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Ultrabasic Mass in the Higashiakaishiyama District, Shikoku, Southwest Japan

By

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with 25 Text-figures and 3 Plates

ABSTRACT: The ultrabasic mass of Higashiakaishiyama occurs within a zone of recumbent fold developed in the Sambagawa crystalline schist zone in Shikoku, Southwest Japan. The ultrabasic body consists largely of dunite with small amounts of clinopyroxene-bearing peridotite, clinopyroxenite, and eclogite, and it also contains several large masses of hornblendic and clinopyroxenic rocks. This body is interpreted as an ultrabasic complex that has been brought up from below through an orogenic process. Within the ultrabasic body individual minerals, such as olivine in the massive dunite and in the massive peridotite, black clinopyroxene in the massive peridotite, and light-coloured clinopyroxene in the massive peridotite, in the clinopyroxenite, and in the eclogite, show marked preferred orientation. Hornblende, clinopyroxene, and epidote in the hornblendic and clinopyroxenic rocks also show preferred orientation. It is highly probable that the tectonite minerals contained in the ultrabasic body acquired their observed state of preferred orientation at an earlier stage of orogeny involving the formation of the Sambagawa metamorphic belt, and in a deeper part of the metamorphic belt. Multiform patterns of preferred orientation of olivine suggest that the mechanical conditions under which the olivine was oriented were not homogeneous throughout the ultrabasic mass. It seems that the ultrabasic body has been intruded into the folded zone through a stage subsequent to development of the preferred orientation of the tectonite minerals in the ultrabasic body. The megascopic foliation and lineation of foliated dunite must have originated during the intrusion of the ultrabasic body.

CONTENTS

I. INTRODUCTION

The large lenticular ultrabasic body, which occurs in the Besshi spotted schist zone, is exposed extending east-west for more than 4.5 km across the peak of Mt. Higashiakaishiyama (1706.9 m), Shikoku, Southwest Japan (Fig. 1). The name "Higashi-akaishi-yama" may be translated litterally as "Eastern mountain of red

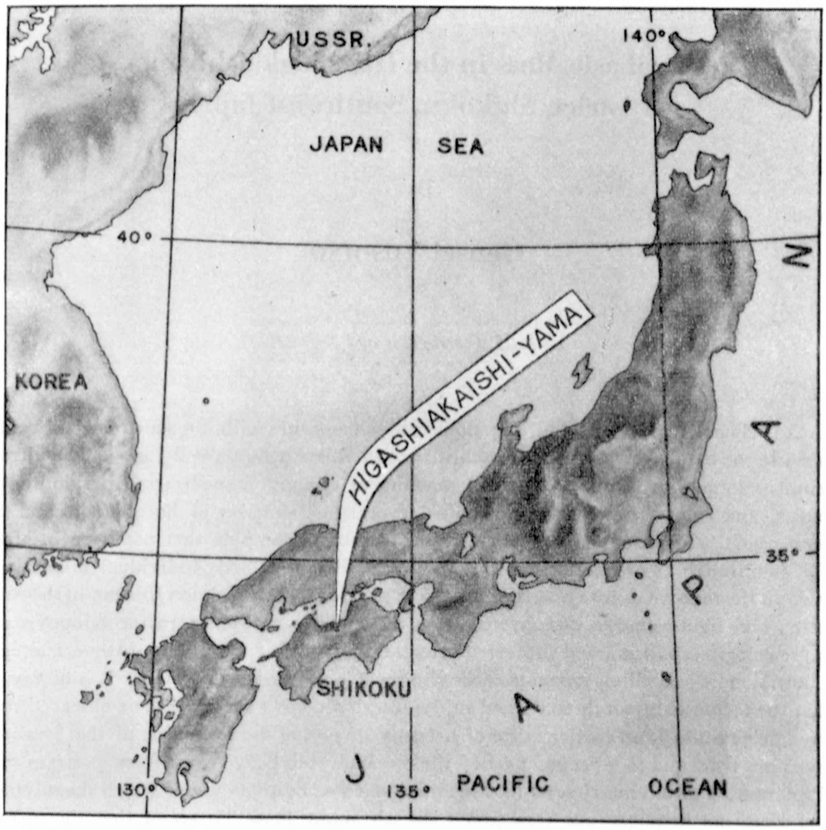


FIG. 1. Map indicating the location of the Higashiakaishiyama ultrabasic mass.

stone". Many geologists and mineralogists have hitherto studied the ultrabasic mass (K. KINOSHITA, 1936; Y. HORIKOSHI, 1937a, 1937b; Z. HARADA, 1943; Y. UCHIDA, 1949; T. BANBA, 1953) since T. KATÔ (1921) discussed the genesis of the banded chromite ores in this ultrabasic mass. For the past decade the geological setting of the Higashiakaishiyama ultrabasic complex has been clarified chiefly through the studies of the Besshi spotted schist zone by G. KOJIMA, K. HIDE, and G. YOSHINO (G. KOJIMA, 1951a, 1951b, 1951c, 1953, 1963; G. KOJIMA, K. HIDE, and G. YOSHINO, 1956; G. KOJIMA and K. HIDE, 1957, 1958; K. HIDE, 1954; K. HIDE, G. YOSHINO, and G. KOJIMA, 1956; G. YOSHINO and G. KOJIMA, 1953).

In 1952 the author began the geological and structural-petrological studies of the crystalline schist system in the Higashiakaishiyama district, and since 1957 he has carried out microfabric analyses of the dunite and the associated rocks of this district. In the previous paper (G. YOSHINO, 1961) the orientation patterns for olivine in the Higashiakaishiyama ultrabasic body were reported in detail, and the clinopyroxene fabrics of some eclogitic rocks occurring in the ultrabasic body were also recorded, but little has been said about the mutual geometric relationships of regular orientation of the individual minerals in the ultrabasic body. The present paper is a supplement to the preceding publication (1961). This paper deals mainly with the result of the studies on the microfabrics of clinopyroxene-bearing rocks, such as clinopyroxene-bearing peridotite, clinopyroxenite, eclogite, and hornblendic and clinopyroxenic rock occurring in the Higashiakaishiyama ultrabasic body. In this paper, the mutual geometric relations of olivine, clinopyroxene, hornblende, and epidote fabrics are examined in detail, and some considerations are given to the problems on the origin of the Higashiakaishiyama ultrabasic mass.

ACKNOWLEDGEMENTS: The author is especially indebted to Professor George KOJIMA of Hiroshima University for suggesting this study and for critical review of the manuscript. The author wishes to express his thanks to Professors Sotoji IMAMURA and Yoshiharu UMEGAKI of Hiroshima University for their encouragement throughout the course of the work. The author also wishes to thank the members of the Petrologists' Club of Hiroshima University for fruitful discussions. To the members of the staff at the Akaishi Mine, Meiji Mining Co., Ltd. and at the Iratsu Office, Sumitomo Forestry Co., Ltd., who made possible the author's field works in the Higashiakaishiyama district, the author is greatly indebted. This study has been supported in part by the Grant in Aid for Scientific Researches from the Ministry of Education, Japan.

II. STRUCTURES AND FABRICS OF ULTRABASIC MASS

The Higashiakaishiyama ultrabasic body lies in the Besshi-Shirataki recumbent fold zone developed in the Sambagawa metamorphic belt; it is a north-dipping lenticular body bounded on the north by the coarser-grained Iratsu amphibole schist containing garnet-porphyroblasts and on the south by spotted black schist (Fig. 2). The ultrabasic body is regionally concordant with the adjacent crystalline schist beds, but it seems to transgress locally the bedding of the latter. The axis of regional folding in the Besshi-Shirataki recumbent fold zone plunges about 15° in the direction ESE. The linear structures of the spotted schist beds in this recumbent fold zone coincide in orientation with the B-axis of the regional folding. The linear structures developed in the main part of the Iratsu amphibole schist bed bounding the ultrabasic body on its north differ in attitude from the linear structures developed in the spotted schist beds constituting this recumbent fold zone (G. YOSHINO, 1961).

The Higashiakaishiyama ultrabasic body is made up of massive and foliated dunites accompanied by small amounts of clinopyroxene-bearing peridotite, clinopyroxenite, eclogite, and hornblendic and clinopyroxenic rocks (G. YOSHINO, 1961). In the massive dunite any megascopic planar and linear structures can hardly be recognized, whereas the foliated dunite is megascopically characterized by foliated and lineated fabrics. The boundary between the massive part and the foliated part in the ultrabasic body is usually distinct. The lower zone of the lenticular ultrabasic

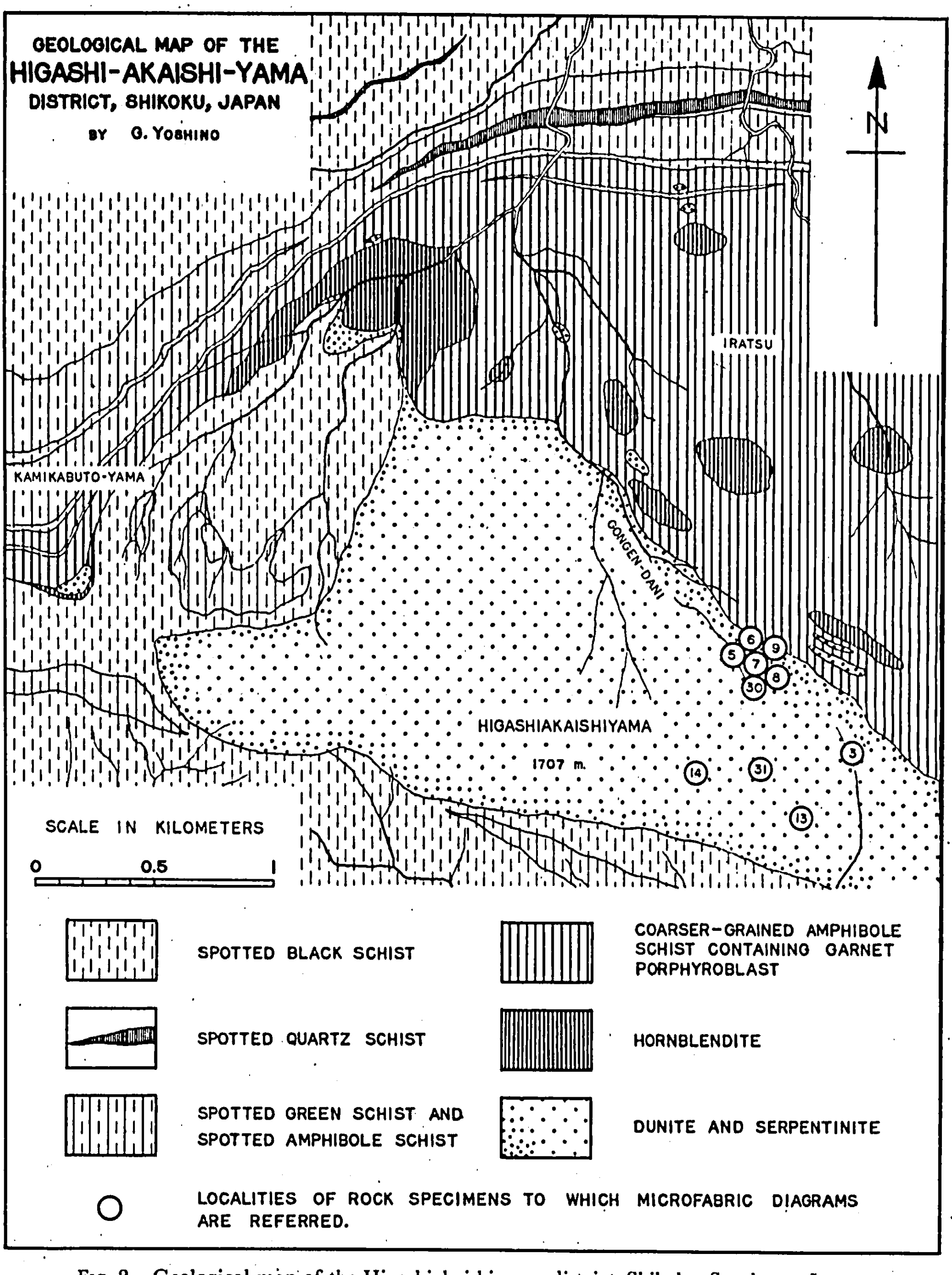


Fig. 2. Geological map of the Higashiakaishiyama district, Shikoku, Southwest Japan.

body is occupied mainly by foliated dunite. The clinopyroxene-bearing peridotite is contained mainly within the upper zone of the ultrabasic body, and occurs as layers subparallel to the upper margin of the ultrabasic body. The variety of clinopyroxene in such peridotite is megascopically black to gray, and is named "black clinopyroxene" in this paper though colourless in thin section. Sometimes, large grains of black clinopyroxene are scattered sparsely within the domain of dunite. Olivine is uniform in optical properties ($2V = 86° - 89°$; sign +) throughout the dunite and peridotite bodies. Seams and bands of chromite are found mainly in the massive dunite, being arranged subparallel to each other as well as to the lenticular shape of the ultrabasic body. The banded chromite ores are not limited in distribution to any specific part of the massive dunite body. Being oriented parallel to the upper border of the ultrabasic body, closely spaced subparallel streaks and bands, and isolated lenticular masses of clinopyroxenite and of eclogite occur mainly within the upper zone of this ultrabasic body. The variety of clinopyroxene composing such clinopyroxenite and eclogite is megascopically light-coloured, and it is unlike the black clinopyroxene in peridotite part. Sometimes, grains of the black clinopyroxene are contained within the domain of light-coloured clinopyroxenite or eclogite. Several large masses consisting of hornblendic and clinopyroxenic rocks are found also within both the upper and the inner parts of this ultrabasic body. Below, and almost parallel to, the upper margin of the Higashiakaishiyama ultrabasic body, zones of mylonite are developed, locally bordering the ultrabasic body.

A. Structures and Fabrics of Representative Specimens

The author has carried out fabric analyses on orientation of minerals observed in the Higashiakaishiyama ultrabasic body. The orientation of crystal grains was determined by measuring the directions of optic elasticity axes X, Y, and Z in individual grains in the oriented thin section. The measured directions were plotted individually on an equal-area projection from the lower hemisphere. Then, contoured orientation diagrams for X, Y, and Z in each mineral were made. In the following diagrams N, E, S, and W represent the geographical directions of north, east, south, and west, respectively. In description that follows, attention is focused mainly on the mutual geometric relations of orientation of individual minerals in the ultrabasic body.

1. *Olivine fabric in massive dunite, in foliated dunite, and in dunite-mylonite*

The details of olivine fabric in the representative specimens of dunite were given in the previous paper (G. Yoshino, 1961). The massive dunite consists almost entirely of equant grains of olivine showing marked preferred orientation of space lattice type. Although the symmetry of the olivine orientation in the massive dunite is seen to be practically monoclinic, there is a certain range of orientation pattern among the orientation diagrams for olivine in the massive dunite. Some orientation patterns of olivine show orthorhombic symmetry. In general, preferred orientation of olivine is less remarkable in the foliated dunite than in the massive dunite. In the foliated dunite the preferred orientation pattern of olivine does not always share a common symmetry with the pattern of megascopic foliation and lineation. The orientation pattern of olivine in the mylonite suggests that the preference in olivine orientation has been disturbed during the mylonitization.

2. Mutual geometric relationships of olivine, black clinopyroxene, light-coloured clinopyroxene, and hornblende subfabrics in peridotite

Specimen 1: GY 59 VIII 18-5.*

Rock name: Peridotite.

Locality: No. 9 in Fig. 2 and in Plate 32, Fig. 1.

Occurrence: The rock occurs as a north-dipping layer in the upper zone of the ultrabasic body.

Megascopic features: The rock is speckled with large crystals of black clinopyroxene. Grains of the clinopyroxene are short prismatic or rounded. The specimen has somewhat foliated and lineated fabrics defined by weak preferred location of black clinopyroxene grains.

Microscopic features (Thin Section GY 59 VIII 18-5): The specimen consists mostly of black clinopyroxene, olivine, and light-coloured clinopyroxene, with small amounts of garnet and opaque mineral. Subordinate amounts of serpentine mineral and hornblende are also contained. The larger grains of black clinopyroxene are scattered in the fine-grained aggregates of olivine, light-coloured clinopyroxene, and others.

Black clinopyroxene. The mineral ranges from 0.6 mm to 7.0 mm in grain diameter. It is colourless in thin section; (110) cleavage is distinct, parting on (100) is well developed. The optic axial plane is parallel to (010), the extinction angle (c^Z) in (010) is about 42°, the optic sign is positive, and the optic axial angle is about 57°. Innumerable fine rods of opaque material are included within the black clinopyroxene grains. The rods are oriented with the longer diameter parallel to (010) plane in the host black clinopyroxene. In the (010) plane are two directions to which the longer diameter of the inclusions is precisely parallel, and the linear parallelism of inclusions in the (010) plane shows a definite orientation with respect to the crystallographic c-axis in the host crystal of black clinopyroxene. The angle between the two directions is about 71° (Fig. 3 and Plate 33, Fig. 1). The marginal zone of the clinopyroxene grains is usually free from such inclusions. Small olivine grains are frequently enclosed within the marginal zone of the clinopyroxene. Sometimes, the large grain of black clinopyroxene encloses small clinopyroxene grains differing in extinction position from the host black clinopyroxene. Hornblende occurs frequently within the grain of black clinopyroxene. Exsolution lamellae cannot be found in the black clinopyroxene grain.

Light-coloured clinopyroxene. The mineral ranges from 0.05 mm to 0.6 mm in grain diameter, rarely attaining to 1.0 mm. In the clinopyroxene, (110) cleavage is distinct, parting on (100) is common. The extinction angle (c^Z) in (010) is about 39°; the optic sign is positive, the optic axial angle (2V) is about 56°.

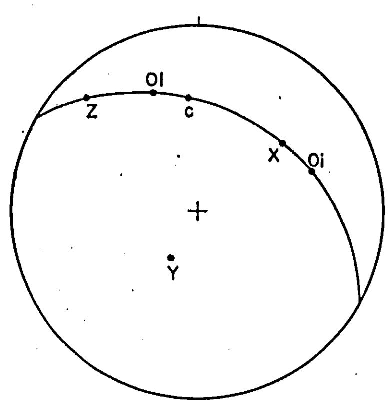


FIG. 3. Lower hemisphere projection of data from a black clinopyroxene grain (Plate 31, Fig. 1) in Section GY 59 VIII 18-5. Oi is the orientation of longer diameter of rod-like opaque inclusions.

* An outline of this specimen has been given in the previous paper (G. YOSHINO, 1961, p. 385).

Olivine. The mineral ranges from 0.05 mm to 1.0 mm in grain diameter. The grains of olivine are equidimensional and show no dimensional orientation. Some large grains of olivine display weak undulatory extinction. Small grains of olivine are included frequently within the marginal zone of the large grains of black clinopyroxene. In the optical properties olivine enclosed in the black clinopyroxene grain is quite identical with olivine occurring outside the black clinopyroxene grain. The optic sign of olivine is positive, the optic axial angle is about 88°.

Hornblende. The mineral occurs mainly within the black clinopyroxene grains, sharing common optical axial plane with the host clinopyroxene grain. The extinction angle ($c\hat{}Z$) in (010) is about 24°; the optic sign is positive, the optic axial angle is about 84°. In thin section, the mineral is colourless or weakly pleochroic with X = pale-yellow, Y = pale-yellowish-green.

Garnet. The mineral occurs in irregular grains ranging from 0.1 mm to 1.0 mm.

Orientation patterns of minerals in Thin Section GY 59 VIII 18-5:

The section was made perpendicular to the linear structure of this specimen.

Olivine. The orientation diagrams for X, Y, and Z in 200 grains of olivine occurring outside the large grain of black clinopyroxene are shown in Fig. 4a, b, and c. The X in olivine shows a tendency to be dispersed along the periphery of the diagram, and several separate maxima occur within the great-circle-girdle of X. Lying at and near the pole of the great-circle-girdle of X, several separate maxima of the Y in olivine occur. Although the Z in olivine tends to be concentrated within several maxima, it shows little preferred orientation. These diagrams show the symmetry of olivine orientation to be monoclinic.

The distribution of X, Y, and Z in 21 grains of olivine enclosed within 10 grains of black clinopyroxene

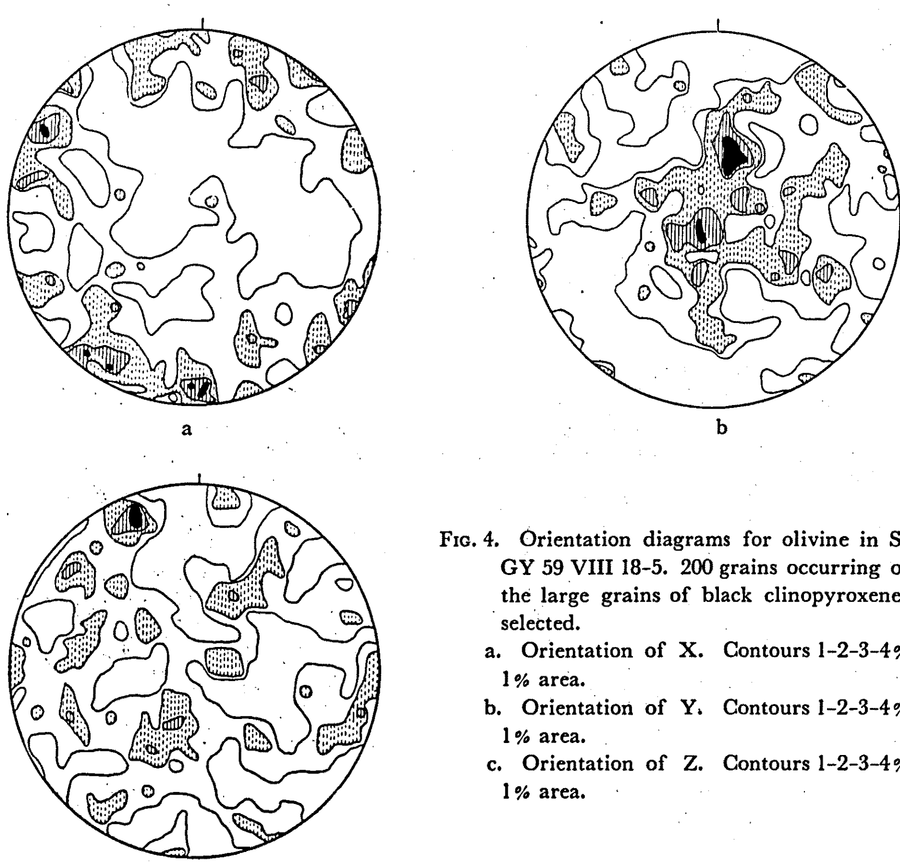
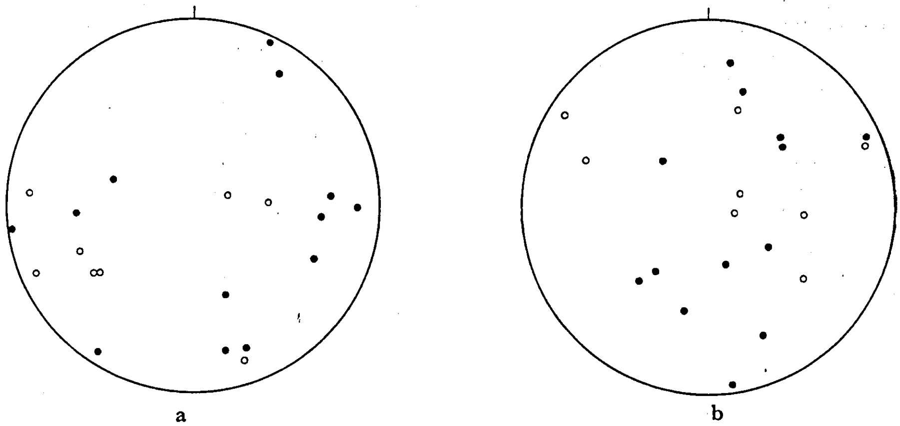


FIG. 4. Orientation diagrams for olivine in Section GY 59 VIII 18-5. 200 grains occurring outside the large grains of black clinopyroxene were selected.

a. Orientation of X. Contours 1-2-3-4% per 1% area.

b. Orientation of Y. Contours 1-2-3-4% per 1% area.

c. Orientation of Z. Contours 1-2-3-4% per 1% area.



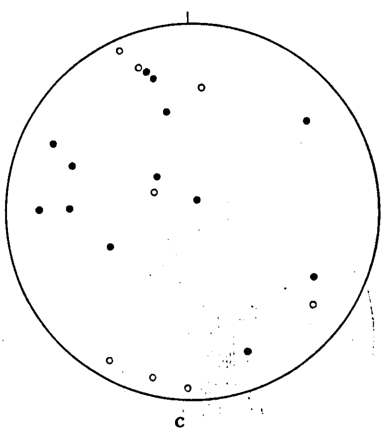


FIG. 5. Orientation diagrams for olivine in Section GY 59 VIII 18-5. 21 grains enclosed within 10 grains of black clinopyroxene were selected. Open circles show the orientation of olivine grains enclosed together within one large grain of black clinopyroxene.
a. Plot of X.
b. Plot of Y.
c. Plot of Z.

FIG. 6. Orientation diagrams for light-coloured clinopyroxene in Section GY 59 VIII 18-5. 200 grains existing outside the large grains of black clinopyroxene were selected.
a. Orientation of Y. Contours 1-2-3-4-5% per 1% area.
b. Orientation of Z. Contours 1-2-3-4-5% per 1% area.

is shown in Fig. 5a, b, and c. In each of the three diagrams, eight open circles show the orientation of X, Y, or Z in olivine grains enclosed together within one large grain of black clinopyroxene. In the diagrams for olivine enclosed within the black clinopyroxene grain can be found no preferred orientation.

Light-coloured clinopyroxene. The orientation diagrams for Y and Z in 200 clinopyroxene grains existing outside the grain of black clinopyroxene are shown in Fig. 6a and b. The Y in clinopyroxene is distributed mainly within the peripheral area of the diagram, and the Z is concentrated mainly within the central area of the diagram. From the relation of the orientation patterns of the clinopyroxene and of the olivine (Figs. 4 and 6), it is indicated that the crystallographic c-axis in clinopyroxene grain has the preferred orientation nearly parallel to the direction of maximum concentration of Y=[001] in olivine grain occurring outside the black clinopyroxene grain.

Black clinopyroxene. The orientation diagrams for Y and Z in 37 black clinopyroxene grains are shown in Fig. 7a and b. The orientation patterns are similar to those of light-coloured clinopyroxene (Fig. 6). The black clinopyroxene tends to be arranged with the crystallographic c-axis parallel to the direction of preferred orientation of crystallographic c-axis in light-coloured clinopyroxene occurring outside the black clinopyroxene grains.

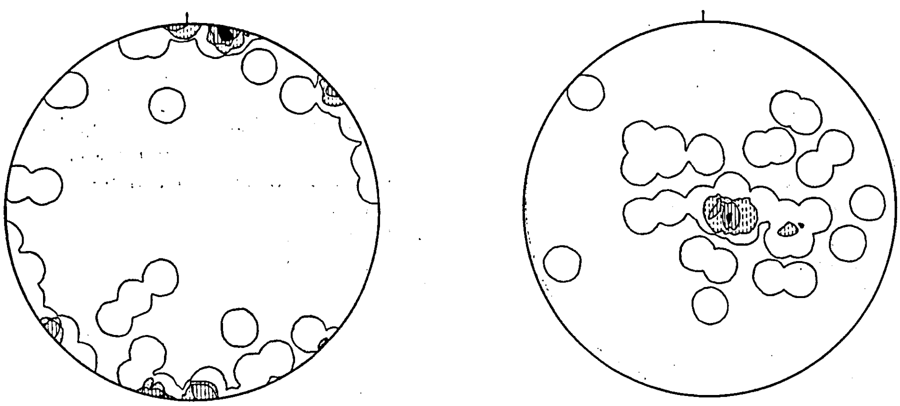


FIG. 7. Orientation diagrams for 37 grains of black clinopyroxene in Section GY 59 VIII 18-5.
a. Orientation of Y. Contours 2.7-8-11-16% per 1% area.
b. Orientation of Z. Contours 2.7-8-14-19% per 1% area.

Hornblende. The distribution of X, Y, and Z in 16 hornblende grains observed within 16 black clinopyroxene grains is shown in Fig. 8a, b, and c. The hornblende in the black clinopyroxene grain tends to share common (010) plane with the host clinopyroxene.

3. Geometric relation of light-coloured clinopyroxene fabric in both clinopyroxenite and eclogite to olivine fabric in the adjoining massive dunite.

Specimen 2: GY 58 VIII 26-3.*

Rock name: Massive dunite containing clinopyroxenite-streaks with swollen parts.

Locality: No. 8 in Fig. 2 and in Plate 32, Fig. 1.

Occurrence: In the massive dunite body at the locality occur closely spaced subparallel streaks of clinopyroxenite and eclogite.

Megascopic features: The dunite specimen has chromite-seams which strike N 80° W and dip 65° N. In the massive dunite, light-greenish clinopyroxenite-streaks, 1 mm to 5 mm thick with intervals of 1 mm to 10 mm, run subparallel to the chromite-seams, partly swollen into roundish lens. Irregular grains of pink garnet are dispersed in the greenish clinopyroxene-aggregate. The clinopyroxenite-streaks are occasion-

* An outline of this specimen has been given in the previous paper (G. YOSHINO, 1961, p. 386).

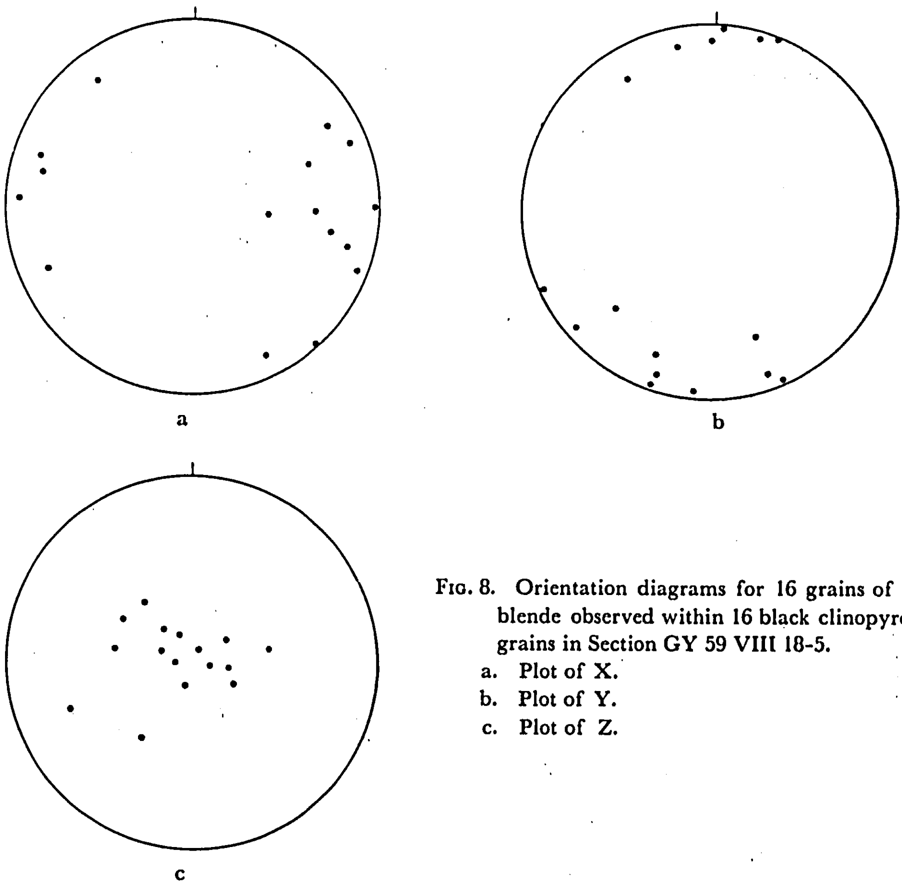


FIG. 8. Orientation diagrams for 16 grains of hornblende observed within 16 black clinopyroxene grains in Section GY 59 VIII 18-5.
a. Plot of X.
b. Plot of Y.
c. Plot of Z.

ally bifurcated. The streaks are bent near the swollen parts of the adjacent streak. Sometimes, large grains of black clinopyroxene occur in the greenish clinopyroxenite-streak.

Microscopic features (Thin Section GY 58 VIII 26-3): The boundary between the part of light-coloured clinopyroxenite and the part of olivine-chromite-aggregate is not always regular. Small grains of olivine and chromite are occasionally found within the clinopyroxenite-streaks. Separate grains of light-coloured clinopyroxene occur also in the part of olivine-chromite-aggregate, being frequently arranged parallel to the adjacent clinopyroxenite-streak. Chromite seams extending in the olivine-aggregate near the clinopyroxenite-streak are frequently bent along the swollen part of the streak, being locally intersected by the outer surface of the swellings. The clinopyroxenite-streak contains a small amount of garnet. Hornblende occurs in the large crystals of black clinopyroxene. Olivine ranges from 0.02 mm to 0.5 mm in grain diameter, rarely attaining to 1.0 mm. The optic sign of olivine is positive, the optic axial angle is about 89°. The light-coloured clinopyroxene ranges from 0.05 mm to 0.8 mm in grain diameter. In the light-coloured clinopyroxene (110) cleavage is distinct and parting on (100) is usually observed; the extinction angle (c^Z) in (010) is about 39°, the optic sign is positive, and the optic axial angle (2V) is about 58°. The hornblende is colourless in thin section; the extinction angle (c^Z) in (010) is about 23°, the optic sign is positive, and the optic axial angle is about 84°.

Orientation patterns of olivine and light-coloured clinopyroxene in Thin Section GY 58 VIII 26-3: Orientation diagrams for X, Y, and Z in 155 olivine grains are shown in Fig. 9a, b, and c. Collected together in one diagram, orientation patterns of Y and Z in 150 grains of light-coloured clinopyroxene are shown in Fig. 10. The patterns of clinopyroxene are compiled from the diagrams given in the pre-

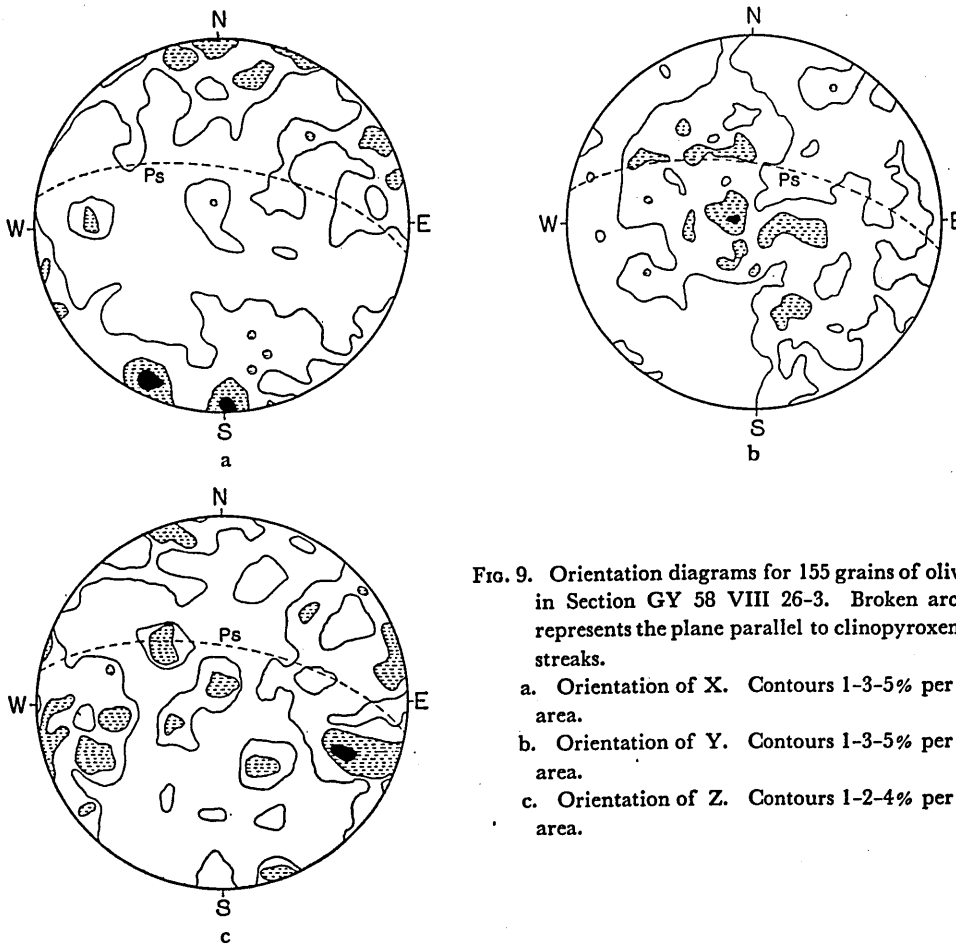


FIG. 9. Orientation diagrams for 155 grains of olivine in Section GY 58 VIII 26-3. Broken arc Ps represents the plane parallel to clinopyroxenite-streaks.

a. Orientation of X. Contours 1-3-5% per 1% area.

b. Orientation of Y. Contours 1-3-5% per 1% area.

c. Orientation of Z. Contours 1-2-4% per 1% area.

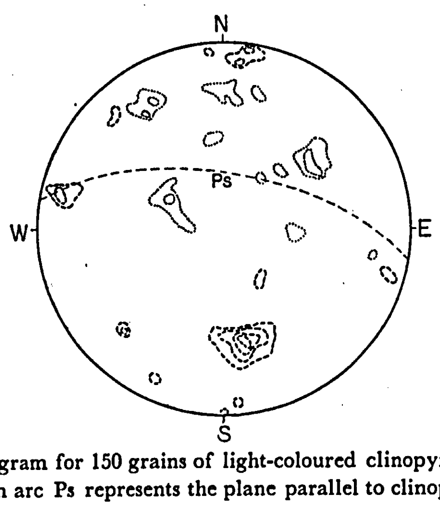


FIG. 10. Orientation diagram for 150 grains of light-coloured clinopyroxene in Section GY 58 VIII 26-3. Broken arc Ps represents the plane parallel to clinopyroxenite-streaks. Contours: Y, 3-4-5-6% (broken lines); Z, 3-4% (dotted lines).

vious publication (G. YOSHINO, 1961, p. 387). In Figs. 9 and 10 the plane parallel to the clinopyroxenite-streaks is shown by great circle Ps. The orientation patterns of olivine and clinopyroxene suggest that the crystallographic c-axis in clinopyroxene tends to be arranged parallel to the crystallographic c-axis in olivine occurring near the clinopyroxenite-streak, and that both the (010) plane in clinopyroxene and the (010) plane in olivine tend to lie parallel to the clinopyroxenite-streak.

Specimen 3: GY 58 VIII 26-1.

Rock name: Massive dunite containing clinopyroxenite-streaks.

Locality: No. 30 in Fig. 2 and in Plate 32, Fig. 1.

Occurrence: In the massive dunite body at the locality numerous streaks of clinopyroxenite and eclogite run subparallel to one another.

Megascopic features: In the massive dunite the light-greenish clinopyroxenite-streaks, 2-5 mm thick with intervals of several centimeters, strike EW and dip 40° N. Black clinopyroxene grains are dispersed in the light-greenish clinopyroxenite-streak.

Microscopic features (Thin Section GY 58 VIII 26-1): The boundary between the part of light-coloured clinopyroxene-aggregate and the part of olivine-aggregate is not regular. In the light-coloured clinopyroxenite-streak, a small amount of hornblende is contained, but garnet is rare. Separate grains of light-coloured clinopyroxene are scattered in relatively fine-grained olivine-aggregate that surrounds the streak of clinopyroxene-aggregate. Large and small grains of black clinopyroxene are dispersed in the light-coloured clinopyroxenite-streak. Olivine grains are equidimensional, ranging from 0.02 mm to 1.0mm in diameter. In the larger grains of olivine undulatory extinction band is frequently developed parallel to (100). In the olivine, the optic sign is positive and the optic axial angle is about 89°. The light-coloured clinopyroxene ranges from 0.02 mm to 1.0 mm in grain diameter. In the light-coloured clinopyroxene, parting on (100) is conspicuous, and the extinction angle ($c \wedge Z$) in (010) is about 38°, the optic sign is positive, and the optic axial angle (2V) is about 57°. In the hornblende, the extinction angle ($c \wedge Z$) in (010) is about 24°, the optic sign is positive, and the optic axial angle is about 81°. The hornblende is colourless or pale yellow in thin section.

Orientation patterns of olivine and light-coloured clinopyroxene in Thin Section GY 58 VIII 26-1: Three domains, A, B, and C, are recognized within this thin section, as is shown in Fig. 11. Domain A consists mainly of olivine-aggregate. Domain C is made up of light-coloured clinopyroxene-aggregate (Plate 33, Fig. 2). Domain B, which surrounds domain C, is distributed between domain A and domain C, and is composed of relatively fine-grained olivine-aggregate with separate grains of light-coloured clinopyroxene (Plate 33, Fig. 2). Selective orientation diagrams for X, Y, and Z in olivine and clino-

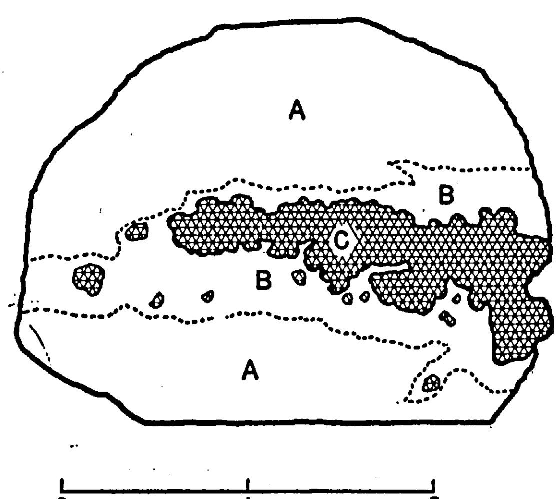
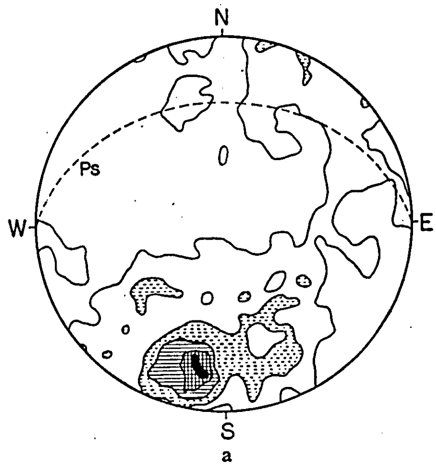
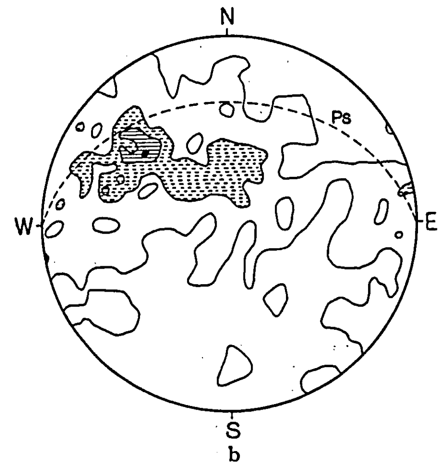


FIG. 11. Sketch of three domains, A, B, and C, in Section GY 58 VIII 26-1.





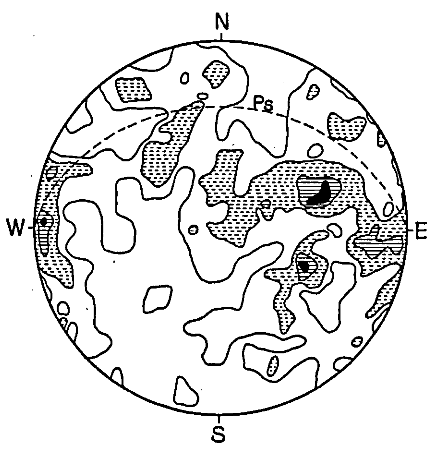


FIG. 12. Orientation diagrams for 200 grains of olivine within domain A in Section GY 58 VIII 26-1. Broken arc Ps represents the plane parallel to the general trend of clinopyroxenite-streak.
a. Orientation of X. Contours 1-3-5-7-9% per 1% area.
b. Orientation of Y. Contours 1-3-5-7% per 1% area.
c. Orientation of Z. Contours 1-2-3-4% per 1% area.

pyroxene occurring within this section were prepared. The orientation diagrams for 200 olivine grains within domain A are shown in Fig. 12a, b, and c. The orientation diagrams for 150 olivine grains within domain B are shown in Fig. 13a, b, and c. The orientation diagrams for 75 separate grains of light-coloured clinopyroxene within domain B are shown in Fig. 14a and b. The orientation diagrams for 125 grains of light-coloured clinopyroxene within domain C are shown in Fig. 15a and b. Great circle Ps in these diagrams represents the plane parallel to the general trend of the clinopyroxenite-streaks in this specimen. The olivine fabric is essentially homogeneous within this section. The patterns of preferred orientation of clinopyroxene are found identical in both domain B and domain C. Common to the diagrams of olivine in both domain A and domain B are tendencies for the (010) plane to be oriented mainly parallel to the clinopyroxenite-streak and for the crystallographic c-axis to be concentrated mainly parallel to a definite direction. The diagrams for clinopyroxene in both domain C and domain B reveal a state of preferred orientation with the (010) plane oriented mainly parallel to the clinopyroxenite-streak and with the crystallographic c-axis concentrated mainly parallel to the definite direction of maximum concentration of the crystallographic c-axis in olivine occurring around the streak.

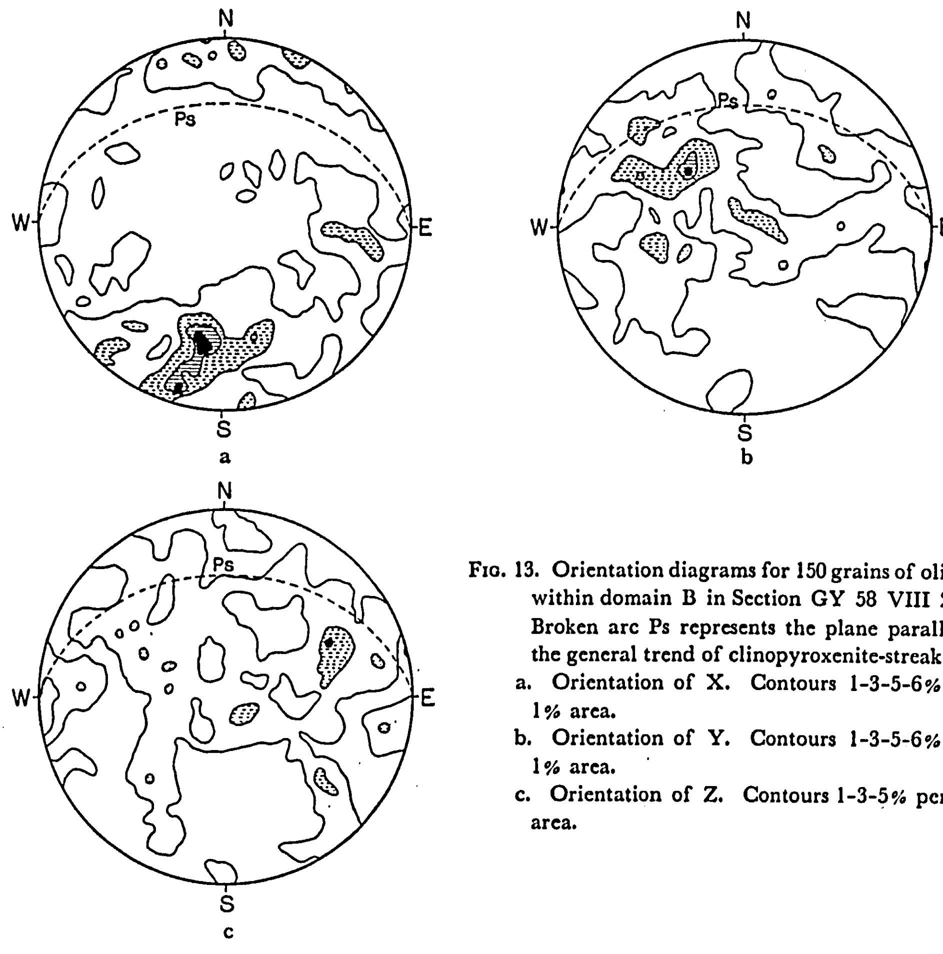


FIG. 13. Orientation diagrams for 150 grains of olivine within domain B in Section GY 58 VIII 26-1. Broken arc Ps represents the plane parallel to the general trend of clinopyroxenite-streak.
a. Orientation of X. Contours 1-3-5-6% per 1% area.
b. Orientation of Y. Contours 1-3-5-6% per 1% area.
c. Orientation of Z. Contours 1-3-5% per 1% area.

Specimen 4: GY 57 X 24-3.*

Rock name: Light-coloured clinopyroxenite containing pink garnet.

Locality: No. 5 in Fig. 2 and in Plate 32, Fig. 1.

Occurrence: The rock occurs as a band, about 3 cm thick, in the massive dunite body. The band strikes N 60° E and dips 35° NW.

Megascopic features: The specimen is a light-greenish clinopyroxenite plate. In the specimen aggregates of pink garnet are scattered, spreading parallel to the surface of the plate. On the surface of the plate can be found no megascopic linear structure.

Microscopic features (Thin Section GY 57 X 42-3): The rock consists almost entirely of light-coloured clinopyroxene with a small amount of garnet (Plate 33, Fig. 3). Black clinopyroxene and hornblende are present in small amounts. The light-coloured clinopyroxene ranges from 0.05 mm to 1.5 mm in grain diameter. In the light-coloured clinopyroxene, parting on (100) is common, the extinction angle (c^Z) in (010) is about 37°, the optic sign is positive, and the optic axial angle (2V) is about 58°. In the hornblende, the extinction angle (c^Z) in (010) is about 22°, the optic sign is positive, and the optic axial angle (2V) is about 82°. The garnet ranges from 0.5 mm to 2.5 mm in grain diameter.

Orientation pattern of light-coloured clinopyroxene in Thin Section GY 57 X 24-3: Collected together

* An outline of this specimen has been given in the previous publication (G. YOSHINO, 1961, p. 387).

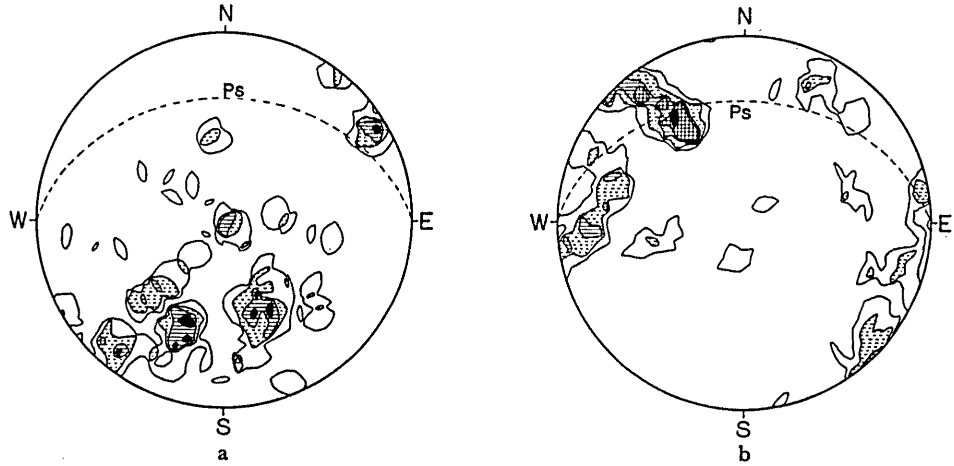


FIG. 14. Orientation diagrams for 75 separate grains of light-coloured clinopyroxene within domain B in Section GY 58 VIII 26-1. Broken arc Ps represents the plane parallel to the general trend of clinopyroxenite-streak.
a. Orientation of Y. Contours 2.7-4-5.3-6.7% per 1% area.
b. Orientation of Z. Contours 2.7-4-5.3-6.7-9.3% per 1% area.

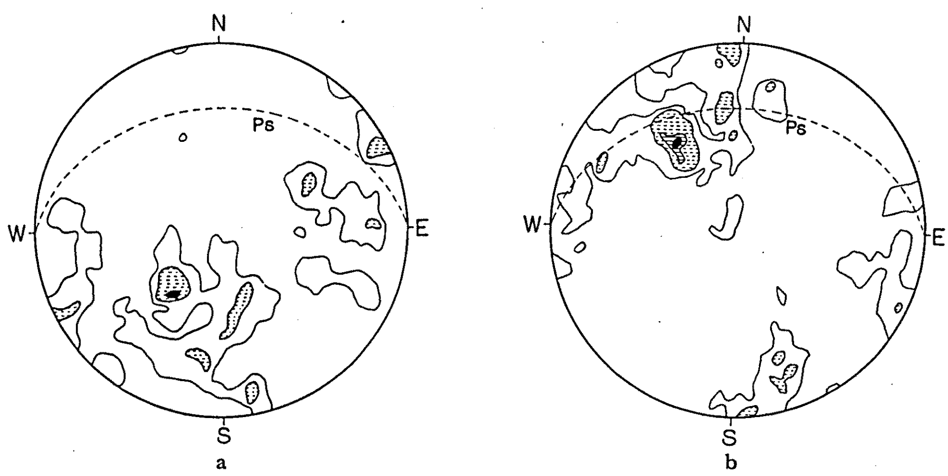


FIG. 15. Orientation diagrams for 125 grains of light-coloured clinopyroxene within domain C in Section GY 58 VIII 26-1. Broken arc Ps represents the plane parallel to the general trend of clinopyroxenite-streak.
a. Orientation of Y. Contours 2-4-6% per 1% area.
b. Orientation of Z. Contours 2-4-6-8% per 1% area.

in one diagram, the orientation patterns of Y and Z in 200 clinopyroxene grains are shown in Fig. 16. These patterns are compiled from the diagrams shown in the previous paper (G. YOSHINO, 1961, p. 388). Great circle Pb in Fig. 16 representes the plane parallel to the surface of clinopyroxenite plate. The distribution of the main maxima of Y in clinopyroxene shows a tendency for the (010) plane to be oriented generally parallel to the surface of the clinopyroxenite plate, and the distribution of the main maxima of Z in clinopyroxene reveals a tendency for the crystallographic c-axis to be concentrated generally parallel to a definite direction lying parallel to the surface of clinopyroxenite plate. The orientation diagram for 200 olivine grains in massive dunite (GY 57 X 26-2) is shown in Fig. 17. Specimen GY 57

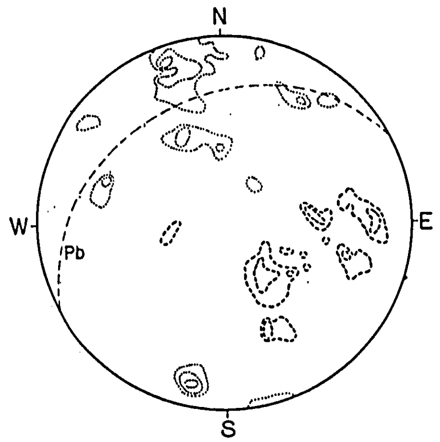


FIG. 16. Orientation diagram for 200 grains of light-coloured clinopyroxene in Section GY 57 X 24-3. Broken arc Pb represents the plane parallel to the surface of clinopyroxenite-plate. Contours: Y, 3-4% (broken lines); Z, 3-4-5% (dotted lines).

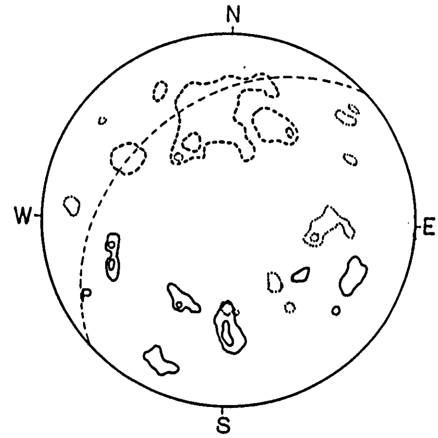


FIG. 17. Orientation diagram for 200 grains of olivine in Section GY 57 X 26-2. Broken arc P represents the plane parallel to the general trend of the adjacent clinopyroxenite-streaks. Contours: X, 3-4% (full lines); Y, 3-5% (broken lines); Z, 3-4% (dotted lines).

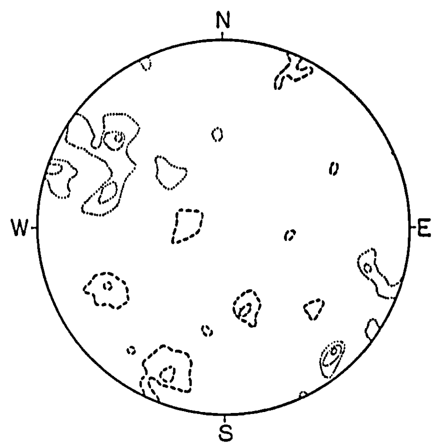


FIG. 18. Orientation diagram for 200 grains of light-coloured clinopyroxene in Section GY 58 VIII 26-5. Contours: Y, 3-4% (broken lines); Z, 3-4-5% (dotted lines).

X 26-2 was taken from the outcrop (No. 6 in Fig. 2 and in Plate 32, Fig. 1) near locality No. 5. Details of the orientation patterns of olivine in this specimen of massive dunite have been given in the previous paper (G. YOSHINO, 1961, p. 381). In Fig. 17 the orientation patterns of X, Y, and Z are collected together. Great circle P represents the plane parallel to the general trend of the adjacent clinopyroxenite-streaks. Figs. 16 and 17 show a tendency for the crystallographic c-axes in the olivine and in the clinopyroxene to be concentrated generally parallel to the definite direction plunging about 30° towards the north.

Specimen 5: GY 58 VIII 26-5.*

Rock name: Eclogite.

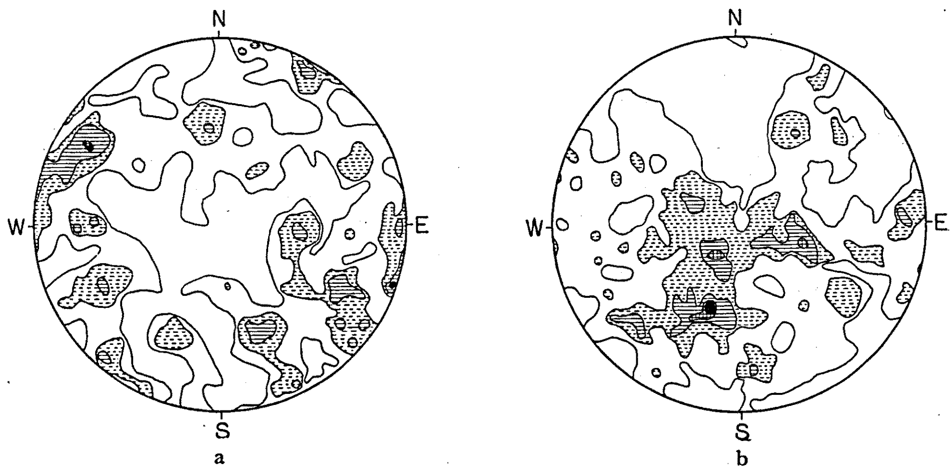
* An outline of this specimen has been given in the previous paper (G. YOSHINO, 1961, p. 388).

Locality: No. 7 in Fig. 2 and in Plate 32, Fig. 1.

Occurrence: This specimen was taken from the edge of an isolated lenticular eclogite-body having a long diameter of about 3 m and a thickness of about 1 m. This lenticular body occurs in the dunite-mylonite zone developed near the clinopyroxenite band described above. On the outer surface of the lenticular body, minute undulation is locally developed, the axis of undulation plunging about 40° towards N 30° W. Neither the grain-size nor the relative proportions of garnet and clinopyroxene are uniform within the eclogite body. The mineralogical banding, occurring locally in the body and extending parallel to the longer dimension of the lenticular body, is intersected obliquely, near the edge of the lens, with the outer surface of the body.

Megascopic features: This specimen consists of light-green clinopyroxene and pink garnet in nearly equal proportions. The specimen is massive, and in it any megascopic planar or linear structures cannot be found.

Microscopic features (Thin Section GY 58 VIII 26-5): In addition to the light-coloured clinopyroxene and pink garnet the rock contains a small amount of rutile. Although not abundant, hornblende and chlorite are also found. The light-coloured clinopyroxene is subhedral or anhedral, ranging in grain diameter from 0.1 mm to 3.0 mm, grains larger than 1.0 mm being predominant. In the light-coloured clinopyroxene, the extinction angle (c^Z) is about 42°, the optic sign is positive, and the optic axial angle



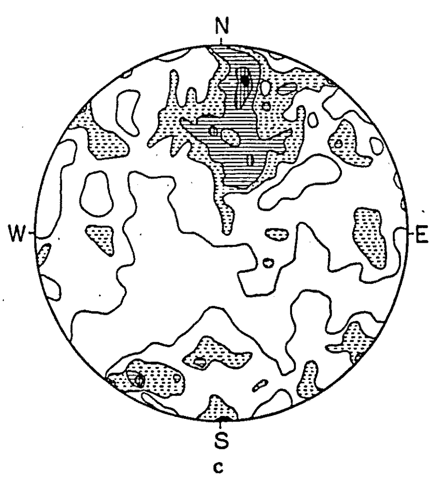


FIG. 19. Orientation diagrams for 200 grains of clinopyroxene in Section GY 61 X 14-2.
a. Orientation of X. Contours 1-2-3-4% per 1% area.
b. Orientation of Y. Contours 1-2-3-4-5% per 1% area.
c. Orientation of Z. Contours 1-2-3-4-5% per 1% area.

(2V) is about 59°. The hornblende is nearly colourless in thin section. In the hornblende, the extinction angle (c^Z) is about 24°, the optic sign is positive, and the optic axial angle (2V) is about 84°.

Orientation pattern of light-coloured clinopyroxene in Thin Section GY 58 VIII 26-5: Compiled from the diagrams presented in the previous paper (G. YOSHINO, 1961, p. 389), the orientation patterns of Y and Z in 200 clinopyroxene grains are shown in Fig. 18. Fig. 18 reveals a tendency for the crystallographic c-axis in clinopyroxene to be concentrated parallel to a definite direction. The orientaion of clinopyroxene in this section differs in attitude from the orientation of clinopyroxene in Thin Section GY 57 X 24-3 presented above.

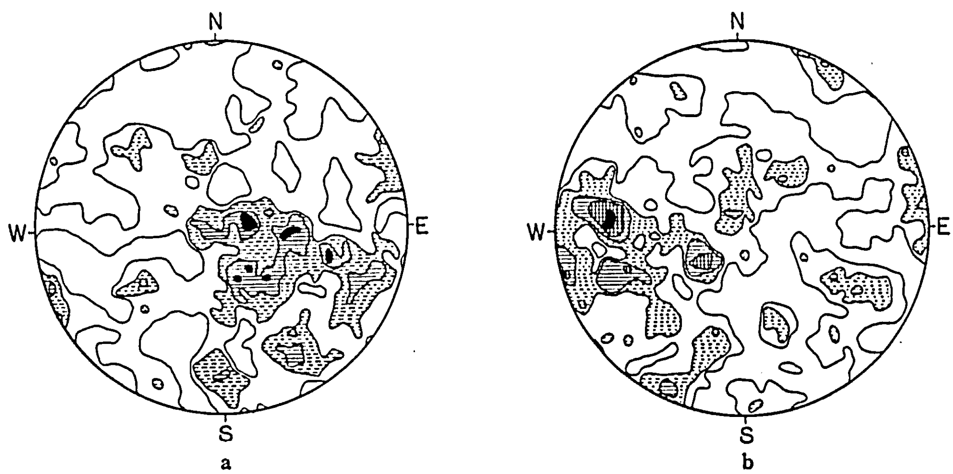
4. Correlation of clinopyroxene, hornblende, and epidote subfabrics in hornblendic and clinopyroxenic rock with olivine fabric in the surrounding massive dunite.

Specimen 6: GY 61 X 14-2.

Rock name: Epidote-hornblende-clinopyroxene-garnet-rock.

Locality: No. 31 in Fig. 2.

Occurrence: This specimen was taken from a mass of hornblendic and clinopyroxenic rock. The mass of hornblendic and clinopyroxenic rock is exposed on the slope about 900 m east of the top of Mt. Higashiakaishiyama, and the exposure on the slope is more than 50 m across. Parallel streaks and thin bands of clinopyroxenite are developed in the massive dunite part near the hornblendic and clinopy-



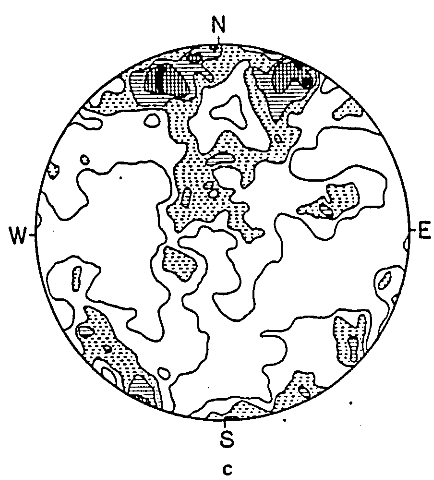


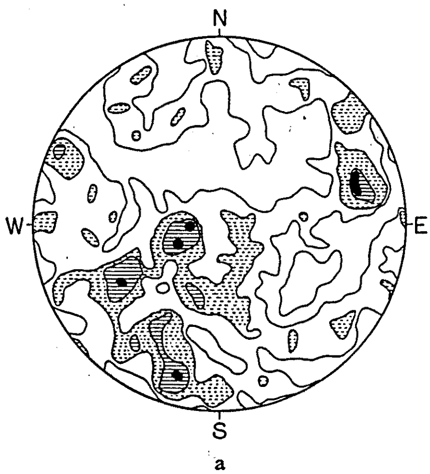
FIG. 20. Orientation diagrams for 200 grains of hornblende in Section GY 61 X 14-2.
a. Orientation of X. Contours 1-2-3-4% per 1% area.
b. Orientation of Y. Contours 1-2-3-4-5% per 1% area.
c. Orientation of Z. Contours 1-2-3-4-5% per 1% area.

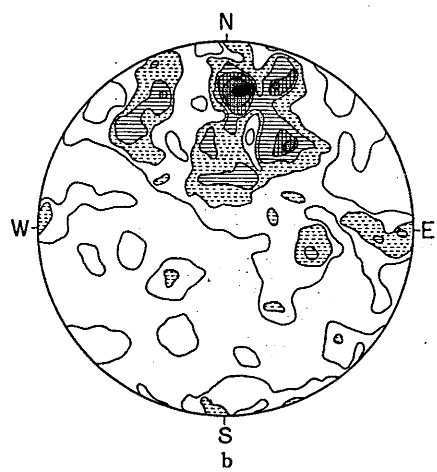
roxenic rock mass.

Megascopic features: This specimen is homogeneous in mineral composition. Megascopic planar or linear structures cannot be found.

Microscopic features (Thin Section GY 61 X 14-2): The rock consists of garnet, epidote, clinopyroxene, and hornblende, with a subordinate amount of chlorite (Plate 33, Fig. 4). The garnet is abundant. Rutile is rarely found. The epidote ranges from 0.05 mm to 2.5 mm in grain diameter. The optic axial angle (2V) in the epidote is about 72°, negative. The clinopyroxene ranges from 0.05 mm to 1.7 mm in grain diameter. In the clinopyroxene, the extinction angle (c^Z) is about 42°, the optic sign is positive, and the optic axial angle (2V) is about 62°. The hornblende ranges from 0.05 mm to 1.0 mm in the longer diameter of grain, and is colourless in thin section. In the hornblende, the extinction angle (c^Z) is about 18°, the optic sign is negative, and the optic axial angle (2V) is about 82°.

Orientation patterns of clinopyroxene, hornblende, and epidote in Thin Section GY 61 X 14-2: Three sets of orientation diagrams for clinopyroxene, hornblende, and epidote in this section were prepared. The diagrams for X, Y, and Z in 200 clinopyroxene grains are shown in Fig. 19a, b, and c. In the orientation pattern of clinopyroxene the conspicuous feature is a tendency for Z to be concentrated in several maxima within an incomplete girdle. The diagrams for X, Y, and Z in 200 hornblende grains are shown in Fig. 20a, b, and c. The orientation pattern of hornblende shows tendencies for Z to be concentrated in several maxima trending close to N and for X to be dispersed in a broad girdle within which several





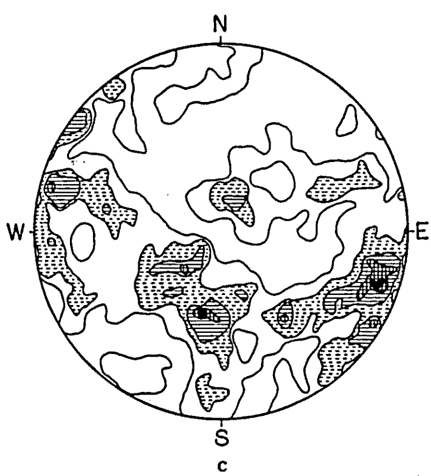


FIG. 21. Orientation diagrams for 200 grains of epidote in Section GY 61 X 14-2.
a. Orientation of X. Contours 1-2-3-4% per 1% area.
b. Orientation of Y. Contours 1-2-3-4-5-6% per 1% area.
c. Orientation of Z. Contours 1-2-3-4-5% per 1% area.

separate maxima occur. The diagrams for X, Y, and Z in 200 epidote grains are shown in Fig. 21a, b, and c. In the orientation pattern of epidote shown is a marked tendency for Y to be concentrated in several maxima lying near N and to spread along a great circle dipping to NE. X and Z in epidote are dispersed within a broad band oriented roughly perpendicular to the girdle of Y in epidote. From the optic-crystallographic relations in the individual minerals the mutual geometric relationships of the clinopyroxene, hornblende, and epidote subfabrics in this specimen are determined. In this specimen the crystallographic c-axis in both clinopyroxene and amphibole, as well as the b-axis in epidote, tend to be concentrated generally parallel to a definite direction plunging about 30° towards N. Although any megascopic planar structures cannot be found in Specimen GY 61 X 14-2, occurrence of the NE-dipping girdle of Y in epidote reveals a definite surface to which the crystallographic b-axis in epidote tends to lie parallel. In the clinopyroxene, the optic elasticity Y-axis is equivalent to the crystallographic b-axis. Occurrence of the Y-maxima in the diagram for clinopyroxene reveals a tendency for the (010) plane in clinopyroxene to be oriented parallel to the great-circle-girdle of Y in epidote.

Now, three specimens of massive dunite occurring around this hornblendic and clinopyroxenic rock mass are selected, the orientation patterns of olivine in the three specimens being given.

Specimen 7: GY 58 VIII 19-5.

Rock name: Massive dunite.

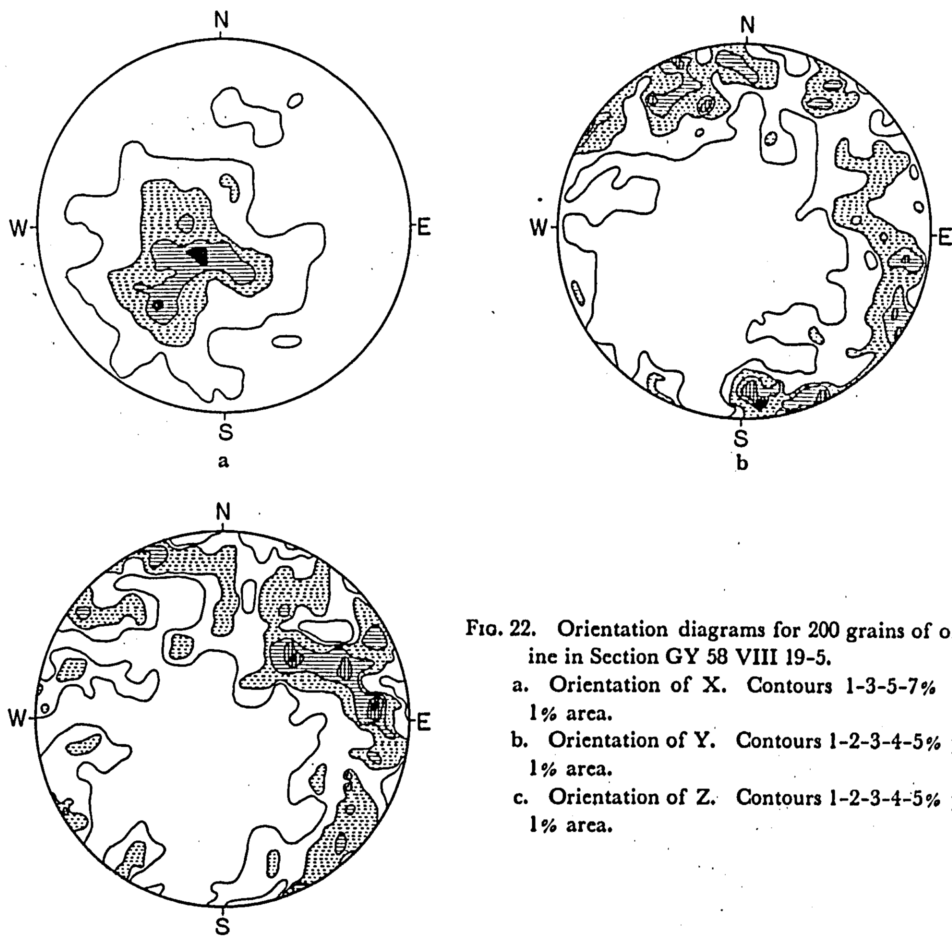


Fig. 22. Orientation diagrams for 200 grains of olivine in Section GY 58 VIII 19-5.

a. Orientation of X. Contours 1-3-5-7% per 1% area.

b. Orientation of Y. Contours 1-2-3-4-5% per 1% area.

c. Orientation of Z. Contours 1-2-3-4-5% per 1% area.

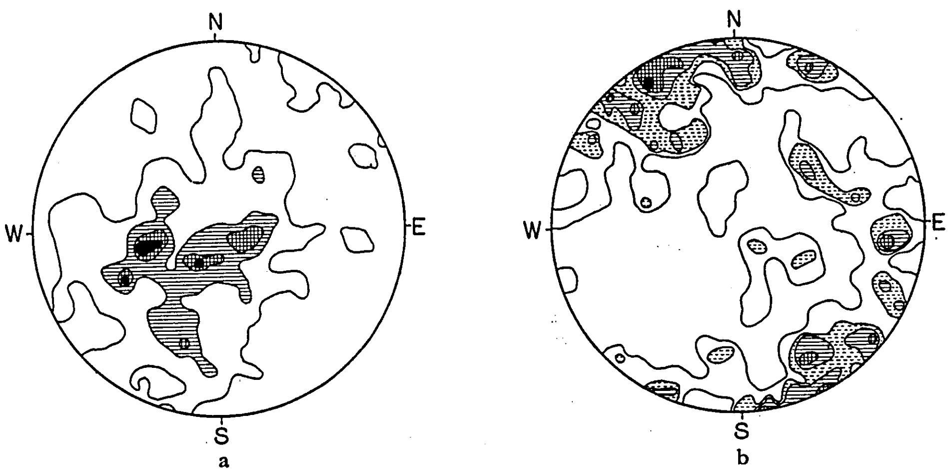
The specimen was taken at locality No. 3 about 400 m N 75° E of locality No. 31 of the hornblendic and clinopyroxenic rock mass (Fig. 2). In the massive dunite body occurring near locality No, 3, several layers of garnet-epidote-hornblende-rock occur, dipping NE. In this specimen of massive dunite megascopic planar or linear structures cannot be found. This specimen consists almost entirely of equidimensional clear grains of olivine ranging from 0.05 mm to 1.0 mm in diameter. Small amounts of chromite and fibrous serpentine mineral are also found. The optic axial angle (2V) in the olivine is about 88°, positive. In the olivine grains, undulatory extinction is rare, and lamellae structure cannot be found.

The orientation diagrams for X, Y, and Z in 200 olivine grains in Thin Section GY 58 VIII 19-5 are shown in Fig. 22a, b, and c. There are marked tendencies for Y and Z to be dispersed within a great-circle-girdle and for X to be concentrated near the pole of the Y- or Z-girdle, as is a characteristic of orieatation pattern of olivine in massive dunite occurring near locality No. 3. The Y-girdle is parallel to the Z-girdle, both dipping about 30° NE. Although several maxima occur within the girdle of Y in olivine, the main maxima of Y tend to converge close to N-S trend.

Specimen 8: GY 58 VIII 19-7.

Rock name: Massive dunite.

The specimen was taken at locality No. 13 about 300 m SE of locality No. 31 of the hornblendic and clinopyroxenic rock mass (Fig. 2). The rock is massive. In the specimen megascopic planar and linear



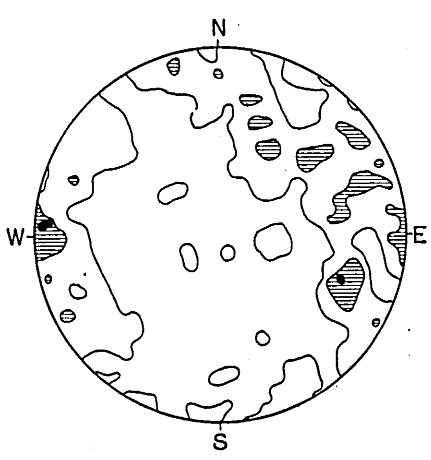


Fig. 23. Orientation diagrams for 200 grains of olivine in Section GY 58 VIII 19-7.
a. Orientation of X. Contours 1-3-5-6% per 1% area.
b. Orientation of Y. Contours 1-2-3-4-5% per 1% area.
c. Orientation of Z. Contours 1-3-5% per 1% area.

structures cannot be found. In addition to olivine (2V=88°; sign +), the rock contains a small amount of chromite. Serpentine mineral is rare. Olivine grains are equidimensional and range from 0.05 mm to 1.5 mm in diameter. Lamellae structure cannot be found in olivine grains, but some of large grains show weak undulatory extinction.

The orientation diagrams for X, Y, and Z in 200 olivine grains in Thin Section GY 58 VIII 19-7 are shown in Fig. 23a, b, and c. There are tendencies for Y and Z to be dispersed within a partial girdle dipping about 20° NE and for X to be concentrated close to the pole of the great-circle-girdle of Y or Z, as is similar to the orientation pattern of olivine in Thin Section GY 58 VIII 19-5 presented above. The main maxima of Y within the girdle tend to be concentrated close to NNW-SSE trend.

Specimen 9: GY 58 VIII 21-4.*

Rock name: Massive dunite.

The specimen was taken at locality No. 14 (the 6th Adit of the Akaishi Mine) about 200 m S 75° W of locality No. 31 of the hornblendic and clinopyroxenic rock mass. Parallel chromite bands, striking N 65° W and dipping about 50° NE, run in the massive dunite at locality No. 14.

Compiled from the diagrams presented in the previous paper (G. YOSHINO, 1961, p. 373), the orientation pattern of 200 olivine grains in Thin Section GY 58 VIII 21-4-P is shown in Fig. 24. Great circle Cb represents the plane parallel to the adjacent chromite band. There are tendencies for Y and Z to be dispersed along a great-circle dipping about 50° NE and for X to be concentrated near the pole of the Y- or Z-girdle.

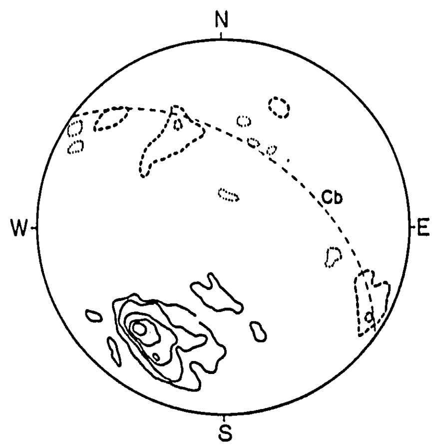


FIG. 24. Orientation diagram for 200 grains of olivine in Section GY 58 VIII 21-4-P. Broken are Cb represents the plane parallel to the adjacent chromite-band. Contours: X, 4-6-8-10-12% (full lines); Y, 4-6% (broken lines); Z, 4% (dotted lines).

The pattern of preferred orientation of olivine is identical in the three thin sections presented above. As has been shown in the previous paper, the olivine fabric was found to be the same in each portion within the massive dunite mass lying over a distance of about 100 m near the Main Adit of the Akaishi Mine. Judging from the collective diagrams with respect to the main maxima of X, Y, and Z in olivine (G. YOSHINO, 1961, p. 392), the massive dunite body occupying the inner part of the Higashiakaishiyama ultrabasic body is fairly homogeneous with respect to the pattern of preferred orientation of olivine. Therefore, the olivine fabric in the massive dunite mass occupying the space containing the three localities of Nos. 3, 13, and 14 can be considered homogeneous. Then, a tendency common to the olivine diagrams for the three portions mentioned above can be regarded as representing a common tendency for the olivine fabric in the whole of massive dunite mass of this space. Finally, it can be said that the olivine in the massive dunite body occurring around the mass of hornblendic and clinopyroxenic rock tends

* Details of olivine fabric in this specimen have been given in the previous paper (G. YOSHINO, 1961).

to be oriented with Y parallel to the surface striking N 30°–55° W and dipping 20°–50° NE and mainly parallel to the direction plunging 10°–40° nearly N.

The surface and the axis both defined by the preferred orientation of epidote in the mass of hornblendic and clinopyroxenic rocks are conformable, respectively, in attitude with the surface and the axis both defined by the preferred orientation of olivine in the surrounding massive dunite body.

B. Olivine, Clinopyroxene, Hornblende, and Epidote Fabrics in Ultrabasic Mass

The rock body, consisting mainly of massive dunite with small amounts of black clinopyroxene-bearing peridotite, light-coloured clinopyroxenite, and eclogite, occurs in the area of Gongendani Valley. It occupies the upper zone of the Higashiakaishiyama ultrabasic body. On the other hand, the rock body exposed in the area extending from the Main Adit to the 6th Adit of the Akaishi Mine is composed almost entirely of massive dunite, and occupies the inner part of the Higashiakaishiyama ultrabasic body. The hornblendic and clinopyroxenic rock mass mentioned in the preceding pages is a large mass occurring within the inner part of this ultrabasic body. Within the Higashiakaishiyama ultrabasic body the individual minerals, such as the olivine in the massive dunite and in the massive peridotite, the black clinopyroxene in the massive peridotite, and the light-coloured clinopyroxene in the massive peridotite, in the clinopyroxenite, and in the eclogite, show respectively a marked preferred orientation. The hornblende, the clinopyroxene, and the epidote in the hornblendic and clinopyroxenic rock possess preferred orientations.

In the olivine diagram for each portion within the upper zone of the Higashiakaishiyama ultrabasic body are found common tendencies for [001] to be concentrated parallel to a definite axis and for [010] to be dispersed within a great-circle-girdle. The definite axis parallel to which [001] tends to be concentrated coincides in orientation with the axis of girdle of the [010] pattern, the plane parallel to the girdle of [010] being only one symmetry plane in the orientation pattern of olivine. Within the upper zone of the Higashiakaishiyama ultrabasic body, the definite axis of maximum concentration of [001] in olivine tends to lie parallel to the surface of compositional layering defined by the alternating bands of clinopyroxene-bearing peridotite, clinopyroxenite, or eclogite in the more abundant dunite, and the definite axis is fairly uniform in orientation throughout both the massive dunite part and the massive peridotite part. Within the girdle pattern of [010] in olivine diagram, the [010] maxima frequently occur near the normal to the plane parallel to the surface of compositional layering. The attitude of the compositional layering developed within the upper zone of the ultrabasic body varies locally. The pattern of preferred orientation of clinopyroxene is indentical in all the clinopyroxene-bearing rocks occurring within the upper zone of the Higashiakaishiyama ultrabasic body. Orientation patterns of X, Y, and Z in clinopyroxene bring out the tendencies for the crystallographic c-axis to be concentrated parallel to a definite axis and for the (010) plane to be oriented parallel to the surface of compositional layering within the upper zone of the ultrabasic body. The definite axis parallel to which the crystallographic c-axis in clinopyroxene tends to be concentrated seems to lie in the plane parallel to the surface of the compositional layering, and it seems also to coincide in orientation with the definite axis of maximum concentration of [001] in olivine grains in the adjacent massive dunite. G. KOJIMA and K. HIDE (1957) reported aegirine-augite oriented with the (010) plane parallel to the bedding-schistosity plane (*ab*) and with the crystallographic c-axis parallel to the tectonic *b*-axis in some quartz schist beds in the vicinity of the Higashiakaishiyama district. Now, it is evident that one *s*-surface and one lineation are both defined by the preferred orientation of olivine or clinopyroxene, or both in such massive rocks as the massive dunite, the clinopyroxene-bearing peridotite, the clinopyroxenite, and the eclogite within the upper zone of the Higashiakaishiyama ultrabasic body. The statistically defined linear structure penetrates throughout the upper zone of the Higashiakaishiyama ultrabasic body, being conformable in regional attitude with the conspicuous lineation developed in the Iratsu amphibole schist bed bounding the ultrabasic body on the north. The upper zone of the ultrabasic body can be considered structurally homogeneous with respect to the linear structure defined statistically. The type of olivine orientation pattern showing approximately such a monoclinic symmetry as is characterized by only one symmetry plane parallel to the great-circle-girdle of [010] is designated in this paper as type B.

The inner part of the Higashiakaishiyama ultrabasic body consists almost entirely of massive dunite. The pattern of preferred orientation of olivine in massive dunite occurring in each portion within the inner part of the ultrabasic body is not always the same. Most of the olivine diagrams for each portion within the inner part show monoclinic symmetry, the sole plane of symmetry being parallel to the great-circle-girdle of [001]. In such olivine diagrams, [010] tends to be concentrated close to the axis of the girdle of [001]. Some of the olivine diagrams show monoclinic symmetry of type B, and others show approximately orthorhombic symmetry. In most of the olivine diagrams for each portion within the inner part of the ultrabasic body is found a tendency for the girdle of [001] to be uniform in attitude. The plane parallel to the girdle of [001] in olivine diagrams within the inner part of the ultrabasic body seems to be harmonic in regional attitude with the surface of compositional layering in the upper zone of the ultrabasic body and also with the upper surface of this lenticular ultrabasic body. As shown in the preceding pages, the surface on which the crystallographic b-axis in epidote tends to lie within the mass of the hornblendic and clinopyroxenic rock is conformable in attitude with the surface on which [001] in olivine tends to lie within the surrounding massive dunite mass which is exposed near the 6th Adit of the Akaishi Mine. As described by C. B. CRAMPTON (1957), G. KOJIMA and K. HIDE (1958), and G. YOSHINO (1961), the epidote in tectonites shows distribution of the crystallographic b-axis within a marked concentration parallel to the fabric *b*-axis and a partial girdle parallel to the *s*-surface. From these facts the plane parallel to the girdle of [001] in olivine diagram can be considered a penetrative surface within the inner part of the Higashiakaishiyama ultrabasic body. It is conceivable that the *s*-surface defined by the preferred orientation of olivine penetrates throughout the inner part of the ultrabasic body. Now, the inner part of the lenticular Higashiakaishiyama ultrabasic body can be considered structurally homogeneous with respect to the planar structure defined statistically. The type of olivine fabric approximating monoclinic symmetry with only one symmetry plane parallel to the great-circle-girdle of [001] is designated in this paper as type S.

III. Origin of Ultrabasic Mass

In the spotted schist zone of the Besshi-Shirataki region are found numerous bodies of ultrabasic rocks. The great majority of the ultrabasic bodies occur within the Upper member of the Minawa formation. The Upper member of the Minawa formation forms a zone of recumbent type of folds in this region of the Sambagawa metamorphic belt (G. Kojima, 1951a, 1951b; G. Kojima, K. Hide, and G. Yoshino, 1956; G. Yoshino, 1961). The Higashiakaishiyama ultrabasic body occurring within the Upper member of the Minawa formation is the largest of all the ultrabasic bndies in this region. The schist complex of the Besshi-Shirataki region has been divided by K. Hide (1961) into 4 zones based on the progressive mineralogical variation of basic rocks, namely, from zone I of lower grade to zone IV of higher grade. K. Hide (1961) has noted a mineralogical variation in ultrabasic bodies distributed in the schist complex in this region (Fig. 25). The Higashiakaishiyama ultrabasic body consisting almost entirely of unserpentinized dunite has been brought into contact with the Iratsu amphibole schist mass which belongs to zone IV (G. Yoshino, 1961; K. Hide, 1961).

F. J. Turner and J. Verhoogen (1951; 1960) commented on the occurrence, the mineralogy, and the adjacent rocks of "alpine type" peridotites and serpentinites occurring in orogenic belts, and discussed comprehensively the origin of the ultrabasic rocks. C. S. Ross, M. D. Foster, and A. T. Myers (1954) made a chemical

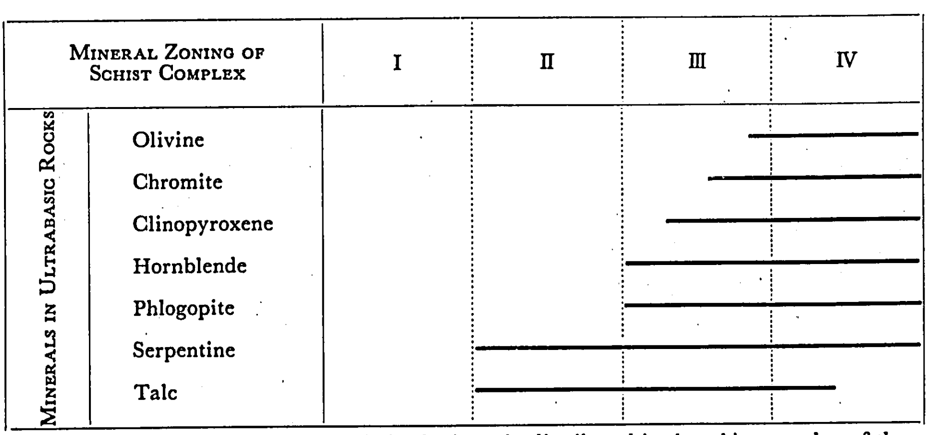


Fig. 25. Mineralogical variation of ultrabasic rocks distributed in the schist complex of the Besshi-Shirataki district (After K. Hide).

study of dunite, and concluded that dunites and related rocks have been brought up from the peridotite substratum by orogenic processes. G. KOJIMA and K. HIDE (1957; 1958), from the geological and petrological studies on the Besshi spotted schist zone, pointed out that the Higashiakaishiyama ultrabasic body is a large tectonic inclusion, and suggested that most of the ultrabasic bodies in this region represent synkinematic intrusions whose physical and chemical agencies played an essential role in the deformation and mineralization of the spotted schists. On the other hand, an orogenic process involved in formation of metamorphic belt with ultrabasic rocks has been discussed by A. MIYASIHRO (1959; 1961).

In the mode of occurrence, the compositional layering defined by alternating bands of clinopyroxenite or clinopyroxene-bearing peridotite in the mass of dunite within the upper zone of the Higashiakaishiyama ultrabasic body (G. YOSHINO, 1961) resembles the layering reported to occur in a number of ultrabasic bodies, e. g., the Miyamori peridotite of the Kitakami mountainland (Y. SEKI, 1952), the Dawros peridotite in Connemara, Eire (A. T. V. ROTHSTEIN, 1957), the ultramafic complex at Union Bay (J. C. RUCKMICK and J. A. NOBLE, 1959), the Tinaquillo peridotite in Northern Venezuela (D. B. MACKENZIE, 1960), the Jotunheim peridotite in Norway (M. H. BATTEY, 1960a), the ultramafic pluton in the Klamath Mountains, California (P. W. LIPMAN, 1964), and so on. Once Y. HORIKOSHI (1937a; 1937b) concluded that the eclogite in the Higashiakaishiyama ultrabasic body represents a pegmatitic part derived from the dunite magma. N. L. BOWEN and O. F. TUTTLE (1949) investigated experimentally the system MgO-SiO_2-H_2O, and suggested that water vapor saturated with SiO_2 and streaming through a crack in dunite could convert the adjacent rock to pyroxenite. On the other hand, R. T. V. ROTHSTEIN (1957) concluded that the Dawros ultramafic rocks are layered as a result of rhythmic accumulation of olivine, magnesian orthopyroxene, chrome-spinel, and diopsidic clinopyroxene in a magma. J. C. RUCKMICK and J. A. NOBLE (1959) regarded the layers of diopside crystals in the dunite core of the ultramafic complex at Union Bay as the primary structure resulted from gravitational setting of crystals from a crystallizing magma. From the fact that the mineral foliation and compositional layering within the ultramafic body in the Klamath Mountains are parallel to the contacts with the metamorphic country rocks and that they are distributed throughout the ultramafic sheet, P. W. LIPMAN (1964) concluded that the layering was originated during intrusion of the ultramafic rocks. The hornblendic and clinopyroxenic rock masses in the Higashiakaishiyama ultrabasic body are rather similar in occurrence to "pseudo-gabbro" masses within a peridotite intrusion in Northern Venezuela (D. B. MACKENZIE, 1960). The gabbroic masses in the Tinaqillo peridotite mass were interpreted (D. B. MACKENZIE, 1960) as large inclusions of the contact-metamorphosed country rock, but H. G. WILSHIRE and R. A. BINNS (1961) considered it possible that differentiation within the mantle has given rise to the gabbros and other non-peridotite rocks which appear as xenoliths.

W. P. DE ROEVER (1961) suggested that the upper part of the earth's mantle consists essentially of a schistose and banded mass of peridotites, with subordinate pyroxenites and rare eclogites, and assumed that the structure of the mass could have been formed by convection currents in the solid mantle material. Recently, H. S. YODER, Jr. and C. E. TILLEY (1962) have revealed a possible relationship of eclogite to basalt and their melting relations, and suggested that eclogites themselves are probably the partial melting product of a more primitive rock, presumably garnet peridotite. They also noted that the transformation of eclogite to basalt at 10 kb is rapid near the solidus but becomes extremely sluggish below 800°C.

Now, it seems reasonable to suppose that the Higashiakaishiyama ultrabasic body has been brought up from such deep-seated rocks as the upper mantle materials through an orogenic process involving the metamorphism of the Sambagawa belt. If it is true, the Higashiakaishiyama ultrabasic complex can be regarded as a source of useful informations about the materials and conditions prevailing in the deeper parts of the crust.

Within the Higashiakaishiyama ultrabasic body, the olivine in both the massive dunite and the massive peridotite shows a marked preferred lattice orientation. Although the pattern of olivine diagram for each portion within both the massive dunite part and the massive peridotite part in the Higashiakaishiyama ultrabasic body is not everywhere the same, a tendency for the maximum concentration of [010] and of [001] in olivine to be uniform in their orientation respectively within the ultrabasic body suggests that the olivine grains in each portion within the massive parts have possessed their observed state of preferred orientation simultaneously under a tectonic condition. From geometric relationships between the olivine fabric and the clinopyroxene fabric in the Higashiakaishiyama ultrabasic body it is inferred that the black clinopyroxene in the massive peridotite and the light-coloured clinopyroxene in the massive peridotite, in the light-coloured clinopyroxenite, and in the eclogite, together with the olivine in both the massive dunite and the massive peridotite, have acquired their observed state of preferred orientation simultaneously under a tectonic condition. Under such a condition the olivine grains enclosed within large grains of black clinopyroxene have not been preferably oriented. The megascopic and microscopic features of the clinopyroxenite and of the eclogite in the ultrabasic body suggest that at least some of the fine streaks of clinopyroxenite and of eclogite were formed synchronously with oriented crystallization of the light-coloured clinopyroxene, although it is not certain whether or not the streak replaced a layer somewhat differing in physico-chemical properties from the adjacent part in the ultrabasic body. In addition, from geometric relations of the clinopyroxene, the epidote and the hornblende subfabrics in the mass of the hornblendic and clinopyroxenic rocks to the olivine fabric in the surrounding massive dunite mass, it is clear that the three tectonite minerals observed in the hornblendic and clinopyroxenic rock masses, together with the olivine in the surrounding massive dunite mass, may have possessed their observed state of preferred orientation simultaneously under a tectonic condition. The masses of hornblendic and clinopyroxenic rocks in the Higashiakaishiyama ultrabasic body may have existed, as masses differing in chemical properties from the adjacent part, prior to development of the preferred orientation of clinopyroxene, of hornblende, and of epidote in the masses, although the original characters of the hornblendic and clinopyroxenic rocks have not been ascertained. Within the Higashiakaishiyama ultrabasic body varieties of hornblende occur frequently, but never abundantly, also in other clinopyroxene-bearing rocks. Some of the hornblendes contained in the clinopyroxene-bearing peridotite, in the light-coloured clinopyroxenite, or in the eclogite, may be varieties which have replaced clinopyroxene during a later phase of the metamorphism.

It is a significant fact that the statistical *s*-surface revealed in both the upper zone and the inner part and the statistical lineation revealed in the upper zone within the Higashiakaishiyama ultrabasic body are parallel in regional attitude respectively to the megascopic foliation and lineation both developed in the Iratsu amphibole schist mass bounding the ultrabasic body on its north. In the Iratsu amphibole schist mass the epidote and hornblende subfabrics show the same symmetry as represented by the megascopic planar and linear structures (G. YOSHINO, 1961). It seems, reasonable, therefore, to suppose that the epidote and the hornblende in the Iratsu amphibole schist mass acquired their observed state of preferred orientation under a tectonic condition at the same stage as the olivine and the clinopyroxene within the Higashiakaishiyama ultrabasic body possessed their observed state of preferred orientation. It is likely that the Iratsu amphibole schist has experienced a history of kinematic development closely related to that of the Higashiakaishiyama ultrabasic complex.

The foliated dunite develops mainly in the lower part of the Higashiakaishiyama ultrabasic body. The preferred orientation of olivine is less remarkable, in general, in the foliated dunite than in the massive one. The olivine fabric is not always harmonic in symmetry with the megascopic foliation and lineation of the foliated dunite (G. YOSHINO, 1961). In megascopic structures the foliated dunite part closely resembles the spotted black schist beds bounding the ultrabasic body on its south. In addition, the megascopic lineation imposed on the foliated dunite of the lower part of the ultrabasic body is parallel in attitude to the conspicuous lineation developed in the spotted black schist bed which comes into contact with the lower part of the ultrabasic body (G. YOSHINO, 1961). On the other hand, the linear structures developed in the main part of the Iratsu amphibole schist mass are not parallel in regional orientation to the linear structures developed in the spotted schist beds which occur around the Higashiakaishiyama ultrabasic body and the associated Iratsu amphibole schist mass and which construct the recumbent fold zone in the Sambagawa metamorphic belt of the Besshi-Shirataki region (G. YOSHINO, 1961). From these facts, it may be concluded that the tectonite minerals observed in both the Higashiakaishiyama ultrabasic body and the associated Iratsu amphibole schist mass had already attained to their observed state of preferred orientation prior to the development of planar and linear structures now observed in the surrounding spotted schist beds that have taken part in the structure of recumbent type of fold in the district.

M. H. BATTEY (1960b) studied the orientation of olivine crystals in the type dunite of Dun Mountain, New Zealand, and concluded: "Olivine orientation at Dun Mountain is related to the axes of regional folding and is very probably produced by the folding forces." A. L. G. COLLÉE (1962) examined elaborately the petrofabrics of some ultrabasic nodule-like inclusions in basalt lavas. He regarded these inclusions as secondary tectonites subjected to deformation in predominantly solid state and concluded that the studied specimens are likely to be fragments of the earth's peridotite shell. F. J. TURNER (1942) and H. W. FAIRBAIRN (1949) interpreted the lattice orientation of olivine grains in peridotite as having been brought about by the effect of solid flow. Recently, experiments on deformation of peridotite have been performed by D. T. GRIGGS, F. J. TURNER, and H. C. HEARD (1960), but the mechanism of preferred orientation of olivine has not been clarified. On the other hand, R. K. VERMA (1960) reported the adiabatic elastic constants of olivine. F. J. TURNER and L. E. WEISS (1963) say: "In the sequence of correlated influences and phenomena concerned in the evolution of a tectonite fabric during flow of a stressed rock, the ultimate fabric is more closely related to the movement picture of flow than to the more remote phenomena of stress and strain. Consequently symmetry of fabric most closely reflects symmetry of the movement picture". If the symmetry of the observed state of olivine fabric in the Higashiakaishiyama ultrabasic body reflects the symmetry of the movement picture, type B and type S of olivine fabric must be related to different types of movement picture. As explained in the preceding chapter, distribution of the type of olivine fabric within the ultrabasic body suggests that the upper part of the Higashiakaishiyama ultrabasic body was dominated by a movement picture related to the olivine fabric of type B and the inner part of the ultrabasic body was dominated by one related to the olivine fabric of type S. In view of the mechanical conditions under which the preferred orientation of olivine was developed in the ultrabasic body, the upper part, which is now composed of alternating layers of peridotite, clinopyroxenite, and eclogite, in the more abundant dunite and which is adjacent to the Iratsu amphibole schist mass, may have differed from the inner part consisting now chiefly of massive dunite.

Although no experiments have been tried with respect to orienting process of olivine, the fact that there have been traced no dimensional orientation and no lamellae structure, except rare undulatory extinction, in olivine grains within the Higashiakaishiyama ultrabasic body suggests the preferred lattice orientation of olivine to have been developed through recrystallizing or neocrystallizing process under the stress condition (G. YOSHINO, 1961).

Lastly, it is of interest to speculate about the picture of progressive change of deformation in the whole space of an orogenic belt. In the broad history of an orogeny, the phase of folding would have migrated with the time through the geosyncline, and each part of the geosynclinal pile would have experienced respective history of kinematic development. Intensive folding accompanying the geosynclinal down-buckling could have effected the uprising of deep-seated materials into the upper level. The presence of the mass of dunite and eclogite within the geosynclinal deposits must be explained in such a manner. As shown in the preceding pages and in the author's previous paper (G. YOSHINO, 1961), the structures of the foliated dunite have been formed in connection with the folding of the spotted black schist bounding the ultrabasic body on its south. It is highly probable that the tectonite minerals observed in both the Higashiakaishiyama ultrabasic body and the swollen part of the Iratsu amphibole schist mass attained to their observed state of preferred orientation in an earlier phase of the orogeny involving the formation of the Sambagawa metamorphic belt, and in the deeper part of the metamorphic belt. Afterwards, in an advanced phase of the orogeny, the ultrabasic body, together with the Iratsu amphibole schist mass, has been brought into contact with such upper formations of the geosyncline as is now represented by the Upper member of Minawa formation. The tectonite minerals observed in the surrounding spotted schists of the Upper member of the Minawa formation may have attained to their observed state of preferred orientation through this phase of orogeny.

LITERATURES

BANBA, T. (1953): The Higashi Akaishi-yama dunite mass in Shikoku (Studies on spinels associated with the ultra-mafic rocks, II) (in Japanese). *Jour. Geol. Soc. Japan*, **59**, (696), 437-445.

BATTEY, M. H. (1960a): Observations on the peridotites and pyroxenites of the Jotunheim complex in Norway. *Intern. Geol. Congress, XXI Session, Norden*, Part 13, 198-207.

BATTEY, M. H. (1960b): The relationship between preferred orientation of olivine in dunite and the tectonic environment. *Amer. Jour. Sci.*, **258**, (10), 716-727.

BOWEN, N. L., and TUTTLE, O. F. (1949): The system $MgO-SiO_2-H_2O$. *Geol. Soc. America Bull.*, **60**, (3), 439-460.

COLLÉE, A. L. G. (1962): A fabric study of lherzolites, with special reference to ultrabasic nodular inclusions in the lavas of Auvergne (France). *Leidse Geol. Med.*, deel 28, 1-102.

CRAMPTON, C. B. (1957): Regional study of epidote, mica, and albite fabrics of the Moines. *Geol. Mag.*, **94**, (2), 89-103.

FAIRBAIRN, H. W. (1949): *Structural petrology of deformed rocks.* Cambridge, Mass., Addison and Wesley Publishing Co.

GRIGGS, D. T., TURNER, F. J., and HEARD, H. C. (1960): Deformation of rocks at 500° to 800°C. *Rock deformation, Geol. Soc. America Mem.* 79, 39-104.

HARADA, Z. (1943): On the chrome minerals of Japan (II) (in Japanese). *Jour. Japan. Assoc. Mineral., Petrol., Economic Geol.*, **29**, (1), 12-13.

HIDE, K. (1954): Geological structure of the Shirataki mining district, Kôchi Prefecture (in Japanese). *Geol. Report Hiroshima Univ.*, (4), 47-83.

HIDE, K., YOSHINO, G., and KOJIMA, G. (1956): Preliminary report on the geologic structure of the Besshi spotted schist zone (in Japanese). *Jour. Geol. Soc. Japan*, **62**, (733), 574-584.

HIDE, K. (1961): Geologic structure and metamorphism of the Sambagawa crystalline schists of the Besshi-Shirataki mining district in Shikoku, Southwest Japan (in Japanese). *Geol. Report Hiroshima Univ.*, (9), 1-82.

HORIKOSHI, Y. (1937a): [Rocks and geology of the Besshi district, Ehime Prefecture] (in Japanese). *Jour. Geol. Soc. Japan*, **44**, (521), 121-140.

HORIKOSHI, Y. (1937b): [On the eclogite in the vicinity of Higashi-Akaishi-Yama in the province of Iyo] (in Japanese). *Jour. Geol. Soc. Japan*, **44**, (521), 141-144.

KATÔ, T. (1921): Notes on the banded chromite ore from the Akaishi mine in the province of Iyo, Japan. *Jour. Geol. Soc. Japan*, **28**, (331), 13-18.

KINOSHITA, K. (1936): Dunite from Akaishi chromite mine, Ehime prefecture (in Japanese). *Jour. Soc. Japan. Mineral. (Our Minerals)*, **5**, (12), 414-417.

KOJIMA, G. (1951a): Uber das "Feld der Metamorphose" der Sanbagawa Kristallinen Schiefer-besonders in Bezug auf Bildung des Kristallinen Schiefergebietes in Zentral-Sikoku. *Jour. Sci. Hiroshima Univ.*, Ser. C, **1**, (1), 1-18.

KOJIMA, G. (1951b): Stratigraphy and geological structure of the crystalline schist region in Central Shikoku (in Japanese). *Jour. Geol. Soc. Japan*, **57**, (668), 177-190.

KOJIMA, G. (1951c): Some subjects on the Sambagawa metamorphism (in Japanese). *Jour. Assoc. Geol. Collaboration Japan (Earth Science)*, **6**, 63-71.

KOJIMA, G. (1953): Contribution to the knowledge of mutual relations between three metamorphic zones of Chûgoku and Shikoku, South-Western Japan, with special reference to the metamorphic and structural features of each metamorphic zone. *Jour. Sci. Hiroshima Univ.*, Ser. C, **1**, (3), 17-46.

KOJIMA, G., HIDE, K, and YOSHINO, G. (1956): The stratigraphical position of Kieslager in the Sambagawa crystalline schist zone in Shikoku (in Japanese). *Jour. Geol. Soc. Japan*, **62**, (727), 39-45.

KOJIMA, G., and HIDE, K. (1957): On new occurrence of aegirine augite-amphibole-quartz-schists in the Sambagawa crystalline schists of the Besshi-Shirataki district, with special reference to the preferred orientation of aegirine augite and amphibole. *Jour. Sci. Hiroshima Univ.*, Ser. C, **2**, (1), 1-20.

KOJIMA, G., and HIDE, K. (1958): Kinematic interpretation of the quartz fabric of triclinic tectonites from Besshi, Central Shikoku, Japan. *Jour. Sci. Hiroshima Univ.*, Ser. C, **2**, (3), 195-226.

KOJIMA, G. (1963): On the fundamental structure of the Sambagawa crystalline schist zone (in Japanese). *Geol. Report Hiroshima Univ.*, (12), 173-182.

LIPMAN, P. W. (1964): Structure and origin of an ultramafic pluton in the Klamath mountains, California. *Amer. Jour. Sci.*, **262**, (2), 199-222.

MACKENZIE, D. B. (1960): High-temperature alpine-type peridotite from Venezuela. *Geol. Soc. America Bull.*, **71**, (3), 303-318.

MIYASHIRO, A. (1959): Abukuma, Ryôke, and Sanbagawa metamorphic belts (in Japanese). *Jour. Geol. Soc. Japan*, **65**, (769), 624-637.

MIYASHIRO, A. (1961): Evolution of metamorphic belts. *Jour. Petrology*, **2**, (3), 277-311.

ROEVER, W. P. DE (1961): Mantelgesteine und Magmen tiefer Herkunft. *Fortschr. Miner.*, **39**, (1), 96-107.

ROSS, C. S., FOSTER, M. D., and MYERS, A. T. (1954): Origin of dunites and of olivine-rich inclusions in basaltic rocks. *Amer. Mineralogist*, **39**, (9-10), 693-737.

ROTHSTEIN, A. T. V. (1957): The Dawros peridotite, Connemara, Eire. *Quart. Jour. Geol. Soc. London*, **113**, (1), 1-25.

RUCKMICK, J. C., and NOBLE, J. A. (1959): Origin of the ultramafic complex at Union bay, Southeastern Alaska. *Geol. Soc. America Bull.*, **77**, (8), 981-1018.

SEKI, Y. (1952): The studies on Miyamori ultrabasic mass, Iwate prefecture, N-E Japan (No. 4) (in Japanese). *Jour. Geol. Soc. Japan*, **58**, (686), 505-516.

TURNER, F. J. (1942): Preferred orientation of olivine crystals in peridotites, with special reference to New Zealand examples. *Roy. Soc. New Zealand Trans.*, **72**, Part 3, 280-300.

TURNER, F. J., and VERHOOGEN, J. (1951; 1960): *Igneous and metamorphic petrology*. New York, McGraw-Hill Book Co.

TURNER, F. J., and WEISS, L. E. (1963): *Structural analysis of metamorphic tectonites*. New York, McGraw-Hill Book Co.

UCHIDA, Y. (1949): On the banded chromite deposits (in Japanese). *Jour. Japan. Assoc. Mineral., Petrol., Economic Geol.*, **33**, (2), 45-50.

VERMA, R. K. (1960): Elasticity of some high-density crystals. *Jour. Geophys. Research*, **65**, (2), 757-766.

WILSHIRE, H. G., and BINNS, R. A. (1961): Basic and ultrabasic xenoliths from volcanic rocks of New South Wales. *Jour. Petrology*, **2**, (2), 185-208.

YODER, H. S. Jr., and TILLEY, C. E. (1962): Origin of basalt magmas: An experimental study of natural and synthetic rock systems. *Jour. Petrology*, **3**, (3), 342-532.

YOSHINO, G., and KOJIMA, G. (1953): Geological structure of the Ehime mining district, Ehime prefecture (in Japanese). *Jour. Geol. Soc. Japan*, **59**, (696), 424-434.

YOSHINO, G. (1961): Structural-petrological studies of peridotite and associated rocks of the Higashi-akaishi-yama district, Shikoku, Japan. *Jour. Sci. Hiroshima Univ.*, Ser. C, **3**, (3), 343-402.

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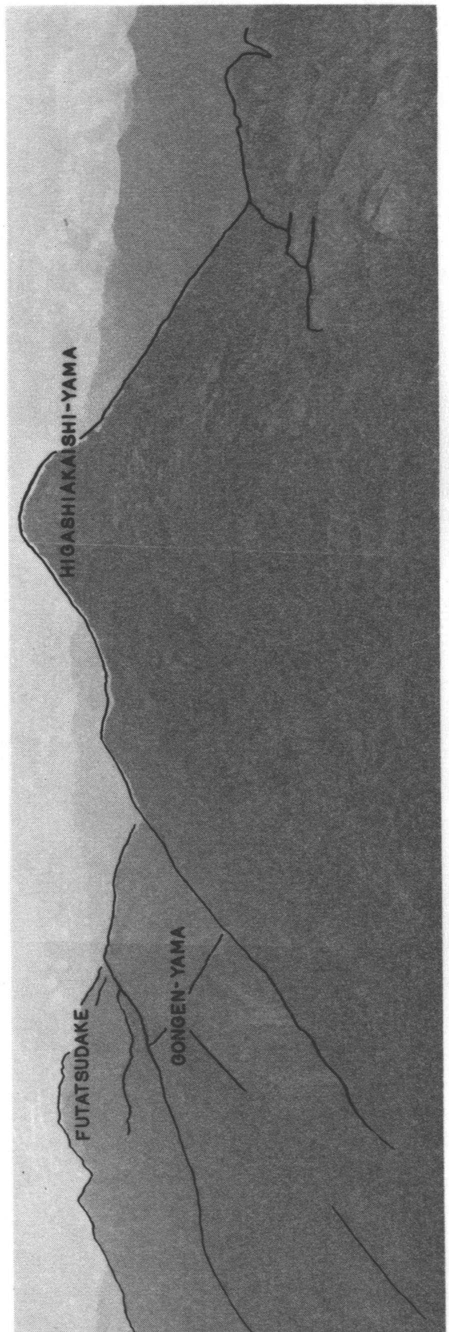
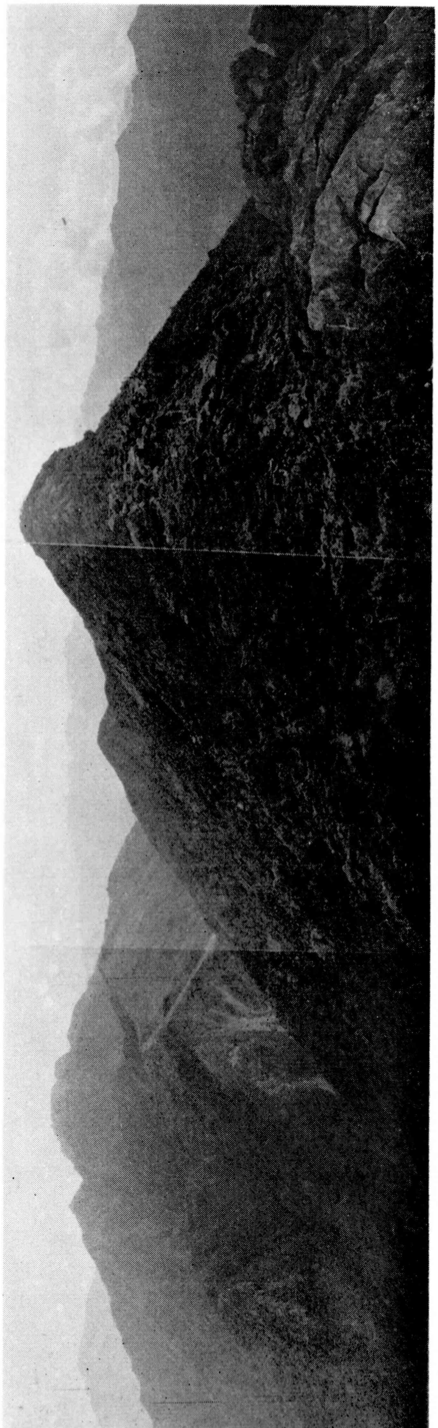


Mt. Higashiakaishiyama. View from west. (Photo by G. YOSHINO.)



Mt. Higashiakaishiyama. View from west. (Photo by G. Yoshino.)

EXPLANATION OF PLATE XXXII

FIG. 1. The upper end of the Gongen-dani valley.
View from west. (Photo by G. YOSHINO.)
Nos. 5, 6, 7, 8, 9, and 30 show localities of rock specimens.

FIG. 2. Lenticular eclogite-body at locality No. 7.

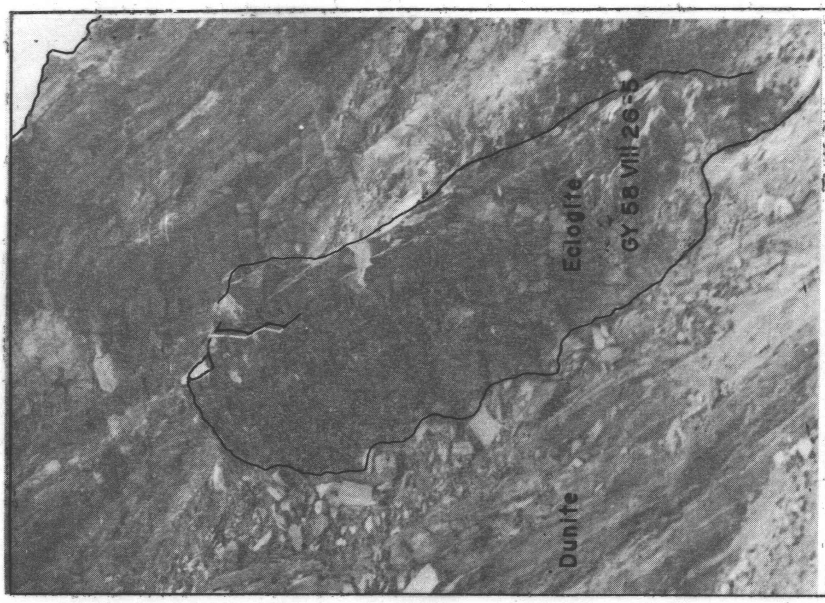


FIG. 2.

FIG. 1.


Fig. 2.

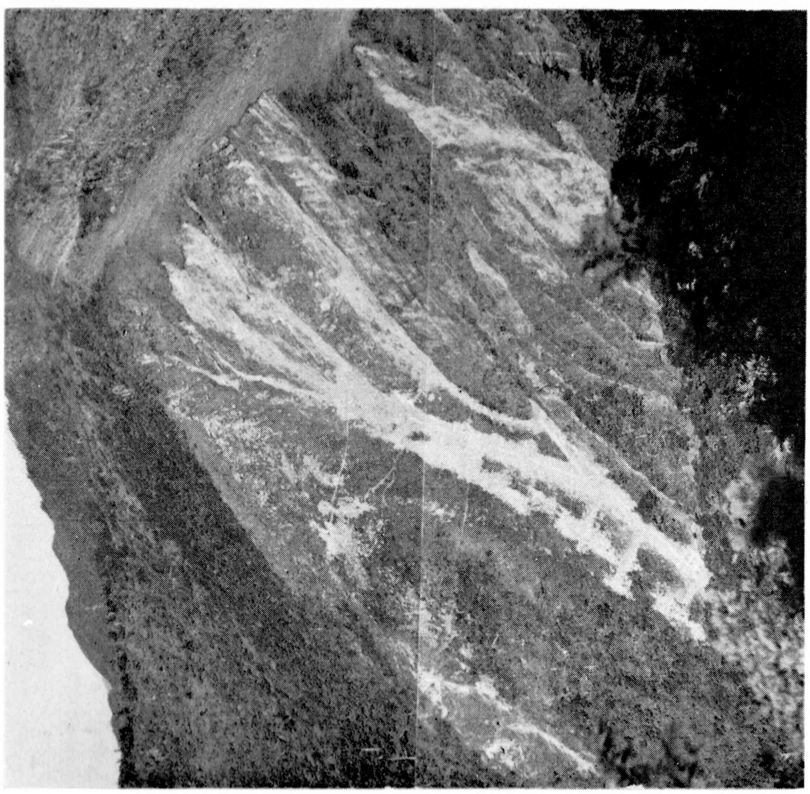


Fig. 1.

Explanation of Plate XXXIII

Fig. 1. Photomicrograph of rod-like opaque inclusions in a black clinopyroxene grain. Thin Section No. GY 59 VIII 18-5; lower nicol only.

Fig. 2. Photomicrograph of massive dunite containing clinopyroxenite-streaks. Thin Section No. GY 58 VIII 26-1; nicols crossed. Upper half illustrates domain C; lower half illustrates domain B.

Fig. 3. Photomicrograph of light-coloured clinopyroxenite. Thin Section No. GY 57 X 24-3; nicols crossed.

Fig. 4. Photomicrograph of epidote-hornblende-clinopyroxene-garnet-rock. Thin Section No. GY 61 X 14-2; nicols crossed.

Fig. 1.

Fig. 2.

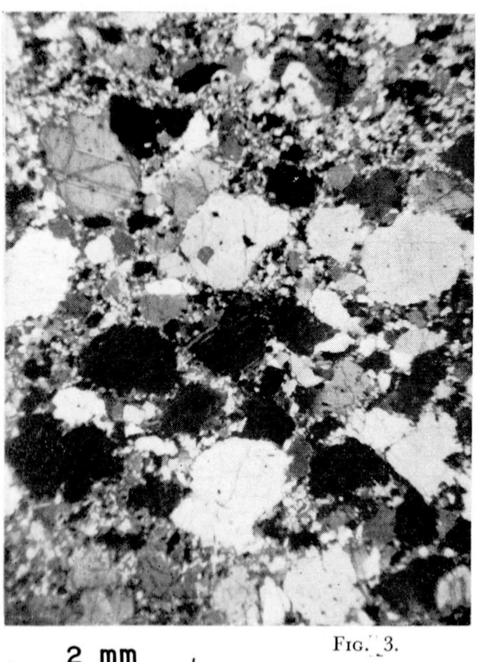


Fig. 3.

Fig. 4.