PETROLOGY OF THE MUROTOMISAKI GABBROIC COMPLEX

TOSHIHIKO YAJIMA

Department of Earth Sciences, Faculty of Education, The Saitama University, Urawa

The Murotomisaki differentiated gabbroic complex locates at the extreme point of the Cape Murotomisaki, Shikoku Island. This complex intruded into the Murotohanto Group of Eocene in age. The zonal arrangement of which complex shows the indication of the fractional crystallization with gravitational sinking. Principal rock types of the complex are as follows: chilled marginal dolerite, picrite gabbro, fine-grained hypersthene bearing olivine augite gabbro, medium-grained hypersthene bearing olivine augite gabbro, augite gabbro pegmatite and ferrogabbro. The pegmatic rocks of the latest stage intruded as small veins. Any grain of pigeonite or inverted pigeonite is not found, whereas a small amount of hypersthene is observable as internal precipitates. Iron concentration in olivine and in augite is conspicuous at the upper part of the complex. Ilmenite is the predominant opaque minerals through the course of fractionation and magnetite appears at the latest stage. Fractional crystallization of OLIVINE THOLEIITE to intermediate iron concentration under low vapour pressure and low oxygen partial pressure is studied on these bases.

1. INTRODUCTION

There are many petrological contributions to the differentiation of basaltic magmas such as Skaergaard Intrusion (Wager and Deer, 1939), Palisade Diabase (Walker, 1940), Stillwater Complex (Hess, 1960), Black Jack Sill (Wilkinson, 1957, 1958) and Guadalupe Igneous Complex (Best, 1963, 1967). These studies are necessary not only for the determination of the process of solidification, but also for the estimation of initial petrochemical condition of the intruded magma. The Skaergaard Intrusion, the Palisade Diabase and the Balck Jack Sill represent the products of high alumina basalt magma, tholeiite basalt magma and alkali olivine basalt magma, respectively.

The contributions to the differentiation of basaltic magmas in the Japanese Islands and in the related islands include those of Morotu Igneous Complex (Yagi, 1953), Atumi Dolerite (Kushiro, 1964), Semi Dolerite (Kuno, unpublished), Koyama Complex (Yamazaki, 1967), basaltic rocks of Oshima (Kuno, et al., 1957), Takakusayama (Tiba, 1966), basaltic rocks of Sidara (Kuno, unpublished), Sanogawa Gabbro-Diorite Complex (Yajima, 1970), etc.

For the identification of the rock types of the differentiated igneous complex, presence or absence of pigeonite is an important indicator. In the tholeiitic intrusive complex as the Palisade Diabase and the Stillwater Igneous complex, pigeonite is present, whereas in the alkalic intrusive complex such as the Black Jack Sill, pigeonite is quite lacking. On the other hand, Kushiro found pigeonite in the Atumi alkali olivine dolerite and the present writer observed inverted pigeonite in the Sanogawa Gabbro-Diorite Complex, which belongs to calc-alkali rock.
These petrochemical and mineralogical characters suggest that the physical conditions of the magmas are independent from the chemical nature of the original magma; in other words, a magma of certain chemical composition does not necessarily crystalize at a certain definite temperature or pressure.

To investigate this problem, it is highly significant to study the gabbroic complex in which pigeonite does not appear. Since the Murotomisaki complex appears to belong to this type, studies on this gabbroic complex have been done in detail.

A geologic map of the Murotohanto Peninsula was prepared by Suzuki (1930), who described the rocks of the igneous complex of Murotomisaki as uniform gabbroic rock. In 1946, when earthquake attacked the Nankai district, the Cape Murotomisaki showed upheaval of 3 to 4 metres, and in consequence, field observation along the continuous exposure of the complex came to be possible. After this upheaval, Yoshizawa (1953, 1954) investigated the complex in optical and petrochemical respects. In these papers, he concluded the Murotomisaki complex to belong to the calc-alkali rock series (hypersthenic rock series defined by Kuno, 1950), on the basis of presence of hypersthene and absence of pigeonite, also on the basis of chemical properties in the AFM diagram (K$_2$O+Na$_2$O-FeO+Fe$_2$O$_3$-MgO diagram).

The present writer studied the same igneous complex and reached a different conclusion. That is, the original magma of the Murotomisaki intrusion belongs to OLIVINE THOLEIITE and has a character of differentiation trend of intermediate iron concentration. Fourteen new chemical analyses of constituent minerals are presented in this paper. On the basis of these chemical data as well as field and microscopic observations, the mineralogy and chemistry of the igneous complex are described. Petrochemistry and differentiation process of the complex will be described and discussed in the following another papers.

2. GENERAL GEOLOGY

The Murotohanto (Muroto Peninsula), occupying the south-eastern end of Shikoku Island, consists mostly of Murotohanto Group of Eocene in age (Katoh, 1961, 1965). (Fig. 1) This group is composed of Oyamamisaki formation (3100 m in thickness), Muroto formation (400 m) and Naharigawa formation (5300 m), in the ascending order. They are in contact with each other and intersected by many faults. Shijiderayama formation (300 m) of Oligocene in age covers Muroto formation with unconformity.

Muroto formation is composed of sandstone-shale alternation, shale, sandstone and conglomerate with pillow lava exposed at the seashore of Shiina. The clastic rocks of Muroto formation show complicated folding of various kinds of scale. The Murotomisaki gabbroic complex intruded into the above clastic rocks, giving thermal effects corresponding up to the grade of pyroxene hornfels facies. The Murotomisaki complex tilts 80° southeastwards. But the zonal arrangement of the differentiated products

![Fig. 1. Locality map.](image-url)
developed parallel to the structure of the entire bodies, and gravitational concentration of heavy mafic minerals as olivine and augite indicates the horizontal intrusion of the magma.

3. Petrography

1. General profile of the complex

The Murotomisaki complex is exposed at the extreme point of the Cape Muroto (Murotomisaki) as inclined sheet with maximum thickness of 230 metres. It tapers northeastwards. The country rocks of this intrusive sheet include shale-sandstone alternation, slate, arkose sandstone and conglomerate. All the contacts between the complex and surrounding rocks are knife sharp and the marginal rocks of the complex exhibit the characteristic feature of rapid cooling of the intruded magma. Distribution of different rock types in the complex show the zonal arrangement parallel to the contact plane, and almost continuous out-
crops from lower to upper contact are observed.

The principal rock types of the complex from the lower to the upper part are as follows: chilled marginal dolerite, basaltic dike (branch of chilled marginal dolerite), picrite gabbro, fine-grained hypersthene bearing olivine augite gabbro, medium-grained hypersthene bearing olivine augite gabbro, augite gabbro pegmatite and ferro-gabbro. The term “picrite gabbro” is used in this paper for the fine-grained hypersthene bearing olivine augite gabbro, in which modal olivine occupies nearly 30%. “Fine-grained hypersthene bearing olivine augite gabbro” is for rocks without any significant variation of modal minerals in handspecimen, while “medium-grained hypersthene bearing olivine augite gabbro” is for rocks with remarkable variation as compositional bandings. The former is characteristic to the lower part of the sheet, whereas the latter to the middle part. “Ferro-gabbro” is used for rocks with olivine and augite, both of which are enriched in iron. Plagioclase with considerable amounts of ilmenite and magnetite are also characteristic to this rock type.

2. Country rocks

The country rocks of the complex within about 20 m from the contact are very much hardened like hornfels, and composed essentially of plagioclase, quartz and alkali feldspar with small amount of chlorite and sericite. There are many reddish brown lenses reaching 20 cm in size, concentrated with jarosite, pyrite, hematite and magnetite. Near the contact, pseudomorphs of hypersthene and cordierite are observed.

At some parts of the contact, the country rocks of arkose sandstone origin exhibits granitic fabric under the microscope, and at the northeastern end of Bishagoiwa, some portion of country rocks intruded into the chilled margin of the complex as small dikes of 20 cm in width (Fig. 5). A quartz-feldspathic white vein parallel to the contact boundary is observed at the chilled marginal part of the Kobishagoiwa. This vein may reach 10 metres in extension and 30 centimetres in width. Chemical composition of this vein is given in Table 1. This rock is composed essentially of normative quartz and feldspar (An19.4Ab67.8Or12.8) with small amount of normative corundum. Since this composition is quite different from those of ordinary other differentiation products of this complex, this rock is thought to have been formed by the mechanical mobilization and partial melting of the country rock by the heat supplied from the intruded magma.
Table 1. Chemical analysis and norm value of quartz-feldspathic vein from upper marginal part of the gabbroic complex.

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>H₂O(+)</th>
<th>H₂O(−)</th>
<th>P₂O₅</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>norm</td>
<td>64.68</td>
<td>0.81</td>
<td>14.33</td>
<td>0.94</td>
<td>4.20</td>
<td>0.08</td>
<td>2.41</td>
<td>2.49</td>
<td>4.67</td>
<td>1.26</td>
<td>3.57</td>
<td>0.18</td>
<td>0.16</td>
<td>99.78</td>
</tr>
</tbody>
</table>

Including CO₂ (1852, T.Y. 67042103. Analyst: H. Haramura)

![Country Rocks and Chilled Margin](image)

Fig. 6. A sketch of blocks of chilled marginal dolerite in the country rock.

Many small blocks of chilled marginal dolerite are enclosed in the country rock at some parts of the contact as shown in Fig. 6. The diameter of these blocks attains to 20 cm. These blocks are deduced to have been formed from the chilled marginal dolerite by the action of mobilized country rock. The melting point of the country rocks is estimated to be lower than that of dolerite, because chemical composition of the country rock corresponds to granitic igneous rocks. Then, it is deduced that there was a certain stage when marginal part of the intruded gabbroic magma was solidified while country rocks showed inclination of mobilization.

There are many small ptygmatically folded veins in the chilled marginal parts within the narrow belt of about 50 cm from the contact. Width of these veins reaches 1 cm. These folded veins are deduced to have been formed by the deformation of the chilled marginal parts which enclosed the country rocks as xenolith at the time of magmatic intrusion.

Both of the lower and upper chilled margins are traversed at numerous localities by small white veins composed mostly of quartz, calcite and prehnite. They intruded along joint planes or small faults which distribute almost vertically to the contact planes. The width of them reaches about 5 cm. These veins are probably the products of later hydrothermal stage after the solidification of the main part of the complex.

3. Chilled marginal dolerite

The marginal part of the complex is composed of fine-grained chilled marginal dolerite, the width of which attains 2 m. The marginal part shows fine-grained basaltic texture, however, many extremely thin white veins intersect one another, forming networks. The principal constituents are plagioclase (An₆₅±) and ilmenite, with small amount of magnetite. The mafic minerals were altered into chlorite or actinolite. Except this narrow basaltic band in the chilled marginal rocks, alteration of mafic minerals is not remarkable, so that the principal constituents of the chilled margin are olivine, augite, plagioclase and ilmenite with small amount of magnetite and hypersthene. Olivine within this chilled marginal part is partly altered in some grains. Alteration products are in some cases grayish green to straw yellow nontronite-like mineral with an extremely low birefringence. In this
marginal rocks, ophitic texture is characteristic. The opaque minerals are largely ilmenite with small amounts of pyrrhotite and magnetite.

At the northeastern margin of this complex there are dikes of basalt branching from the chilled marginal dolerite (Fig. 7). These dikes are extremely hard, possibly because of a sort of recrystallization by the heat sustained in the country rock after the consolidation of main part of the complex. Chlorite, actinolite, epidote, plagioclase and ilmenite are the principal constituents of these dikes. The chemical composition of the dike rock suggests that it was formed from a later differentiated magma intruded into this area. The schematic field relation to the chilled marginal dolerite is illustrated in Fig. 8.

4. Picrite gabbro

Picrite gabbro containing magnesian olivine (Fo27±) more than 30 volume % occupies the southeastern part of the complex (lower part of the sheet) for 20 m in thickness. This part shows pale greenish appearance. The main constituents of this picrite gabbro are olivine, augite, plagioclase and ilmenite with small amounts of hypersthene and chlorite. Because of the intervening sheared zone between the chilled margin and the picrite gabbro. The relation between them is not observed in this portion, but continuous, gradational relation is observed at the Maruyama differentiated gabbroic complex, which locates at the seashore 6 km northeast of Murotomisaki. The same relation is, therefore, expected in this complex. After the investigation about variation of modal abundance of olivine in both sides of the intervening sheared zone, a rock with the maximum modal abundance of olivine is surmised to be present at the central part of the dissected sheared zone. Tabular plagioclase crystals are arranged parallel to the lower contact plane.

5. Fine-grained hypersthene-bearing olivine augite gabbro

The picrite gabbro shows a decrease of olivine content apart from the marginal part, and the rock changes gradually to fine-grained hypersthene bearing olivine augite gabbro. This rock contains about 20 volume % of olivine, and plagioclase crystals are arranged parallel to the boundary of the complex. Augite forms many large clots of about 4 cm in diameter. In these clots a large number of olivine and plagioclase grains are involved. A very small amounts of hypersthene is observed in the interstices as rim of olivine or in the altered part of olivine.

6. Medium-grained hypersthene-bearing olivine augite gabbro

The continuous gradation of rock types
from fine-grained olivine augite gabbro to medium-grained hypersthene-bearing olivine augite gabbro is observed. This medium-grained gabbro is characterized by the presence of small compositional bandings and wavy pegmatitic pockets, and especially by the gabbro pegmatite veins. Olivine and pyroxene from this rock type are a little more enriched in iron component compared with those from the marginal part, while plagioclase is a little more sodic (An$_{59}$ ±).  

7. Compositional banding in the above rock type

Compositional banding is characteristic to the melanocratic part of the medium grained hypersthene bearing olivine augite gabbro, being accompanied by the small wavy pegmatitic veins. Mineral compositions are the same as those of surrounding medium grained gabbro, however, volume ratio of mafic minerals to felsic minerals is quite different. Separation of these two mineral groups is conspicuous. Width of the compositional banding becomes gradually broader upwards, and at the end of broadest banding, there appear small wavy pegmatitic veins as shown in Fig. 8. The compositional banding shows wavy curvature, wave length of which is less than 1 to 2 m. The direction is almost parallel to the extension of the intruded body. Arrangements of the compositional bandings and wavy pegmatitic veins suggest that the banding represents the squeezed residual liquid formed in situ.  

8. Wavy pegmatitic vein

At the lower part of the medium-grained hypersthene-bearing olivine augite gabbro, many small pegmatitic veins of wavy structure are observed (Fig. 9, 10). It's wave length is from 0.3 to 1.0 m. Petrographical and mineralogical characters of this wavy pegmatitic veins are completely the same as those of olivine augite gabbro pegmatite. But the veins are found exclusively in the lower part of part of the medium grained gabbro, and closely associated with the compositional bandings.

Judging from the several sections of these structures in the field, those wavy veinlets would have a disk like form. The upper part is composed essentially of plagioclase, while the lower part is principally composed of olivine and augite. They were formed as closed system of residual liquid in the medium grained-gabbro. This system is considered to be a product of later stage of solidification of the magma, because there are many independent and isolated wavy veins apart only several tens centimetres from the neighbouring one.  

9. Olivine augite gabbro pegmatite vein

This rock occupies the central part of the differentiated complex as veins, the width of which is from 0.2 to 2.0 m, or as pockets of several metres across. These veins run in NE-SW direction without exception, that is, they are parallel to the contact plane of the intrusive complex. The maximum length of these veins may reach 20 m. In most cases, it is within 10 m. Their three dimensional perspective views observed at the Murotomisaki complex indicate that they have a form of a centre-thick

![Fig. 8. Transitional field relations from compositional bandings into wavy pegmatitic veinlets.](image-url)
Fig. 9. A schematic illustration of process of formation of wavy pegmatitic veinlets. At the locally low pressure parts of the intruded magma, which is mushy state with suspending crystals, residual liquid concentrates as small lense in parallel to the direction of the intruded magma. (1). The intermediate plagioclase crystallizes at first, floating in the heavier liquid and showing foliation of feldspars. (2). Intermediate to sodic plagioclase crystallizes in secondary place, which shows vertical elongation to the lense (3). Thirdly, augite begins to precipitate, with small amount of sodic plagioclase (4). Iron ore concentrates at the lowest part of the wavy veinlet, which indicates the concentration of ferriferous liquid in this portion (5).

disk formed by condensation of residual liquid.

Foliation of plagioclase is characteristic in the upper part of the vein for 5 to 10 cm. (Fig.10-2), showing parallel direction to the extension of the vein. Plagioclase from this narrow foliated part shows weak zoning while mafic minerals therefrom exhibit mostly of alteration by hydrothermal reaction. Large plagioclase crystals reaching 5 cm in length are found to be arranged vertically to the elongation of the vein (Fig. 10-3). Mafic minerals as olivine, augite and ilmenite are concentrated in the lower part of the vein with a little amount of sodic plagioclase (Fig. 10-4, 5). Sometimes augite includes small grains of olivine and sometimes the latter occur as isolated grains.

10. Augite gabbro pegmatite

At the upper horizon of the complex, gabbro pegmatite consisting mostly of augite, plagioclase, ilmenite and magnetite is present. The most conspicuous petrological character in this rock type is the absence of olivine. Olivine or orthopyroxene is utterly absent in this augite gabbro pegmatite except at the lowest portion. The average length of augite or plagioclase is 3 cm, while the maximum length of augite attains to 20 cm, and that of plagioclase 6 cm. Variation of grain size in this rock is very prevailing, although the variation of chemical composition is not so distinct. In this gabbro pegmatite zone, there are a great number of regularly arranged melanocratic patches containing brownish-green hornblende and chlorite. About 10% of clinopyroxene therein was altered into fibrous actinolitic hornblende. Compositions of augite and plagioclase from these patches are almost identical with those of the surrounding parts. According to the study on this rock by fission-track method, uranium is ascertained
to be more concentrated in the patches than the surrounding rocks.

At several lowest part of this augite gabbro pegmatite, this rock contacts with ferro gabbro with a continuous gradation relation, while at another point, this rock contacts with hypersthene bearing olivine augite gabbro pegmatite with a sharp boundary. At the upper part, this rock contacts with fine-grained hypersthene bearing olivine augite gabbro with a continuous gradation at the interval of several metres.

11. Ferrogabbro

At the central part of the differentiated complex is exposed ferrogabbro bordering to the lowest part of pegmatitic vein. This ferrogabbro consists of olivine (Fa30), augite, sodic plagioclase (An45±) and ilmenite with a considerable amount of magnetite also with small amount of pyrrhotite and chalcopyrite. The ferrogabbro is the most iron enriched rock in this complex. Reddish-brown colour due to the oxidation of iron ores is characteristic in the field appearance of this rock.

12. Upper fine-grained olivine augite gabbro

The uppermost part of the augite gabbro pegmatite contacts with fine-grained olivine augite gabbro with a sharp boundary. Olivine from this part is relatively magnesian (Fa30±).

13. Actinolitic hornblende gabbro

This rock has a porphyritic texture with phenocrysts of actinolitic hornblende, as observed at the northeastern upper marginal part of the Murotomisaki complex. The main constituents are fibrous actinilitic

---

Fig. 11. A branch of country rocks which intruded into the chilled marginal part of the complex.
Fig. 12. Quartz-feldspathic vein in the chilled marginal part of the complex.
Fig. 13. Ptygmatically folded small veins in the chilled marginal part of the complex.
Fig. 14. Contact aureole of the complex.
Fig. 15. Basaltic dike branching from the chilled marginal part of the complex.
Fig. 16. Compositional bandings in medium-grained gabbro.
Fig. 17. Wavy pegmatitic veinlets.
Fig. 18. Ditto.
hornblende, plagioclase and opaque minerals. Sometimes core of augite is observed within the hornblende crystals, suggesting it to be an alteration product of augite by hydrothermal reaction.

4. MINERALOGY

1. Mineralogical characteristics

<table>
<thead>
<tr>
<th>OLIVINE</th>
<th>CLINOPYXENE</th>
<th>ORTHOPYXENE</th>
<th>HORNBLINDE</th>
<th>BIOTITE</th>
<th>ILMENITE</th>
<th>MAGNETITE</th>
<th>PLAGIOCLASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fa 31</td>
<td>Fa 27</td>
<td>Fa 32</td>
<td>Fa 40</td>
<td>Fa 42 - 52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WeEn45Fs13</td>
<td>WeEn44Fs14</td>
<td>WeEn43Fs16</td>
<td>WeEn39Fs10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 27. Mineral parageneses of rocks of the Murotomisaki complex.

Fig. 28. Modal abundance of constituting minerals.

Fig. 19. A wavy pegmatitic veinlet.
Fig. 20. Swarm of compositional bandings and wavy veinlets.
Fig. 21. Small fragment of picritic gabbro in the medium-grained hypersthene bearing olivine augite gabbro.
Fig. 22. Swarm of olivine augite gabbro pegmatite veins.
Fig. 23. Lower part of a olivine augite gabbro pegmatite.
Fig. 24. Olivine augite gabbro pegmatite.
Fig. 25. Close-up photo of augite gabbro pegmatite.
Fig. 26. Olivine augite gabbro pegmatite.
The principal minerals of the complex are olivine, augite, plagioclase (labradorite to andesine), ilmenite and magnetite with small amounts of orthopyroxene (bronzite to hypersthene) and hornblendes (brown common hornblende and green common hornblende). In some places, actinolitic hornblende is one of the principal constituents. A very small amount of biotite is present in the chilled margin and in the ferrogabbro which is a product of the latest stage.

The accessory minerals are serpentine, chlorite, actinolite, prehnite, calcite, apatite, pyrrhotite and pyrite. The mineral paragenesis and modal abundance of constituting minerals of the complex are summarized in Fig. 27 and in Fig. 28.

As far as examined, pigeonite is not found and orthopyroxene is rare and not so petrologically significant if present as stated later. Plagioclases are fairly variable in compositions ranging from An\textsubscript{70} to An\textsubscript{30}. Quartz seems to be absent even in the product of the latest stage, but it is found along joint planes of some gabbros or it is found as veinlets probably of country rock origin.

One of the most characteristic features of the mineral paragenesis is the disappearance of olivine in augite gabbro pegmatite and reappearance in ferrogabbro of the latest stage product. Another characteristic is the appearance of considerable amount of magnetite in gabbro pegmatites formed at the latest stage of solidification.

2. Olivine

The compositions of olivines were estimated by the X-ray powder method of measuring d\textsubscript{130} value (Yoder and Sahama, 1957). The results including the most magnesian (Fo\textsubscript{70}) and the most ferroan (Fo\textsubscript{48}) are shown in Table 2. The later value is an exceptional case and generally Fo\textsubscript{45} is the limit composition of olivine of the latest stage product. The compositional variation in a single hand specimen is very conspicuous especially in ferrogabbro. As stated in the chapter of petrography, there is an expected compositional difference between those of independent grains and those of inclusions in augite.

Olivines are short prismatic in form, and less than 2 mm in grain size. Generally, olivines are unaltered. But along the lower marginal part of the complex they are partially replaced by the aggregates of light green chlorite and serpentine under the microscope, sometimes leaving the pseudomorph. Very locally a green to yellow nontronite-like mineral replaces them in the lower marginal gabbro, whereas red dish brown iddingsite is a characteristic alteration product of olivine in some parts of ferrogabbro.

Besides the above described alteration products, occasional presence of orthopyroxene is worth mentioning. Orthopyroxene is found sometimes in the pseudod-
morph of olivine in olivine-bearing gabbro, but not found in the gabbro free from olivine.

3. Clinopyroxene

In this complex, clinopyroxene is exclusively augite (+) 2V about 45°, and

Table 3. Chemical analyses and atomic numbers of clinopyroxene (Analyst: H. Haramura)

<table>
<thead>
<tr>
<th>Sample-Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>50.12</td>
<td>50.68</td>
<td>50.60</td>
<td>49.75</td>
<td>50.35</td>
<td>50.37</td>
<td>50.88</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.95</td>
<td>0.73</td>
<td>0.71</td>
<td>0.84</td>
<td>1.36</td>
<td>1.43</td>
<td>1.05</td>
</tr>
<tr>
<td>Al2O3</td>
<td>4.02</td>
<td>2.96</td>
<td>2.80</td>
<td>2.61</td>
<td>2.54</td>
<td>2.22</td>
<td>0.51</td>
</tr>
<tr>
<td>FeO</td>
<td>1.55</td>
<td>1.39</td>
<td>1.43</td>
<td>1.36</td>
<td>2.05</td>
<td>2.62</td>
<td>3.72</td>
</tr>
<tr>
<td>FeO</td>
<td>6.61</td>
<td>8.01</td>
<td>8.71</td>
<td>10.93</td>
<td>8.96</td>
<td>8.99</td>
<td>8.61</td>
</tr>
<tr>
<td>MnO</td>
<td>0.20</td>
<td>0.22</td>
<td>0.24</td>
<td>0.31</td>
<td>0.26</td>
<td>0.30</td>
<td>0.23</td>
</tr>
<tr>
<td>CaO</td>
<td>20.07</td>
<td>20.60</td>
<td>20.72</td>
<td>20.11</td>
<td>19.60</td>
<td>19.47</td>
<td>19.70</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.56</td>
<td>0.42</td>
<td>0.43</td>
<td>0.48</td>
<td>0.54</td>
<td>0.42</td>
<td>0.35</td>
</tr>
<tr>
<td>K2O</td>
<td>0.06</td>
<td>0.05</td>
<td>0.03</td>
<td>&lt;0.03</td>
<td>0.04</td>
<td>0.03</td>
<td>trace</td>
</tr>
<tr>
<td>H2O (+)</td>
<td>0.67</td>
<td>0.08</td>
<td>0.16</td>
<td>0.15</td>
<td>0.13</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>H2O (-)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Cr2O3</td>
<td>...</td>
<td>0.25</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total</th>
<th>100.26</th>
<th>100.34</th>
<th>100.27</th>
<th>100.34</th>
<th>100.49</th>
<th>100.43</th>
<th>99.99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.865</td>
<td>1.890</td>
<td>1.891</td>
<td>1.880</td>
<td>1.881</td>
<td>1.885</td>
<td>1.914</td>
</tr>
<tr>
<td>Ti</td>
<td>0.027</td>
<td>0.020</td>
<td>0.020</td>
<td>0.024</td>
<td>0.038</td>
<td>0.040</td>
<td>0.030</td>
</tr>
<tr>
<td>Al</td>
<td>0.176</td>
<td>0.121</td>
<td>0.123</td>
<td>0.116</td>
<td>0.112</td>
<td>0.098</td>
<td>0.023</td>
</tr>
<tr>
<td>Fe+3</td>
<td>0.043</td>
<td>0.039</td>
<td>0.040</td>
<td>0.039</td>
<td>0.057</td>
<td>0.074</td>
<td>0.105</td>
</tr>
<tr>
<td>Fe+2</td>
<td>0.206</td>
<td>0.250</td>
<td>0.272</td>
<td>0.345</td>
<td>0.280</td>
<td>0.281</td>
<td>0.271</td>
</tr>
<tr>
<td>Mn</td>
<td>0.006</td>
<td>0.007</td>
<td>0.008</td>
<td>0.010</td>
<td>0.008</td>
<td>0.009</td>
<td>0.007</td>
</tr>
<tr>
<td>Mg</td>
<td>0.855</td>
<td>0.829</td>
<td>0.804</td>
<td>0.774</td>
<td>0.814</td>
<td>0.805</td>
<td>0.832</td>
</tr>
<tr>
<td>Ca</td>
<td>0.800</td>
<td>0.823</td>
<td>0.829</td>
<td>0.814</td>
<td>0.784</td>
<td>0.780</td>
<td>0.794</td>
</tr>
<tr>
<td>Na</td>
<td>0.020</td>
<td>0.030</td>
<td>0.031</td>
<td>0.035</td>
<td>0.039</td>
<td>0.031</td>
<td>0.026</td>
</tr>
<tr>
<td>K</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
<td>0.001</td>
<td>...</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>4.000</td>
<td>4.011</td>
<td>4.019</td>
<td>4.037</td>
<td>4.015</td>
<td>4.005</td>
<td>4.003</td>
</tr>
</tbody>
</table>

1. Augite from picrite gabbro, lower marginal part of the complex, (1779, T.Y. 670422071a)
2. Augite from small augite gabbro pegmatite vein, lower part of the complex (1773, T.Y. 67042101)
3. Augite from augite gabbro pegmatite, uppermost part of the complex, (1782, T.Y. 67042203)
4. Augite from ferrogabbro (1790, T.Y. 67042101')
5. Augite from large vein of olivine augite gabbro pegmatite, central part of the complex (B., T.Y. 670422072)
6. Augite from small vein of olivine augite gabbro pegmatite, central part of the complex (A., T.Y. 67042310)
7. Augite from leucocratic part of large vein of olivine augite gabbro pegmatite (1826, T.Y. 670422073)
Table 4. Optical properties of clinopyroxenes

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>1.695</td>
<td>1.681</td>
<td>1.690</td>
<td>1.702</td>
<td>...</td>
<td>1.700</td>
<td>1.690</td>
<td>1.697</td>
</tr>
<tr>
<td>$\beta$</td>
<td>...</td>
<td>...</td>
<td>1.714</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.714</td>
<td>1.710</td>
<td>1.721</td>
<td>1.712</td>
<td>...</td>
<td>1.713</td>
<td>1.705</td>
<td>1.719</td>
</tr>
<tr>
<td>$2\nu$</td>
<td>...</td>
<td>...</td>
<td>45</td>
<td>...</td>
<td>...</td>
<td>45</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Sample number corresponds to that of Table 3., except number 8, which is chemically unanalyzed augite from chilled marginal dolerite (T.Y. 68051903).

Pigeonite or inverted pigeonite is not found as far as examined. The augite exhibits idiomorphic outline in the marginal hypersthene-bearing olivine augite gabbro, whereas irregular outline in augite gabbro pegmatite.

In fine- and medium-grained gabbros, separate augite grains show simultaneous extinction frequently in thin section, but do not always suggest the three-dimensional continuity of the grains. Augites from gabbro pegmatites are not so rarely idiomorphic. The maximum length is 20 cm. In spite of such a large size, zoning is not observed optically. Pleochroism is remarkable from pale bluish green to pale yellowish green, especially in the augite from the gabbro pegmatite of the latest formation.

Seven chemical analyses of augites from this complex are given in Table 3. They contain low Na$_2$O + K$_2$O (0.4-0.6 wt%), relatively low Al$_2$O$_3$ (0.5-4.0 wt%) and low TiO$_2$ (0.7-1.4 wt%), like the augites from the other gabbros of tholeiite or calc-alkali type. Wollastonite molecules of these augites are about 42 mole %, and they are on a trend almost parallel to that of augites from the Skaergaard intrusion. Augite from the picrite gabbro has a higher MgO and a little lower CaO contents compared with those from the differentiated products of later stage. Variation of Fe$^{2+}$/Mg$^{2+}$ ratio is restricted within a narrow range.

4. Orthopyroxene

Orthopyroxene of this complex is rather subordinate in modal abundance, i.e., up to 0.1 modal %. In the chilled marginal dolerite, isolated grains are found under the microscope in the neighbourhood of olivine, exhibiting reaction relation between them. However, in most cases, it is found as fibrous small grains near the central parts of altered olivine grains. The pleochroism of the orthopyroxene from inner part of the complex is extremely weak from pale pink to colourless, and less remarkable than that of orthopyroxene from the other parts. The range of $(+)$ 2V of orthopyroxene is from 77° to 53°, corresponding to En$_{80}$Fs$_{20}$–En$_{58}$Fs$_{42}$ after Hess (1952). Orthopyroxenes are exclusively found in the rocks containing olivine and especially in the altered parts along leucocratic veinlets less than 1 mm width. From this microscopical feature, orthopyroxene of this complex may well be regarded as of internal precipitation origin; that is, they may have
been formed by the reaction of olivine and a solution of deuteric origin. This solution might have been under the effect of country sedimentary rocks, so that the solution was slightly silica rich, being accompanied by the reaction mentioned above. Thus orthopyroxene in this complex is regarded as product of secondary and not as product of primary crystallization stage at which most part of the intruded magma was solidified.

5. Plagioclase

Plagioclase of chilled marginal dolerite shows generally a weak zoning from An$_{65}$ to An$_{55}$, but such distinct zoning is rather exceptional. The most calcic plagioclase (An$_{60}$±) is found in basaltic dike, which forms a branch of chilled marginal dolerite, while the most sodic one (An$_{55}$±) is found in ferrogabbro, which is a product of the later stage. Chemical composition of plagioclase from picrite gabbro is about An$_{71}$, whereas normative plagioclase composition of the chilled marginal dolerite is about An$_{64}$. Accordingly, at the earliest stage of solidification, plagioclase of An$_{71}$ was crystallized from the magma, however, normative plagioclase of the rock was about An$_{64}$. In this complex, chemically analyzed values are nearly equal to those normative composition values. This coincidence of modal compositions with normative ones may be due to the low content of Al$_2$O$_3$ in clinopyroxene; most of Al$_2$O$_3$ in the rock allotted to normative plagioclase is estimated to be used up to form modal plagioclase.

Alteration product of plagioclase is quite lacking except several cases at some parts of augite gabbro pegmatite. Five plagioclases were chemically analyzed, the result of which are shown in Table 5. There is not so much outstanding regularity in the variation of normative orthoclase components compared with normative components (Fig. 30). Plagioclase of picrite gabbro represents highest

Table 5. Chemical analyses of plagioclase

<table>
<thead>
<tr>
<th>Sample-Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>50.13</td>
<td>55.73</td>
<td>55.85</td>
<td>57.68</td>
<td>58.45</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.03</td>
<td>trace</td>
<td>0.05</td>
<td>trace</td>
<td>0.03</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>30.65</td>
<td>26.76</td>
<td>27.09</td>
<td>23.72</td>
<td>25.19</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.49</td>
<td>0.46</td>
<td>0.50</td>
<td>0.11</td>
<td>0.28</td>
</tr>
<tr>
<td>FeO</td>
<td>0.14</td>
<td>0.16</td>
<td>0.33</td>
<td>0.24</td>
<td>0.18</td>
</tr>
<tr>
<td>MnO</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>MgO</td>
<td>0.11</td>
<td>0.20</td>
<td>0.25</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>CaO</td>
<td>14.02</td>
<td>9.38</td>
<td>9.51</td>
<td>8.62</td>
<td>7.17</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>2.97</td>
<td>5.78</td>
<td>5.97</td>
<td>6.94</td>
<td>7.08</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.33</td>
<td>0.20</td>
<td>0.14</td>
<td>0.39</td>
<td>0.29</td>
</tr>
<tr>
<td>H$_2$O(+)</td>
<td>0.95</td>
<td>0.78</td>
<td>0.15</td>
<td>1.85</td>
<td>1.05</td>
</tr>
<tr>
<td>H$_2$O(-)</td>
<td>0.05</td>
<td>0.22</td>
<td>0.00</td>
<td>0.15</td>
<td>0.33</td>
</tr>
<tr>
<td>FeO$_5$</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Total</td>
<td>99.90</td>
<td>99.70</td>
<td>99.86</td>
<td>99.78</td>
<td>100.16</td>
</tr>
</tbody>
</table>

Table 5. Chemical analyses of plagioclase (Analyst; H. Harmaura)

<table>
<thead>
<tr>
<th>Atomic Number (0=32)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>Al</td>
</tr>
<tr>
<td>Fe$^{3+}$</td>
</tr>
<tr>
<td>Fe$^{2+}$</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Mg</td>
</tr>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>Na</td>
</tr>
<tr>
<td>K</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>Ab</td>
</tr>
<tr>
<td>An</td>
</tr>
<tr>
<td>Or</td>
</tr>
</tbody>
</table>

1. Plagioclase from picrite gabbro, lower marginal part of the complex (1784, T.Y. 670422071)
2. Plagioclase from augite gabbro pegmatite, uppermost part of the complex (1825, T.Y. 67042203)
3. Plagioclase from ferrogabbro (1783, T.Y. 67042101)
4. Plagioclase from augite gabbro pegmatite vein (1824, T.Y. 67042101)
5. Plagioclase from augite gabbro pegmatite (1827, T.Y. 670422073)
value of orthoclase component. According to the results of X-ray powder pattern studies, the values of $2\theta$ (131)–$2\theta$ (131) of plagioclases represent high form at the early stage, while low form at the latter stage. For this determination the figure proposed by Smith and Yoder (1955) is used. (Fig. 31)

<table>
<thead>
<tr>
<th></th>
<th>$d$ (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.3907±0.0011</td>
</tr>
<tr>
<td>2</td>
<td>8.3885</td>
</tr>
<tr>
<td>3</td>
<td>8.3919</td>
</tr>
</tbody>
</table>

1. Augite gabbro pegmatite (T.Y. 67042203)
2. Olivine augite gabbro pegmatite (T.Y. 68042310)
3. Olivine augite gabbro pegmatite (T.Y. 670422072)

6. Ilmenite and magnetite

Opaque minerals of this complex were studied by reflection microscope, and X-ray diffraction patterns were used for determination of their lattice constants (Table 6). The most predominant opaque minerals are iron oxides, ilmenite and magnetite. They are found as independent grains, but not as pararellel intergrowth of exsolution products. Ilmenite is found in all rock species without exception, while magnetite is observed only in the gabbro pegmatite of later stage. Therefore, in the early half stage of differentiation of the magma, ilmenite was the only predominant opaque mineral, whereas magnetite appeared in the later pegmatitic stage. This characteristic mineral parageneses throw light upon the intermediate iron concentration in this complex. This character may have been due to intermediate Po$_4$ in the magma intruded into this region.

Pyrrhotite and chalcopyrites are found as subordinate opaque minerals in ferrogabbro.
5. DISCUSSIONS

It is one of the most characteristic mineralogical features of this complex that olivine disappears at augite gabbro pegmatite stage and it reappears at the stage of ferrogabbro which is possibly a product of the latest differentiation stage. The mineral parageneses are shown in Fig. 27.

At the upper part of the Murotomisaki intrusive sheet is present augite gabbro pegmatite without olivine. This rock is in contact with medium-grained hypersthene-bearing olivine augite gabbro. Ferrogabbro including considerable amounts of olivine, augite, ilmenite and magnetite, is present as small pockets in augite gabbro pegmatite or along the lower boundary between augite gabbro pegmatite and medium-grained hypersthene-bearing olivine augite gabbro. The most iron rich olivine in medium-grained gabbro is about Fa40 in composition, while the most magnesian olivine in ferrogabbro is about Fa42. Hence, there is no significant range gap between them, suggesting the presence of continuous succession in compositional variation of olivine.

On the contrary, composition of plagioclase of ferrogabbro is a little more sodic than that of augite gabbro pegmatite, while the latter is a little more sodic than that of medium-grained gabbro. Then, there is a short range gap in plagioclase compositions of ferrogabbro and medium-grained gabbro. The compositional gap is also found in augites, that is, augites from ferrogabbro are a little more enriched in ferrosilite molecule than that of augite gabbro pegmatite, which is a little more enriched in ferrosilite molecule than that of medium-grained gabbro.

In ferrogabbro, two different modes of occurrences of olivine are recognized; in one case olivine is included in augite grains, and in another case, olivine is present as isolated grains. The presence of two different modes of occurrences and of compositional range in olivines in ferrogabbro suggests that olivines crystallized at least in two different stages; one is early pegmatitic stage and another is later pegmatitic stage. In the former stage, olivine precipitated down to the lower parts of the molten body, while in the latter, olivine crystallized in situ and did not precipitate. Magnetite crystallized also at this stage. However, there was a stage between the above-mentioned two stages, when olivine was not formed as proved by the formation of olivine-free augite gabbro pegmatite.

These petrographical and mineralogical characteristics suggest that some parts of ferrogabbro were formed after the solidification of main parts of augite gabbro pegmatite and other parts of ferrogabbro were formed contemporaneously. In other words, the ferrogabbro proves that it includes the products of successive differentiation and of contemporaneous formation and there was a stage when olivine was not

Fig. 40. Photomicrograph of picrite gabbro (open nicol).
Fig. 41. Photomicrograph of fine-grained olivine augite gabbro (crossed nicols).
Fig. 42. Photomicrograph of medium-grained olivine augite gabbro (crossed nicols).
Fig. 43. Photomicrograph of augite gabbro pegmatite (open nicol).
Fig. 44. Ditto (crossed nicols).
Fig. 45. Photomicrograph of ferrogabbro (open nicol).
Fig. 46. Photomicrograph of ferrogabbro, olivines in augite (crossed nicols).
Fig. 47. Photomicrograph of hypersthene in medium-grained olivine augite gabbro (open nicol).
crystallized within the successive differentiation process.

The disappearance and reappearance of olivine are possibly explained in the light of the system forsterite-diopside-silica system by Kushiro and Schairer (1963) as will be discussed hereafter.

The main constituents of this complex are olivine, augite, plagioclase, ilmenite and magnetite as described in the preceding chapters. Since, it is necessary for the interpretation of differentiation of the magma to refer the synthetic systems including following components:

1. Olivine (Forsterite-Fayalite)
2. Augite (Diopside-Hedenbergite-Enstatite-Ferrosilite)
3. Plagioclase (Anorthite-Albite)
4. Ilmenite, Magnetite.

Orthoclase component in plagioclase is negligible in this case (2.1-0.8 mole %). TiO₂ content of augite is very small (1.43 -0.48 wt%), and crystallization of ilmenite is only one principal factor of regulating TiO₂ content in the residual liquid, and in consequence, precipitation of ilmenite took place. Crystallization of magnetite has a much more important role in the course of differentiation, governing the chemical compositions of augite and olivine. Therefore, it is necessary to refer the natural and synthetic systems including oxidation-reduction of iron. The synthetic systems chemically close to the magma of this complex are as follows;

1. MgO-FeO-SiO₂ system (Bowen and Schairer, 1935)
2. Diop-An-Ab system (Bowen, 1915; Yoder, 1965)
3. Diop-Fo-SiO₂ system (Bowen, 1914; Kushiro and Schairer, 1963)
4. Hed-Fa-SiO₂ system (Bowen, Shairer and Posnajak, 1933)
5. Wo-Fo-FeO-SiO₂ system (Osborn, 1964, based on Bowen, 1914, Schairer and Bowen, 1942; Osborn and Muan, 1960; Bowen and Schairer, 1935; Bowen, Schairer and Posnajak, 1933)
6. Wo-Fo-Fe₂O₃-SiO₂ system (Osborn, 1964; Muan and Osborn, 1956)
7. Wo-MgO-FeO(Fe₂O₃)-SiO₂ system (Presnall, 1966)
8. MgO-FeO-Fe₂O₃-CaAl₂Si₂O₈-SiO₂ system (Roeder and Osborn, 1966).

The last two systems, 7 and 8, cover the all ranges of the above other systems. The process of the crystallization, therefore, will be reasonably followed in the Wo-MgO-FeO(Fe₂O₃)-SiO₂ system, by considering the effect of Anorthite-Albite content in this system.

Principal mineral parageneses of this complex are summarized as follows;

A. Intrusion of magma and start of crystallization of olivine, followed by crystallization of plagioclase,
B. Start of crystallization of augite,
C. Disappearance of olivine and appearance of magnetite,
D. Local crystallization of Fe-olivine.

The course of differentiation of magma is schematically shown in Fig. 48. Chemical composition of the intruded magma locates at a point in the olivine volume in this tetrahedron (A). After the precipitation of a certain amount of olivine, magma changes its composition towards B, which is on the extension of a line connecting point Fo and point A. At point B, the magma reaches the boundary surface (cotectic surface) between olivine volume and diopsidic pyroxene volume (Ca-pyroxene volume), and starts to precipitate augite, forming olivine augite gabbro. At point C, precipitation of magnetite begins in this tetrahedron. On the contectic line X-Y,
parallel crystallization of forsterite, diopside and magnetite (also with plagioclase and ilmenite in the natural system) continues, however, fractional crystallization of forsterite in large amounts result poverty of this component in the residual magma, following disappearance of olivine (C-D-E). In this case, there is a possibility of reappearance of olivine after subtraction of fairly amounts of diopsidic pyroxene (augite) from the magma at point F. For this course of crystallization, reaction of olivine with clinopyroxene is necessary.

Diop-Fo-En-SiO₂ phase diagram corresponds to a projection of this process on the Wo-MgO-SiO₂ plane of that tetrahedron (Fig. 49). In the Diop-Fo-En-SiO₂ system, following course of crystallization is concluded. After the precipitation of forsterite from original magma A, the residual liquid changes its composition to B. At point B, crystallization of diopsidic pyroxene begins. Brokened lines represent the direction of variation of residual liquid and b, c, d, e represent the composition of clinopyroxene at each differentiation stage. Precipitating clinopyroxene of c from liquid C, the residual liquid changes its composition to D, where olivine does not crystallize. Precipitating clinopyroxene of d, e, from liquid D,E, the residual liquid reaches to cotectic line and follows reappearance of olivine.

6. SUMMARY

The Murotomisaki differentiated gabbroic complex locates at the extreme point of the Cape Murotomisaki, Shikoku Island. This complex intruded into the Murotohanto Group of Eocene in age. The zonal arrangement of this complex shows the indication of the fractional crystallization with gravitational sinking in situ. Principal rock types of the complex are as follows: chilled marginal dolerite, picrite gabbro, fine-grained hypersthene bearing olivine augite gabbro, medium-grained hypersthene bearing olivine augite gabbro, augite gabbro pegmatite and ferrogabbro. The pegmatic rocks of the latest stage situate at the upper part of the complex as small veins. Any grain of pigeonite or inverted pigeonite is not found, whereas a
small amount of hypersthene is recognized as internal precipitates. Iron concentration in olivine and augite is conspicuous at the upper part of the complex. Olivine is absent in the augite gabbro pegmatite, whereas present in ferrogabbro which contains a considerable amount of magnetite. The absence of olivine in the augite gabbro pegmatite is explained by the experimental results of the forsterite-diopside-silica system at 1 atm. Because of the precipitation of magnetite at the middle stage of solidification, the concentration of iron in the residual liquid was not so conspicuous compared with the Skaergaard intrusion, leading to the formation of a rock type with intermediate degree of iron concentration during the process of fractionation. Petrochemical study about this complex will be published in another papers.

ACKNOWLEDGEMENTS

Main part of this work was carried out at the Geological Institute, University of Tokyo, under the guidance of late Professor Hisashi Kuno, to whom I am greatly thankful for valuable suggestions.

The author is also indebted to Drs. S. Aramaki, I. Kushiro and A. Kato, who have critically reviewed the manuscript.

The writer also wishes to express his thanks to Mr. H. Haramura for chemical analyses of rocks and minerals.

REFERENCES


(1967), Compositions and crystallization of mafic minerals in the Guadalupe igneous complex, California. Amer. Min. 52, 436-474.


(1962), Reaction series for subalkaline igneous rocks based on different oxigen pressure conditions. Amer. Min. 47., 211-226.


Petrology of the Murotomisaki gabbroic complex


室戸岬はんれい岩体の岩石学的研究

矢島敬彦

室戸岬はんれい岩体は始新世期の室戸層群を貫く、厚さ最高230mの層状分化岩体であって、重力場における结晶分化作用のために、岩体下部より上部にかけて、広範囲にわたる岩相の変化がみられる。即ち、下部より周縁部粗粒玄武岩（急冷相）、ビクリタイト質ハンレイ岩、含紫蘇輝石ｆかられん石—普通輝石ハンレイ岩、普通輝石ハンレイ岩質ペダマタイト、鉄質ハンレイ岩等である。かんらん石、普通輝石には酸性、中性の鉱分の増加が認められる。不透明鉱物は主としてチタン鉱鉱で、磁鉱鉱は斜方晶となって、磁鉱鉱は石英の付きを伴った低水蒸気圧、低気圧下での晶出分化による、中程度の鉱分濃集の分化経路が研究された。特に、かんらん石と普通輝石との間の反応関係の存在が推論された。