ON SOME MUTUAL RELATIONS AMONG THE MINERAL CONSTITUENTS OF PLUTONIC ROCK SERIES

By

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(With 13 Figures)

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CONTENTS

Introduction

As most igneous rocks are composed chiefly of quartz and felspars which play the most significant role, these standard minerals have attracted much attention in connection with rock classification by many petrographers since the older times. In the division as well as in considerations as to the origin of various igneous rocks, the combination and the mutual volume ratio of these essential minerals are usually examined.

It is generally believed that the mafic minerals are early crystallized products from magma, while quartz and potash felspar are regarded as the last products from it. Actually in plutonic masses, the crystallization stage of potash felspar usually differs from that of plagioclase and sometimes is rather later than that of quartz. Accordingly it is desirable to deal with quartz and potash felspar together in considering the petrogenetical problem associated with the plutonic rock series.

To represent the volumetric relation among the chief components by means of a diagram, mafic minerals (M), felspars (F) and quartz

(Q) triangle has been generally adopted. But for the above mentioned reason the writer uses a new diagram in which potash felspar is severed from felspars and transferred to the quartz corner. This new Mf–Pl–Q+KF diagram which shows volume percentages of mafic minerals (Mf), plagioclase (Pl) and quartz plus potash felspar (Q+KF), seems to be rather convenient to express clearly the mutual relations among the chief modal components in the plutonic rock series*. Some comparison is shown in the order of the above mentioned two systems in each of which the same data are plotted.

The Mutual Relations Among the Modal Constituent Minerals

Quantitative researches making use of modal composition in all the igneous rocks are not always possible. If the rocks are holocrystalline and chiefly composed of coarse mineral grains, it is generally easy to determine the mode of them. But if the rocks are glassy or if they consist mostly of very fine grains, the modal measurements of them are impossible or at best troublesome. Accordingly the modal data cited in this paper are all selected from those of plutonic rocks obtained from various districts.

The most of the data from Japan were measured by the writer himself, but many data from various regions out of this country have been selected from several reports.

As is shown in Figures 1 and 2, it is noticeable that the points fall almost entirely within the specific area, which may show certain plutonic field, though some points of syenitic or anorthositic rocks are outside of the limited area. Practically some metamorphics such as common quartz schists are also far outside of it.

Lately the writer has attempted to express the mutual relation of the mineral components of plutonic rocks by using a tetrahedron: Mf–Pl–KF–Q. This must be a very efficient way to express those relationships, if it can be easily used, but it is very troublesome and difficult to represent those relationships simply in a plane figure.

Classifications of the general plutonic rocks based upon their quantitative mineralogical composition have been made by some authorities

* Though some albitic plagioclases should rather better be treated as analogous to potash felspar, it is difficult to distinguish each minute grain of albitic plagioclase from common plagioclase in all parts of thin slice.

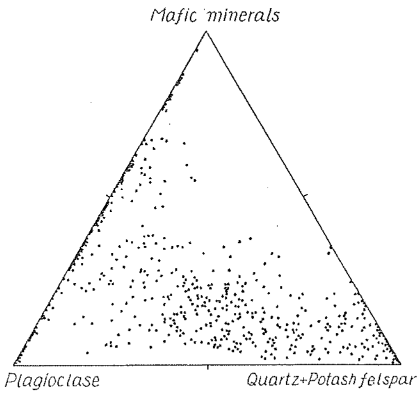


Fig. 1 a

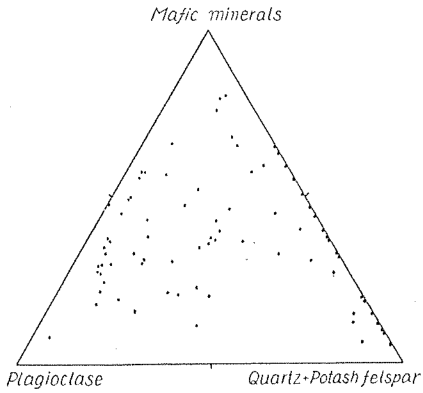


Fig. 1 b

Figure 1 Common plutonics excluding Japanese ones plotted on the Mf, Pl and Q+KF diagram which show volume percent of mafic minerals, plagioclase and quartz plus potash felspar.

Muscovite is included in mafic minerals in this paper. Data mostly from Johannsen (1932).

(1a) Diagram of plutonic rocks excluding syenitic rocks.

(2b) Diagram of syenitic rocks.

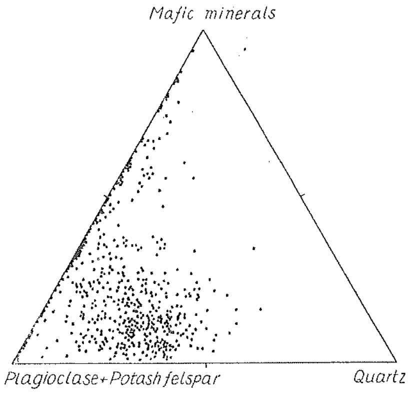


Fig. 2 a

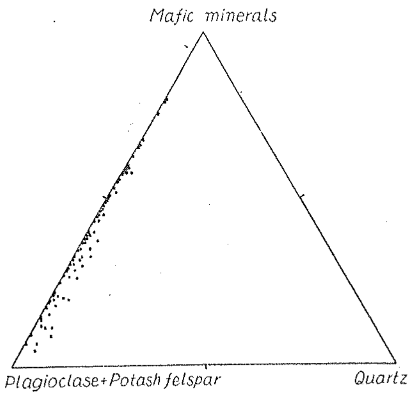


Fig. 2 b

Figure 2 Volume percent of mafic minerals (Mf), felspars (Pl+KF) and quartz (Q) system.

(2a) Diagram of plutonic rocks excluding syenitic rocks.

(2b) Diagram of syenitic rocks.

(Figs. 1a and 2a contain 510 points, Figs. 1b and 2b contain 79 points.)

such as TYRRELL, TRÖGER, LARSEN, WASHINGTON & ADAMS, SHAND and ELLIS. In each of the two diagrams: Mf–Pl–Q+KF system and Mf–Pl+KF–Q system, the corresponding data from these authorities are respectively plotted, as shown in Figures 3 and 4 for the sake of comparison between them.

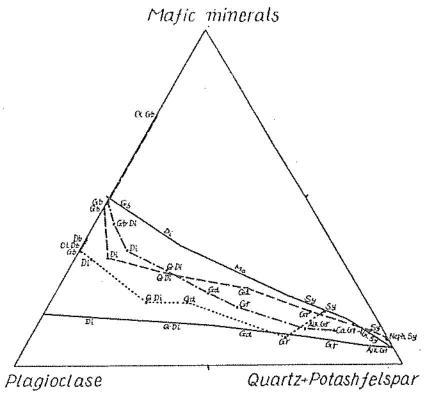


Fig. 3

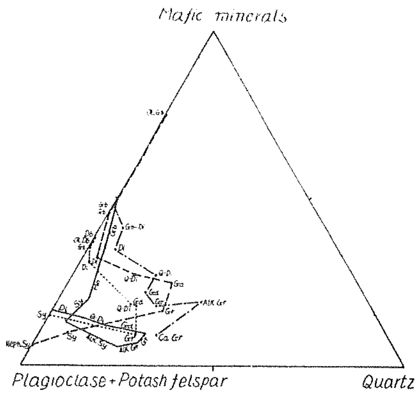


Fig. 4

Figure 3 Mineralogical classification of plutonics in Mf, Pl and Q+KF system.

Full line: TYRRELL (1926)
Chain line: TRÖGER (1935)
Dotted line: LARSEN (1942)
Broken line: WASHINGTON & ADAMS (1951)

Felspathoids are included in potash felspar in both Figures 3 and 4. The rock names in TYRRELL's classification indicate a certain range on his lines. The names of other classifications mean the points. The lines connecting each point are drawn by the writer.

Abbreviations. Ol. Gb: Olivine gabbro, Gb: Gabbro, Gb-Di: Gabbrodiorite, Ol. Db: Olivine diabase, Db: Diabase, Di: Diorite, Q-Di: Quartz diorite, Gd: Granodiorite, Gr: Granite, Ca-Gr: Calci granite, Alk-Gr: Alkali granite, Mo: Monzonite, Sy: Syenite, Alk-Sy: Alkali syenite, Neph-Sy: Nepheline syenite.

Figure 4 The classification of plutonics on Mf-Pl+KF-Q diagram. The explanation of the lines are the same as in Figure 3.

It is not easy to determine whether one figure is more fundamental or meaningful than the other, but on contrasting the two, it can be easily seen that Figure 3 show the mutual relations and natural arrangement in the plutonic series more clearly than Figure 4 does.

It will be found from the above figures that TYRRELL's lines roughly show the two borders of the field of the plutonic rocks, and those of WASHINGTON & ADAMS, LARSEN and TRÖGER generally indicate the average values of the field. Moreover, it may be seen that Figure 3 shows some characteristic differences among the petrographical fields, especially syenitic rocks seem to form a group in specific area, being poor in plagioclase. On the other hand, if use is made of the system Mf-Pl+KF-Q (Figure 4), the data on syenitic rocks are mingled among those on plagioclase-rich rocks such as diorite, anorthosite, albitite and others and show the difficult distinctions among them. At least for treating the rocks of syenitic nature, it seems that the system Mf–Pl–Q+KF is more convenient than the other. According to TYRRELL's division, the rocks of syenitic nature are shown by the upper line in the figure.

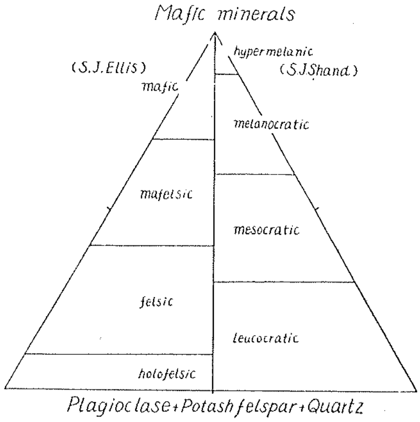


Figure 5 The classifications related to color index by ELLIS (1948) and SHAND (1950).

The Relations Between Silica Content and Modal Composition

For examining the relations between chemical and modal compositions, the writer selected data from certain literatures on rocks, whose both compositions have been made known, and plotted those data in the diagram. In order to discuss that relation, the writer took up the silica content as a representation of chemical composition, as it was used as the basis of the earliest chemical classification of igneous rocks and is still widely adopted. As is shown in Figure 6, the silica content shown fairly regular distribution and a close relation to the mineral compostion of the rocks. But in this case, it is difficult to treat the syenitic rocks in the same manner as the other common calcalkaline rocks, because the typical syenite is characterized by a large content of potash felspar and comparatively little of silica, comparing with the common calcalkaline rocks. When still closer scrutiny is applied it is seen that many values of the plutonics from Japan fall into the formerly cited field, showing that

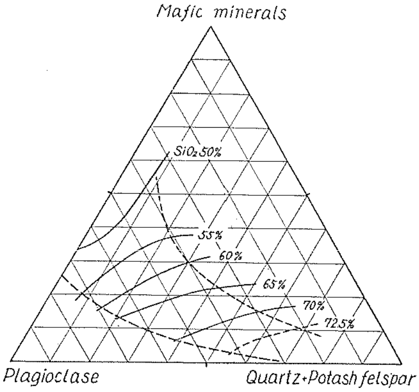


Figure 6 Relation between silica contents and volume percent of Mf, Pl and Q+KF system. The broken lines (excluding the contour line of SiO_2 72.5%) are drawn to indicate the main area of the Japanese plutonics shown in the Figure 7; they roughly indicate the modal plutonic field.

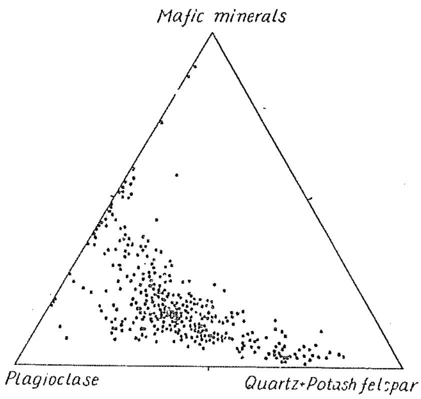


Figure 7 Mineral constituents of Japanese plutonics plotted in Mf, Pl and Q+KF diagram.
Data from Suzuki (1952 a, 1953, 1954 a and 1954 b), Gorai, (1944), Watanabe (1952), Watanabe, Sotozaki, and Gorai (1953), Kuroda and Yamada (1954), Inamori (1949), Shibata (1939) and Yamada (1954).

the most of them are typical calcalkalic rocks. As is shown in Figure 7, it is remarkable that certain rocks with similar silica content, show always similar modal results, though the localities of them are widely different. When one gives further attention, he may notice that the values of Japanese rocks posit nearly along the lower border of the plutonic field indicated in Figures 1 and 3, showing that they are comparatively rich in plagioclase components. It has been known that, in comparison with European and American types, Japanese granitic rocks generally show high average normative quartz content and poor normative potash felspar. Such rocks are also characterized by comparatively high content of plagioclase in the norm for the silica relations (J. Suzuki and T. Nemoto, 1935). It would be expected that the proportion of the normative minerals may be roughly parallel with that of their modal minerals, though this is not always so, at least so far as groups of minerals are concerned.

For this reason, Japanese plutonics having high silica content corresponding to that of granite, are sometimes called granodiorite or tonalites according to the sort and volume of the felspar content. Thus confusion in terminology has often been caused, but when the new diagram above mentioned is used, such difficulties may be considerably obviated.

The association of chief mafic minerals in plutonic rocks generally vary corresponding to their salic

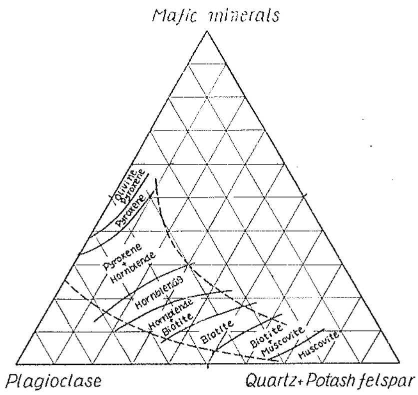


Figure 8 The association of mafic minerals in Mf, Pl and Q+KF diagram.

composition and silica contents; such relations are shown by reference to the diagram in Figure 8. The area of each association of mafic minerals is pretty obviously limited, and corresponds also to silica contents (see Figure 6), though it shows rather little relation to color index (see Figure 5).

The Application of the Mf–Pl–Q+KF Diagram

It may be questionable whether this diagram is useful to explain the plutonic series clearly from the genetical point of view, but it is convenient for understanding the local characteristics of every plutonic mass of various localities. It is not a little interesting when the modal values of the plutonic rocks from several localities are plotted in the Mf–Pl–Q+KF diagram, that the data on variated rocks which are considered as co-magmatic series, generally fall clearly along a certain line or within a comparatively small area. Several examples are shown in Figure 9.*

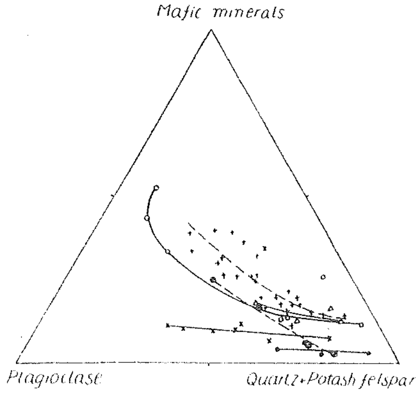


Figure 9 The examples of variations of mineral composition of Adirondack area, New York.
The lines connecting each point of the igneous series are drawn by the writer.
Data of the full lines from BUDDINGTON (1939), data of broken lines from BUDDINGTON (1953).
Triangle—Diana complex.
Diagonal cross—Santa Clara complex.
White circle—Tupper Saranac complex.
Black circle—Younger granite.
Cross—Saranac series.
Double circle—Loon Lake complex.

The scale of observations and considerations may be limited and be controlled by the various units, however, the direct observations are generally based first upon handspecimens, to which the name of the rocks will be given. If, however, the whole rock mass is taken into consideration as a geological unit, then same name applicable in a broad sense may be necessary. When the whole mass shows a homogeneous

* Previously the writer reported on certain granodioritic masses in the Kitakami mountainland in which the rocks are considered to be partly hybrid products of two extreme components, gabbroic and aplitic, from not only geological but also from petrological evidence (SUZUKI, Y. 1952 a & 1953). This relationship is shown in Figure 10 b.

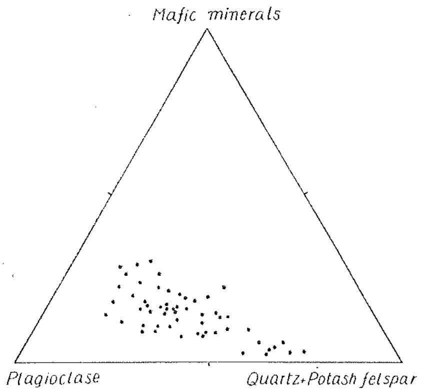


Fig. 10 a (Hokkaido)

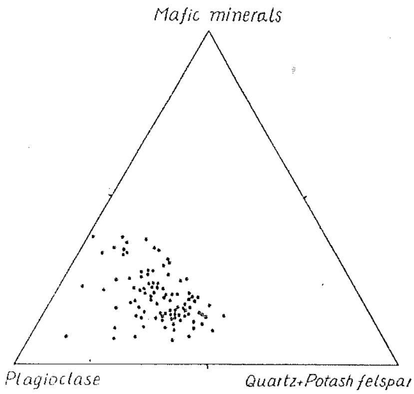


Fig. 10 b (Kitakami)

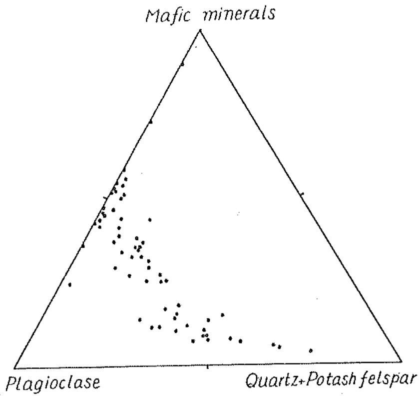


Fig. 10 c (Abukuma)

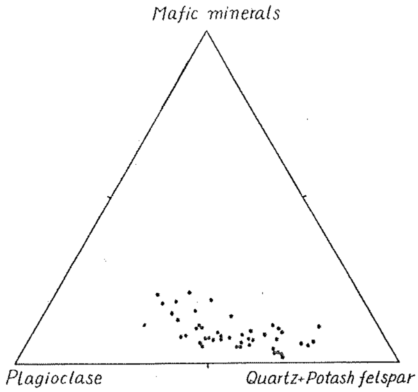


Fig. 10 d (Tsukuba)

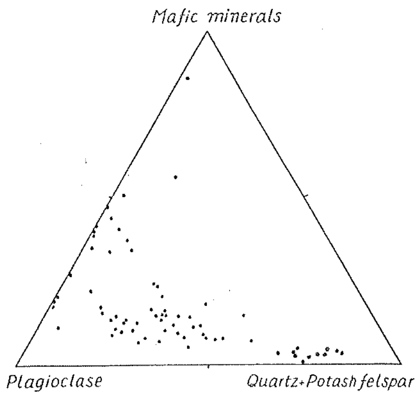


Fig. 10 e
(Hida and Naegi)

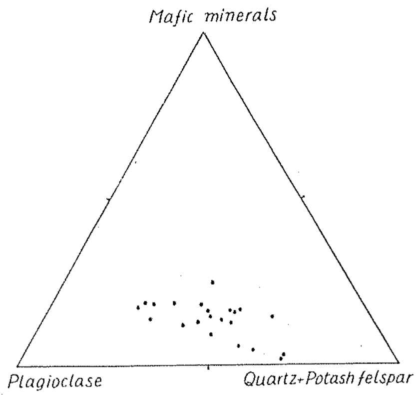
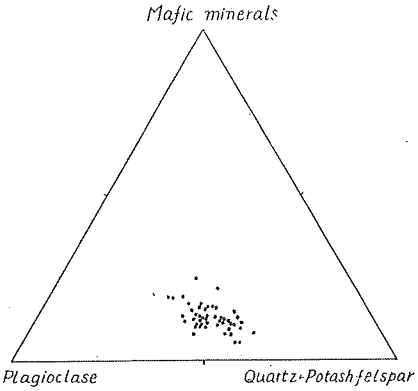


Fig. 10 f
(Southwestern part of Japan)

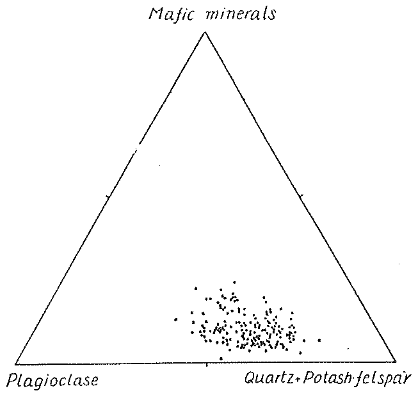
nature, its character is assumed from even one thin section, but practically one thin section does not always accurately represent the specimen, and of course, also, the specimen does not represent the whole mass. At this juncture, the mass name and the handspecimen name will have to be distinguished. So it is most reasonable to determine the rock mass name using the statistical mean value among the numerous handspecimens which were randomly sampled through the



(Inzan)

Figure 11 Granite mass in the Inzan district in Korea. Data from SUZUKI (1952 b).

Figures 11 and 12 are shown as examples of the masses having rather homogeneous nature, for the comparison with the heterogeneous characters shown in Figures 10 a–10 f.



(New England)

Figure 12 Several granite masses in New England, U. S. A. Data from CHAYES (1950 a, 1950 b and 1952).

Figure 10 The Mf, Pl and Q+KF diagrams for Japanese plutonics.

(a) Granitic masses in Hokkaido. Rocks from three plutonic masses in the Hidaka mountainland collected by S. HASHIMOTO and H. SATO, and rocks from several small masses in the area of the upper reaches of the Ishikari river collected by Y. KATSUI. All data measured by the writer.

(b) Two granodiorite masses in the Kitakami mountainland. Data from SUZUKI (1952 a, and 1953 1954 b).

(c) Plutonic masses in the Abukuma mountainland. Data from GORAI (1944), WATANABE (1952), WATANABE, SOTOZAKI and GORAI (1953), and KURODA and YAMADA (1954).

(d) Two granite masses in the Tsukuba district. Data from SUZUKI (1954 a).

(e) Several plutonic masses in the Hida mountainland and the Naegi district. Data from SHIBATA (1939) and YAMADA (1954). YAMADA's data were measured by himself and partly by H. KOBAYASHI.

(f) Several plutonic masses in the outer zone of the Southwestern part of Japan. Data from SUZUKI (1954 a) and INAMORI (1949).

whole mass.

For instance, in the cases of the Kesengawa and southern Tono masses in the Kitakami mountainland (Figure 10b), the character of the specimens vary from diorite to granite, but the masses are most suitably called granodiorite from the statistical standpoint. As indicated in Figures 10a–10f, the data of each plutonic mass in several localities show tolerable dispersion, and each mass name may be advisably determined upon the bases of the mean value, deviation and number of samples.

Conclusions

1) The writer offers for consideration the system of mineralogical division for plutonics, consisting of three chief components: mafic minearls, plagioclase and quartz plus potash felspar. Such a system is more convenient to express the mutual relations among the modal compositions of plutonic rocks.

2) From the standpoint of mineralogical composition, the plutonic rocks vary continuously from granite to gabbro; they are grouped together in a comparatively limited area in the figure illustrating the proposed new system of classification.

3) Among the alkalic plutonics, especially the syenitic group is characterised be occupying a special area which lies out of the field of common calcalkalic plutonic series.

4) The relation between mineral composition and silica content is shown in Figure 6, in which the both series of data correspond closely to each other.

5) The intimate relation among quartz, felspars and the sorts of accompanying mafic minerals in the plutonic series is shown in Figure 8.

6) As a whole the situation of rocks as based upon modal composition are shown in Figure 13.

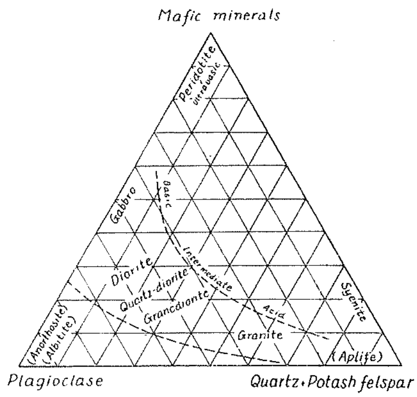


Figure 13 The names of plutonics for Mf, Pl and Q+KF diagram on the basis of silica contents, which refer to the divisions of JOHANNSEN (1932), DALY (1942), ESKOLA (1948) and WILLIAMS, TURNER & GILBERT (1954).

Over a period of many years, many genetical considerations on rocks have been published by many authorities, and especially for plutonic rocks various problems such as magmatic differentiation, contamination, granitization and others have been discussed by them. Though the writer is not concerned with those problems, in the present paper, he believes that the Mf–Pl–Q+KF diagram may be suitable to use at least, in a discussion of the natures of various migmatites. He consideres this because there may be many such rocks which had originated from some rocks due to metasomatism by the addition of silica and potash-rich materials. The writer has not here deeply touches upon how the diagram may have petrogenetical meaning, however, from the graphs as presented, the writer wishes to express only the actual natures of the plutonic rocks as disclosed by quantitative mineralogical treatment, and the diagram may be somewhat useful in the study of petrology in the future.

The writer desires to express his sincere thanks for the valuable guidance and criticism given at all times by Professors T. ISHIKAWA and J. SUZUKI, and he is also indebted to Messrs. S. HASHIMOTO, H. KOBAYASHI, Y. KATSUI, K. YAMADA and H. SATO of the Hokkaido University, for the use of unpublished data on many plutonic rocks.

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