GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN NO. 6.

THE BORDER RELATIONS OF THE DUNITE AT SIORARSSUIT, SUKKERTOPPEN DISTRICT, WEST GREENLAND

BY

HENNING SØRENSEN

WITH 9 FIGURES IN THE TEXT AND 7 PLATES

REPRINTED FROM
MEDDELELSER OM GRØNLAND BD. 135. No. 4

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A-S
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CONTENTS

Abstract.

The dunite at Siorarssuit is conformably enclosed by granulite facies gneisses from which it is separated by a zone of bronzitite. The latter passes gradually into the dunite while it has a black-wall of phlogopitic mica against the gneiss. A rock consisting of bronzite, plagioclase, diopside and mica is occasionally found outside the black-wall.

Joints and fractures in the dunite are occupied by rocks resembling those of the border.

The bronzititic border is interpreted as a result of reactions between gneiss and dunite at conditions of P, T corresponding to the granulite facies of regional metamorphism. The chemical changes are discussed and it is shown that the Mg/Fe ratio of the bronzite decreases when passing from the dunite to the gneiss.

The "dykes" in the dunite are regarded as results of similar reactions along the fractures in the ultrabasic mass.

The reactions between ultrabasics and surroundings at different conditions of P, T are discussed and it is emphasized that the zone of bronzitite is a high temperature equivalent of the more familiar zones of chrysotile, actinolite, talc. etc. formed at lower temperatures.

INTRODUCTION

It is generally agreed that the *mise en place* of the ultrabasic rocks of the orogenic zones has taken place in the first phases of folding. For this reason the original contacts of the ultrabasic bodies have most often disappeared, the ultrabasics having been exposed to metamorphism during all subsequent phases of deformation. During the evolution of the mountain chains there is a reaction between the ultrabasic rocks and their surroundings and various types of border rocks are formed.

Many descriptions of these border relations have been published and especially the ultrabasic bodies of the uppermost parts of the orogenic zones have attracted the attention of the geologists, see for instance the papers of PHILLIPS and HESS (26), READ (29) and DU RIETZ (11). Thus, the types of borders are well-known in the greenschist and the epidote-amphibolite facies of regional metamorphism.

As to the borders of the ultrabasics of the deeper zones of the mountains, descriptions are more scarce. The writer has in earlier papers (34 and 35) discussed some of the types of zones of reaction between the ultrabasics and their country rocks under metamorphism corresponding to the amphibolite facies. The last-named paper also deals with the conditions in the granulite facies.

The purpose of the present paper is to give a description of the border relations of the dunite at Siorarssuit, Sukkertoppen District West Greenland, this occurrence being chosen as an example of an ultrabasic mass enclosed in gneisses formed at granulite facies conditions.

The dunite at Siorarssuit has been mentioned repeatedly in the literature since its discovery in 1808 by K. L. GIESECKE (14). Thus, J. A. D. JENSEN (19) gave in 1889 a short description of the locality and K. RØRDAM (32) published at the same time the results of a chemical examination of the rock. The occurrence has later been mentioned by O. B. BØGGILD (7 and 8) and by A. NOE-NYGAARD (25). In 1951 the late Mr. R. BØGVAD, chief geologist at Kryolitselskabet ØRESUND A/S, and the writer published the results of a technical and geological examination of the dunite (9 and 33). In a later paper by the writer (35) references have been made to the occurrence.

I have payed two brief visits to the locality, namely in 1948 and 1949 as a member of the G. G. U. (Greenland Geological Survey) mapping expeditions to the Pre-cambrian of West Greenland. In 1951 Mr. E. KOCH, mag. scient., visited the locality and collected some specimens for me.

I wish to express my gratitude to Professor A. NOE-NYGAARD, who is the leader of the above-mentioned expeditions, and to my colleagues in the field work, especially to Mr. M. WALTHER, who assisted me in 1949 and to Mr. E. KOCH for valuable notes, photographs and rock-specimens.

Miss Me MOURITZEN, civil engineer, and Mr. A. H. NIELSEN, Kryolitselskabet ØRESUND A/S, undertook the chemical analyses, Mr. K. ELLITSGAARD-RASMUSSEN, mag. scient., examined two of the rocks spectrographically and Mr. C. HALKIER, Conservator at the Mineralogisk Museum, Copenhagen, prepared the microphotographs. It is a pleasant duty to acknowledge their valuable help.

I am most grateful to Mr. H. PAULY, mag. scient., Kryolitselskabet ØRESUND A/S, for kindly placing the photographs taken by Mr. R. BØGVAD at Siorarssuit at my disposal and for examining the ores of some of the rocks, to Mr. H. MICHEELSEN for determining the range in the refractive indices of the bronzite of some of the rocks, and to Mr. P. PADGET, M.Sc., for kindly correcting the English of the manuscript.

The map, fig. 1 is based on the topographical maps of the Geodetic Institute, Copenhagen.

Copenhagen, April 1954.

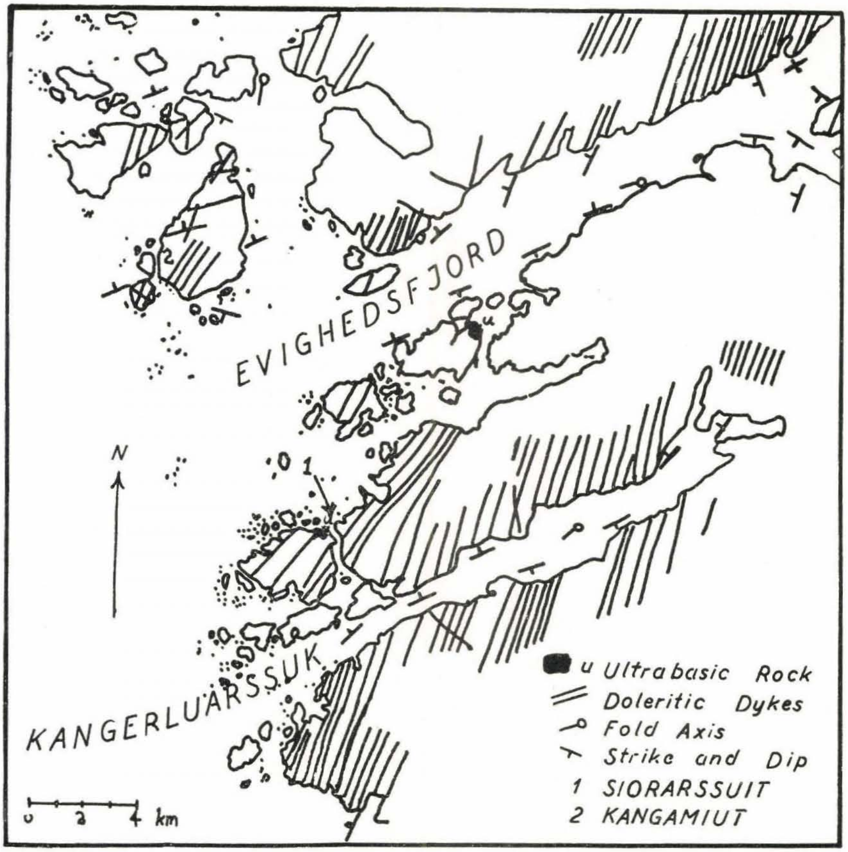

Fig. 1. Geological map of the country around Siorarssuit. The mapping undertaken so far is of a preliminary character, therefore observations are scarce in some areas which explains the casual omission of the dykes of dolerite.

GEOLOGICAL DESCRIPTION OF THE LOCALITY

Siorarssuit is situated on the southern coast of the great fiord Evighedsfjord immediately west of the entrance to the narrow sound Ikerasârssuk which connects the Evighedsfjord with the more southerly fiord Kangerdluarssuk. The small village Kangâmiut just to the north of Siorarssuit is the nearest inhabited place (fig. 1).

The dunitic mass is situated at the shore and forms a ten to fifteen meter high cliff towards the sea (fig. 2 and 3). Two small skerries in the fiord just to the north of the occurrence, and connected with the latter at low tide, consist also of dunite. Thus a part of the dunitic mass has been eroded away by the sea. At the base of the cliff there is, at low tide, a narrow beach consisting of olivine sand and for this reason the

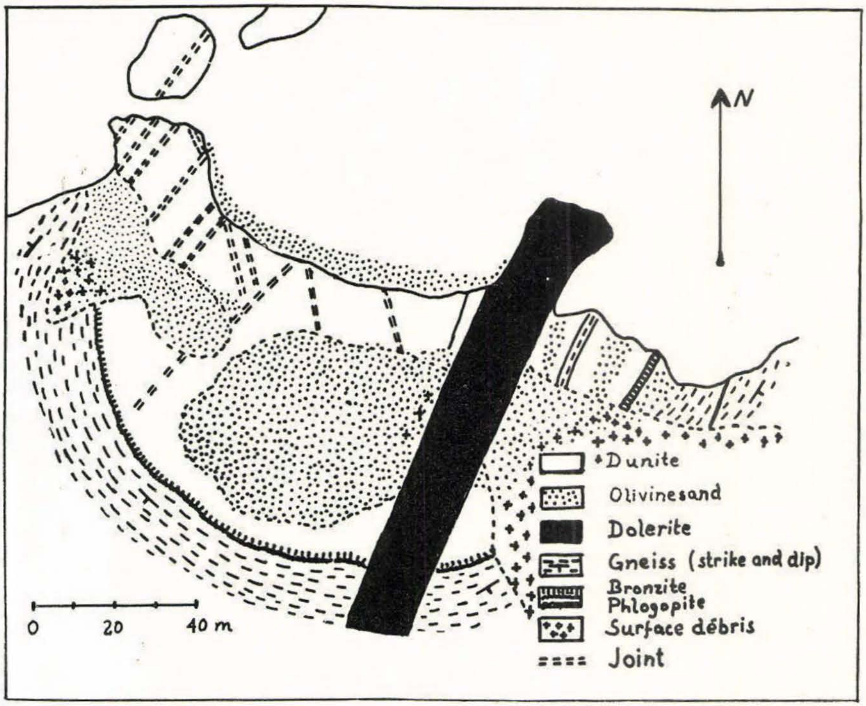

Fig. 2. Geological sketch map of the dunite at Siorarssuit. The map is based on a free hand drawing.

name Siorarssuit (meaning sand in the Greenlandish language) has been given to the occurrence which for a long time has attracted the attention of the Greenlanders because of its bright green colour in the middle of a landscape built up of rusty-coloured gneisses.

The dunitic mass reaches an altitude of about 40 metres over the sea and is then bounded by the gneiss. The greatest part of the surface of the dunite is covered by rock débris, in part formed by the weathering of the dunite, in part consisting of boulders of the surrounding rocks (figs. 6 and 7).

The dunite is conformably enclosed in a rusty-coloured, hypersthene-bearing gneiss which according to its paragenesis was formed at conditions of P, T corresponding to the granulite facies. The gneiss has formerly been called Sukkertoppen granite because of its massive appearance. Associated with the gneiss are layers of granulite (quartz-feldspar-garnet-rock) and sillimanite gneisses. Granulitic rocks are observed immediately to the west of the occurrence. Sulphide-bearing rusty zones are common in some parts of the area. Amphibolitic rocks are rare, being present mainly as thin bands or as inclusions in the gneiss. A pronounced agmatitic structure is occasionally observed.

Fig. 3. Siorarssuit seen from the Evighedsfiord. To the left the dyke, in the background the hypersthene-bearing gneiss which has a fairly steep wall towards the crumbling dunite. Note the rock débris on the surface of the dunite.

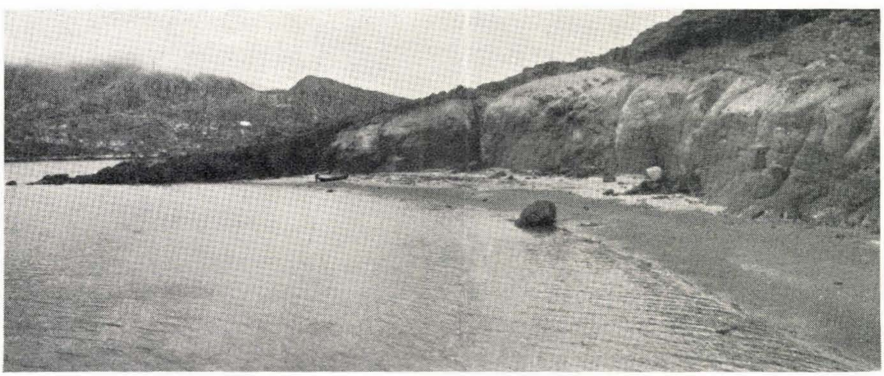

Fig. 4. The dunite to the west of the dyke which is seen behind the boat. A few of the joints in the dunite may be seen. The beach consists of olivine sand.

Ultrabasic rocks are fairly common although rarely in larger bodies. The ultrabasics most often met with are small, bronzite-rich inclusions in the gneiss. The sapphirine-bearing rock at Sukkertoppen, about 50 km to the south of Siorarssuit, belongs, according to Ramberg (28), to this group of rocks. Ramberg believes that there is a genetical relation between a primary olivine-bearing, ultrabasic rock and the sapphirine-bearing complex. The writer, who visited this occurrence in 1953, is of

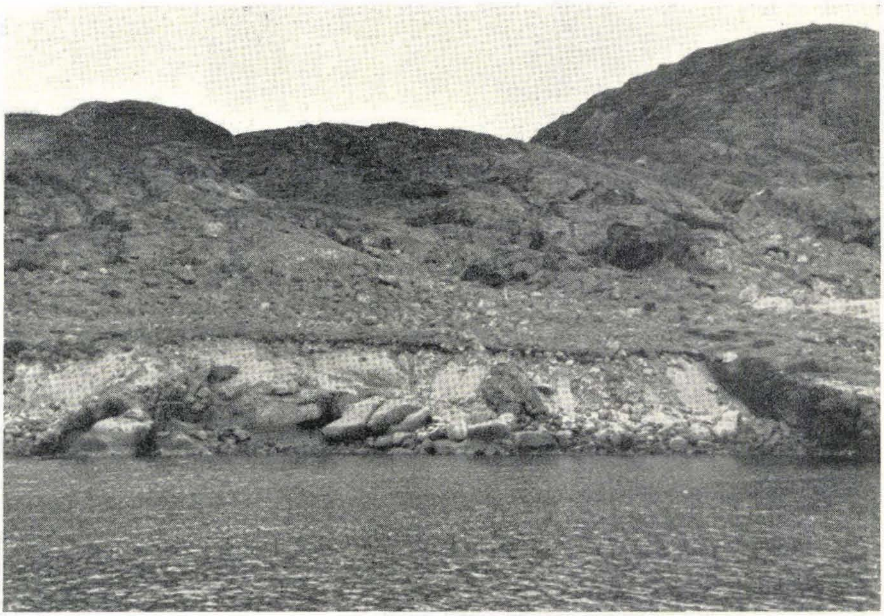

Fig. 5. The dunite to the east of the dyke which is seen to the extreme right. Separated from the dyke by boulders and sand is the layer of gneiss. To the left a ridge of bronzitite in sand of olivine (R. BØGVAD phot.).

the same opinion. The sapphirine-bearing complex is clearly an "outrolled" and hybridized ultrabasic body, the scattered remnants of the latter now being enclosed in a strongly lineated, hypersthene-rich gneiss, which is most probably to be regarded as a hybrid rock. The similarities to the occurrences Ol. 2 (see 34) and Ol. 1 (see 35) further south are great. Thus the large ultrabasic body Ol. 1 has in its outermost, hybrid zone small masses consisting of hornblende, corundum, sapphirine and plagioclase, the sapphirine being present as reaction rims between corundum and plagioclase. The sapphirine-bearing rock has not yet been described.

A great number of doleritic dykes are present in the area and form a dyke swarm. One of these dykes cuts the dunite. The contact towards the dunite is extremely sharp, but the dunite is, close to the dyke, penetrated by small apophyses.

The dunite at Siorarssuit is, as mentioned above, to a great extent covered by surface débris. Where exposed, the dunite is of a light green colour and fairly massive with an average grain-size of 0.2 cm. It easily crumbles. The appearance of the rock varies in the different parts of the body; it may be a pure olivine rock but may also contain a good deal of bronzite and/or phlogopite. The two last-named minerals are especially abundant towards the borders of the body and adjacent to the joints and fractures mentioned below.

Fig. 6. Olivine sand on the top of the occurrence. (R. Bøgvad phot.).

In some parts of the dunitic mass aggregates of diopside and hornblende occur. Scattered small grains of diopside and hornblende are common all over the body. The weathering of pyrrhotite associated with the aggregates has, in places, given the surrounding dunite a rusty-red colour.

The border between the gneiss and the dunite is well defined. The hypersthene-bearing gneiss, which normally has a light to dark brown colour, gets darker and darker as the dunite is approached owing to an increasing amount of biotite and hypersthene. The border zone of the dunite is about one meter thick and has generally towards the gneiss a zone composed almost entirely of phlogopite in flakes up to $^1/_2$ cm arranged parallel to the border. Most often this zone has been removed by erosion and its place is then marked by a narrow furrow. This zone is the black wall of the dunite and it is towards the dunite followed by a zone composed of bronzite in fairly large prismatic grains mainly arranged parallel to the border. The grain-size of this rock is somewhat varying; the prismae may in places attain a length of several centimetres. Small flakes of mica and small white spots of plagioclase are fairly common in this zone, grains of pyrrhotite are more scarce. The bronzititic zone has a gradual transition to the dunite which is of a bluish-black colour close to the border because of a separation of magnetite dust in the fractures of the olivine grains.

The simple border relations described in the above may be complicated in various ways because of the partial replacement of the bron-

Fig. 7. Typical block-weathering of the dunite. (R. BØGVAD phot.).

zite by plagioclase, phlogopite and diopside. Bronzite-bearing border rocks may then be found outside the zone of phlogopite.

The dunitic body is, in its north-eastern part, separated into two masses by a layer of gneiss and associated pegmatites (fig. 5). The gneiss is as dark as the gneiss outside the marginal zone of phlogopite mentioned above. The gneiss, as well as the pegmatites, have grains up to one centimeter in size, of a uralitized diopside.

The dunite is cut by a great number of joints and fractures (fig. 4). One system of vertical joints (N 20-40° W) has often slickensided surfaces and has zones rich in phlogopite towards the dunite. These joints may occasionally be occupied by diopside and hornblende in their central parts and by bronzite towards the dunite. Another system of joints, conjugate with the first-mentioned, is almost vertical and strikes N 40-60° E. It is often occupied by narrow pegmatites. A third system of joints is almost horizontal. In addition some more irregular fractures are present. The dunite is often dark adjacent to the joints and fractures.

PETROGRAPHY

In this chapter descriptions of the most important rocks will be given, namely first the dunite, next the rocks from the border and finally the rocks in the joints.

The Dunite:

This rock was examined in 11 thin-sections. Specimen No. **13591** is a good representative of the dunite. It is medium to coarse-grained and consists almost entirely of olivine. The texture is interlocking the rock being built up of larger elongated and smaller more polygonal grains (plate **1**, fig. 1). The elongation of the grains is parallel to the c-axis of the olivine. There is in places a slight tendency to parallelism between the elongated grains.

"Strain-lamellae" in the olivine are faintly developed in this specimen but are more pronounced in the mica-rich parts of the rock and adjacent to the joints and fractures. The lamellae are parallel to the crystallographic c-axis.

The components are: olivine (94.9 $^0/_0$ by weight), phlogopite (2.1 $^0/_0$), ore (0.8 $^0/_0$), hornblende (0.5 $^0/_0$), bronzite (0.2 $^0/_0$, and serpentine + carbonate (1.5 $^0/_0$).

The olivine has, in addition to the irregular fractures, well-developed cleavages parallel to 001 also. $2V = (+)\ 88°$, $n\gamma = 1.689$, $n\beta = 1.671$ and $n\alpha = 1.654$. This gives according to Poldervaart (27) a composition corresponding to about 9 $^0/_0$ fayalite (fa). The olivine is unusually fresh only being altered along the fractures and cracks. Lines of dark pigmentation (probably magnetite) are present in the olivine.

Phlogopite ($n\gamma$ = ca. 1.595) and bronzite ($2V = (+)\ 80°$), diopside and hornblende occur in scattered small grains, most often interstitially. The first-named is found as small, almost colourless flakes which may have bent cleavages, the second, which is present in fairly irregular grains of a corroded appearance, may be enclosed in the olivine (plate 1, fig. 2 shows an example of bronzite in olivine in another specimen of the dunite: No. **13458**). The grains of hornblende and diopside are most often rounded but small fibres of hornblende, apparently replacing the olivine, also occur.

Chromite and magnetite are present as small inclusions in the olivine but in a very subordinate amount. A few sulphide grains (chalcopyrite, pyrite and pentlandite) are seen.

The alteration products: serpentine, magnetite dust, and grains of a carbonate mineral, probably calcite, are confined to fractures in the rock and to the cracks in the olivine. An incipient alteration has also progressed along the grain boundaries.

In some parts of the occurrence the dunite contains up to 10 % of phlogopite. The phlogopite is in part interstitial but it may also penetrate the olivine grains and is more rarely enclosed in the latter. The phlogopite occurs in smaller grains than the olivine, the flakes are generally of a somewhat irregular habit. The cleavages may be bent. The mica is faintly pleochroic (colourless to light brownish), it is sometimes present in aggregates made up of several flakes. Sometimes there seems to be a parallelism between the elongated olivines and the flakes of mica.

The dunite may contain a good deal of bronzite in its marginal parts. These rocks will be mentioned below.

As mentioned on page 13 the grains of olivine have been exposed to mechanical deformation which has resulted in the formation of strain lamellae. The lamellation may be so indistinct that the extinction is undulatory. In specimen No. **13457** (plate 2, fig. 1) which was collected close to a fracture zone in the dunite, it may be seen that the olivine grains in places are split up into columns in their marginal parts. There may be a transition from strain lamellae to these columns (?). The columns are embedded in a matrix of carbonate and hornblende.

Aggregates of Diopside and Hornblende in the Dunite.

As mentioned on page 11 small grains of diopside and hornblende are scattered through the whole body of dunite. The amount of these minerals is generally insignificant, but in places they are found in small aggregates in the dunite.

Specimen No. **13458**, which was collected in the central part of the cliff, is a dunite made up of normally developed elongated grains of olivine. The rock has a polygonal texture in restricted zones and then consists of small grains of olivine, diopside, hornblende and ores (pyrrhotite, pentlandite, chalcopyrite). These zones "branch out" between the adjacent larger grains of olivine which may have inclusions of bronzite ($2V = (+) 80°$, see plate 1, fig. 2).

In No. **13457**, which was collected close to 13458, the diopside and hornblende form small aggregates of one centimetre across which are penetrated by small flakes of phlogopite (the cleavages are often bent). The mutual boundaries between the constituents of the aggregates are most often rectilinear. The borders against the olivine are on the contrary most irregular, it appears as if the olivine corrodes the aggregates. $n\gamma$ of the diopside is about 1.705.

The diopside and hornblende are in direct contact with the olivine. Adjacent to the aggregates, diopside, hornblende, and phlogopite (with bent cleavages) occur interstitially, but also as inclusions in the olivine. A few small prismatic grains of bronzite are found in the same way.

These two samples have their origin fairly close to one of the fissures in the olivine. The same applies to a diopside-bearing rock (No. 13450) of a different appearance, taken in the easternmost part of the occurrence.

In **13450** hornblende occurs in prismatic grains which may attain a length of 0.3 cm. It has a good deal of pigmentation and is somewhat transformed along the cleavages. It has "glomeroblastic" extinction, 2 V is (—) 87° and $c:\gamma = 20°$.

Diopside ($n\gamma$ = ca. 1.705) is present in part as inclusions in the hornblende (often in homoaxial intergrowth), in part as independent small grains which have "glomeroblastic" extinction and contain a good deal of pigmentation (in part at least consisting of hornblende). Some grains have small inclusions of bronzite.

Bronzite is the predominant mineral of the rock and occurs in large porphyroblasts poikilitically enclosing diopside and hornblende (some parts of the bronzite are crowded with inclusions). 2V = (+) 80°, $n\gamma = 1.676$. The porphyroblasts are fairly fresh but a slight alteration has taken place along the cleavages into a carbonate mineral and to a fibrous mineral of slightly oblique extinction (most probably a tremolitic hornblende).

Outside the porphyroblasts, elongated grains of olivine are found, they appear to surround the bronzite. 2V is as in the dunite (+) 88°. It has inclusions of the above-mentioned minerals and has in places faintly developed strain lamellae.

The relation between olivine and bronzite is indeed most puzzling. On the one hand certain features, as for instance the fact that the bronzite has straight or convex borders against the olivine, indicates that bronzite is the last formed mineral, while other features indicate the opposite thing. For instance the olivine appears to grow along the cleavages of the bronzite for a short distance. The border between the two minerals is absolutely rectilinear, but here and there the olivine crosses from one cleavage to another in a very irregular way and then follows that for some distance. These penetrating olivines are in continuity with the surrounding ones outside the bronzite.

The Borders of the Dunite.

A great part of the border is concealed by boulders of gneiss etc. but exposures are nevertheless sufficient to give an impression of the border relations of the dunite.

In the north-eastern part of the occurrence there is a ridge of bronzitite protruding in an area of olivine sand (fig. 5). There seems to be little doubt that this is the border of the dunite, since there is very little sand outside the ridge.

The bronzitite (No. **13448**) consists of bronzite ($n\gamma = 1.680$) in prismatic grains which may attain a length of several centimetres. It is lamellar and colourless and is slightly altered along the cleavages.

A faintly green hornblende is present in small grains which may be homoaxially intergrown with the bronzite. Phlogopite is found in small grains interstitially and there are a few grains of pyrrhotite.

The bronzitite has a gradual transition to the dunite (No. **13449**). This rock has bronzite ($n\gamma = 1.678$) and olivine ($n\gamma = 1.691$) as the chief components.

The bronzite is present in fairly large prismatic grains which have lamellar structure. The grains have sometimes irregular extinction and they may, as illustrated in plate 3, fig. 1, be crushed so that they now form aggregates of small grains approximately with a common optical orientation. The bronzite is faintly altered along the cleavages.

The bronzite is intergrown with olivine (fig. 8) and may embrace the latter. Therefore, the olivine occurs as fairly irregular grains which appear to be fragmented.

Small flakes of phlogopite penetrate the olivine, the flakes have pigmentation in their central parts.

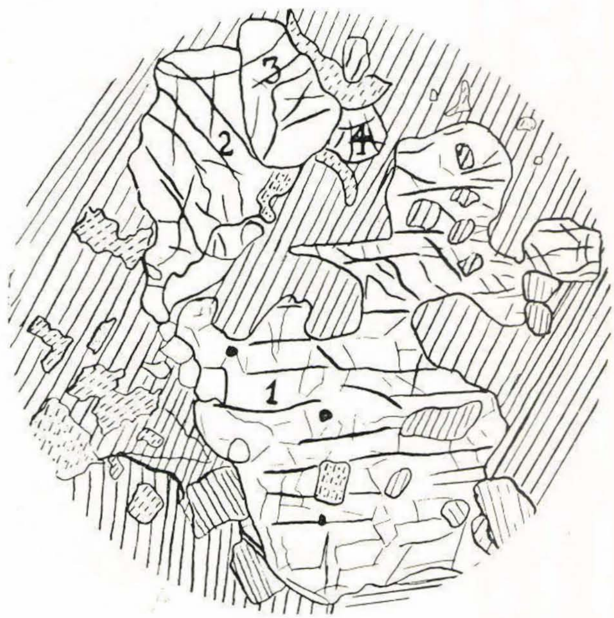

Fig. 8. No. 13449, 16×, +nic. Corroded grain of olivine (1) surrounded by a large grain of bronzite. "Inclusions" of bronzite in the olivine belong to the same large grain, thus this grain is also found under (or above) the olivine. (Olivine: irregular fractures, bronzite: full lines, diopside: broken lines, hornblende: broken lines and dots, phlogopite: dots). Three small black spots of ore. Bottom left a grain of diopside being replaced by the bronzite. 2, 3 and 4 are small grains of olivine.

The rock contains a few grains of diopside and hornblende which are highly corroded and often are divided into a great number of fragments with common optical orientation. This is also the case when they are enclosed in several adjoining grains of bronzite. Hornblende is also found between the olivines.

The olivine contains small grains of chromite, and a sulphidic ore is found between the grains of bronzite.

Towards the south the border relations are more complicated. Here the bronzititic border zone (No. **13464 a**) is mainly composed of prismatic grains of bronzite most of which are arranged in two mutually perpendicular directions in the plane of the border. The outlines of the grains are most often somewhat irregular. Between these prismatic grains smaller rounded grains of bronzite occur.

The components of No. **13464a** are: bronzite (94.2 °/₀ by weight), phlogopite (3.1 °/₀), plagioclase and quartz (1.4 °/₀), and hornblende (1.3 °/₀). In addition small blebs of pyrite are seen.

The bronzite is lamellar and colourless. $n\gamma$ was observed to vary from 1.677 to 1.689. In one small crystal $n\gamma$ was determined to be 1.682, $n\beta = 1.676$, and $n\alpha = 1.671$. $2V\gamma$ was seen in 13 determinations by means of the universal stage to vary from 84° to 91°. Two grains gave 90°, four 88°, one 86, one 85°, and one 84°, In one grain $2V\gamma$ was found to be 84° in one part of the grain and 91° in another part. A mechanically deformed grain had $2V = 86°$ in its central part, 86°,5 in an intermediate zone, and 84° along the margin. Now the uncertainty in the determination of the axial angle is estimated to be $\pm$ 2°, the difference in 2V in the last-named example is well within this limit. Still there seems to be a slight variation indicating a corresponding variation in chemical composition. $2V = (+)$ 88° may be taken as an average value. (There may be a connection between the mechanical deformation and the changes in 2V).

The bronzite is the subject of incipient replacement by plagioclase and phlogopite. The first-named is present in small, irregular, antiperthitic grains with undulatory extinction and indistinct twin lamellae. It has a certain pigmentation and may be associated with phlogopite and quartz (plate 2, fig. 2). Besides the bronzite is also being replaced by a colourless hornblende and by phlogopite along the cleavages. The last-named mineral is also formed interstitially.

The bronzite is almost unaltered apart from the replacement processes just mentioned. There is in places a development of dark pigmentation (probably magnetite) which may be concentrated in small aggregates or it may occur in zones of pigmentation cutting several grains of bronzite.

The formation of the last-named zones should most probably belong to a period when the rock was exposed to severe mechanical deformation. Other results of this treatment are seen in irregular extinction of the bronzite, in displacements along the cleavages and in the development of secondary twin lamellae transverse to the crystallographic c-axis (plate 3, fig. 2). These lamellae are identical with the phenomena described by A. Lacroix (23, page 234) from the Pyrenees and by E. Jeremine (20, page 21) from Quebec. The deformation of the bronzitite at Siorarssuit is less pronounced than in the Pyrenees.

The amount of mica increases in the bronzitite towards the surrounding zone of phlogopite. The boundary between the two rocks is nevertheless fairly sharp owing to the friability of the phlogopite.

The zone of phlogopite (No. **13464b**) consists of a network of flakes of phlogopite. The flakes are fairly parallel and parallel to the border, but they have a wavy arrangement. They are rectangular in shape and approximately of the same size. The invidual flakes are contiguous and the cleavages are often bent.

The phlogopite is faintly pleochroic (colourless to light brown) and is practically uniaxial with $n\gamma = n\beta = 1.605$, $n\alpha = 1.564$.

Scattered through the whole rock occur small corroded prismae of bronzite ($2V = (-)$ 88°,5, $n\gamma = 1.687$. They have approximately the same orientation all over the section and are parallel to the flakes of mica. The bronzite is obviously being replaced by the mica, since the latter often has undigested remnants of bronzite close to the larger prismae and these small grains have the same optical orientation as the adjacent larger grains (plate 4, fig. 2).

Ore is almost totally absent in this rock.

The rock has by weight 95.1 % phlogopite and 4.9 % bronzite.

The border sequence: olivine—bronzite—phlogopite—gneiss is locally modified in various ways. In 13464a an incipient introduction of plagioclase in the bronzitite was observed. In 13461a collected outside the zone of mica this replacement has been pushed a step further.

In specimen No. **13461a** the predominant mineral is, as in 13464a, bronzite, but $n\gamma$ is now 1.690. It occurs also here in large, prismatic grains parallel arranged so that they have almost identical extinction positions. It is lamellar and the extinction is slightly undulatory.

The prismae are highly corroded by plagioclase, occasionally to such an extent that they are divided into several irregular fragments still having a common optical orientation.

The plagioclase is antiperthitic, somewhat turbid and it is polysynthetically twinned according to the albite, the albite-ala complex law and the acline law. The anorthite content is about 35 %. There is no zoning.

The plagioclase has the same orientation over the whole section in such a way that the twin lamellae continue undisturbed on both sides of the corroded grains of bronzite which are often enclosed in the plagioclase. The pericline lamellae of the plagioclase are closely parallel to the cleavages of the bronzite and in a few cases acicular remnants of bronzite in the plagioclase are arranged along the pericline lamellae of the latter.

The contact between bronzite and plagioclase is most often sharp but in places there is a thin rim of diopside ($2V = (+)\ 58°$. $c:\gamma =$ about $36°$) between the two minerals. The diopside is clearly replacing the bronzite (plate 5, fig. 1). The plagioclase may have a narrow zone of orthoclase against the bronzite. This zone should most probably be taken as a special form of antiperthite since the optical orientations are identical in these rims and in the inclusions in the plagioclase. (A single small grain of perthite has been observed).

Lines of dark pigmentation in the plagioclase can be followed into the bronzite.

Phlogopite is scarce as interstitial small flakes and as inclusions in bronzite and plagioclase. Towards the zone of phlogopite there is an increase in the amount of mica.

A few small grains of hornblende have been observed.

Thus there is an incipient formation of diopside in this rock. In specimen No. **13461b**, which belongs to the same zone, a bright green diopside is present in grains of a centimetre's size. The rock is coarse-grained and has in the hand specimen a pronounced linear structure, the lineation being parallel to the border of the dunite and almost horizontal. Prismae of bronzite and diopside are embedded in a white groundmass of plagioclase.

Under the microscope it is seen that the large grains of bronzite are heavily corroded by plagioclase, mica and diopside. The bronzite is lamellar as usual and has an undulatory extinction (having secondary twin lamellae transverse to the cleavages). Occasionally a zonal structure has been formed.

2V = (—) 76° and $n\gamma$ = 1.695, but there seems to be a slight variation in composition. Neighbouring grains of bronzite have most often the same optical orientation, but small deviations may be seen. The grains of bronzite are cut by parallel zones of pigmentation.

The plagioclase (35 % An) is still antiperthitic and has wavy extinction. There is polysynthetic twinning according to the pericline law. The grains have the same orientation over fairly large areas as in **13461a**, but the twinning is more irregular. In addition there are small grains of plagioclase of diverging orientation. Lines of dark pigmentation continue into the bronzite, but they are scarce.

The diopside (2V = (+) 57°, $c:\gamma$ = 38° and $n\gamma$ = 1.715) is still present as mantles on the bronzite (plate 5, fig. 2), but is more common as independent, larger grains. The diopside may enclose remnants of bronzite (plate 6, fig. 1). Homoaxial intergrowth of bronzite and diopside is also seen (plate 5, fig. 2). The diopside is lamellar and has a spotted extinction. The small spots have "parallel extinction" and may be undigested remnants of bronzite. The lamellae are approximately parallel to the β direction. In addition to bronzite there are inclusions of plagioclase, often with a rim of hornblende against the diopside and a rim of orthoclase against the plagioclase.

The mica, which is of a darker brown colour than in the above-mentioned rocks, should probably be termed a biotite. It is present in fairly large, irregular flakes, especially in the plagioclase, but also interstitially. It may replace the bronzite along the cleavages.

In restricted zones (probably of cataclastic origin) biotite is found as numerous small flakes associated with plagioclase and quartz.

The replacement processes described in the above may be even more pronounced as is the case in No. **13461c**.

This rock consists on its dunite side of larger prismatic grains of bronzite which are lamellar, faintly pleochroic and with $n\gamma$ = 1.690—1.695. The bronzite is surrounded by and intergrown with fairly large flakes of mica arranged parallel to the border. This zone has a few inclusions of diopside and hornblende in the bronzite which is again the subject of an incipient replacement by plagioclase. The amount of plagioclase increases outwards. Immediately inside the outer border of these grains of bronzite, there is a zone rich in flakes of biotite arranged parallel to the border (plate 6, fig. 2).

Outside these prismatic grains of bronzite, bronzite is still the predominant mineral, but there is now a good deal of plagioclase (47-51 % anorthite) with beautifully developed stripes of pigmentation which can be followed into the bronzite. The latter is now of a corroded appearance and may even be divided into several grains of common optical orientation which gives the rock a granular aspect (plate 6, fig. 2). The bronzite is faintly spotted and bears the marks of mechanical deformation. Biotite is present on the cleavages of the bronzite and also in flakes smaller than in the zone just inside.

Outwards, larger grains of diopside appear, in part as inclusions in the bronzite, but also as independent, lobed grains which seem to grow at the expense of the bronzite. It is characteristically spotted as in **13461b**. Small grains of a colourless hornblende are found as inclusions in the bronzite.

The rock, which appears to be directionless when seen in the hand specimen, has, when seen under the microscope, clearly preserved the original structure of the bronzititic border rock with closely parallel arrangement of bronzite (and biotite).

The biotite of this rock has contrary to all micas mentioned in the above, inclusions of zircon, but there are no pleochroic rings. The mica has also small accumulations of ore.

The Gneiss.

The gneiss outside the above-mentioned endogenic border rocks is very dark because of a greater content of dark minerals (hypersthene and biotite) than usually and because of the dark colour of the plagioclase.

The gneiss south of the occurrence (No. **13461 d**) is medium-grained with thin, somewhat contorted layers consisting of small flakes of a dark brown biotite.

Hypersthene ($2V = (-)\ 54°$, $n\gamma = 1.707$, faintly pleochroic) is present in small, rounded, lamellar grains which may be bent or broken. The grains are parallel and it was noted in the course of the determination of the axial angle by means of the universal stage, that the grains are of almost identical optical orientation. Within smaller areas it is seen, when rotating the stage of the microscope, that the extinction changes in a regular way from grain to grain, so that the difference in extinction positions is small between adjacent grains but larger for more distant grains. Since the few larger grains of hypersthene extinguish in the same way, it seems as if the smaller grains are formed by the mechanical break-down of larger ones.

Small grains of a lamellar diopside are present; they are abundant in some parts of the rock.

Plagioclase is the predominant mineral and is found in irregular grains with repeated twinning according to the albite- and pericline laws. They have wavy extinction and dark pigmentation arranged in stripes or in intricate patterns. The content of anorthite is seen to vary from 32-42 %. In one case inverse zonal structure was observed with 32 % anorthite in the core and 38 % along the margin.

In subordinate amounts occur: quartz, apatite and ore. The latter is especially associated with the biotite, but there is also a separation of sulphides along the cleavages of the pyroxenes and in the fissures of the rock. Ilmenite, pyrrhotite, pentlandite and chalcopyrite were noted.

The rock bears the stamp of cataclastic deformation, especially in the zones rich in biotite. The schistosity formed in this way seems to cut the original lineation (the orientation of the grains of hypersthene) under a small angle.

The gneiss layer in the easternmost part of the dunitic mass is represented by No. **13452**.

Plagioclase is the main constituent and occurs in up to one centimetre large, irregular grains. It has numerous twin lamellae according to the pericline- and the complex albite-ala laws. The anothite content is 25 %. The plagioclase is cloudy and has irregular extinction.

Quartz and potassium feldspar are present in very small quantities.

Diopside occurs in scattered, up to one centimetre large, prismatic grains with lamellation parallel to (001). $2V = (+) 58°$, $c:\gamma = 41°$. It is slightly uralitized and has inclusions of biotite, plagioclase, hypersthene, apatite, and more rarely garnet.

The rock has a few small grains of hornblende ($2V = (-) 77°$, $c:\gamma = 17°$) associated with a green biotite. It may have inclusions of uralitized diopside.

Hypersthene ($n\gamma = 1.703$) occurs in small grains associated with hornblende and/or a brown biotite and also with diopside.

On the border between the dunite and this layer of gneiss there is a zone rich in hypersthene and biotite (phlogopite).

Against the dunite, a clear plagioclase is the predominant mineral, but grains of a lamellar hypersthene ($n\gamma = 1.700$, $2V = (-) 75°$), phlogopite and quartz also occur. Then follows a zone almost entirely consisting of mica ($n\gamma = 1.606$) in small flakes (plate 4, fig. 1) and a few grains of hypersthene, then a zone of hypersthene (with mica and plagioclase). The hypersthene here is corroded by the plagioclase, but it is fairly unaltered. Then follows another zone of a clear plagioclase (25 %₀ anorthite). This zone passes into the normal gneiss with a cloudy plagioclase, lines of pigmentation, zonal structure and bent twin lamellae. Occasionally the clouding is confined to the central parts of the grains.

The gneiss surrounding the dunite is, a few metres from the contact, developed as a typical "charnockitic" rock which is rusty-coloured, more coarse-grained and consists of a perthitic microcline, plagioclase (myrmekitic), quartz, and hypersthene ($n\gamma = 1.714$).

In all the above-mentioned examples of border types there were no zones of reaction between the plagioclase and the dark minerals (with the possible exception of the mantles of diopside on the bronzite of No. 13461a). For comparison a brief description of the conditions in the inner part of the fiord Kangerdluarssuk south of Siorarssuit will be given.

The Borders of a Small Ultrabasic Body in Kangerdluarssuk.

The occurrence, which is a few metres in diameter, is situated on the south coast of the inner part of the fiord.

The ultrabasic rock is enclosed by a hypersthene-bearing gneiss.

The ultrabasic rock (No. **13444**) is of bahiaïtic type. It is equigranular and consists of equidimensional grains of bronzite, hornblende, diopside, and green spinel. The grain size is about 0,1 cm and the texture polygonal. Thus the rock resembles the bahiaites at Tovqussaq (35).

Bronzite is the predominant constituent and is present in part as aggregates consisting of several larger grains, in part as independent grains.

Hornblende occupies the interspaces between the bronzites and seems to grow at the expense of the latter.

Diopside is scarce, the spinel minerals are abundant.

The rock is cut by displacement zones along which crushing and recrystallization have taken place with the formation of biotite, iron ore, and small fibres of a colourless mineral, probably a monoclinic hornblende. This statement is supported by the presence of colourless parts in the hornblende (cf 34, page 240).

The outermost part of the mass contains small grains of biotite and plagioclase. Simultaneously with the appearance of plagioclase the hornblende and the spinel disappear in conformity with the fact that the reactions across the border have taken place under conditions of P, T corresponding to the granulite facies. Thus the marginal 0.5 cm or so of the occurrence consists of plagioclase, bronzite and some diopside. The bronzite is corroded and is embedded in a mass of a colourless, fibrous mineral with oblique extinction. This mineral, which is most probably a tremolitic hornblende, is associated with small flakes of a brown biotite, and small grains of iron ore. The fibres are also found in cracks in the bronzite. The colourless zone is separated from the plagioclase by a narrow green rim. This zone passes outwards into a narrow zone mainly composed of pigmented grains of a uralitized diopside which may have inclusions of bronzite, separated from the latter by a zone of iron ore (against the bronzite) and a colourless zone (against the diopside). The diopside may be lacking in places in which case the border of the ultrabasic mass is made up of bronzite which is separated from the geniss by the fibrous mineral.

Plagioclase is the predominant mineral of the gneiss, it is clear against the ultrabasic rock but cloudy further away. The anorthite content is about 30 $^0/_0$. It is antiperthitic. The twin lamellae may be bent. The remaining minerals are quartz, a uralitized hypersthene, and apatite. A mineral of high refringence may be zircon or monazite. Pigmentation by iron ore and a green flaky mineral is found in some parts of the rock.

The reaction rims will be discussed on page 39.

Veins in the Dunite.

In this chapter examples of the veins mentioned on page 12 will be given. The veins are of two types, namely bronzititic and pegmatitic.

A. Bronzititic Veins: Specimen No. **13456** is a fairly good representative of this type of vein.

The dunite is adjacent to the veins of a bluish-black colour because of a separation of magnetite in the cracks. Close to the veins, 2V was found to vary from (+) 88° to (—) 88°, $n\gamma$ was determined to be 1.690. (This corresponds to a slightly higher content of fayalite than in the central part of the occurrence, but the deviations are well within the limits of the uncertainty in the determinations). In this connection may be noted that FOSLIE (13) and DU RIETZ (11, page 247) have found a decrease in the fayalite contents of olivines in which a separation of iron ore has taken place.

Apart from the observed increase in dust of iron ore the olivine is of a similar appearance close to the veins as elsewhere in the mass, but the development of strain lamellae is more pronounced (fig. 9 and plate 7, fig. 1). Also there is, close to the bronzitite, a small amount of a brown iddingsite-looking mineral in the cracks of the olivine.

The dunite has close to the vein interstitial grains of bronzite and small, bent flakes of phlogopite, both minerals most often growing approximately perpendicular on the border. Grains of hornblende and diopside are also found. The bronzite replaces the olivine and may have inclusions of this mineral having the same optical orientation as the adjacent larger grains of olivine. The inclusions may have iddingsite-filled cracks when they are situated in the zone in which this mineral is found. The bronzite is lamellar and has irregular extinction.

Fig. 9. No. 13456. 16 ×, + nic. Dunite (to the left) bordering on bronzitite (on the right). Note the inclusions of olivine in the bronzite, strain lamellae in two grains of olivine and the iddingsite (black) in the olivine (also in the inclusions in the bronzite).

The border between dunite and bronzitite is somewhat irregular since the bronzite grows in between the olivines replacing the latter (fig. 9). Small grains of pyrrhotite are occasionally associated with the bronzite. In places there may be small grains of hornblende between the olivine and the bronzite.

The optical constants of the prismae of bronzite are highly interesting. In grains close to the olivine $2V\gamma$ was observed to vary from 77° to 86° (in one grain the core had $2V\gamma = 83°$, the margin had $2V\gamma = 80°$), $n\gamma$ is close to 1.680. Towards the zone of diopside mentioned below $n\gamma$ was about 1.686.

Some of the thin veins consist only of bronzite but more commonly the veins are symmetric with a central zone rich in diopside and hornblende.

In No. **13456** the zone of diopside is very thin. About one centimetre from the olivine there is, in the bronzitite, a zone rich in flakes of phlogopite and small grains of a faintly green hornblende ($n\beta = 1.632$, approximately), the hornblende may be in homoaxial intergrowths with the bronzite. Diopside is scarce in this zone, but increases in amount towards the central part of the vein. It has $n\gamma = 1.715$.

Some veins of 20 centimetres and more have bronzititic borders, then comes, towards the interior of the vein, a zone in which the bright green diopside is the main component; bronzite, hornblende, and mica also occur. The central part of the veins has a concentration of large prismae of a black hornblende in a matrix of diopside. Bronzite is almost totally lacking in this zone.

No. **13586** is from the central part of a vein in the easternmost part of the occurrence, and is a rock with prismae of hornblende in a matrix of diopside.

Seen under the microscope the rock is made up of a "network" of prismae of hornblende (up to $^1/_2$ cm in length). The interspaces between these prismae are occupied by diopside.

The hornblende is almost colourless, faintly pleochroic from colourless to light-green. The prismae-faces are fairly well developed, the cleavages may be bent and the grains are often "glomeroblastic". $2V\alpha$ is observed varying from 83 to 90°, $c:\gamma$ varies correspondingly from 26 to 20°, $n\beta$ is about 1.645. The hornblende is almost unaltered, but it may have mica, plagioclase, and bronzite on the cleavages. A carbonate mineral is also found.

The diopside occurs in smaller, more irregular grains. 2V is (+) 57°, $c:\gamma = 40°$, $n\gamma = 1.711$, $n\beta = 1.690$. It is colourless, has indistinct lamellation and is "glomeroblastic". From the bright green colour of the mineral when seen in the hand specimen, one should expect a certain content of chromium, but a qualitative test showed no traces of that element. The diopside is somewhat more altered than the hornblende, the alteration product has a greenish tinge and larger grains are identified as hornblende. In this connection it should be mentioned that diopside occasionally is found homoaxially enclosed by the hornblende. Also an intimate intergrowth of hornblende and plagioclase may be seen in an extremely thin zone between diopside and hornblende.

A good deal of interstitial sulphides: pyrrhotite, pentlandite[1]), chalcopyrite, valleriite, bravoite and pyrite are seen, often in complicated intergrowths. These minerals will be described by Mr. H. Pauly when additional examinations have been undertaken in the field.

B. Pegmatitic Veins:

A 4 cm thick vein from the western part of the occurrence (No. **13465**) will be mentioned.

It is separated from the dunite by a thin layer of mica and consists entirely of salic minerals of which large grains (of one centimetre) of a black potassium feldspar are most prominent.

The potassium feldspar (without visible microline structure) is of the typical granulite facies habit which by Michot has been termed mesoperthite (24, page 270). It has equal amounts of plagioclase and potassium feldspar in perthitic intergrowth (plate 7, fig. 2). Similar feldspars have been described by Barth (2, plate 1) from Seiland. The structure may be inter-

[1]) Pentlandite is present in two generations of exsolution lamellae, one consisting of larger lamellae, the other of smaller ones.

preted as exsolution which shows that the feldspar was formed at such a high temperature that it could have corresponding amounts of Na and K in solution (cf ROSENQVIST, 31, page 86.

Large grains of quartz are present between the feldpars and smaller grains of plagioclase (25 $^0/_0$ An) occur in the same way. They are twinned according to the complex albite-ala law and are often myrmekitic.

The feldspar has a faint pigmentation. The quartz is clear with wavy extinction and with an incipient granulation along the margins.

CHEMISTRY

Three of the rocks were analyzed, namely the dunite, and the bronzitite and the phlogopite of the border. The results of the analyses are recorded in table 1.

More analyses of the dunite may be found in (9) and (32),

The analyses will be further discussed on page 34.

The three rocks are almost monomineralic and the rock analyses should therefore correspond fairly well to the chemical composition of the three minerals in question, i. e. olivine, bronzite and phlogopite. In order to give a more true picture of the chemical conditions, the analyses were corrected in accordance with the volumetric analyses of the three rocks. First the analysis of the phlogopite was recalculated after the subtraction of the 4.9 % bronzite, the composition of which was estimated from the nγ. The values obtained were used when correcting the analyses of the dunite and of the bronzitite. The remaining components of these two rocks are of less importance but their estimated compositions were nevertheless subtracted before the final recalculation of these analyses. The approximate compositions of the three minerals are given in table 2.

The mineral analyses were again recalculated by the method of WARREN (cf. GROVES, 16, page 211). The formulae thereby obtained are given below.

The Olivine. In this analysis the amounts of Cr_2O_3 and Fe_2O_3 were calculated as chromite and magnetite. The composition of the bronzite was estimated from 2V, the hornblende was taken as a slightly aluminous actinolite and the carbonate as calcite. The recalculation according to WARREN gave the following formula:

$$Mg_{1.81}Fe_{0.16}(Mn, Ni)_{0.01}Si_{1.01}O_4,$$

this corresponds to 8.2 mol % fayalite (fa) or 8,6 mol % fa if Mn and Ni are included.

The results of the optical examination of the olivine and the hereby obtained values of the content of fa (after POLDERVAART) are:

	$2V = (+)\ 88°$	corresponding to	9.0 % fa,
	$n\gamma = 1.689 \pm 0.002$	—	– 9.5 – –
	$n\beta = 1.671 \pm 0.002$	—	– – – –
and	$n\alpha = 1.654 \pm 0.002$	—	– – – –

Rørdam (32) states that the specific gravity of the dunite was determined to be 3.31 for small pieces, 3.29 for larger ones. Bøggild (7) has given the value 3.31 for the fresh rock, 3,08 for the serpentinized one. The present examination of larger pieces of the rock gave values of about 3.30 at 20° C. According to Poldervaart the value ought to be 3.40.

The Bronzite. The composition of the mineral was calculated as in the case of the olivine. Two recalculations were made. First the Fe_2O_3 was calculated as magnetite since there is a good deal of ore pigmentation in the mineral. Now it is impossible to say how great a fraction of the Fe_2O_3 is found in the dust. Therefore the analysis was also recalculated with Fe_2O_3 preserved. In the first case the formula was found to be:

$$Mg_{1.73}Fe^{\cdot\cdot}{}_{0.18}Mn_{0.01}Ca_{0.01}Ni_{0.01}Al_{0.03}Si_{2.01}O_6,$$

this corresponds to 9.2 mol % of ferrosilite (fs) (or 9.5 if Mn is included).

In the second case the formula is:

$$Mg_{1.71}Fe^{\cdot\cdot}{}_{0.20}Mn_{0.01}Ca_{0.01}Ni_{0.01}Fe^{\cdot\cdot\cdot}{}_{0.03}Al_{0.03}Si_{1.99}O_6,$$

corresponding to 10.3 % fs (or 10.5 if Mn is included).

The optical determinations gave:

$2V = (+)\ 88°$	corresponding to	11 % fs,
$n\gamma = 1.682 \pm 0.002$...........	—	– 10.5 % –
$n\beta = 1.676 \pm 0.002$		
$n\alpha = 1.671 \pm 0.003$...........	—	– 11.5 % –

($n\alpha$ vas determined by mounting a fragment of a crystal on a glass rod and subsequently rotating around the c-axis of the bronzite).

The specific gravity of the rock is 3.26 at 20° C.

As mentioned on page 17 the bronzite of the rock appears to vary in composition. The analysis therefore only represent an average value.

It is seen from table 2 that the bronzite contains small amounts of TiO_2, Al_2O_3, CaO, Cr_2O_3, NiO and (Fe_2O_3). The two first- and the last-

Table 1.

	Dunite (13591) Analyst Miss M. MOURITZEN	Bronzitite (13464) Analyst Mr. A. H. NIELSEN	Phlogopite (13464) Analyst Mr. A. H. NIELSEN
	Weight %	Weight %	Weight %
SiO_2	40.83	57.00	40.32
TiO_2	0.00	0.15	0.95
Al_2O_3	0.46	1.42	16.55
Fe_2O_3	0.25	1.01	1.59
FeO	8.07	6.78	4.37
MnO	0.13	0.16	0.01
MgO	48.28	32.20	22.69
CaO	0.53	0.56	0.00
Na_2O	tr	tr	0.63
K_2O	0.10	tr	8.71
NiO	0.35	0.31	0.25
Cr_2O_3	0.18	0.12	0.10
SrO	–	–	0.10
Li_2O	–	–	tr
P_2O_5	0.02	–	tr
$H_2O +$	0.14	0.48	3.59
$H_2O \div$	0.10	0.07	0.18
CO_2	0.40	–	–
F	–	–	0.10
Cl	–	–	tr
S	–	0.05	0.06
Total	99.84	100.31	100.20
		÷ 0.03	÷ 0.07
		100.28	100.13
Sp. Gr.	3.30	3.26	2.87
Mode:	Olivine 94.9 % Phlogopite 2.1 - ore 0.8 - hornblende 0.5 - bronzite 0.2 - serpentine + carbonate 1.5 -	Bronzite 94.2 % Phlogopite 3.1 % Plagioclase and Quartz 1.4 - hornblende + carbonate 1.3 -	Phlogopite 95.1 % Bronzite 4.9 -

named are common constituents of bronzites. CaO is often described as occurring in "exsolution" lamellae in bronzite. In the present case all the lamellae appear to have similar refractive indices and they may therefore be of the type described by HENRY (17). As to NiO and Cr_2O_3, they may be constituents of the mineral but they may also be associated

Table 2.

	Chemical Compositions, recalculated of			
	Olivine (13591)	Bronzite (13464)		Phlogopite (13464)
		$-Fe_2O_3$	$+Fe_2O_3$	
SiO_2	41.55	58.19	57.34	39.55
TiO_2		0.13	0.13	1.00
Al_2O_3		0.67	0.66	17.41
Fe_2O_3			1.02	1.68
FeO	8.01	6.40	6.74	3.91
MnO	0.14	0.17	0.17	0.01
MgO	49.99	33.63	33.14	22.22
CaO	..	0.36	0.35	..
Na_2O	..	..	..	0.66
K_2O	..	..	..	9.19
Cr_2O_3	..	0.13	0.13	0.11
NiO	0.31	0.32	0.32	0.26
SrO	..	..	..	0.11
H_2O	..	..	..	3.78
F	..	..	..	0.11
Total ...	100.00	100.00	100.00	100.00
				÷0.06
				99.94

with the fine dust in the bronzite. Mr. H. PAULY has observed a few small blebs of chromite.

It should be mentioned that Mr. A. H. NIELSEN has examined two other samples for NiO and he found 0.41 and 0.68 %, respectively. The material was free from larger grains of ore. Mr. K. ELLITSGAARD-RASMUSSEN examined another specimen spectrographically and found about 0.7 % NiO. Thus the amount of NiO varies in the different parts of the dust which may mean that it is at least partly associated with the dust.

The spectrographic examination revealed small amounts of Co (0.35 %) and V (0.005 %) and traces of Os. The remaining platinum metals and Mo, Ag and Cu, were not present. Co may in part be associated with small blebs of pyrite in the bronzite.

The phlogopite. Recalculation of the analysis according to WARREN gave the formula:

$$(Na_{0.09}K_{0.83})\,(Mg_{2.35}Fe^{\cdot\cdot}_{0.23}Ni_{0.02}Fe^{\cdot\cdot\cdot}_{0.09}Ti_{0.05}Al_{0.26})$$
$$(Al_{1.19}Si_{2.80})\,(F_{0.03}OH_{1.79}O_{10})$$

this gives about 9 mol % of the Fe component, i. e. the Mg/Fe ratio of the phlogopite is slightly higher than that of the neighbouring zone of bronzite.

$$(-)\ 2V \text{ is about } 0°,$$
$$n\gamma = n\beta = 1.605 \pm 0.002,\ n\alpha = 1.564 \pm 0.003.$$

($n\alpha$ was determined by mounting a tiny flake of mica on a thin glass rod).

The specific gravity of the rock is 2.87 at 20° C.

The mica is in the hand-specimens fairly dark, but transparent in thin flakes. It is faintly pleochroic from colourless to light brownish. The mica may thus be termed an iron-rich phlogopite or an iron-poor biotite.

Since the mica is almost perfectly free from ore, Fe_2O_3, NiO and Cr_2O_3 may be components of the mineral. The low content of F should be seen in connection with the fact that fluorine is extremely rare in this part of Greenland.

Mr. K. ELLITSGAARD-RASMUSSEN found spectroscopically 0,17 % V, 0,15 % Co, traces of Os while the remaining platinum metals and Mo, Ag and Cu were lacking.

DISCUSSION OF THE BORDER RELATIONS

As mentioned in the introduction of this paper most petrologists agree on the point that the emplacement of the ultrabasic rocks has taken place during the opening phases of orogeny. Most ultrabasic rocks have, therefore, experienced all the subsequent phases of deformation and they have, owing to their original great rigidity, often been severely sheared or fractured, for instance with the formation of boudinage structures.

While huge masses of ultrabasic rocks are found in the fairly unmetamorphosed sediments of the upper parts of the orogens, as it may be seen in the most recent mountain chains (e. g. New Caledonia where masses of peridotite have an extension of more than 100 kilometres (AVIAS, 1), the ultrabasics of the deeper and more intensively metamorphosed parts of the orogens are found in much smaller masses, often linealy arranged like "strings of beads" which may be followed for hundreds of kilometers along the strike of the mountains. These rows of ultrabasic bodies may be folded with the enclosing sediments and often give the impression of having been formed by fracturing of an originally larger, continuous mass. In extreme cases the ultrabasics may be reduced to fragments of very modest size as for instance has been described by CHENEVOY (10). Generally it may be stated that the ultrabasics of the Pre-cambrian areas are of an insignificant size in comparison with the Alpine ones. (We exclude from these considerations the non-orogenic ultrabasics of Bushveld type).

Only in the most recent formations is there any chance of finding the primary contacts of the ultrabasic rocks, but even here faults and crush zones most often separate these rocks from their neighbours, since the boundaries are marked discontinuity zones. In many cases tectonic processes have removed the ultrabasics from their place of birth and transported them into new environments—a view which has recently been advocated with strength by HIESSLEITNER (18). One should *a priori* expect these "secondary intrusions" to be most common in incompetent rocks such as schists. The "intrusion" may have been facilitated by the serpentinization of the peridotites, processes of great importance in the higher levels of the crust.

In the deeper levels of the orogens, exposed for study in the older chains of mountains and especially in the Pre-cambrian ones, the ultrabasic rocks, which are fairly resistant to metamorphism, may have been through several phases of deformation and even granitization and degranitization processes. The individual members of the ultrabasic "strings of beads" (which in many cases are derived from a few larger masses) have been exposed to varying tectonic and physico-chemical conditions which may all in one way or another have printed their stamp on the rocks. In connection with the mechanical deformation, chemical reactions took place across the borders between the ultrabasics and their neighbours and metamorphic minerals stable at the prevailing conditions of P,T were formed.

For the above-mentioned reasons one may search in vain for the original contacts and it is therefore not surprising that the contact metamorphism around the ultrabasics is insignificant (which in fact is one of the most characteristic features of these rocks). What we see are the results of the interaction between incompatible rocks.

The dunite at Siorarssuit may have been through a long and complex existence. The small lens enclosed in degranitized granulite facies gneisses may be a remnant of a former huge mass enclosed in geosynclinal sediments. In comparison with similar rocks of other regions, the dunite is remarkably fresh and unaltered. There is no pronounced serpentinization as in higher levels of the crust and the mechanical deformation of the interior of the mass is inconspicuous, being confined to a faint development of strain lamellae, especially in the marginal parts of the mass (and in the marginal parts of the grains of olivine). There is no crushing as for instance in the famous lherzolites of the Pyrenees. Whether a "Gefüge-Regelung" has taken place or not has not as yet been examined. The fact that the dunite is hardly marked by cataclastic deformation shows that it soon after its formation has been transported down into the deeper parts of the orogen where a plastic deformation prevailed. If it had stayed for a longer time in a level of clastic deformation, it ought to resemble for instance the peridotites of Northern Sweden described by DU RIETZ (11), i. e. with pronounced crush-phenomena. (Since olivine is not a metamorphic mineral, healing of the crushed zones by recrystallization ought to result in the formation of common metamorphic minerals). These facts may speak in favour of an origin of the dunite in these deep levels of the crust.

The dunite and its rim of bronzitite form a well defined unit. In the descriptive part of this paper this rim has been regarded as a result of reactions between dunite and gneiss. It might be objected that the rim could as well be regarded as an original endogenic rim of pyroxenite as has been suggested for a great number of similar occurrences.

To this it should be pointed out: 1) it is very unlikely that the primary contact could be preserved during such a long period of deformation as that to which the dunite has been exposed, 2) BOWEN and others have questioned the existence of a peridotitic magma, 3) even if such a magma exists and even if the primary contacts have survived the deformation, the composition of the border rock is inconsistent with the diagram of differentiation developed by BOWEN. If the bronzitite is a contact rim one should either expect it to be more basic than the main rock (if the crystallization started from the margins, cf. FOSLIE, 12) or to be of basaltic composition as is the case in the dykes of peridotite in Skye (BOWEN, 5, page 148). A primary chilled zone should recrystallize into gabbro or amphibolite and an association with these rocks might be expected (cf HIESSLEITNER, 18, page 510). In this connection it should be mentioned that these amphibolites may be of quite a different origin if the writer's view on the peridodite problem is accepted (cf 35).

The discussion above is only forwarded for the sake of completeness since the study of the bronzitite leaves no doubt as to the origin of this rock. The observations recorded in the descriptive part of this paper clearly show this rock to be formed through reactions between the dunite and the surrounding quartzo-feldspathic rocks. The bronzite is formed at the expense of the olivine and replaces that mineral.

The writer has in an earlier paper (35, page 52) given a thorough discussion of the retrogressive metamorphism of ultrabasic rocks at conditions of P, T corresponding to the granulite facies. While the former paper treated the transformation of small masses rich in orthorhombic pyroxene, the present study deals with a larger mass with olivine as the main component.

As was done in the previous paper a distinction will be made between the central and the marginal parts of the occurrence.

Since the internal shearing of the dunite is little advanced there has been no access of material from the surroundings to the interior of the dunite. The latter has therefore acted as a unit during metamorphism and subsequent cooling. The rock consists almost entirely of olivine and the possibility of reactions within the body is small. There is only an incipient formation of hornblende and phlogopite (possibly also bronzite, diopside and sulphidic ores).

The formation of serpentine, carbonate and magnetite may be related to weathering processes (cf ZAVARITSKY and BETEKHTIN, 37; serpentinization is confined to the upper part of a great mass of dunite in the Urals).

Thus the almost perfect protection from the reacting materials (the dispersed phase) has resulted in the preservation of a paragenesis which is stable at much higher temperatures than those reigning during the metamorphism. The dunite is, as stated in (35), page 54, an "armed relic".

Along the margins and along joints in the dunite reactions have progressed a bit further during the formation of minerals stable at the granulite facies conditions of P, T. As at Tovqussaq there is a formation of bronzite and mica. The reactions are in principle much alike in the two localities.

Olivine is not stable in contact with quartzo-feldspathic rocks at the P, T in question and it is absorbed and replaced by bronzite. The study of the thin-sections has demonstrated that this replacement has taken place without any disturbance of the structure of the rock. There is a gradual transition from dunite to bronzitite. Similarly, although the border between the bronzitite and the zone of mica is relatively sharp, because of a pronounced difference in hardness, the presence of fragments of apparently undisturbed bronzite in the phlogopite shows that there may also have been replacement here (perhaps associated with mechanical deformation).

Although the consideration of the three analyses in table 1 gives a good impression of the changes in chemistry, a recalculation of the analyses to standard cells (as proposed by BARTH (3)) gives a much better picture of the changes. This recalculation is permissible since it is a question of replacement processes. The analyses are in table 3 recalculated in such a way that the number of cations corresponds to 160 ions of oxygen.

The examination of the three analyses shows that there is first an introduction of Si (Al and H_2O) into the dunite giving rise to the substitution of olivine by bronzite. Simultaneously there is a removal of $Fe^{\cdot\cdot}$ (which is in part oxydized to $Fe^{\cdot\cdot\cdot}$) and of Mg. These elements are probably to be found in the enrichment in mica outside the ultrabasic mass. It is worth noting that Ca-bearing minerals are not found in this bronzititic zone (apart from a very small amount of plagioclase and hornblende).

This front of Si is followed by the zone of phlogopite in which there is a concentration of Al, K and H_2O, and a decrease in the contents of Si and Mg.

Ca-bearing minerals replace the bronzite outside the zone of phlogopite. Unfortunately, these rocks have not been analyzed. The pre-

Table 3.
Number of Cat-ions in Standard Cell.

	Dunite (13591)	Bronzitite (13464)	Phlogopite (13464)
Si	40.1	52.3	38.2
Ti	–	0.1	0.7
Al	0.5	1.5	18.5
Fe···	0.2	0.7	1.1
Fe··	6.6	5.2	3.5
Mn	0.1	0.1	0.0
Mg	70.6	44.0	32.0
Ca	0.6	0.6	–
Na	–	–	1.2
K	0.1	–	10.5
Cr	0.1	0.1	0.1
Ni	0.3	0.2	0.2
H	0.9	2.9	22.6
Total	120.1	107.7	128.6
(Ideal)[1]	(120.0)	(106.8)	(133.0)

	The Dunite may have passed into the Bronzitite	
	by Adding	by Subtracting
	12.2 ions of Si 0.1 ion of Ti 1.0 ion of Al 0.5 ion of Fe··· 2.0 ions of H	1.4 ions of Fe·· 26.6 ions of Mg 0.1 ion of Ni
Total representing	15.8 cations 55.7 valences	28.1 cations 56.2 valences

	The Bronzitite may have passed into the Phlogopite	
	by Adding	by Subtracting
	0.6 ions of Ti 17.0 ions of Al 0.4 ions of Fe··· 1.1 ions of Na 10.4 ions of K 19.7 ions of H	14.1 ions of Si 1.7 ions of Fe·· 0.1 ion of Mn 12.0 ions of Mg 0.6 ions of Ca
Total representing	69.2 cations 85.8 valences	28.5 cations 85.2 valences

[1]) Numbers of cat-ions in olivine, bronzite and mica according to Barth (3).

dominant mineral is plagioclase which clearly replaces the bronzite, diopside is of importance in some parts of the rock and is also of a replacing character. Phlogopite often grows along the cleavages of the bronzite.

Let us first consider the chemical changes taking place across the border. The introduction of Si into the marginal part of the dunite was accompanied by a rearrangement of the Mg/Fe ratio in this zone. This geochemical culmination (cf D. L, REYNOLDS, 30) of Si marks the interior front of the transformations. It is accompanied by a corresponding geochemical depression of Si in the zone of phlogopite. It is hard to tell whether this desilicification is connected with the silicification in the bronzitite or whether it is a result of a difference in velocities of diffusion of the ions in question, i. e. that Si should migrate faster than Al, K and H_2O. In any case, a front of mica appears to be a common feature in these border reactions. Similar zones (but thinner) have been described from Tovqussaq (35, pages 31 and 32) and from other localities (op. cit. page 65). These fronts are most often found in the innermost part of the zone in which plagioclase behaves in a replacing way (cf pages 19 and 21).

Outside the phlogopite there is a concentration of Ca, Na and Al in the zone rich in plagioclase. The Mg and Fe released is in part fixed in the diopside and in part in the phlogopite. The diopside should most probably be regarded as a metastable mineral (cf 35, page 49) its formation being determined by a deficiency in H_2O and by a surplus of Mg and Fe which was not removed from the place but instead reacted with the Ca introduced. The potassium introduced was in the first stages of the deformation fixed in the phlogopite and perhaps also in the plagioclase (if the antiperthitic inclusions in the latter may be regarded as exsolution products, see page 25). Later, grains of a perthitic potassium feldspar were formed and a few may be observed in this border rock.

The plagioclase of this rock is approximately of the same composition as the plagioclase of the gneiss. At Tovqussaq there was an increase in the anorthite content of the plagioclase when approaching the ultrabasic rock (35, page 54). The reason for this is that the dunite at Siorarssuit originally was free from Ca, while at Tovqussaq the ultrabasic rocks were rich in hornblende, which is not stable in quartzo-feldspathic rocks in the granulite facies and consequently is dissolved. Therefore the decrease in Ca content in the plagioclase when passing from ultrabasic rock to pegmatite at Tovqussaq reflects the gradient along which the Ca was removed.

As at Tovqussaq the orthorhombic pyroxene is found in direct contact with the quartzo-feldspathic rocks (in contradistinction to hornblende). The plagioclase of the gneiss, which is normally turbid, is quite clear in contact with the ultrabasic rock. It appears that the latter drains all femic materials within reach.

As mentioned on page 18 all the bronzite in the thin section of no. 13461 a is of the same optical orientation. The plagioclase also appears to form only one individual. The directions of the cleavages of the bronzite and of the pericline lamellae of the plagioclase are parallel (but the planes form an angle of about 20° with one another). In a few cases, inclusions of bronzite in the plagioclase are arranged along the pericline lamellae of the latter. The development of pericline twinning is not very pronounced. Now, the arrangement of the prismae of bronzite is determined by the direction of the pressure in operation during the metamorphism. Similarly pericline twinning is often regarded as being produced by stress (cf Køhler and Raaz, 22). Therefore the above-mentioned parallelism need not be casual.

The prismae of bronzite of the border often bear the stamp of deformation in the form of crushing, displacement along the cleavages, "rolling" extinction and strain lamellae. The three last-named are probably of the same age as the replacement by plagioclase. The comparatively plastic fashion of deformation may have taken place at fairly high temperature and has probably facilitated the replacement processes in giving access to the material introduced from the outside. In this connection it should be mentioned that the pyroxene of the gneiss just outside the dunite has "rolling" extinction in the larger grains. The smaller ones extinguish in the same way with a slight deviation in extinction position from grain to grain. This gneiss may therefore represent a still further stage in the replacement processes in which plagioclase substitutes for the pyroxene. (Note that the plagioclase is of almost identical composition in these rocks). The crushing of the bronzite (see plate 3, fig. 1) is connected with the above-mentioned deformation in a gradual way since it appears to be a further development of the "rolling" extinction. Therefore it need not be much later than the plastic deformation and represents probably the last stages of the latter.

In table 4 the determinations of the optical constants of the orthorhombic pyroxenes at Siorarssuit are recorded and their contents of ferrosilite are given according to the diagrams of Poldervaart (27). The data are arranged according to their position in the occurrence with the bronzite of the dunite first, the hypersthene of the gneiss last. The table shows that we have here—as elsewhere—a composition gradient reflected by a decreasing ratio of Mg/Fe in the bronzite when passing from the dunite to the gneiss. In contradistinction to the bronzite, the olivine is of approximately the same composition throughout the whole body. The olivine is a primary mineral

Table 4.

The Optical Properties and the Ferrosilite Contents of the Orthorhombic Pyroxenes at Siorarssuit.[1])

(% fs according to POLDERVAART (27)).

		2 V	% fs	$n\gamma$ ($\pm$ 0.002)	% fs
13450.	from dunite	(+) 80°	8	1.676	5.5
13449.	from border (close to dunite)	..	..	1.678	7.5
13448.	from bronzitite	..	..	1.680	9
13456.	vein, close to dunite	(+) 86°	10	1.680	9
13456.	vein, central part	..	..	1.685	13
13464a.	from bronzitite	(+) 88°	11	1.682	10.5
13464b.	from phlogopite	(÷)88°,5	12.5	1.687	15
13462.	from bronzitite	..	..	1.686	14
13461a.	Border (5 determinations)	..	..	1.690	17.5
13461c.	Border, diopside-bearing	..	..	1.695	21.5
13461b.	border, diopside-bearing	(÷) 79°	21	1.696	22
13452.	from border	(÷) 75°	20	1.700	26
13452.	from gneiss		..	1.703	28.5
13464e.	from gneiss	(÷) 55°	38	1.706	31
13447.	from gneiss	..	..	1.714	38

[1]) The composition of the bronzite changes somewhat within the rocks. Thus $n\gamma$ was observed to vary from 1.677 to 1.689 in 13464a; in 13449, 13456 and 13448 values of $n\gamma$ as low as 1.676 were observed.

and has not been able to take part in the metamorphic processes. Its place has been taken by the bronzite, which is stable at the conditions of P, T prevailing, and the change in composition of the bronzite is an expression of the exchanges of matter going on in order to reestablish a state of equilibrium.

Table 4 shows that the bronzite in contact with the olivine (cf nos. 13450, 13449 and 13456) has a higher Mg/Fe ratio than the latter. When comparing the compositions of the two minerals one might assume that they were originally in equilibrium. On the other hand, the observed maximum of Si and the minimum of Fe in the bronzite close to the olivine may also be seen in connection with the chemical changes across the bronzitite. The hypersthene stable in the gneiss has a lower ratio of Mg/Fe than the orthopyroxenes of the bronzitite.

When judging from the refractive indices the Mg/Fe ratio of the mica seems to decrease from dunite to gneiss. As mentioned on page 30 the phlogopite in contact with the bronzite has a slightly higher ratio of Mg/Fe than the coexisting bronzite.

In spite of the fact that the dunite has been exposed to the highest temperatures and pressures of regional metamorphism, the zone of reaction between dunite and gneiss is very thin because of the slowness of the diffusion processes held responsible for the reactions. When protected from the dispersed phase (migrating ions, vapours and solutions) a rock may exist in a "hostile milieu" through extended periods (cf HIESSLEITNER (18), page 509). If the dunite had been sheared we would certainly not be able to find such a large, unaltered mass to-day.

As mentioned in the above, secondary, low temperature minerals are very scarce in the dunite. Also corona minerals are lacking. This indicates that the cooling (and the raising towards the surface of the crust) has been very rapid and that it has taken place under quiet conditions. At Kangerdluarssuk, on the contrary, there is a development of zones of reaction between the minerals of the ultrabasic body described on page 22. The minerals formed are stable at amphibolite (possibly epidote-amphibolite) facies conditions. This may be due to a slower cooling, but is more probably related to a zone of later crushing in the vicinity. (This body has also a marginal zone rich in diopside).

Pegmatites are comparatively rare in granulite facies areas. Therefore, we have not in Siorarssuit, as in many other localities in West Greenland, a pegmatitic zone between the ultrabasic rock and the gneiss and there are only a few narrow pegmatites in the rigid dunite.

If a complex, formed at granulite facies conditions, is exposed for instance to conditions of P, T of the amphibolite facies during a sufficiently long period, a new mineral association will be superimposed on the granulite facies minerals. The bronzite is no longer stable in contact with the gneiss and is replaced by hornblende which is again separated from the gneiss by a black wall of biotite. An example of this will be described in another paper.

With decreasing temperature of metamorphism the minerals stable in the amphibolite facies are substituted by at first actinolite and biotite/chlorite (epidote-amphibolite facies) and later by talc, carbonate and chlorite of the greenschist facies.

Detailed chemical examinations of the border relations of ultrabasic rocks at P, T conditions corresponding to the greenschist and the epidote-amphibolite facies have been published by READ (29) and by PHILLIPS and HESS (26). Their results may be compared with the conditions at Siorarssuit.

In this locality the zone of bronzitite represents a culmination of Si, the phlogopite a culmination of K, Al, Ti and H_2O and a depression of Si. The zone where the bronzite is being replaced by plagioclase, diopside and mica represents a culmination of Ca and Na. The zone of phlogopite has the same content of SiO_2 as the original dunite.

READ found at Unst that bodies of serpentine were zoned in such a way that internally the serpentine was replaced by talc (culmination of Si), then followed outwards a zone of actinolite (culmination of Ca) and then zones of chlorite and biotite with culminations of Al, K, Na and H_2O and with a depression of SiO_2 (the amount of which is of the same order as in the serpentine).

PHILLIPS and HESS found in their low temperature border type a central zone of serpentine surrounded by talc (culm. of Si) and chlorite culm. of Al, K and H_2O and depression of Si). Ca is here found in carbonates.

At higher temperature they found centrally serpentine, then actinolite (culm. of Si and Ca) and marginally biotite. The writer has noted similar sequences in amphibolite facies complexes.

Thus there is an internal front of Si in all facies, but while Ca is found inside Al, K and H_2O in the lower facies, the opposite may be true for the granulite facies. More granulite facies examples should however be examined before more general statements may be advanced. The primary composition of the ultrabasics may naturally play an important rôle.

The serpentinization of the ultrabasic rocks increases generally with height in the crust. Thus DU RIETZ (11, page 245) has demonstrated that in Northern Sweden the ultrabasic rocks are fairly well preserved when enclosed in greisses and mica-schists, while they are more transformed when enclosed in phyllites. This may be due to a greater permeability of the phyllites and to a greater content of water in these rocks, but it should be remenbered that the gneisses were formed at higher temperatures (than the phyllites) at which the serpentinization is slow.

The formation of talc is by many writers considered to be associated with granitic rocks (cf for instance HIESSLEITNER, 18, page 523). The writer has so far only studied soapstones in amphibolite facies complexes where the steatitization is clearly connected with granitization (35, page 71). In a recent paper WIIK (36, page 12) has stated that in the area examined by him in the Carelian zone in Finland there is no increase in steatitization towards an area of granites; the soapstones are more numerous in a zone of schistose rocks.

The steatitization of the margins of the ultrabasic rocks in the higher levels of the crust is a low temperature equivalent of the bronzititic rims described in this paper. Both are the results of metamorphic reactions between incompatible rocks and they can neither be regarded as primary zones of contact nor as products of autometamorphism. KOARK (21, page 446) has reviewed this problem as it is presented in the Alps and he also favours an origin by "Stoffaustausch"; many other examples of this way of interpretation could be quoted.

The writer considers the greater part of the "magmatic differentiation" in the ultrabasic masses of the orogenic zones described in the literature to be the results of metamorphic processes.

DYKES AND VEINS IN THE DUNITE

Many descriptions of ultrabasic rocks deal with the ultrabasic dykes and veins which are so common features in the bodies of these rocks. They are always confined to the ultrabasic masses and do not cross the borders between ultrabasics and their country rocks. Possible ultrabasic "dykes" outside the ultrabasics are most often tectonic "intrusions" as has been especially emphasized by HIESSLEITNER (18).

The dykes and veins in question are generally regarded as being related to residual melts migrating through the cooling magma (which in modern petrology is considered to consist of a mesh of crystals), for eventually to crystallize in joints in the ultrabasic body provoked by cooling.

This interpretation cannot be true for many reasons. First, it is very unlikely that these dykes, if formed during the cooling of the ultrabasics (while these rocks still occured in huge masses), should be able to exist during the deformation which transformed the large ultrabasic bodies into "strings" of smaller ones. And it is even more unlikely that the residual melts should follow the separated small masses and find a sheltered place of crystallization there.

At Siorarssuit the magmatic explanation is hopelessly inadequate since the margins of the occurrence and the dykes are of similar composition. The field and laboratory studies also disclosed that the fractures and joints, with which the dykes are associated, are connected with the deformation (slickensided surfaces, increase in the development of strain lamellae in the olivine towards the joints). Further, the bronzite of the pyroxenitic veins replaces the olivine in the same way as in the marginal zone of the dunite, and the bronzite is also here followed by diopside. These "dykes" are obviously of the same origin as the bronzititic borders and they are formed in the same period as the latter through reactions between the dunite and the dispersed phase which migrated through the joints.

Thus, these "dykes" are, together with for instance the bahïaites of Southern Norway described by BARTH (4, page 627), proofs of the theory developed by Bowen and Tuttle (6, page 459), namely, that the veins of bronzite in dunite are formed by a metasomatic silicification of the olivine along fractures and joints.

At Siorarssuit the material migrating in the fissures was of a similar composition to the material which reacted with the dunite along its boundaries. At first there was a formation of bronzite at the expense of the olivine. The bronzititic rims are generally of a thickness of a centimetre and they represent a culmination of Si. In their external parts there is a concentration of mica in a narrow zone (cf. page 36). This zone has also hornblende replacing the bronzite along its cleavages. Then follows a rock with bronzite and hornblende in a subordinate amount and with diopside as the main constituent. The central parts of the fissures have a concentration of large prismae of hornblende which in part replace the diopside. This rock contains also grains of sulphidic ore and plagioclase.

The migrating material need not have been much different from that normally found in pegmatite-filled fractures. The pegmatitic minerals are lacking because of the abundance of Mg and Fe released during the silicification of the olivine. The narrowness of the fissures has prevented the material from escaping and it has been fixed in the diopside and in the hornblende. The lack of Al and alkalis in the rocks of the veins shows that there may have been a deficiency of these elements in the first phases of reaction.

The pegmatites in the dunite are extremely narrow. They differ from most other pegmatites in ultrabasic rocks studied by the writer in having a great amount of potassium feldspar (mesoperthite). Their formation has most probably taken place in a system of more open joints than those in which the basic veins were formed. The pegmatite-filled joints may have opened up in a later phase of deformation than the pyroxenite-filled ones. The presence of mesoperthite indicates that they were formed at granulite facies conditions.

One of the "pegmatites", namely the layer of gneiss in the eastern part of the occurrence, deserves a special discussion. It is most probably formed by a pegmatitic replacement of a zone of fissuring of the dunite and it resembles the gneiss just outside the marginal, bronzititic rim of the dunite.

The aggregates of diopside and hornblende in the dunite differ from the hornblende/diopside of the veins in being in direct contact with the olivine. Sometimes olivine and bronzite appear to corrode and replace the lime-bearing minerals. For this reason it was tentatively suggested in the preliminary description of the occurrence (33, page 65) that the aggregates represent remnants of lime-silicate rocks enclosed by the dunite (perhaps by replacement processes).

On the other hand there may also exist a connection between the aggregates and the veins. Thus, the aggregates are apparently most numerous close to the veins; in the central parts of the dunite singular interstitial grains of diopside and hornblende are more common. Further, it is seen along the contacts of the veins that the dunite contains interstitial grains of bronzite, phlogopite, diopside and hornblende, in places in great number and clearly associated with the bronzititic borders of the veins which may be very irregular. The diopside and the hornblende have glomeroblastic structure in the veins as well as in some of the aggregates, but whether this structure is a result of growth (cf GOODSPEED, 15) or of breakdown has not yet been decided. Finally should be mentioned that the diopside of the veins has $n\gamma$ about 1.710, which corresponds to the diopside of the border zone between dunite and gneiss while the diopside of the aggregates has $n\gamma$ about 1.705.

The points mentioned above may be taken in favour of a connection between the veins and the aggregates. This might be by secretion processes, the concentrations of the Ca-bearing minerals being more stable than the scattering of these minerals over the whole occurrence. The similarities of the veins to the marginal zones of reaction between gneiss and dunite render this explanation less probable and support rather the view that the aggregates are of the same origin as the veins, namely representing material introduced into the dunitic body.

Additional explanations could be advanced. Thus Mr. H. PAULY has on the basis of a study of the ore minerals, suggested, that the aggregates may be recrystallized ore-bearing parts of the original dunite. However, a further visit to Siorarssuit is necessary for solving the problem of the origin of the aggregates of diopside and hornblende.

We may now discuss the dykes and veins in ultrabasic rocks in accordance with the discussion of the retrogressive metamorphism of the ultrabasics in the preceding chapter.

The pyroxenitic veins are formed at granulite facies conditions through reaction between migrating pegmatitic material (the dispersed phase) and the ultrabasic rocks.

At amphibolite facies conditions, issitic veins (i. e. rocks of aluminium-bearing hornblende often associated with biotite) are found. At special conditions, as discussed in (34) anthophyllite may occur. Desilicated pegmatites are not uncommon.

In still lower facies, dykes and veins of tremolite-actinolite, chrysotile, talc, chlorite and carbonates are the results of similar processes.

It should at this point be mentioned that some dykes in ultrabasic rocks may be of a different origin, the dykes in Seiland described by Barth (2) could be quoted as examples.

The purpose of this paper has been to emphasize the dependence of the reactions transforming the ultrabasic rocks on the conditions of metamorphism. Modern petrologic studies have given many examples of the applicability of metamorphic processes in this field of petrology and the writer finds that metamorphism rather than magmatism is the clue to most problems concerning the ultrabasic rocks.

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Færdig fra trykkeriet den 25. november 1954.

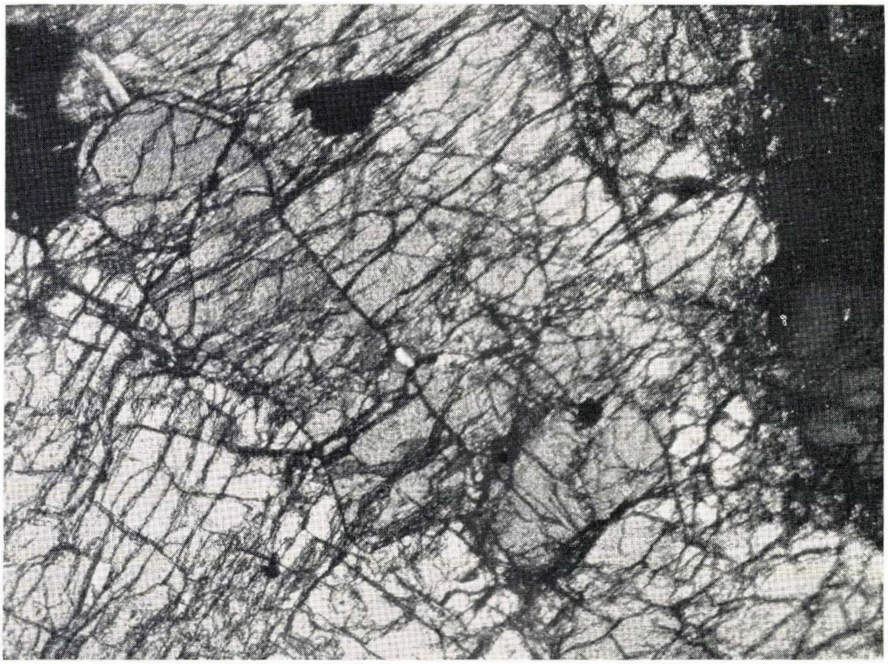
PLATES

Plate 1.

Fig. 1. No. 13591, 25 ×, + nic. The dunite. Note the elongated grains of olivine. A few black grains of ore.

Fig. 2. No. 13458, 25 ×, + nic. The dunite. Corroded grain of bronzite enclosed by olivine. Note the small grains of bronzite to the top right which are now separated from the large grain by the olivine.

(C. HALKIER phot.).



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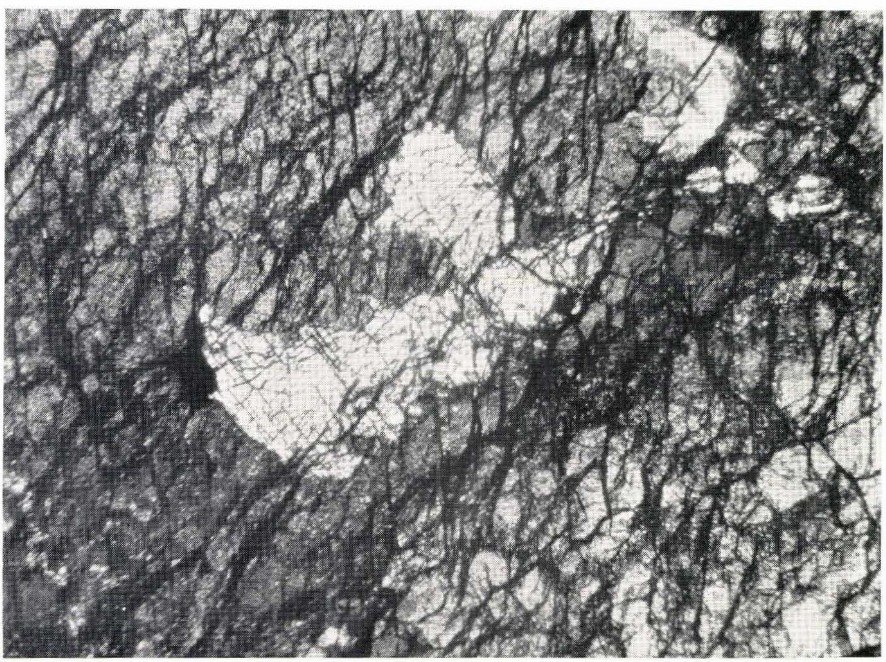


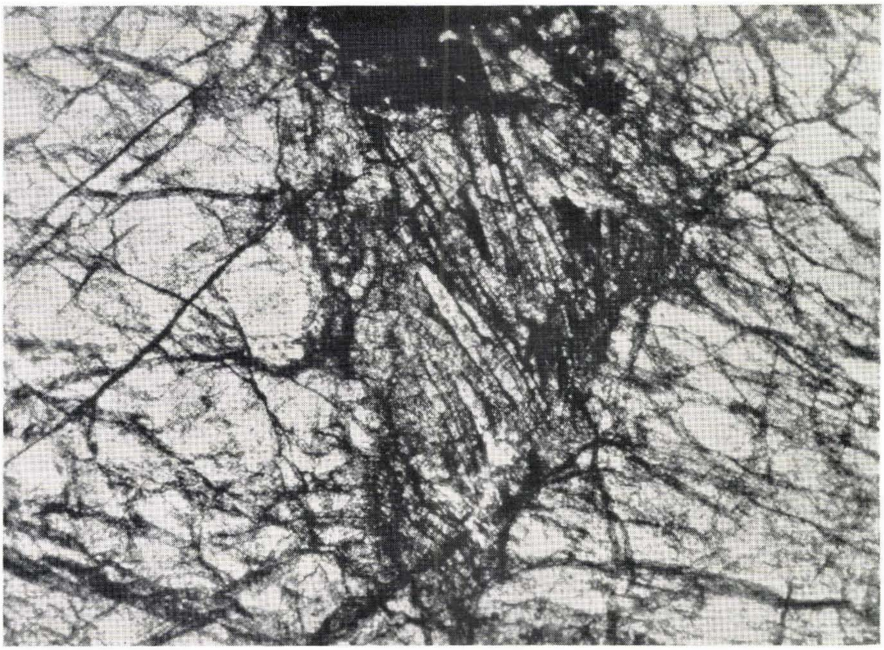
Fig. 2.

Plate 2.

Fig. 1. No. 13457, 25 ×, + nic. The dunite. Columnar olivine in a matrix of hornblende and carbonate.

Fig. 2. No. 13464a, 25 ×, + nic. The bronzitite. Large grains of bronzite, in centre association of plagioclase and mica.

(C. HALKIER phot.).



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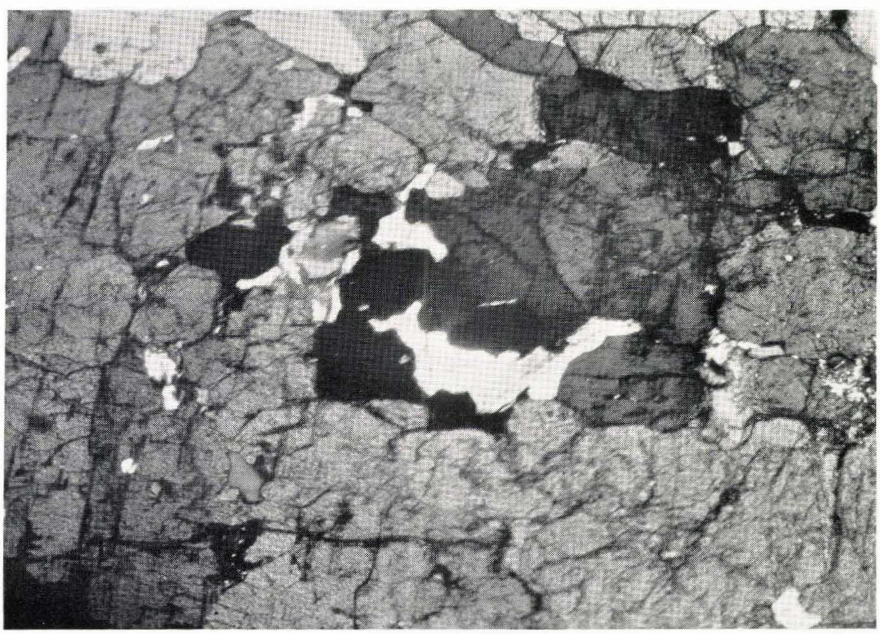


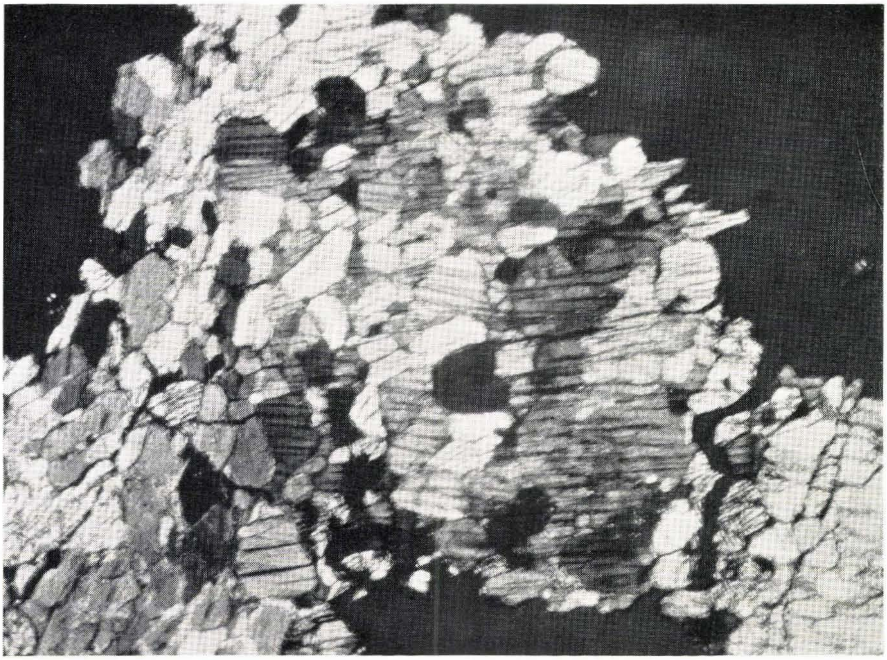
Fig. 2.

Plate 3.

Fig. 1. No. 13449, 33 ×, + nic. Crushed grain of bronzite. Note that the largest fragment of the grain (bottom right) has an extinction pattern corresponding to the crushing in other parts of the grain.

Fig. 2. No. 13464a, 25 ×, + nic. Bronzite with strain lamellae transverse to the c—axis.

(C. Halkier phot.).



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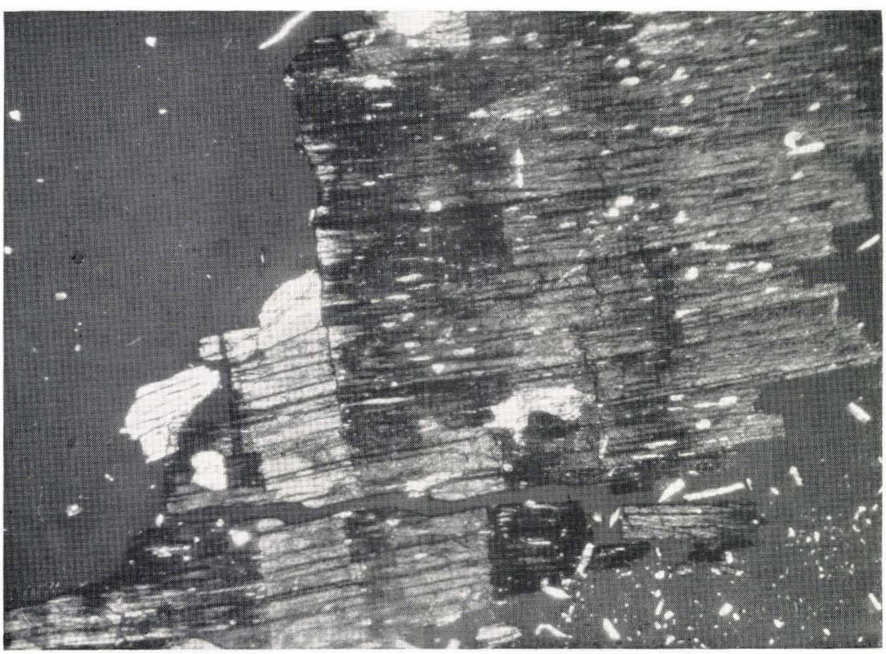


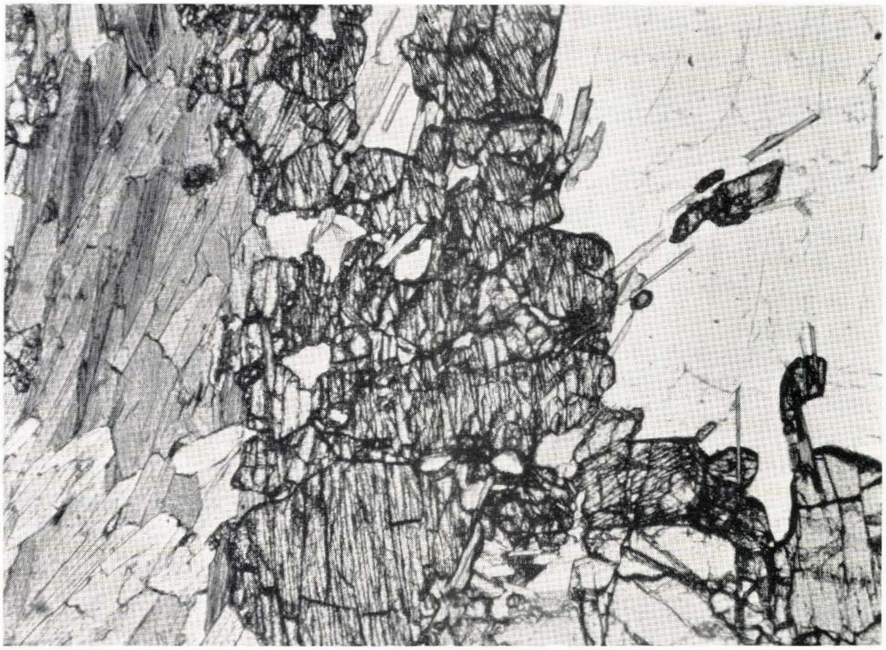
Fig. 2.

Plate 4.

Fig. 1. No. 13452, 25 ×, 1 nic. Border between gneiss (to the right) and bronzite (centre). The zone of mica to the left.

Fig. 2. No. 13464b, 30 ×, 1 nic. Inclusions of bronzite in phlogopite. Note the small fragments of bronzite below the large grain (top right).

(C. Halkier phot.).



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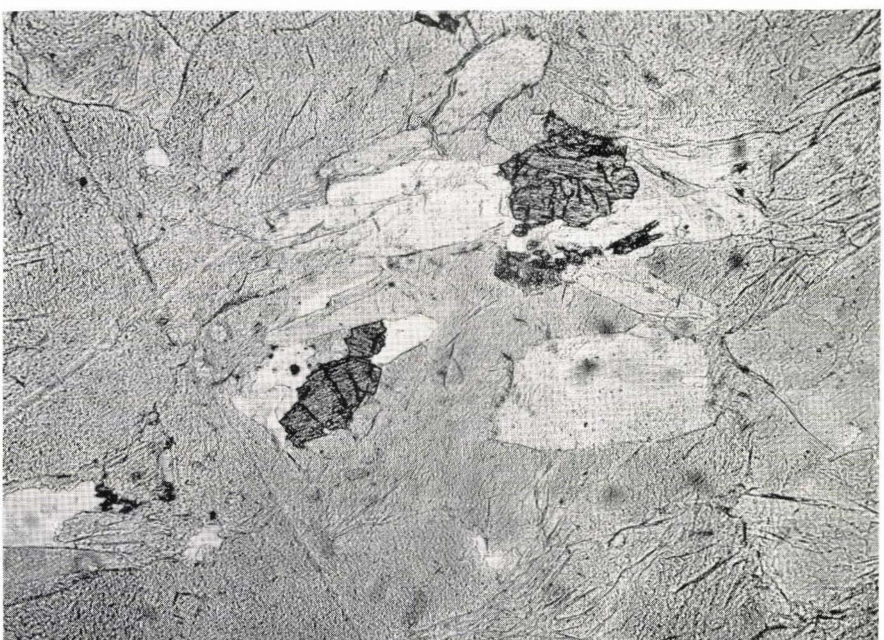


Fig. 2.

Plate 5.

Fig. 1. No. 13461a, 25 × + nic. Grains of bronzite corroded by antiperthite. A mantle of diopside on some of the bronzites is black. The grain of plagioclase (bottom right) has a rim of potassium feldspar. Top left: pericline lamellae in the plagioclase. The thin dark line in the plagioclase immediately below centre left) is an inclusion of bronzite parallel to the lamellae of pericline.

Fig. 2. No. 13461b, 25 ×, + nic. The bottom part of the photo is occupied by two grains of diopside. Top right: grain of bronzite (dark) being replaced by diopside and plagioclase and having inclusions of mica. Below centre: inclusion of bronzite in diopside homoaxially intergrown with the latter. Top left: tiny flakes of mica.

(C. Halkier phot.).

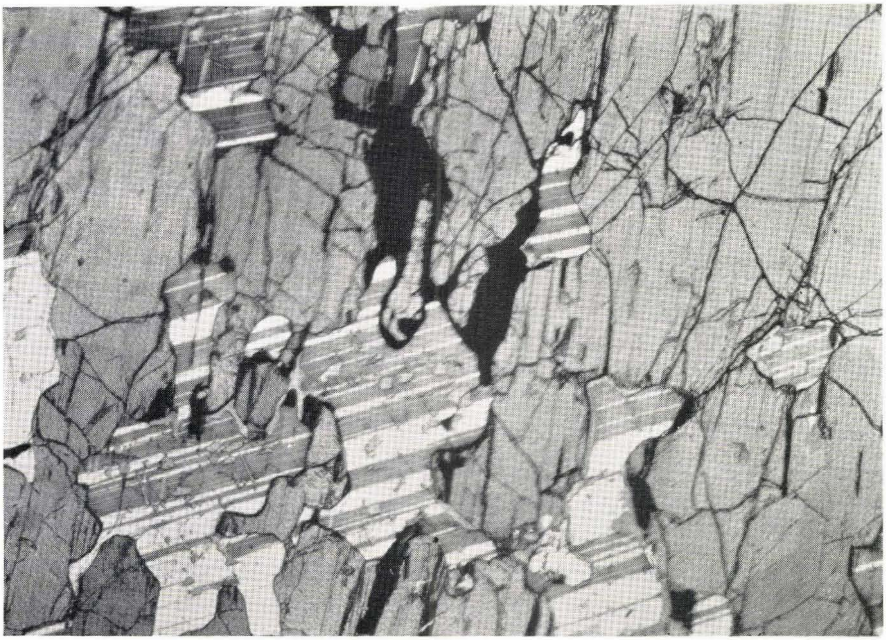


Fig. 1.

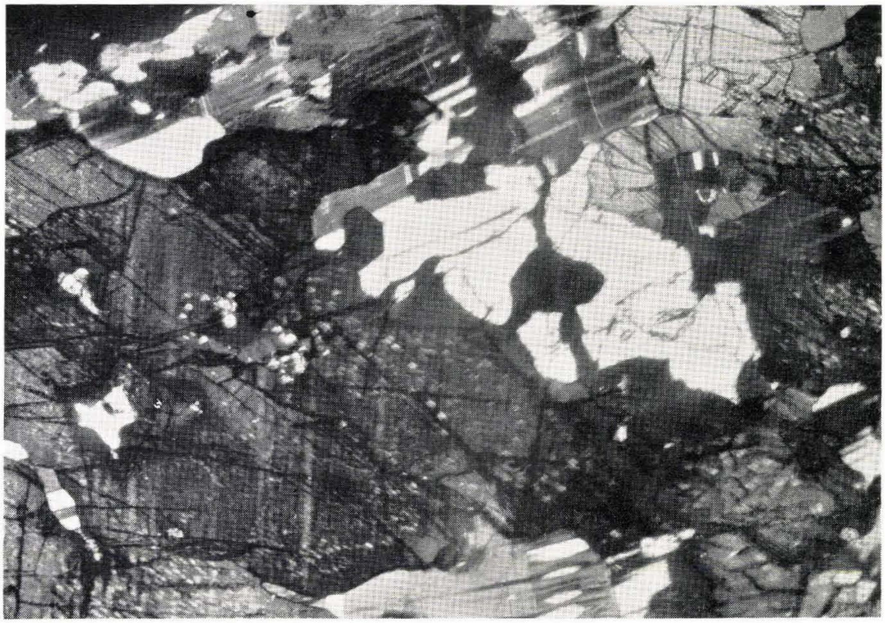
Fig. 2.

Plate 6.

Fig. 1. No. 13461b, 25 ×, + nic. Spotted and lamellar grain of diopside with bronzite and plagioclase. (The white grain centre right is bronzite).

Fig. 2. No. 13461c, 25 ×, 1 nic. To the left fairly well preserved grains of bronzite. Centre left: zone of large flakes of mica. To the right: highly corroded grains of bronzite with plagioclase and mica.

(C. Halkier phot.).



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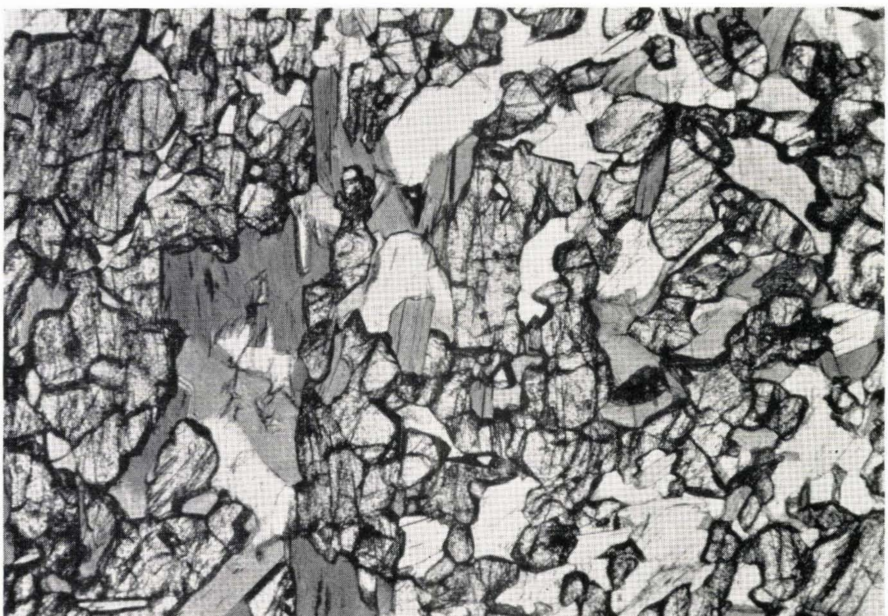

Fig. 2.

Plate 7.

Fig. 1. No. 13456. 25 ×, + nic. Border between dunite (left) and bronzite (right). Note strain lamellae in olivine (centre) and inclusions of olivine in bronzite (top right).

Fig. 2. No. 13465, 30 × + nic. Two grains of mesoperthite. In centre quartz and myrmekitic plagioclase.

(C. HALKIER phot.).

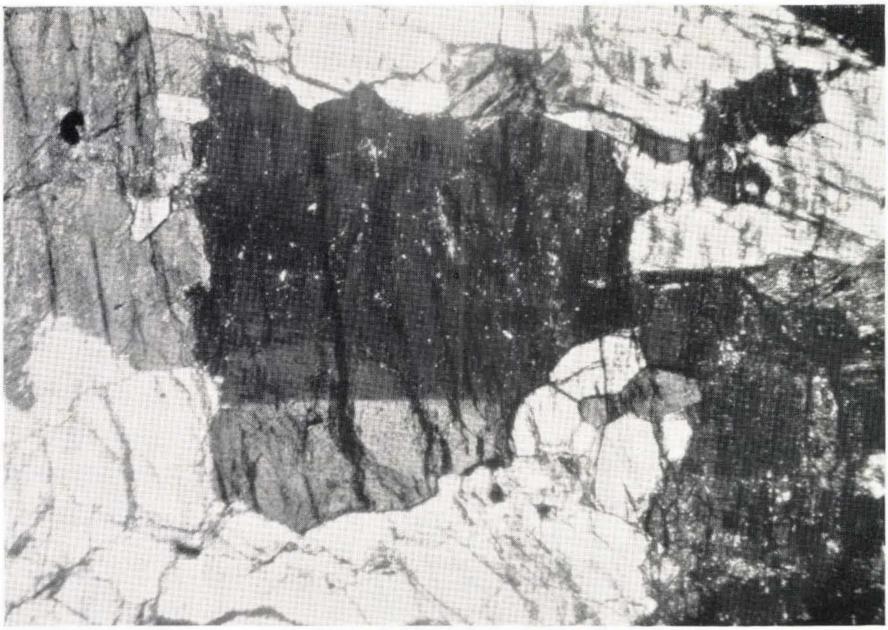

Fig. 1.

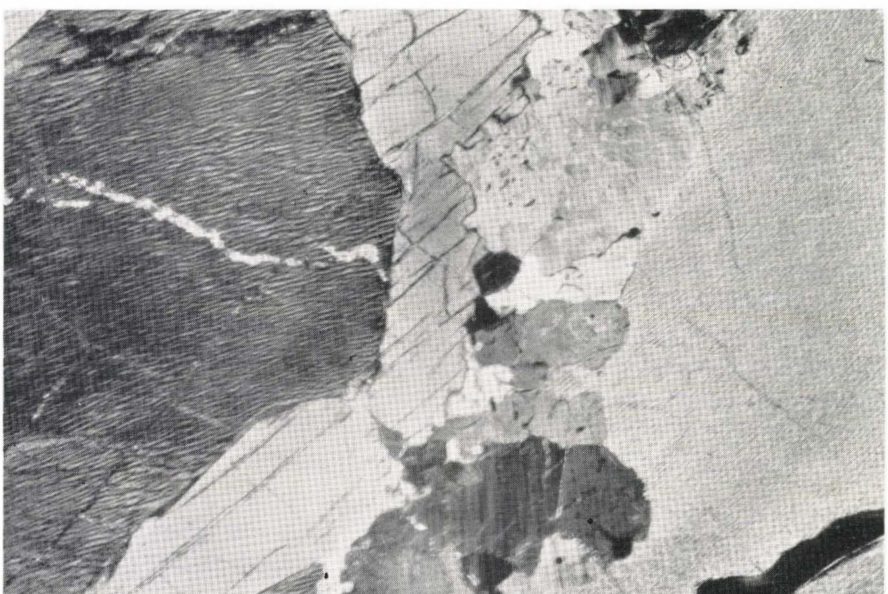

Fig. 2.