemical nature of the basement rocks for the Shirakawa granitoids have not been well established, because the large part is covered by the Cretaceous Nohi rhyolites. We tentatively hold a mantle derived hypothesis for the origin of the granitoids in the

interpretation of available information including unpublished data from the Chugoku batholith.

Conclusions

Major elements and minor elements (F, Cl, Sr, Rb, Li, Zn, Cu, Pb, Sn, Be) are analyzed for 48 Cretaceous granitoids from a N-S transection along the western part of the Chubu district in central Japan. $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio, hence normative mt (+hm) and en/en+fs ratios, are high in the north (to the continental side). The same tendency is faintly observed on $\text{Na}_2\text{O}+\text{K}_2\text{O}$, Na_2O (not K_2O), MgO and TiO_2 . Normative corundum increases from north to south to the Ryoke III granitoids, and they are low in the north (Shirakawa granitoids). F, Rb, Li, Pb, Sn and Be are lowest in the Shirakawa granitoids and are highest in the middle zone (Toki granitoids).

Systematic change of alkalis and Rb across island arcs, which have been well documented in the studies of volcanic rocks, is not observed on the Cretaceous granitoids. Mantle-derived hypotheses are not likely the case for the granitic magmatism, although the statement "the deeper the generation, the closer to the marginal sea" seems to be valid. The most prominent variation of ferric/ferrous ratio indicates the contribution of carbon-bearing materials. The reduced granitoids with high contents of the lithophile elements in the south are considered to have resulted from the magmas generated within the continental crust, while the oxidized granitoids in the north derived from much deeper levels.

In combining the chemical data and geological evidences, it is suggested that the Ryoke granitoids were originated in pelitic and psammitic metamorphic rocks with some mafic igneous materials in the middle to lower crust along a tectonic zone that had an unusually high rate of heat flow and solidified under a stress environment. The Toki granitoids may have been originated in similar depth of salic materials and solidified from completely melted and well fractionated magmas at a shallower horizon

than the Ryoke granitoids. The Shirakawa granitoids may have been generated in the deepest level, possibly in the upper mantle or eclogitic layer, but solidified at the shallowest level among three groups of the granitic magmas. Thus the regional chemical variation is considered essentially due to different source materials wherein the granitic magmas were generated.

References

- ADACHI, M., 1973: Pelitic and quartzo-feldspathic gneisses in the Kamiaso conglomerate—A study of Precambrian geology in Japan and East Asia. *Jour. Geol. Soc. Japan*, **79**, 181—192.
- ARAMAKI, S., HIRAYAMA, K., and NOZAWA, T., 1972: Chemical composition of Japanese granites, Part 2. Variation trends and average composition of 1,200 analyses. *Ibid.*, **78**, 39—49.
- BATEMAN, P. C. and EATON, J. P., 1967: Sierra Nevada batholith. *Science*, **158**, 1407—1417.
- and DODGE, F. C. W., 1970: Variations of major chemical constituents across the central Sierra Nevada batholith. *Geol. Soc. Amer. Bull.*, **81**, 409—420.
- CHAYES, F., 1956: *Petrographic modal analysis*. John Wiley & Sons, Inc., N. Y., 113p.
- DODGE, F. C. W., 1972: Variation of ferrous-ferric ratios in the central Sierra Nevada batholith, U.S.A. *Proc. 24th IGC*, Sec. 10, 12—19.
- , FABBI, B. P. and ROSS, D. C., 1970: Potassium and rubidium in granitic rocks of central California, *U. S. Geol. Surv. Prof. Paper*, 700-D, 108—115.
- GORAI, M., 1960: Ultimate origin of granite. *Earth Sci. (Chikyu Kagaku)*, no. 52, 1—8.
- , 1967: Origin of granitic magmas. *Bull. Volc. Soc. Japan*, **12**, 70—79.
- , KAGAMI, H. and IZUMI, S., 1972: Re-examination on the source material of granitic magmas. *Jour. Geol. Soc. Japan*, **78**, 549—559.
- HOBBS, S. W. and ELLIOTT, E., 1973: Tungsten in the United States mineral resources. *U. S. Geol. Surv. Prof. Paper*, 820, 667—678.
- ISHIHARA, S., 1971a: Major molybdenum deposits and related granitic rocks in Japan. *Rept. Geol. Surv. Japan*, no. 239, 178p.
- , 1971b: Modal and chemical composition of the granitic rocks related to the major

- molybdenum and tungsten deposits in the Inner Zone of Southwest Japan. *Jour. Geol. Soc. Japan*, **77**, 441—452.
- , 1973: The Mo-W metallogenic provinces and the related granitic provinces. *Mining Geol. (Tokyo)*, **23**, 13—32.
- , 1974: Tin-tungsten-molybdenum metallogenic provinces in East Asia and some problems involved in their plate tectonics interpretation. In STEMPROK *et al.*, ed.: *Mineralization Associated with Acid Magmatism*, **3** (in press)
- , 1975: Magnetite-series and ilmenite-series granitic rocks (abs.). *Rec. Proc. 13th. Pacific Sci. Cong.*, **1**, 403.
- and SUZUKI, Y., 1969: Basement granites of the Toki uranium deposits in Tono region. *Rept. Geol. Surv. Japan*, no. 232, 113—127.
- , SEKINE, S., MOCHIZUKI, T., and OBA, K., 1969: Contents of uranium and thorium in granitic rocks and their petrogenetic significance. *Ibid.*, no. 232, 179—219.
- KANAYA, H. and ISHIHARA, S., 1973: Regional variation of magnetic susceptibility of the granitic rocks in Japan. *Jour. Japan. Assoc. Miner. Petrol. Econ. Geol.*, **68**, 211—224.
- KAWAI, M., HIRAYAMA, K., and YAMADA, N., 1957: 1/50,000 scale geological sheet map "Arashimadake" and its explanatory text. 110p., Geol. Surv. Japan.
- KAWANO, Y. and UEDA, Y., 1966: K-A dating on the igneous rocks in Japan (V). Granitic rocks in southwestern Japan. *Jour. Japan. Assoc. Miner. Petrol. Econ. Geol.*, **56**, 191—211.
- KIKUCHI, J., 1974: The Japanese Cretaceous granitic province based on Kuno's silica—total alkalis variation diagram. *Jour. Geol. Soc. Japan*, **80**, 251—259.
- KISTLER, R.W. and PETERMAN, Z.E., 1973: Variations in Sr, Rb, K, Na, and initial $\text{Sr}^{87}/\text{Sr}^{86}$ in Mesozoic granitic rocks and intruded wall rocks in central California. *Geol. Soc. Amer. Bull.*, **84**, 3489—3512.
- KUNO, H., 1966: Lateral variation of basalt magma type across continental margins and island arcs. *Bull. Volcanol.*, **29**, 195—222.
- MOORE, J.G., 1959: The quartz diorite boundary line in the western United States. *Jour. Geol.*, **67**, 198—210.
- SHIBATA, K., NOZAWA, T. and WANLESS, R. K., 1970: Rb-Sr geochronology of the Hida metamorphic belt, Japan. *Can. Jour. Earth Sci.*, **7**, 1383—1401.
- and ADACHI, M., 1974: Rb-Sr whole-rock ages of Precambrian metamorphic rocks in the Kamiaso conglomerate from central Japan. *Earth Planet. Sci. Let.* **21**, 277—287.
- and ISHIHARA, S., 1974: K-Ar ages of the major tungsten and molybdenum deposits in Japan. *Econ. Geol.*, **69**, 1207—1214.
- STRECKEISEN, A. L. *et al.*, 1973: Plutonic rocks—Classification and nomenclature recommended by the IUGS subcommission on the systematics of igneous rocks. *Geotimes*, **18**, 26—30.
- SUZUKI, M., 1975: On the petrochemical character of the pelitic gneiss from the southwestern part in the Hida metamorphic belt, central Japan. *Jour. Sci. Hiroshima Univ.*, [C], **7**, 133—148.
- SUZUKI, Y. and ISHIHARA, S., 1969: Modal compositions of granitic plutons of Toki-Okazaki region, central Japan. *Rept. Geol. Surv. Japan*, no. 232, 155—168.
- TANEDA, S., 1962: Chemical compositions of granitic and volcanic rocks in Japan. *Jour. Geol. Soc. Japan*, **68**, 118—124.
- , 1965: "Areal rock character" in Japan. *Mem. Fac. Sci. Kyushu Univ.*, [D], **8**, 1—61.
- TERASHIMA, S., 1970: Determination of sodium, potassium, magnesium, calcium, manganese and iron in the silicate rocks and terrestrial water by atomic absorption spectrophotometry. *Bull. Geol. Surv. Japan*, **21**, 693—707.
- , 1971: Determination of cobalt, chromium, copper, lithium, lead, strontium and zinc in silicates by atomic absorption spectrophotometry. *Ibid.*, **22**, 245—249.
- , 1973: Atomic absorption analyses of Be, V, Ba and Rb in rocks and flame emission analysis of Rb. *Ibid.*, **24**, 469—485.
- , 1974: Spectrophotometric determination of chlorine and fluorine in the standard silicate rocks. *Ibid.*, **25**, 175—179.
- , 1975: Atomic absorption analyses of arsenic, antimony, tin and calcium in rocks. *Ibid.*, **26**, 53—70.
- THORNTON, C. P. and TUTTLE, O. F., 1960: Chemistry of igneous rocks, I; Differentiation index. *Amer. Jour. Sci.*, **258**, 664—684.
- TSUSUE, A. and ISHIHARA, S., 1974: The iron-

titanium oxides in the granitic rocks of Southwest Japan. *Mining Geol. (Tokyo)*, **24**, 13—30.

WOLLENBERG, A. H. and SMITH, A. R., 1970: Radiogenic heat production in pre-batholithic rocks of the central Sierra Nevada. *Jour. Geoph. Res.*, **75**, 431—438.

YAMADA, N., KATADA, M., HAYAMA, Y., YAMADA, T., NAKAI, Y., KUTSUKAKE, T., SUWA, K., and MIYAKAWA, K., 1974: Geological map of the Ryoke belt, central Japan (1/200,000 scale). Geol. Surv. Japan.

Appendix: Sample numbers and localities of the analyzed specimens

Analysis No.	Sample No.	Locality
1	67RS-88	A large xenolithic block at Tsubakihara power station, Shirakawa vil., Ōno co., Gifu Pref.
2	67RS-87	Salic matrix of the block.
3	67RS-91	1.2km due south of the Tsubakihara dam site, Shirakawa vil.
4	66RS-8	50 m from compressor, main tunnel, Hirase moly-mine, Shirakawa vil.
5	66RS-9	Shaft site by 13th vein, main tunnel, Hirase moly-mine.
6	67RS-119	50m east of inclined shaft, 9th level adit, Hirase moly-mine.
7	67RS-69	1.3km west of the entrance, Oshirakawa gravel road, Shirakawa vil.
8	67RS-57	500 m southwest of Manago gulch, Oshirakawa gravel road, Shirakawa vil.
9	71HD-3	South of power station at Kadohara, Ōno city, Fikui Pref.
10	71HD-2	100 m upper stream side of Hotokehara dam site, Ōno city.
11	65T-41	400m southwest of Nishibora, Mitake town, Kani co., Gifu Pref.
12	65T-38	500m southwest of Tsubashi, Mitake town.
13	65T-44	Garaishi bridge, Tsukiyoshi, Mizunami city, Gifu Pref.
14	65T-51	Behind Hachiōji shrine at Shukubora, Mizunami city.
15	65T-82	500m north of Dachi, Toki city, Gifu Pref.
16	65T-25	500m south of Maruyama dam site, Fukazawa, Mizunami city.
17	65T-2	Loop part of old route No. 21, Jyōrinji, Toki city.
18	67T-175	Quarry at Shinden, Hirukawa vil., Ena co., Gifu Pref.
19	6911-213	Quarry at Ichinose, Hirukawa vil.
20	6911-211	Quarry at Narai, Hirukawa vil.
21	66T-139	1.6km southwest of Nishi-ichinono, Fujioka vil. Nishikamo co., Aichi Pref.
22	65T-97	Ōhira, Obara vil., Nishi-kamo co.
23	66T-105	500m north of school at Ōhata Toyota city, Aichi Pref.
24	66T-110	Hirose, Yamaoka town, Ena co., Gifu Pref.
25	66T-109	500m north of Sanage shrine, Toyota city, Aichi Pref.
26	66T-114	Between Mitsukuri and Kawaguchi, 140m above sea level, Fujioka vil., Nishi-kamo co.
27	65T-94	Between Kamigo and Kakinno, 395 m above sea level, Toki city, Gifu Pref.
28	65T-60	Between Ori and Sue (1 km south of Kaore), Mizunami city.
29	66T-145	2 km east of Kami-shinano, Seto city, Aichi Pref.
30	65T-70	Dam site at Tsurusato near prefectural border, Toki city, Gifu Pref.
31	66T-128	Koda, Asahi town, Higashikamo co., Aichi Pref.
32	65T-75	3 km south of Asuke. Kawabata, Asuke town, Higashikamo co.
33	66T-129	500 m north of Ōi, Asuke town.
34	65T-71	Hirado bridge, Hirai, Toyota

35	66T-126	city. Nakayama bridge, Fujinai, Akechi town, Ena co., Gifu Pref.	42	65T-76	kyu, Nukata town, Nukata co. Quarry near Jyumyozan, Asuke town, Higashi-kamo co.
36	67T-165	Mafic xenolith at 700m south of Asuke, Asuke town, Higa- shi-kamo co., Aichi Pref.	43	67T-173	Quarry at 1.2 km east of Sakuragata, Nukata town, Nukata co.
37	67T-168	25 cm from the edge of the xenolith.	44	67T-173A	Biotite-rich band, 10cm wide.
38	67T-167	Salic rim of the xenolith.	45	67T-173B	Biotite-poor band, 7 cm wide.
39	65T-79	1.4 km south of Higashi- ōnuma, Shimoyama vil, Hi- gashi-kamo co.	46	66T-136	Quarry at 1.5 km west of Kamadate, Okazaki city.
40	66T-151	1 km west of junction at Kamidono, Shimoyama vil.	47	65T-81	Quarry at Ubayage, Yonego- chi, Okazaki city.
41	66T-135	600 m east-northeast of Ho-	48	66T-133	Quarry to the west of Ma- tsudaira, Matsudaira town, Higashi-kamo co.

西南日本の白亜紀花崗岩類にみられる化学的性質の南北変化

——白川・土岐・岡崎横断面——

石原 舜三・寺島 滋

(要 旨)

中部地方西部の白亜紀花崗岩類, 48 個の主成分 および微量成分 (F, Cl, Sr, Rb, Li, Zn, Cu, Pb, Sn, Be) の分析結果から, 広域的な変化を論じた. 主成分については, 白川帯と苗木帯+領家帯との間に差が認められ, 前者では $\text{Fe}_2\text{O}_3/\text{FeO}$ が高く, したがって, ノルム en/en+fs も高い. 後者ではこれらが低い. $\text{Na}_2\text{O} + \text{K}_2\text{O}$, Na_2O , MgO , TiO_2 も若干の同様な傾向を示す. ノルム C は南方へ増加し, 両雲母モンゾ花崗岩 (武節) でもっとも高い.

微量成分のうち F, Rb, Li, Pb, Sn, Be は苗木帯+領家帯では DI 値の増加とともに増加する傾向を示す (“増加型”) が, 白川帯では DI 値に対して変化しない (“一定型”), したがって白川帯の岩石は全体としてこれらの成分に乏しい.

$\text{Fe}_2\text{O}_3/\text{FeO}$ は磁鉄鉱の存在の有無に関係する. 磁鉄

鉱を含まない花崗岩類 (苗木帯+領家帯) の成因には炭質物を含む地殻物質の関与が重要であることを考慮し, Rb などの親石元素や過剰 Al_2O_3 の多いこと, 変成岩類との密接な関係などの理由から, 苗木帯+領家帯の花崗岩類は地殻起源と考えられた. 苗木帯で親石元素がとくに著しく富む現象は現在の浸食レベルにも関係している. 上記両帯と性質が異なる白川帯の花崗岩類は親石元素に乏しい物質を出発物質とし, 大陸地殻最下部か上部マントル起源と考えられた.

Kadohara	勝原	Nukata	額田
Koda	小田	Ori	小里
Manago	間名古	Sue	陶
Mizunami	瑞浪	Toki	土岐