BULLETIN 61

Petrology of the Gneisses of Cumberland Sound, Baffin Island, Northwest Territories

G. C. Riley

1960

PETROLOGY OF THE GNEISSES OF CUMBERLAND SOUND, BAFFIN ISLAND, NORTHWEST TERRITORIES

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Plate I. *View looking up Shark Fiord to the northwest, showing steep cliffs, types of exposure and character of coastal topography.*

GEOLOGICAL SURVEY
OF CANADA

BULLETIN 61

PETROLOGY OF THE GNEISSES OF CUMBERLAND SOUND, BAFFIN ISLAND, NORTHWEST TERRITORIES

By
G. C. Riley

DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
CANADA

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PREFACE

During a reconnaissance geological survey about Cumberland Sound the author had occasion to make an intensive study of the gneiss complex widespread in that region.

The conclusions from that study and from the petrographic examination of many specimens are presented in this report and are applicable in many parts of the Canadian Shield.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, October 21, 1959

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Illustrations

PETROLOGY OF THE GNEISSES OF CUMBERLAND SOUND, BAFFIN ISLAND, NORTHWEST TERRITORIES

Abstract

The petrology and petrography of the complex of Precambrian metamorphic and igneous rocks of Cumberland Sound have been investigated. Optical studies of over 400 samples were made and chemical X-ray and spectrographic analyses were obtained.

The rocks are distributed into five orderly arranged metamorphic zones. Pyroxene-bearing, granitic-looking, predominantly massive rocks, classified as charnockites are believed to have been formed by plutonic metamorphism of rocks of high metamorphic facies. They exhibit the highest grade of metamorphism. Rocks in the second zone, called granulites, are divided into five varieties that are all produced by metamorphism under conditions of the granulites facies. Pyroxene-amphibole gneisses are intermediate in composition and metamorphic grade between the granulites and the amphibole-bearing rocks. Epidote-bearing rocks exhibit the lowest grade of metamorphism. Mineral assemblages in aluminum-rich layers were used to help to define the metamorphic facies of the rock groups in which they are found.

Differences in optical properties of potash feldspar, perthite, pyroxene-amphibole and titanium-bearing minerals were recognized in each zone and are related to changes in temperature and pressure. Charnockites probably formed at 650° to 750°C; granulites at 600° to 675°C; and pyroxene-amphibole rocks at 500° to 600°C. It is suggested that the type of potash feldspar and perthite is directly related to the grade of metamorphism. Amphibole and biotite are shown to be stable in charnockites and granulites, and cordierite is not considered alien to the granulite facies.

Résumé

On a fait l'étude de la pétrologie et de la pétrographie du complexe de roches métamorphiques et ignées d'âge précambrien, qui se trouvent dans la région de la baie Cumberland. Plus de 400 échantillons ont été l'objet d'un examen optique, et l'on a obtenu des analyses chimiques ainsi que des déterminations aux rayons X et au spectrographe.

Ces roches se répartissent en cinq zones métamorphiques disposées de façon ordonnée. Des roches en majeure partie massives, riches en pyroxène et d'aspect granitique, ont été rattachées à la classe des charnockites; elles ont été formées, croit-on, par métamorphisme plutonique de roches à faciès hautement métamorphique. Ces roches sont celles qui portent les traces d'un métamorphisme le plus élevé. Celles de la deuxième zone, appelées granulites, se divisent en cinq variétés qui ont toutes été produites par métamorphisme suivant les conditions du faciès des granulites. Quant aux gneiss à pyroxène-amphibole, ils se situent, par leur composition et leur degré de métamorphisme, entre les granulites et les roches à amphibole. Les roches contenant de l'épidote sont celles qui ont été

le moins marquées par le métamorphisme. Les assemblages de minéraux découverts dans les couches riches en aluminium ont aidé à définir le faciès métamorphique des groupes de roches dans lesquels ils se trouvent.

Des différences dans les propriétés optiques du feldspath potassique, de la perthite, de minéraux pyroxène-amphibole et de minéraux contenant du titane ont été notées dans chaque zone; elles se rattachent à des changements de température et de pression. Les charnockites se sont probablement formées entre 650 et 750°C, les granulites, entre 600 et 675°C, et les roches à pyroxène-amphibole, entre 500 et 600°C. On suppose que le type de feldspath potassique et de perthite se rattache directement au degré de métamorphisme. Il est montré que l'amphibole et la biotite sont stables au sein des charnockites et des granulites. D'autre part, la cordiérite ne semble pas étrangère au faciès des granulites.

Chapter I

INTRODUCTION

The area surrounding Cumberland Sound, Baffin Island, is underlain by a complex of rocks, here for convenience called the Cumberland Sound Complex, distributed into orderly arranged metamorphic zones. Five zones are recognized, each comprising various rock types. Each type in general contains some minerals that are common to all or most other types within the same zone. Younger rocks that post-date the development of the zones are briefly described. The purpose of this report is to outline the zonal arrangement, to describe the petrography of each zone, and to discuss some petrological implications of the zones.

Location and Previous Work

Cumberland Sound is a broad, deep indentation into the east coast of Baffin Island just south of the Arctic Circle. Pangnirtung, near the head of the sound, is the main settlement and has a population of about 50, whites and natives.

As may well be imagined, transportation to and from, and in this area is a great problem to both Eskimo and whites. At present, two supply ships visit Pangnirtung yearly in the late summer, and in the autumn a police patrol from Lake Harbour occasionally visits Cumberland Sound. During the winter, dog teams are used to travel between the native villages and/or other major settlements on Baffin Island, and in the period of open water small boats are used along the coast. Canoes with outboard motors are suitable for use along sheltered shorelines, and whale boats and well-decked Peterheads for open water.

Charter or military aircraft are the only means of reaching the area before "breakup". Ski-wheeled Dakotas have been used with great success, depending on the condition of the sea ice, and ski-wheeled Norseman, which may be later fitted with floats, would be of great assistance to a party working in the region.

Numerous scientific expeditions have visited Baffin Island, and in particular, the area of Cumberland Sound. In August 1883, F. Boas landed at Kekerten to begin a year of anthropological studies around Cumberland Sound. Much information of an ethnological and geographical nature was obtained, but little detailed information on the geology. Between 1902 and 1909, scattered observations were made in the Sound by members of Dominion Government expeditions to the Eastern Arctic. In 1903 and 1904, A. P. Low reported on the geology of Kaxodluin, Blacklead, and Kekerten Islands. In 1907, on her way south, the CGS *Arctic* visited Niantilik, Blacklead, and Kekerten, and two years later J. G. MacMillan, as a member of the 1908-09 Dominion Government expedition to the Eastern Arctic, visited Blacklead Island and reported on the geology of a graphite deposit there.

In the autumn of 1925, L. J. Weeks of the Geological Survey of Canada made a short visit to Pangnirtung; he returned the next year with M. H. Haycock to spend a year mapping and investigating the northern part of Cumberland Sound. This was the first organized geological expedition that visited the area; no further geological mapping of the Sound was undertaken until 1951, when a reconnaissance of Cumberland Sound was made by the author for the Geological Survey of Canada. Two years later, in the early spring, an Arctic Institute expedition under Colonel P. D. Baird landed at Pangnirtung. This party was in transit to the Penny Highlands, where they continued a program similar to that started on the Barnes Ice Cap and Clyde River district of northeastern Baffin Island in 1950.

Scope of Investigation and Acknowledgments

Most of the area was mapped for publication on a scale of 1 inch to 8 miles but certain areas were investigated in more detail. Geological work started in April 1951 and continued into October. The geology was mapped by traverses on foot and by canoe and boat, and by these means some 2,000 miles of shore was covered, supplemented by traverses inland. Over 400 thin sections were studied under the microscope and 450 samples in all were collected. X-ray, chemical, and spectrographic analyses were obtained for various minerals.

Grateful acknowledgment is made to Dr. E. H. Kranck of McGill University for helpful and critical comments.

Physiography and Glaciology

The Cumberland Sound area occupies a low trough that decreases in height to the northwest; it is bounded on the southwest and northeast by the higher ground of Hall and Cumberland Peninsulas.

Few large rivers drain directly or indirectly into Cumberland Sound and most of the drainage is accomplished by small streams which, after connecting innumerable chains of small lakes, flow into the fiords and bays. The drainage pattern over the entire area is irregular, although there is a more definite trend in the northwestern part.

Within most of the Cumberland Sound region, a recent and youthful cycle of river erosion has resulted in narrow valleys that are cut into a broad, rolling, old erosion surface. The expressions of the recent youthful cycle of river erosion may differ, depending on the topography features. In the eastern part, for instance, glacial valleys, greatly over-deepened and commonly broad, hold small youthful streams whereas in the uplands other streams barely cut through the light overburden.

The preglacial surface evidently had a dendritic drainage pattern the product of a well-established mature-to-old-age drainage system. The surface was broad and rolling with a low relief, in some respects like a peneplane. Prior to the onset of glaciation, a period of differential uplift commenced. In conjunction with this uplift there was considerable faulting and fracturing, partly along pre-existing rifts, but probably in part new. The streams thus rejuvenated started to modify the older surface and initiate the present-day topography. The surface was then further modified by alpine and continental glaciation.

The effect of ice erosion on the preglacial landform may be observed on the highland, upland, and coastal surfaces. The Penny Highlands and hills in the Popham Bay district show the effect of sculpture and modification by the mountain ice-sheet alpine glaciers. In the lower lying country, evidence may be observed of sculpture by lowland ice-sheets.

The continental ice-sheet must have had a semi-protective effect on the upland surface, but where the local relief was sufficiently great and at or near the margins of the ice-sheet erosion occurred. It is difficult, however, to distinguish between erosional features due to piedmont glaciers and those due to the main ice-sheet. Clearwater and Kangilo Fiords resemble piedmont lakes, but they may have been carved out by the early terminal lobe of the lowland ice-sheet as it advanced towards the Sound.

Lateral moraines lie along many of the walls of the main valley and a few of the tributary valleys in the uplands. Only a few terminal moraines occur in the mountain country, and these are all related to presently active glaciers. A few glaciers advanced locally in recent times, and north of Pangnirtung, in the "Pass", some good examples of moraine-dammed lakes exist. Most glaciers, however, show the effects of strong ablation and retreat.

The adjustment due to deglaciation in the Cumberland Sound district, is illustrated by such features as the Bay Head terraces, terraced deltas and outwash fans, and raised beaches that may be seen along the coast between Kingnait Fiord and Opingivik. Some of these are as much as 200 feet above sea-level. No marine fossils were found.

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Chapter II

GENERAL GEOLOGY

Many types of rock, mostly metamorphic, that range in composition from alaskite to pyroxenite underlie the area. Most of these rock types have mineral compositions, and some textures and structures, that permit their classification into zones. Others cannot be so classified and are probably younger. The zoned rocks are arranged systematically in bands from near the head of Cumberland Sound southward. All rocks in the region except for some late dykes are relatively deformed and all are believed to be of Precambrian age.

Definition and Distribution of Zones

Five zones are recognized, for convenience designated as follows:

Zone of charnockites
Zone of granulites
Zone of pyroxene-amphibole-bearing rocks
Chidliak gneisses
Zone of epidote-bearing rocks (Finger Land and Misty Island gneisses).

Their distribution is shown in Figure 1.

Zone of Charnockites

The zone of charnockites consists solely of charnockitic rocks that, here and there, hold small felsic and mafic inclusions. In decreasing order of abundance, all contain quartz, potassium-feldspar, potassium-sodium perthite, plagioclase (commonly oligoclase), hypersthene, diopside-hedenbergite and titaniferous magnetite with ilmenite. Some contain flakes of graphite; some contain garnet (pyralspite), some do not.

The charnockites mineralogically resemble some of the granulites, but can be distinguished by textural features.

Zone of Granulites

Rocks in the zone of granulites range from felsic to mafic in composition. Minerals characteristic of the felsic varieties are quartz, potassium-sodium perthite, plagioclase (mostly oligoclase), and commonly hypersthene. Minerals characteristic of the more mafic varieties are andesine-labradorite, hypersthene, and diopside-hedenbergite. Titaniferous magnetite is common in both varieties. The following are characteristic mineral assemblages:

1. Quartz-K(Na)perthite-potassium feldspar-oligoclase-pyroxene-biotite (granitic granulite).
2. Quartz-K(Na)perthite-oligoclase-hypersthene-diopside-augite-biotite (granodiorite granulite).

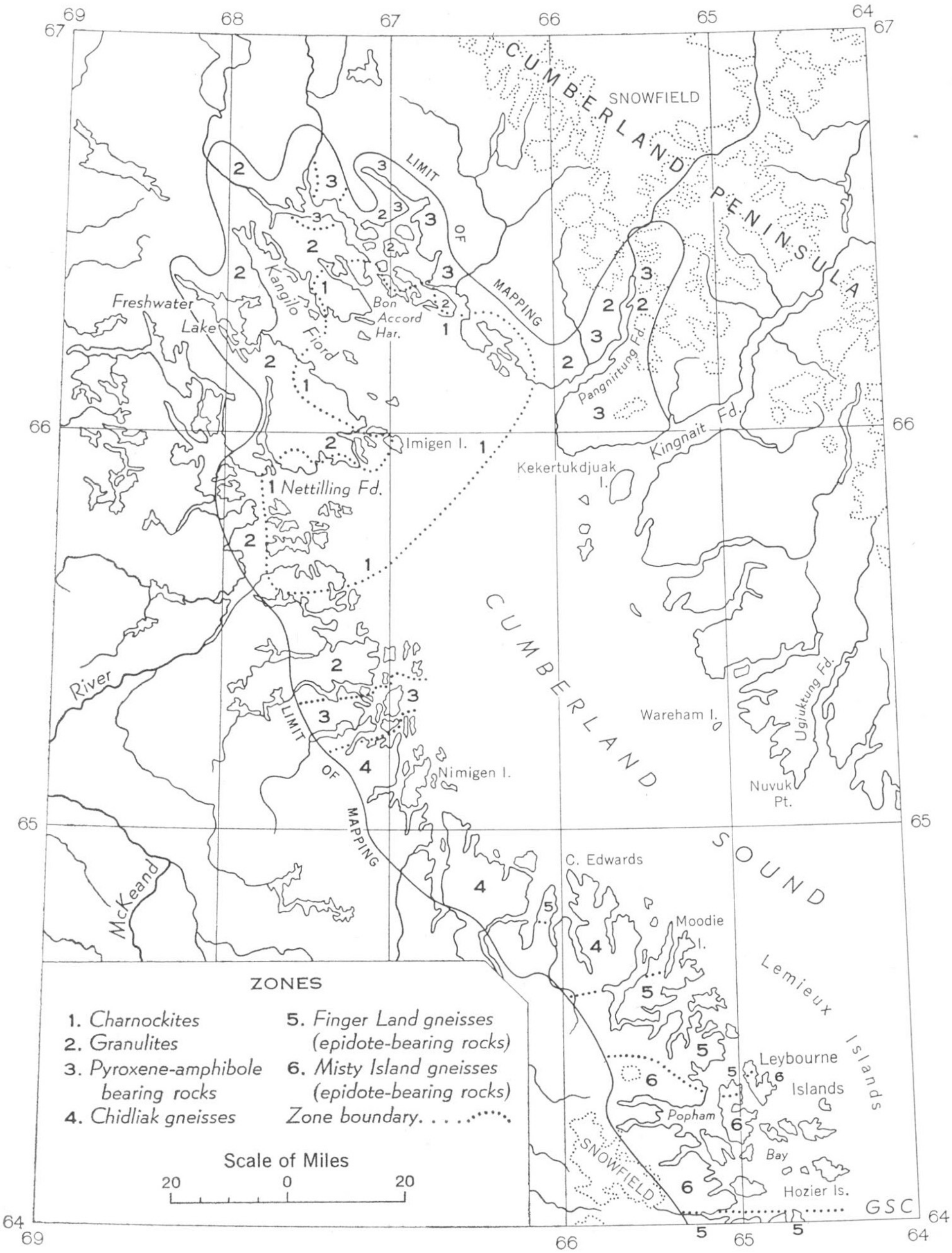

Figure 1. **Distribution of metamorphic zones, Cumberland Sound.**

3. Quartz-potassium and perthitic feldspar-oligoclase-pyralspite-garnet, with or without hypersthene and clinopyroxene (light coloured, quartz-feldspar granulites).
4. K(Na) and microcline perthite-oligoclase-andesine-quartz-hypersthene, with or without cordierite and/or garnet (pyralspite) (mafic granulite with quartz and feldspar).
5. Andesine-labradorite-hypersthene-clinopyroxene-titaniferous magnetite (mafic granulites with little or no quartz).

Associated with the granulites and part of the zone are the following rock types:

1. Quartz-sillimanite-biotite gneiss.
2. Crystalline limestone (commonly containing diopsidic pyroxene).
3. Lime-silicate rocks having the following mineral assemblages:
   3a. Pigeonite-calcite-yellow mica-spinel-apatite.
   3b. Diopside-hedenbergite-K(Na)perthite.
   3c. Cordierite-wollastonite-diopsidic pyroxene-sphene-calcite.

Zone of Pyroxene-Amphibole-bearing Rocks

The zone of pyroxene-amphibole-bearing rocks also ranges in composition from felsic to mafic varieties. The minerals characteristic of the felsic varieties are the same as those that comprise the felsic varieties of the granulites but include water-deficient amphibole and more clinopyroxene. The minerals characteristic of the mafic varieties are andesine-labradorite-diopside-hedenbergite-dark green amphibole. Orthopyroxene is not found in the mafic variety. The following mineral assemblages are characteristic:

1. Microcline and K(Na)perthite-quartz-oligoclase dark green-brown hornblende-biotite-clinopyroxene. (Pyroxene-amphibole granite gneiss.)
2. Quartz-oligoclase-andesine-microcline and K(Na)perthite-dark green-brown hornblende-hypersthene and clinopyroxene-biotite. (Pyroxene-amphibole granodiorite gneiss.)
3. Labradorite-dark green hornblende-diopsidic hedenbergite-biotite. (Pyroxene-amphibole feldspar gneiss.)

Sillimanite-bearing gneiss, associated with the pyroxene-amphibole-bearing rocks in part of the zone, contains the following characteristic mineral assemblage: quartz-K(Na)perthite, K(Na)feldspar and microcline-oligoclase-biotite-pyralspite garnet-sillimanite.

Zone of Chidliak Gneisses

The Chidliak gneisses zone consists of felsic to mafic amphibole-bearing rocks. The minerals diagnostic of this zone are common amphibole, biotite, and sphene. Perthite is absent. The following three rock types were recognized:

1. Rock rich in felsic minerals.
2. Mafic rocks containing felsic minerals.

3. Rocks composed almost entirely of ferromagnesian minerals.

Minerals characteristic of the felsic variety of the Chidliak gneisses are quartz-microcline and/or oligoclase-amphibole and biotite.

Minerals characteristic of the mafic variety are andesine-amphibole minor amounts of quartz. Many of the more mafic varieties are typical amphibolites (more than 90 per cent amphibole). Many contain intercalated layers of graphite.

Part of the zone of the Chidliak gneisses are the following rock types:

1. Sillimanite-bearing gneiss with the following mineral assemblages: quartz-muscovite-biotite-oligoclase-sillimanite.
2. Crystalline limestone, commonly containing tremolite and diopsidic-pyroxene.
3. Lime-silicate rocks with the following mineral assemblages: diopside-tremolite-calcite-plagioclase.

Zone of the Finger Land and Misty Island Gneisses

The zone of epidote-bearing rocks comprises felsic to mafic rock types all of which contain epidote. They may be divided according to the presence or absence of amphibole into two main groups, the Finger Land gneisses and the Misty Island gneisses, respectively. The minerals characteristic of the felsic varieties are quartz-microcline-oligoclase-amphibole, and/or biotite, and epidote; minerals characteristic of the mafic varieties are labradorite-amphibole and/or biotite, and epidote. Sphene is commonly present in both the Finger Land and Misty Island gneisses.

Mutual Relations of Zones

The contact relations between rocks of the charnockite and granulite zones are complex, but of three general types: sharp contacts, layered contacts, fault or shear zone contacts. Moreover in a few areas, such as south of Kudjak, the contact is an arbitrary line drawn on the basis of increasing gneissosity. The first may be seen at the southern tip of the Sanigut Islands, where a sharp contact between gneissic garnetiferous granitic granulite and the main body of massive charnockite is exposed along strike for more than 100 yards. No change in the grain size of the gneissic rock is visible as the contact is approached, but a slight decrease of grain size in the charnockite is visible towards the contact. This decrease is commonly limited to within a few inches from the contact but in places may occur over a few feet. Neither chilled borders nor intrusive tongues were seen. Small metacrysts of green feldspar are developed in the gneiss as far as 10 feet from the contact, most metacrysts having their long axes parallel with the gneissosity. The strike of the contact varies but does not appear to cut the gneissosity. A similar contact relationship occurs south of Bon Accord, between a medium-grained more or less equigranular gneissic granitic granulite and a coarse-grained porphyroblastic charnockite. The grain size of the charnockite decreases towards the contact. Although one-quarter-inch-long metacrysts of feldspar are developed in the granulite for at least 10 feet from the contact, no change in the grain size of the granulite is visible. The contact is marked by an increase in the percentage of ferromagnesian minerals, probably pyroxene, and sometimes by the development of feldspar crystals across the contact. Schistosity parallels the contact, which has a low dip. The contact transects the strike of the gneisses. Parts of the charnockite appear to have been thrust, during some stage, over the granulites in this locality.

The second type of contact is visible in the Livingstone Fiord area. There metacrystic greenish grey charnockites are in bands interlayered with the granulite (Pl. V B). Mixtures are also present in which banded mafic, garnetiferous granulites with quartzo-feldspathic bands contain lenses and layers of charnockite. In part this mixture is intensely folded, grades into a mafic-looking brecciated migmatite, and finally passes into a relatively fine-grained charnockite that still contains prominent bands of mafic granulite.

The third type of contact is widely distributed and commonly marked by, or near, a shear zone. The transition from the granulite zone to the zone of pyroxene-amphibole-bearing rocks may take place over a short distance or through a zone up to three quarters of a mile wide in which the number of pyroxene-amphibole-bearing bands and lenses gradually increases until granulites are no longer present. The position of a contact or isograd between the zones is dependent on the ratio of pyroxene-amphibole-bearing gneisses to granulites and must therefore be arbitrarily selected. Outcrops that show the change from the granulites to the pyroxene-amphibole-bearing rocks are best exposed along the north shore of Clearwater Fiord. Many of these contacts are however vaguely defined and for the most part the rock units are structurally conformable. Both sharp and gradational contacts are present. The former are characteristic of sill-like bands of mafic pyroxene-amphibole-bearing material in the granitic and granodioritic granulites and the latter of the contacts between irregularly shaped masses of granulites in the pyroxene-amphibole-bearing gneisses. At Pangnirtung and within the area of Pangnirtung Fiord, the granulites are either interbanded with or overlain conformably by pyroxene-amphibole granite-gneiss. In many outcrops these contacts are somewhat diffuse.

Pyroxene-amphibole-bearing rocks pass into the Chidliak gneisses over a wide transition zone, in the vicinity of Robert Peel Inlet, although an arbitrary line or isograd has been drawn to indicate the southerly limit of gneisses with pyroxene as a primary constituent. This transition zone is similar to that between the granulites and the pyroxene-amphibole-bearing rocks but, with more field work, a better defined line could be established.

The transition of the Chidliak gneisses to the epidote-bearing rocks of otherwise similar mineral composition and appearance (Finger Land gneisses) is almost imperceptible. South of Ugjuk Island banding possibly becomes less intense, and vein gneiss is perhaps more common.

Description and Distribution of Younger Rocks

Younger rocks, whose emplacement apparently post-dates the development of the zones, consist of fine- to coarse-grained granite, aplite dykes, pegmatite bodies ranging from 3 inches to 4 feet in width, and lamprophyre and diabase dykes. The granite is commonly composed of quartz, microcline, and/or microcline perthite with or without biotite, muscovite, or plagioclase. The diabase consists of labradorite, pigeonite, and augite.

The diabase cuts charnockites, granulites, and amphibole-bearing rocks. Thin fine-grained granite dykes and sills cut charnockites and granulites. Thin, medium- to coarse-grained granite sills and dykes cut epidote-bearing rocks. Pegmatitic and aplitic material is scattered through all the older rocks.

Structure

Although to understand fully the structure of the Cumberland Sound area more detailed work is needed, the region has been divided into four areas with characteristic tectonic features, each related to one or more of the rock groups previously described. They are:

1. The tectonic area underlain by charnockitic rocks.
2. The tectonic area underlain by granulites, and pyroxene-amphibole-bearing gneisses.
3. The tectonic area underlain by the Chidliak gneisses.
4. The tectonic area underlain by the Finger Land and Misty Island gneisses.

Tectonic Area 1

The structures characteristic of this area occur in massive, unfoliated charnockitic rocks. They consist of fractures and faults of unknown displacement.

The faults, inferred largely from aerial photographs, lie mainly in two directions; the more prominent set with a westerly or northwesterly trend, and a second set with a less pronounced northeasterly trend. Most of the faults dip steeply. On one of the few faults seen, on the southern tip of Sanigut Island, striae trending N18°W and plunging 42°N, together with the topographic evidence, indicate that the north side of the fault moved downward. More prominent than the fault pattern is a well-defined vertical joint or fracture system, trending N50°W. A more or less continuous zone of these joints is visible along the northeastern coast of the Sound, from Tesseralik to Shark Fiord, but is more obvious on aerial photographs than on the ground. Intermittent movement must have occurred along this zone, with the latest activity recorded by minute wrinkles on epidote faces along joint planes. Where this zone intersects a well-smoothed and glaciated surface, it appears that some glacial grooves are displaced vertically one eighth to one sixteenth of an inch.

Although foliation in inclusions does not indicate any definite pattern of deformation, in the vicinity of Imigen it conforms to the trend of the adjacent gneisses which is northwesterly, and it is apparent that major deformations have taken place both before and during crystallization. No folded structures are visible in the main charnockitic mass.

Considerable fracturing has probably taken place in comparatively recent time as indicated by displaced, glacial grooves and smoothed surfaces. The author believes that some of this movement took place along pre-existing zones of weakness, developed during previous periods of crustal adjustment.

Tectonic Area 2

Structures characteristic of this area occur in pyroxene and pyroxene-amphibole-bearing rocks. They comprise numerous folds with simple and complex patterns exposed. Structures with simple patterns at the surface are gently plunging closed anticlines and synclines situated some distance away from the charnockitic rocks. Elliptical forms, presumably doubly plunging anticlines, were noticed on aerial photographs in the western interior and in areas in which charnockites are believed to be absent 10 or more miles inland along the western coast of the Sound. The more complex structural areas lie close to the main charnockitic bodies, notably that immediately southwest of the entrance to Shark Fiord. In that area, the folding is almost isoclinal, the fold axes plunge steeply and vary considerably in direction but trend generally northeast. Two different mineral lineations are present. The more prominent lineation trends northwest, the other northeast, with a variable plunge. It was not possible to determine whether these lineations are reflections of two separate periods of deformation, or whether they were caused by only one period of folding.

South of Nettilling Lake, in the vicinity of Opingivik, the trend changes from northeasterly to northwesterly, and the intensity of folding is not as great. Both folds and lineation plunge moderately in a northwesterly direction, reflecting the change in the regional trend. Most of these gneisses are asymmetrically folded and, in some areas, the folds are almost isoclinal. Moderate to steep dips are common, and, in a few localities, strata are overturned. The fold pattern in this region is somewhat similar to that of the Clearwater Fiord district, where gently plunging, closed folds, with two directions of mineral lineation are visible.

As a unit, the trends of structures in tectonic area 2 are northwesterly and northeasterly, with culminations that are common in the areas where the fold axes and lineation plunge gently and where the two trends intersect, as in the vicinity of Shark Fiord.

The topographic expression of faults and fractures in the Clearwater-Shark Fiords region is visible on aerial photographs, and was also noticed during field investigations (*see* Pl. II A). North of Nettilling Fiord, the fault pattern is similar to that found in the tectonic area 1. Actual measurements of relative movement, with few exceptions, are unobtainable. Two major trends are visible. The best developed faults are roughly parallel and have a northwesterly trend and an almost vertical dip. The second set of faults are less well developed and have vertical dips and an almost radial pattern, but have a distinct easterly trend and no apparent focal point. Minor faults, with northerly and northeasterly strikes, are also present. The actual intersection of faults of the two major systems was not seen on the ground, but is inferred from a study of aerial photographs.

Fracture zones, however, are visible on the ground, and, in many areas, are parallel with, and in the same position as, the inferred major faults.

A pronounced shear zone that strikes at N20°E parallel with the gneissosity was seen southwest of the entrance to Shark Fiord. The zone, about 30 feet wide, carries iron sulphide minerals. Lineation in the fault plane plunges at 40° and trends N20°E. The direction of relative movement, however, could not be determined. The fault is on the west limb of a plunging, closed syncline.

The age relationships of the faulting and folding from oldest to youngest are as follows: folding—easterly faulting—northwesterly faulting—north and northeasterly faulting—post-glacial movement along northwesterly zones.

Numerous joints are present in the area, and, like the fracture pattern, a dominant northwesterly and a secondary northeasterly trend are visible. Northerly jointing is common in the Freshwater Lake area.

Forces originating from the southwest and northeast were probably responsible for the fracture system and folds in rocks in tectonic area 2. The deformation could be the result of one or more periods of activity. To produce the fracture pattern, it is necessary to have relatively horizontal compressive forces acting in northeast and southwest directions. Because of the stable charnockitic area, it is probable that a couple was superimposed upon the compressive forces. Later activity followed along pre-existing zones of weakness.

Tectonic Area 3

Tectonic area 3 is the Chidliak gneiss between Opingivik and the northwest shore of Littlecote Channel. It is characterized by gneissosity and lineation with a more or less uniform northwesterly orientation, although the orientation varies somewhat along the southeastern side of Chidliak Fiord. In the northern part of this area, the structure appears to be homoclinal and its moderate westerly dip steepens. The structure probably represents the eastern limb of a large syncline that has a northwesterly plunge of about 45°. Steep and vertical dips are however present at the south end of Robert Peel Inlet, which, together with sheared small-scale drag-folds, suggest that overturning or isoclinal folding has taken place.

The structures in the southern part of area 3 gradually become more complicated. A series of possibly open anticlines and synclines, which strike N45°W, and plunge gently to the northwest, are present along the southeast shore of Ptarmigan Fiord. These folds are probably related to a change of rock type. Closed folds are visible on the northwest side of the Fiord. These folds have a northwesterly strike and a west-northwesterly plunge. Between Niante Harbour and Blacklead Island, fold axes apparently trend and plunge in a northwesterly direction. In this area, severe drag-folding has complicated a previously formed anticlinal-synclinal structure. It is exceedingly difficult to define the attitude of the axial planes of the folds, but both symmetrical and asymmetrical structures are evidently present.

Considerable movement affected the gneisses between Blacklead Island and the mainland. Crests of minute drag-folds in the crenulated mafic gneisses are sheared and filled with granitic material. Bands up to 200 feet thick, with numerous severely drag-folded and overturned layers, are moderately sheared. Lineation on the folds plunges 60° in a northwesterly direction. Another zone of relatively intense shearing with a similar northwesterly trend occurs at the south end of Robert Peel Inlet. East of Chidliak the presence of transverse faults, striking north-northeasterly, is inferred from a study of aerial photographs. However, except for a confused fold pattern, no evidence of faulting is seen along the shore.

Tectonic Area 4

Tectonic area 4 is characterized by generally open folds, commonly trending east or northeast, in the epidote-bearing Finger Land and Misty Island gneisses. The structural pattern between Moodie Island and Cape St. David reflects a considerable change from the northwesterly fold axes in the previous structural area. On the north end of Moodie Island, for instance, a closed, probably overturned, asymmetrical fold trends about N20°E. The north end of this fold is almost isoclinal. It is apparent that its axis as shown on the map has a considerable curve. The direction of lineation, obtained from elongated prismatic and tabular minerals, in the vicinity of Ugjuk Island suggests a northerly or northeasterly trend; the plunge of the fold was not determined.

Numerous small folds between Angmallik Harbour and Hall Island plunge in a southwesterly or northerly direction. A southwesterly trend, prominent south of Finger Land, continues in the region between Misty Island and the southern boundary of the map-area. There the folds have a plunge that steepens in a westerly direction. At Misty Island gently dipping gneisses are folding into a series of symmetrical, probably parallel, anticlines and synclines, trending about N80°E with low easterly plunges. This east-west fold pattern apparently extends into the Leybourne Islands, and then curves to the northeast. Elsewhere in Popham Bay, culminations with northeasterly and southwesterly trending lineations are common, but the position of the fold axes could not be obtained.

With the exception of a northerly striking, vertical fault zone seen west of Angmallik Harbour, the existence of other faults in this area is inferred from a study of aerial photographs. Small shears across crests of drag-folds are numerous in areas where the gneisses are highly contorted, as may be seen in the region west of Hall Island. There, scattered exposures of migmatite are also common.

Chapter III

PETROGRAPHIC DESCRIPTIONS

Zone of Charnockites

Lithological Varieties

The charnockites are divisible into two varieties, those with garnet and those without. The relationship between the two types is obscure, as the two were rarely seen in contact. Where seen, they appear to intergrade. Both coarse- and fine-grained phases occur in each variety. In places these grade into each other and in places the contact between them is sharp. Mixtures of coarse- and finer-grained phases are numerous and in part coarse-grained material holds small inclusions of finer-grained rock (*see* Pl. II B). The fine-grained phase generally however invades the coarse-grained phase. Centred near Usualuk, a coarse-grained inequigranular, more or less massive rock passes gradationally outwards into a finer-grained more equigranular and less massive rock.

Appearance

The charnockites range from medium to coarse grained and are predominantly metacrystic (*see* Pl. III). The average grain size of the matrix in the coarse-grained rocks is one quarter inch, and that of the finer-grained varieties is one eighth inch. In any large outcrop, the rock is predominantly olive-green, but greenish grey, bluish grey, and brownish grey colours are visible in hand specimens. Weathered surfaces are commonly brown. Coarse-grained feldspar segregations occur in a sugary, commonly equigranular groundmass composed of quartz, green feldspar, scattered pyroxene and biotite and black metallic minerals.

Quartz grains are bluish and vitreous. Tabular metacrysts of olive-green or grey-green potash feldspar, up to 5 inches wide and 7 inches long, impart an almost pegmatitic appearance to the coarser-grained varieties, although the average size of the potash feldspar grains is 1½ inches by ½ inch. Metacrysts of plagioclase feldspar with a smaller average size are common, but are not so numerous as those of potash feldspar. The size of the feldspar metacrysts decreases as the grain size of the host rocks decreases to the point where the charnockites may become almost equigranular and fine to medium grained. Small crystals of pink garnet, up to one half inch wide, are scattered through a few of the coarser-grained charnockites. This garnet commonly occurs at the borders of feldspar crystals, and is outlined by a concentration of ferromagnesian minerals that includes biotite. Clusters of semi-angular pink garnet in grains up to one eighth inch in diameter, unassociated with ferromagnesian minerals, occur in extremely felsic varieties of the charnockite. Small flakes of graphite were identified in a few samples, noticeably those from north of Usualuk. This mineral is not present in the charnockites elsewhere, although chemical analysis shows the presence of minor amounts of CO_2.

One of the distinguishing features of the charnockites is their massive texture and general lack of visible foliation and lineation. This is, however, not invariably true for scattered throughout this map-unit are rocks that do possess lineation and a rough banding or foliation imparted by parallel, planar inclusions or lenses. In a few areas the feldspar metacrysts are aligned and, here and there, streaks or schlieren of fine-grained, granitic material are present. The banding is however rarely traceable over more than a few feet, as it becomes distorted or highly diffuse.

Under the microscope, the charnockites are seen to be inequigranular. Coarse, subhedral, leucocratic quartz and feldspar metacrysts are set in a medium-grained, equigranular, granoblastic aggregate of felsic and mafic minerals (*see* Pl. IV). Mortar and sieve structures are numerous, and implication fabric is commonly present. Most samples show slight preferred optical orientation and in some the long axes of minerals are aligned.

Composition

The following minerals were identified in the charnockites. Major constituents: quartz, myrmekite, high temperature orthoclase, K(Na)feldspar, microcline, K(Na)perthite, microcline perthite, plagioclase, antiperthite, pyroxene, amphibole, biotite, garnet; minor constituents: apatite, zircon; ore minerals: titaniferous magnetite, ilmenite, pyrite, pyrrhotite, spinel, graphite; secondary minerals: serpentine, chlorite, biotite, sericite, muscovite, epidote, zoisite, calcite.

The modal compositions of a few of the charnockites were determined by Rosiwal analyses, however certain qualifications must be borne in mind, especially if chemical compositions are to be calculated from the mode. As mentioned, numerous large feldspar metacrysts are present. As it was not practical to include these in the Rosiwal measurements, their contribution to the total mineral composition was computed by estimating their proportion to that of the matrix. Smaller metacrysts were measured by the usual Rosiwal traverses on three or more sections of the same rock, and by averaging the results. The composition of perthite grains was obtained individually under 100X magnification. The refractive indices of the feldspar in the matrix and in the plagioclase blebs were obtained in order to establish the type of potash feldspar and the An content of the plagioclase. It is felt that despite the considerable variation in grain size of the rock, reasonable accuracy was obtained by the use of the Rosiwal method.

Modal compositions of three charnockites are tabulated in Table I, and their chemical composition is listed in Table II.

Table I

Modal Composition of Charnockites

		1	2	3
Quartz		27.7	23.9	29.6
Perthite	K(Na) feldspar	—	42.4	—
		37.0	—	48.3
	Plagioclase	—	12.4	—
Plagioclase (An_{10} to An_{50} mode An_{28})		24.4	11.7	15.9
Pyroxene		8.7	4.4	3.8
Amphibole		—	0.7	1.0
Biotite		0.6	—	—
Magnetite (Ti)		1.3	3.9	1.0
Zircon		0.1	1.0	0.1
Apatite		0.5	0.1	0.1
		100.3	100.5	99.8

Samples 1. Coarse-grained charnockite—Quickstep Harbour (near Usualuk).
Samples 2. Medium-grained charnockite—near Usualuk.
Samples 3. Coarse-grained charnockite—near Nunatak settlement on Nunatak Island.

Table II

Chemical Composition of Charnockites

	1	2	3
SiO_2	66.73	69.6	70.73
Al_2O_3	15.48	13.7	14.29
Fe_2O_3	0.88	2.5	1.02
FeO	3.19	2.2	1.92
CaO	2.60	2.1	1.50
MgO	1.17	0.6	0.64
Na_2O	2.50	3.2	2.54
K_2O	5.66	5.6	6.55
H_2O+	0.30		0.14
H_2O-	0.13		0.14
TiO_2	0.75	0.2	0.44
P_2O_5	0.20		0.22
MnO	0.04	—	0.04
CO_2	0.02	—	—
ZrO_2	0.03	0.7	—
C	0.06	—	—
Total	99.74	100.4	100.17
Sp. gr.	2.66	2.64	2.68

Samples 1. Charnockite—Quickstep Harbour. Analyst: J. A. Maxwell.
Samples 2. Charnockite—near Usualuk—from modal analysis.
Samples 3. Charnockite—near Nunatak. Analyst: J. A. Maxwell.

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Descriptive Mineralogy

Quartz

Quartz varies considerably in grain size and shape. Irregular, blocky grains up to 5 mm across, and lenticular grains up to 3 mm wide by 7 mm long are present in the coarse-grained charnockites. The quartz grains in the finer-grained rocks are correspondingly smaller. Numerous semi-angular to rounded grains have diameters of about 0.2 mm. A few grains have relatively smooth outlines but most are serrated, and consertal fabrics are common. Corrosion shapes, although not numerous, were observed, normally in the form of embayments and by the introduction of foreign material into the quartz grains. Rupture lines, strain shadows, Bohm's lamellae, and granulated borders are common. Undulose extinction is visible in all quartz grains, except in those associated with myrmekite although the intensity of strain varies from place to place. The resulting fabric is however obscured by recrystallization of the quartz during or after the deformation. In many samples for instance, granulated rupture lines and borders are partly healed, and fragments along rupture lines commonly grade into unruptured quartz. Trails of gas bubbles, parallel and subparallel lines of dust particles, and other inclusions, all less than 0.01 mm wide and commonly forming parallelograms, are numerous. The orientation of these probably post-deformation forms shows no consistent relationship to that of the rupture lines or Bohm's lamellae. Although quartz is invariably full of inclusions there is much variation in the amount of foreign material present. Diffuse, dust-like particles are scattered through many of the quartz grains. A few grains, especially in the more felsic varieties of the charnockites, contain numerous acicular inclusions, less than 0.001 mm in width are oriented in a haphazard manner or along the crystallographic axes of the quartz. Quartz also contains inclusions of zircon, apatite, biotite and pyroxene.

The blue colour of the quartz, prominent in hand specimens, is not as intense, or is missing altogether, in thin section. A few of the more intensely blue-coloured grains, although almost free of inclusions, are definitely turbid.

Potash Feldspar

Potash feldspars, free of perthitic structure, are uncommon. They are in anhedral crystals with either sub-angular or blocky outlines. The sub-angular grains are up to 1 mm long and average about 0.6 mm in length; the blocky grains range from 0.1 to 0.6 mm in width, with an average of 0.2 mm. The boundary between the blocky grains and other minerals is sharp but irregular. Twinning is common. Prominent 001 cleavage is developed, and the extinction angles in many grains are anomalous. Identification of the feldspars was established by measuring the index of refraction, by optical methods and by means of the Universal Stage. Three types of non-perthitic potash feldspar were identified, and their optical properties are listed in Table III.

Table III

Optical Properties of Three Potash Feldspars

Mineral	2 V	N_Z	Extinction Angle	System
High temp. K. feldspar	Extremely low, negative	1.53 ± <1.535	⊥ x z ∧ 001 = 90° ± 1° ⊥ x z ∧ 001 = 0° Ca	Monoclinic
K(Na)feldspar.........	−63	1.525 ±	⊥ z x ∧ 001 = 9°	Monoclinic
Microcline...........	−80° ± 1°	1.525 ±	⊥ x z ∧ 001 = 3° ⊥ z x ∧ 001 = 10°	Triclinic

The anomalous 2 V of the high temperature potash feldspar makes positive identification somewhat difficult. These properties are similar to those recorded for sanidine and anorthoclase (Winchell and Winchell, 1951, pp. 275, 276, 286), but lack the characteristic anorthoclase twinning.

Slight variations of the optical properties, commonly in the size of the optic angle, occur in microcline and other differences were noticed in the value of the extinction angle measured against 010 and 001 cleavage in sections normal to the bisectrixes. The values of the latter differed from those listed by Winchell by as much as 3° (1951, pp. 286, 299, 300) for both K(Na)feldspar and microcline. It must be emphasized that there is so little perthite-free potash feldspar in the charnockites that the above data were obtained from extremely few, haphazardly oriented grains.

Plagioclase

Plagioclase feldspars are anhedral to subhedral and have a blocky or tabular outline. Grains range in width from less than 1 mm to more than 4 mm; blebs 0.05 mm in diameter occur in occasional samples. Most plagioclase grains are bent, with curved twinning lines, offset, bent cleavage planes, strain shadows, and slightly granulated borders. Anomalous shadows in progressively zoned grains probably may be attributed to stress. Prominent 001 and 010 cleavages have been developed. Coarse twinning according to the albite, albite-carlsbad, or pericline laws is visible in all sections. Other coarse twinning is rare, but a few examples of twins according to the Mannebach and Baveno laws were recognized. Fine albite twinning is rarely present. Untwinned plagioclase is rare, although in each thin section it comprises 2 per cent of the plagioclase. The width of the twin planes does not appear to bear any relationship to the intensity of straining. Sieve structure is present in some grains. The plagioclase contains inclusions of quartz, zircon, pyroxene, and, in a few sections, clear rounded grains (about 0.05 mm in diameter) of either quartz or albite. In other samples, it contains small aligned inclusions of microcline. The plagioclase commonly contains small clouds of dust-like flakes as well as minute fragments of an opaque black material, probably magnetite or ilmenite.

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The potash and plagioclase feldspars are little altered, indeed the freshness of the plagioclase is characteristic of the charnockites. Brown, dust-like specks are present in the potash feldspar, and both feldspars are slightly sericitized. Minor amounts of calcite, zoisite, and epidote were noticed in a few of the more calcic plagioclases. In a few samples, it is difficult to distinguish epidote that was formed by the breakdown of ferromagnesian minerals from that related to the alteration of calcic plagioclase. The An content of the plagioclase, determined from tables based on other optical properties, shows little difference from that based on the refractive index measurements.

Perthite

Perthite occurs in anhedral to subhedral grains, smoothly outlined and tabular grains (13 by 18 cm) to blockish and irregularly shaped (less than 1 mm at their greatest dimension). Numerous tabular grains, 9 by 3½ mm or as little as one half mm, are present in the coarse-grained charnockites. Sieve structure is a common feature of many perthites, with guests of quartz, pyroxene, zoned or unzoned plagioclase, apatite, and zircon. Cross-hatching, characteristic of microcline, is common, but many grains are untwinned. Zoning or strain shadows are present here and there, and prominent 001 and 010 cleavages are visible in all grains. Alteration is similar to that of the non-perthitic potash feldspars. In many samples, the contact between two or more perthite grains is marked by a concentration of dusty brown coloured flakes. This material is scattered but has subparallel orientation in a few grains. Though normally unaltered, some plagioclase blebs are slightly sericitized. Exsolution perthites are a characteristic of the charnockite but replacement types are rare. Plagioclase blebs are classified in Table IV, and fall closely into Ailling's (1932) divisions. At least four types of blebs are recognized.

Table IV

Classification of Plagioclase Blebs in Perthite

Type	Characteristics
1. Stringlets	(a) Extremely slender, closely spaced needles, double ended or slightly wedge-shaped (0.008 × 0.001 mm) (b) Extremely slender sinuous forms (0.04 × 0.005 mm)
2. Strings	Double ended needles of various sizes; dominant dimensions 0.06 × 0.01 mm
3. Rods	(a) Slightly sinuous irregularly shaped rods (0.04 × 0.02 mm) (b) Rods with rounded ends (0.1 × 0.04 mm); these forms range up to veins 0.6 mm long (Ailling's bands ?)
4. Films	(a) Irregular or semi-rectangular flakes with some interconnection (0.02 × 0.02 mm) (b) Amoebic forms, some vein-like (0.08 × 0.05 mm)

Type 1 (a) is the dominant bleb of the coarser-grained insets, and 1 (b) may or may not be present. All four types are found in the finer-grained perthites. In a few samples, 1 (a) grades into type 2, and 3 (b) is superimposed upon the whole grain. A definite relationship, controlled possibly by temperature, exists between the four types. Type 1 forms early in the crystallization history, followed in successive stages by types 2, 3, and 4. The so-called low temperature patch perthite is rarely found in the charnockites. The direction of orientation of the blebs in the host varies widely. Commonly the blebs are parallel with simple crystallographic planes, but rarely are they parallel with the major cleavages. Types 1 and 2, in a few grains, are parallel with 010 and 001, but normally are parallel with 100 and 110 and frequently at an angle of about 80° to 001 cleavage. Type 3, commonly parallel with 100, is, in a few samples, parallel with 001. Type 4 (a) is commonly parallel with 100 and 110, which, in a few grains, gives rise to a hatched appearance.

Perthites with blebs of types 1, 2, and 3 have almost invariably plagioclase-free outer zones. Zones surrounding inclusions in the perthites are also devoid of visible plagioclase, being particularly wide, round quartz inclusions.

Film perthite has cross-hatch twinning and grades here and there into a patch perthite for which a replacement origin is almost mandatory. These grains have thin rims of soda plagioclase that connect with the patch, vein, and film type blebs within the perthite. Plagioclase in these grains is less than An_{10}.

Table V

Optical Properties of Two Perthites

Material	2 V	N_X	N_Y	N_Z	Extinction Angle
1. K (Na) feldspar............	−60° ± 2°		1.524	1.526	⊥ z x ∧ 001 = 8°
An_{23}......................		1.54	1.544		
2. Microcline.................	−81°			1.525	⊥ z x ∧ 001 = 10°
An_{25}......................			1.545+		⊥ x z ∧ 010 = 81°

1. Perthite soda calculated to range from 21% to 30%; perthite contains 22% plagioclase.
2. Microcline perthite; perthite contains 20% plagioclase.

Anomalous optical properties of charnockitic perthites are numerous; a few of them are listed in Table VI.

Table VI

Anomalous Optical Properties of Two Charnockitic Perthites

Material	2 V	N_Z	Extinction Angle
1......................................	−30°		⊥ optic axis ∧ 001 = 4°
2......................................	+65°	< 1.540	⊥ x z ∧ 001 = 0°

1. Probably a high temperature K (Na) feldspar.
2. This is the only perthite identified with a positive optic angle.

Antiperthites, although common in other charnockitic regions, are rare in the charnockites of Cumberland Sound. Two rock samples, both near the centre of the area, contain minor amounts of antiperthite which usually is less than one per cent of the total feldspar. A few pseudo-antiperthites are probably replacement features caused by the introduction of a less calcic feldspar into the host plagioclase.

Antiperthite contains flakes of potash feldspar, commonly tabular, up to 0.8 mm by 0.1 mm, orientated parallel with 010. These flakes are not connected to the borders of the host. In a few samples, they are finely perthitic or microperthitic, and normally have a large negative optic angle. These potash flakes comprise less than 10 per cent of the antiperthite. The host varies in shape, size, and amount of An. In a single sample, however, the An content of the host is the same as that of the non-antiperthitic plagioclase.

Myrmekite

Myrmekite, intergrowths between quartz and plagioclase, and ropy intergrowths at boundaries between plagioclase and perthite, especially when in close proximity to quartz, are common features in the charnockites. A ropy, vein-like growth, up to 1 mm wide, composed of rounded 0.02 mm grains of intimately mixed quartz and feldspar, occurs in a few samples. In part myrmekitic material in vein-like forms about 0.05 mm wide defines the contacts between adjoining perthite grains. Wherever ropy structure is present, quartz eyes are found in a plagioclase host.

Pyroxene

Orthopyroxene and clinopyroxene grains vary in shape from subhedral, tabular to anhedral, blocky and range from 0.2 to 3 mm in length and from 0.2 to 1 mm in width. They may assume peculiar shapes with irregular outlines at contacts between quartz and feldspar or they may cut sharply into the felsic minerals. Pyroxene is commonly poikilitic, containing inclusions of quartz and apatite. Intergrowths of orthopyroxene and clinopyroxene are common. Clinopyroxene occurs as thin lamellae or bands oriented parallel with 010 in the rhombic host. Another type of intergrowth, perhaps due to successive recrystallization, is in the form of orthopyroxene kernels enveloped by rims of clinopyroxene. In some sections the two types of pyroxene occur as semi-angular individual, but intimately mixed, grains. The boundary relationships suggest that the orthopyroxene started to form slightly before the clinopyroxene.

Both pyroxenes are untwinned. Schillerization of orthopyroxene is common, and both pyroxenes are associated with subhedral to anhedral grains of titaniferous magnetite which form along parting and cleavage planes and at crystal boundaries. Some clinopyroxene envelops kernels of subhedral iron oxides but the metallic minerals are more commonly associated with orthopyroxene.

The pyroxenes show various degrees of alteration, ranging from grains in which no trace of the original mineral remains to those that are unaltered. Serpentinization of both pyroxenes is common. Some pyroxene is replaced by serpentine which, in part, is altered to a green chloritic mass. In a few samples, minor amounts of biotite and brownish green amphibole grow from both the serpentine and chlorite. Minor amounts of epidote are associated with a few of the serpentinized pyroxenes.

Table VII

Optical Properties of the Pyroxenes in the Charnockites

Material	2 V	N_Z	Extinction	Pleochroic Formula
1. Ortho....................	–65	1.705	parallel	x = brilliant pink
Ortho....................	–56	1.730	parallel	y = pale pink
Ortho....................	–50	1.728	parallel	z = green
2. Clino....................	+64	1.730	z ∧ c = 45°	x = pale green
3. Clino....................	+60	1.73+ 1.728	z ∧ c = 47°	y = pale green z = green

1. The orthopyroxenes range from En_{70} to En_{50} (Kennedy, 1947, p. 564).
2. These properties approximate those of a pyroxene with augite tendency in diopside-hedenbergite series with diopside $_{45}$ hedenbergite $_{55}$ (Winchell and Winchell, 1951, pp. 410, 413).
3. These properties approximate those of a pyroxene similar to (2) with diopside $_{40}$ hedenbergite $_{60}$ (idem).

Amphibole

The amphiboles characteristically are deep brownish green, strongly pleochroic, and unaltered. They are in slightly larger grains than the pyroxenes and comprise less than 2 per cent of the typical charnockite. They are late minerals in the crystallization sequence and are normally later than the main deformation.

Table VIII

Optical Properties of Amphiboles in the Charnockites

Mineral	2 V	N_X	N_Y	N_Z	Extinction Angle	Pleochroic Formula
1............	–50°	1.687	1.695	<1.705	z ∧ c = 18°	x = pale yellow-green y = brownish green z = dark brown-green
2............	–68° to –71°		1.680	1.685	z ∧ c = 16°	x = yellow-green y = brownish green to pale brownish green z = brownish green to dark olive-brown
3............	+86°			1.645	z ∧ c = 27°	x = yellow-green y = light brown-green z = brownish green

1. and 2. These properties are similar to those of abnormally water-deficient hornblende (Kunitz, 1930, p. 206; van de Putte, 1939, p. 14).
3. These properties are similar to those of hastingsitic amphibole (Winchell and Winchell, 1951, p. 435).

Commonly they envelop a few euhedral crystals of quartz, grains of potash and plagioclase feldspar and pyroxene, serpentine, and chlorite. Amphibole is closely associated with the alteration products of pyroxene.

Biotite

The biotites are dark coloured with vivid pleochroism, and are unaltered. They are in anhedral grains up to 0.7 by 1 mm, and 0.01 mm inclusions of either rounded or euhedral zircons, and small eyes of quartz and feldspar are common. A few grains are strained and exhibit bent and fractured cleavage. Pleochroic haloes around inclusions of zircon are a common feature; the size of the inclusions is not related to the intensity of the halo. Bleached biotites, and a few unbleached grains associated with iron oxides, have slightly chloritized borders. The relationship between iron oxides, serpentine, and biotite is difficult to establish. Biotite when found in conjunction with the breakdown of pyroxene is in contact with 0.01 mm fragments of serpentine, and with pyroxene. When biotite grows out of serpentine directly, iron oxides are at a minimum. Rarely a fibrous variety of mica is intergrown with iron oxides and serpentine. In a few samples, where a relatively large amount of iron oxides is associated with unserpentinized pyroxene, a deep reddish brown biotite cuts the pyroxene, and the boundary between the two minerals is marked by a concentration of iron oxides. In these samples, the cleavage in the biotite is bent and pleochroic haloes are common.

Biotite also envelops cuts, and in one sample, probably replaces garnet, although in a few samples garnet envelops fragments of biotite.

Biotite, as a primary late mineral, normally crystallizes at the boundaries of quartz and feldspar grains. Its optical properties (*see* Table IX) are those of an iron-rich mica (Winchell and Winchell, 1951, pp. 374, 375).

Table IX

Optical Properties of Biotite in the Charnockites

2V	N_Z	B	Optic Plane	Pleochroic Formula
−10°	1.645+	0.05	parallel with 010	x = yellow-brown, yellow-green, or yellow y = reddish brown z = dark reddish brown or dark olive-brown

Garnet

Garnet normally is related to the lighter coloured rocks which, in many areas, are near the boundary of the charnockites. It is light pink and commonly in anhedral, irregularly outlined grains that vary in size. The grains range from 0.7 mm to more than 3 mm in length. Curved parting and fracture planes are numerous, and many of them are filled with veins of biotite up to 0.02 mm wide. Sieve structure is well developed in a few grains, and most grains contain inclusions of one or more of the following minerals: euhedral quartz, perthite, plagioclase, iron oxides, zircon and apatite. Garnet does not show helicitic structure or other evidence of rotation, although, in a few samples, adjacent grains of quartz and feldspar are moderately deformed. Garnet, commonly ringed by biotite and chlorite, does not show reaction rings when in contact with feldspar.

The mineral is isotropic, and has a refractive index of 1.790+ and a specific gravity of 4.07. These properties indicate pyralspite trending towards a lime-bearing pyrope-almandine (Winchell and Winchell, 1951, p. 485; *also* Kennedy, 1947, pp. 570-573).

Accessory Minerals

Apatite, a common accessory mineral, occurs in all the charnockitic rocks. It is commonly in euhedral grains but some are rounded and semi-rounded. Needle-like forms are numerous. Apatite ranges in size from rounded grains 0.1 mm across to prismatic grains up to 0.3 mm wide by 1.2 mm long. It forms inclusions in all minerals of the charnockites, and, except for some zircon, is itself free of inclusions.

Zircon, another common accessory mineral, is found in many of the charnockites. The mineral varies in size and shape ranging from rounded grains 0.05 mm in diameter, to euhedral, prismatic crystals up to 0.4 mm wide by 1 mm long. The rounded grains are characteristically metamict, and commonly zoned. This type of zircon, in many samples, is enveloped by euhedral apatite. Euhedral zircon is zoned and unaltered and, in one sample, contains a rounded grain of apatite. Euhedral apatite and zircon are contemporaneous.

Ilmenite, titaniferous magnetite, and magnetite are scattered through the charnockites as individual grains or as veins up to 0.03 mm wide. The grains vary in size and shape, but are dominantly anhedral, irregularly outlined, and range from 0.01 mm granules to sinuous blebs more than 2 mm in length. The metallic minerals are commonly associated with pyroxene, amphibole, and the alteration products of pyroxene. Where occurring as inclusions in pyroxene and amphibole, they are irregularly scattered through the minerals or are confined to cleavage planes.

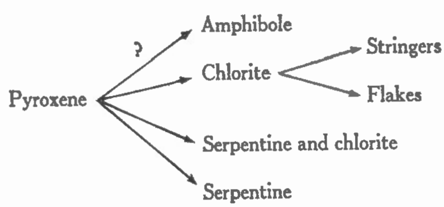
Pyrite and pyrrhotite are uncommon; they are in anhedral grains, irregular in outline and less than 0.5 mm in width. These minerals are associated with ilmenite and magnetite, but are not related to the alteration products of pyroxene.

Secondary Minerals

The charnockites normally are only lightly altered with some breakdown of the pyroxene and a late alteration of potash and plagioclase feldspar. Serpentine is the most common mineral developed by the alteration of pyroxene, and is closely associated with chlorite and an olive-green biotite. It is normally orange-brown and forms veins or fibrous mats. All stages of the alteration of pyroxene to serpentine are present. General serpentinization is related to both cleavage and crystal planes, but the veins are not confined to the cleavage of the pyroxene, although the metallic minerals commonly associated with serpentinization are concentrated along cleavage planes and the borders of the mineral.

Chlorite, in a few samples, replaces the borders of pyroxene grains and, in some, most of the grain. It is however more commonly related to serpentine, and occurs in many samples between grains of serpentine and perthite. Where pyroxenes are mostly enveloped by perthite or plagioclase, chlorite is prominent, but where pyroxene is surrounded mostly by quartz, serpentine is the common alteration product. Serpentine otherwise is normally related to orthopyroxene and chlorite to clinopyroxene.

The alteration of pyroxene is graphically shown as follows:



Minor amounts of sericite and possibly kaolinite are present, and plagioclase, where in contact with pyroxene, may be partly replaced by chlorite.

Inclusions

Inclusions of various compositions are present at different places but those at Quickstep Harbour are typical. Two types occur there:

1. Mafic inclusions, rich in garnet and mica, elliptical with long diameters up to 6 inches and with both sharp and gradational contacts.
2. Felsic inclusions, granitic in composition, in lenses or blocks up to 1 foot wide (*see* Pl. II B) or resembling semi-angular boulders up to 4 feet wide. In many places they appear to grade into the country rock.

The mafic inclusions resemble in appearance and in many mineralogical aspects the mafic granulites, and the felsic inclusions in many respects resemble the granodioritic granulites. The inclusions are most plentiful near the contact between the charnockites and granulites.

Mafic inclusions in the charnockites, commonly fine grained and dark coloured, are finer grained than the host rock but mineralogically they are similar. The light coloured felsic inclusions, in many localities, are sugary and they too are finer grained than the host rock. Both are holocrystalline and granoblastic and exhibit a sutured texture.

Table X

Range of Modal Composition of Inclusion in Charnockite

Mineral	Felsic %	Mafic %
Quartz	40—55	0—25
Myrmekite	< 1—2	0—5
Orthoclase and microcline perthites	35—50	0—45
Plagioclase	0—20 (An_{35})	15—70 (An_{32-37})
Pyroxene	—	1—14
Amphibole	—)	0—1
	0—5)	
Biotite	—)	0—15
Garnet	0—5	5—10

Quartz grains are commonly embayed. The perthites, where in contact with each other, have intensely serrated mutual borders and are commonly enveloped by 0.08 mm rings of soda feldspar. Alteration of the feldspar is more intense than in the charnockites. A brown, dust-like material renders the potash feldspar almost opaque, and saussuritization of plagioclase is common. Chlorite has formed at the contacts between plagioclase and perthite. The optical properties of pyroxene in the inclusions are shown in Table XI.

Table XI

Optical Properties of Pyroxene in the Inclusions in Charnockite

Mineral	2 V	N_z	Extinction
Pyroxene[1]	–51°	1.725	parallel

[1] $Enstatite_{55}$ $hypersthene_{45}$ (Kennedy, 1947, p. 564).

Zone of Granulites

The granulites are divisible into five varieties as follows:

1. Granitic granulite
2. Granodioritic granulite
3. Quartzo-feldspathic granulite
4. Mafic granulite containing quartz and feldspar
5. Mafic granulite containing little or no quartz (black granulite).

Associated with these are:

1. Sillimanite-bearing gneiss
2. Crystalline limestone
3. Lime-silicate rocks.

The granitic granulites exhibit sharp and gradational, conformable contacts, and both ill-defined and sharp, nonconformable contacts with the granodioritic granulites, and are in fault contact with the black granulite at one locality.

The granodioritic granulites commonly grade into the other varieties although sharp and ill-defined transgressional contacts are present. Even within the banded granodioritic unit, gradational changes were noticed between its component bands.

The quartzitic and siliceous mafic granulites are not in contact with the black granulite but it is possible that the mafic granulite with quartz contains lenses or bands of the black granulite or is cut by them, but, as the two are so alike, this was not recognized. The sillimanite-bearing gneisses are in sharp contact with, and structurally conformable to, the granodioritic granulites.

Crystalline limestone is in contact with garnetiferous granitic and granodioritic granulites. Most of the skarn rocks are associated with the crystalline limestone but some lime silicate schists and gneisses are unrelated to any recognizable carbonate rocks. Only a little of the schists and gneisses was found, but more may be present although not observed because of the scale of the investigation.

The skarn rocks, present near all outcrops of crystalline limestones, are either next to or at most not far from the limestones. Where adjacent to them, they form a buffer between the enclosing gneiss and the limestone. The contact between the skarn and the gneiss is gradational, although in some places, for example south of Kudjak, a baked contact was seen. In this same area, it is evident that much assimilation has taken place. The width of the lime-silicate bands ranges from a little more than an inch to about 50 feet. Commonly the skarn bands are narrowest where thick bands of crystalline limestone are present. The band of crystalline limestone at Freshwater Lake for example is more than 100 feet thick, and the skarn band is extremely thin. Elsewhere, where the bands of marble are less than 6 inches thick, the bordering skarn bands are up to 10 feet wide.

The structural trend of the carbonate zones normally conforms to the regional trend, but, in some areas the effects of flowage folding have confused the picture.

Granitic Granulites

Appearance

The granitic granulites appear equigranular in hand specimens and are commonly medium grained (*see* Pl. V A). They are mostly massive although faint banding and linear structures are present. Fresh surfaces of the rock are mostly light coloured with a pale pink tinge, but darker varieties are present. Weathered surfaces are commonly reddish and crumbly. The quartz grains are normally vitreous and greyish and some assume a lens or plate-like form. Feldspar, predominantly pale pink, is commonly tabular, but, in a few localities, is augen-shaped.

Under the microscope, the granitic granulites are predominantly inequigranular and are comprised of coarse-grained quartz and feldspar set in a medium-grained, equigranular, granoblastic groundmass of quartz, feldspar, and ferromagnesian minerals. Mortar structure is common and a few sutured grains were seen. Here and there, granulation and slight recrystallization have occurred. Preferred optical orientation is present in all samples but mineral alignment is only faintly developed.

Composition

The following minerals were identified in the granitic granulites. Major constituents: quartz, myrmekite, K(Na)feldspar, microcline, K(Na)perthite, microcline perthite, plagioclase, pyroxene, biotite; accessory minerals: apatite, zircon; ore minerals: magnetite, ilmenite; secondary minerals: amphibole, serpentine, chlorite, muscovite, sericite, epidote, albite, calcite.

Table XII

Range of Modal Composition of Granitic Granulites

Mineral	%	Typical %
Quartz	30—45	35
Potash feldspar, including perthite	5—55	40
Plagioclase (An_{15} to An_{38}, mode An_{28})	5—60	15
Ferromagnesian minerals	5—15	10

Descriptive Mineralogy

Quartz

Quartz grains are strained with numerous Bohm's lamellae, strain shadows, and rupture lines. In many samples mortar structure occurs along grain borders, and minor healing is evident. Scattered ropy intergrowths are present between grains of quartz and potash feldspar.

Plagioclase

The plagioclase, like that in the charnockites, is anhedral and strained grains with bent and fractured cleavage and anomalous shadows and extinction are numerous. Prominent 001 and 010 cleavage has been developed together with normal, parallel, and particularly complex twinning. The plagioclase is slightly altered to sericite and a little sassurite.

Perthite

The perthite is similar to that in the charnockites, although a few grains have rims of clear potash feldspar or clear plagioclase (An_{15}). Inclusions of zircon and plagioclase are scattered through the perthite.

Pyroxene and Biotite

The pyroxene is diopsidic, grading towards jadeite. It is altered to serpentine, chlorite, and, less commonly, amphibole.

Biotite is similar in habit to that found in the charnockites, and is characterized by its brownish red colour.

Granodioritic Granulites

Appearance

Granodioritic granulites, commonly equigranular in hand specimens, are medium grained, but both coarse- and fine-grained types are present (*see* Pl. VI A). Fresh surfaces are brownish green and light brown weathered surfaces are common. Quartz grains are vitreous and many are bluish. They commonly assume a lens or plate-like form. Feldspar is normally olive-green although lighter coloured grains are present. Scattered, black ferromagnesian minerals commonly impart a salt-and-pepper appearance to the rocks, but, in many samples, a rude banding or segregation is more prominent. Mineral lineation is a dominant feature and foliation may or may not be present. Relict structure resembling crossbedding and bedding planes, though rare, are present.

Under the microscope, the rocks are seen to be coarse to fine grained and granoblastic. The groundmass is composed of quartz, feldspar, and ferromagnesian minerals through which are scattered slightly larger, irregularly shaped grains of quartz and feldspar. Mortar structure and granulation are common, and sutured contacts, with minor replacement, can be seen in most sections. A preferred optical orientation is a normal feature, but mineral alignment is not obvious in thin section.

Table XIII

Rosiwal Analysis of Granodioritic Granulites

	Modal Composition					Chemical Composition Computed from No. 5	
Mineral	1	2	3	4	5	Oxide	%
Quartz	28.4	30.8	24.8	41.6	28.5	SiO_2	70.8
Myrmekite					3.8	Al_2O_3	11.1
K (Na)feldspar+microcline		5.6				Fe_2O_3	1.1
K(Na)feldspar+microcline perthite range in rock 1.9-40	33.6	25.6	53.5	34.1	43.9	FeO	6.0
Plagioclase range An_{9-50} mode An_{33}	32.2	29.4	16.1	21.8	1.9	CaO	0.6
Pyroxene	4.2	1.6	4.0	0.7	13.3	MgO	2.4
Amphibole			0.7			Na_2O	1.4
Biotite	0.9	7.0		1.0	6.8	K_2O	6.4
Magnetite—ilmenite	0.5	trace	0.7	0.5	1.8	H_2O	0.1
Apatite	trace	trace	0.1	trace	trace	TiO_2	0.1
Zircon	0.1	trace	0.1	0.3	trace	P_2O_5	trace
Total	99.9	100.0	100.0	100.0	100.0	ZrO_2	trace
Sp. gr.	2.64	2.66	2.65	2.63	2.68	Total	100.0

1. Granodioritic granulite, Pangnirtung Fiord
2. Granodioritic granulite, Tesseralik
3. Granodioritic granulite, Shark Fiord
4. Granodioritic granulite, Kangilo Fiord
5. Granodioritic granulite, Shilmilik Bay

Composition

The following minerals were identified in the granodioritic granulites. Major constituents: quartz, myrmekite, K(Na)perthite, microcline perthite, sanidine, K(Na)feldspar, microcline, plagioclase, antiperthite, pyroxene, biotite, garnet; accessory minerals: zircon, apatite; ore minerals: magnetite, ilmenite, pyrite, pyrrhotite, green spinel; secondary minerals: amphibole, serpentine, chlorite, biotite, sericite, muscovite, kaolinite, epidote, leucoxene.

Modal Rosiwal analysis of five granodioritic granulites and a chemical composition computed from modal analysis No. 5 are given in Table XIII.

Descriptive Mineralogy

Quartz

Coarse and medium, blocky quartz grains are common. The borders of most grains are serrated and granulated, but a few are smooth. Quartz is strained and Bohm's lamellae, ruptured lines, and strain shadows are present in all samples. The intensity of granulation and the degree of healing vary. Trails of minute inclusions cut across rupture lines without dislocation. Needle-shaped inclusions, 0.001 mm long, probably rutile, are common.

Potassium Feldspar

Non-perthitic potash feldspar is uncommon, but microcline, K(Na)feldspar, and, in one sample only, sanidine were identified. They are in medium-to-fine anhedral grains, with smooth and, here and there, serrated outlines. Cleavage along 001 is prominent. Grid twinning is common in microcline, but no twinning was observed in either the K(Na)feldspar or sanidine. Anomalous extinction is common in microcline. The K(Na)feldspar and microcline, in a few samples, are enveloped by microperthite, and some cross-hatched microcline grades into an untwinned perthitic microcline.

The optical properties indicate the presence of 25 per cent $NaAlSi_3O_8$ in the K(Na)feldspar. This percentage of soda together with the anomalous extinction suggests the presence of cryptoperthite in the potash feldspars, however the anomalous extinction angle may be due to strain.

Plagioclase

The plagioclase feldspars are in anhedral, coarse to medium-sized grains with blocky shapes or in fine grains with irregular margins. They show the effects of deformation, such as bent or displaced cleavage, strain shadows, and granulated borders. Cleavages 001 and 010 are well developed. Albite and albite-carlsbad twins are common, but many grains are untwinned or, rarely, incompletely twinned. Inclusions, other than a few 0.5 mm fragments of microcline perthite, are uncommon. Many lightly sericitized grains of plagioclase are enveloped by rims of unaltered, more sodic plagioclase. Zoned plagioclase is rarely present.

Both potash and plagioclase feldspars are little altered, but much of the plagioclase is incompletely sericitized. Albitization is rare, but a fine, dust-like growth is noticeable in many of the grains.

Perthite

Perthites occur in large to small anhedral, smooth, serrated, or irregular grains. Sieve structures are common. Inclusions of quartz, pyroxene, biotite, plagioclase, zircon, apatite, and black metallic minerals are numerous. The inclusions of quartz and pyroxene range from anhedral to subhedral and have cross-sections measuring from 0.01 to 1 mm. The plagioclase grains, commonly 0.5 mm in width, are irregularly shaped. Many perthites are untwinned, but cross-hatch twinning is common. A few grains are zoned and many perthites are enveloped by rims of clear or cryptoperthitic potash feldspar. Anomalous extinction, due to stress, is present in a few samples.

Alteration of the perthites is not extensive. A brown, dust-like material, probably kaolinite, is scattered through most grains and many plagioclase blebs are lightly sericitized.

The classification of the perthites in the granulites is similar to that in the charnockites. Stringlets, strings and rods are common. Film perthites are more numerous than in the charnockites, and a few patch perthites are present.

Perthite cuts or replaces plagioclase and is replaced, in part, by myrmekite. The relationship between perthite and non-perthitic potash feldspar is obscure.

Antiperthite

Antiperthites are slightly more numerous than in the charnockites. They are in anhedral, medium-to-fine, irregularly shaped grains. Cleavages along 001 and 010 are prominent. Albite twinning is common; zoning is rare but anomalous extinction due to stress is visible in many grains, especially those with bent and fractured cleavage planes and twin traces.

Potash feldspar in the antiperthites occurs as irregular or tabular-shaped flakes or as needles up to 0.01 by 0.4 mm in dimensions. The flakes are normally oriented roughly parallel with the 010 cleavage and the needles with either 010 or 110 plane of the host. Both types of antiperthite have potash-free rims. Some antiperthite contains flaky blebs of potash feldspar.

The potash components are not twinned, show no cleavage, and possess a large negative optic angle. The An content of the plagioclase host is slightly different from that of the potash-free plagioclase. It ranges from An_9 to An_{38}, and is normally An_{28}, whereas the potash-free plagioclase ranges from An_{20} to An_{50} and is normally An_{33}. Minor amounts of sericite and possibly kaolinite are present in the antiperthite, but the alteration is not extensive and most grains are unaffected.

Myrmekite

Myrmekite is common at the contacts between quartz and plagioclase and between perthite and plagioclase. It also occurs near quartz, and, in a few samples, it is associated with late albite.

Pyroxene

Major amounts of orthopyroxene and minor amounts of clinopyroxene are scattered through all samples. Both types are in fine anhedral grains with blocky or tabular shapes. Many grains are poikilitic. Cleavage 110 is well developed, diallage is common, and twinning is rare. Schiller structure, probably due to inclusions of titaniferous material, in part rutile, is common in many orthopyroxenes. Titaniferous iron oxides are associated with both orthopyroxenes and clinopyroxenes. Intergrowths occur in many samples, and lamellae of diopsidic pyroxene have formed parallel with the 010 axis of the host orthopyroxene. This is similar to the banded intergrowths of pyroxene in the charnockites.

Although most of the pyroxene is unaltered and its breakdown rarely complete, serpentine was seen in most samples. The sequence of alteration of pyroxene and associated plagioclase is simplified as follows:

$$\begin{tikzcd}
 & & \text{Serpentine in contact with chlorite} & \\
\text{Pyroxene} \arrow[r] \arrow[ddrr] & \text{Amphibole} \arrow[ur] \arrow[dr] & & \\
 & & \text{Chlorite} \arrow[r] & \text{replaces plagioclase} \\
 & & \text{Serpentine} &
\end{tikzcd}$$

The optical properties of the orthopyroxene are those of hypersthene (50 to 60 per cent $FeSiO_3$), and those of the clinopyroxenes indicate both diopsidic material and augite ($Ca_{32}Mg_{42}Fe_{26}$).

Amphibole and Biotite

Some of the amphibole and biotite present may be of primary origin, but most of it is the product of alteration or recrystallization. The primary amphibole and biotite are optically similar to those with a low OH content found in the charnockites. Both these minerals are in areas adjacent to pyroxene-amphibole-bearing gneisses, although biotite is more widespread. This mineral formed late in the crystallization sequence, commonly abutting quartz and feldspar, and some contains fragments of the felsic minerals. It is also closely related to iron oxides, commonly enveloping them.

Garnet

Anhedral pink garnet grains with irregular outline are scattered through a few samples. They have the following optical properties: N=1.800; sp. gr.=3.99, which suggest pyralspite trending towards lime-bearing pyrope-almandine (Winchell and Winchell, 1951, p. 485).

Quartzo-Feldspathic Granulites

Appearance

Rocks of this division are predominantly light coloured, although a few darker coloured bands occur in places along the shores of Pangnirtung Fiord.

The light coloured rocks are fine to medium grained, commonly equigranular and banded (*see* Pl. VI B). They are composed primarily of quartz, potash and plagioclase feldspar, and garnet. Some of these rocks contain features resembling original bedding, and in a few localities are associated with sillimanite-bearing gneiss. Outcrops resembling deformed conglomerates with both rounded and elongated pebbles were found at two localities.

The dark bands, fine grained and equigranular, are composed primarily of pyroxene and green feldspar. They have been placed in this division because of features resembling bedding and crossbedding. These rocks are foliated and commonly lineated. They are not banded but normally exist as part of a banded formation or as a single unit in another rock type.

The quartz grains are bluish and vitreous. Tabular, white feldspar crystals, up to one half inch wide, are visible. Clusters of pink garnet, up to one half inch wide, and single garnets, more than one quarter inch across, are numerous.

Microscopically, rocks of this division are inequigranular and are composed of medium-sized grains of quartz, perthite, plagioclase, and garnet, set in an equigranular, fine- to medium-grained, granoblastic matrix of quartz and feldspar. Grains of pyroxene and biotite are scattered through the lighter coloured rocks. Porphyroblastic structure is visible in a few samples. Rounded and sutured grains are numerous and granulation with later recrystallization is noticeable. Mineral alignment and a slight preferred optical orientation are visible in most thin sections.

Composition

The minerals identified in this division are similar to those found in the granitic granulites.

Table XIV

Range of Modal Composition of Quartzo-Feldspathic Granulites, Light Coloured Variety

Mineral	%	Typical %
Quartz	25—74	45
Potash feldspar including perthite	10—55	26
Plagioclase (An_{18} to An_{32} bi-modal An_{20} and An_{30})	0—35	24
Ferromagnesian minerals and garnet	1—15	5

Descriptive Mineralogy

Quartz

Most of the quartz grains are anhedral and have irregular outline, but a few are rounded. They contain trails of inclusions consisting of curved or straight, semiparallel or parallel lines of minute bubbles or needles. Most grains are deformed but a few are not strained and appear to be secondary or the result of post-stress recrystallization.

Feldspar

Non-perthitic potash feldspar is rare. Replacement perthite is found in one sample with blebs of plagioclase (An_{21}) in K(Na)feldspar host.

Pyroxene

Anhedral orthopyroxene and clinopyroxene are common in the darker coloured rocks of this division and rare in the lighter coloured rocks. Clinopyroxene is dominant and intergrowths of the two do not occur. Rounded grains of both pyroxenes are scattered through a few samples.

Table XV

Optical Properties of Pyroxenes in Quartzo-Feldspathic Granulites

Material	2 V	N_X	N_Y	N_Z	Extinction
1. Orthopyroxene................	−58	1.684	1.693	1.701	parallel
2. Clinopyroxene................	+51	1.670	1.676	1.684	$Z \wedge C = 39°$

1. Hypersthene, 28% $FeSiO_3$ (Kennedy, 1947, p. 564).
2. 36% $(CaSiO_3)_2$, 62% $(MgSiO_3)_2$, 2% $(FeSiO_3)_2$ (Winchell and Winchell, 1951, p. 410).

Biotite

Biotite probably an alteration product, is commonly reddish brown, but may be greenish brown or brown-yellow.

Garnet

Garnets are present as single grains or crystals up to 1 mm wide or as clusters up to 3 mm wide. They are light pink, anhedral, isotropic, and poikilitic, with inclusions of quartz, plagioclase, perthite, zircon, apatite, and rarely, iron oxides. They have the following optical properties: N=1.798 and sp. gr.=4.08, and are classified as pyralspite, trending towards lime-bearing, pyrope-almandine (Winchell and Winchell, 1951, p. 485; *also* Kennedy, 1947, pp. 570-573).

Mafic Granulites Containing Quartz and Feldspar

Appearance

These granulites are predominantly inequigranular and medium to coarse grained (*see* Pl. VII A). They are commonly dark olive-brown and weather reddish brown. Quartz is commonly blue and vitreous and feldspars are olive-green or brown, although some are greyish white. Dark grey-green metacrysts of perthite are present in many of the coarse-grained rocks. Dark coloured or black ferromagnesian minerals occur in thin bands or are disseminated through the rocks, but both the colour and composition of these granulites vary considerably. Mineral lineation and foliation, and prominent banding are characteristic of this division in many localities, but the rocks in a few outcrops have a massive texture.

Under the microscope, the mafic granulites are seen to be commonly porphyroblastic, containing coarse metacrysts of perthite and quartz in an equigranular, medium- to fine-grained, granoblastic matrix of feldspar, quartz, and ferromagnesian minerals. Mortar structure, sutured grains, and replacement features are common. Minor recrystallization and a preferred optical and mineral orientation are present.

Composition

The following minerals were identified in the mafic granulites with quartz and feldspar. Major constituents: quartz, myrmekite, K(Na)feldspar, K(Na)perthite, microcline perthite, plagioclase, antiperthite, pyroxene, cordierite, biotite, garnet; accessory minerals: apatite, zircon; ore minerals: magnetite-ilmenite, pyrrhotite, siderite; secondary minerals: serpentine, chlorite, biotite, sericite, kaolinite, epidote, zoisite, amphibole.

Table XVI

Rosiwal Analysis of Mafic Granulite Containing Quartz and Feldspar

Mineral	1	2	3
Quartz	15.2	11.3	20.4
K(Na)perthite and microcline perthite	10.0	59.5	38.2
Plagioclase (An_8-An_{38}, mode An_{30})	16.1	14.1	31.0
Antiperthite	19.0	—	—
Pyroxene	8.4	8.1	1.5
Cordierite	9.4	—	—
Amphibole	—	—	1.5
Biotite	13.9	5.7	—
Chlorite	—	—	5.8
Garnet	7.8	trace	—
Zircon	trace	trace	0.1
Apatite	trace	—	0.1
Iron ores	trace	1.3	1.4
Total	99.8	100.0	100.0

Descriptive Mineralogy

Quartz

Quartz grains in these rocks vary in size and shape but all are anhedral. Most are fine to medium sized; coarse grains and extremely fine grains occur. A few are smoothly rounded and others are intensely corroded. The quartz in this division is intensely strained and has ruptured grains, Bohm's lamellae, undulous extinction, and a few optic angles of 3°. Recrystallization has occurred in numerous samples.

Feldspar

Feldspars are similar in most respects to those previously described in the other granulites, except that antiperthite and replacement perthite are more common in rocks of this division.

Pyroxene

The optical characteristics of the orthopyroxene present indicate that it is hypersthene (35% $FeOSiO_4$, 65% $MgOSiO_4$). Rare, small intergrowths of diopsidic lamellae are present.

Amphibole and Biotite

Amphibole and biotite commonly result from the breakdown of pyroxene, and, in many samples, are associated with myrmekite. Many of them have the optical properties of water-deficient minerals.

Cordierite

Cordierite was found in a few banded, dark coloured rocks that contain alternate garnetiferous, ferromagnesian-rich layers and less ferromagnesian-rich layers. Garnets are associated only with the more mafic layers.

This cordierite is in anhedral, ragged grains that range in width from 0.8 to 0.09 mm. The smaller grains are smoother than the larger. Cleavage 010 is prominent and 001 cleavage less well developed. Inclusions up to 0.01 mm in diameter are numerous, most of them zircons that have vivid pleochroic haloes. Cordierite is intimately associated and intermixed with biotite, and is unaltered.

Table XVII

Optical Properties of Cordierite in Mafic Granulite Containing Quartz and Feldspar

Mineral	N_X	N_Y	N_Z	2 V
Cordierite....................................	1.537	1.543	1.550	+88°

Estimated composition: 65% $Mg_2Al_4Si_5O_{18}$ (Winchell and Winchell, 1951, p. 471).

Garnet

Pink, anhedral, and isotropic garnets commonly occur as single crystals up to 0.6 mm wide and as clusters. They are poikilitic, holding inclusions of quartz and feldspar, and black needles up to 0.001 mm long. A few grains contain small flakes of biotite. The optical properties of the garnets are N=1.788, sp. gr.=3.99, which suggest pyralspite trending towards lime-bearing, pyrope-almandine (Winchell and Winchell, 1951, p. 487; *also* Kennedy, 1947, pp. 570-573).

Mafic Granulites Containing Little or No Quartz (Black Granulites)

Appearance

The black granulites are fine grained and commonly equigranular and are composed predominantly of plagioclase and pyroxene (*see* Pl. VII B). In a few samples minor amounts of pink garnet are present. These granulites are characterized by their grey-black or green-black colour. Foliation is common but lineation is rarely present in hand specimens.

Microscopically, the rocks are fine to medium grained and consist predominantly of equigranular, granoblastic although in part allotriomorphic granular, aggregates of plagioclase, ferromagnesian minerals, and scattered black metallic minerals. Preferred optical and mineral orientation is common.

Composition

The following minerals were identified. Major constituents: quartz, plagioclase, antiperthite, pyroxene, garnet, amphibole, biotite; ore minerals: ilmenite-magnetite, pyrite, pyrrhotite, hematite; secondary minerals: serpentine, chlorite, muscovite, sericite, epidote-zoisite, calcite.

Table XVIII

Modal Composition of Mafic Granulites Containing Little or No Quartz

Mineral	Range %	Typical Mode
Quartz	0—10	0
Plagioclase (An_{38} to An_{60}, mode An_{50})	25—60	56
Pyroxene	20—37	35
Garnet	0—31	0
Biotite	0—14	5
Apatite	>0—3	>.5<1.0
Black metallic minerals	1—10	3

Descriptive Mineralogy

Plagioclase

Plagioclase occurs in fine- to medium-sized, commonly anhedral grains with semi-rounded or irregular outline, although some are subhedral and vaguely tabular. Numerous grains are strained with anomalous shadows and bent and offset cleavage. Twinning according to albite, albite-carlsbad and pericline laws is common, but acline twinning is rare. Untwinned grains with normal zoning are numerous. Alteration of the plagioclase is not common, although in one sample it is almost complete. In this sample, alteration has resulted in the growth of two new feldspars, one with a composition of An_{16} and the other An_{60}. Each of these is unaltered, whereas only traces of the original plagioclase show through a complex of alteration products which includes epidote, sericite, and muscovite.

Pyroxene

The pyroxenes are similar in many respects to those found in other granulites. Both hypersthene and clinopyroxene occur as individual grains and some are intergrown. Alteration is rarely complete. Amphibole and biotite occur as late, probably alteration, products.

Garnet

Pink garnets are present in one sample only and are in anhedral grains with an irregular outline. They are poikilitic, containing numerous inclusions of plagioclase and quartz, and occur as individual grains or in clusters up to 1 mm wide. Their refractive index is 1.803.

Rocks Associated with the Granulites

The following are the three principal rock types associated with the granulites:

1. Quartz-sillimanite-biotite gneiss
2. Crystalline limestone
3. Lime-silicate rocks.

Quartz-Sillimanite-Biotite Gneiss

Sillimanite-bearing gneisses occur in steeply or vertically dipping bands a few feet wide that generally trend north. They mostly have a greyish fresh surface but in many exposures along strike both fresh and weathered surfaces are pure white. They are medium-grained, inequigranular rocks composed of quartz, sillimanite, and scattered flakes of biotite (*see* Pl. X A). Fine-grained aligned rods of sillimanite are surrounded by medium-sized quartz grains (*see* Pl. X B). Preferred mineral and optical orientation is well developed.

The modal analysis of the average sillimanite gneiss is as follows: quartz 65%, sillimanite 30%, biotite 5%.

The quartz is in anhedral, blocky, irregular-shaped strained grains. They contain minute needles of sillimanite that occur in clusters and in a rectangular pattern.

The sillimanite occurs as subhedral to euhedral, equigranular, fine- to medium-sized, tabular crystals. Its optic angle is +28° and N_z=1.681.

Crystalline Limestone

The area occupied by crystalline limestone is not extensive. Widths of more than 200 feet are rare and many bands measure only 2 or 3 inches. These bands extend along strike for several hundred yards.

The crystalline limestones associated with granulites are relatively pure, containing more than 85 per cent calcite. Diopsidic-pyroxene is common. One sample contains 5 per cent olivine and another 2 per cent each of scapolite and quartz.

Lime-Silicate Rocks

Three main types of lime-silicate rocks are present, each with a distinctive mineral assemblage:

A. Pigeonite, calcite, yellow mica, spinel, apatite
B. Diopside, hedenbergite, K(Na)perthite
C. Cordierite, wollastonite, diopsidic pyroxene, sphene, calcite.

Type A

The first of these types is a skarn that separates marble from garnetiferous granite gneiss; it ranges in width from 1 inch to 2 feet. It is medium to coarse grained, more or less equigranular, and contains clusters of ferromagnesian minerals and eyes of calcite that contain 1-mm grains of blue apatite. There is no optical or dimensional mineral alignment.

The following is the modal composition of a sample adjacent to the charnockite zone:

Mineral	%
Pyroxene	50
Calcite	15
Spinel (hercynite)	10
Biotite	15
Amphibole	9
Apatite	1

Pyroxene

The pyroxene is in pinkish, anhedral and irregularly outlined grains with a well-developed cleavage. The optical properties, shown in Table XIX, suggest pigeonite (Winchell and Winchell, 1951, pp. 408,409).

Table XIX

Optical Properties of Pyroxene in Skarn, North End of Brown Inlet

2 V	N_X	N_Y	N_Z	Extinction Angle
+5°	1.708	1.709	1.728	$z \wedge c = 38°$

Spinel

The spinel is in dark green, anhedral and irregularly outlined, isotropic grains. Its refractive index is slightly greater than 1.715 and less than 1.728.

Type B

Type B is also a skarn and is associated with marble that is in contact with medium-grained granitic granulite. The rock is pale yellow, medium to coarse grained, and ranges in texture from granoblastic to hypidiomorphic. Although more or less equigranular and composed predominantly of potash feldspar and pyroxene, it varies considerably in grain size and composition.

The following is the modal composition of a sample taken from the centre of the granulite zone:

Mineral	%
K(Na)perthite	32
Pyroxene	66
Sphene	<0.1
Calcite	<0.5
Magnetite-ilmenite	<0.5
Pyrrhotite	<0.5

Pyroxene

The optical properties of pyroxene, shown in Table XX, suggest diopside-hedenbergite (Winchell and Winchell, 1951, pp. 410, 413 and 415).

Table XX

Optical Properties of Pyroxene in Skarn at South End of Brown Inlet

2 V	N_X	N_Y	N_Z	Extinction Angle
+55° to 60°	1.690	1.701	1.719	$z \wedge c = 44°$

Type C

Type C is a lime-silicate rock found within the mafic granulite. It outcrops as a lenticular mass, 10 by 40 feet in size, remote from any limestone or skarn. Its weathered surface is pitted and greyish white, and its fresh surface is pale yellow speckled with black. It is roughly banded, inequigranular, and porphyroblastic. It contains pale yellow, lineated metacrysts of wollastonite up to 1 inch in length, in a glassy, fine- to medium-grained, granoblastic, microfolded matrix. Minerals in the groundmass show a slight preferred dimensional and optical orientation.

The following is the modal composition of a sample taken from near the zone of the pyroxene-amphibole gneisses:

Mineral	%
Wollastonite	35
Cordierite	45
Pyroxene	15
Sphene	3
Calcite	2

Wollastonite and Cordierite

Table XXI

Optical Properties of Wollastonite and Cordierite in Lime-Silicate Rock at Narrow Bay, Freshwater Lake

Mineral	2 V	N_X	N_Y	N_Z
Wollastonite	−39°	1.619	1.631	1.633
Cordierite[1]	−69°	1.545	1.550	1.553

[1]The optical properties indicate 40% $Fe_2Al_4Si_5O_{18}$ (Winchell and Winchell, 1951, p. 471).

Pyroxene

The pyroxene is thought to be diopsidic although its optical properties are not diagnostic.

Table XXII

Optical Properties of Pyroxene in Lime-Silicate Rock at Narrow Bay, Freshwater Lake

2 V	N_X	N_Y	N_Z	Extinction Angle
+55° to 60°	1.705	1.705+	1.725	$z \wedge c = 39° - 43°$

Zone of Pyroxene-Amphibole-bearing Rocks

The rocks in this zone are divided into the following varieties:

1. Pyroxene-amphibole granite-gneiss
2. Pyroxene-amphibole granodiorite-gneiss
3. Pyroxene-amphibole-feldspar gneiss.

Associated with them as part of the zone is sillimanite gneiss.

The granite-gneiss occurs in both sharp and gradational contact with the granodiorite-gneiss, and both are cut by sill-like bodies of the pyroxene-amphibole-feldspar gneiss.

The sillimanite gneisses outcrop as a part of a banded gneiss, of granitic composition that includes structurally conformable interbands of felsic, mafic, and garnetiferous material. The contacts of the component bands with each other are sharp and well defined.

Pyroxene-Amphibole Granite-Gneiss

Appearance

Rocks of this variety are predominantly medium to fine grained and inequigranular. They are characteristically light coloured and have a pale pink tinge. Weathered surfaces are also light coloured. The quartz is glassy and bluish tinged and the feldspar, light coloured or pink. Foliation is apparent in all samples and lineation is visible in many outcrops. The quartz, though not platy, and the feldspar are both orientated along foliation planes. Ferromagnesian minerals commonly impart a streakiness, or a slight salt-and-pepper appearance to the rock. They also occur in extremely fine, closely spaced layers.

Under the microscope, rocks of the granitic variety are predominantly inequigranular and comprise medium-grained, granoblastic aggregate of quartz, potash and plagioclase feldspar, and scattered ferromagnesian minerals. This aggregate contains slightly coarser, irregularly shaped grains of quartz and perthite. Recrystallized or secondary feldspar has formed at grain boundaries in a few samples. Sutured contacts, mortar textures and replacement and recrystallization features are numerous. Preferred optical orientation and some mineral alignment and rude banding are present.

Composition

The minerals identified are the same as those in the granitic granulites, with the addition of water-deficient amphibole.

Table XXIII

Modal Composition of Pyroxene-Amphibole Granite-Gneiss

Mineral	Range %	Typical Mode
Quartz	35—55	38
Microcline perthite	35—60	44
Potash feldspar	0— 5	0
Plagioclase (An_{10} to An_{22}, mode An_{20})	0—20	10
Pyroxene	0— 5	<1
Amphibole	0—10	4
Biotite	1—15	3

Descriptive Mineralogy

Quartz

Most quartz grains have a ragged outline and, in many samples, replacement and sutured borders. Dust-covered borders are numerous and all grains are strained.

Plagioclase

The plagioclase occurs in fine to medium, anhedral, blocky, deformed grains. Twinning and cleavage are commonly parallel and well developed along 010.

Perthite

The perthite is anhedral and predominantly medium grained. Both exsolution and replacement blebs of plagioclase (An_{10}) are common, and plagioclase comprises up to 50 per cent of any perthite grain. The host potash feldspar is dominantly microcline, but stringlet-type blebs are normally found in a host with a low optic angle, probably K(Na)feldspar.

Pyroxene

The clinopyroxene is in anhedral, rounded or tabular, normally fine grains. Its optical properties indicate aegirin-augite.

Amphibole

The amphibole is in anhedral, semi-tabular or ragged, medium to fine grains, occurring either singly or in clusters. Its colour ranges from dark green to dark greenish brown.

Table XXIV

Optical Properties of Amphibole in Pyroxene-Amphibole Granite-Gneiss

2 V	N_Z	Extinction Angle	Pleochroic Formula	
−65°	1.685±	17°	x = pale yellow-brown y = brownish green z = dark brown-green	pale yellow-green yellow-green dark green

These are the properties of hornblende of intermediate water content. Other amphiboles, with green or pale green absorption, are common alteration products.

Biotite

The biotite is similar in appearance and habit to that found in the granulites. It is dark reddish brown and has a small, negative optic angle.

Alteration Products

Alteration of these rocks is not as intense as in the granitic granulites. The plagioclase is sericitized, and brown, dust-like material, probably kaolinite, is present in perthite. The pyroxene is altered to blue-green amphibole, and brown amphibole is altered to chlorite or biotite. Soda feldspars form rims around perthite grains, resulting, in a few samples, in replacement perthite.

Pyroxene-Amphibole Granodiorite-Gneiss

Appearance

The rocks of this variety are medium grained and commonly inequigranular (*see* Pl. VIII A). They are pale olive-green although some are brownish weathered. The quartz is in semi-tabular but rarely elongated grains. It is vitreous and, in many samples, bluish. The feldspar is pale green and metacrysts are rare. Foliation is a normal feature, banding is present here and there, and lineation is noted in most samples.

Under the microscope, the rocks are an inequigranular aggregate consisting of medium to coarse quartz grains in a medium-to-fine-grained, more or less equigranular, granoblastic assemblage of quartz, feldspar and ferromagnesian minerals (*see* Pl. VIII B). A fine-grained, cataclastic groundmass is present in a few samples, and stress features are visible in all sections. Sutured contacts are numerous and recrystallization of grain borders is common. Rarely differences in grain size impart a rough banding to the rock. Preferred optical orientation is present in all samples and mineral alignment in most.

Composition

Mineralogy, except for the presence of amphibole and the absence of sanidine, antiperthite, and green spinel, is basically similar to that of the granodioritic granulites.

The modal and chemical compositions of two samples are given in Tables XXV and XXVI.

Table XXV

Modal Composition of Pyroxene-Amphibole Granodiorite-Gneiss

Mineral	Sample 1 %	Sample 2 %	Range	Typical Mode
Quartz	35.8	21.6	20—40	32
K(Na) feldspar	—	—	0— 1	—
Microcline	—	0.1	0—0.5	—
K(Na) perthite	—	—	0—10	2
Microcline perthite	17.9	38.4	17—40	26
Plagioclase (An_{15} to An_{38}, bimodal common compositions An_{27} and An_{36})	36.7	23.6	20—40	31
Pyroxene	—	1.7	0— 5	2
Amphibole	5.6	6.8	1—10	4
Biotite	—	5.3	0—10	2
Magnetite	1.6	1.0	1— 2	1
Zircon	0.3	trace	trace	trace
Apatite	trace	trace	trace	trace
Serpentine	1.9	1.5	trace	trace
Total	99.8	100.0		100.0

Table XXVI

Chemical Composition of Pyroxene-Amphibole Granodiorite-Gneiss

Constituent	Sample 1 %	Sample 2 %
SiO_2	73.4	62.90
Al_2O_3	12.7	14.17
Fe_2O_3	1.2	2.34
FeO	1.0	4.94
CaO	2.8	4.21
MgO	1.6	2.18
Na_2O	3.5	2.42
K_2O	2.7	4.69
H_2O^+	0.5	0.35
H_2O^-	—	0.14
TiO_2	0.2	0.97
P_2O_5	trace	0.24
MnO	—	0.10
CO_2	—	0.01
ZrO_2	0.2	0.00
Total	99.8	99.66
Sp. gr	2.64	2.76

Samples 1. Pyroxene-amphibole granodiorite-gneiss, 10 miles northwest of Usualuk. Computed from modal analysis.

Samples 2. Pyroxene-amphibole granodiorite-gneiss, Pangnirtung. Analyst: J. A. Maxwell.

Descriptive Mineralogy

Quartz and Myrmekite

The quartz is similar to that found in the granodioritic granulites. Myrmekite is common and typically ropy, and formed at contacts between plagioclase and perthite.

Plagioclase

Plagioclase is in anhedral blocky, strained crystals, which exhibit bent cleavage and granulated borders. Here and there, they are poikilitic, with inclusions of microcline.

Perthite

The perthites are predominantly microcline. They are in anhedral grains with blocky or semi-tabular outlines and, with rare coarse exceptions, of medium to fine size. Strained perthites are present in all samples and a few slightly zoned grains are present in the more mafic rocks. Cleavage and microcline grid twinning are well developed. Film and rod plagioclase blebs were identified and most grains have plagioclase-free rims. Typical patch perthite is uncommon, but many plagioclase blebs are intermediate between film and patch types. Film blebs in numerous samples are superimposed upon rods and, in most grains, at least two sizes of rods are visible. The amount of plagioclase in the perthite varies from slide to slide and from grain to grain. The amount of plagioclase appears relatively uniform where rod blebs are present, but where the film types are found, the variability is most apparent. The perthites commonly contain 15 per cent plagioclase (An_{20} or slightly less).

Pyroxene

Pyroxene in these rocks is predominantly orthorhombic, but minor amounts of clinopyroxene are present. Both serpentine and green amphibole are present in various stages of development, as alteration products.

Amphibole

Two types of amphibole are present. The first is characteristically in anhedral grains with tabular or irregular outlines. These grains range in size from fine to medium and are commonly dark green or greenish brown. The second type, an alteration product, is also in anhedral grains, but is bladed or fibrous, and possesses a distinctive light green colour.

Table XXVII

Optical Properties of Dark Coloured Amphibole in Pyroxene-Amphibole Granodiorite-Gneiss

2 V	N_Y	N_Z	Extinction Angle	Pleochroic Formula
$-65°$ to $71°$	$<=1.680$	Just $>=1.685$	$z \wedge c = 12° - 17°$	x = yellow-brown y = green-brown z = dark brown-green

These properties suggest hornblende of intermediate water content.

Biotite

Biotite is in dark, reddish brown, anhedral, fine flakes. In a few samples its optic angle is —10°.

Pyroxene-Amphibole-Feldspar Gneiss

These rocks range from medium to coarse grained and are commonly equigranular. They are characteristically dark green-black and foliation and mineral lineation are prominent in all outcrops.

Microscopically, they are predominantly a medium-grained allotriomorphic-granular aggregate of medium-grained, ferromagnesian minerals and a slightly finer grained plagioclase matrix. Preferred optical and dimensional orientation was seen in all samples.

Green hornblende, diopsidic hedenbergite pyroxene, and plagioclase are the characteristic minerals of these rocks. Orthopyroxene was not found and accessory minerals are scarce.

Table XXVIII

Modal Composition of Pyroxene-Amphibole-Feldspar Gneiss

Mineral	Range %	Typical Mode
Amphibole	20—35	30
Pyroxene	19—40	25
Biotite	5—14	10
Plagioclase (An_{45} to An_{68}, mode An_{56})	15—40	35
Black metallic minerals	0— 0.5	0

Rocks Associated with Pyroxene-Amphibole Gneisses

Sillimanite-bearing Gneiss

The sillimanite-bearing gneisses associated with pyroxene-amphibole rocks have a greyish weathered surface and are medium grained. Foliation is well developed, and in some outcrops a strong mineral lineation is present. The sillimanite-rich bands range from one half inch to more than 4 feet in width, and in some areas extend along strike for more than several hundred yards. In the Chidliak Fiord area medium- to coarse-grained sills of garnetiferous granite have invaded pyroxene-amphibole gneiss that contain sillimanite-bearing bands. The sillimanite-bearing layers are medium grained, equigranular, and granoblastic.

Sillimanite

The sillimanite occurs as massive, euhedral to subhedral, medium to fine, bladed or tabular crystals, ranging in length from less than 0.1 mm to 4 mm. It replaces biotite in a few samples. The sillimanite in the rocks near Chidliak is in coarser grains than in those at Kingnait Fiord. There it is in euhedral grains with tabular outlines that are as much as 2 inches long. Massive, felty aggregates, more than 2 inches across, are common.

Table XXIX

Modal Analysis of Three Sillimanite-bearing Bands in Pyroxene-Amphibole Granite-Gneiss at Kingnait Fiord

Mineral	%	%	%
Quartz	20	35	35
K(Na)feldspar and microcline	10	20	5
K(Na)perthite	—	—	20
Plagioclase	15 (An_{28})	25 (An_{30})	15 (An_{24})
Garnet	20	10	5
Biotite	25	5	10
Sillimanite	10	5	10

Table XXX

Modal Composition of a Sillimanite-bearing Band in Pyroxene-Amphibole Gneiss near Chidliak Point

Mineral	%
Quartz	23
Microcline	4
K(Na)perthite	21
Plagioclase (An_{22})	22
Biotite	22
Garnet	3
Sillimanite and fibrolite	5

Garnet

The garnet grains are pink coloured, anhedral and irregularly outlined, medium to large sized with long axes up to one half inch in length; they are commonly poikilitic. They have the following optical properties: N=1.80; sp. gr.=3.95+; cell edge=11.53Å. These suggest pyralspite trending towards lime-bearing pyrope-almandine.

Accessory minerals in this type of sillimanite-bearing gneiss include titaniferous magnetite, apatite, and zircon.

Zone of Chidliak Gneisses

The Chidliak gneisses all contain amphibole and comprise three types:

1. Rocks rich in felsic minerals (granitic)
2. Mafic rocks containing felsic minerals (mafic)
3. Rocks composed almost entirely of ferromagnesian minerals.

The following rock types are associated with Chidliak gneisses:

1. Sillimanite-bearing gneiss
2. Crystalline limestone
3. Lime-silicate rocks.

The three varieties of the Chidliak gneisses are commonly interbanded with one another. Fine- to medium-grained, vein granite-gneiss is interbanded with vein amphibole- and biotite-rich gneiss. Shear planes, parallel with the gneissosity of the basic bands, are filled with medium- to coarse-grained granite. Sharp contact exists between individual components of the banded amphibole granite-gneisses, but textural and mineralogical changes within the bands are gradational.

The sillimanite-bearing gneiss occurs as a thin band of variable thickness marking the contact between a band of felsic gneiss and a band of intensely drag-folded and crenulated mafic gneiss. Scattered sillimanite is also present in the mafic gneiss near the contact.

The crystalline limestone occurs in discontinuous layers up to 3 inches wide in contact with a 10-foot-wide band of skarn that occurs in an area of granitic variety of the Chidliak gneisses near Angmallik Harbour. This is a folded and sheared, carbonate-rich terrain.

The Chidliak gneisses are commonly equigranular and medium grained, with few fine-grained components. Amphibole, biotite, and sphene are diagnostic minerals. Perthite was not found. These rocks are similar in many respects to the pyroxene-amphibole gneisses, but the quartz is colourless and the feldspars are grey or white.

Only the granitic variety is described in detail because the minerals contained in the mafic and ferromagnesian-rich varieties differ little from those in the granitic variety. The An content of the plagioclase in the more basic varieties is similar to that of the plagioclase in the more basic units of the granulites and pyroxene-amphibole gneisses.

Rocks Rich in Felsic Minerals (Granitic Variety)

The rocks of the granitic variety of the Chidliak gneisses are composed primarily of quartz, microcline and/or plagioclase, scattered amphibole and biotite, iron ores, and sphene. They are typically grey (*see* Pl. IX A); predominantly medium to fine grained, more or less massive or banded, and contain bands or discontinuous layers rich in amphibole and biotite that separate similar bands or layers composed of white quartz and feldspar. The rocks contain thin, discontinuous, parallel lenses of feldspathic material that are conformable with the gneissosity. These lenses pinch out along strike, but lenses appear a few millimetres farther along in the same plane or in one slightly offset. The ferromagnesian minerals either are scattered through the rocks, imparting a salt-and-pepper appearance, or are present in layers less than 1 mm wide in otherwise felsic bands. They are also the predominant components of mafic bands. Streakiness, due to a slight alignment of the amphibole, is apparent in a few of the more massive rocks. The banded granitic members are up to 100 feet wide, although 40 feet is more common.

Microscopically these are medium- to fine-grained, commonly equigranular rocks with a granoblastic texture. They are composed predominantly of leucocratic grains, the mafic minerals being either scattered through the rocks or confined to narrow bands (*see* Pl. IX B). Scattered porphyroblasts of poikilitic feldspar are set in a finer grained granoblastic matrix. Preferred optic and dimensional orientations are well developed.

The following minerals were identified. Major constituents: quartz, microcline, plagioclase, amphibole, biotite, muscovite; accessory minerals: zircon, apatite, sphene; tourmaline; ore minerals: magnetite; secondary minerals: serpentine, chlorite, muscovite, sericite, epidote, zoisite.

Table XXXI

Modal Composition of Granitic Variety of the Chidliak Gneisses

Microcline Present			Microcline Absent (Granodioritic)		
Mineral	Range %	Typical Mode	Mineral	Range %	Typical Mode
Quartz	20—45	35	Quartz	35—60	37
Microcline	15—35	30	Plagioclase (An_{28}—An_{30}, mode An_{24})	10—50	45
Plagioclase (An_{18}—An_{24}, mode An_{20})	20—40	25	Amphibole	5—15	5
Amphibole	0—3	1	Biotite	5—15	12
Biotite	2—25	7	Iron ores	1—3	1
Iron ores	1—2	1	Alteration products	0—1	1
Alteration products	1—3	2			

Quartz

Quartz in anhedral and rounded grains that contain dusty material concentrated along their borders was observed in a few samples. It is strained and contains numerous parallel and curved trails of inclusions.

Plagioclase

The plagioclase is in anhedral and commonly strained grains. Cleavage and twinning are normally well developed, but a few clear feldspar crystals without these features were noted in one sample. Poikilitic grains are scattered and plagioclase is replaced by microcline in a few samples.

Amphibole

The amphibole is in anhedral and irregularly outlined green grains. Its optic angle is $-55°$; $z \wedge c = 18° - 22°$; x is pale olive-green and z is dark green.

Biotite

The biotite is in anhedral and irregularly outlined grains that contain numerous inclusions of zircon with pleochroic haloes. Its pleochroism is as follows:

x = pale yellow-green; pale orange; pale yellow-green; olive-brown; light olive-yellow.

z = reddish brown; orange-red; dark green-brown; blackish brown; olive-brown.

Mafic Rocks Containing Felsic Minerals (Mafic Variety)

This variety has a wide range of composition, from allotriomorphic carbonate-rich rocks near skarn areas to granoblastic rocks composed predominantly of plagioclase but including quartz, potash feldspar, amphibole, and biotite. These rocks are dark grey and medium to fine grained, commonly equigranular. Their characteristic feature is the small amount of quartz, commonly less than 5 per cent. They are similar in appearance to the mafic granulites, and rocks with banded and veined structures are typical.

Rocks Composed Almost Entirely of Ferromagnesian Minerals

Many of these rocks are typical amphibolites but a few varieties grade into gneisses containing up to 80 per cent amphibole and biotite, with calcite and plagioclase. They are medium to fine grained and equigranular, but coarse-grained units are common in the thicker bands. Many of the typical amphibolites lie near skarn or limestone areas.

These rocks are similar in appearance to the black granulites and outcrop as conformable lenses or bands within the other two varieties. The lenses and bands are up to 20 feet in width and massive, but, when present in sheared zones, have here and there a faint lineation.

Rocks Associated with the Chidliak Gneisses

The following rock types are present:

1. Sillimanite-bearing gneiss
2. Crystalline limestone
3. Lime-silicate rocks.

The sillimanite-bearing rocks are grey, equigranular, and finely banded, they have micaceous layers less than one sixteenth inch wide separating felsic layers one eighth inch wide. Small grains of smoky quartz and white feldspar are elongated in the plane of foliation.

Table XXXII

Modal Composition of a Sillimanite-bearing Band in the Chidliak Gneiss

Mineral	%
Quartz	57
Plagioclase (An_{17})	13
Biotite	14
Muscovite	16
Sillimanite	1

The crystalline limestones associated with Chidliak gneisses contain tremolite, diopside, and more than 90 per cent calcite.

The lime-silicate rock is fine to medium grained and inequigranular. It has laths of pyroxene and grains of calcite set in an extremely fine-grained green groundmass. The rock appears massive, but under the microscope, exhibits a slight preferred optical orientation.

Table XXXIII

Modal Composition of Skarn near Angmallik Harbour, and Optical Properties of Contained Pyroxene

Mineral	%	Mineral	2 V	N_X	Extinction Angle
Pyroxene	83	Diopside	+55°	±1.672	$z \wedge c = 40°$
Tremolite	10				
Calcite	7				
Plagioclase (An_{20})	<1				
Sphene	<0.1				

Zone of Epidote-bearing Rocks (Finger Land and Misty Island Gneisses)

These rocks have been divided into two groups, those containing amphibole (Finger Land gneisses) and those containing biotite but no amphibole (Misty Island gneisses). Felsic, intermediate, and mafic varieties are present.

The Finger Land gneisses are characterized by numerous light grey, slightly banded but well-foliated rocks with well-displayed salt-and-pepper appearance. Small inclusions or segregations of amphibole-rich material are numerous, oriented in planes parallel with the gneissosity.

In many of the exposures south of Ugjuk Island, the rocks are drawn out, drag-folded, and sheared. This deformation may have some bearing on the development of epidote in the rocks of the southern region. Mineralogical variations in the Finger Land group are few.

The Misty Island gneisses include banded and vein granite-gneiss, as well as scattered occurrences of banded and porphyroblastic mafic gneisses. The difference between the granitic and mafic gneisses is slight, and they bear a strong resemblance to the equivalent units of the Finger Land gneisses. Some undeformed felsic varieties are very finely banded, suggesting a primary stratification.

The felsic varieties are composed predominantly of quartz, feldspar, ferromagnesian minerals, and epidote. They are light grey, fine- to medium-grained rocks, for the most part equigranular. They commonly consist of alternating layers with felsic and mafic components. The mafic bands range in width from one sixteenth inch to more than 3 feet and the felsic bands from one quarter inch to more than 10 feet.

Granoblastic and minor porphyroblastic textures are common but some specimens showed a trend towards an allotriomorphic texture. Sutured contacts are numerous and mortar fabric is a characteristic feature of these rocks. Stress features and preferred dimensional and optical orientation were noticed in all samples.

Varieties in the epidote-bearing gneisses were established by microscopic methods, and their modal limits are shown in Table XXXIV.

Table XXXIV

Modal Composition of Finger Land and Misty Island Gneisses

	Finger Land Gneisses Range %			Misty Island Gneisses Range %
Mineral	Felsic	Interm.	Mafic	Felsic
Quartz	30—60	5—15	0	25—50
Microcline	1—30	0	0	0—45
Plagioclase	15—45	60—80	70—85	10—60
Plagioclase per cent An, mode	An_{27}	An_{40}	An_{55}	An_{26}
Amphibole	1—5	4—10	10—20	0
Biotite	5—20	2—10	3—9	5—15
Epidote	1—2	1—5	1—4	1—2

Quartz

The quartz is commonly in anhedral and irregularly outlined, here and there rounded, grains, all of which are strained. Scattered, dust-like, black inclusions, flaky inclusions, and semiparallel to parallel trains of these inclusions are numerous.

Microcline

The microcline is intensely cross-hatched, and in many samples, contains rounded inclusions of quartz.

Plagioclase

The plagioclase is in anhedral blocky grains most of which are strained. Anomalous extinction and bent or broken cleavages are numerous. Many grains are untwinned and most are extensively altered.

Amphibole

Amphibole is in anhedral blocky grains. It is typically blue-green and has the following range of pleochroism:

x = light yellow-green; light olive-green; light olive-green
y = light blue-green; blue-green; olive-green
z = blue-green; dark olive-green; dark green

Biotite

The biotite is in anhedral and irregularly outlined flakes that are slightly chloritized and contain numerous inclusions with pleochroic haloes.

Table XXXV

Range of Pleochroism of Biotite in the Finger Land and Misty Island Gneisses

Rock	X	Y	Z
Finger Land gneisses.........	pale yellow pale orange-yellow pale olive-yellow pale yellow	olive-brown red-brown dark olive-green brown	olive-brown dark red-brown dark olive-green brown
Misty Island gneisses.........	pale olive-yellow pale olive-green or brown	dark olive-green dark olive-brown	dark olive-green dark olive-brown

Epidote

The epidote is in anhedral and irregularly outlined pale yellow-green grains. It is scattered through rocks of both groups, occurring in many samples at the contacts between mafic minerals and, in a few samples, between felsic grains. Its optical properties vary. Optical angles range from +85° to —75°, extinction angles from 0° to 2°, and N_z from 1.743 to 1.751.

Euhedral, 0.01 mm crystals of sphene are numerous and allanite enveloping 0.001 mm grains of zircon was seen in one sample.

Chapter IV

SOME PETROLOGICAL ASPECTS OF THE CUMBERLAND SOUND COMPLEX

Résumé of Petrography

The charnockites are characterized by the presence of blue quartz, orthopyroxene and clinopyroxene, K(Na)perthite, titaniferous magnetite, and so-called high temperature potash feldspar. The mineralogy of the granodioritic granulites is almost identical to that of the charnockites, and minerals that are characteristic of the other varieties of granulites may also be found in the charnockites. There is little difference between the chemical composition of the granodioritic granulites and that of the charnockites; the bulk composition of each of the other varieties of granulite differs from this and from each other.

The pyroxene-amphibole gneisses are characterized by the presence of water-deficient amphibole in contrast to the rocks in the zones of charnockite and granulite where even this type of amphibole is uncommon. Each variety of the pyroxene-amphibole gneiss has a similar bulk composition as its counterpart in the granulites.

The properties of the perthite, pyroxene and amphibole in the charnockites, granulites, and pyroxene-amphibole gneisses are in each case slightly different.

The Chidliak gneisses differ from the gneisses mentioned above and are characterized by the absence of perthite and pyroxene, and by the presence of common hornblende and sphene. The bulk compositions of the varieties in this zone are similar to those of corresponding varieties in the granulites and pyroxene-amphibole gneisses. The epidote-bearing rocks of the Finger Land and Misty Island gneisses are similar in many respects to the amphibole gneisses.

The mineralogy of the sillimanite-bearing rocks associated with the granulites and pyroxene-amphibole gneisses is much the same, but perthite and potash feldspar are absent in sillimanite-bearing bands associated with the Chidliak gneisses.

The main difference in mineralogy between the lime-bearing rocks associated with the granulites and those associated with the amphibole gneisses is the absence of tremolite in skarns associated with the granulites.

Temperature of Formation of Certain Minerals

From mineralogical differences in the pyroxene, potash feldspar, perthite, amphibole, and titanium-bearing minerals in each of the rock groups, it is possible to estimate the temperature at which each was formed.

The orthopyroxene and clinopyroxene are intergrown in the charnockite and granodioritic granulites but not in the other rocks of Cumberland Sound. According to Hess (1941, p. 515) this type of crystallization takes place at a high temperature. Although the pressure at which the experiments were made was only one atmosphere, it is improbable that there would be a significant difference at the pressures present at a depth of 25 or 30 kilometres. That there will be some difference is evident, as the rise in the melting point of diopside with pressure is 10° for each 1,000 bars (Yoder, 1952a, p. 372) and an increase in pressure will in most samples raise the temperature of transformation (Ramberg, 1952, p. 23).

The term K(Na)feldspar is used for a monoclinic, soda-bearing potash feldspar, thought by the author to be intermediate in temperature between sanidine and microcline, although accurate data on the potash feldspars are still largely missing.

The so-called high temperature potash feldspar is present in the charnockites and in the granodioritic granulites. The K(Na)feldspar is common in the charnockites and granulites, less common in the pyroxene-amphibole gneisses and absent in the Chidliak, Finger Land, and Misty Island gneisses. In these groups microcline is the dominant potash feldspar.

A survey of postulated transformation temperatures for microcline-sanidine indicates 700°C as an average figure (Laves, 1952, p. 560; Ramberg, 1952, p. 23).

The charnockites and granulites contain both monoclinic and triclinic perthites. The pyroxene-amphibole gneisses contain a predominance of triclinic perthite. Phase diagrams of Oftedahl indicate a maximum temperature of over 700°C for perthite crystallization. Laves gave a lower temperature for some samples and also in his phase diagrams. However, when mentioning cryptoperthite with exsolved albite, he noted that the material remains unmixed after heating to 1,060°C for a period of two weeks (Laves, 1952, p. 567). The problem is complicated by the presence of monoclinic perthite. Many of the phase diagrams show perthites below the inversion point microcline $\leftrightarrows$ sanidine, and in these the potash member of the perthite would probably be microcline. It is apparent from the phase diagrams that monoclinic perthites may form at temperatures of about 700°C. Triclinic perthites probably crystallize, depending on the composition of the mineral, at about 600°C. High temperature perthites are prominent in the charnockites and granodioritic granulites, whereas high to medium temperature perthites are present in the other granulites. Intermediate and a few low temperature patch perthites are present in the pyroxene-amphibole gneisses.

The amphibole appears to be stable in all the rock groups except the Misty Island gneisses. The optical characteristics of the amphibole indicate that the mineral in the first three rock groups is abnormally water-deficient. In the Chidliak gneisses, the mineral exhibits properties of common hydrous hornblende. Both types of amphibole are present near the contact between the pyroxene-amphibole gneiss and the Chidliak gneisses.

No definite figures can be given for the temperature of crystallization of the amphiboles in the first three rock groups, but it can be shown that the temperature at which the amphibole in the pyroxene-amphibole gneisses is stable is probably lower than it is for amphibole in the granulites.

Sphene is present in the Chidliak gneisses, but not in the pyroxene-amphibole gneisses, granulites, or charnockites. "The mineralogical environment under which sphene can exist stably at high pressure and temperature becomes very restricted." (Ramberg, 1952, p. 73). Ilmenite, however, is present in rocks from which sphene is absent. Rutile, in contrast to both charnockites and granulites from other regions, is exceedingly rare. This is probably explained by the TiO_2 combining with iron oxides to form titaniferous magnetite and ilmenite rather than rutile, and also because it probably enters into the hornblende and biotite. High temperature biotite, according to Ramberg (1952, p. 45), needs to contain a relatively high percentage of titanium in order to remain stable. The presence of a relatively high percentage of TiO_2 in magnetite and slight exsolution phenomena in magnetite-ilmenite in the charnockites and some granulites would indicate a temperature of 700° to 800°C (Ingerson, 1955b, pp. 469, 471).

Temperature of Formation of Charnockite, Granulite and Pyroxene-Amphibole Gneisses

The estimated temperatures of formation given below are based on the characteristics of certain minerals in certain rock units in the charnockites, granulites, and pyroxene-amphibole gneisses having about the same bulk composition. The temperature of formation of charnockites is probably about 650° to 750°C and that for granulites is about 600° to 675°C. The higher temperature for the granulites is that of the granodioritic granulites. The temperature of formation for the pyroxene-amphibole gneisses is estimated to be 500° to 600°C.

Petrology of the Charnockites

The Cumberland Sound charnockites are considered in a broad sense to be "acid charnockites", even though the complete charnockite series is not present.

The field relationships and such significant microscopic characteristics as mineral assemblage, fabric, and type and sequence of minerals present all suggest a similarity to the acid charnockites in other areas (Naidu, 1955). Chemical analyses indicate that a relatively high proportion of silica and alumina is present and K_2O predominates over Na_2O. The analyses bear a marked similarity to those of acid charnockites described by Holland, Groves, Paulose and Wilson, and to the felsic charnockites of Quensel. Many of these are tabulated by Pichamuthu (1953a).

Origin of Charnockites

It is interesting to speculate on the origin of the charnockites of Cumberland Sound, although it is well known that charnockites in different areas may originate in many different ways (Pichamuthu, 1950). It is probable that the Cumberland Sound charnockites were formed by plutonic metamorphism of rocks of high metamorphic facies, and that mobility and local igneous characteristics were imparted by either anatexis in localized areas, or by partial fusion taking place in scattered areas (Groves, 1935, pp. 198-200; Quensel, 1951, p. 299). Dunn (1942, p. 231) had previously generalized ". . . that the charnockites are the products of partial or complete palingenesis of very deep-seated rocks which had lost their water content", and Quensel (1951, p. 314) suggested that, in part, the felsic charnockites ". . . represent the direct plutometamorphic transformation of the surrounding orthogneiss". The concept of rheomorphism is suggested to explain some of the igneous characteristics of the rock. "If as much as 10 or 15 per cent of the interstitial material in a solid rock is converted to liquid by solution or melting, the aggregate may become sufficiently mobilized to flow in response to stress." (Wahlstrom, 1950, p. 238).

A decrease in the grain size of the charnockites outwards from the centre of the area in which they are developed towards the surrounding granulites, and the fact that in many areas as the grain size decreases the gneissosity increases, support the hypothesis proposed. Sharp, intrusive contacts, gradational contacts over a width of 1 mile or 2 miles, and indefinite diffuse contacts, all with granulites, also support the hypothesis.

A slight decrease in grain size of charnockite at sharp contacts with the granulites suggests an intrusive relationship whereas the development of porphyroblasts of feldspar across the contact and in the adjoining gneiss and the lack of baking effects or intrusive tongues all indicate a metamorphic origin. The concentration of inclusions in the charnockites near the contact with the granulites and the similarity of the inclusions to the granulites suggest an ultra-metamorphic origin for the charnockites.

From the suggested temperature at which the charnockites formed and the conditions of large uniform pressure indicated by presence of minerals of small specific volume, it is suggested that the charnockites were formed at great depths. Certain exceptions to Groves' arguments for metamorphic origin, such as: The predominant lack of mineral alignment, the presence of C and CO_2, and the relative absence of secondary features in the quartz, are all evidence in favour of the hypothecated method of formation rather than a purely metamorphic origin. The occurrence of graphite in the charnockites probably indicates the presence of sedimentary material. The lack of mineral alignment even though some preferred optical orientation is present would indicate an origin under uniform pressure with little or no directed stress. The quartz, as previously mentioned, has been slightly deformed and both primary and secondary characteristics are present. The modification of the primary features was probably the result of refusion and recrystallization.

Petrology of the Granulites

The term granulite is used in this paper in the sense originally defined by Eskola (1939, 1952b), and further outlined by him in his description of the Lappish granulites. It embraces all rocks of the granulite facies. To be more explicit, however, it is necessary to add a petrographic prefix to the term granulite.

The granulites of the Cumberland Sound are presumed to have formed in anhydrous conditions under high temperatures and relatively high confining pressure, from a source comprising rocks of intrusive, sedimentary and probably, volcanic origin.

Granitic granulites resemble granite, but many are relatively rich in K_2O and Al_2O_3. The excess of K_2O and Al_2O_3 may be explained by many hypotheses, but only two are suggested here: (1) by the incorporation or granitization of a sediment rich in SiO_2 and Al_2O_3 by a previously formed rock of granitic composition; (2) by basification and granitization in which Si, Na, K, O and H_2O are squeezed out of deep-seated granulitic rocks (Ramberg, 1951, p. 33). It is possible that the granitic and granodioritic granulites formed nearer the surface than the basic granulites and thus have more new material added to the original rocks. There is, however, no conclusive evidence as to whether the original rocks were of magmatic or sedimentary origin.

The granodioritic variety has some features that indicate an intrusive origin and others that indicate, in part at least, a sedimentary origin. A sillimanite-rich band, apparently conforming to the trend of the granodioritic granulite unit as a whole, shows the presence of alumina-rich material. Probably metamorphic differentiation has modified the composition of the original band, which may have contained a high percentage of kaolin. Scattered bands of what might have been conglomerate are also present. In one area this type of granulite grades into a rock that exhibits structures resembling bedding. One hypothesis is that the granodioritic granulites formed by the metamorphism of sedimentary strata composed of material similar to sandy shale. As the temperature and pressure increased a metasomatic change to a rock of granodioritic composition may have resulted. Another hypothesis is that a large amount of granitic material was introduced into an area containing minor amounts of sedimentary material, and this was followed by a period of intense metamorphism.

The origin of the quartzo-feldspathic rocks must have been very similar to the origin suggested for the two units discussed above. Probably the primary rocks consisted of granitic material and large amounts of sedimentary material, such as impure sandstone containing carbonate and alumina-rich layers.

The mafic granulites, noticeably those lacking quartz and feldspar, have some characteristics of intrusive or extrusive basic rocks, except that, where these rocks outcrop as sill-like bands, it is possible that they are the metamorphic derivatives of lime-rich sedimentary rocks.

Amphibole, Biotite and Cordierite

Amphibole and biotite, and cordierite because of its stability relationships, are considered by some to be anomalous in rocks of the granulite facies.

In the Cumberland Sound granulites, which are believed to have been formed under anhydrous conditions, it was found that both the amphibole and the biotite are water deficient. The use of the mineralogical phase rule with OH as a component, the lack of water in the system, and the relative stability of both minerals suggest that the presence of amphibole and biotite does not necessarily indicate disequilibrium. In water-deficient systems, water can become a component permitting the presence of an additional phase such as amphibole or biotite. The amount of water in both the charnockites and granulites is small because of either the high temperature prevailing during the formation of the rocks or the lack of water in the original rock. It is also possible that a combination of both these factors exists. The stability relations of hornblende are most complicated. It is sufficient to note that, whereas the introduction of Fe at the expense of Mg and a relatively large percentage of Ti will expand the stability range of the mineral, an excess of silica and potassium tends to decrease it (Ramberg, 1952, pp. 68-70).

In the Cumberland Sound granulites, biotite, garnet, cordierite, potash feldspar, and hypersthene are apparently in relative equilibrium. The garnets contain about 30 per cent pyrope; the orthopyroxene about 65 per cent $MgSiO_5$. Apparently the per cent of Mn present in the garnet is exceedingly low. It would appear that the presence of cordierite is not solely dependent on the percentage of K_2O in the rock. Ramberg (1952) showed that, provided the pressure is not great, cordierite may form at high temperature together with hypersthene. On the other hand, high pressure is necessary to stabilize large amounts of pyrope in pyralspite. It is interesting to note that the percentage of pyrope, Mn content of garnet, and the Mg/Fe ratio of the mafic minerals in the Cumberland Sound granulites are similar to those found in other granulite areas (Eskola, 1952b, p. 152; Folinsbee, 1941, pp. 50-52; Ramberg, 1952, pp. 60-62). The stability of cordierite in the presence of ferromagnesian minerals and garnet, with K_2O in the system, is probably dependent, to a large extent, on the Mg/Fe ratio (Ramberg, 1952, pp. 57-62).

The presence of cordierite in the Cumberland Sound granulites is controlled, to a major extent, by the bulk composition of the rock, and in part at least by the pressure prevailing at the time of formation.

Petrology of Rocks Associated with the Granulites

Sillimanite-rich Rocks

The mineralogy of the sillimanite-rich bands (quartz, sillimanite, and minor amounts of biotite) is not characteristic of either the sillimanite-almandine subfacies or the granulite facies. The mineral reaction, muscovite $+$ silica $\leftrightarrows$ orthoclase $+$ sillimanite $+$ water, is characteristic of the sillimanite-almandine subfacies. According to Ramberg (1952) the reaction, biotite $+$ sillimanite $\leftrightarrows$ garnet $+$ potash feldspar $+$ water, occurs near the transition point between the granulite and amphibolite facies. The presence of sillimanite and minor amounts of biotite in what is thought to be a granulitic environment is probably dependent on the Mg/Fe ratio and Mn percentage of the system, as well as on the physical conditions.

Lime-Silicate Rocks

Only a brief reference will be made to lime-silicate rocks associated with the granulites and that only to the skarn. K(Na)perthite was found in one skarn and its presence presupposes a high temperature of formation. Wollastonite and calcite are present in skarns adjacent to the pyroxene-amphibole gneisses. The stability of these minerals is dependent upon the pressure-temperature conditions of the calc-silicate system. With increased pressures, the equilibrium temperature of wollastonite + CO_2 is elevated. The absence of wollastonite in the other granulites, if the bulk composition was suitable, may be attributed to a high pressure (Ramberg, 1952, p. 49, fig. 26). If the mineralogical phase rule is applied to skarns in the granulites, it is apparent that there are a few phases too many unless MgO, FeO, and the other individual oxides are considered as single components (Turner, 1948, pp. 70-75). That each of them should react, so would be due to the special conditions under which the rocks formed, and probably due to a small amount of silica and a large amount of Al_2O_3. It is possible, however, that chemical equilibrium does not exist. It is interesting to compare these assemblages with those of the pyroxene-hornfels facies described by Turner.

It appears, however, from the mineralogy, that the skarn rocks, associated with the granulites have formed under conditions of the granulite facies. It is possible that the slight mineralogical differences within the skarns may be explained by relatively small differences in temperature and pressure. The bulk composition, excluding OH, must also be considered, for slight differences in the amount of MgO and SiO_2, as well as other oxides, would effect a different mineral assemblage.

Petrology of the Pyroxene-Amphibole Gneisses and the Chidliak Gneisses

The mode of origin of the pyroxene-amphibole gneisses and amphibole bearing the Chidliak gneisses is probably similar to that of the granulites, but the intensity of metamorphism was not so great.

Mineral assemblages in the granitic and granodioritic units of the pyroxene-amphibole-bearing rocks are those that are stable under conditions for the high amphibolite facies. The mineralogy of the pyroxene-amphibole-feldspar gneiss is also suggestive of similar conditions, but the mineral assemblages, particularly the felsic ones, are relatively stable under a wide range of physical conditions. The occurrence of sillimanite-bearing gneisses, with a mineral assemblage typical of the sillimanite-almandine subfacies in the pyroxene-amphibole-felsic gneisses, is sufficient evidence as to the position of this group of rocks. It must be noted that the assemblage quartz-biotite-plagioclase-sillimanite-almandine-orthoclase is an ideal one, and therefore suggests a condition of equilibrium. The mineral assemblage in the Chidliak gneisses are those found in the low temperature phase of the amphibolite facies. The mineral assemblage of the skarn associated with the Chidliak gneisses is that for the low temperature and pressure phase.

The felsic units of the pyroxene-amphibole and Chidliak gneisses are probably the metamorphic derivatives of a mixture of sedimentary and igneous materials. The mafic units, noticeably those that cut the gneissosity of the host rocks, are probably metamorphic remnants of dykes or volcanic feeders. Their chemical composition is similar to that of diabase or gabbro. Units having sill-like habits may be remnants of volcanic flows or sills of andesitic and basaltic composition. A few of the units that are composed of calcium-rich amphibole, calcite, and plagioclase are probably layers of metamorphosed impure limestone.

The association of sillimanite-rich bands with the pyroxene-amphibole and Chidliak gneisses, and of carbonate-rich areas with the latter group suggest the original presence of sedimentary material. The occurrence of graphite-rich layers with the Chidliak gneisses is of interest, as these layers are not commonly related to carbonate-rich bands or to any intrusive rocks. It is suggested that the graphitic units were originally sediments and that their carbon is of organic origin.

The incorporation of sedimentary material in the felsic gneisses must have taken place in areas adjacent to the sillimanite- and carbonate-rich bands. Further modification of the bulk composition of the gneisses probably took place by means of metamorphic differentiation and metasomatism.

The pyroxene-amphibole gneisses are transitional between the granulites and the Chidliak gneisses in regards to position and mineral composition. Field relationships of this group of rocks, such as gradational contacts with the granulites and Chidliak gneisses and the slight change of colour between the main rock types, are indicative of this transition. The minerals characteristic of the rocks, indicative of this intermediate position, include hornblende as an important primary constituent. This mineral, according to its optical properties, contains more water than that of the primary hornblende in either the granulites or charnockites. More patch perthite is present than in the granulites, and the host potash feldspar is predominantly microcline. These mineralogical features are indicative of a lower temperature of crystallization which may be caused by a slight increase in the water content. A decreasing temperature gradient, due to the decreasing depth of formation, was probably present at the outer margins of the bodies of pyroxene-amphibole gneisses.

Origin of the Cumberland Sound Complex

The Cumberland Sound Complex is believed to be part of an old geosynclinal area into which was deposited material resulting in the formation of conglomerate, alumina-rich layers, limestone and probably dolomite, graphite-rich layers, and possibly micaceous sandstone. A considerable thickness of sedimentary material of geosynclinal origin was probably deposited.

After this period of deposition and subsidence, it is possible that granitic material was emplaced at deeper levels. The charnockitic and granulitic regions represent the most deeply downfolded section, and the epidote-bearing rocks the least downfolded. The intensity of metamorphism of each rock group is in part related to its horizontal distance from the centre of the Complex. This distance probably because of differential downwarping, determined the relative depth of burial, which in turn affected the degree of regional metamorphism. A second factor to which the intensity of metamorphism of the Complex may be related is the presence of charnockite and because the charnockite in some localities appears to cut the gneiss, it is in part post-tectonic. Further metamorphism was thus superimposed on rocks previously regionally metamorphosed.

Summary and Conclusions

The rocks of Cumberland Sound region are divided into different assemblages, collectively referred to as the Cumberland Sound Complex.

Pyroxene-bearing, granitic-looking, predominantly massive rocks are classified as charnockites. It is believed that these rocks were formed by plutonic metamorphism of rocks of high metamorphic facies. Rocks in a second zone are called granulites. These granulites are divided into five varieties by field mapping and mineralogical methods, all were produced by metamorphism under the conditions of the granulite facies. Pyroxene-amphibole gneisses are intermediate in mineralogy and metamorphic grade between the granulites and the Chidliak gneisses.

The charnockites exhibit the highest grade of metamorphism, the epidote-bearing Finger Land and Misty Island gneisses the lowest, and the others are intermediate in grade.

Mineral assemblages characteristic of the granulite facies and sillimanite-almandine subfacies and low amphibolite facies were recognized in the sillimanite-rich rocks. These alumina-rich layers were used to help to define the metamorphic facies of the rock groups in which they are found.

Differences in optical properties of potash feldspar, perthite, pyroxene, amphibole, and titanium-bearing minerals were recognized in each of the zones. These differences are related to changes in temperature and pressure and a temperature gradient for the main rock groups is established. The charnockites probably formed at 650° to 750°C, the granulites at 600° to 675°C, and the pyroxene-amphibole-bearing gneisses from 500° to 600°C.

It is suggested that the type of potash feldspar and perthite is directly related to the grade of metamorphism. Hornblende and biotite are known to be stable in the charnockites and granulites, and cordierite is not considered to be alien to the granulite facies.

The Cumberland Sound Complex is composed of metamorphic rocks of sedimentary and igneous origin. It is believed that many of the felsic gneisses were originally sedimentary.

K-Ar age determinations carried out in laboratories of the Geological Survey of Canada on micas indicate ages falling between 1,600 and 1,700 million years. *See* GSC Paper 60-17, samples GSC 59-37 and 59-38.

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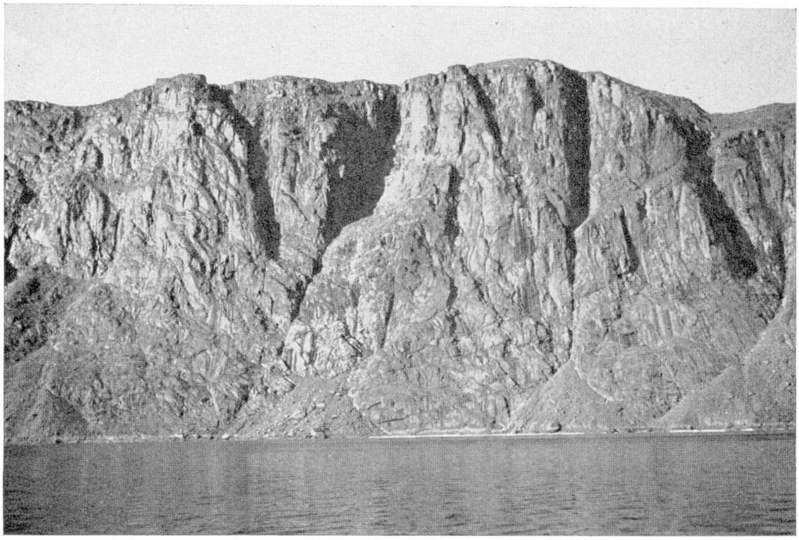
PLATES II to X



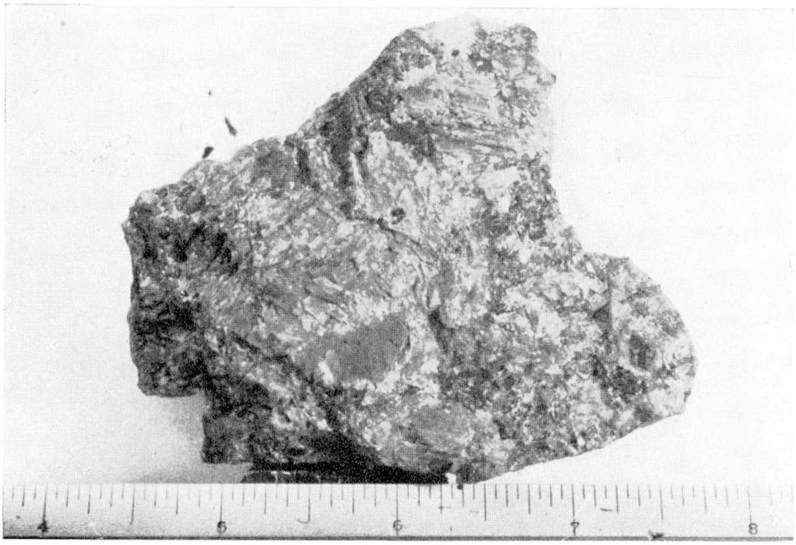
111121

A. Cliff face about 1,900 feet high. View looking N45°E on northeast shore of upper Shark Fiord, showing northwesterly, northerly, and northeasterly fracture systems.

Plate II

B. Charnockite with fine-grained granitic inclusion at Quickstep Harbour.

111124



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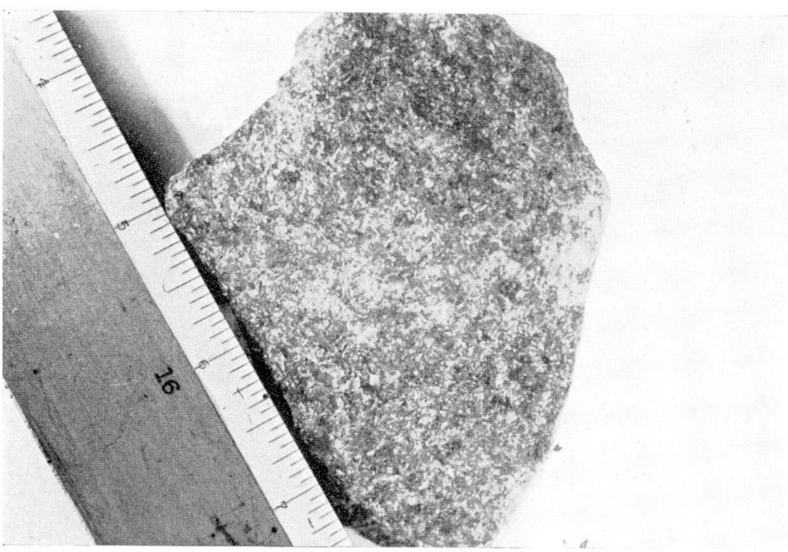
A. Coarse-grained charnockite. Usualuk type.

Plate III

B. Medium-grained charnockite. Imigen type.



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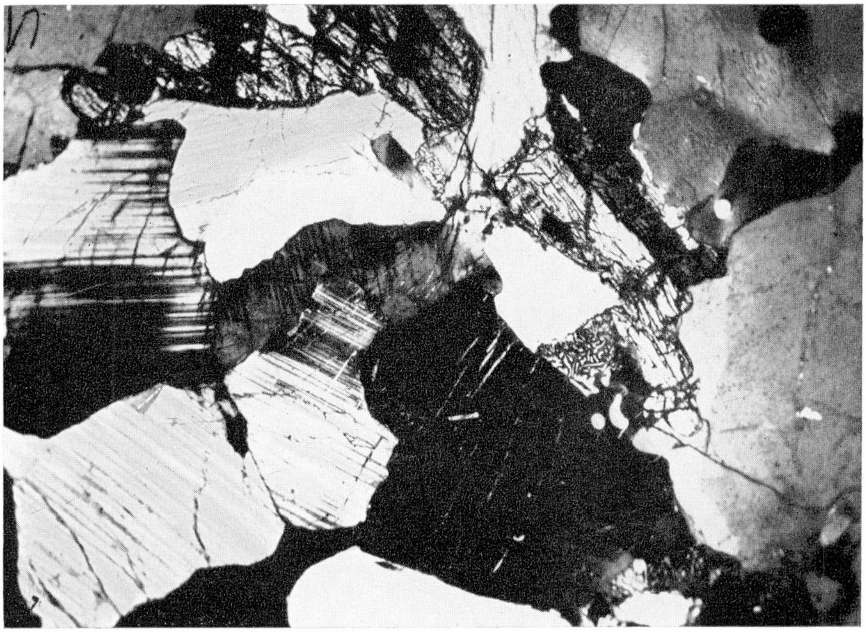
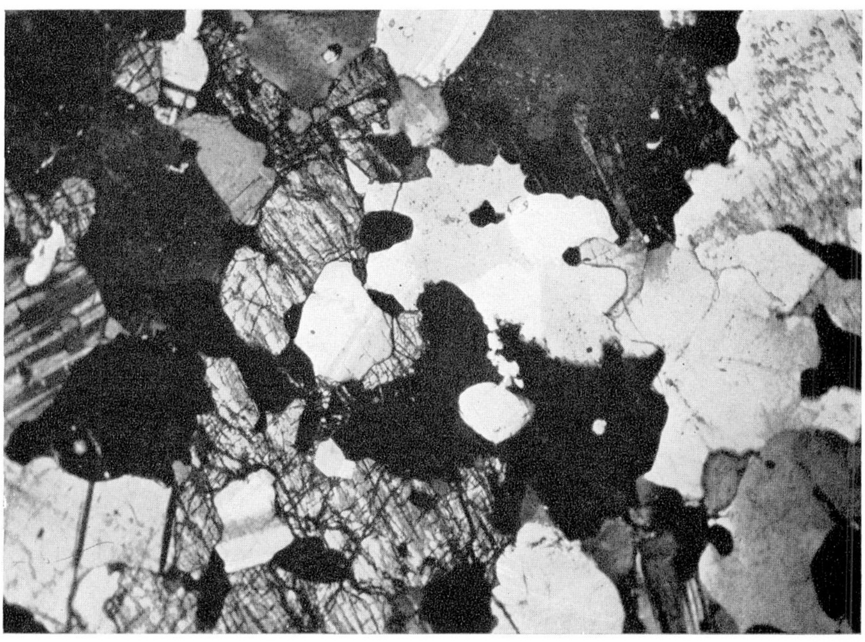


111129

A. Texture of coarse-grained charnockite. Crossed nicols x19.2.

Plate IV

B. Texture of medium-grained charnockite. Crossed nicols x19.2.



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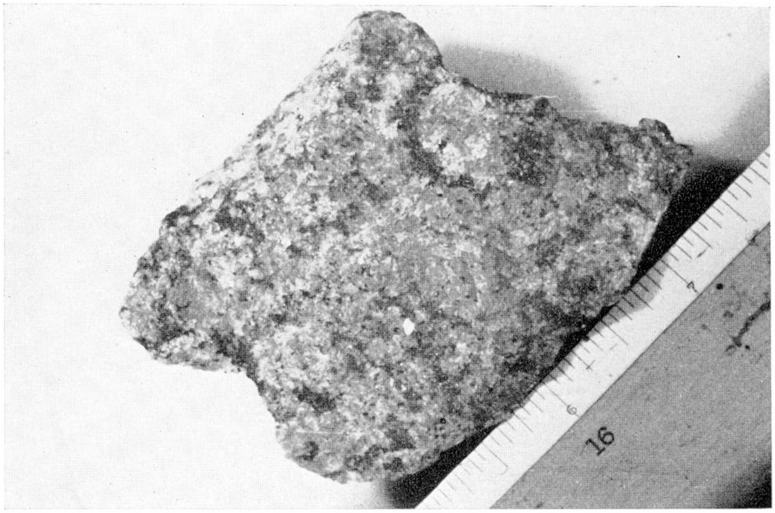
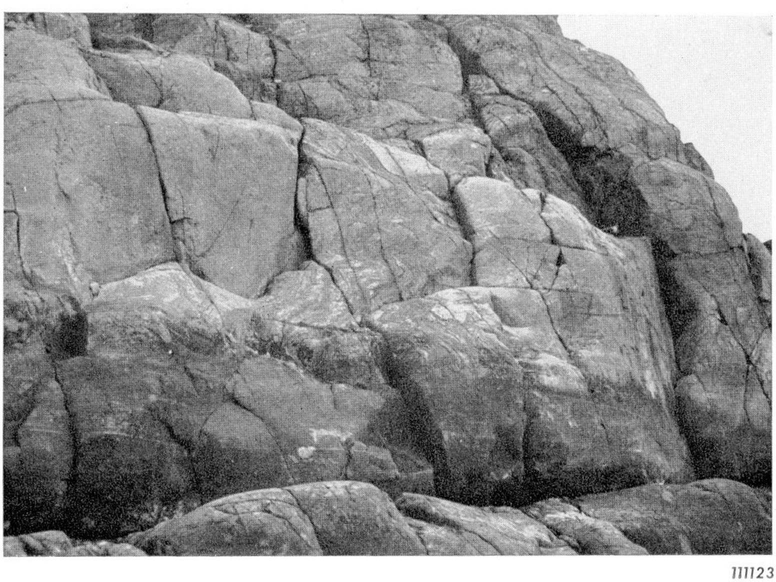


GCR 9-18-59

A. Granitic granulite.

Plate V

B. Rock on southeast shore at entrance to Livingstone Fiord showing contact between charnockite and flow banded vein granitic granulite. Granulite in centre of photograph bounded by massive charnockite.



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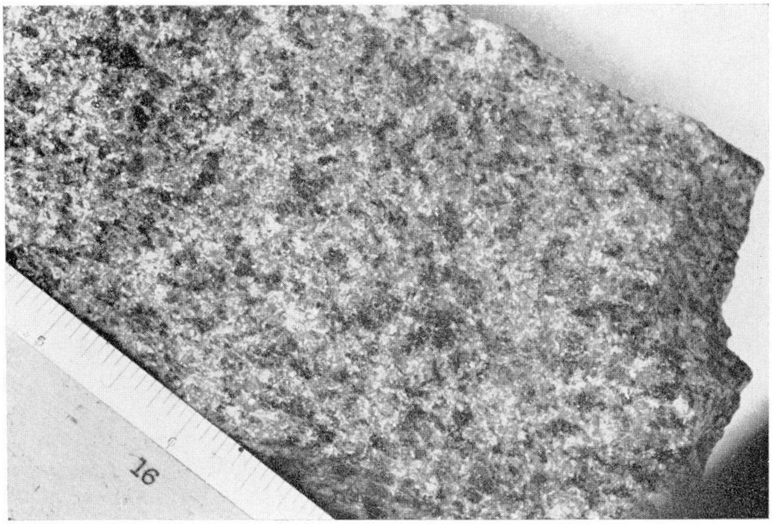

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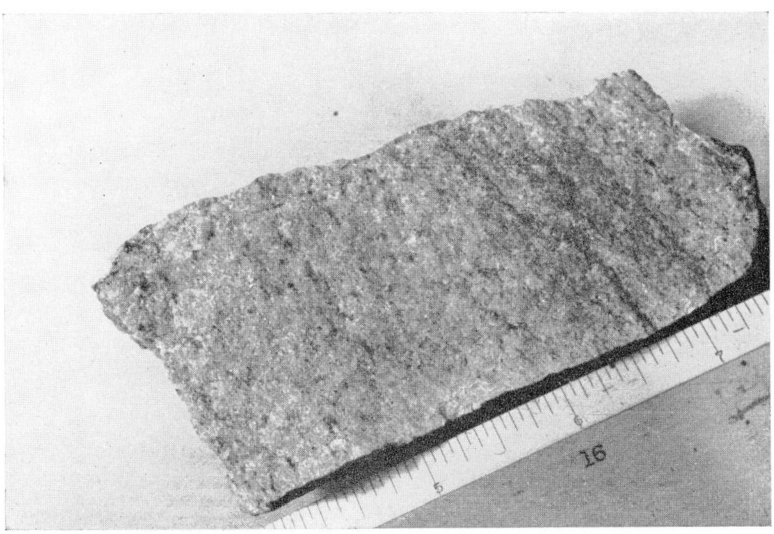
A. Granodioritic granulite.

Plate VI

B. Quartzo-feldspathic granulite.



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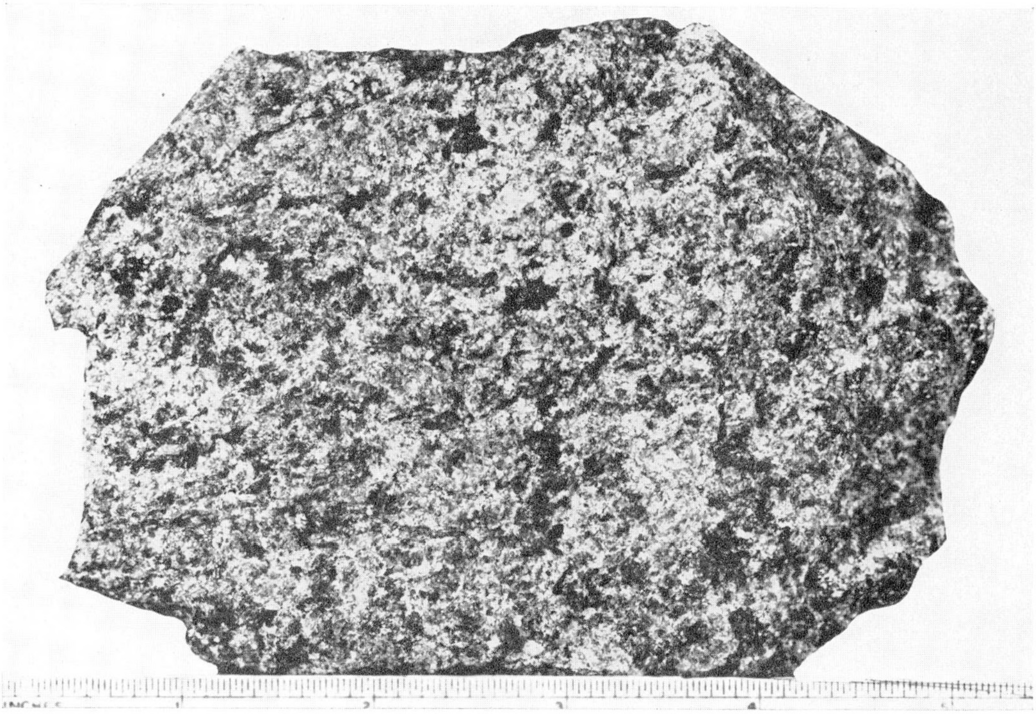
GCR 9-21-59

A. Mafic granulite containing quartz and feldspar.

Plate VII

B. Mafic granulite containing little or no quartz.

GCR 9-20-59

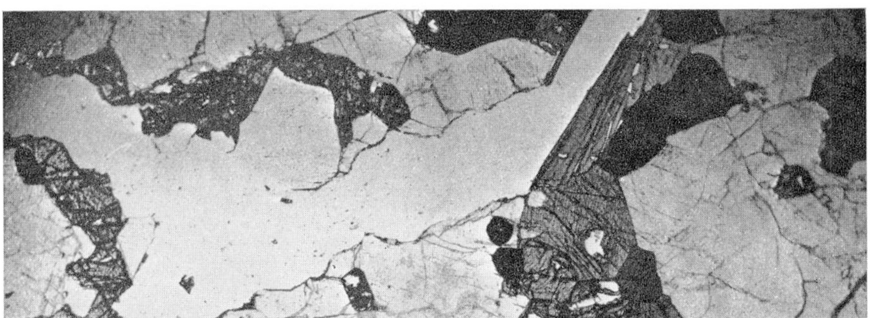


111132

A. Pyroxene-amphibole granodiorite-gneiss.

Plate VIII

B. Texture of pyroxene-amphibole granodiorite-gneiss. Crossed nicols x19.2.



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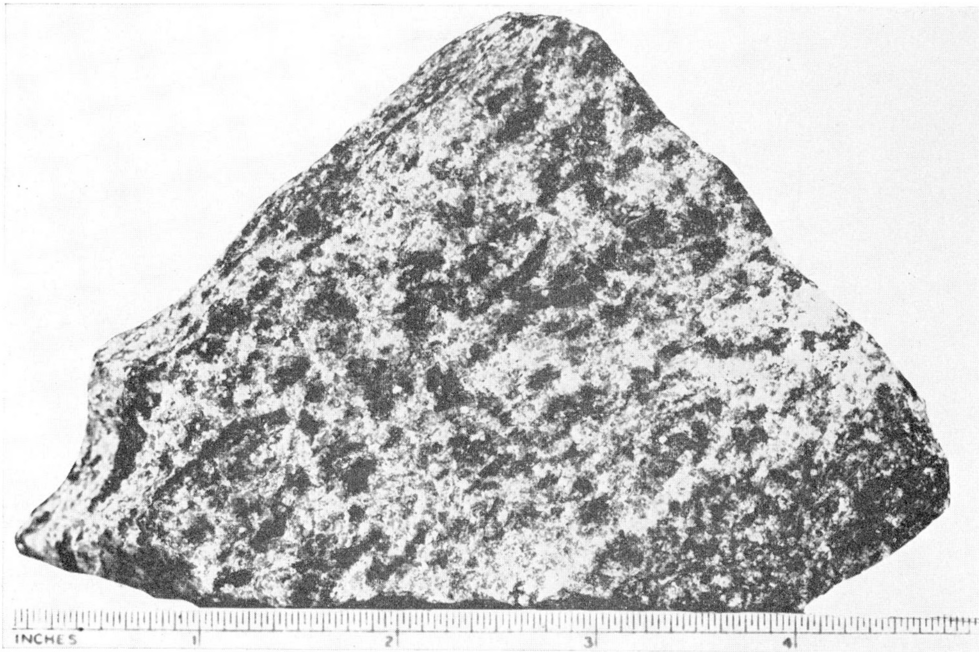
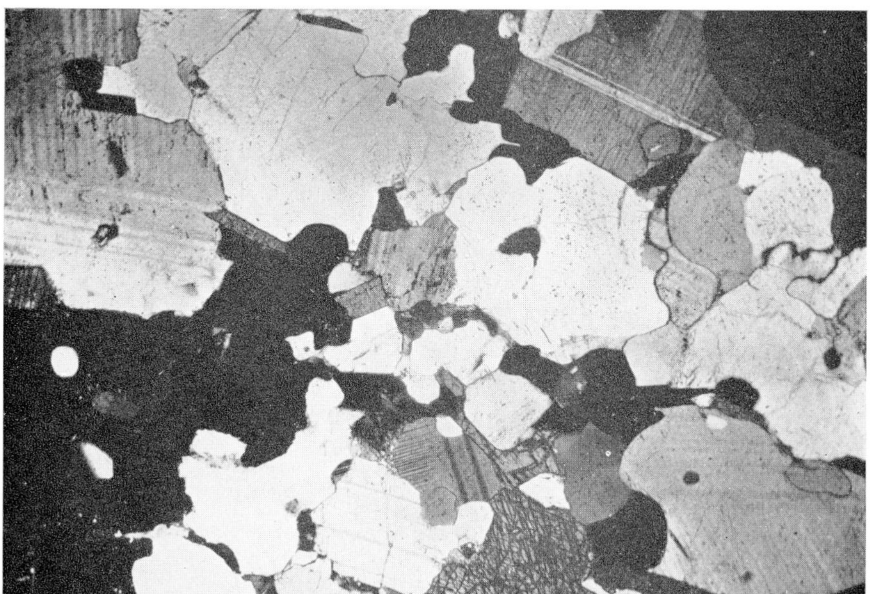


111130

A. Granitic variety of the Chidliak gneisses.

Plate IX

B. Texture of the granitic variety of the Chidliak gneisses. Crossed nicols x19.2.



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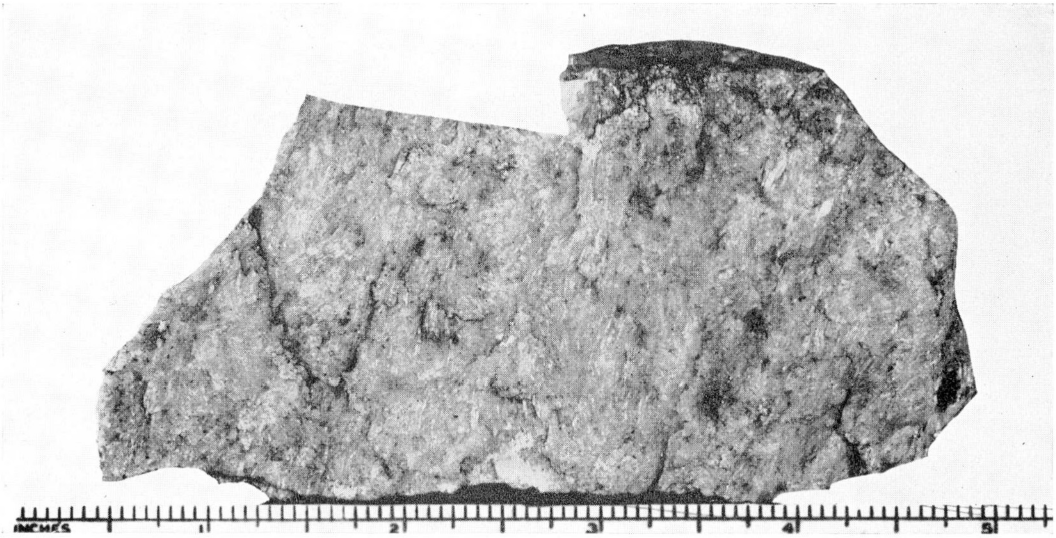
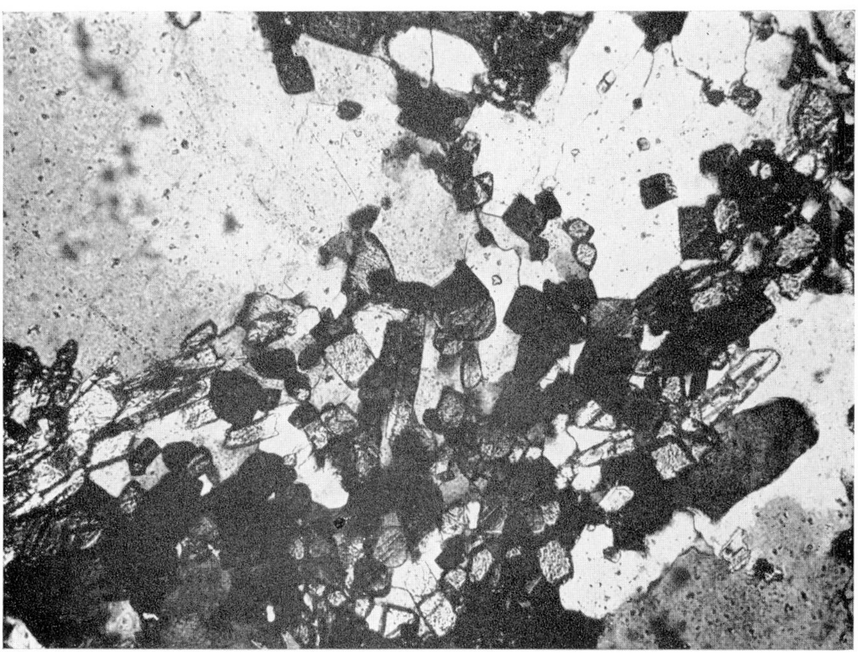


111131

A. Sillimanite-bearing gneiss.

Plate X

B. Texture of sillimanite-bearing gneiss. Crossed nicols x60.



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