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THE COMPOSITION OF PLAGIOCLASES AND THEIR SPATIAL DISTRIBUTION IN THE KISOKOMA GRANODIORITE, CENTRAL JAPAN

by

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(with 2 tables and 26 text-figures)

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I. Introduction

Since Dr. Kim's first publication of about plagiclase composition in a gabbroic mass of the Hidaka metamorphic belt, Hokkaido, Japan (Kim 1961), the investigation to determine plagioclase compositions and or their ordering states by a large number of measurements, from 100 to 300 grains of plagioclase within a thin section, has come to be recognized as a practical procedure to describe actual state of a rock specimen. The measurements have been carried out using universal stage and the results have been represented by An-frequency curves after statistical calculation of the arithmetic mean with a unit range of ±2.5An%in each respective specimen. Consequent to this study a surprizingly wide distribution of plagioclases with different compositions have been found to co-exist even in the extent of a thin section in many plutonic and metamorphic rocks. Nevertheless, the actual manner of distribution of such plagioclases in the specimens and the significance of the co-existence of plagioclases with such different compositions, which are facts, considered to be against the common sense of up-to-date petrology, that have not been successfully explained until now. With the purpose of clarifing those ploblems the writer examined the two-dimensional distribution of An-content within thin sections together with An-frequency histograms in this paper. The material came from the Kisokoma granodiorite which consists of four different lithofacies and a large number of basic enclaves with three different lithofacies. The values were obtained consistently from optical measurements of the core and the outest layer of zoned plagioclases.

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II. Geological Setting of the Kisokoma Granodiorite Massif

The Kisokoma granodiorite massif is located at the north-western extremity of the Ryoke metamorphic belt of central Japan. It forms the Mt. Kisokoma-gatake (2,956m), the highest peak of the Kiso mountain range, (known as the Japanese Central Alps), which rises at the northern part of the range. It has a bulb-shape of about 13km in the north-south direction and about 7km in the east-west direction with its long axis parallel to the direction of the mountain range. The area where the massif was intruded corresponds geologically to the part where the Ryoke metamorphic rocks decrease their metamorphic grade from banded gneiss to schistose hornfels II, schistose hornfels I and biotite slate in order from southeast to northwest. The massif was intruded into the transitional zone of the biotite slate and the schistose

Fig. 1. Index map of the Kisokoma massif.

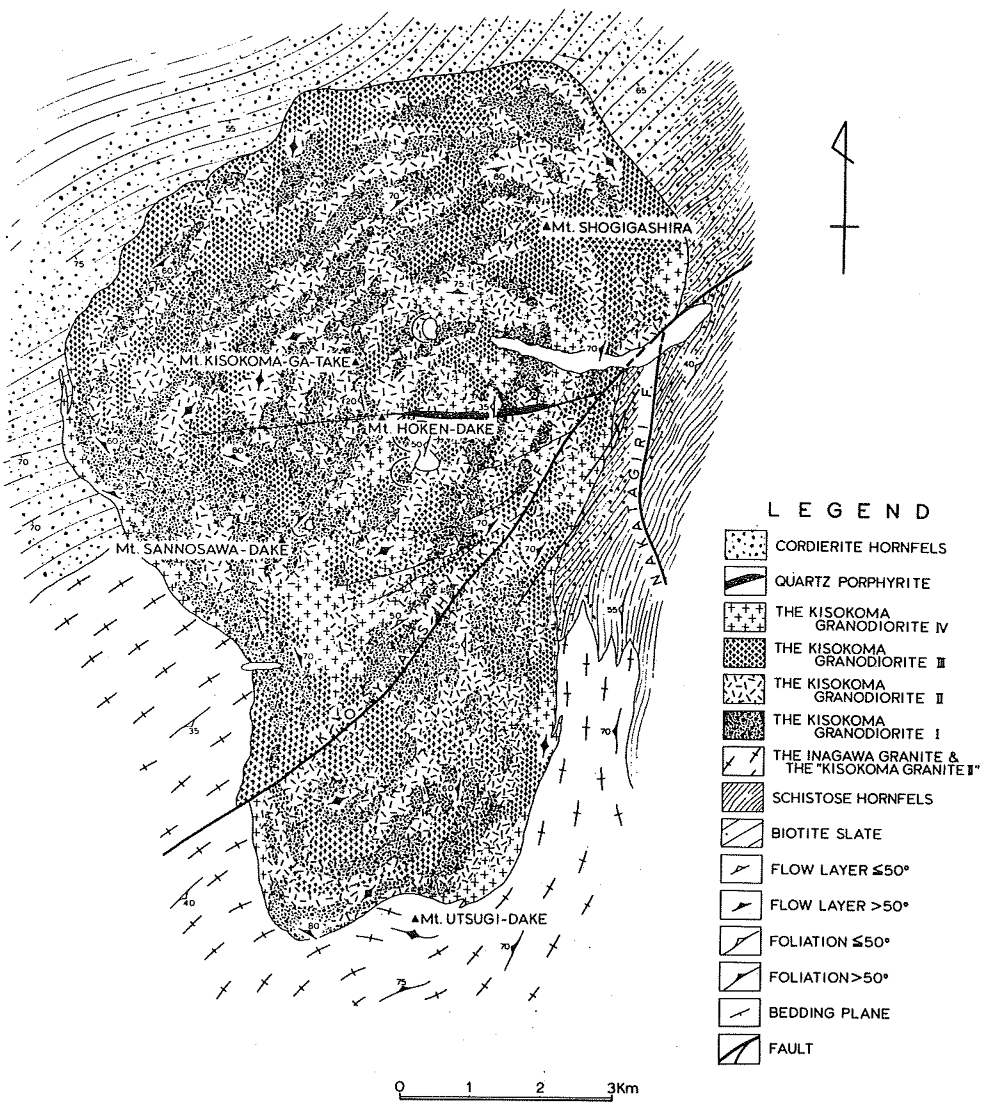

Fig. 2. Lithofacies map of the Kisokoma massif.

hornfels I. Therefore, to the western side of the massif the rocks are biotite slate and non-metamorphosed Paleozoic strata and to the eastern side the Ryoke metamorphic rocks of higher grade are present. Rocks at the western side have a rather simple homoclinal structure with strike and dip about N40°E, 50°–80°SE. On the other hand the eastern side shows a bulb-shaped dome structure (The Otagiri Dome) (Tsuchiya, 1966) with its long axis in a N30°E direction and having parallel to subparallel sheets of biotite muscovite granite (Otagiri granite) in its central part. In the southern part, the massif is in contact with the Inagawa granite, another Ryoke granite characterized by abundant porphyroblasts of potashfeldspar and distinct gneissosity. The Inagawa granite shows steep dip with strike in N20°E. However, the structure of the granite turns to east-west strike and dip of 35°S to almost vertical around the Kisokoma granodiorite massif in the western side. The Kisokoma massif was intruded discordantly to these structures of the surrounding metamorphic rocks and granite.

Obliquely crossing the zonation of the Ryoke metamorphic rocks a conspicuous hornfels zone 1 to 1.5km in width characterized by pinitized cordierite spots, encloses round the massif and the surrounding metamorphic rocks. This cordierite hornfels zone is broader at the northwestern margin of the massif (about 1.5km) in comparison with the eastern margin of it. No such thermal effect can be recognized, however, in the Inagawa granite. Flow structure of the interior of the massif can be traced by a faint arrangement of the mafic minerals almost all around the interior. According to the result of the survey, the flowage is arranged harmoneously parallel to the outline of the massif, steeply inclined towards its inner part, and has a funnel-shape as a whole with two cores in the centre of it which are gently inclined towards the west. As to the tectonic movement of the massif the writer previously reported in detail (Tsuchiya, 1967a). The massif intruded like as it turned up reversely at first from a southeast direction at lower level then from northwest direction at higher level.

As to the petrographic nature of the massif, since Shibata (1955) first reported about the chemical problem, several geologists who surveyed around this area regarded the massif as a homogenuous granodiorite pluton. The following facts, however, related to the petrographical problem came clear to the writer from the results of a detailed survey: A large number of almost rounded basic enclaves with size from a few centimeters to about 80cm in diameter, are included in the massif. They show various appearences. In several localities layers of aggregated basic enclaves are found (Fig. 3). They have a few meter to ten meters in thickness. Most of them are interlayered harmoniously to the flowage of the mother rock, however some of them are distinctly oblique to it. This means that the basic enclaves were originated in different ways prior to the migration of the mother rock. The distribution of the basic enclaves is not equal in density throughout the massif but enclaves are found almost in the whole area of the massif. On the other hand, the granodiorite suite which includes basic enclaves is rather abundant in mafic minerals compared to that with no basic enclaves and both show slightly different lithofacies. Therefore the writer treated the basic enclaves suite and the granodiorite suite separately in this paper.

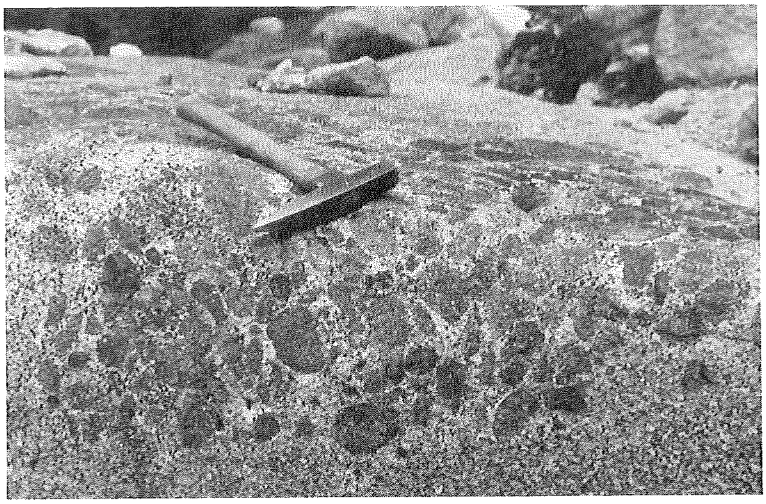

Fig. 3. An outcrop showing a layer of aggregated numerous basic enclaves. From the river Shozawa.

A. Basic Enclave Suite

Basic enclaves generally take an ellipsoidal shape with clear boundaries with the mother rock, but there are also those which show irregular "schlieren"-like boundary with an indistinct border. Most of the enclaves have 3cm to 20cm in their longest diameter and in some cases it attains up to 80cm as a maximum. They are commonly scattered as individually separated xenoliths in the granodiorite. However, aggregates of them are often found forming a layer as stated above. There is tendency in the distribution of enclaves to be more abundant in the western side of the massif compared to the eastern side. They are lacking around the marginal part of the massif except for the contact zone with the Inagawa granite.

These basic enclaves exhibit petrographically various appearances from a fine-grained homogeneous one to a coarse porphyritic one, and are classified into the following three lithofacies;

1) melanocratic fine-grained lithofacies
2) biotite porphyritic lithofacies
3) biotite plagioclase porphyritic lithofacies

Occurence and microscopical characters of each lithofacies are shown in Table 1. The melanocratic fine grained enclaves often remained in the biotite porphyritic and the biotite plagioclase porphyritic enclaves as a relict (Fig. 4). The size of these enclaves commonly varies from 1cm to 8cm and is smaller than that of the others lithofacies. The melanocratic fine-grained enclaves and

name of lithofacies	melanocratic fine grained lithofacies	biotite porphyritic lithofacies	biotite plagioclase porphyritic lithofacies	granodiorite I	granodiorite II	granodiorite III	granodiorite IV
appearance	melanocratic fine, 1–8cm in size	melanocratic to dark gray biotiteporphyritic 5–10cm in size	gray to grayish white biotite and plagioclase porphyritic 5–20cm in size	including basic enclaves colour index=10–15	including basic enclaves colour index=10–20	without basic enclaves colour index=10–15	without basic enclaves colour index=5–10
texture	fine equigranular ophitic	fine biotite poikilitic partially ophitic	porphyritic coarse plagioclase rich in quartz and potash-feldspar	equigranular idiomorphic to hipidiomorphic plagioclase quartz and potash-feldspar are always interstitial nature			
quartz	—	intersticial wavy extinction is weak	intersticial weak extinction	intersticial wavy extinction intense			
potash feldspar	—	—	intersticial less amount 2Vx=50°–65°	orthoclase 2Vx=44°–64° microcline 2Vx=66°–83°	orthoclase 2Vx=58°–70° microcline 2Vx=74°–81°	orthoclase 2Vx=40°–60° microcline 2Vx=61°–75°	orthoclase 2Vx=40°–68° microcline 2Vx=55°–79°
plagioclase	idiomorphic to hipidiomorphic granular weak zoning rarely twined	idiomorphic to hipidiomorphic prismatic weak zoning rarely twined	xenomorphic porphyboblast with remarkable zoning and fine grain with weak zoning	idiomorphic to hipidiomorphic remarkable zoning, heterogeneous core with chess board structure and fresh outer mantle			
biotite	fine x=yellowish brown y=z=dark brown	poikilitic x=pal yellow y=z=dark brown	xenomorphic porphyroblast and fine flake	meduim chloritization in common x=light yellow y=z=dark brown			
hornblende	fine xenomorphic granular x=pale brown y=greenish brown z=dark brown			medium hipidiomorphic to idiomorphic often zoned x=light brown y=greenish brown z=dark greenish brown			
	2Vx=65°–76.5° C∧Z=11°–20°	2Vx=62°–79° C∧Z=13°–23°	2Vx=68°–84° C∧Z=13°–18°	2Vx=71°–85° C∧Z=6°–16°	2Vx=63°–76° C∧Z=6°–18°	2Vx=60°–73° C∧Z=12.5°–20°	2Vx=68°–88° C∧Z=12°–18.5°
others	zircon sphene apatite tourmaline opaques chlorite sericite			zircon sphene apatite tourmaline epidote opaques chlorite sericite calcite			

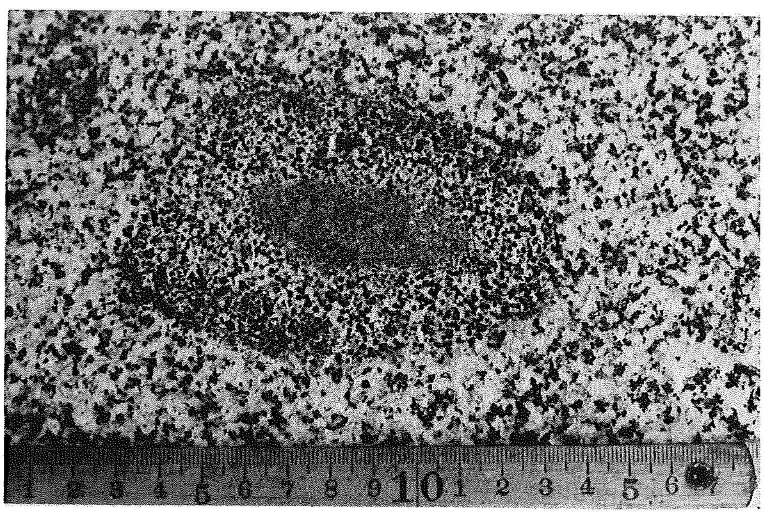

Fig 4. Zoned basic enclave showing the sequence of metasomatic process. The core represents the melanocratic fine-grained lithofacies and the mantle shows the biotite plagioclase porphyritic lithofacies.

the biotite porphyritic enclaves are not as common as the biotite plagioclase prophyritic ones, but they have distinct boundaries with the granodiorite. The biotite plagioclase porphyritic enclaves increase their dioritic or quartz dioritic to granodioritic character parallel with the increment of porphyritic plagioclases, quartz and potash feldspar and result in a mafic mineral rich part with an indistinct boundary with the mother rock.

From microscopical observation the plagioclases in each lithofacies have the following characteristics: In the melanocratic fine-grained enclaves plagioclases are fine grained hypidiomorphic equigranular lath shaped and sometimes xenomorphic porphyroblast with abundant pigmental inclusions. Twining is not developed. Zonal structure is not remarkable. Plagioclases in the biotite porphyritic enclaves are fine grained and lath shaped and the crystal size increases up to about 0.5mm x 0.25mm. Porphyritic plagioclases which form glomeroporhyroblasts are often found. In the biotite plagioclase porphyritic enclaves these glomeroporphyritic plagioclases become the main constiturent plagioclase of this lithofacies and among them fine grained lath shaped plagioclases are also found. Porphyritic plagioclases present remarkanle zonal structure and twinning. Irregular shaped abnormal extinction domains and chess-board structure are common in the core of these porphyritic plagioclases in contrast to an homogeneous, fresh mantle. Inclusions of small flakes of biotite and hornblende are also common in the core. It is noteworthy that these characters of the porphyritic plagioclase of this lithofacies are equally preserved in the plagioclases of the granodiorite.

B. Granodiorire Suite

The mother rock of the massif is a medium grained grayish white granodiorite to diorite. The rock has been considered as one of the typical pluton-type granitic masses with homogeneous nature in the Ryoke metamorphic belt, although Murayama and Katada (1957) and Oki and Shibata (1958) have pointed out the existence of acidic marginal facies. However, two different parts, one including basic enclaves and often lacking them can be distinguished in this massif. Further more both parts can be divided into two sub-facies respectively according to minute differences in the volume of mafic minerals. According to this the writer classified the mother rock into the following four lithofacies (Tsuchiya 1967b).

1) granodiorite I (mafic mineral poor lithofacies with basic enclaves)
2) granodiorite II (mafic mineral rich lithofacies with basic enclaves)
3) granodiorite III (mafic mineral rich lithofacies without any basic enclaves)
4) granodiorite IV (mafic mineral poor lithofacies without any basic enclaves)

The petrographical properties of each lithofacies are shown in Table 1. Granodiorite belonging to each lithofacies varies gradually to each other in the field. The distribution of them is harmoneous to the flowage of the mass in large scale as shown in Figure 2. Generally speaking, the lithofacies of granodiorite I and II are dominant in the central part and the western side of the massif, and in contrast to this, granodiorite III and IV are found in the eastern side and marginal zone of the massif. Granodiorite II is found in the central part of the massif wrapping up rather irregularly formed granodiorite I. The fact may signify successive origin of lithofacies from granodiorite I to granodiorite II. Granodiorite III is found mainly in the northern half marginal zone of the massif and in the sourthwestern part including the granodiorite I and II. Granodiorite IV is distributed in the marginal area and in the central part filling the interspaces of distribution of the other lithofacies.

Grain size of constituent minerals in the massif far north from Mt. Shogi-gashira is smaller than that of main part of the massif regardless of the differences in lithofacies. Plagioclases found in the former area have a more idiomorphic nature than those of the later area. This idiomorphic nature of the plagioclases is also found in the specimens from the marginal area even if in the southern part of the massif.

III. Studies on Plagioclases

Since Kim (1961) first published the result of a large number of measurements of plagioclase composition from a gabbro massif in the Hidaka metamorphic belt, the major tectonic unit in Hokkaido island, many have been done by other collaborators in plutonic and metamorphic rocks. These studies show the existence of a surprizingly wide difference in chemical composition and structural state among co-existing plagioclases in these rocks even to the extent of a thin section. Some of the results about distribution of An-content and ordering problem have been published (Kim, 1961, 1962, 1963, 1964a, b, c, 1966, Kim, Tsuchiya and Sako, 1962, Tsuchiya, 1967b, 1972, Hunahashi, Kim, Ohta and Tsuchiya, 1968). The measurement have been made consistently by optics of the plagioclase grains with universal stage using Kaaden's estimation diagram (Kaaden, 1955) and the 2V diagram presented by J. R. Smith (1958). As to the composition, the data were given as frequency curves by the arithmetic mean with ±2.5An% unit range which was determined considering the accuracy of measurements along the whole range of the plagioclase series. The fact that the modes and sub-modes of frequency curves are fixed on special composition regardless the rock species, that is, An22%, 27%, 33%, 43%, 47%, 50%, 55%, 57%, 62% 65%, 67% and 78% was pointed out through examination of many plutonic and metamorphic rocks (Hunahashi, Kim, Ohta and Tsuchiya, 1968). Some of these compositions are in good coincidence with stable composition estimated by structural studies of plagioclase crystals (DeVore, 1956, Doman, Cinnamon and Bailey, 1965, Bambauer, Corlett, Eberhard and Viswanathan, 1967).

At the same time the author has attempted to examine analytically the frequency curves in which compositions range in so wide an extent that their differences attain up to 50%An even in one thin section. This study was first carried out on the Tenryukyo granite, one of the synkinematic granites in the Ryoke metamorphic belt (Tsuchiya, 1972). Generally speaking, the accuracy of the measurement of plagioclase composition by this optical method depends on both the skill of the measurer and the accuracy of the estimation diagrams. In the Kaaden's estimation diagram the composition interval between An0% to about An50% is wider than that of the higher An-content range and higher accuracy should be expected in this lower An range. In fact, the difference in compositions obtained by repeated measurements at the same position in one grain ranged within 3An%. This means one can fix the statistical unit range at ±1.5An%. The study on the Tenryukyo granite was carried out with this statistical unit range. Therefore, by using the ±1.5An% unit range the writer recalculated the arithmetic mean of the data from the compositional measurements of respictive lithofacies in the Kisokoma granodiorite massif which had been reported previousely by unit range of ±2.5An%. Resulting histograms are examined in this paper.

On the other hand the examination of the meaning and actual mode of distribution of co-existing plagioclases with such a wide compositional range at a thin section scale is very important for the elucidation of the rock forming processes. For that purpose, the present writer examined the composition of every plagioclase grain and the spatial relation within the original thin sections. Figure 6, for example, corresponds to the histograms of plagioclase composition of core and mantle of the granodiorite III calculated by using the ±1.5An% unit range. Though the frequency curves both for the core and the mantle of this lithofacies drawn by using the unit range of ±2.5An% show the most distinct normal distribution curves among all those of the lithofacies of the massif (Fig. 5, cf. Figs. 9, 12, 15, 18, 21, 24) three groups of concentration of composition appeared on both histograms drawn by using the unit range ±1.5An%. At the histogram of the core a tendency of grouped concentration into three parts (a, b and c) can be recognized and they are divided at An38% and An47%. The concentration centre for each group is located at An52% (group a), An43% (group b) and An33% (group c) respectively. It is clear that the group b constitutes the main part of the frequency curve for the core

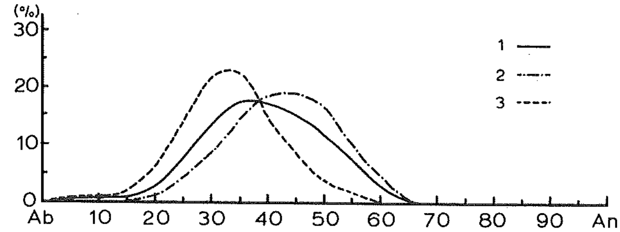

Fig. 5. An-frequency curves based on unit range ±2.5An% of the granodiorite III. 1. Total 2. Core 3. Mantle

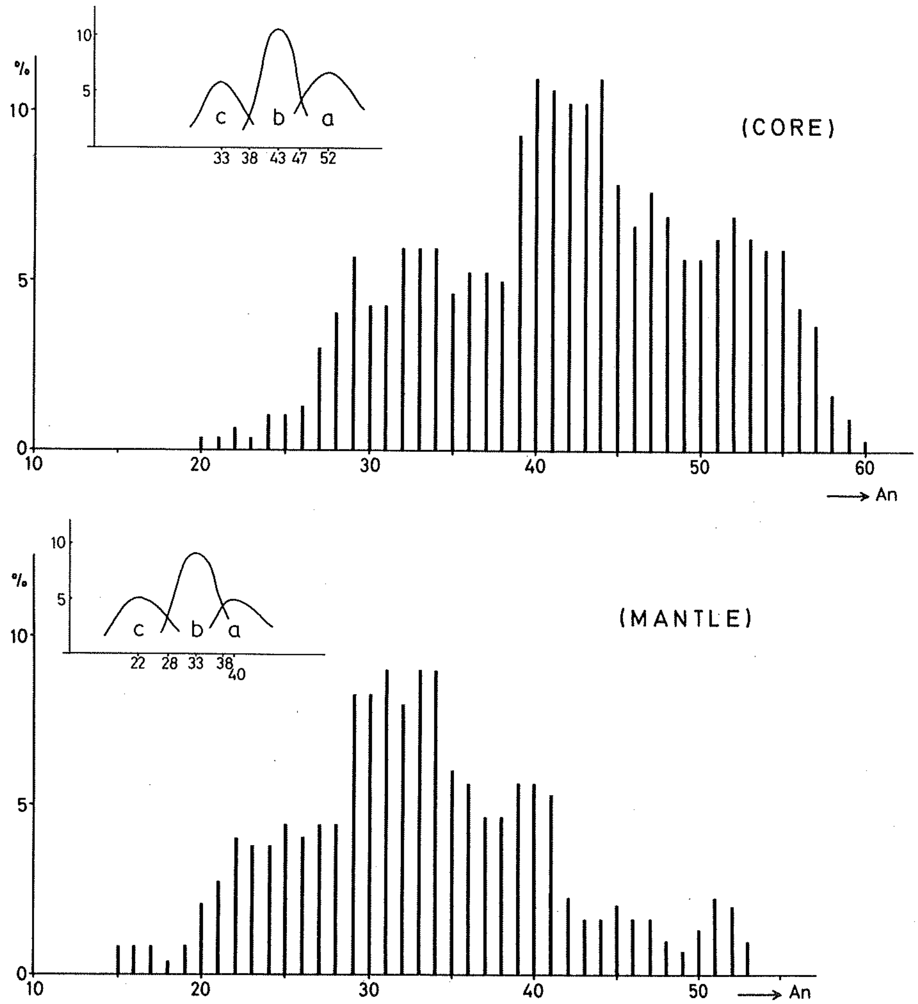

Fig. 6. An-frequency histograms based on unit range ±1.5An% of the granodiorite III.

(Fig. 5), and the concentration centre of this group (An43%) coincides with the mode of the frequency curve. Groups a and c coincide with both slopes on the frequency curve. On the other hand, on the histogram for the mantle three groups, of concentration (a, b and c) are also recognized, points of division being located at compositions An28% and An38%. Concentration centers for these groups are at An40% (group a), An33% (group b) and An22% (group c). It is evident that group b forms the main part of the frequency curve of the mantle (Fig. 5) and its concentration centre, An33%, coincides with the mode of the frequency curve. Group a and c form the two slopes on the frequency curve.

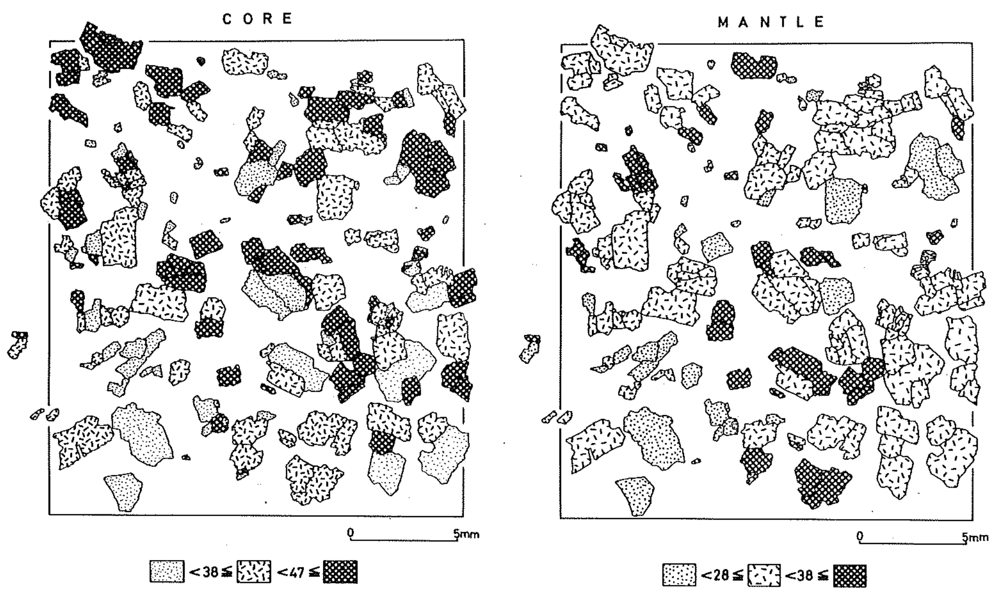

Fig. 7. Sketches of the thin section showing the plagioclases and their An-content of the granodiorite III. The vacant spaces are occupied by minerals other than plagioclase. The subdivisions correspond to the group a, b and c designated in Fig. 6.

Spatial position of the plagioclase grains marked separately by the above-mentioned groups of composition is shown in Figure 7. It can be recognized from this figure that there are some tendencies for an aggregative arrangement of the plagioclases belonging to the same group of composition. They are in contact or they tend to occupy particular area even if the crystals are separated by vacant spaces. This tendency to form aggregates is clearly observed in the figure of the mantle. Plagioclases belonging to group b

(An28–37%) occupy a wide area crowded with several grains in this figure. Plagioclases belonging to groups a and c show also a tendency to the concentrated in small extent among plagioclases of group b.

To distinctly indicate these spatial relation among plagioclases belonging to different composition-groups, the writer prepared a kind of histogram of the core and the mantle separately for each lithofacies. The histograms were drawn on the basis of a unit area of 0.1mm^2 which was determined considering grain size. The arithmetic mean of the composition of all plagioclases contained in a unit area was calculated for the center of every unit area on the respective measured thin section. This was done by moving the unit area by every half of it, these mean values were contoured by content-lines of each compositional group. The histogram will be called the two-dimensional distribution map of An-content in this paper.

Figure 8 represents the two-dimensional destribution maps of An-content for the granodiorite III. The relation among composition groups presented in figure 7 is emphasized in the map. Both, in the core and the mantle, field corresponding to composition of group b is widely spread over the whole area of the thin section and it could be taken as the statistical base or host of the map. The fields corresponding to composition of groups a and c are found as

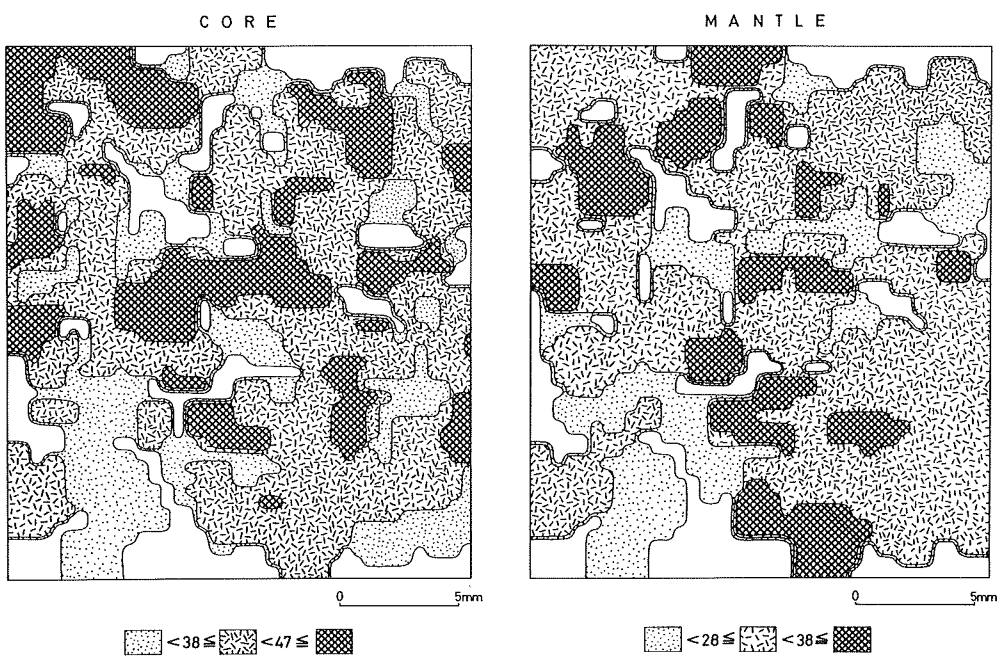

Fig. 8. Two-dimensional distribution maps of An-content of the granodiorite III by statistical contouring. Unit area is $0.1\ \text{mm}^2$.

small domains in this host field. The vacant spaces in the map correspond to wider opennings in the thin section actually occupied by other minerals than plagioclase.

The two-dimensional distribution map of An-content for the other lithofacies will be explained in the following together with An-frequency curves based on ±2.5An% unit range and frequency histogram made by using a ±1.5An% unit range.

A. Basic Enclaves Suite

i) Melanocratic fine-grained lithofacies

The An-frequency curves for the core and the mantle drawn based on the result of 241 points of measurement are shown in Figure 9. Both present

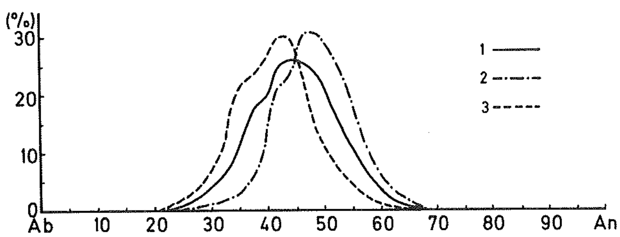

Fig. 9. An-frequency curves based on unit range ±2.5An% of the melanocratic fine-grained enclaves.
1. Total 2. Core 3. Mantle

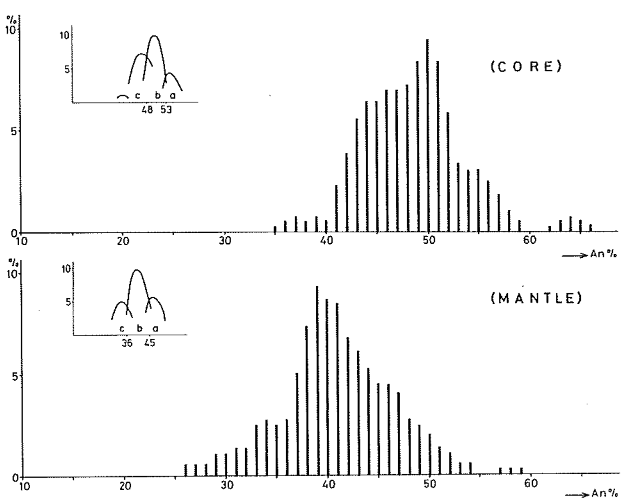

Fig. 10. An-frequency histograms based on unit range ±1.5An% of the melanocratic fine-grained enclaves.

analogous features of statistically abnormal distribution having a mode and a sub-mode. The mode of the core's curve is located at An47% and the sub-mode around An43%. Those for the mantle's curve are located at An43% and An37% respectively. In spite of such analogous curves, the distribution of plagioclases on frequency histograms with a unit range of ±1.5An% shows different features for the core and the mantle (Fig. 10). The core's histogram shows one prominent concentration at An50% and two subordinated concentration groups at both sides of it located around An55% and An46%. The latter subordinate concentration is better defined. Therefore group a (≧An53%), group b (An48–52%) and group c (≦An45%) are separated in this paper. On the other hand, a prominent concentration is found around An40% and two subordinate concentration groups are recognized around An33–34% and An46–47% in the maintle's histogram. Separation between prominent concentration and subordinated one around An46–47% is not distinct, but three groups are defined by An36% and An45% and called as group a (≧An45%), group b (An36–44%) and group c (≦An35%) in the mantle. Two-dimensional distribution maps of An-content of this lithofacies are shown in Figure 11. In

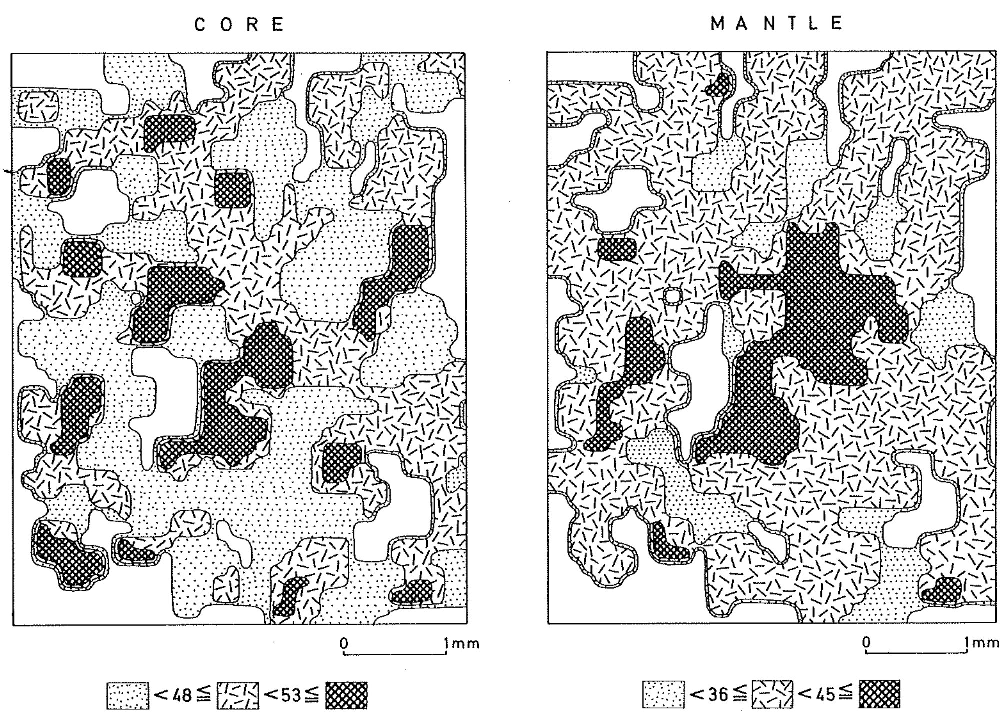

Fig. 11. Two-dimentional distribution maps of An-content of the melanocratic fine-grained enclaves by statistical contouring. Unit area is 0.1 mm^2.

the core's map plagioclases belonging to group a form several domains of small scale and are enclosed in the fields of group b. The fields of group b have a tendency to form host area connecting each domain by means of narrow channels. The area of group shows a large spreading on the map and forms host field filling up the interspaces of domains of group a and b. On the other hand in the mantle's map domains of group a and c are found in the host field of group b.

ii) Biotite porphyritic lithofacies

The An-frequency curve of this lithofacies is shown in Figure 12. The curves were drawn based on the result of 290 points measurement. There are two equivalent modes at An33% and at An43% on the frequency curve of the core and a weak sub-mode is located around An50%. The curve for the mantle has a mode at An33% and a sub-mode around An24%. Five small concentration groups almost equivalent in height appear on the core's frequency histogram with unit range ± 1.5An% (Fig. 13), their modes being located around An30%, An34%, An38%, An43% and An48%. Among them, the group concentrated around An38% is the most important though it is not recognized as a peak on

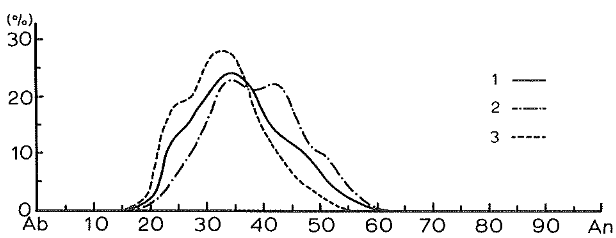

Fig 12. An-frequency curves based on unit range ±2.5An% of the biotite porphyritic enclaves.
1. Total 2. Core 3. Mantle

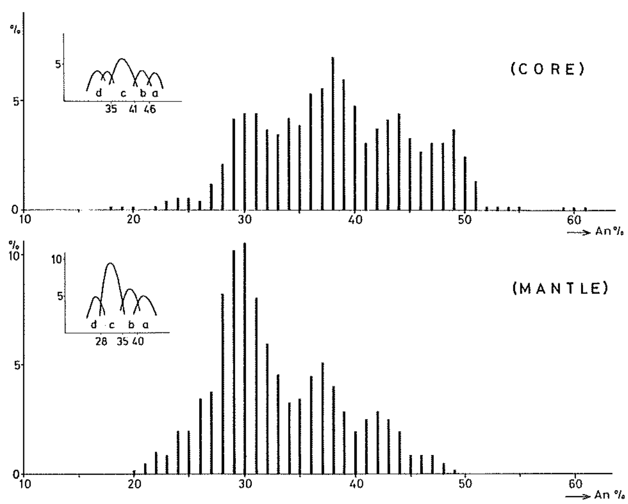

Fig. 13. An-frequency histograms based on unit range ±1.5An% of the biotite porphyritic enclaves.

the corresponding An-frequency curve. The histogram for the core is divided into four groups, i.e. group a (≧An46%), group b (An41–45%), group c (An35–40%), and group d (≦An34%). On the other hand, the frequency histogram for the mantle is characterized by a well concentrated group with a mode located around An30%. Three less dominant groups of an equivalent nature appear around An42%, An37% and An27%. The mode of the An-frequency curve for the mantle (An33%) shifts to An30% in this analytical histogram. Concentration groups are named as group a (≧ An40%), group b (An35–39%), group c (An28–34%) and group d (≦An27%). Two-dimensional distribution maps of An-content of this lithofacies are shown in Figure 14. Though the figures are slightly intricated in both maps, the fields of plagioclases for the dominant group (An35–40% in the core's histogram; An28–34% in the mantle's histogram) are constituting the host areas and plagioclases belonging to the other groups form small domains enclosed in them.

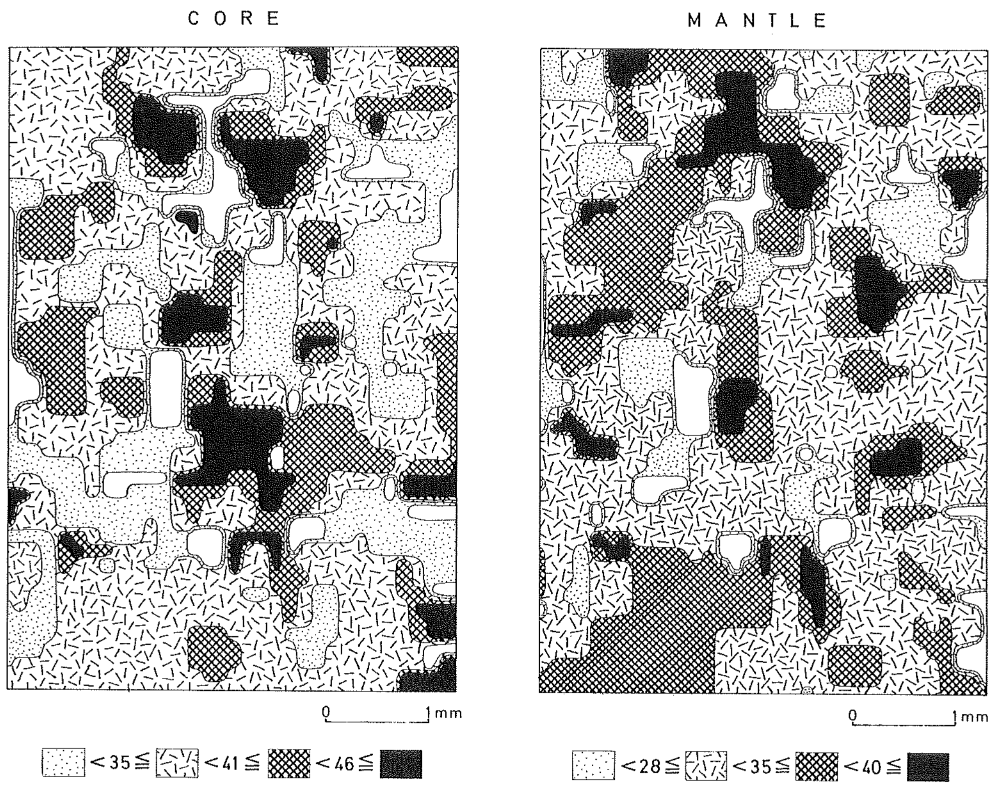

Fig. 14. Two-dimensional distribution maps of the biotite porphyritic enclaves by statistical contouring. Unit range is 0.1 mm^2.

iii) Biotite plagioclase porphyritic lithofacies

The An-frequency curve of this lithofacies is shown in Figure 15. The curve is based on the result of 298 points measurement. The core has its mode at An47% and two sub-modes located around An40% and An55%. The mantle has its mode at An 43% and a sub-mode around An33%. Figure 16 is the frequency histogram of this lithofacies drawn by using a unit range of ± 1.5An%. As to the core, the histogram can be divided into three groups, i.e. group a (≧An52%), group b (An45–51%) and group c (≦An44%). As to the mantle, two remarkable groups of concentration can be recognized, i.e. one around An40–41%, the other around An46%. Minor concentrations are found in both sides of these two conspicuous groups. Groups are defined by dividing the histogram at An45% and An37%. Group a means an An concentration higher than An45%, group b is located between concentration An45–36% and group c contains all concentrations lower than An36%.

The two-dimensional distribution maps of this lithofacies are shown in Figure 17. The fields of the main group (An45–51% for the core; An37–44%

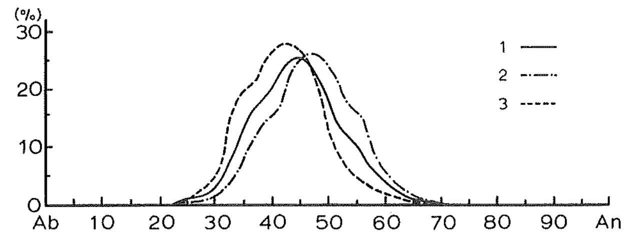

Fig. 15. An-frequency curves based on unit range ±2.5An% of the biotite plagioclase porphyritic enclaves.
1. Total 2. Core 3. Mantle

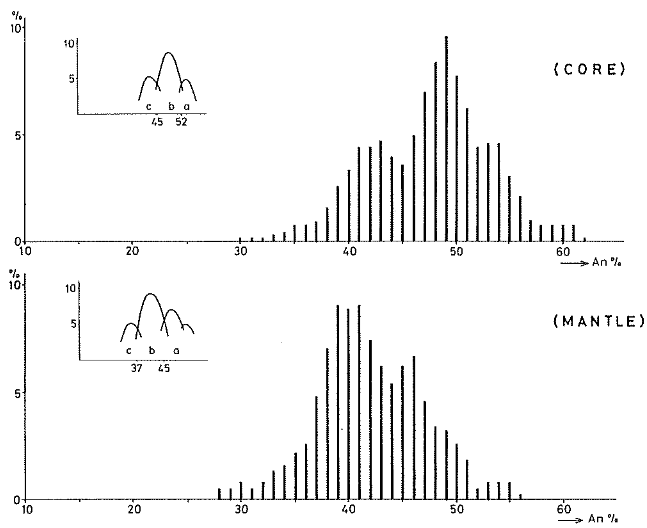

Fig. 16. An-frequency histograms based on unit range ± 1.5An% of the biotite plagioclass porphyritic enclaves.

for the mantle) are well developed and several domains of plagioclases belonging to group a and c are found enclosed by these host fields. This feature is clearer in the map for the mantle.

B. Granodiorite Suite

i) Granodiorite I

The An-frequency curve of this lithofacies is shown in Figure 18. The curve is based on the result of the measurement of 320 points. The curve for the core shows statistically distinct abnormal features having its mode at An43% and a

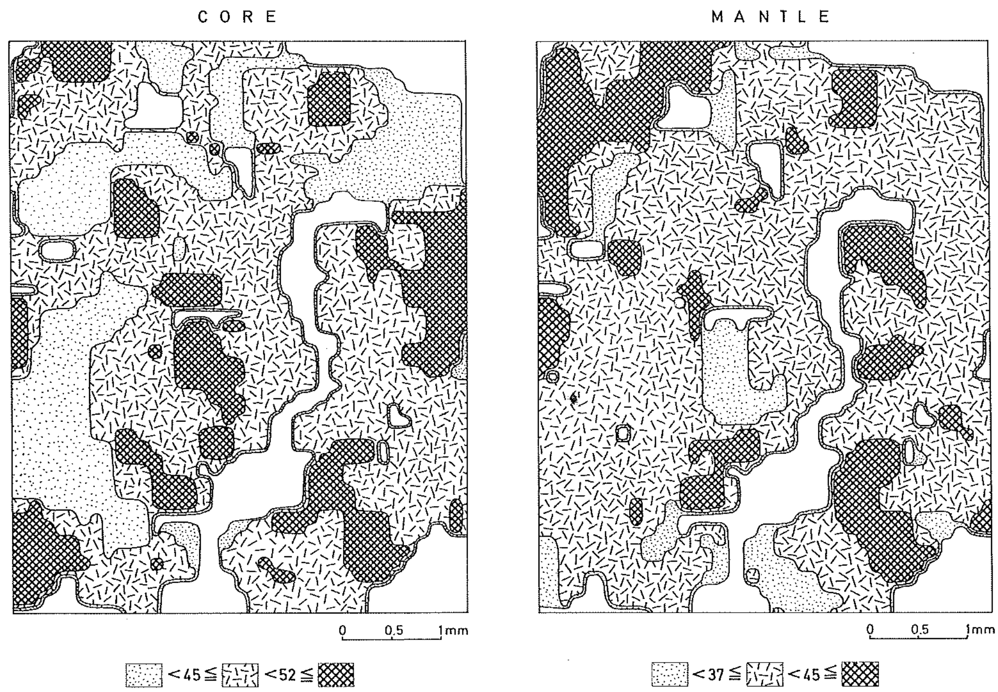

Fig. 17. Two-dimensional distribution maps of An-content of the biotite plagioclase porphyritic enclaves by statistical contouring. Unit area is 0.1 mm^2.

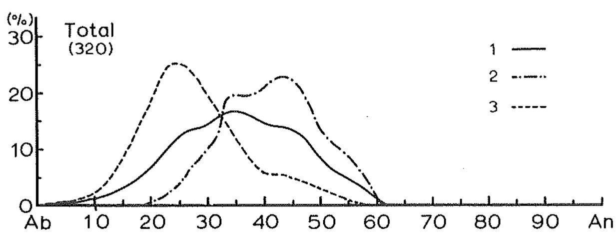

Fig. 18. An-frequency curves based on unit range ±2.5An% of the granodiorite I.
1. Total 2. Core 3. Mantle

sub-mode at An33%. In contrast to this, the curve of the mantle has a statistically normal distribution with its mode at An24% though a weak concentration is seen around An43%. At least four concentration groups are recognized in the figure of the frequency histogram for the core (Fig. 19), that is, concentration around An50%, An40%, An35% and An30%. Among them, the concentration around An40% is the most predominant and the concentration around An30% is weak and undistinguishable from that of An35%. Therefore dividing points are established at An36% and An46% resulting in three groups: group a (≧An46%), group b (An36–45%) and group c (≦An 35%). As to the mantle, four concentration groups are recognizable in the frequency histogram. They have their mode around An22%, An27%, An37% and An43% respectively. Due to the fact that the last two concentrations are very weak as compared to the others, dividing points are established at An26% and An33%, giving rise to group a (≧An33%), group b (An26–32%) and group c (≦An25%). The two-dimensional distribution maps of An-content drawn based on these criteria of groups show relations of distribution for the plagioclases belonging to each group within the thin section (Fig. 20). In the core's map the subordinate concentrations, group a and c, form island-like domains in the host field of the group b which has the dominant concentration as shown in the frequency histogram. The subordinated groups a and b in the mantle's two-dimensional distribution map form also domains in the host field of plagioclase belonging to group c, the one with the most dominant concentration. It is a remarkable feature that the domains of group a which has a more different composition than group b is compared to the main concentration of group c are always found in the domains of group b. In other

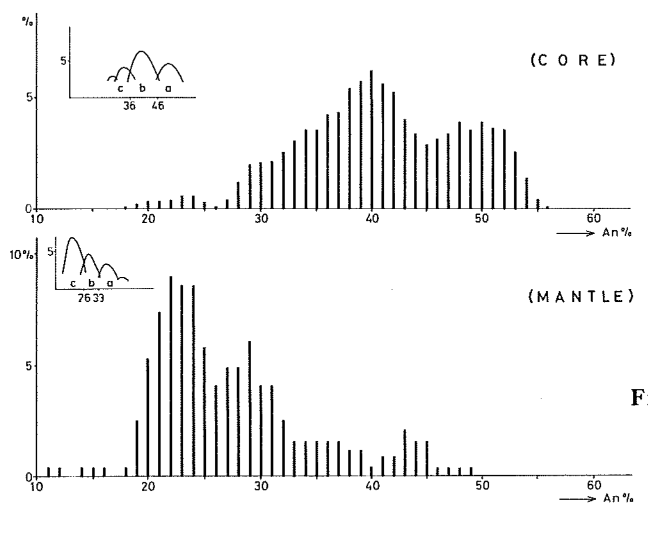

Fig. 19. An-frequency histograms based on unit range ±1.5An% of the granodiorite I.

words, there is no such an example in which the isolated domain of group a is facing directly to the field of group c.

ii) Granodiorite II

The An-frequency curves of the core and the mantle drawn from the result of 332 points measurement using an statistical unit range of ±2.5An% show a rather normal distribution with their modes at An47% (core) and An30% (mantle). However, the degree of concentration of both modes is not high

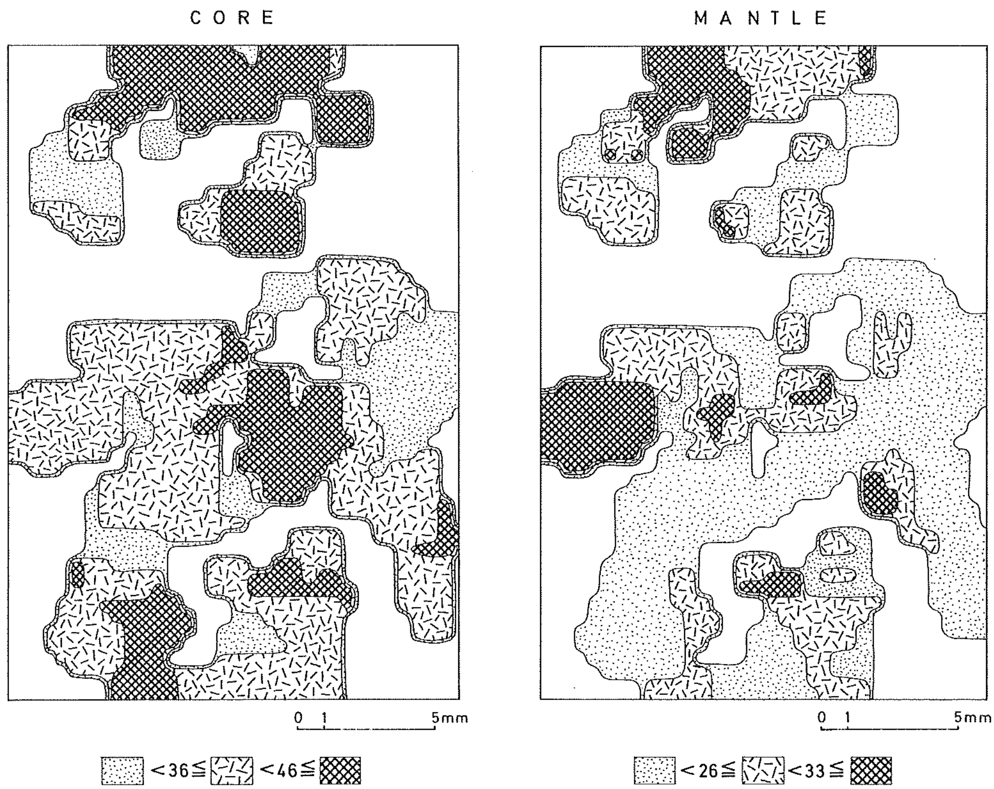

Fig. 20. Two-dimensional distribution maps of An-content of the granodiorite I by statistical contouring. Unit area is 0.1 mm^2.

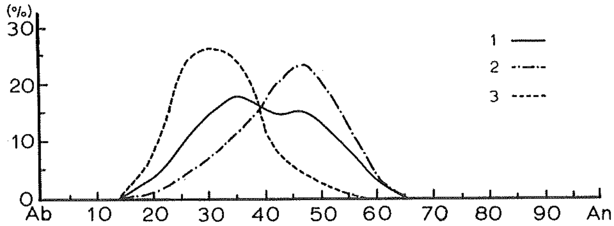

Fig. 21. An-frequency curves based on unit range ±2.5An% of the granodiorite II. 1. Total 2. Core 3. Mantle

because of their wide range of distribution (Fig. 21). Especially, the curve of the core has an anisotropic distribution widening towards the lower An-content. Examining the frequency histograms with a unit range of ±1.5An% to analyze these frequency curves, is comes clear that these frequency curves consist of sevral groups of a smaller scale concentration (Fig. 22). In the frequency histogram of the core, six concentrations of smaller scale can be recognized. The modes of these small scale concentrations are located around An52%, An48%, An43–44%, An38–39%, An35% and An31%. However, the separation of these concentrations and the position of their modes are not so distinct. The histogram has been divided into three groups by taking the values An41% and An47% as boundaries and they are named group a, b and c from higher to lower An composition. The frequency histogram of the mantle has a simmular nature as compared to that of the mantle of granodiorite I. Three concentration groups are recognized in the histogram, the one with the lowest An content being the most dominant. This concentration has its mode at An28%. The other two subordinated concentrations have their modes at An33% and An43%. Three groups are separated by taking the values An31% and An39% as boundaries and they are named group a, b, and c from higher to lower An composition.

The two-dimensional distribution maps of An-content of this lithofacies are shown in Figure 23. In both maps groups a and b form island-like domains in the host field of group c. The domains of group a are always enclosed by wider domains of group b. This form of distribution is quite analogous to that of granodiorite I.

iii) Granodiorite III

The spatial distribution of the plagioclases of this lithofacies has been

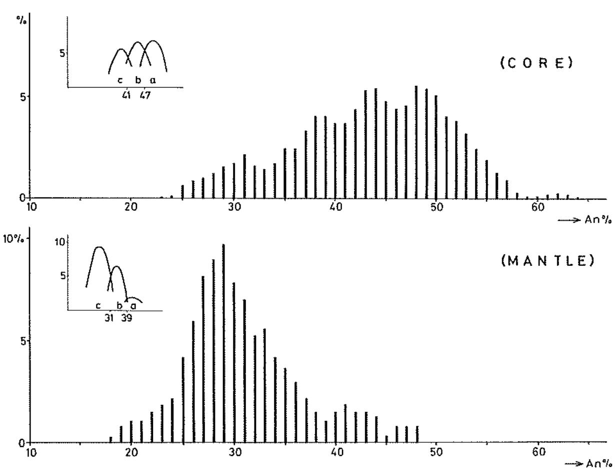

Fig. 22. An-frequency histograms based on unit range ±1.5An% of the granodiorite II.

previously explained in detail in relation to the frequency histogram.

iv) Granodiorite IV

The An-frequency curves of the core and the mantle of this lithofacies constructed based on the measurement of 205 points are shown in Figure 24. The core's frequency curve has an statistically abnormal feature with its mode at An43% and sub-mode around An35%. The mantle's frequency curve shows a rather normal statistical distribution having its mode at An33% although its shape is not symmetric against the mode composition because of its widened slope towards the high An composition. However, the frequency histograms made by using a unit range ± 1.5An% show a slightly different feature as compared with the An-frequency curves both in core and mantle (Fig. 25).

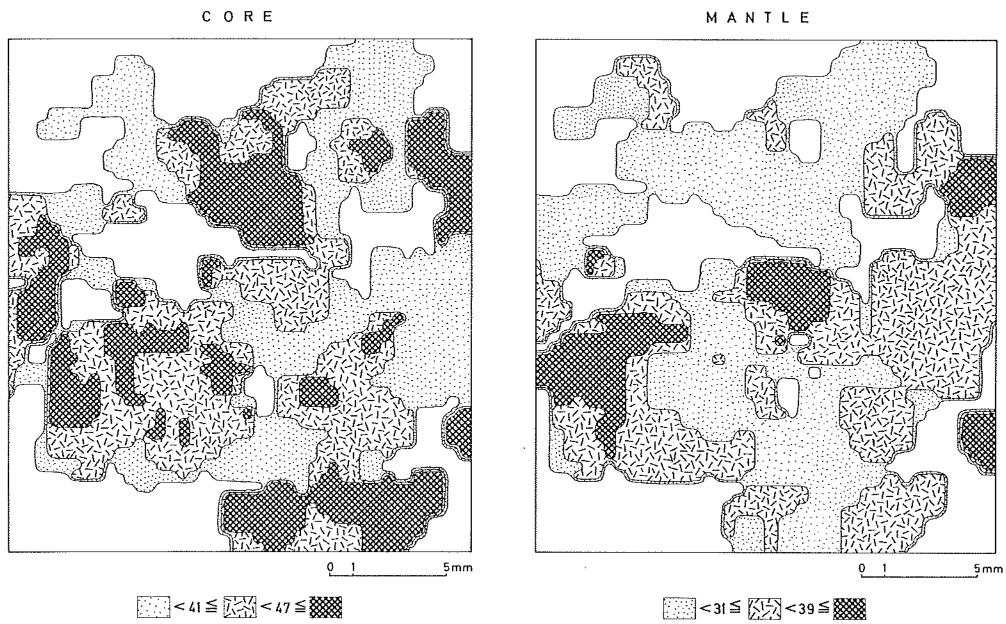

Fig. 23. Two-dimensional distribution maps of An-content of the granodiorite II by statistical contouring. Unit area is 0.1 mm^2.

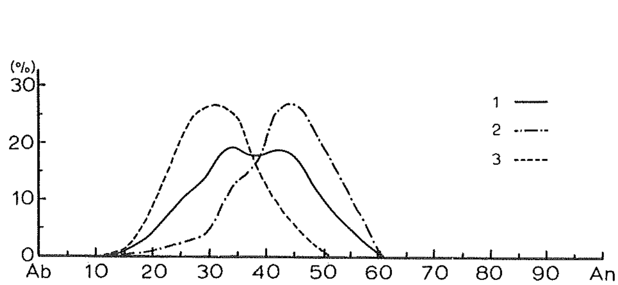

Fig. 24. An-frequency curves based on unit range ±2.5An% of the granodiorite IV.
1. Total 2. Core 3. Mantle

Four prominent concentration groups with centres at An39%, An42–43%, An47% and An50% respectively together with a very slight peak at An29% are

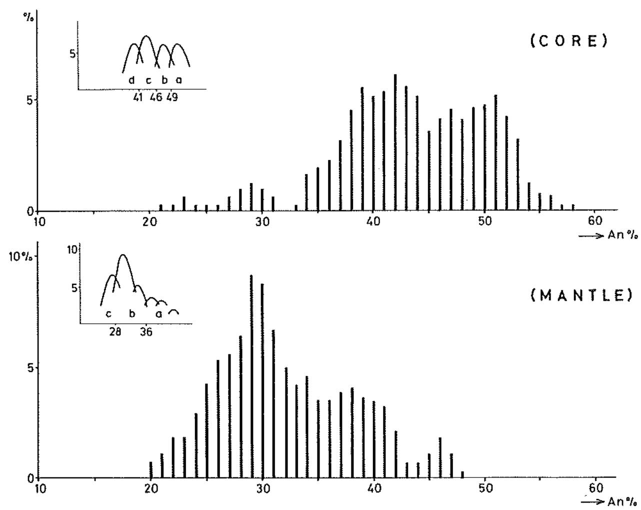

Fig. 25. An-frequency histograms based on unit range ±1.5An% of the granodiorite IV.

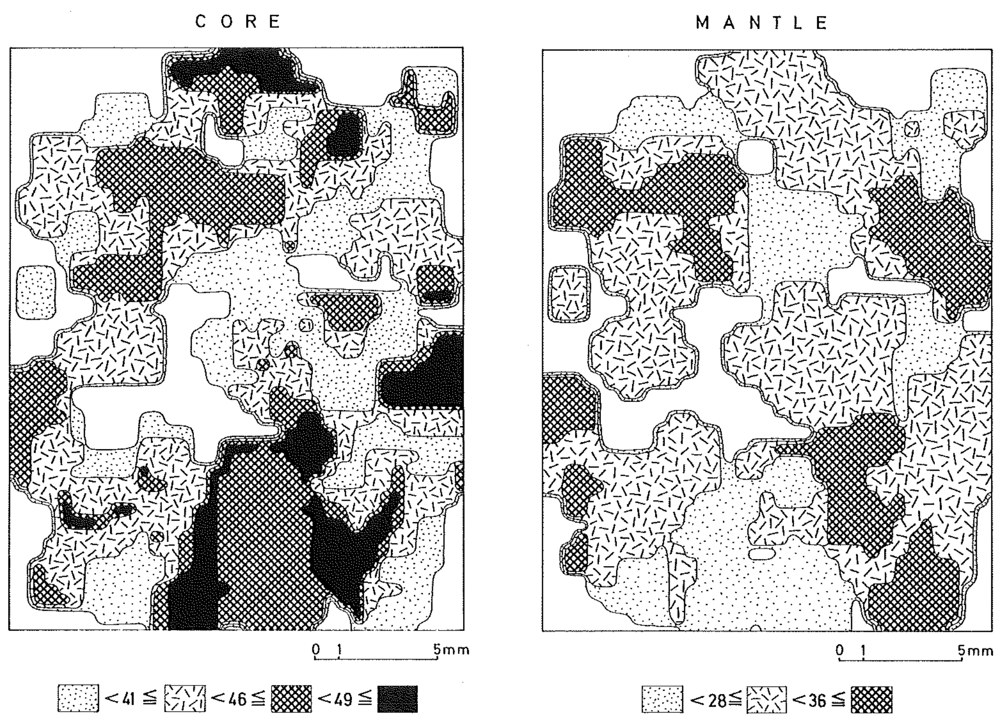

Fig. 26. Two-dimensional distribution maps of An-content of the granodiorite IV by statistical contouring. Unit area is 0.1 mm^2.

found in the core's histogram. These concentrations are not recognized on the frequency curve. Therefore the histogram has been divided into four groups by taking the values An41%, An46% and An49% as boundaries, they are group a (≧An49%), group b (An46–48%), group c (An41–45%) and group d (≦An40%). Except for a remarkable concentration around An30%, subordinate concentration groups are found around An38% and An46% on the mantle's histogram. The prominent concentration coincides with the mode of the An-frequency curve, but the subordinate concentrations are not recognized in this. Therefore groups can be determined as group a (≧An36%), group b (An28–35%) and group c (≦An27%).

The two dimensional distribution map of An-content of this lithofacies are shown in Figure 26. In the core's map, plagioclases belonging to group a form island-like domains. They are surrounded by domains of group b. Plagioclases belonging to group c occupy a rather wide area in the histogram and form the host field including the domains of groups a and b. Several domains of group d are also found in the host field but they show a rather host character in the middle part of the histogram. Plagioclases having composition with a prominent concentration in the mantle's histogram (group b) are the host field in the distribution map of the mantle including many domains of groups a and c.

IV. Discussion and conclusions

The writer previously reported about the transition in the An-content of the plagioclases with the formation of each lithofacies both in the basic enclaves suite and in the granodiorite suite of this massif (Tsuchiya, 1967b). According to this, the original basic enclaves – which are considered simmilar to the melanocratic fine-grained enclaves – were formed prior to the formation of each lithofacies of the granodiorite, and were captured later by the granodiorite mass in the course of the migration of the massif. Both, enclaves and granodiorite slightly changed their chemical compositions and appearances due to metasomatic reaction and the various lithofacies described in chapter II resulted. The transition of the An-content of the plagioclases in each lithofacies proves the process of this reaction. In the basic enclaves suite, the strongly abnormal mode found in the An-frequency curve for the core of the biotite porphyritic enclaves signifies an unstable phase caused by metasomatic reaction. In a later stage this reaction finally led to the formation of the plagioclase porphyroblasts with a simmilar An-content and nature in the biotite plagioclase porphyritic enclaves than those plagioclases constituting the mother rock.

Accompanying these processes in the basic enclaves, a transition of the An-content of the plagioclases is also recognized in the granodiorite suite. The effects are clearly represented on the An-frequency curves for the granodiorite II which is a rather mafic mineral rich lithofacies including basic inclaves as mentioned before. Both frequency curves, for the core and for the mantle, have their modes at a higher An composition (An47% for the core and An30% for the mantle) compared to those for the granodiorite I. An-frequency curves for the core of granodiorite II shows an statistically normal distribution different from that for granodiorite I which shows a strongly abnormal distribution.

These compositional changes towards An rich plagioclases in granodiorite II (anorthitization of plagioclase) and the unstable distribution of the frequency curves of granodiorite I are interpreted as the effects of metasomatic reaction with basic enclaves.

Throughout all these processes the transition of modes on the An-frequency curves were taking place following a rule. Along the albite-anorthite series there are several conspicuous composition values that show a high degree of concentration. These values have been obtained from statistical treatment of a large number of measurements of plagioclase compositions of many different types of plutonic and metamorphic rocks (Hunahashi, Kim, Ohta and Tsuchiya, 1968). These special composition values are estimated as An22%, An27%, An33%, An43%, An47%, An50%, An55%, An57%, An62%, An65%, An67% and An78%. Among them An22%, An33%, An43% and An50% are the commonest An concentration values. The modes and sub-modes of the An-frequency curves of this massif fall at values An24%, An27%, An30%, An33%, An43%, An47% and An50%. Most of them coincide with the above-mentioned special An values. Based on this fact, the transition of the An-content of the plagioclases of this massif is considered to have proceeded step by step regulated by these special compositions.

The reason why such peculiar An compositions have the nature of being high concentration points is unknown yet. However, the compositions An33%, An50% and An68% are assumed to be structural discordant points by Doman, Cinnamon and Bailey (1965). The same has been assumed for composition An33%, An48%, An50% and An78% by Bambauer, Corlett, Eberhard and Viswanathan (1967). DeVore (1965) considered compositions, An43%, An57%, An65%, An67%, An80% and An83% as being theoretically stable composition in addition to them. Therefore, some of the concentrations at the above-mentioned peculiar compositions could be present due to structural discontinuities of the crystal.

The constitution of an An-frequency curve with a wide distribution range up to more than An40% is confirmed in this paper. Several small scale concentrations are recognized in every frequency histogram with a unit range ± 1.5An%. They should be regarded as fundamental constituent units of the An-frequency curve. Each individual constituent unit would approximately cover an An-range of 9–10% and it shows a high concentration. The values of An of the modes of such constituent units in the frequency histograms in this paper are represented by several compositions (Table 2). It is noteworthy that most

name of lithofacies	core	mantle
Melanocratic fine grained lithofacies	46, **50**, 55	33-34, **40**, 46-47
Biotite porphyritic lithofacies	30, 34, **38**, 43, 48	27, **30**, 37, 42
Biotite plagioclase porphyritic lithofacies	43, **49**, 53	**40-41**, 46
Granodiorite I	30, 35, **40**, 50	22, 27, 37, 43
Granodiorite II	31, 35, 38-39, **43-44**, **48**, 52	**28**, 33, 43
Granodiorite III	33, **43**, 52	22, **33**, 40
Granodiorite IV	39, **42-43**, 47, **50**	**30**, 38, 46

Table 2. The An-values of modes and sub-modes of concentrations appeared on the An-frequency histograms of each lithofacies. The values written in bold letters are those of modes of prominent concentrations in the histograms.

of them coincide with the above-mentioned peculiar high concentration compositions indicated from the An-frequency curves. Mode compositions other than those coinciding with the peculiar compositions are An30%, An31%, An35%, An39%, An40–41%, An52% and An53%. Among them, An30%, An40% and An52–53% appear several times in the table, however, the significance of these particular compositions remains an unsolved problem. Therefore, the ideal distribution of the constituent units of the An-frequency curve may be a statistically normal one with a distribution range about 10An% having its mode at one of the above-mentioned peculiar compositions, and the An-frequency curve is composed of some of such fundamental units. This model is supported by the result of examination of plagioclase composition in garnet gneiss carried out by Kim, of which An-frequency curve shows remarkably high concentration at An22% covering the range of around 10An% (Hunahashi, Kim, Ohta and Tsuchiya, 1968).

There may be an opinion that such fundamental units of concentration of plagioclase composition crystallized possibly through the same process and under the same conditions. The writer has little to add about this problem because no new scheme for intermediate plagioclase based on recent physico-chemical information has been proposed. However, the actual transition in composition of plagioclase is traceable on the frequency histograms as a step by step transition within the extent of the fundamental units. For example, prominent concentration around An40% on the core's frequency histogram of the granodiorite I (Fig. 19) is reduced to a subordinated conentration on that of the granodiorite II (Fig. 22). In turn, the subordinated concentration around An50% on the frequency histogram of the granodiorite I becomes a prominent concentration on that of the granodiorite II by anorthitization of the plagioclase caused by metasomatic reaction with the basic enclaves. This suggests that it may be reasonable to explain the existence of such units of concentration as products of a continuous sequence of granitization of the basic enclaves suite and the granodiorite suite.

From this viewpoint, a prominent unit of concentration on the frequency histogram indicates suitable products for representative physico-chemical conditions of that lithofacies. Subordinated concentration units located at both sides of the prominent concentration, (when the rock corresponding to the histogram is experimenting granitization with its plagioclase changing in composition towards a more albitic one) would indicate unstable concentrations for that main physico-chemical condition. In this case the subordinated concentration with a higher An-content than that of the prominent concentration should be regarded as a "relict" one suitable for equilbrium with previous physico-chemical conditions. On the other hand the subordinated concentration with a lower An-content than that of the prominent concentration should be considered as a newly forming concentration being suitable for the next set of physico-chemical conditions. These relations for each fundamental unit are well represented on the two-diemensional distribution maps of An-content for each lithofacies.

Comparing the maps for the core and the mantle belonging to the same lithofacies, a different relationship for the host field and domains between both maps can be pointed out. In the core's map, the plagioclases corresponding to prominent concentration units occupy a wide area of the map and make host fields. Several domains of a relict nature are present in that host field, and domains corresponding to a new condition appear around or at the interespaces of the host field. On the other hand, in the mantle's map there are no domains of a lower Ancomposition than that of the host field. Domains corresponding to a subordinated concentration include other small domains of higher

An-content. All of them are in turn included by the host field corresponding to the prominent concentration of plagioclases. This difference appears also on the manner of distribution of the frequency histogram.

It can be also pointed out that no correlation exists between compositions of plagioclases on the maps for the core and the mantle. This fact would imply that the existing physical conditions were quite different when the core and the mantle crystallized. And that some disturbances would have taken place after the core was formed. The writer has already pointed out this problem from the examination of the An-frequency curves (Tsuchiya, 1967b).

The distribution of the An-content ranging in such a wide extent as the one shown in this paper proves that homogeneity of chemical composition has not been attained even in a pluton type granodiorite as the Kisokoma massif which has been regarded as a relatively homogeneous massif.

The domain structure within the spatial distribution map presented in this paper is the actual mode of plagioclases having a wide range composition. Although the maps represent the two-dimenstional way of distribution of the plagioclases, the same results can be expected in a three dimensional representation because the thin sections were prepared in a random orientation and anisotropy of specimens is weak. Therefore, imagining a three dimensional distribution of such domain structured plagioclases, the host field, which can be regarded as stable composition, builds up a spongy-like body with openings; relict and newly forming domains could be compared to small lacunae in this body. The openings are filled up by other minerals than plagioclase. Though the composition of plagioclases is heterogeneous and it does not attain equilibrium as a whole at the thin section, sub-equilibrium conditions are preserved within the unit of those domain structures. This scheme may be equivalent to the conceptions of local equilibrium or mosaic equilibrium proposed by Thompson (1959) and Korzhinskii (1959).

The writer examined spatial distribution of plagioclases with different composition ignoring other constituent minerals. The relationship of these domain structures to other minerals remains as a further problem.

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