Abstract

The East Ongul Island on the coast of the Lützow-Holm Bukt, East Antarctica, was investigated from the tectonical and petrographical points of view. The rocks exposed in the island are petrographically classified into the following seven types: 1) Metabasites, 2) Pyroxene gneisses, 3) Hornblende gneisses, 4) Garnet gneisses, 5) Granites, 6) Feldspathic rocks, and 7) Pegmatites.

It is verified that the unique structural feature of the island is represented by the isoclinal fold recumbent to the west with the frontal zone in which many small anticlinal as well as synclinal folds occur. The inner core of the main anticline is generally composed of the garnet gneisses with the pyroxene gneisses forming the outer mantle. The hornblende gneisses, which are distributed in front of the recumbent anticline, occur in the same horizon as the pyroxene gneiss, so the former may have been converted from the latter. This is also confirmed by the geological and petrographical observations. Besides, the hornblende gneiss zone coincides with the zone of granite and subsequent microcline pegmatite emplacement.

The lineation of the rocks, represented by the undulating foliation, is defined to be a *b*-lineation parallel to the fold axis, but another lineation with the same character but perpendicular to the fold axis is also found. The fracture systems indicated by the pegmatite and joint patterns were analyzed by tectonic dating. The pegmatite intruded at the earlier folding stage, whereas the joint pattern was formed at the later upwarping stage.

The gneisses and granites are classified mainly by the characteristic mafic minerals, and their modes of occurrence as well as the optical mineralogy are described. The optical data of the constituent minerals revealed that there is a tendency that the Fe/Mg ratio of the mafic minerals such as pyroxene, hornblende, biotite and garnet, may increase with acidity of the rocks, from the matabasites to the granites. The anorthite content of plagioclase is restricted within a rather narrow range between 22% and 35% when feldspar coexists with potash-feldspar, although that of plagioclase in metabasite and basic enderbitic pyroxene gneiss free from potash-feldspar ranges widely from 42% to 93%. The triclinicity of the potash-feldspar may become higher in the granite than the gneisses judging from the data of their 2V values.

It is probable that the gneisses were formed originally under the condition

of a granulite facies in the regional metamorphism. At the same time, the widespread developement of hornblende and biotite in the metabasites and gneisses suggests subsequent changes in temperature and pressure or the presence of water as well as changes in chemical composition which facilitated the mobilization and plastic deformation of the rocks. It is considered that two phases of metamorphism may be detected in the area; the granulite facies at an earlier phase and the amphibolite facies at a later phase. This has been suggested by the investigations not only in other regions of the East Antarctica but also in other Precambrian shields of the world.

I. INTRODUCTION

Preliminary surveys and investigations of the geology along the Lützow-Holm Bukt Coast including the Ongul Islands were carried out and reported by T. TATSUMI and T. KIKUCHI, members of the first wintering party of the JARE (T. TATSUMI and T. KIKUCHI, 1959). The author was a member of the fourth wintering party in 1960-1961, and explored the southern part of the Lützow-Holm Bukt Coast and the Yamato Sanmyaku (Mountains). He further tried to study in more detail the East Ongul Island as well as the Skarvsnes district.

The East Ongul Island, 2.5 km from north to south, and 2 km from east to west, is surrounded by a few small islands. The island is geomorphologically a rather flat and smooth land mass, about 30 meters above sea level. The highest altitude, 43.3 meters, is found in the central part of the island. The geology and structure of the East Ongul Island were studied and mapped in January, 1961 (K. KIZAKI, 1962). A topographical map on a scale of 1 : 5,000, prepared by the Geographical Survey Institute of Japan, was available as a base for geological mapping.

II. GEOLOGY

On the east coast of Lützow-Holm Bukt, many islands and coastal outcrops occur in an area which extends about 120 km north-south between the Shirase Hyoga (Glacier) and the Ongul Islands. These islands and coastal outcrops consist of many kinds of metamorphic and granitic rocks. Fig. 1 is a geological map of this area. Topographical map is based on the Lars CHRISTENSEN's Expedition, 1936-1937 (HANSEN, 1946). The trend of gneissosity of these rocks varies from place to place, showing no definite direction. Gentle folds are observed in some outcrops.

The rocks exposed in the area along the Lützow-Holm Bukt are classified as follows:

1) Metabasites
2) Marbles and quartzites
3) Pyroxene gneisses
4) Hornblende gneisses
5) Garnet gneisses
6) Granitic gneisses and granites
7) Pegmatites

On the East Ongul Island, all the rock species stated above, except marbles and quartzites, have been observed.

The island is structurally characterized by an isoclinal fold plunging to the south. The mantle of the fold is composed of charnockitic pyroxene gneisses, while the core is mainly occupied by garnet gneisses. Patches of pyroxene gneiss, however, occur at some places in the core. Some sheet-like bodies of garnet gneiss also occur in the pyroxene gneiss in the southeastern part of the island. In the western part of the island, pyroxene gneiss and hornblende gneiss are concordant with each other. Along the west coast, the thickness of these alternating layers is several tens of centimeters. In the areas where alternating hornblende and pyroxene gneiss are dominant, granite sheets and microcline pegmatites usually occur. The small granitic sheets have been concordantly intruded into the hornblende gneisses along the frontal zone of the isoclinal fold. As will be mentioned later, the hornblende gneiss seems to have been derived from pyroxene gneisses. Metabasite bands occur generally as lenses or thin beds in certain horizons, and they are usuful key beds in structural

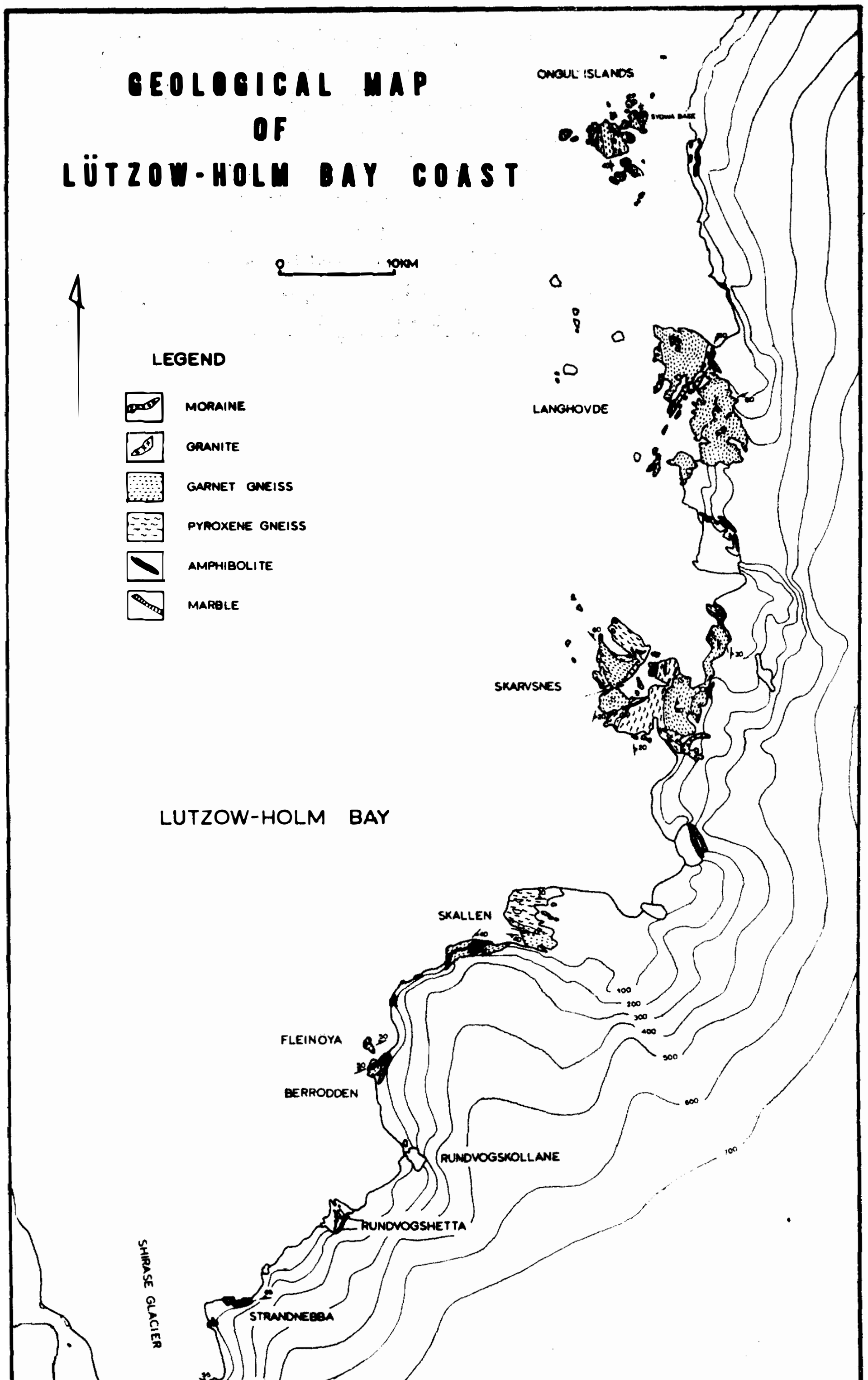
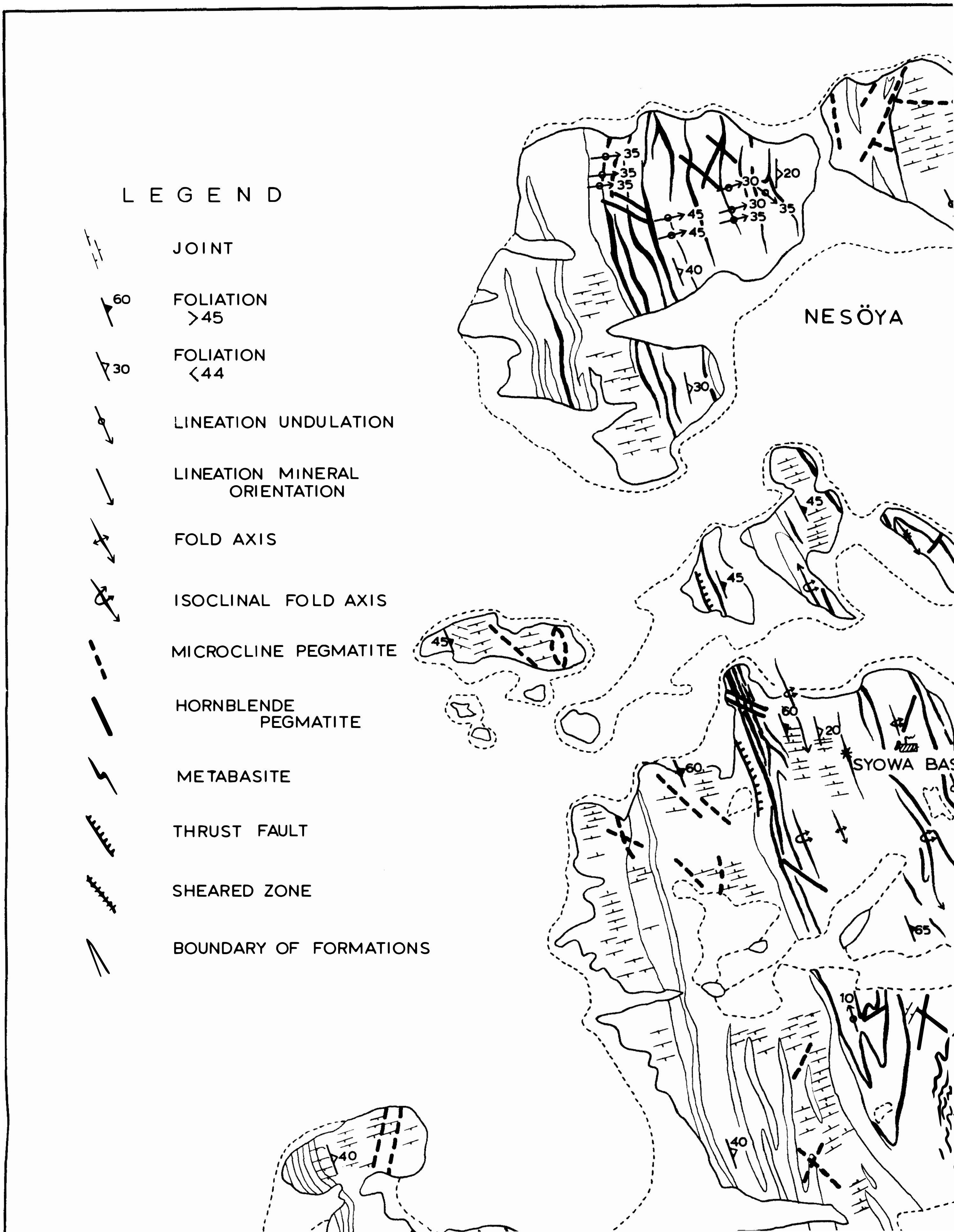


Fig. 1. Geological map of Lützow-Holm Bay Coast. After Tatsumi and Kikuchi (1959), modified by K. Kizaki.

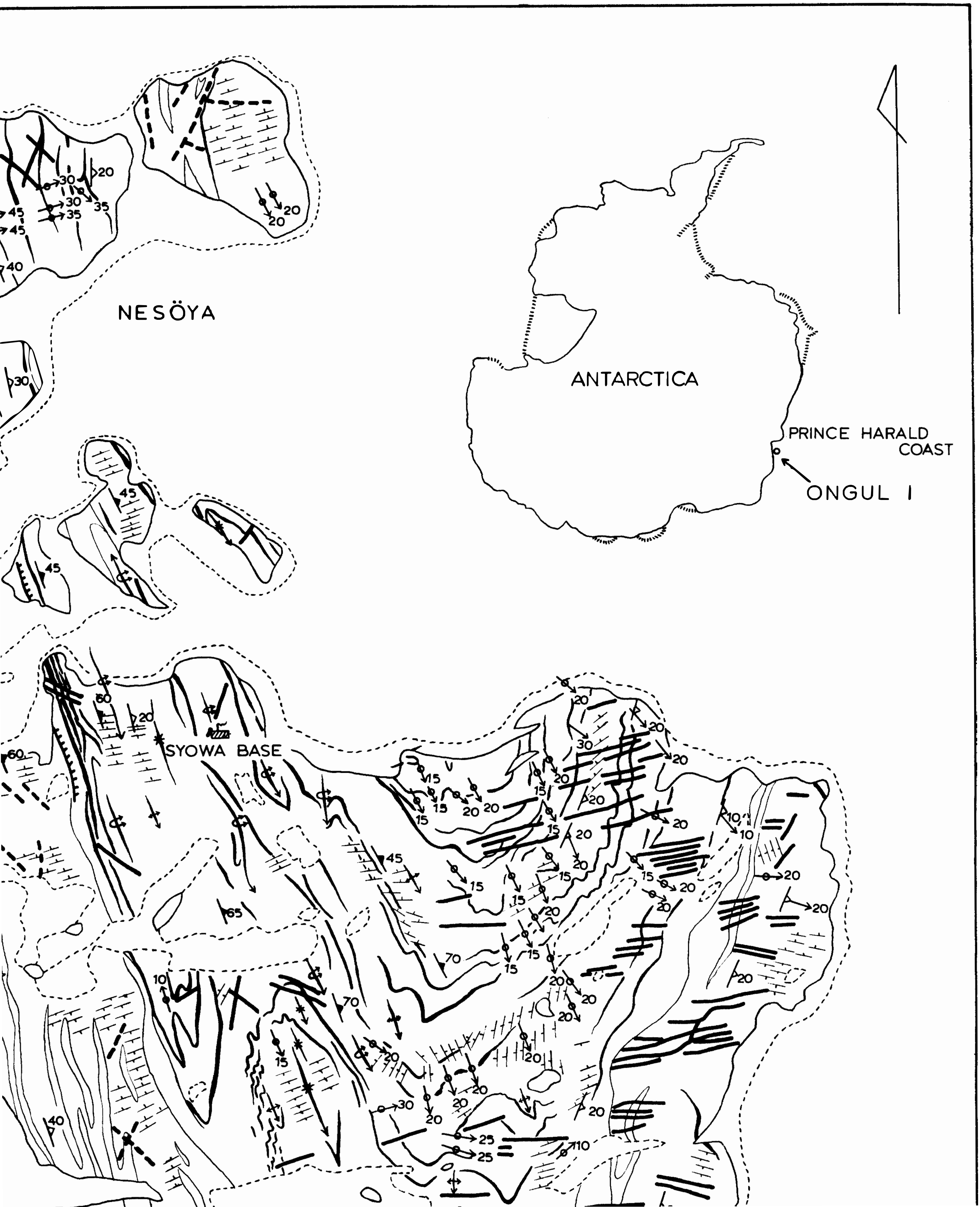
analysis. The gneisses are intruded by numerous pegmatite dikes, which are of two types, microcline pegmatite and hornblende pegmatite. Part of the pyroxene gneiss along dikes of the microcline pegmatites which cut the former is altered to the hornblende gneiss in petrographic characters.

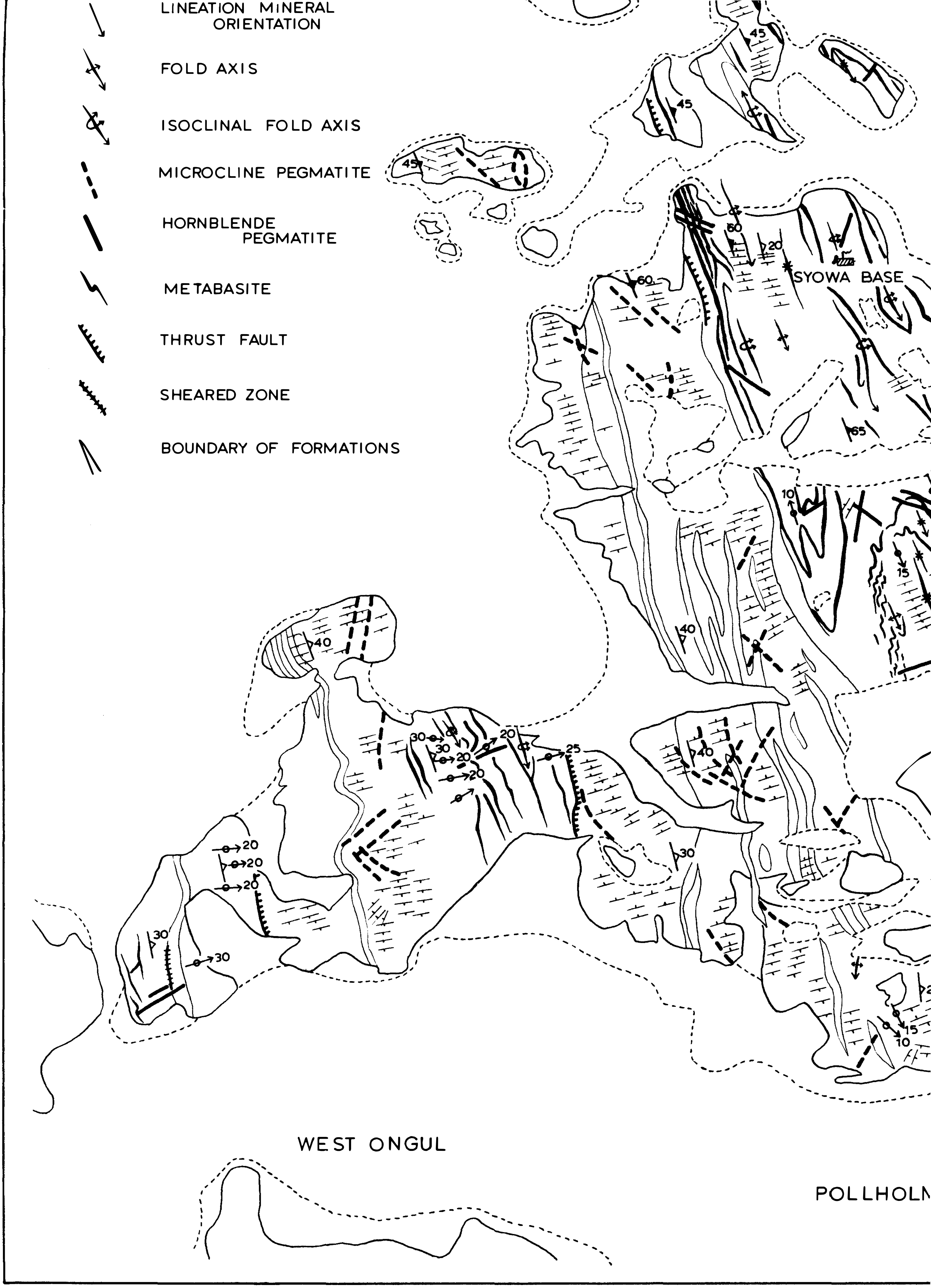
Charnockitic gneisses in Antarctica were originally believed to be Precambrian in age on the basis of the petrographical characteristics. Recently, the absolute age of the rocks from the Lützow-Holm Bukt region was determined as about 4.7×10^8 years (U-Pb method) by SAITO et al. (1961) and as about 4.7×10^8 years (Rb-Sr method) by NICOLAYSON et al. (1961). Thus, the last metamorphic event in the charnockitic gneisses of this region took place in Lower Palaeozoic time.

Fig. 2. TECTONIC MAP OF EAST ON



OF EAST ONGUL ISLAND





LINEATION MINERAL ORIENTATION
FOLD AXIS
ISOCLINAL FOLD AXIS
MICROCLINE PEGMATITE
HORNBLENDE PEGMATITE
METABASITE
THRUST FAULT
SHEARED ZONE
BOUNDARY OF FORMATIONS
SYOWA BASE
WEST ONGUL


PRINCE HARALD COAST
ONGUL I
SYOWA BASE
POLLHOLMEN
0
500M

III. TECTONICS

(Fig. 2)

The most characteristic structural feature of the islands is represented by the isoclinal fold in a zone about 1 km wide and about 6 km long in the eastern part of the island. The northern part of the fold is hidden under the sea.

The average strike of the foliation (gneissosity) and fold axes is approximately N 20°W, and the dip of the foliation ranges from 10°E in the eastern limb of the fold to 40°E in the western limb.

The core of the anticline is generally composed of garnet gneiss which is locally intercalated with pyroxene gneiss. In the eastern and westernmost parts of the island, the pyroxene gneiss is found to constitute the outer mantle of the anticline where the dip of its foliation is very gentle. In the western limb of the fold is found a zone of small scale anticlines and synclines, being composed of garnet gneiss associated with metabasite bands. This 500 m wide zone extends from north to south through the median zone of the island.

A small thrust fault was observed near the western limit of the anticline. The fault dips 50°E, as defined by a shear zone. The amount of displacement is not clear.

The western half of the island is occupied by hornblende gneiss and pyroxene gneiss occurring alternately. They have a gentle easterly dip.

Foliation

The rocks of this area have more or less distinct s-planes. S-planes are defined by the preferred orientation of platy or elongate minerals such as mica and prismatic amphibole, and also by alternating layers of varying mineral compositions, such as mafic-rich and quartzofeldspathic layers. These structures are referred to as foliations. They are pronounced in the hornblende gneiss, especially in the metabasite and its intercalations, whereas they are rather weak or absent in some of the pyroxene gneisses, garnet gneisses and granitic gneisses. Narrow bands of pyroxene-bearing amphibolite showing a conspicuous foliation serve as key horizons for structural analysis, although the foliation itself is contorted asymmetrically in some cases.

The general strike of the foliation is N 20°W, except in the eastern limb of the anticline where it is N 20°E. The dip is about 10-20°E in the eastern limb, and usually 30-40° or rarely as steep as 60° in the western limb.

Lineation

A conspicuous feature of the megascopic fabric is the strong lineation which can be recognized in almost all rocks, but it is most marked in the garnet gneiss constituting the anticlinal core.

The visible lineation is characterized by the following features:

1. The lineation marks the axis of undulations on the foliation plane with 10 to 100 cm wave length, which may be involved in the anticlinal fold of a larger scale.

2. In some garnet gneisses the preferred orientation of mineral grains defines the lineation. The plunge of the lineation is the same as those of the axis of undulations. It is N 20°W, 20°SE in the maximum as seen in Fig. 3.

Fig. 2 shows the orientation of the two kinds of lineations known in the area, and Fig. 3 is an equal area diagram showing the poles of 98 lineations. It can be seen in Fig. 2 that the strike of the lineation is rather uniform in the area of the anticline, regardless of the variations in the strike of foliation or rock species.

The lineation is parallel to the fabric axis and is defined as a B (= *b*) lineation because the maxima of the poles of the lineation in Fig. 3 coincide with those of the axes of the folds in Fig. 4. However, in the western area where the frontal part of the recumbent anticline is located, the strike of the lineation changes to the east as represented as a submaximum in Fig. 3, and is oriented at right angle to the *b*-axis. Then, there are two types of lineation; *b*-lineation perpendicular to the direction of tectonic transport, and *a*-lineation parallel to the direction of transport. These two lineations, however, both present uniform undulations.

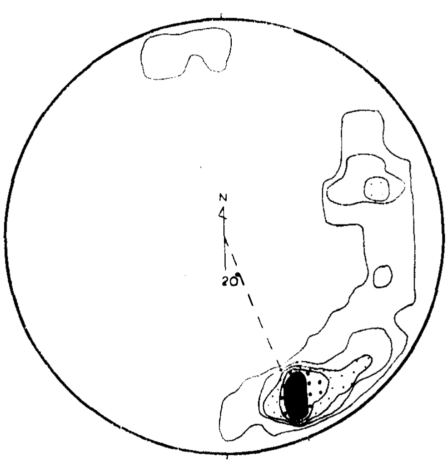


Fig. 3. 98 lineations measured in the whole area, the maximum coincides with that of the fold and the submaximum normal to the fold axis: contours 5-10-15-20, max. 22 per cent per 1 per cent area.

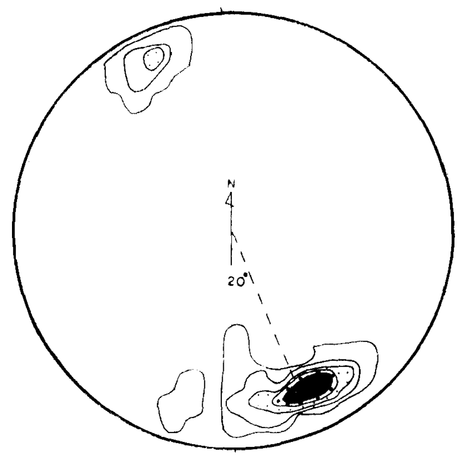


Fig. 4. 39 fold axes measured in the whole area: contours 5-10-15-20, max. 28 per cent per 1 per cent area.

For a long time, the relationship between lineation and tectonic transport was the subject of discussion among many investigators (e. g. E. CLOOS, 1946, etc.). In the present case without more precise investigations, it is uncertain whether the lineations of different directions have resulted from a triclinic deformation related to the tectonic transport or they are due to superposition of lineations in which an older lineation has been reoriented by subsequent deformation.

Folds

The isoclinal fold in the main part of the island is a unique structural feature of the area surveyed. The main fold associated with smaller ones plunges to the south, and the northern limb may plunge to the north on the Nesöya Island, although the northern half of the fold is beneath the sea. This fold seems to be a structural unit, lenticular in shape, and is possibly an elongated dome (BERTHELSEN, 1950).

Many small anticlinal and synclinal folds have been identified. They are recognized in the frontal zone, 500 m wide, of the isoclinal recumbent fold. Fig. 4 is an equiareal projection of 39 fold axes. On the basis of data collected chiefly from the southern half of the main fold, it has been revealed that dominant strike of the fold axes is N 20°W, and that most of the axes plunge to the south.

Conspicuous drag folds have been identified in the inner core of the main fold. They are manifested especially in the metabasite bands within the garnet gneiss. It is clear that the drag folds were formed by shear dislocation during the folding.

The western limb of the fold structure is truncated by a thrust fault which becomes indistinct toward the south, probably due to its small scale.

Joints

Joints observed in the area are divided into two systems, one in the inner core of the fold and the other in the outer mantle.

Fig. 5*a* is a strike frequency diagram of 120 joints measured within the inner core of the fold. The majority of joint planes are parallel or subparallel to the structural axis *c*, showing a pair of (*hko*) joints in the inner core of the fold. Moreover, the strike of the joint acutely intersects the fold axis toward the southern

Fig. 5. Strike frequency of joints.
a. Inner core of the main fold showing shear joint.
b. Outer mantle of the fold showing tension joint.

limb. Most of the *(hko)* joinis have been diagnosed as shear joints. It seems evident that the joints under consideration were produced by shearing, subsequent to the folding caused by the main stress normal to the fold axis.

The *ac* joint perpendicular or subperpendicular to the fold axis is the commonest joint in the outer mantle area, as Fig. 5*b* shows. In the hornblende gneiss, the joints are markedly developed in every exposure. They are comparatively planar and open, and show all characteristics of tension fracture, though their length is shorter than the other joint sets. Their apparent length ranges from 50 to 100 cm.

The *ac* joint occurs not only in the hornblende gneiss but also in the pyroxene gneiss that constitutes the outer mantle, whereas the garnet gneiss in the inner core of the fold has *(hko)* joint. It is worthy of note that tensional stretching through the outer mantle has produced the *ac* joint, while the *(hko)* joint caused by shearing predominates in the inner core, having been formed during the later stage of folding characterized by upwarping.

Pegmatites

Pegmatites are distributed all over the area, especially in the eastern part where pegmatite swarms are found. Pegmatites of this area comprise two types as defined by mineral composition; (1) hornblende pegmatites in the eastern half of the island, and (2) microcline pegmatites in the western part.

Like the joint sets, the gegmatites can be divided structurally into two systems. Axial stretching through the fold axis produced the pegmatite pattern parallel or subparallel to *ac* joint in the eastern limb. Conversely, the western part of the island, including the central folded zone which has many small scale folds, is distinctly a compressional area. Therefore, the shear pattern will be represented by many sets of microcline pegmatites over the area (Fig. 2).

There is a conspicuous overlap of the distribution of shear and tension patterns, as indicated by the joint and the pegmatite sets. The *ac* pegmatites are developed even in the inner core of the fold where only shear joints occur, and the shear pegmatites occur in the western part of the island where *ac* joints predominate.

For an explanation of this overlap, dating of the sequence is required. According to field observations, the pegmatites are traversed by subsequent joints and are slightly folded in some localities. The difference between the pegmatite and joint patterns may be ascribed to the different types of tectonic style which characterized deformational events.

Pegmatites were intruded when the direction of tectonic transport was east-west, i. e., normal to the fold axis, and the movement culminated in an earlier stage. They were controlled by the axial tension in the eastern limb of the fold, independent of the compressional shearing (flattening) in the western part of the frontal zone and the adjacent area. Subsequent upwarping of the inner core of the fold has produced the joint pattern described above.

Structural development

The East Ongul Island is composed of a unique structural unit, a lenticular recumbent fold associated with small folds in its frontal zone. The folding appears to have occurred as a result of compression from east to west. The underlying garnet gneiss, which was upwarped, constitutes the inner core of the fold. The hornblende gneiss is distributed in the adjacent frontal zone of the fold, and is characterized by the intrusion of granitic sheets and microcline pegmatites. Granitization which converted pyroxene gneiss into hornblende gneiss had presumably accelerated the compressional stress, as suggested by tne pegmatite emplacement pattern and the intrusion of granite. The folded zone was intruded by the hornblende pegmatite at the same time. The subsequent upwarping of the fold, during a period of less pronounced horizontal stress, seems to have formed the joint systems and the small scale thrust fault (Fig. 6).

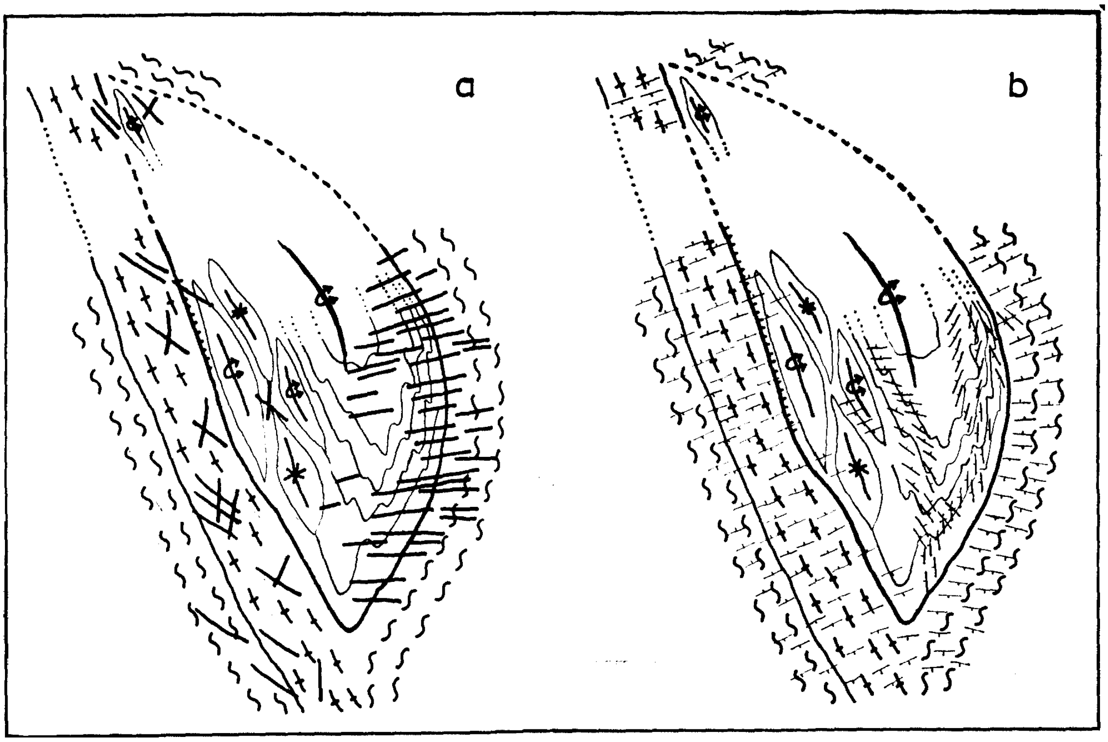


Fig. 6. Schematic sketch of evolution of fracture system represented by pegmatites and joints. a. Folding stage with pegmatite intrusion. b. Upwarping stage with jointing.

IV. PETROGRAPHY

(Fig. 7)

The rocks in the East Ongul island are classified petrographically into the following seven types:

a) Metabasites
b) Pyroxene gneisses
c) Hornblende gneisses
d) Garnet gneisses
e) Granites
f) Feldspathic bands
g) Pegmatites

Tables 1-5 give modal analyses of the rocks and petrographic characters of their constituents.

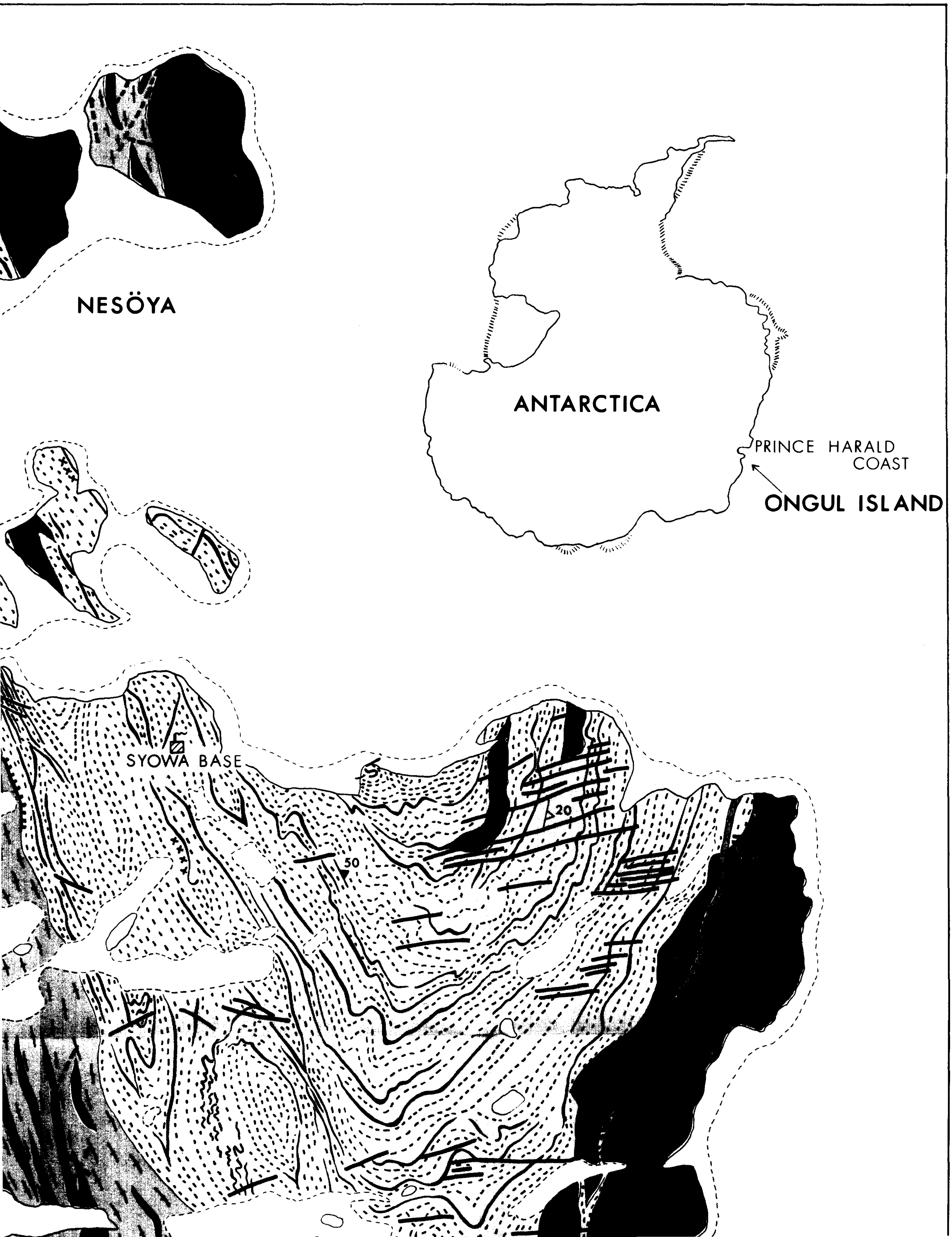
Table 1. Modal analysis of the rocks.

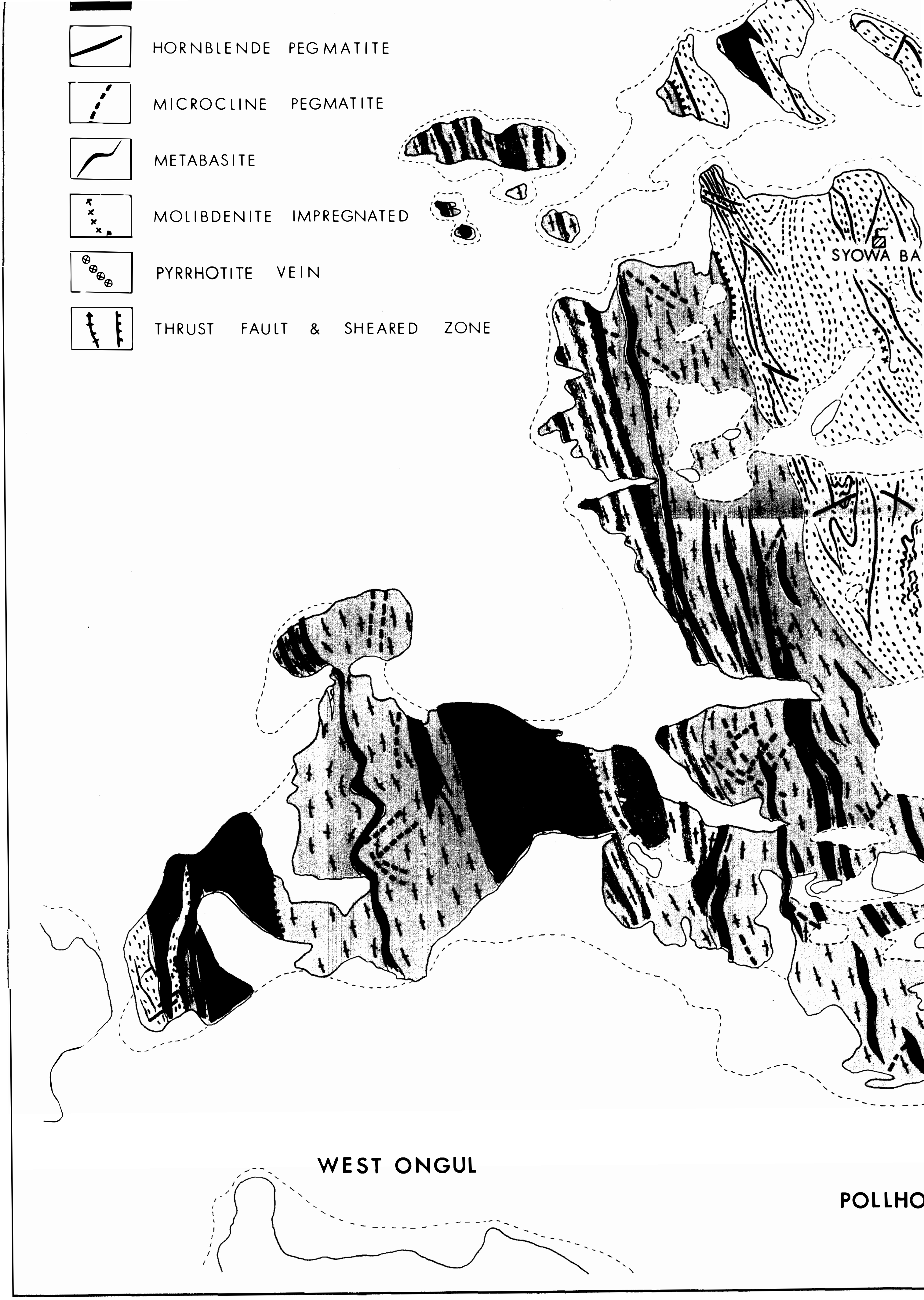
a.

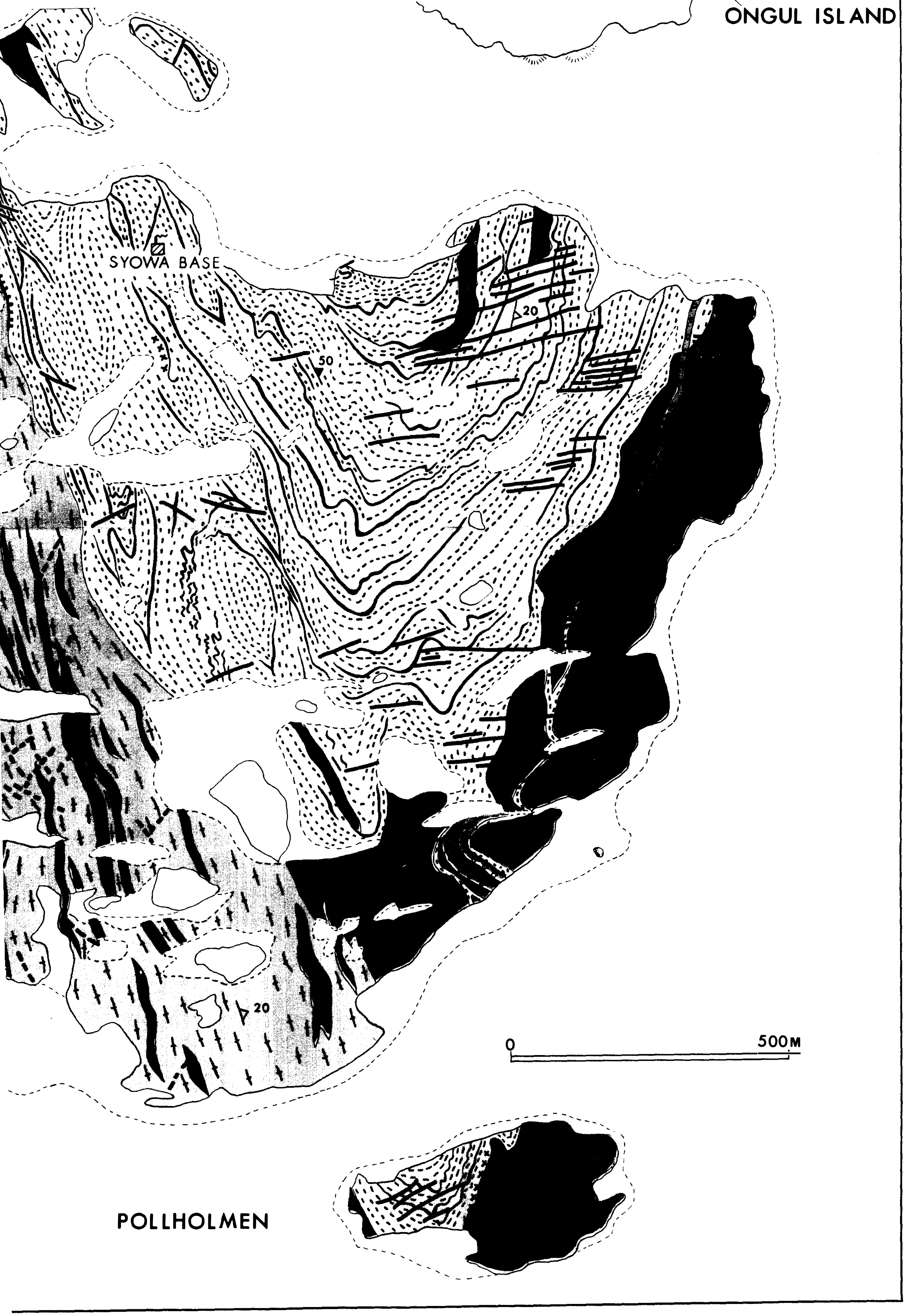
Rock type	Pyroxenite	Pyroxene amphibolite
Sample number	0-1204	60030901
Olivine	1.6	—
Hypersthene	12.8	2.9
Diopside	64.6	17.5
Hornblende	20.5	34.9
Biotite	0.5	6.8
Plagioclase	—	37.9

Fig. 7. GEOLOGICAL MAP OF EAST

P OF EAST ONGUL ISLAND




HORNBLENDE PEGMATITE
MICROCLINE PEGMATITE
METABASITE
MOLIBDENITE IMPREGNATED
PYRRHOTITE VEIN
THRUST FAULT & SHEARED ZONE
SYOWA BA
WEST ONGUL
POLLHO


ONGUL ISLAND
SYOWA BASE
20
50
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POLLHOLMEN

b.

Rock type	Basic enderbitic pyroxene gneiss	Charnockitic pyroxene gneiss	
Sample number	0–0156	0–1216	0–1230
Quartz	—	26.4	44.4
Potashfeldspar	—	17.0	29.5
Plagioclase	54.5	44.0	10.4
Hypersthene	8.2	6.7	0.3
Diopside	3.8	3.4	1.4
Hornblende	29.7	0.4	12.5
Biotite	3.9	0.8	0.9
Myrmekite	—	0.1	0.2

c.

Rock type	Garnet gneiss				
Sample number	60030703	0–0163	60030705	0–0161	0–1201
Quartz	36.5	55.4	46.3	38.6	36.5
Potashfeldspar	35.3	31.5	26.9	35.4	48.5
Plagioclase	12.2	4.9	8.6	11.8	8.6
Garnet	—	1.9	14.4	8.0	—
Diopside	4.7	—	—	—	—
Hornblende	—	—	—	0.6	0.3
Biotite	10.9	5.0	0.1	0.1	3.6
Myrmekite	0.3	0.1	0.5	1.1	1.0
Others	0.2	1.2	3.0	4.5	—

d.

Rock type	Hornblende gneiss			
Sample number	0–1227	0–1225	0–0160	0–1224
Quartz	24.9	49.6	37.7	58.6
Potashfeldspar	44.6	32.2	26.5	29.3
Plagioclase	10.1	5.4	17.4	1.8
Hornblende	16.0	9.6	16.0	4.9
Biotite	2.3	1.7	1.0	1.5
Myrmekite	0.3	—	0.2	0.4
Others	1.8	2.5	1.4	3.6

e.

Rock type	Granitic gneiss		Hornblende granite	
Sample number	0–1202	0–0149	0–0159	0–0145
Quartz	32. 1	35. 2	40. 0	30. 9
Potashfeldspar	49. 5	42. 7	50. 4	50. 4
Plagioclase	13. 7	9. 7	3. 7	5. 4
Hornblende	—	4. 6	2. 5	11. 2
Biotite	1. 1	—	1. 0	. 2
Garnet	—	5. 7	—	—
Myrmekite	1. 1	0. 8	0. 5	0. 3
Others	2. 5	1. 4	2. 0	1. 7

a) ***Metabasites***

Metabasites occur as thin beds, lenses or irregular-shaped inclusions of various sizes within all varieties of gneisses. They are generally massive, but sometimes show a gneissose structure. They are fine-to medium-grained and black or dark-bluish black in color. The metabasites are mainly pyroxene amphibolite. The rocks are divided into the following subspecies by their mineral assemblages; pyroxene amphibolites, pyroxenite and garnet-bearing pyroxene amphibolite.

1) Pyroxene amphibolite. This is the most abundant metabasite in this area. It is composed mainly of hornblende, diopside, hypersthene and plagioclase, with a minor amount of pale brown biotite.

2) Pyroxenite. A pyroxene-rich and plagioclase-free variety of pyroxene amphibolite occurs as basic ovoidal inclusions, generally in the pyroxene gneiss zone of the eastern coast of the island. The rock is composed of rhombic pyroxene, diopside, hornblende, olivine and biotite.

3) Garnet-bearing pyroxene amphibolite. The rock occurs only locally. Main constituents are hornblende and garnet in the garnet gneiss zone, but pyroxene and garnet are predominant in the pyroxene gneiss zone (Table 2).

b) ***Pyroxene gneisses***

Pyroxene gneisses are exprosed on the eastern and the western sides of the island. They constitute the mantle of the anticline. In the western half of the island, these gneisses occur as alternations with hornblende gneiss, which are sometimes several tens of centimeters thick. In the area of garnet gneiss, the contact between the pyroxene gneiss and garnet gneiss is generally transitional. The rock has a medium- to fine-grained granoblastic texture, and generally shows a weak gneissosity. The rock is characterized by its light brown color, which is due to the presence of brown colored feldspars and quartz crystals.

The pyroxene gneisses are divided into the following subspecies: basic enderbitic pyroxene gneiss, charnockitic pyroxene gneiss and garnet-bearing enderbitic pyroxene gneiss.

Table 2. Petrographic properties of constituents of n

	Olivine	Pyroxene		Amphibole
		Monoclinic	Rhombic	
Pyroxene amphibolite	none	Diopside round grain 0.5 mm in diameter faintly pleochronic, pale grain or almost colorless $2Vz=56°-53°$, $\widehat{CZ}=45°-43°$	Hypersthene round grain 0.5 mm in diameter $2Vx=63°-56°$ $Nz=1.711$	Hornblende anhedral strongly pleochroic X-pale br. green Y-pale brown Z-brown, sometimes reddish brown $2Vx=88°$, $\widehat{CZ}=19°$ $Nz=1.682$ alters to brown biotite
Pyroxenite	Olivine round grain 0.3 mm in size $2Vx=87°$ $Ny=1.698$	Diopside, 0.5–1.0 mm in size sometimes poikilitic $2Vz=56°-50°$ $\widehat{CZ}=43°-38°$	Hypersthene, 0.5–1.0 mm in size $2Vx=84°-56°$ $Nz=1.699$ (Enstatite $2Vz=90°-76°$)	Hornblende anhedral rounded grain 0.5 mm in diameter pleochroic X-pale grn. yellow Y-pale yellow Z-pale grn. brown $2Vz=85°-76°$ $\widehat{CZ}=17°$ $Nz=1.676$ $Nx=1.646$
Garnet-bearing pyroxene amphibolite	none	Diopside, 0.5–1.0 mm in size poikilitic $2Vz=56°-50°$ $\widehat{Cz}=40°-34°$ $Nz=1.710$ alters to h'bl	Hypersthene, 0.5–1.0 mm in size round grain $2Vx=58°-47°$ $Nz=1.712$ alters to h'bl	Brown hornblende anhedral, 2–3 mm in size occasionally shows bluish green tint $2Vx=80°-72°$ $\widehat{CZ}=12°-3°$ $Nz=1.684$, $Nx=1.66$

rographic properties of constituents of metabasites.

	Amphibole	Mica	Garnet	Feldspar
	Hornblende anhedral strongly pleochroic X-pale br. green Y-pale brown Z-brown, sometimes reddish brown 2Vx=88°, $C\wedge Z$=19° Nz=1.682 alters to brown biotite	Biotite 0.5–1.0 mm in size strongly pleochroic X-colorless Y-pale grn. brown Z-light brown Nz=1.619	none	Plagioclase anhedral shows twinning & zonal structure An42 for porphyroblastic one An93 for intergranular one An57 (margin) to An90 (core) for zoned one
mm 76°)	Hornblende anhedral rounded grain 0.5 mm in diameter pleochroic X-pale grn. yellow Y-pale yellow Z-pale grn. brown 2Vz=85°–76° $C\wedge Z$=17° Nz=1.676 Nx=1.646	Biotite strongly pleochroic X-colorless Y-pale red. brown Z-light red. brown	none	none
mm	Brown hornblende anhedral, 2–3 mm in size occasionally shows bluish green tint 2Vx=80°–72° $C\wedge Z$=12°–3° Nz=1.684, Nx=1.663	Biotite alteration product from h'bl	Pinkish garnet porphyroblastic 3.0 mm in size N=1.787 G=3.98	Plagioclase anhedral shows twinning & zonal structure An54–71 An55 (margin) to An67 (core) for zoned one

Table 3. Petrographic properties of constituents of pyroxen

	Pyroxene		Amphibole	Mica	
	Monoclinic	Phombic			
Basic enderbitic pyroxene gneiss	none	Hypersthene most abundant anhedral rounded 0.5 mm in average of 1.5 mm in max. scattered in porphyro- brastic plagioclase 2Vx=77°–70° (fresh) 60°–55° (altered) Nz=1.697 (fresh)	Hornblende anhedral X-pale yellow Y-pale grn. yellow Z-pale grn. brown 2Vx=86°–76° $\widehat{CZ}$=23°–15° Nz=1.687	Biotite 2.0 mm in length X-pale yellow Y-pale yel. brown Z-yellow ochre Nz=1.615	
Charnockitic pyroxene gneiss	Diopside small in amount	Hypersthene alters to chlorite carbonates & sericite along cleavages or margin	Hornblende X-pale grn. yellow Y-pale green Z-brownish green 2Vx=64°–60° $\widehat{CZ}$=17°–9°	Biotite small in amount	
Garnet-bearing enderbitic pyroxene gneiss	Diopside 2Vz=61°–44° $\widehat{CZ}$=44°–31° Nz=1.712 alters to brown h'bl &/or biotite	Hypersthene 2Vx=54°–50° Nz=1.714 alters to br. h'bl or/& biotite	Hornblende anhedral 1.0 mm in max. X-pale grn. yellow Y-greenish brown Y-brown 2Vx=72°–67° $\widehat{CZ}$=17°–11° Nz=1.708	Biotite 1.5 mm in length less abundant X-pale yel. brown Y-pale brown Z-reddish brown Nz=1.662	Garne porph 1.0 mr N=1.7

raphic properties of constituents of pyroxene gneisses.

Mica	Garnet	Feldspar	Others
Biotite 2.0 mm in length X-pale yellow Y-pale yel. brown Z-yellow ochre Nz=1.615	none	Plagioclase most abundant anhedral, 3.0 mm in max. has polysynthetic twins and zonal structure An52 (average) 53 (margin) to 78–86 (core) or 58 (core) to 78 (margin)	
Biotite small in amount	none	K-feldspar may be orth. with hair perthite, but no cross hetches Plagioclase 2.0 mm in max. has polysynthetic twins and antiperthetic texture, but no zoned structure An27–38%	Quartz main constituent 2.0 mm in max. Scapolite Apatite Zircon
Biotite 1.5 mm in length less abundant X-pale yel. brown Y-pale brown Z-reddish brown Nz=1.662	Garnet porphyroblastic 1.0 mm in diameter N=1.787	Plagioclase polysynthetic twin antiperthetic An50-65	

Table 4. Petrographic properties of constituents of hornblende gneiss and garnet gn

	Pyroxene	Amphibole	Mica	Garnet	
Hornblende gneiss	Pyroxene occurs as relict mineral	Hornblende anhedral, 3.0 mm in max. X-pale yellow ochre Y-greenish yel. ochre Z-yellow green $2V_x=64°-40°$ $\widehat{CZ}=24°-5°$ $N_z=1.705-1.712$ $N_x=1.698-1.696$ some show pseudomorph after pyroxene	none	none	K-felds 3.0 mm charact perthite sometin 2Vx=5 68° i may be with a of micr Plagiocl max. p An22-3
Garnet gneiss	Hypersthene occurs as relict mineral alter to sericite, carbonates, chlorite	none	Biotite 0.5 mm in length 3.0 mm in max. X-pale br. yellow Y-pale brown Z-dark red. brown $N_z=1.677$	Garnet 3.0 mm in max. porphyroblastic $N=1.803$	K-felds 1.5 mm charact hair-pe sometin twin. 2Vx=5 Plagiocl 1.0 mm anhedra polysya antipert An28-3

Table 4. Petrographic properties of constituents of hornblende gneiss and garnet gneiss.

hibole	Mica	Garnet	Feldspar	Others
mm in max. v ochre el. ochre en 12 596 seudomorph ne	none	none	K-feldspar 3.0 mm in max. characterized by perthite structure sometimes show micr. twin. 2Vx=58°–68°, 68° in average may be orth. mixing with a small amount of micr. Plagioclase 1.0 mm in max. polysynthetic twin. An22–30%	Quartz 1.5 mm in size Myrmekite Scapolite occurs generally near boundary between pyr. gn. & h'bl gn. Anhedral No=1.561 Ne=1.547
ne	Biotite 0.5 mm in length 3.0 mm in max. X-pale br. yellow Y-pale brown Z-dark red. brown Nz=1.677	Garnet 3.0 mm in max. porphyroblastic N=1.803	K-feldspar 1.5 mm in max. characterized by hair-perthite sometimes show micr. twin. 2Vx=58°–72° Plagioclase 1.0 mm in max. anhedral polysyathetic & antiperthite An28–34%	Quartz 2.0 mm in max.

Table 5. Petrographic properties of constituents of granites.

		Amphibole	Mica	Garnet	Feldspar	Q
Granites	Hornblende granite	Hornblende anhedral 1.0 mm in length X-pale br. green Y-brownish green Z-dark green 2Vx-56°-48° $\widehat{CV}=29^\circ-0^\circ$ Nz=1.722 Nx=1.698	Biotite minor amount	none	K-feldspar 4.0 mm in max. microcline perthite 2Vx=62°-86° Plagioclase polysynthetic twin antiperthite An23%	Fresh 1.0 mm i
	Garnet-bearing hornblende granite	Hornblende partially alter to biotite X-pale gr. brown Y-brownish green Z-dark green	Biotite minor amount	Garnet 4.0 mm in max. porphyroblastic	K-feldspar 1.5 mm in size microcline perthite 2Vx=56°-68° Plagioclase 1.0 mm in size polysynthetic twin An26%	Fresh 2.0 mm i
	Biotite granite	Hornblende	Biotite reddish brown	none	K-feldspar Plagioclase	Quartz
Feldspathic band		Hornblende gr. brown 2Vx=75°-71° $\widehat{CZ}=18^\circ-7^\circ$ some show pseudomorph after pyroxene	Biotite 2.0 mm in size X-pale brown Y≒Z=reddish brown Muscovite	none	Plagioclase 5.0 mm in max. polysynthetic twin antiperthite An 37-57% An57 (core) to An45 (margin) for zoned one	Quartz rarely fo

Table 5. Petrographic properties of constituents of granites.

	Garnet	Feldspar	Quartz	Others
	none	K-feldspar 4.0 mm in max. microcline perthite 2Vx=62°-86° Plagioclase polysynthetic twin antiperthite An23%	Fresh 1.0 mm in size	Scapolite rarely found Apatite Zircon Opaque mins.
	Garnet 4.0 mm in max. porphyroblastic	K-feldspar 1.5 mm in size microcline perthite 2Vx=56°-68° Plagioclase 1.0 mm in size polysynthetic twin An26%	Fresh 2.0 mm in max	Apatite Zircon Opaque mins.
	none	K-feldspar Plagioclase	Quartz	* Biotite rich variety of hornblende granite
brown	none	Plagioclase 5.0 mm in max. polysynthetic twin antiperthite An 37-57% An57 (core) to An45 (margin) for zoned one	Quartz rarely found	Carbonate Apatite

1) Basic enderbitic pyroxene gneisses. The rock is usually associated with amphibolites, so it may be a variety of metabasite. The rocks are composed of plagioclase, hypersthene, biotite and hornblende.

2) Charnockitic pyroxene gneiss. The rock is characterized by potash-feldspar and quartz, in addition to the mineral assemblage of basic enderbitic pyroxene gneiss, though the mineral composition is somewhat variable.

3) Garnet-bearing enderbitic pyroxene gneiss. This rock is found near the boundary between the pyroxene gneisses and the garnet gneisses. The rock is gneissose and composed of plagioclase, quartz, hypersthene, diopside and garnet with minor amounts of hornblende, biotite, titanite, apatite and opaque minerals.

In some cases, plagioclase occurs as scattered porphyroblasts of 2-3 cm in diameter, or as a main constituent, in the feldspathized pyroxene gneiss on the eastern side of the island. The brownish grey feldspathized rocks are composed mainly of potash-feldspar, quartz and plagioclase. Potash-feldspar with hair-perthite is in part microcline-twinned. Plagioclase with distinct twinning includes antiperthite exsolution patches. Aggregates of carbonate, sericite and biotite represent pseudomorphs of altered hypersthene. Feldspathization may be responsible for the formation of feldspath-rich bands (Fig. 7 and Table 3).

c) *Hornblende gneisses*

The hornblende gneisses occur only in the western half of the island, especially in the frontal zone of the recumbent anticline. The thin layers of pyroxene gneiss are interlayered with hornblende gneiss. From a tectonic point of view, hornblende gneiss may have played the same role as did the pyroxene gneiss. The stratigraphic horizon of the hornblende gneiss in the frontal zone is similar to that of the pyroxene gneiss in the mantle zone. The hornblende gneiss represents the granitized equivalent of the pyroxene gneiss. The hornblende gneiss derived from the pyroxene gneiss is also found near the contact of pyroxene gneiss with pink microcline pegmatite (Fig. 8).

The hornblende gneisses are medium-grained and brownish grey to pinkish grey in appearnce, showing a weak gneissosity and granular texture. The gneisses are subdivided into hornblende gneiss and scapolite-bearing hornblende gneiss.

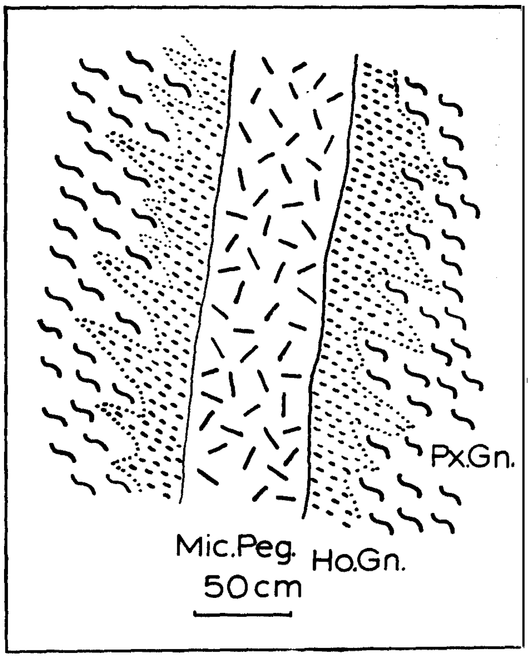

Fig. 8. Pyroxene gneiss grading into hornblende gneiss at the boundary with microcline pegmatite.

The hornblende gneiss is composed of potash-feldspar, plagioclase, quartz and hornblende. Biotite, sericite, carbonate, apatite, allanite, zoisite, chlorite, zircon and opaque minerals are accessories. Some of the hornblende may by pseudomorphous after pyroxene, which is occasionally observed as decomposed relicts. Scapolite occurs generally near the boundary between pyroxene and hornblende gneisses. It is typically anhedral, and occurs as grains up to 1 mm in maximum diameter (Table 4).

d) ***Garnet gneisses***

The garnet gneisses are found mainly in the core of the anticline. Thin layers of garnet gneiss also occur in the pyroxene gneiss along the coast of the island and in the western peninsula. The rock is medium- to fine-grained, and is usually white to grey in color. Gneissose structure is generally conspicuous, and banded structure due to the alternation of biotite-rich and leucocratic layers is occasionally present. These gneisses grade into pyroxene gneiss in rather short distances without a distinct boundary. Irregular patches of pyroxene gneiss are found in the garnet gneiss (Fig. 7), and elongate blocks up to 1 meter or so in longer diameter are also randomly distributed in the garnet gneiss (Fig.9). As seen in conspicuous drag folds, the garnet gneiss has been much more plastically deformed than the pyroxene gneiss, and appears to have become highly mobile. Consequently the pyroxene gneiss included in the garnet gneiss has been boudinaged or lensed out. It is probable that some garnet gneisses have been metasomatically derived from the pyroxene gneisses.

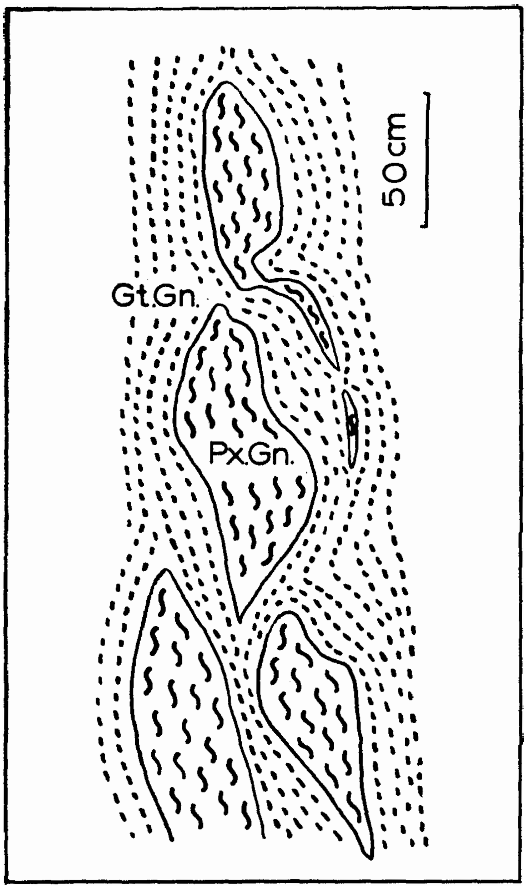

Fig. 9. Pyroxene gneiss blocks in garnet gneiss

The garnet gneiss has a granoblastic equigranular texture, and is composed of potash-feldspar, quartz, plagioclase, garnet and biotite. Accessory minerals are zircon, apatite, and secondary zoisite, carbonate, sericite and chlorite (Table 4).

e) ***Granites***

The granitic rocks have been emplaced as small concordant sheets and lenses in the gneisses, especially in the hornblende gneiss of the frontal zone of the anticline. At the contact between the granite sheet and the hornblende gneiss, pink potash-feldspar porphyroblasts have developed in the hornblende gneiss, and alternation of the pink granitic and hornblende-rich layers forms banded gneisses, which are gradationally homogenized to granitic rocks. Sometimes, the granite includes small lenses of hornblende gneiss as palaeosome.

The granite is pink-colored. medium-grained and usually massive, but occasionally it has a gneissose structure. The rock is composed mainly of potash-feldspar, quartz and plagioclase and is subdivided by the kind of characteristic minerals as follows: Hornblende granite, garnet-bearing hornblende granite and biotite granite.

1) Hornblende granite. The granite occurs in the hornblende gneiss zone, and is characterized by green hornblende.

2) Garnet-bearing hornblende granite. The rock occurs near the boundary between the granite and the hornblende gneiss, within the area where the garnet gneisses occur. The rock is medium-grained, and shows a weak gneissosity.

3) Biotite gneiss. The rock is a variety of the granite described above. The rock is characterized by the presence of reddish-brown biotite (Table 5).

f) *Feldspathic band*

In the eastern part of the island, one or two narrow feldspar-rich bands are layered with the pyroxene gneiss parallel to the foliation. Agmatitic portions have been observed on the northeastern coast. Palaeosomes of pyroxene gneiss up to 20 centimeters in diameter are distributed in the feldspathized zones, which are characterized by porphyritic plagioclase. The plagioclase (3 mm in maximum) shows clear polysynthetic twinning as well as a minor antiperthite texture. Its anorthite content ranges from 37 per cent to 50 per cent. Greenish-brown hornblende, reddish-brown biotite, carbonate, apatite and quartz are accessories. The hornblende crystals are occasionally pseudomorphous after hypersthene or diopside. The mineralogy of the narrow plagioclase-rich bands is the same as the agmatitic portions. The rock is medium- to coarse-grained, white colored and massive, with a porphyritic texture. Plagioclase (5 mm in maximum) is the main constituent. Sometimes, leucocratic bands extremely rich in plagioclase are observed. Anorthite content of the plagioclase ranges from 42 to 64 per cent. Accessory minerals such as hornblende, biotite, muscovite, carbonate and zoisite, are very small in amount and their grain size is also small. Pyroxene relicts, altered to chlorite, zoisite, biotite and hornblende, are occasionally observed.

g) *Pegmatites*

Two kinds of pegmatite, hornblende pegmatite and microcline pegmatite, are found in the island. The emplacement of these pegmatite dikes has been tectonically controlled as stated in the above chapter.

The hornblende pegmatite varies in composition, as observed in several localities. Most of the hornblende pegmatites are composed mainly of potash-feldspar (perthite), quartz, hornblende and plagioclase. Occassionally, they contain diopside and hypersthene. Pegmatite in the metabasite is composed of diopside, hypersthene, hornblende and plagioclase, without potash-feldspar. The microcline pegmatite is characterized by pink perthitic microcline crystals, associated with plagioclase, biotite, quartz and magnetite.

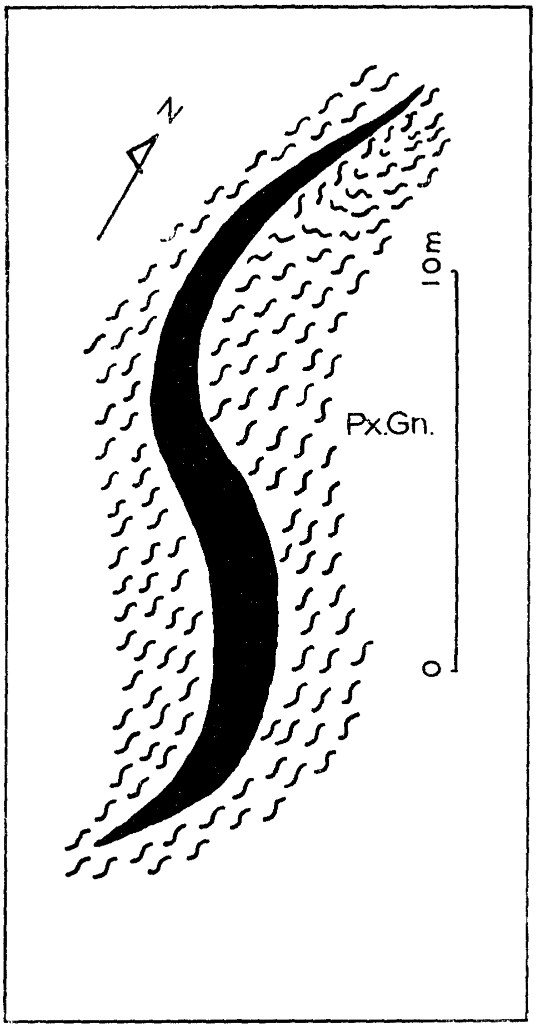

Fig. 10. Pyrrhotite vein in pyroxene gneiss.

The mineral assemblages of the pegmatites seem to be controlled by that of their country rocks (RAMBERG, 1949).

h) ***Molybdenite***

A zone of molybdenite impregnation was found in the central part of the island, where minor folds are develop in the frontal zone of the recumbent isoclinal fold. The molybdenite occurs as crystals up to 5 mm in diameter in the pyroxene amphibolites, especially in the somewhat acidified part of the rocks (Fig. 7).

i) ***Pyrrhotite***

Several pyrrhotite veins, parallel to the gneissosity of a layer of the garnet gneiss, occur only in the pyroxene gneiss on the southeastern coast of the island. A twisted lens, 1.5 m thick and 20 m long, of these veins (Fig. 10) is composed mainly of large hexagonal crystals of pyrrhotite up to 10 cm in diameter. Minor chalcopyrite also occurs in the lenses.

V. PETROGRAPHIC CHARACTERISTICS

The gneisses and granites have been classified on the basis of characteristic mafic minerals including pyroxene, garnet, hornblende and so on, but it would be difficult to classify these rocks by salic minerals, except the metabasites and the basic enderbitic pyroxene gneisses. The anorthite content of plagioclase is restricted to a rather narrow range (22% to 35%) in the rocks containing co-existent plagioclase and potash-feldspar which include the pyroxene gneisses. The anorthite content ranges however, from 42% to 93% in the metabasites and the basic enderbitic pyroxene gneisses, which are free from potash-feldspar.

The 2 Vx of potash-feldspar ranges from 58° to 72° in the garnet gneisses, 58°-88° in the hornblende gneisses and 62°-86° in the hornblende granite. It seems, therefore, that the triclinicity of the potash-feldspar may become higher in the hornblende granite than in the garnet gneisses. The change is consistent with the tendency toward increased microcline twinning in the potash-feldspar. The modal relations given in Q•Kf-Pl-Mf and Q-Pl-Kf diagrams are shown in Figs. 11 and 12. In these diagrams, the compositional fields of pyroxene gneiss, hornblende gneiss, garnet gneiss and granite rich in salic minerals overlap each other with the exception of the granites with abundant potash-feldspar (Figs. 11). This overlap suggests an intimate interrelationship between the

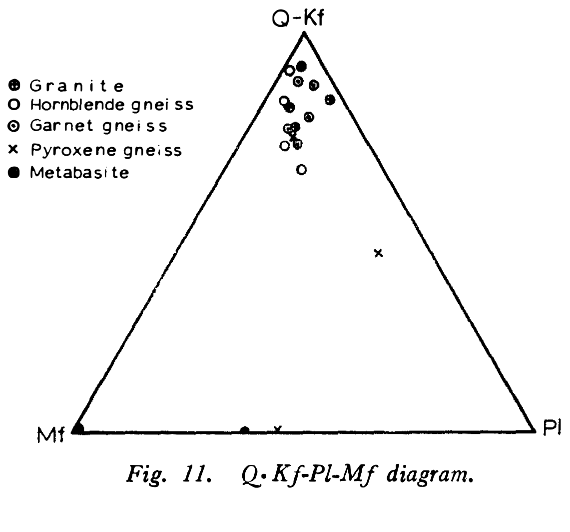

Fig. 11. Q•Kf-Pl-Mf diagram.

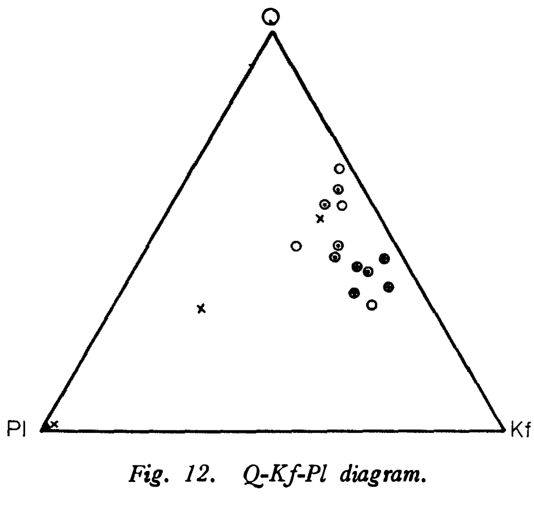

Fig. 12. Q-Kf-Pl diagram.

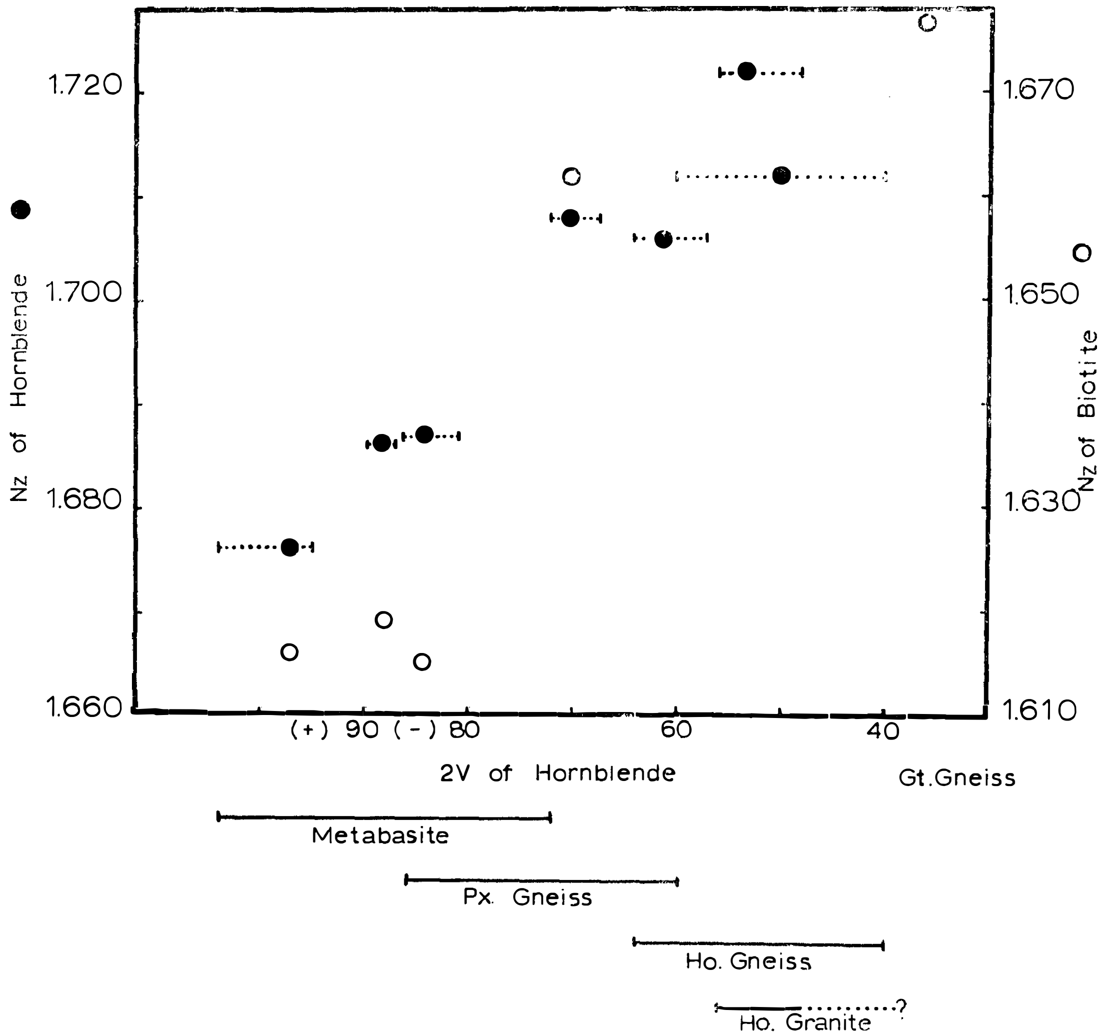

Fig. 13. Relationship between refractive indices and 2 V values of hornblende, and refractive indices of associated biotite.

gneisses and the granites.

The metabasites, gneisses with the exception of the garnet gneiss, and granites characteristically contain hornblende. Fig. 13 shows the relationship of 2 V of hornblende with Nz of hornblende or of biotite. The Nz of both hornblende and biotite is higher in hornblende gneisses or granites than in the pyroxene gneisses and metabasites; and the 2 Vx of the hornblende shows a reverse relationship. This relationship is controlled by the increase of the Fe/Mg ratio in the rockes from metabasite to granite. The similar tendency in hypersthene from metabasite to pyroxene gneiss is suggested by the 2V-index diagram as shown in Fig. 14.

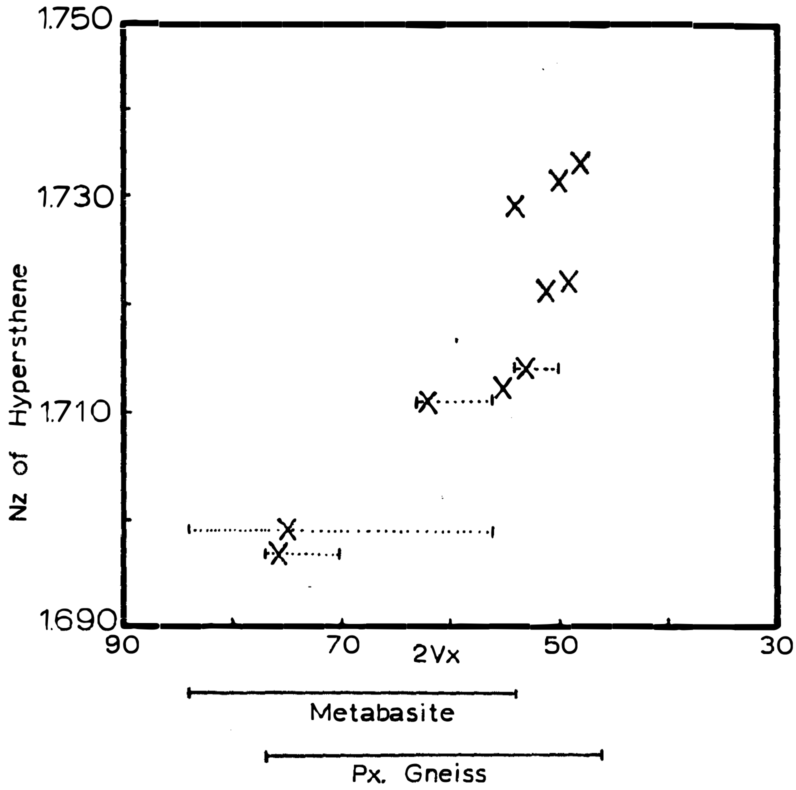

Fig. 14. Relationship between refractive indices and 2 V values of hypersthene.

VI. DISCUSSION

The metabasites and pyroxene gneisses in the island correspond to basic and intermediate or acid charnockites as suggested by TATSUMI and KIKUCHI (1959). The evidence presented here shows clearly that the gneisses of the island, far from being magmatic in origin, are metamorphic rocks of the granulite facies. The metabasites, which were originally basic igneous rocks or tuffs concordant with the structure of the country rocks, have been metamorphosed under the same condition as the country rocks have undergone.

After the initial formation, the rocks have more or less suffered more modification by subsequent metamorphic, metasomatic and tectonic events represented by two kinds of granitization. A feldspathization characterized by the enrichment of plagioclase porphyroblasts has developed as narrow bands in the pyroxene gneisses, after displaying an agmatitic appearance with palaeosomes of pyroxene gneiss (Plate IV). The feldspathization was intimately related to the formation of hornblende pegmatites. Another modification was the formation of the hornblende gneiss. There is extensive and clear evidence that some of the pyroxene gneisses have been altered to hornblende gneisses by a granitization related to the emplacement of granite as well as of microcline pegmatites. By the continuous action of this process, they have been converted to granitic gneisses and/or to hornblende granites, with a little or no trace of the parent rocks. The tectonic style represented by the frontal zone of the recumbent isoclinal fold my define the limits of the hornblende gneiss formation. The diaphthoretic changes involved are always accompanied by the transformation of pyroxenes to hornblendes and by the hydration of many kinds of minerals in the most modified rocks.

The difference between the feldspathization of pyroxene gneisses by hornblende pegmatites, and the granitization of hornblende gneisses that is intimately associated with hornblende granite as well as microcline pegmatite, is probably related to the difference in the degree of deformation experienced by each. RAVICH and VORONOV (1958) have suggested that, in the Bunger Oasis area, the migmatization characterized by the invasion of plagioclase granite into pyroxene gneiss took place in an earlier stage than that of pink microcline granite.

Some garnet gneisses were derived from pyroxene gneisses near the compositional transition zone between the two types, as indicated by the presence of relic pyroxenes and palaeosomes of the pyroxene gneiss within the garnent gneiss. The garnet gneiss has been more highly deformed and mobilized than the pyroxene gneiss. It is probable that the different competency between these two gneisses is due to difference in chemical composition and structural position. There are considerable field evidences to support the derivation of basic enderbitic gneisses from the metabasites, by the permeation of granitic material rich in silica and alkali from the surrounding rocks during tectonism.

It is probable that these rocks were formed originally under the conditions of a granulite facies. Concurrently, the extensive development of hornblende and biotite in the metabasite and gneisses suggests subsequent changes in pressure and temperature or the presence of water as well as changes in chemical composition which facilitated the mobilization and plastic deformation of the rocks. The hornblende gneisses were probably recrystallized under physical conditions approaching the amphibolite facies (RAVICH and VORONOV, 1958, COORAY, 1961). Therefore, two phases of metamorphism my be detected in the area ; the granulite facies at an earlier phase and the amphibolite facies at a later phase. The similar occurrences have been suggested by the investigations not only in other regions of the East Antarctica but also in other Precambrian shields of the world, and further by the measurements of the absolute ages (RABICH et al. 1962, PICCIOTTO and COPPEZ, 1963).

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