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ON THE RELATIONS BETWEEN THE MINERAL AND CHEMICAL COMPOSITIONS OF SOME ACID PLUTONIC ROCKS IN JAPAN

By

Yoshio SUZUKI

(With 6 Tables and 5 Figures)

Contribution from the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, Sapporo, No. 528

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Introduction

Various kinds of acid plutonic rocks are of comparatively wide distribution in Japan. They have been dealt with geologically and petrologically by many investigators up to date, though much work remains to be done in connection with the nature and origin of them. The writer has also made some study especially on the volumetric relations of the chief mineral constituents of some granitic rocks. In the course of his investigation, particular attention has been given to the relations between the modal and chemical compositions of the acid plutonics. In the present study the writer proposes to consider the rocks of the outer zone of south-western Japan, and the Tsukuba District of Ibaraki Pref., central Japan, because a comparatively large number of rocks in these districts have been subjected to chemical analyses by many petrologists. Furthermore, these districts are the best areas hitherto studied for illustrating the relationships between the mineral and chemical compositions of those rocks.

The writer wishes to express his sincere thanks to Prof. T. ISHIKAWA, for his valuable suggestions and criticism in the preparation of this paper, and also the writer is indebted to Prof. J. SUZUKI and Mr.

Y. KATSUI of the Hokkaido University, to Prof. H. SHIBATA, Dr. M. GORAI and Mr. S. OKADA of the Tokyo University of Education and to Mr. T. ARITA of the Kanazawa University, for their works and kind advices on the problem.

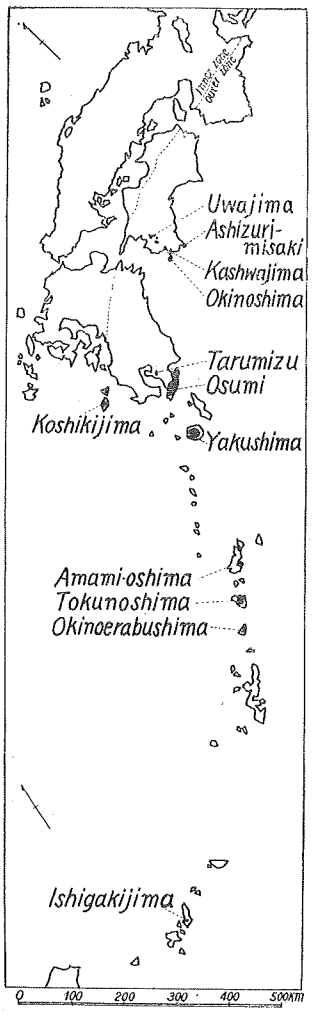


Fig. 1.
Distribution map of granitic rocks in the outer zone of south-western Japan.
Granitic rocks are found in black localities.

Granitic Rocks of the Outer Zone of South-western Japan

Granitic rocks have an especially great development in the inner zone of south-western Japan; those rocks however are distinctly few in the outer zone of it. Passing from the southern part of the Kii Peninsula, through southern Shikoku and southern Kyushu, to Ishigaki Island, in the region of the outer zone of south-western Japan, there are chains of small acid igneous masses (Figure 1).

According to the previous investigations these igneous masses are divided into three main groups from their modes of occurrence and petrological natures; (a) masses showing purely granitic characters and plutonic occurrences, (b) small lenticular masses with granitic characters, which generally occur in limited zones, some of which are often accompanied with serpentinite or other basic rocks, and the most of which are observed to have been effected by a regional metamorphism, and (c) masses occupying comparatively extensive areas, which show a gradual transition from equigranular to porphyritic in structure and most of which rather indicate volcanic occurrences.

In this report, the writer proposes to comment on the masses belonging to category (a) and to treat the rocks from the localities shown in Figure 1 and Table 2.

The largest body in those masses of the

outer zone, develops, in the southern part of the Osumi Peninsula of Kagoshima Prefecture in Kyushu, extending about 40 km in EW direction and about 15 km in NS direction. The masses in the other localities in the zone are generally very small, and none of them exceeds 20 km in apparent diameter.

As the ages of intrusions of those masses, including that of the Osumi Peninsula, are much the same and are considered by many geologists to be late or post-Cretaceous, all these masses can reasonably be treated together in this paper.

Generally the rocks from the above-cited localities, are granodioritic in nature. They are composed principally of quartz, potash felspar and plagioclase though either biotite and/or hornblende is always present as an additional constituent. There can be seen some characteristic rock facies in them, which contain special accessory constituents such as tourmaline (Uwajima, Koshikijima, Yakushima and Osumi), garnet (Kashiwajima), allanite (Okinoshima, Koshikijima, and Osumi), corundum, spinel and rutile (Amami-oshima), some of which are clearly due to the contaminating effects of local intrusions.

The rocks of Ishigaki Island, which is situated at the southern extremity of the outer zone, show some different natures in comparison with the other granodioritic masses in this region. As is indicated in

TABLE 1. Modal analyses of granitic rocks in the Osumi Peninsula.

	Quartz	Potash felspar	Plagioclase	Hornblende	Biotite	Other minerals
1	30.6	8.5	37.0	0.0	22.4	1.5
3	23.3	15.2	49.6	0.0	10.8	1.1
7	27.9	22.3	32.3	0.0	16.8	0.7
13	26.8	13.0	41.6	1.5	16.7	0.4
15	38.2	8.5	38.8	1.3	12.9	0.3
18	21.5	20.4	41.1	2.3	14.4	0.3
21	28.2	17.5	44.7	1.8	7.8	0.0
24	28.9	13.8	41.3	2.5	13.3	0.2
25	33.1	15.5	34.7	0.0	16.5	0.2
Average	28.7	15.0	40.1	1.1	14.6	0.5

Modal values of the granitic rocks in this paper were measured by the writer, excepting Nos. 6 and 7 in Table 2 which were done by INAMORI.

Total of modal values of each rock is 100.

Table 2, the most noticeable feature is their leucocratic character with dominantly miarolitic cavities; their chemical compositions and the microscopical characters of constituent minerals are remarkably different as compared with the granitic rock found at other localities. For the above reasons it is not determinable whether the granitic mass of Ishigaki Island is comparable in age to other granitic masses in the outer zone or whether it belongs to some other series.

It seems that the granitic masses of the outer of south-western Japan are not always common with each other in respect to mineral compositions, and that partial variation of mineral composition is also seen in each granitic mass itself, as shown in an example from the Osumi Peninsula.

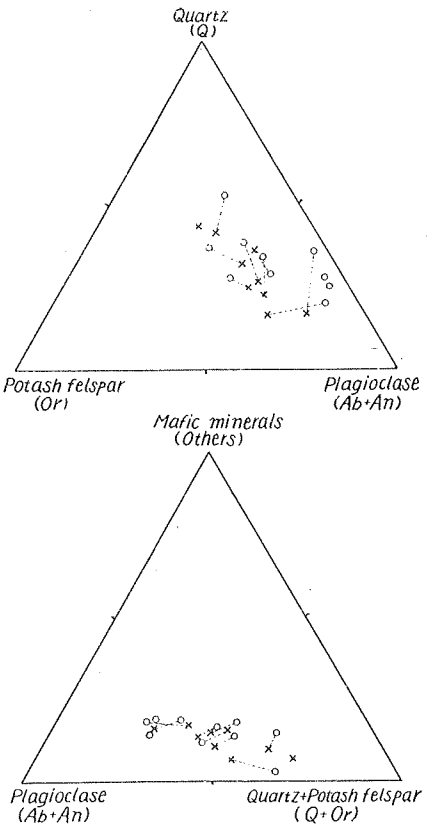


Fig. 2. Difference between mode and norm of granitic rocks of the outer zone of south-western Japan.
White circle: Mode.
Diagonal cross: Norm.
Corresponding values are connected by dotted line.

The volume proportions of the mineral constituents of the rocks of the granitic masses in south-western Japan, which are analysed by point counter for each thin section of them, are shown in Table 2. Especially the samples from the large granitic mass in the Osumi Peninsula were carefully collected by the writer from nearly north to south through its western marginal zone, in which locality No. 1 is its northern-most part and No. 25 is its southern-most part. The modal compositions on each thin section are also tabulated in Table 1. within this single granitic mass, the chief constituents show a noticeable fluctuation.

The granitic rocks of the outer zone of south-western Japan vary in nature, over a comparatively wide range, but on the whole they may from the petrographical viewpoint,

be suitably called granodiorite as judged by their mineralogical and chemical compositions. In order to compare the relation of mineral and chemical compositions of the acid plutonics in this zone, their chemical compositions and the normative values calculated from them are show in Table 2. Most of the thin sections for volumetric analyses

TABLE 2. Modal analyses and chemical compositions of granitic rock of the outer zone of south-western Japan.

Modes (%)

	1	2	3	4	5	6	7	8	9
Quartz	33.1	43.6	23.0	28.7		25.8	25.4	13.0	24.3
Potash felspar	15.6	15.8	3.6	15.0		1.6	9.2	1.1	25.6
Plagioclase	34.3	25.4	54.9	40.1		57.0	51.6	69.5	36.5
Hornblende	0.0	0.4	1.9	1.1		6.3	3.7	4.7	0.0
Biotite	15.0	4.1	16.2	14.6		8.5	5.7	9.7	12.8
Others	2.0	10.7	0.4	0.5		0.8	0.9	2.1	0.8

Chemical compositions.

	1	2	3	4	5	6	7	8	9
SiO_2	65.96	74.52		67.20	75.24				68.60
TiO_2	0.51	0.16		0.25	0.36				0.22
Al_2O_3	15.82	14.12		15.52	12.71				16.02
Fe_2O_3	0.72	0.24		0.48	0.70				0.16
FeO	3.95	2.66		4.32	1.19				3.74
MnO	0.04	0.03		0.07	0.03				0.08
MgO	1.81	0.60		1.70	0.40				1.10
CaO	3.35	0.84		2.80	1.33				2.86
Na_2O	3.05	2.96		3.79	2.19				3.43
K_2O	3.22	3.89		3.44	4.63				3.84
P_2O_5	—	—		—	0.07				—
$H_2O^{(+)}$	—	—		—	0.51				—
$H_2O^{(-)}$	—	—		—	0.20				—
Ign. loss	1.50	0.40		0.81	—				0.50
Total	99.93	100.42		100.38	99.56				100.55
Analyst	R. Hiratsuka	R. Hiratsuka		M. Sekine	K. Yamaguchi				M. Sekine

TABLE 2 (Continued).

Norms calculated from the above chemical compositions

	1	2	3	4	5	6	7	8	9
Q	23.1	37.4		19.9	40.8				23.0
Or	19.0	23.0		20.3	27.3				22.7
Ab	25.8	25.0		32.0	18.5				29.0
An	16.6	4.2		13.9	6.2				14.2
C	1.2	3.5		0.5	1.8				1.0
Wo	—	—		—	—				—
Fs	5.9	4.5		7.3	1.1				6.5
En	4.5	1.5		4.2	1.0				2.7
Mg	1.0	0.4		0.7	1.0				0.2
Il	1.0	0.3		0.5	0.7				0.4
Ap	—	—		—	0.2				—

Biotite of Uwajima in modes includes chlorite (11.9%).

Others of Uwajima in mode includes tourmaline (0.9%); of Kashiwajima, garnet (9.8 %); of Okinoshima, allanite (0.1%); of Amamioshima-(A) corundum and spinel; of Amamioshima-(B) corundum (0.25%) and spinel (0.9%).

1. Onigashiro-yama, Uwajima, Ehime Prefecture.
2. Kashiwajima, Hada-gun, Kochi Prefecture.
3. Okinoshima, Kochi Prefecture.
4. This mode is the average value of those of the Osumi Peninsula, already shown in Table 1. The locality of chemicaly analysed rock is the southern part of Mt. Tsuji, Kimotsuki-gun, Kagoshima Prefecture.
5. Tarumizu, Kimotsuki-gun, Kagoshima Prefecture, Chemical data of Nos. 4 and 5 from Yamaguchi (1929).
6. Shimokoshikijima, Satsuma-gun, Kagoshima Prefecture.
7. Loc. ditto. Acid part. (Datum from Inamori (1949)).
8. Loc. ditto. Basic part. (Datum from Inamori (1949)).
9. Sentozan, Yakushima, Kagoshima Prefecture.

Modes (%)

	10 (A)	10 (B)	11	12	13			14*
Quartz	15.5	16.9	25.6	29.9	31.3	36.7	41.7	36.6
Potash felspar	6.9	7.2	15.7	2.5	28.2	31.6	26.7	28.8
Plagioclase	59.1	56.7	46.0	49.0	35.4	29.2	28.7	31.1
Hornblende	0.0	0.0	0.0	5.8	1.2	0.0	0.1	0.4
Biotite	10.8	9.5	12.4	12.8	1.9	2.4	2.8	2.4
Others	7.7	9.7	0.3	0.0	2.0	0.1	0.0	0.7

Chemical compositions

	10	11	12	15	16	17	18
SiO_2	62.18	68.14	61.97	73.90	75.67	74.82	69.53
TiO_2	0,31	0.57	0.85	0.12	0.13	0.12	0.31
Al_2O_3	16.80	16.79	17.75	12.54	13.77	13.96	14.85
Fe_2O_3	0.32	0.40	0.80	0.32	0.47	0.08	1.12
FeO	4.46	4.03	4.20	2.15	1.00	1.30	2.87
MnO	0.08	0.08	0.09	0.03	0.03	0.03	0.06
MgO	2.90	1.39	2.52	0.42	0.15	0.26	0.51
CaO	4.51	2.86	4.69	0.84	0.56	0.73	1.37
Na_2O	2.94	2.79	3.94	3.93	4.13	3.94	5.16
K_2O	3.50	2.62	2.14	4.44	3.63	4.56	2.77
Ign. loss	1.69	0.38	0.76	1.15	0.69	0.50	1.42
Total	99.69	100.05	99.71	99.84	100.23	100.30	99.97
Analyst	M. Sekine	M. Sekine	K. Isono	K. Isono	M. Sekine	K. Isono	R. Hiratsuka

Norms calculated from the above chemical compositions.

	10	11	12	15	16	17	18	19*
Q	14.1	30.6	14.2	29.9	35.5	31.3	23.2	30.0
Or	20.6	15.5	12.7	26.2	21.4	26.9	16.4	22.7
Ab	24.9	23.6	33.3	33.2	34.9	33.3	43.6	36.3
An	22.2	14.2	23.3	3.4	2.8	3.6	6.8	4.1
C	—	4.1	0.4	—	2.0	1.2	0.9	1.0
Wo	0.1	—	—	0.3	—	—	—	—
Fs	7.6	6.3	5.8	3.5	1.3	2.2	3.9	2.7
En	7.2	3.5	6.3	1.0	0.4	0.6	1.3	0.8
Mt	0.5	0.6	1.2	0.5	0.7	0.1	1.6	0.7
Il	0.6	1.1	1.6	0.2	0.2	0.2	0.6	0.3

10. Ishizaki, Amamioshima, Kagoshima Prefecture. Two modes (A, B) are from the same locality.
11. Todoroki, Higashiamagi-mura, Tokunoshima, Kagoshima Prefecture.
12. Koshiyama, Okinoerabushima, Oshima-gun, Kagoshima Prefecture.
13. Ishigakijima, Okinawa Prefecture.
14.* Average of Modes of Ishigakijima.
15. The south of Kawahira, Ishigakijima, Okinawa Prefecture.
16. 17 and 18. Omotodake, Ishigakijima, Okinawa Prefecture.
19.* Average of Norms of those from Ishigakijima.

Data of chemical analyses are cited from J. SUZUKI (1937), excepting Nos. 4 and 5.

cited in Table 2, are made respectively from corresponding samples which were used for chemical analysis. Though the thin sections from the Osumi mass are not exactly in accord with the samples for chemical analyses. It can be seen from a glance at Table 2 that there are conspicuous differences between modal values and their corresponding normative values. The relations of these values are shown in Figure 2.

Granitic Rocks of the Tsukuba District of Central Japan

The Tsukuba District occupies the north-eastern corner of the Kanto plain and is made up essentally of plutonic masses which are dominantly granitic in character with a minor development of gabbroic rock and various kinds of dike rocks. In the surrounding Paleozoic sedimentaries there are some interesting metamorphics, gneiss, hornfels, etc., along the zone of contact with granite, which have resulted from the granite intrusion.

The granitic masses in the district occur in the form of large stock-like intrusions whose area measures twenty km by ten. There are many good outcrops and large quarries in granitic masses. They have been more particularly studied than those in other districts, because of their relatively greater economic importance. From the petrographical natures the granitic masses in this district have been divided by H. SHIBATA (1944), into two main types, the Inada type and the Tsukuba type. The former has lately been subdivided into two, the Inada-type proper and the Kamishiro type, which are distinguished especially by their chemical compositin (H. SHIBATA ; 1953). However for convenience these latter two are treated together as the original Inada type in this paper, because the distribution of rocks of each subdivided type is yet uncertain.

All acid plutonic rocks from the district are principally composed of quartz, potash felspar, plagioclase and biotite, though some of them often contain muscovite and rarely hornblende. The rocks of the Inada type are medium-grained and homogeneous but those of the Tsukuba type are generally coarse-grained and sometimes conspicuous heterogeneous.

Minor dike rocks intrude into the granitic mass of each of the above described types, especially the Tsukuba type. The petrological character of the most of these minor masses except pegmatites and

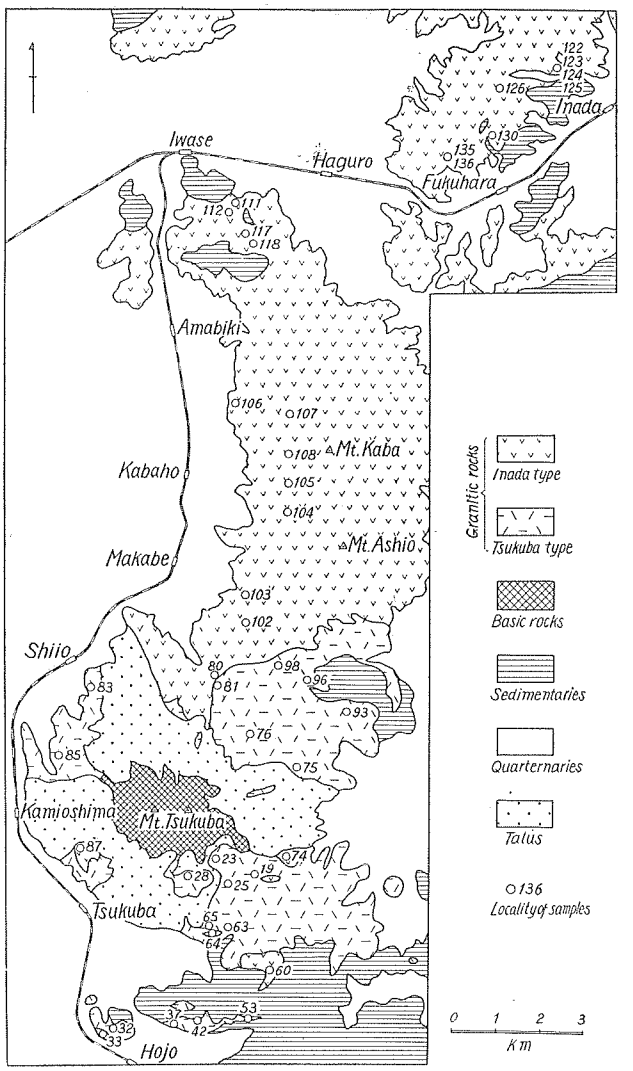


Fig. 3. Geological map of the Tsukuba District.

This map is compiled from the maps made by YAMADA (1888), ŌHASHI (1912), SATŌ (1926) and SHIBATA (1944). The data of the writer and Okada are added.

TABLE 3. Modal analyses of granitic rocks in the Tukuba District.

Tsukuba type

	Quartz	Potashfelspar	Plagioclase	Hornblende	Mica	Others
19	23.4	15.9	52.4	0.05	8.15	0.1
23	33.8	34.3	29.8	0.0	2.1	0.0
25	29.1	31.5	30.4	0.0	8.7	0.3
28	43.7	27.7	22.2	0.0	6.3	0.1
32	15.3	11.9	52.5	0.0	19.8	0.5
37	31.3	1.6	48.6	0.0	16.1	2.4
42	26.0	22.2	37.0	0.2	14.2	0.4
53	37.2	2.0	45.7	0.1	14.9	0.1
63	26.3	2.8	52.5	1.1	16.6	0.7
65	19.5	22.2	39.3	0.0	18.5	0.5
76	32.7	0.8	51.3	0.0	14.6	0.6
81	21.5	20.5	46.9	0.0	10.9	0.2
83	27.5	36.7	28.3	0.0	7.3	0.2
85	25.3	11.6	50.6	0.0	11.7	0.8
93*	1.7	72.5	19.2	0.0	5.9	0.7
96*	43.7	29.2	15.2	0.0	5.9	6.0
98	26.2	35.2	27.2	0.0	11.0	0.4
Average	27.9	18.4	41.0	0.1	12.1	0.5

Inada type

	Quartz	Potash felspar	Plagioclase	Hornblende	Mica	Others
80	29.9	27.0	35.5	0.0	7.3	0.3
102	31.2	24.4	37.8	0.0	6.4	0.2
103	33.4	23.1	33.6	0.0	9.6	0.3
104	35.1	20.0	36.2	0.0	7.6	1.1
105	33.0	12.6	46.5	0.0	7.2	0.7
106	28.8	16.4	48.3	0.0	6.3	0.2
107	27.6	24.4	40.0	0.0	7.7	0.3
108	25.5	23.7	42.3	0.0	8.3	0.2
111	26.9	30.9	34.8	0.0	5.9	1.5
112	25.4	17.2	46.0	0.0	11.0	0.4
117	30.7	16.5	45.2	0.0	7.4	0,2
118	32.2	25.8	36.0	0.0	4.9	1.1
122	27.2	14.8	47.4	0.0	9.9	0.7
123	25.0	20.1	48.9	0.0	5.7	0.3
124	17.2	50.4	29.3	0.0	3.0	0.1
125	51.7	14.7	30.3	0.6	2.6	0.1
126	36.2	19.9	38.4	0.3	5.0	0.2
130	32.2	32.7	30.6	0.4	3.8	0.3
135	26.6	22.5	42.9	0.0	7.3	0.7
136	24.9	14.9	51.5	0.0	8.5	0.2
Average	30.0	22.6	40.1	0.1	6.8	0.4

TABLE 3 (continued)

Minor intrusive bodies in granitic rocks of the Tsukuba type.

	Quartz	Potash felspar	Plagioclase	Hornblende	Mica	Others
33A**	38.3	25.1	26.3	0.0	5.7	4.6
33B**	40.2	24.2	26.5	0.0	4.4	4.7
60	46.2	27.4	21.0	0.0	5.1	0.3
64	31.6	23.8	39.3	0.0	5.1	0.2
74	22.8	24.8	44.7	0.0	7.5	0.2
75	39.2	25.4	30.6	0.0	4.6	0.2
87	31.3	16.5	42.8	0.0	7.7	1.7

The numbers of the specimens correspond to those of locality in Figure 3.

* Specimens Nos. 93 and 96 are omitted from calculation for average, because of their macroscopical heterogeneity, and they are not indicated in Figures 4 and 5.

** No. 33 A includes andalusite, sillimanite and garnet (0.4%). No. 33 B includes the same (0.3%).

aplites are generally similar to those of the Inada type but it is noticeable that some of them contain garnet, andalusite, sillimanite etc. as accessory constituents. In this paper these granitic intrusives are treated the same as the main major masses for reference.

In Table 3, are writer shown the modal analyses of 44 thin sections of the granitic rocks from Tsukuba District, based upon measurement carried out by the "Integrationstisch". Localities of samples are plotted on Figure 3.

The volumetric relations among the principal constituents, quartz, potash felspar and plagioclase, in the granitic rocks of these two types in the Tsukuba District, are shown in Figure 4. when the sum of quartz, potash felspar and plagioclase is plotted on the abscissa and each component respectively on the ordinate, the figure shows the remarkable difference between the two types of rock. It is remarkable that the rocks of the Inada type are more leucocratic than those of the Tsukuba type.

From the mode of occurrence, it is considered that the granitic mass of Tsukuba type should be accepted as the older type in the district. It may indicate that there were at least two distinct periods of granitic intrusion. The margin of Inada type intrusions is some times sharply defined at the contact with Tsukuba type mass.

The measured values on the rocks of the Tsukuba type extend over a comparatively wide range, but those of the Inada type, especially the rocks from the district of Mt. Kaba bear a striking resemblance to each other. These results might be much concerned with the grain

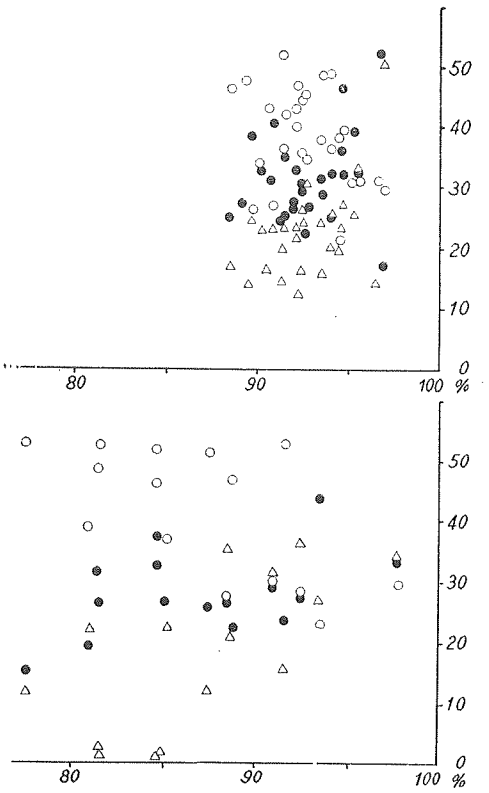


Fig. 4. Relation diagram of modal salic minerals of granitic rocks in the Tsukuba District.
Upper: Inada type, including minor intrusives.
Lower: Tsukuba type.
White circle: Plagioclase.
Black circle: Quartz.
Triangle: Potash felspar.
Abscissa: sum of quartz, potash felspar and plagioclase.

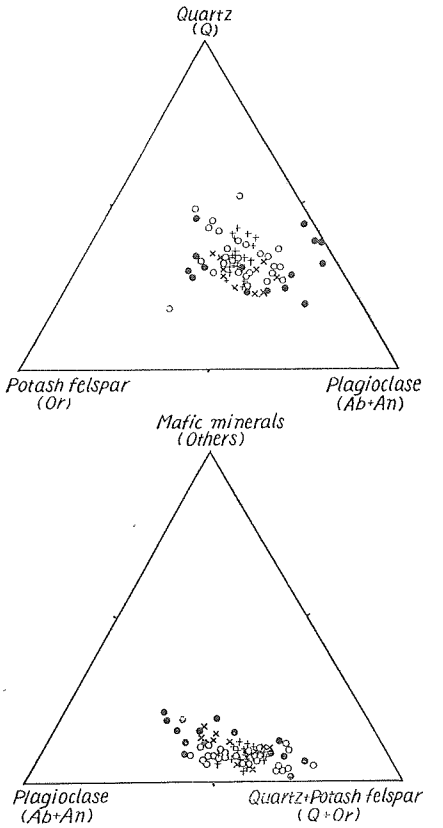


Fig. 5. Relation diagram of the granitic rocks in the Tsukuba District.
White circle: Mode of Inada type,
Black circle: Mode of Tsukuba type.
Cross: Norm of Inada type.
Diagonal cross: Norm of Tsukuba type.

size of constituent minerals. That is, there may be a tendency indicating that the finer the grains are the smaller the range of variation of measuring values become. However the reasons of these results may be concerned not only with grain size, but also with the homogeneity of the rock masses themselves.

The chemical analyses regarding the granitic rocks from the Tsukuba District which were published in various references are tabulated in Table 4 and also normative values calculated from them are subjoined.

TABLE 4. Chemical compositions of granitic rocks in the Tukuba district.

Granitic rocks of the Tsukuba type. Chemical composition

	1	2	3	4	5	6	7	8	9	10
SiO_2	72.72	68.02	66.60	66.21	66.63	73.16	73.63	64.76	71.26	71.75
TiO_2	0.36	0.36	0.58	0.50	0.58	0.40	0.09	0.90	0.35	0.23
Al_2O_3	12.10	16.31	17.94	17.29	16.28	12.32	13.80	17.32	14.84	14.48
Fe_2O_3	1.43	0.69	0.33	0.18	0.15	0.62	0.61	0.22	0.60	0.86
FeO	1.41	2.62	2.99	3.07	4.47	1.41	1.16	3.22	2.24	1.52
MnO	tr.	0.07	0.02	0.05	0.09	tr.	0.02	0.02	0.02	0.03
MgO	0.62	0.21	1.22	1.21	1.24	0.76	0.34	1.58	0.29	0.17
CaO	2.24	2.83	3.54	3.11	3.33	2.48	1.59	4.18	2.38	2.02
Na_2O	2.99	3.34	2.86	3.56	3.53	3.29	3.63	3.21	3.70	3.50
K_2O	4.66	3.54	2.82	3.89	2.59	4.53	4.89	3.37	4.86	4.93
P_2O_5	0.09	0.40	0.06	0.23	0.21	0.05	0.06	0.22	0.25	0.24
$H_2O^{(+)}$	0.78	0.76	0.68	0.62	0.66	0.52	0.69	0.94	0.65	0.78
$H_2O^{(-)}$	0.28	0.35	0.50	0.37	0.12	0.40	0.33	0.64	0.30	0.19
Total	99.68	99.50	100.14	100.29	99.88	99.94	100.84	100.58	100.54	100.70
Analyst	S. Okada	H. Shibata	S. Okada	H. Shibata	S. Tanaka	S. Okada	H. Shibata	S. Okada	H. Shibata	H. Shibata
Norms calculated from the above chemical compositions.										
Q	32.4	27.5	27.7	20.7	24.2	30.8	29.0	20.2	24.7	27.9
Or	27.5	21.1	16.6	22.8	15.6	26.7	28.9	19.9	28.9	28.9
Ab	25.3	28.3	24.1	29.9	29.9	27.8	30.9	27.1	31.4	29.3
An	5.8	11.7	17.2	13.6	14.7	5.4	6.7	19.5	9.2	8.3
C	—	2.7	2.8	2.2	2.1	—	—	1.2	—	0.4
Wo	2.0	—	—	—	—	2.8	0.5	—	0.4	—
Fs	0.8	3.8	4.3	4.9	7.3	1.4	1.5	4.3	3.0	1.7
En	1.5	0.5	3.0	3.0	3.1	1.9	0.8	4.0	0.7	0.4
Mt	2.1	0.9	0.5	0.2	0.2	0.9	0.9	0.3	0.9	1.2
Il	0.7	0.8	1.1	0.9	1.1	0.8	0.2	1.7	0.6	0.5
Ap	0.2	1.0	0.1	0.7	0.7	0.1	—	0.5	0.7	0.7

All localities are in Ibaraki Prefecture, The locality of chemical analysis is roughly corrsponding to that of modal analysis, which is shown by number next to the literature.

1. Shirataki, Tai-mura, Tsukuba-gun; H. SHIBATA (1953); No. 25.
2. Locality ditto; H. SHIBATA (1944); No. 25.
3. Hirasawa, Oda-mura, Tsukuba-gun; H. SHIBATA (1953); Nos. 37 and 42.
4. Loc. ditto; H. SHIBATA (1944); Nos. 37 and 42.
5. Loc. ditto; H. SUGI (1930); Nos. 37 and 42.
6. Yubukuro, Obata-mura, Niihari-gun; H. SHIBATA (1953); No. 76.
7. Loc. ditto; H. SHIBATA (1944); No. 76.
8. Yamaguchi, Oda-mura, Tsukuba-gun; H. SHIBATA (1953); No. 42.
9. Hadori-mura, Makabe-gun; H. SHIBATA (1944).
10. Nanae, Niihari-gun; H. SHIBATA (1944).

TABLE 4 (continued)

Granitic rocks of the Inada type. Chemical composition

	11	12	13	14	15	16	17	18
SiO_2	70.51	70.86	70.54	70.91	71.80	71.78	71.66	73.05
TiO_2	0.26	0.34	0.58	0.36	0.34	—	0.42	0.37
Al_2O_3	15.37	15.25	14.05	14.36	15.11	14.66	13.60	13.62
Fe_2O_3	0.55	0.59	0.87	0.40	0.28	2.63	1.00	0.83
FeO	1.98	2.27	1.98	2.54	2.03	—	1.82	1.43
MnO	0.02	0.02	nd.	0.30	0.18	0.11	nd.	nd.
MgO	0.35	0.34	0.84	0.28	0.20	0.60	0.82	0.52
CaO	2.24	2.42	3.07	2.60	2.27	2.33	2.89	2.22
Na_2O	3.54	3.16	3.21	3.30	3.24	3.30	3.05	3.16
K_2O	4.49	4.11	3.90	2.59	2.93	4.07	4.12	4.08
P_2O_5	0.54	0.06	0.07	0.32	0.24	—	0.04	0.12
$H_2O^{(+)}$	0.44	0.72	0.63	0.89	0.77	—	0.55	0.90
$H_2O^{(-)}$	0.26	0.23	0.60	0.25	0.32	—	0.36	0.41
ZrO_2	—	—	—	0.02	0.02	—	—	—
S	—	—	—	0.11	0.05	—	—	—
Ign. loss	—	—	—	—	—	0.63	—	—
Total	100.55	100.37	100.34	99.23	99.78	100.11	100.32	100.71
Analyst	H. Shibata	H. Shibata	S. Okada	T. Ohashi	T. Ohashi		S. Okada	S. Okada

Norms calculated from the above chemical compositions.

Q	27.1	29.2	28.6	34.7	36.1	31.2	30.4	32.8
Or	26.7	24.5	23.0	15.6	17.2	23.9	24.3	24.1
Ab	29.9	26.7	27.1	27.8	27.3	27.8	25.8	26.7
An	7.8	12.0	12.3	10.8	9.5	11.7	11.2	10.3
C	1.7	1.1	—	2.1	3.2	0.5	—	0.2
Wo	—	—	1.0	—	—	—	1.2	—
Fs	2.9	3.2	2.0	Hy 4.9	Hy 3.8	—	1.8	1.3
En	0.9	0.8	2.1			1.5	2.0	1.3
Mt	0.7	0.9	1.3	0.7	0.5	0.5	1.5	1.2
Hm	—	—	—	—	—	2.4	—	—
Il	0.5	0.6	1.1	0.8	0.6	—	0.8	0.7
Ap	1.3	0.1	0.2	0.7	0.7	—	0.1	0.3

11. Hadori, Shiio-mura, Makabe-gun; H. SHIBATA (1944).
12. Yamanoo, Makabe-machi, Makabe-gun; H. SHIBATA (1944); No. 102.
13. Denshoji, Makabe-machi, Makabe-gun; H. SHIBATA (1953); No. 103.
14. Shirai-Takiishi quarry, Kabaho-mura, Makabe-gun; INOUE (1912); No. 107 and 108.
15. Obata-Fujitayama quarry, Kabaho-mura, Makabe-gun; INOUE (1912); No. 106.
16. Kamiobata, Kabaho-mura, Makabe-gun; Okurasho (1921); No. 106.
17. Higashi-ida, Kabaho-mura, Makabe-gun; H. SHIBATA (1953); No. 106.
18. Mito, Higashinaka-mura, Nishiibaraki-gun; H. SHIBATA (1953); Nos. 111, 112, 117 and 118.

TABLE 4 (continued)

Granitic rocks of the Inada type (continued) Chemical composition

	19	20	21	22	23	24	25	26
SiO_2	72.32	73.80	72.10	70.07	74.38	73.17	74.42	71.85
TiO_2	0.31	—	—	—	0.18	0.20	0.27	—
Al_2O_3	13.87	13.20	14.63	14.93	14.33	15.24	13.97	13.53
Fe_2O_3	0.82	2.20	2.83	2.63	0.26	0.28	0.30	3.36
FeO	1.62	—	—	—	1.40	1.43	1.80	—
MnO	nd.	0.30	0.09	0.30	0.11	0.13	0.07	0.04
MgO	0.69	0.34	0.50	0.34	0.17	0.28	0.29	0.32
CaO	2.52	1.29	2.04	2.20	1.80	1.82	2.05	1.77
Na_2O	3.60	4.15	3.62	4.40	3.10	3.15	3.05	4.12
K_2O	3.51	4.40	3.83	4.30	3.48	3.54	3.40	5.01
P_2O_5	0.07	—	—	—	0.15	0.17	0.21	—
$H_2O^{(+)}$	0.57	—	—	—	0.65	0.49	0.32	—
$H_2O^{(-)}$	0.45	—	—	—	0.26	0.21	0.20	—
ZrO_2	—	—	—	—	0.05	0.07	0.02	—
S	—	—	—	—	0.03	0.03	0.04	—
Ign. loss	—	0.44	0.47	0.56	—	—	—	—
Total	100.35	100.12	100.31	99.73	100.35	100.21	100.41	100.00
Analyst	S. Okada				T. Ohashi	N. Yoshioka	T. Ohashi	

Norms calculated from the above chemical compositions.

Q	30.8	29.4	31.1	23.0	38.3	36.7	38.6	25.5
Or	20.7	26.1	22.8	25.6	20.6	20.6	20.0	29.5
Ab	30.4	35.1	30.4	37.2	26.2	26.7	25.7	34.6
An	11.2	4.2	10.0	8.1	8.1	8.1	8.3	3.6
C	—	—	0.8	—	2.5	3.3	2.2	—
Wo	0.4	0.9	—	1.2	—	—	—	2.2
Fs	1.7	0.5	—	—	Hy 2.6	Hy 2.8	Hy 3.3	—
En	1.7	0.8	1.2	0.8				0.8
Mt	1.2	—	0.2	0.9	0.5	0.5	0.5	0.2
Hm	—	2.2	2.7	2.1	—	—	—	3.2
Il	0.6	—	—	—	0.3	0.5	0.6	—
Ap	0.5	—	—	—	0.3	0.3	0.7	—

19. Kitanakayama, Nishiyamauchi-mura, Nishiibaraki-gun ; H. SHIBATA (1953) ; Nos. 135 and 136.
20. and 21. Inada, Nishiyamauchi-mura, Nishiibaraki-gun ; Okurasho (1921) ; Nos. 122, 123, 124 and 125.
22. Nishiyamauchi-mura, Nishiibaraki-gun ; Okurasho (1921) ; Nos. ditto.
23. Inada Hikage quarry, Nishiyamauchi-mura, Nishiibaraki-gun ; INOUE (1921).
24. Inada Nishizawa quarry, Nishiyamauchi-mura, Nishiibaraki-gun ; INOUE (1912) ; No. 126.
25. Ikegame 2 nd quarry, Kitanaka-mura, Nishiibaraki-gun ; INOUE (1912).
26. Ōgodo, Nishiyamauchi-mura, Nishiibaraki-gun ; Okurasho (1921) ; No. 121.

The graphs showing the relation between the modal and normative values of each rock are shown in Figure 5. In this case, the chemically analysed specimens are not the same as those which have been volumetrically measured, but it is certain that both specimens have been collected at least from the same quarry or spot in the district.

From a glance at Figure 5, it will be seen that each relation between normative values of the rocks of the Inada and those of the Tsukuba types, shows the same tendency as the relation between the modal values of these types, though the range of normative values is somewhat limited being smaller than those of modal values.

Relations between Mineral and Chemical Compositions of Acid Plutonics

It is an interesting study to compare and contrast the mineral composition of acid plutonics with the chemical composition of the same rock. In this regard chemical analyses of the rocks in conjunction with detailed petrographical investigation would undoubtedly be of some scientific value.

As is shown in the previous two examples, there are various differences between the modal values and normative values of the same plutonics. It seems that the differences may be due to various causes. For examining the general tendencies of the rock composition, the writer has selected for reference about 100 examples from already known data of acid plutonic rocks in foreign countries, which are all over SiO_2 60% in chemical composition excepting alkalic rock.

As it seems that there are comparatively few examples which were analysed both chemically and volumetrically for a single specimen, the writer cited here acid plutonics from the same localities for which both of the analyses had been done.

Some of the older granitic rocks are gneissic in structure, and they are often called roughly gneissose granite or granite gneiss. The data have been gathered from various sources in the world, but those from northern Europe and North America are especially numerous. Strictly speaking with regard to some of those specimens it is not mentioned clearly whether they are of magmatic or of metasomatic origin. Therefore the writer has simply treated all those granitic rocks without distinction of origin, in this paper. For preparing those data, various methods of modal measurements might had been used,

though in many cases they are not clearly described. There can be found some data of modal composition which were recalculated from chemical analyses by contraries, but these will not be considered here.

For examining the mineral composition, there are two ways to express them by volume or by weight proportion, but the distinction of these ways is not generally specified. In the treatment of acid plutonics, the differences of densities among essential constituents (quartz, potash felspar and plagioclase) are usually slight, and the volume of mafic minerals is generally very small, so practically, the differences between volume proportion and weight proportion in them might not need to be treated as important. For this reason there may also be no objection to comparing the modal composition directly to the normative composition of acid plutonic rocks.

When real modal values are compared with normative values which were calculated from chemical analyses, meaningful combinations of direct comparisons between normative and modal values would be thought in the following three cases: norm Q to mode quartz, norm Or to mode potash felspar, and norm (Ab+An) to mode plagioclase.

TABLE 5. The number of specimens in which the numerical values of mode exceed those of corresponding norm.

	No. of specimens	Quartz & Q	Potash-felspar & Or	Plagioclase & (Ab+An)
Fennoscandia	43	32	4	8
Germany & Austria	6	3	3	2
Western part of N. America	30	22	8	3
Eastern part of N. America	7	5	5	1
Ontario, Canada & Minnesota, America	5	2	3	3
West Indies	1	1	—	1
Ceylon, India	3	3	2	1
Encounter Bay, Australia	2	2	1	—
Middendorf Fjord, Siberia	1	—	—	1
Total	98	70	26	20
Tsukuba District	11	6	4	5
Outer Zone of SW Japan	8	7	3	2

The data in Tables 5 and 6 are mostly quoted from "A descriptive petrography of the igneous rocks, vol. II (1932) pp. 185–192, 324–330, 332–343, 380–385 by A. JOHANNSEN", and numerical values in the Table were calculated by the writer on the data.

The number of rocks in which the numerical values of mode exceed those of corresponding norm in respect of the above three combinations is cited in Table 5. As is shown in the table, 70 of total 98 specimens are less in numerical value of norm Q than those of mode quartz, and norm Or and (Ab+An) are both generally found in much more numerous specimens than modal potash felspar and plagioclase.

As for a normative calculation, pyroxene and corundum components are generally calculated, but in the mode of normal calcalkalic granitic rocks mica and/or hornblende are contained. Those minerals in granitic rocks have pretty good quantity of alkalis, but when norms are calculated, all alkalic contents are included in Or and Ab. For this reason, the norm felspar would be calculated to have a higher value than the mode felspar.

The higher the calculated normative felspar, the more SiO_2 are alloted for those, and norm Q may consequently have a tendency to be calculated to lesser amout than modal quartz contents. As some of granitic rocks may contain various alkali felspar, soda-orthoclase, perthite, antiperthite, anorthoclase, etc., such rocks may occasionally

TABLE 6. The geometrical mean value of the differences between the modal values and corresponding normative values.

	No. of specimens	Quartz & Q	Potash-felspar & Or	Plagioclase & (Ab+An)
Fennoscandia	43	3.5	6.4	4.1
Germany & Austria	6	6.2	9.2	12.8
Western part of N. America	30	5.9	6.8	11.5
Eastern part of N. America	7	4.2	16.2	17.4
Ontario, Canada & Minnesota, America	5	3.1	7.8	6.8
West Indies	1	0.1	2.5	0.7
Ceylon, India	3	1.0	2.1	3.6
Encounter Bay, Australia	2	7.0	10.7	10.4
Middendoorf Fjord, Siberia	1	1.5	5.8	5.7
Average	(Total)98	4.6	7.9	9.2
Tsukuba District	11	4.3	2.8	4.1
Outer Zone of SW Japan	8	8.2	7.3	7.8

Numerical values in the table show by percent excepting the number of specimens in the first column.

show more complicated relation between their modal and normative values. In Table 6, the differences between the values of two systems, norm and mode, are shown as geometrical mean values.

Though the data are not tabulated in this paper, it seems that the differences between modal and normative values of the granitic rocks which predominanty contain microcline in the mode of potash felspar, are generally smaller than those of rocks which mainly contain orthoclase.

It seems that the differences between modal and normative values of acid plutonics of northern Europe (Fennoscandia) are generally small and those of North America are mostly larger than those of the former. Though the ages of intrusion of rocks, cited in Table 6, are often uncertain, the masses of pre-Cambrian age stand out generlly in northern Europe, while Paleozoic or post-Paleozoic masses predominate in North America.

It is not entirely clear whether the differences between the norm and the mode and the ages of intrusion are correlated to each other or not, but it would be reasonable to consider that the special difference in values between northern Europe and North America may be rather due to the geological conditions. The rocks in which normative value resembles closely the corresponding modal value as these in northern Europe, would seem to occur geologically under deep and stable condition. That is to say, it seems probable that when granitic materials are formed, keeping a comparatively perfect equilibrium, normative values of rocks might be tolerably coincident with modal values.

On the other hand, the rocks which show a marked difference between normative and modal values in the identical sample, tend predominantly to occur under comparatively shallow and unstable conditions or perhaps in a geosynclinal zone where the rock would be formed under conditions of some contamination. The plutonic rock from the eastern and western coasts of North America and already mentioned two localities in Japan may be considered to belong to this type. As mentioned previously, the masses of these two regions of Japan are very small and are considered to have intruded in unstable Japanese archipelago, as compared with the fore-mentioned examples from foreign countries.

Regarding the examples of the outer zone of south-western Japan and the Tsukuba District, the differences between normative and modal values of the former are much larger not only than the latter but

also than the most of the other foreign countries. Both values, norm and mode, in the rocks of the Tsukuba District resemble each other comparatively closely. It appears geologically probable that the masses in the Tsukuba District were consolidated under deeper and more stable condition rather than those in the outer zone of south-western Japan.

Taking a general view of the whole plutonic mass of the Tsukuba District, the differences between two values of norm and mode in the Inada type are smaller than those in the Tsukuba type. This fact suggests that the former may show more equilibrium facies which are probably formed under more stable state than the latter.

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