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Author(s)	Hoe, Soeng Gi
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PETROLOGY OF THE KESENGAWA GRANODIORITE, KITAKAMI MOUNTAINS, NORTHEAST JAPAN

by

Soeng Gi Hoe

(with 31 text-figures and 1 table)

(Contribution from the Department of Geology and Mineralogy,
Faculty of Science, Hokkaido University, No. 1532)

Abstract

The Kesengawa granodiorite mass, a representative Cretaceous granitoid intrusive of the Kitakami mountain region, is divided into a basic and an acidic rock group. The basic rock group (melanocratic fine-grained porphyritic rocks) consists of microdiorite (facies 1), porphyritic microdiorite (facies 2) and quartz diorite (facies 3), and the acidic group (leucocratic coarse-grained equigranular rocks) consists of granodiorite-I (facies 4) and granodiorite-II (facies 5).

A large number of measurements of the optical properties of plagioclases presented in each rock facies has been carried out. In general, the author could always discriminate four *domains* for the anorthite content of the plagioclase in each rock facies. These *domains* are tentatively called here as A, B, C and D.

The plots of optically measured anorthite contents on the standard line gradually shift from the basic towards the acidic side in accordance with the change of rock facies from (1) to (5). Such tendency is summarized as follows:

A, (B) (facies 1) → C, (B, D) (facies 2) ↔ B, (A) (facies 3) → C, (B, D) (facies 4) → C, D (facies 5)—in the core part of plagioclases. C, (D) (facies 1) → C (facies 2) ↔ C (facies 3) → D, (C) (facies 4) → D, (C) (facies 5)—in the mantle part of plagioclases.

A vast number of dykes (plagioclase porphyrite, microdiorite and diabase) intruded into Palaeozoic and Mesozoic sedimentary strata prior to the emplacement of the Kesengawa granodiorite mass. The anorthite contents of plagioclases in these dykes fall into the same *domain* of facies (1).

The author concludes that the generation process of the Kesengawa granodiorite mass can be interpreted as follows:

1) Subsequent to the generation of the dykes, melanocratic fine-grained porphyritic rock facies such as (1), (2) and (3) were formed along a fracture zone. 2) These basic facies were partially assimilated by the acidic rock facies, especially granodiorite-I (facies 4) which was generated after the former basic rocks. 3) Finally, granodiorite-II (facies 5) intruded into the formerly generated rocks.

Introduction

The Kitakami mountain region, one of the major geotectonic units of the Japanese islands, occupies the outer belt of northeast Honshu. It has a north-south structural trend of approximately 300 km in length and 100 km in

width and mainly consists of Palaeozoic formations fringed by Mesozoic units. Minato and his co-workers have carried out long and detailed biostratigraphic and geotectonic studies of the Palaeozoic of the region (Minato, 1944, 1950a, 1950b; Minato et al., 1959a,b,c; Minato, 1960; Minato et al (ed.), 1965; Minato, 1966). As a result, a standard scheme for the Japanese Palaeozoic stratigraphy and the detailed tectonic structures of the region have been established in a highly comprehensive form. This previous knowledge has been an invaluable help in the present study.

Apart from the Palaeozoic and Mesozoic stratified rocks, one of the prominent geologic features of the region is the intrusion of large volumes of granitoids which are arranged there in three zones running with a NNW trend. Each zone, however, is not represented by a continuous intrusive mass, but by an arrangement of many comparatively small swollen bodies, all of them discordantly intruding the surrounding palaeozoic and Mesozoic formations. Most of these granitoids have been believed to be late Cretaceous in age (Ishii et al., 1953, 1955, 1960; Kano, 1954, 1955, 1957, 1958a,b,c; Kanisawa, 1969, 1970; Katada et al., 1971, 1974; Kawano and Ueda, 1964; Minato, 1950b, 1953, 1967; Minato et al (ed.), 1965; Shibata and Okada, 1955; Shimazu, 1955, 1958, 1962, 1964; Suzuki, 1952, 1953, 1954, 1958; Watanabe, 1950; Yamada, 1953).

Many of the late Cretaceous granitoids in the Japanese islands have been considered somewhat peculiar as to their genesis, since they differ from synkinematically generated granitoids which are commonly found closely associated with gneisses and migmatites in the central core of an orogenic belt. They have been considered to be intrusives formed along fracture zones at a shallower tectonic level in a non-metamorphic terrain (Ichikawa et al (ed.), 1970; Yamashita, 1957). Such plutonic activities in the Japanese islands are related to the Yenshan movement, a main Mesozoic disturbance which affected the East Asiatic Continent and which is characterized by a particular tectonic style called "fracturing tectonics" (Ichikawa, 1966; Nishida, 1966; Sun, 1966; Yamada, 1966; Yamashita, 1966). The "Hiroshima granite", widely distributed along the inner zone of southwest Japan, is interpreted as belonging to this type of intrusions (Ichikawa, 1966; Kojima, 1954). The late Cretaceous granitoids of the Kitakami mountains can also be referred to such peculiar sort of intrusions.

The Kesengawa granodiorite to which the present study is mainly concerned, is distributed in the central part of the southern Kitakami mountains and belongs to the central zone of the granite intrusion (Katada et al., 1971, 1974; Suzuki, 1952; Watanabe, 1950). The Tono granodiorite, the largest granitoid mass in the Kitakami mountains, discontinuously outcrops



Fig. 1 Distribution of granitoids in the Kitakami mountains (after Watanabe, 1950, Katada et al., 1974). black: western zone. dotted: central zone (heavy; western flank. light; eastern flank). hatched: eastern zone (heavy; western flank. light; eastern flank). T = The Taro tectonic line. K = The Kuzumaki tectonic line. M-G = The Morioka-Goyozan tectonic line. H-G = The Hayachine-Goyozan tectonic line. H-K = The Hizume-Kesennuma tectonic line. To = The Tono granodiorite mass. Ke = The Kesengawa granodiorite mass. Hi = The Hirota granodiorite mass. Ku = The Kurihashi granodiorite mass. Go = The Goyozan granodiorite mass.

immediately north of the Kesengawa granodiorite. Towards the south, the Kesengawa granodiorite gradually passes to the Hirota granodiorite which is considered to belong to a different intrusive unit.

The petrographical feature of the Tono granodiorite are quite similar to those of the Kesengawa granodiorite while the Hirota granodiorite shows a more acidic nature, e.g. it is rich in leucocratic facies. Such leucocratic facies is also found in the southern part of the Kesengawa granodiorite mass. In this respect, the geological and petrological features in and around the Kesengawa granodiorite mass have been studied in detail in order to interpret the progressive development of the late Cretaceous granitoid activity in the Kitakami mountain region.

The author has intended to study the petrogenesis of the granodiorite suite based on detailed optical measurements of the constituent plagioclases. A particular shifting in the optical properties of these feldspars would permit to conclude that the Kesengawa granodiorite mass has evolved from an early dioritic nature to a late granitic character.

General Geology

The Kesengawa granodiorite (Figs. 2, 3) crops out over an extent in 2 km wide and 30 km long at the eastern side of the Kesengawa River and with a north-south trend. A prominent structural feature of the region is represented by Setamai-Tennanzan anticlinorium which has the role of a structural center for the Palaeozoic system consisting of Carboniferous and Permian formations (Minato, 1941). The anticlinorium is laid along the western side of the Kesengawa River. The long belt of exposures of the Kesengawa granodiorite is roughly parallel to this anticlinorium though it cuts the Carboniferous and Permian formations particularly in the northern and southern areas.

In the northern part, the granodiorite mass gradually gets narrow and disappears beneath the Permian formations. Further to the north, another large intrusive body, the Tono granodiorite with a circular outline of about 20 km radius is present. Although the Tono granodiorite is much larger in volume and shows a different intrusive form as compared with the Kesengawa mass, the petrographical features of both granodiorite masses are quite similar. This similarity is reflected in rock facies, modes of occurrence of each rock facies, volume ratios of constituent minerals in each facies and other aspects.

At its southern extension the Kesengawa intrusive body gradually changes in composition to different rock facies without any interruption in the outcrops of the mass. Although actual boundary relations are obscured by the cover of thick Diluvium deposits, this southernmost part is separated as a different intrusive unit known as the Hirota granodiorite.

At first sight, the Kesengawa granodiorite seems to be concordant with the geologic structure of the surrounding rocks. However, it has already been noted

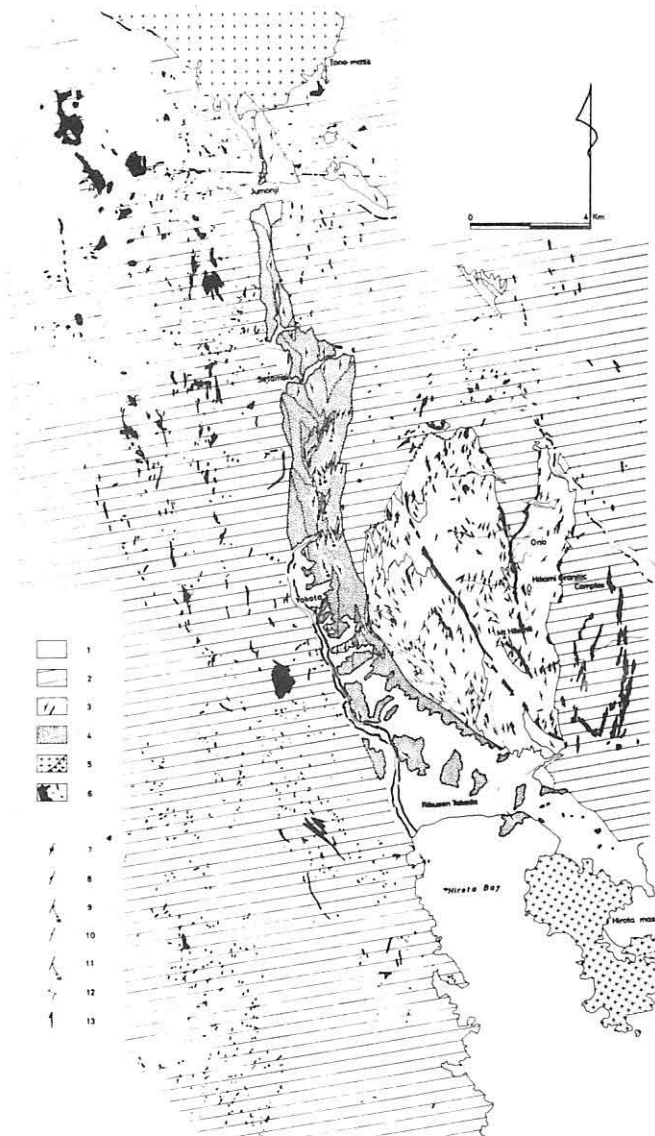


Fig. 2 A structural map showing the distribution of dykes (compiled from Minato et al.'s geological map, unpublished), of the Kesengawa granodiorite and the Hikami granitic complex (Hoe, 1976).

1: Alluvial and Diluvial deposits. 2: Palaeozoic and Mesozoic formations. 3: The Hikami type of granite. 4: The Kesengawa granodiorite. 5: The Tono and the Hirota granodiorite. 6: Dyke rocks. 7: Flow structure showing a vertical dip. 8: Flow structure showing 70° over dip. 9: Flow structure (70° under dip) and lineation. 10: Foliation (70° over dip) and lineation. 11: Foliation (70° under dip) and lineation. 12: Mylonitized zone. 13: Fault.

that the contacts of the intrusive mass show a distinct discordant relation with the country rocks. Around the intrusive mass, contact aureoles less than 2 km wide have been formed, in which Palaeozoic sedimentary rocks are well preserved. Neither schists nor gneisses are known to be present in the neighbouring area.

Another interesting feature of the region is given by the presence of porphyrites which intrude into the sedimentary rocks and into the Hikami granitic complex (Hoe, 1976) as dykes or sheets believed to be prior to the intrusion of the late Cretaceous granodiorite. Although the size of these dykes and sheets is variable, they are usually less than 100 m long. Some large masses attaining up to 2 km long are also known. They occur all over the region as shown in Fig. 2. These dyke rocks commonly contain plagioclase phenocrysts in a holocrystalline groundmass. The most basic facies represented among these dykes is diabase.

The fabric elements of the Kesengawa granodiorite will be described next.

Foliation due to flowage of minerals is well developed. The foliation plane is always sub-parallel to the elongation of the mass through its whole extent. In any part of the mass the foliation plane always tend to a dip of 60° – 80° to the west or to the east. The lineation direction is about 45° S in the area from Setamai to Taya, the northern half of the mass. In the southern part, the lineation is more steeply inclined and up to 75° S. The structural features are presented in Fig. 2. Joints are well developed and the vertical elements are so prominent as to form distinct columnar joint systems.

Petrography of the Kesengawa Granodiorite

Although the late Cretaceous acidic intrusives of the region have been customarily referred to as "granites", their actual petrographical character corresponds to a granodiorite. Granitic features are rather subordinate in rocks of this area.

Nevertheless each intrusive mass is not represented by a single homogeneous rock facies. It is rather common to see a commingled facies arrangement varying from basic to acidic members. In the Kesengawa granodiorite mass, there are fine-grained, small basic enclaves contained in a dark coloured, coarser-grained facies which has developed in an areal extent attaining some 30 – 40% of the total volume of the mass. On the other hand, a coarser-grained leucocratic facies cuts or impregnates the dark coloured facies. Such leucocratic facies becomes predominant in the southern parts of the mass and it represents most of the volume of the Hirota granodiorite.

The following five rock facies can be recognized in the Kesengawa

granodiorite (Fig. 3):

- (1) microdiorite facies
- (2) porphyritic microdiorite facies
- (3) quartz diorite facies
- (4) granodiorite facies-I
- (5) granodiorite facies-II

Similar rock facies also occur in the Tono, Hirota and Goyozan masses. Modal analyses of the different rock facies of the Kesengawa granodiorite mass are represented in Fig. 6. As shown there, the increasing trend in the amount of potash feldspar does not exceed 25%.

Plagioclase, hornblende and biotite are the commonest constituent minerals in each rock facies. In the acidic facies quartz and potash feldspar are also present. Two main types of textures are observed. One corresponds to a porphyritic texture with large plagioclase phenocrysts in a fine-grained groundmass and is typically observed in rock facies (1), (2) and (3). The other is a hypidiomorphic granular texture with coarse-grained equigranular constituents, typically observed in facies (4) and (5).

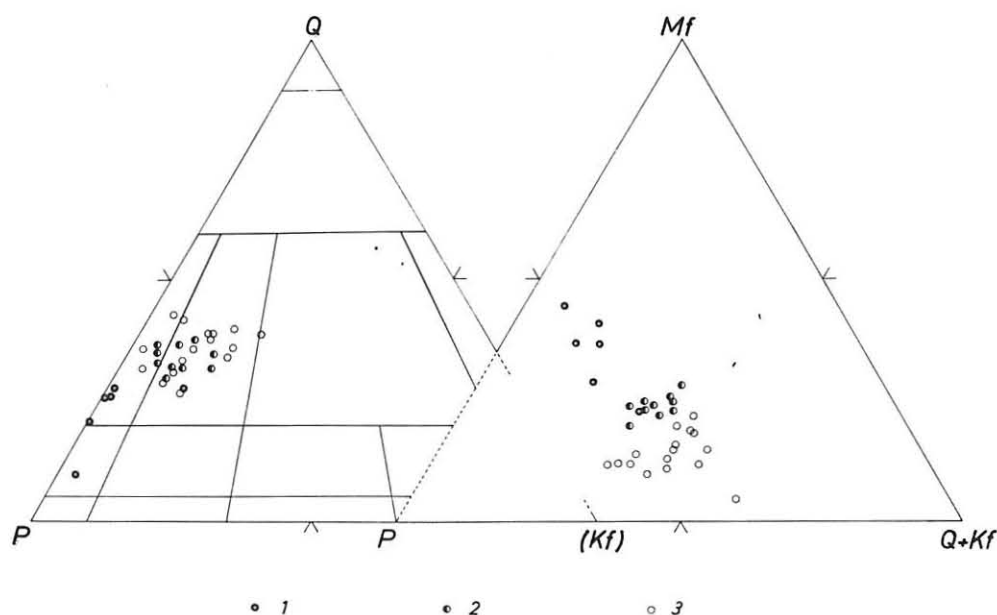


Fig. 4 Modal analyses of the Goyozan granodiorite mass. Rock names are based on the IUGS recommended nomenclature (1973), *idem* for Figs. 4 to 6. 1: quartz diorite. 2: granodiorite-I. 3: granodiorite-II.

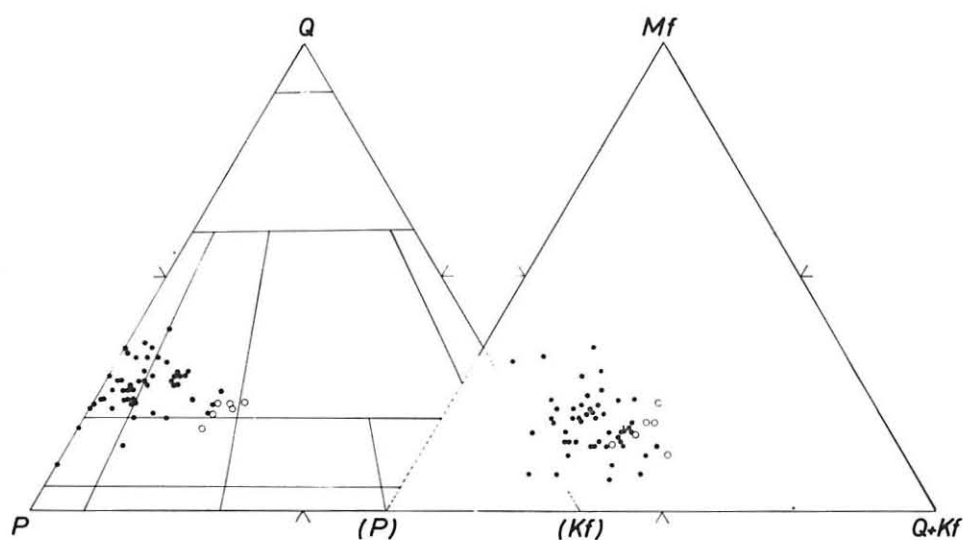


Fig. 5 Modal analyses of the Tono and the Hirota granodiorite masses (partly rewritten Katada et al., 1974). solid: Southern half of the Tono granodiorite mass. open: The Hirota granodiorite mass.

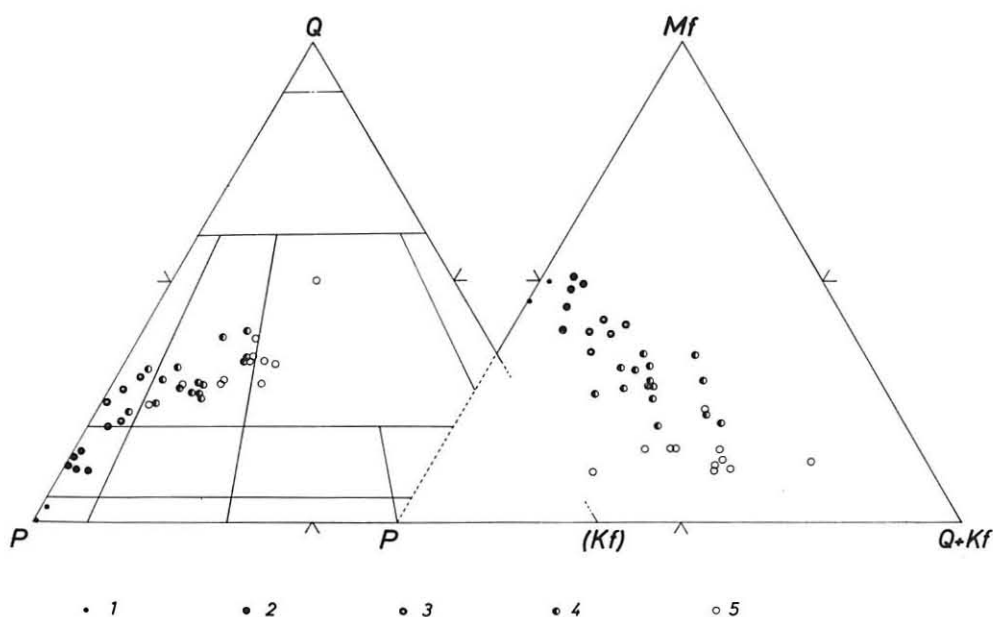


Fig. 6 Modal analyses of the Kesengawa granodiorite mass.
1: microdiorite. 2: porphyritic microdiorite. 3: quartz diorite. 4: granodiorite-I.
5: granodiorite-II.

Description of rock facies .

The main features of each rock facies are given, especially in relation to textural characteristics.

microdiorite: This facies contains large-sized plagioclase phenocrysts having a platy habit, and minor amounts of microphenocrysts of hornblende and plagioclase. The groundmass is composed of stout plagioclase prisms 0.01 mm long, xenomorphic hornblende and accompanying biotite filling plagioclase interstices. Difference in grain size between those of phenocrysts and in the groundmass is distinct. The plagioclase phenocrysts show a turbid core which is mostly altered to an aggregate of fine-grained sericite and chlorite. The core is surrounded by a more sodic clear mantle. The groundmass plagioclase shows no prominent zonal structure.

Hornblende is of the greenish type with X = light yellowish brown, Y = deep grayish green, Z = deep bluish green. No zonal structure is apparent except for some microphenocrysts of hornblende showing a turbid core. Biotite is of the brownish type having no reddish tint and is formed at the interstitial sites of plagioclase quite similar with the manner of occurrence of hornblende.

porphyritic microdiorite: Although the texture is nearly the same described for the microdiorite facies, the amount of plagioclase phenocrysts increases here and the grain size of the groundmass is slightly coarser as compared with that of the microdiorite facies. Also some plagioclase microphenocrysts appear in this rock. The habit of both phenocrysts and groundmass plagioclases changes to stout prismatic forms as compared with the platy ones observed in facies (1). However, in the groundmass of this porphyritic microdiorite facies, part of the plagioclase takes a fine granular shape filling the interstices of the idiomorphic plagioclase in close association with opaque minerals. Such texture may indicate the existence of different stages in the groundmass formation.

Some plagioclase phenocrysts consist of an aggregation of individuals. The external side of such single aggregation is wholly surrounded by a common mantle.

Hornblende is of the brownish green type similar to the one in facies (1); X = light yellowish brown, Y = deep grayish green, Z = deep grass green. In large hornblende crystals, a zonal structure with a brownish core surrounded by a grass green mantle is commonly seen. Biotite is brownish and reddish tints are not observed.

quartz diorite: In this facies, a small amount of quartz is added to the mineral constituents of the preceding two facies and the amount of mafic minerals decreases. Distinct idiomorphic plagioclase phenocrysts similar to those present in the foregoing two facies are also observed here. However, due to the

prominent coarsening in grain size of the groundmass plagioclase, the distinct porphyritic texture characterizing facies (1) and (2) becomes obscure. Some of the groundmass plagioclase crystals grow to a phenocryst size among the variable, smaller sized plagioclases, to show hypidiomorphic granular texture. The prismatic habit of the plagioclase crystals is prominent and the mafic components occupy the feldspar interstitial sites.

The colour of hornblende and biotite is nearly the same as in facies (1) and (2). Aggregations of small quartz grains fills in the interspace of the another minerals.

granodiorite-I: No porphyritic texture is observable in this rock facies. A coarse-grained, equigranular, granoblastic texture is the prominent feature. The amount of quartz increases in accordance with potash feldspar whereas mafic components decrease. Plagioclase is represented by prismatic forms with a maximum size of 10×8 mm. Its idiomorphism is strongly expressed against quartz and potash feldspar. Quartz and potash feldspar fill the pool-like irregular interspaces of plagioclase, with potash feldspar unevenly distributed. Potash feldspar is present as perthite or microcline perthite showing scarce and feeble lamellae. Hornblende and biotite have similar grain size as plagioclase. Hornblende shows a distinct zonal structure with a deep brownish core and a deep grass green mantle. Biotite is brownish and similar to those in the foregoing three facies.

granodiorite-II: Compared with the granodiorite-I facies, quartz and potash

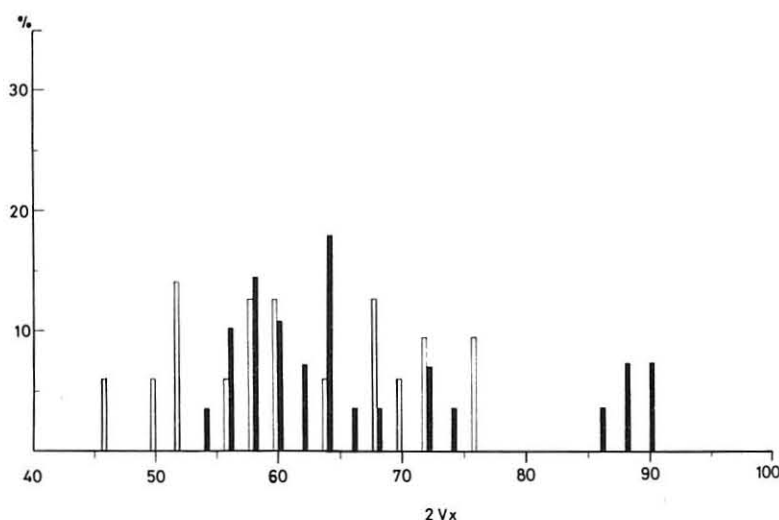


Fig. 7 Histogram of $2Vx$ values of potash feldspar in granodiorite-I and -II. solid: perthite in granodiorite-I. open: perthite in granodiorite-II.

feldspar are more dominant in this facies. The hypautomorphic equigranular texture is more distinctly developed. Plagioclase crystals are stout prismatic 12×10 mm in maximum size but showing a xenomorphic ovoidal shape in a few places. Zonal structure is also observed. Potash feldspar grows larger than the plagioclase and in some cases, a microcline twinning is revealed in small areas within a crystal. Myrmekite texture is always formed at the contact between quartz and potash feldspar.

Although the potash feldspars are perthite or microcline perthite in granodiorite-I and -II, $2V_x$ values differ in these two facies. In granodiorite-I, the range of $2V_x$ is 54° to 90° , with values especially concentrated between 55° to 65° . While in granodiorite-II the range is 45° to 76° with two concentration intervals, one between 68° and 76° and the other between 52° and 65° (Fig. 7).

Hornblende is deep brownish green (Table 1).

Table 1 Optical properties of hornblende in the different rock facies.

rock facies	$2V_x$	CZ	axial colour
(1)	$45^\circ - 62^\circ$	$14^\circ - 27^\circ$	x = light yellowish green y = light grayish green z = deep bluish green
(2), (3)	$57^\circ - 75^\circ$	$14^\circ - 21^\circ$	x = light yellowish brown y = deep grayish green z = deep grass green
(4)	$62^\circ - 76^\circ$	$15^\circ - 23^\circ$	x = light yellowish green yellowish green y = deep grayish green z = deep grass green
(5)	$62^\circ - 79^\circ$	$14^\circ - 24^\circ$	x = colourless to light yellowish green y = green to light yellowish green z = deep brownish green

Notes on the porphyrite: The presence of fairly large plagioclase phenocrysts, up to 3 cm in diameter, is a characteristic feature of the regional porphyrites. The crystals show a thin platy habit, their average length/width ratio is about 3 to 2, and they are contained in a greenish gray fine-grained groundmass. However, in a few places, the occurrence of porphyrites of a microdioritic nature is also known, in which cases a plutonic equigranular texture is observed.

Most porphyrites of the region have suffered a severe hydrothermal

alteration as a result of which chloritized mafic minerals and turbid plagioclase are commonly found. Close to the granitoid mass, the porphyrites are in cases changed to hornfels.

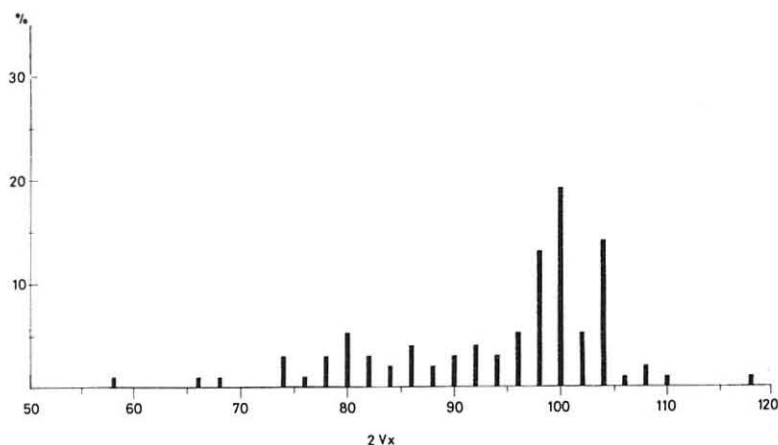


Fig. 8 Histogram of $2V_x$ values of plagioclase in the plagioclase porphyrite.

Zonal structure in plagioclase

The zonal structure of plagioclase has long been debated (Barth, 1969; Blackerby, 1968; Bottinga et al., 1966; Car, 1954; Crawford, 1966; Fraser, 1966; Greenwood and McTaggart, 1957; Härme and Siivolla, 1966; Homma, 1936a,b; Jorgenson, 1971; Ketskhoeli and Shengelia, 1966; Vance and Gilreath, 1967). Zoning is the most prominent feature of the plagioclase in the Kesengawa granodiorite mass.

In the present case, a fundamental feature of zoning common to all the rock facies, is the presence of a large calcic core surrounded by a narrow more sodic mantle. The core is often altered to an aggregate of fine sericite and chlorite flakes, and, in some cases, turned into an optically anomalous state that shows no perfect extinction due to the probable formation of submicroscopical lamellae or of an "unmixing structure" (Dickson, 1968; Ramberg, 1962). On the contrary, the mantle is always free from alteration. A weak "oscillatory zoning" (Figs. 9a,b,c) of different orientation is also prominent. At least, there is a distinct feature from which two steps in the formation process of the constituent plagioclase can be recognized. Such zoning feature is prominent in the phenocryst and microphenocryst plagioclase, but it is indistinct in the fine-grained groundmass plagioclase.

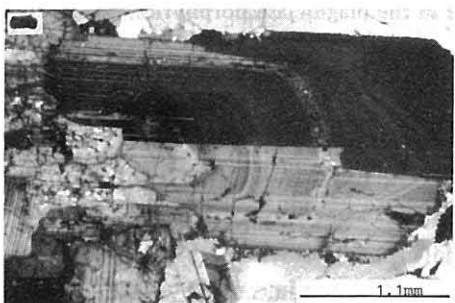
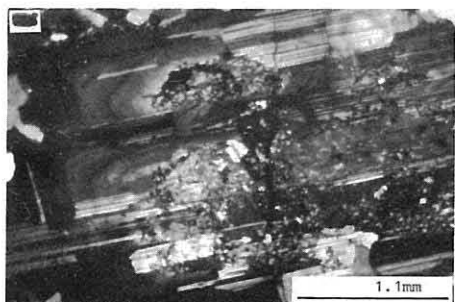
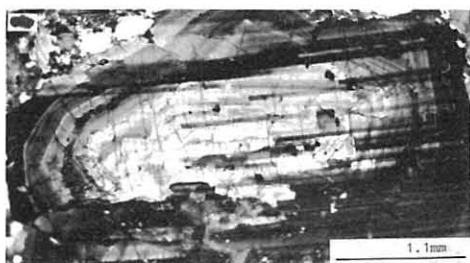


Fig. 9a,b,c

Photomicrographs showing oscillatory zoning in plagioclase.

- a: Gradual extinction from core to mantle is observed. Twinning lamellae extend to the mantle region regardless of the zonation. Loc. Nangyo, Rikuzen Takada City (sp. no.36). Rock type: granodiorite-I.
- b: Center of the crystal showing abnormal extinction which the author considers as a "product of unmixing". Some resorption bands are observed. Twinning lamellae do not continue to the mantle. Loc. Nangyo, Rikuzen Takada city (sp. no.36). Rock type: granodiorite-I.
- c: Plagioclase crystal with "doubly zoned" texture (termed by Crump et al., 1953). The inner zones are oscillatory. Resorption bands are clearly seen between the inner and the outer zones. Some corroded forms are also observed in the outer zone. This crystal is "half twinned" (termed by Crump et al., 1953). Loc. Nakanosawa, Rikuzen Takada city (sp. no.154). Rock type: granodiorite-II.

The following three patterns of zoning can be distinguished in the core of zoned plagioclases. Pattern(a); Irregularly shaped domains, considered to be a product of an unmixing process, are scattered for the whole extent of the core. These domains are compositionally more sodic than the surrounding host and in some cases they attain up to half of the core in volume (Figs. 10a,b). These irregularly shaped domains often form a "Chess board structure" (Battey, 1955; Callegari and Pieri, 1967; Starkey, 1959), every domain of which is bounded by planes parallel to the main crystal faces defining the habit of the crystal. Pattern (b); A calcic mass with a distinct corroded shape is present at the center of the core, which is itself more or less sericitized. Completely

**Fig. 10a,b**

Photomicrographs showing (a)-pattern of zoning.

- a: Chess board structure is well developed. A filmy mantle is observed at the bottom of the picture. Loc. Taya, Setamai-machi (sp. no.211-II). Rock type: quartz diorite.
- b: Large calcic core and some "unmixing" products are clearly seen. Loc. Kubota, Setamai-machi (sp. no.474). Rock type: quartz diorite.

surrounding the corroded part, another clear, fresh portion, is always formed. Its outer margin is idiomorphic and is succeeded, through a sharp boundary, by a mantle zone (Figs. 11a,b,c). Pattern (c); The core is cracked and cracks are occupied by a more sodic component. The sodic part is free from alteration and is optically continuous with the mantle material (Figs. 12a,b,c). Chloritization is rarely seen along the finely developed cracks of the core, which is surrounded by a fresh mantle.

Twinning types of the plagioclase

Several types of plagioclase twinning co-exist in one rock facies (Gorai, 1951; Kim and Hunahashi, 1972; Naidu, 1954; Seifert, 1964; Suwa, 1956, 1968; Suwa et al., 1974; Tonozaiki, 1966; Turner, 1951). In the Kesengawa granodiorite, some variations in the ratio of the existing twinning types are known. The following twinning types are discernible through all the rock facies.

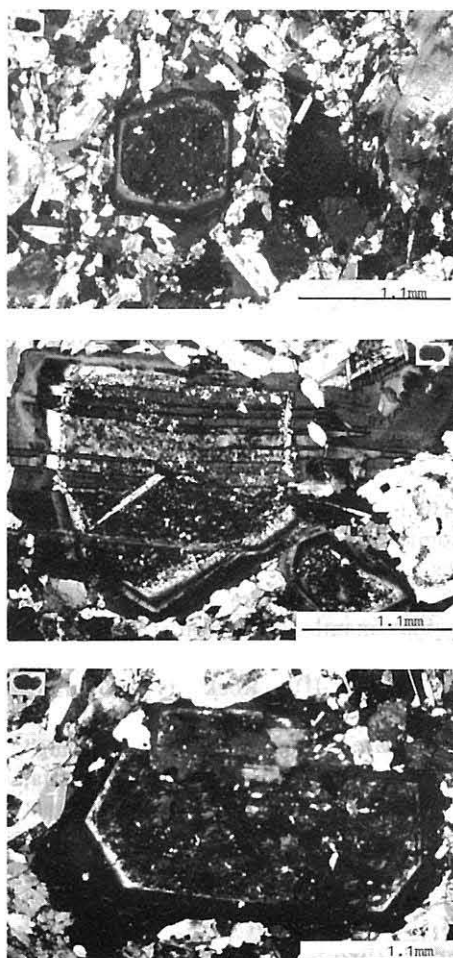


Fig. 11a,b,c

Photomicrographs showing (b)-pattern of zoning. A distinct corrosion form is seen in the core. Resorption bands between core and mantle are clearly observed. Sericitization is clearly seen in the core. Twinning lamellae are obscure in Figs. a and c.

- a: Loc. Tabata-sawa, Setamai-machi (sp. no.38). Rock type: porphyritic microdiorite.
- b: Loc. Yamaya-sawa, Setamai-machi (sp. no.60-I). Rock type: porphyritic microdiorite.
- c: Loc. Nakanosawa, Rikuzen Takada city (sp. no.154). Rock type: granodiorite-II.

- i) Albite twin (polysynthetic twinning)
- ii) Carlsbad twin (polysynthetic twinning)
- iii) Albite-Carlsbad twin (polysynthetic twinning)
- iv) Pericline twin (polysynthetic twinning)
- v) Other twins (Manebach, Acline, Albite-Ala B, etc)
- vi) untwinned

The relative abundance of the twinning types in each rock facies is shown in Fig. 13. It is observed here that the abundance of each twinning type varies from one facies to another. The percentage of plagioclase individuals twinned according the Carlsbad law is 24% in the microdiorite gradually falling to 16% in the porphyritic microdiorite, 8% in the granodiorite-I to finally reach 3% in the granodiorite-II facies. On the contrary, the percentage of Albite twinned plagioclase individuals increases from basic to acidic rock facies.



Fig. 12a,b,c

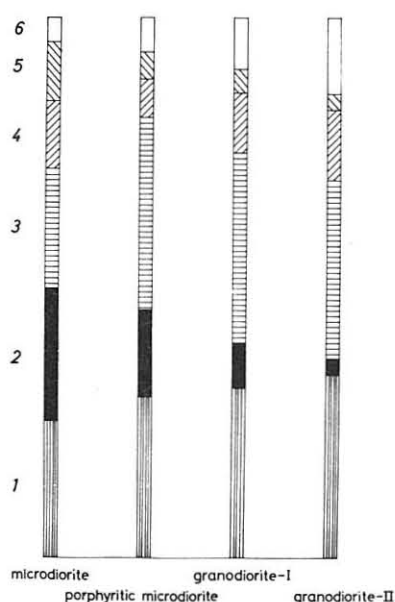
Photomicrographs showing (c)-pattern of zoning.

- a: Some corrosion bands are developed. Sodic lamellae are cut by the above-mentioned bands. Cracks are distinctly developed. Loc. Okuhinotsuchi, Kamiarisu-mura (sp. no.E-1). Rock type; plagioclase porphyrite.
- b: Core is cracked. A sodic zone of the same nature as mantle is formed along the cracks. Loc. Taya, Setamai-machi (sp. no.211-II). Rock type; quartz diorite.
- c: Oscillatory bands are well developed in remnants of the turbid core. Chloritization is thoroughly taken place along the cracks. Sodic twin lamellae are distinctly developed. Loc. Yamaya-sawa, Rikuzen Takada city (sp. no.184). Rock type; granodiorite-II.

Mode of occurrence of each rock facies in the Kesengawa granodiorite mass

The microdiorite (facies 1) is found as small enclaves of angular or subangular breccia form, which takes ovoidal shape in some cases (Fig. 14). They occur exclusively within the granodiorite-I facies and present sharp boundaries with the host rock due to grain size and/or colour contrast. Although these enclaves occur where the granodiorite-I facies is predominant, a particular concentration of them is known to occur around the Setamai and Tsukisawa areas in the middle part of the intrusive mass.

The occurrence of the porphyritic microdiorite (facies 2) is essentially similar to that of the microdiorite facies: It is present at the interior of the granodiorite-I facies as enclaves of homogeneous size. However, they appear as large blocks of several hundred meters in some places. The degree of aggregation of the plagioclase phenocrysts is irregular even within the extent of

**Fig. 13**

Types of plagioclase twinning in the different rock facies.

- 1: Albite twin. 2: Carlsbad twin.
- 3: Albite-Carlsbad twin.
- 4: Pericline twin.
- 5: untwin. 6: Other twins.

several centimeters. Often, areas characterized by the richness of phenocrysts become particularly coarse-grained. Some leucocratic coarse-grained facies are also associated with this porphyritic microdiorite facies. The above-mentioned leucocratic and melanocratic facies grade into each other without any sharp boundary.

The leucocratic fraction of the quartz diorite (facies 3), is formed around irregular seams of the granodiorite-I facies impregnated against the porphyritic microdiorite. So, this leucocratic fraction is considered to be the product of hybridization, a process in which the porphyritic microdiorite might have played the role of host rock.

The granodiorite-I (facies 4) has a coarser-grained texture as compared with those of facies (1), (2) and (3), so, every constituent mineral is discernible with naked eyes. The aspect of the granodiorite-I facies is homogeneous throughout the mass. Flow structure showing a N-S trend is observable (Fig. 2)

The granodiorite-II (facies 5) is also a coarse-grained rock and is mainly developed in the southern half of the intrusive mass although some isolated, smaller bodies, are found in the vicinity of Setamai in the northern part of the mass. Facies (5) is distinctly leucocratic as compared with all the preceding ones and develops over a wide extent with a homogeneous appearance. It has also a distinct flow structure showing a discordant relation to that of granodiorite-I and to all the other rock facies already described.

Aplitic or pegmatitic veins and dykes are more frequently associated with

granodiorite-II than with the other facies.

In the Kesengawa granodiorite mass, the melanocratic fine-grained porphyritic rock facies (microdiorite, porphyritic microdiorite and quartz diorite) occupy about one-third of the total volume and are located in the central and northern areas. On the other hand, the leucocratic coarse-grained equigranular rock facies (granodiorite-I and -II) attain about two-thirds in volume and mainly distributed in the southern half of the mass.

Optical properties of plagioclases, especially referred to their composition and ordering state

A large number of measurements of the optical properties of plagioclases constituting each rock facies has been carried out.

As already stated by many previous workers, a wide extent of variation is found in the optical properties of rock forming plagioclases laid side by side

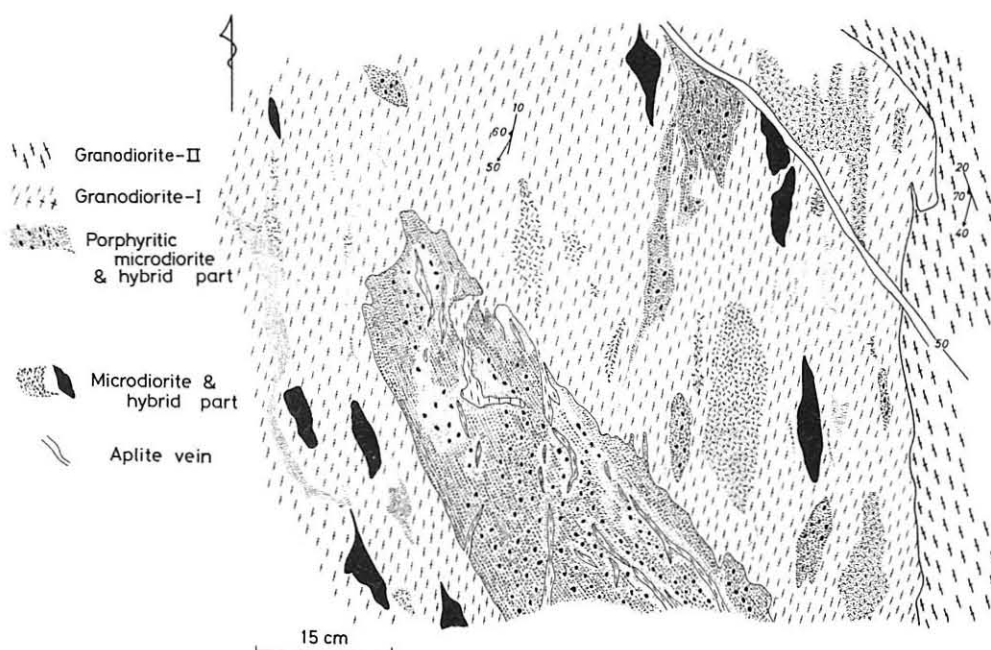


Fig. 14 Xenolithic occurrence of basic facies (microdiorite, porphyritic microdiorite and quartz diorite) in the granodiorite-I. The microdiorite and a part of the porphyritic microdiorite have suffered hybridization by the granodiorite-I. In turn, the granodiorite-I is crossed by the granodiorite-II. Middle course of the Kesengawa River, vicinity of Nangyo, Rikuzen Takada city.

even within the limit of a thin section, irrespective of a metamorphic, plutonic or volcanic origin. Although this variation extends to cover a wide range, statistical treatment of the data reveals that there exist some concentration centers of anorthite content (Hunahashi et al., 1968; Hunahashi, 1971, 1973a,b,c; Kim, 1961, 1962, 1964a,b,c; Kim and Sako, 1967a; Kim et al., 1967b; Kim and Hunahashi, 1972; Tsuchiya, 1967, 1972, 1975), degree of ordering state (Bambauer et al., 1967; DeVore, 1956; Marfunin, 1962; Megaw, 1960; Smith, 1960, 1974) and twinning style among the neighbouring plagioclases. In the Kesengawa granodiorite the same situation is found. There is no rock facies which contains exclusively identical plagioclase crystals as to their chemical composition, ordering degree, etc.

Several important contributions concerning the measurement of plagioclase properties with the "U-stage" are known (Crump and Ketner, 1953; Duparc and Reinhard, 1923; Emmons and Gates, 1943a,b; Köhler, 1941, 1942; Slemmons, 1962; Turner, 1947; Uruno, 1958, 1963). To the author's astonishment, the plots of the optical orientations of plagioclases obtained through his measurements do not fall close to the standard line of An content in the diagrams proposed by Van der Kaaden (1951), or by Burri et al. (1967)'s. The deviation from the standard line is larger in the more basic members. However, most of the points fall between the lines of order and disorder in the granodiorite facies. Deviation itself is considered to be the indicator of an unstable state, at least, a peculiar state of the plagioclase under examination. The individuals measured include plagioclases of such different textural situations as phenocrysts, microphenocrysts, groundmass, and large and small crystals in close contact.

The results of the measurements in each rock facies are interpreted in the following text and are illustrated by figures 15 to 28.

microdiorite: Most of the orientations corresponding to the cores of the plagioclase phenocrysts widely distribute in an area located above the line of An 65 content and extending towards the more calcic end. The points corresponding to the mantle distribute in the more sodic side, below the line of An 45 content. As to the groundmass plagioclases, their distribution is surprisingly dispersed from the extremely calcic side down to An 30 (Fig. 15).

The groundmass texture seems to be uniform, and its constituent plagioclase is not too differentiated. However, the optical measurements revealed the existence of two groups of groundmass plagioclase having different habit and optic orientation. One is calcic in composition and is made of nearly isometric crystals 0.01 mm in size surrounded by a thin sodic rim. The other group is of sodic composition, the crystal habit is lath-shaped and a tight

aggregate of three to five crystals of the same habit is the rule. Between each aggregated crystal a vague feature, similar to twinning lamellae, seems to be present. On Fig. 15, the main concentration areas for both groups may be suggested to be located above the An 65 content line for the calcic group and between the An 30 and An 50 content lines for the sodic group. There are also intermediate plots corresponding to individuals of intermediate habit.

Detailed measurements on several parts of a single zoned phenocrysts of plagioclase of the microdiorite has been carried out. The result is presented in Fig. 16. In general, the phenocryst is composed by three prominent zones: the core (dotted), the intermediate zone (oblique lined) and the outer mantle (blank). Between the intermediate zone and the outer mantle, some corrosive forms are often observed.

Plots of core parts fall in the area around An 50 – 65; Intermediate parts shift to the more sodic side, around An 45 while the outer mantle plots fall in a distinct sodic region, below An 30.

Many more sodic small domains are formed within the basic core area, the author gives them the tentative name of “unmixing products”. The state of such unmixing blocks is nearly the same as that of the outer mantle. Seldom, fringing around such unmixing blocks (3 in Fig. 16) extremely basic rims (4 in Fig. 16) are formed as if they were the result of a differentiation process.

porphyritic microdiorite: Although the texture in this rock facies is almost similar to those of the microdiorite or the porphyrite, the optic properties of the plagioclases present a quite different scheme. As shown in Figs. 17 and 18, the plots are concentrated in the intermediate area without any difference between phenocrysts and groundmass. No calcic core plots above An 60. Actually, a zonal structure is well developed in the phenocryst plagioclases, however, the difference in composition between core and mantle is very indistinct compared with those cited earlier. As shown by the core/mantle tie-lines there are many cases of reverse zoning and of zoning grading from an ordered state to a disordered one or *vice versa*. Further, the plots of groundmass plagioclase are also concentrated in the same *domain* defined by the phenocryst plagioclases (Fig. 17).

Contrary to the case of the microdiorite and porphyrite (see Figs. 26, 27), the distribution of plots in the porphyritic microdiorite shows quite different pattern. As a whole, it coincides exclusively with the groundmass domain of other rock facies. Other types of plagioclases are not detected in this rock facies.

The result of measurements on a single phenocryst plagioclase is shown in Fig. 19. The phenocryst is also found to consist of three main zones: core,

intermediate zone and outer mantle. All plots of the core zone fall between An 40-An 45. Those of the intermediate zone and the outer mantle are close to An 20 and An 35 respectively. Every plagioclase phenocryst is not strictly represented by a single crystal, but is an aggregation of a few crystals entirely surrounded by a common outer mantle. This aggregation may be controlled by the forces of twin formation and may arise at the stage of formation of the core or of the intermediate zone.

quartz diorite: In Fig. 20, two prominent concentrations formed by the plots of core and mantle are observed. Values for the core fall in the area between An 50 and An 65 while those of the mantle are concentrated in the area between An 30 and An 45 to form a well defined *domain*. About one-third of the plots are shifted to the side of the X-Y plane from the standard line.

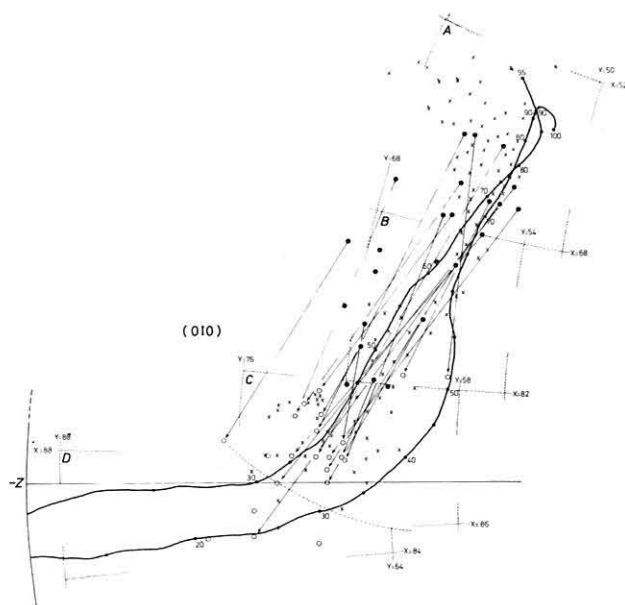
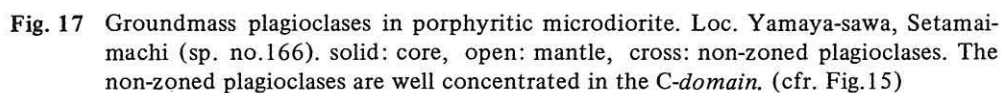
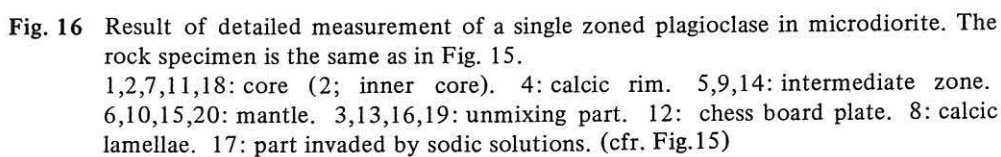


Fig. 15 Optical orientation and composition of plagioclases in microdiorite. solid: core. open: mantle. cross: groundmass plagioclases Loc. Yamaya-sawa, Setamai-machi (sp. no.179). Although the cores of the phenocryst plagioclases are plotted in the A- and the B-domains, the groundmass plagioclases are widely distributed from the A- to the C-domains.

The arrow (tie-line) shows the shifting of optical nature from core to mantle in each individual. Burri et al.'s optical determination curves (1967) were used. The accuracy of individual determinations by U-stage is believed to be of ± 1 degree. small x: major E-W circle of Wulff's net. small y: major N-S circle of Wulff's net. Capital letters A, B, C and D represent the *domains*. (Figures 15 to 31 are drawn following the same procedure).



The zonation of a phenocryst plagioclase has been measured layer by layer (Fig. 21). Extremely calcic parts are detected within the core (1, 8). The plots of the intermediate zone are shifted to the area around An 40 to An 50. The points corresponding to the outer mantle fall in the sodic side, below An 30. Between the outer mantle and the intermediate zone, some corrosion features are also apparent.

granodiorite-I: As a whole, the points are shifted towards the sodic side as compared with the foregoing facies. The deviation of the plotted points from the standard lines is negligible. A greater part of the plots is remarkably restricted to the X-Y side (Fig. 22). Two *domains* corresponding to those of the core and the mantle are also revealed in this facies. The *domain* referred to the core lies in the area between An 30 and An 50, plots for the mantle fall in the more sodic side, below An 20 and around An 30 (Fig. 22). More calcic cores, above An 50, are also present but they are scarce.

The zonation of single plagioclase crystal has been measured. The core is divided into several parts which are, however, restricted within the area An 30 – An 50. The intermediate zone is referred to the area around An 30, and the mantle to the area between An 20 and An 30 (Fig. 23).

granodiorite-II General features of this facies are similar to those of

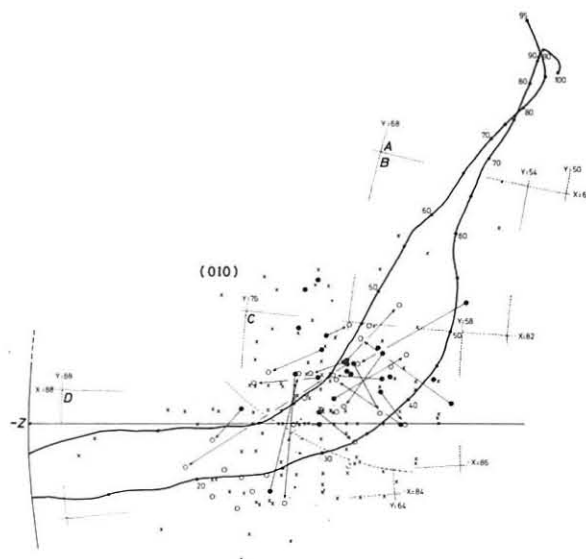


Fig. 18 Phenocryst plagioclases in porphyritic microdiorite. The rock specimen is the same as in Fig.17. solid: core, open: mantle, cross: non-zoned or indistinctly zoned plagioclases. A few crystals present reverse zonation. (cfr. Fig.15)

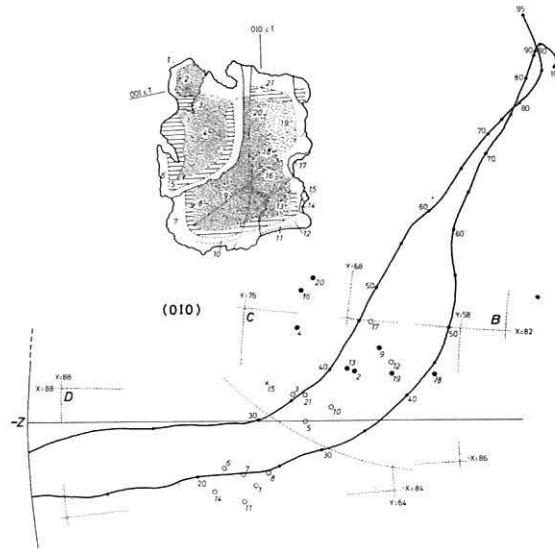


Fig. 19 Detail of a zoned plagioclase in porphyritic microdiorite. The rock specimen is the same as in Figs.17, 18.

2,4,9,13,16,18,19,20: core (18,19,20; outer core). 3,5,8,21: intermediate zone.
1,6,7,10,11,12,14,15,17: mantle (10,11,12; inner mantle). (cfr. Fig.15)

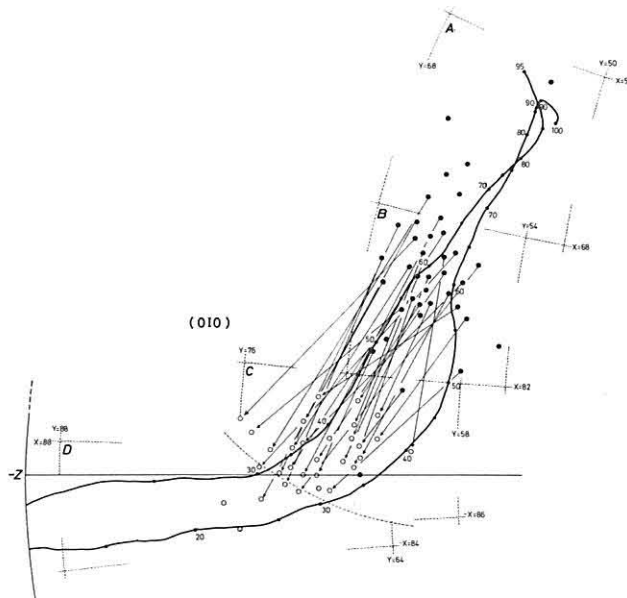


Fig. 20 Plagioclases in quartz diorite. Loc. Taya, Setamai-machi (sp. no.213). solid: core, open: mantle. Core points are mainly concentrated in the B-domain, and mantle parts in the C-domain. (cfr. Fig.15)

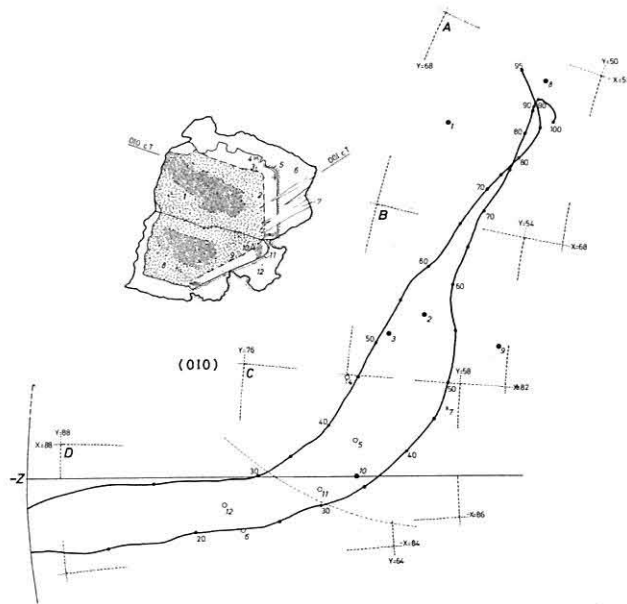


Fig. 21 Detail of a zoned plagioclase in quartz diorite. The rock specimen is the same as in Fig.20.

1,8: inner core. 2,9: outer core. 3,10: inner oscillatory band. 4: outer oscillatory band. 5,11: inner side of mantle. 6,12: mantle. 7: patchy.

At the external side (right half) of the sketch a filmy albitic rim is observed. The inner core is altered to chlorite and sericite. (cfr. Fig.15)

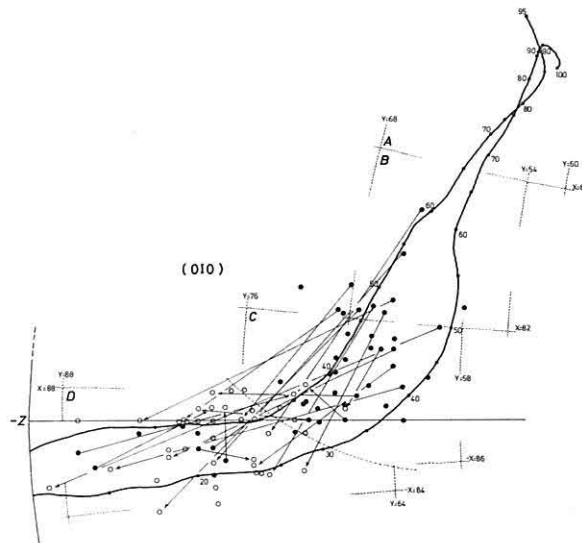


Fig. 22 Plagioclases in granodiorite-I. Loc. Nangyo, Rikuzen Takada city (sp. no.36). solid: core. open: mantle.

A few crystals present reverse zoning. (cfr. Fig.15)

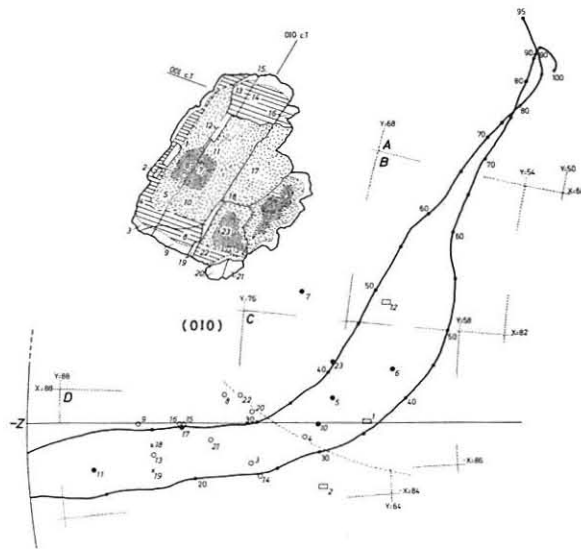


Fig. 23 Detail of a zoned plagioclase in granodiorite-I. The rock specimen is the same as in Fig.22.

5,6,7,10,11,17,23: core (6,7,23; inner core, 5,10,11,17; outer core).
 4,8,13,14,16,22: intermediate zone. 3,9,15: mantle. 1,2: chess board plates.
 12: calcic lamellae. 18,19: sodic lamellae. 20,21: adhered plagioclase crystal. (cfr. Fig.15)

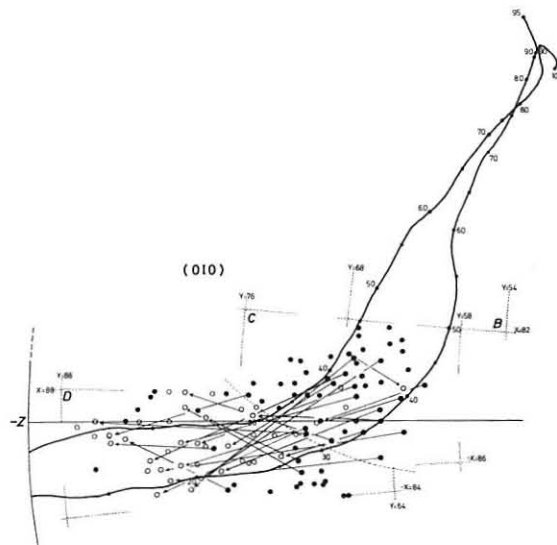


Fig. 24 Plagioclases in granodiorite-II. Loc. Nakanosawa, Rikuzen Takada city (sp. no.154).
 solid: core. open: mantle. (cfr. Fig.15)

granodiorite-I, e.g. the *domain* of the core is restricted to the area between An 30 and An 45, and that of the mantle to the area between An 20 and An 30 (Fig. 24). However, another sort of plot is known from this facies, which is divided from the non-zoned plagioclase enclosed by potash feldspar. Embedded non-zoned plagioclase has a turbid appearance with a reaction rim against potash feldspar. All the points corresponding to plagioclases of such peculiar occurrence fall into deviated positions beyond the standard lines both for ordered and disordered plagioclases (Fig. 24).

The zoning state is normal becoming more sodic from core to mantle. The intermediate zone corresponds to the area between An 30 and An 45. The location of the chess board plates is related to the boundary between the intermediate zone and the mantle (Fig. 25).

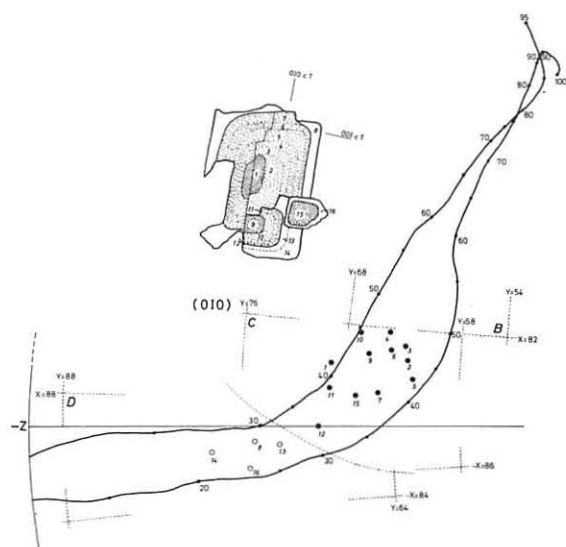


Fig. 25 Detail of a zoned plagioclase in granodiorite-II. Loc. Yamaya-sawa, Rikuzen Takada city (sp. no.62). 1-7, 9-12,15: core (1,9,15; inner core 7,12; outer core). 8,13,14,16: mantle. (cfr. Fig.15)

porphyrite: Three representative rock types, classified according to their petrographic texture and the optic properties of the plagioclase, have been examined.

- porphyrite with no distinctive porphyritic texture,
- porphyrite with a large quantity of phenocrysts and microphenocrysts,
- porphyrite with a nearly equigranular, coarse-grained, texture.

In the corresponding diagrams (Fig. 26, 27, 28), it is seen that the points are distributed into several vague *domains*. Core and mantle values in zoned

microphenocrysts are separated by a boundary line close to An 65. The sodic side of the mantle *domain* is also separated from that of the groundmass

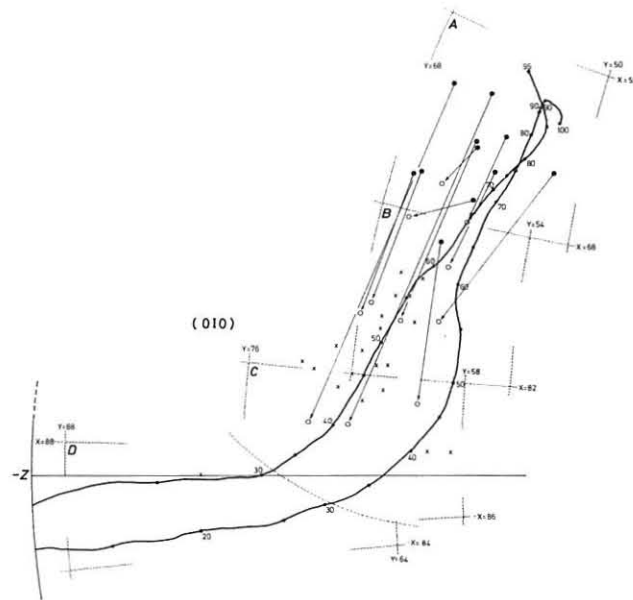


Fig. 26 Plagioclases in plagioclase porphyrite. Loc. Mt. Kinoko, Ofunato city (sp. no.636). solid: core. open: mantle. cross: non-zoned plagioclases. (cfr. Fig.15)

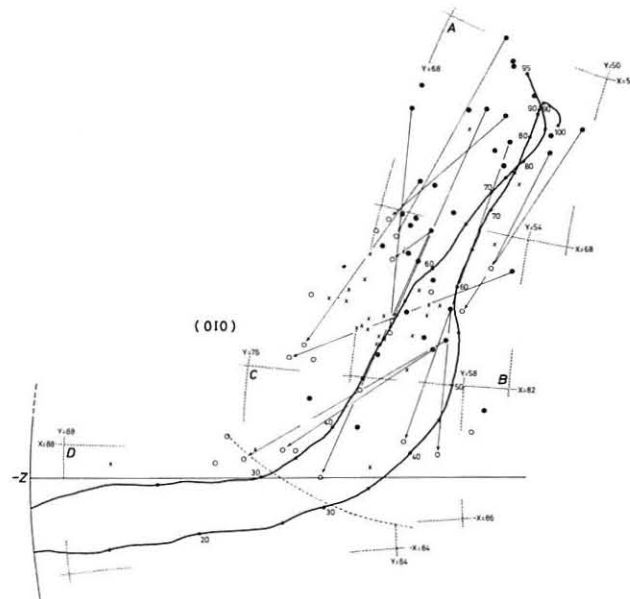


Fig. 27 Plagioclases in plagioclase porphyrite. Loc. Mt. Raijin, Rikuzen Takada city (sp. no.613). solid: core. open: mantle. cross: non-zoned plagioclases. The core shifts to more sodic composition in comparison with Fig.26. (cfr. Fig.15)

plagioclase, for which the boundary line may be drawn around An 45 – 50. The implications of the boundary line between the *domains* of microphenocrysts and groundmass will be now discussed. Within the *domain* of the mantle, many plots of non-zoned microphenocrysts appear. At the same time some zoned microphenocrysts are plotted in the groundmass *domain* while a small number of points from more calcic groundmass plagioclases are seen in the mantle *domain*. These phenomena can be considered as an indication of transitional conditions between microphenocrysts and groundmass plagioclases which might have been reflected in this mantle *domain* (Fig. 26).

A representative case of zonal structure in a phenocryst plagioclase is shown in Fig. 28. Several parts of the large core of the plagioclase show an extremely calcic character. The following intermediate zone falls in the area between An 60 and An 70. The filmy mantle is of a distinct sodic nature and is plotted in the area An 30 – An 45. The composition of the chess board textured area making up the core is quite similar to that of the intermediate zone. The difference in composition between core and mantle is quite conspicuous compared with those of the other rock facies.

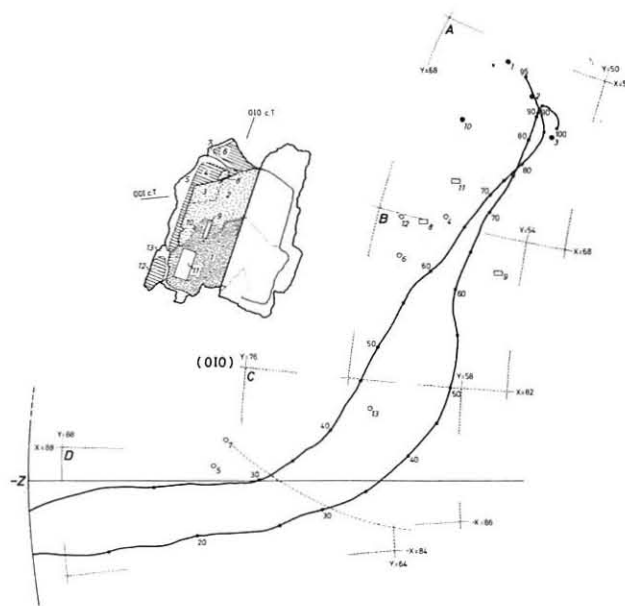


Fig. 28 Detail of a zoned plagioclase in plagioclase porphyrite. The rock specimen is the same as in Fig.27.

1,10: inner core. 2,3: outer core. 4,6,12: intermediate zone. 5,7,13: mantle. 8,9,11: chess board plates and unmixing parts.

The mantle part (5,7) is plotted in the D-domain, while chess board plates and unmixing parts are plotted in the vicinity of the intermediate zone. (cfr. Fig.15)

Summing up, the author has been able to distinguish several compositional *domains* based on the optical orientation of the constituent plagioclases as given in each diagram for the respective rock facies. The *domains* are generally expanded and widely deviate from the standard line, especially in the more basic facies.

Four *domains* can be established for the whole rock series of the Kesengawa granodiorite and the surrounding porphyrite. The author tentatively calls these *domains* A, B, C and D. The boundaries of each *domain* are tabulated below.

X	Y	An value where <i>domain</i> boundary crosses the standard line
A) 52 – 68	50 – 68	An 100 – An 65
B) 68 – 82	54 – 68	An 65 – An 50
C) 82 – 86 (-X)	58 – 76	An 50 – An 30
D) 88 – 84 (-X)	64 – 88	An 30 – An 20

In this respect, the state of the constituent plagioclases of the quartz diorite and granodiorite facies of the Goyozan granodiorite mass, another Cretaceous granodiorite in the Kitakami mountain region (Fig. 1), have been examined in a similar way. As shown in Figs. 29 – 31, their general tendency in optical properties is the same as those presented for the kesengawa granodiorite mass.

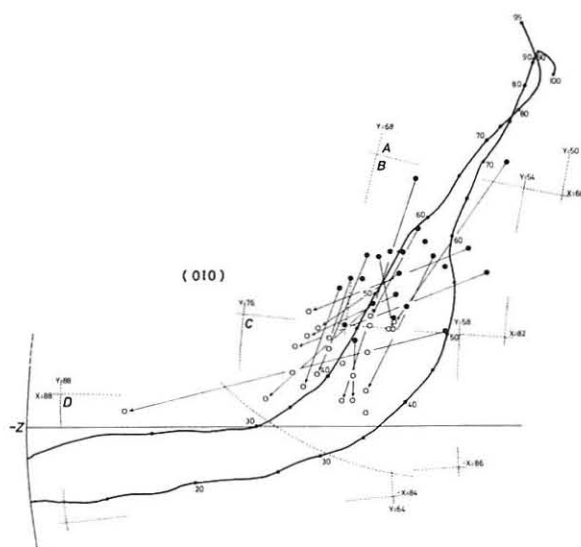


Fig. 29 Quartz diorite in the Goyozan granodiorite mass. Loc. Kokabe, Sanriku-machi, Iwate Prefecture (sp. no.67). solid: core. open: mantle. (cfr. Fig.15)

In the Goyozan granodiorite mass, the A, B, C and D *domains* are also established in a quite similar manner as in the kesengawa granodiorite. The plotted points of the quartz diorite facies in the Goyozan mass are located towards the more calcic side as a whole. On the contrary, the plots of plagioclases from the granodiorite facies are shifted towards the more sodic side, and the plots of the mantle belong to the D-domain.

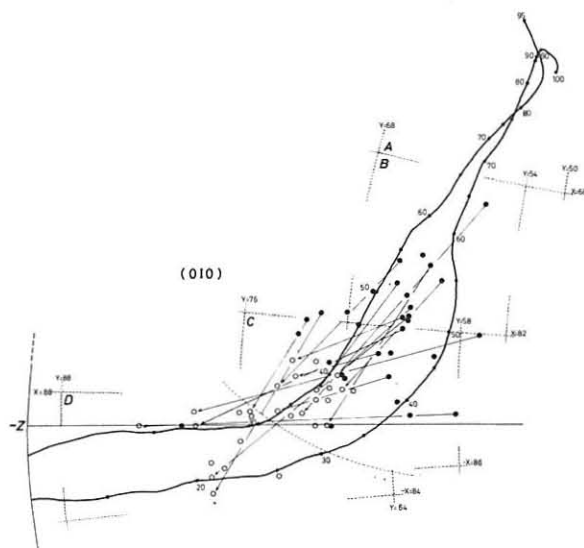


Fig. 30 Granodiorite in the Goyozan granodiorite mass. Loc. Rasho Toge, Sanriku-machi, Iwate Prefecture (sp. no.192). solid: core. open: mantle. (cfr. Fig.15)

Considerations and conclusions

As it has already been mentioned, the most prominent petrographical feature of the Kesengawa granodiorite is the remarkable contrast existing between the melanocratic fine-grained porphyritic rock facies and the leucocratic coarse-grained equigranular rock facies (Fig. 3). This contrast is always clear in the field and expresses in the way of sharp boundaries. This feature may be an important indicator for the interpretation of the main petrogenetic events related to the formation of this intrusive mass. However, the results obtained through the detailed measurement of rock forming plagioclases in each rock facies indicate that there may exist several types of interreaction between both contrasting sets of rock facies.

The microdiorite facies is the most basic rock type in the Kesengawa granodiorite mass and is characterized by the presence of melanocratic constituents, typical porphyritic texture and a fine-grained groundmass. Its

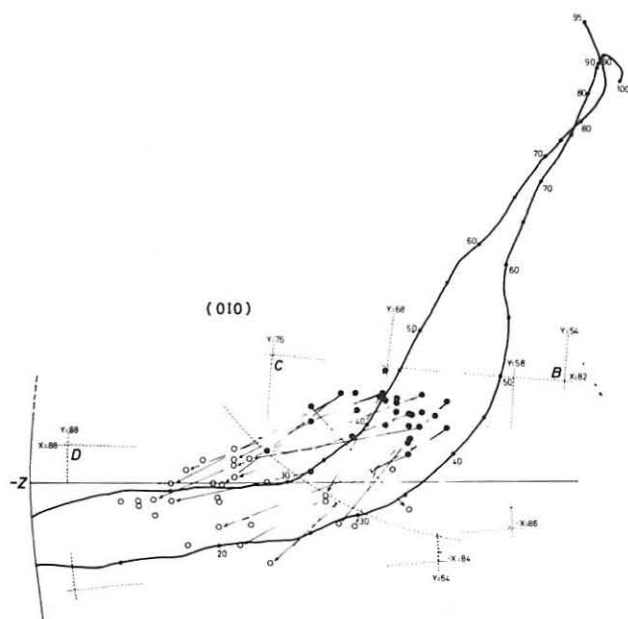


Fig. 31 Granodiorite in the Goyozan granodiorite mass. Loc. Upstream of Yoshihama River, Sanriku-machi, Iwate Prefecture (sp. no.358). solid: core. open: mantle. (cfr. Fig.15)

zoned plagioclase phenocrysts show the widest compositional range between core and mantle. As shown in Fig. 15, the points corresponding to the mantle are concentrated in the *C-domain*. Although there are some points located in the intermediate position (*B-domain*), the concentration in the *A-* and *C-domains* is apparent. Points corresponding to the groundmass plagioclase are roughly grouped into two *domains*, namely, the *A-* and *C-domains*. The difference in crystal habit of the groundmass plagioclase belonging to the *A-* and *C-domains* is distinct; the former is isometric granular, while the latter is long prismatic and appears always as an aggregation of individuals. Such types of plagioclases might have been produced through duplicated rock forming circumstances. The first step would be the formation of a basic porphyritic fine-grained rock facies which is now evidenced by the core of the plagioclase phenocrysts. The isometric, granular groundmass plagioclase was contemporaneously formed. The microdiorite facies occur as small enclaves inside the granodiorite-I facies. In this connection, the basic enclaves might have suffered a process of assimilation and saturation by the granodiorite-I. As the plagioclase was probably formed under such circumstances, the plots are concentrated into the *C-domain*. In this way, the compositional plots for the phenocrysts mantle as well as those for the groundmass plagioclase can be considered as the

interaction product between the basic and the acidic rock facies. Some additional growth around phenocrysts and lath-shaped groundmass plagioclases should have occurred due to the action of the granodiorite magma on the microdiorite inclusions. The aggregation of groundmass plagioclases above-noted may have been achieved through such a process.

In the microdiorite facies, there are no plots belonging to the *D-domain*. Points falling in this *domain* are a characteristic feature of the granodiorite group. It may be suspected therefore the primitive material, the porphyritic fine-grained rock facies, was eventually imprinted with some granodioritic features. Detailed measurements on a phenocryst of plagioclase have been carried out and the results are presented in Fig. 16. Several points belonging to the *D-domain* are observed and this fact could be interpreted as the result of the granodioritic activity. Apparently, the core does not seem to be intensely affected by the granodiorite, but the inner structure of the core becomes very irregular (Fig. 16). Interaction effects may have even affected the inner part of the phenocrysts re-modelling the structure of the core.

The quartz diorite which is formed by the assimilation of the granodiorite-I is coarser-grained as compared with microdiorite and porphyritic microdiorite. With the fresh introduction of quartz as a part of the constituent association, the groundmass becomes coarse-grained and equigranular in texture. The plagioclase plots distribute in two main groups as shown in Fig. 20. The ones derived from the zoned core fall inside the *B-domain* while those related to the mantle, inside the *C-domain*. A few plots inside the *A-domain* correspond to non-zoned crystals. As seen in Fig. 21, the zonation in a plagioclase phenocryst shows several vague patches of extremely calcic composition in the central part of the core whose composition fall inside the *A-domain*. Plots corresponding to points of the intermediate zone fall either in the *B-* or *C-domains* (Fig. 21). The plots representing the frilled mantle are enclosed in the *D-domain*. The whole range extending from the *A-* to the *D-domain* is thus covered in this case. From these facts, the following interpretation can be made. The extremely calcic cores are the remnants representing the first phase in the rock formation process, the products resulting from interaction would cover the fields of the *B-* and *C-domains* including the extremely sodic members falling in the *D-domain*. In this respect, the concentration of points in the *B-domain*, may indicate the changes produced by the action of the granodiorite.

The rock texture of the porphyritic microdiorite is quite different from those of the other rock facies, e.g. its plagioclase phenocrysts seem to be porphyroblastic, and the groundmass plagioclase as well as the phenocryst plagioclase are formed as an aggregation of a few individuals. Between aggregated individuals a twinning relation is well developed. As to the origin of

such aggregation and rock texture, one can take the view that these textural features may be acquired through a metasomatic replacement of a basic fine-grained rock as far as it is quite free from any remnant of a pre-existing rock facies (Hunahashi and Hoe, 1973a). The rock forming process is here interpreted in such a peculiar form. The plots corresponding to the interaction products between the porphyritic microdiorite and the granodiorite-I are widely spread covering from the C- to the D-*domains* with some of them even falling in part of the B-*domain*. However, their main concentration is found at the center of the C-*domain*. The above referred *domains* in this facies are the same for phenocrysts and groundmass plagioclases. In relation to the type of zonal structure, reverse and normal orders from core to mantle co-exist.

The result of detailed examination of zoning in a phenocryst plagioclase of porphyritic microdiorite is shown in Fig. 18. Although points are scattered forming several concentrated areas, a tendency exists for the plots from the core to concentrate into the C-*domain* and around the boundary between the C- and D-*domains*. Moreover, three plots corresponding to the rim are located inside the D-*domain*. As a whole, plagioclases showing a normal zoning are predominant.

The compositional character of the plagioclases of the granodiorite-I is somewhat irregular in spite of its textural homogeneity. The character of the plagioclases is similar in some aspects to those of the porphyritic microdiorite. The grain size of the constituent plagioclases attain a much larger size than those of the porphyritic microdiorite and aggregations are prominently developed in this rock facies. These aggregations consist of a few small individuals having a common mantle layer and they are also found in the porphyritic microdiorite facies. Points representative of their optical character are chiefly concentrated into the C- and the D-*domains*, those of the core in the C-*domain* and those of the mantle in the D-*domain*. A few points corresponding to the core are more calcic than An 50 and fall into the B-*domain*. Most of the zoning is normal, but some is reverse or those succeeded by different degree of ordering state. The results obtained in a detailed examination of zonation is shown in Fig. 23. The examination has been carried out on an aggregated crystal as above-stated. Each individual contains more calcic patches in its core. The aggregation may have been produced during the formation process of the outer part of the core. There, the compositional variation shifts in a normal order.

The character of the plagioclase in the granodiorite-II facies is presented in Fig. 24. Plots of core and mantle distribute in *domains* C- and D- respectively. However, another feature is also shown, namely the existence of deviated plots obtained from non-zoned plagioclase individuals enclosed inside potash

feldspar. Most of the plots related to these plagioclases are deviated from the normal ordered line towards the side of the X-Y plane. There are also other plots deviated towards the Y axis from the disorder line.

It is considered that the primitive plagioclase is turned into an unstable form if it is accompanied by potash feldspar. On the other hand, basic individuals are rarely found in other plagioclases. Its zoning character is presented in detail in Fig. 25. Points corresponding to the core are plotted into the *B-domain*. In this respect, although the constituent minerals of the granodiorite are homogeneous, large-sized crystals showing simple zoning, fine-grained clusters of plagioclase, hornblende and biotite can be occasionally found among the single crystals of large-sized plagioclases. The morphological features of these fine-grained clusters suggest the possibility that they were derived from the microdiorite.

It is here suggested that the formation of the granodiorite characterized by a coarse-grained equigranular texture may be achieved through the metasomatic replacement of fine-grained, basic rock facies. In detail, patch-formed plagioclases in basic rocks are enclosed in the above described coarse-grained homogeneous rocks.

At any rate, as above-stated in detail, there exists a fundamental contrast between the melanocratic basic rock facies and the acidic leucocratic rock facies in the Kesengawa granodiorite mass. This is clearly shown in the rock appearance and in the spatial arrangement of each rock facies.

Through the vast quantity of measurements of the optical character of the constituent plagioclases these contrasting features are revealed in detail. As already mentioned the basic rock facies may be considered as showing a family relationship among microdiorite, porphyritic microdiorite and quartz diorite. Among these the most primitive phase would be represented by the microdiorite. Although about half of its plagioclases were changed by reaction with the invading granodiorite, relic plagioclases belonging to a primary generation and free from acidification are found. Regarding the acidic rock facies of the Kesengawa granodiorite, viz. the granodiorite facies-I and -II, plots of their plagioclases are widely distributed within the *D-domain*. Considering the character of this granodiorite facies, the formation of a mantle whose compositional values fall inside the *D-domain*, seems to be the peculiar feature of this facies.

The gradational character of the basic rock facies, from the microdiorite to the porphyritic microdiorite and quartz diorite, is revealed by the presence of features resulting from the interaction between the basic and acidic rock facies.

Basic rocks always show a porphyritic fine-grained texture. Petrographically, this texture is closely referable to the ones present in the rock

facies of the porphyrite dyke swarm, which was generated as the precursor of the Kesengawa granodiorite mass. As shown in Figs. 26, 27, some common features, presence of plagioclase belonging to the three *domains* from A- to C-, may be traced in both acidic and basic rock facies. In this respect the author considers that the porphyrite found in the surrounding region may not be genetically different from the Kesengawa granodiorite mass, which further extended to the granodiorite masses of the Tono, Goyozan and the Hirota.

In all rock facies examined, there exists a large quantity of plagioclases of which the optical orientation anomalously deviate to a considerable extent from the standard lines of order and disorder. Although this fact had been already found, such a prominent deviation has never been detected in our previous plagioclase examination (Hunahashi et al., 1968; Hunahashi and Hoe, 1973; Kim, 1961, 1962, 1964a,b,c; Kim and Sako, 1967a; Kim et al., 1967b; Kim and Hunahashi, 1972; Tsuchiya, 1967, 1972, 1975). In general, the deviation seems to be more prominent in the basic members declining towards the acidic side. The deviation is most distinct in the basic rock group, especially in basic facies remaining the basic core of porphyritic plagioclase. The deviation is also observed in zones partially altered under the influence of acidic intrusions. Plots corresponding to zoned plagioclases from the basic rock facies are far dispersed as compared with the acidic leucocratic facies. Such deviation, produced by the new circumstances derived from alteration, characterized the primary plagioclase as an unstable form having a relictic character. The modes of occurrence of these rocks in the field as well as their microscopic features are suggestive of such an origin.

The deviation shown by the non-zoned plagioclase crystals enclosed by potash feldspar is also the indicator of an unstable state caused by the crystallization of potash feldspar in a late stage.

As to the petrographic character of each rock facies, the nature of the basic rock group is characterized by the presence of plagioclases having their core compositions plotted into the A- and B-*domains* and their mantle compositions inside the C-*domain*. The granodiorite group as a whole is characterized by the presence of plagioclases having core compositions plotted into the C-*domain* and the mantle into the D-*domain*. Several features which may have been produced by the interaction between basic and acidic rocks can be traced by the formation of D-*domain* plots for the mantle and, in the acidic facies, of B-*domain* plots for the remnant cores.

As a result of detailed field and optical studies of the Kesengawa granodiorite and its surrounding units, the following sequence of events is thought to have taken place:

- 1) A vast amount of dykes (plagioclase porphyrite, microdiorite and

diabase), precursors of the Kesengawa granodiorite, intruded into Palaeozoic and late Mesozoic formations and into the Hikami granitic complex.

2) Following to these intrusive rocks, such melanocratic facies as microdiorite, porphyritic microdiorite and quartz diorite intruded along the fracture zone (namely the Kesengawa tectonic line*).

3) The melanocratic rocks, classified into three facies by the author, i.e. facies (1), (2) and (3), were then assimilated under acidic conditions, produced by the intrusion of the granodiorite-I facies.

4) Finally, the granodiorite-II facies intruded into the formerly activated rocks.

Although this study refers only to the Kesengawa granodiorite, other granitoid units in the Kitakami mountains, specially some masses in the central zone, might have a quite similar petrogenetic history. They have a mode of occurrence and optical properties of their plagioclases quite similar to those of the Kesengawa granodiorite mass. The author therefore concludes that the granitoids of this region might have been generated under similar circumstances and by the action of the same type of processes.

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* after Minato, personal communication

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