

## On the Petrochemistry of Shishigawa Granodiorite

by

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### Abstract

The most prominent character of Shishigawa granodiorite is the high content of alkalis, especially of potash. It approaches to the Daly's average of granitic rocks in the world.

Aluminous schist xenolith with corundum and spinel is supposed to originate from muscovite schist.

### Preface

To study the petrochemistry of Shishigawa granodiorite, T. Nozawa executed field surveys in 1950 and 1957. K. Takahashi carried out chemical analyses on the major and minor constituents in 1958.

The writers' acknowledgements are due to the members of Sheet-mapping and Geochemical Research Sections, Geological Survey of Japan and Dr. A. Miyashiro in Tokyo University. They are also indebted to Mr. H. Kishi who carried out the chemical analyses of uranium.

### I. Scope of the study

The writers have been inclined to establish the petrochemical classification of granitic rocks in Japan.

Granitic rocks in Southwest Japan are believed to form zonal petrographic provinces. Such rocks in the provinces of the outer zone, Pacific side, were once comprehensively studied by J. Suzuki, but many of the rocks have been left to precise petrological and petrochemical studies. So, one of the scopes of this paper is to contribute to the elucidation of their general character.

Another scope lies in the explanation on the origin of aluminous metamorphic inclusions which are common in the igneous rocks of the outer zone. These inclusions are quite different from xenoliths derived directly from the country rocks. Namely, the former is schist, but the latter is hornfels.

A special attention is being paid for the behavior of minor constituents in these xenoliths and their host.

For these scopes, the writers chose Shishigawa granodiorite as a typical granitic rock of the outer zone of Southwest Japan.

### II. Short description of geology and petrology of Shishigawa granodiorite

Shishigawa granodiorite occur in central Kyushu, Miyazaki prefecture. (Fig. 1a) It is limited by a rather smooth and rounded outline about 10 km in diameter. This granodiorite is intruded into the Mesozoic rocks, mainly sandy rocks. Some part of its roof remains free from eroding out. (Pl. 1)

Rocks forming this granodiorite mass are mainly leucocratic and medium to coarse-grained granodiorite and quartz diorite. Under the microscope, their essential components are biotite, potash feldspar, plagioclase and quartz accompanying iron ore and apatite as accessory components. Some of them bear green hornblende accompanied with biotite. The hornblende crystal sometimes contains diopsidic core in a replacement relation.

Aplite and pegmatite develop abundantly, especially near the contact to the wall and the roof. Tourmaline is characteristically abundant in them.

Contact effect to the Mesozoic sandstone or shale prevails quite irregularly, from one to several kilometers in width. Biotite, with or without cordierite, is the commonest metamorphic mineral in the aureole. (Pl. 2)

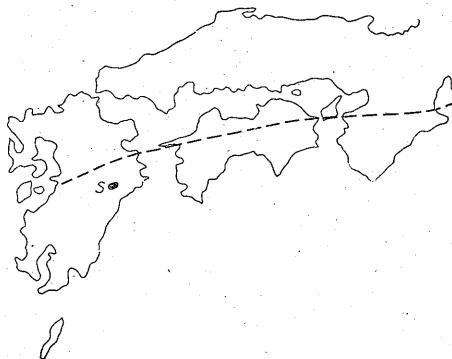


Fig. 1a Location of Shishigawa granodiorite. Broken line indicates the Median Tectonic Line.

The granodiorite intrudes the Mesozoic formation and the volcanic rocks and conglomerate probably more younger than the Mesozoic age. As to the age of intrusion, M. Saito, N. Kambe and M. Katada (1958) believe it Tertiary.

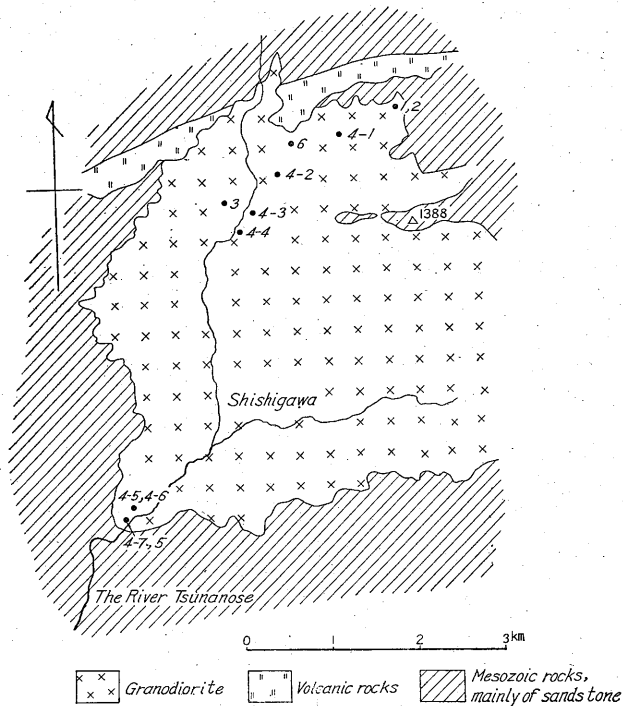


Fig. 1b Geological map of Shishigawa district  
Solid circles indicate localities of analysed samples, with numbers corresponding to those of the analyses in the tables.

Table 1 Chemical Compositions of Shishigawa Granodiorite and Related Rocks

Analyst: Kiyoshi Takahashi

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	(1)1609-C	(2)1609-D	(3)1801	(4-1)1611	(4-2)1612	(4-3)1803	(4-4)1804	(4-5)1806A	(4-6)1806B	(4-7)1807B	(4)Average	(5)1807A	(6)1613
SiO <sub>2</sub>	52.37	61.89	65.24	68.71	68.14	67.34	65.85	65.40	69.51	64.68	67.09	74.46	85.18
TiO <sub>2</sub>	0.47	0.43	0.65	0.39	0.48	0.41	0.38	0.58	0.39	0.43	0.44	0.12	0.05
Al <sub>2</sub> O <sub>3</sub>	18.97	16.17	15.81	14.85	15.36	15.13	16.47	16.09	15.03	16.31	15.61	14.06	9.43
Fe <sub>2</sub> O <sub>3</sub>	1.54	1.34	1.34	0.87	0.67	1.44	0.86	0.86	0.77	1.05	0.93	0.39	0.52
FeO	8.06	5.61	3.62	2.59	3.02	2.93	3.46	3.46	2.07	3.63	3.02	0.61	0.47
MnO	0.14	0.11	0.06	0.09	0.08	0.09	0.06	0.12	0.05	0.06	0.08	0.02	0.01
MgO	2.83	2.03	1.81	1.35	1.38	1.64	1.56	1.57	1.04	1.55	1.44	0.09	0.11
CaO	1.55	1.37	1.68	2.70	2.79	2.69	3.59	3.64	2.92	3.70	3.12	0.88	0.36
Na <sub>2</sub> O	2.51	2.13	2.87	3.03	3.13	3.39	3.41	3.43	3.03	3.27	3.24	2.33	0.23
K <sub>2</sub> O	8.43	6.79	4.91	3.66	3.99	4.13	3.18	3.61	3.90	3.69	3.74	5.91	1.78
P <sub>2</sub> O <sub>5</sub>	0.12	0.10	0.15	0.15	0.14	0.08	0.10	0.09	0.11	0.12	0.11	0.11	0.10
H <sub>2</sub> O+	2.55	1.23	0.92	0.77	0.61	0.51	0.99	0.88	0.68	1.13	0.79	0.41	1.23
H <sub>2</sub> O-	0.31	0.32	0.34	0.09	0.10	0.14	0.08	0.10	0.22	0.18	0.13	0.20	0.12
Total	99.85	99.52	99.40	99.25	99.89	99.92	99.99	99.83	99.72	99.80	99.74	99.59	99.59
Minor constituents expressed as parts per million													
Li	600	300	200	40	60	150	40	25	20	25	51	10	20
Rb	700	500	250	100	150	150	80	150	200	100	133	400	100
Sr	280	230	280	150	120	200	230	230	250	200	197	60	10
Ba	600	400	280	150	150	200	200	250	250	180	197	80	—
Ni	40	25	15	3	3	—	3	4	2	4	2.7	—	—
Co	15	10	12	5	10	5	10	12	8	8	7.3	—	—
Cr	40	35	20	6	5	3	3	4	3	8	4.8	3	—
V	100	130	100	60	60	40	70	80	70	100	69	—	—
Sn	30	18	15	7	5	—	7	5	—	12	5	10	40
Pb	30	15	25	10	10	7	20	15	12	10	12	80	150
Ga	40	22	25	18	18	15	15	18	15	25	18	12	6
B	60	40	35	25	25	7	25	15	20	30	21	200	800
U*	1.8	1.7	1.9	1.7	2.5	1.6	1.9	1.2	1.4	2.1	1.8	2.5	5.7

(1) Spinel-corundum-biotite schist (xenolith)

(3) Fine-grained biotite granodiorite

(4-3) Porphyritic biotite granodiorite

(4-4) Porphyritic hornblende-biotite granodiorite

(4-6) Augite-bearing hornblende-biotite granodiorite

(5) Tourmaline aplite

(2) Fine-grained biotite granodiorite (transitional zone between schist and granodiorite)

(4-1) Porphyritic biotite granodiorite

(4-4) Porphyritic hornblende-biotite granodiorite

(4-7) Biotite aplitic granodiorite

(6) Tourmaline pegmatite

(4-2) Biotite granodiorite

(4-5) Augite-bearing hornblende-biotite granodiorite

(4av.) Average composition of the seven granodiorites

\* Analyst for uranium: Haruo Kishi

### III. Chemical characters of Shishigawa granodiorite

To get petrochemical characters as a whole, samples for chemical analysis were taken evenly at various points of various heights, from the top under the roof to the bottom of the Tsunanose river. Sampling points are plotted in Fig. 1b. The height of each locality is as follows.

1	1020 m	above the sea level
2	940 "	"
3	760 "	"
4-1	710 "	"
4-2	480 "	"
4-3	480 "	"
4-4	410 "	"
5	1100 "	"
6	410 "	"

Samples numbered 1~3 are schist-xenolith and its related facies, and those belonging to No. 4 are ordinary facies of the granodiorite, and those numbered 5~6 are aplitic and pegmatitic facies.

*Main constituents* (Table 1 and Figs. 2~4)

One remarkable feature of Shishigawa granodiorite is homogeneity and regularity of variation of many constituents and their relations. For instance, MgO is nearly constant, about 1.49% regardless to the kind of mafic mineral of analysed samples, and bears nearly constant ratio, about 12 per cent in the diagram MgO : FeO : Na<sub>2</sub>O+K<sub>2</sub>O.

Points representing each analysis tend to crowd to one narrow field in some diagrams as follows.

{	MgO	12	{	Q	24	{	Or	36	{	Q	27
	FeO	32		M	11		Ab	42		Or	26
	Na <sub>2</sub> O+K <sub>2</sub> O	56		F	65		Ani	22		P	47

Linear relations are found between Na<sub>2</sub>O : K<sub>2</sub>O, CaO : Na<sub>2</sub>O+K<sub>2</sub>O and MgO : FeO.

Characteristic features of some prominent constituents are as follows. Al<sub>2</sub>O<sub>3</sub> is higher than Japanese average\* and the southern Kyushu's\*\*. FeO is higher than Japanese and the southern Kyushu's. MgO is nearly the same or slightly higher than Japanese and the southern Kyushu's. CaO is lower than Japanese and slightly higher than the southern Kyushu's. It is one of the prominent features that K<sub>2</sub>O is higher than Na<sub>2</sub>O. Na<sub>2</sub>O is slightly lower than Japanese and the southern Kyushu's. K<sub>2</sub>O is higher than Japanese and the southern Kyushu's.

Alkali in total is higher than Japanese average and nearly the same as the southern Kyushu's. The ratio MgO : FeO is slightly greater than Japanese and the southern Kyushu's.

Mafic ratio in the diagram of F : Q : M (F = total normative feldspar, M = total normative mafic minerals) is slightly greater than Japanese average and the southern Kyushu's. And Q ratio in the diagram Q : Or : P is smaller than Japanese and the southern Kyushu's and nearly the same as Daly's average.

In the diagram of C : En : Fs : W, C ratio is slightly greater than Japanese average and smaller than the southern Kyushu's. Shishigawa granodiorite, as well

\*. About these averages, see the explanation of Fig. 3.

\*\* cf. Table 3.

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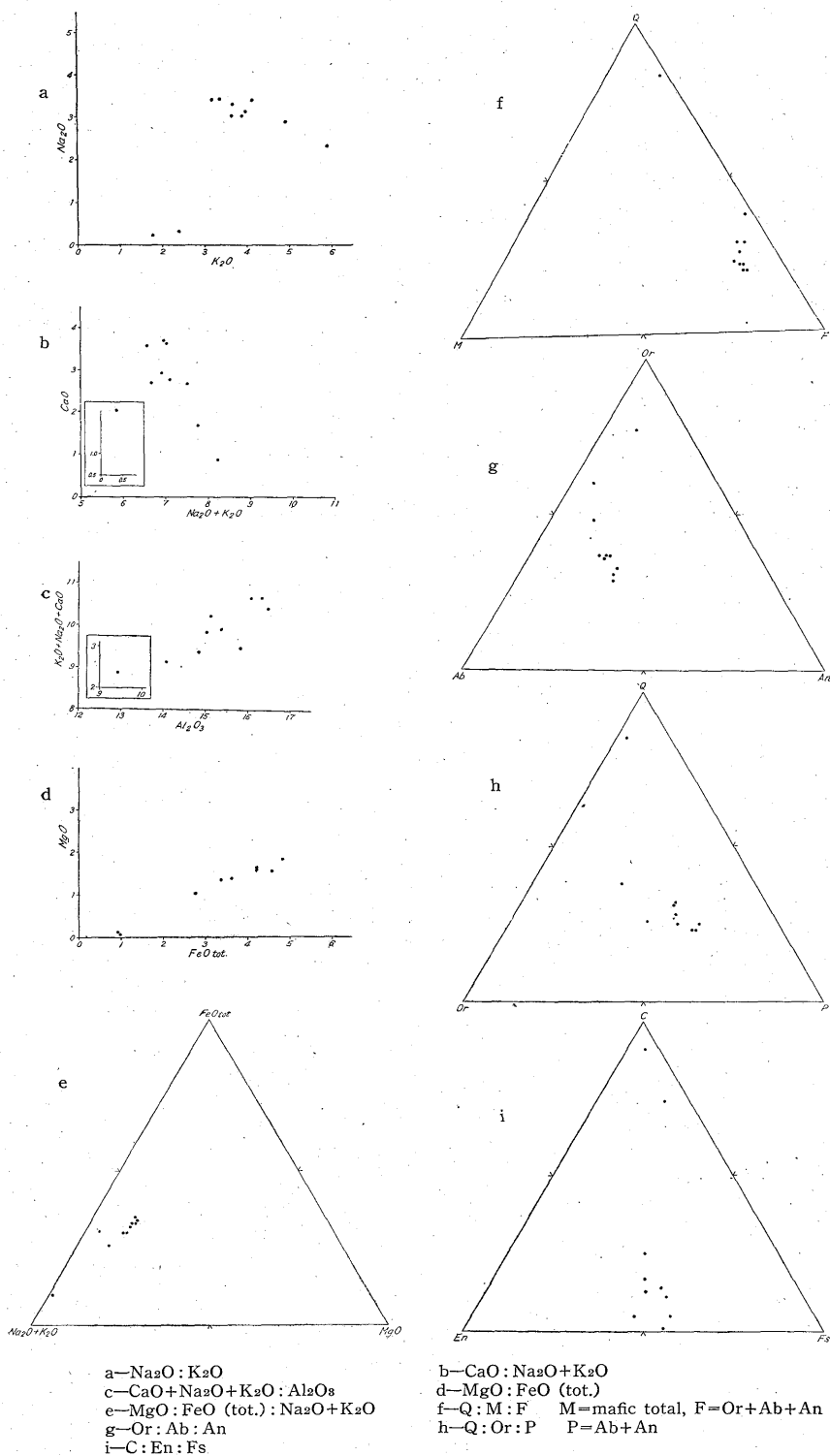


Fig. 2 Relations among the major constituents and the normative mineral components of Shishigawa granodiorite.

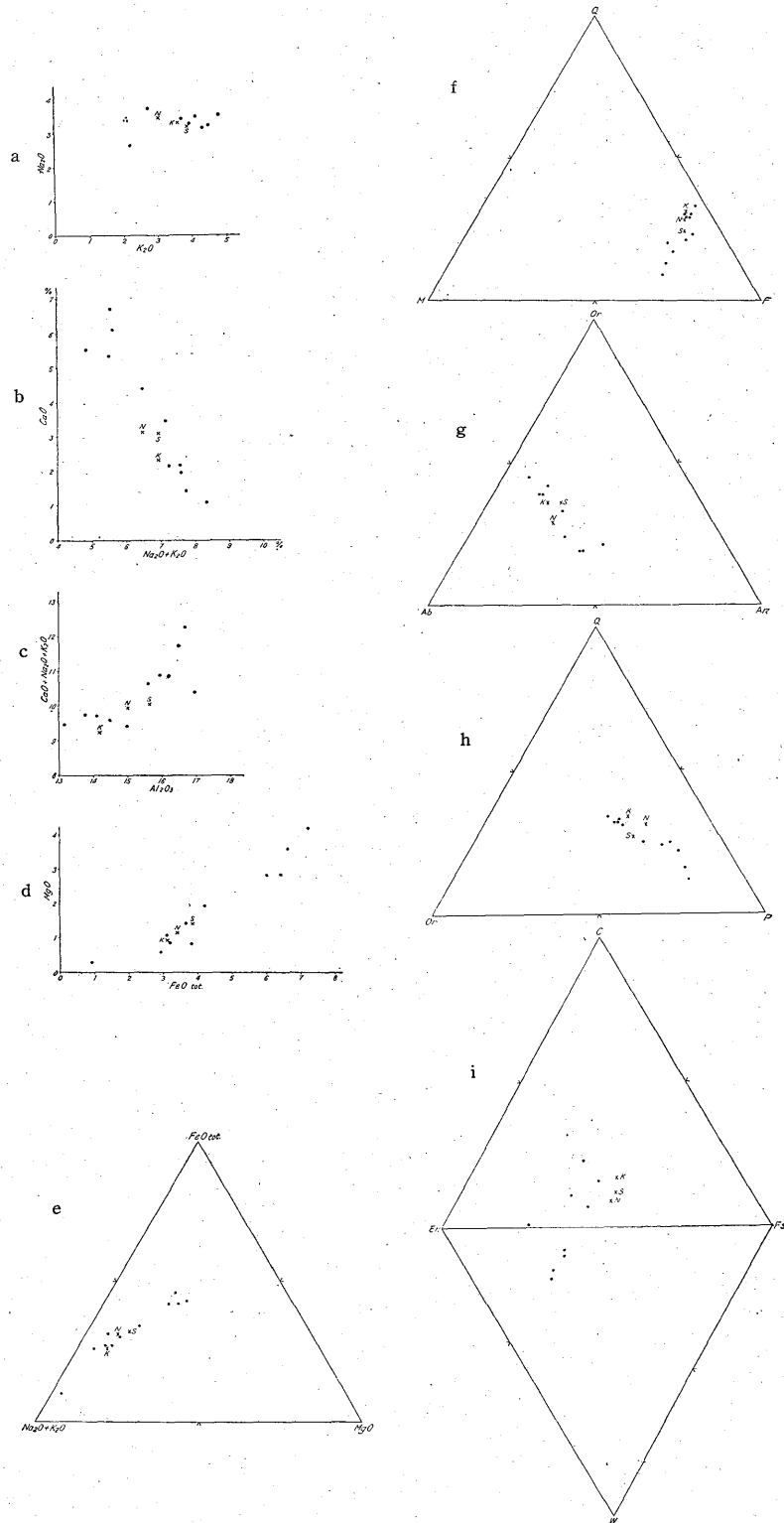


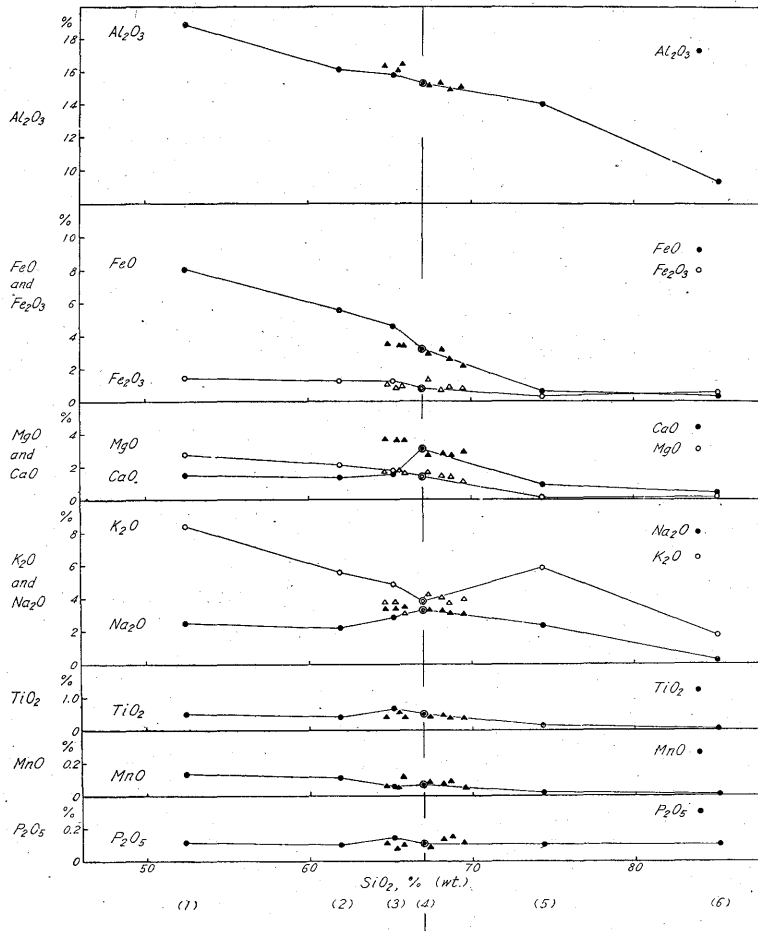
Fig. 3 Relation among the major chemical constituents and the normative mineral components of the average of granitic rocks in the world, Japan, outer zone of Southwest Japan and Shishigawa. a~i: the same as Fig. 2

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- 1) Solid circle—averages of the world after R. A. Daly (Igneous Rocks and the Depth of the Earth, New York, 1933); diorite excluding quartz diorite, diorite including quartz diorite, tonalite, quartz diorite, granodiorite, quartz monzonite, Precambrian granite, Postcambrian granite, granite of Sweden, granite of all period.
- 2) Symbol N—average of Japanese granitic rocks, calculated from 440 analyses, by H. Hattori and T. Nozawa (It will be published soon in another paper.)
- 3) Symbol K—average of granitic rocks of southern Kyushu calculated from 6 analyses, by T. Nozawa.
- 4) Symbol S—average of granodiorites in Shishigawa.

as Japanese and the southern Kyushu's is characterized by the smallness of En ratio than Daly's.

In short, if compared to Japanese and southern Kyushu's, alkalis, especially  $K_2O$ , is quite higher than Japanese and similar to southern Kyushu's. But Shishigawa



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- ⊙ (4av.) Average composition of the seven granodiorites
- (5) Tourmaline aplite
- (6) Tourmaline pegmatite

Fig. 4 Variation diagram for major constituents

granodiorite is more basic than the southern Kyushu's. Namely,  $\text{SiO}_2$  is lower, and FeO, MgO and CaO are higher.

After all, Shishigawa granodiorite is akin to southern Kyushu's. In fact, one of the granodiorite in southern Kyushu is quite similar to Shishigawa granodiorite. (Table 3)

*Minor constituents*

Minor constituents are analysed spectrochemically by DC arc method using the JACO 3.4 m stigmatic grating spectrograph.

It is significant that in two series to which the writers paid a special attention—xenolith of schist to granodiorite, and granodiorite to aplite and pegmatite—each minor constituent follows closely major constituent with which the minor constituent can form a replaceable relation respectively.

Li, Ni, Co and Cr follow Mg and Mg+Fe; Rb, Ba and Pb follow K; Sr follows K and Ca; and Ga follows Al.

Table 2 gives ratios of each of the minor constituent to its replaceable major constituent.

(Li)

Li is camouflaged in minerals containing great quantity of similar elements such as Mg and Fe (probably in biotite).

As seen in Fig. 5, the Li contents of the xenolith (1), 600 ppm, is much more than that of the granodiorite (4), about 50 ppm. It corresponds to the fact that in (1)~(4) series, biotite and muscovite tend to decrease gradually.

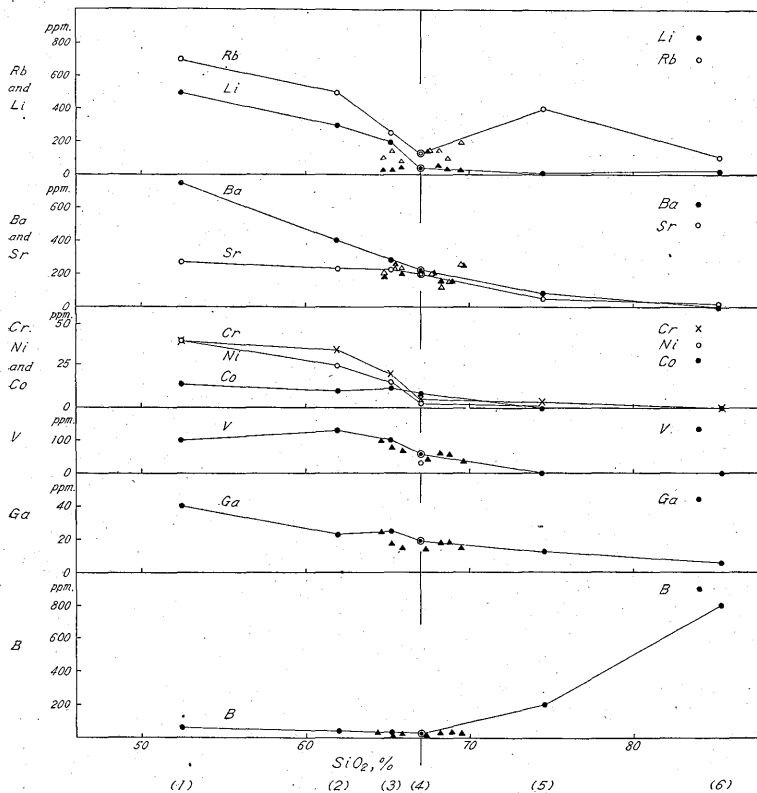


Fig. 5 Variation diagram for minor constituents (see symbols of Fig. 4)



Heier and Taylor (1959), potash-felspar is quite low in Li, averaging 1 ppm in Norwegian alkali-felspar.

Mafic mineral, such as biotite, decreases towards aplitic and pegmatitic rocks and Li shows also the same tendency in the (4)~(6) series. Li/Mg and Li/Mg+Fe ratios for the (1)~(4) series, decrease towards the granodiorite. (Table 2)

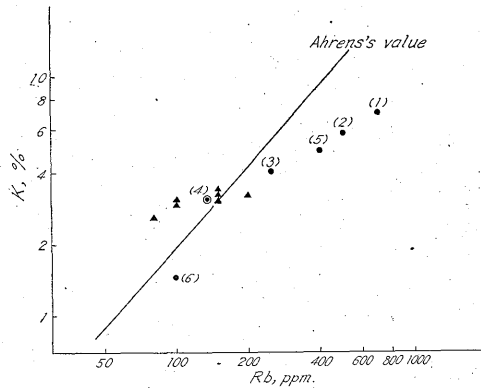
Table 2 Ratios of minor to major constituents in the analysed rocks

Ratio	1	2	3	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4 (average)	5	6
Li/Mg	35.1	24.4	18.3	4.9	7.2	15.2	4.3	2.7	3.2	2.7	5.7	1.9	3.0
Li/Mg+Fe	6.6	4.0	4.1	1.2	1.6	3.5	1.0	0.6	0.7	0.6	1.3	1.2	2.5
Rb/K	10.0	8.7	6.1	3.3	4.5	4.3	3.1	5.0	6.2	3.3	4.2	8.2	6.8
Sr/Ca	25.2	23.4	20.8	7.8	6.1	10.4	9.0	8.9	12.0	7.6	8.8	12.7	3.9
Ni/Mg	2.34	2.04	1.37	0.37	0.37	—	0.32	0.42	0.32	0.43	0.32	—	—
Ni/Mg+Fe	0.44	0.38	0.31	0.09	0.08	—	0.07	0.09	0.07	0.09	0.07	—	—
Co/Mg+Fe	0.17	0.15	0.25	0.15	0.27	0.12	0.24	0.28	0.29	0.18	0.22	—	—
Cr/Mg+Fe	0.44	0.54	0.41	0.19	0.14	0.07	0.07	0.09	0.11	0.18	0.12	0.31	—
Ga/Al	0.25	0.26	0.30	0.23	0.22	0.19	0.17	0.21	0.19	0.29	0.23	0.16	0.12
Pb/K	0.43	0.26	0.61	0.33	0.30	0.20	0.76	0.50	0.37	0.32	0.39	1.63	84.5

Ratios are expressed as numbers multiplied by 1000.

(Rb)

Rb and K have similar geochemical properties and closely similar ionic radii (Rb: 1.47A; K: 1.33A). Rb, therefore, is markedly enriched in potassium minerals, such as alkali feldspars and micas. As seen in the variation diagrams for minor constituents (Fig. 5), Rb is concentrated in xenolith of schist and aplite, and shows decrease in the (1)~(4) series, but increase in the (4)~(6) series.



- (1) Spinel-corundum-biotite schist (xenolith)
- (2) Fine-grained biotite granodiorite (transitional zone between schist and granodiorite)
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- (4-1) Porphyritic biotite granodiorite
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- ◎ (4av.) Average composition of the seven granodiorites
- (5) Tourmaline aplite
- (6) Tourmaline pegmatite

Fig. 6 Relation between K and Rb in Shishigawa granodiorite and related rocks

Ahrens et al. (1952) calculated the ratio Rb/K in common igneous rocks. Their result shows constancy of the ratio in various rocks. (Fig. 6)

As to the ratio Rb/K (Table 2), xenolith of schist and the aplitic and pegmatitic rocks show higher value than the ordinary granodiorite, because of the higher contents of biotite and potash-felspars in them. The association of Rb and K in these rocks is seen in Fig. 6.

(Sr and Ba)

Sr follows Ca constantly in minerals and rocks. Ba does not generally replace Ca, but extensively follows for K, because the size of ionic radii are closely similar.

As seen in the variation diagrams, in the (1)~(4) series, Sr does not show any remarkable tendency, as well as Ca. On the contrary, Ba tends to decrease towards the granodiorite as K does.

The Sr/Ca ratio shows a slight Sr-enrichment in xenolith of schist, and the Ba/K ratio, too. (Fig. 7)

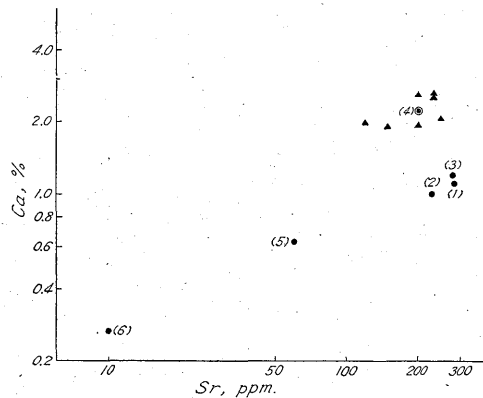


Fig. 7 Relation between Ca and Sr in Shishigawa granodiorite and related rocks (See symbols of Fig. 6)

Turekian and Kulp (1956) have reported that Sr follows Ca in both Ca-poor (0.1~1%) and Ca-rich (above 1%) granitic rocks. The Sr/Ca ratio of Shishigawa granodiorite is slightly lower than the Turekian's value.

Rock	Average (%) Ca	Average (ppm) Sr	Sr/Ca × 1000
Granitic rocks (175)	Turekian and Kulp (1956)		
0.1~1.0% Ca	0.6	100	16.7
1.0~5.0% Ca	1.9	440	23.0
Schist	3.1	242	7.9
Shishigawa granodiorite (7)	2.25	200	8.8
xenolith of schist	1.15	280	25.2

(Ni, Co and Cr)

Ni, Co and Cr follow Mg, Fe and Mn. The ionic radii of Ni, 0.78 Å; Co, 0.82 Å and Cr, 0.64 Å are close to those of Fe, 0.83 Å; Mg, 0.78 Å and Mn, 0.91 Å.

Ni, Co and Cr have a tendency to become enriched in magnesian and ferromagnesian minerals. Vogt (1923) found that Ni, Co and Cr in granitic rocks are mostly contained in biotite, and felspars are devoid of these elements.

De Vore (1955) reported analytical data of major and minor elements for biotites, hornblendes and garnets in various metamorphic facies. The analytical

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data for biotites indicate that average contents of Ni, Co and Cr are 174 ppm Ni; 70 ppm Co; 300 ppm Cr for 6 specimens in epidote-amphibolite facies; 380 ppm Ni; 75 ppm Co; 290 ppm Cr for 4 specimens in amphibolite facies and 49 ppm Ni; 47 ppm Co; 62 ppm Cr for 12 specimens in granulite facies, respectively.

Ogura (1959) also reported that during the granitization process of basic rocks in Abukuma area, biotite in the metamorphic and granitic rocks concentrated Ni, Co and Cr.

In Shishigawa granodiorite, contents of Ni, Co and Cr in the (1)~(4) series

Table 3 Chemical composition of granitic rocks in southern Kyushu

	1	2	3	4	5	6	Average
SiO <sub>2</sub>	75.24	72.19	71.80	67.20	71.88	66.74	70.84
TiO <sub>2</sub>	0.36	0.28	0.22	0.25	0.61	0.38	0.35
Al <sub>2</sub> O <sub>3</sub>	12.71	13.43	13.68	15.52	13.89	15.87	14.18
Fe <sub>2</sub> O <sub>3</sub>	0.70	0.52	0.45	0.48	0.65	1.83	0.77
FeO	1.19	2.23	2.30	4.32	2.04	2.50	2.43
MnO	0.03	0.08	0.06	0.07	0.06	0.07	0.06
MgO	0.40	0.62	0.64	1.70	0.69	1.53	0.93
CaO	1.33	2.05	2.13	2.80	2.17	3.43	2.32
Na <sub>2</sub> O	2.19	3.58	3.74	3.79	3.67	2.83	3.30
K <sub>2</sub> O	4.63	3.06	3.06	3.44	3.44	4.07	3.62
P <sub>2</sub> O <sub>5</sub>	0.07	0.24	0.18		0.37	0.13	0.20
H <sub>2</sub> O+	0.51	0.52	0.53	}lg. loss =0.81	0.52	0.51	0.52
H <sub>2</sub> O-	0.20	0.22	0.20		0.20	0.17	0.20
LiO <sub>2</sub>		tr.	tr.				
B <sub>2</sub> O <sub>3</sub>		0.04	0.02				
Total	99.56	99.06	99.01	100.38	100.19	100.06	99.72
(Norm)							
Q	41.34	33.36	31.50	20.04	31.74	24.25	30.54
C	2.04	1.12	0.61	0.41	1.12	0.88	1.02
Or	27.27	18.37	18.37	20.59	20.59	24.04	21.15
Ab	18.35	30.41	31.46	31.98	30.93	23.96	27.79
An	5.84	8.34	9.74	13.91	8.07	16.19	10.57
Sal. tot.	94.84	91.60	91.68	86.93	92.45	89.32	91.07
En	1.00	1.51	2.71	4.22	1.71	3.81	2.31
Fs	1.06	3.30	3.56	7.26	2.24	2.57	3.43
Mt	0.93	0.70	0.70	0.70	0.93	2.66	1.16
Il	0.76	0.61	0.46	0.46	1.21	0.73	0.61
Ap	0.34	0.67	0.34		1.01	0.30	0.34
Fem. tot.	4.09	6.79	7.77	12.64	7.10	10.07	7.85
Total	98.93	98.39	99.45	99.57	99.55	99.39	98.92

- (1) Two mica granite, at Tarumi, K. Yamaguchi, Jour. Geol. Soc. Jap., Vol. 36, No. 426, p. 109, 1929
- (2) Granite, at Tarumi, K. Takimoto, Jap. Jour. Geol. Geogr., Vol. 19, Nos. 1~4, p. 205, 1944
- (3) Granite, at Tarumi, *ibid.*
- (4) Two mica granite, at Neshime, J. Suzuki, Jour. Geol. Soc. Jap., Vol. 44, No. 526, p. 645
- (5) Granite, at Sata, K. Takimoto, Jap. Jour. Geol. Geogr., Vol. 19, Nos. 1~4, p. 205
- (6) Biotite granodiorite, at Sata, newly analysed by K. Takahashi

and (4)~(6) series, tend to decrease from xenolith of schist to granodiorite, and also decrease towards aplitic and pegmatitic rocks, as seen in the variation diagrams.

Such a behaviour corresponds remarkably to the quantities of mafic minerals, especially on the quantity of biotite in these rocks.

(Ga)

Ga sensibly follows aluminium.

It is controlled principally by diadochy between ions of Ga and Al. The Ga/Al ratio shows a slight decrease towards aplitic and pegmatitic rocks, but any remarkable tendency of the ratio Ga/Al is not observed in both the (1)~(4) and (4)~(6) series. (Table 2)

(B)

Shishigawa granodiorite bears characteristically tourmaline. Therefore, the average content of B, 21 ppm, is higher than that of common granitic rocks. The tourmaline aplite and pegmatite have, of course, remarkably higher content of B than ordinary granodiorite.

B in xenolith of schist, 60 ppm, is probably derived from biotite.

(Sn and Pb)

Sn and Pb are generally enriched in the latest products of magmatic differentiation. And Pb follows K.

The variation diagrams for Sn and Pb in Shishigawa granodiorite coincide to the general rule as mentioned above.

#### IV. Schist xenolith with high content of potash

It has been noticed that in many of igneous rocks in the outer zone of Southwest Japan, there were found abundant xenoliths of aluminous schist or aluminous metamorphic minerals. In Shishigawa granodiorite, too, many schistose xenoliths are widely dispersed. Schist-xenolith is, generally speaking, 5~20 cm in diameter and angular in shape. It graduates into granodiorite passing through the transitional zone, 5~15 cm in width.

Analysed sample (Pls. 3, 4), taken from the northern part of the granodiorite mass, is composed of rather irregular alternation of leucocratic and melanocratic bands, 1~3 mm in width respectively. Under the microscope, the melanocratic bands comprise mainly biotite and a little smaller quantity of potash feldspar and plagioclase. Beside them, corundum and spinel occur as fine grains crowded in pool or in chain, or rather larger rounded grains. Rarely sillimanite occurs in association with spinel and corundum. Secondary muscovite is often accompanied by these corundum and spinel. Leucocratic bands comprise potash feldspar and a little smaller quantity of plagioclase and quartz. Where quartz increases, spinel or corundum disappear entirely. Quartz occurs never in direct contact to spinel or corundum, though it occurs so closely as 1 mm from spinel or corundum.

The transitional zone, fine-grained and rather melanocratic, comprises mainly biotite, potash feldspar, quartz and plagioclase which is always replaced by potash feldspar to some extent from the peripheral portion.

Potash content of this schist-xenolith is remarkably high up to 8.43 per cent. It decreases in the transitional zone to 6.79 per cent which is nevertheless higher than that of the granodiorite, 3.88 per cent in average.

Inspecting the melanocratic band, the writers found a slender streak composed of muscovite flakes. These flakes of muscovite are thought to be primary, different from secondary ones which are accompanied by spinel or corundum. For, they are larger in size, and form a distinct band of themselves and they change into biotite,

even in a single crystal, at the peripheral portion of the band.

Now the writers take these muscovite into consideration to explain the high content of potash of schist-xenoliths and the origin of spinel and corundum. If they assume that the schist-xenoliths were originally muscovite schist, it is easy to infer the high content of potash and an extreme deficiency of silica and excess of alumina. For the sake of convenience, the writers assign the formulae of the main component minerals as follows :

muscovite	$H_2KAl_3Si_3O_{12}$
biotite	$H_2KFe_3AlSi_3O_{12}$
potash felspar	$KAlSi_3O_8$

Their constituents in weight percentage are as follows :

	muscovite	biotite	potash felspar
SiO <sub>2</sub>	45	35	65
Al <sub>2</sub> O <sub>3</sub>	38	10	18
FeO	0	41	0
K <sub>2</sub> O	12	9	17
H <sub>2</sub> O	5	5	0

As seen in the table above, the more the decomposition of muscovite into biotite and potash felspar proceeds under the interaction of granitic magma, the more deficient is SiO<sub>2</sub> and the more excess is Al<sub>2</sub>O<sub>3</sub>. There are formed corundum or spinel.

The writers do not think that the cause of high concentration of alumina and potash can be attributed only to muscovite in original xenolith. Perhaps some clay minerals may be allotted some part of the content of the elements in original xenolith.

## V. Discussion

1) One of the most prominent features of the granitic rocks in the outer zone of Southwest Japan is high content of K<sub>2</sub>O. Another feature is abundance of aluminous xenoliths and aluminous metamorphic minerals such as corundum, spinel, sillimanite, cordierite and garnet. The writers suppose these two features may have a genetical relation.

2) Some problems remain on the origin of muscovite schist which has given rise to spinel corundum biotite schist with high content of potash in Shishigawa granodiorite. Concerning the real content of potash in sericite or muscovite and sericite schist, there are not many instances which have so high content as schist-xenolith now in problem.

Some instances taken from Hitachi mine are as follows (Seto, K., Jour. Jap. Assoc. Min. Petr. Econ. Geol., Vol. 1, No. 3, p. 124, 1929). K<sub>2</sub>O content in sericite is 9.98 per cent and in sericite schist, 4.56 per cent. There are also reported muscovites with more content of K<sub>2</sub>O, for example, up to 11.67 per cent (J. D. Dana, The System of Mineralogy, 1915). But the value of Hitachi is thought to be the commonest one.

Also the content of FeO in the schist-xenolith is extremely high. The high content of these elements will be better explained by the aid of concentration through metamorphic differentiation having taken place in the original schist which is, of course, rich in these elements originally.

3) About the origin of spinel in granitic rocks of the outer zone of Southwest Japan, three ways of explanation are to be taken into consideration. The first is an original existence of spinel in schist, for instance, a schist found by H. Yamamoto

(1958) in Higo gneiss in central Kyushu. The second is a product of metamorphic differentiation in the xenolith included in granite magma. The third is a product of interaction between xenolith and granitic magma. Formerly Nozawa put stress on the second cause in the case of the Osuzu acidic rock. Now he has to modify his former idea in the case of Shishigawa granodiorite. It is most probable to consider the interaction between xenolith and granitic magma as well as the metamorphic differentiation.

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#### 鹿川花崗閃緑岩の岩石化学的性質について

野 沢 保 高 橋 清

#### 要 旨

鹿川花崗閃緑岩は、西南日本外帯に分布する花崗岩質岩石の代表的な1つなので、主成分および微量成分からみた特徴を明らかにした。

また西南日本外帯の火成岩類に特徴的な礫土質変成岩捕獲岩片の成因について考察を加えた。

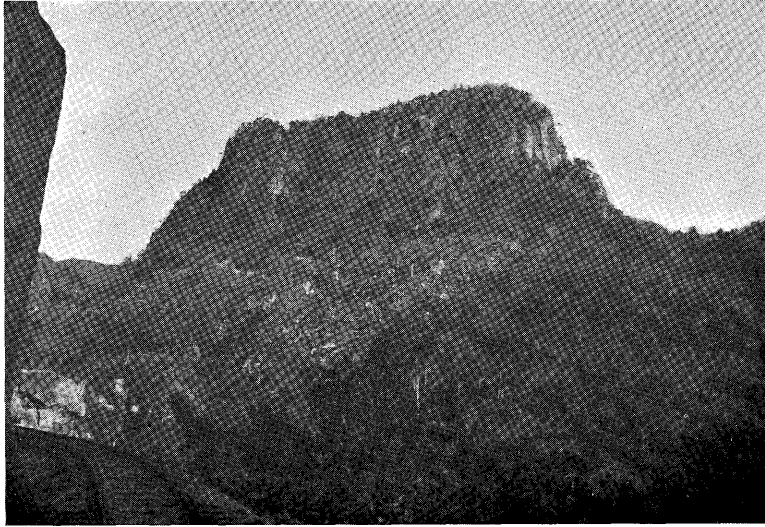


Plate 1 Table-land, 1388 m high, in the midst of Shishigawa granodiorite mass, with the roof pendant of the Mesozoic sandstone



Plate 2 Contact of the granodiorite to the Mesozoic sandstone, Shimoshishigawa

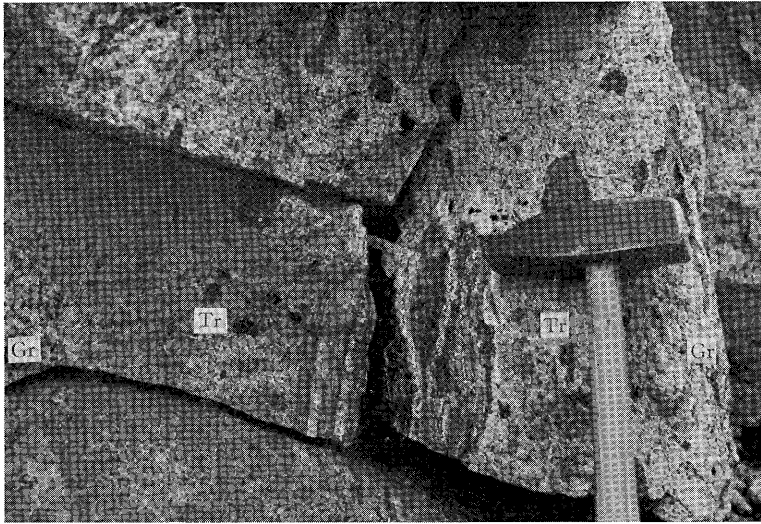


Plate 3 Schist-xenolith. Fine-grained transitional zone (Tr) and the granodiorite (Gr) are observed.

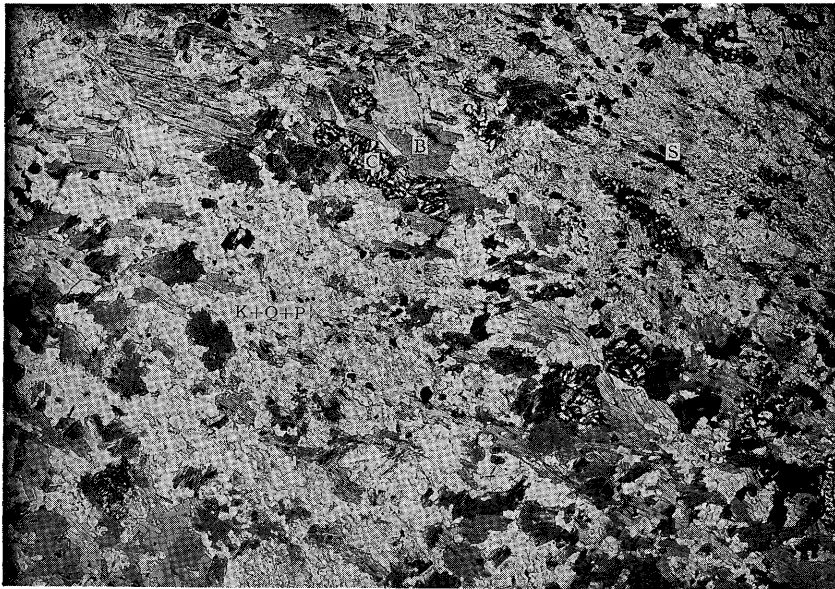


Plate 4 Corundum-spinel-biotite schist, inclusion in the granodiorite  
crossed nicols Chem. anal. (1)

Symbols	C: corundum	S: spinel	B: biotite
	Q: quartz	P: plagioclase	K: potash felspar



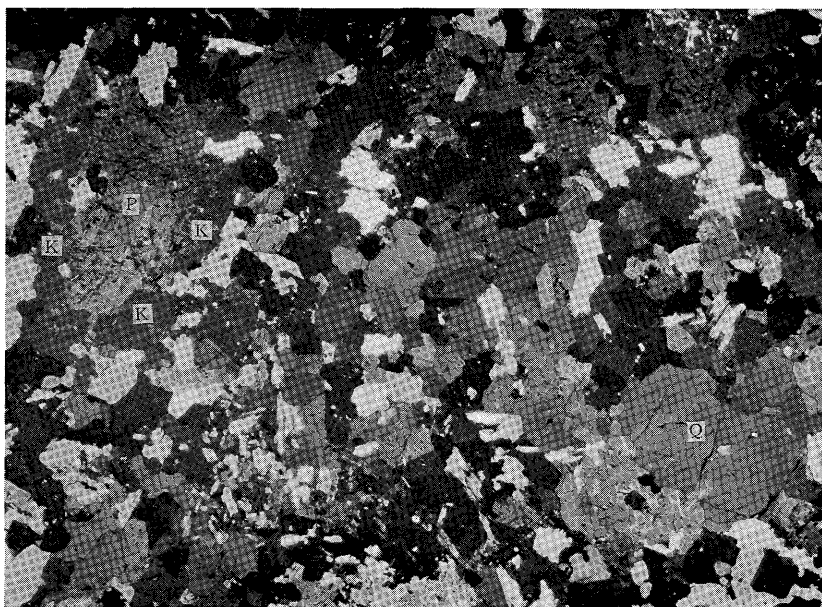


Plate 5 Fine-grained biotite granodiorite, transitional zone between schist-xenolith and the ordinary facies of granodiorite  
crossed nicols Chem. anal. (2)

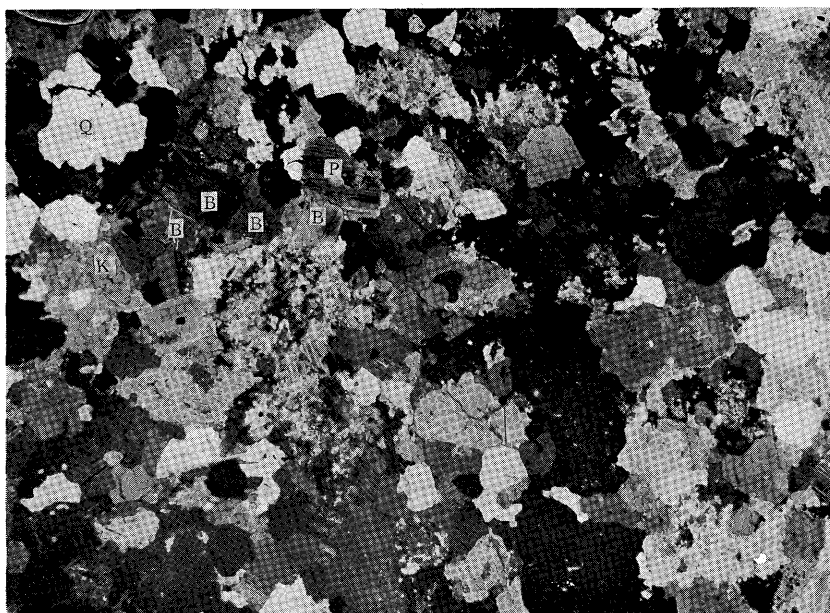
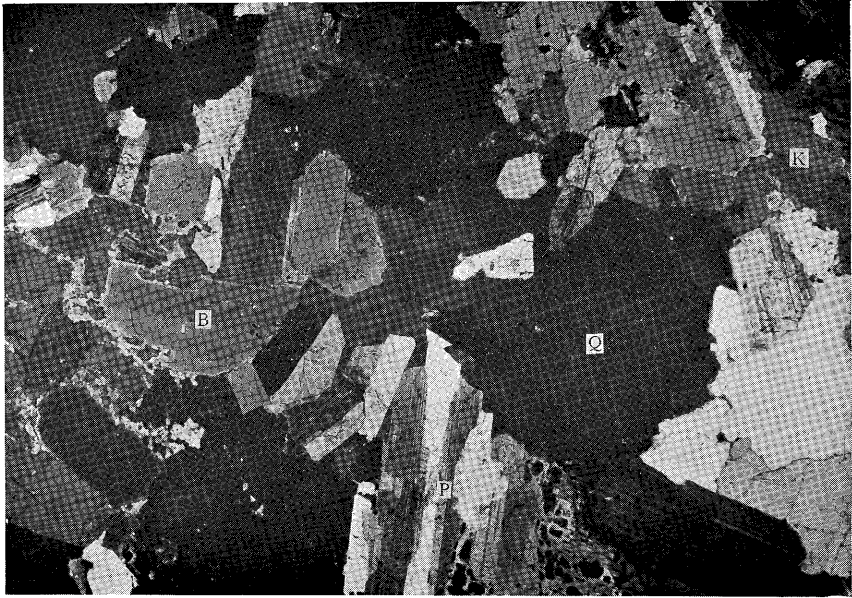


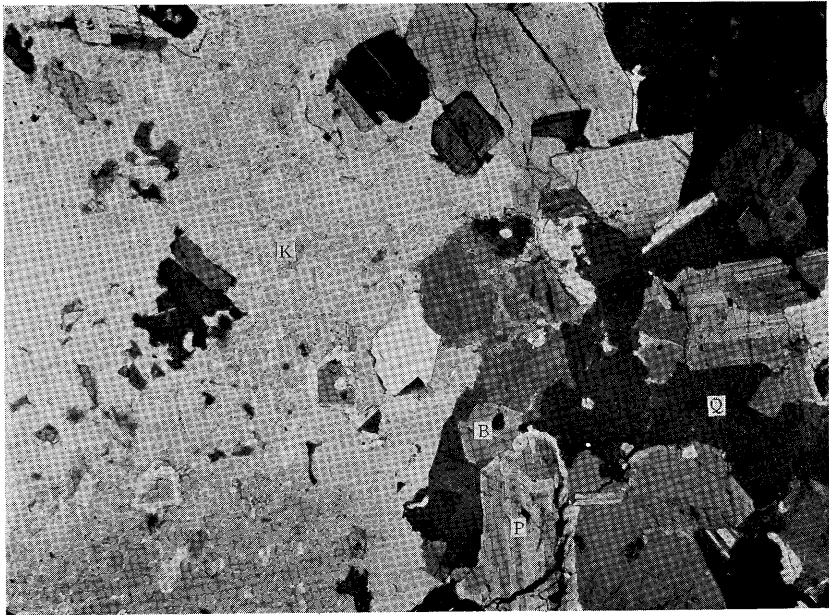
Plate 6 Fine-grained biotite granodiorite  
crossed nicols Chem. anal. (3)



0 1 2 3 4 5 mm

Plate 7 Porphyritic biotite granodiorite  
crossed nicols

Chem. anal. (4)



0 1 2 3 4 5 mm

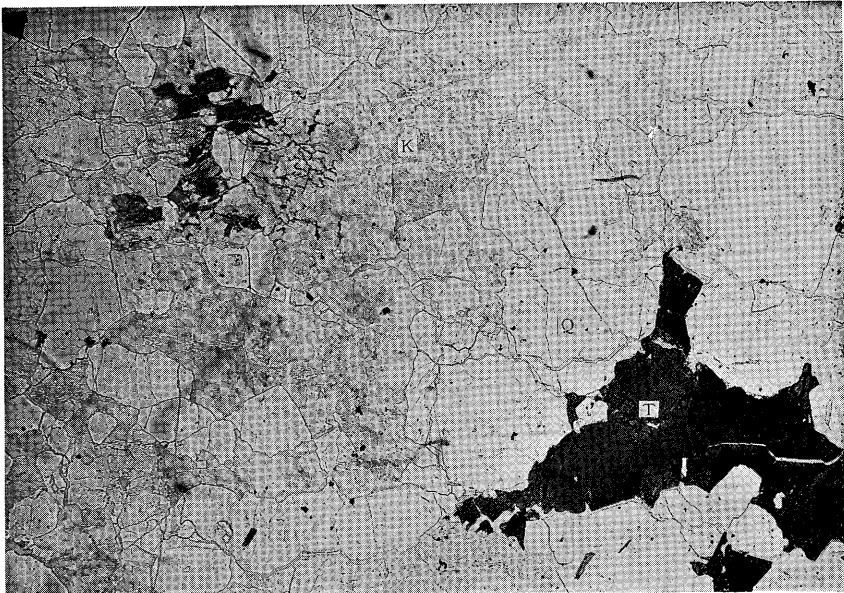
Plate 8 Porphyritic hornblende-biotite granodiorite  
crossed nicols

Chem. anal. (4-4)



0 1 2 3 4 5mm

Plate 9 Augite-bearing hornblende-biotite-quartz diorite  
crossed nicols Chem. anal. (4-5)



0 1 2 3 4 5mm

Plate 10 Tourmaline aplite  
crossed nicols Chem. anal. (5)