GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN NO. 71

CONTRASTED TYPES OF METAMORPHISM OF BASIC INTRUSIONS

IN THE PRECAMBRIAN BASEMENT OF THE TASÎUSSAQ AREA, SOUTH GREENLAND

BY

PETER R. DAWES

WITH 17 FIGURES AND 6 TABLES IN THE TEXT
AND 3 PLATES

Reprinted from
Meddelelser om Grønland, Bd. 185, Nr. 4

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
1968

GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 71

CONTRASTED TYPES OF METAMORPHISM OF BASIC INTRUSIONS IN THE PRECAMBRIAN BASEMENT OF THE TASÎUSSAQ AREA, SOUTH GREENLAND

BY

PETER R. DAWES

WITH 17 FIGURES AND 6 TABLES IN THE TEXT
AND 3 PLATES

Reprinted from
Meddelelser om Grønland, Bd. 185, Nr. 4

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
1968

Abstract

Metamorphosed rocks of three distinct episodes of basic intrusion can be recognised in the Precambrian basement of the Tasîussaq area, South Greenland. The oldest intrusions, represented by sills and dykes, are pyriclasites and biotite-pyriclasites; the second episode intrusions, in the form of dykes, are pyroxene-metadolerites and the third episode intrusions, represented by dykes and small bodies, are metagabbros, metadolerites, metanorites and amphibolites. The metamorphic nature of the rocks of the three episodes is a reflection of age. Chemical and modal analyses of rocks from the three episodes are presented. Fresh diorite sills and dolerite dykes represent later episodes of Precambrian basic intrusion.

The basic rocks depict the varying types of metamorphic conditions which affected the area in Precambrian time and these are seen to differ from the established metamorphic history in areas to the north-west in South Greenland. The pyriclasites and biotite-pyriclasites have been derived through granulite facies metamorphism; the pyroxene-metadolerites by dipsenic metamorphism under conditions corresponding to the amphibolite facies and the metagabbros, metadolerites, metanorites and amphibolites through amphibolitisation during amphibolite facies metamorphism. It is suggested that the metamorphism producing the pyroxene-metadolerites (Sanerutian in age) was controlled by dipsenic conditions inherited from earlier granulite facies metamorphism (Ketilidian in age). This implies that the Ketilidian and Sanerutian metamorphisms in the Tasîussaq area are not separated by a long span of time and that the break in plutonism marked by the pyroxene-metadolerites cannot be regarded as a significant cratogenic hiatus between two separate plutonisms. The importance of water in controlling trends in the metamorphism of dolerites is stressed.

The 1st episode intrusions have undergone severe changes since intrusion and no palimpsest features indicative of primary texture or mineralogy remain. The majority of the 2nd episode intrusions display a granular texture, but some display sub-ophitic and relic sub-ophitic textures. The 3rd episode intrusions display a range from ophitic, sub-ophitic and microporphyritic textures to relic stages of these textures.

The 1st episode intrusions were emplaced into a geosynclinal pile of sediments and were probably connected with the volcanicity which occurred at the end of sedimentation. The 2nd and 3rd episode intrusions were emplaced into granitic and metamorphic rocks at a later stage in the same ‘geological cycle’. Both the 2nd and 3rd episode intrusions are considered to indicate trends in the crust towards brittle conditions marking temporary partial withdrawals of the thermal front. Their preserved ophitic and sub-ophitic textures are *not* indicative of emplacement and crystallisation in cratogenic conditions.

CONTENTS

ACKNOWLEDGEMENTS

The work for this study was carried out in the universities of Exeter and Copenhagen and it forms part of a Ph. D. thesis submitted to the University of Exeter in 1965. Field work was carried out in the summers of 1962 and 1963. I am most grateful to Dr Kenneth Coe for his supervision of the research work at Exeter and for his continual encouragement and support. I am also indebted to Professors Arne Noe-Nygaard and Scott Simpson for providing working facilities in Copenhagen and Exeter Universities respectively, and to mag. scient. K. Ellitsgaard-Rasmussen, Director of the Geological Survey of Greenland (GGU) for the opportunity of working in Greenland, for allowing me to use the Greenland material for the Exeter thesis and for permission to publish this paper.

Assistance in the field from stud. mag. Frederick Larsen-Badse in 1962 and stud. mag. Preben Christensen in 1963 is greatly appreciated. The awards from the Department of Scientific and Industrial Research of a Research Scholarship tenable at Exeter University and of a N.A.T.O. Research Scholarship enabling me to work in Copenhagen University, are gratefully acknowledged.

My thanks are further directed to Mr B. I. Borgen for the determination of the chemical analyses presented here; to Mr Povel Povelsen, GGU photographer, for the preparation of the photographs printed here as text-figures, to Mr J. Saunders, University of Exeter, for the microphotographs included here as plates, and to all members of GGU for their help and discussions, in particular Mr C. Pulvertaft and Dr J. Allaart for suggesting improvements to an earlier draft of this paper.

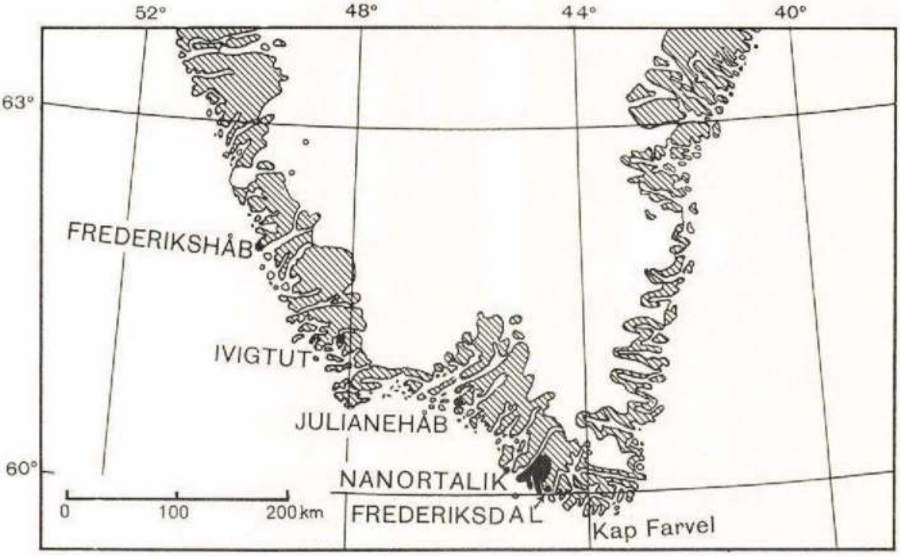


Fig. 1. Map of South Greenland showing the position of the Tasîussaq area (black).

INTRODUCTION

Basic rocks have long been used as an instrument in establishing chronologies and since the works of J. J. SEDERHOLM from the Precambrian of southern Finland, the 'basic dyke method' has enjoyed wide success. Basic rocks can be used to unravel geological history and to separate geological events and they also act as a base on which later geological processes can be measured and assessed.

The purpose of this paper is to describe metamorphosed basic intrusions of three distinct ages from a single area in South Greenland in order to reveal the varying type of metamorphism prevalent in Precambrian time. This is of special interest since the metamorphic state of the basic rocks differs markedly from that in other areas to the north-west in South Greenland.

Present Investigation

The geology of the Tasîussaq area is the subject of a Ph. D. thesis by the author (DAWES, 1965) and the basic rocks treated here are all found within this area. The area is situated on the south-west coast of Greenland between latitudes 60°3′ N and 60°18′ N covering approximately 450 km² (fig. 1). It is bounded on the north-west by Tasermiut fjord, which lies approximately 75 km to the north-west of Kap Farvel. The

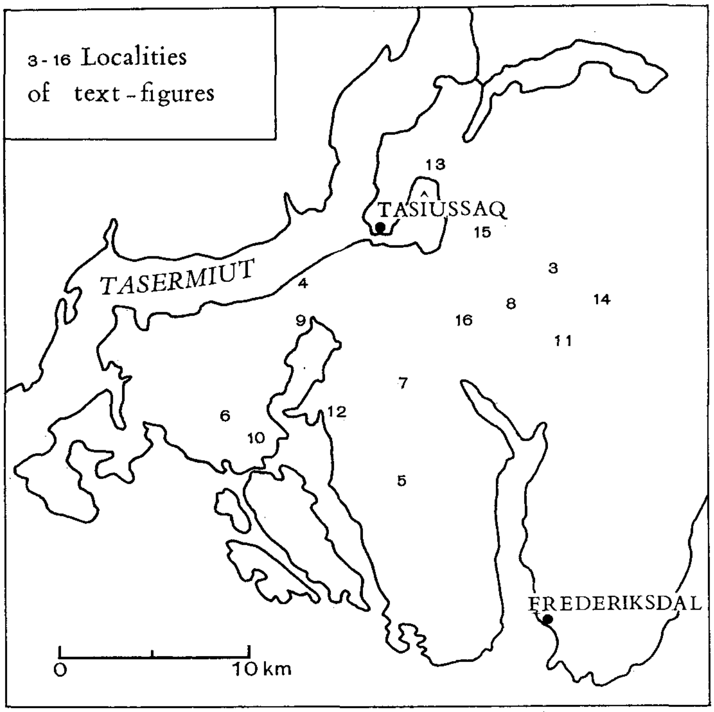


Fig. 2. Outline map of the Tasîussaq area showing the localities of text-figures 3 to 16.

settlement of Tasîussaq, giving rise to the name of the area under consideration, is situated on the Tasermiut fjord coast (fig. 2).

The geological investigations in the Tasîussaq area were carried out in the summers of 1962 and 1963 under the auspices of the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse — GGU), which in the years 1954–1963 mapped, on the scale of 1:20 000, the whole coast from north of Ivigtut to Frederiksdal (fig. 1). The Tasîussaq area was the most south-easterly region investigated during this period and the only area of granulite facies rocks. The basement to the north-west of the Tasîussaq area is characterised by amphibolite facies or lower grade rocks. In 1965 GGU carried out reconnaissance mapping to the east and south-east of the Tasîussaq area in the Kap Farvel region (Bridgwater, Sutton and Watterson, 1966). Wallis (1966), working independently from GGU has investigated the area immediately north and north-east of the Tasîussaq area.

Previous Investigations in the Tasîussaq Area

Very few references exist in the literature about the rocks of the Tasîussaq area and nothing was known about the basic rocks discussed in this paper prior to the investigations in 1962 and 1963. It seems that the Frederiksdal 'granite' massif bordering the Tasîussaq area on the south, drew the attention of the early geologists who apparently concentrated on the coastal districts and rarely penetrated inland (SYLOW, 1883; TÖRNEBOHN, 1886; KNUTSEN and EBERLIN, 1889; GIESECKE, 1910).

JESSEN (1896) was the first to visit the Tasîussaq area during his trip into Tasermiut fjord and he distinguished between gneisses and older and younger granites. WEGMANN in 1937 also visited Tasermiut fjord and in a small-scale map indicated both amphibolite and granulite facies rocks and younger granite in the Tasîussaq area (WEGMANN, 1939). The only other observer prior to the present study, was the late G. H. FRANCIS, who as a member of the British Museum Cape Farewell Expedition of 1957 visited the northern part of the Tasîussaq area for approximately two weeks for the purpose of making collections of the basement gneisses and younger granites (FRANCIS, 1957).

Regional Geological Setting

WEGMANN (1938, 1939) laid the foundations of the present geological chronological division of South Greenland on the basis of 'orogenic cycles' by recognising 'an old basement' and 'younger formations'. The basement consists of the remains of an old mountain chain to which WEGMANN gave the name 'Ketilides', the sediments and the subsequent metamorphism, deformation, migmatisation and the formation of granites becoming known as Ketilidian. This cycle is separated by a period of erosion from the Gardar cycle in which the Igaliko sandstone and porphyry formation were formed and the intrusion of the alkaline batholiths and various types of dykes occurred. He also recognised a pre-Ketilidian cycle as a basement to the Ketilidian supracrustal rocks and considered most of the gneisses exposed on the Ivigtut peninsula (the 'Ivigtut gneisses') as representative of the earlier cycle (WEGMANN, 1939, p. 206).

BERTHELSEN (1961) as a result of GGU mapping in the Ivigtut area revised WEGMANN's chronology and introduced the terms 'Kuanitic' and 'Sanerutian' to refer to periods between the Ketilidian and the Gardar. The Kuanitic is marked by the intrusion of doleritic dykes after the waning of the Ketilidian plutonism while Sanerutian was coined to refer to the post-Kuanitic metamorphism, deformation and reactivation of the Ketilidian rocks. Thus the picture arose of two distinct 'plutonic' periods separated by the intrusion of cratogenic doleritic dykes (WATTERSON, 1965; WINDLEY, 1966a).

However, BRIDGWATER (1965) and BRIDGWATER and WALTON (1964) have questioned the significance of the Kuanitic period as a major break separating two plutonic episodes, and they have suggested that the Ketilidian and Sanerutian may be closely spaced in time and that the Kuanitic period of dyking may have a reduced significance representing a "temporary volcanic phase in the development of a single orogeny". Furthermore, doubt was cast on the chronological position of the dykes originally called Kuanitic by BERTHELSEN as early as in 1962 when BONDESEN reported a basal unconformity between supracrustal rocks (Ketilidian) and gneisses (pre-Ketilidian) north of Ivigtut (HIGGINS and BONDESEN, 1966), a relationship interpreted by BERTHELSEN (1961) as a migmatitic infrastructure overlain by a non-migmatitic superstructure, both of Ketilidian age. Thus the possibility arose that the holotype dykes of the Kuanitic period which cut the gneisses referred to above (i.e. 'Ivigtut gneisses') were pre-Ketilidian in age and this has led directly to the unsuitability of the term 'Kuanitic' to describe the period between the Ketilidian and the Sanerutian, a period which is nevertheless marked by basic dyking, albeit on a much smaller scale than that seen in the Ivigtut area.

Sanerutian and Gardar rocks from South Greenland have been isotopically dated and from these dates plus data from other parts of Greenland and by comparison with events in other fold belts, BRIDGWATER (1965) has suggested the following dates of geological events in South Greenland: pre-Ketilidian 2000–2700 m.y., Ketilidian 1700–2000 m.y., Kuanitic 1650–1700 m.y., Sanerutian 1500–1650 m.y., and Gardar 1020–1500 m.y.

As a result of all these interpretations and of continued mapping by GGU the terminology of the Precambrian basement of South Greenland is under critical review. WATTERSON (1965) from the Ilordleq area, south of Ivigtut, suggests a revision of terminology and regards the term 'Kuanitic' as unsuitable but retains it "because no suitable alternative has yet been agreed upon". ALLAART (in press) from the Julianehåb area abandons both Kuanitic and Sanerutian and extends the Ketilidian to incorporate all events from the Ketilidian sedimentation to the Gardar, thus reverting to WEGMANN's (1938) original chronological terminology, while N. HENRIKSEN (personal communication) favours the retention of the term 'Sanerutian' to describe the 2nd episode of plutonism in ALLAART's extended Ketilidian period (also see WATTERSON, 1965, p. 132).

This paper is essentially a study of the metamorphism of basic rocks but since it has some implications in the chronological terminology of the basement of South Greenland and references are made to other areas in South Greenland, the above brief review is given. For a more detailed treatment of the Precambrian basement of South Greenland, the reader is referred to the papers quoted above and to the review by ALLAART (1964).

Table 1. *Generalised Precambrian chronology of the Tasîussaq area.*

Gardar	Intrusion of dolerite dykes with faulting and epidotisation
– – – – – ? – – – – –	Intrusion of diorite sills and ultrabasic dykes
	Intrusion of microgranite
	Amphibolite facies metamorphism
	Intrusion of hornblende rapakivi granite
Sanerutian	Intrusion of dolerite, gabbro and norite (*3rd episode basic intrusions*)
	Intrusion of biotite rapakivi granite
	Main phase of aplites and pegmatites
	Reactivation of the earlier granites and gneisses — formation of microcline granite
	Amphibolite facies metamorphism
– – – – – ? – – – – –	
	Intrusion of dolerite dykes (*2nd episode basic intrusions*)
Ketilidian	Folding, granulite facies metamorphism, migmatisation and the genesis of synkinematic granites
	Intrusion of basic sills (*1st episode basic intrusions*)
	Sedimentation and volcanicity
– – – – – – – – – – – –	
pre-Ketilidian	Formation of granites and gneisses represented by pebbles in the psephitic supracrustal rocks of Ketilidian age and by possible areas of reworked gneiss

Terminological Remarks Applying to the Tasîussaq Area

The author in describing geological events in the Tasîussaq area in this paper discards the term 'Kuanitic' and uses the terms 'Ketilidian' and 'Sanerutian' for convenience in the way outlined in table 1. The misleading derivation of the term 'Kuanitic' mentioned above necessitates its abandonment and furthermore, since the term was initially used to name a distinct period during which cratogenic basic dykes were intruded in an area over 230 km away from the Tasîussaq area, it cannot be directly applied to the Tasîussaq area where plutonic activity was essentially continuous. However, despite the fact that 'Sanerutian' was coined with respect to the Kuanitic period, i.e. as post-Kuanitic, pre-Gardar (see Berthelsen, 1961, p. 333), it is retained here as suitable to describe the late-plutonic granite series (autochthonous microcline granite, the rapakivi granites and the allochthonous microgranite) generated after the main plutonic phase of metamorphism and deformation. The boundary separating the Ketilidian and the Sanerutian shown in table 1 is purely arbitrary (see page 42). It becomes impossible to apply strictly defined limits to an essentially continuous Precambrian evolution, the pattern and time of events of which vary within the foldbelt, especially when such limits have been erected in distant areas and are themselves in dispute.

Metamorphosed basic dykes in the basement of South Greenland have been commonly described by the convenient term 'discordant amphibolite', abbreviated to 'DA' and followed by a number to indicate the 'period' of intrusion (see WATTERSON, 1965; WALTON, 1965; WINDLEY, 1966a). This system is not employed here and the term 'episode' is used to describe the age of the basic intrusions in preference to 'period' which in a geological sense implies a main division of time. The 1st, 2nd and the great majority of the 3rd episode basic rocks of the Tasîussaq area are not amphibolites. The 1st and 2nd episode basic rocks contain no essential hornblende and the few 3rd episode basic rocks having a plagioclase-hornblende assemblage all have well preserved ophitic texture and would be called metadolerites or metagabbros by the majority of geologists.

The terms '2nd episode basic intrusions', '2nd episode basic rocks', '2nd episode basic dykes' and '2nd episode intrusions' are used synonymously in the text.

The terms 'ophitic' and 'sub-ophitic' referring to the textures of basic rocks in the Tasîussaq area are used in the sense of CLARK (1952).

General Geology of the Tasîussaq Area

The Precambrian evolution of the Tasîussaq area is essentially that of a 'geological cycle' including the deposition of a geosynclinal pile of sediments together with volcanicity and basic intrusion, followed by folding, metamorphism, migmatisation and the formation of granites (*Ketilidian*). After an episode of basic dyking, plutonic activity continued with granitisation and the formation of post-tectonic granites together with basic intrusion (*Sanerutian*). Further basic intrusion with intermittent faulting (*Gardar*) ended the Precambrian activity. The *pre-Ketilidian* is represented by pebbles of gneiss, granite and basic rock in the psephitic supracrustal rocks of Ketilidian age and by possible reworked areas of gneiss.

The supracrustal rocks consist of three main units: a pelitic unit with some calcareous layers, a psammitic and psephitic unit and volcanic unit characterised by pillow lavas. Basic rocks mainly in the form of sills (1st episode basic intrusions) were intruded into the supracrustal pile. During the main plutonism these rocks were subjected to granulite facies metamorphism and this produced a high-grade complex of gneisses, granites, schists, basic rocks, metavolcanics and metasediments (DAWES, in prep.). Two main periods of folding can be recognised: a first major isoclinal phase producing large- and small-scale structures often recumbent in style with NNE axes, and a later phase producing more open folds with dominantly NW axes. Nappe-like structures with closures to the south-east are locally preserved and the tectonic transport of large masses of rock is suggested by an isolated klippe. Migmatisation was widespread and occurred in phases throughout the deformational history. Synkinematic granites, mainly hypersthene- and garnet-bearing, now occur both as layers in the gneisses and as larger masses. After an episode of dolerite dyke intrusion (2nd episode basic intrusions) a series of granites was formed. An early microcline granite was produced by the reactivation and granitisation of the earlier gneisses and associated regional pegmatites and this was followed by the intrusion of rapakivi granites which have a long and complicated history and which are associated with the intrusion of a suite of dolerite-norite rocks — the 3rd episode basic intrusions (DAWES, 1966). A late microgranite was emplaced following the potash metasomatism of the rapakivi granites. Aplites and pegmatites were associated with each granite phase. Following the intrusion of the microgranite, two generations of diorite sills and some ultrabasic dykes were emplaced. The last events in the Precambrian evolution were the intrusion of dolerite dykes together with faulting, shearing and associated epidotisation.

The general Precambrian chronology of the Tasîussaq area is diagrammatically represented in table 1, in which the ages of the three groups of metamorphosed basic intrusions, dealt with in this paper, are indicated. A general account of the geology of the Tasîussaq area has been written (DAWES, in prep.).

The localities of text-figures 3 to 16 are indicated in figure 2.

THE BASIC ROCKS

Age Relations of the Basic Intrusions

The age relations between the three episodes of basic intrusions are based on field aspects and no absolute age date determinations are available at the present time. The three sets are clearly recognisable in the field. The oldest intrusions form sills in the basement gneisses and they have been folded, refolded and migmatised with the gneisses. The 2nd episode basic intrusions form dykes which sharply truncate the sills and the gneisses but which pre-date the later microcline granite. The 3rd episode basic intrusions occur as dykes and small bodies and, although not found in cross-cutting relationship with the 2nd episode basic dykes, are known to be younger since they post-date the emplacement of the biotite rapakivi granite, which itself post-dates the 2nd episode basic intrusions and the Sanerutian microcline granite. The 3rd episode dykes are truncated by the later hornblende rapakivi. These relationships are diagrammatically represented in table 1.

1st Episode Basic Intrusions

Field Aspects

The majority of basic rocks referred to in this group occur as sills in the basement gneisses varying in thickness from a few centimetres to 4 m. The majority, however, are between 10 cm and 1.5 m. Two horizons are somewhat larger, reaching up to 20 m. Dykes, sharply discordant to the host rock foliation, are less common, only three having been recognised. The sills are continuous and where exposures permit they have been followed over 100 m along their length. Passages from dykes to sills are rare but examples exist where sills become discordant to host rock foliation for short distances only to return to a general concordant habit. The contacts between the gneisses and sills are sharp and distinct (fig. 3). In the Ketilidian and Sanerutian granites the 1st episode basic rocks are present as isolated inclusions having been broken up and agmatised (fig. 4).

Megascopically the basic rocks vary in colour from dark grey to brown and pale green; in a few sills the rock is distinctly green due to

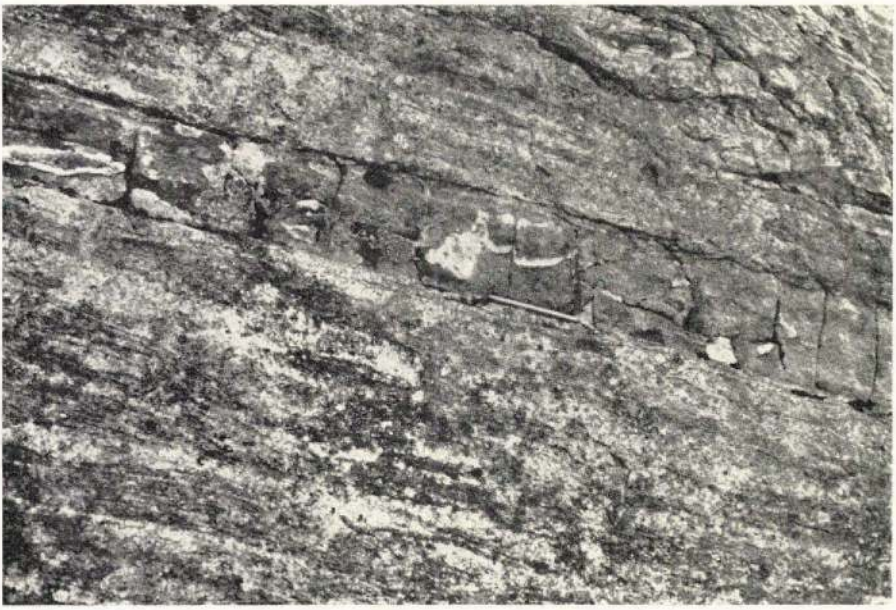


Fig. 3. Pyriclasite sill within hypersthene-garnet gneiss. The sill has sharp contacts to the gneiss and tension cracks have developed in the basic rock, not in the gneiss.

Fig. 4. Folded inclusions of pyriclasite in mobilised early Sanerutian granite.

Fig. 5. Folded and broken pyriclasite sill in hypersthene-garnet granitic gneiss showing compositional zoning produced by a basic core and less basic margins.

the predominance of hypersthene. Commonly the sills contain a lustrous brown biotite aligned parallel to the foliation of the host gneisses. Some sills display a compositional zoning produced by basic cores and less basic marginal zones (fig. 5). The sills have been migmatised with the host rocks and as a result bear streaks and small veins of quartzo-felspathic material parallel to the migmatitic structure of the gneisses. Such streaks help to show up local discordances that exist between the sills and the gneiss (fig. 6).

The sills pre-date the Ketilidian deformation and regional metamorphism and they have been folded (fig. 7) and refolded (fig. 8) or have suffered boudinage, according to their orientation relative to the deforming forces (fig. 9). They have been affected by the early NNE isoclinal folding of the area (fig. 10). The sills were probably intruded

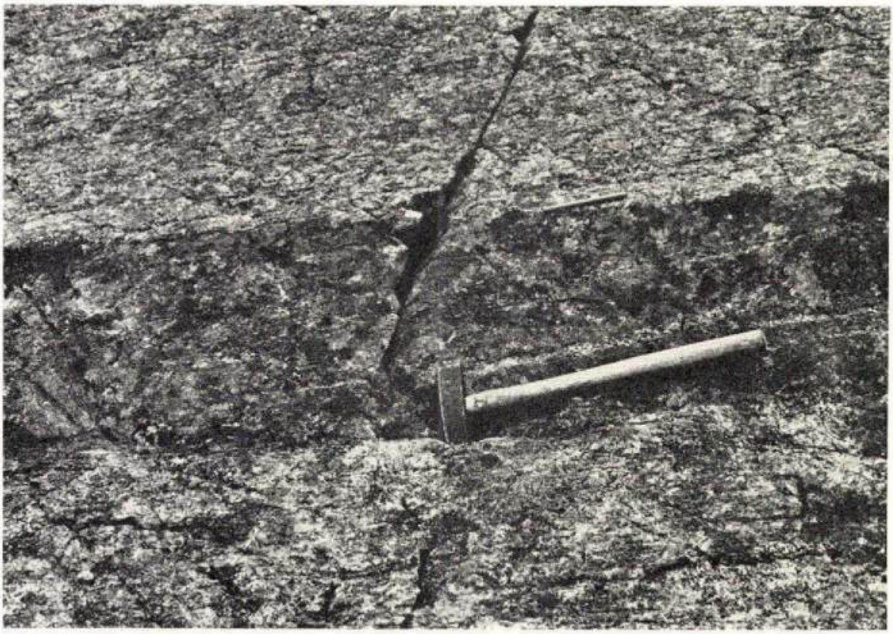


Fig. 6. Pyriclasite sill in quartzo-felspathic hypersthene gneiss showing slight discordancy to the foliation of the gneiss. Quartzo-felspathic streaks in the pyriclasite are parallel to the gneiss foliation.

into the geosynclinal pile of sediments, being connected with the volcanicity which produced the youngest supracrustal rocks of the area.

Petrography

The composition of the 1st episode basic rocks varies from pyriclasite to biotite-pyriclasite. Berthelsen (1960) in a suggestion "towards a better nomenclature for 'basic granulites' " coined the term 'pyriclasite' for rocks composed of both ortho- and clinopyroxene (pyr) and plagioclase (clasite) but it seems unnecessary to restrict its use only to rocks bearing two pyroxenes. Pyriclasite is used here for rocks composed mainly of hypersthene and plagioclase in which clinopyroxene may be absent. Biotite-pyriclasite is suggested here for pyriclasites in which biotite exceeds 50% of the pyroxene content. Modal analyses of pyriclasites and biotite-pyriclasites are given in table 2 and a single chemical analysis in table 3.

The rocks are fine- to medium-grained and are composed of orthopyroxene, biotite and plagioclase with or without smaller amounts of quartz, clinopyroxene and garnet. The main accessories are apatite, sphene, hornblende, penninite, sericite and ore. The texture varies from heteroblastic, with large pyroxene crystals present in a plagioclase

Table 2. *Modal analyses of pyriclasites (P) and biotite-pyriclasites (BP) (1st episode basic intrusions).*

GGU Sample No.	54481 (BP)	58522 (P)	58608 (P)	58686 (BP)	58687 (P)	66994 (BP)	67038 (BP)	67112 (BP)	67168 (P)	67184 (P)	67198 (P)
Pyroxene ...	32.8	50.2	59.2	52.2	68.8	19.7	25.6	45.4	49.0	29.3	39.9
Biotite......	55.7	21.3	15.6	26.2	2.9	37.5	15.7	34.1	10.2	9.4	9.6
Plagioclase . .	11.2	24.2	24.7	20.9	25.9	38.8	56.4	20.2	37.3	50.6	42.6
Quartz......	–	–	–	0.3	–	2.9	–	–	2.1	9.8	4.3
Accessories . .	0.3	4.3	0.5	0.4	2.4	1.1	2.3	0.3	1.4	0.9	3.6

Accessories include apatite, hornblende, penninite, sericite, sphene and ore.

matrix, to homeoblastic, with the pyroxene approximately equal in size to the plagioclase. The former characterises the majority of examples where poeciloblastic texture is common, with large hypersthene crystals enclosing smaller grains of plagioclase and biotite (plate 1, a). From this there is a transition towards a more homeoblastic texture with an increase in the amount of plagioclase relative to pyroxene. As the felspar becomes more abundant the individuality of the pyroxene crystals becomes less distinct and the large crystals are split into isolated parts. Even where only small equigranular individuals finally exist in a matrix of plagioclase with perhaps lesser amounts of quartz and biotite, it is

Table 3. *Chemical analyses of 1st (pyriclasite), 2nd (pyroxene-metadolerite), and 3rd (metagabbro and metadolerites) episode basic intrusions.*

GGU Sample No.	Pyriclasite 67194	Pyroxene-metadolerite 54488	Metagabbro 66847	Metadolerite 66941	Metadolerite 67180
SiO_2..........	50.90	50.89	51.05	48.90	48.64
TiO_2..........	0.72	0.55	1.01	0.94	1.38
Al_2O_3.........	9.53	14.97	16.56	16.58	16.32
Fe_2O_3.........	0.37	0.31	0.55	1.38	1.15
FeO	9.78	8.69	9.95	8.71	11.19
MnO	0.17	0.16	0.17	0.18	0.18
MgO	14.98	9.00	6.36	6.63	6.23
CaO	10.15	10.28	8.65	8.97	9.03
Na_2O.........	0.62	1.82	2.93	3.17	2.81
K_2O..........	0.64	0.82	0.82	0.82	0.64
P_2O_5	0.20	0.23	0.19	0.17	0.21
H_2O +........	1.09	1.48	1.20	3.03	1.99
CO_2..........	+	+	+	+	+
Cr_2O_3.........	0.30	not det.	not det.	not det.	not det.
Total.........	99.45	99.20	99.44	99.48	99.77

Analyst: B. I. BORGEN

Fig. 7. Strongly folded pyriclasite sill in granitic gneiss cut by later pegmatite veins.

usually possible to determine the original outline of the pyroxene crystals through the optical continuity of the component parts.

Hypersthene varies in colour from neutral to pale green or pale red, and it is generally markedly pleochroic, although occasionally pleochroism is non-existent to weak. It occurs in xenomorphic to hypidiomorphic crystals varying from less than 1 mm to 1 cm and it displays well marked cleavage and commonly schiller structure. Oblique extinction is frequently displayed. The mineral commonly contains inclusions of plagioclase, biotite and quartz and it is in places replaced by hornblende and late biotite.

Biotite exists in the sills as small flakes varying from less than 0.5 mm up to 3 mm in size. It varies in amount from approximately 3 % to

Fig. 8. Refolded pyriclasite sill in granitic gneiss. Development of pegmatite in the axial plane of the 1st phase isoclinal fold (top left) has partly obscured the hinge. 2nd phase fold refolds the isocline and the whole structure is cut by an unfolded pegmatite.

55 %. It is pleochroic from neutral to brown, pale brown to red brown and pale brown to brown. Two types can be recognised:

1. Biotite which gives to the rock a marked foliation and schistosity, the texture in parts approaching lepidoblastic. Such biotite is present in tightly packed sheaves, in places showing curved traces.

2. Biotite which is present in less well defined crystals and which usually has no preferred orientation. This is commonly found replacing hypersthene and diopside and is of a younger generation than the bent and folded biotite.

Plagioclase (An_{60-75}) constitutes as little as 10 % of the melanocratic types and up to approximately 57 % of the more acid varieties. Characteristically it forms small grains of less than 0.5 mm, xenomorphic in shape and displaying albite-twinning. It has two distinct habits in the texture, either being included in the hypersthene in a poeciloblastic manner or forming a matrix in which the hypersthene is situated. In the latter case the mineral is present in larger crystals ranging up to 2 mm and these show evidence of having replaced pyroxene.

Diopside is present in some samples but it never exceeds orthopyroxene in amount. It is colourless and occurs in crystals up to 2 mm

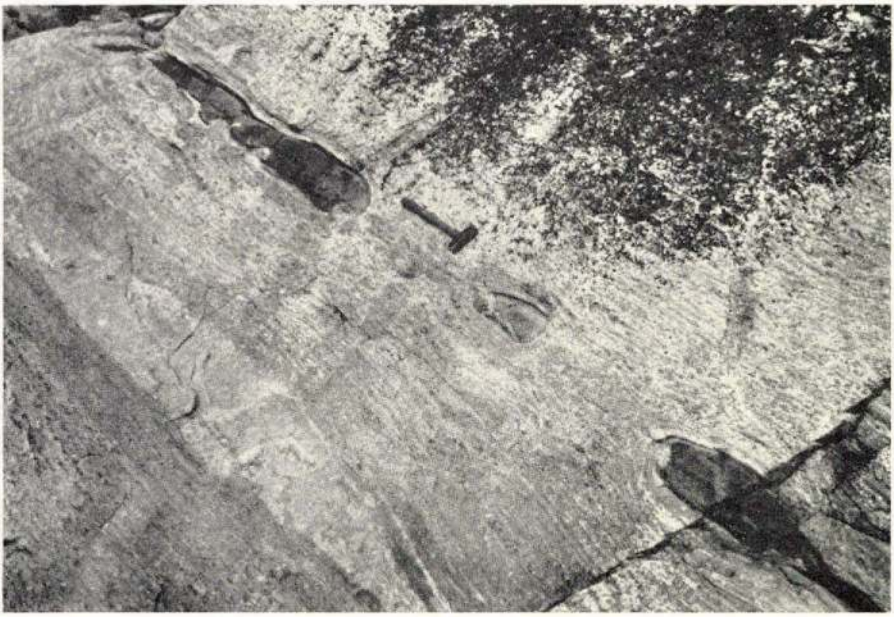


Fig. 9. Boudinaged pyriclasite sill in hypersthene-garnet gneiss. Movement of boudins due to flowage of the gneiss. The dark colour in top right is lichen growth.

Fig. 10. Isoclinally folded pyriclasite sill in hypersthene-garnet gneiss. Small fold developed on the lowest limb. The sill is flanked in part by pegmatite which fills the breaks in the sill. The note-book is 17 cm in length.

in essentially the same habit as the hypersthene. *Diallage*, a variety of diopside showing a prominent parting, also exists occasionally.

Myrmekite was noted in a few samples. The plagioclase forms the host mineral in which small elongated blebs of quartz are present. At some junctions between plagioclase grains, the quartz blebs cross the contact and replace the plagioclase of both grains.

Quartz apart from the myrmekite is present in some rocks as small grains up to 1 mm in diameter having a similar habit to the equigranular plagioclase grains. It is included in both the pyroxene and plagioclase. It increases in amount in the basic rocks that have been migmatised and xenomorphic grains then reach 2 mm in diameter.

Penninite in places replaces biotite and hypersthene and *sericite* occurs as a secondary mineral after *plagioclase*. *Hornblende* where present replaces pyroxene.

2nd Episode Basic Intrusions

Field Aspects

The basic material of this episode occurs as pyroxene-metadolerite dykes, fifteen in number, lying in two main directions; one group strikes between N 5–40° W and the other between N 10–30° E. Only one intersection was noted where a NNW dyke cuts a NNE one. They vary in width from 20 cm to 5 m but the majority are less than 1.5 m. The rock type is homogeneous and no phenocrysts exist. In colour the rock varies from dark brown to dark grey and in grain-size from fine to medium.

The form of the dykes varies according to the type and age of the surrounding host rocks. Those present in Ketilidian gneisses and granites appear as straight sharp-bordered dykes cutting transgressively across structures in the host rocks (fig. 11). They are persistent and frequently have chilled margins. The longest traceable dyke in Ketilidian rocks is approximately 1 km. Within Sanerutian reactivated rocks the dykes are not persistent and they are agmatised and attacked by acid material (fig. 12). In two localities in the Sanerutian microcline granite folded pyroxene-metadolerite dykes were found. This local deformation is probably connected to the development of the microcline granite through reactivation of the earlier gneisses.

The dykes are distinctly later than the formation of the folded Ketilidian gneisses and granites and they post-date Ketilidian migmatisation features. They sharply truncate the pyriclasite and biotite-pyriclasite sills in the gneisses. The dykes are cut by Sanerutian aplites and pegmatites.

Fig. 11. Pyroxene-metadolerite dykes cutting sharply through Ketilidian granite and granitic gneiss. Younger basic sills are present in the higher parts of the mountains to the left.

Petrography

The rock type of the dykes is metadoleritic, composed of three principal minerals, pyroxene, plagioclase and biotite, with minor amounts of quartz and hornblende in some dykes. Magnetite and apatite are the dominant accessory minerals. Modal analyses of eight 2nd episode basic dykes are given in table 4 and a single chemical analysis in table 3. Textures vary from sub-ophitic (plate 1, b), to relic sub-ophitic (blastophitic, plate 1, c), to allotriomorphic-equigranular (granoblastic, plate 2, a) with increased recrystallisation.

Table 4. *Modal analyses of pyroxene-metadolerites (2nd episode basic intrusions).*

GGU Sample No.	54488	58578	58584	58604	58685	67003	67096	67192
Pyroxene	47.5	20.7	35.7	42.6	40.1	31.3	35.3	49.3
Biotite............	18.7	20.2	10.4	20.8	2.2	8.4	13.9	15.4
Plagioclase	32.4	33.4	40.4	35.5	51.5	43.4	50.0	33.6
Hornblende	—	8.0	—	—	—	12.9	—	—
Quartz............	—	11.8	11.7	0.4	1.8	1.9	—	—
Accessories	1.4	5.9	1.8	0.7	4.4	2.1	0.8	1.7

Accessories include penninite, apatite, epidote, sericite and ore.

Fig. 12. Pyroxene-metadolerite dyke in Sanerutian reactivated granite. The dyke has been broken and in places offset but its original form is well preserved.

Pyroxene is represented by both clinopyroxene (diopsidic augite) and orthopyroxene (hypersthene) and these may occur together. Two generations of pyroxene can be distinguished. Primary hypersthenes up to 1 mm in length are present in the least altered types having subophitic texture. In the majority of dykes however all the pyroxene has recrystallised and it is represented by small grains up to 0.3 mm of both diopsidic augite and hypersthene. In such dykes it is still possible to detect original 'igneous' texture with granules of pyroxene surrounding corroded plagioclase laths (plate 1, c).

Biotite occurs in flakes varying from 0.2 mm to 1.5 mm in length and it is strongly pleochroic from pale brown to brown, yellow brown to red brown and red brown to dark brown. It occasionally forms a foliation. The biotite in the dykes is secondary having been formed after the formation of the original sub-ophitic texture. In places biotite tends to form 'vein' concentrations but occasionally it replaces pyroxene.

Plagioclase (An_{45-60}) is characterised by albite-twinning. Two distinct habits are present and these are a direct reflection of their age. In the rocks showing remnant sub-ophitic textures, laths of plagioclase up to 2 mm long occur between which the pyroxene is situated. The plagioclase in places is corroded by the recrystallisation of the pyroxene which took place before the recrystallisation of the plagioclase. Some plagioclase laths show signs of deformation by their bent twin-planes while in other dykes the plagioclase has recrystallised into smaller sub-grains and these are more equigranular than the primary mineral habit, reaching a maximum of 0.5 mm in length. In places the plagioclase is in association with much smaller quartz grains in myrmekite.

Quartz apart from the occurrences of myrmekite, exists in a few dykes. It is present in allotriomorphic grains occasionally replacing plagioclase or it occurs in small cavities and pockets. Where present in some amount it forms a granoblastic felsic matrix with the plagioclase.

Hornblende is present in two dykes replacing pyroxene. It is a pale green variety. It does not form a major part of the mineralogy of the metadolerites.

3rd Episode Basic Intrusions

Field Aspects

The basic rocks of this episode of intrusion occur as dykes and small bodies. In two places a transition from a body to a dyke occurs but no cross-cutting relationship of the two forms exists. The basic material varies from fine-grained in the dykes to medium- and coarse-grained in the bodies. In the coarser varieties ophitic texture is discernible (fig. 13). The basic material varies from black and dark grey in the fine-grained dykes to brown in some of the coarser varieties.

The basic rocks are Sanerutian in age and are connected in time with the development of rapakivi granites (Dawes, 1966). The dykes and bodies sharply truncate the Ketilidian basement gneisses and granites, the 1st episode basic sills and the early Sanerutian granite which post-dates the 2nd episode basic dykes. The basic rocks post-date the emplacement of the biotite rapakivi granite and they cut the primary internal structures of the granite. They are however attacked by the late potash metasomatism of the granite. The basic rocks pre-date the intrusion of the later hornblende rapakivi granite and the dykes of this episode are sharply truncated at the contacts of this rapakivi (fig. 14).

Fig. 13. Texture of metagabbro (3rd episode basic intrusion). The primary pyroxene has been partially replaced by hornblende but with the preservation of the ophitic texture. Diameter of the coin 2.2 cm. Photo: PREBEN CHRISTENSEN.

Thirteen bodies of this episode exist in the Tasiussaq area. The bodies are either true discordant bosses or flat-lying lens-shaped masses. The lens-shaped masses vary in size from being sheet-like at the periphery to a maximum thickness of 75 m in the centre. In lateral extent the largest body is approximately 2.5 km. The discordant bosses have outward-dipping contacts which vary from 70° to vertical. They are mostly rounded in outline, the largest having an area of approximately 2.5 km^2.

Thirty-two dykes of this episode have been identified and these lie in two main directions: one group N 10–30° E and an older swarm N 10–30° W. The dykes vary in width from 10 cm to 6 m but the majority are between 50 cm and 1.5 m. In attitude they vary from 70° to vertical. In the Ketilidian rocks they are continuous and have sharp, chilled contacts with the host gneisses. Some dykes in the biotite rapakivi granite have less continuous more irregular forms due to action by the granite (fig. 15).

In places in both the basement gneisses and biotite rapakivi, the dykes and bodies show in their outermost parts an encroachment of acid material in a net-veined form and there have been metamorphic contact effects in the basic rock adjacent to the acid. Some of these

Fig. 14. Contact between hornblende rapakivi (dark) and Ketilidian gneiss and granite (light). A swarm of metadolerite dykes (3rd episode basic dykes), cutting through the gneiss and granite diagonally from upper left, are sharply truncated at the contact of the rapakivi. Height from the glacier to the summit of the highest peak is 700 m.

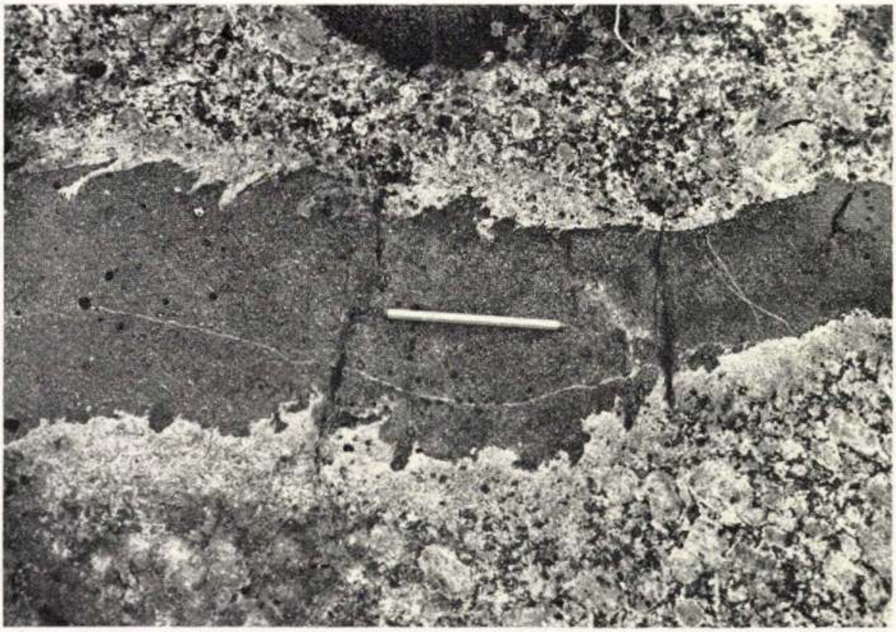


Fig. 15. Metadolerite dyke (3rd episode basic intrusion) in biotite rapakivi granite showing acid encroachment of the dolerite by the granite.

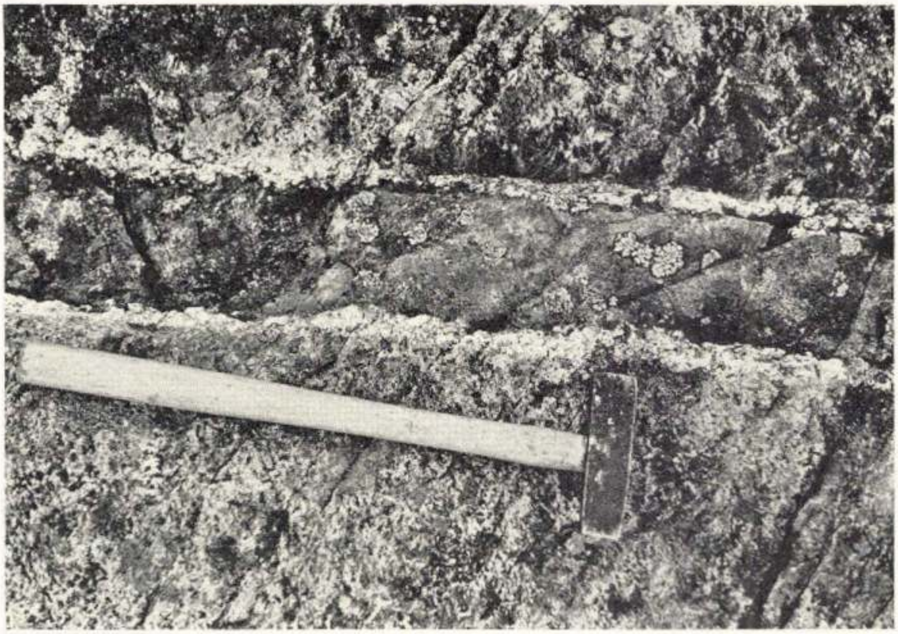


Fig. 16. Metadolerite dyke (3rd episode basic intrusion) flanked by aplitic margins cutting Ketilidian granitic gneiss.

effects from the Tasiussaq area are cited in a paper by Windley (1965) and it is not the aim of the present paper to describe such local changes. A few dykes in the gneisses have aplitic borders (fig. 16) but usually no acid veining exists. The metamorphic state of the basic material treated here is assessed from the dykes and bodies not affected by local changes due to acid veining.

Petrography

The 3rd episode basic rocks are members of the dolerite-norite suite of rocks. Three chemical analyses are available (table 3). Various rock types exist depending on the essential minerals present and there is a gradation from gabbro to norite with the fluctuating importance of clino- and orthopyroxene. Many of the gabbros contain some orthopyroxene and the norites some clinopyroxene. The appearance of olivine in some types gives rise to olivine-dolerites, olivine-gabbros and olivine-norites but the olivine content never exceeds 10 %. Biotite occasionally is present in some types in amounts up to 20 %, enough to warrant the term biotite-dolerite. Accessories are magnetite, apatite and quartz.

Metamorphism has led to the production of amphibole at the expense of the primary pyroxene and this has produced a gradation from dolerite, gabbro and norite to metadolerite, metagabbro and metanorite

Table 5. *Modal analyses of dolerites (3rd episode basic intrusions) to illustrate the variation in the pyroxene-hornblende ratio with increased metamorphism.*

GGU Sample No.	67098	67043	67160	58583	67141	67142
Pyroxene	39.1	32.6	26.1	22.1	6.7	–
Biotite........	11.2	6.4	11.0	2.7	4.0	14.3
Hornblende ...	–	4.5	8.9	21.2	52.7	47.8
Plagioclase....	45.8	45.7	48.5	46.7	35.9	35.2
Olivine	–	8.6	4.2	–	–	–
Accessories	3.9	2.2	1.3	7.3	0.7	2.7

Accessories include apatite, quartz, magnetite, sphene, penninite and antigorite.

and finally to amphibole-plagioclase rocks. Modal analyses showing this transition are given in tables 5 and 6.

Fresh rock types: For the sake of clarity the least metamorphosed basic material found in the dykes and bodies will be described below so that it may act as a base on which the metamorphic effects can be assessed.

The basic material is characterised by a hypidiomorphic, undirectional texture which varies from fine-grained in the dykes to coarse-grained in the bodies. The texture varies from ophitic in the coarser grained gabbros (plate 2, b) to sub-ophitic in the dykes (plate 2, c). Some dykes are porphyritic or microporphyritic with plagioclase phenocrysts embedded in a finer grained mesostasis (plate 3, a).

Plagioclase (An_{60-75}) occurs in euhedral to subhedral laths varying from 0.1 mm to 2 mm in length in the dykes, and from 0.5 mm to 1 cm

Table 6. *Modal analyses of gabbros (3rd episode basic intrusions) to illustrate the variation in the pyroxene-hornblende ratio with increase in metamorphism.*

GGU Sample No.	66840	66984	58561	67156	66843	66982	66983
Pyroxene	39.9	22.3	26.4	28.8	10.8	0.5	–
Biotite........	12.6	4.4	13.6	11.5	9.7	5.9	7.9 (+ chlorite)
Hornblende ...	–	–	0.8	3.0	22.6	45.1	38.3
Plagioclase....	46.4	63.9	54.4	53.3	56.1	48.1	53.0
Olivine	–	7.6	–	–	–	–	–
Accessories	1.1	1.8	4.8	3.4	0.8	0.4	0.8

Accessories include apatite, quartz, sphene, magnetite and antigorite.

in the gabbros. Phenocrysts in some of the dykes reach over 1 cm in length. Albite and combined albite-carlsbad twinning are common. In the gabbros the laths are completely (ophitically) or partially (sub-ophitically) enclosed within the pyroxene crystals and in places in the olivine, while in the dyke rock the laths are either in a sub-ophitic relationship with the pyroxene or they form an incomplete framework in which the grains of pyroxene are situated. The plagioclase is locally altered to sericite.

Pyroxene is represented by both augite and hypersthene. The *hypersthene* occurs in subhedral crystals varying in size in the dykes from less than 0.2 mm to 2 mm, and in the gabbros the grains reach over 1 cm in length. It is commonly pleochroic from colourless to pale pink and it frequently displays schiller structure. *Augite* occurs in much the same habit as the orthopyroxene, occurring in the dolerites as small anhedral grains situated between the plagioclase laths. In the gabbros grains reach 1.5 mm in size. The mineral is colourless and non-pleochroic.

Biotite forms a subsidiary mafic mineral in the mineral assemblage. It occurs as flakes varying from less than 0.1 mm to 0.6 mm in length. The mineral is commonly associated with the hypersthene either being contained within or forming small rims to the crystals. Some flakes are included in plagioclase laths. The mineral is a dark brown variety and is strongly pleochroic. Occasionally a green biotite is present locally as a replacement of primary pyroxene. Penninite replaces the biotite.

Olivine occurs in the dykes of the NNE group but not in the NNW swarm. It varies in amount from scattered grains to approximately $10\,^0/_0$. In the gabbros the mineral occurs in amounts up to $8\,^0/_0$ where it is commonly in association with the hypersthene, being rimmed by the pyroxene (plate 2, b). Occasionally olivine is present in poikilitic texture with the plagioclase, either completely or partially enclosing the felspar. The mineral occurs in subhedral to anhedral grains varying from 0.2 mm to 1 mm in diameter and it may be associated with magnetite. Alteration to antigorite and magnetite along dominant fractures has occurred.

Metamorphosed rock types: The textures of the metamorphosed rocks vary from crystalloblastic to palimpsest according to the state of metamorphism and from hypautomorphic to xenomorphic. Ophitic and sub-ophitic textures are preserved despite a complete replacement of the pyroxene and this can be easily seen in hand sample of the gabbros and norites. For descriptive purposes four development stages are described below to illustrate the transition from slightly metamorphosed rock to plagioclase-amphibole rocks.

Stage 1 is marked by the first appearance of hornblende replacing the primary pyroxene. The replacement takes place essentially in the outer parts of the pyroxene crystals and in this stage complete pseudomorphing of pyroxene is absent. The original textures are preserved and the plagioclase is only mildly altered. Olivine, where present, has begun to break down to antigorite along irregular fractures and in some cases the olivine is surrounded by a rim of hornblende by replacement of the original pyroxene rim.

Stage 2 is marked where secondary hornblende and the primary pyroxene form approximately equal amounts. The original textures are preserved. Relic pyroxene forms the centre of the pseudomorphed crystals (plate 3, b). The plagioclase maintains its lath-like nature but in places it has been sericitised. Olivine has completely broken down with the production of antigorite and secondary magnetite.

Stage 3 is characterised by the dominance of amphibole over pyroxene and only small relics of pyroxene are preserved in the cores of the pseudomorphs (plate 3, c). Despite the severe replacement of the pyroxene by hornblende, the original textures have been preserved. The plagioclase is altered but no recrystallisation of it has taken place.

Stage 4, shown by the most severely altered rocks, is characterised by an amphibole-plagioclase assemblage with or without biotite. In places both the hornblende and plagioclase show signs of recrystallising into sub-grains. The original texture has been preserved and this is visible in hand sample in the gabbros and norites. Penninite occurs as a replacement of biotite.

The transition from fresh rock types to metamorphosed is well illustrated by the dykes of the NNW swarm which are metadolerites of stage 1 in the south-east of the area and metadolerites of stage 3 in the north-west, some 8 km away. In some of the larger bodies in the north of the area, the transition from fresh gabbro and norite in the centre of the bodies to amphibole-plagioclase rocks in the peripheral zones, can be demonstrated.

Certain of the dykes connected spatially with the biotite rapakivi granite display a granular texture in contrast to the ophitic and sub-ophitic textures described here. These have been considered by the author (DAWES, 1965) to depict the environment in which the rocks were intruded and to have crystallised in much the same way as envisaged by ANTUN (1962) for some noritic dykes from Ørsdalen, SW Norway. They have been omitted from the present account since the ophitic and sub-ophitic textured material acts as a better base on which to recognise the effects of the metamorphism and the preservation of the textures during the metamorphic changes.

THE METAMORPHISM

Nature of the Metamorphism

The present characteristics of the basic rocks of the three episodes are conditioned by their original magmatic composition and the nature of the metamorphism affecting the rocks after intrusion. The 1st episode basic rocks have undergone severe changes since intrusion and thus it is difficult to determine the original nature of the material. The 2nd and 3rd episode intrusions have been less severely altered and their intrinsic characters suggest that they were originally doleritic. However, by comparison of the chemical analyses presented in table 3, it seems that the 1st episode intrusions have a comparable composition to the 2nd and 3rd episode intrusions. Certainly the difference in composition between the 1st episode intrusions and the 2nd and 3rd episode intrusions is not significant enough to invalidate the assumption that the present characteristics of the basic rocks of the three episodes are due to three contrasted types of metamorphism and not to differences in the original nature of the intruded basic metarial.

1st Episode Basic Intrusions

These rocks are devoid of palimpsest features indicative of primary textural or mineralogical nature. The basic material has been recrystallised and the rock type has gained a distinct foliation parallel to that of the host rock gneisses. There can be no doubt that the original rock was of igneous origin; local discordances with the host rocks have been preserved. The age of the basic intrusions is pre-deformation and migmatisation and thus it might be argued that a sill-like habit could be produced through rotation of cross-cutting dykes parallel to host rock foliation during intense deformation. However, while such a tendency no doubt exists, the sill form of the basic material is clearly shown by the low angle of discordances between the basic material and the supracrustal rocks bearing original sedimentary features.

One chemical analysis of a pyriclasite is available (table 3). It is somewhat richer in MgO than the second and third episode basic material and deficient in Al_2O_3. The mineral composition of the rocks, characterised by hypersthene is a product of granulite facies metamorphism of original basic (tholeiitic?) intrusions which were emplaced into pelitic, psammitic and psephitic rocks. The sills depict the same metamorphic history as do the high-grade basement gneisses: high-grade metamorphism followed by retrogressive metamorphism with some hornblende and biotite developing at the expense of high-grade pyroxene. The retrogressive metamorphism however has not altered the high-grade mineral assemblage.

Similar rocks to those described here exist in other granulite facies basement areas of the world but they have been described under a variety of terms e.g. 'basic granulite' (HEPWORTH, 1964; SINGH, 1966), 'basic charnockite' (PARRAS, 1958), 'pyroxene granulite' (SUBRAMANIAM, 1959) and 'basic charnockitic granulite' (EVANS, 1965). Occurrences of pyroxene-plagioclase basic rocks have also been described from the Precambrian of West Greenland. Pyriclasites and pyribolites occurring as conformable layers in the hypersthene gneisses of Tovqussap nunâ have been suggested by BERTHELSEN (1960) to have formed by granulite facies metamorphism of original volcanic horizons. WINDLEY (1966b) considers that hypersthene-plagioclase rocks occurring in the Fiskenæsset region as horizons intercalated with chromite-layered anorthosites, were formed by granulite facies metamorphism of basic rocks forming an integral part of a pre-orogenic Bushveld-type anorthosite-norite complex.

2nd Episode Basic Intrusions

The preservation of sub-ophitic texture in some dykes, plus the mineralogical and chemical composition suggests that the second episode basic intrusions were initially doleritic. The rocks have undergone recrystallisation to become pyroxene-metadolerites. The metamorphism is revealed by the recrystallisation of the pyroxene and plagioclase and the later production of biotite. The recrystallisation of the primary pyroxene results in a trend towards a granoblastic texture. Some bent plagioclase grains show the effect of deformation, others have recrystallised.

The presence of biotite is not unexpected in metamorphosed dolerites (HARKER, 1950) but in the Tasîussaq area it is frequently a retrograde mineral replacing the recrystallised pyroxene. The tendency of biotite to appear in 'vein' concentrations suggests that some crystallised from late K-bearing fluid penetrations after the main recrystallisation.

Since the majority of the dykes have undergone a complete recrystallisation with the production of secondary granular pyroxene, it is difficult to comment on the original mineral composition of the dykes, especially the nature of the pyroxene. Primary hypersthene exists in a few dykes and thus at least some were originally hypersthene-dolerites. According to YODER and TILLEY (1962), later supported by MACDONALD and KATSURA (1964), basalts having hypersthene to the exclusion of olivine, as appears to be the case here, are essentially tholeiites. One chemical analysis given in table 3 supports this view.

The sparse and restricted development of hornblende and the predominance of pyroxene in the make-up of the metadolerites creates a striking difference between these dykes and basic dykes further to the north-west in South Greenland. From the investigation of WISEMAN (1934) such a pyroxene-metadolerite assemblage should be considered as 'abnormal' in comparison with the 'normal' scheme of transformation outlined by WISEMAN from the central and south-west Highlands of Scotland, in which the first formed minerals due to metamorphism are chlorite, albite and epidote. SUTTON and WATSON (1951) however found that the characteristic metamorphic changes in the metadolerites in the north-west Highlands of Scotland and Banffshire, where hornblende was the first formed femic mineral, were the same as those occurring in WISEMAN's 'abnormal' dykes. They concluded "that no metamorphic rock can be looked on as abnormal or anomalous because it fails to conform to types shown to exist in another area".

Examples of the trend of dolerite metamorphism characterised by the presence of pyroxene in all stages of metamorphism have been described by various workers, including STILLWELL (1918) from Adelie Land, Antarctica, TILLEY (1921) from the Eyre Peninsula, South Australia, GROVES (1935) from Uganda, POLDERVAART and VON BACKSTRÖM (1949) from the Kakamas area, Cape Province, and by WILCOX and POLDERVAART (1958) from North Carolina. This type of transformation has been considered as related to the granulite facies of metamorphism and for this reason it has become known as the 'granulitic' trend.

SUTTON and WATSON (1951) have summarised the three trends of dolerite metamorphism mentioned above and concluded that the "divergent trends of dolerite metamorphism seem to reflect comparable variations of the metamorphic provinces in which the different groups occur". POLDERVAART (1953) and WILCOX and POLDERVAART (1958) have reinterpreted SUTTON and WATSON's possible dolerite trends as dependent on water content rather than on any differences in temperature and pressure conditions and this has been supported by the recent work of YODER and TILLEY (1962, p. 469), who state, when discussing the metamorphism of basaltic rocks, that "reduction of the water content or partial pressure of water would expand the 'granulite' field".

POLDERVAART (1953, p. 270) states:

"Theoretically there is no reason why three or more trends of metamorphic evolution of basaltic rocks could not be produced from the same original rocks in the same terrain and under the same temperature-pressure conditions, provided there were differences in water-vapor pressure and ionic concentrations in different parts of the terrain".

Wilcox and Poldervaart (1958, p. 1323) state:

"Differences between subophitic plagioclase-pyroxene and granoblastic plagioclase-hornblende dike rocks are attributed to differences in water content during recrystallization at essentially the same temperatures and total pressures. The abnormal granulitic trend of metamorphic recrystallization of basaltic rocks is due to water-deficient conditions. This type of recrystallization can occur both in the granulite and the amphibolite facies of metamorphism".

The mineral characteristics of the pyroxene-metadolerite dykes suggest a connection to the 'granulite' trend as referred to above but it remains to examine the possible explanations of genesis of such a high-grade mineralogy. Five possibilities are considered below:

1. The dykes have followed the sequence of events outlined by both Sutton and Watson (1951) and Wiseman (1934) in which primary pyroxene is replaced by hornblende only to be converted into new pyroxene in the highest stages of metamorphism. Such a type of metamorphism is also described by Harker (1950) and Groves (1935).

2. The dykes have recrystallised under granulite facies conditions of metamorphism and thus have acquired a corresponding high-grade mineral assemblage in much the same way as described by Stillwell (1918), Temperley (1938) and Almond (1962, and personal communication).

3. The dykes have acquired their high-grade mineralogy through intrusion and crystallisation under regional metamorphic conditions. Such an explanation has been used by Antun (1962) for certain noritic dykes from Ørsdalen, SW Norway while Bridgwater, Sutton and Watterson (1966) favour it for the granular pyroxene-bearing dykes in the Kap Farvel area of South Greenland.

4. The dykes have been metamorphosed by non-regional action e.g. thermal metamorphism by the effect of granites. Such an origin is suggested by Tilley (1921) for the pyroxene-plagioclase metadolerites of the Eyre peninsula, South Australia.

5. The dykes have been recrystallised under similar pressure and temperature conditions as those of Wiseman's 'normal' and 'abnormal' dykes (P-T conditions below those of the granulite facies) but in a water deficient environment, i.e. dipsenic metamorphism (Rosenqvist, 1952). Examples of a pyroxene-plagioclase metadoleritic assemblage being caused by such conditions have been described by Poldervaart (1953), Wilcox and Poldervaart (1958), Buddington (1963) and Prinz (1964).

Possibility 1: This explanation is not supported by the dykes in question, since no evidence exists of the secondary pyroxene having been produced from hornblende. On the contrary hornblende plays only a very minor role in the mineralogy of the dykes only being detected in two dykes where it shows evidence of replacing pyroxene.

Possibility 2: On field evidence the pyroxene-metadolerite dykes post-date the Ketilidian granulite facies metamophism and it appears that metamorphism in later time did not reach such a high grade. The high-grade hypersthene-bearing gneisses have been slightly retrogressed by amphibolite facies metamorphism and the appearance of hypersthene in the Sanerutian is restricted to intrusive norites (3rd episode basic intrusions). This conclusion is supported by the difference in character between the pyriclasites (1st episode basic intrusions) and these 2nd episode basic dykes.

Possibility 3: Antun (1962) considers that the Ørsdalen norites, which cut gneisses which "developed in the charnockite and in the high-amphibolite mineral facies", have been "emplaced at great depth, under P-T-conditions not very different from those which governed the recrystallisation of the surrounding gneisses". He states that for the granoblastic texture of the dykes to have developed "the regional temperature must have been high and similar to that which governed the mineral paragenesis of the surrounding gneisses". Bridgwater, Sutton and Watterson (1966) consider the high-grade granular texture of the dykes in the Kap Farvel area to be due to the primary crystallisation of a basic magma under regional metamorphic conditions corresponding to the amphibolite facies. While the present author recognises the possibility of environmental control on the crystallisation of dolerite magma and indeed has postulated a primary origin for the granular texture of pyroxene-bearing dykes associated with the rapakivi granites of the Tasîussaq area (Dawes, 1965 and page 29 here), it does not seem to be the explanation for the 2nd episode basic rocks for the following reasons:

a) The recognition of sub-ophitic and relic sub-ophitic texture in some of the Tasîussaq dykes in stages prior to the development of granular texture.

b) The recrystallisation of the pyroxene into rounded grains which encroach upon the plagioclase laths of the sub-ophitic texture.

c) The dykes do not show features indicative of being emplaced into such hot rocks as envisaged by Antun (*op. cit.*) and Bridgwater *et al.* (*op. cit.*). None of the features described by Watterson (1965) and Windley (1966a) as being indicative of basic dyke intrusion into hot host rock, i.e. in a plutonic environment capable of controlling the mineral characteristics and texture of the dykes, are present in the Tasîussaq material. On the contrary, chilled margins exist in the dykes and while this does not necessarily imply emplacement into cold rocks i.e. cratogenic conditions, it does indicate a temperature difference between host rocks and intruded material. The dykes, where they cut older host rocks, are straight and continuous and it is doubtful whether the dykes were emplaced into such hot rocks as would be necessary for the production of a high-grade pyroxene-granular texture.

Possibility 4: The Tasîussaq pyroxene-metadolerites seem very similar to the dykes described by Tilley (1921) from the Eyre peninsula with a texture varying from blastophitic to granoblastic. As regards the metamorphism bringing about the recrystallisation, Tilley concludes that it was an "intense thermal metamorphism" brought about by engulfing in a granitic magma and that the dykes are pre-gneissic in age. While there seems another possibility as regards the age of the dykes as is pointed out below (see page 39), it does seem feasible that an intense thermal metamorphism could account for such a pyroxene-metadoleritic assemblage. However, the Tasîussaq dykes have not been "engulfed in a granitic magma" and although the thermal front rose in Sanerutian time in did not render the main mass of Ketilidian gneiss mobile. Even in areas where cross-cutting dykes have sharp chilled contacts against the Ketilidian host rock gneisses, i.e. in areas where the dykes have certainly not experienced the action of granitic magmas, the pyroxene-metadoleritic assemblage still prevails. It seems unlikely that Tilley's explanation is sufficient to explain the transformation of the Tasîussaq dykes.

Possibility 5: It is apparent from a study of the literature that it is not exceptional to find basic dykes bearing a high-grade mineralogy cutting areas of granulite facies gneiss and granite. This has also been noted by Sutton and Watson (1951). It is known that 'dry' conditions existed during the early granulite facies metamorphism before the intrusion of the 2nd episode basic rocks and a theory based on dipsenic metamorphism is considered most applicable. This possibility is thus considered the most plausible for the formation of the pyroxene-metadolerites of the Tasîussaq area from both the intrinsic features of the dykes and their geological setting.

It is suggested that the dipsenic conditions of the early granulite facies metamorphism prevailed after the temperature and pressure had decreased from the granulite facies field. This enabled original doleritic dykes to acquire a high-grade assemblage through recrystallisation at lower temperature-pressure conditions than those normal in the granulite facies, for as Poldervaart (1953, p. 265) states, "depending on 'dry' or 'wet' conditions, either diabasic granulites or amphibolites were formed from the same initial basaltic rocks under the same metamorphic intensity".

This suggestion for the Tasîussaq dykes is supported by the great similarity between these dykes and the examples of water-deficient metamorphism of dolerites described by POLDERVAART (1953) and WILCOX and POLDERVAART (1958). Of note here are the latters' observations regarding changes taking place in the metadoleritic dyke swarm in North Carolina where there is a partial preservation of original textures, a replacement of the original sub-ophitic pyroxene by "granoblastic aggregates" of secondary pyroxene and the recrystallisation of the original plagioclase laths into granoblastic grains. These changes are very similar to those observed in the Tasîussaq dykes.

There is some evidence of both biotite and hornblende replacing the pyroxene in the metadoleritic dykes. These mineral alterations postdate the recrystallisation of the pyroxene and they are connected with a later metamorphism, the effects of which are seen in the 3rd episode basic intrusions described in the following.

3rd Episode Basic Intrusions

Unlike the 1st and 2nd episode basic intrusions the original nature of the 3rd episode basic dykes is known since the original minerals of the rocks have often been preserved. The metamorphic effects are characterised by the replacement of the primary igneous pyroxene by hornblende, and this type of metamorphic trend contrasts with the metamorphic effects in the 1st and 2nd episode intrusions. Many examples simulating this type of metamorphism of dolerites have been described in the literature e.g. SUTTON and WATSON (1951) from the north-west Highlands of Scotland, and GREEN (1956) from the Storkollen-Blankenberg area, Kragerø, Norway. The changes characterised by the appearance of hornblende as the first femic mineral produced by metamorphism correspond to WISEMAN'S (1934) 'abnormal' trend of metamorphism. WISEMAN'S 'normal' trend of metamorphism is characterised by chlorite as the first formed femic mineral.

BONDESEN and HENRIKSEN (1965) have described a group of metadoleritic intrusions in the Ivigtut area, SW Greenland, showing variable states of metamorphic alteration. The least metamorphosed dolerites described by them (their stage 1) have blastophitic texture with preserved primary plagioclase and with hornblende completely pseudomorphing the pyroxene. Such a condition corresponds to the most severely altered 3rd episode intrusions in the Tasîussaq area.

The Tasîussaq material can be referred to stages 1 and 2 in SUTTON and WATSON'S (1951) metamorphic scheme for the dolerites of the north-west Highlands of Scotland. The metamorphism of the 3rd episode dolerites and gabbros in the Tasîussaq area has not taken place with accompanying deformation. The primary plagioclase is never strained and only in the severely altered types does it show a tendency to recrystallise into sub-grains. In these cases the lath-like outline of the plagioclase is still clearly preserved and no secondary fabric has been superimposed on the rock.

It is concluded that the metamorphism responsible for the amphibolitisation of the basic material was strongest in the north-west of the area and decreased towards the south-east. The metamorphic effects on the basic rocks have only been slight compared to the examples from the Highlands of Scotland (Wiseman, 1934; Sutton and Watson, 1951), the Ivigtut area (Bondesen and Henriksen, 1965) and Kragerø, Norway (Green, 1956) since original igneous textures have been preserved and are clearly recognisable in hand sample and primary plagioclase exists.

Correlation

Basic intrusions similar to the 1st episode basic rocks described here have been recorded by Escher (1966) from the amphibolite facies terrain on the Nanortalik peninsula to the west of the Tasîussaq area and Tasermiut fjord. He states (p. 9), "At several places small amphibolite bodies or dykes (DA 1) were observed. These amphibolites show, when examined closely, a small but distinct discordance with the bedding. They are however folded and refolded together with the host rock". Such rocks can be correlated with the pyriclasite and biotite-pyriclasite sills of the Tasîussaq area but in mineral composition they differ markedly. The boundary between the granulite facies rocks of the Tasîussaq area and the lower grade rocks to the north-west lies in the area of Tasermiut fjord. The intrusions of the Nanortalik peninsula were metamorphosed to amphibolites under amphibolite facies conditions while in the Tasîussaq area such intrusions were subjected to granulite facies metamorphism and thus acquired their high-grade mineralogy characterised by hypersthene.

Escher (1966) also reports on the Nanortalik peninsula, basic dykes having a similar chronological position to the pyroxene-metadolerites described here. These dykes, called by Escher "DA 2 dykes", are amphibolitised dolerites composed of plagioclase, hornblende and biotite. Escher states (1966, p. 84), "Relict ophitic texture is generally clearly defined by subhedral-euhedral laths of plagioclase. Pyroxene is scarce, only appearing as relic grains surrounded by hornblende". Escher also records a second "generation" of metadolerites ("DA 3 dykes") comparable to the 3rd episode basic rocks of the Tasîussaq area. These are also amphibolitised dolerites composed of hornblende, plagioclase and biotite. Thus it is clear that the metamorphism affecting ESCHER's "DA 2 dykes" differed from that in the Tasîussaq area although later metamorphism had the effect of amphibolitising dolerites in both areas. It is apparent that the early dolerites in ESCHER's area, intruded into amphibolite facies gneisses and schists, subsequently became metamorphosed to metadolerites in which hornblende pseudomorphed the pyroxene with the partial preservation of ophitic textures. In the Tasîussaq area, however, similar dolerites were emplaced into granulite facies gneisses (hypersthene gneisses characterised by the *absence* of hornblende) and were subsequently metamorphosed to metadolerites in which the pyroxene recrystallised with the partial preservation of sub-ophitic textures. This illustrates a relationship between the granulite facies terrain and younger cross-cutting pyroxene-metadolerites. It is suggested that both trends in the metamorphism of dolerites took place in similar P-T conditions but the dolerites of the Tasîussaq area were affected by dipsenic metamorphism; the dolerites in the amphibolite facies terrain to the west of Tasermiut fjord were not. Metamorphism in both areas after the intrusion of the later dolerites was not dipsenic and thus it can be assumed that the effect of the dry conditions of the granulite facies metamorphism did not persist long. In both areas the later basic rocks were amphibolitised with the production of hornblende replacing the primary pyroxene.

Basic dykes showing similar field occurrences and a similar chronological position to the pyroxene-metadolerites described here occur in the Kap Farvel area to the south-east and east of the Tasîussaq area (BRIDGWATER, SUTTON and WATTERSON, 1966). As mentioned earlier (page 34), these dykes show a high-grade granular texture similar to the Tasîussaq dykes although ophitic or sub-ophitic texture has not been observed. BRIDGWATER, SUTTON and WATTERSON consider the granular texture to be due to the primary crystallisation of a basic magma under regional metamorphic conditions. Detailed comment on the comparison with these dykes must wait until more information is available about the dykes in the Kap Farvel area but one point should be raised here.

It is quite possible that the dykes to the east and south-east of the Tasîussaq area were emplaced into country rocks which were capable of producing a primary granular texture while in the Tasîussaq area conditions permitted the crystallisation of normal igneous textures. However the author believes that the fact that such pyroxene-metadolerites only occur in the Precambrian basement of South Greenland to the east of Tasermiut fjord and are restricted to the granulite facies terrain, is highly significant. This strongly suggests that some aspect of the granulite facies metamorphism, e.g. water-deficient conditions, has been the critical controlling factor affecting the character of the dykes.

This non-coincidental relationship between granulite facies terrain and younger cross-cutting pyroxene-metadolerites has been remarked on by SUTTON and WATSON (1951) who note that "metadolerites in which the first new femic mineral is a secondary pyroxene have been found only in extensive areas of gneisses which are often charnockitic in character". From the present evidence it is concluded that the water-deficient conditions of an earlier metamorphism have persisted long enough to influence the metamorphism of later dolerites.

Such an explanation of dipsenic metamorphism may well be considered in respect to other basement areas where high-grade dykes cut areas of high-grade gneisses and granite. An example is furnished by TILLEY's interpretation of the Eyre peninsula dolerites (TILLEY, 1921). TILLEY noted the apparent lack of similarity between the field features of his metadolerites and their plagioclase-pyroxene composition and he states (1921, p. 125), "At first sight, these rocks appear to be characteristic dyke-rocks cutting the acid gneisses. When, however, the high-grade metamorphism is established, this opinion must be considered open to doubt". TILLEY considered the dykes as older than the formation of the gneiss in order to account for their high-grade mineralogy. By doing this the indispensable field observations were overlooked. It seems most probable that the dolerites of the Eyre peninsula were intruded into the gneisses, i.e. are post-gneissic in age, a view supported by the field observations, and that by later metamorphism they were altered to pyroxene-metadolerites. It seems impossible to accept TILLEY's explanation of the pre-gneissic age for the dykes since if they were, as he suggests, "engulfed in a granitic magma" it is mysterious that they show no evidence of acid encroachment, despite the fact that adjacent amphibolites, considered to be the same age by TILLEY, are readily attacked by the acid material. In the light of the recent work on dipsenic metamorphism by many authors it seems reasonable to interpret the texture and mineralogy of the dykes as due to a metamorphism after the high-grade metamorphism forming the gneisses, being controlled by dipsenic conditions.

CHRONOLOGICAL SIGNIFICANCE OF THE BASIC INTRUSIONS

The mineralogy and texture of the basic rocks of the three ages has been explained by metamorphism of igneous rocks intruded at different stages of a Precambrian 'geological cycle'. The environment into which the intrusions were emplaced differed; the 1st episode basic rocks were intruded into a geosynclinal pile of sediments while the 2nd and 3rd episode basic rocks were emplaced into metamorphosed sediments and granitic rocks. It is probable that the P-T conditions of the environment during the three episodes of basic intrusion differed.

Basic intrusions are known to occur in many environments and settings, and both plutonic (in the sense of READ, 1957) and cratogenic basic intrusions exist. J. J. SEDERHOLM in his classical work on the Precambrian basement of southern Finland stressed the inseparable connection between dolerite dyke intrusion and non-plutonic conditions but in recent years this hypothesis has been questioned and it is known that such intrusions may be emplaced in environments other than cratogenic. In South Greenland for example dolerites displaying igneous textures were emplaced during the Sanerutian plutonic episode (BRIDGWATER, 1963; DAWES, 1965; ESCHER, 1966). It is clear that the ophitic texture, so typical of dolerites emplaced in cratogenic conditions, can occur in other environments depending on deformation and stress conditions. The quiet crystallisation conditions necessary for the production of ophitic texture from a dolerite magma, may also exist in environments other than truly cratogenic (DAWES, 1965; ALLAART, in press).

With regard to the 1st episode basic intrusions it can only be assumed, on account of their complete transformation, that they were emplaced into the unmetamorphosed sediments under non-plutonic conditions. It is quite possible that they are genetically connected with the Ketilidian volcanic activity which occurred at the end of sedimentation. ESCHER (1966) considers this connection probable for comparable basic sills on the Nanortalik peninsula to the west of the Tasîussaq area.

It is considered that the 2nd and 3rd episode basic rocks, intruded at a later stage in the same Precambrian 'geological cycle', were not emplaced under cratogenic conditions, i.e. are not comparable in type to the dolerites of the Tertiary Volcanic Province of Scotland, although at the time of emplacement, metamorphic conditions were not high enough to prevent the formation of dolerites with igneous textures.

Accepting the hypothesis that the dipsenic conditions of the early granulite facies metamorphism also influenced the metamorphism of the later pyroxene-metadolerites, the implication follows that the later metamorphism followed closely on the first. This in turn implies that the Sanerutian and Ketilidian events in the Tasîussaq area are not separated by a long span of time and that the break marked by the pyroxene-metadolerites cannot be regarded as a significant cratogenic hiatus between two separate plutonisms. The writer prefers to regard the Sanerutian in the Tasîussaq area as the late stage of the plutonism which started in Ketilidian time, and the 2nd episode basic intrusions as indicating a trend in the crust towards brittle conditions. The 2nd episode basic rocks have chilled margins adjacent to the high-grade gneisses, indicating a marked temperature difference between the intruded material and that of the host rocks at the time of intrusion. Chilled margins however provide little information about the actual temperature of the host rocks and they are not, as sometimes inferred, indicative of intrusion into cold rocks. It is possible for chilled margins to form in dykes emplaced into heated rocks under plutonic conditions. This point has previously been stressed by WATTERSON (1965) and ALLAART (in press) in connection with South Greenland dykes.

The 3rd episode basic intrusions are connected in time with the genesis of the rapakivi granites of the Tasîussaq area, being intruded after the initial emplacement of the biotite rapakivi but before the late potash metasomatism (DAWES, 1966). The rapakivi granites were intruded during the late stages of the Sanerutian plutonic activity. It has been mentioned earlier (page 29) that some of the basic rocks connected to the biotite rapakivi display primary textures closely similar to the textures of metamorphic rocks due to their intrusion into heated granite. However the majority of the 3rd episode intrusions display original ophitic and sub-ophitic textures. The biotite rapakivi granite has a long and complicated history but it is clear that the 3rd episode basic rocks displaying ophitic and sub-ophitic textures do not represent cratogenic conditions during the genesis of the rapakivi. This conclusion is at variance with the opinion of WATTERSON (1965, p. 100) who regards "normal metabasaltic dykes" displaying ophitic textures as representing "a complete and significant break in plutonic activity".

The 3rd period intrusions of the Tasîussaq area are considered to represent a brief lull in metamorphic conditions during the waning of the Sanerutian plutonism since the intrusions post-date the dipsenic metamorphism responsible for the formation of the pyroxene-metadolerites but pre-date a rise in the thermal front which amphibolitised them. During Sanerutian time in the Tasîussaq area, conditions of metamorphism varied from dipsenic to non-dipsenic and water was introduced into the environment after the metamorphism of the 2nd episode basic intrusions. It is suggested that this influx of water was connected to the emplacement of the Sanerutian granites.

The 2nd and 3rd episode basic intrusions were metamorphosed under similar P-T conditions — the critical factor being the amount of water available in the environment. Metamorphic conditions decreased at the end of the Sanerutian and diorite sheets and later Gardar dolerite dykes were not metamorphosed. They have only suffered local alteration along shear and fault zones.

The basic intrusions provide a means of analysing the plutonic development of the Tasîussaq area and their intrinsic characters indicate fluctuations in both P-T conditions and water content in the crust during Precambrian time. Figure 17 attempts to diagrammatically represent the relationship between time and temperature in the Tasîussaq area. The plotted curve is undoubtedly more complicated than represented and other fluctuations in temperature presumably occurred during the Precambrian history. The boundaries between the Ketilidian and the Sanerutian and the Sanerutian and the Gardar drawn on figure 17 are purely arbitrary.

Some comment has already been made (page 9) on the boundary of the Ketilidian and Sanerutian and the use of the term 'Kuanitic'. In the Ilordleq and Julianehåb areas the dykes emplaced between the Ketilidian and the Sanerutian (the so-called '2nd period basic dykes') are strikingly different in character to the '3rd period basic dykes' emplaced during the Sanerutian plutonism (Watterson, 1965; Windley, 1966a). The '2nd period dykes' in these areas crystallised as ordinary dolerites with ophitic textures while the '3rd period dykes' are synkinematic in type and are characterised by igneous textures which closely simulate crystalloblastic textures (i.e. 'primary metamorphic textures'). Mainly because of this contrast, the cratogenic nature of the '2nd period dykes' and the significance of the break in plutonism marked by them have been strongly emphasised (Watterson, 1965). However, between true cratogenic ophitic textured dykes and dykes bearing 'primary metamorphic textures' there is a wide range of textural and mineralogical possibilities depending both on the character of the host rocks and the nature of the intruded material; dykes with ophitic texture are not necessarily confined to the extreme end of a transition between cratogenic dykes and synkinematic dykes with 'primary metamorphic textures'. In the Tasîussaq area, the Sanerutian basic intrusions (3rd episode

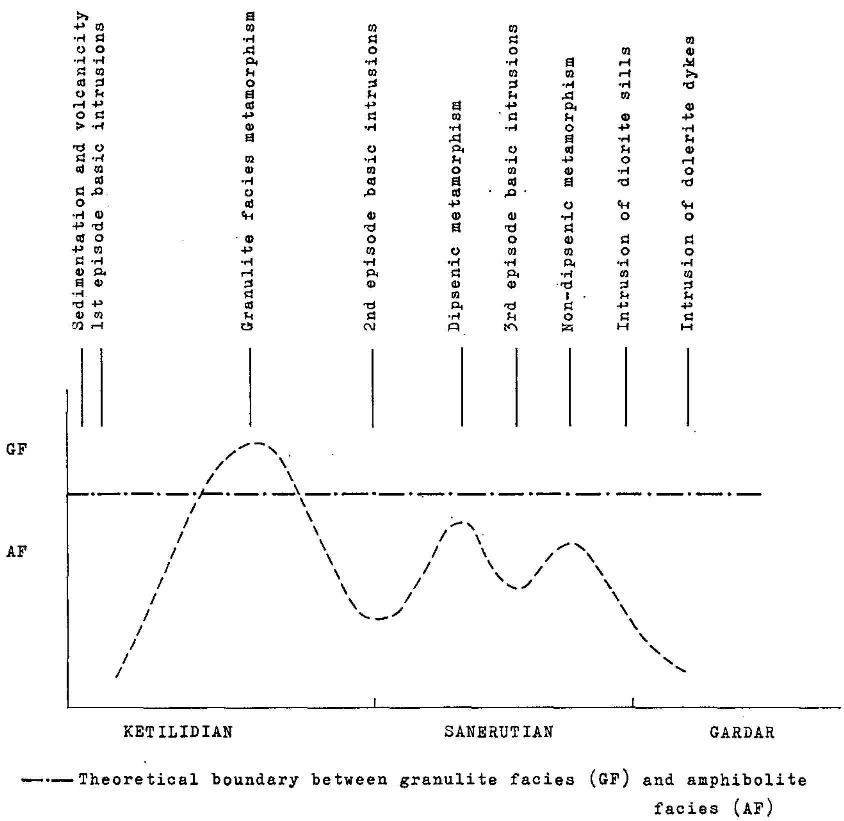


Fig. 17. Diagrammatical representation of the relationship between time and temperature in the Tasîussaq area. The curve is simplified but it implies an essentially continuous plutonic evolution without cratogenic breaks.

intrusions) displaying ophitic and sub-ophitic textures are similar to the 2nd episode intrusions and consequently less significance is attached to the 2nd episode basic dykes emplaced 'between' the Ketilidian and the Sanerutian. Both the 2nd and 3rd episode intrusions were emplaced during the Ketilidian-Sanerutian plutonism and neither are suitable to separate major divisions of the Precambrian history.

The recognition of the Gardar period in the Tasîussaq area is based solely on the presence of dolerite dykes which can be correlated by both field features and palaeomagnetic investigations (see Tarling, 1966) with dykes of known Gardar age further to the north-west in South Greenland. In the Julianehåb area the Gardar dolerites are clearly recognisable from the earlier episodes of dolerite dyking since the pre-Gardar dolerite dykes are all amphibolites with few relics of primary pyroxene preserved (Allaart, in press). This distinction between pre-Gardar and Gardar dolerites is not evident in the Tasîussaq area where some fresh Sanerutian doleritic, gabbroic and noritic rocks exist associated in time with the rapakivi granites (see also Bridgwater, 1963, p. 180). In the south-east of the Tasîussaq area dolerite dykes of the 3rd episode intrusion are remarkably similar to dykes of Gardar age and it is only when such dykes are traced north-westwards where they become metamorphosed and penetrated by acid veins from the biotite rapakivi that their Sanerutian age is established. The thermal history of the crust between the Ketilidian-Sanerutian events and the Gardar as recognised in the Julianehåb area may not be directly comparable to that in the Tasîussaq area or environs and thus it is impracticable to apply to the chronology any strict limits of the Gardar as recognised in the Julianehåb area.

REFERENCES

ALLAART, J. H. (1964): Review of the work on the Precambrian Basement (pre-Gardar) between Kobberminebugt and Frederiksdal, South Greenland. Rapp. Grønlands geol. Unders., Nr. 1, 38 pp.

— (in press): Basic and intermediate igneous activity and its relationships to the evolution of the Julianehåb granite, South Greenland. Medd. Grønland, Bd. 175, Nr. 1.

ALMOND, D. C. (1962): Explanation of the geology of sheet 15 (Kitgum). Geol. Surv. Uganda, Rep. Nr. 8, 55 pp.

ANTUN, P. (1962): On some noritic dikes from Ørsdalen. Norsk geol. Tidsskr., Bd. 42, 269–274.

BERTHELSEN, A. (1960): Structural studies in the Pre-Cambrian of Western Greenland. Part II. Geology of Tovqussap Nunâ. Medd. Grønland, Bd. 123, Nr. 1, 223 pp.

— (1961): On the chronology of the Precambrian of Western Greenland. *In* RAASCH, G.O. (edit.) Geology of the Arctic. Proc. 1st Int. Symp. Arctic Geol., Vol. 1, 329–338. Univ. Toronto Press.

BONDESEN, E. and HENRIKSEN, N. (1965): On some Pre-Cambrian metadolerites from the central Ivigtut region, SW Greenland. Medd. Grønland, Bd. 179, Nr. 2, 42 pp.

BRIDGWATER, D. (1963): A review of the Sydprøven granite and other "New granites" of South Greenland. Medd. dansk geol. Foren., Bd. 15, 167–182.

— (1965): Isotopic age determinations from South Greenland and their geological setting. Medd. Grønland, Bd. 179, Nr. 4, 56 pp.

BRIDGWATER, D., SUTTON, J. and WATTERSON, J. S. (1966): The Precambrian rapakivi suite and surrounding gneisses of the Kap Farvel area, South Greenland. *In* Rapp. Grønlands geol. Unders., Nr. 11, 52–54.

BRIDGWATER, D. and WALTON, B. J. (1964): The tectono-magmatic evolution of the Svecofennid chelogenic cycle in South Greenland. Nature, Lond., Vol. 203, 278–281.

BUDDINGTON, A. F. (1963): Isograds and the role of H_2O in metamorphic facies of orthogneisses of the Northwest Adirondack area, New York. Bull. geol. Soc. Amer., Vol. 74, 1155–1181.

CLARK, R. H. (1952): The significance of flow structure in the microporphyritic ophitic basalts of Arthur's Seat. Trans. Edinb. geol. Soc., vol. 15, 69–83.

DAWES, P. R. (1965): The genesis of rapakivi granite and its position in the evolution of the Precambrian of the Tasiussak area, South Greenland. Unpubl. Ph.D. thesis. Univ. Exeter, England.

— (1966): Genesis of rapakivi. Nature, Lond., Vol. 209, 569–571.

— (in prep.): The Precambrian geology of the Tasîussaq area, South Greenland, with special reference to a high-grade gneiss complex. Medd. Grønland.

ESCHER, A. (1966): The deformation and granitisation of Ketilidian rocks in the Nanortalik area, S. Greenland. Medd. Grønland, Bd. 172, Nr. 9, 102 pp.

EVANS, R. K. (1965): The geology of the Shire Highlands. Geol. Surv. Malawi, Bull. No. 18, 54 pp.

FRANCIS, G. F. (1957): Geological observations in the Tasermiut fjord and neighbouring area. Unpubl. manuscript, Brit. Mus. (Nat. Hist.) archives.

[GIESECKE, K. L.] (1910): Karl Ludwig Gieseckes mineralogisches Reisejournal über Grönland, 1806–1813. Medd. Grønland, Bd. 35, 478 pp.

GREEN, J. C. (1956): Geology of the Storkollen-Blankenberg area, Kragerø, Norway. Norsk geol. Tidsskr., Bd. 36, 89–140.

GROVES, A. W. (1935): The charnockite series of Uganda, British East Africa. Quart. J. geol. Soc. Lond., Vol. 91, 150–205.

HARKER, A. (1950): Metamorphism. A study of the transformation of rock-masses. (2nd ed.) London: Methuen and Co., 362 pp.

HEPWORTH, J. V. (1964): Explanation of the geology of sheets 19, 20, 28 and 29 (Southern West Nile). Geol. Surv. Uganda, Rep. Nr. 10, 123 pp.

HIGGINS, A. K. and BONDESEN, E. (1966): Supracrustals of pre-Ketilidian age (the Tartoq Group) and their relationships with Ketilidian supracrustals in the Ivigtut region, South-West Greenland. Rapp. Grønlands geol. Unders., No. 8, 21 pp.

JESSEN, A. (1896): Geologiske Iagttagelser. *In* MOLTKE, C., Opmaalingsexpeditionen til Julianehaabs-distrikt 1894. Medd. Grønland, Bd. 16, 123–169.

KNUTSEN, H. and EBERLIN, P. (1889): Om de geologiske forhold i Dansk Østgrønland. Medd. Grønland, Bd. 9, 235–270.

MACDONALD, G. A. and KATSURA, T. (1964): Chemical composition of Hawaiian lavas. J. Petrol., Vol. 5, 82–133.

PARRAS, K. (1958): On the charnockites in the light of a highly metamorphic rock complex in Southwestern Finland. Bull. Comm. géol. Finl., No. 181, 1–137.

POLDERVAART, A. (1953): Metamorphism of basaltic rocks: a review. Bull. geol. Soc. Amer., Vol. 64, 259–274.

POLDERVAART, A. and BACKSTRÖM, J. W. VON (1949): A study of an area at Kakamas (Cape Province). Trans. geol. Soc. S. Africa., Vol. 52, 433–495.

PRINZ, M. (1964): Geologic evolution of the Beartooth Mountains, Montana and Wyoming. Part 5. Mafic dike swarms of the Southern Beartooth Mountains. Bull. geol. Soc. Amer., Vol. 75, 1217–1248.

READ, H. H. (1957): The granite controversy. London: Thomas Murby and Co., 430 pp.

ROSENQVIST, I. TH. (1952): The metamorphic facies and the feldspar minerals. Årb. Univ. Bergen naturv. R., Nr. 4, 108 pp.

SINGH, S. (1966): Orthopyroxene-bearing rocks of charnockitic affinities in the South Savanna-Kanuku Complex of British Guiana. J. Petrol., Vol. 7, 171–192.

STILLWELL, F. L. (1918): The metamorphic rocks of Adelie Land. Australasian Antarctic Exped. 1911–1914, Sci. rep. Ser. A, Vol. 3, pt. 1, 230 pp.

SUBRAMANIAM, A. P. (1959): Charnockites of the type area near Madras — a reinterpretation. Amer. J. Sci., Vol. 257, 321–353.

SUTTON, J. and WATSON, J. (1951): Varying trends in the metamorphism of dolerites. Geol. Mag., Vol. 88, 25–35.

SYLOW, P. (1883): *In* HOLM, G. F., Geographisk Undersøgelse af Grønlands sydligste Del. Medd. Grønland, Bd. 6, 178–180.

TARLING, D. H. (1966): Remanent magnetic directions of some dykes from southern West Greenland. *In* Rapp. Grønlands geol. Unders., Nr. 11, 36–37.

TEMPERLEY, B. N. (1938): The geology of the country around Mpwapwa. Geol. Surv. Tanganyika, Short paper 19, 60 pp.

TILLEY, C. E. (1921): The granite-gneisses of Southern Eyre peninsula (South Australia) and their associated amphibolites. Quart. J. geol. Soc. Lond., Vol. 77, 75–131.

TÖRNEBOHN, A. E. (1886): Karakteristik af bergartsprof, insamlade af den svenska expeditionen till Grönland år 1883. Geol. Fören. Stockh. Förh., Bd. 8, 431–441.

WALLIS, R. H. (1966): The geology of North-east Tasermiut fjord, South Greenland. Unpubl. Ph.D. thesis, Univ. Birmingham, England.

WALTON, B. J. (1965): Sanerutian appinitic rocks and Gardar dykes and diatremes, North of Narssarssuaq, South Greenland. Medd. Grønland, Bd. 179, Nr. 9, 66 pp.

WATTERSON, J. (1965): Plutonic development of the Ilordleq area, South Greenland. Part I: Chronology, and the occurrence and recognition of metamorphosed basic dykes. Medd. Grønland, Bd. 172, Nr. 7, 147 pp.

WEGMANN, C. E. (1938): Geological investigations in Southern Greenland. Part I. On the structural divisions of Southern Greenland. Medd. Grønland, Bd. 113, Nr. 2, 148 pp.

— (1939): Übersicht über die Geologie Südgrönlands. Mitt. naturf. Ges. Schaffh. (Schweiz), Bd. 16, 188–212.

WILCOX, R. E. and POLDERVAART, A. (1958): Metadolerite dike swarm in Bakersville-Roan mountain area, North Carolina. Bull. geol. Soc. Amer., Vol. 69, 1323–1368.

WINDLEY, B. [F.] (1965): The role of cooling cracks formed at high temperatures and of released gas in the formation of chilled basic margins in net-veined intrusions. Geol. Mag., Vol. 102, 521–530.

— (1966a): The Precambrian geology of the Sårdloq area, South Greenland. Rapp. Grønlands geol. Unders., Nr. 5, 49 pp.

— (1966b): Anorthosites and polymetamorphism between Ravns Storø and Sukkertoppen, West Greenland. *In* Rapp. Grønlands geol. Unders., Nr. 11, 27–29.

WISEMAN, J. D. H. (1934): The Central and South-west Highland epidiorites: a study in progressive metamorphism. Quart. J. geol. Soc. Lond., Vol. 90, 354–417.

YODER, H. S. and TILLEY, C. E. (1962): Origin of basalt magmas: an experimental study of natural and synthetic rock systems. J. Petrol., Vol. 3, 342–532.

Færdig fra trykkeriet den 31. januar 1968.

PLATES

Plate 1

a – 1st episode basic rock
b and c – 2nd episode basic rocks

a

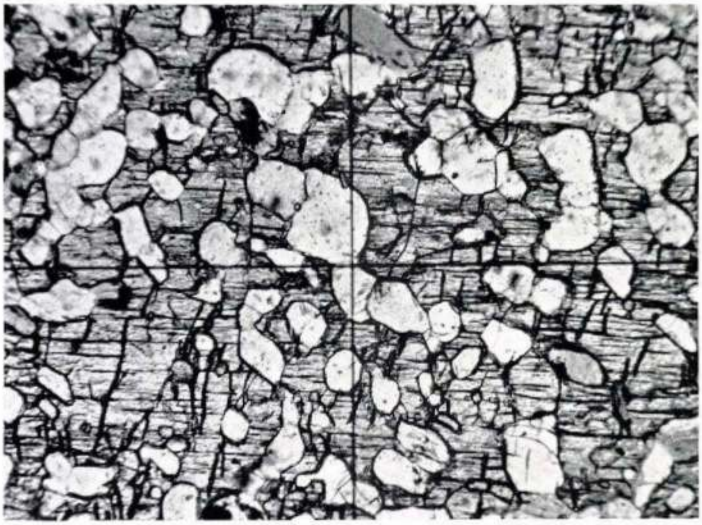
Microphotograph of pyriclasite. The hypersthene displays poeciloblastic texture (sieve structure) containing small rounded crystals of plagioclase and occasionally biotite. GGU 67193, plain light, × 40. Text reference page 16.

b

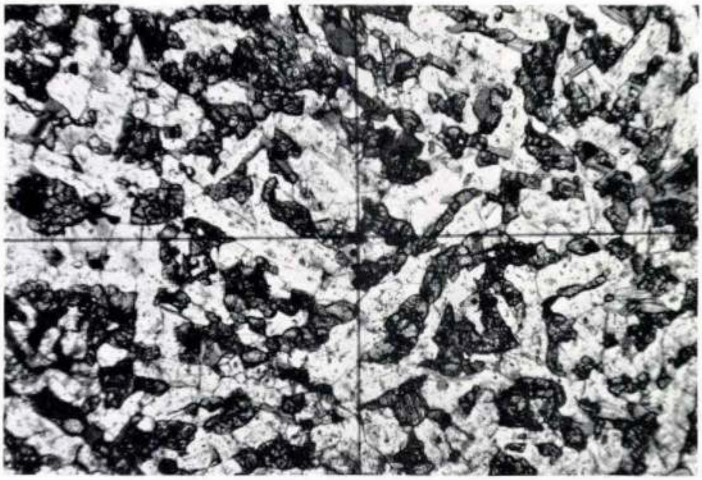
Microphotograph of pyroxene-metadolerite. The texture is sub-ophitic with plagioclase laths randomly orientated. Pyroxene occurs in small grains, some probably through recrystallisation of larger crystals. Small flakes of biotite exist. GGU 67176, plain light, × 40. Text reference page 21.

c

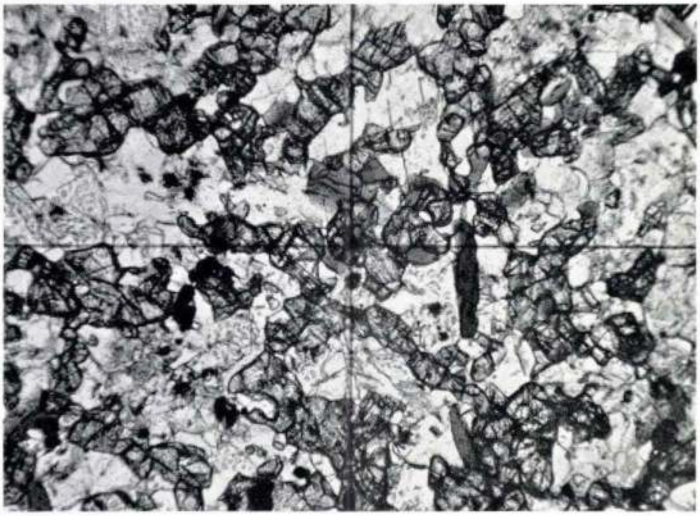
Microphotograph of pyroxene-metadolerite showing relic sub-ophitic texture. The plagioclase has been corroded and encroached upon by the recrystallisation of the pyroxene but the lath-shape of the felspar is still recognisable. Some recrystallisation of the plagioclase has taken place. Biotite occurs in a small amount. GGU 58584, plain light, × 40. Text reference page 21.



a



b



c

Plate 2

a – 2nd episode basic rock
b and c – 3rd episode basic rocks

a

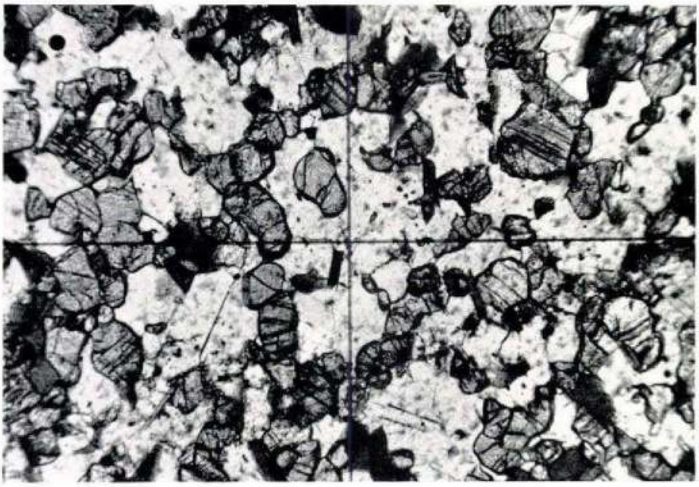
Microphotograph of pyroxene-metadolerite. The texture approaches granoblastic through recrystallisation of both the pyroxene and the plagioclase. Some biotite exists. The lath-shaped plagioclase crystals of plate 1, b and c are notably absent and the sub-ophitic texture has been destroyed. GGU 67192, plain light, × 45. Text reference page 21.

b

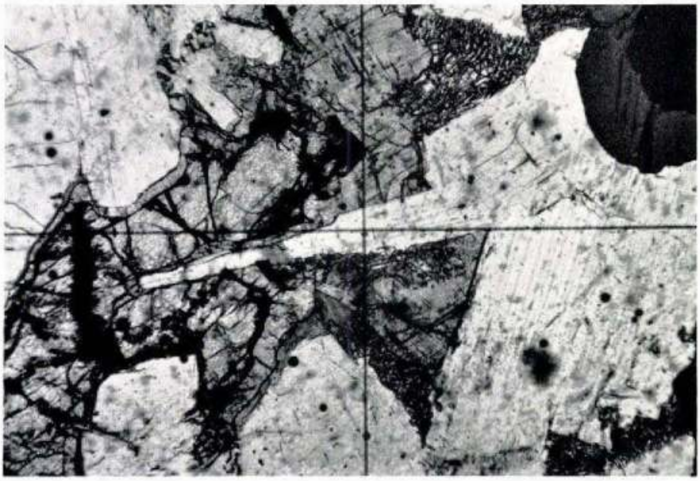
Microphotograph of olivine norite showing ophitic texture. A large crystal of hypersthene (centre) forms a rim to the olivine (centre left) and encloses a lath of plagioclase. Biotite replaces the hypersthene (lower centre). Magnetite also occurs (top right). GGU 66984, plain light, × 45. Text reference page 28.

c

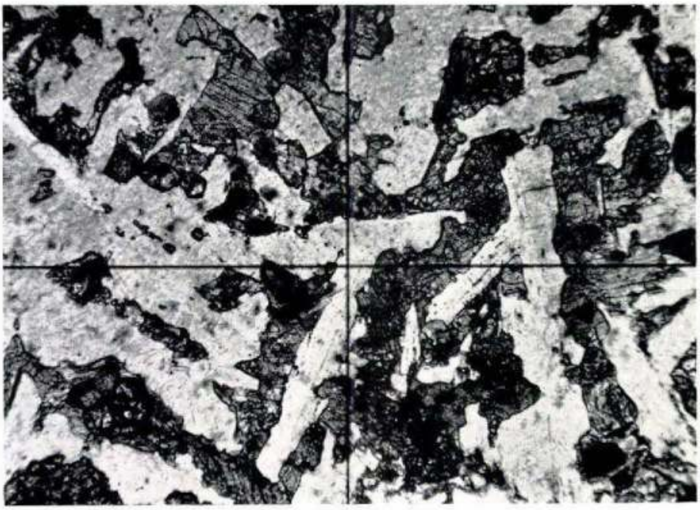
Microphotograph of olivine dolerite. The texture is sub-ophitic composed of randomly orientated plagioclase laths partly enclosed in pyroxene. Olivine (lower left) occurs in a few grains in association with the pyroxene. GGU 67043, plain light, × 40. Text reference page 27.



a



b



c

Plate 3

a, b and c – 3rd episode basic rocks

a

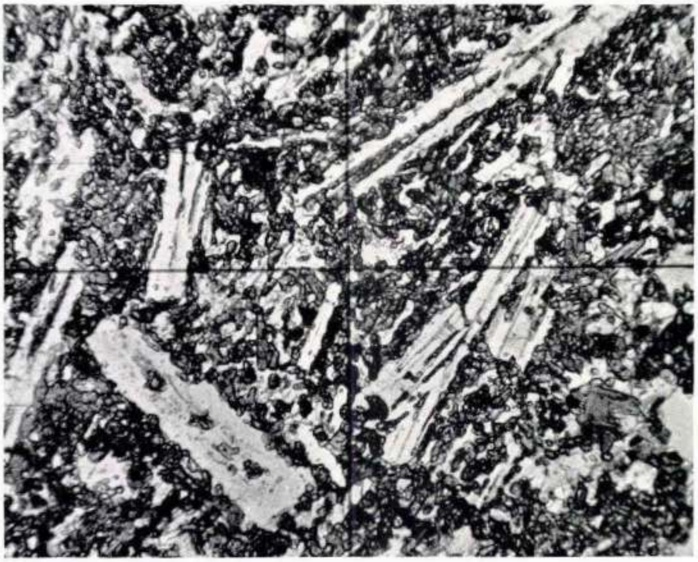
Microphotograph of dolerite showing microporphyritic texture composed of randomly orientated laths of plagioclase in a finer grained mesostasis of plagioclase and pyroxene. GGU 58580, plain light, × 40. Text reference page 27.

b

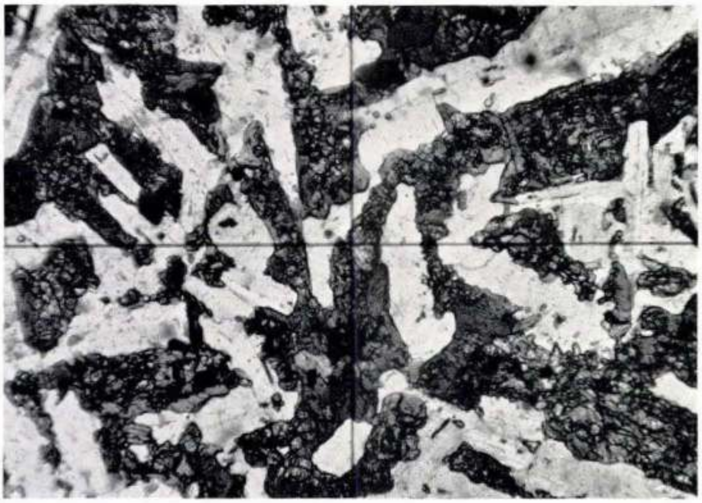
Microphotograph of metadolerite. The pyroxene has been partially replaced by hornblende but the primary igneous texture is preserved. The plagioclase has not started to recrystallise. GGU 58583, plain light, × 40. Text reference page 29.

c

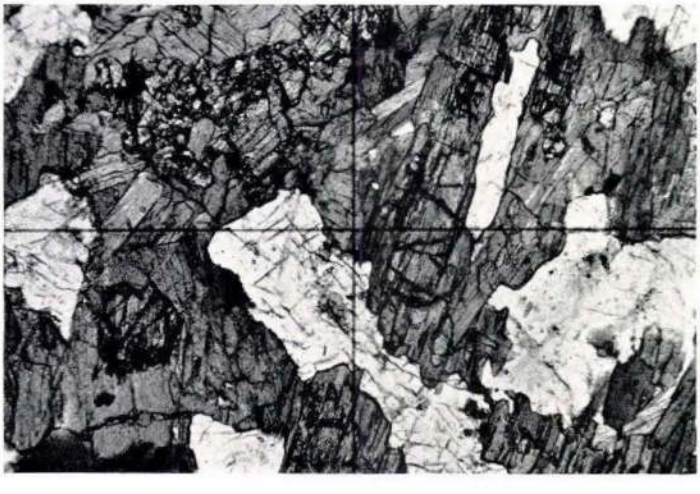
Microphotograph of metagabbro. The pyroxene has been replaced by hornblende and remnants are preserved in the centre of pseudomorphed crystals. The plagioclase has not recrystallised and the primary lath-shape of the crystals is preserved despite a slight corrosion by the hornblende. One lath is completely enclosed in a pseudomorph of pyroxene. Such ophitic texture is preserved even in completely amphibolitised gabbro. GGU 66843, plain light, × 40. Text reference page 29.



a



b



c