Studies on the Green Tuff Formation in the Futamata Region nearby Toyoha Mine, Southwest Hokkaido, Japan

— on Propylite and its Properties of Alteration, and its Geological Significance —

(Studies on the Alteration of the Green Tuff Formation, II)

By

Akihiko YOSHITANI *

(Received Jan. 27, 1970)

Abstract

The Green Tuff Formation, the Neogene Tertiary system, distributed in the Futamata region is altered through hydrothermal processes in a certain degree. By secondary minerals, the present formation is divided into three alteration zones as follows; pale green chlorite zone, yellowish green chlorite zone and saponite zone. The alteration-grade changes from higher to lower in the above mentioned order. The alteration may be surely caused by hydrothermal activities in a certain post-action stage, after the successive volcanic and sub-volcanic activities, probably in the upper middle or lower upper Miocene period.

As for propylites, of being developed in the Futamata region, they are fundamentally intrusive rocks and erupt through geotectonic zone. Their activities occur, when the sedimentary basin is in the motion from sinking to upheaval, furthermore, ta¹·e the lead of the following igneous activities occurring in geoanticlined part. Especially, propylites are generally closely associated with the Tertiary hollocrystalline rocks, such as diorite-porphyrites.

For the purpose of making clear the relationships between alteration-grade and compositional change of altered plagioclases, secondary albitized plagioclases were investigated. The optical type, either plutonic or volcanic type, of secondary albitized plagioclases is just the same as that of the initial plagioclases. Compositional changes of plagioclases through albitization may suggest those of the definite or rather indefinite ranges judging from their frequency curves. As for the relationships between twin lamellation on the albite-law and zonal structures, both become gradually vague in appearance, as albitization goes on. However, zonal structures are entirely disappeared on account of intense albitization, then the albite twinnings are comparatively sharply recognized in appearance. The compositions in this stage are nearly equivalent to An20-23 for plutonic type and also to An 32-33 or An22-23 for volcanic type plagioclases. Albitization going on moreover, twin lamella on the albite-law becomes again obvious in appearance.

CONTENTS

* Laboratory of Earth Sciences, Faculty of Education, Tottori University

I. Introduction

In the inner belt of the Japanese Island arc, the so-called "Green Tuff Forma-
tion", which consists mainly of voluminous Miocene volcanics, is widely distributed.
One of the remarkable phenomena of the present formation is hydrothermal alteration
of rocks resulting in greenish colour. On account of the intense alteration, the geolo-
gical studies on the "Green Tuff Formation" have not been sufficiently carried out.
However, since the geotectonic significance of the Green Tuff region had been pointed
out in 1956 (MINATO, M. *et al.* 1956), the "Green Tuff" movement representing the
violent igneous activities has become the object of geologists' attention as the Late
Alpine crustal movement in Japan. From that time downward, many stratigraphical
and petrological studies of the Green Tuff Formation have been accomplished. The
results of these studies were published collectively in 1965 and 1966. The whole as-
pects of the Green Tuff movement has been gradually made clear, but there is some-
thing yet to study.

According to the past studies on the alteration of the Green Tuff Formation, the
mineral assemblage shows the low grade metamorphosed facies as the same grade as
green schist facies or less. However, in the present alteration, four types can be distin-
guished as follows.

1. Alteration through diagenetic processes.
2. Alteration by hydrothermal solutions in the so-called "post action stage".
3. Alteration by impregnation of ore fluids in ore depositional region.
4. Alteration by contact effects, being found in the area around plutonic or hypabys-
sal intrusive bodies.

Hitherto, as for the hydrothermal alteration of igneous rocks, it has been vaguely
supported that altered volcanics were caused by certain kinds of autometasomatic

processes. Nevertheless, there are no obvious facts substantiating autometasomatic processes.

Since 1959, the writer has investigated the alteration of the Green Tuff Formation; from 1959 to 1961, he studied the Neogene Tertiary strata, distributed in the eastern part of Tanzawa mountainland, Central Japan, with a view to studying the low-grade metamorphic facies of the Green Tuff Formation. Thereafter, however, his attention was directed to so-called "propylite-problem", which was unsolved at that time. In Japan, propylite is one of the important member of the Green Tuff Formation. Furthermore, it is also closely accompanied with non-iron metalliferous deposits. Some investigations concerning about propylite are found in foreign literatures. Especially, D. S. KORZINSKIY (1957) systematically studied on propylite developed in ore-depositional region in U.S.S.R., and established propylite-facies by making use of thermodynamics. In Japan, some reports on propylite of being closely accompanied with ore deposits were offered by mining geologists. Nevertheless, the whole aspects of propylite has been scarcely known.

Since 1963, the writer has examined propylite-problem with the purpose of solving definitely geological significance of propylite being importantly situated in the Late Alpine crustal movement in Japan. In order to effecting his object, the writer has surveyed propylite developed in the Futamata region nearby Toyoha Mine,
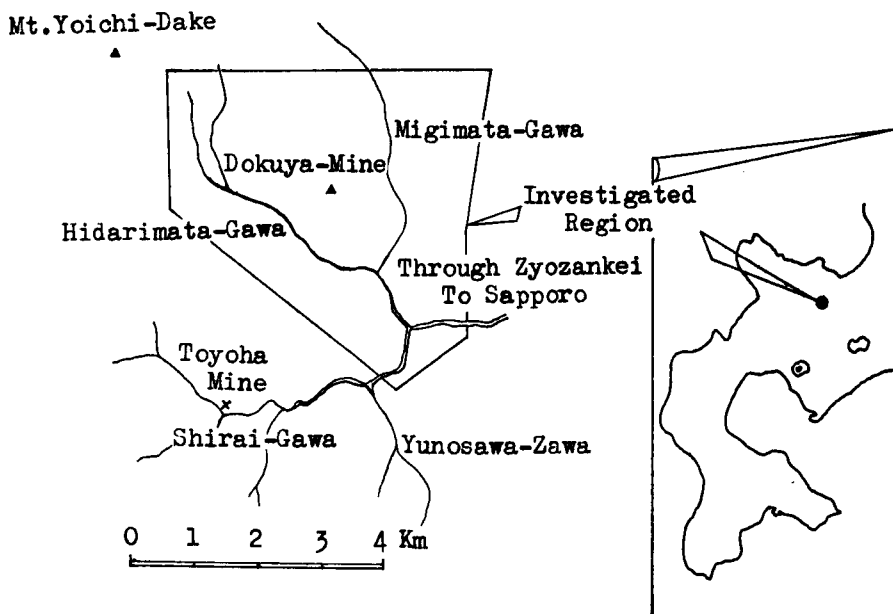

Fig. 1 Index Map

Southwest Hokkaido. In the Green Tuff Formation distributed in Southwest Hok-
kaido, many metalliferous deposits have been well known for long. Toyoha mine is
one of them, and is developed in the Neogene strata consisting of propylites, pyro-
clastics and sediments. In this mine, galena and zincblende are chiefly produced.
The Futamata region, of being examined by the writer, is 3 km northeast from Toyoha
mine.

Ever since 1953, few noticeable studies concerning about the present region have
been given out. However, in 1953, Doi, S. and Sugimoto, R. published their geolo-
gical maps (scale, 1/50,000) and explanatory texts. Their studies were the first areal
geological investigations in more details. After then, some mining geological reports
on Toyoha mine and its environs were offered; (Akome, K. *et al.* 1963). However, the
"propylite-problem" has been remained unsolved. Through the writer's investiga-
tions, some informations concerning with proptilite-problem were obtained, and
they are described and discussed in this paper.

II. Geological Setting

The Neogene strata distributed in the Futamata region were investigated by
Doi, S. and Sugimoto, R., and the stratigraphical successions were given as shown

Table 1

			Doi,S. (1953)			Sugimoto,R. (1953)
Miocene	Zyozazankei Group	Yunosawa Formation	Alternation of Sandstone and Shale Member	Zenibako Group	Otarunaigawa Formation	Migimatagawa Acidic Green Tuff Member
			Green Tuff Member			
			Conglomerate Member			Yoichigawa Arkose Sandstone and Shale Member
			∼∼∼∼? ∼∼∼∼			
		Toyoha Formation	Green Tuff Member		Teine Formation	Hidarimatagawa Propylite Member
			Conglomerate Member			

Green Tuff Formation in the Futamata Region

Table 2

Southwest Hokkaido				Zyozankei District Doi,S. (1953)			Zenibako District Sugimoto,R.(1953)		Futamata Region Yoshitani,A. (1967)		
Miocene	Upper	Middle Miocene	Yakumo Stage	Takenosawa Group	Itawari-zawa Formation		Zenibako Group	Otarunaigawa Formation	Zyozankei Group	Toyoha Formation	Yunosawa Tuff Member	Migimata Acidic Tuff Member
					Ichino-sawa Formation							
					~?~							
					Hyakumatsu-zawa Formation						Futamata Propylite Member	
	Lower	Middle Miocene	Kunnui Stage	Zyozankei Group	Yunosawa Formation							
					~?~			Teine Formation			Hidarimata Tuff Member	
	Upper	Lower Miocene			Shirai-gawa Formation	Toyoha Formation						
					Shiramizu-gawa Formation						?	

Table 3

Geological Series					
Miocene	Zyozankei Group	Toyoha Formation	Yunosawa Tuff Member		Migimata Acidic Tuff Member
			Futamata Propylite Member		
			Hidarimata Tuff Member		

in Table 1. According to their studies, the present strata were divided into two formations; Toyoha formation and Yunosawa formation by Doi, S. (1953), or Teine formation and Otarunaigawa formation by Sugimoto, R. (1953). However, by the writer's investigations, it is concluded that the present Neogene strata are successible, and they belong to one formation - Toyoha formation - at all. Furthermore, judging from the litho-facies and fossils, the geological age of the present strata is considered as Miocene, ranging from upper lower - to upper middle Miocene. The geological succession given by the writer is also shown in Table 2.

As shown in Table 3, the Toyoha formation forms a part of the Zyozankei group being named by Doi, S. Moreover, the Toyoha formation is lithologically divided into four members as follows; the lower Hidarimata tuff member, the middle Futamata propylite member, and the upper Migimata acidic tuff and Yunosawa tuff members.

The Hidarimata tuff member consists of conglomerate, tuffaceous sand- and mudstones and tuff-breccias of augite-andesitic composition. The Futamata propylite member is chiefly composed of propylites and their pyroclastics. For propylites, they form intrusive-bodies showing their arrangements in NNW - SSE direction. The Migimata acidic tuff member is mainly composed of rhyolite-flows, rhyolitic pumice-flows and rhyolitic tuff-breccias. These avobe mentioned three members are conformable with eachother. However, for the Yunosawa tuff member, consisting of conglomerates, tuffaceous sand-and mudstones, tuffs and tuff-breccias of dacitic and rhyolitic compositions, it covers the Futamata propylite member unconformably in almost parts, but conformable successions are found at some parts. From the lithological and stratigraphical viewpoints, the present and the Migimata acidic tuff members seem to be the hetropic facies of the same age.

The Toyoha formation is penetrated by many intrusives, i.e., diorite-porphyrite, augite andesites, dacites, quartz-porphyry and lithoiditic rhyolites in intrusing order.

As like as propylites, these intrusive rocks, excepting for rhyolites, are strongly controlled by NNW - SSE or NW - SE direction.

The Neogene system including intrusive rocks is more or less altered. By the clay minerals resulted from the alteration, three zones of alteration are established. These alteration zones are developed in zone by zone, and also they are stretched to NNW - SSE or NW - SE direction.

In Southwest Hokkaido, in general, the remarkable geotectonic structures observed in both the basement complex and the Neogene system exhibit the NNW - SSE or NW - SE direction. Accordingly, it is estimated that the igneous activities, as well as the alteration, had been closely connected with the geotectonic movements in the Futamata region.

III. Stratigraphy

As already mentioned, the Toyoha formation is stratigraphically divided into four members of three horizons by rock-facies as follows; the lower Hidarimata tuff member, the middle Futamata propylite member and the upper Migimata acidic tuff and Yunosawa tuff members.

(I) Hidarimata Tuff Member

The Hidarimata tuff member is typically exposed along the upper stream of the Hidarimata-gawa, and is constituted of conglomerates, tuffaceous sand-and mudstones and tuff-breccias.

In the conglomerates, sub-angular and sub-rounded gravels are mostly common, and angular ones are also found. They are 2-20 cm in diameter. These gravels consist chiefly of andesites, and sometimes of black shales and quartz-porphyries. The matrix-materials are tuffaceous ones of andesitic composition.

The pyroclastic rocks are presumed to be originally of augite-andesitic composition. The present member, furthermore, is strongly suffered from the alteration in the two different stages. Namely, in the first stage, this member is given the contact effects by the intrusion of the diorite-porphyrite body. In the second stage, moreover, as like as the other member, it is widely altered by the hydrothermal fluids owing to the so-called "post action".

The above mentioned contact effects characterized with silicification and tourmalinization are observed within 50 meters width apart from the contact point at the river-sides of the Hidarimata-gawa. For the succeeding hydrothermal alteration, it is described later in this paper. The geological structures of the Hidarimata tuff member are complicated.

(II) Futamata Propylite Member

As already noticed, several propylite-masses and associating pyroclastic rocks

Fig. 2 Geological Map

1. Yoichi-Dake Lava-flows	10. Hornblende bearing Propylite
2. Rhyolite	11. Andesitic and Doleritic Tuff-breccias
3. Quartz Porphyry	12. Variegated Tuff-breccia
4. Dacite	13. Tuffaceous Sand- & Mud-stones
5. Augite Andesite	14. Variegated Propylite-breccia
6. Diorite Porphyrite	15. Uni-coloured Propylite-breccia
7. Yunosawa Tuff Member	16. Andesitic and Doleritic Propylites
8. Rhyolitic Tuff-breccia	17. Hidarimata Tuff Member
9. Rhyolitic Lava-flows	18. Fault System

are elementary components of the present member. These rocks are well exposed along the river-sides in this region.

Propylites are recognized as six propylite-bodies in the Futamata region; one in the area of the Hidarimata-gawa and the others in the area of the Migimata-gawa. Each of them penetrates the Hidarimata tuff member at the central part, and also

covers conformably the same member at the marginal part of the propylite body. The effusive-facies is composed of propylitic lava-flows and propylite-breccias. As for the effusive-facies, lava-flow gradually changes horizontally and vertically to propylite-breccia. Propylite-breccia appears to be tuff-breccia or agglomerate, but both of breccia like parts and matrix like parts are of same igneous origin. The breccia like parts found in the propylite-breccia are usually 2 - 30cm in diameter, and their outlines are obsequre. Additionally, it is sometimes observed that the thin beds as such as propylitic lava-flows, tuff-breccias, lapilli-tuffs and tuffaceous sand- and mudstones are interstratified in the massive propylite-breccia.

With the increase of the detrital fragments in the matrix like parts of the propylite-breccia, the propylite-breccia also changes gradually to tuff-breccia. The tuff-
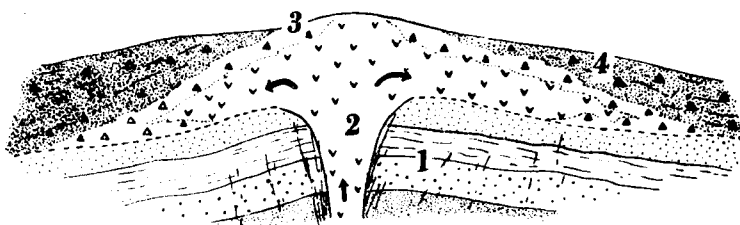
Fig. 3   Idealized Profile of Propylite-body

1. Hidarimata Tuff Member   3. Propylite-breccia
2. Propylite   4. Tuff-breccia

breccia is usually massive, and the joint-systems are scarcely observed. The rock fragments in the tuff-breccia are 2-50cm in diameter, and they become smaller as being apart from the propylite-body. The rock fragments are composed chiefly of essential and accessory ejecta, and accidental ejecta are rarely found. The essential and the accessory ejecta are as follows; propylites, propylite-breccias, propylitic tuff-breccias and tuffs and tuffaceous sand-and mudstones. As for the accidental ejecta, such rock species are ascertained as follows; silicified sand-and mudstones, silicified conglomerates, black shales and acidic volcanic or hypabyssal rocks as like as quartz-porphyries and trachytic rhyolites. Most of these accidental ejecta are probably derived from the Hidarimata tuff member intruded by the propylite-bodies. The thin beds of tuffaceous sand- and mudstones and lapilli- or fine-tuffs are interstratified as lense in the massive tuff-breccias.

These tuffaceous sediments are mainly observed along the gorge of the Migimata-gawa, especially at the river-sides nearby the junction of the Migimata-gawa and the Hidarimata-gawa.

It is note-worthy that some beds of pyroclastic flows and tuff-flows of 2 - 10m in thickness intercalate in the propylite member developed in the area of the Migimata-gawa. Judging from the lithofacies of propylites, it will be considerable that the Futamata propylite member is resulted from the abrupt intrusions and the eruptions on land, or in shallow waters.

The Futamata propylite member is also hydrothermally altered. The present member can be divided into three alteration zones on account of the secondary mineral-assemblages as described in the chapter IV.

As already mentioned, the six propylite-bodies are recognized in the examined region. One of them is distributed in the reaches of the Hidarimata-gawa, and it is associated with the so-called "uni-coloured" propylite-breccias and tuff-breccias, which are light green in colour. On the other hand, the other five propylite-bodies are developed in the reaches of the Migimata-gawa, and they are usually accompanied with the so-called "variegated" propylite-breccias, tuff-breccias and tuffaceous sediments, which include the breccia-like parts or the detrital rock fragments of various colours; green, light green, yellow, reddish brown, purplish red and so on. This difference in colour between the two types in the propylite-bodies probably indicates the geneses and stabilities of the iron minerals through the hydrothermal alteration. That is, in the unicoloured propylite-body, pyrite usually, and leucoxene sometimes are found. On the contrary, in the variegated propylite-bodies, such paragenetic iron minerals as hematite and magnetite are commonly observed, and ilmenite is often, and pyrite is also found in small amounts.

The Futamata propylite member is too massive on the whole, and so it is difficult to make its geological structures clear in details. Nevertheless, owing to the sedimentary thin-beds intercalating in the present member, the general aspect of the volcano-stratigraphy of the Futamata propylite member is slightly known. The total thickness of the present member attains to 600m ± in the surveyed region.

(III)   Migimata Acidic Tuff Member

The Migimata acidic tuff member is distributed in the eastern part of the examined area, and it is conformable with the Futamata propylite member. The present member consists of rhyolite-flows, rhyolitic tuff-breccias and rhyolitic pumice-flows. Generally speaking, the tuff-breccias are prominent in the lower, and the pumice-flows in the upper horizon.

In the investigated region, two layers of rhyolite-flows are recognized. They are similar to lithoiditic rhyolites and have remarkable flow-structures. Some thin beds of rhyolitic tuff-breccias are interstratified as lense in the lower lava-flow. Each of the two lava-flows has about 50-70m in thickness respectively.

The rhyolitic tuff-breccias occur closely associated with the lava-flows. In the rhyolitic tuff-breccias, rhyolite - fragments are abundant and rhyolitic pumices are

also sometimes observed. The rhyolite-fragments, measuring 2 to 30cm in diameter, are usually angular, and rarely sub-angular. The rhyolitic pumices, being 1 to 5cm in diameter, are often thinned out, and are entirely devitrified. They are pale green or light yellowish green in colour. Moreover, the accidental ejecta such as andesitic fragments and tuff-breccias are rarely found in the rhyolitic tuff-breccias. They are probably derived from the Futamata propylite member, but they are slightly altered.

Several thick rhyolitic pumice-flows alternate with the rhyolitic tuff-breccias. The pumices found in the pumice-flows are generally thinned out along the flowing-planes, and they are strongly devitrified, and are altered to light greenish coloured, secondary minerals. Thin rhyolitic tuffs are often interbedded in the pumice-flows.

Besides, one lava-flow of hornblende bearing pyroxene-andesite is interbedded in the rhyolitic tuff-breccias. This lava-flow is about 5m or less in thickness. It is closely similar to the lava-flows distributed typically in the Toyoha mine and its environs. It is also hydrothermally altered and stongly weathered, and so no fresh specimen can be obtained.

The Migimata acidic tuff member forms monoclinic structure; the trend is nearly NNW - SSE or NW - SE direction, and the dip is about 20° to 30° NE. The total thickness of this member is not known on account of the writer's incomplete investigation.

(IV) Yunosawa Tuff Member

The Yunosawa tuff member occupies the western part of the Futamata region. The type locality of the present member is located in the river-sides of the Yunosawa-gawa, one of the branches of the Shirai-gawa. It is about 2 km south-westwards distant from the examined region.

In the Futamata region, the Yunosawa tuff member covers unconformably successions are found at some parts. This member, from the lithological point, is roughly divided into three alternations as follows; alternations of conglomerate and coarse sandstone, alternations of tuffaceous sand-and mudstones, and alternations of tuff, tuffaceous sandstone and tuff-breccia in ascending order.

Most of the gravels in the conglomerates are well-rounded, though with some sub-rounded ones. They are usually 1 to 5cm in diameter as large as pebble or cobble. The most of these gravels are propylites; the rest are green coloured tuffs, tuffaceous sand-and mudstones and rhyolites. The gravels of igneous origin are usually hydro-thermally altered in slight degree. Additionally, some fragments of plant-fossil or carbonaceous materials are often found in the matrices of the conglomerates. In the green tuffaceous coarse sandstones, alternating with the conglomerates, some thin coal-beds of 20 to 30 cm in thickness are recognized. The total thickness of these alternations is about 70m in the examined region.

The alternations of tuffaceous sandstone and mudstone are generally rhyolitic in

composition, and are light greenish in colour. However, the amounts of the dacitic fragments increase gradually from the lower to the upper horizon. Besides, thin tuff-breccia beds sometimes are intercalated as lense in the present alternations. The total thickness attains about 70m in the examined area.

For the uppermost alternations, the dacitic fragments are commonly observed, but the rhyolitic ones are sometimes found. Moreover, thin dacitic tuff-breccia and pumice beds are sometimes interbedded as lense in the present strata. Both the dacitic fragments and the same pumices are 0.5 to 5cm in size as large as pebble or less, and light yellowish green or pale green in colour.

From the lithological viewpoint, it is considerable that the Yunosawa tuff member is correlated with the Migimata acidic tuff member. Though the dacitic fragments are dominant in amount in the Yunosawa tuff member, on the contrary, the rhyolitic fragments are predominant in the Migimata acidic tuff member. Furthermore, Doi, S. reported the following fossils from the Yunosawa tuff member at the river-sides of the Yunosawa-gawa (DOI, S. 1953).

> *Pecten var. kimurai* Yokoyama
> *Venericardia sp.*

In the investigated region, it seems that the Yunosawa tuff member forms a gentle basin-structure. The present member is about 180m in total thickness.

IV. Petrography

Part 1.   Investigations of Original Properties of Igneous Rocks

The Neogene and the Quarternary volcanics are widely distributed in the Futamata region. As for the Neogene volcanic rocks, these species are recognized as follows; propylites and their associated effusive rocks, rhyolite lava-flows and hornblende bearing pyroxene andesite-lavas. These effusive rocks are also the important members of the Toyoha formation. Moreover, they are subjected more or less to the hydrothermal alteration, and so, fresh rock-specimens, being unaltered or slightly altered, are scarcely obtained. For the Quarternary volcanics, the augite-hypersthene andesite lava-flows composing the Mt. Yoichi-dake volcano are distributed in the Futamata region.

In the Miocene period, several intrusive activities, together with the above-mentioned volcanic ones, simultaneously occured. They are represented by a series of these rocks as follows; diorite-porphyrite, augite andesite, rhyolite, dacite and quartz-porphyry, in intruding order. They are also altered, more or less through the hydrothermal action.

Both effusive and intrusive rocks were examined under the microscope. The descriptions of the unaltered or slightly altered specimens are mentioned here as much as possible in order to know the original properties of these rocks. The general descriptions of the altered igneous and sedimentary rocks are done later in details (Part II). The descriptions for the secondary minerals resulted from the decompositions of the primary minerals, and also for the ones filling the amygdaloidal cavities are given in part II (Chapter IV).

(I) Propylite

Propylites and their associated rocks are important constitutors of the Neogene strata in the Futamata region. Propylites are strongly subjected to the alteration through the hydrothermal processes.

Generally speaking, they are massive and poor in joint-system.

The six propylite-bodies are recognized in the Futamata region. One of them occurs in the area of Riv. Hidarimata, and the others distribute in the Migimata Valley. There are two kinds among these bodies in their original rock-varieties; the five of the above-mentioned propylite-bodies are originally augite-andesite and the one is also originally hypersthene-augite dolerite. The andesitic propylite-bodies are distributed in the areas of both Riv. Hidarimata and Riv. Migimata. However, the doleritic propylite-body is only found in the lower courses of Riv. Migimata.

(a) *Andesitic Propylite*

In general, andesitic propylites are stongly altered, and so, it is very difficult to ascertain the original properties of andesitic propylites. Furthermore, the original mafic minerals are so extremely altered that unaltered or the weak-altered ones are scarcely found. In several rock-specimens, however, the relict mafic minerals are fortunately found.

Texture: porphyritic texture

Phenocrysts: plagioclase and augite

Plagioclases are idiomorphic and usually of tabular or prismatic habit. These crystals show generally albite-lamellation, often combined with pericline and Carlsbad twinnings. They are 2.0 to 1.2 mm in size and they are strongly zoned, showing a change from bytownite (An80Ab20—An73Ab27) or labradorite (An55Ab45—An66Ab34) in the core part to andesine (An31Ab69—An48Ab52) or oligoclase (An16Ab84—An28Ab72) at the margin.

Augite is also euhedral and of prismatic habit. On account of the strong alteration being occured at the margin and cleavages or rarely on twinning planes, its optical properties can be scarcely examined. The augite-crystals are generally colourless, but a few of them are sometimes light yellowish green in colour. Most of augites are lack of sensible pleochroisim, but few of them show the following weak pleochroism.

X : colourless
Y : faint yellowish green
Z : colourless
Optical angles are following.
2Vz : 50° - 51° (usual)
2Vz : 51° - 54° (rare)
The indices of augite could not be examined at all.
Groundmass : moderate flow-structures are usually observed.   The constituent
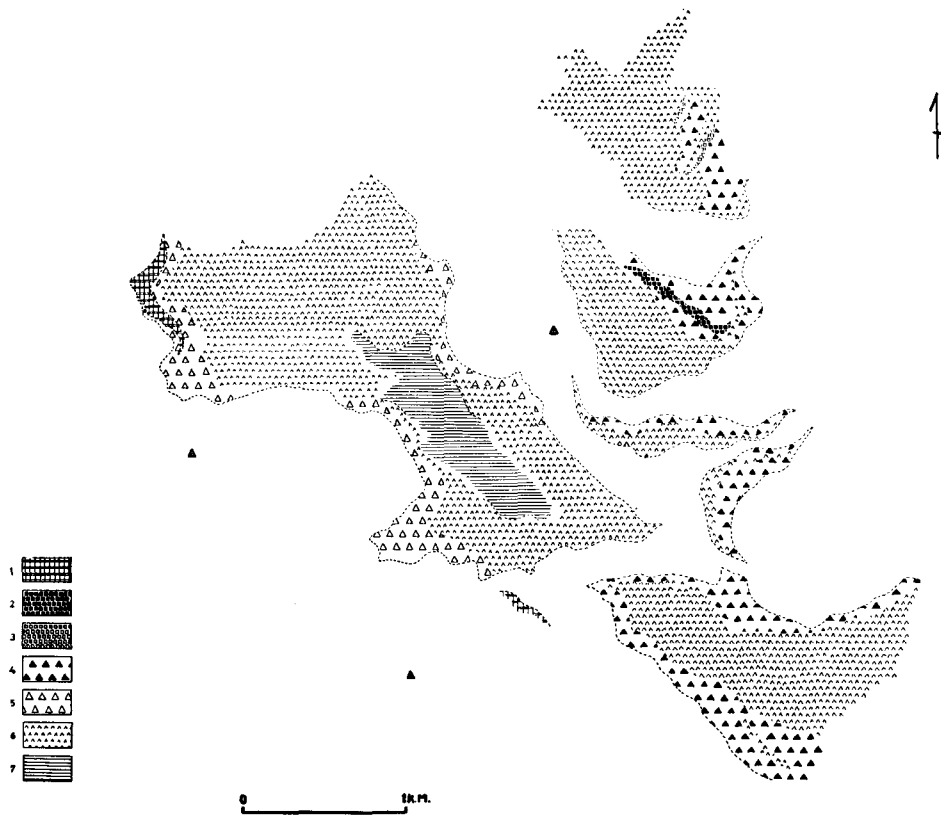
Fig. 4

1. Hornblende bearing Propylite
2. Variegated Tuff-breccia
3. Tuffaceous Sand- and Mud-stones
4. Variegated Propylite-breccia
5. Uni-coloured Propylite-breccia
6. Propylite
7. Hidarimata Tuff Member

minerals in groundmass are plagioclases and augite. Besides, it seems that the ground-
mass was originally glassy in some degree. Nevertheless, there is no glass owing to
devitrification through the alteration.

Plagioclases build small lath-shaped crystals in general. These crystals are often
slightly zoned, being andesine (An31Ab69—An48Ab52) or labradorite (An55Ab45—
An42Ab58) in the center. However, they are too minute crystals, and so their com-
positions can not be determined at the margin. They show albite-lamellation and often
Carlsbad twinning, but without repetition.

Augite, being usually anhedral, rarely hypidiomorphic, forms minute grains.
This mineral is usually faint light green without sensible pleochroism. It is also too
altered to be examined the optical properties. Furthermore, in the groundmass of
the effusive rocks, some vesicles showing amygdaloidal structure are observed, in
which are filled by secondary products. For these secondary minerals are later des-
cribed in details.

(b) *Doleritic Propylite*

As previous noticed, doleritic propylite are developed in the down stream of the
river of Migimata. Judging from the volcano-stratigraphical evidences, it is con-
siderable that doleritic propylite ensued successively to andesitic propylites. Doleritic
propylite is generally less subjected to the alteration than andesitic propylites, and so
it is rather easy to obtain the informations about the original characters of it.

Texture:

Ophitic and porphyritic textures. In the doleritic propylite body, two textures are
recognized; the ophitic texture is chiefly found at the central part of the present body,
and the porphyritic texture is well recognized at the maginal parts.

Constituent minerals:

The constituent minerals are commonly plagioclases, augite, hypersthene and
green hornblende. However, ferroaugite is very rarely observed. The present mineral
shows the tendency to associate with hypersthene. As for ferroaugite, it is difficult to
reason the occurrence of it, but it is probably considered that the present mineral oc-
curs as a xenocryst.

(1) *Ophitic texture*

Plagioclases are commonly euhedral and sometimes subhedral, with columnar
or sometimes tabular habit. The present crystals show generally albite-lamellation,
often combined with Carlsbad twinning. They are oscillatory zoned, showing a change
from bytownite (An80Ab20—An70Ab30) or labradorite (An69Ab31—An65Ab
35) in the core to andesine (An49Ab51—An32Ab68) at the margin. Augite is idiomor-
phic and sometimes hypidiomorphic crystals. The orthopinacoidal twin is common.
This mineral is usually faint light green without sensible pleochroism. The optical
properties are given as follows;

2Vz : 49° - 51°

α : 1.697

The relationships between the values of optical angle and the indices of clino-pyroxene are collectively shown in Fig. 5.

Furthermore, green hornblende usually occurs as rims surrounding augite.

Hypersthene is sometimes observed. It builds idiomorphic crystals with columnar habit. This mineral is usually colourless or faintly light green in colour and shows sensible pleochroism. The optical properties are shown as follows;

Pleochroism: X   :   light yellowish green

                Y   :   colourless

                Z   :   colourless

2Vz   :   116° - 117°

β :   1.701

The optical properties are illustrated in Fig. 6.

Green hornblende occurs commonly as rims surrounding augite or hypersthene, and it builds subhedral crystals. However, sometimes euhedral crystals are
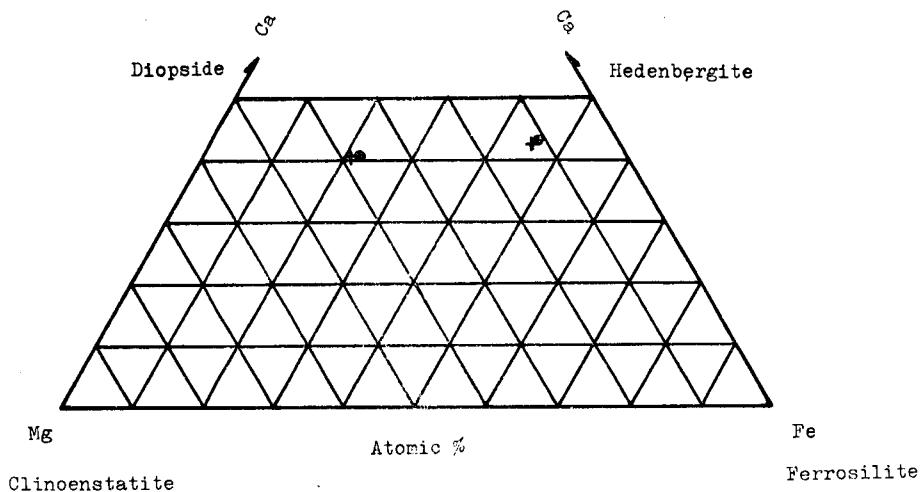
Fig. 5   + ;   Pyroxene in Diorite Porphyrite   ● ;   Pyroxene in Doleritic Propylite

also observed. It shows strong pleochroism. On account of the intense alteration, the optical properties could be insufficiently examined, excepting for the following characters.

Pleochroism;   X   :   light yellowish green

                Y   :   dark green
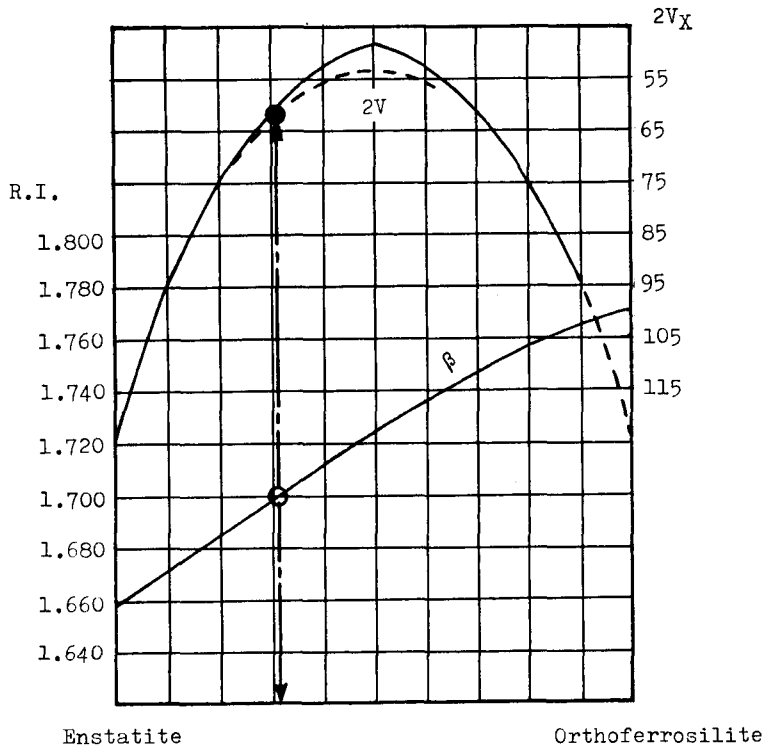
Fig. 6

$$
\begin{array}{rcl}
Z & : & dark\ green \\
C \wedge Z & : & 18° - 19° \\
2Vz & : & 110° - 112°
\end{array}
$$

(2) *Porphyritic texture:*

In comparison with the constituent minerals found in the rock showing ophitic texture, those in the rock of porphyritic texture are characterized by increasing of green hornblende in amount. The dolerite-fragments showing ophitic textures are often found in the effusive-facies of porphyritic textures. The phenocrysts consisting of plagioclases, augite and green hornblende and sometimes hypersthene are commonly idiomorphic crystals. However, green hornblende builds sometimes subhedral crystals occurring at the rims of the crystals of augite or hypersthene. On augite, the optical properties are some variable. Namely, the values of 2Vz vary from 49° to 55° and the values of indices (α) also change correspondingly from 1.697 to 1.670.

Besides, the occurrence of ferroaugite is rarely recognized. The optical properties are given as follows;

Table 4

An-Content of Plagioclase

in Augite Andesitic Propylite and Tuff-breccia

			Sample Number		An-Content	Note
Propylite Associated with Uni-coloured Propylite-breccia and Tuff-breccia	Propylite	8178	(P)	$An_{33} - An_{35}$	(P) : Phenocryst
			(G)	$An_{31} - An_{35}$	
		72717	(P)	$An_{55} - An_{57}$	
			(G)	$An_{43} - An_{47}$	
	Propylite Breccia	883	(P) (G)	$An_{33} - An_{44}$ $An_{39} - An_{45}$	(G) : Plagioclase in Groundmass
		8171	(P) (G)	An_{35} An_{37}	
	Tuff Breccia	813		$An_{25} - An_{28}$	Large Crystal Fragment
		8177		$An_{29} - An_{33}$	

An-Content Values were determined by albite-Carlsbad Twin Method

Table 5

An-Content of Plagioclase

in Augite Andesitic Propylite and Propylite-breccia

		Sample Number		An-Content	Note
Green Tuff Formation in the Futamata Region — Propylite Associated with Variegated Propylite-breccia	Propylite	885	(P)	An_{27}	(P): Phenocryst
			(G)	$An_{31} - An_{35}$	
		8243	(P) *	An_{13}	(G): Plagioclase in Groundmass
			(P) **	An_{19}	
			(G)	An_{13}	(P) *: Tabular Phenocryst
		7234	(P)	$An_{32} - An_{37}$	(P)**: Lath-shaped Phenocryst
		8253	(P)	$An_{9}.$	
		892	(P)	An_{61}	
			(G)	An_{48}	
	Propylite Breccia	7233	(B)	$An_{38} - An_{40}$	(B): Breccia-like Figure Part
			(M)	An_{32}	
		7212	(B)	An_{23}	(M): Matrix-like Figure Part

An-Content Values were determined by albite-Carlsbad Twin Method

Pleochroism;   X   :   light yellowish green
                 Y   :   pale brownish
                 Z   :   light yellowish green
2Vz   :   58°
 α   :   1.725

The present mineral is identifiable with ferroaugite as shown in Fig. 5, (After, HESS, H. H. 1941, 1949). It is commonly hypidiomorphic and is rarely idiomorphic crystals, and of tabular or prismatic habit.

Groundmass:

The texture of groundmass is sometimes characterized by remarkable fluidal structures being subjected to intense devitrification. Moreover, amydales being filled with secondary products are commonly found. The constituent minerals are plagioclases and augite. Plagioclases build commonly little lath-shaped crystals and sometimes little prismatic ones. They are idiomorphic crystals. Augite is anhedral crystals forming minute grains. These constituent minerals are altered to secondary products, owing to the hydrothermal alteration. Namely, plagioclases show ghosty crystals through the alteration and augite is entirely decomposed.

According to the above-mentioned observations, doleritic propylite is originally identified of green hornblende bearing hypersthene-augite dolerite. Moreover, augite varies from Mg rich augite to Fe rich augite in composition.

(II)   Diorite-Porphyrite

In the Futamata region, diorite-porphyrites are well developed. One of them forms an intrusive-mass distributed in the upperstream of the river of Hidarimata; the others as dykes. For the diorite-porphyrite mass, it shows basin-like form. Furthermore, at the central part of the present mass, hollocrystalline, granular textures are prominently observed, however, the porphyritic textures with coarse or fine-grained hollocrystalline groundmass are commonly found at the marginal parts of the mass. The dykes showing their arrangements of nearly NW-SE direction are dolerite and sometimes diorite-porphyrite in textures.

These diorite-porphyrites are also altered through the hydrothermal alteration. Especially the primary minerals are extremely decomposed, and so it is very difficult to determine their original optical properties.

Here, from both the textures and the constituent minerals of being described later, the nomenclature of "Diorite-porphyrite" is given to the present rocks occurring as mass and dykes. (A. HARKER. 1895)

(a)   *Diorite-Porphyrite Mass*

Texture: As previous described, in the diorite-porphyrite mass, medium grained, granular texture is observed in the interior and fine-grained granular texture or porphyritic texture with aphanitic hollocrystalline groundmass in the margin. Further-

more, the intrusive mass gives some kinds of contact effect, such as tourmallinization and silicification, to the surrounding Neogene strata.

Constituent Minerals: The constituent minerals are these as follows; plagioclases, quartz and augite are common, green hornblende is often and green biotite is very rare.

Plagioclases in granular texture are commonly subhedral and sometimes euhedral crystals. On the contrary, in porphyritic texture, euhedral crystals are dominant for the phenocrysts of plagioclases. They show usually tabular or prismatic habit, measurring 2 to 0.5mm in size. Besides, in hollocrystalline groundmass, plagioclases are usually idiomorphic crystals, and of columnar habit, attainning 0.5 to 0.1mm in length.

Plagioclases have oscillatory zoning in more or less, showing a change from labradorite (An69Ab31—An50Ab50) in the interior to andesine (An37Ab63—An30Ab70) or sometimes oligoclase (An16Ab84—An27Ab73) at the margin. Twin lamellation on the albite law is common and is often combined with Carlsbad twinning and the pericline law is sometimes observed.

Augite is generally hypidiomorphic and sometimes idiomorphic crystals. It is commonly prismatic and sometimes tabular crystals, and of colourless or often faint pale green in colour. The present mineral shows no pleochroism, but rarely faint pleochroism. The optical properties of augite with faint pleochroism are as follows;

Pleochroism: X : faint yellowish green
                  Y : light brownish yellow
                  Z : faint yellowish green
2Vz : 48° - 50°
  α : 1.696

Furthermore, pyroxene, being identified to ferroaugite, is very rarely observed. The present mineral is hypidiomorphic crystals with slight pleochroism. Its optical properties are the followings;

Pleochroism: X : light yellowish green
                  Y : pale brownish green
                  Z : light yellowish green
2Vz : 58° - 59°
  α : 1.726

Green hornblende builds idiomorphic or sometimes hypidiomorphic crystals and of columnar or tabular habit with a moderate pleochroism. The present mineral is almost subjected to decomposition through the alteration, and so the original qualities are scarcely examined. Some optical properties are given as follows;

Pleochroism: X : yellowish green
                  Y : light brownish green

              Z   :   green

2Vz   : 97° - 103°

C∧Z   : 17° - 19°

Sometimes, hornblende having the values of 2Vz (113° - 120°) is observed. Besides, the intergrowth of green hornblede and augite is often found.

Green biotite is minute euhedral of sometimes subhedral flakes with a moderate pleochroism, and it usually occurs in intergrowth with green hornblende. Green biotite exhibites strong pleochroism as follows;

    Pleochroism: X : colourless or pale green

                    Y : deep brownish green

                    Z : deep brownish green

Green biotite sometimes becomes light green or colourless by decomposition through the alteration. Furthermore, brownish biotite is rarely occurs. It shows the following pleochroism.

    Pleochroism: X : colourless

                    Y : deep brown

                    Z : deep brown

It is assumed that brown biotite occurs as relict mineral of being saved from the hydrothermal alteration.

Finally, quartz builds anhedral crystal and its shape is irregular. Furthermore, as the secondary products of the alteration, vermicular quartz and albitized plagioclase aggregate together like a myrmekite.

    (b) *Diorite-Porphyrite Dykes*

    Texture: The diorite-porphyrite dykes are similar to dolerite or diorite-porphyrite from their textures. Namely, the medium or fine grained, granular textures or sometimes porphyritic textures with fine grained, hollocrystalline groundmass are observed in the dykes being similar to diorite-porphyrite. Moreover, in the dykes being similar to dolerite, the ophitic texture is commonly noticed.

    Constituent minerals:

The constituent minerals composing these dykes are just the same as those found in the diorite-porphyrite mass. Nevertheless, green or brown biotite can not be observed. Moreover, the constituent minerals of these dyke-rocks are characterized with the decreasing of quartz, and also with the rare occurrence of brown hornblende. The last mineral is idiomorphic or sometimes hypidiomorphic crystals, and of moderate pleochroism; X: light brown, Y: deep brown, Z: deep brown. It is probably assumed that brown hornblende is saved from the alteration.

(III) Augite Andesite

In the examined region, the dyke-swarms, showing their arrangements of nearly NW - SE, or sometimes of about NE - SW in direction, are recognized. On account

of the intense hydrothermal alteration, the original lithological properties of these dyke-rocks can not be sufficiently ascertained.

Texture: Porphyritic texture with glassy groundmass.

Constituent minerals:

The phenocrysts of the constituent minerals are plagioclases and mafic minerals. Plagioclases are euhedral crystals, and of tabular or prismatic habit. The present minerals are strongly zoned, showing an oscillatory change from bytownite (An81Ab 19—An70Ab30) or sometimes labradorite (An51Ab49—An69Ab31) in the core to andesine (An36Ab64—An47Ab53) at the magin. The lamellation on the albite law is common, and is often combined with Carlsbad twinning. The pericline twinning is also sometimes found, and is often associated with the albite twinning. Plagioclases measure 2 to 0.5mm in size.

The mafic minerals are entirely decomposed, and exhibit pseudomorphic crystals of secondary products. Judging from the crystal habit of the pseudomorphic minerals, they are certainly assumed to be originally augite.

Groundmass:

In the groundmass, remarkable fluidal structures are commonly noticed, and without any glass owing to devitrification through the alteration. The constituent minerals found in the groundmass are plagioclases and mafic minerals. These constituent minerals are subjected to the alteration, however, the relict plagioclases are often found, but mafic minerals are exceedingly decomposed at all.

Plagioclases are little long lath-shaped crystals and are idiomorphic habits. They are often simple, and are commonly twined on the albite law, being rarely combined with Carlsbad twinning. The present minerals are also zoned in some degree, showing a transitional change from labradorite (An51Ab49—An67Ab33) interior to andesine (An32Ab68—An47Ab53) at the margin. In general, plagioclases become ghosty crystals due to the alteration.

The mafic minerals, being almost minute granulared, anhedral habit, are extremely decomposed.

Amygdales, being filled with the secondary products, are commonly observed.

Judging from the above noticed descriptions, these basic andesite dykes are probably ascertained as augite andesite of original composition.

(IV) Dacite

In the investigated region, dacites are distributed in the area of Riv. Migimata. They are petrographically divided into two types; hypersthene dacite and green hornblende dacite. The former is recognized in the upper reaches of the river of Migimata; the latter is found as dykes of nearly E - W in direction in the downstream of Riv. Migimata.

The dome-structured mass, however in the upper parts of the present mass, the

effusive facies with well-developed columnar joints are recognized. Generally speak-
ing, in these dacites remarkable flow structures are usually found, and large pheno-
crysts occur sparsely.

(a) *Hypersthene Dacite*

Texture: porphyritic texture

Constituent minerals:

Plagioclases and hypersthene are commonly, and quartz is rarely recognized.
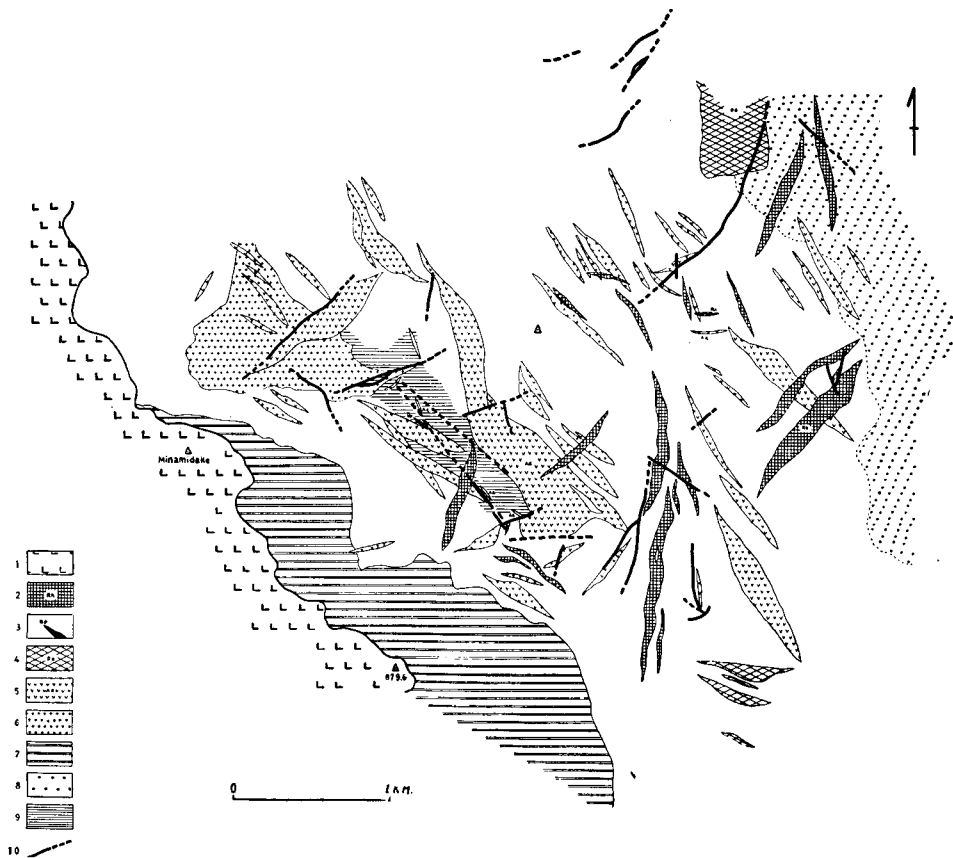
Fig. 7

1. Yocihi-Dake Lava-flows
2. Rhyolite
3. Quartz Porphyry
4. Hornblende and Hypersthene Dacites
5. Augite Andesite

6. Diorite Porphyrite
7. Yunosawa Tuff Member
8. Migimata Acidic Tuff Member
9. Hidarimata Tuff Member
10. Fault System

Plagioclases are euhedral crystals, and of tabular or prismatic habit. They are commonly zoned in more or less, showing oscillatory change from labradorite (An 66 Ab 34) in the core to andesine (An 45 Ab 55) at the margin. Twin lamella on the albite law is frequently observed, and is often associated with twinning on the Carlsbad or sometimes on the pericline law. They are 1 to 2mm in size.

Hypersthene is in idiomorphic prisms, measurring nearly 1 to 1.5mm in size. It is pale green in colour in thin section. Owing to the intense alteration, the optical properties could not be sufficiently determined.

    Pleochroism: X :   pale yellowish green
               Y :   colourless
               Z :   colourless
  2Vz :   117°-118°

Quartz is rarely found and forms euhedral or sometimes subhedral crystals with inlets of the groundmass.

    Groundmass:

In the groundmass with remarkable flow structures, the initial constituent minerals, however the mafic minerals are decomposed at all.

Plagioclases are little long lath-shaped, idiomorphic crysyals. They are often weakly zoned, and are almost andesine (An 43—57) in composition. The original mafic minerals, probably hypersthene, are entirely decomposed, and consequently are pseudomorphs of the secondary minerals. Furthermore, amygdales filled with the secondary minerals are sometimes observed.

    (b) *Green Hornblende Dacite*
    Texture: porphyritic texture
    Constituent minerals: Plagioclases, green hornblende and quartz.

Plagioclases are also tabular or prismatic, and idiomorphic. Oscillatory zoning is commonly observed, showing a change from labradorite (An60Ab40—An65Ab35) in the interior to andesine (An30Ab70—An40Ab60) or sometimes oligoclase (An25 Ab75—An30Ab70) at the outer most part. Twin lamella on the albite law is commonly observed, and is often associated with the Carlsbad twin or the pericline twin. They are 1 to 4mm in size.

Green hornblende, being idiomorphic crystals with distinct pleochroism and often twined, is prismatic habit.

    Its optical properites are as follows;
    Pleochroism: X :   yellowish green
                  Y :   dark green
                  Z :   dark green
  C∧Z : 18° - 19°
  2Vz : 110° - 111°

α :   1.658

Quartz is rarely recognized, and it forms usually euhedral crystals. Besides, the present crystals exhibiting good hexagonal pyramids are rarely found.

Groundmass:

The constituent minerals in groundmass with distinct fluidal structures is intensely decomposed on account of the alteration. However, for plagioclases and green hornblende, some of them are still remained as the relicts.

Plagioclases are minute lath-shaped form, and are andesine (An43Ab57) or sometimes oligoclase (An 27 Ab 73) in composition.

Green hornblende occurs as minute subhedral crystals. Furthermore, spherulitic structures, of being composed of oligoclase (An22Ab78—An28Ab72) or of the intergrowth of oligoclase and quartz, are commonly observed.

(V)   Quartz Porphyry

Quartz porphyry occurs as one dyke with NW - SE direction in the Hidarimata valley. It is nearly 1m in width, and gives weak contact effects, such as silicification, to the wall rocks.

The present rock is intensely altered, and consequently, it is very difficult to examine its original characters from petrographical point.

Texture: Porphyritic texture

Constituent minerals:

The relict phenocrysts, being saved from the alteration, are quartz and plagioclases; the mafic minerals are entirely decomposed.

Plagioclases of idiomorphic or sometimes hypidomorphic are tabular or prismatic habit. Twin lamella on the albite law is commonly observed, and is often combined with the Carlsbad twin and sometimes with the pericline twin. They are usually zoned, showing a change from labradorite (An 55 Ab 45) or Ca-rich andesine (An 45 Ab 55) in the core to oligoclase (An22Ab78—An30Ab70) at the most outer part. They measure 1 to 4mm in size.

Quartz is generally corroded and rounded, and is in abundant inclusions of amorphous or cryptocrystalline materials.

The mafic minerals can not be decidedly identified to any original minerals owing to the decomposition through the alteration.

Groundmass:

The groundmass is composed of felsic minerals such as plagioclases and quartz, and is of fine grained, hollocrystalline texture. Quartz is generally recrystallized with the inlets of the groundmass.

Plagioclases become ghosty crystals because of albitization and are commonly oligoclase (An20Ab80—An27Ab73) in composotion.

(VI)   Rhyolite

In the investigated region, rhyolites occur as the dyke rocks, showing their zonal arrangements surrounding the diorite-porphyrite mass. The rhyolite dykes have commonly chilled margin with well-developed small columnar joints. They are generally lithoiditic in texture.

Texture: : Porphyritic texture

Constituent minerals:

Constituent minerals, as phenocrysts, are quartz, plagioclase and often green hornblende. Quartz is corroded in some degrees and rounded with the inlets of the groundmass, and sometimes in good hexagonal pyramids. In the quartz crystals, many cryptocrystalline inclusions are recognized.

Plagioclases are idiomorphic, and of tabular or prismatic habit. They are moderately zoned in usual, showing oscillatory change from labradorite (An 51 Ab 49—An 60 Ab 40) or Ca-rich andesine (An 40 Ab 60—An 48 Ab 52) in the interior to Na-rich andesine (An 32 Ab 68 — An 34 Ab 66) or oligoclase (An 20 Ab 80) at the most outer part. Twinning on the albite law is commonly observed, and is often combined with the Carlsbad and the pericline twinnings. The present minerals are 1 to 2mm in size.

Green hornblende, of euhedral prisms, is deep green in colour. It is often twined and also shows distinct pleochroism.

Pleochroism: X   :   yellowish green
                 Y   :   deep green
                 Z   :   deep green

C∧Z   :   18°

2Vz   :   97° — 102°

Groundmass:

The groundmass is certainly recognized to be originally vitreous, however, the glass is devitrified at all, and it is altered to the secondary minerals such as quartz or cryptocrystalline minerals. Small spherulitic structures with oligoclase or with the intergrowth of quartz and oligoclase are abundantly recognized. The primary mafic minerals in the groundmass are perfectly decomposed at all. The minute long lath-shaped plagioclases become ghosty crystals on account of the alteration. The primary fluidal structures are scarcely recognized.

Part II   Studies on the Altered Igneous and Sedimentary Rocks.

(1) General Remarks

As already mentioned, the Neogene system in the Futamata region is generally subjected to the alteration through the hydrothermal processes. By the mafic characteristic clay minerals, of being resulted from the decompositions of the initial minerals,

the Neogene system can be divided petrographically into three alteration zones as follows; pale green chlorite zone, yellowish green chlorite zone and saponite zone. Each of these alteration zones is arranged zone by zone, and with nearly NW-SE in direction. These alteration zones are illustrated in Fig. 9. Furthermore, the alteration zones are established without regard to the qualities of the original rock-species, and also to the stratigraphical structures of the Neogene system, hence it may be infered that these alteration zones were caused by the hydrothermal alteration at a certain post-action stage.

Fig. 8

1. Yoichi-Dake Lava-flows
2. Rhyolite
3. Quartz Porphyry

4. Hornblende and Hypersthene Dacites
5. Diorite-porphyrite
6. Fault System

The index caly minerals, mentioned above as the characteristic clay minerals, which are the most useful in order to divide the altered Neogene system into some alteration zones from the petrographical viewpoint, are pale green chlorite, yellowish green chlorite and saponite. These clay minerals were examined by means of microscope and X-ray powder diffraction. Each of them is described.

(II) Index Clay Minerals

Pale Green Chlorite

Pale green chlorite is usually pale green, or often pale bluish green or faint pale green in colour in thin section. In the present mineral, two types are recognized, i.e., orthochlorite type and leptochlorite type. The former is sometimes found, and is small flakes with perfect (001) cleavage. Furthermore, it is rarely twined parallel to the base (001). The latter is commonly recognized, and it shows imbricate or fibrous habit, and sometimes minute grained without any cleavages. In thin section, pale green chlorite is characterized by the pleochroism, which is commonly insensible, though often weak as follows;

X'	Z'
very pale green	pale green
pale green	light green
pale bluish green	bluish green

Furthermore, the birefringence is usually decidedly weak, and is often imperceptible. Pale green chlorite shows distinctive abnormal interfernce colours; ultra blue is common and dark auburn is rather rare.

Yellowish Green Chlorite

Yellowish green chlorite is yellowish green or sometimes light green in colour. It belongs to leptochlorite type, and shows imbricate or fibrous habit, though sometimes fine grained aggregates. The cleavages are unrecognized in general, but the perfect basal cleavages parallel to (001) are rarely observed. The pleochroism is the following, X':pale green, Z'; yellowish green. The birefringence of the present mineral is nearly the same as that of sericite. In abnormal interference, dark auburn or ultra blue is sometimes observed.

Saponite

Saponite is generally deep green in colour. It builds fibrous or flakelike aggre-

gates. The prefect basal cleavages are sometimes recognized. The following distinctive pleochroism is observed in thin section; X': yellowish green, Z': deep green. The interference colour is nearly the same as those of sericite, and abnormal interference colour is commonly observed, and are similar to those found in epidote or clinozoisite. On account of X-ray powder diffraction, the present clay mineral exhibits its peculiar pattern being equivalent of that of saponite.

For each of the three alteration zones, it is described from the petrographical point. However, for the descriptions of plagioclases, their values of An-content are
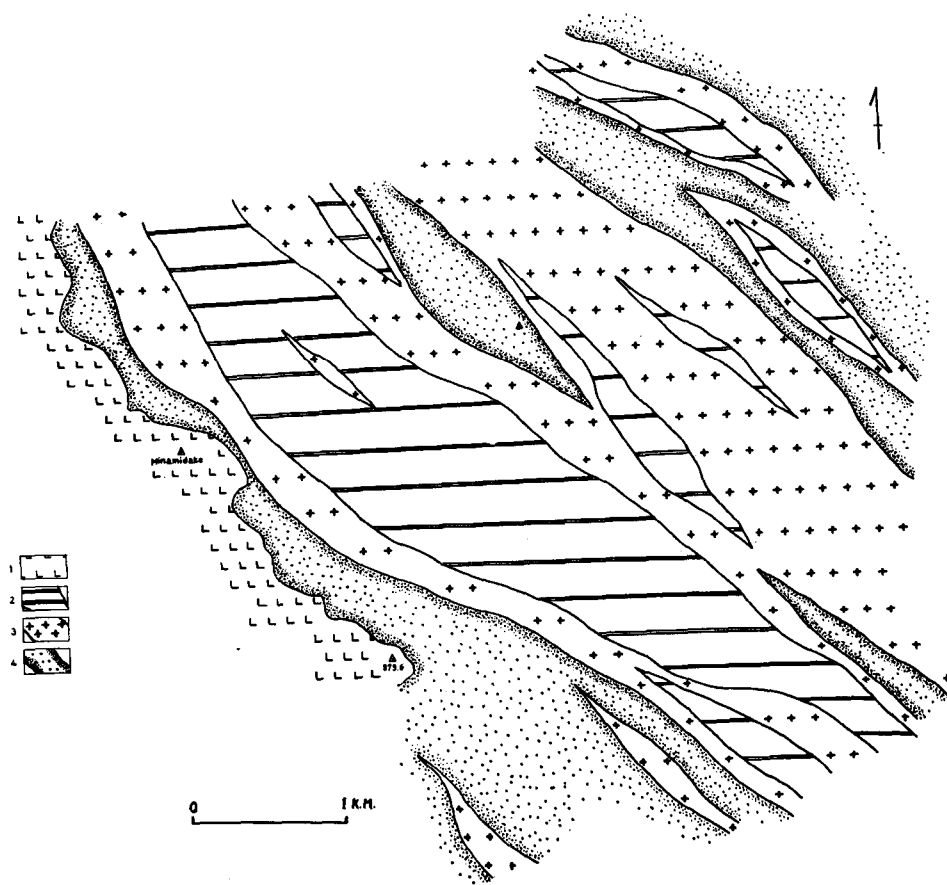
Fig. 9

1. Yoichi-Dake Lava-flows
2. Pale Green Chlorite Zone
3. Yellowish Green Chlorite Zone
4. Saponite Zone

described at all in details in part III (chapter IV).

(III) Pale Green Chlorite Zone

  In the Futamata region, the pale green chlorite zone is distributed in nearly agreement with the axes of the igneous activites represented by propylites and diorite-porphyrites, as shown in Fig. 10. The secondary minerals found in the altered rocks belonged to the present alteration zone are almost in common with those in the other alteration zones. However, the occurrence of pale green chlorite distinguishes the present alteration zone from the others. The altered igneous and sedimentary rocks belonging to the present zone are described below in details.

—Description—

(a) *Hidarimata Tuff Member*

  The Hidarimata tuff member belongs wholly to the pale green chlorite zone.

  The present member has, in addition, the contact effects, such as silicification and tourmallinization, by the intrusion of the diorite-porphyrite mass. The contact metasomatized zone is within nearly 50m in width apart from the contact point. Furthermore, the present zone is once more transmuted by the hydrothermal alteration. For an example, the fine andesitic tuff (Sample No.815) is affected with the two actions mentioned above at the different stage. In this specimen, the original minerals with exception of quartz are decomposed at all, and are changed to the secondary products as follows; quartz, albitized plagioclase, pale green chlorite, epidote, tourmaline, sericite, carbonates, apatite and pyrite. The detrital plagioclase fragments exhibit ghosty crystals showing albite (An5-An10) in composition. Each of them, in general, is also replaced partially by pale green chlorite, sericite, carbonates and epidote and also often by tourmalline. On the other hand, however, all of the detrital mafic minerals, may be originally pyroxenes, are entirely altered to the pseudomorphs of pale green chlorite.

  For tourmalline, it builds idiomorphic crystals, and of prismatic habit. It shows often radial arrangement. The optical properties are given as follows;

   Pleochroism; O(Z) dark green

          E(X) pale yellowish green

  Tourmalline is rarely replaced in partially by pale green chlorite or sericite.

  Epidote is fine-grained anhedral granules, having slightly sensible pleochroism. The present mineral replaces mainly plagioclases and sometimes mafic minerals.

  Apatite, being as minute six-seded prismatic crystals, shows columnar or needle shaped form. The present mineral is pale green in colour without sensible pleochroism. It is closely paragenetic with quartz. Namely, in the recrystallized parts of the quartz grains, the minute short-columnar or needle-shaped crystals of apatite are frequently recognized. Furthermore, apatite is also rarely associated with the quartz grains exhibiting mosaic aggregates in the veinlets.

  From the above mentioned occurrences of the apatite crystals, some of these crystals are obviously the secondary products through the hydrothermal alteration accompanied with fluorine and chlorine elements. Furthermore, in the other altered sedimentary and igneous rocks in the Futamata region, apatite crystals of being ascertained as the secondary products are frequently recognized.

  In general, these secondary minerals such as pale green chlorite, fine-grained epidote, sericite, quartz and albitized plagioclase are closely paragenetic with each other. Nevertheless, carbonate

minerals are reciprocally associated with the above described secondary minerals. Small vein, consisting of quartz, pale green chlorite and carbonates, is sometimes noticed.

In the other altered rocks having none of influences of the contact metasomatism, the secondary minerals, with the exception of tourmalline and remarkable recrystallized quartz, are just the same as those above mentioned. In general, the tuff-breccias have some kinds of the rock fragments, which are specialized by the different secondary mineral assemblages. For an example, in the andesitic tuff-breccia (Sample No.8177), the following rock fragments of igneous origin are found, and are characterized by the distinctive secondary minerals; the rock fragments having pale green chlorite as the main constituent, those consisting mainly of sericite and those consisting chiefly of epidote.
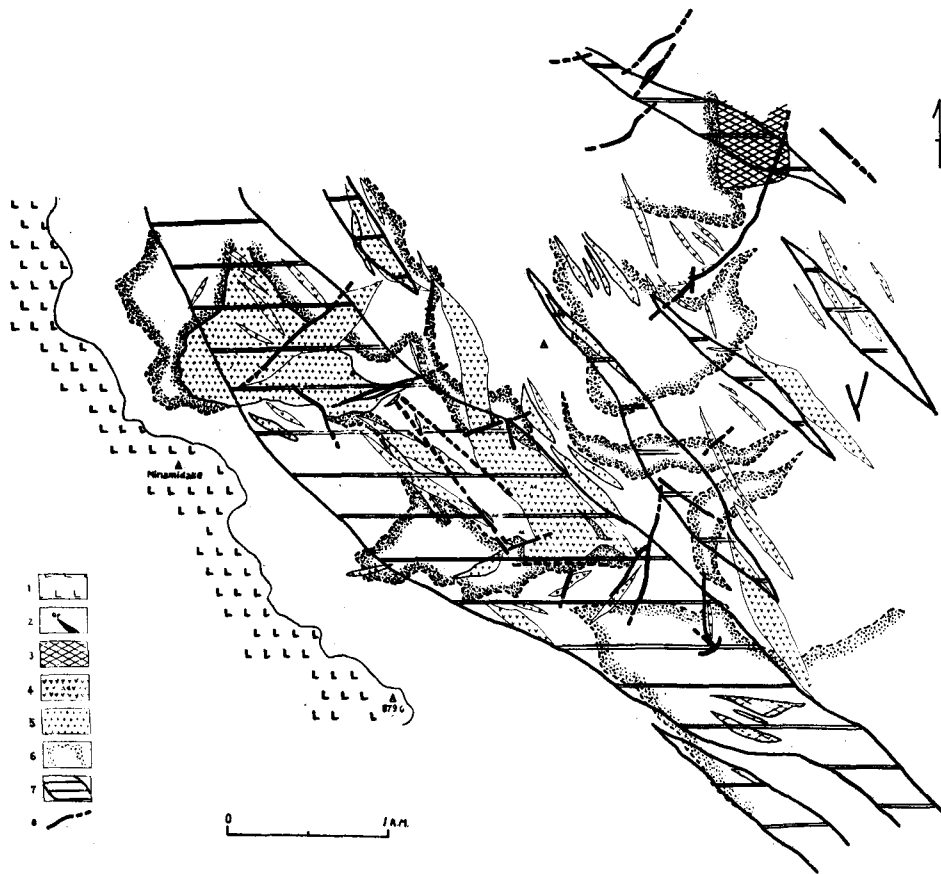
Fig. 10

1. Yoichi-Dake Lava-flows	5. Diorite Porphyrite
2. Quartz Porphyry	6. Propylite Body
3. Hornblende and Hypersthene Dacites	7. Pale Green Chlorite Zone
4. Augite Andesite	8. Fault System

The rock fragments of the first type shows the following mineral assemblage; pale green chlorite, fine grained epidote, albitized plagioclase (An 32) and sericite. This mineral assemblage is characterized by either the absence of or the very rare occurrence of carbonate minerals.

In the second type, sericite is paragenetic with the following minerals; albitized plagioclase, pale green chlorite and apatite. The present type is also peculiarized by either the absences of or the least quantities of carbonates and epidote.

The last type has the distinguished mineral assemblage; epidote, carbonate minerals and in addition sometimes pale green chlorite. Epidote is almost idiomorphic and of prismatic habit, and shows often radial arrangement. It is pale yellowish green in colour.

Pleochroism: X: pale green
                       Y: greenish yellow
                       Z: greenish yellow

$2Vz$: $104° — 109°$
$X \wedge C$: $3° — 4°$

The matrices of the present specimen are extremely altered and are composed of the following minerals; pale green chlorite, fine grained epidote, carbonates as the main constituents, and quartz and apatite as the accessory minerals. For the fine-grained epidote, it is hypidiomorphic or anhedral crystals, and of granular habit. It is yellowish green in colour, with moderate pleochroism.

Pleochroism: X: pale green
                       Y: yellowish green
                       Z: yellowish green

$2Vz$: $112°$
$X \wedge C$: $3°$

Moreover, the veinlets filled with either carbonates only or carbonates + epidote are sometimes observed.

It may be noticeable that the optical properties of the fine grained epidote differ somewhat to that of the idiomorphic and prismatic one. The former is closely paragenetic with pale green chlorite; the latter with carbonates.

(b) Futamata Propylite Member

The Futamata propylite member can be divided into three alteration zones on standing petrographical point. In the pale green chlorite zone, the secondary minerals coexisting with pale green chlorite are the followings; albitized plagioclase, sericite, actionolite, epidote, carbonates, iron ores and uncertain clay minerals in usual, and often quartz and apatite.

Present member is also effected by the contact metasomatism represented with silicification and sericitization in a weak degree, with the intrusion of the diorite-porphyrite mass in the Hidarimata valley.

The present member is composed of propylite, propylite-breccia and propylitic pyroclastics, and so each of these altered constituents is described.

Propylite

Propylite is hydrothermally altered in a certain degree: the phenocrysts are extremely decomposed, but the textures of the groundmass scarcely remain. However, in general, andesitic propylites are altered in more degree than the doleritic propylite.

(Andesitic Propylite)

For andesitic propylites, six bodies of them are recognized in the Futamata region; one in the area of the river of Hidarimata, and the others in the area of Riv. Migimata.

In the first, andesitic propylite developed in the Hidarimata valley is described. For the phenocrysts of plagioclases, they are so entirely altered that it is very difficult to determine their compositions, viz. An contents. But, the slightly altered plagioclases are often found, though their original oscillatory zonings disappear at all. As shown in Table 4, 5, these slightly altered plagioc-

lases vary in composition from andesine to labradorite, but are usually andesine.

The secondary products through the decompositions of the original plagioclases are as follows; albitized plagioclases, pale green chlorite, sericite and carbonates are in common, and epidote, apatite, quartz and uncertain clay minerals are sometimes observed. Here, epidote, being very closely associated with pale green chlorite, shows anhedral minute granules, or sometimes hypidiomorphic short columnar crystals.

For the uncertain clay minerals, they are flake-like in usual, and form often intergrowth with pale green chlorite. The present minerals in thin section are colourless in usual, but sometimes faint pale green in colour. The optical properties are given as follows;

Pleochroism: X':   colourless or faint pale green
                 Z':   pale green
Birefringence: strong, and the highest interference colours are nearly the same as those of
                 sericite

The present minerals are distinguished from the other clay minerals by the optical properties under the microscope, and so they are named as "Type A" chlorite for convenience in this paper.

This "Type A" chlorite is extremely minute, and so it is very difficult to seperate from the other clay minerals for the purpose to determine its mineralogical characters.

The original mafic minerals are entirely decomposed, and are almost altered to the pseudomorphs of the secondary minerals, which are the followings; pale green chlorite, actinolite, epidote, carbonates and iron ores (pyrite). These secondary minerals are sometimes associated with sericite or "Type A" chorite in small amounts.

The groundmass is ecceedingly decomposed, although the fluidal structures scarcely remain. The microcrystals, such as plagioclase and augite, are decomposed and show ghosty crystals. The secondary minerals found in the groundmass are essentially similar to those replacing the phenocrysts. However, in comparison with the secondary minerals in the phenocrysts, those in the groundmass are peculiarized by the decreasing of carbonate minerals and also by the increasing of the following minerals; pale green chlorite, sericite, albitized plagioclase and fine grained epidote in amounts. Furthermore, amygdales and veinlets are sometimed found. The mineral assemblage consisting of amygdales is quartz + pale green chlorite + sericite + pyrite, and that of veinlets is carbonates or pale green chlorite only, or pyrite + pale green chlorite.

In andesitic propylite, the breccia-like figures resembling to the appearance of tuff-breccia caused of the alteration are sometimes observed by naked eyes. For an example, in the rock specimen (Sample No.8178), the breccia-like figures are in all shades of green. However, they are composed of two kinds of the breccia-like figures. They show vague boundaries of each other; the one of them is constituted by carbonate minerals as the chief component, and the other mainly by sericite. Such breccia-like figures may be represented by the selective alterations through the hydrothermal processses.

Andesitic propylites, developed in the area of the river of Migimata, are less altered generally than andesitic propylite in the Hidarimata valley, and also characterized by the decreasing of carbonate minerals and pyrite, and by the increasing of iron oxides in amounts.

The phenocrysts of plagioclases are moderately altered, and the original oscillatory zonings are almost disappeared, but, weak zonal structures are sometimes observerd. As shown in Table 5, the plagioclases without zonal structures vary their compositions from albite to andesine, and are mostly andesine or oilgoclase. Plagioclases having weak zonal structures show a change from labradorite in the interior to andesine at the margin. The secondary minerals replacing the phenocrysts of plagioclases are nearly same as those occurring in andesitic propylite in the Hidarimata valley.

However, in comparison with the secondary minerals found in andesitic propylite in the Hidarimata valley, those in the Migimata valley are peculiarized by the decreasings in amount of

the "Type A" chlorite, apatite and carbonate minerals. Among the secondary minerals, these minerals such as pale green chlorite, sericite and fine-grained epidote are reciprocally associated with carbonate minerals. However, a certain kind of chlorite is recognized in the altered plagioclases in the present rock-specimen. It is green in colour, and is closely accompanied with carbonate minerals. Besides, its birefringence and interference colours are higher than those of pale green chlorite. This clay mineral is also named as "Type B" chlorite for convenience.

The mafic minerals are decomposed at all, and are altered to the following mineral assemblage; pale green chlorite + fine grained epidote + iron ores. However, carbonate minerals and quartz, being reciprocally accompanied by the above mentioned assemblage, are sometimes recognized. For iron ores, pyrite is common, and hematite or magnetite is often.

The groundmass is intensely transmuted, although the flow structures are still recognized. Plagioclases in the groundmass exhibit ghosty in general, but some slightly altered plagioclases are commonly oligoclase or sometimes andesine. The original mafic minerals are entirely decomposed and are changed to the following mineral assemblages; pale green chlorite + fine-grained epidote, pale green chlorite + iron ores, and carbonates or pale green chlorite only.

Amygdales and veinlets are commonly observed. The amygdales show usually zoning structure. Namely, the secondary minerals filling the amygdales are arranged zone by zone, and they are grouped together by the following assemblages. In each of these assemblages, the constituent minerals are placed in order from inner to outer side.

1. (carbonates) + pale green chlorite + (epidote) + quartz
2. pale green chlorite + sericite + quartz
3. quartz + (carbonates) + pale green chlorite
4. carbonate minerals + quartz or quartz + carbonate minerals
5. "Type A" chlorite + pale green chlorite + quartz
6. pale green chlorite + carbonates
7. (quartz) + "Type A" chlorite + yellowish green chlorite
8. carbonate minerals + yellowish green chlorite

Here, the parenthesized minerals are small in amount, or often absent. (The same expression shall apply hereinafter). The first six kinds of the above mentioned mineral assemblages are commonly observed, but the last two are rare.

For the veinlets, quartz-vein and carbonates-vein are commonly observed. However, the veinlets having zonal structures are sometimes recognized. The following mineral assemblages are found in these veinlets;

1. quartz + pale green chlorite + (sericite)
2. quartz + carbonates
3. carbonates + yellowish green chlorite

The last mineral assemblage occurs frequently.

(Doleritic Propylite)

Doleritic propylite is less altered than andesitic propylites in usual. Plagioclase phenocrysts are strongly albitized and are transmuted to andesine or oligoclase in their compositions. The original oscillatory zoned structures disappear at all. These plagioclases are replaced by the secondary minerals as follows; pale green chlorite, sericite, carbonate minerals and fine-grained epidote in usual and quartz and apatie in sometimes. Sphene very rarely replaces the phenocrysts of plagioclase in partially. As for these secondary minerals, pale green chlorite, fine-grained epidote and sericite are closely paragenetic with each other and they are, however, reciprocally accompanied by carbonate minerals. Apatite is usually associated with pale green chlorite and quartz.

The original mafic minerals are entirely decomposed, and change to pseudomorphs of the secondary minerals showing the following assemblages.

1. pale green chlorite + fine grained epidote
2. "Type B" chlorite + fine grained epidote
3. carbonates + (pale green chlorite) + quartz
4. carbonates + (quartz)

Here, the first assemblage is the most commonly observed, and the others are sometimes recognized.

For the groundmass, the remarkable fluidal structures are scarcely remained, though the primary minerals are intensely decomposed. Plagioclases in the groundmass are transmuted to andesine or oligoclase. They are almost ghosty crystals. The present minerals are replaced usually in some degrees by sericite, pale green chlorite and carbonates and occasionally by quartz or fine grained epidote. The original mafic minerals are entirely decomposed, and sometimes occur pseudomorphic crystals of pale green chlorite and often of carbonate minerals.

Some amygdales and veinlets are also found. The mineral assemblage found in the amygdales is the following;

quartz + carbonate minerals + fine grained epidote + (pale green chlorite)

Furthermore, the veinlets have the following mineral assemblages;

carbonate minerals + quartz

carbonate minerals + pale green chlorite

Propylite-breccia

In the propylite member, two kinds of propylite-breccia are recognized; viz. the light greenish, so-called "unicoloured propylite-breccia" and "variegated propylite-breccia". The former is distributed in the area of Riv. Hidarimata and the latter in the Migimata valley.

Regarding the unicoloured propylite-breccia, it is characterized by the remarkable alteration closely associated with carbonate minerals and pyrite in great amount. It consists of breccia- and matrix-like parts in all shades of green. The mineral assemblages of the secondary products in the breccia-like part are nearly same as those in the matrix-like part, nevertheless, the former differs from the latter on the quantities of certain secondary minerals.

For an example, the rock specimen (Sample No.8144) is given: The present specimen consists of breccia- and matrix-like parts in all shades of green. The breccia-like parts show varguely their boundaries with the matrix-like parts, and are pale green or light pale green in colour. The secondary minerals found in them are albitized palgioclase, sericite, carbonate minerals, fine-grained epidote and apatite, and are characterized by either the absence or the very rare existence of pale green chlorite. These secondary minerals are grouped together in the following assemblages;

1. albitized plagioclase + sericite
2. sericite + fine grained epidote + apatite
3. carbonate minerals + fine grained epidote
4. carbonate minerals + albitized plagioclase
5. carbonate minerals + sericite

Here, the last three assemblages are recognized in the large phenocrysts of plagioclases, and the second type is found mainly in the altered, columnar shaped, minor plagioclases. The albitized plagioclases, having no zonal structures, are in general mostly andesine (An 40 Ab 60—An 33 Ab 67) or sometimes oligoclase (An 16 Ab 84—An 29 Ab 71) in composition. On the other hand, the matrix-like parts, being dark green in colour, are constituted with the following secondary minerals; pale green chlorite, sericite, albitized plagioclase, fine grained epidote, apatite and iron ore (pyrite). The phenocrysts of plagioclases, being mostly andesine (An 45 Ab 55—An 32 Ab 68) or sometimes oligoclase (An 20 Ab 80—An 28 Ab 72) in their compositions, are entirely decomposed and any zonal structures are not recognized. The mineral assemblages of the secondary minerals replacing the phenocrysts of plagioclases are those as follows;

1. carbonate minerals + albitized plagioclase
2. carbonate minerals + sericite
3. carbonate minerals + (fine-grained epidote)
4. pale green chlorite + sericite + albitized plagioclase + fine-grained epidote + apatite + (carbonate minerals)

The last mineral assemblage is found in the altered minor, columnar-shaped plagioclases. The phenocrysts of the mafic minerals are extremely decomposed and are altered to the pseudomorphic crystals of pale green chlorite or pale green chlorite + fine-grained epidote in common, and often of carbonate minerals. The groundmass of the matrix-like parts, constituting plagioclases and augite, is entirely decomposed. The secondary products from them are pale green chlorite, sericite, apatite and small, scattered iron ores (pyrite).

Collectively speaking on the alterations of the present specimen, both the breccia-like parts and the large phenocrystal plagioclases in the matrix-like parts are characterized by carbonate minerals and sericite as the main secondary minerals. However, these secondary minerals, such as pale green chlorite, sericite, fine-grained epidote and pyrite, occur chiefly in the matrix-like parts excepting for the large phenocrysts of plagioclases. Although both the breccia- and matrix-like parts are the same rock of igneous origin, it may be ascertained that the differences between the two parts are emphasized by the selective alterations.

Furthermore, the rock specimen (Sample No.823), being not associated with carbonates for the secondary products, is described.

The breccia-like parts sometimes include the cumulophyric plagioclases as the core. The large phenocrysts of plagioclases are entirely decomposed and are more or less altered to the secondary products; pale green chlorite, sericite and albitized plagioclase in usual, and sometimes quartz or iron ore (pyrite). These secondary minerals coexist with each other. Moreover, fine-grained epidote is rarely found. The altered plagioclases are mostly oligoclase (An 20 Ab 80—An 28 Ab 72) or sometimes andesine (An 30 Ab 70—An 40 Ab 60). The original mafic minerals are transmuted to the pseudomorphic crystals of pale green chlorite or pyrite. Thus, pale green chlorite and sericite are the main constituent minerals in the breccia-like parts.

The matrix-like parts are mostly originated from the groundmasses of augite andesites. In the matrix-like parts, secondary minerals are nearly the same as these found in the breccia-like parts; viz. albitized plagioclase, sericite and quartz are commonly, pale green chlorite, apatite, iron ore (pyrite) and fine grained epidote is sometimes observed, however, present parts are peculiarized by the following mineral assemblage as the main; sericite + quartz + albitized plagioclase. Namely, the secondary products found in both the breccia- and the matrix-like parts are common, however, there is somewhat difference between the main mineral assemblages. For the present psecimen, it is surely ascertained that the breccia-like figures are due to the selective alteration through the hydrothermal processes.

In general, for the genesis of the breccia-like figures in propylite-breccias, two cases may be considered; it is original and is embossed by the selective hydrothermal alteration, or, it is caused by only selective hydrothermal alteration. The first case is less observed in the unicoloured propylite-brecccias.

As for the variegated propylite-breccias, they are classified petrographically into two types; the one is originated from augite andesite and the other from green hornblende bearing two pyroxene dolerite.

In the first, the variegated propylite-breccias derived from augite andesites are described. They are distributed in only the Migimata valley. In the variegated propylite-breccias, both the breccia-like parts and the matrix-like parts are the same in igneous origin and show the indistinct boundaries with each other. As like as the unicoloured propylite-breocias, most of the breccia-figures in the

variegated propylite-breccias are primary and are also strongly embossed by the selective alterations through the hydrothermal processes.

For an example, the rock specimen (Sample No.7212) is given. The breccia-like parts are mostly light green or sometimes purplish dark green in colour. The glomeroporphyritic plagioclases exhibit usually breccia-figures owing to the hydrothermal alterations. The secondary minerals constituting the breccia-like parts are the followings; carbonate minerals, pale green chlorite and quartz are common, and iron ore and apatite sometimes observed. The mineral assemblage, such as carbonate minerals + pale green chlorite + quartz, is the essential. Apatite is closely associated with quartz. Moreover, the amygdales showing zonal structures are commonly found in the breccia-parts. They are composed of these minerals; pale green chlorite in the inner side and quartz in the outer side. The primary textures are entirely decomposed.

The matrix-like parts have dark shades of reddish purple in colours. Their dark tones of colours are due to iron oxides, hamatite and magnetite. In the present parts, the primary textures are moderately preserved. The phenocrysts of plagioclases are intensely albitized, and are commonly oligoclase (An 23 Ab 77). The other secondary minerals replacing wholly or partly the phenocrysts of plagioclases are given as follows; pale green chlorite, sericite, quartz, carbonate minerals and iron ores (hematite and magnetite). Among these secondary minerals, albitized plagioclase (oligoclase), pale green chlorite and sericite are the essentials. The original mafic minerals are extremely transmuted and are altered to the pseudomorphous crystals of pale green chlorite or pale green chlorite + carbonates in common, and sometimes of carbonate minerals + quartz. These mineral assemblages are accompanied with iron oxides.

The groundmass is intensely decomposed. For the secondary minerals, pale green chlorite is the main constituent mineral in the groundmass. The other secondary products, such as albitized plagioclases, carbonate minerals, sericite, quartz and iron exides are also found.

The matrix-like parts are characterized by these minerals, such as pale green chlorite, sericite and iron oxides, as the main constituents.

As for the another example, the rock specimen (Sample No.7233) is described. The present specimen show undecidedly breccia-figures. Namely, it is composed of two parts; the reddish or redish brown part and the purplish dark greenish part. Each of these parts shows irregular and undistinguishable boundaries and inlets with each other. The reddish parts are characterized by the abundant quantities of iron oxides; hematite in common and sometimes magnetite. On the other hand, the purplish dark greenish parts are also peculiarized by the presences of pale green chlorite and quartz and by the small amounts of iron oxides.

For the reddish parts, they are derived chiefly from the groundmasses of the original rocks. Nevertheless, some phenocrysts of plagioclases are found. The phenocrysts of plagioclases are albitized, and commonly andesine (An 38 Ab 62—An 40 Ab 60). The secondary minerals, replacing partially the phenocrysts of plagioclases, are the followings; albitized plagioclases, sericite, quartz, carbonate minerals, and iron oxides. The mineral assemblage, such as albitized plagioclases + sericite + pale green chlorite, is commonly observed, and the following assemblages are sometimes found; quartz + pale green chlorite, and carbonate minerals + albitized plagioclases + sericite + iron oxides. The primary mafic minerals are quite decomposed and are altered to the pseudomorphous crystals of iron oxides or iron oxides + quartz (small amount). The groundmass, composing chiefly the reddish parts, is entirely decomposed, but the original textures are scarcely observed. The long lath-shaped plagioclases exhibit ghosty crystals or are decomposed to albitized plagioclase and sericite, or iron oxides alone.

As above described, the main mineral assemblage of the secondary products is the followings; iron oxides + albitized plagioclases + sericite.

The purplish dark green parts somewhat differ from the reddish parts for the secondary mine-

rals. The secondary products through the alterations are pale green chlorite, sericite and quartz as the main constituents. The purplish dark green parts are mainly composed of the altered cumulo-phyric plagioclases and the amygdales. The cumulophyric plagioclases are altered to the secondary minerals, which are grouped into the following mineral assemblages; albitized plagioclases (An 32) + sericite + pale green chlorite (small amount), or carbonate minerals + quartz. The first assemblage is common. The secondary minerals found in the decomposed mafic minerals assemble with each other as follows; pale green chlorite + quartz, and carbonate minerals + quartz.

The amygdales and veinlets are also commonly observed in the present parts. They show sometimes zonal structures, and are filled with quartz or carbonates alone, or quartz (inner side) + carbonate minerals (outer side).

The variegated propylite-breccia originated from the doleritic rocks is also mentioned. Here, the rock specimen (Sample No.7205) is taken as an example. The breccia-like figures are moderately embossed, but have indistinct outlines. The breccia-like parts are commonly yellowish green or sometimes dark purplish green in colour. On the other hand, the matrix-like parts are dark green or sometimes reddish purple in colour. The present specimen is generally subjected to the strong alterations, and so the primary constituent minerals and textures are entirely decomposed at all. The phenocrysts of plagioclases are extremely decomposed and are replaced wholly by these secondary minerals; sericite, carbonate minerals and pale green chlorite in common, and sometimes quartz or iron ores (pyrite or iron oxides). Quartz is always accompanied with apatite. The primary mafic minerals are entirely altered and are wholly decomposed at all. In the altered groundmass, quartz and pale green chlorite occur as the main constituents and apatite closely associated with quartz is sometimes observed.

For the matrix-like parts, the secondary minerals found in these parts show the following assemblage; quartz + sericite + carbonate minerals + pale green chlorite + apatite + iron ores (mainly iron oxides and sometimes pyrite).

Collectively speaking, most of the breccia-like figures in propylite-breccias are the primary and are further embossed by the selective alteration through the hydrothermal processes. However, some of them may be only caused by the selective alterations. Furthermore, the general colour-effects of propylite-breccias are attributable to the secondary mineral assemblages including iron ores as the important constituents. And consequently, the difference in colours between the unicoloured and the variegated propylite-breccias are based on the stabilities of some kinds of iron ores, such as pyrite, hematite and magnetite.

Tuff-breccia

In the Futamata region, tuff-breccias, constituting the Futamata propylite member, are widely distributed. Tuff-breccias are also divided into two types; the unicoloured tuff-breccias and the variegated tuff-breccias. The former are mostly developed in the Hidarimata valley, but sometimes gradually change to the latter. On the other hand, in the Migimata valley, the variegated tuff-breccias are mostly observed, however, sometimes the unicoloured tuff-breccias partially found.

The secondary minerals found in the altered tuff-breccias are fundamentally the same as these in propylite, or in propylite-breccias.

For tuff-breccias being distributed in the Hidarimata valley, the rock specimen (Sample No. 8171) is given as an example. In the present specimen, the essential rock fragments, are propylites. Furthermore, the accessory and the accidental rock fragments are also sometimes observed. The accessory fragments are andesitic tuffaceous sandstones; the accidentals are similar to quartz-porphyry in original qualities.

The essential rock fragments, propylites, are deep green in colour. The phenocrysts of plagioclase, exhibiting large tabular and small columnar crystals, are intensely albitized and are mostly andesine (An 35 Ab 65—An 37 Ab 63). The primary oscillatory zonings are entirely vanished. As the

secondary minerals wholly or partially replacing these plagioclases, pale green chlorite and sericite are commonly recognized; carbonate minerals, quartz and iron ores (pyrite) occur in small amount and are found only in the large tabular plagioclases. The primary mafic minerals are exceedingly decomposed and are altered to pale green chlorite and iron ores (pyrite). The primary minerals in the groundmass are extremely decomposed, however, the fluidal structures of original rock are scarcely preserved. The mineral assemblage found in the altered groundmass is given as follows; pale green chlorite + sericite + albitized plagioclases + quartz + carbonate minerals + iron ores (pyrite). Amont these minerals, pale green chlorite, sericite and albitized plagioclases are most commonly observed. Small amygdaloidal structures including the phenocrystals of plagioclases or mafic minerals as the cores are commonly observed. These amygdales are irregular in form and are filled,with the secondary minerals being arranged zone by zone from inner side to outer side in the following order; (carbonate minerals) + pale green chlorite + pyrite.

Tuffaceous sandstones, as the accessory fragments, are extremely altered and the primary textures vanish al all. The secondary minerals found in the present fragments are as follows; recrystallized quartz + sericite + albitized plagioclases (mostly oligoclase) + pale green chlorite + carbonate minerals. The last two minerals are small in amount. These sedimentary rock fragments seems to be derived from the Hidarimata tuff member.

Among the accidental rock fragments, the fragments of quartz porphyry are rarely observed. Owing to the intense hydrothermal alterations, the original textures are quite undistinguished. The secondary minerals show the following assemblage; albitized plagioclases (mostly oligoclase) + sericite + quartz + pale green chlorite. Here, the last mineral is very small in amount.

The secondary minerals in the matrices are nearly same as these in the essential rock fragments, but quartz is rather abundant. The mineral assemblage of them is given; quartz + sericite + carbonate minerals + pale green chlorite + albitized palgioclases (mostly oligoclase) + apatite. The last mineral is always associated closely with quartz, exhibiting irregular or sometimes rounded crystals and show mosaic aggregates.

In the present specimen, these minerals, such as pale green chlorite, sericite and quartz, are the main constituent minerals as the secondary products, although there are small differences for the secondary products among the altered rock fragments or the matrices.

In general, the mineral seemblages found in the altered tuff-breccias are rather variable, however, the following assemblage among them is the fundamental, and is commonly observed; pale green chlorite + sericite + epidote + corbonate minerals + quartz. Pale green chlorite is closely associated with fine grained epidote and sericite. Furthermore, the idiomorphic or sometimes hypidiomorphic epidote is always associated with carbonate minerals. Carbonate minerals are reciprocally related, in amount, to pale green chlorite and sericite.

For the tuff-breccias, being developed in the Migimata valley, they are composed chiefly of the variegated tuff-breccias.

The variegated tuff-breccias, being associated with andesitic propylite bodies, are given. The rock specimen (Sample No.7232) is taken as an example. The rock fragments found in this specimen are composed mainly of the essential fragments, and the accessory ones are rarely observed. The essential rock fragments, being of andesitic propylite, are commonly dark green or sometimes purplish dark green in colour. The reddish fragments are rarely observed. For the rock fragments, the essential phenocrysts are extremely altered, and also original mafic minerals are decomposed at all, changing to the pseudomorphic crystals of the following mineral assemblages, viz. carbonate minerals + iron ores, or yellowish green chlorite + iron ores. On the other hand, plagioclases are moderately albitized and are mostly andesine (An 36 Ab 64—An 40 Ab 60) or often oligoclase (An 24 Ab 76—An 30 Ab 70).

The secondary minerals, replacing plagioclases in whole or partial, are grouped together into

two types. The first type, being composed of carbonate minerals as the main constituent, is given; carbonate minerals + quartz + sericite + apatite (small amount), in order of amount. The second type exhibits the following assemblage; albitized plagioclases (An 30 Ab 70) + sericite + carbonate minerals + pale green chlorite, in order of quantity. However, the first type is less in amount observed than the second type.

The primary minerals in the groundmasses are generally decomposed. However, the original textures are scarcely recognized. The secondary minerals found in the altered groundmasses are the followings; albitized plagioclases (An 24 Ab 76—An 36 Ab 64), sericite, pale green chlorite, iron ores, quartz, carbonates and apatite in order of quantity. These secondary minerals are grouped into two types by the main assemblage; either carbonate minerals + quartz + sericite + apatite, or albitized plagioclases (mostly oligolcase) + sericite + carbonate minerals + pale green chlorite, in order of amount, respectively. The first type is far less observed than the second type.

For the matrices of the present specimen, they are mainly composed of crystal fragments and secondary small grained quartz. The last mineral is irregular or often rounded crystals, showing a certain mosaic aggregates. Plagioclase fragments are wholly or partially transmuted to the minerals as follows; sericite, albitized plagioclases (mostly andesine (An 40 Ab 60—An 30 Ab 70) or sometimes oligoclase (An 23 Ab 77—An 28 Ab 72)), quartz, pale green chlorite, apatite and iron ores. The secondary minerals are grouped together into the following assemblages;

1. pale green chlorite + quartz + apatite + sericite + albitized plagioclase + iron ores.
2. carbonate minerals + quartz + sericite + albitized plagioclases + iron ores

Here, pale green chlorite reciprocally coexists with carbonate minerals, and apatite is closely paragenetic with the secondary quartz. The mafic mineral fragments are wholly altered mainly to yellowish green chlorite or sometimes to pale green chlorite; these chlorites are usually accompanied with iron ores.

In the matrices, the vesicles and the veinlets, filled with carbonate minerals or sometimes with carbonate minerals and quartz, are often recognized.

In general, as compared with the secondary products found in the rock fragments, those in the matrices are peculiarized by the increasings of the secondary quartz and carbonate minerals and also by the decreasing of pale green chlorite.

The same variegated tuff-breccias, being associated with doleritic propylite distributed in the downstream of the river of Migimata, are described. The rock specimen (sample No.7205) is given as an example.

The rock fragments in this specimen are usually dark green and sometimes reddish purple or light pale green in colour. On account of the strong hydrothermal alterations, the breccia-shapes are vague and undistinguished with the matrices at their margins.

The phenocrysts of plagiolcases in the rock fragments are mostly pseudomorphic crystals of the secondary minerals as follows; sericite, carbonate minerals, pale green chlorite, iron ores, quartz and apatite in descending order in amount. The first mineral, sericite, is the most common. The mafic minerals are entirely decomposed, and even their pseudomorphic crystals are not recognized at all.

The primary minerals in the groundmass also are entirely decomposed, and the original fluidal structures are in very poor preservations. The groundmass consists of the secondary products, such as quartz, pale green chlorite, iron ores and apatite. The last mineral is, as usual, closely associated with the secondary quartz. For iron ores, iron oxides are accompanied with pale green chlorite or sericite, and on the other hand, pyrite is commonly accompanied by carbonate minerals or secondary quartz.

The matrices of the present specimen are constituted from the secondary products; fine-grained quartz, sericite, pale green chlorite, carbonate minerals, iron ores and apatite. Owing to the existences of iron oxides, which are in small amount, and are paragenetic with pale green chlorite or sericite,

the matrix-parts are sometimes reddish purple or purplish dark green in colour. Furthermore, in the matrices, minute flaky or scaly sericite fill the spaces among the small rounded, recrystallized primary quartz grains.

Collectively speaking of the general aspects of the mineral assemblages in the variegated tuff-breccias, as mentioned above, the following assemblages of the secondary minerals are the essentials; pale green chlorite + sericite + quartz, and carbonate minerals + quartz + sericite.

The former is recognized in the groundmasses of the rock-fragments and also in the matrices; the latter is usually observed at the phenocrysts of minerals in the rock fragments or at the large crystal fragments in the matrices. Moreover, as epidote concerns, the fine grained epdote is closely paragenetic with pale green chlorite or sericite, and the idiomorphic or sometimes hypidiomorphic epidote shows a tendency to coexist always with carbonate minerals, and also frequently with the secondary quartz. For an example, in the specimen (Sample No.8134) being sampled from the variegated tuff-breccias developed in the valley of Riv. Migimata, the idiomorphic prisms of epidote are of pale yellowish green in colour and intimately associated with carbonates or secondary quartz. They replace mainly the phenocrysts of plagioclases in the rock fragments of propylite or sometimes plagiolcases in the matrices. On the other hand, the fine-grained, anhedral epidote, coexisting with pale green chlorite, is mostly recognized in the groundmass and in the altered mafic pseudomorphic crystals in the fragments of propylite. The idiomorphic or hypidiomorphic crystals of epidote exhibit the following optical properties.

$$Pleochroism: \quad X: \quad \text{pale yellow}$$
$$Y: \quad \text{yellowish green}$$
$$Z: \quad \text{yellowish green}$$

2Vz : 103° - 107°

X∧C: 4° - 6°

(c) Migimata Acidic Tuff Member

In the Migimata acidic tuff member distributed in the examined region, the pale green chlorite zone is rarely established. Both rhyolitic lava flows and tuff-breccias in the pale green chlorite zone are light pale green or whitish pale green in colour.

In rhyolitic lava flows, the phenocrysts of plagioclases are moderately albitized and are mostly andesine (An 42.Ab 58 — An 32 Ab 68) or sometimes oligoclase (An 23 Ab 77—An 30 Ab 70). The primary oscillatory zonings are usually preserved. The other secondary minerals, replacing partially these plagioclases, are the followings; pale green chlorite, sericite, quartz and carbonate minerals. The last minerals are small in amount. The phenocrysts of the mafic minerals are strongly decomposed, however, the relict minerals, green hornblende, are often recognized. These mafic minerals are altered wholly or partially to pale green chlorite in usual, and often to yellowish green chlorite. These secondary products are associated with carbonate minerals.

The primary minerals in the groundmass of rhyolitic lava flows are entirely decomposed; the secondary minerals in it show the assemblage as follows; pale green chlorite + sericite + albitized plagioclases (mostly oligoclase) + quartz + iron ores. Here, carbonate minerals are rarely found. The glassy materials are transmuted to the secondary products. They exhibit likely amygdaloidal structures, which show sometimes annular structures and are filled with pale green chlorite or yellwish green chlorite (inner side) and quartz (outer side).

The characters of the alterations examined in rhyolitic tuff-breccias are nearly the same as these in rhyolitic lava flows. However, in general, especially in the matrices, the secondary quartz increases in amount as the main constituent. The present quartz is very rarely associated with apatite.

(d) Intrusive Rocks

In the Futamata region five kinds of the intrusive rocks, such as diorite-porphyrite, andesite, dacite, quartz-porphyry and lithoiditic rhyolite in intrusive order, are recognized. Each of them, be-

ing situated in the pale green chlorite zone, is described respectively.

   Diorite-porphyrite

   In general, diorite-porphyrites are situated at the axes of the pale green chlorite zone. These rocks are divided into two types, viz. large intrusive mass and small dykes.

   In the first, diorite-porphyrite mass is described. Generally and briefly speaking, plagioclases are usually albitized in some degrees and are wholly or partially replaced by the following secondary minerals; sericite, pale green chlorite, fine-grained, anhedral or idiomorphic prismatic epidote, quartz and carbonate minerals. Among these secondary products, pale green chlorite, sericite and albitized plagioclases are the main constituents. They decrease relatively in amount in the slightly albitized plagioclases, in which the primary oscillatory zonal structures are moderately preserved, and also decrease as increasing of quartz and carbonate minerals. Quartz is commonly recrystallized, and is closely accompanied by apatite. The present mineral, moreover, builds sometimes myrmekitic structures with albitized plagioclases. The mafic minerals are also decomposed, and are commonly altered to the following secondary products; actinolite, pale green chlorite, carbonate minerals, pyrite, quartz, epidote, "Type A" chlorite and "Type B" chlorite. For the "Type B" chlorite, it builds flake-like or scaly crystals, and of pale green in colour. Its optical properties are given as follows;

   Pleochroism: X':   pale green
                     Z':   brownish green
   interference colour : abnormal, ultra blue or auburn

   Besides, the present mineral is intimately associated with pale green chlorite or sometimes carbonate minerals in small amount.

   In general, chlorite minerals, such as pale green chlorite and "Type A" and "Type B" chlorites show a tendency of being reciprocally associated with carbonate minerals.

   Quartz is always recrystallized and sometimes includes the minerals as follows; apatite, sericite, pale green chlorite and epidote. The last mineral is rare in amount.

   The rock specimen (Sample No.7302) is also taken as an example. Among the initial constituent minerals, plagioclases are remarkably altered, and show their undistinct outlines at the margins. The primary oscillatory zonings and twinnings are entirely disappeared, and so, albitized plagioclases are not able to be determined their composition under the microscope. The secondary minerals replacing plagioclases are the followings; sericite, pale green chlorite, carbonate minerals, quartz, apatite and albitized plagioclase. Among these secondary products, sericite and pale green chlorite are the main, and are associated with carbonate minerals. Apatite is always associated with the secondary quartz.

   The mafic minerals, being initially augite and common hornblende, are extremely decomposed. The pseudomorphic crystals are sometimes observed. The secondary products caused of the decompositions of the mafic minerals are carbonate minerals, pale green chlorite, yellowish green chlorite, iron ores, "Type A" chlorite, quartz, apatite and fine grained epidote. Here, carbonate minerals in the altered mafic minerals are more abundant than those found in the altered plagioclases. Furthermore, "Type A" chlorite coexists usually with pale green chlorite. Among the secondary minerals, they, such as pale green chlorite, iron ores, carbonate minerals and "Type A" chlorite, are the essentials.

   Quartz is usually recrystallized, and builds sometimes myrmekitic structures with albitized plagioclases. The present mineral has abundant inclusions, such as apatite, sericite, pale green chlorite and epidote. The last mineral builds fine grained, and minute anhedral crystals.

   Moreover, in the present specimen, small veinlets filled with carbonate minerals are sometimes recognized, and are like as segregated veins.

   As another example, the rock specimen (Sample No.862) is given. The present specimen shows

hollocrystalline doleritic textures rather than granular textures. On account of weak alteration, the initial constituent minerals are moderately preserved. Plagioclases are comparatively fresh, and oscillatory zonal structures are well distinguished. However, they are somewhat ghosty at the marginal parts. These relict minerals are commonly labradorite (An 63 Ab 37—An 59 Ab 41) or often andesine (An 30 Ab 70—An 47 Ab 53) and sometimes oligoclase (An 15 Ab 85—An 28 Ab 72) in composition at the margins. The present minerals are partially replaced by these secondary products as follows; sericite, albitized plagioclases (mostly Na-rich oligoclase (An 11 Ab 89—An 28 Ab 72)), quartz, carbonates, apatite, fine-grained epidote, pale green chlorite and sphene. Among them, sericite, albitized plagioclase, quartz and carbonate minerals are the main. Sphene is very rare, and builds anhedral crystals, being always associated with pale green chlorite and also with fine-grained epidote.

As the mafic minerals concern, augite is entirely altered to actinolite. Pale green chlorite and iron ores, replacing partially augite, also sometimes observed.

Common hornblende is relatively decolourized, on account of the alterations, commonly to pale green, however having sensible pleochroism. On the other hand, the relict hornblende, viz. brown hornblende being very rarely recognized, is also sometimes replaced partially by carbonate minerals and iron ores. Common hornblende is usually transmuted to actinolite, and sometimes is replaced partially by pale green chlorite, or by carbonate minerals. The present pale green chlorite is sometimes accompanied with fine grained, yellowish green epidote.

In this specimen, the minute flake-like biotite is very rarely recognized. The present mineral is often strongly decolourized owing to the hydrothermal alterations. It is sometimes changed partial to the following secondary products; iron ores and pale green chlorite. The last mineral is sometimes closely associated with the fine-grained anhedral epidote.

Quartz is generally recrystallized and is accompanied by apatite. Apatite builds long columnar or long needle-shaped crystals, and is pale green or sometimes clourless in colour. The present mineral occurs sometimes nearby brown biotite.

In the next, the diorite-porphyrite dykes are described. These dyke rocks show generally doleritic textures that is somewhat similar to fine-grained ophitic textures, rather than granular ones. The qualities of the alterations of them are almost the same as those of the diorite-porphyrite mass as mentioned above. For the example, the rock specimen (Sample No.8121) is given here. In the present specimen, plagioclases, augite and quartz are the primary constituents minerals. Plagioclases are remarkable oscillatory zonings preserved, and are mostly andesine (An 50 Ab 50) in the cores. They are replaced partially by the following secondary products; albitized plagioclases (mostly oligoclase (An20Ab80-An30Ab70), quartz, carbonate minerals, pale green chlorite, apatite, fine-grained epidote and sericite. Among them, the main constituents are the followings; albitized plagioclases, quartz and carbonate minerals. Quartz is always accompanied by needle-shaped apatite and forms myrmekitic structures with albitized plagioclases. On the other hand, albitized plagioclases are closely paragenetic with sericite and pale green chlorite, and associated with carbonate minerals.

Augite is almost decomposed, however, its relict crystals are rarely recognized. The secondary products replacing it are grouped into the following assemblages; pale green chlorite + iron ores + fine grained epidote, and quartz + carbonate minerals. Furthermore, small veinlets, being like segregated veins, are frequently observed. They are filled by the following minerals; carbonate minerals only, carbonate minerals + quartz, and pale green chlorite in amount order.

Generally speaking in brief, both the mass and the dykes, of diorite-porphyrite, exhibit almost same qualities of the alterations through hydrothermal processes, although there are a certain differences between them in rock-composition.

Augite Andesite

In the investigated region, the augite andesitic dykes are also subjected to the alterations in some degrees. Augite andesite, being classified into the pale green chlorite zone, are chiefly distributed in the Hidarimata valley.

For their alterations, the phenocrysts of crystals, such as plagioclases and augite, are usually replaced by the secondary products in various degree, and are sometimes entirely decomposed. Moreover, the constituent minerals in the groundmass are also relatively decomposed. However, the fluidal structures are scarcely preserved.

The phenocrysts of plagioclases are wholly or partially replaced by the following secondary minerals; albitized plagioclases (mostly oligoclase (An20 Ab80—An30 Ab70) and sometimes andesine (An 30 Ab 70—An 44 Ab 56)), pale green chlorite, carbonate minerals, sericite, quartz and epidote. Pale green chlorite, as a rule, is associated with carbonate minerals, however it is intimately paragenetic with fine-grained, anhedral epidote. On the other hand, carbonate minerals coexist closely with idiomorphic or hypidiomorphic epidote, and also rarely with zoisite. The secondary quartz builds sometimes myrmekitic structures with albitized plagioclase. Besides, the oscillatory zonal structures in the initial plagioclases are comparatively preserved.

Augite is commonly decomposed, nevertheless, the relict crystals are somemties recognized. These minerals, such as pale green chlorite, quartz and carbonate minerals, chiefly replace it in whole or partial. The first mineral is frequently accompanied by fine-grained epidote.

The rock specimen (Sample No.8179) from the Hidarimata valley, is described as example.

The phenocrysts of plagioclases are mostly changed to andesine (An 37 Ab 63) and the initial oscillatory zonings are extremely undistinguished, but the slightly altered plagioclases having weak zonal structures are sometimes ascertained. The secondary products replacing, in some degrees, plagioclases are the followings; pale green chlorite, albitized plagioclases, carbonate minerals, epidote, apatite and sericite. Pale green chlorite occurs as networks, and is sometimes accompanied by the fine-grained, anhedral epidote. Carbonate minerals are frequently associated with the anhedral fine-grains or the idiomorphic prisms of epidote, which shows sometimes radial aggregates, and its optical properties is given as follows;

Pleochroism: X: pale yellow
Y: lemon yellow
Z: yellowish green
X∧C: 3° - 4°
2Vz : 108° - 110°

Apatite exhibits long columnar or needle shaped crystals, and is closely paragenetic with albitized plagioclases and often carbonates. The phenocrysts of augite are perfectly decomposed, and even pseudomorphic crystals can not be recognized at all. The present minerals may be altered to pale green chlorite and epidote.

The primary minerals in the groundmass are intensely decomposed. However, the lath-shaped plagioclases in the groundmass are comparatively fresh, and have remarkable zonal structures, which change from andesine (An 37 Ab 63—An 50 Ab 50) in the interior to oligoclase (An 24 Ab 76—An 30 Ab 70) in composition at the margin.

Nevertheless, the extremely decomposed plagioclases are sometimes observed. They are ghosty crystals, and the zonal structures are entirely disappeared. The secondary minerals replacing these plagioclases are the followings; albitized plagioclases (mostly oligoclases (An 20 Ab 80—An 30 Ab 70)), sericite, pale green chlorite, apatite, epidote and carbonate minerals. However, plagioclases replaced mainly by sericite + pale green chlorite assemblage are less decomposed than those replaced chiefly by epidote + carbonate minerals assemblage.

Augite in the groundmass is perfectly decomposed at all, and is altered to pale green chlorite and epidote. As for epidote, caused of the decompositions of plagioclases and of augite, it is hypi-

diomorphic, or often anhedral crystals, and show moderate pleochroism. It is intimately associated
with carbonate minerals rather than pale green chlorite. Its optical characters are somewhat differ-
ent from those of epidote replacing the phenocrysts of plagioclases.

Pleochroism: X: faint yellowish green
                   Y: yellowish green
                   Z :   yellowish green

X∧C: 4° - 5°

2Vz :   109° - 110°

For the second example, the rock specimen (Sample No.851) is also described. The present
specimen is so strongly altered that the initial constituents, especially mafic minerals, are almost
decomposed. The primary minerals in this specimen are also altered to the secondary products as
neary same as those found in the above mentioned example. In the groundmass, amygdaloidal struc-
tures and veinlets filled with the secondary minerals are frequently ascertained. They show usually
zonal structures, and are filled by the minerals, showing such assemblages as follows; carbonate
minerals + pale green chlorite + quartz (inner→outer), quartz + pale green chlorite + (carbonate
minerals), (inner→outer), and quartz alone. Moreover owing to the selective alterations, breccia-
like figures in the groundmass are rarely observed. For an example, in the groundmass of the rock
specimen (Sample No.876), the breccia-like figures consisting of pale green parts and dark green
parts in colour are recognized. The pale green parts are composed mainly of carbonate minerals and
quartz, and of pale green chlorite in small amount, on the contrary, pale green chlorite and quartz
are mostly found in the dark green parts. Each of the two parts shows undistinguished outlines and
change gradually into each other.

Hornblende Dacite

In the Futamata region, dacite, belonging to the pale green chlorite zone, is very partially as-
certained. Here, green hornblende dacite is typically described.

The phenocrysts of plagioclases and green hornblende are altered in some degrees to the second-
ary products. Plagioclases are moderately decomposed, but the initial zonal structures are relatively
preserved. The secondary products found in them are the followings; oligoclase (An 24 Ab 76—An
30 Ab 70), pale green chlorite, sericite, carbonate minerals, quartz, apatite and fine grained epidote.
For these secondary minerals, pale green chlorite, oligoclase and sericite are the essentials. The
needle-shaped apatite is small in amount and is always paragenetic intimately with the secondary
quartz or sometimes oligoclase.

The relict green hornblende is frequently observed, but it is replaced in partial by the secondary
minerals, which are chiefly pale green chlorite and iron ores, and sometimes quartz and fine grained
epidote. Carbonate minerals are also observed and rarely recognized.

As quartz concerns, it is generally recrystallized and shows rounded or often corroded crystals
without any undulatory extinctions. Furthermore, the secondary minerals being included in quartz
are sometimes recognized, and they are the followings; pale green chlorite, sericite, carbonates and
apatite.

Plagioclases in the groundmass are usually ghosty crystals of oligoclase in composition, owing
to the albitization. Furthermore, some secondary minerals replacing partially them are sometimes
ascertained and are the followings; pale green chlorite, sericite and quartz are in common, on the
contrary, carbonate minerals are in rare. The secondary minerals caused of the devitrifications of
glass materials exhibit amygdaloidal structures, and are composed of pale green chlorite, quartz and
carbonate minerals. For these minerals, they are grouped into the following assemblage, pale green
chlorite + quartz or carbonate minerals + quartz.

Quartz Porphyry

Quartz porphyry, being distributed in the only one place in the Futamata region, is very ex-

tremely transmuted through the hydrothermal processes. The primary phenocrysts, such as plagioclases, quartz and hornblende, are intensely decomposed to the secondary products.

Plagioclases are almost replaced by the following secondary minerals; oligoclase, sericite, pale green chlorite and quartz. Furthermore, quartz crystals, showing rounded or often corroded crystals without any undulatory extinctions, are sometimes associated with apatite, and have some inclusions, such as sericite, apatite, pale green chlorite and carbonate minerals.

Green hornblende is extremely decomposed at all. Even pseudomorphic crystals are almost undistinguished. In rare case, the present mineral is entirely replaced by pale green chlorite, carbonate minerals, iron ores and quartz. The last mineral is rare in amount, and the first two are the essentials.

The groundmass is exceedingly altered, and so, original textures are entirely disappeared. the consituent minerals of the altered groundmass are those as follows; quartz, sericite, pale green chlorite, apatite, carbonate minerals, albitized plagioclases (oligoclase), iron ores and minute fine grained epidote. Here, the mineral assemblage, such as, quartz + carbonate minerals + iron ores (pyrite) + (apatite), quartz + carbonate minerals, and pale green chlorite + sericite + (fine grained epidote), are mainly and commonly recognized. Furthermore, some veinlets as like as networks are also observed in the groundmass. They are filled with quartz and or carbonate minerals.

Rhyolite

As an example of rhyolites belonging to the pale green chlorite zone, the rock specimen (Sample No.8181), obtained in the Hidarimata valley, is described. Although rhyolite is originally lithoiditic ones in general, the phenocrysts of plagioclases and green hornblende are sometimes observed. The phenocrysts of plagioclases are wholly changed to the pseudomorphic crystals of the secondary products as follows; carbonate minerals, epidote, pale green chlorite, sericite, quartz, pyrite and albitized plagioclases (mostly oligoclase). Here, the last three minerals are infrequently observed. Among these minerals, carbonate minerals have quitely reciprocal associations with pale green chlorite and sericite. Epidote replacing the phenocrysts of plagioclases is divided into two types; the one is idiomorphic or sometimes hypidiomorphic crystals with faint pelochroism, and very light pale yellow in color, on the other hand, the other builds hypidiomorphic or anhedral crystals with sensible pleochroism, and is yellowish green in colour. The former is always associated with carbonate minerals; the latter is usually accompanied by pale green chlorite. The optical properties of the former are given as follows;

Pleochroism: X: colourless
                Y: pale yellowish green
                Z: colourless

$X \wedge C$: $2° - 3°$

$2Vz$: $104°$

The initial mafic mineral, green hornblende, is entirely decomposed, and even pseudomorphic crystals are scarcely recognized. From some pseudomorphs, green hornblende is transmuted into the secondary minerals showing the following assemblages as the main; pale green chlorite + epidote, and carbonate minerals + quartz + (epidote).

The primary minerals in the groundmass are intensely decomposed. Plagioclases are extremely albitized, and exhibit ghosty crystals of oligoclase. However, the pseudomorphous crystals of sericite or pale green chlorite are occasionally recognized. The secondary products caused of the decompositions of the partial alterations of plagioclases are mainly sericite, carbonate minerals, pale green chlorite and albitized plagioclases, furthermore, are occasionally quartz, epidote and iron ores. The primary mafic mineral is perfectly transmuted to pale green chlorite and carbonate minerals respectively as the main products. Pale green chlorite is sometimes accompanied by the minute fine-grained epidote. Besides, carbonate minerals are also sometimes paragenetic with the idiomorphic or often hypidiomorphic crystals of epidote, of which optical properties are given as follows;

Pleochroism: X: colourless
                 Y: yellowish green
                 Z: yellowish green

$X \wedge C$: $4° - 5°$

$2Vz$: $102°$

In the groundmass, moreover, amygdaloidal structures which are large or small in scale, are frequently recognized. The secondary minerals found in them show usually zonal arrangements. Namely, in each of the following mineral assemblages, these minerals are arranged from inner to outer side.

1. sericite + (quartz) + pale green chlorite + quartz
2. pale green chlorite + (sericite) + quartz
3. sericite + (quartz) + pale green chlorite + carbonate minerals + epidote

Among these three assemblages, the first two assemblages are far more frequently recognized than the third. In the third mineral assemblage, the idiomorphic or sometimes hypidiomorphic crystals of epidote are also ascertained green or yellowish green in colour, and shows sensible pleochroism. It always intimately coexists with carbonate minerals. Its optical properties of are given as follows;

Pleochroism: X: pale yellowish green
                 Y: lemon yellow
                 Z :   yellowish green

$X \wedge C$: $4° - 6°$

$2Vz$: $103° - 106°$

The veinlets, assumed to be of segregation origin, are recognized in the groundmass. They show somewhat band-like structures filled with the secondary minerals. The veinlets are grouped into three types, as follows;

1. sericite
2. sericite + carbonates
3. sericite + carbonates + epidote

As the second or the third type concerns, each of the constituent minerals is arranged in order from inner to outer side in the above mentioned order.

(e) General aspects of the pale green chlorite zone.

Although there are a certain differences among the original rocks distributed in the Futamata region, the secondary minerals found in the altered rocks consist chiefly and commonly of the following minerals; pale green chlorite, albitized plagioclases, sericite, epidote, carbonate minerals, quartz, apatite and iron ores. These essential secondary minerals are gouped into the following assemblages.

1. pale green chlorite + albitized plagioclases + sericite + (quartz) + (fine grained epidote) + (apatite) + (iron ores).
2. carbonate minerals + quartz + epidote + apatite + (iron ores) + (albitized plagioclases)
3. albitized plagioclases + quartz + sericite + apatite + (pale green chlorite)
4. pale green chlorite + iron ores + (fine grained epidote) + (quartz) + (apatite)
5. carbonate minerals + epidote
6. carbonate minerals + epidote + quartz + (apatite) + (pale green chlorite)

Furthermore, though the otherwise mineral assemblages are frequently recognized, these above-mentioned ones are exceedingly of the essentials, and are recognized in indepedent of the qualities of the original rocks. Furthermore, in one rock species, and even in one thin section of the rock specimen, two or more different assemblages can be sometimes recognized.

Judging from the descriptions of the alterations of the original and the altered rocks, it may be surely considerable that the pale green chlorite zone, as well as the other alteration zones, is estab-

lished through the hydrothermal processes. Namely, for an example, it will be reasonable that apatite was generated with the enrichments of flourine and/or chlorine through the hydrothermal processes: on the genesis of the alteration zones, it is discussed in details in the end of this part 11.

(IV) Yellowish Green Chlorite Zone

The yellowish green chlorite zone is always situated on the both sides of the pale green chlorite zone, and is mainly distributed in the Migimata valley. In general, the Neogene system, belonging to the present zone, is subjected to the alterations in less degree than in the pale green chlorite zone.

—Description—

(a) Futamata Propylite Member

In the Futamata propylite member, yellowish green chlorite is commonly paragenetic with pale green chlorite of being small or large in amount.

Propylite

In the first, augite andesitic propylite is mentioned. For an example, the rock specimen (Sample No.8245) is taken here. The phenocrysts are intensely altered. The phenocrysts of plagioclases are usually albitized in a greater degree, and the primary oscillatory zonings are scarcely preserved. The secondary minerals replacing plagioclases are the followings; oligoclase, sericite, carbonate minerals, pale green chlorite, quartz, yellowish green chlorite and fine grained epidote. Among these secondary minerals, oligoclase, sericite, carbonate minerals, pale green chlorite and yellowish green chlorite are the essentials, which assemble with each other as follows;

1. oligoclase + sericite + pale green chlorite + (yellowish green chlorite)
2. carbonate minerals + yellowish green chlorite + (oligoclase) + (sericite)

Carbonate minerals are ordinary associated with yellowish green chlorite, and rarely with pale green chlorite. Moreover, yellowish green chlorite is sometimes accompanied with fine-grained epidote.

Augite is entirely decomposed, and even pseudomorphic crystals are undistinguished. The secondary products of it are as follows; pale green and yellowish green chlorites in usual, carbonate minerals, iron ores, fine-grained epidote and quartz in often. Yellowish green chlorite coexists commonly with pale green chlorite, and is sometimes associated with carbonate minerals and fine grained epidote. In general, carbonate minerals are small in amount, and are often paragenetic with the secondary quartz.

In the groundmass of the present specimen, the original fluidal structures are entirely decomposed. The secondary minerals found in the altered groundmass are the followings; albitized plagioclases (mostly oligoclase (An 24 Ab 76—An 30 Ab 70)), quartz, pale green chlorite, yellowish green chlorite, carbonate minerals, fine grained epidote and iron ores. Among these, oligoclase, quartz, pale green and yellowish green chlorites and iron ores, are of the essentials.

Furthermore, in the groundmass, the amygdaloidal structures are sometimes recognized, showing zonal structures. They are generally filled with quartz in the interior side and with carbonate minerals in the outer side. Carbonate minerals are occasionally absent.

In next, doleritic propylite, distributed in the Migimata valley, is described. The rock specimen (Sample No.8311) is taken as an typical example. The present specimen has comparatively indistinct fluidal structures in the groundmass on account of the alterations.
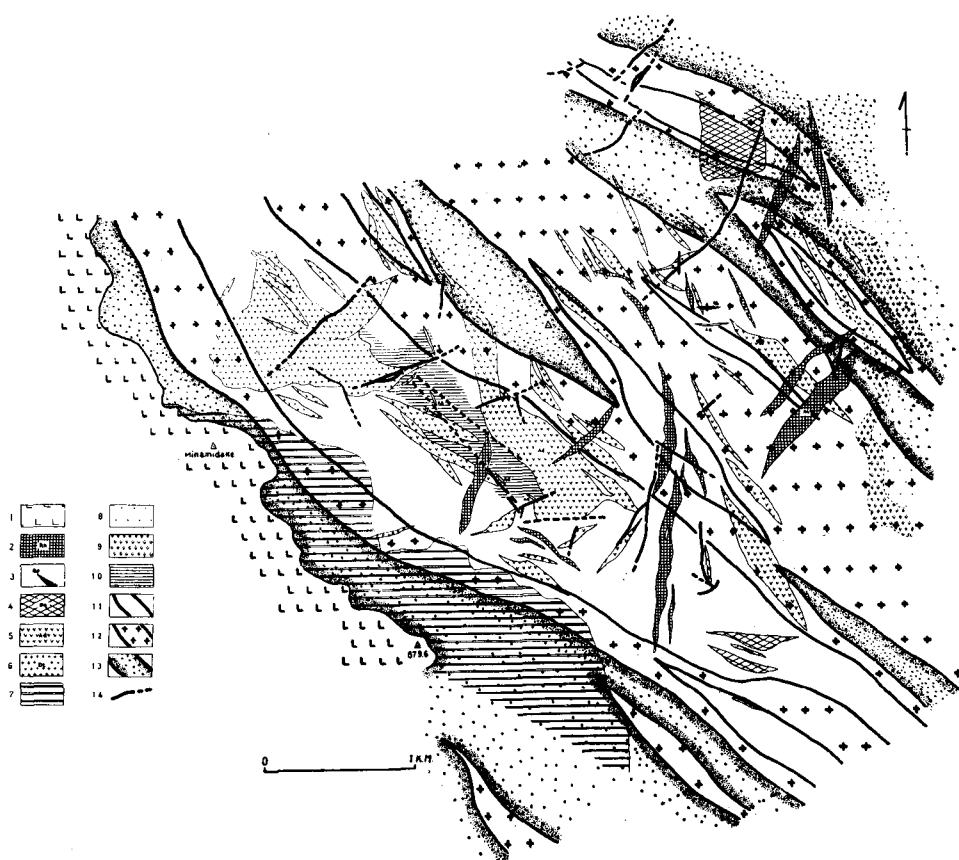
Fig. 11

1. Yoichi-Dake Lava-flows
2. Rhyolite
3. Quartz Porphyry
4. Hornblende & Hypersthene Dacites
5. Augite Andesite
6. Diorite Porphyrite
7. Yunosawa Tuff Member

8. Rhyolitic Tuff-breccia
9. Rhyolite Flow
10. Hidarimata Tuff Member
11. Pale Green Chlorite Zone
12. Yellowish Green Chlorite Zone
13. Saponite Zone
14. Fault System

The phenocrysts of plagioclases are moderately albitized, and weak oscillatory zonings, showing a change from andesine (An 41 Ab 59—An 50 Ab 50) or labradorite (An 62 Ab 38—An 69 Ab 31) in the interior to oligoclase (An 20 Ab 80—An 29 Ab 71) or andesine (An 36 Ab 64—An 49 Ab 51) at the margin, are usually recognized. The secondary products, due to the partial alterations of plagioclases, are as follows; albitized plagioclases (mostly oligoclase), sericite and yellowish green

chlorite in common, and moreover, quartz, carbonates and fine grained epidote in small or rare amount. Here, yellowish green chlorite is intimately associated with sericite.

The phenocrysts of augite are moderately altered, and, therefore, the relicts are sometimes recognized. The secondary products of augite are saponite, epidote, iron ores, yellowish green chlorite and quartz in quantitative order. The last two minerals are small in amount.

The essential minerals in the groundmass are the followings; yellowish green chlorite, oligoclase, saponite, quartz and epidote. Especially, yellowish green chlorite, oligoclase and saponite are the main. Furthermore, the following assemblages are commonly observed;
1. yellowish green chlorite + saponite + epidote + (quartz)
2. yellowish green chlorite + oligoclase + quartz + saponite

The large or small amygdales having banded or annular structures are frequently recognized, and are filled with these minerals, such as yellowish green chlorite in the inner and quartz in the outer sides.

Propylite-breccia
For the unicoloured propylite-breccias, being developed in the Hidarimata valley, as an example the rock specimen (Sample No.8183) is taken here. In the present specimen, as well as other propylite-breccias, both the breccia-like and matrix-like parts are also ascertained, though they show undistinct boundaries with each other, and are of the same origin, viz. igneous origin. For the present specimen, the breccia-like parts are whitish pale green or pale green in colour, and are characterized by the secondary quartz as the main constituent mineral, on the other hand, the matrix-like parts are light pale green or dark green in colour, and are also characterized by the following minerals, such as pale green and yellowish green chlorites, carbonate minerals and sericite, as the essential constituents among the secondary products.

The breccia-like parts are more altered and decomposed than the matrix-like parts, and so, the initial phenocrysts of plagioclases and augite, and the primary minerals in the groundmass are entirely decomposed. Moreover, even pseudomorphic crystals are scarcely distinguished. The secondary minerals found in the altered present parts are those as follows; quartz, sericite, pale green chorite, oligoclase or sometimes albite, carbonate minerals and iron ores (pyrite). The first two minerals are the essentials. Furthermore, the amygdaloidal structures, showing zonal structures, are sometimes observed. They are usually composed of these minerals, viz. pale green chlorite in the interior and quartz in the outer side.

In the matrix-like parts, the primary minerals are intensely decomposed, and the relict crystals are very scarcely recognized. The phenocrysts of plagioclases are wholly altered to the secondary products, such as sericite, carbonate minerals, yellowish green chlorite and oligoclase or albite. Beside, these minerals, which are quartz and iron ores, are also recognized, but in small amount.

Angite is perfectly decomposed mainly to pale green chlorite and pyrite. Besides, these minerals, of being sericite, carbonate minerals and quartz, are also recognized, but are small in amount.

In the groundmass of the matrix-like parts, lath-shaped plagioclases exhibit ghosty, and augite is extremely decomposed. The essential assemblages of the secondary minerals are as follows;
1. sericite + oligoclase + pale green chlorite + (fine grained epidote)
2. carbonate minerals + (oligoclase) + quartz + (epidote) + (pale green chlorite)

Furthermore, the amygdaloidal structures, having zonal structures, are commonly observed in the altered groundmass of the matrix-like parts. The constituent minerals show the following three assemblages, and they are arranged from inner to outer side as the following order for each assemblage.
1. carbonate minerals + pale green chlorite + quartz
2. sericite + pale green chlorite + quartz

3. pale green chlorite + quartz

In next, as an example of the variegated propylite-breccias, the rock specimen (Sample No.8191) is described. In the present specimen, both the breccia-like and the matrix-like parts are also recognized, and the boundaries between them are very vargue.

Though the breccia-like parts are reddish purple or dark green by naked eye, they are dark brown or black under the microscope. In the present part, iron ores, such as hematite and magnetite, are very rich in amount.

The phenocrysts of plagioclases are strongly albitized, and wholly altered to the secondary products. These secondary minerals are the followings; sericite, "Type A" chlorite, iron oxides, carbonate minerals, oligoclase and pale green chlorite. The first three minerals are dominant, and the others are small in amount. Furthermore, "Type A" chlorite is intimately associated with pale green chlorite and sericite.

Augite is quitely decomposed at all, and its secondary products are the followings; iron oxides, yellowish green chlorite, "Type A" chlorite, carbonate minerals and quartz in quantitative order. The first three minerals, especially iron oxides, are dominant in amount, and are also the essentials.

Though the groundmass of the breccia-like parts is intensely altered, the fluidal structures are well preserved. The long lath-shaped plagioclases are transmuted to oligoclase or sometimes to albite. The other secondary minerals, replacing plagioclases, are the followings; iron oxides, pale green chlorite, "Type A" chlorite, quartz and sericite. Nevertheless, the last two minerals are rare in amount. The primary anhedral augite in the groundmass is generally and extremely decomposed, and even its pseudomorphic crystals are scarcely ascertained. It is altered to the secondary products assembling with each other as follows; yellowish green chlorite + iron oxides, and carbonate minerals + iron oxides. The amygdaloidal structures are not found at all in the goundmass.

The matrix-like parts are usually pale green or dark green in colour, and are characterized by the presence of many amygdaloidal structures filled with the secondary products.

The phenocrysts of plagioclases are almost intensely transmuted to the secondary minerals, such as carbonate minerals, quartz, albitized plagioclases (mostly oligoclase or sometimes albite) and "Type A" chlorite in common, and pale green chlorite in often. Here, carbonate minerals are reciprocally associated with pale green chlorite or albitized plagioclases.

The phenocrysts of augite are altered to the pseudomorphic crystals of the secondary products, assembling paragenetically with each other as follows;
1. yellowish green chlorite + "Type A" chlorite + (quartz) + (iron ores)
2. carbonate minerals + quartz + (iron ores)

In the groundmass of the matrix-like parts, the initial crystals are almost decomposed, although the fluidal structures are moderately preserved. The long lath-shaped plagioclases are moderately transmuted to the secondary minerals showing the following assemblages;
1. oligoclase + pale green chlorite + "Type A" chlorite + (sericite) + (iron ores)
2. carbonate minerals + quartz + (iron ores) + (sericite)

The original mafic mineral in the groundmass is also decomposed at all, and is changed to the pseudomorphous crystals of yellowish green chlorite or of carbonate minerals. These secondary minerals, especially yellowish green chlorite, is accompanied by iron ores, such as hematite and magnetite or pyrite.

In the groundmass of the matrix-like parts, the amygdaloidal structures, which are irregular in form and show zonal structures, are commonly observed. In each of them, the secondary minerals are arranged with each other from inner to outer side as the following order;
1. yellowish green chlorite + "Type A" chlorite + quartz
2. "Type A" chlorite + quartz

3. quartz alone

Collectively speaking, in brief, of the present propylite-breccia, the breccia-like and the matrix-like parts are of the same origin, and the differences in appearence and also in mineral assemblage between them are only embossed through the alterations. Namely, the breccia-like parts are characterized by the increasing of pale green chlorite, sericite, "Type A" chlorite and carbonate minerals in amount, in comparison with the matrix-like parts.

For the variegated propylite-breccia of the doleritic composition, the properties of its alterations are nearly similar to those of the variegated propylite-breccias of augite andesitic composition.

Tuff-breccia

For tuff-breccias, the qualities of their alterations are almost the same as those of found in propylite or propylite-breccias, although they are remarkably peculiarized by the presence of the primary quartz in large amount. The secondary minerals found in both andesitic and doleritic tuff-breccias are nearly the same in common.

As an example, the rock specimen (Sample No.8171) is given and described. For the rock fragments in the present specimen, they are composed of augite andesite, augite dolerite and andesitic tuff. In the first, andesitic fragments are described. The phenocrysts of plagioclases are altered to the secondary products as follows; sericite, albitized plagioclases (mostly oligoclase (An 20 Ab 80—An 28 Ab 72) or often albite (An 9 Ab 91)), yellowish green chlorite, carbonate minerals, iron ores and quartz. These minerals assemble with each other as follows;

1. sericite + albitized plagioclases + yellowish green chlorite + (iron ores) + (quartz)
2. carbonate minerals + quartz + (iron ores) + (yellowish green chlorite)

The primary phenocrysts of augite are perfectly decomposed at all, and their secondary products is usually yellowish green chlorite, which is commonly paragenetic with iron ores.

In the decomposed groundmass, the secondary minerals are the followings; yellowish green chlorite, sericite, albitized plagioclases (mostly oligoclase and sometimes albite), iron ores, quartz and carbonate minerals. The first mineral is very rich in amount, on the other hand, the last two are rarely.

For the doleritic rock fragments, they occur frequently, and their qualities of the alterations are almost the same as those of the above-mentioned andesitic fragments.

Among the rock fragments in the present specimen, the fragments of andesitic tuff are occasionally recognized. They are intensely altered, and are composed of quartz, sericite, apatite, pale green chlorite and carbonate minerals in amount order. Quartz is of almost secondary origin, and builds irregular or sometimes rounded crystals, paragenetic with apatite. Besides, small, a certain amygdaloidal structures, composed of carbonate minerals and sericite, are sometimes observed.

In whole aspects, the rock fragments are divided into two types, which are independent of the qualities of the original rocks. Namely, the first type fragments are generally pale green or sometimes whitish pale green in colour, and are characterized by the following mineral assemblage as the essential, quartz + sericite + pale green chlorite. On the contrary, the other type fragments are dark green or purplish brown in colour, and the main minerals, being paragenetic with eachother, are the followings; sericite, yellowish green chlorite and iron oxides.

For the matrix parts they are fundamentally constituted by the crystal fragments, such as palgioclases, mafic minerals, quartz, and glass materials. However, these initial crystal fragments are mostly decomposed, and especially glass materials are perfectly altered to the secondary products. The crystal fragments of plagioclases are in some degrees transmuted to these secondary minerals as follows; albitized plagioclases (mostly oligoclase or often albite), sericite, yellowish green chlorite, iron ores, quartz, apatite and carbonate minerals in amount order. Here, yellowish green chlorite is sometimes accompanied by sericite or apatite or iron ores. Carbonate minerals are closely associated with the secondary quartz.

The secondary products due to the perfect decompositions, of the primary mafic minerals, are those as given below; yellowish green chlorite, iron ores, quartz, sericite and carbonate minerals. Among them, the first two minerals are the essentials and the others are the accessories. The crystal fragments of quartz are entirely recrystallized, and some crystals showing the undulatory extinctions are recognized. Quartz has usually many inclusions, such as iron ores, sericite and carbonate minerals. Moreover, the quartz crystals aggregate with eachother. In the last, the original glass materials are perfectly changed to the following secondary products; carbonate minerals, sericite, yellowish green chlorite, pale green chlorite and quartz.

(b) Migimata Acidic Tuff Member

The Migimata acidic tuff member belonging to the yellowish green chlorite zone is described. The characteristics of the alterations of the present member are nearly the same as those of the alterations of the other rocks belonging to the same alteration zone. Nevertheless, in general, quartz including both the initial and the secondary is rich in amount.

In rhyolitic tuff-breccias and rhyolitic lava flows, the secondary minerals forming the essentials are the followings; albitized plagioclases (mostly oligoclase or sometimes albite), quartz, yellowish green chlorite, sericite, carbonate minerals, apatite and iron ores in amount order. Furthermore, pale green and "Type A" chlorites are sometimes recognized.

In both the groundmass of rhyolite flows and the matrices of rhyolitic tuff-breccias, the amygdaloidal structures of various scale are sometimes found. They are filled with the following minerals as the main constituents, showing zonal arrangements from inner to outer side in the following order in each assemblage; carbonate minerals + quartz + (pale green chlorite) + (fine grained epidote), or (carbonate minerals) + quartz + (yellowish green chlorite) + pale green chlorite + (fine grained epidote).

(c) Yunosawa Tuff Member

The properties of the alterations observed in the Yunosawa Tuff member are nearly the same as those of the alterations of the Hidarimata acidic tuff member belonging to the same alteration zone. However, the present member is remarkably characterized by the increasing of sericite and the secondary quartz.

(d) Intrusive Rocks

The intrusive rocks belonging to the yellowish green chlorite zone are mostly distributed in the Migimata valley.

Diorite-porphyrite

In the diorite-porphyrite mass in the Hidarimata valley, the altered rocks classified into the present zone are recognized in certain part. The rock specimen (Sample No.861), as na example, is taken. The primary essential constituents are decomposed to the secondary minerals. Plagioclases are strongly albitized and are generally transmuted to the secondary minerals as follows; yellowish green chlorite, albitized plagioclases (mostly oligoclase or sometimes albite), sericite in common, and carbonate minerals, quartz and fine grained epidote in small or rare amount. The fine-grained epidote is always associated with yellowish green chlorite. The secondary quartz is generally irregular in form and is sometimes accompanied by apatite which builds short or long columnar or needle shaped crystals. The primary mafic minerals are perfectly decomposed, and even pseudomorphic crystals are undistinguished. They are wholly replaced by yellowish green chlorite, of being closely associated with fine grained, anhedral crystals of epidote. The original crystals of quartz are irregular in form and are moderately recrystallized, and are sometimes accompanied by the secondary apatite. Furthermore, in the recrystallized quartz, many inclusions, such as apatite, yellowish green chlorite, carbonate minerals and sericite, are observed.

The veinlets are also sometimes observed. They are filled by the secondary minerals, assembling with each other as follows;

1. carbonate minerals alone
2. yellowish green chlorite alone
3. carbonate minerals + yellowish green chlorite

The secondary products caused of the decompositions of the primary essential minerals in the diorite-porphyrite dykes, which belong to the yellowish green chlorite zone, are nearly the same as those of the above-mentioned specimen.

Augite Andesite

The augite andesitic dykes are mostly recognized in the Migimata valley, and they are moderately altered. The rock specimen (Sample No.7243), one of the dykes, is described as an example.

The phenocrysts of plagioclases are mostly altered in a great degree to the secondary minerals as given below; oligoclase, sericite, yellowish green and pale green chlorites and fine grained epidote in common, and carbonate minerals, the secondary quartz and iron ores in small amount. They are grouped into the following assemblages.

1. oligoclase + sericite + yellowish green chlorite + pale green chlorite + fine grained epidote + (iron ores) + (secondary quartz)
2. oligoclase + carbonate minerals + secondary quartz + yellowish green chlorite + (sericite)

Carbonate minerals are reciprocally associated with yellowish green and pale green chlorites. The phenocrysts of mafic minerals are entirely decomposed at all. The secondary minerals replacing them are yellowish green chlorite and "Type A" chlorite as the essentials, and are fine grained epidote, quartz, carbonate minerals and iron ores in small or rare amount.

In the groundmass, the primary constituent minerals are extremely decomposed, and so the fluidal structures are quite uncertained, and the glass materials are not preserved at all. The constituent minerals found in the altered groundmass are the followings in amount order; yellowish green chlorite, oligoclase, secondary quartz, fine-grained epidote and carbonate minerals. Moreover, the amygdales or the fine veinlets are also commonly found. The amygdales, which are small or large ones with zonal structures, are filled with the secondary minerals showing the following arrangement from inner to outer side; (secondary quartz) + "Type A" chlorite + yellowish green chlorite. However, most of the amygdales without the secondary quartz show the double zonal arrangements of the secondary minerals from inner to outer side as follows; "Type A" chlorite + yellowish green chlorite + "Type A" chlorite + yellowish green chlorite. The fine veinlets are also commonly observed, and are filled by carbonate minerals and yellowish green chlorite.

Dacite

Both the large massive body and the dykes of dacite, which are classified into the yellowish green chlorite zone, are also subjected to the alterations as nearly like as those of the augite andesitic dykes in the same alteration zone. However, the alterations of the dacitic rocks are characterized by the increasing of both the secondary quartz and yellowish green chlorite.

Rhyolite

The lithoiditic rhyolites, belonging to the present alterlation zone occurring as the dykes, are also altered in a certain degree. The rock specimen (Sample No.8221) is taken as an example, of rhyolite being intensely altered.

The phenocrysts of plagioclases exhibit mostly ghosty crystals, and their zonal structures are entirely disappeared. The secondary products are the followings; albitized plagioclases (mostly oligoclase (An 19 Ab 81—An 28 Ab 72) or rarely albite (An 10 Ab 90)), yellowish green chlorite, fine and medium-grained epidote, pale green chlorite, carbonate minerals and quartz in amount order. Carbonate minerals are closely associated with the secondary quartz, and also with the idiomorphic or often hypidiomorphic crystals of epidote. On the contrary, yellowish green chlorite usually coexists with albitized plagioclases, pale green chlorite and fine-grained epidote. The optical

properties of epidote associated with carbonate minerals are the followings;

Pleochroism: X: yellowish green

                Y: lemon yellow

                Z: yellowish green

X$\wedge$C: 6° - 7°

2Vz: 108° - 111°

The phenocrysts of green hornblende are perfectly decomposed. The secondary products in them are as follows; yellowish green chlorite and carbonate minerals in common, and pale green chlorite, epidote and quartz in small or rare amount.

The groundmass is extremely altered. The constituent minerals found in it are oligoclase (An 16 Ab 84 —An 27 Ab 73), yellowish green chlorite, epidote, carbonate minerals, pale green chlorite and quartz in amount order. The idiomorphic prisms of epidote, which are closely associated with carbonate minerals or the secondary quartz. Their optical characters are given below.

Pleochroism: X: yellowish green

                Y: lemon yellow

                Z: yellowish green

X$\wedge$C: 7°

2Vz: 109°

Of cause, the primary crystals in the groundmass are exceedingly altered. Namely, the minute lath-shaped plagioclases are mostly ghosty and the mafic crystals are perfectly decomposed. Furthermore, the glass materials are devitrified and change to the secondary products, such as quartz, yellowish green and pale green chlorites, carbonate minerals in amount order.

Beside, the amygdaloidal cavities showing zonal structures are occasionally ascertained. They are filled with the secondary minerals, which are arranged from interior to outer side as the following order; carbonate minerals + quartz + pale green chlorite + (fine-grained epidote).

As the another example, the rock specimen (Sample No.8222) is given. The secondary minerals found in this specimen are somewhat different from those in the above-mentioned specimen. In general, this specimen is far less altered than the other. The phenocrysts of plagioclases are usually replaced very partially by yellowish green chlorite and sericite. The initial oscillatory zonings are quite preserved. Green hornblende is mostly saved from alterations. Nevertheless, Plagioclases in the groundmass are mostly albitized, and so they are ghosty crystals of oligoclase (An 20 Ab 80—An 30 Ab 70). The hypidiomorphic or anhedral crystals of green hornblende are almost decomposed into yellowish green chlorite and iron ores.

The secondary minerals composing the altered groundmass excepting for the amygdaloidal structures are the followings; oligoclase, secondary quartz, yellowish green chlorite and iron ores in amount order.

The amygdaloidal cavities are commonly observed. Most of them may be surely caused of the devitrifications of the glass materials. They are composed of the secondary products showing the zonal arrangement from inner to outer side as the following order; yellowish green chlorite + quartz + zeolitic mineral. The zeolitic mineral exhibits fibrous crystals without any pleochroism, and shows always a certain spherulitic aggregates. Judging from the optical properties examined under the microscope, the present mineral may be estimated as mordenite.

In comparison with the pale green chlorite zone, the yellowish green cholorite zone is generally characterized by the increasing of both secondary quartz and albitized plagioclases, of cause, as well as yellowish green chlorite, in amount, and also by the decreasing of these minerals, such as sericite, "Type A" chlorite and fine-grained epidote in amount, although the secondary minerals found in the yellowish green chlorite zone are nearly the same as those in the pale green chlorite zone, excepting for the index clay mineral.

(V) Saponite Zone

In the investigated region, the saponite zone is always situated on the both outer sides of the yellowish green chlorite zone. The present zone is developed chiefly in both the eastern and the western parts in the Futamata region. The Neogene system classified into the present alteration zone is generally far less altered than those in the other zones.

—Description—

(a) Futamata Propylite Member

The Futamata propylite member being belonged to the saponite zone is developed in the restricted area as shown in Fig. 12.

Propylite

The rock specimen (Sample No.8251) is taken as an example. In general, the present specimen is far less altered, and so, the initial constituent minerals are usually freshly preserved.

The phenocrysts of plagioclases are very partially altered to the secondary minerals as follows; albitized plagioclases (mostly andesine (An 38 Ab 62—An 50 Ab 50) or often labradorite (An 52 Ab 48—An 56 Ab 44)), saponite, carbonate minerals and quartz. Among these secondary products, the first two minerals are the essentials, and the others are the accessories. The original zonal structures of plagioclases are well preserved.

The primary phenocrysts of augite is also replaced in partial by the secondary minerals, such as iron oxides, fine-grained epidote and quartz. These secondary minerals occur at the marginal parts of augite-crystals as like as reaction-rims. In the groundmass of being moderately altered, the initial fluidal structures are well preserved, although the constituent minerals are moderately transmuted to the secondary minerals. The lath-shaped plagioclases shown mostly ghosty crystals of andesine (An 48 Ab 52) or sometimes of labradorite (An 55 Ab 45), although having weak zonal structures. The secondary minerals found them are the followings; saponite and the above-mentioned albitized plagioclases as the essentials, and quartz, fine-grained epidote, sericite and apatite in small or rare amount. The fine-grained epidote coexists intimately with saponite. Apatite are always paragenetic with the secondary quartz. The anhedral or sometimes hypidiomorphic crystals of augite in the groundmass are mostly decomposed at all. Their secondary products are the followings; saponite, fine-grained epidote, iron oxides and quartz. The fine-grained epidote is closely associated with saponite or iron oxides. The secondary quartz is very small in amount. Furthermore, the glass materials are perfectly altered to quartz and saponite.

In the downstream of the river of Migimata, doleritic propylite is developed. The present propylite is also subjected to the alterations as nearly same as those of the above mentioned andesitic propylite.

Propylite-breccia

Propylite-breccias belonging to the saponite zone are scarcely recognized in the unicoloured ones developed in the Hidarimata valley. On the contrary, in the variegated ones destributed in the Migimata valley, propylite-breccias classified into the present zone are occasionally observed.

The breccia-like parts are of light shades of green or purplish brown in colour. Most of them have usually the cumulophyric plagioclases, being sometimes aggregated with the mafic minerals, as the cores of the breccia-like parts. The secondary minerals constituting the present parts are the following; albitized plagioclases (mostly oliogclase (An 16 Ab 84—An 28 Ab 72) or sometimes andesine (An 32 Ab 68—An 48 Ab 52), quartz, apatite, fine grained epidote, saponite and iron oxides.
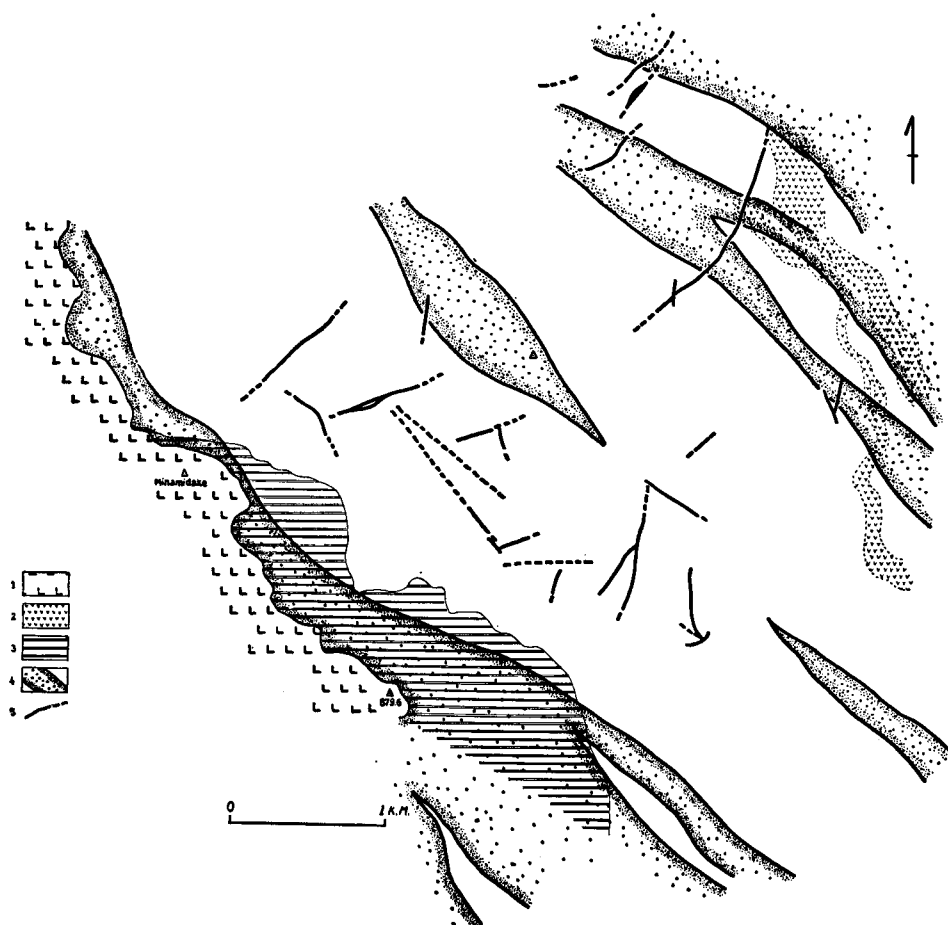
Fig. 12

1. Yoichi-Dake Lava-flows
2. Rhyolite Flow
3. Yunosawa Tuff Member

4. Saponite Zone
5. Fault System

Among these secondary minerals, the first two minerals are the essentials, and the others are small or less in amount. Furthermore, the phenocrysts of the mafic minerals are occasionally recognized in the breccia-like parts. They are partially altered to the secondary minerals as follows; iron oxides, saponite, fine grained epidote and actinolite in amount order. The groundmass of the present parts occupies very small in amount, and they are moderately altered. The lath-shaped plagioclases become ghosty crystals having no zonal structures in common, showing mostly oligoclase (An 20 Ab

80—An 28 Ab 72) or sometimes andesine (An 36 Ab 64—An 48 Ab 52) in composition. The second-ary minerals, replacing them, are just the same as those found in the phenocrysts of plagioclases. The hypidiomorphic or anhedral crystals of augite are perfectly decomposed. The secondary pro-ducts from them are also nearly the same as those in the phenocrysts of the mafic crystals, among which saponite, iron oxides and fine grained epidote are the essentials. Moreover, the amygdaloidal structure having the cumulophyric plagioclases as its cores are commonly recognized. They are fil-led mainly with the secondary quartz, which is closely accompanied by apatite and is commonly ir-regular in form. The present mineral shows a certain mosaic aggregates in usual.

The matrix-like parts are reddish purple or dark green or purplish green in colour. The initial minerals are less altered than those found in the breccia-like parts. In general, the alterations ob-served in the matrix-like parts are nearly the same as those in the breccia-like parts, however, they are peculiarized by the increasing of both iron oxides (hematite and magnetite) and saponite in amount, and also by the relative decreasing of sericite, albitized plagioclases and fine-grained epi-dote.

It may be surely ascertained that the breccia-like figures in the present specimen are caused of the selective alterations through the hydrothermal processes.

Tuff-breccia

Although tuff-breccias, may be, consist of originally augite andesitic and doleritic ones, the secondary minerals found in them are fundamentally of the same kinds as those in propylite-brec-cias. However, among the secondary minerals, these minerals, such as secondary quartz and sapo-nite, comparatively increase in their amounts. Secondary quartz is commonly irregular in its form, and is occasionally accompanied with apatite. Moreover, saponite is sometimes associated with fine-grained epidote.

(b) Migimata Acidic Tuff Member

The Migimata acidic tuff member belonging to the saponite zone is generally altered in a slight degree. For the secondary minerals, being nearly the same kinds as those found in the other rocks belonging to the same alteration zone, they are composed mainly of secondary quartz, saponite and sericite. Especially, the primary quartz crystal fragments are mostly recrystallized, and are often paragenetic with apatite. The glassy materials are perfectly devitrified, and are replaced by the secondary minerals as follows; saponite, secondary quartz, sericite and carbonate minerals in amount order. The last mineral is very small in amount. Furthermore, the amygdaloidal struc-tures and the cavities are commonly recognized. They show usually annular structures and are respectively filled with the secondary minerals showing the following arrangements from inner to outer side; (quartz) + saponite + carbonate minerals, or saponite + quartz + (carbonate minerals).

(c) Yunosawa Tuff Member

The Yunosawa tuff member belonging to the saponite zone are widely distributed in the western part in the Hidarimata valley. The present member is also moderately altered, and the secondary minerals observed are nearly common. The secondary minerals are the followings; secondary quartz, saponite, yellowish green chlorite, albitized plagioclases, sericite, carbonate minerals, fine-grained epidote, iron ores and apatite. Among them, such as secondary quartz, saponite, albitized plagioclases (mostly oligoclase (An 18 Ab 82—An 28 Ab 72) or sometimes andesine (An 32 Ab 68 —An 42 Ab 58) and carbonate minerals are the essentials. Saponite is relatively associated with sericite and find-grained epidote, and on the other hand, the present mineral shows a tendency to associate reciprocally with carbonate minerals which are paragenetic intimately with secondary quartz. Apatite are always accompanied by secondary quartz. As for iron ores, iron oxides, such as hematite and magnetite, are usually associated with saponite and albitized plagioclases or often with yellowish green chlorite. Moreover, pyrite is commonly paragenetic intimately with carbonate minerals or often with secondary quartz.

The pumices, found in pumiceous tuff-breccias or in pumiceous tuffs, are remarkably subjected to the alterations. Namely, they are perfectly devitrified, and the secondary minerals found in them are saponite and felsic minerals as the essentials. The last minerals are composed of secondary quartz and cryptocrystalline oligoclase. Furthermore, zeolitic mineral, may be, mordenite, showing spherulitic aggregates, is very rarely observed.

(d) Intrusive Rocks

The intrusive rocks belonging to the saponite zone are as follows; augite andesite, dacite and rhyolite. The main secondary minerals caused of the decompositions of the primary constituent minerals are as follows; albitized plagioclases (mostly oligoclase and sometimes andesine), saponite and secondary quartz.

Augite Andesite

The rock specimen (Sample No.875) is taken as an example. This specimen is relatively more altered than the others.

The phenocrysts of plagioclases are usually albitized in a slight degree, however, their moderate or sometimes remarkable zonal structures are well preserved. Plagioclases are replaced in partial by the following secondary minerals; oligoclase (An 11 Ab 89—An 30 Ab 70) and sometimes andesine (An 32 Ab 68—An 42 Ab 58), sericite, saponite, carbonate minerals, quartz and fine grained epidote in amount order. The first three minerals are the essentials, and carbonate minerals are sometimes absent. Saponite is closely associated with fine grained, anhedral crystals of epidote, and sericite.

The augite phenocrysts are perfectly altered to the pseudomorphs of the secondary minerals showing the following assemblages;

1. saponite + fine grained epidote + iron ores
2. carbonate minerals + (saponite) + iron ores

The primary minerals in the groundmass are mostly decomposed. The lath-shaped plagioclases exhibit ghosty crystals of oligoclase (An 12 Ab 88—An 30 Ab 70), and their original weak zonal structures are entirely disappeared. Furthermore, they are partially replaced by the secondary minerals of same as those in the phenocrysts of plagioclases. The hypidiomorphic or often anhedral crystals of augite are replaced by the same secondary minerals as those in the phenocrysts of augite. Besides, in the groundmass, the amygdaloidal cavities filled with both quartz and carbonate minerals in together are commonly recognized. They are often irregular in form.

Dacite

The altered dacitic rocks belonging to the present zone are recognized only in the dacite mass developed in the upper reaches of the river of Migimata. As an example, the rock specimen (Sample No.887) is given and described. The initial constituent is also moderately replaced by the secondary minerals, but without any carbonate minerals.

The phenocrysts of plagioclases exhibit moderate zonal structures, and are replaced by the following secondary minerals; albitized plagioclases (mostly andesine (An 32 Ab 68—An 48 Ab 52) or sometimes oligoclase (An 22 Ab 78—An 28 Ab 72)), saponite, quartz and iron oxides in amount order. The first two minerals are the main, and the others are really rare in amount. Saponite builds commonly scaly or flake-like crystals with sensible pleochroism, and is deep green in colour. The present mineral occurs along the cleavages or the crucks, and also along the twinning planes of plagioclases.

The initial crystals of hypersthene are partially replaced by the secondary minerals, such as saponite and iron oxides, in a slight degree.

The constituent minerals in the groundmass are more altered than the phenocrysts. Namely, the lath-shaped plagioclases are comparatively albitized, and they are andesine (An 38 Ab 62—An 43 Ab 57) without any zonal structures. Furthermore, they are partially replaced by the secondary minerals as follows; andesine, saponite, quartz and iron ores. The first two minerals are the essen-

tials, on the other hand, the other minerals are very small in amount. Furthermore, the hypidio-morphic or anhedral crystals of hypersthene are perfectly decomposed, and even pseudomorphic crystals are scarcely recognized. This mineral is entirely altered to saponite of being associated close-ly with iron oxides.

In the altered groundmass, the amygdaloidal structures are scattered. They show a certain an-nular like structures filled with the following secondary minerals from the inner to the outer side; cristobalite + saponite + quartz. For cristobalite, it builds minute irregular crystals, exhibiting often mosaic aggregates. Its optical properties are given as follows;

> Optical sign: uniaxial positive
> relief: low, n<balsam
> birefringence: very weak, and the interference colour is very low.

Furthermore, fine veinlets filled with quartz showing mosaic aggregates are commonly recog-nized.

> Rhyolite

Some of lithoiditic rhyolites distributed in the Migimata valley are belonged to the saponite zone. They are also moderately altered. In general, the secondary minerals found in them, excepting of the index minerals, are nearly the same as those observed in rhyolites in the yellowish green chlo-rite zone. However, among the secondary minerals, epidote, albitized plagioclases and sericite dec-rease, and on the other hand, secondary quartz increases in amount. Carbonate minerals occur in small amount, though they are occasionally absent.

The phenocrysts of plagioclases are partially altered in a slight degree. They show weak zonal structures, and albitized plagioclases are mostly oligoclase (An 23 Ab 77—An 28 Ab 72) or some-times andesine (An 32 Ab68—An 42 Ab 58). The initial crystals of green hornblende are well pre-served, although they are slightly replaced by saponite and iron oxides.

The primary constituent minerals in the groundmass are generally far altered. Namely, the hypidiomorphic or anhedral crystals of green hornblende are perfectly decomposed at all. Besides, the lath-shaped plagioclases are commonly replaced partially by the following secondary minerals; albitized plagioclases (mostly oligoclase (An 22 Ab 78—An 27 Ab 73) or often andesine (An 31 Ab 69—An 38 Ab 62)), saponite, sericite, secondary quartz and iron ores in amount order. Besides, their original weak zonal structures are entirely disappeared.

Owing to the devitrification, the glass materials are perfectly changed to the secondary mine-rals, such as saponite and quartz in common, and zeolitic mineral being similar to mordenite in very less amount. These minerals assemble with each other in amygdaloidals.

(IV) Notices on the Three Alteration Zones

As already described, in the Neogene system developed in the Futamata region, three alteration zones are established by using the index clay minerals. However, the other secondary minerals found in each of the alteration zones are almost the same in kind, but they are noticeably different in amount in usual. Namely these secondary minerals, such as albitized plagioclases, secondary quartz, sericite, epidote, iron ores, apatite and carbonate minerals, are ascertained in each alteration zone, though their quantities are variable.

In general, each of the three alteration zones is peculiarized by the distinctive secondary minerals being closely associated with the index clay mineral as given be-

low.

The pale green chlorite zone is characterized by the presences of the secondary minerals coexisting with pale green chlorite as follows; sericite, epidote, "Type A" chlorite and actinolite in large amount. Carbonate minerals are also abundantly recognized, but they are associated reciprocally in amount with pale green chlorite and also with the others. Furthermore, carbonate minerals are intimately accompanied by secondary quartz and the medium grained epidote, which builds idiomorphic and often hypidiomorphic crystals.

As the yellowish green chlorite zone concerns, although most of the secondary minerals observed are common to those found in the pale green chlorite zone, in comparison with the secondary minerals in the pale green chlorite zone, these minerals, such as pale green chlorite, sericite, fine grained, anhedral crystals of epidote, apatite and "Type A" chlorite, decrease in amount, and on the other hand, secondary quartz, as well as yellowish green chlorite, increases comparatively in amount. Pale green chlorite is always associated intimately with yellowish green chlorite.

In the altered rocks belonging to the saponite zone, the primary constituent minerals are comparatively well preserved. In the present zone, the following secondary minerals are recognized; albitized plagioclases, sericite, saponite, secondary quartz, apatite, iron ores and carbonate minerals. Nevertheless, carbonate minerals are sometimes absent. Moreover, these minerals, such as "Type A" chlorite and epidote, are quite unrecognized in the saponite zone.

For iron oxides, in general through the three alteration zones, they are closely associated with the index clay minerals, and on the contrary pyrite exhibits a tendency to co-exist with carbonate minerals.

The properties of the alteration zones are summarized as follows;

1. The Neogene system in the Futamata region is generally altered in a certain degree. It is divided into the following three alteration zones by the mineral assemblages of the secondary minerals; pale green chlorite zone, yellowish green chlorite zone and saponite zone.

2. The three alteration zones are arranged zone by zone. Namely, the pale green chlorite zone is situated in the inner side, through the yellowish green chlorite zone, the saponite zone is also situated in the outer side.

3. The central axes of each alteration zone are stretched to NNW - SSE or NW - SE in direction. The present direction is quitely accordant with that of the important geotectonics in the Neogene system in southwest Hokkaido.

4. The alteration zones are estabilshed with regardless to the stratigraphical structures of the Neogene strata.

5. The alteration zones are also established independently to the qualities of the original rocks of varing from dolerite to rhyolite in species. Besides, in

each of these zones, the mineral assemblages of the secondary minerals found in the altered rocks, which are either the sedimentary rocks or the intrusive rocks, are nearly the same.

6. In general, the properties of the alteration observed in these zones increase in degree as the following order; the saponite zone through the yellowish green chlorite zone to the pale green chlorite zone. Because, in one rock-species, the primary mafic minerals in the saponite zone are the most well preserved, and these in the pale green chlorite zone are usually entirely decomposed at all. Furthermore, in a some rock species, secondary apatite is abundantly recognized in the pale green chlorite and the yellowish green chlorite zones, however, in the saponite zone, the present mineral is scarcely observed. Additionally, the albitization of plagioclases exhibits a tendency to increase in degree from the saponite zone through the yellowish green chlorite zone to the pale green chlorite zone. (The above mentioned phenomena are described and discussed in details in part III).

Judging from the whole aspects of the alterations, it may be surely ascertained that the three alteration zones are caused of the hydrothermal alterations in a certain post-action stage. Of cause, the present hydrothermal processes should be occurred through the tectonic zones, and be also associated with the metasomatic effects, which caused secondary apatite for an example. However, the exact geological age of the above described "post-action stage" is not clarified at all, and is remained as an important problem, which must be solved in the future.

Furthermore, the alterations found in the altered sedimentary rocks may be caused by both the hydrothermal and the diagenetic processes, but this interpretation is not able to prove at all.

Part III   Investigation on the alterations of plagioclases

(I)   General remarks

In 1942, KöHLER, A. pointed out that there exist two distinctive types of plagioclases; low temperature plagioclases and high temperature plagioclases, since then many studies on the optical characters of all plagioclases, in various composition have been carried out. Furthermore, the investigations of the structural properties of plagioclases ranging from anorthite to albite have been also accomplished, since the essential similarity of the principal structural features of all feldspars was shown in 1933 and 1934 (TAYLOR, W. H., 1933; TAYLOR, W. H., DARBYSHIRE, J. A. and H. STRUNZ, 1934). Especially, complex and layered lattices were established in plagioclases of intermediate composition (CHAO and TAYLOR, 1940); the structural change from the albitic type through intermediate towards the anorthitic one was attributed

to the appearence of superstructures. However, all these changes were regarded as the result of the compositional difference of the range from albite to anorthite. Furthermore, in 1949, COLE, SÖRUM and KENNARD pointed out that in a sanidinized orthoclase the atoms of Al and Si are distributed in disorder. In 1956, DEVORE also offered that the compositional change in plagioclases depends fundamentally on Al-Si positions in lattices of plagioclases. However, the relationships between the optical orientations and the structures of plagioclases are quitely unsolved at all. Besides, even optical orientations of the altered plagioclases through the hydrothermal processes are not entirely investigated; the relationships between the optical orientations and the compositions of plagioclases through the hydrothermal processes have not been entirely examined. Though, KIM, C. W. (1964), and KIM, C. W. and SAKO, T. (1967) investigated on the composition and ordering of plagioclases observed in Neogene propylites and hollocrystalline rocks, and they discussed on the so-called "ordering or disordering" of plagioclases.

Then, the conception of "ordering" or "disordering" of plagioclases was hypothetically proposed, and also has been used for meaning the structural change of plagioclases. Additionally, it was experimentally clarified that the structural changes between the high- and the low- temperature series are sometimes reversible. The difference between the high- and the low-temperature type states is a matter of the degree of order in the distribution of Si and Al stoms among the tetrahedral sites. Accordingly, it must be said that KIM, C. W. et al. made one-sided interpretations for "ordering" or "disordering" of plagioclases, only from the optical properties. Because, for plagioclases the relationships between the optical orientations and the lattice structures have not been clarified at all.

The writer has examined the relationships between the composition and optical orientation of plagioclases of various composition altered by the hydrothermal processes. His studies have been made in accordance with SLEMMONS' method (SLEMMONS, D. B., 1964). Some new informations concerning of the relationships between the composition and the optical orientation of plagioclases, and also the relationships between the two types of plagioclases, viz. high- and low- temperature plagioclases, and their optical orientations, are obtained as given below.

(II) Investigation on the composition and optical orientation of the altered plagioclases

 The writer examined plagioclases altered in a certain degree through the hydrothermal processes in some rock specimens, viz. doleritic propylite, augite andesite and diorite-porphyrite. These specimens are divided into each of the three alteration zones respectively from the mineralogical viewpoint, as shown in Table 6.

The writer measured the composition of plagioclases according to SLEMMONS' method by using universal stage, and determined statistically the distribution curve of the composition. The writer used the following statistic method. On the supposition that the composition of plagioclases was determined within 5% ca. error. This error in measurements exhibits normal distribution with the standard deviation; $\sigma = 2$, each An-content within the range of the error occurs with the expectation as given in Table 7 and Fig. 13, in case of the total expectations are equal to 100.

In this paper, the term *"plutonic type plagioclases"* or *"volcanic type plagioclases"* is used, and it is equivalent to low temperature plagioclases or high temperature plagioclases respectively.

(a) Doleritic propylite

The rock specimen (Sample No.8311, 8312 and 8313) are taken as the examples of doleritic popylite. These specimens are altered in the least degree in each of the three alteration zones.

The specimen (Sample No.8313) belonging to the pale green chlorite zone, the phenocrysts of plagioclases are strongly albitized, and the primary oscillatory zonings are not preserved, and disappeared at all. The histogram of the composition of plagioclases is given in Fig. 15, showing remarkable two peaks representing the predominant composition at the points An 37 and An 23. However, all the examined plagioclases consist of the plutonic type plagioclases in 40% and the volcanic type plagioclasses in 60%. As shown in Fig. 16, the most predominant composition of the plutonic type is given as An 23, and on the other hand,the volcanic type plagioclases show their most predominant compositions in An 37. Furthermore, in the distribution curve of the composition of the plutonic type plagioclases, the small peaks at An 40, An 32

Table 6

Rock Species	Sample Number	Alteration Zone
Doleritic Propylite	8313 8311 8312	Pale Green Chlorite Yellowish Green Chlorite Saponite
Diorite Porphyrite	7283 7312 8198	Pale Green Chlorite Yellowish Green Chlorite Yellowish Green Chlorite
Augite Andesite	876 7243 875	Pale Green Chlorite Yellowish Green Chlorite Saponite

Table 7

Akihiko Yoshitani

An-Content	An_α $An_{\alpha+1}$												Total
Numbers of the Articles	•	• •	•	•	•	a	b	•	•	•	•	•	Σ
+ 4	•	•	•	•	•	•	•	•	•	3a	3b	•	
+ 3	•	•	•	•	•	•	•	•	7a	7b	•	•	
+ 2	•	•	•	•	•	•	•	12a	12b	•	•	•	
+ 1	•	•	•	•	•	•	18a	18b	•	•	•	•	
0	•	•	•	•	•	20a	20b	•	•	•	•	•	
− 1	•	•	•	•	18a	18b	•	•	•	•	•	•	
− 2	•	•	•	12a	12b	•	•	•	•	•	•	•	
− 3	•	•	7a	7b	•	•	•	•	•	•	•	•	
− 4	•	3a	3b	•	•	•	•	•	•	•	•	•	
Total Numbers of Expectations in Each An-Content	•	3a	7a + 3b	12a + 7b	18a + 12b	20a + 18b	18a + 20b	12a + 18b	7a + 12b	3a + 7b	3b	•	
Frequency	•	$(3a)/\Sigma$	$(7a(+)3b)/\Sigma$	$(12a(+)7b)/\Sigma$	$(18a(+)12b)/\Sigma$	$(20a(+)18b)/\Sigma$	$(18a(+)20b)/\Sigma$	$(12a(+)18b)/\Sigma$	$(7a(+)12b)/\Sigma$	$(3a(+)7b)/\Sigma$	$(3b)/\Sigma$	•	

and An 16 are recognized and also in that of the volcanic type plagioclases the small peaks at An 24 and An 19-20 are ascretained.

The rock specimen (Sample No.8311) is given as an example belonged to the yellowish green chlorite zone. The pheocrysts of plagioclases are moderately albitized,

Fig. 13

Fig. 14

Akihiko YOSHITANI
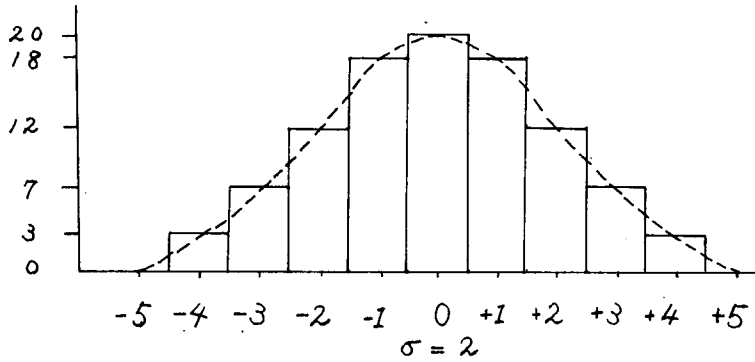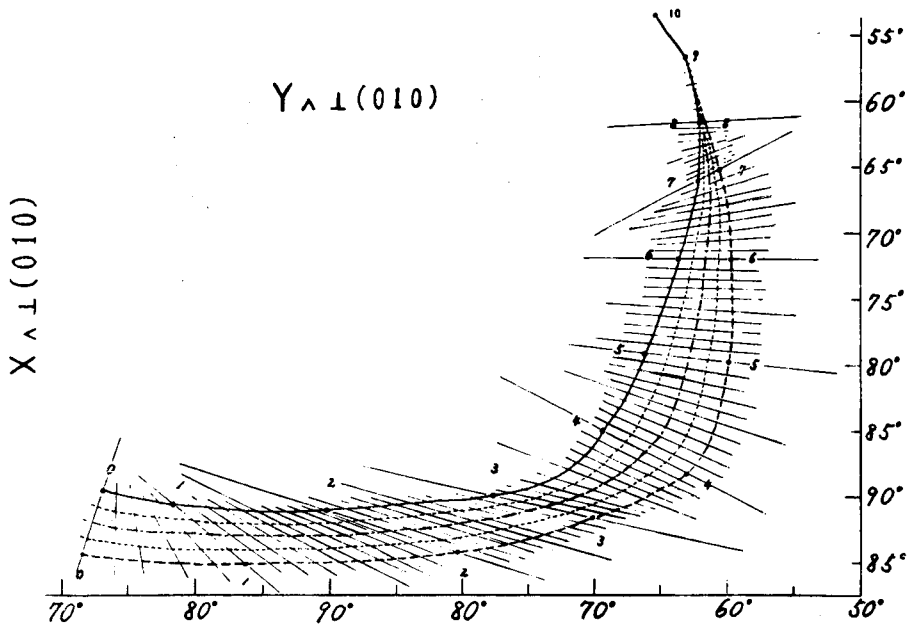
although the initial zonal structures are comparatively preserved. The writer determined the composition in the core and the outer most parts of the zonal structures; especially these two parts are the most albitized than the other parts. In the histogram of the composition in the core part, two distinguished peaks representing An 69 and An 82 are recognized, as shown in Fig. 18. However, the core parts of all examined plagioclases are composed of the plutonic type plagioclases in 64 % and the volcanic plagioclases in 36 % amount. The distribution curve of the composition of the plutonic type plagioclases or the volcanic type plagioclases is shown in Fig. 19, or in Fig. 20, respectively. As to both types, the most predominant composition is equally An 69. Besides, the plutonic type plagioclases show dominantly or somewhat remarkably An 82 or 61-62. On the contrary, the volcanic type plagioclases exhibit An 100, An 91, An 84, An 76-77 and An 62. Namely, plagioclases having anorthite content richer than An 82-84 are more found in volcanic type rather than in plutonic tpye.

The frequency curve of the composition in the outermost parts of the zonal structures is given in Fig. 21, and 22. In the histogram of the composition of the plutonic type plagioclases, the remarkable peaks representing An 81-82, An 65 and An 50-52 are recognized. On the contrary, in that of the volcanic type plagioclases, the most
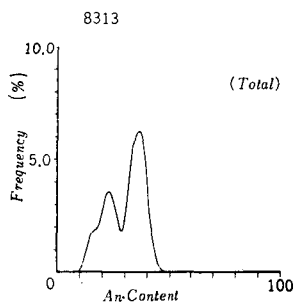
Fig. 15
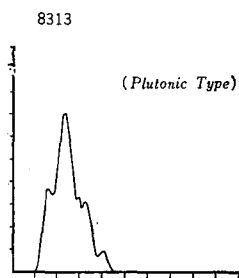
Fig. 16
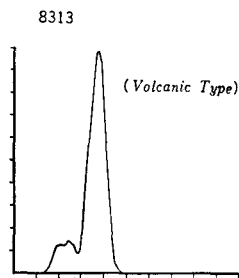
Fig. 17
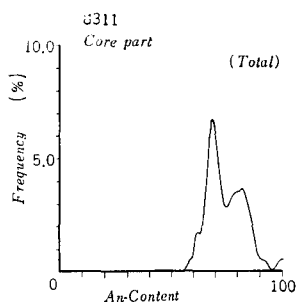
Fig. 18
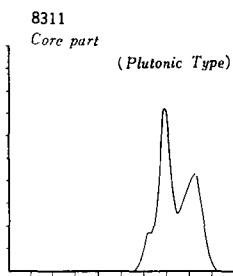
Fig. 19
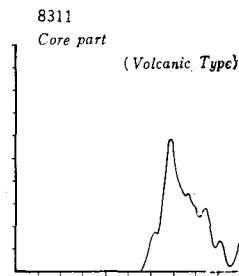
Fig. 20
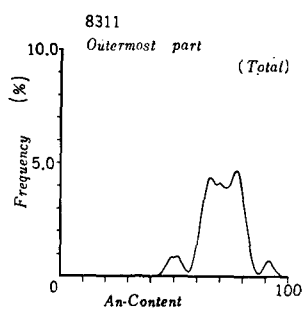
Fig. 21
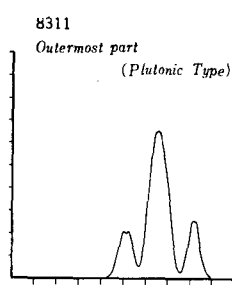
Fig. 22
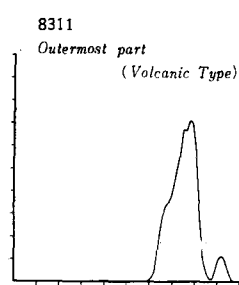
Fig. 23
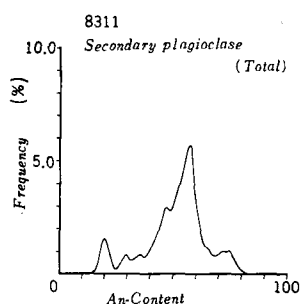
Fig. 24
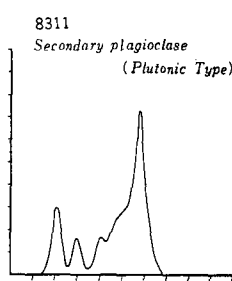
Fig. 25
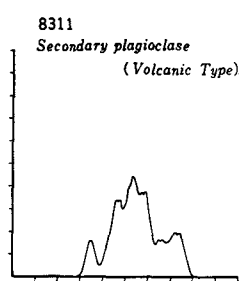
Fig. 26

predominant composition is An 78, and the compositions representing An 92 and An 75 are slso remarkably noticed. In general, the An richer plagioclases are recognized in the volcanic type rather than in the plutonic type plagioclases.

The secondary albitized plagioclases replacing mostly the outermost parts, and sometimes the core parts of the zonal structures are also investigated. These secondary plagioclases are constituted by the plutonic type (52%) and the volcanic type plagioclases (48%). In the distribution curve of the composition of the plutonic type, the peak representing the most predominant composition is ascertained in An 57, and the other moderate peaks showing An 40-41, An 29 and An 20 are also recognized. However, in that of the volcanic type plagioclases, many peaks showing the range from An 74 to An 35 are observed, though the most predominant composition is represented by the peak situated in An 53, as shown in Fig. 26.

Furthermore, it is noteworthy that the secondary albitized plagioclases entirely inherit the relationships between the optical orientation and the composition of the initial plagioclases. Namely, the secondary albitized plagioclases replacing the initial plagioclases are classified into the same type, either the plutonic type or the volcanic type, as that of the initial plagioclases. In other words, from the plutonic type plagio-

clases, the same type secondary albitized plagioclases are only derived.

On the rock specimen (Sample No.8312) belonging to the saponite zone here is described. The phenocrysts of plagioclases in this specimen are the least altered than those in the other specimens in the same alteration zone. They show, in general, remarkable oscillatory zonings, and are determined their compositions in the core and the most outer parts of the zonal structures.

As for the composition in the core parts, as shown in Fig. 27, 28 and 29, the most predominant composition is An 69 for the plutonic type, and An 78-79 for the volcanic type plagioclases.

In the histograms of the compositions in the present most outer parts, for the plutonic type plagioclases, the remarkable peaks showing An 80, An 69, An 64-65 and An 49-51 in composition are recognized. On the other hand, as the volcanic type plagioclases concern, the predominant compositions are represented by An 54 and An 76. In comparison with the composition of the volcanic type plagioclases, that of the plutonic type plagioclases is more variable ranging from An 49 to An 80, and is generally more rich in Ab-component.

The distribution curve of the composition of the secondary albitized plagioclases replacing mainly the most outer parts, sometimes the core parts of the initial zonal structures, is shown in Fig. 33, 34 and 35. As to the plutonic type plagioclases, the most predominant composition is An 18, though the dominant composition ranging from An 18 to An 64. However, for the volcanic type, the predominant compositions are ascertained as An 19, An 32 and An 55-57, and are generally rich in An-content rather than those of the plutonic type plagioclases.

Furthermore, the relationships between the initial and the secondary plagioclases are illustrated by Fig. 36. This diagram was proposed by SLEMMONS (1964), showing the relationships between the optical orientation and the composition of plagioclases. In this diagram, the central solid curve divides the volcanic type plagioclases zone as the inner side from the plutonic type plagioclases zone as the outer side. The open
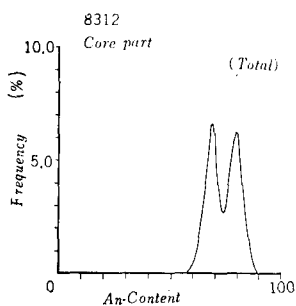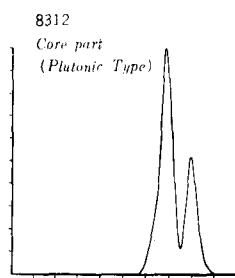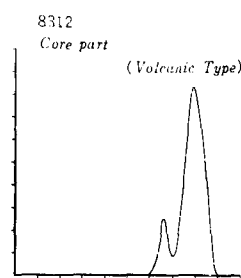
Fig. 27   Fig. 28   Fig. 29
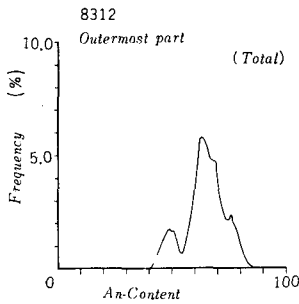
Fig. 30
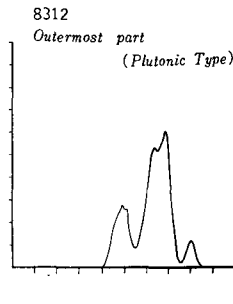
Fig. 31
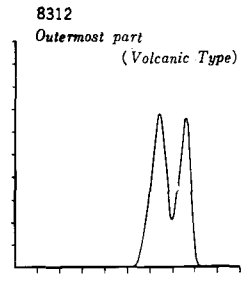
Fig. 32
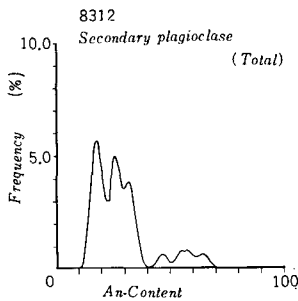
Fig. 33
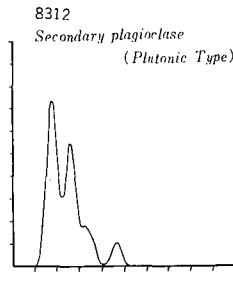
Fig. 34
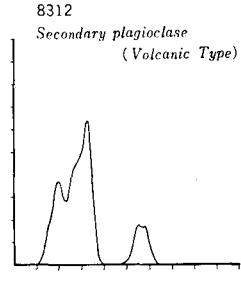
Fig. 35

circles and triangles represent the values of the optical orientation of the initial plagioclases, and the solid circles and triangles show that of the secondary albitized plagioclases. The open and the solid circles, or the open and the solid triangles are respectively tied by the arrow lines. As shown in Fig. 37, it is obviously ascertained that the values of the optical orientations of the initial plagioclases and of the secondary plagioclases replacing them are plotted in the same zone, either the plutonic type or the volcanic type plagioclases zone. Though the cause of this fact is not clarified enough, it is hypothetically estimated that this phenomena depend on the lattice structure being unchangeable through the albitization in the hydrothermal processes.

As to the compositions of the secondary albitized plagioclases, there is every indication that they go on increasing of Ab-content, from the saponite zone through the yellowish green chlorite zone to the pale green chlorite zone. Furthermore, in the distribution curve of the composition, the numbers of the peaks representing the predominant or the dominant composition go gradually on decreasing, and also their ranges of An-content are reduced as changing from the saponite zone through the yellowish green chlorite zone to the pale green chlorite zone.

(b) Diorite-porphyrite

The altered plagioclases in the rock specimens (Sample No.7283, 8198 and 7312) are examined. Among these rock specimens, the one (Sample No. 7283) is grouped into the pale green chlorite zone, and the others are into the yellowish green chlorite zone. They are altered in the least degree in each of the alteration zones. However, the saponite zone is lacking in diorite-porphyrite.

In the rock specimen (Sample No.7283), the large crystals of plagioclases are moderately albitized, although the minute lath-shaped plagioclases turn into ghosty crystals on account of the strong alterations. For the large crystals of plagioclases, the weak zonal structures are recognized in 59%, and are uncertained in 41% in amount.

As for the large crystals with the weak zonal structures, the compositions in the core parts are determined. Furthermore, the secondary albitized plagioclases are also examined. The histrograms of the composition in the core parts is given in Fig. 38, 39 and 40. In these distribution curves, the peaks exhibiting the predominant composition are equivalent to An 61 and An 81-82 for the plutonic type, and An 60 for the volcanic type plagioclases. Furthermore, in the histogram of the composition of the plutonic type plagioclases, some peaks showing the dominant composition are ascertained as An 50, An 70 and An 98-99, and on the other hand, in that of the volcanic type plagioclases, these peaks being equivalent to An 53, An 67 and An 90 are recognized as the dominant composition.

Fig. 36

$Y \wedge \perp (010)$

$X \wedge \perp (010)$
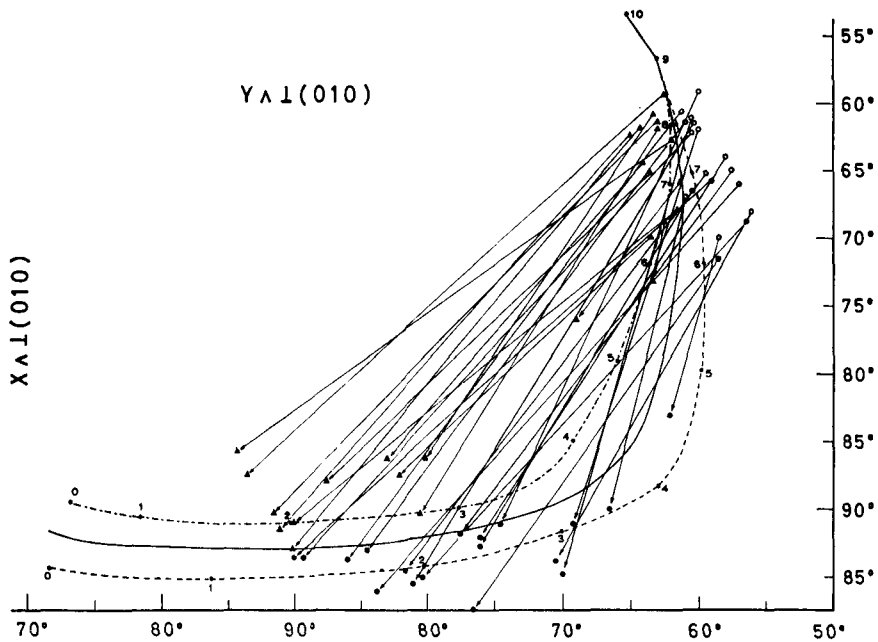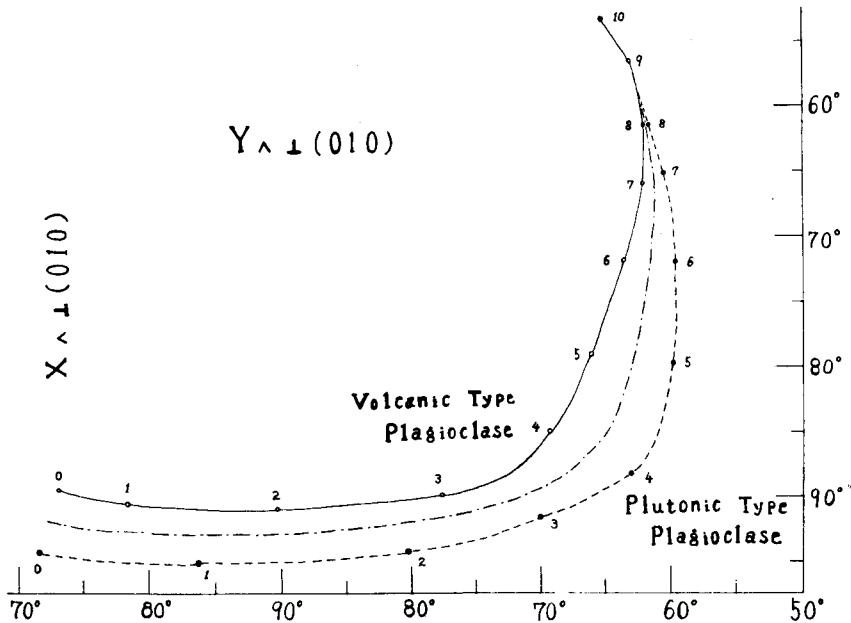
Fig. 37

In the distribution curves of the compositions of plagioclases without any zonal structures, as given in Fig. 41, 42 and 43, the most predominant composition is equivalent to An 60-61 for the plutonic type, and to An 57 for the volcanic type plagioclases. The composition of the plutonic type plagioclases shows nearly normal distribution curve, though that of the volcanic type plagioclases exhibits three peaks representing An 57, An 63 and An 76.

The secondary albitized plagioclases replacing mainly the marginal and sometimes the inner parts of the primary plagioclases are also examined. The histograms of their compositions are illustrated in Fig. 44, 45, and 46. In the distribution curve of the composition of the plutonic type plagioclases, two peaks having the values of An 16 and An 27 are remarkably ascertained, on the contrary, in that of the volcanic type, the values of the predominant composition is equal to An 30 only. Judging from these data, the plutonic type plagioclases among the secondary plagioclases are richer in Ab-content rather than the volcanic type plagioclases.

As the examples of the altered rocks belonging to the yellowish green chlorite zone, two rock specimens (Sample No.7312 and 8198) are taken.

Plagioclases in these specimens are strongly albitized, and their original zonal structures are quite disappeared at all, though they seem quite fresh in appearance.

The distribution curves of the compositions of the albitized plagioclases are illust-
rated in Fig. 47 to 58.

As to the altered plagioclases in the rock specimen (Sample No.7312), the values
of the predominant composition of the plutonic type plagioclases are determined as
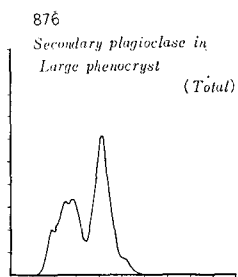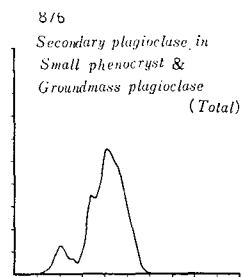An 30 and An 23, and on the other hand, the volcanic type plagioclases exhibit their
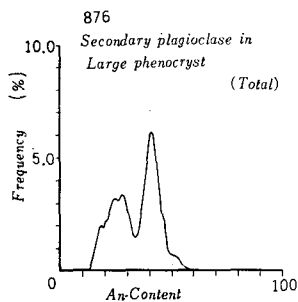predominant composition as An 34.
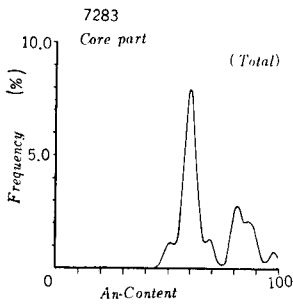

Fig. 38
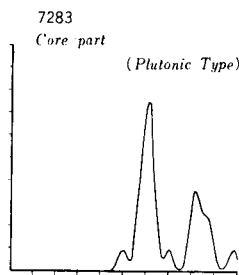
Fig.39
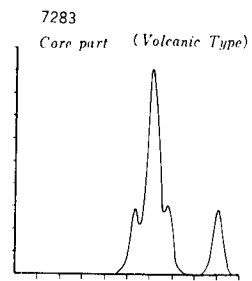

Fig.40
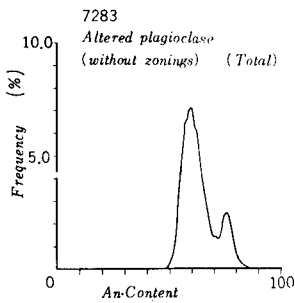
Fig.41
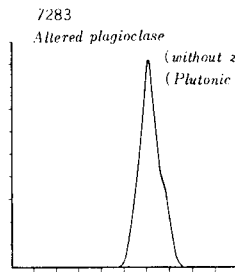
Fig.42
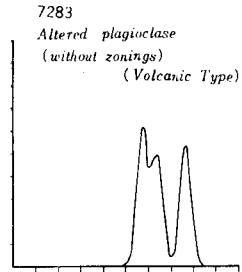
Fig.43

Fig.44

Fig.45

Fig.46

Fig.47

Fig.48

Fig.49

Fig.50

Fig.51

Fig.52
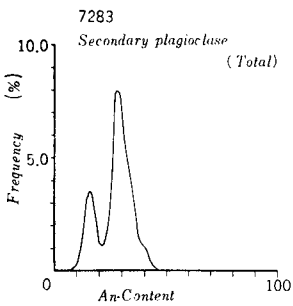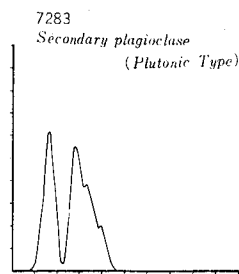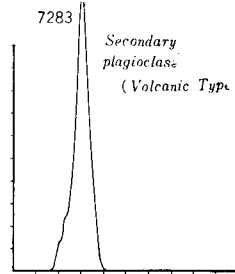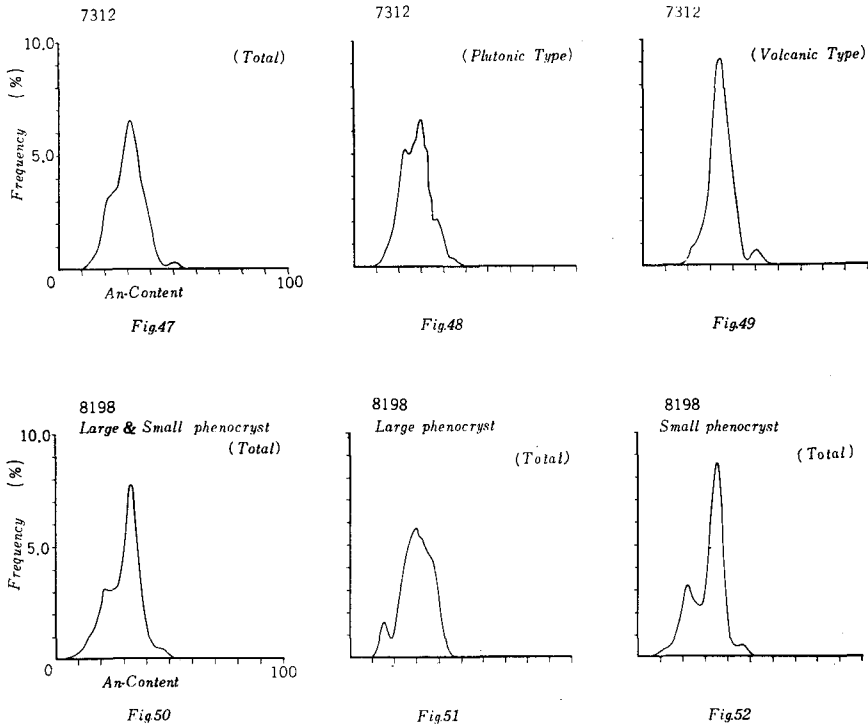
For the altered plagioclases in the rock specimen (Sample No.8198), the small phenocrysts are richer in Ab-content rather than the large phenocrysts. Besides, in general, the composition of the plutonic type in this specimen is comparatively richer in Ab-content rather than that of the volcanic type plagioclases, as well as in the another specimen (Sample No.7312).

For the secondary albitized plagioclases, they show a tendency that Ab-content of their compositions increases in amount in the pale green chlorite zone as compared with the yellowish green chlorite zone.

(c) Augite andesite

The rock specimens (Sample No.876, 7243 and 875) are given as the examples of augite andesite. Each of them is classified into the different altered zone respectively, as shown in Table 6. In the rock specimen (Sample No.876), the large phenocrysts of plagioclases are moderately albitized, and have the weak zonal structures. The distribution curves of the compositions in the inner parts are shown in Fig. 62, 63 and 64. The values of the predominant composition of the plutonic type plagioclases are nearly the same as those of the volcanic type plagioclases. However, the composition of the plutonic type plagioclases is generally more variable than that of the
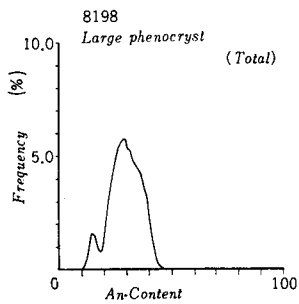
Fig.53.
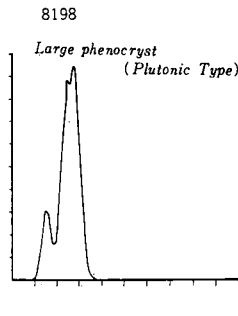
Fig.54
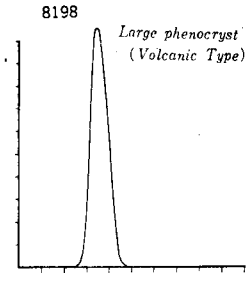
Fig.55
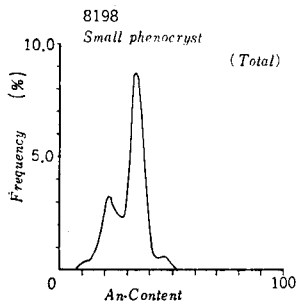
Fig.56
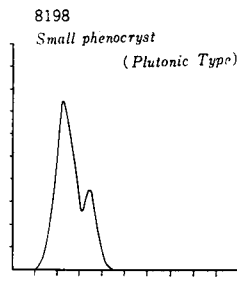
Fig.57
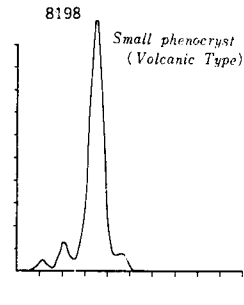
Fig.58

volcanic type. In the distribution curves of the compositions of the secondary albitized plagioclases replacing chiefly the marginal or often the inner parts of the large phenocrysts, as shown in Fig. 71, 72 and 73, the values of the predominant composition are nearly common in both two types of plagioclases.

As to both the small phenocrysts and the lath-shaped plagioclases in the groundmass of the same rock specimen, they are moderately albitized, and show mostly waek zonal structures. The predominant composition of the plutonic type plagioclases is equivalent to An 50, though that of the volcanic type is recognized as An 47 and An 54, as given in Fig. 65, 66 and 67. The distribution curve of the composition of the plutonic type shows the predominant peak being equal to An 41-44, and on the other hand, that of the volcanic type exhibits remarkable two peaks being equivalent to An 34 and An 41. These secondary plagioclases replace mostly the marginal and often the inner parts of the primary plagioclases.

The rock specimen (Sample No.7243) is taken as an example for the yellowish green chlorite zone. Plagioclases are strongly albitized and so, the original zonal structures are entirely disappeared. The 74% of the examined phenocrysts of plagioclases are partially replaced by a certain alkali-feldspars. These alkali-feldspars are too

minute to determine precisely their optical properties. They are almost anhedral or rarely hypidiomorphic crystals showing somewhat vermiculated forms. The values of their 2Vz are variable from 92° to 156°, however, are grouped into three types; 130° - 156°, 113° - 130° and 92° - 106°.

From the distribution curves of the compositions of the phenocrysts of being not replaced by alkali-feldspars, the predominant composition of the plutonic type is ascertained as An 22, but that of the volcanic type is equivalent to An 33.
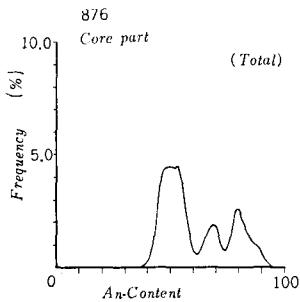

Fig.59
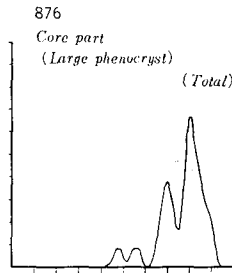
Fig.60
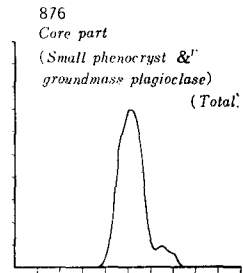
Fig.61
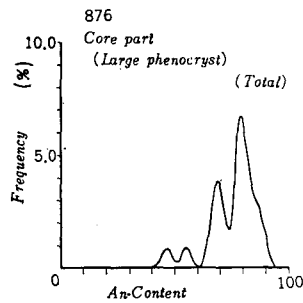
Fig.62
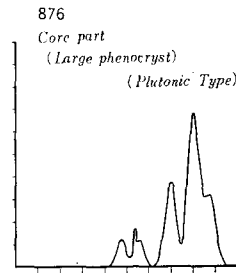
Fig.63
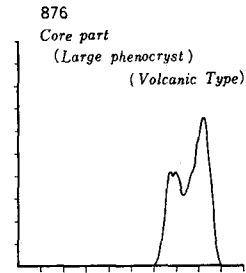
Fig.64
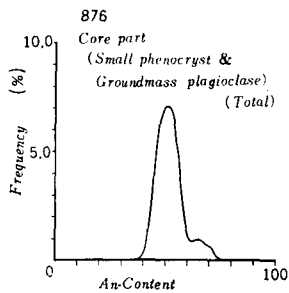
Fig.65
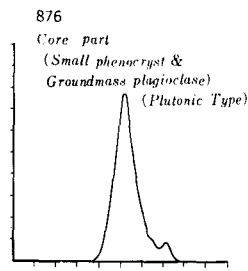
Fig.66
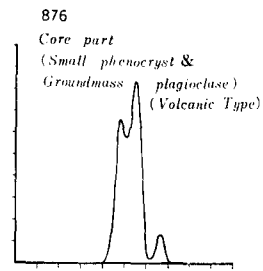
Fig.67

Furthermore, from the histograms of the compositions of the phenocrysts of plagioclases replaced partially by alkali-feldspars, the dominant compositions of the plutonic type are determined as An 22 and An 27-28, and on the other hand, the predominant composition of the volcanic type is equivalent to An 33.

The dominant compositions of the plutonic type or the volcanic type are almost independent of the existence of alkali-feldspars in the altered plagioclases.
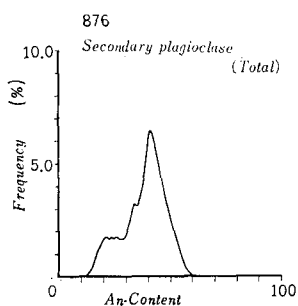
Fig.68

Fig.69

Fig.70

Fig.71
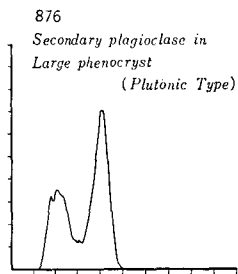
Fig.72
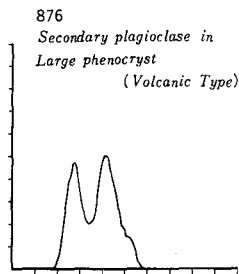
Fig.73

Fig.74

Fig.75

Fig.76

tion in the Futamata Region

Green Tuff Formation in the Futamata Region 165
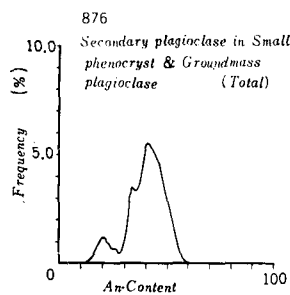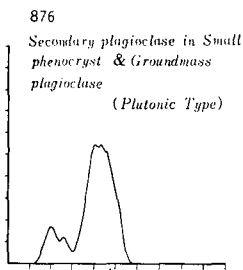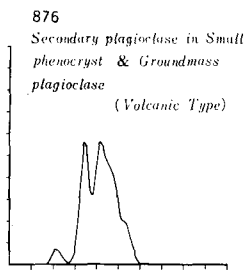
The distribution curves of the compositions of the lath-shaped plagioclases in the groundmass are illustrated in Fig. 86, 87 and 88. As shown in these histograms, the predominant composition of either the plutonic type or the volcanic type is equivalent to An 20-21 or An 33-34 prespectively.

Generally speaking, the value of the predominant composition of the plutonic type, in spite of the large phenocrysts and the lath-shaped crystals in the goundmass, is corresponding to An 20-22 and also, that of the volcanic type is equivalent to An 33-34.

The rock specimen (Sample No.875) is taken as an example for the saponite zone. Plagioclases in this specimen are moderately albitized. However, the large phenocrysts have weak zonal structures, but the lath-shaped plagioclases in the groundmass have not any ones. The histograms of the compositions in the inner parts of the weak zonal structures of the phenocrysts are illustrated in Fig. 92 to 94.

As to the composition of the plutonic type plagioclases, the predominant compositions are equivalent to An 50 and An 65 for the large phenocrysts; An 40-41 and An 51 for the small phenocrysts and plagioclases in the groundmass. On the other hand, these values for the volcanic type plagioclases, such as An 36-37 for the large
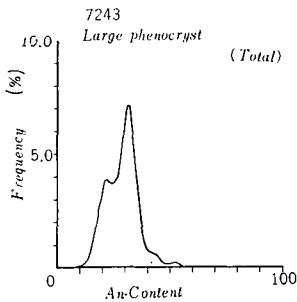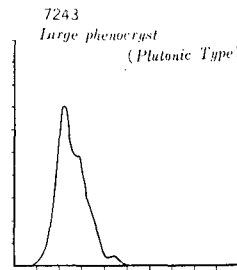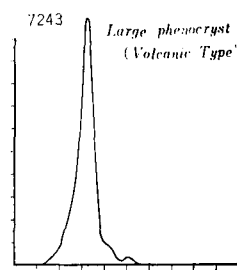
Fig.77 Fig.78 Fig.79
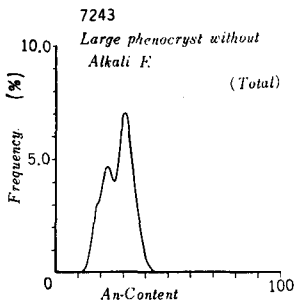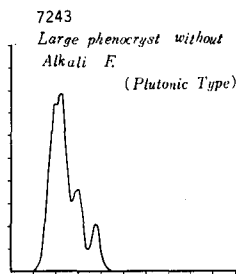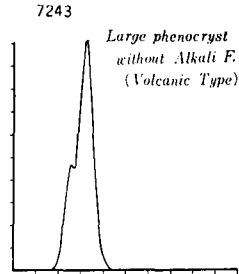
Fig.80 Fig.81 Fig.82

phenocrysts and An 51 and An 37 for the small phenocrysts and plagioclases in the groundmass are ascertained. Judging from these data, the compositions of the plutonic type are more variable, and some of them are richer in Ab-content rather than those of the volcanic type plagioclases.

The compositions of the secondary albitized plagioclases replacing mostly the outer most and often the inner parts of the initial plagioclases are also statistically determined, and are illustrated in Fig. 98 to 106.

As to the secondary plagioclases caused by the alterations of the large phenocrysts, the values representing the predominant composition are determined as An 35 and An 33 for the plutonic type, and An 42 and An 30 for the volcanic type plagioclases respectively. Furthermore, in the histograms of the compositions of the secondary albitized plagioclases replacing the small phenocrysts or plagioclases in the groundmass, the values of the predominant composition of the plutonic type are variable and are determined as An 53, An 51, An 41 and An 33, and on the other hand, the predominant composition of the volcanic type is ascertained as An 38.

From these data on the secondary albitized plagioclases, it may be surely concluded that the composition of the secondary plagioclases replacing the large pheno-
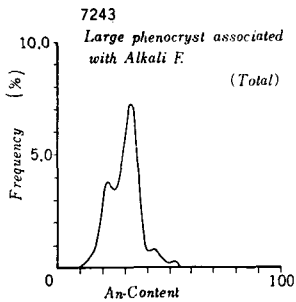
Fig.83
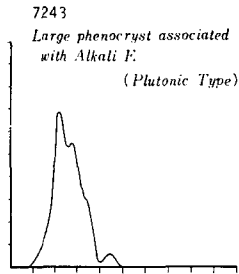
Fig.84
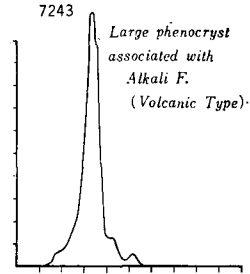
Fig.85
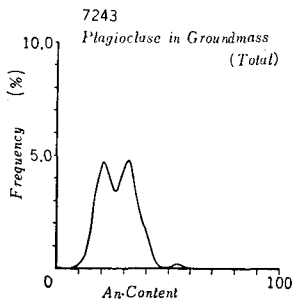
Fig.86
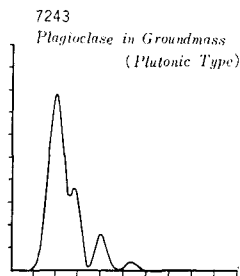
Fig.87
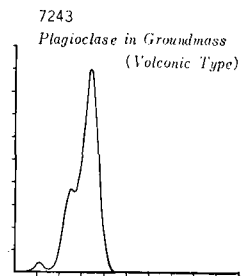
Fig.88

crysts is generally richer in An-content than that of the secondary plagioclases caused by the albitizations of the small phenocrysts and the groundmass plagioclases. Moreover, it is also obviously recognized that the plutonic type plagioclases are commonly albitized strongly as compared with the volcanic type plagioclases.

Generally considering, the compositions of plagioclases in augite andesite show a tendency to decrease in An-content, as the alteration-degree increases, namely from
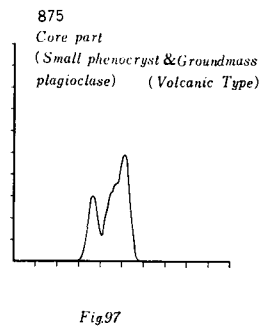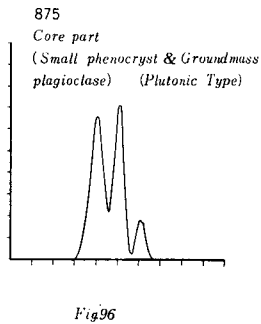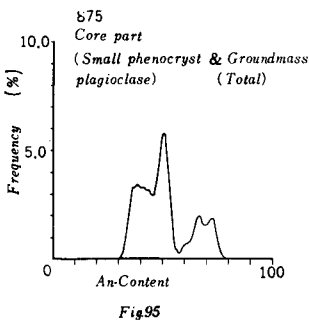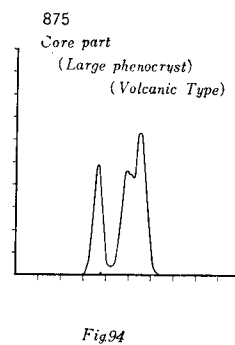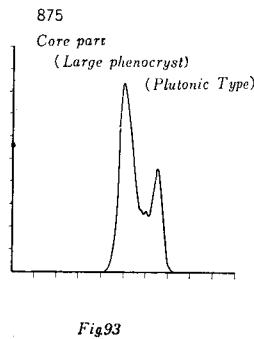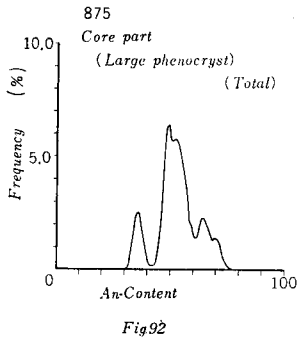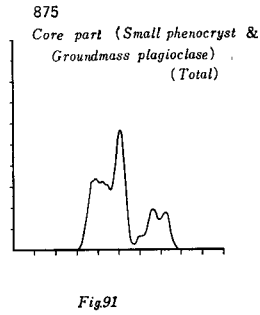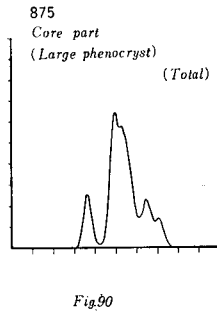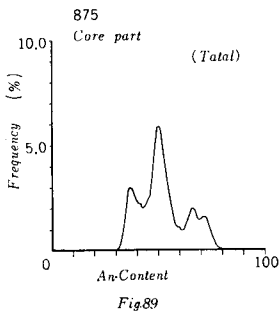
Fig.89

Fig.90

Fig.91

Fig.92

Fig.93

Fig.94

Fig.95

Fig.96

Fig.97

the saponite zone through the yellowish green chlorite zone to the pale green chlorite zone, though plagioclases in the examined rock specimen belonging to the pale green chlorite zone are somewaht An-content rich in composition.

　　Furthermore, in general, plagioclases being rich in Ab-content are abundantly recognized in the plutonic type plagioclases compared with the volcanic type ones.
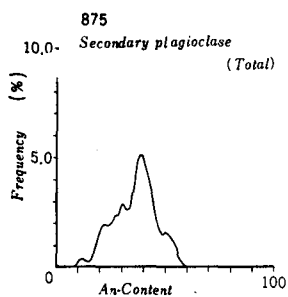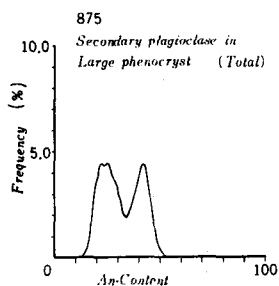

Fig.98
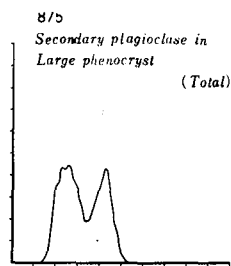
Fig.99
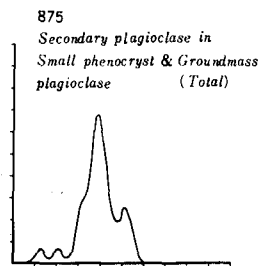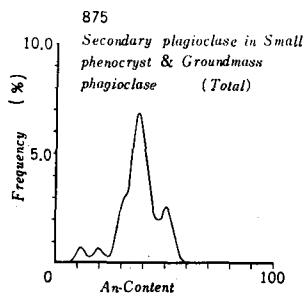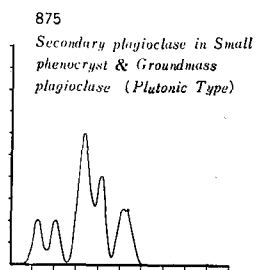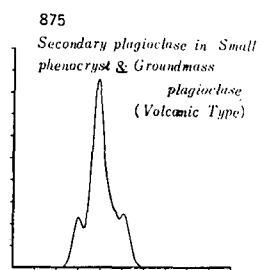
Fig.100

Fig.101
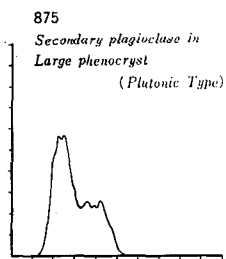
Fig.102
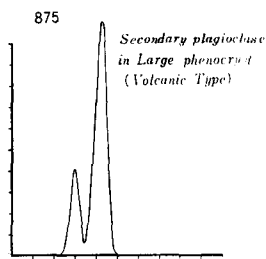
Fig.103

Fig.104

Fig.105

Fig.106

(III) Interpretations on the compositions of plagioclases

The predominant and the dominant compositions of plagioclases examined are schematized in Table 8. The under-lined An-contents exhibit the most predominant compositions of each plagioclases, and the parenthesized An-contents represent the dominant ones. The solid or the broken arrow lines show the directions of the albitizations through the hydrothermal processes; the former is common and the latter is often.

As to the compositions in the inner or the most outer parts of the zonal structures of plagioclases, it is generally recognized that the values of the compositions, such as An 78-81, An 69, An 64-65 and An 49-51 are the common to the two, i.e., plutonic and volcanic types of plagioclases, though the some values of the compositions, such as An 60-61 and An 40-41 for the plutonic type, or An 75-76, An 57, An 54-55 and An 36-37 for the volcanic type plagioclases, are the peculiar in each of the two types of plagioclases.

Besides, with regarding the compositions of the secondary albitized plagioclases, the values of the compositions, such as An 55-57, An 41-42, An 37-38, An 34-35, An 32-33, An 25-28, An 22-23 and An 19-21, are the common to the two types of plagioclases. Nevertheless, in the composition of the plutonic type, such values as An 64, An 46, An 18 and An 16 are the singular, and on the other hand, these compositions such as An 53, An 30 and An 28 are quite peculiar to the volcanic type platioclases.

These An-content values of being common to the two types of plagioclases may suggest a certain important fact concerning with the composition of plagioclases. Namely, *it will be able to offer that each of these values may indicate the most stable range of plagioclases changing from anorthite to albite in composition and the trough between the remarkable peaks in the distribution curve may be impliedly equivalent to the compositional range in which plagioclases can be scarcely generated or they are unstable.* In other words, it may be able to consider that the solid solution system of plagioclases is not so simple as ever known, and has some gaps or a certain unstable range for plagioclases.

As for the optical type of the secondary albitized plagioclases, viz., the plutonic or the volcanic type, the secondary plagioclases inherit the intitial plagioclases' type, in spite of changes of the compositions, and probably of the lattice structures, through the albitization in the hydrothermal stage. Nevertheless, this phenomenon has not been clarified by any basal factors.

Furthermore, as the composition of plagioclases having zonal structures, it decreases in An-content through the albitization, the twin lamellation on the albite law, as well as the zonal structures, becomes gradually sharpless in appearance. However, when the zonal structures are quite disappeared at all, the lamellation of the albite twinning is generally recognized with the very sharp appearance. And then,

Akihiko YOSHITANI

Rock Species	Sample Number	Pale Green Chlorite Zone		Yellowish Green Chlorite Zone		Saponite Zone	
		(A)	(B)	(A)	(B)	(A)	(B)

the albitization goes on moreover, this lamellation becomes gradually sharpless again.

For the examined plagioclases, their compositions are equivalent to An 20-23 for the plutonic type, also to An 32-33 or An 22-23 for the volcanic type plagioclases, then the zonal structures are entirely unascertained, and the twin lamellation on the albite law is comparatively sharp in appearance.

It may be also permitted that there is a certain relationship between the albite twinnings and the zonal structures in plagioclases, but any reasonable causes why these phenomena happen have not been offered yet.

V. Conclusion

(I) *The history of the geological developments*

In the Futamata region and its environs, the history of the geological develop-ments of the Neogene basin is summarized in Fig. 107, and may be divided into three stages from the geotectonical viewpoint. Namely, the stage represented by the depo-sitions of the Hidarimata tuff member, and the successive eruptions, as well as the intrusions, of the Futamata propylite member is the first. In the second stage, the depositions of the Migimata acidic tuff member and the Yunosawa tuff member oc-cured. The stage represented by a series of the igneous activities, such as diorite-porphyrite, augite andesite, dacite, quartz porphyry and rhyolite in intrusive order in the last.

The present Neogene basin, in which the Hidarimata tuff member had been deposited at the beginning, showed a tendency of upheaval in graduals, when propy-lites intruded and erupted violently. And then, the sinking parts of the basin were divided into two parts; the eastern and the western parts. In the eastern part, the Yunosawa tuff member of being conformable in part or slightly unconformable in part, to the Futamata propylite member was successively deposited. On the other

---

Table 8 (p. 170)

(A)	:	Primary Plagioclase
(B)	:	Secondary Plagioclase
(L)	:	Large Phenocryst of Plagioclase
(M)	:	Small Phenocryst of Plagioclase and Plagioclase in Groundmass
(P)	:	Plutonic Type Plagioclase
(P)*	:	Core Part of Zoned Plutonic Type Plagioclase
(P)**	:	Outermost Part of Zoned Plutonic Type Plagioclase
(V)	:	Volcanic Type Plagioclase
(V)*	:	Core Part of Zoned Volcanic Type Plagioclase
(V)**	:	Outermost Part of Zoned Volcanic Type Plagioclase

hand, in the western part, the depositions of the Migimata acidic tuff member of being entirely conformable to the Futamata propylite member occured. The present eastern part became extinct soon after on account of the gradual upheaved movement. However, for the western part, the sinking parts locomoted gradually towards the further west. The central part between these small basins separted in the east and the west sides exhibited the further upheaval. The shallow basin in the central part was entirely disappeared through the activities of propylites, and became the land of being similar to small geoanticlinal part. By the way, the igneous activities in the first stage, are characterized by augite andesite. On the contrary, those in the second stage, are also characterized by hypersthene green hornblende dacite and green hornblende rhyolite.

As to the third stage in which the sedimentary basins were almost disappeared, it is characterized by a series of the successive activities of the following igneous rocks; diorite-porphyrite, augite andesite, dacite, quartz porphyry and rhyolite in the intrusive order. Most of these intrusive rocks, excepting for rhyolite, extend in NNW-SSE or NW-SE direction. The present direction is quite accordant with the one of the essential geotectonical structures in the Neogene system distributed in southwest Hokkaido. However, the lithoiditic rhyolites show the zonal arrangement surrounding the diorite-porphyrite mass developed in the Hidarimata valley.

Generàlly speaking in a word, at the third stage, the igneous activities, which were fundamentally controlled by the tectonical movements exhibiting nearly NW-SE in direction, occurred in the central part, in which the sedimentary basin had been entirely disappeared at all. The present central part, being as similar as a certain geoanticlinorium, was the very area of the intrusive activities, and also was equivalent to the axis of the intrusive zone.

And finally, in a certain stage of the upper middle or the lower upper Miocene, the hydrothermal alterations occurred through the entire tectonic zones, and were closely associated with the metasomatic effects, happened in the Futamata region. Owing to the present alterations, both the Neogene strata and the intrusive rocks are altered in a certain degree.

As for the correlation of the Neogene strata distributed in the Futamata region with the standard in southwest Hokkaido, it is shown in Table 2.

(II) *On propylite*

For propylites of being developed typically and only in the so-called "Green Tuff region" in Japan, their whole aspects have not been yet known all. However, the lava flows and the intrusive bodies of propylites distributed in the Tohoku Back-bone district of the northeastern part of Japan were investigated, and their essential characters were revealed. (HUNAHASHI *et al.*, 1966). That is, the activities of propylites are fundamentally controlled by the tectonic movements, and they occur through these

1st stage

Neogene Basin

Volcanic (Propylite) Activity Zone

Geoanticline Axis

direction of Movement of Sinking Part of Basin

2nd stage

Western Part

Eastern Part

3rd stage

Igneous Activity Zone
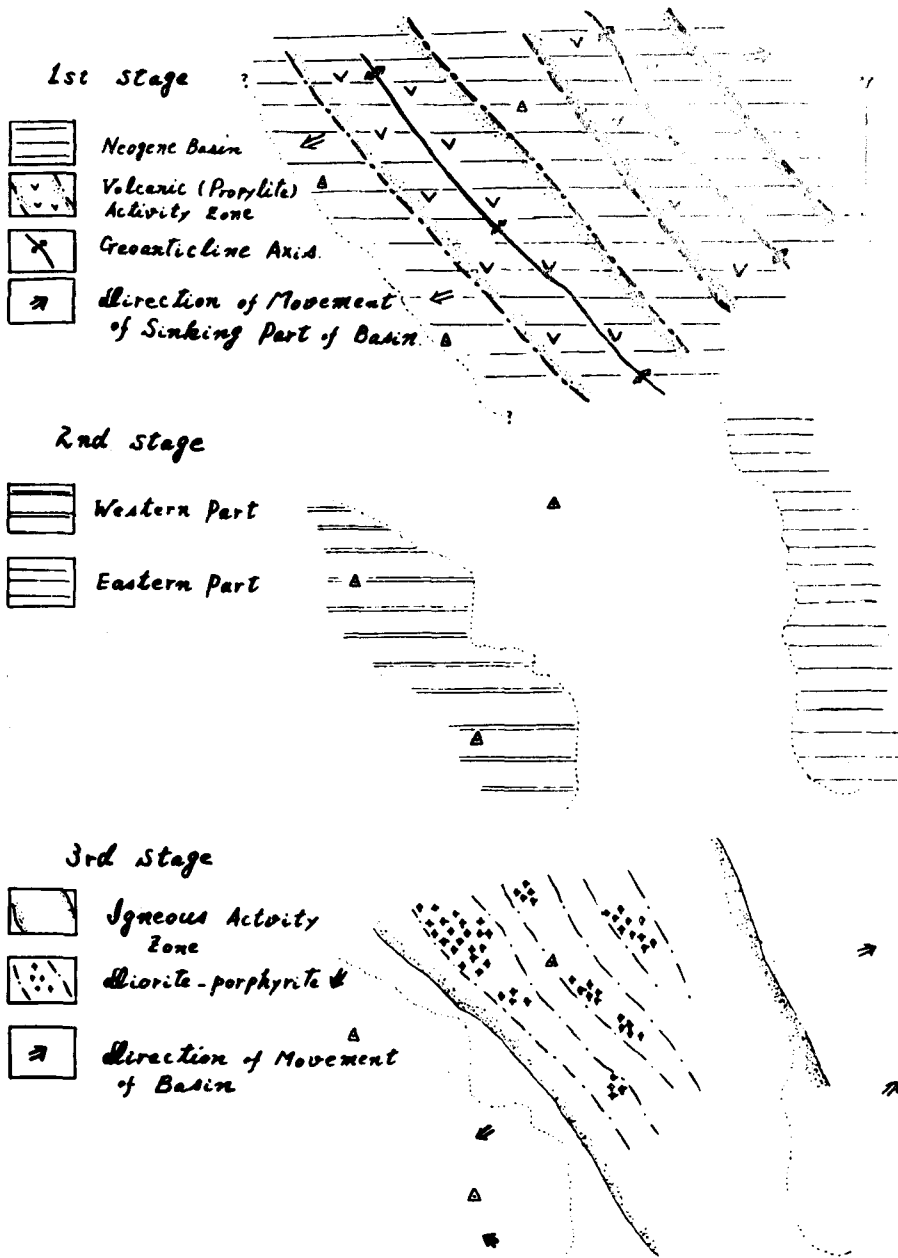
diorite-porphyrite

direction of Movement of Basin

Fig. 107

tectonic zones. Besides, they characterize essentially the igneous activities in the low Miocene period.

From the writer's investigation on propylites developed in the Futamata region, next conclusions are able to offer as follows;

(a) Propylite is fundamentally an intrusive rock, and it intrudes and erupts through the geotectonic zone. Furthermore, in its profile, it exhibits generally the shape like a morning-glory.

(b) The activity of propylite occurs, when the sedimentary basin is in the motion from sinking to upheaval.

(c) The activity of propylite takes the lead of the following igneous activities occurring in the geoanticlined part. Especially, propylite is generally closely associated with the Tertiary hollocrystalline rocks, such as diorite-porphyrites, as well as seen in the other Green Tuff basins.

(d) Propylite is hydrothermally altered, however, its alteration is not caused by the so-called autometasomatic actions in a certain post magmatic stage, but by the hydrothermal solutions in a certain post-action stage.

(III) *Alteration*

For the alterations of the Neogene system distributed in the Futamata region, three alteration zones are established; viz. the pale green chlorite zone, the yellowish green chlorite zone and the saponite zone. These alteration zones extend in nearly NNW - SSE direction, and are arranged zone by zone in the above mentioned order, as shown in Fig. 9. Most of the secondary minerals excepting for the index standard clay minerals and some other minerals, such as epidote, Type A and B chlorites and sphene, are common in the three alteration zones which are established with independent of the properties of the initial rocks, of being variety in species from dolerite to rhyolite, or of the stratigraphical structures.

Among these alteration zones, especially, the pale green chlorite zone is equivalent to the axial parts of the volcanic activities which occurred mainly at the geoanticlinal central part in the Futamata region. Furthermore, owing to the investigations on the altered plagioclases, the alteration-grade changes from higher to lower in the following order; the pale green chlorite zone, the yellowish green chlorite zone and the saponite zone.

Judging from these data, it may be surely concluded that the alterations observed in the Neogene system in the Futamata region were quite caused by the hydrothermal processes in a certain post-action stage, after the successive volcanic activities, probably in the upper middle or lower upper Miocene period.

(IV) *On the alterations of plagioclases*

The relationships between the optical orientations and the compositions, and the 2Vz values, of the altered plagioclases were investigated.

Especially, on the secondary albitized plagioclases through the hydrothermal processes, some informations were obtained as given below.

(a) The optical type, either the plutonic or the volcanic type, of the secondary albitized plagioclases is just the same as that of the initial plagioclases, though the compositions and probably the lattice structures are changeable through the albitization.

(b) The compositional changes of plagioclases through the albitization may suggest the stable or unstable ranges for plagioclases. Namely, the albitization of plagioclases may be considered as not so simple as ever known, but somewhat complicated.

(c) As for the relationships between the twin lamellation on the albite-law and the zonal structures, both become gradually vague in appearance, as the albitization goes on. However, the zonal structures are entirely disappeared on account of the intense albitization, then the albite twinnings are comparatively sharply recognized in appearance. As the altered plagioclases in the examined rock specimens concern, the compositions in this stage are nearly equivalent to An 20-23 for the plutonic type and also to An 32-33 or An 22-23 for the volcanic type plagioclases. The albitization goes on moreover, the twin lamellation on the albite-law becomes again in obvious in appearance.

VI. Acknowledgements

VII. References

AKIBA, C., FUJIE, T., MATSUI, M., OKABE, K., SAKO, S. and UOZUMI, S. (1966): Igneous activity and crustal movements in southwest Hokkaido. *Monograph of the Association for the Geological Collaboration in Japan*, No. 12, 16-24.

————— , YASHIMA, R., WATANABE, J., YOSHITANI, A. and YAJIMA J. (1966): Early Miocene Green Tuff activity along the National Railway Yokote-Kurosawajiri Line over the backbone range of northeast Japan. *Monograph of the Association for the Geological Collaboration in Japan*, No. 12, 25-34.

AKAME, K., and HARAGUCHI, M. (1963): Geology and ore deposit of the Toyoha mine. *Mining Geology; Jour. Soc. Min. Geol. Jap.*, Vol.13 (6), 93-99

COOMBS, D.S. (1953): The pumpellyite mineral series. *Min. Mag.*, Vo. 30, 113-135.

————— , ELLIS, A.J., FYFE, W.S. and TAYLOR, A.M. (1959): The zeolite facies, with comments on the interpretation of hydrothermal syntheses. *Geoch. et Cosmochi. Acta,* Vol. 17, 53-107.

DEVORE, G.W. (1956): Al-Si position in ordered plagioclase feldspars. *Zeit. Kristallogr.,* Vol.107, 247-264.

DOI, S. (1953): Zyozankei, geological map of Japan. *Hokkaido Development Agency.*

FUJITA, Y. (1960): On the laws concerning to the paleogeography and geotectonics of the Green Tuff Geosyncline in northeastern Japan. *Earth Science,* No. 50-51, 22-35.

————— , KAKIMI, T., KUTSUZAWA, A., MITSUNASHI, T., MIZUNO, A., SATO, J. and YAMASHITA, N. (1966): Neogene tectonic movements in the backbone range of northeast Japan. *Monograph of the Association for the Geological Collaboration in Japan,* No.12, 42-58.

GORAI, M. (1951): Petrological studies on plagioclase twins. *American Mineralogist,* Vol. 36, 884-901.

HUJIOKA, K. (1956): The Neogene volcano-stratigraphy of the Green Tuff region in the inner Japan. *Jub. Pub. in the Commemoration of Prof. J., Suzuki, M.T.A. Sixtieth Birthday,* 511-518.

HUNAHASHI, M. (1966): Igneous activity of the "Green Tuff" region. *Monograph of the Association for the Geological Collaboration in Japan,* No. 12, 138-146.

————— , and YOSHIMURA, T. (1966): Characteristic rock alterations in the "Green Tuff" region. *Monograph of the Association for the Geological Collaboration in Japan,* No.12, 147-164.

IIJIMA, H. and UTADA, M. (1965): Phillipsite, analcite and laumontite in sedimentary rocks. *Jour. Geol. Soc. Jap.,* Vol. 71, 56-65.

INABA, A. (1959): Hydrothermal alteration of the Miocene volcanic rocks of the Uchimura District, Nagano Prefecture. *Earth Science,* No. 43, 11-22.

INOUE, T. (1956): The Tertiary igneous activities in Akita oil field, Japan. *Jub. Pub. in the Commemoration of Prof. J. Suzuki, M.T.A. Sixtieth Birthday,* 538-544.

————— , (1960): The stratigraphical studies of the igneous rocks accompanied by the oil bearing Tertiary and the basement Green Tuff in the Akita oil field, northeastern Japan. *Rep. Res. Inst. of Underground Resources Mining Coll. Akita Univ.* No. 23, 1-79.

IWAO, S. (1960): Argillization and clayey deposits in "Green Volcanic Formations" in Japan. *Mining Geology; Jour. Soc. Min. Geol. Jap.,* Vol.11, 351-355.

————— , (1961): The alteration of the volcanic rocks in the "Green Tuff" region. *Rep. Symp. Geol. Soc. Jap.,* 7-15.

KANO, H. (1955): High-temperature optics of natural sodic plagioclase. *Miner. Jour.,* Vol. 1, 255-277.

————— , YANAI, K., TUSJI, M., KAWASE, A. and KANIZAWA, S. (1966): Structure of some basement granitic masses and their significance in geotectonics of the Green Tuff region. *Monograph of the Association for the Geological Collaboration in Japan,* No. 12, 1-15.

KIM, C.W. (1964): On some behaviour of plagioclase feldspars during the formation and the hydrothermal alteration of propylites. *Jour. Geol. Soc. Jap.,* Vol. 70, 423-433.

————— , and SAKO, S. (1967): On composition and ordering of plagioclases in Neogene Tertiary hollocrystalline rocks. *Jour. Geol. Soc. Jap.,* Vol. 73, 7-17.

————— , TSUCHIYA, T. and SAKO, S. (1967): Compositional variation and ordering states of pla-

gioclases in Neogene Tertiary hollocrystalline rocks of Ainumanai, southwest Hokkaido. *Jour. Geol. Soc. Jap.,* **Vol. 71,** 389-399.

KORZHINSKIY. D.S. (1959 a): The advancing wave of acidic components in ascending solution and hydrothermal acid-base differentiation. *Geoch. et Cosmoch. Acta,* **Vol. 17,** 17-20.

—————————— , (1959 b): Phisicochemical basis of the analysis of the paragenesis of minerals. (translated from Russian) *Consultants Bureau, Inc., New York.*

KÖHLER, A. (1941): Die Abhängigkeit der Plagioklasoptik vom vorangegangenen Wärmeverhalten. *Mineral. Petroger. Mitt. Tscherm.,* **Bd. 53,** 24-49.

KUNO, H. (1960): High alumina basalt. *Jour. Pet.,* **Vol. 1,** pt. 2, 121-145.

KUTZUZAWA, A. and other members of the Taiheizan Research Group (1966): Geology and structure of the Neogene system in the southern marginal area of the Taiheizan Massif, northeast Japan, with special reference to relations between the "Green Tuff" activity, sedimentation and fracture-development. *Monograph of the Association for the Geological Collaboration in Japan,* No. 12 73-94.

MARFUNIN, A.S. (1969): The feldspars; phase relations, optical properties, and geological distribution. (translated from Russian) *Israel Program for Scientific Translations, Jerusalem.*

MATSUDA, T. and KURIYAGAWA, S. (1965): Lower grade metamorphism in the eastern Akaishi mountains, central Japan. *Bull. Earthq. Res. Inst. Univ. Tokyo,* **Vol. 43,** 209-235.

MATSUMOTO, T. and WADATSUMI, K. (1960): Some aspects of the igneous activities during the "Green Tuff Period" in Honshu arc, Japan. *Earth Science,* No. 50-51, 66-74.

MINATO, M. (1952): On the "Green Tuff" region. *The Cenozoic Research* No.13, 1-10.

—————————— , YAGI, K. and HUNAHASHI, M. (1956): Geotectonic synthesis of the green tuff regions in Japan. *Bull. Earthq. Res. Inst. Univ. Tokyo,* **Vol. 34,** 237-265.

—————————— , GORAI, M. and HUNAHASHI, M. (1965): The geologic developments of the Japanese Islands. *Tsukiji Co., Tokyo.*

NAKAJIMA, W. and KOIZUMI, K. (1962): Zeolites in the tertiary beds located along the Okoku Line, northeastern Honshu, Japan. *Earth Science,* No. 58, 26-31.

NASHAR, B. and DAVIES, M. (1960): Secondary minerals of the Tertiary basalts, Barrington, New South Wales. *Min. Mag.,* **Vol. 32,** 480-491.

OIDE, K., YAJIMA, J., ORIMOTO, S., YAMAGISHI, I., YASHIMA, R., URUNO, K. and KATO, Y. (1966): On a Tertiary granitoid mass in the backbone range of northeast Japan. *Monograph of the Association for the Geological Collaboration in Japan,* No. 12, 35-41.

——————, and ORIMOTO, S. (1966): Tertiary granitoids as volcano-plutonic complexes. *Monograph of the Association for the Geological Collaboration in Japan,* No. 12, 127-137.

PACKHAM, G.H. and CROOK, K.A.W. (1960): The principle of diagenetic facies and some of its implications. *Jour. Geol.,* **Vol. 68,** 392-407.

SEKI, Y. (1965): Behaviour of carbon-dioxide in low-grade regional metamorphism. *Jour. Assoc. Min. Petrol. Economic Geologists,* **Vol. 54,** 1-13.

Sendai Research Gourp. (1966): A Late Miocene volcano-tectonic depression in northeast Japan. *Monograph of the Association for the Geological Collaboration in Japan,* No.12, 112-126.

SHIMAZU, M. and SATO, A. (1966): On the diagenetic alteration of the volcanic rocks in the Ainai-Jinba Area, northern Akita District, northeastern Japan. *Rep. Sci. Fac. Geol. Min. Inst. of Niigata Univ.,* No. 1, 59-95.

SLEMMONS, D.B. (1962): Determination of volcanic and plutonic plagioclases using a three or four - axis universal stage. *Geol. Soc. Am. Special Paper,* No. 69.

SUDO, T., NISHIYAMA, T., CHIN, K. and HAYASHI, H. (1963): Mordenite and clinoptilolite in glassy tuffs of Japan. *Jour. Geol. Soc. Jap.,* **Vol. 69,** 1-14.

SUGIMOTO, R. (1953): Zenibako, geological map of Japan. *Hokkaido Development Agency.*

SUWA, K. (1968): Notes on plagioclase, with special reference to its twining. *Earth Science*, No. 22-3, 156-163.

TAKADA, S. (1967): On the geology in Hutamata region along the Riv. Shirai, Zyozankei District, southwest Hokkaido. *The Komazawa Review; Iwamizawa High School attached to Komazawa Univ.*

URUNO, K. (1963): Optical study on the ordering degree of plagioclases. *Sci. Rep. Tohoku Univ., Ser. 3*, Vol. 8, 171-220.

WALKER, G.P.L. (1960): Zeolite zone and dike distribution in relation to the structure of the basalts of eastern Iceland. *Jour. Geol.*, Vol. 68, 515-528.

YAMAGISHI, I. (1965): Alteration Minerals of Green Tuffs in the Uchimura District, Nagano Prefecture. *Jour. Geol. Soc. Jap.*, Vol. 71, 215-227.

YASHIMA, R. and OIDE, K. (1966): Volcanism and rock alteration in the Early Miocene field along the Pacific Coast of northeast Japan. *Monograph of the Association for the Geological Collaboration in Japan*, No. 12, 103-111.

YOSHITANI, A. (1965): Zeolites in the Neogene pyroclastic rocks in the eastern part of Tanzawa Mountainland, central Japan. *Mem. of College of Sci. Univ. of Kyoto, Ser. B*, Vol. 31, 1-15.

ZEN, E-AN. (1961): The Zeolite facies: an interpretation. *Am. Jour. Sci.*, Vol. 259, 401-409.