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GRØNLANDS GEOLOGISKE UNDERSØGELSE

GEOLOGICAL MAP OF GREENLAND 1:100 000

IVIGTUT 61 V. 1 SYD

THE OROGENIC AND CRATOGENIC GEOLOGY
OF A PRECAMBRIAN SHIELD AREA

DESCRIPTIVE TEXT
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WITH 62 FIGURES AND 9 TABLES IN THE TEXT,
AND 8 PLATES

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Abstract

The Ivigtut region forms part of the Precambrian shield of Greenland. The region includes the northern boundary zone of the Ketilidian fold belt (1800 m.y.) of south Greenland, and in the foreland area to the north two pre-Ketilidian orogenies can be distinguished. The oldest orogeny (Senilian) is characterised by alpinotype structures and the high grade metamorphism and migmatisation of a sequence of gneisses and amphibolites. The younger orogeny (Maturian) influenced a post-Senilian supracrustal sequence and led to reactivation of the adjacent Senilian basement rocks; low- to medium-grade metamorphic conditions were reached in the northernmost part of the Ivigtut region.

Swarms of basic dykes (Iggavik dykes) were emplaced under cratogenic conditions after the Maturian orogeny, but prior to the deposition of Ketilidian supracrustal rocks which rest unconformably on the pre-Ketilidian basement.

The Ketilidian supracrustals are weakly deformed and metamorphosed in the north but towards the south both these and the underlying gneisses are increasingly affected by the Ketilidian deformation and plutonism, and the original unconformity between pre-Ketilidian gneisses and Ketilidian supracrustals is obliterated. This change is accompanied by an increase in metamorphic grade from low greenschist facies to amphibolite facies. A series of autochthonous to allochthonous Ketilidian granites occur in abundance in the southern part of the Ivigtut region.

The cratogenic Gardar period in the Ivigtut region ($\geqslant$ 1250 m.y.) encompasses formation of intrusive complexes, emplacement of numerous swarms of dykes of various composition and extensive faulting activity.

Intrusion of Mesozoic basic dykes and sills reflects the latest pre-Quaternary events.

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INTRODUCTION

General

The 1:100000 Ivigtut sheet (61 V. 1 Syd) takes its name from the cryolite mine settlement on the south side of Arsuk Fjord in the central part of the map sheet area. The position of the map sheet area in south-west Greenland is indicated on the cover sheet.

Systematic mapping of the Ivigtut region by the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse = GGU) was started in 1956 and continued during the seasons 1957–58 and 1960–63. The work was GGU's first systematic regional survey, and this particular region was selected primarily to establish the general geological framework of the region around the only profitable mine in Greenland at that time, the Ivigtut cryolite deposit. While cryolite prospecting was not specifically carried out by the Survey during mapping, the geological results were made available to Kryolitselskabet Øresund (the Cryolite Company), which made use of the information for regional cryolite prospecting. Unfortunately no new finds of cryolite were demonstrated and the mine at Ivigtut closed down in 1962.

The Ivigtut region was well chosen as the Survey's first map sheet area. It proved to be a geological key region encompassing a fold belt boundary between the early Proterozoic Ketilidian fold belt to the south and older Archaean rocks to the north. The Archaean rocks preserve signs of a further two distinct orogenic events. Cratogenic periods characterised by faulting and high level intrusions predate and post-date the Ketilidian orogeny.

The regional geological mapping was carried out by 15 geologists, many of whom participated in the work for several seasons. In all 33 geologist-summers, each of 2–3 months duration, were expended on the mapping which covered an area of approximately 2240 km^2. Many of the participating geologists have later presented results in internal GGU reports and published accounts.

The geologists who participated in the mapping of the Ivigtut region were: Stephen Neville Ayrton, Univ. Lausanne; Asger Berthelsen, GGU; Erling Bondesen, Univ. Copenhagen; Lucien F. Bonnard, Univ. Lausanne; David Bridgwater, GGU; Marcel Burri, Univ.

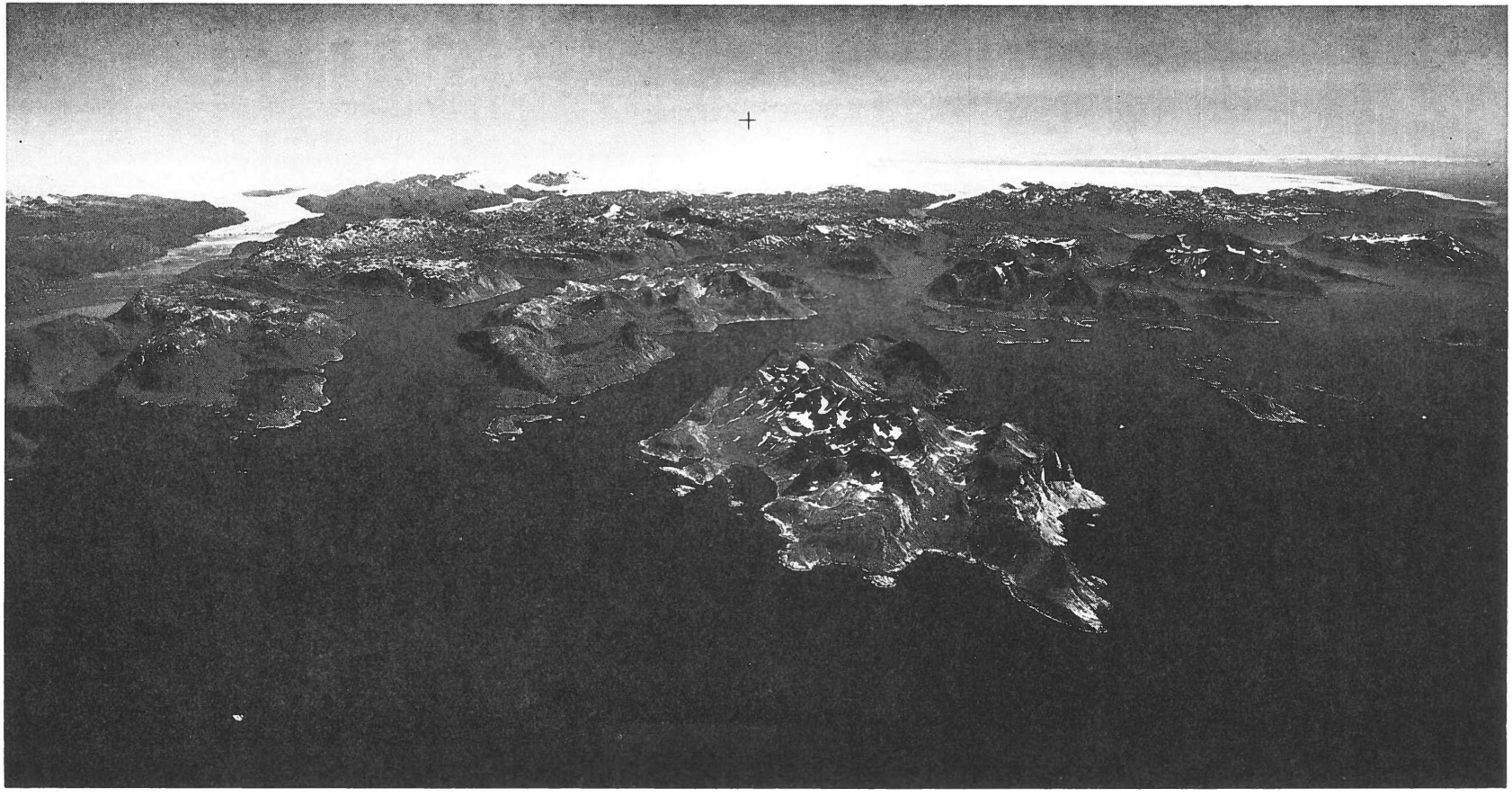


Fig. 1. Oblique aerial view of the Ivigtut region looking towards the south-east from 4000 m altitude. In the foreground the island Sermersût. Route 503 A no. 7787. Copyright Geodetic Institute, Denmark.

Lausanne; C. H. EMELEUS, Univ. Durham; CLAUDE FROIDEVAUX, Univ. Neuchâtel; NIELS HENRIKSEN, Univ. Copenhagen; FRITZ LYNGSIE JACOBSEN, Univ. Copenhagen; STIG BAK JENSEN, GGU; JACQUES MULLER, Univ. Neuchâtel; T. C. R. PULVERTAFT, GGU; B. G. J. UPTON, Univ. Oxford and MARC WEIDMANN, Univ. Lausanne. The working areas of the various geologists are indicated on a key map on the map sheet. The mapping project was led and coordinated by ASGER BERTHELSEN.

During the two first years of the mapping campaign the field parties were supported only by a GGU motor cutter and a small motorboat. From 1958 two helicopters provided additional transport support and regularly moved the inland camps.

The petrological classification used during the mapping was based on JOHANNSEN's (1939) divisions. The structural classification used for the gneisses was that of BERTHELSEN (1961). During field work and in subsequent descriptions various metamorphic facies conceptions have been used, but in this description the nomenclature suggested by TURNER (1968) is employed.

The compilation of both the map and the description has involved extensive use of material collected by the 15 geologists who participated in the work. This material consists of both published and unpublished results, the latter in the form of field maps and reports to the Survey. All unpublished results are maintained in the GGU archives and are available for special reference purposes. Credit and references have been given as extensively as is possible within the limits imposed by a work of compilatory nature.

The completion of the general description of GGU's mapping of the Ivigtut region, more than ten years after the conclusion of the last field work, has to some extent benefited from later work carried out to the north and south of the Ivigtut region; answers have been given to some problems which could not be solved within the boundaries of the Ivigtut map sheet, and the knowledge of the general geology of West Greenland has given the local geology a wider perspective.

Topographical base maps and scale of field mapping

The topographical base for the mapping in most of the Ivigtut region has been maps at a scale of 1:20000, generally with 50 m, and occasionally 25 m, contour intervals. The maps were prepared by the Geodetic Institute, Copenhagen.

A zone, approximately 10 km in width, bordering the inland ice was not covered by the 1:20000 maps. The mapping to the south of Arsuk Fjord in this zone was therefore based on a simple 1:100000 map and a slotted-template map at a scale of 1:20000 prepared by GGU. To the

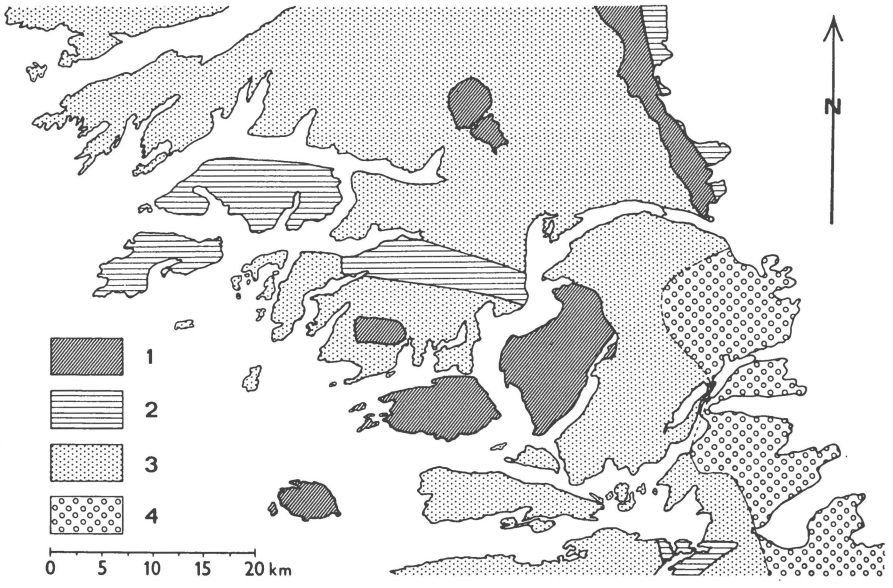


Fig. 2. Index map showing scale of basic field mapping. 1: Detailed mapping at 1:10000; 2: Detailed regional mapping at 1:10000–1:20000; 3: Regional mapping at 1:20000; 4: Regional and reconnaissance mapping at 1:20000–1:100000.

north of Arsuk Fjord, in Grænseland a special map at a scale of 1:10000 prepared by the Geodetic Institute in 1960 was used.

Not all areas within the map sheet have been mapped to the same degree of detail. Geologically important areas or those with special problems have been given greater attention, and in parts of the easternmost areas lack of suitable topographical maps has prevented detailed mapping. The field mapping scale for various parts of the Ivigtut sheet is shown in fig. 2.

Aerial photographs

Vertical aerial photographs at a scale of approximately 1:40000 and oblique photographs taken from 3000 m and 4000 m altitude cover most of the Ivigtut region. Both types of pictures were used during the mapping, but have been of restricted value as many geological features are insignificant and snow cover is often extensive.

A new series of vertical photographs at a scale of 1:20000 covering an approximately 10–15 km wide belt bordering the inland ice was taken in 1958 and supplied at a time when only the mapping of Grænseland remained. Geologically these photographs proved extremely useful during field work in Grænseland and during the compilation of the 1:100000 map sheet. Alterations and corrections of field mapping done prior to 1958 have been made using the new vertical photographs, but significant

changes usually involved consultation with the geologist who undertook the primary mapping.

Geological base maps, scale of representation and symbols

The basic material used for the compilation of the map sheet has been clean-drawn copies of the original maps kept in GGU's map archive. The Gardar intrusions of the Grønnedal-Íka complex and the Kûngnât complex have, however, been simplified from published maps.

The general aim has been to represent the geology at true scale. For technical reasons various geological features less than 50 m in size cannot be reproduced at true scale. Features such as dykes from 30 to 50 m in width are therefore shown by 0.4 mm line thickness, and 10–30 m wide features by 0.1–0.2 mm line thickness.

The thinnest geological features on the map are those with a minimum thickness of 10 m. A series of important thin dykes (lamprophyres, trachytes and acid dykes) is, however, represented by a selection of dykes, although these mainly are less than 10 m wide.

The lithological divisions on the map sheet are based on a standard legend prepared by the Survey as a working basis for the compilation of the 1:100000 geological map sheets. The standard legend in principle is based on lithological divisions with the purpose of indicating observed data rather than interpreted information.

Representation of Quaternary cover

Quaternary cover has only been indicated on the map where these deposits have been found extensively and continuously over areas above a certain size. Such areas are generally found in the bottom of some of the major valleys, in front of major glacier lobes and on some scree-covered mountain slopes.

PREVIOUS WORK

General

The geological investigation of South-West and West Greenland was initiated by Carl Ludwig Giesecke, who in the years 1806–13 undertook extensive journeys and collected a wealth of data on the occurrences of minerals and rocks. His diaries were published posthumously by Johnstrup (1878) and were subsequently reprinted (Giesecke, 1910). A. Jessen working under the auspicies of the Commission for the Geological and the Geographical Survey of Greenland (founded in 1878 on the initiative

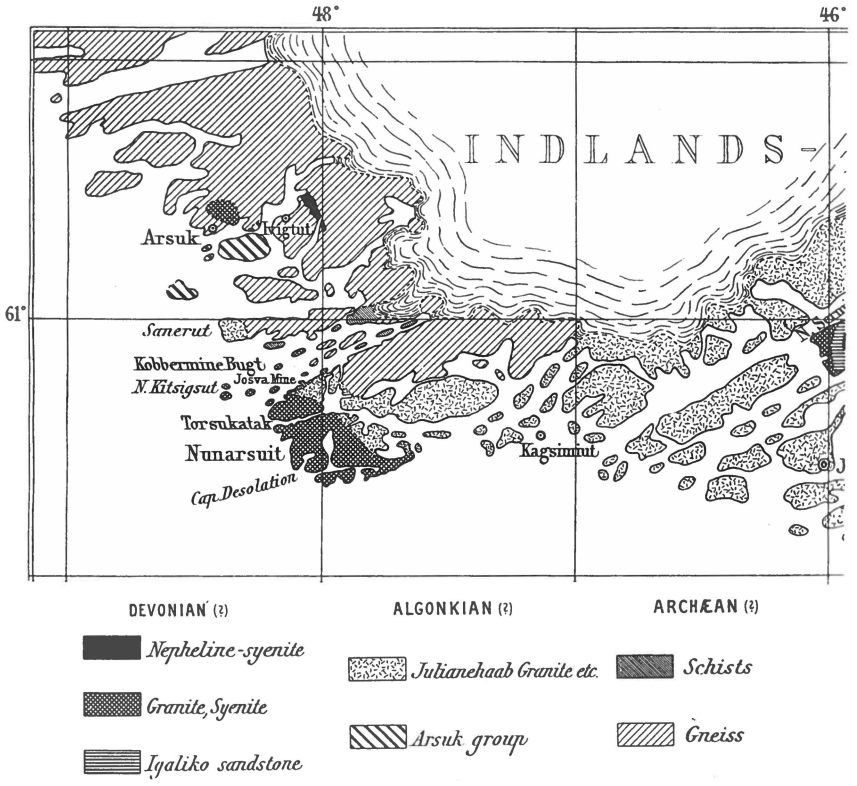


Fig. 3. Reproduction of north-western part of USSING's (1912) "Geological map of the southernmost part of Greenland".

of F. JOHNSTRUP) gave the first review of the geology and geography of the Ivigtut region (JESSEN, 1896).

N. V. USSING visited the Ivigtut region during his journeys in 1900 and 1908, and a brief account on the stratigraphic classification of the Ivigtut rocks is found in his classic memoir on the geology of the Ilímaussaq region (Ussing, 1912). USSING classified the gneisses of the Ivigtut region as well as the schists south and east of Sánerut as Archaean (fig. 3) while the intensely folded slates, phyllites, dolomites, quartzites, graphite schists and metamorphosed diabase and tuffs of the Arsuk Group were considered a younger sequence which he tentatively correlated with the late Algonkian rocks of Labrador. He moreover suggested that the Julianehåb granite intruded subsequent to the folding affecting the Arsuk Group, but before the close of the late Algonkian time. USSING (1912) assigned a Devonian (?) age to the younger sandstones, volcanics and alkaline plutonic rocks of South Greenland.

While the efforts of the many expeditions sent out to Greenland in the succeeding years (1910–35) were mainly concentrated on the explora-

tion of more remote regions in North-West, North and East Greenland, a renewed interest in the regional geology of South Greenland resulted from LAUGE KOCH's (1935, p. 151) suggestion that the Caledonian fold belt of East Greenland should extend along the east coast, through South Greenland and onward to Newfoundland. As a member of LAUGE KOCH's expeditions, C. E. WEGMANN carried out extensive investigations in South Greenland in the seasons of 1936, 1937 and 1938 (WEGMANN, 1938, 1939, 1948; CROMMELIN, 1937).

In particular WEGMANN's 1938 memoir based on the results obtained during a single field season in 1936, has become a widely known and classic account. In this paper, WEGMANN divided the rocks of South Greenland into:

a. an older basement comprising the remnant of a major fold belt, called the Ketilides.

b. the younger Gardar Formation, comprising the Igaliko sandstone, large volcanic masses with various associated hypabyssal and abyssal rocks, i.e. the rocks assigned to the Devonian (?) by USSING (1912).

WEGMANN stated (p. 135) that "the Ketilides should probably be referred to one of the Precambrian orogenic cycles", while "the Gardar Formation may be referred either to the younger Precambrian or to the Palaeozoic".

The Ketilides

WEGMANN named the Ketilides after the old Norse name for Tasermiut fjord, east of Nanortalik, and stated (1938, p. 56) that "so far the boundaries of the Ketilides are not known". He mentioned that formations similar to the Ketilidian were observable at Fiskenæsset and in the vicinity of Godthåb, and wrote that the Ketilides "no doubt continue towards the northeast a long distance up the east coast". In his review from 1939, this latter statement was further substantiated.

The material of this ancient mountain chain was divided into:

1. the old material of the mountain range, i.e. fragments of older ranges which had become included in the Ketilidian belt of kinetic transformation.

2. the younger material which during the first part of the Ketilidian orogenic cycle was deposited on an old (pre-Ketilidian) foundation.

WEGMANN (1938) described two main areas where Ketilidian supracrustals form extensive exposures: 1. a southern area—around the Søndre Sermilik-Tasermiut fjords, and 2. a northern area comprising the country from Kobberminebugt and northwards into the Arsuk Ø area of the central Ivigtut region.

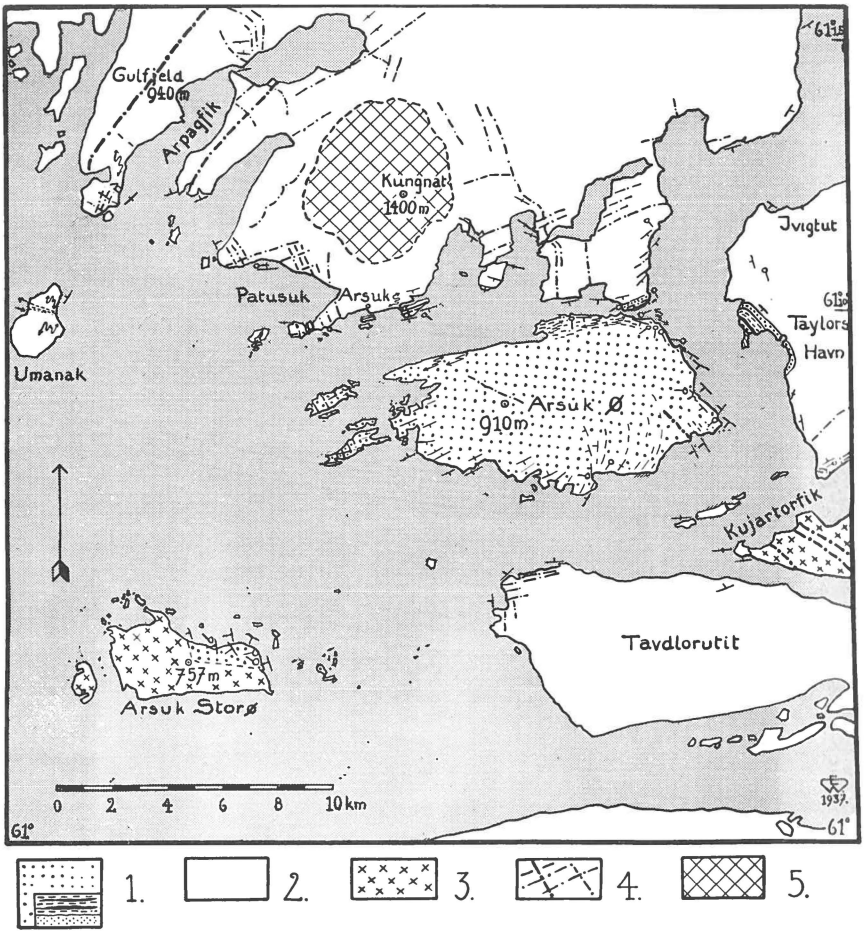


Fig. 4. Reproduction of WEGMANN's (1938) sketch map of the Arsuk area. 1. Ketilidian groups (partly undivided); at the base, the Sermilik group with quartzites, schists, dolomitic and limestone beds; above, the Arsuk Group, chiefly volcanic beds; 2. Migmatites; 3. Granite of the younger Julianehåb generation; 4. Systems of basic dykes of the Gardar Formation (only schematical); 5. Kûngnât granite.

A vast granite country (the Julianehåb granite) separates these two areas.

WEGMANN's studies were confined to the southern and central parts of the Ivigtut region. He gave a detailed account of the Ketilidian supracrustal rocks of the Arsuk Ø area (Taylers Havn, Arsuk Ø, Storø): see fig. 4. These rocks were referred to the Arsuk Group by USSING (1912), but WEGMANN redefined the term, restricting it to the upper, almost purely volcanic, part of the supracrustal sequence, while he placed the underlying metasediments, exposed mainly at Taylers Havn, in the

Sermilik group established on the section of metasediments occurring in the southern area around Søndre Sermilik fjord.

While Ussing (1912) grouped the supracrustal schists of southern Sánerut–Qipisarqo together with the Archaean gneisses of the central and northern Ivigtut region, Wegmann (1938) pointed out that they formed part of the Ketilidian sequence together with the supracrustals exposed on the islands and south coast of Kobberminebugt.

Wegmann (1938) also discussed the relation of the Julianehåb granite to the Ketilidian formations at some length and concluded that intrusive as well as impregnation contacts occur. Extensive development of migmatites was taken as characteristic of the impregnation contacts.

Wegmann (1938) expressed himself rather vaguely about the occurrence of pre-Ketilidian material in the Ketilides. However, in his paper of 1939 (p. 206) as well as in his 1948 paper, he explicitly stated that the gneisses of the Ivigtut peninsula comprised old, i.e. pre-Ketilidian material.

In 1954 GGU, following preparatory photogeological studies, located several new occurrences of supracrustal rocks. The greenschists and metasediments of south Sánerut–Qipisarqo were traced northwards into a so-called "eastern belt" extending from Qôrnoq fjord along the margin of the inland ice to the northern border of the map.

Extensive occurrences of supracrustal rocks were also discovered further north in the country around the inner parts of Sermiligârssuk and in the north-western part of the map sheet. These northern supracrustals were grouped into the so-called Tartoq belt.

During the seasons of 1956, 1957 and 1958 the greater part of the Ivigtut region was mapped on a scale of 1:20000. This mapping lent support to the assumption that the supracrustal rocks of the Tartoq belt continued into those of the "eastern belt", and that both belts comprised Ketilidian supracrustals.

The results obtained by the various members of the mapping team (1956–58) were summarised by Berthelsen (1960). Two contrasting Ketilidian tectonic levels were distinguished:

1. a suprastructure (made up of the metamorphosed, but non-migmatitic sediments and volcanics of the Sermilik group and Arsuk Group), and

2. an infrastructure built up by migmatites and gneisses with local interlayering of schist horizons.

In the infrastructural rocks three successive phases of folding were traced:

1. Older movements producing recumbent, isoclinal folds, probably of pre-migmatitic age.

2. A mainly syn-migmatitic phase of folding, causing the development of a large, anticlinorium of disharmonic folds with NW-SE trending axes.

3. A 3rd phase of folding, during which the movements within the two tectonic levels became distinctly disharmonious. In the infrastructure, the 3rd phase was believed to be expressed mainly by semiplastic refolding, twisting and bending of the earlier-formed anticlinorium into a large-scale S-shape. In the suprastructure, the production of ENE-oriented folds led to an almost complete obliteration of older folds (with the exception of those mentioned above under 2, and the border between the two tectonic levels developed into a structural break.

Although BERTHELSEN (1960) admitted the probable existence of wedges and slices of pre-Ketilidian rocks within the infrastructure, he considered most gneisses and migmatites of the Ivigtut region as having evolved through transformation of former Ketilidian supracrustals.

However, mapping of the Grænseland area (1960–61) in the north-east of the map sheet soon imposed the need of an at least partial revision of this scheme, since here the Ketilidian formations were found to overlie a pre-Ketilidian gneiss basement with a marked unconformity (BONDESEN, 1962). While BONDESEN concluded that most Ivigtut gneisses were thus pre-Ketilidian, BERTHELSEN (1962) still upheld a Ketilidian age and explained the proven basement rocks in Grænseland as representing an upthrust wedge of pre-Ketilidian material which had escaped the influence of Ketilidian migmatisation. In taking this view he recalled the gradational transition from gneisses into supracrustals in the Tårtoq area as well as in the Bikuben area (later described by WEIDMANN, 1964). In the review of the Precambrian of Greenland (BERTHELSEN & NOE-NYGAARD, 1965 (but written 1963)) this "conservative" point of view was further elaborated.

In Midternæs, north of Grænseland and just beyond the border of the Ivigtut sheet A. K. HIGGINS observed in 1965 that not only the gneisses but also the supracrustal rocks of the Tartoq belt were unconformably overlain by Ketilidian sediments and volcanics showing only faint influence of metamorphism (HIGGINS & BONDESEN, 1966). This discovery put an end to the current discussion on the general stratigraphical relations between the supracrustal rocks and the gneisses.

In order to explain the full significance of this discovery, it is necessary to refer to the chronological scheme (table 1) proposed by BERTHELSEN (1960), and referred to extensively in publications by AYRTON (1963), BERTHELSEN (1962), BERTHELSEN & NOE-NYGAARD (1965), BONDESEN & HENRIKSEN (1965), HENRIKSEN (1960) and WEIDMANN (1964).

According to this scheme, the Ketilidian orogeny was succeeded by a cratonic episode during which several generations of basic dyke swarms

Table 1. *Revision of chronology*

Berthelsen (1960)		
	Quaternary	Glaciation
	? Post-Gardar	Dolerites
Precambrian	Gardar	Faulting, dyking, plutonic centres
	Sanerutian	Folding & plutonism
	Kuanitic	Dykes
	Ketilidian	Orogeny Geosynclinal development

This paper		
	Quaternary	
	Mesozoic intrusions	
Precambrian	Gardar	Faulting, dyking, plutonic centres
	Ketilidian	Orogeny Geosynclinal development
	Iggavik dykes	
	Pre-Ketilidian	Orogenies

intruded. Such dykes are typically developed around Kuánit fjord and they were named the Kuanitic dykes; their time of intrusion was termed the Kuanitic period.

In the south-eastern half of the Ivigtut region, the Kuanitic dykes had, however, suffered from subsequent metamorphism and deformation and had become altered into so-called discordant amphibolites, which in places were cut by younger granitic rocks. To cover this post-Kuanitic, but pre-Gardar, episode of metamorphism, deformation and plutonic processes, BERTHELSEN (1960) introduced the term Sanerutian. In the light of subsequent discoveries, this term appears superfluous, since in reality it was merely a synonymon for the Ketilidian orogeny. What BERTHELSEN (1962) considered to represent the north-west border of Sanerutian remobilisation was in fact the border between the Ketilidian fold belt and its foreland of pre-Ketilidian rocks.

The revised view also offered a logical explanation to the otherwise anomalous fact that the Kuanitic dykes intersect the supracrustal rocks of the (pre-Ketilidian) Tartoq belt, while they appeared to be absent in the (Ketilidian) supracrustal rocks of the Arsuk Ø area and the "eastern belt".

In the extreme south-east part of the Ivigtut region, as well as further south, there occur, however, some thin discordant amphibolites called DAs which intersect the Ketilidian supracrustal rocks and the Ketilidian granites. These dykes, some of which are described as synkinematic intrusions, have been studied by WATTERSON (1965, 1968), who worked south of the Ivigtut region. He distinguished discordant amphibolites from three periods and he re-defined the term Sanerutian to cover a late-Ketilidian plutonic episode during which the "mid-Ketilidian" emplaced DA_2 dykes were metamorphosed and deformed together with their granitic country rocks (WATTERSON, 1965 p. 132). He also suggested (p. 10) that the term Kuanitic should no longer be used. However, ALLAART (1967) considers the DA_2 dykes to be without critical chronological value and as probably marking the beginning of late orogenic activity of basic-intermediate magmas during late stages of Ketilidian plutonism. Therefore the term Sanerutian, according to ALLAART (1967, p. 137) should be disregarded.

Gardar

USSING (1907–1908) gave a brief account of the cryolite deposit at Ivigtut and suggested its genetic relationship to the alkaline intrusion nearby, at Grønnedal, which he grouped among the younger (Devonian?) intrusions. WEGMANN (1938) reported on the widespread occurrence of dyke rocks of Gardar age in the Ivigtut region.

The dyke rocks referred to the Gardar period were divided into an older group of black dykes trending mainly NE–SW and a younger group of brown dykes trending mainly NW–SE.

CALLISEN (1943) presented the first petrographic description of the Gardar nepheline syenites of the Grønnedal-Íka igneous complex, while BØGVAD (1947, 1951) supplied information on the "limestone" and magnetite occurrence near Grønnedal.

When GGU in 1954 began its reconnaissance work in the Ivigtut region, it was realised that the "limestones" were carbonatites associated with the adjacent nepheline syenites (BONDAM, 1954). The Grønnedal-Íka complex was subsequently mapped and described in great detail by EMELEUS (1964), while the alkaline rocks of the Kûngnât complex (west of Ivigtut) were made the object of a detailed survey by UPTON (1960).

GENERAL CHRONOLOGY AND ITS PRINCIPLES

This chapter serves as an introduction to the revised chronology which is adopted as a base for the description of the rocks of the Ivigtut region. It moreover contains a discussion of the principles on which this chronology is based.

In preparing the map and the accompanying explanation all available information has been studied and earlier results and conclusions reevaluated. This work has established that the rocks of the Ivigtut region evolved during not less than three orogenies with intermittent cratonic intervals; these were succeeded by a cratonic time span comprising the Gardar, the Mesozoic and the Quaternary events.

It seems probable that the Ivigtut region will remain a key area for the Precambrian chronology of Greenland, and it has been considered worth-while to present and discuss a thoroughly revised stratigraphic classification of the Ivigtut rocks.

The revised chronology is summarised in fig. 5.

In this scheme distinction is made between: 1. depositional events; 2. orogenic events; and 3. cratonic events. There are few problems with classifying rocks of supracrustal origin, and the intrusive magmatic rocks of the cratonic environments. With respect to the orogenic events the relationships are more problematic. An orogenic event may have given rise to the formation of a rock body, or may be purely deformational, i.e. it may be reflected only by changes in the geometric relations in older rock units whose origins are not genetically related to the event. However, most geometrical changes caused by orogenic deformational events were at deeper crustal levels accompanied by recrystallisation or mobilisation processes: regional metamorphism, migmatisation, or anatexis. Orogenic

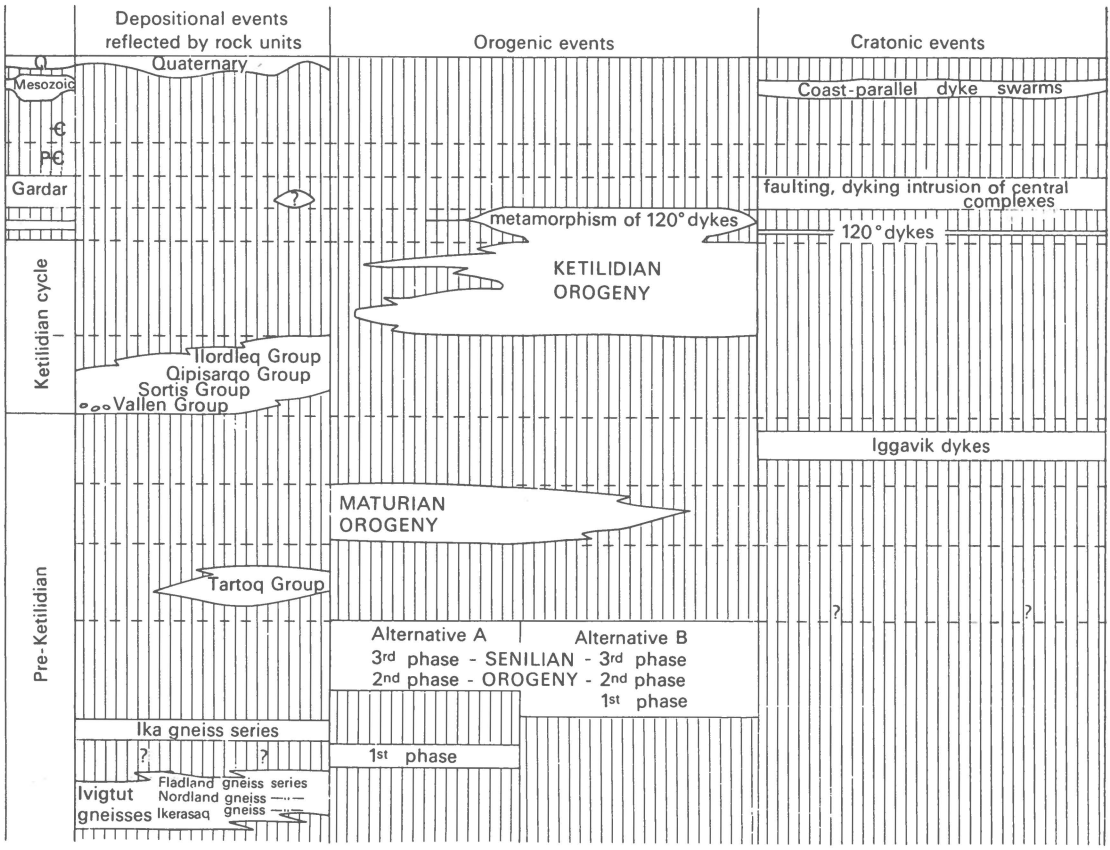


Fig. 5. Chronology of the Ivigtut region.

events therefore may possibly be inferred from traces left by such processes.

The distinction between a cratonic and an orogenic event is not always easy to make objectively. If, for example, a deformational event such as large scale wrench faulting is accompanied by metamorphism (or even anatexis), the event should be viewed in relation to preceding and succeeding events in nearby and more distant regions and classified accordingly.

The term "orogeny" is used in accordance with the definition by DENNIS (1967) as "profound deformation of rock bodies along restricted zones and within a limited time interval". Where a crustal segment or zone has acquired a common structural plan due to intense folding associated by regional metamorphism and migmatisation, the remnants of an "orogeny" or fold belt is recognised. The duration of an orogeny or orogenic interval comprises the time covered by the various (both primary

and secondary) orogenic events which have contributed to the general deformational plan of a major unit. As orogenic actions die away, the folded segment is said to become tectonically consolidated, and when it is transected by persistent basic dyke swarms, it is considered to have become part of a cratonic segment.

The recognition of the deformational plan of an orogene is most easily made where the rocks of the folded segment can be divided into young supracrustal material, and old material representing the basement to the geosynclinal formations. In these cases, the structures of the young material and the deformed basal unconformity clearly reveal the deformational plan of the belt, while in the more or less reworked old material of the basement, structural trends of different ages interfere.

This type of structural environment is encountered in most Phanerozoic fold belts, and it is from the tectonic experience gained from extensive studies of these belts that the concept of an orogenic cycle (or geotectonic era) has grown.

The cycle concept claims in a uniformitarian way that, (1) the geosynclinal evolution, (2) the orogeny, and (3) an ultimate interval (where consolidation takes place) all form one coherent cycle. The applicability of this cycle concept in Precambrian geology has been much debated during the last few decades, and the unfortunate fact that in Precambrian geology major conclusions have often been based on scant data has led to criticism of the concept.

The use of the cycle concept is restricted here to the instances where the stratigraphic record is sufficiently complete so that: (1) a safe distinction between old and young material of the orogene can be made; and (2) a coherence in geosynclinal and orogenic evolution can be demonstrated. Thus the Ketilidian cycle originally introduced by WEGMANN (1938) is retained for the time span of the Ketilidian geosynclinal evolution and the Ketilidian orogeny. However, the close of this cycle is placed somewhat earlier than WEGMANN proposed (fig. 5).

WEGMANN (1938) employed the sub-Ketilidian and the sub-Gardar unconformities to define the lower and the upper time limit of the Ketilidian cycle. Mapping in the north-east part of the Ivigtut region has, however, shown that the Ketilides here are transected by a post-orogenic basic dyke swarm (the 120° dykes) and that these dykes were slightly metamorphosed after their intrusion. These dykes and their metamorphism are chronologically placed between the Ketilidian and the Gardar events. The Gardar dolerites, which were intruded subsequent to the production of the sub-Gardar peneplain, have not been metamorphosed.

The Ketilidian rocks make up less than half of the Ivigtut region. The north-west parts of the map sheet are built up by pre-Ketilidian rocks which hardly suffered any influence of the Ketilidian deformation.

The pre-Ketilidian rocks are mainly gneisses and migmatites, and only locally (as around Târtoq and Bikuben) are rocks of distinct supracrustal origin encountered. The detailed structural mapping of the pre-Ketilidian complexes (believed at the time to be Ketilidian) has shown that profound folding, regional metamorphism and migmatisation affected these rocks; there is reason to conclude that the rocks of these complexes were moulded during at least one, and in some cases two orogenies.

HENRIKSEN (1969a) distinguished two "plutonic episodes" separated by the period of formation of the rocks of the Tartoq Group. He also suggested that a macroscopic disconformity between WNW-striking axes of the central gneisses and the N–S to NE-trending axes found in the supracrustals around Târtoq, could represent a reworked original major unconformity.

A renewed analysis has been made of the structures of these pre-Ketilidian complexes. Fortunately the Ivigtut region fulfills the requirements of detailed structural analysis: (1) good outcrops permitting detailed structural mapping; (2) marker horizons or characteristic litho-structural units of regional extension are present; (3) traces left by successive deformational episodes are separable in time, and also in space geographic borders between sufficiently large units of different "structural age" can be traced.

The structural analysis began with construction of different structural parametres from each tectonic domain and using this information as a basis for further analysis. Fold axes constructed using stereograms for a large number of tectonic "homogeneous" subareas were an important basic part of the work. In these first phases of the work only structural parametres which reflected a factual structural unit in the field were constructed. The results obtained from one tectonic domain were thereafter compared with those arrived at in others. The presence of regional marker horizons made this comparison possible on a megascopic scale and a regional structural pattern was thereby obtained and not merely a relative division into fold phases (F_1, F_2, F_3 etc.) according to fold style and attitude of axial surface.

When the structural data had been processed and their limitations were known, the next step in the structural analysis comprised the semi-experimental method, which among students has become known as the "paper and scissors method". In the authors' experience this is the best way to produce a satisfactory geometric and kinematic model to fit the data from different domains. The model was formed by working with sheets of paper (plasticene can also be used: REYNOLD & HOLMES, 1954) which were folded, refolded and cut until a result which satisfied both the large scale map pattern and the more local parametres was obtained. The model analysis was started in a number of well mapped key areas

and was thereafter gradually extended to larger and larger regions. By enlarging the size of the regions the number of models which fitted the framework of structural dates was reduced and finally the results obtained in the different parts of the map area were combined into a general model comprising the whole map sheet.

The results obtained by the "model" analysis are illustrated by construction of tectonograms, which involves transfer of the structural parametres and the map pattern into an isometric block diagram, thereafter filling out the three-dimensional model obtained to fit the constructed frame of the diagram.

It should be stressed that the mechanical principles used to produce a model which simulates Nature have no bearing to the natural mechanics, but only serves the purpose of identification of the kinematic sequence and the resulting geometric picture.

STRUCTURAL DIVISIONS

Main orogenic units

The renewed structural analysis of the Ivigtut region has confirmed the views of HENRIKSEN (1969a) that two pre-Ketilidian orogenic complexes, each of a particular "structural age" may be distinguished. An older central complex is bounded to the north-west by a younger complex (fig. 6). Both are older than Ketilidian deposition and the subsequent orogenic events. The orogeny responsible for the deformational plans of the older central complex is called the Senilian orogeny*, and that which caused the prevailing structures of the younger orogenic complex in the north-west of the region is here termed the Maturian orogeny† (BERTHELSEN, 1972). The suggested names Senilian and Maturian refer to crustal segments possessing characteristic structural plans of different relative age. Thus defined, the terms have no stratigraphic meaning. Because of this, the names have not been derived from locality names, but have been chosen in a manner that is mnemotechnically satisfactory, and which should be used only for those rock complexes for which a direct structural continuity with the respective segments of the Ivigtut map sheet can be proved.

The rocks characterising the Senilian orogenic complex are divisable into four lithostructural units comprising gneisses and migmatites, as

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* The term Senilian is derived from *senilis* (latin: having the characteristics of old age; WEBSTER, 1904).

† Maturian is derived from *maturus* (latin: of full age; WEBSTER, 1904).

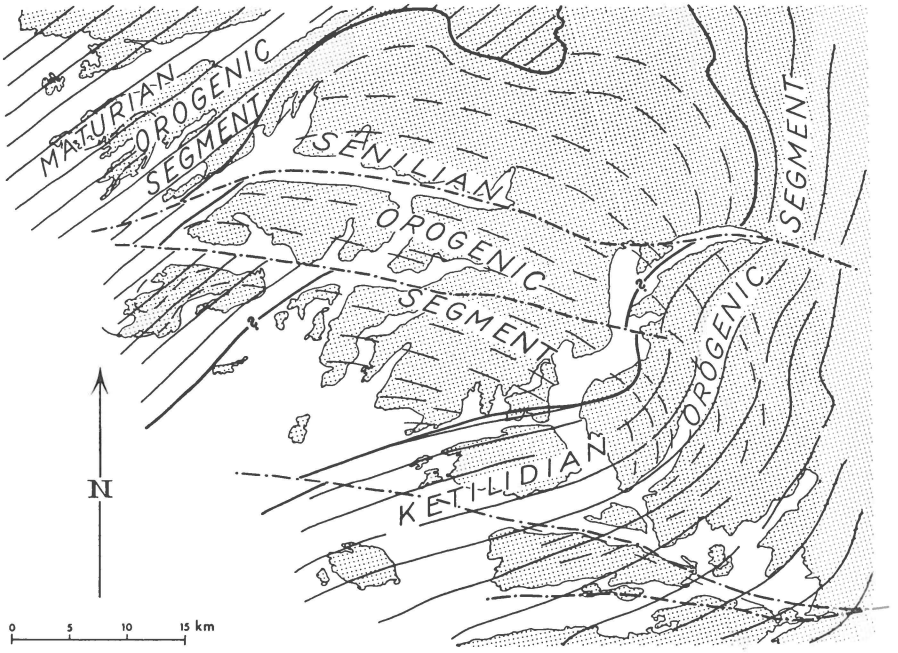


Fig. 6. Structural sketch map of the Ivigtut region showing distribution of the areas influenced by the three different orogenies. Later wrench faults have displaced the orogenic fronts.

well as "layers", "bands" and inclusions of rocks of distinct sedimentary or igneous origin. Four such units have been mapped out:

Structurally highest	The Íka gneiss series	
	The Fladland gneiss series	The Ivigtut gneisses
Structurally lowest	The Nordland gneiss series	
	The Ikerasak gneiss series	

The rocks of the Íka gneiss series have only been identified with certainty within a part of the Senilian orogene which became reworked during the Ketilidian orogeny. The three underlying series, which are grouped together as the Ivigtut gneisses, build up the intact central part of the Senilian orogene, and form also part of the Maturian and the Ketilidian deformed segments. All four units are described in detail in later sections.

Even if, as in the following, expressions such as Nordland gneisses, the Fladland unit etc. have been used, it has not been the intention that these successions should be considered as lithostratigraphic units. The units were built up bit by bit from a study of their mesoscopic structures and lithological characteristics. The units described are "lithostructural" units established for the purposes of the structural analysis; since the

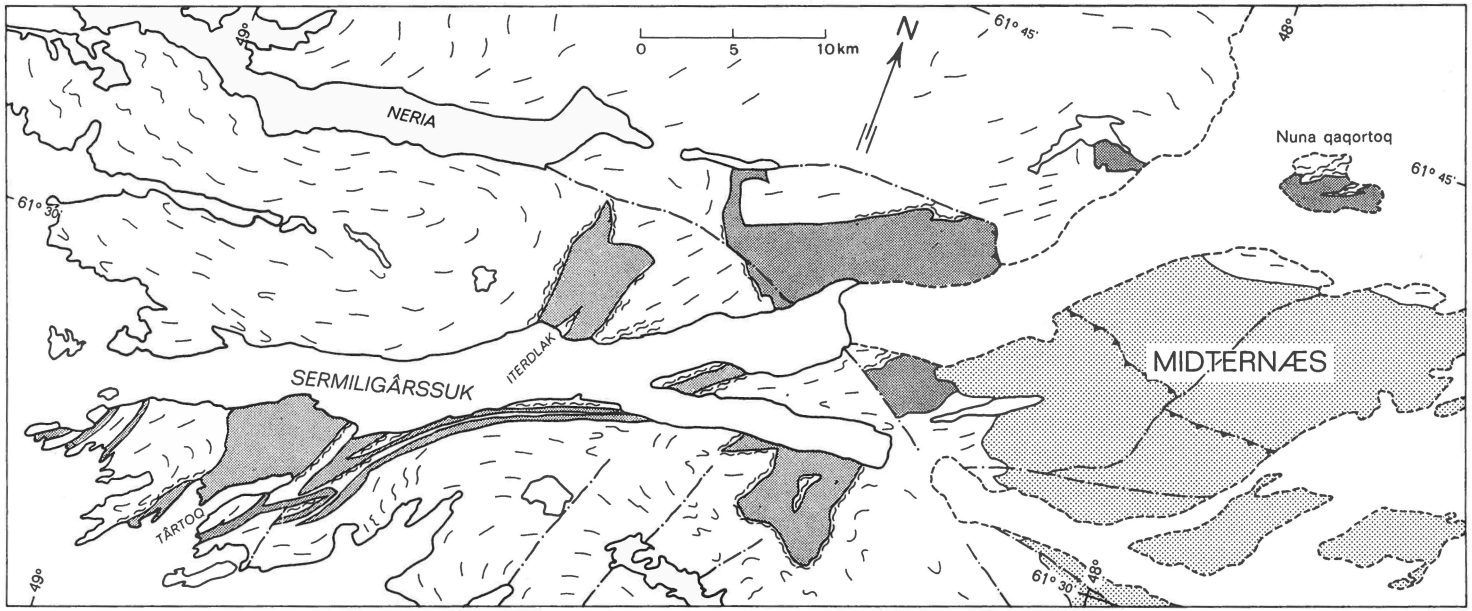


Fig. 7. The Tartoq Group areas in the Târtoq-Sermiligârssuk-Midternæs region. After HIGGINS (1968).

latter could not be carried through to the ultimate point where all structures have been resolved, the stratigraphic content and position of the units is in most cases unknown.

Senilian structures can be traced north-westwards into the Maturian segment where Maturian trends are superimposed on them; traced to the south-east the Senilian features are overprinted by the Ketilidian deformation. The intact segment of the Senilian orogene is thus limited to the north-west by a Maturian orogenic front and to the east and south-east by a Ketilidian orogenic front (fig. 6).

The Maturian orogenic segment comprises a supracrustal sequence — the Tartoq Group — which only displays Maturian structures and an infracrustal unit formerly affected by the Senilian orogeny. North-east of the map sheet (on Midternæs) Ketilidian geosynclinal rocks overlie the Maturian deformed rocks of the Tartoq Group (fig. 7) with a major unconformity (HIGGINS & BONDESEN, 1966).

Main deformation episodes

Three major phases of folding can be traced in the Ivigtut gneisses; each phase gave rise to formation of large-scale structures which influenced the map pattern. More detailed microtectonic studies could undoubtedly lead to distinction of several sub-phases, but the structural analysis presented here is based on the geometry of the large-scale structures.

The Senilian segment acquired its main deformational plan during the 2nd major phase of folding. The large structures of this phase greatly influence the map pattern and control the course of the borders between the various gneiss series. The structures formed during the 1st major phase are tight to isoclinal folds, which have amplitudes of several kilometres. These structures are outlined by local marker horizons within the three series of the Ivigtut gneisses. They have not been identified in the rocks of the Íka gneiss series, but whether this is due to lack of development, lack of observation or the erasing effect of superimposed Ketilidian deformations is not known.

The relation between the 1st phase structures and the 2nd phase structures is particularly well displayed in eastern Sermersût. As has also been shown by BONDESEN (1960) the 1st phase isoclines are heteroaxially refolded into larger recumbent 2nd phase structures (fig. 8).

As a whole, however, the 1st phase structures are of a too scattered occurrence and are too strongly refolded to be analysed in a regional context. All that can be said is that their axes appear to have trended obliquely or at right angles to those of the succeeding phase.

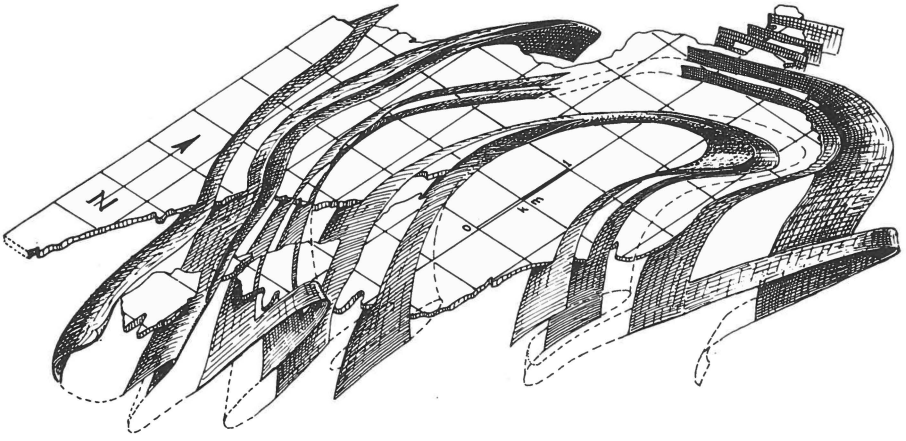


Fig. 8. First phase isoclines heteroaxially refolded by larger, recumbent second phase structures; outlined by amphibolite bands on south-east Sermersût. Redrawn from Bondesen (1960).

The 3rd major phase of folding acted homoaxially in relation to the 2nd, and probably it was also closely allied to the latter in time. The large WNW–ESE trending nappes and overfolds formed during the 2nd phase were refolded into upright or inclined folds during the 3rd phase, and the large-scale map pattern was modified accordingly.

Since the 2nd and the 3rd phases of folding were responsible for the production of the main deformational plan in the Senilian orogenic segment, both phases are "by definition" Senilian deformational episodes. The position of the 1st phase of folding in relation to the Senilian orogeny, is, however, more controversial. It may either represent an independant, pre-Senilian deformational event, or it could represent an "initial phase" of the Senilian orogeny.

If the 1st phase was an independant pre-Senilian event, it could possibly even be older than the rocks of the Íka gneiss series. Because of this uncertainty, two alternative solutions in the chronological scheme (fig. 5 alternatives A and B) have been indicated.

The separation of the Senilian and the Maturian orogenies rests on the results of the structural analysis. No certain traces have been found of basic dykes which cut Senilian structures but which are influenced by Maturian deformation. The three "dyke-shaped" belts of greenschists on Nordre Kangeq could possibly represent feeders to the volcanics of the Tartoq Group; they trend parallel to the axial surfaces of the Maturian structures and apparently they show discordant relations to (reworked) Senilian structures in the neighbouring gneisses.

The Maturian deformation (the 4th major phase of folding) caused a large-scale plastic to semi-plastic refolding of the Senilian structures and

exerted a strong influence on the rocks of the Tartoq Group. Intense shearing, slicing and thrusting took place along and around the contact between the Senilian-deformed gneisses and the overlying Târtoq rocks. The structures exhibited by the greenschists of the Tartoq Group show that at least two local phases of folding can be distinguished.

It is generally assumed that the Maturian segment attained a typical cratonic character prior to Ketilidian sedimentation. This cratonic stage is inferred from the occurrence of several swarms of basic dykes of different trends and age. The dykes cut both Senilian and Maturian structures, but intruded prior to the Ketilidian deformation. It is these dykes which formerly were called the Kuanitic dykes. However, since the "Kuanitic" was defined in a chronostratigraphic context which proved incorrect this term is best disregarded.

There remains, however, a need for a term for these basic dykes. Although it is generally believed that they were intruded before Ketilidian sedimentation began, it has also been suggested (BONDESEN, 1970, p. 183) that they, or at least the younger of them, represent the feeders to the Ketilidian volcanics. This difference in point of view makes it the more important to provide a new and neutral term for the dykes. It is therefore proposed that they be termed the Iggavik dykes after a locality at the head of Kuánit fjord, where they are well displayed.

After the intrusion of the Iggavik dykes and the formation of the Ketilidian supracrustal rocks, strong Ketilidian deformation affected the south-east half of the Ivigtut region. This deformation could be described as the 5th major phase of folding. It comprises several sub-phases, which have left their visible records in the structures of the Ketilidian supracrustals, but which cannot with any certainty be distinguished in the refolding-effect they exerted on Senilian structures in the "old material" of the Ketilides. This point is of great importance, because it suggests that the Senilian and the Maturian deformations conceivably were of the same magnitude and complexity as that of the Ketilidian.

Table 2. *Chronology of deformation (major phases)*

This paper	Berthelsen (1960)	
5th Ketilidian 4th Maturian	3rd	Ketilidian
3rd Senilian 2nd	2nd	
1st pre-Senilian?	1st	

Table 2 shows how the deformational phases of this paper correspond to the phases mentioned by BERTHELSEN (1960).

Structural analysis

It is customary in structural analysis to begin with the youngest structures and to work backwards in time, but in the present instance almost the reverse procedure was followed as the large-scale fold structures of the pre-Ketilidian gneisses no longer form a coherent pattern. Younger faults and in particular some major wrench faults have distorted the pattern. The fault blocks were displaced laterally and vertically so that different structural levels are exposed side by side at the present erosional surface.

If the pre-faulting geometry of the gneiss structures had been known in detail in all parts of the map area, the kinematics of the faulting could have been established. This was possible locally (HENRIKSEN, 1960) in the case of the Laksenæs fault (plate 8). However, in general, only the main tendency of the fault movement is known, and knowledge of the pre-faulting fold pattern is incomplete. Different reconstructions of the fault blocks produce varying outcrop fold patterns.

Analysis of the region began with the structures of the islands of Tôrnârssuk and Sermersût and around Kuánit fjord using the borders between the different gneiss series, particularly the lower and upper border of the Nordland gneiss series, as structural surfaces. Structures were then correlated across the Laksenæs fault along its course between Kuánit and the Arsuk Fjord. From this basis the regional picture was gradually built up.

The map of plate 3 shows the post-faulting distribution of the major mainly pre-Ketilidian structures. They are depicted by the trace of their axial surfaces (with pitch directions indicated), by the course of the borders between the lithostructural units, and by local trend lines. Where possible a distinction is made between the 2nd and the 3rd episodes of the Senilian structures and between Senilian and Maturian phases. The assumed extension of structures and lithostructural borders across sea-covered areas is also shown. The major Ketilidian structures can be inferred from their refolding effect on the older, Senilian structures.

The structural map (plate 3) should be compared with the coloured, geological map (plate 1) and with the interpretative map of plate 4. Plate 4 purposes to show the pre-faulting pattern of the major fold structures. The symbols used for rock units and axial surfaces in the map and profiles of plate 4 correspond to those of plate 3. Some important structures have been specifically indicated (A-D) and can be traced from the profiles in both the pre- and post-faulting maps.

In the map and profiles of plate 4, the lithostructural units have each been numbered for ease of reference. The Ikerasak gneiss series is marked as 1; the Nordland gneiss series as 2. The rocks of the gneiss areas 3, 4 and 9 belong to the Fladland gneiss series, as do probably those of areas 7 and 8. The position of the easternmost and south-eastern gneisses remains speculative.

In the area north of the Laksenæs fault, on both sides of the strait named Ikerasak, there occur two WNW–ESE trending belts of steeply dipping Nordland gneisses each a few kilometres wide. Around Tôrnârssukløb and Isaløb amphibolitic marker horizons in the gneiss area marked (9) form large recumbent folds refolding the 1st phase isoclines. This implies that recumbent folds of even larger scale may occur. Lithological similarities between the gneisses south (9) and north (4) of the double belt of Nordland gneisses, and dissimilarities between these gneisses and those (1), which separate the two (shaded) belts, point to the possibility that these two belts of Nordland gneiss represent the rooting flanks of a large nappe structure, culminating west of Kuánit and plunging ESE to SE around Arsuk Fjord. Due to this plunge, the Nordland gneisses, which outline the nappe structures, thin out on the Ivigtut peninsula and disappear at Íka.

This nappe model explains both the local attitudes of the constructed fold axes, and the regional outcrop pattern of the different gneiss units. It also offers a logical explanation of the structures found around the Maturian-deformed Tartoq belt. It appears that the western part of the nappe underwent strong Maturian refolding. A culmination was produced in the thickened "drooping nose" of the nappe (see plate 4), while at the same time a synformal depression was formed further to the north-east. In the core of this depression, the rocks of the Tartoq Group have been preserved from erosion. This situation is illustrated in the tectonogram of fig. 9. From this it can be seen how the D-antiform (2nd Senilian phase) plunges below the axis of the main synform influencing the Tartoq Group in order to reappear further west. Here it is refolded by a Maturian antiform into a large asymmetric crescentic structure.

The eastern end of the nappe structure outlined by the Nordland gneisses is modified by the 3rd phase of homoaxial (Senilian) refolding. The thickened "drooping nose" plunges beneath the level of exposure, and only the crest of an upright to reclined 3rd phase fold allows the Nordland gneiss to continue across the Ivigtut peninsula. Here, the antiformal crest is rotated clockwise as it becomes involved in Ketilidian refolding. In the entrance of Íka a tight Ketilidian antiform forces the hinge line of this 3rd phase antiform in the Nordland gneisses into an accentuated culmination. North of this Ketilidian antiform, a broad synform causes a depression in the 3rd phase antiform. The core of the broad

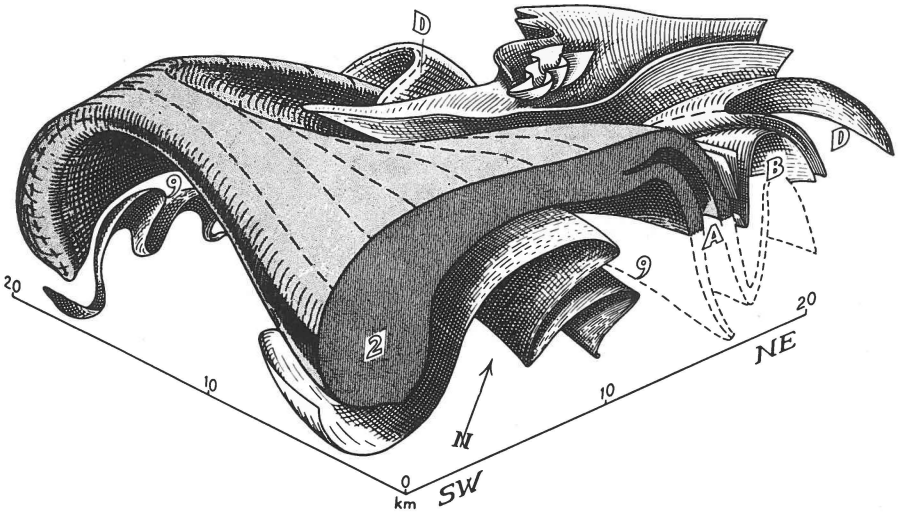


Fig. 9. Tectonogram of the north-west part of the Ivigtut region, showing the structures on Sermersût, Tôrnârssuk and around the Târtoq area. Compare with plate 4; symbols used are as on plate 4.

Ketilidian synform is made up of the Ketilidian geosynclinal formations of the Arsuk Ø area.

In this eastern part of the large nappe structure, the Iggavik dykes can be used to differentiate between the influence of the 3rd phase refolding (pre-dyke) and Ketilidian deformation (post-dyke).

The structural setting in the area around the Ivigtut peninsula is illustrated in fig. 10. From this figure it may also be seen that the Íka gneiss series occupies a large isocline (2nd major phase) which, due to refolding during the 3rd phase, winds its way around the southern tip of the Nordland gneiss exposures before it abuts on the sub-Ketilidian unconformity below the southern part of the Arsuk Ø basin (cross-ruled). The south flank of the Arsuk Ø basin is also influenced by the antiformal Ketilidian structure, which refolds the Nordland gneisses at the entrance of the fjord Íka.

Within the Ketilidian-reworked part of the pre-Ketilidian gneisses, the Senilian structures describe a broad arch which extends across the Ivigtut peninsula to Tavdlorutit. As mentioned above this is due to the formation of an open WSW-plunging Ketilidian synform, the axis of which trends from Mellemfjeldene to Taylers Havn on the Ivigtut peninsula and through the southern part of Arsuk Ø. The synform is slightly overturned to the north-west. The fact that the deformed and metamorphosed dykes of the Ivigtut peninsula show the same arcuate trend confirms the Ketilidian age of this structure.

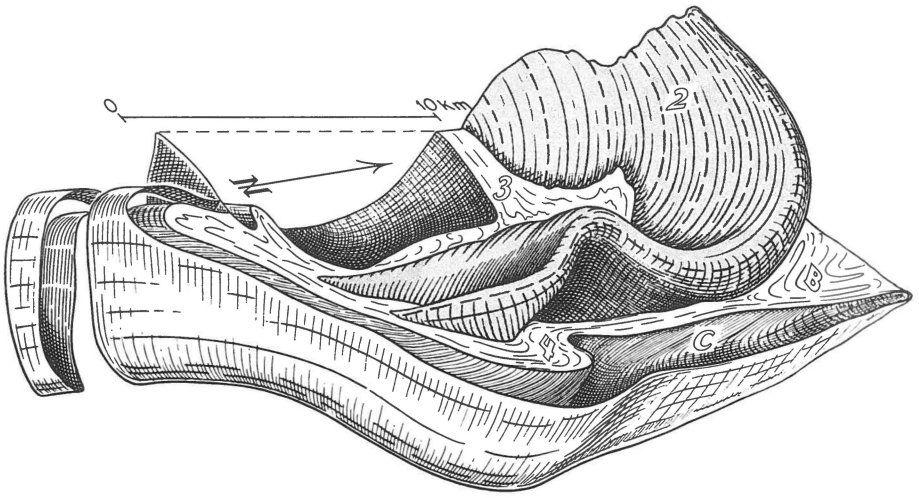


Fig. 10. Tectonogram of the central part of the Ivigtut region showing the structures east of the Arsuk Ø basin on the Ivigtut peninsula and on the western part of Tavdlorutit. Compare with plate 4; symbols used are as on plate 4.

The WSW-plunging composite antiform which involves the rocks of the Íka gneiss series in central Tavdlorutit, could at first sight be considered as a Ketilidian antiform. However, detailed studies suggest that it represents the upwards continuation of the appressed 3rd phase Senilian antiform which brought the Nordland gneisses across the Ivigtut peninsula to the entrance of the fjord Íka. The Senilian structures of the Ketilidian-reworked south-eastern part of the map area seem to have become strongly reoriented and have a general parallelism with the WSW–ENE trend of this part of the Ketilides.

IKERASAK GNEISS SERIES

The Ikerasak gneiss series represents the structurally lowermost lithostructural unit of the Senilian orogenic complex. The series occupies the core of the large nappe outlined by the Nordland gneisses and is exposed as a strip a few kilometres wide extending from north-west Tôrnârssuk, to the west coasts of Ikerasak, and from the east coast of this strait through the mainland north of Kuánit, across the head of this fjord to Christians Havn Sø.

The Ikerasak gneisses are mainly biotite-bearing banded gneisses which contain a large proportion of amphibolitic rocks in the form of layers, bands, lenses and schlieren (fig. 11). Ultramafic rocks, hornblendite, serpentinised dunite and talc rocks also form part of the unit,



Fig. 11. Ikerasak gneiss series, north-east Tôrnârssuk. Banded gneisses with amphibolites and local minor thrust plane. Photo: E. BONDESEN.

and concordant to subconcordant pegmatites vein this entity, thereby adding to its general banded to veined appearance.

The petrography of the Ikerasak rocks has been dealt with by BONDESEN (1960), HENRIKSEN (1960) and the hornblendic rocks in particular by OEN ING SOEN (1962). The main component of the unit is a quartz dioritic or locally a granodioritic biotite gneiss. In places, hornblende may form an important constituent. The plagioclase is an oligoclase, and epidote, sphene, apatite, opaque minerals and zircon form common minor or accessory constituents.

The amphibolites are mainly composed of green hornblende and oligoclase-andesine, but varying mineral contents may be found in the banded or schistose types. Diopside may be present, plagioclase may be altered to epidote minerals; biotite may replace hornblende; sphene may amount to as much as 5%; in some types quartz and/or garnet are major constituents. Apatite, tourmaline, allanite and opaque minerals are usually present as accessories.

Gradual transitions from amphibolitic rocks to hornblenditic types have been observed, but sharp contacts between ultramafics and amphibolite or gneiss also occur.

The hornblendic ultramafics may in addition to green hornblende contain diopside which may be concentrated in bands. Occasionally appreciable amounts of sulphides (pyrite-pyrrhotite-chalcopyrite-pent-

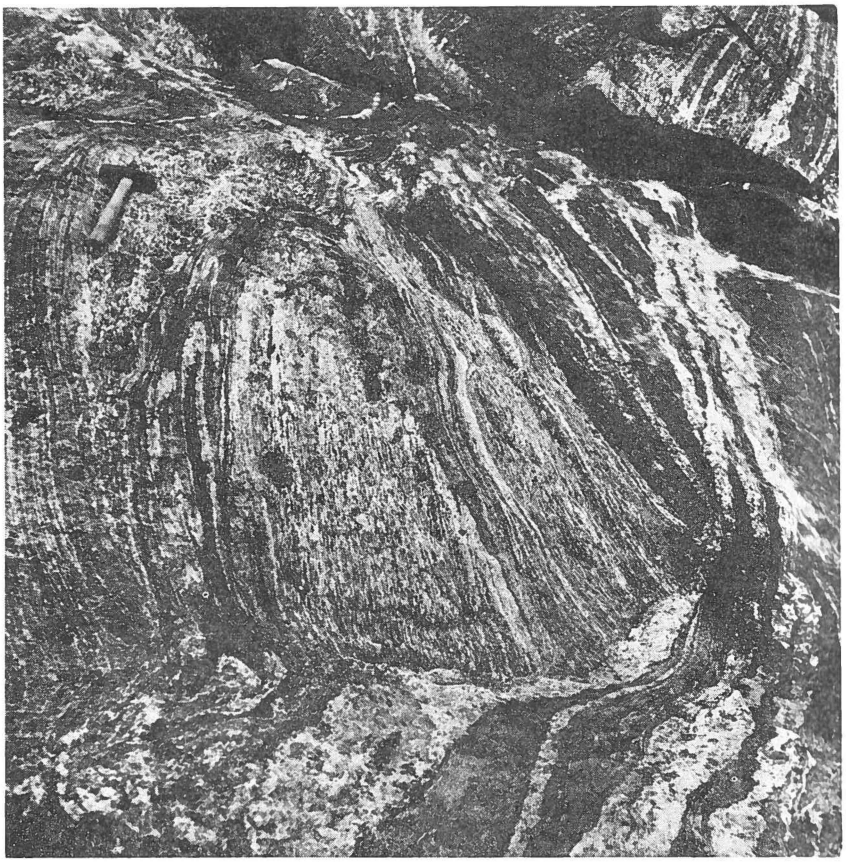


Fig. 12. Gabbro-anorthosite inclusions in banded and veined gneiss. A gabbro-anorthosite inclusion in the centre is cut by gneissic layers.

landite) and magnetite-ilmenite are found in these rocks, and weather to rust zones. However, rust zones also developed through weathering of biotite-plagioclase-quartz schists, which contain only a small content of opaque minerals.

Some ultramafic lenses consist of tremolite, tremolite-chlorite or serpentine rocks, and are often surrounded by reaction rims. North of the head of Kuánit, there occurs an ultramafic lens which has undergone less metamorphic alteration. It is composed of 85% olivine (7% Fa) besides anthophyllite, talc, opaque minerals and serpentine.

The rocks of the Ikerasak gneiss series are highly deformed. Tight to isoclinal small folds and larger structures are common; some folds have sheared-out limbs or have been cut into thrust slices (cf. OEN ING SOEN, 1962, fig. 2). The fold axes trend more or less parallel to the general strike direction and exhibit shallow to moderate plunges. A gentle culmination occurs north of the head of Kuánit fjord.

No lower limit of the Ikerasak gneiss series can be indicated.

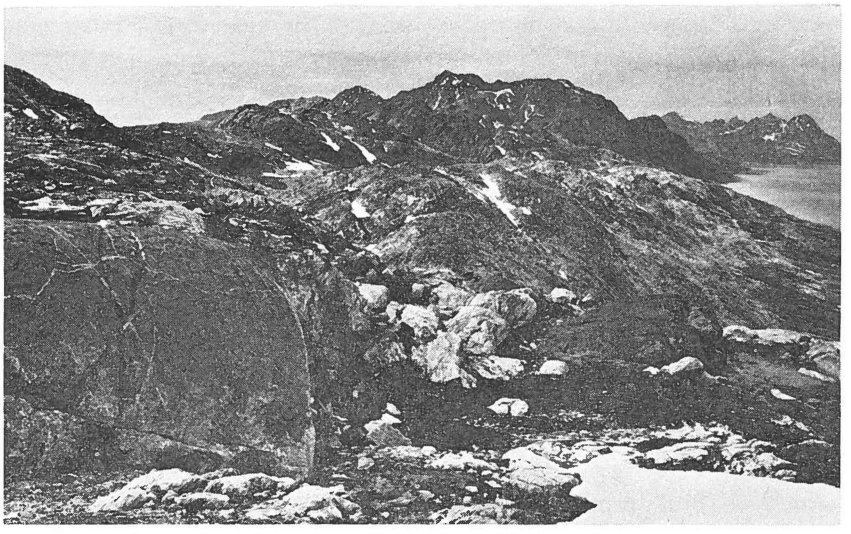


Fig. 13. Dark ultrabasic lenses in leucocratic gneisses. White pegmatite occurs between the lenses. Figure in left centre foreground is scale. South of the head of Kuánit.

NORDLAND GNEISS SERIES

In the western and central parts of the map sheet there is a specific series of gneisses characterised by the occurrence of enclaves of gabbro-anorthositic rocks (fig. 12) which have been metamorphosed together with the enclosing rocks. This gneiss series, previously described as the gabbro-anorthosite series, is here termed the Nordland gneiss series. Nordland is a broad promontory on the north coast of Arsuk Fjord, north of Ivigtut. The Nordland gneisses form extensive exposures on the island of Sermersût and Tôrnârssuk, on the mainland between these islands and Arsuk Fjord, and on the Ivigtut peninsula. The Nordland gneisses thus outline a large refolded recumbent structure, the core of which is made up of the Ikerasak gneiss series, and which is enveloped by the Fladland gneiss series (plates 3 and 4).

The gneisses of the Nordland series are mainly veined to banded or streaky, medium-grained biotite gneisses commonly cut by pegmatitic and aplitic veins and with a migmatitic appearance. In some places they contain hornblende in addition to biotite, but hornblende gneisses without biotite are rare. The composition is mostly granodioritic, but both quartz-dioritic and adamellitic varieties also occur. On Tôrnârssuk and Sermersût they have a more granitic composition. The plagioclase (mostly oligoclase) is usually sericitised or saussuritised. Quartz in general makes up between 10 and 30%, but may amount to 50% in some types. The mafic minerals rarely exceed 10–15%. Epidote is often present in small

quantities. Muscovite is common in the granitic varieties of the western island. Apatite, sphene, opaque minerals and zircon form accessories.

Amphibolite schlieren and bands are encountered in discontinuous zones. Lenses or enclaves of ultramafic rocks, from a few to 15 m in length, occur scattered in the gneiss, sometimes being confined to certain lithological horizons (fig. 13). The ultramafics comprise serpentine, talc and hornblende. Biotite is often found in reaction rims.

The Nordland gneiss series is characterised and distinguished from other gneisses by its content of abundant gabbro-anorthositic enclaves. These inclusions consist mainly of calcic plagioclase and hornblende, and occasionally biotite. On average, the mafics make up between 20 and 30%. In addition to hornblende and biotite, diopside and phlogopite may occur. Quartz makes up only 1–3%, and epidote, calcite and chlorite are often found in minor quantities. Apatite and sphene are accessories. Plagioclase, the dominant mineral constituent, shows great variation in its An-content, reflecting the complex metamorphic evolution of these rocks. The plagioclase of the pre-metamorphic gabbro-anorthosites apparently had an An-content of at least 50 to 75%.

Although most gabbro-anorthosites are now medium-grained equigranular rocks due to recrystallisation, their structure often indicates that originally they were more coarse-grained. In the enclaves, flaser-structure and banded types are often found. The banded rocks may be composed of alternating bands of pure anorthosite and ultramafic rocks. In the flaser-structure rocks, elongated lenses of feldspar about 1 cm thick are surrounded and separated by mafic minerals. Enclaves consisting solely of anorthosite or of ultramafic rocks (hornblendite) also occur.

Relying on the estimated average composition, the collective term gabbro-anorthosite is used for these enclave rocks, although it would be more correct, but less convenient, to speak of metamorphosed, strongly differentiated, anorthositic gabbro.

The gabbro-anorthosite enclaves often have a boudin shape occurring as trains or trails of elongate inclusions arranged parallel to the foliation of the surrounding gneiss. Bands of gabbro-anorthosite showing incipient necking have also been found, and a few examples of bands with minor folds have been reported. Most bands, boudins and lenses of gabbro-anorthosite are between 20 cm and 2 m thick. Where boudinage structures are developed, the gneiss often has flowed into the space between the blocks and scar folds are developed. Pegmatitic and leucocratic material also commonly separates boudins. In some cases boudins appear to have been rotated (fig. 14).

The gabbro-anorthositic rocks were initially considered to have a metamorphic-metasomatic origin (BONDAM, 1955; BERTHELSEN, 1956), and were believed to represent metamorphosed marly sediments. How-

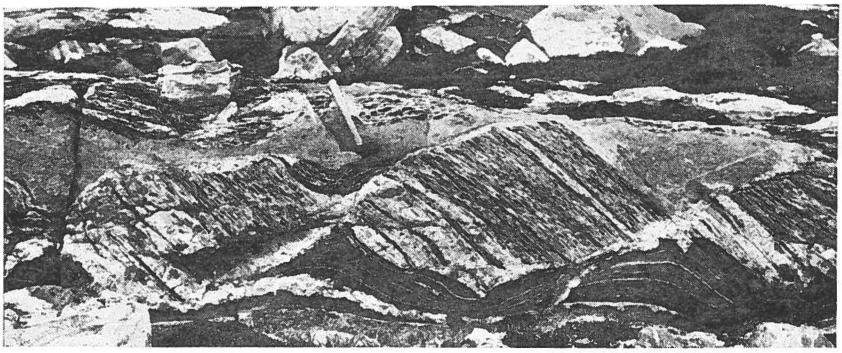


Fig. 14. Boudinaged and "rotated" gabbro-anorthosite inclusions in gneiss with amphibolite bands. This structure could be caused by strong flattening in a direction oblique to the original attitude of the gabbro-anorthosite "sheet". The Nordland gneiss series. Tømmerbugt, north-west Sermersût. Photo: E. BONDESEN.

ever, this point of view is no longer upheld, because an intrusive layered anorthosite complex with bands of chromite and basic layers has been found in the region around Fiskenæsset approximately 250 km north of Ivigtut (WINDLEY, 1969a, b; GHISLER & WINDLEY, 1967). Rocks in this complex are very similar to those found as enclaves in the Nordland gneiss series and they are therefore believed to be of a common magmatic origin. The banding in the gabbro-anorthosites of the Ivigtut region could therefore well be a relic magmatic banding, and the flaser-structure types may represent sheared megacryst bearing anorthosites.

In the Nordland gneiss series, the quantity of gabbro-anorthositic enclaves varies considerably. In the enclave-rich zones, which are up to a few hundred metres wide, the gabbro-anorthosite form more than 10% of the bulk. Outside these zones, their quantity may decrease to almost zero.

In the hinges of larger folds in the gabbro-anorthosite bearing gneisses, very complicated structures are found (figs 15, 16). The gneiss banding sweeps around the rotated enclaves, and the number of inclusions is often much greater than on the limbs of the folds. Such structures are well seen in the eastern part of the Ivigtut peninsula (plate 2).

In the gneisses of the Nordland gneiss series, there occur scattered patches or bodies of more homogeneous adamellitic rocks, which may show both transitional and cross-cutting contacts. These bodies measure from a few to more than a hundred metres across.

The border between the Nordland gneisses and the gneisses of the two adjacent gneiss series is mostly gradational and only mappable as an arbitrary line drawn between areas with and without gabbro-anorthositic enclaves. However, mapped according to this criterion, the border does appear to be conformable to the mesoscopic banding of the gneisses.

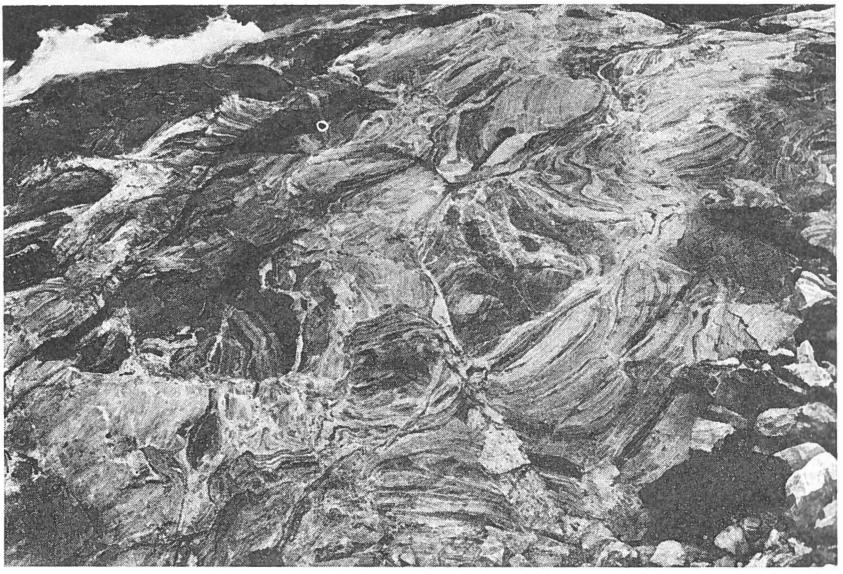


Fig. 15. Highly mobile, minor folding in banded biotite gneiss with gabbro-anorthosite enclaves. South of head of Kuánit.

Where the internal structures of the Nordland gneisses have been mapped in detail (plate 2) the enclave-rich zones also show a conformable relation to the gneiss banding.

FLADLAND GNEISS SERIES

According to the proposed structural model the rocks of the Fladland gneiss series overlie the Nordland gneiss unit and form the envelope to the large recumbent structure outlined by the enclave-bearing Nordland unit (plate 4).

The Fladland gneiss series is overlain by the Íka gneiss series occurring in the major isocline stretching from Lakseelv, south of Arsuk Fjord, across the head of Íka to central Tavdlorutit. Because this isocline lies within the part of the Senilian segment reworked during Ketilidian orogeny, nothing definite can be stated about the border-relations between the Fladland and the Íka gneisses; there may or may not have been an original unconformable relationship. It is difficult therefore to define an upper border for the Fladland gneiss series in the northern regions of the map area. The gneisses from the northern areas, therefore, will partly be described as structural and partly as lithological units.

As mentioned earlier lithological similarities exist between the gneisses south-west and north-east of the two rooting belts of Nordland gneiss



Fig. 16. Fold interference patterns in banded hornblende-biotite gneiss of the Nordland gneiss series. Nordland, east of Christians Havn.

running across Ikerasak and Kuánit. The following description of the gneisses in these two areas, below and above the nappe, indicates these similarities.

The Isaløb area

This area comprises southern Tôrnârssuk, southern and eastern Sermersût, the small group of islands around Nunánguit-Isa, Arfarfik and outer Kuánit. The Fladland gneisses of this western area occur below the Nordland gneiss nappe. As may be seen from plate 4 and fig. 9, they form part of a combined broad culmination (to the south-west) and an overturned depression (to the north-east), imposed on the nappe by Maturian deformation. This large scale refolding generally does not seem to be reflected on a minor scale in the gneisses, but it appears to have been accompanied by metamorphism corresponding to transitional greenschist-amphibolite facies.



Fig. 17. Wavy, veined, biotite gneiss with garnet-bearing pegmatites. Coast of Sermersût qagssia, Sermersût. Photo: E. BONDESEN.

On Tôrnârssuk a narrow zone with enclaves of gabbro-anorthosite occurs within the Fladland gneisses about a kilometre south of the main border to the Nordland gneisses. It is not known whether this enclave-bearing zone represents the relics of a former separate intrusion of gabbro-anorthosite, or whether it is a digitation on the lower flank of the nappe. In antiform B which affects the Fladland gneisses north of Puiátoq and on Langenæs gabbro-anorthositic enclaves also occur in narrow zones in the gneisses, but here structures of the 1st phase is a further complication.

Apart from this local zone with gabbro-anorthosite enclaves, the Fladland gneisses of this western area form a well-defined lithological unit, consisting mainly of quartz dioritic and granodioritic, light-coloured, biotite and garnet-biotite gneisses. Typical of the series are layers of banded amphibolite with ultramafic bands, or with thin intercalations of mica schists. Both the amphibolites and the mica schists are often garnetiferous. Pegmatite veins are common.



Fig. 18. Biotite gneiss with inclusions of dark, homogeneous biotite gneiss. Coast of Sermersût qagssia, Sermersût. Photo: E. BONDESEN.

Gneisses

The gneisses are often banded, but may pass into streaky, wavy veined (fig. 17) and nebulitic types. In some parts of the area, e.g. on central Sermersût, there is a gneiss variety with a characteristic internal structure; abundant inclusions of medium-grained biotite and hornblende gneiss are enclosed in a matrix of finer-grained biotite gneiss (fig. 18). This variety represents strongly mobilised wavy gneisses. Pegmatite veins may occur along planes of flexure.

In addition to biotite and garnet (often altered to biotite), the gneisses comprise oligoclase (recrystallised along grain boundaries), quartz and varying amounts of microcline. Muscovite is found in microcline-rich types. Epidote minerals are common constituents, and hornblende occurs locally; most amphibole has, however, been altered to biotite. Opaque minerals, apatite and sphene are common accessories, while allanite and zircon are more scarce. It may be noted that the allanite

occurrences of the Ivigtut region all appear to be located in gneisses of the Fladland series. Even when the allanite occurs in cross-cutting pegmatites, the rare-earth elements of this mineral may have been derived from the surrounding gneisses. Allanite-bearing pegmatites are for example common on the island Isa.

Amphibolites, ultramafics and schists

The rocks indicated on the map as amphibolite may range from mesocratic biotite-hornblende gneisses to hornblenditic types, but usually the bulk composition of the banded layers is amphibolitic. The plagioclase is an oligoclase-andesine, often strongly saussuritised and recrystallised along the grain boundaries. Epidote and garnet are often found in the amphibolite bands, and sphene, opaques and apatite are common accessories. Calcite may also occur.

A number of talc-chlorite lenses have been reported in contact with some of the amphibolites found on south-east Tôrnârssuk and south-west Sermersût. Similar rocks occur in the Ikerasak gneiss series. Some of the amphibolite layers on Isa and in the mainland further east contain mica schist bands in which oligoclase, quartz, muscovite, biotite and sometimes chlorite are the main constituents. In a few samples of these schists, porphyroblastic garnet and staurolite occur.

Pegmatites

The Fladland gneisses of the western area contain abundant pegmatites belonging to at least two generations. The older of these comprises more or less concordant, vein-like, biotite pegmatites. Where pegmatites are developed in more competent units, such as the amphibolite layers, they tend to be more discordant. The younger pegmatites are broad, coarse-grained biotite pegmatites, usually of clearly cross-cutting character. It is these younger pegmatites which may contain appreciable concentrations of allanite. After their common occurrence on the island Isa, they are referred to as the Isa pegmatites.

Metamorphic development

The Fladland gneisses of the western area appear first to have been metamorphosed under amphibolite facies conditions and subsequently to have suffered from a partial adjustment greenschist-amphibolite transition facies or low amphibolite facies.

Sermersût breccia

On the point east of Sermersût qagssia there occur a few small intrusive breccias of highly irregular shape (BONDESEN, 1964). The in-

clusions of the breccia are partly "exotic" ultramafics, and partly gabbro-anorthosite blocks and fragments of different gneiss types, amphibolite and vein rocks. The matrix consists of mineral fragments of mineral grains derived from the wall rocks, i.e. migmatitic, pegmatite-veined gneisses with amphibolite layers and bands. The ultramafic inclusions may measure more than 10 m across, and consist mainly of talc-soapstone. BONDESEN (1964) suggests that the breccias intruded by means of gas-drilling and that their formation was related to emplacement of ultramafics, which also formed more "normal" plug-like intrusions in the surrounding region (e.g. at Qârusuk, on the south coast of Tôrnârssuk).

BONDESEN (1964) places the time of formation of the breccia at a stage of consolidation between an older period characterised by plastic folding, migmatisation and amphibolite facies metamorphism, and a younger period of large scale deformation under epidote amphibolite facies metamorphism. He relates the formation of the flexures in the wavy gneisses to the later phase of deformation. Rectilinear younger pegmatites cut the (slightly deformed and partly recrystallised) breccia, and these pegmatites are in turn cut by the Iggavik dykes (termed Kuanitic dykes by BONDESEN). BONDESEN also mentions (p. 31) the possibility that the ultramafic rocks which are associated with the breccia could represent geosynclinal serpentinites (in the sense of HESS) intruded into a gneissic basement. While this may be the case, the possibility hinted at by BONDESEN that the ultramafics might represent early Ketilidian geosynclinal serpentinites can be excluded with our present knowledge of the Ivigtut region. It is probable that they represent post-Senilian but pre-Maturian serpentinites perhaps correlatable with the ultramafic bodies found in the Tartoq Group and with plugs in the pre-Tartoq Group gneisses in the northern part of the map area (e.g. north of Kangârssuk).

The younger pegmatites (the Isa pegmatites) which cut the breccia and the rocks of the Fladland gneisses consequently could be given a late to post-Maturian age. According to BONDESEN (1964) they are often developed in fissures with minor faulting.

The Fladland area

This comprises the area around Fladland and the adjacent country south of the Puiátoq fault.

Lithology

Fladland, after which the entire gneiss series is named, is a gently sloping area on the west coast of Arsuk Fjord. Here, and in the adjacent country, the rocks of the Fladland gneiss series are developed as leu-

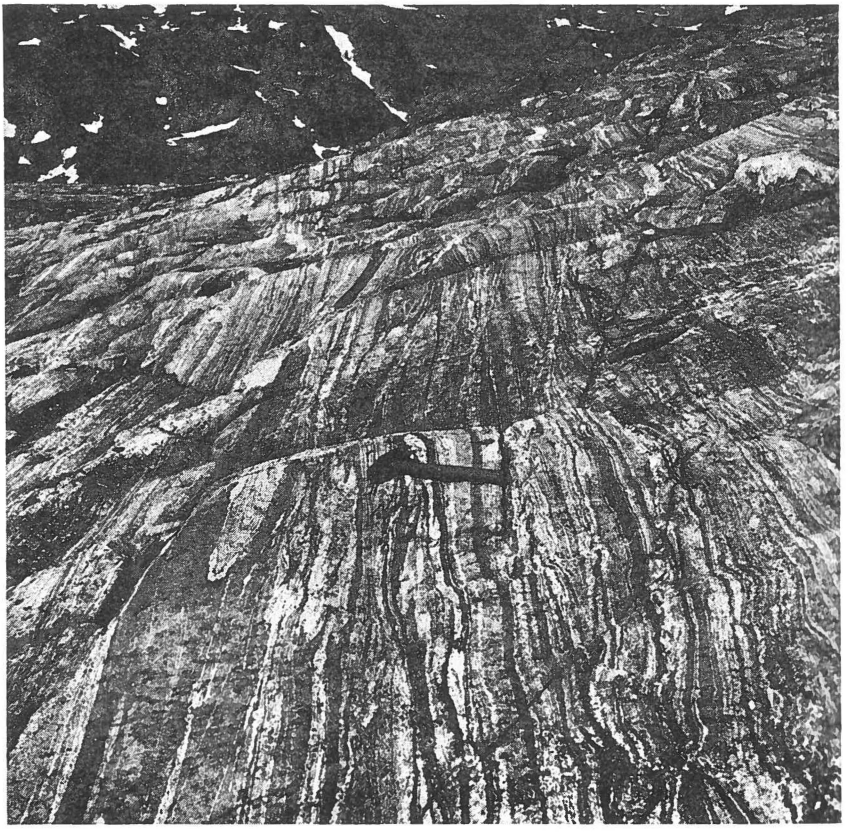


Fig. 19. Banded garnet-biotite gneiss. Fladland, north of Arsuk Fjord.

cocratic, banded, "pinch-and-swell" biotite and garnet-biotite gneisses (fig. 19); they often contain mica-rich bands and streaks, which weather with rusty colours. The mica-rich gneisses contain conformable pegmatite veins which accentuate the banded appearance. These veins often contain scattered garnets. The following description is based mainly on HENRIKSEN (1961).

In the southern part of the area, mica-rich garnet-bearing bands (up to 5 cm broad) are particularly abundant, while further north biotite and garnet appear more evenly distributed in the gneisses.

Although granodioritic types are rather common, most gneisses of this north-eastern area are of quartz dioritic composition. They comprise oligoclase-andesine, quartz, biotite, some garnet, late epidote, chlorite and sericite, as well as accessory amounts of opaque minerals, apatite and zircon. South of Puiátoq, small areas of more homogeneous, leucocratic, muscovite-bearing adamellitic rocks are found.

Amphibolitic material is found in certain zones and may form up to 40 m wide bands, one of which has been traced for 10 km. In the amphibolite layers, one or sometimes two distinct bands of garnet-mica schist, with numerous "pinch-and-swell" veins, may occur. Near the lake 415 m, south-east of the head of Puiátoq, amphibolitic zones and bands are widespread and rusty weathering bands of garnet-mica schists are common.

Oen Ing Soen (1962) has described the petrography of these rocks in detail. He interpreted the garnet-mica schist bands as heavily sheared and pegmatised original hornblendic rocks while the authors consider it more probable that they were formed from pelitic sediments.

The amphibolites comprise andesine, hornblende and a little biotite and quartz; garnet may be present, and apatite, sphene and opaques are common accessories.

The mica schists often contain appreciable amounts of andesine, biotite and garnet; the garnet forms porphyroblasts whose growth post-dates the schistosity outlined by biotite. Sillimanite, staurolite and anthophyllitic-cummingtonite have also been reported from the mica schists.

Slightly discordant pegmatitic veins up to 10 m thick occur in the amphibolite-schist layers. They may contain appreciable amounts of allanite, apart from the ubiquitous biotite. Outside the amphibolite-schist layers the thickness of the pegmatites is only about 2–3 m, and they only occasionally contain allanite. Their chronological position corresponds to the Isa pegmatites in the western area of the Fladland gneisses.

Metamorphism

The gneisses of this north-eastern area have recrystallised under amphibolite facies conditions. Petrographic studies suggest they have undergone metamorphism of this grade on at least two occasions, prior and subsequent to emplacement of the Iggavik dykes; the second amphibolite facies metamorphism was of Ketilidian age.

The pre-Iggavik dyke metamorphism is most likely to be of a Senilian age, the Maturian orogenic front being 30 km further north, and reaching only lowermost amphibolite facies within the limits of the map sheet. Further details are considered in the chapter on regional metamorphism.

South-east of the Ketilidian orogenic front, which runs approximately through the NE–SW trending part of Arsuk Fjord, Ketilidian amphibolite facies metamorphism and kinetic transformations were very extensive, and it is unlikely that traces of earlier metamorphic imprints

can be traced except very locally, even though the banding and the foliation of the infracrustal gneisses still conform to the 3rd phase Senilian fold axes.

GNEISSES NORTH OF THE PUIÁTOQ FAULT

Structural setting

In Fladland and the adjacent country to the north, steep dips predominate. However, just north of Puiátoq, typical garnet-biotite gneisses of the Fladland series show almost horizontal attitudes in the core of an open synform. To the north, this synform is followed by a broad and composite antiform (antiform B: see profiles of plate 4). WEIDMANN (1964, p. 113) describes this antiform as "une large voûte anticlinale dont le flanc S est plus redressé que le flanc N; de nombreux replis situés dans le plan axial de cette structure et souvent déversés vers le N ont replissé les plis NS dus à la première phase tectonique . . . et compliquent l'allure générale; le plongement axial est variable, si bien que ce grand anticlinal dessine localement des dômes ou des "cuvettes" de formes douces".

The antiform B is displaced 2 km sinistrally by the Puiátoq fault, and south of Ellerslie Havn it plunges towards the south-east (plate 3).

To the east, the antiform B is succeeded by synform C, which is well-developed south of Fox Havn, and which north of the large wrench fault stretches—with horizontal axis—across the south tip of the Pyramidefjeld granite.

The antiform B can be traced westwards to the peninsula Akuliaruserssuaq where it attains a westerly plunge. Synform C accompanies it to Gaffelsø. Further to the west, it is cut out due to the overthrusting of antiform D, which west of Akuliaruserssuaq structurally overlies the antiform B (cf. maps in AYRTON, 1963).

On Akuliarusínguaq, the antiform D plunges almost due west below the chloritic agmatites and thrust slices along the south-eastern border of the main Maturian synformal structure occupied by the Tartoq Group supracrustals.

Banded gneisses

The B and D structures as well as the intervening synform C have all been mapped out in leucocratic banded gneisses, which commonly contain concordant to semi-concordant pegmatitic veins often showing "pinch-and-swell" structure (AYRTON, 1963, p. 31; WEIDMANN, 1964, p. 28). AYRTON noted that the more discordant pegmatitic veins exhibited

ptygmatic structures. The gneisses are mainly of quartz dioritic composition. Plagioclase (5–30 % An) is the dominant mineral (> 50 %), quartz is abundant, and biotite is present in appreciable amounts in some bands. Muscovite, epidote and garnet may occur, while apatite, sphene, opaques, tourmaline and zircon may be present as accessories; chlorite and carbonate are present as secondary minerals. Hornblende may occur in some bands, and amphibolic layers may be interbedded in the gneiss.

North of Arsuk Fjord, around Store Fox Sø, the banded gneisses are rich in amphibolitic material in a zone corresponding to the common flank between synform C and antiform D. The amphibolite zone, which may be traced for several kilometres along the strike, comprises hornblende, andesine-labradorite as well as some biotite.

Amphibolite-banded gneisses also occur between antiform B and synform C south of Gaffelsø. Here, lenses or thin impersistent bands of gabbro-anorthositic rocks also occur, probably reflecting older isoclinal folding (1st episode deformation).

Homogeneous gneisses

Nebulitic to homogeneous gneisses make up two large regions. One is situated between Dubletsø and Stabelland, and the second north of Gaffelsø and Svampesø. In the eastern region the gneisses are leucocratic to pink, often granodioritic, with oligoclase and perthitic microcline, quartz (*c.* 30 %), as well as biotite, muscovite and chlorite. Structurally they occupy the core of antiform D. In the Dubletsø-Stabelland region the gneisses contain less microcline, and muscovite is the dominant mica.

West of the high terrain of Stabelland, the homogeneous gneisses are thrust over the migmatitic gneisses surrounding the Tartoq Group rocks of the Bikuben area. The thrust is developed as a 20–100 m thick zone where penetrative movements were concentrated. Weidmann (1964, p. 120) indicates a dip of 10–30° for the thrust and a maximum thrust displacement of about 2000 m. The thrust was formed after the migmatisation of the Tartoq Group rocks nearby and before intrusion of the Iggavik dykes; i.e. it may be considered a late Maturian structure.

In the Dubletsø-Stabelland region, the development of the homogeneous gneisses is not bound to a particular structural level or structure. Locally the mobilisation has been very intense and led to the development of small pegmatite-veined granodioritic bodies up to a few hundred square metres in area.

Ultramafics and amphibolites

Isolated ultramafic lenses and plug-like bodies are scattered throughout the gneiss area north of the Puiátoq fault. They range in composition

from impure serpentinites to impure soapstones, often with a high percentage of carbonates and chlorite. Along the borders reaction zones with biotitic rims and tremolitic mantles are developed. Relics of olivine are occasionally found in the central parts of the bodies, which in places are cut by pegmatites. As mentioned earlier, these ultramafics may belong to a suite of post-Senilian serpentinites which embrace also the ultramafics of the Tartoq Group.

Structurally overlying the plunging nose of the antiform D and structurally underlying the rocks making up the Maturian thrust slices, a series of banded and agmatitic gneisses occur on the island Tingmik and the mainland north-east of this island (BONDESEN, 1958). The amphibolitic bands contain scattered ultrabasic lenses which may be 20 to 40 m long and which consist mainly of serpentine and talc. In between the amphibolite bands, zones with strips of mica schists occur. Further north, agmatitic to more homogeneous gneisses are found.

The amphibolitic gneisses are unlike any of the banded gneisses described from the regions further east, and north of the Puiátoq fault. Structurally, they overlie those of the antiform B of Akuliaruserssuaq, and since these latter probably belong to the Fladland gneiss series, the amphibolitic gneisses might be referred to the Íka gneiss series? However, if emplacement of the amphibolites and the ultramafics was related to the extrusion of the Tartoq Group volcanics, their host rocks, mica schists and banded gneisses, could well be described as Fladland gneisses. Dyke-like zones of basic rocks also occur in the gneisses of Nordre Kangeq, west of the major Maturian synform of Târtoq.

GNEISSES SOUTH OF ARSUK FJORD

As may be seen from the structural map of plate 3, antiform B, synform C and antiform D are all developed south of Arsuk Fjord. Careful mapping of the fault pattern in and around the Grønnedal-Íka complex (EMELEUS, 1964) has made it possible to reconstruct the fold pattern of the gneisses of the surrounding region.

Gneisses in the Langenæs–Niaqornârssuk zone

West and north of synform C occurs a zone of gneisses traceable from Langenæs at Arsuk Fjord in the north to Niaqornârssuk on Tavdlorutit in the south. North-east of the broad belt of Nordland gneisses across the Ivigtut peninsula, rocks of the Fladland gneiss unit occur. On Langenæs, the antiform B shows a SSE plunge and a level with enclaves of gabbro-anorthosite occurs on both limbs. Between Laksepynt and

Grønnedal, the Nordland gneisses are involved in a minor antiformal structure, which locally causes them to overlie the Fladland gneisses. Further south, north of Snævringen in Íka, typical garnet-biotite gneisses with veins showing "pinch-and-swell" structure are in steep contact with the western Nordland gneiss. East and south of Snævringen, Ketilidian refolding has caused an S-shaped loop in the strike.

According to the interpretation shown in plate 3, rocks of the Fladland gneiss series occur on the south shore of the fjord Íka. In this region, the amphibolite enclaves marked in the gneiss also include Ketilidian reworked Iggavik dykes (discordant amphibolites). The Fladland gneisses of the south coast of Íka are thought to be in structural continuation with those of the western Ivigtut peninsula. The closure at Niaqornârssuk, a point on northern Tavdlorutit, marks the south-east extension of the connecting gneisses.

The gneisses of the western Ivigtut peninsula do not, however, show particularly great similarities with those of Fladland. They are mainly quartz dioritic biotite and biotite-hornblende gneisses of banded to veined appearance. Amphibolite-rich banded horizons occur, but they are not extensively developed. Small, more or less agmatitic lenses and bodies of hornblendite have been found at a few localities. In the southern part of the peninsula veins and dykes as well as larger irregular masses of Ketilidian granodiorite intersect both gneisses and the discordant amphibolite dykes (Iggavik dykes). In the gneiss, the dykes are semi-concordant, and may show shearing.

The Íka gneiss series in the Lakseelv–Blæseren zone

South of Arsuk Fjord, the SSE plunging synform C causes the Íka gneiss series to outcrop in the mountains north and south of Lakseelv, and between Langesø and Ikasletten. Here, where the Ketilidian kinetic and metamorphic transformations have less effect than further south, the Íka gneiss unit is developed as a succession of schistose and porphyroblastic gneisses with abundant intercalations of amphibolite, greenschists, mica schists, and even quartzite containing bands or lenticles of marble and calc-silicate rocks. South of Langesø, at the border between mica schists and a 60 m wide quartzite layer, a few metres of dark pyritic schists occur.

In the closure north of Langesø, the gneisses and interbanded schists are intensely folded in tight accordian style folds. The axis plunges southwards at low angles.

The supracrustal rocks east of the Grønnedal-Íka complex were first described by Bondam (1954) as Ketilidian metasediments and metavolcanics. While reminiscent in some respects of the Ketilidian rocks occur-

ring at Taylers Havn, their pre-Ketilidian age has now been demonstrated. However, the Íka series supracrustals do contrast with the gneisses of the underlying units, and the possibility that they were originally unconformable to older units of the Ivigtut gneisses should not be overlooked.

South of the fjord Íka the supracrustals of the synform C apparently occur in a more gneissified state. Leucocratic biotite and garnet-biotite gneisses here contain occasional lenses of amphibolite, quartzite, rusty mica schists and diopside-rimmed marble lenses. Supracrustal relics became less common as the isoclinal synform is traced through its arching course to Blæseren. Diopside lenses, which may have marble cores, occur in light grey biotite gneisses forming part of the fold closure in central Tavdlorutit. A mappable zone of porphyroblastic gneisses forms part of this association.

The amphibolites of the Íka gneiss series comprise hornblende and actinolitic hornblende, oligoclase-andesine (often zoned) and biotite as their main minerals. Quartz and epidote are generally present in addition to accessory opaque minerals, sphene, apatite and calcite.

The mica schists and dark schists often contain garnet porphyroblasts in a matrix of oligoclase, quartz, biotite, sometimes muscovite, and often sillimanite. Sphene, apatite, calcite and a riebeckitic amphibole are present in small amounts.

The diopside lenses consist of granular diopside with additional hornblende, microcline and plagioclase. The plagioclase grains show recrystallised rims. Accessory minerals are muscovite, quartz, opaque minerals and epidote. The granular calcareous rocks, forming the core of some lenticles, are dolomitic.

The gneisses in which the supracrustal relics are found are mostly granodioritic biotite gneisses. Adamellitic types contain up to 1 cm large microcline porphyroblasts. In some of these rocks it can be seen that the plagioclase grains were broken or bent before microcline was introduced. Albite rims on plagioclase and myrmekite may also be developed.

Taken as a whole, the rocks of the Íka gneiss series south of Íka bear witness to medium- to high-grade amphibolite facies metamorphism and mobilisation of "granitising agencies". Apparently, the cataclasis recorded in many textures affected rocks which had already been exposed to a Ketilidian metamorphism, and the influx of the mobilisate, the feldspar-blastesis, and partial healing of the cataclastic textures may belong to a late stage of Ketilidian thermal activity.

Gneisses in the inner Arsuk Fjord-Qôrnoq zone

The synform C occupied by the rocks of the Íka gneiss series is to the east bordered by a belt of veined to streaky, locally banded, biotite

gneisses. On the south coast of the Arsuk Fjord, the rocks of this belt underly synform C, and are in structural continuity with the Fladland gneisses of the antiform B on Langenæs. The steeply W-dipping gneisses of this belt are succeeded to the east by the rocks of the broad northerly plunging antiform D, which here is called the Laksefjeld antiform. This antiform is cut into several segments by later faults and in its eastern flank a large Ketilidian granite, the "Tvillingsøer granite", was formed (see p. 87). The gneisses of the Laksefjeld antiform are similar to the banded, streaky and homogeneous gneisses found north of inner Arsuk Fjord. They are mainly quartz dioritic to granodioritic, fine- to medium-grained gneisses with oligoclase, microcline, quartz and biotite. Muscovite sometimes accompanies biotite. Opaque minerals, sphene, epidote, apatite, cordierite, zircon and allanite have been found in small amounts.

Locally, these gneisses contain bands and lenses of amphibolite and enclaves of gabbro-anorthosite. Lenses (up to 10 m long) of soapstone and serpentinite also occur.

The homogeneous gneisses appear to have formed by granitisation of the banded, streaky or veined types. They are typically developed in the core of the Laksefjeld antiform, but local examples of smaller granitised areas with nebulitic structures are abundant.

East of the Laksefjeld antiform, two other major structures, a SSE-plunging synform and an antiform can be traced in the pre-Ketilidian gneisses, and these are truncated unconformably by the Ketilidian supracrustals of the "eastern belt" along the inland ice.

Gneisses of Tavdlorutit and Sánerut

In the composite fold closure in the central and northern part of Tavdlorutit the Íka gneiss series is represented by migmatitic and usually banded biotite gneiss with bands, schlieren and inclusions of amphibolite, mica schists and quartzite, as well as lenses of calc-silicates. The gneisses forming the actual core of the closure are believed to belong to the Fladland gneiss series, and since the rocks of the Íka gneiss series are thought to make up a large synformal isocline (refolded by the 3rd phase closure), the gneisses on the convex side of the closure should also be the structural equivalents of the Fladland gneisses. They are generally developed as quartz dioritic to granodioritic biotite gneisses. Immediately south-west of the antiformal closure a narrow synform occurs. The rocks here are granodioritic and contain porphyroblastic oligoclase and microcline. The smaller porphyroblasts ($\leqslant$ 1 cm) are mostly arranged with their long axes parallel to the foliation, while the larger ($\sim$ 2 cm) and more idioblastic ones occur without preferred orientation. Biotite and epidote are the main mafic constituents, and abundant idiomorphic sphene crystals, a few millimetres in length, are characteristic.

On the western part of Tavdlorutit, west of the thrust, the gneisses become more homogeneous and are often nebulitic and contain microcline porphyroblasts. Along the north-west facing coast, there is a zone of gneisses with lenses of mica schists, quartzite and calcareous rocks. Both the gneiss and the metasediments are rich in epidote. The proximity of Ketilidian supracrustal rocks on the islands around Simpson Passage taken with the intensity of Ketilidian orogenesis in this region raises the possibility that, most probably, the rocks of this zone represent the gneissified lower part of the Ketilidian supracrustal succession.

The gneisses of central and western Tavdlorutit have recrystallised under amphibolite facies conditions, but a greenschist-amphibolite transition facies to a low amphibolite facies metamorphism has also had some influence. This later down-grading of presumably Ketilidian age is quite prominent in the north-west part of the island.

The gneisses of south-east Tavdlorutit are migmatitic, generally banded biotite gneisses which contain enclaves of gabbro-anorthosite, either of scattered occurrence or concentrated in horizons. A few talcstone lenses have been reported, while schlieren and bands of amphibolite are common. These gneisses appear to be in structural continuity with those of the Laksefjeld antiform.

The gneisses of Sánerut are migmatitic, mostly banded biotite gneisses of quartz dioritic to granodioritic composition. They occasionally contain amphibolite bands and lenses, but no inclusions of gabbro-anorthosite have been found. Acid veins and pegmatites often transect the gneisses. In the north-west part of the island, the gneisses are nebulitic or homogeneous due to granitisation. Microcline-porphyroblastic types of true granitic composition also occur.

On eastern Sánerut, the gneisses form an east-plunging antiform, which on its south-east flank is overlain by Ketilidian supracrustals. As shown in the interpreted structural map of plate 3, this antiform appears to fit into the general pattern of Senilian structures, but later the rocks were strongly affected by Ketilidian shearing, in particular in the vicinity of the sub-Ketilidian unconformity.

ROCK DIVISIONS AND STRUCTURES OF THE MATURIAN COMPLEX

The north-west part of the map sheet has been strongly influenced by deformation and metamorphic events attributed to the Maturian orogeny (fig. 6). The outcrop pattern of a supracrustal sequence—the Tartoq Group (fig. 7)—deposited subsequent to the Senilian orogenic

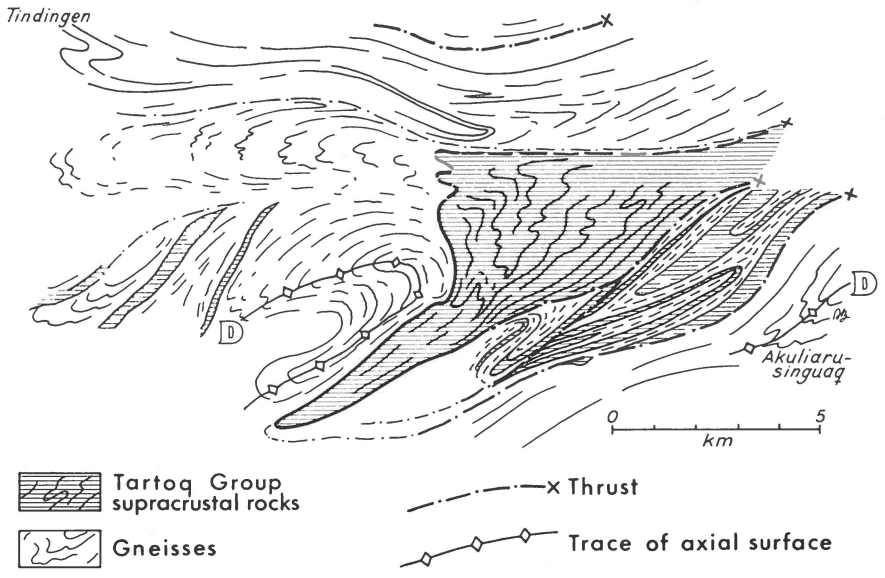


Fig. 20. Constructed profile (perpendicular to the fold axis) through the western part of the Maturian orogenic segment.

events, reflects only the influence of the Maturian orogeny. The surrounding gneisses display Senilian structures overprinted to a variable extent by those of the Maturian orogeny. The Tartoq Group (Higgins & Bondesen, 1966) comprises mixed metasedimentary and metavolcanic rocks. Ultramafic sills intruded this sequence, possibly during the initial phases of the Maturian orogeny; ultramafic plugs also occur in the gneisses which lie north-west of the Tartoq belt orogenic front (see fig. 21).

Structural pattern

The major Maturian structures have an ENE strike which is strongly reflected by the occurrence of the Tartoq Group supracrustals which occur in broad or narrow strips within the gneisses. The somewhat misleading designation of "greenstone belt" has been given to this part of the region by Windley & Bridgwater (1971).

The projected section of fig. 20 across the Târtoq region between Tindingen and Akuliarusínguaq shows the supracrustal rocks to occur in a composite synform overturned to the south-east. The contact between the Tartoq Group rocks and the reworked Senilian gneisses is either a tectonic one or it is marked by the occurrence of mostly agmatitic "grainy" quartz diorites, which for structural grounds are grouped with the supracrustal rocks.

A belt of "grainy" quartz diorite can be traced from the east coast of Søndre Kangeq along the western border of the supracrustals to just

east of Tuapait on the south shore of Sermiligârssuk. From the head of the fjord Târtoq a narrower belt of similar rocks marks the eastern border of the supracrustal rocks forming the core of the synform. East of the fjord Târtoq, a zone of thrust slices about 3 km across occurs. Each slice comprises "layers" of metavolcanics and metasediments, separated by biotite-chlorite gneisses which in places contain enclaves of "greenschist". Both the gneiss and the greenschist "layers" are cut by younger acid veins. The gneisses forming the core of the synform south of the fjord Târtoq (which almost reaches the small bay Tigssaluk) are chloritic, contain greenschist inclusions and are strongly reminiscent of the "grainy" quartz diorites. Probably all the gneiss sheets of the thrust slices represent tectonised and somewhat migmatised editions of this particular border-type rock.

Below (and south-east of) this zone of thrust slices there occur Senilian-deformed rocks, which suffered but little kinetic influence of the Maturian orogeny. In its overturned western flank the Maturian main synform is overlain by similar rocks, but here they have been strongly influenced by Maturian deformation, which caused large-scale, macroplastic refolding and reorientation of the Senilian structures.

West of the main synform in the Târtoq area an asymmetric crescentic structure occurs in the gneisses which represents the refolded hinge of the Senilian antiform D.

North of Sermiligârssuk a major Maturian recumbent (reclined) synform occurs around Kangârssuk. This synform is overthrust by a thick series of tight to isoclinally folded gneisses. This northern unit forms part of a large gneiss recumbent fold of nappe dimensions; it has an amplitude of at least 15 km (see fig. 7), but most of this impressive structure lies north of the map sheet boundary. Reference should also be made to p. 30 and p. 39 where descriptions are given of the structures and rocks of Sermersût and western Tôrnârssuk, which areas were also influenced, but to a lesser degree, by the Maturian orogeny.

Gneisses north of Sermiligârssuk

The banded, to veined, or sometimes streaky, quartz- to granodioritic gneisses of this area are biotite- and hornblende-bearing and usually contain epidote. North of Tuno a number of amphibolite bands outline a large reclined fold in the south-facing mountain wall. Lenses and discontinuous bands of amphibolite and quartz-amphibole rocks or amphibole-rich gneisses also occur. In the western part, at Tindingen, bands of garnet amphibolite with rusty horizons form another reclined structure. North of the thrust below the 756 m summit, the gneisses contain many thin amphibolite bands and conformable, up to 10 m long, lenses of

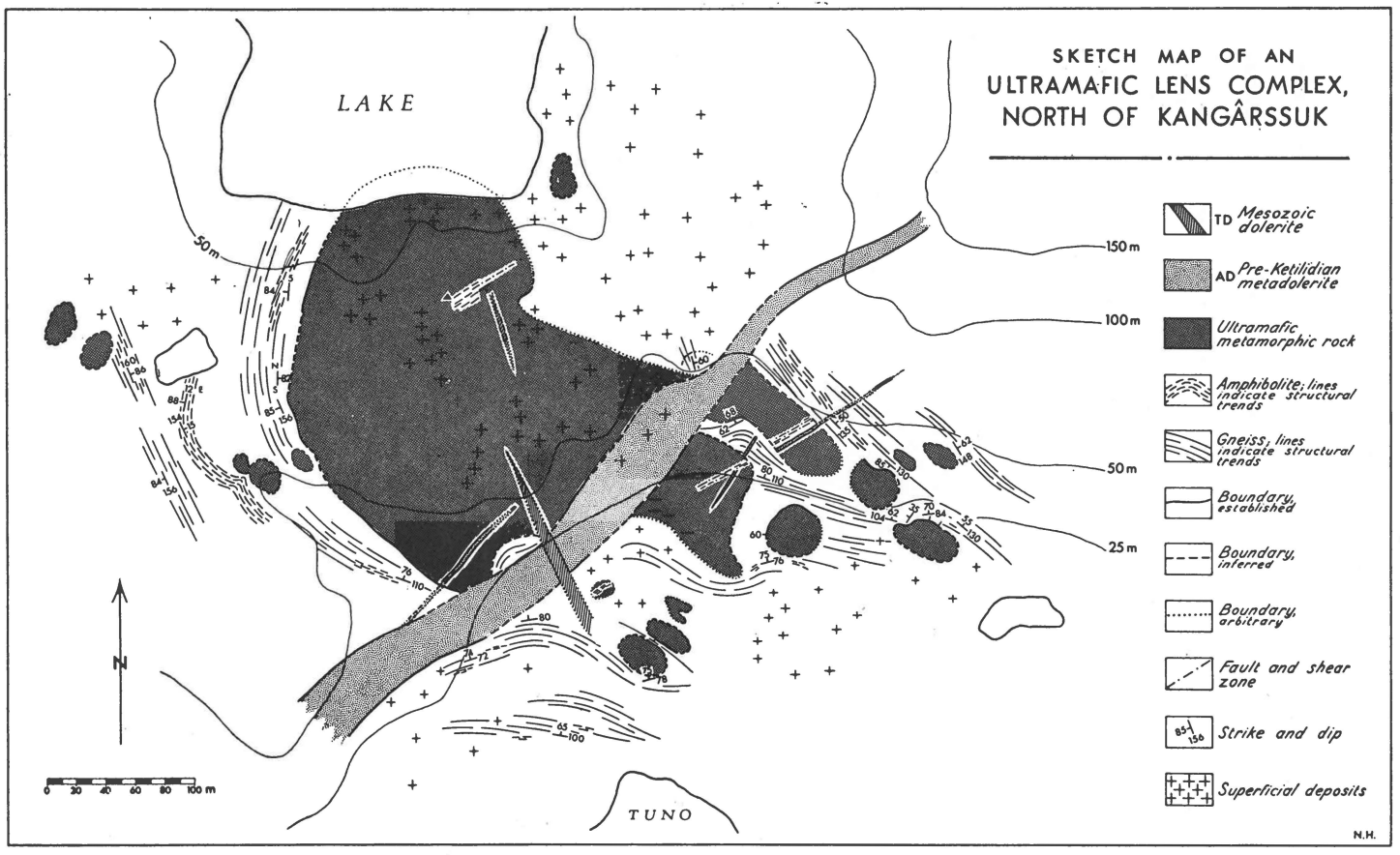


Fig. 21. Sketch map of an ultramafic lens complex north of Kangârssuk.

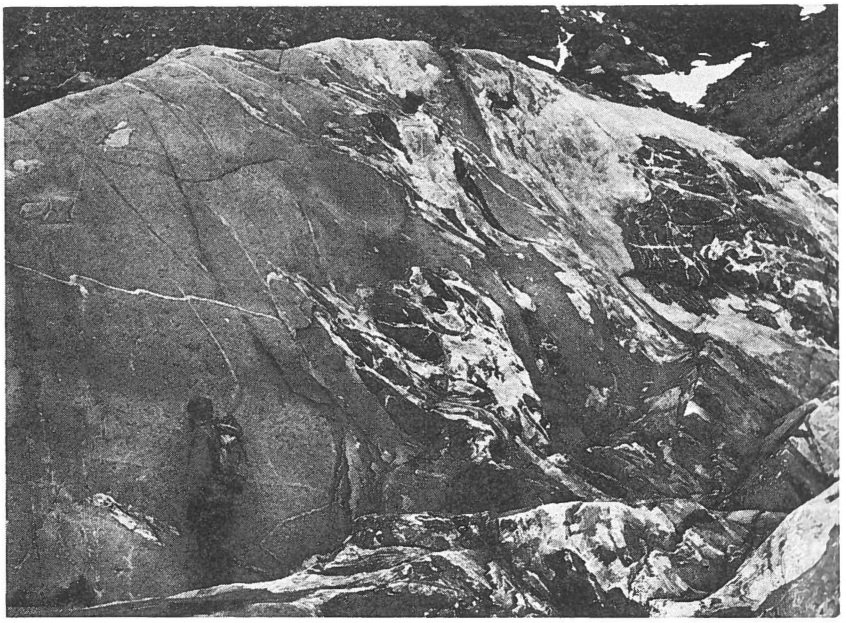


Fig. 22. Post-migmatite granodiorite to quartz diorite body. Near Kigssaviat, on the north side of the mouth of Sermiligârssuk.

ultramafics. The lenses show sheared borders rich in biotite and chlorite and consist mainly of actinolite, serpentine and talc. About 3 km north of Kangârssuk, a larger mass of ultramafic rocks about 400 m across occurs (fig. 21). This mass mainly consists of serpentinised peridotite with relic pyroxene and olivine. It is believed to represent an original plug-like intrusion, which was broken up during the Maturian refolding of the enclosing gneiss. Maturian metamorphism led to development of reaction zones around all the individual fragments. A cross-cutting Iggavik dyke confirms a pre-Ketilidian age for the ultramafic complex (? early Maturian).

The rocks of the northern gneiss unit are cut by numerous migmatitic veins, which are fine grained and usually less than 10–20 cm wide. They show a concordant to semi-concordant arrangement in relation to the gneiss banding. Broader veins, up to 2 m wide, and discordant quartzofeldspathic pegmatites contain small amounts of biotite and epidote. Both the migmatitic veins and the pegmatites have been folded.

Along the well-exposed coasts between Tuno and Tindingen, as well as on the small islands close to Kangârssûp ūmânâ, post-migmatitic, but metamorphosed and slightly deformed bodies of biotite-bearing, leucocratic granodiorites or quartz diorites of fine- to medium-grain size occur (fig. 22). Along the coast of the mainland irregular, sometimes dyke-

like, bodies measuring 10 to 20 m across are common. They appear partly discordant and partly replacive. The large mass on the islands is clearly discordant. Weakly folded aplitic veins and rectilinear dilational pegmatites cut these bodies.

The migmatitic gneisses of the northern unit appear to have been downgraded from medium amphibolite facies to a slightly lower grade, probably due to a Maturian retrogression, during which the reaction rims of the ultramafic bodies also developed.

Gneiss area west of Târtoq

Between Eqalugkat and Nordre Kangeq, small-scale folded, banded and agmatitic gneisses, containing hornblende and/or chlorite as mafic minerals, surround and border three zones of greenschists. These zones are cut by pegmatite veins and by sheared and amphibolitised Iggavik dykes.

The shearing of the Iggavik dykes is a notable feature of this area, since they are almost unaffected by Ketilidian kinetic transformations in areas to the east and south. Recrystallisation and development of a mineral fabric in the dykes first becomes general about 5 to 10 km northwest of Arsuk Fjord. The shearing in the area west of Târtoq suggests the possibility of a (NW-dipping?) Ketilidian shear zone trending ENE through the entrance of Sermiligârssuk.

East of the fault running into Eqalugkat the gneisses are mainly biotite bearing. The biotite may be chloritised and the plagioclase (25–30 % An), by far the dominant feldspar, may be saussuritised and sericitised. Epidote is always present and sphene and apatite are common accessories. More or less conformable veins and pegmatites are often found, in particular in the gneisses adjacent to the "grainy" and agmatitic quartz diorite along the west flank of the synform.

Quartz dioritic gneisses adjacent to the Tartoq Group

Along the west flank of the main synform in the Târtoq area the greenschists and greenstone of the Tartoq Group are separated from the western gneisses by a belt of "grainy" and agmatitic quartz diorite (fig. 23). Jacobsen (1961), who mapped the southern part of this border zone, describes a gradual transition between the gneisses and the quartz diorite and presents modal and rapid chemical analysis in support of the view that the quartz diorite could have formed from the greenschist by metasomatic addition of Si and some Na and K and loss of Ca, Fe and Mg. Further north, at Pudefjeld an almost hornblendic "basic front" is developed in the amphibolitic greenschists where they border on the

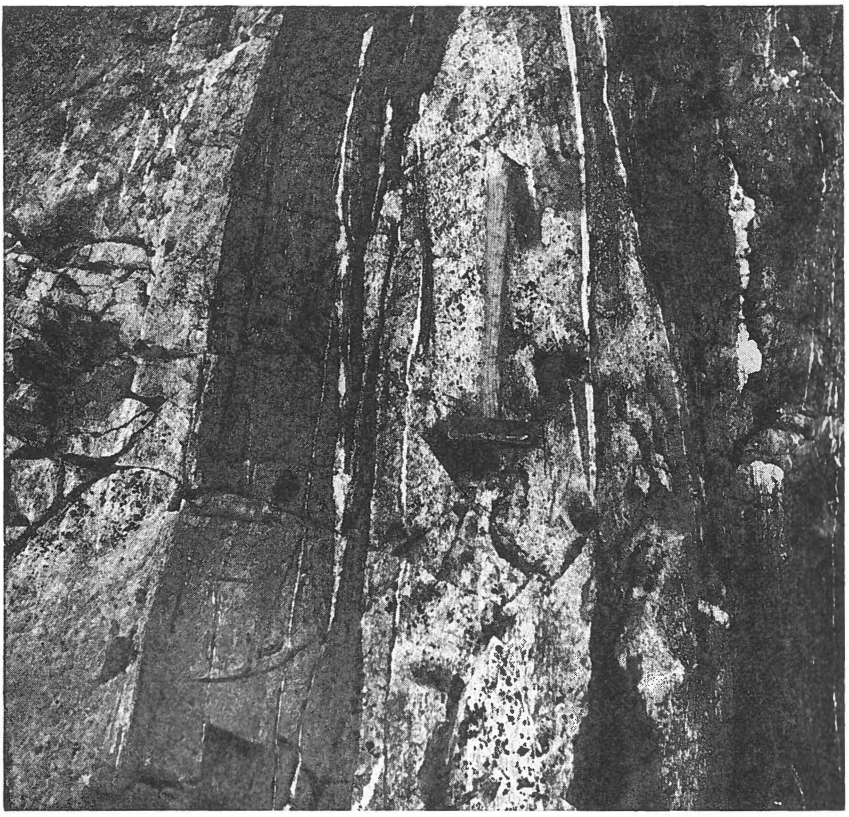


Fig. 23. Alternating bands of well foliated greenschists (dark) and gneissic quartz diorite (light); modified Tartoq Group metavolcanics. Head of Târtoq, eastern shore. Photo: F. L. JACOBSEN.

quartz diorite, but here, the quartz diorites also form intrusion breccias in the greenstone. Analysis from the rocks of the border zone are shown in table 3. The chemical variations might also be viewed as a consequence of progressive intrusive introduction of leucocratic material (cf. HIGGINS, 1968).

In the mountains above Târtuarssuk, the quartz diorite also appears in some exposures to be transgressive towards the amphibolite greenschists. Where further north the quartz diorite zone is broad, it is traversed by numerous aplitic dykes and pegmatites. If such *lit par lit* veining is intensive, and accompanies differential shear movements with concomitant recrystallisation, the small-scale augen-structured (i.e. "grainy") and agmatitic and gneissose quartz diorite could also be formed more or less *in situ*, even if metasomatism only played a quite subordinate role in the process.

Table 3. *Chemical analysis of Tartoq Group metavolcanics after* JACOBSEN *(1961)*

Sample no.	32215	39821	32240	32242	39813
SiO_2	52.1	52.9	52.9	54.1	60.5
TiO_2	0.6	0.6	0.8	0.6	0.7
Al_2O_3	14.3	14.4	16.4	16.9	15.3
Fe_2O_3	1.8	1.7	1.9	3.3	1.9
FeO	8.8	8.5	6.7	5.0	4.4
MnO	0.3	0.3	0.2	0.3	0.1
MgO	7.4	8.0	6.7	4.9	3.9
CaO	10.9	8.1	8.3	7.2	5.9
Na_2O	1.6	2.0	3.1	5.2	3.1
K_2O	0.2	0.2	0.8	0.4	1.6
P_2O_5	0.1	0.1	0.3	0.2	0.2
H_2O	0.9	2.5	1.4	1.3	1.5
	99.0	99.3	99.5	99.4	99.1

CIPW	weight 32215	norm 39821	
q	6.22	7.02	
or	1.18	1.18	ab – an – or triangle:
ab	13.52	16.90	32215: 29.45 67.97 2.58
an	31.21	29.69	39821: 35.38 62.14 2.48
di	18.23	9.27	
hy	23.77	23.21	
ol	0.00	0.00	
mt	2.61	2.46	
il	1.14	1.14	
ap	0.24	0.24	

Increasing "gneissification" ↓

32215: Actinolitic greenschist, with pillow structures. North of Târtoq.

32321: Actinolitic greenschist, with pillow structures. North of Târtoq.

32240: Mafic quartz diorite, with small plagioclase porphyroblasts. North of Târtoq.

32242: Mafic quartz diorite, with small plagioclase porphyroblasts. North of Târtoq.

39813: Quartz diorite, with small plagioclase porphyroblasts. North of Târtoq.

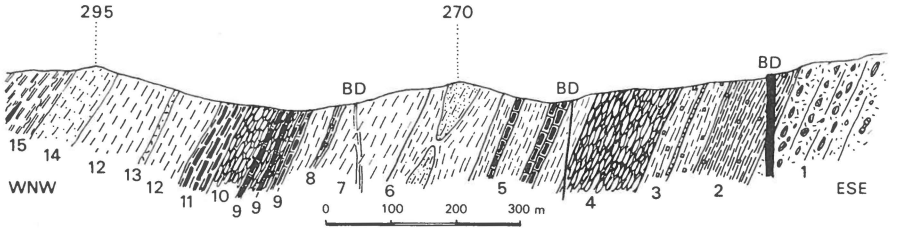


Fig. 24. Compiled section of supposed lower Tartoq Group; south-east of Nûluk. After sketch in M. WEIDMANN's diary, 1958.

1. Quartz dioritic gneiss with greenschist inclusions.
2. Massive melanocratic actinolitic schists, sometimes with pyrite.
3. Chlorite schist, light or dark, with pyrite; contains a thin quartzite band.
4. Actinolite-bearing greenschist with pillow structures; locally with pyrite.
5. Chlorite schist with rusty coloured carbonate bands.
6. Chlorite schist, light coloured, with boudinaged band of quartzitic schist.
7. Chlorite schist, very light coloured.
8. Amphibolite band, dark, massive with pyrite.
9. Calcite-bearing schist, with limonite, rusty weathering.
10. Actinolite-bearing greenschist with pillow structures; locally with pyrite.
11. Chlorite schist, locally very calcareous; forms a rust zone.
12. Chlorite schist, light coloured.
13. Quartz dioritic gneiss; gradational transition to adjacent chlorite schists.
14. Quartzitic chlorite schist, light coloured.
15. Chlorite schist, dark coloured, with pegmatites and quartz veins; contains a talc-serpentine-chlorite lens.

BD Gardar dolerites.

South of Tuapait, the border between the western gneiss and the quartz diorite coincides with a thrust, which further south, with a different dip, can be traced through the quartz diorite into the greenschists. Here it follows a thin ultramafic sill which in places has been drawn out into lenses and is also folded.

Tartoq Group supracrustals

Târtoq area

The supracrustals of the synform-core north of the fjord Târtoq may be considered as the type area of the Tartoq Group. The Tartoq Group as established by HIGGINS & BONDESEN (1966) includes all the greenschist areas of the Târtoq-Sermiligârssuk-Midternæs region (fig. 7), but no type section was defined. In the Târtoq area the group may be divided into a lower part (*c.* 1000 m) comprising alternating metasedimentary and metavolcanic rocks, and an upper part (1000 m +) consisting almost entirely of metavolcanics. Pillow structures preserved in the upper part suggest the synform is a true syncline.

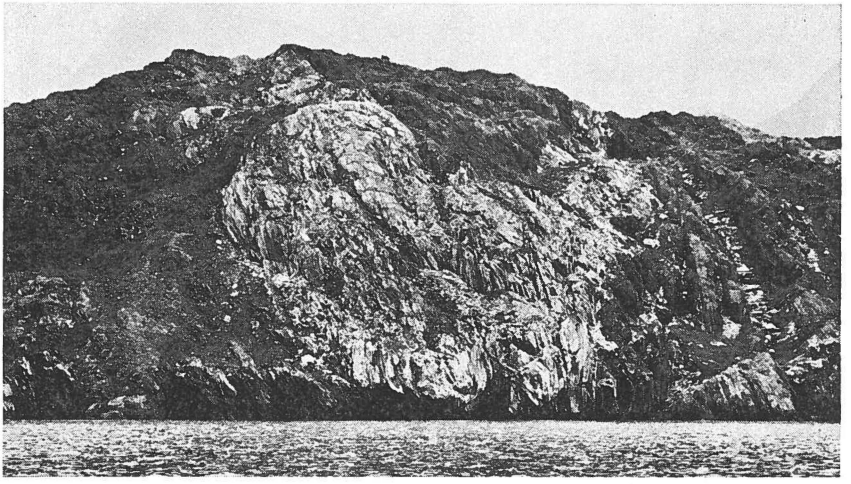


Fig. 25. Synform of micaceous quartzite in greenschists; Tartoq Group—east of Nûluk, south side of Sermiligârssuk. Profile height about 75 metres. Note development of axial plane schistosity. Photo: F. L. JACOBSEN.

An impression of the lithological variations in the lower part of the group is shown in fig. 24. The metasedimentary layers, which may incorporate some volcanic material fall largely into two categories; (1) rusty brown weathered calcareous-siliceous schists containing talc and chlorite as well as quartz and carbonate; and (2) pale-coloured and sometimes banded micaceous or talc-bearing quartzites which are often strongly schistose. The talc-chlorite schists and the schistose quartzites form layers up to 60 m broad, but may thin out and form lenses. A layer of schistose quartzite forming a parasitic synform is well exposed on the south coast of Sermiligârssuk (fig. 25). The strong schistosity is parallel to the axial surface of the fold. The metavolcanics of the lower part of the group are preserved as amphibolitic greenschists and dark chlorite schists.

The lower part of the Tartoq Group is found only in the south-east limb of the syncline. In the overturned north-west limb, the bordering quartz diorites are in direct contact with the metamorphosed pillow lavas of the upper part (fig. 26).

In addition to pillow lavas the upper part comprises a few, discontinuous bands and lenticles of plagioclase-epidote-bearing quartzites, generally less than 50 m thick. In the greenschist thin quartz veins (*c.* 1 cm) are developed parallel to the schistosity.

Sills of serpentinised ultramafics, usually less than 1 m thick, occur parallel to thrust or schistosity planes.

The pillow structures of least deformed areas measure 15–150 cm in diameter. They are rimmed by dark zones rich in hornblende. The matrix

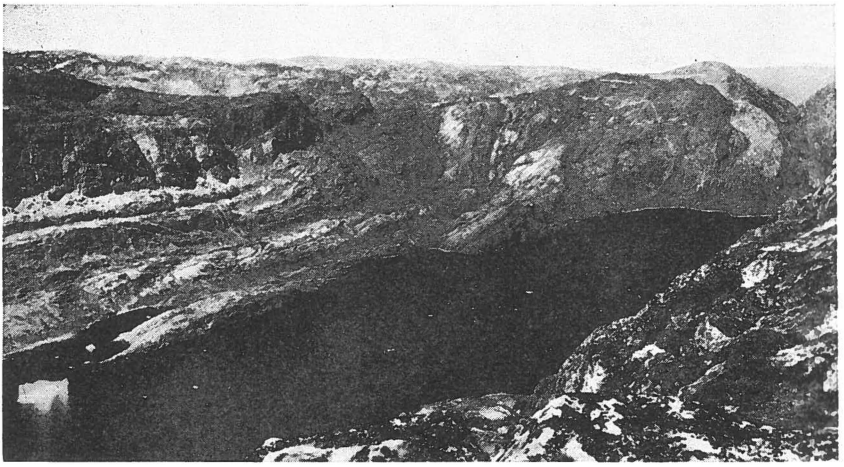


Fig. 26. Well-defined stratigraphical units of the Tartoq Group at the head of the fjord Târtoq; metasediments lighter colours, metavolcanics dark. Photo: E. BONDESEN.

between the pillows consists of quartz and epidote, with some chlorite and carbonate minerals (fig. 27). JACOBSEN (1961) reports that the greenstones consist mainly of bluish-green to colourless amphibole (*c.* 66–75 %) with epidote, plagioclase and quartz present in minor amounts (each less than 10 %). Pyrite and apatite form common accessories. Norm calculations on two analysed pillow lavas (table 3) indicate that the lavas should be classified as oversaturated tholeiites with normative quartz and hypersthene according to WILKINSON's (1967) classification. JACOBSEN's study also shows that the supracrustals of the Tartoq Group around Târtoq recrystallised under greenschist-amphibolite transition facies conditions.

Thrust slices east of Târtoq

In the thrust slices in the lower part of the major synformal structure (see fig. 20) "layers" of greenschists and metasediments are interfingered with agmatitic gneisses. AYRTON (1963) describes the fine-grained greenschists here as comprising principally chlorite and/or amphibole, the latter mineral giving the rocks their dark colour. A gradual transition from rocks with actinolitic hornblende and biotite into lower-grade chloritic types was traced. Intercalated pelitic schists consist mainly of chlorite, sericite, quartz and albite-oligoclase, with lesser amounts of epidote, apatite, biotite, magnetite, limonite, pyrite and sphene. Quartzofeldspathic schists and carbonate-bearing, talc-sericite-chlorite schists



Fig. 27. Relic pillow structure in metavolcanics of the Tartoq Group. Peninsula at Târtuarssuk near entrance to Târtoq. Photo: F. L. JACOBSEN.

also occur. These supracrustals, which are comparable to the lower part of the Tartoq Group in the Târtoq area, are veined and cut by acid dykes and pegmatites together with the neighbouring agmatitic gneisses.

Bikuben area

The Tartoq Group of the Bikuben area situated at the north edge of the map sheet is part of a larger area occurring along the south side of Sermiligârssuk (fig. 7).

According to WEIDMANN (1964), the supracrustals of the Bikuben area consist largely of dark greenschists. These are fine- to medium-grained, massive to schistose rocks with occasional relic textures and structures indicating derivation from tuffs and lapilli, pillow lavas and gabbro sills.

The main mineral assemblages are: epidote-chlorite-calcite-sphene; epidote-chlorite-actinolite-sphene; hornblende-epidote-biotite-almandine; hornblende-chlorite-biotite-calcite-sphene-epidote; plagioclase with An $< 25\%$ is an essential constituent, quartz makes up less than 5% and apatite, opaque minerals, muscovite, allanite and tourmaline are found in accessory amounts.

Thin bands or impersistent horizons of quartzitic, quartzo-feldspatic, pelitic and calcareous schists occur intercalated in the greenschists. The only horizons which can be traced for any distance are rusty zones (zones rouillées), which vary from a few tens to several hundreds of metres in width. The rocks of these zones differ from the surrounding greenschists in containing abundant quartz and muscovite as well as iron oxides and sulphides.

The greenschists and associated schists of the Bikuben area are folded in a complex system of almost N-plunging folds with plunges of up to 60°. They are veined by thick muscovite pegmatites. The agmatitic zone occurring along the "base" of the greenschists is also cut by numerous muscovite pegmatites.

Ultramafics of the Bikuben area

In the supracrustal rocks of the Bikuben area a number of ultramafic bodies are found. The three largest examples are shown on the map (plate 1), together with some of the sill-shaped intrusions, which may attain a thickness of 25 m. In places, the sills can be traced as rows of lenses. The contacts of these bodies are often concordant, but locally their discordant nature can be demonstrated. The greenschists often have a strongly sheared and folded development near to the contacts of the larger bodies. The ultramafics are all serpentinites, and no traces of pyroxenes or olivine have been found; 60–85 % is serpentine, while talc, carbonate, chlorite and opaque minerals account for the remainder. In spite of the serpentinisation primary igneous banding has been preserved in some of the larger bodies, and is outlined by concentrations of magnetite in certain bands. Along the contacts of the ultramafics metamorphic reaction zones with talc-actinolite-biotite are well-developed. The bodies are cut by muscovite pegmatites.

WEIDMANN (1964) dates the intrusion of these ultramafic bodies as later than the formation of the Tartoq Group rocks but prior to the folding, metamorphism and migmatisation which affected them. While WEIDMANN follows BERTHELSEN's (1960) scheme of chronology in terming these features Ketilidian, the deformation affecting these ultramafics should now be referred to as Maturian (pre-Ketilidian).

The ultramafics of the Bikuben area can be presumed to represent early Maturian emplaced serpentinites (in the sense of HESS).

IGGAVIK DYKES

The swarms of metamorphosed basic dykes and discordant amphibolites which cut the pre-Ketilidian gneisses of the Ivigtut region and

have been intruded prior to the Ketilidian deformation have been redefined as the Iggavik dykes (p. 28). Their distribution is shown in plate 5, which shows also a few metamorphosed Ketilidian dykes discussed in a later section (p. 101). The Iggavik dykes are virtually confined to the pre-Ketilidian gneisses and are generally considered to be of pre-Ketilidian age, though BONDESEN (1970, p. 183) maintains some may be feeders to the Ketilidian Sortis Group lavas.

The Iggavik dykes have been described in some detail in various areas under their previously used designation as AD (amphibolite discordant) or Kuanitic dykes. Those north of Tigssalûp ilua have been described by AYRTON (1963) and WEIDMANN (1964), and those west of Arsuk Fjord by BONDESEN & HENRIKSEN (1965). Their regional distribution has been discussed by BERTHELSEN (1962) and their chemical composition by HENRIKSEN (1969b).

Setting and mutual chronological relations

The metadolerites and the discordant amphibolitic dykes occur as swarms in the pre-Ketilidian basement. They were emplaced under cratonic conditions subsequent to the last pre-Ketilidian (i.e. Maturian) folding and migmatisation. The Iggavik dykes do not occur in the Ketilidian supracrustal rocks.

In the northern part of the Ivigtut region, where the Ketilidian deformation is superficial, the dykes are mostly rectilinear and often quite persistent. In the south-east, however, the dykes are generally deformed, boudinaged and sometimes markedly folded.

In the northern part of the region, where the dykes have preserved many of their original features, it is possible to distinguish four main dyke generations of regional distribution.

These sets are:

	Set no.	trend
Youngest	4	WNW to E–W
	3	NNE to NE
	2	NNW
Oldest	1	E–W to WNW

In addition to these main sets there occur occasional dykes with other trends, but these are without regional importance.

The distribution of the various dykes is shown on plate 5 and an analysis of their trends in the northern part of the region is indicated on the rose diagrams on fig. 28.

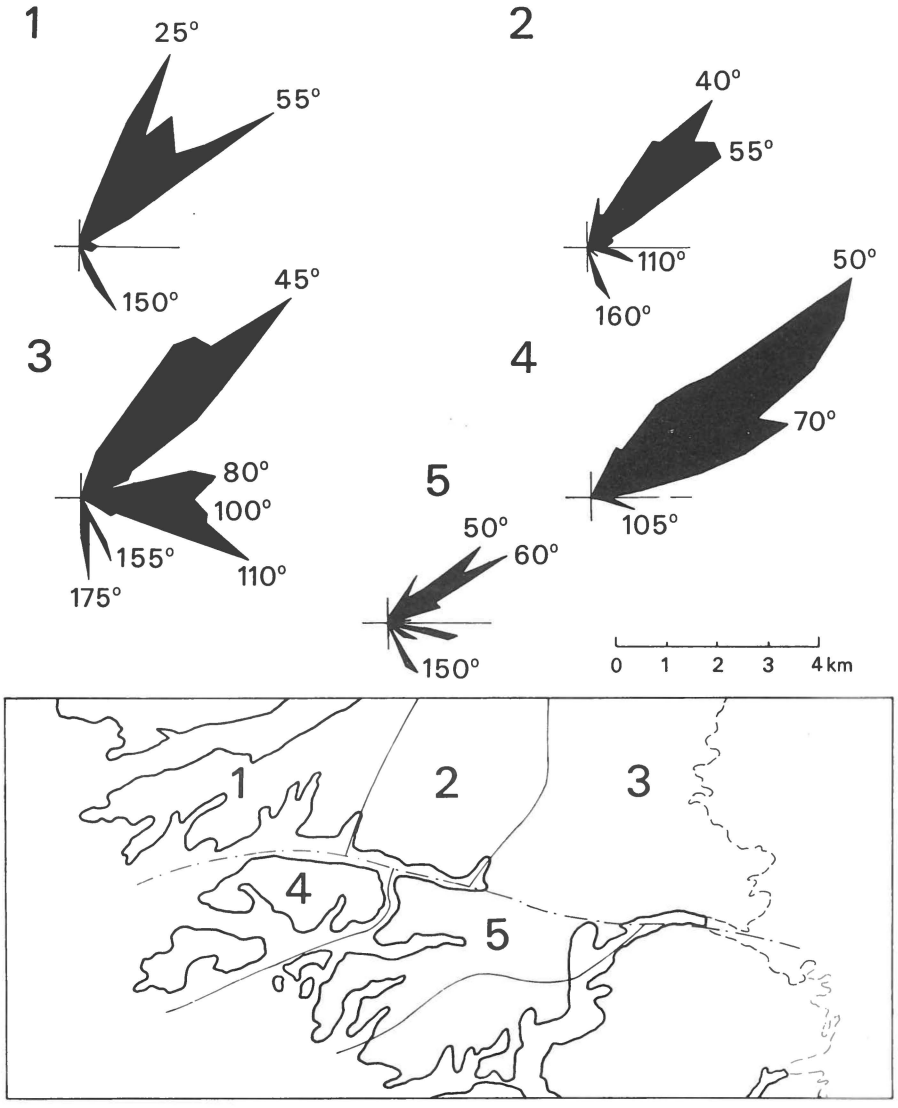


Fig. 28. Rose diagrams showing trends of Iggavik dykes in 5 subareas.

Occurrences of the various sets

Set no. 1: There are only few examples of these oldest dykes. Their trend is approximately E–W to WNW and they often form rather thick (10–50 m) single vertical dykes distributed widely over the area on both sides of Tigssalûp ilua.

Set no. 2: This is formed by a group of quite thick (20–150 m) persistent dykes trending approximately NNW. Examples of these dykes can be traced from east and west of Ivigtut to Sermiligârssuk, and they

are known to continue north of Sermiligârssuk as well. They are vertical or steeply dipping and only gentle undulations have been observed in their otherwise constant trends.

Set no. 3: The third set, trending NNE-NE, forms the majority of the metamorphosed dykes known in the area. They often occur in swarms and their regional density therefore varies. The dykes belonging to this set are often from 5 to 20 m in width, but dykes of up to 50 m across are not unusual, and a few reach nearly 100 m. Many of the dykes can be traced for several kilometres and they often show a somewhat irregular trend. The majority are steep to vertical, but some have a dip of approximately 70° to the north-west and a few have dips as low as 45°.

Intersections between individual dykes of the 3rd set show that there were at least three pulses of intrusion.

Set no. 4: The youngest major set of these metamorphosed basic dykes has E–W to WNW trends. Such dykes occur most abundantly around the Kuánit fjord and on Tôrnârssuk, where they form a narrow swarm from 20–150 m wide. Dykes belonging to this swarm can be traced from Arsuk Fjord to the western part of Tôrnârssuk. The dykes are very persistent althouth their trends are somewhat irregular, often curving, with the result that they locally attain ENE trends. A marked characteristic of some of these dykes is their varying content of plagioclase megacrysts.

From the occurrence of a few intersections among dykes of this set, and from the existence of multiple intrusions, it can be demonstrated that this 4th set of dykes also comprises a sequence of intrusions.

Distribution

The general distribution of the metamorphosed Iggavik dykes and their deformed counterparts suggests that their regional density decreases rapidly towards the south-east part of the region. South of Íka and on Tavdlorutit only a few proven dyke relics have been found and none are reported from Sánerut. Although some "discordant amphibolites" may not have been distinguished from primary amphibolite bands in the southern areas, the evidence as a whole suggests that the southern part of the Ivigtut region marks the original southern limit of these vast swarms of basic dykes. North of the Ivigtut region the swarms continue for several hundred kilometres.

Deformation

In the northern part of the Ivigtut region the Iggavik dykes are nearly always clearly dyke-shaped, intersecting the surrounding gneisses discordantly and often showing other primary intrusive features such as

apophyses, *en bajonet* and *en echelon* structures. Relic chilled margins, xenocrysts and phenocrysts, ophitic texture, and in a few cases xenoliths also occur. The grain size is medium to coarse in the central part of very wide dykes, but in dykes of more usual thickness (10–15 m) the grain size generally does not exceed 1 cm. Thin dykes are fine grained. The weathering colours are generally dark green to greenish-black, and occasionally brown.

In the south-east part of the region the Iggavik dykes are generally affected by Ketilidian deformation. The degree of deformation generally increases towards the south-east and folded dykes are mainly found in the area south-east of Arsuk Fjord.

In the area around Tigssalûp ilua deformation of the dykes is superficial, most often taking the form of sheared contacts seen most commonly in the NE-trending dykes. The shearing is sometimes accompanied by quartz and calcite veining.

In the area north and south of the head of Arsuk Fjord the dykes are clearly distorted, NE-trending dykes being deformed into open flexures concave to the south. South of the fjord the dykes are often also disrupted and boudinaged, only the originally thick and persistent dykes showing more coherent forms.

On the Ivigtut peninsula (plate 2) the original dyke forms are often preserved, but many are found as trains of lenses and some are mesoscopically folded. The dykes show a general curved trend pattern almost conformable to the general trend of the gneisses. On a small scale, however, the dykes are clearly discordant and cut most mesoscopic structures.

East of Íka fjord the dykes are highly deformed. They are almost always found as lenses or trains of lenses and are generally conformable to the major structural trends in the surrounding gneisses. Occasionally such lenses can be seen to cut small-scale structures in the gneisses.

Metamorphism

The metamorphic grade of the Iggavik dykes increases in line with the degree of deformation from north-west to south-east. In the north-west the dykes are only partially recrystallised under greenschist facies conditions, while in the south-east they are completely recrystallised under amphibolite facies conditions. BONDESEN & HENRIKSEN (1965) distinguished six stages of increasing alteration between western Tôrnârssuk and Arsuk Fjord.

Stage 1. Preserved primary plagioclase and uralitic hornblende. Chlorite present. Ophitic texture.

Stage 2. Alteration of primary plagioclase (saussuritisation and sericitisation). Uralitic hornblende. Relic ophitic texture.

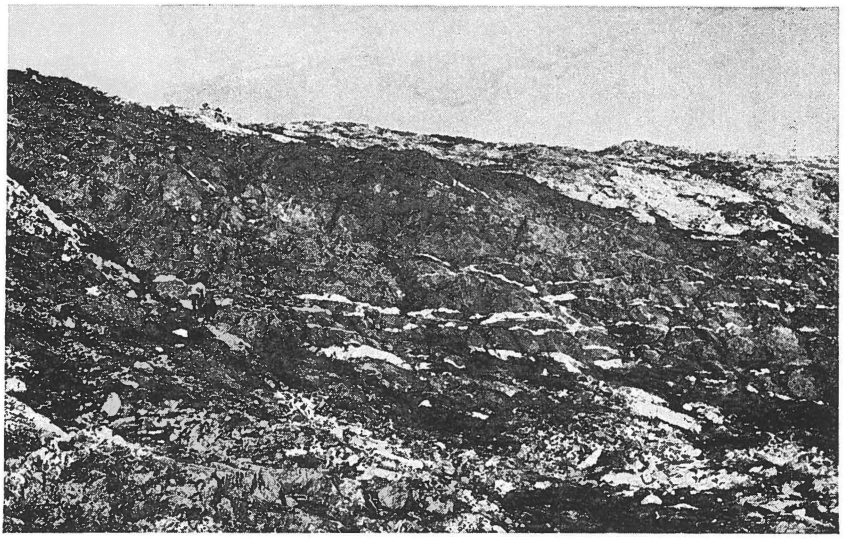


Fig. 29. Discordant amphibolitic Iggavik dyke cut by Ketilidian pegmatites and aplites. North-east of Christians Havn, north of Arsuk Fjord.

Stage 3. Recrystallisation of plagioclase (0.05–0.10 mm grain size) and uralitic hornblende. Traces of ophitic texture.

Stage 4. Further recrystallisation of plagioclase (up to 0.2 mm grains) and amphibole. Hemi-granoblastic* texture.

Stage 5. Non-oriented completely recrystallised amphibole and granular recrystallised plagioclase often showing twins. Hemi-granoblastic texture.

Stage 6. Foliated and lineated amphibole aggregates, and up to 0.5 mm twinned plagioclase grains. Nematoblastic texture.

The regional pattern of metamorphic alterations in the dykes follows these stages rather closely, except for some variations in the extreme north-west. Here the dykes show alterations similar to stage 1, but some of the least altered dykes also contain relic pyroxene. In broad dykes the central part is only weakly uralitised and has the appearance of fresh dolerite. Further variations occur in the area around Nordre Kangeq, south of the entrance to the fjord Sermiligârssuk, where the thick irregular swarm of NE-trending dykes is strongly sheared (see p. 57).

In the area south-east of Arsuk Fjord all dykes and dyke remnants are completely recrystallised. They generally consist almost exclusively of plagioclase (oligoclase–andesine) and hornblende, with only small

* Textural terminology in the sense of Berthelsen (1960).

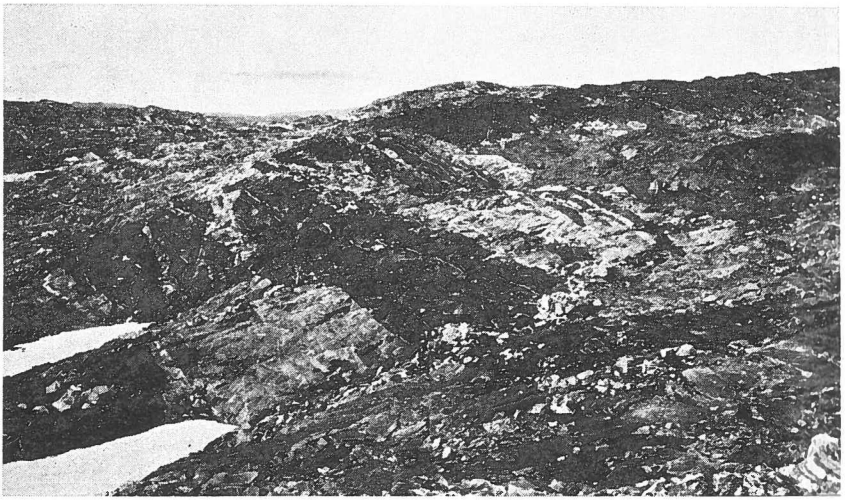


Fig. 30. Veins of Ketilidian granite cutting amphibolitic Iggavik dyke. Note man in right hand center of picture. North-east of Tvillingsøer. Photo: S. B. JENSEN.

amounts of quartz, biotite, ore and sphene. The metamorphic grade has generally reached amphibolite facies conditions.

In the central and southern part of the Ivigtut region the metamorphic alterations are associated with the emplacement of Ketilidian acid dykes. Immediately north-west of Arsuk Fjord the basic dykes are cut by scattered aplites and pegmatites (fig. 29), which south-east of the fjord are abundant. Veins of medium-grained non-foliated, white biotite granite cut also the discordant amphibolites, and are especially numerous near the Ketilidian plutonic granites (fig. 30).

Chemical composition

Analyses of twelve representative samples from the metadolerites and discordant amphibolitic dykes were published by HENRIKSEN (1969b). The analyses indicate that the earlier dykes, represented by samples from sets no. 2 and 3, had tholeiitic affinities and that the later dykes (set no. 4) had a more alkaline composition. Petrochemical calculations show all analysed examples to contain both normative olivine and hypersthene. Only samples representing the NNE–NE trending set no. 3 contained also normative quartz in addition.

Three of the analyses represent different metamorphic facies conditions of one and the same dyke. These analyses were remarkably similar and indicate that Ketilidian metamorphism in the northern part of the Ivigtut area took place under isochemical conditions.

Comparison between the chemical composition of the Iggavik metadolerites and Ketilidian metavolcanics from the Sortis Group (p. 75) reveals certain compositional differences (HENRIKSEN, 1969b). It was therefore concluded that the metavolcanics and the metadolerites were not derived at the same time from the same source and hence the dykes were considered not to be Ketilidian feeders.

Regional chronological setting

The Iggavik dykes cut clearly the folded and migmatised infracrustal gneisses in the central and northern part of the Ivigtut region. Three of the four sets distinguished cut the structures of the Tartoq Group supracrustals in the Târtoq area and near Bikuben and are therefore clearly not feeders to these volcanics and post-date Maturian deformation.

The virtual absence of metadolerites in the Ketilidian supracrustals suggests that the main Iggavik dyke swarms pre-date Ketilidian deposition. Comparison of chemistry of the Iggavik dykes and Sortis Group lavas does not support a feeder relationship.

The deformation and metamorphism the Iggavik dykes have suffered closely parallels what the Ketilidian supracrustals have suffered, and may be referred to Ketilidian orogeny. In both dykes and supracrustals intensity of metamorphism and deformation increases towards the south-east.

It can be concluded that the Iggavik dykes were intruded subsequent to Maturian deformation and are probably largely prior to Ketilidian deposition.

LITHOLOGY AND STRUCTURES OF KETILIDIAN SUPRACRUSTAL ROCKS

General review

Ketilidian sedimentary and volcanic rocks resting on the pre-Ketilidian gneiss complexes occur in two regions: (1) an eastern belt bordering the inland ice stretching from Grænseland southwards to Qôrnoq, and to Kînâlik and Qipisarqo and (2) the Arsuk Ø area including the surroundings of Taylers Havn, Evqitsut and Storø. South of Sânerut, the rocks of these two regions probably unite. North of the map sheet, the eastern belt widens eastwards in the large semi-nunatak area of Midternæs (HIGGINS, 1970).

Detailed lithostratigraphic studies of the Ketilidian sequence have been undertaken both in Grænseland (BONDESEN, 1970) and in the Arsuk Ø region (MULLER, 1974). In general, the Ketilidian metamorphism and

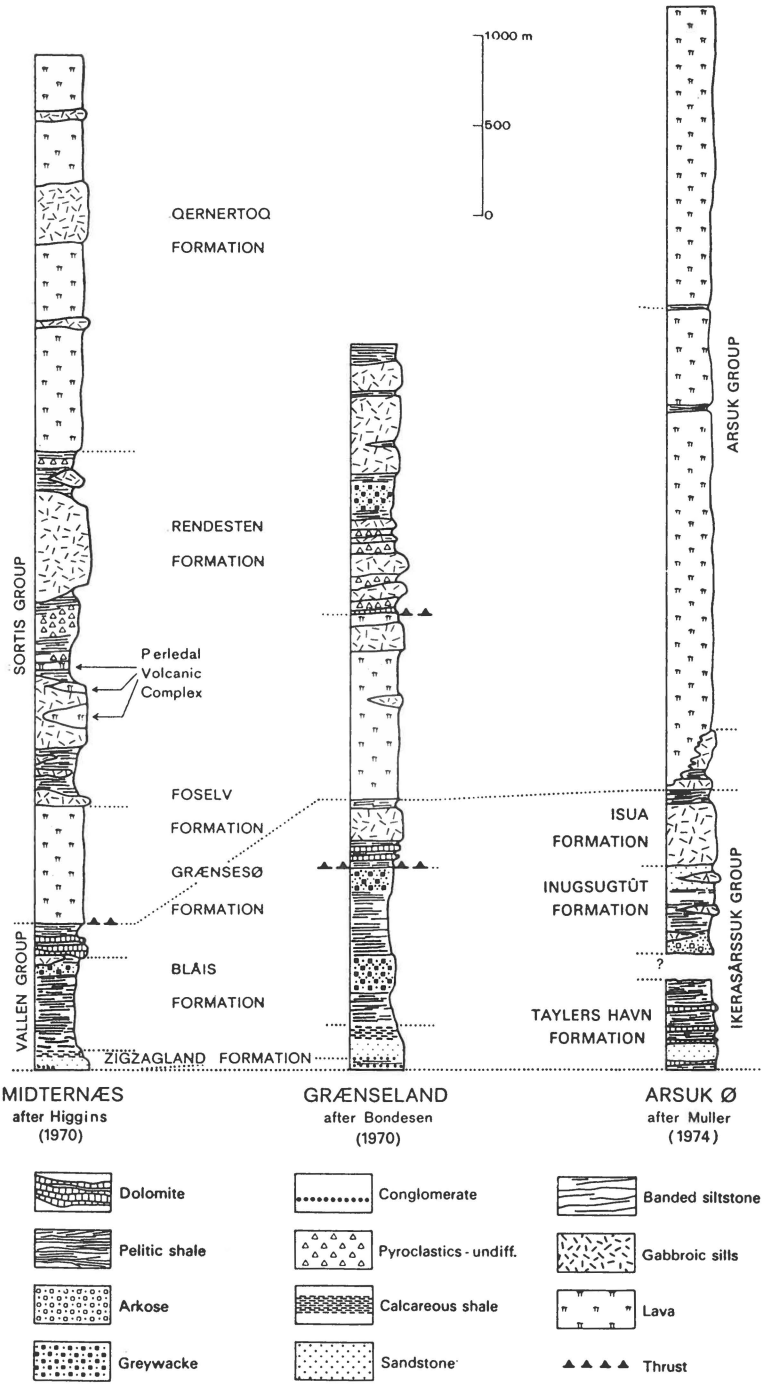


Fig. 31. The Ketilidian successions of Midternæs, Grænseland and the Arsuk Ø area. After HIGGINS (1970).

Table 4. *Ketilidian supracrustal rocks in the Ivigtut region*

Grænseland After Bondesen (1970)	Arsuk Fjord – Qipisarqo	Arsuk Ø area After Muller (1974)
	Ilordleq Group (mainly volcanics)	
	Qipisarqo Group (sediments)	
– – – ? – – –		– – – – ? – – –
Sortis Group (mainly volcanics and pyroclastics) Rendesten Fm Foselv Fm	Amphibolites (locally with pillow lava structures) and occasional mica schists	Arsuk Group (mainly volcanics)
Vallen Group (sediments) Grænsesø Fm	Mica schists	Ikera-sârssuk Group (sediments) Isua Fm
Blåis Fm	Mica schists + dolomites	Inugsugtût Fm
	Quartzites	
Zigzagland Fm	Mica schists–gneissic schists	Taylers Havn Fm

deformation increases southwards, and Grænseland therefore is one of the most favourable sites for a study of the stratigraphy of the Ketilidian sedimentary formations; here metamorphic conditions appear to be of greenschist facies type, with low quartz-albite-muscovite-chlorite subfacies in the northern part, and higher quartz-albite-muscovite-biotite subfacies in the southern part.

In Grænseland the preserved part of the Ketilidian sequence measures at least 4400 m; on Midternæs it amounts to more than 5000 m, and in the Arsuk Ø area it is estimated to about 5500 m. All sequences include a high pillow-lava proportion whose mode of accumulation may lead to over-estimates of thickness (Allaart, pers. comm.). In the southeast part of the map area, probably younger Ketilidian formations totalling several thousand metres occur.

Correlation of the individual members and formations even within each region is uncertain owing to marked facies variations. However, it seems probable that the lower sedimentary groups of Grænseland and of the Arsuk Ø area formed more or less simultaneously, and that the volcanic formations of the Sortis and the Arsuk Groups are correlatable (table 4, fig. 31). The rocks of the Qipisarqo Group found in the southwest part of the map area are probably younger than those of the Sortis

and Arsuk Groups, though BONDESEN (1970) suggests they may be equivalent to the upper part of the Sortis Group.

Recent age determinations on muscovite schists of Ketilidian age at Qôrnoq gave a metamorphic age of 1800 m.y. (LARSEN, 1971). These support estimates by BONDESEN *et al.* (1967) of *c.* 2000 m.y. for deposition of the earliest Ketilidian formations.

Grænseland and Arsuk Ø area

Studies of the sub-Ketilidian surface in Grænseland by BONDESEN (1970) show it to be a peneplane with minor and local irregularities. During early Ketilidian sedimentation old faults in the basement were revived and had a controlling influence on basin formation and facies distribution. These phenomena cannot be demonstrated in other regions owing to the greater intensity of Ketilidian deformation and metamorphism.

In small and local depressions in the sub-Ketilidian surface in Grænseland traces of possible continental-fluviatile sedimentation have been found. These deposits embrace arkoses, gravels and conglomerates only a few metres thick. They are of particular interest as they contain boulders of orthoquartzites and cherts (of unknown parentage), as well as fragments and boulders of gneiss, altered amphibolite, chlorite schists, vein quartz and arkose. The residual arkosic and conglomeratic deposits form part of the lowermost unit of the Zigzagland Formation (table 5) while the remaining part of the formation is of probable marine origin (BONDESEN, 1970).

The deposition of the marine, lower part of the Zigzagland Formation in southern Grænseland was accompanied by a deep-reaching alteration (carbonatisation) of the underlying residual deposits and the pre-Ketilidian gneisses. To a depth of 3–10 m in the gneisses all minerals except quartz have been replaced by carbonates (dolomite), chlorite and opaque minerals. Mafic rocks are mainly altered into chlorite, pyrite and magnetite. Below this intensely altered zone a 10–20 m thick zone of partly altered gneiss occurs, and carbonate-filled veins extend probably to a depth of 100 m below the unconformity.

Northern Grænseland was not inudated by the Ketilidian geosyncline until the time of deposition of the upper Zigzagland Formation, and here as on Midternæs no traces of similar alteration have been found.

According to BONDESEN (1970), the alteration most probably took place in a submarine environment associated with deposition of the Lower Dolomite Member and a concomitant formation of chert lenticles.

Transgression of northern Grænseland and parts of Midternæs occurred during the deposition of the Ore Conglomerate Member the

Table 5. *Ketilidian supracrustal rocks in the Grænseland area (after* BERTHELSEN & NOE-NYGAARD, *1965, based on* BONDESEN, *pers. comm. 1963, and* BONDESEN, *1970)*

SORTIS GROUP	Rendesten Formation		Banded semipelites and pelites including varved shales and quartzitic slabs (500 m) Pelites, semipelites (100 m) or bedded psammites with pelites and greywackes (300 m) Pyroclastics (200 m) Semipelites, graded greywackes (200 m) or pelites, pyroclastics (400 m) Pyroclastics (0–1000 m) Dolomites and pelites (0–100 m)
	Foselv Formation *c.* 1000 m		The Upper Pillow Member (> 700 m) The Anthracite-Carbonaceous Shale Member (1–3 m) The Lower Pillow Member (300 m)
VALLEN GROUP	Grænsesø Formation (20–100 m)		Cherty quartzite, pelite and dolomite *Vallenia* Massive dolomite Carbonaceous pelites
	Blåis Formation (40–800 m)		Rock units with strong facies variations comprising: { Graded or banded greywackes semipelites—banded shales and slates. Pelites—finely laminated, interbedded shales and slates.
	Zigzagland Formation	Upper	The Dolomite Shale Member (0–150 m) The Banded Quartzite Member (3–140 m) The Ore Conglomerate Member (1–10 m)
		Lower	The Rusty Dolomite Member (0–8 m) The Varved Shale Member (2–20 m) The Lower Dolomite Member (3 m) Residual deposits on the sub-Ketilidian surface
	Unconformity		Pre-Ketilidian gneisses

entire Midternæs area not being inudated until the time of deposition of the succeeding quartzitic member.

The Ore Conglomerate Member of Grænseland is notable for the high content of opaque minerals (mainly magnetite) in the matrix. The boulders are variously coloured cherts in Grænseland, but on Midternæs boulders of gneiss and amphibolite also occur. The deposits are regarded as original black sands which have suffered a metamorphic rearrangement of the ore constituents. South of Lappesø, the matrix comprises pyrite and quartz.

Equivalents to the Ore Conglomerate Member are not known south of Arsuk Bræ, or in the Arsuk Ø area.

The development of the Banded Quartzite Member in Grænseland still reflects the transgressive phase of the Ketilidian sea, a variety of synsedimentary structures indicating predominance of shallow turbulent waters. The upper part of the Member may have been deposited in deeper water. The succeeding Dolomite Shale Member marks a return to carbonate sedimentation.

The Blåis Formation, which in terms of thickness is the most important formation in the Vallen Group, shows strong lateral facies changes apparently related to movements on the NW–SE trending Bæversø fault. Close to the fault a polymict conglomerate with gneiss boulders was found (the "Wildflysch"-arkose unit) (BONDESEN, 1970). A general deepening of the sea during the deposition of the Blåis Formation is suggested by the presence of graded greywacke deposited as turbidites.

A new phase in the basin development opened with the deposition of the Grænsesø Formation, where carbonaceous shales alternate with siliceous dolomites and are succeeded by cherty quartzites and pyritic shales.

The Grænseland rocks have yielded a variety of structures of organic origin, as well as traces of organic compounds (BONDESEN *et al.*, 1967; PEDERSEN & LAM, 1968; LAM & PEDERSEN, 1968). Of particular interest is a globular structure of *c.* 0.5 mm diameter known as *Vallenia* occurring in abundance in a dolomite of the Grænsesø Formation. Following its initial discovery by BONDESEN, it has been found at 5 widely separated localities in Grænseland (and Midternæs) at the same stratigraphical level.

In the Arsuk Ø area, the lower sedimentary group of the Ketilidian sequence, the Ikerasârssuk Group (MULLER, 1974), comprises from 1000 to 1500 m of arenaceous, argillaceous and carbonate rocks in a varied succession (table 6); lithological units are less distinct than in Grænseland. The top part of the Ikerasârssuk Group is also, however, characterised by pyritic phyllites with chert lenticles.

Ketilidian volcanism began in the Arsuk Ø area and in Grænseland with the submarine eruption of pillow lavas; their appearance in the successions marks the commencement of the Arsuk Group and Sortis Group respectively (table 4). The sequence on Arsuk Ø totals 4200 m of lavas with subordinate sedimentary intercalations. In Grænseland only about 1000 m of lavas occur (the Foselv Formation) but they are succeeded by the thick pyroclastic deposits and sediments of the Rendesten Formation.

Gabbroic sills, often of rather irregular shape and varying thickness, occur at all levels in the Sortis Group; a thick sill is usually found in the Grænsesø Formation throughout most of its outcrop.

Table 6. *Ketilidian supracrustal rocks in the Arsuk Ø area (after* MULLER, *1974).*

ARSUK GROUP		Basic lava, massive and with pillow structures (4100 m); with interbedded volcanic breccias, tuffs and lapillis, and cherts (50–100 m) Phyllites and cherts (7 m) and massive lava
IKERASÂRSSUK GROUP	Isua Formation	Phyllites with basic sill
	Inugsugtût Formation	Phyllites and quartzites with basic sills
	Unexposed	
	Taylers Havn Formation	Micaceous, pyritic and graphitic schists with interbedded calcareous metasediments Dolomitic calcareous metasediment (6–7 m) Phyllites and calcareous quartzites Quartzites (110 m)

The Ketilidian basic effusives and intrusives appear to be of tholeiitic composition with the very low K_2O content which appears to be characteristic of Precambrian geosynclinal volcanism (BARAGER, 1968). Chemical analyses of the Ketilidian volcanics have been presented by HENRIKSEN (1969b), BONDESEN (1970) and HIGGINS (1970).

MULLER (1974) gives a detailed description of the primary structures of the volcanics of the Arsuk Ø area. He distinguishes between ellipsoidal and amoeboid pillows, pillow breccias, massive flows, tuffs, lapilli and detrital volcanic breccias. Feeding tubes to individual pillows have quite commonly been observed. Thin dykes with xenoliths of gneiss and quartzite brought up from below cut the pillow lavas and the massive flows, and are considered to form part of the volcanic association. The interstratified sediments are pyritic phyllites with lenticles and slabs of chert or quartzite.

On Arsuk Ø, ultramafic rocks are associated with the volcanics. Masses, 100 to 200 m long and 5 m thick, composed of more or less serpentinised olivine and brown hornblende, occur at the base of a thick metagabbro flow. More irregular masses of serpentinised dunite also occur.

The association on Arsuk Ø of sediments, pillow lavas, diabase, gabbro, and ultramafics is strongly reminiscent of the Alpine ophiolitic assemblages thought to represent upthrust oceanic crust. The metasediments, metavolcanics and ultramafics of the Tartoq Group also show



Fig. 32. Ketilidian interbanded quartzite and mica schists. West side of inner Qôrnoq. Photo: S. B. JENSEN.

ophiolitic affinities. In both cases, however, the age is Precambrian, and as for the Ketilidian we know for sure that the ophiolitic rocks were formed on a continental crust made up of pre-Ketilidian gneisses.

Eastern belt south of Arsuk Bræ

The supracrustal rocks south of Arsuk Bræ have been studied by S. BAK JENSEN, the following review being based largely on unpublished field- and laboratory reports (JENSEN, 1957, 1958; see also WINDLEY *et al.*, 1966).

Throughout its extension from Skjortesø south-east of Arsuk Bræ, via Blindtarmen, Qôrnoq, Kînâlik, to south of Qipisarqo, this belt of supracrustals comprises a lower division of mica schists with often prominent layers or intercalations of quartzite (fig. 32), calcareous schists and dolomitic marbles. In some places, quartzites and quartzitic schists form the lowermost units, while in others, mica schists border on gneissic schists and gneisses derived from metamorphosed supracrustals or reworked pre-Ketilidian rocks. On Kînâlik the supracrustals are bordered by transgressive Ketilidian granite.

The lower metasedimentary division is succeeded by amphibolitic greenstones. East and south-east of Skjortesø relic pillow structures have been found in the upper part of the greenstones (Fig. 33). JENSEN (1960) mentions that the lower part may be derived from gabbro. Mapping in this region was hampered by lack of reliable topographic maps, and the

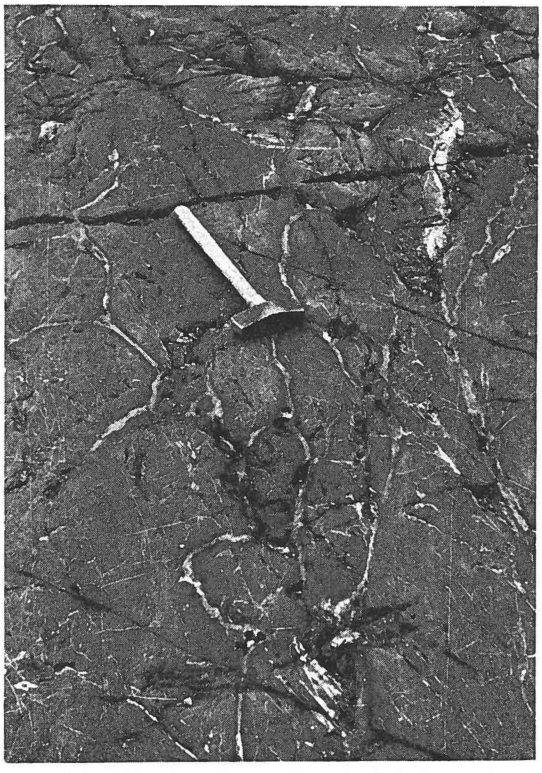


Fig. 33. Ketilidian metavolcanic. Pillow structures in Ketilidian basic metavolcanics. West side of Hoveddal, north of head of Qôrnoq. Photo: S. B. JENSEN.

outcrop pattern shown on the geological map (plate 1) is partly based on photogeological interpretations. At present, it is therefore difficult to correlate in detail rock units across Arsuk Bræ. However, it is probable that the lower metasedimentary division corresponds to the Vallen Group of Grænseland, and that the greenstones are in part equivalent to the metavolcanics of the Sortis Group.

The greenstones south-east of Skjortesø are overlain by a conglomerate unit, which also occurs at a few localities along the river flowing down Hoveddal. A larger area of exposures occur west of Hoveddal and east of Qôrnoq Langsø, where an E-W trending wrench fault cuts the south flank of an open Ketilidian syncline. At Blindtarmen and Qôrnoq, where the conglomerates are not present the greenstone unit is in contact with the younger Qôrnoq augen granite (p. 88), which make up the country east of Qôrnoq. On Kînâlik and south of Qipisarqo pillow structures, sometimes highly deformed, are found in the amphibolitic greenstones, and in both areas they are overlain by conglomeratic deposits very similar to those found north of Qôrnoq (fig. 34). The matrix of these conglomerates

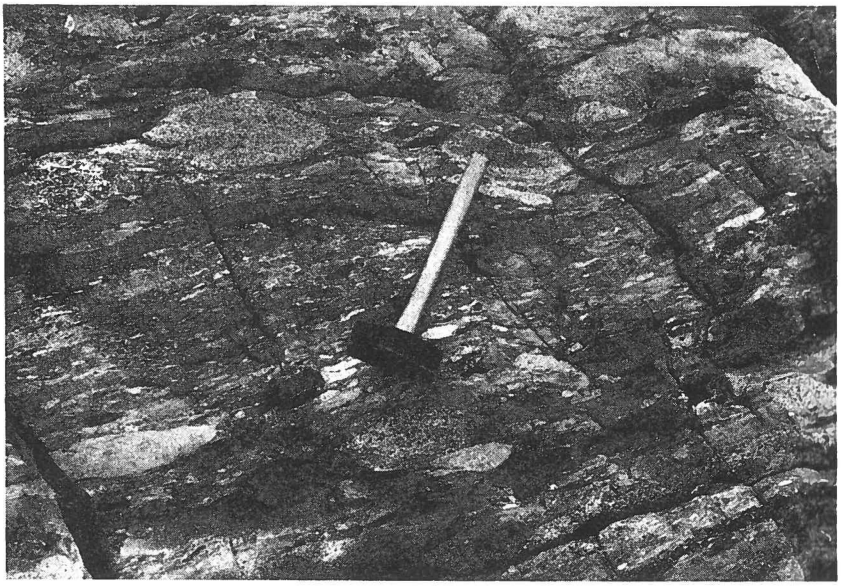


Fig. 34. Deformed Ketilidian conglomerate in the lowest part of the Qipisarqo Group. Kînâlik south of the mouth to Qôrnoq. Photo: S. B. JENSEN.

is gritty, and besides quartz and feldspar varying amounts of hornblende and epidote occur. In the Qipisarqo area, the last two minerals predominate in the matrix. The conglomerate is polymict and contains boulders and cobbles of both gneiss and epidote-amphibolite. Usually the boulders are much flattened.

The conglomeratic beds pass upwards gradually into gritty quartzitic, greywacke-like or semipelitic metasediments. In the Qipisarqo area (BERTHELSEN *et al.*, 1962) a thick succession of red-brown to greenish biotite and biotite-muscovite schists form the uppermost unit of this supracrustal sequence, which has been referred to as the Qipisarqo Group (BERTHELSEN & NOE-NYGAARD, 1965, p. 128).

The presence of crystalline boulders in the Qipisarqo conglomerate, which overlies the greenstones over a distance of more than 30 km, suggests radical change in the conditions controlling the Ketilidian sedimentation.

S. BAK JENSEN has mapped the Qipisarqo Group rocks and the supracrustals underlying them in a belt along the south coast of the island just south of Sánerut. The West Sánerut granite (p. 100) intrudes semipelites which probably belong to the upper part of the Qipisarqo Group. The pillow-structured greenschists and metasediments which underlie the Qipisarqo Group rocks of south Sánerut total a few hundred metres.

In the extreme south-eastern part of the map, pelites, greenschists containing sedimentary intercalations, and metavolcanics occur as an east-north-east continuation of the supracrustals of Kobberminebugt and the Ilordleq area (WATTERSON, 1965). These rocks are described in the description to the Nunarssuit map sheet 60 V. 1 N (PULVERTAFT, in prep.)

KETILIDIAN DEFORMATION OF THE SUPRACRUSTAL ROCKS

Detailed structural analyses have been made in several of the areas of Ketilidian supracrustals, but the individual areas are too widely separated and data too scanty to permit a comprehensive regional synthesis. Emplacement of granites and wrench fault displacements are further complicating factors. As the areal descriptions which follow indicate, the structures in the cover rocks reflect the Ketilidian deformation of the basement gneisses, and there is a similar increase in intensity of deformation from north to south.

Arsuk Ø area

MULLER's study of the Arsuk Ø area also includes a detailed account of the Ketilidian deformation (MULLER, 1974). The oldest phase distinguished resulted in the production of an axial surface cleavage (S_1). In the sedimentary Ikerasârssuk Group the cleavage was developed in connection with formation of "plis de cisaillement" of shear fold type and development of quartz rods. In the volcanics, development of the cleavage accompanied a considerable stretching of the pillows. The linear elements formed parallel to the axis of a major reclined structure seen in the north-western mountain slopes of Arsuk Ø (see WEGMANN, 1938, fig. 27), which suggests westward transport of the upper units. Originally the axes of the folds formed during the first phase may have trended N–S, but considerable variations in plunge and trend are now found due to subsequent refolding.

During a second phase of deformation the S_1 cleavage was modified to a crenulation cleavage with concomitant development of an S_2 cleavage. The style of the second phase folds is notably different in the two major lithological groups, which acted as distinct structural levels. The two disharmonious levels are separated by a zone of transition where a complex "tectonic mélange" of sedimentary and volcanic rocks is found. In the upper level, exposed in the central and western parts of Arsuk Ø, a large syncline with a SW or WSW-plunging axis and an overturned southern limb was formed, while in the lower unit (e.g. on the east coast

of Arsuk Ø) tight to isoclinal folds and mainly northwards-directed thrusts developed. In this lower level the axes plunge W or NW.

The structures of the third phase distinguished by MULLER are best seen at Taylers Havn, where they are represented by a marked syncline plunging S or SSW. The S_2 cleavage was distorted into accordion folds of a few millimetres to about 10 cm amplitude and an S_3 fracture cleavage formed.

MULLER suggests that the second phase structure developed in conjunction with vertical movements in the basement to the east and south so that a northward-directed *décollement* of the Ketilidian formations into the depression developed. Further rise of the basement region to the east may have accompanied the third phase folds which are most intensely developed in the Ketilidian sediments along the border of the Ivigtut peninsula. The rise in the basement may also have caused the tectonic break at the contact between the Ketilidian sediments and the pre-Ketilidian gneisses, and accentuated the earlier-formed depression.

According to MULLER (1974), the first phase of deformation took place at *P-T* conditions corresponding to a high greenschist facies within the biotite zone. In the basic volcanics, the S_1 cleavage is marked by growth of chlorite, alteration of ilmenite to leucoxene and growth of albite.

Metamorphism reached its culmination between the first and the third phases of deformation, a low amphibolite facies being reached in the Ikerasârssuk Group. The third phase caused reorientation of the amphibolite facies minerals and was accompanied and succeeded by a mobilisation of silica.

Independant analyses of the structure pattern in the Ketilidian supracrustals of Arsuk Ø by MULLER and the surrounding pre-Ketilidian gneisses by the authors show striking similarity. The development of the tight Ketilidian antiform (between Ikapynt and Quiartorfik), which refolded the nose of the Nordland gneisses in outer Íka (fig. 35), is reflected very well by the NNW-wards transport direction shown by the structures in the upper structural level of the Arsuk Group. Not surprisingly, the oldest minor recumbent phases in the Ikerasârssuk Group could not be isolated in the pre-Ketilidian gneisses. As mentioned by WEGMANN (1938), the presence of the various structures show that the present limitation of the Arsuk Ø basin does not correspond to an original shape as a depositional basin.

Grænseland

In Grænseland, the intensity of deformation, and metamorphism, increases from north to south. BONDESEN (1970) established two principal deformational phases and a third of minor importance in an area south

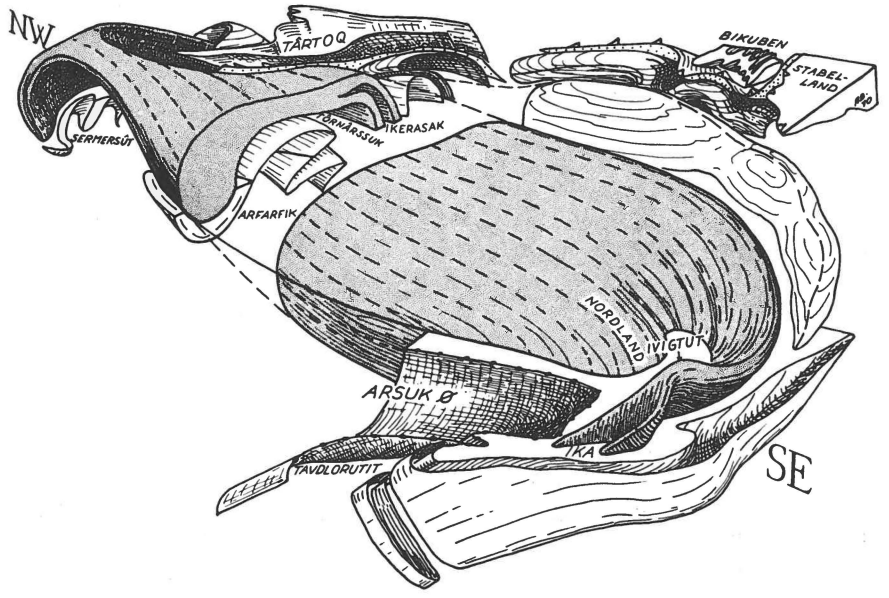


Fig. 35. Tectonogram of the central and north-west part of the Ivigtut region. Compare with plate 4. Shaded unit indicates the Nordland gneiss series.

of Vallen where the structures of the Dolomite Shale Member were studied in detail. Overturned, asymmetrical, ESE-plunging similar folds with axial plane cleavage (F_1) were here overprinted by smaller scale ENE-plunging Z-shaped folds with NNW-dipping axial plane cleavage (F_2). Locally, the axial plane cleavage of the F_2 folds was found to be folded into small open folds with steep NW or NNW plunges.

From this key area, BONDESEN (1970) traced F_2 folds on all scales throughout Grænseland, while F_1 folds appeared restricted to the incompetent members of the Vallen Group.

A prominent thrust zone south of Vallen was also the subject of a detailed study by BONDESEN (1970). This study reveals that F_1 structures were shown to be more common below the thrust, and F_2 structures more strongly developed above the thrust. Close to the thrust a scatter in the attitudes of the linear structures was noted. The direction of the trending appears to be parallel to the direction of the tectonic transport during the F_2 folding.

A major thrust at the base of the Grænsesø Formation, which north and south of Lappesø transgresses large scale F_2 folds in the Blåis Formation, is believed to have formed as a prolongation of F_2 deformation with movement from NNW towards the SSE (plate 3).

BONDESEN (1970, pp. 167–169 and fig. 65) presented a model intended to explain F_1 folding and thrusting as a consequence of concomitant

fault-controlled tilting of the rigid basement and large-scale, flexural-slip folding of the major competent units of the supracrustal succession. The ENE-dipping supracrustals of Grænseland were considered to form part of a large NNW–SSE trending synclinal flexure most strongly developed in its SSE portions. The inland ice, however, hides all but the western flank of this hypothetical structure.

The model presented by BONDESEN has, however, some serious drawbacks. Even if it explains the overfolding and thrusting which occurred in the incompetent units during the F_1 deformation, it cannot explain how the far more important F_2 folding and thrusting from NNW directions could have developed; particularly since the F_2 folding and the related thrusting increases in magnitude in the direction of increased compression of the hypothetical flexural syncline.

Since the Ketilidian reactivation of the basement increases towards the south-east, it is of note that the strongest folding in Grænseland, the F_2 folding, shows overturning towards the SSE or south, and that the major thrust unit apparently moved in the same direction, i.e. towards the front of kinetic transformation as traced from the structures in the basement rocks. This setting could be explained if F_2 folding and the related overthrusting were viewed as gravitationally induced epidermal gliding (in the sense of VAN BEMMELEN), and would explain the close relation between basin shape and fold development.

Arsuk Bræ to Qipisarqo

WINDLEY *et al.* (1966) presented some schematic sections through the supracrustals of the eastern belt. The sections are drawn parallel to the general strike direction along the contact between Ketilidian supracrustal and infracrustal rocks. In the section for that part of the eastern belt which lies south of Arsuk Bræ, structures with overfolding towards the south are shown which involve both the supracrustal sequence and the infracrustal (i.e. basement) rocks immediately adjacent to the original unconformity surface. There is, however, no evidence to support the assumption of a southerly "Vergenz" in the folds of this region, and in the supracrustals between Qôrnoq Langsø and Arsuk Bræ the larger ENE-plunging folds are overturned north-westwards. East of Qôrnoq Langsø, one of these folds involves the conglomerates of the Qipisarqo Group in its core.

JENSEN (in BERTHELSEN *et al.*, 1962) describes the structures in the Ketilidian supracrustals of the Qipisarqo area. Fold axes were constructed for small subareas. In the south-west area SW plunges occur, but further to the east the plunge increases and becomes southerly. In

the north-east, SE to eastern plunges are found. This change in attitude indicates that the fold axes of the supracrustals describe a large flexure around the hinge zone of the E-plunging antiform found in the gneisses of eastern Sánerut. This axial flexure is reminiscent of that shown by the oldest folds in the supracrustals in the syncline on Arsuk Ø, except that it is antiformal.

KETILIDIAN GRANITES *(sensu lato)*

Ketilidian granites are the most abundant rock types in the south and south-eastern part of the Ivigtut region coincident with the greatest intensity of Ketilidian deformation. In the north part of the region there occurs only one Ketilidian intrusive complex, north of the fjord Puiátoq, which is the northernmost Ketilidian granite recorded in South-West Greenland.

The Ketilidian granites in the Ivigtut region may be divided into two main units according to their relations with the surrounding rocks. One of these comprises autochthonous-parautochthonous granites with syn- to late-kinematic features, and the other comprises allochthonous granites with post-kinematic features. The autochthonous-parautochthonous granites are generally found in the borderzone between Ketilidian supracrustals and the pre-Ketilidian basement in the south and south-east parts of the region. The allochthonous granites form plugs and plutons in the Ketilidian border zone and in the pre-Ketilidian foreland.

Autochthonous-parautochthonous granites

These granites may be divided into a group of foliated and a group of foliated to homogeneous types. The first comprises synkinematic rocks and the second spans varieties ranging from foliated types with overgrowths of non-directional feldspar porphyroblasts to more homogeneous granites. The period of emplacement of the second group of granites probably outlasted that of the former. The relative age relations between the different types are not completely known.

The granites occur in an arching belt, concave to the north-west which follows the border between the Ketilidian supracrustals and the pre-Ketilidian infracrustal basement. The granites occur both in the supracrustal rocks and in the infracrustal rocks, but it is characteristic that the various types of granite are found almost exclusively in either the one or the other environment.

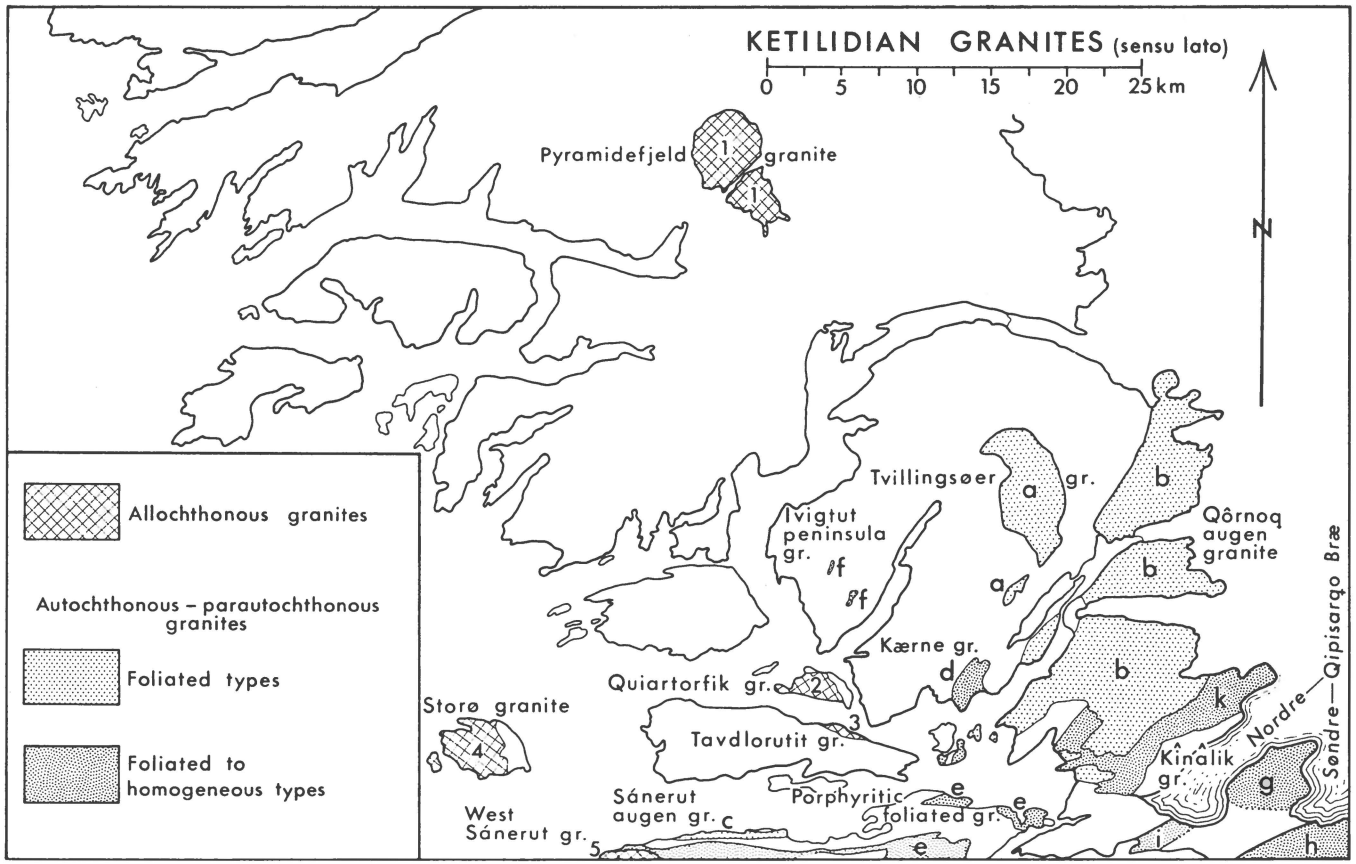


Fig. 36. Ketilidian granites (*sensu lato*) in the Ivigtut region.

The description of these granites is mainly based on the work of JENSEN (1957, 1958, 1960). Fig. 36 shows the distribution and classification of the various Ketilidian granites.

Foliated types

This group comprises three different types of foliated granites formed under a regional kinematic influence:
(a) The Tvillingsøer granites between Arsuk Fjord and Blindtarmen.
(b) The Qôrnoq augen granite north and south of the head of Qôrnoq fjord.
(c) The Sánerut augen granite found in a narrow belt along the north coast of the western part of Sánerut.

(*a*) *Tvillingsøer granites*

There are two main granite bodies. The northern body is oval shaped, *c.* 9×4 km in area and oriented with its longest axis north-south, conformable to the regional orientation in the surrounding gneisses. The smaller body is found just to the south and is *c.* 2.5×0.5 km in size.

Both bodies consist of foliated, often gneissic, granites. The borders to the surrounding gneisses are mainly gradational but granite veins and pegmatites related to the main bodies have clearly intrusive features. They contain numerous gneissic inclusions, which have preserved their orientation undisturbed, conformable with the structures in the surrounding gneisses. Relics of pre-Ketilidian discordant amphibolitic Iggavik dykes occur abundantly. They are found as boudinaged and broken dyke remnants cut by granitic veins and pegmatites related to the granite. The trend of the dyke relics within the granite is also conformable to the general trend of the surrounding gneisses. It can therefore be assumed that the general north-south trending structures in this part of the area were already in existence at the time of emplacement of the Tvillingsøer granites.

Granitic and pegmatitic dykes and veins occur abundantly near the main bodies in the surrounding rocks. The density of these acid veins increases rapidly towards the autochthonous granite indicating that they must be related to the emplacement of the main body. Late granitic and pegmatitic veins also cross-cut the main bodies with their inclusions of gneissic and relic discordant amphibolitic dykes.

The larger of the two bodies is a fine- to medium-grained biotite granite with a granodioritic to adamellitic composition. K-feldspar porphyroblasts sometimes occur in the western part. To the north of Tvillingsøer the granite is often more gneissic than it is to the south.

The rock is leucocratic with 5–10% mafics, of which biotite is dominant. Other constituents are oligoclase, quartz, microcline, muscovite, epidote, opaque minerals, chlorite and small, relic garnet grains. Sphene, apatite and zircon are accessories.

The small body west of Blindtarmen has the same characteristics as the southern part of the larger body.

(b) Qôrnoq augen granite

The large augen granite area occurring both north and south of the head of the fjord Qôrnoq is the most extensive granite in the Ivigtut region. It is exposed over an area approximately 30 km in length and up to about 10 km in width. To the east it is bordered by the icecap covering an unknown extension, and to the west by Ketilidian supracrustal rocks. To the south the boundary is formed by the younger Ketilidian Kînâlik granite and by Ketilidian supracrustal rocks. The western boundary and the foliation in the granite are here conformable to the trend of the adjacent Ketilidian supracrustal belt. The southern boundary is more irregular, but some parallelism with the trends of the Ketilidian supracrustal rocks does exist. On a large scale, the granite appears structurally highly influenced by the Ketilidian structures.

The Qôrnoq augen granite is clearly younger than the surrounding Ketilidian supracrustal rocks. This relation is evident from localities which show discordant relationship between the supracrustal rocks and the granite (fig. 37). However, in most cases the boundary to the supracrustal rocks is conformable.

Lenses of the supracrustal rocks are sometimes found within the granite near their mutual boundary (fig. 38), and granitisation phenomena in the supracrustal rocks can be observed occasionally in a zone close to the border.

At the entrance to the fjord Qôrnoq the supracrustal rocks occur on both sides of the fjord separated by a zone of augen granite more than two kilometres wide. The structural relations in these supracrustal bands, both younging from west to east, suggest that the two areas of supracrustals may have been separated by the widening effects of emplacement of the granite. This interpretation implies an intrusive emplacement of the granitic material in this area.

The Qôrnoq augen granite is a fine- to medium-grained foliated augen granite, with augen developments up to 2×7 cm in size, although usually smaller. The orientation of the elongated augen is parallel to the foliation. The rock generally has an adamellitic composition, although granitic and granodioritic varieties occur. The augen consist mainly of aggregations of xenoblastic microcline grains, each with an average size

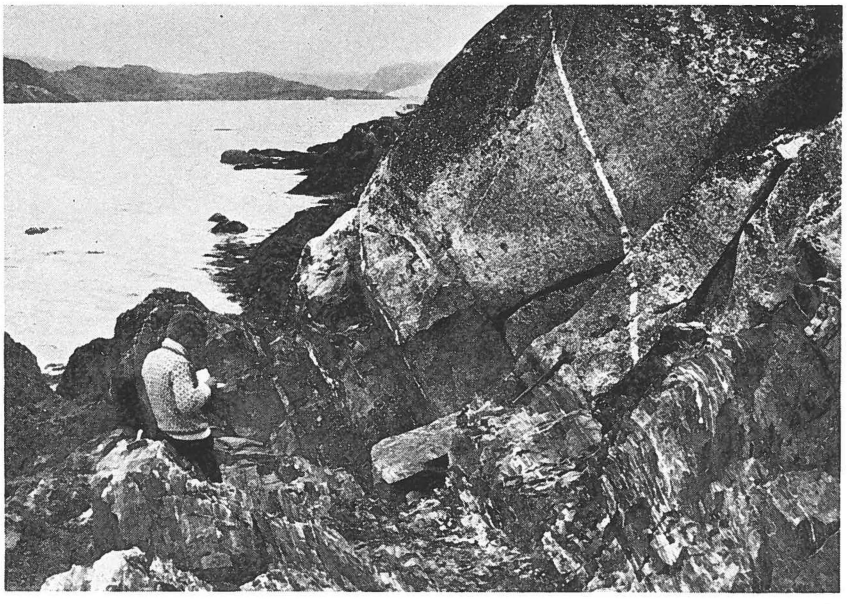


Fig. 37. Qôrnoq augen granite in contact with Ketilidian mica schists. The contact zone is offset by minor faults. Small island north-north-west of Kînâlik. Photo: S. B. JENSEN.

much larger than that found in the groundmass. The foliation and the mafic seams of the groundmass sweep smoothly around the augen, which developed synkinematically.

The rock consists primarily of microcline, oligoclase and quartz. The plagioclase is partly replaced by microcline and often an albite rim is developed on the boundary between plagioclase and microcline. The mafic minerals are usually concentrated in seams. Biotite dominates, but hornblende is sometimes also present. In small amounts muscovite, opaque minerals, epidote and allanite have been found; and sphene, zircon and fluorite are accessories. Fluorite occurs occasionally in small cracks, and it is clearly formed later than minerals in the host rocks.

(*c*) *Sánerut augen granite*

This body *c.* 8×0.5 km in area occurs along the north coast of the western part of Sánerut. It is a foliated augen granite in which the structures are conformable to the surrounding gneisses. The boundary to the gneisses is mostly gradational, but discordant relationships have been recorded. Close to the boundary the adjacent gneiss is mostly homogeneous whilst further away it becomes banded. The foliation in the granite is approximately E–W, and dips steeply. The augen are elongated



Fig. 38. Qôrnoq augen granite with inclusions of schists. South side of outer Qôrnoq. Photo: S. B. JENSEN.

with their longest axes in the plane of foliation and average *c.* 1 cm in length. The granite is rather uniformally developed, contains biotite-rich schlieren and is cut by granitic veins and younger pegmatites.

The composition is adamellite to granodiorite, oligoclase, microcline, quartz and biotite being the main constituents. Sphene, apatite, allanite and epidote are found in small amounts; chlorite and sericite are secondary products. The rock is fine to medium grained with a granoblastic to catablastic texture. The augen comprise xenoblastic microcline grains, which often are bordered by myrmekite. Microcline replaces plagioclase. Following formation of the larger microcline xenoblasts the rock suffered cataclasis and partial recrystallisation.

Foliated to homogeneous types

Of these granites some developed primarily in a syn-kinematic stage with only a limited degree of late kinematic growth, while others formed mainly in a late kinematic stage. Feldspar porphyroblasts in some of the granites grew after kinematic control had ceased.

The various granites in this group are nowhere in direct contact with each other, and their mutual age relations therefore cannot be directly established. The granites occur in the Ketilidian supracrustal rocks as well as in the infracrustal gneisses. On the basis of occurrence they are divided into:

(A) Granites occurring in the infracrustal region.

(d) The Kærne granite, occurring north of the entrance to the fjord Qôrnoq.

(e) Porphyritic foliated granite bodies on Sánerut and on the small islands in Qôrnoq.

(f) Ivigtut peninsula granites.

(B) Granites occurring in the supracrustal region. These are all found in the extreme south-east part of the area covered by the map sheet.

(g) The granite on the nunatak between Nordre and Søndre Qipisarqo Bræ.

(h) The granite south of Søndre Qipisarqo Bræ.

(i) The granite in front of Nordre Qipisarqo Bræ.

(k) The Kînâlik granite, which outcrops mainly north of Nordre Qipisarqo Bræ.

All these granites, with the exception of the Kînâlik granite, are believed to have formed over a span of time covering both syn- and late-kinematic stages and they are thus, on a large scale, considered to be more or less contemporaneous. The Kînâlik granite is different and formed mainly in a late kinematic stage, and thus could be of slightly later date. There is a possibility that the Kînâlik granite may represent a transitional stage between the parautochthonous and allochthonous granites, and that the late kinematic parautochthonous granites in the fold belt and the allochthonous granites found in the foreland north-west of the Ketilidian folded area may be contemporaneous.

The above-mentioned seven granites are described as follows:

(*d*) *Kærne granite*

This body, about 2 × 3.5 km in outcrop, occupies the core of a slightly dome-shaped antiformal structure south-west of Blindtarmen on the north side of the fjord Qôrnoq. It has gradational borders with the surrounding gneisses, which are homogeneous near the granite. It is medium grained and locally contains non-orientated semi-porphyric microcline grains. In some places the rock is weakly foliated, but usually exhibits non-directional textures. The composition is adamellitic, comprising almost equal amounts of quartz, microcline and oligoclase. The mafics, forming approximately 5 % of the rock, are primarily biotite, and opaque minerals, allanite and muscovite occurring in small amounts.



Fig. 39. Porphyritic foliated granite. South side of Sánerut. Photo: S. B. JENSEN.

(*e*) *Porphyritic foliated granite*

This type occurs mainly on the island of Sánerut, but is also found on some of the small islands at the entrance to the fjord Qôrnoq. On Sánerut it occurs in two areas: the smaller on the north-east of the island is cut and displaced by a WNW sinistral fault; the larger granite area is irregular in shape and can be traced for more than 20 km in an east–west direction on southern Sánerut. The width of the larger body varies from approximately 100 m to more than 4 km.

Borders with the surrounding gneisses are generally gradual although locally they may be sharp. On south Sánerut (outside the map sheet) locally discordant borders to the Ketilidian metasediments have been recorded. Occasionally the boundaries to the gneisses may be very diffuse, the granite being gneissic towards the borders and the gneisses containing feldspar porphyroblasts similar to those found in the granite.

The rock is fine to medium-grained, foliated, and characterised by abundant well-shaped 1–3 cm long non-directed microcline porphyroblasts (fig. 39). The composition is granite to granodiorite. Microcline porphyroblasts are idiomorphic to xenomorphic and may reach a maximum length of up to 5 cm. The foliation and the main outlines of the bodies are conformable with the regional structures.

The granite consists generally of microcline, oligoclase, quartz and biotite. Muscovite, opaque minerals, epidote, sphene, allanite and apatite occur in small amounts, with chlorite as an alteration product. The

textural relations indicate that the groundmass of the granite formed synkinematically, and that the porphyroblasts formed later under static conditions.

(*f*) *Ivigtut peninsula granites*

As shown on the geological map of the Ivigtut peninsula (plate 2), several small granite bodies up to 1 km in length occur in the southern part of this peninsula.

A SW–NE trending zone of bodies is found north of Randfjeldene. On the map, a discordant amphibolite is shown to continue through the largest of these. This picture holds true considering the scale of the map, but in the field, the granite can be seen to give off veins and dykes which cut the almost intact amphibolite dyke (a metamorphosed Iggavik dyke). The contacts of this granite body are very irregular as the granite veins the surrounding gneiss, generally more or less parallel to the gneiss banding.

Another long and narrow body is found west of Blokdalen. A light coloured to pink, medium-grained granite here forms the groundmass of an intrusion breccia where it abuts on the north end of the folded and amphibolitised dyke. The angular, basic blocks of this breccia show varying grades of assimilation or granitisation.

Veins and dykes of coarse-grained, slightly porphyric granodiorite also occur. Northwards they are succeeded by non-dilational pegmatite veins, which in the vicinity of Ivigtut are muscovite-bearing.

(*g*) *The granite nunatak between Nordre and Søndre Qipisarqo Bræ*

This granite is approximately 7 × 3 km in area, completely surrounded by ice, and without exposed border relations. It is a medium-grained rock, but not completely homogeneous, the degree of foliation, mafic index and composition all varying to some extent (D. Bridgwater, pers. comm.). The granite may contain gneissic relics, particularly in the north-west part of the nunatak. In a northern zone hornblende is characteristic, but further south biotite is the main mafic mineral and forms 10–15 % of the rock. Non-orientated K-feldspar phenocrysts occur in the south and in the south-east corner the granite is more basic and contains hornblende. Near this mafic area greenschist relics are found in the granite. The whole area is transected by numerous veins of aplitic granite. Several relics of hornblende-bearing ultramafics probably belonging to an appinitic suite are found within the granite.



Fig. 40. Mica schists cut by network of dykes of Kînâlik granite. The dykes are 5 20 m wide. North of Nordre Qipisarqo Bræ, near the inland ice. Photo: S. B. JENSEN.

(*h*) *Granite south of Søndre Qipisarqo Bræ*

This body forms part of the northern marginal zone of the vast Julianehåb granite, which can be traced continuously for more than 100 km to the east-south-east (ALLAART, 1967). The part of the granite exposed on the Ivigtut map sheet is a non-foliated granite containing K-feldspar phenocrysts in its central part (D. BRIDGWATER, per. comm.). It is mainly leucocratic, but may locally contain up to 30% mafics, particularly near the greenschists to the north. The Julianehåb granite as a whole is of complex composite development (ALLAART, 1973).

(*i*) *Granite in front of Nordre Qipisarqo Bræ*

This is a medium-grained, foliated and reactivated granite, a rectangular body with margins conformable to the bordering Ketilidian metasediments. It contains large non-orientated microcline porphyroblasts. Its continuation to the south-west has been described in some detail by WATTERSON (1965), who shows that the porphyroblasts are a post-kinematic feature.

(*k*) *Kînâlik granite*

The Kînâlik granite is an irregularly shaped body found north of Nordre Qipisarqo Bræ. On a large scale its outlines are conformable to the general north-east trend of the surrounding rocks, but on a small scale the granite clearly cuts the Ketilidian metasediments and the Qôrnoq augen granite.



Fig. 41. Dyke of Kînâlik granite cutting Qôrnoq augen granite. East of Qôrnoq. Photo: S. B. JENSEN.

The border relation with the supracrustal rocks south of the granite is very complex and can best be described as migmatitic. An extensive network of veins cuts the mica schists (fig. 40). Traced towards the granite there is often a gradual increase in vein density and a transitional zone of the granite contains abundant schlieren and lenses of schists.

The boundary with the Qôrnoq augen granite is often difficult to place precisely, as the Kînâlik granite extensively veins the augen granite (fig. 41) and there may exist gradational transitions; the Kînâlik granite is clearly the younger. Intrusive dykes and veins of the Kînâlik granite are also found in the zone of supracrustal rocks south of the fjord Qôrnoq. The granite derives its name from the point Kînâlik, at the tip of the peninsula where veining of the supracrustals is conspicuous.

The Kînâlik granite is fine grained, sometimes medium grained, and is of granitic to adamellitic composition, with microcline, quartz and oligoclase as the most abundant minerals; about 5–10% muscovite or muscovite and biotite, and garnet may be present in small amounts. The microcline, which replaces plagioclase, has a slight tendency to porphyritic development. The common accessory minerals are zircon, opaque minerals, apatite and occasionally sphene.

Allochthonous granites

Five main bodies of allochthonous granites are found within the Ivigtut region; these were emplaced, probably as mobile bodies both into

pre-Ketilidian infracrustal rocks in the foreland region and into domains composed of early Ketilidian rocks. The granites are mostly clearly discordant stocks and may contain xenoliths of the surrounding rocks.

The granites classified here as allochthonous are:

Emplaced in pre-Ketilidian rocks

(1) The Pyramidefjeld granite complex

(2) The Quiartorfik granite

(3) The Tavdlorutit granite

Emplaced in Ketilidian rocks

(4) The Storø granite

(5) The West-Sánerut granite.

The granites are described individually below, although they are generally very similar. Their distribution is shown in fig. 36. The bodies 2 and 3 probably represent two parts of one original granite intrusion which has been divided by faulting.

The Pyramidefjeld granite complex is the northernmost of the allochthonous granites, and is the only one emplaced in pre-Ketilidian basement not affected by Ketilidian deformation to any marked degree. All other allochthonous granites were emplaced in either basement rocks modified by the Ketilidian orogeny, or in deformed Ketilidian supracrustals.

(*1*) *Pyramidefjeld granite complex*

The Pyramidefjeld granite complex situated north of the head of the fjord Puiátoq, was mapped and described by BONDAM (1956) and later by EMELEUS (1957a, 1958, 1963). It was recently renamed after the mountain Pyramidefjeld (ANDREWS & EMELEUS, 1971), but in earlier papers has been referred to as the Tigssaluk granite after the fjord Tigssalûp ilua which during the field work was known as Tigssaluk Fjord.

According to EMELEUS the intrusion comprises two granite stocks emplaced side by side. That in the north-west is about 20 km² in area and about 5 km in diameter. It forms a mountain rising to 1279 m, some 500 m higher than the surrounding gneiss plateau (fig. 42). The south-east granite has an area of about 10 km² and its highest point is 1130 m.

The borders of both stocks transect clearly the surrounding gneisses and the marginal part of the granite sometimes contains disoriented gneiss xenoliths. The margins dip steeply outwards. The outer 100 m of the granite margin is of slightly finer grain size, but there is no marked chilling. The contact of the north-west stock is rather regular, but that of

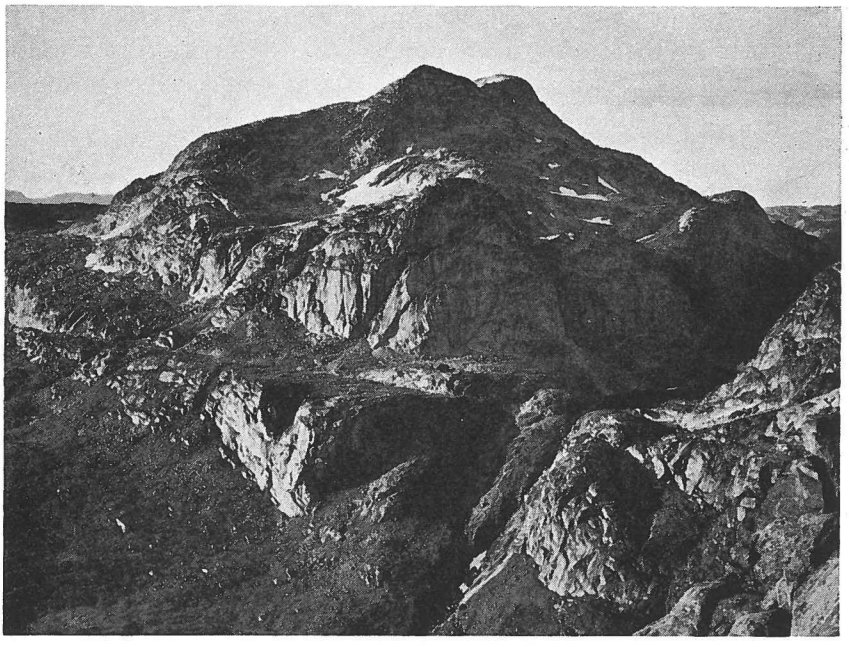


Fig. 42. Pyramidefjeld from the south-west showing the northern stock of the Pyramidefjeld granite complex. North-east of Puiátoq. Photo: L. F. BONNARD.

the south-east has a highly irregular outline owing to the lobate form of the border and the occurrence in the surrounding gneisses of granite sheets and veins; EMELEUS considers these veins to be more or less contemporaneous with the main south-east granite. Veins of the same type also cut the southern part of the north-west stock. The latter was thus of earlier emplacement, though both are of the same general age.

The main rocks of both stocks are coarse- to medium-grained granites (*sensu stricto*). They comprise microcline, microperthite, acid oligoclase, quartz and biotite. Accessory minerals are fluorite, which is characteristic of the rock, sphene, apatite, allanite, opaque minerals and occasionally zircon. The north-west body contains abundant alkali feldspar phenocrysts, usually between 0.5 and 1 cm in size but sometimes reaching 5 cm. Phenocrysts are seldom found in the south-east, and smaller, body.

Both bodies preserve good mineral layering formed by concentrations several centimetres thick of biotite, opaque minerals, sphene and allanite. These layers can be followed for up to 100 m and are best developed in the higher parts of the intrusion within 200 m of the gneiss contacts. The dip of the layering is mostly gentle and a few examples of fold and slump-like structures are recorded (EMELEUS, 1963).

Numerous rounded basic inclusions of biotite diorite often with lobate outlines are a common feature of both stocks. They have no regular

distribution. Their boundaries are usually sharp, but various stages of assimilation by the granite may be seen. In the north-west granite a small boss of biotite diorite occurs. This was emplaced, according to EMELEUS, later than the surrounding granite although its genesis is considered to be related to the diorite found as basic inclusions.

The emplacement of the two stocks has caused no, or very little, disturbance to the gneiss structure and there is practically no indication of reaction between the intrusive rocks and the bordering gneisses.

The Pyramidefjeld granite complex clearly cuts the Iggavik dykes, but is itself transected by the Gardar dykes. There may be some relation between small swarms of NE–trending micro-granitic dykes occurring north-east of the complex and the Pyramidefjeld granite itself (WEIDMANN, 1964).

(*2*) *Quiartorfik granite*

The major part of the island Quiartorfik comprises granite, which has been described by JENSEN (1957) and EMELEUS (1957b). In many respects it resembles the Pyramidefjeld granites. The contacts are sharp and the western marginal zone may contain rotated gneiss xenoliths. The grain size decreases towards the contacts. The north-east margin apparently contains numerous non-rotated gneiss xenoliths, but it is possible that this feature is due to the outcrop surface coinciding with the boundary surface of the granite. In the north-east of Quiartorfik both the granite and the gneiss are cut by aplite veins.

The granite contains rounded basic inclusions at a number of localities. These inclusions are biotite-rich and, like the granite itself, locally foliated. Some of the basic inclusions form rows of agmatitic inclusions.

This granite is medium to coarse grained with phenocrysts of alkali feldspar and has a granite (*sensu stricto*) composition. It consists of pinkish microcline, quartz, white plagioclase and around 5% biotite. Accessories are sphene, opaque minerals and apatite. Purple fluorite crystals are common and the same mineral is nearly everywhere also present interstitially and in small cracks.

(*3*) *Tavdlorutit granite*

This granite forms a belt some hundred metres wide and approximately 3 km in length. It is situated on the north coast of the island Tavdlorutit and may once have formed, with the Quiartorfik granite, a stock-like body 2–4 km in diameter.

The Tavdlorutit granite is a homogeneous, somewhat foliated granite, with alkali feldspar phenocrysts (JENSEN, 1957). The main petrolo-

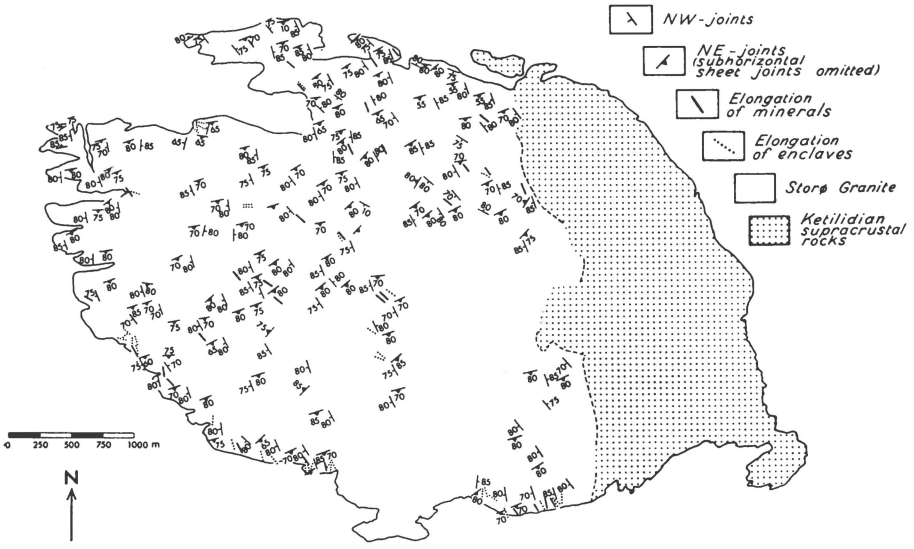


Fig. 43. Tectonic map of the Storø granite, modified after FROIDEVAUX & MULLER (1958).

gical characteristics are similar to the Quiartorfik granite, with the exception that it does not normally contain basic inclusions or fluorite. The southern boundary with the nebulitic gneisses is sharp and the granite is finer grained in the marginal zone, being elsewhere medium to coarse grained. The boundary to the north is a fault, which may represent a displacement separating the Quiartorfik and the Tavdlorutit granites.

(4) Storø granite

About 75% of the island Storø, and the small islands to the west, is granite. This granite, mapped and described by FROIDEVAUX & MULLER (1958), cuts the folded Ketilidian supracrustal rocks outcropping in the eastern part of Storø.

The Storø granite is a homogeneous, grey-white, often coarse-grained, biotite granite. In places the granite is porphyritic and feldspar phenocrysts reach 5 cm in length. A very faint banding has been observed in the granite in the northern part of Storø.

Boundary relations with the supracrustal rocks vary somewhat. The northern part of the contact is a 1 m wide "sharp" fault zone. Further south the border is also sharp, but not sheared; and here enclaves of supracrustal rocks occur in the granite. Near the south coast several enclaves of gabbro and schists are found in the granite close to the border, and numerous fine-grained granitic veins cut the adjacent gabbro. Generally the grain size of the granite decreases towards the contact and

at some localities thermal metamorphic alterations are found in the adjacent supracrustal rocks.

The granite consists mainly of abundant, often pink, alkali feldspar, quartz, scattered white or greenish-white plagioclase and biotite. Small sphene crystals are relatively common. Compared to some of the other allochthonous granites fluorite is not abundant. The feldspar phenocrysts are generally oriented in sub-vertical planes trending at 150°; a prominent jointing is developed along these planes.

Small enclaves of greenschists occur locally, especially near the boundary with the supracrustals. The enclaves, which are elongated, lie mostly in planes parallel to those containing the feldspar phenocrysts (fig. 43). The mineral elongation plunges at shallow angles to the southeast.

Three prominent joint systems can be distinguished in the granite. The most common is subvertical and trends approximately 150°. A second system with a strike of 060° and a dip of 60–90° SE is also the locus of abundant aplitic veins. A third major joint system is flat-lying or gently dipping and approximately perpendicular to the other two systems.

The prominent development of orientated features in the granite implies that it was emplaced and cooled under stress.

(*5*) *West Sánerut granite*

On the western end of the island of Sánerut a granite body more than 4 km across occurs. As most of the outcrop is bordered by the sea it can be assumed to be part of a somewhat larger intrusion. Only a narrow northern rim of the granite falls within the area of the Ivigtut sheet, the rest of the body lying within the confines of the Nunarssuit sheet (60 V. 1 North).

The granite is a leucocratic, medium-grained, biotite granite with a slight porphyritic development of the feldspar (JENSEN, 1960). It contains scattered grey lenses of a biotite-rich, fine-grained rock occurring with varying intensity, but seldom completely absent. The granite is otherwise rather homogeneous and is cut by only few aplite and pegmatitic veins. The boundary with the bordering "Porphyritic foliated granite" is sharp, the West Sánerut granite being the younger. To the south of the map sheet boundary the West Sánerut granite shows a sharp contact against the gneiss while the contact towards Ketilidian mica schists is characterised by an intense veining of the mica schist by granite.

The West Sánerut granite generally has an adamellite composition with K-feldspar, oligoclase, quartz and biotite as the main constituents. Opaque minerals, sphene and apatite occur in small amounts, and in some rocks muscovite, hornblende, epidote, allanite and zircon are occasionally found.

Chronology of the Ketilidian granites

The Ketilidian granites in the Ivigtut region were all emplaced subsequent to the main Ketilidian deformation. The foliated Qôrnoq augen granite cut already folded Ketilidian supracrustals, and the foliated Tvillingsøer granite seems to be developed later than the major regional Ketilidian flexure which affected the pre-Ketilidian gneisses which surrounds this granite.

The formation of the foliated granites was probably outlasted by the emplacement of the "foliated to homogeneous types". Many of these were later partly or completely reactivated and were the site of late feldspar porphyroblastesis. The Kînâlik granite is probably the youngest of the autochthonous to parautochthonous types. It veins the foliated Qôrnoq augen granite with its content of small interorogenic basic dykes (see p. 102) and only a few late orogenic basic dykes have been found in it. The Kînâlik granite is not reported to have been subjected to Ketilidian deformation.

The allochthonous, post-kinematic Ketilidian granites were probably all late Ketilidian. The West Sânerut granite cuts both the Ketilidian folded supracrustal rocks and the "Porphyritic foliated granite". The Storø granite cuts folded Ketilidian supracrustal rocks. It is likely that all the allochthonous granites should be referred to a late plutonic event in analogy with similar granites found further south (the rapakivi suite granites: ALLAART *et al.*, 1969). However, it cannot be excluded that some of them could be foreland equivalents representative of an earlier plutonic episode.

KETILIDIAN INTER–OROGENIC BASIC DYKES AND METAMORPHOSED POST–KINEMATIC BASIC DYKES

The younger main group of metamorphosed basic dykes in the Ivigtut region comprises intrusions emplaced after deposition of the Ketilidian supracrustals, but which were influenced by a subsequent Ketilidian (or later?) metamorphism. The group consists of three main categories: 1. inter-orogenic and synkinematic basic dykes; 2. hornblendite dykes; and weakly metamorphosed post-kinematic dolerites.

Inter-orogenic and synkinematic basic dykes

A number of thin, impersistant, metamorphosed basic dykes cut the Ketilidian supracrustal rocks and the Ketilidian granites in the eastern and southern part of the Ivigtut region. Within the region of the Ivigtut



Fig. 44. Deformed metadolerite in Qôrnoq augen granite, both cut by younger fine-grained granite veins. East of Qôrnoq. Photo: S. B. JENSEN.

map sheet about six of these dykes have been recorded in the Ketilidian supracrustals. The northernmost example has been recorded in central Grænseland (WINDLEY *et al.*, 1966; BONDESEN, 1970). It is a small ENE-trending discordant amphibolite dyke which can be traced from the infracrustal gneisses into the lower part of the Ketilidian supracrustals. It cuts clearly the unconformity at the base of the Ketilidian metasediments. According to BONDESEN (1970, p. 177) it has, however, locally been folded by the 2nd phase of Ketilidian deformation. In this connection the reader is also referred to p. 83 of this paper.

A few amphibolitic dykes, all less than 1 m wide, have been recorded in the supracrustals south of Arsuk Fjord. One of these intrudes the deformed conglomerate horizon of the lowest part of the Qipisarqo Group and another cuts the overlying gritty quartzites perpendicular to their foliation. This implies the dykes were intruded after the main deformation of the metasediments.

About ten examples of thin discordant amphibolitic dykes have been recorded in the Qôrnoq augen granite. These dykes seldom exceed 1 m

in width and are usually less than 0.5 m wide (fig. 44). They are often somewhat disrupted, slightly folded and most are cut by a number of younger pegmatites and granitic dykes which also cut the augen granite. Subsequent to the formation of a metamorphic foliation in the dykes both the augen granite and the dykes have been somewhat deformed. Many of the granitic veins cutting the discordant amphibolites are presumed to be related to the formation of the Kînâlik granite, and intrusion of many of the metamorphosed basic dykes is likely to have taken place in an interval between emplacement of the two granite bodies.

Scattered amphibolitic dykes of this type occur in other parts of the southern Ivigtut region. On Sánerut some cut the autochthonous porphyritic foliated granite whilst the dykes themselves are cut by sheets from the allochthonous West Sánerut granite. In the young Kînâlik granite there are a few of these dykes and on Storø a 2–3 m wide N–S trending discordant amphibolite sheet, dipping approximately 35° E, cuts the allochthonous granite.

In the granite area south of Søndre Qipisarqo Bræ there occur a few distinct swarms of amphibolitic dykes trending 140–170°, all of them less than 1 m in width. According to BRIDGWATER (pers. comm.) these dykes are similar to the synkinematic dyke group, DA_3, described by WATTERSON (1965).

The inter-orogenic basic dykes are fine grained and some may be foliated. Some may contain small plagioclase phenocrysts, which have preserved their primary outlines. Textures are often lepidoblastic. The rocks contain mainly plagioclase (oligoclase-andesine) hornblende and biotite. The plagioclase may occur both as primary relic grains and in recrystallised form. Sphene, opaque minerals and apatite are present in small amounts, and some rocks also contain a little quartz.

Hornblendite dykes

Three NNW-trending hornblendite dykes occur in the area south of Arsuk Bræ. These ultrabasic dykes are composed nearly exclusively of green hornblende with only minor amounts of feldspar. They are often strongly sheared along the margins, but they are not cut by the granitic veins, which cut the Iggavik dykes in the same area. They are cut by several Gardar lamprophyres and they are therefore interpreted as being of a pre-Gardar origin.

These dykes should probably be regarded as having been emplaced in the later part of the Ketilidian period. Their hornblendic composition suggests a relation with some of the late Ketilidian appinitic rocks found in the Julianehåb district (ALLAART, 1967).

Post-kinematic weakly metamorphosed dolerites (120° dykes)

In the north-east corner of the Ivigtut map sheet there occurs a swarm of metadolerites trending 120°–130° which are only weakly metamorphosed (BONDESEN, 1970). These dykes (120° dykes of fig. 5) cut folded Ketilidian and pre-Ketilidian rocks and are not displaced by the Ketilidian thrusts.

To the north of the Ivigtut region the swarm can be traced for more than 100 km; the swarm disappears under the ice towards the south.

The individual dykes have a consistant thickness of between 5–15 m. Normally they are medium grained in the centre and have chilled margins. The margins are usually weakly sheared. Some dykes contain porphyritic plagioclase.

The degree of metamorphic alteration in the dykes varies, but most of the rocks have preserved a great deal of both primary plagioclase and augite, although metamorphic alterations have caused clouding of feldspar, alteration of augite to chlorite, actinolite and calcite aggregates, and serpentinisation of olivine. In some of the more strongly altered rocks the plagioclase is also partly recrystallised and epidote appears.

These 120°–130° dykes are older than the north-east trending Gardar dolerites and in the region to the north of the map sheet can also be shown to be older than a Gardar lamprophyre (HIGGINS, 1970, p. 66).

Comparable swarms of WNW-trending, weakly metamorphosed dykes are also known from the Julianehåb district (ALLAART, 1967). These dykes are tholeiitic and contain hypersthene. The swarms in the Julianehåb district could be regarded as a continuation of those in the Ivigtut region separated only by the inland ice. While ALLAART (1967, p. 78) grouped these dykes as the latest formed Ketilidian rocks, we prefer to place them as post-Ketilidian but pre-Gardar in our chronological scheme (fig. 5), because we consider the Ketilidian orogeny to have terminated by the time cross-cutting dyke swarms could be emplaced. Obviously this question is a matter of convention and is dependant on the emphasis placed on the kinematic and the plutonic features of the orogeny.

REGIONAL METAMORPHISM

Regional metamorphism appears to have accompanied each of the three orogenies distinguished in the Ivigtut region. The youngest regional metamorphism, the Ketilidian, influences the Ketilidian supracrustals and the Iggavik dykes as well as the older rocks. The regional metamorphism of the Maturian orogeny can be studied in its effects on the Tartoq

Group supracrustals, but is also traceable in the gneissic terrain to the north and south of the Tartoq belt. The oldest regional metamorphism is that which relates to the Senilian orogeny. Presumed traces of this are only preserved in the central and western parts of the Senilian orogenic segment (fig. 6), but the metamorphic paragenesis has always suffered modification by later recrystallisation in connection with one or both of the later regional metamorphic events.

The regional metamorphisms are discussed from youngest to oldest below. This procedure is chosen because the Ketilidian supracrustal rocks and the Iggavik dykes in the foreland have only been subjected to the Ketilidian regional metamorphism, and both therefore offer a good possibility to study the grade of the regional Ketilidian metamorphism. The Ketilidian metamorphic effect on the pre-Ketilidian basement can best be observed by comparison with the metamorphic conditions in the Iggavik dykes.

The description is based on the nomenclature suggested by Turner (1968).

Ketilidian metamorphism

Ketilidian metamorphism and deformation increase strongly from north to south, or from north-west to south-east. Ketilidian supracrustal rocks on Midternæs, north of the map sheet boundary, have been subjected to a weak regional metamorphism with only an incomplete recrystallisation under low greenschist facies conditions, giving rise to formation of chlorite and actinolite in basic rocks, and also of probable stilpnomelane (Higgins, 1970, p. 62).

In Grænseland the Ketilidian supracrustal rocks recrystallised under greenschist facies conditions. Bondesen (1970, p. 173) distinguishes a lower quartz-albite-muscovite-chlorite sub-facies to the north and east, and a quartz-albite-muscovite-biotite sub-facies towards the south-west.

The Ketilidian supracrustal rocks between Arsuk Bræ and Qôrnoq have paragenesis with hornblende, epidote and oligoclase in the basic rocks, and biotite, garnet and staurolite in the mica schists. This indicates conditions corresponding to the greenschist-amphibolite transition facies to low amphibolite facies conditions.

On the south side of Sánerut sillimanite has been found in the Ketilidian metasediments (Windley *et al.*, 1966) indicating middle to high amphibolite facies.

The Ketilidian supracrustal rocks in the Arsuk Ø area were subjected to high greenschist facies metamorphism in the biotite zone during the first phase of folding. In the supracrustals close to the basement, at Taylers Havn and north of Ikerasârssuk, low amphibolite facies condi-

tions were reached between the first and the third phase of folding. This took the form of recrystallisation of andesine, biotite, garnet, tremolite, epidote and other minerals (MULLER, 1974).

The Ketilidian metamorphic effect on the Iggavik dykes has been described previously (p. 68–70). The regional picture is too incomplete to permit construction of isograde for the metamorphism of the dykes. However, in general terms amphibolite facies conditions, with recrystallisation of basic oligoclase—andesine, hornblende and biotite, were reached in the whole region south-east of a line east of Sermersût–Tôrnârssuk, through Gaffelsø, north of Pyramidefjeld to Arsuk Bræ. To the north and west occurs a greenschist facies zone in which amphibole, biotite, and occasionally also albite, were formed, and furthest to the north and north-west low greenschist facies conditions prevailed. In the lowest metamorphic zones primary minerals and textures in the dykes are often preserved (AYRTON, 1963; HENRIKSEN, 1961; JACOBSEN, 1961). The dykes influenced by the amphibolite facies metamorphism contain a few primary mineral and textural relics in the north and west, but around Arsuk Fjord and further south they are all completely recrystallised and most have also become foliated.

Some Iggavik dykes are reported to have been influenced by a weak retrograde metamorphism following the main metamorphism. This is generally seen as a chloritisation of earlier formed hornblende and biotite (WEIDMANN, 1964, p. 69; BONNARD, 1963).

The increasing degree of recrystallisation in the dykes cannot alone be explained by the facies variations, and it was therefore suggested by BONDESEN & HENRIKSEN (1965) that the isofacial variations could be caused by a difference in duration of metamorphic conditions, and by the influence of a catalysing kinematic factor.

The Ketilidian metamorphic influence on the previously metamorphosed rocks in the Ketilidian foreland is limited in the central and western part of the region, but from around Arsuk Fjord and further south all the pre-Ketilidian rocks were completely or almost completely recrystallised under amphibolite facies conditions. The gneisses comprise conformable amphibolite bands with hornblende and oligoclase-andesine, and in the Íka gneiss series paragenesis with staurolite-garnet and garnet-sillimanite in the mica schists and diopside-bearing calc-silicates occur. Only the gneisses of western Tavdlorutit, which may include supracrustal relics of Ketilidian age, recrystallised under greenschist-amphibolite transition facies to low amphibolite facies—possibly indicating a transition to Ketilidian supracrustal rocks presumed to occur just west of the island.

Pre-Ketilidian metamorphism

In the central and western part of the region the last metamorphic influence caused only a partial or a slight recrystallisation. Here, an earlier pre-Ketilidian metamorphic pattern can be recognised (BONDESEN & HENRIKSEN, 1965, p. 40): a primary medium to high amphibolite facies metamorphism and a secondary retrogression to greenschist-amphibolite transition facies. These pre-Ketilidian metamorphic events might now be referred to the Senilian and the Maturian orogenies respectively.

The Tartoq Group supracrustal rocks are preserved in an area subjected to very weak Ketilidian metamorphism, and the main metamorphic imprint must therefore be of a Maturian age. The facies conditions in the Tartoq Group rocks vary from high greenschist facies to greenschist-amphibolite transition facies.

In the Bikuben area the following assemblages occur according to WEIDMANN (1964, p. 13); basic schists: epidote-chlorite-calcite-sphene, epidote-chlorite-actinolite-sphene, hornblende-epidote-biotite-garnet (almandine), hornblende-chlorite-biotite—all with a plagioclase of generally An_{10} but with up to An_{25}; pelitic schists: muscovite, sericite, albite-oligoclase, quartz; quartzo-feldspatic schists: quartz, plagioclase, muscovite, sericite, occasionally biotite, garnet and other minerals.

In the narrow greenschist belts north of Kangerdlugssuaq high greenschist facies conditions have been reached or slightly surpassed; various metavolcanic and metasedimentary schists here contain biotite, and the plagioclase is reported to be albite or occasionally oligoclase (AYRTON, 1963, p. 24).

The Târtoq area comprises metavolcanics which are primarily hornblende-epidote rocks with small amounts of plagioclase, quartz, chlorite and others. Biotite occurs sporadically in some rocks. According to JACOBSEN (1961) the plagioclase is often a high oligoclase, but invariably these oligoclases are heavily saussuritised and they could therefore represent a primary plagioclase, which was unstable under metamorphic conditions. The regional facies conditions in the supracrustal rocks of the Târtoq area should therefore be referred to greenschist-amphibolite transition facies.

The infracrustal rocks adjacent to the Tartoq Group supracrustals all show an increasing degree of metamorphism moving away from the supracrustals. All workers from this part of the region (AYRTON, 1963; WEIDMANN, 1964; and BONNARD, 1971) indicate that the facies in the gneisses increases slightly from north to south approximately corresponding to an increase from greenschist-amphibolite transition facies to low

amphibolite facies conditions. In the gneiss region west of Târtoq and north of Sermiligârssuk amphibolite facies conditions have been reached, but many of these rocks have been partially retrogressed during the Maturian orogeny.

BONDESEN & HENRIKSEN (1965) found that the rocks on Sermersût and Tôrnârssuk and on the adjacent mainland showed a poly-metamorphic pre-Ketilidian development. A primary high amphibolite facies was here followed by a secondary greenschist-amphibolite transition facies to low amphibolite facies. It is tempting to suggest that this represents Maturian retrogression of a possible Senilian amphibolite facies.

The high amphibolite facies metamorphism is the earliest discernible metamorphic event in the Ivigtut region. It has been found in the rocks from Sermersût and Tôrnârssuk and the adjacent mainland. In these areas occur totally recrystallised enclaves of gabbro-anorthosite which contain plagioclase varying from An_{40}–An_{70}, and amphibolitic bands with occasional diopside and in which the plagioclase comprises mainly andesine (BONDESEN, 1960; HENRIKSEN, 1961).

This early amphibolite facies metamorphism has been recognised in Senilian deformed rocks which were unaffected, or only moderately affected, by Maturian and Ketilidian deformations. It is therefore most likely to be related to the Senilian orogeny.

ISOTOPIC AGE DETERMINATIONS

The results of geochronological work carried out on the rocks of the Ivigtut region are presented in fig. 45. Most of the determinations are K/Ar and Rb/Sr mineral ages, only two Rb/Sr whole rock isochron ages have so far been carried out. Additional age determinations were obtained in conjunction with investigations of galena from the Ivigtut cryolite deposit for a National Bureau of Standard programme, and a series of lead isotopic age models have been produced.

The general interpretation of the results are shown in table 7.

The oldest ages were obtained from the lead isotope study of the Gardar mineralisation at Ivigtut. This study shows that the lead is anomalous, and the ages can only be explained adequately by using a multistage model for the origin of the lead, indicating a primary development prior to the Gardar stage. KANASEWICH & SLAWSON (1964) came to the conclusion that the maximum age of the ordinary lead in Ivigtut is either 3520 m.y. or, using a different model, 3020 m.y. ULRYCH (1964) analysed a different set of samples and proposed a primary age of at least 2980 ± 10 m.y.

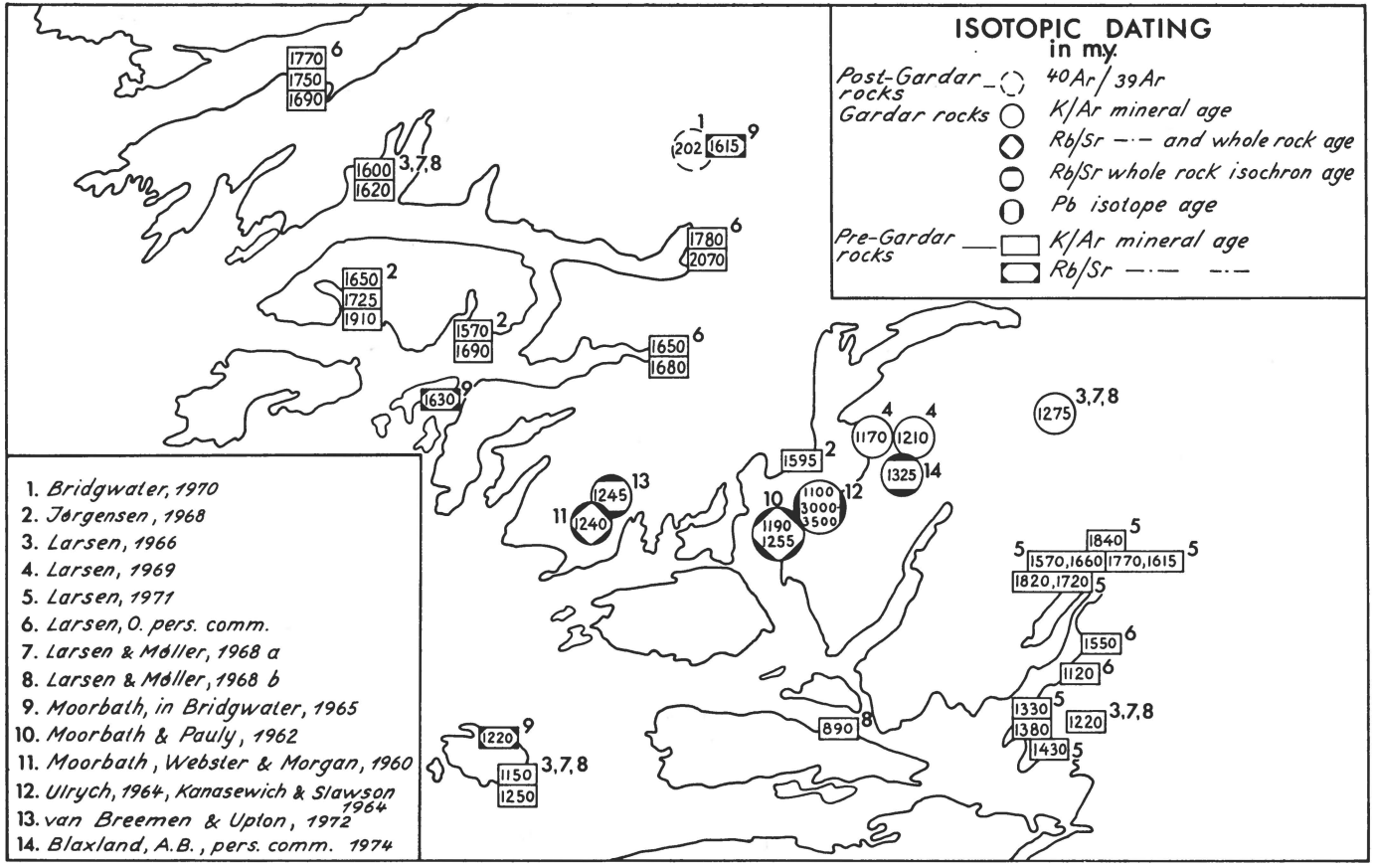


Fig. 45. Sketch map showing the position of isotope dates.

Table 7. *Interpretation of age determinations*

Age group m.y.	Type of determination	Interpretation
140–225	K/Ar & $^{40}Ar/^{39}Ar$	Mesozoic intrusions
1150–1275	K/Ar & Rb/Sr mineral	Gardar intrusions and regional thermal overprinting of Gardar and pre-Gardar rocks
1250	Rb/Sr whole rock isochron	Late Gardar intrusion Kûngnât complex
1325	Rb/Sr whole rock isochron	Earliest Gardar intrusion Grønnedal-Íka complex
1300–1575	K/Ar mineral	Partial updating of some pre-Gardar rocks
1575–1850	K/Ar & Rb/Sr mineral	Ketilidian metamorphism and subsequent closing of mineral systems
1900–2100	K/Ar mineral	Partial updating of pre-Ketilidian rocks
c. 3000–3500	Pb-isotopes	Age of ordinary Pb-isotopes in Ivigtut galena

The indication of a primary age of around 3000 m.y. for the ordinary lead in Ivigtut suggests that material in the surrounding infracrustal rocks might be equally old, but there is no direct evidence to support this view.

The K/Ar and Rb/Sr mineral ages in the range of approximately 1575–1850 m.y. are interpreted as representing the metamorphism in connection with the Ketilidian orogeny and its subsequent thermal effect until the closing of the mineral systems (uplift). Many of the age determinations in this range were carried out on rocks of a pre-Ketilidian origin, and the ages thus clearly demonstrate the updating of the rocks in the Ketilidian foreland zone. The almost even scatter of ages between 1600 and 1800 m.y. presumably reflects the various stages at which different minerals became closed systems with respect to Sr and Ar migration. Generally, muscovite and hornblende give ages greater than the corresponding biotite ages.

K/Ar mineral dates on Ketilidian supracrustal rocks from the southeastern part of the Ivigtut region demonstrate that the Ketilidian meta-

morphic event here is at least 1800 m.y. old (LARSEN, 1971). This is in agreement with results obtained from the central part of the Ketilidian orogenic complex in south Greenland which show that the plutonic activity in the Ketilidian orogene was concentrated around 1800 m.y. (VAN BREEMEN, ALLAART & AFTALION, 1972; GULSON & KROGH, 1972).

Dating of the Gardar rocks from the Ivigtut region shows that the relatively oldest intrusions were emplaced about 1325 m.y. ago. A Rb/Sr whole rock isochron on the Grønnedal-Íka complex gives 1327 ±17 m.y. (ALAN B. BLAXLAND, pers. comm. 1974). The relatively youngest intrusions in the area are the Kûngnât complex, from which a Rb/Sr whole rock isochron of 1250 ±15 m.y. has been obtained (VAN BREEMEN & UPTON, 1972), and the Ivigtut granite, which has given Rb/Sr and K/Ar mineral ages averaging about 1250 m.y. Pegmatites related to this granite have given mineral ages of about 1190 m.y. (MOORBATH & PAULY, 1962). The K/Ar mineral dates on the relatively older Grønnedal-Íka complex give 1170–1210 m.y. and the existence of partially updated pre-Gardar rocks in the southern part of the Ivigtut area indicates that parts of the area was subjected to a late thermal overprinting, probably between 1150 and 1200 m.y. ago.

The Mesozoic intrusions comprise a few thin kimberlite sheets, 225 m.y. old, and a series of coast-parallel basic dykes, 138 to 164 m.y. old (see p. 145).

GARDAR INTRUSIONS

The cratonic Gardar period in the Ivigtut region encompasses formation of three intrusive complexes, emplacement of numerous swarms of dykes of various composition and extensive faulting activity. The general Gardar chronology for the Ivigtut region is summarised in table 8, which shows how emplacement of the intrusive rocks and faulting was intermittent; some minor intrusions and local faults are omitted.

The correlation of the Gardar events in the Ivigtut region with those in South Greenland is still subject to discussion. It was for a long time believed that the major swarms of brown dolerite dykes (BDs) could be used as stratigraphic markers throughout the Gardar region, but recent Rb/Sr whole rock isochron age determinations have indirectly shown that the Gardar olivine dolerite dykes in the north are older than at least the majority of the basic dykes in the south. The youngest Gardar intrusions in the Ivigtut region, the Kûngnât complex and the Ivigtut granite, were both emplaced about 1250 m.y. ago (VAN BREEMEN & UPTON, 1972; MOORBATH & PAULY, 1962). This is earlier than the emplacement of the younger gabbroic dykes in the Julianehåb region, which post-date a

Table 8. *General Gardar chronology for the Ivigtut region*

INTRUSIONS	FAULTING	
	Major	Minor
IVIGTUT GRANITE COMPLEX		
KÛNGNÂT COMPLEX 1250 m.y.		
	0° DEX	
? ALKALINE DYKES	110° SIN	0–30° dex
	? 25–50°; 160–180° DEX	
Microporphyritic dolerites		
	? 60–80° SIN & DEX	
OLIVINE DOLERITIC DYKES (BD_2, BD_1, BD_0)		20–60° dex
	90–120° SIN;	10–30° dex
Big feldspar dykes		
TRACHYTIC-GRANOPHYRIC DYKES		
Basic dykes		
LAMPROPHYRIC DYKES		
GRØNNEDAL-ÍKA COMPLEX		

SIN/sin = sinistral; DEX/dex = dextral

large composite syenite dyke (the Hviddal dyke) dated at 1187 ±9 m.y. (VAN BREEMEN & UPTON, 1972). The recent age determinations have introduced the possibility that the oldest Gardar activity is found in the Ivigtut region, with activity migrating east-south-east towards the Julianehåb region with time (EMELEUS & UPTON, in press).

Grønnedal-Íka alkaline complex

The oldest Gardar intrusion in the Ivigtut region is the Grønnedal-Íka nepheline syenite and carbonatite complex. The complex was described by CALLISEN (1943), and later in detail by EMELEUS (1964) whose account forms the basis for this short summary.

The complex consists of two series of laminated and layered nepheline syenites which, separated by a gneiss raft, formed an original oval-shaped intrusion with concentric structures dipping towards the centre of the complex (fig. 46). These laminated syenites were later cut by a central stock of phenocrystic nepheline syenite containing xenoliths of both earlier syenites and of the surrounding gneisses and amphibolites. Another central plug of xenolithic carbonatite cuts the syenite intrusion and is probably closely related in time to the alkaline intrusion.

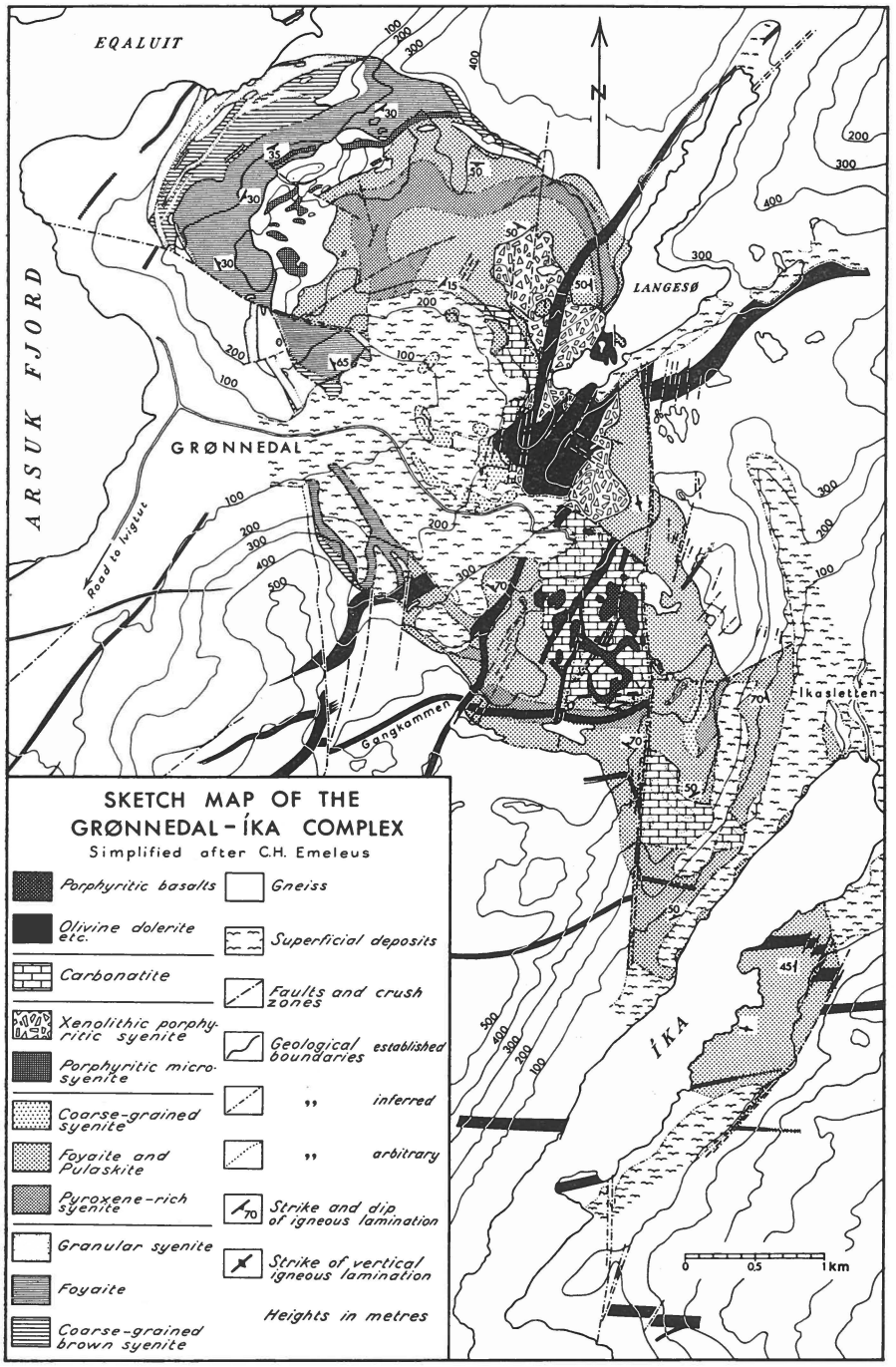


Fig. 46. Sketch map of the Grønnedal-Íka complex.

The two syenite series form two distinct intrusive phases. The lower series is the earliest and consists of medium-grained, well-laminated foyaitic rocks partly rimmed by a belt of generally non-laminated, coarse-grained brown syenite. A dyke-like intrusion of granular syenite is considered by EMELEUS to be an incomplete ring-dyke and probably forms the latest member of the lower series.

The upper series, which forms the bulk of the complex, is dominated by foyaites, sometimes grading into pulaskites, and contains a band of pyroxene-rich syenite, as well as a large enclave of coarse-grained syenite which appears to be an inclusion.

The upper and lower series are separated by a raft-like mass of gneiss which forms the floor of part of the upper series. This gneiss sheet is considered to be a raft which subsided through the magma and settled upon the upper surface of the bottom accumulation, now represented by the foyaite of the lower series, crystallisation continuing in the overlying magma.

The youngest of the major syenite intrusions is a central plug of xenolithic, porphyritic syenite, the xenoliths being surrounded by a matrix of non-laminated nepheline syenite with alkali feldspar phenocrysts.

The syenites are cut by a central plug of carbonatite which was forcibly emplaced into the upper series and the central plug of nepheline syenites. The carbonatite is often xenolithic and the margins may be brecciated. The syenites are metasomatically altered in a zone surrounding the central carbonatite plug.

A small magnetite deposit associated with the carbonatite was investigated by BØGVAD (1947, 1951) but was not considered profitable.

After formation of the alkaline complex and associated carbonatite a number of thick olivine dolerite dykes and numerous small trachytic and phonolitic dykes were intruded. Their chemistry has recently been treated by GILL (1972).

Transcurrent faulting later in the Gardar period has resulted in the somewhat oblong form of the complex. A detailed analysis of the fault pattern is given by EMELEUS (1964).

Lamprophyre dykes

The lamprophyric dykes, the oldest of the Gardar dykes in the Ivigtut region, occur mainly in the central and northern parts of the inland region (plate 6). Most are normally 1 to 4 m wide but dykes up to 8 m in width have been reported. The trend of these dykes is mostly between NE and E–W.

Where most common up to 25 dykes may be present over a stretch of 50 km perpendicular to their strike, corresponding to a widening of 0.1 % at the time of their intrusion.

The dykes are generally rectilinear but may show irregular curving forms. North of Arsuk Fjord individual dykes can often be traced for distances up to nearly 5 km, but south of the fjord they can usually only be traced for some hundred metres, or occasionally 1 or 2 kilometres.

The lamprophyres are melanocratic, rather fine-grained, black, brown or rusty dykes, slightly chilled at the margins. They often exhibit a characteristic intense weathering and have a crumbly, pitted appearance. The internal structure sometimes indicates multiple intrusion or the affects of late-stage hydrothermal processes (WEIDMANN, 1964, p. 87). Xenoliths are present in some dykes.

The petrological composition of the lamprophyres is variable but most dykes can be described as olivine-biotite-augite spessartites; common variations are those in which either olivine or biotite, or both, are absent. Kersantitic types occur much less frequently and are found both with and without olivine and hornblende. Some dykes almost lack feldspar and are classified as of alnöitic-monchiquitic composition. Many dykes are porphyritic containing phenocrysts of the dominating mafic minerals; biotite phenocrysts are particularly common. Plagioclase phenocrysts up to 5 mm in length are found in some dykes. A common characteristic feature of the lamprophyres is a content of small (mm to cm) druses and alveolars which normally are filled with calcite and/or epidote, and phyllosilicates such as chlorite and sericite (AYRTON, 1963,p. 77).

More detailed accounts of these dykes from sub-areas within the map sheet region are given by AYRTON (1963), WEIDMANN (1964) and BONDESEN (1960).

In a 15 km broad ENE trending zone between Arsuk Fjord and the head of Íka the lamprophyres are nearly all somewhat carbonatised. Their marginal parts especially are impregnated with siderite, limonite, ankerite and haematite, and in addition many dykes are sheared and frequently contain quartz veins and cavities filled with quartz crystals.

In the area of the Grønnedal-Íka complex the lamprophyres have been described by EMELEUS (1964). Here they appear to have been intruded over a longer time span than is otherwise normal for the Ivigtut region; inclusions of the earliest lamprophyres are found in the nepheline-syenite and the youngest post-date the olivine dolerite dykes. It is most likely that the local occurrence of "late" lamprophyres is related to the emplacement of the Grønnedal-Íka intrusive complex.

Granophyre and quartz porphyry dykes

Between intrusion of the lamprophyres and the main swarms of olivine dolerites, a group of thin acid and alkaline dykes was emplaced. Of these the acid dykes are easily distinguishable, but the alkaline types are difficult to distinguish lithologically from swarms of dykes emplaced later than the olivine dolerites. Both groups of alkaline dykes are therefore described together in a later section (p. 128).

The acid dykes occur in a narrow ENE trending zone around Isaløb (plate 6). Most dykes are between 2 and 3 m wide, with occasional examples reaching 7 m; they can be traced in some cases for several kilometres. The intrusive form is often somewhat irregular in detail, but their general trend is 60°–80° and their dip is vertical or very steep. They are all light coloured, generally white, yellow or pale red, while fresh surfaces are darker shades of the same colours. Some of the dykes have characteristic rusty oxidation zones on weathered surfaces. The colour sometimes changes along the length of the same dyke. The dykes are chilled against the enclosing rocks with a very fine-grained, sometimes glassy margin. The centres are fine grained or occasionally medium grained.

Phenocrysts are abundant although they rarely exceed 2 mm in diameter. Two main types can be distinguished, one of rounded and corroded quartz grains, and the other of white or pale pink rectangular feldspar grains of orthoclase, or orthoclase with plagioclase cores. Pure plagioclase phenocrysts have also been observed. The groundmass texture is granophyric or xenomorphic granular with primarily alkali feldspar and quartz, and with additional plagioclase, muscovite, ore and sometimes chlorite. Fluorite is a characteristic accessory mineral in many of the dykes. The dykes can be classified as granophyres or quartz porphyries.

Chemical analyses of three granophyres from Sermersût and Tôrnârssuk have been given by BONDESEN (1960), see also WATT (1966, analyses no. 9, 13 & 14).

In addition to the granophyres mentioned above a small swarm of similar dykes occurs near the Pyramidefjeld granite complex (p. 96), which are related by WEIDMANN (1964) to this Ketilidian granite and should not thereby be compared with the Gardar intrusions. A few thin granophyric dykes described from Grænseland by BONDESEN (1970, p. 178) are also thought to be pre-Gardar. A few thin granophyric dykes probably of rather young Gardar age are associated with the Ivigtut granite (p. 135).

Olivine doleritic dykes

Mode of occurrence

Within the Ivigtut region there occur extensive swarms of basic Gardar dykes which generally have been designated brown dykes (BD). They are mainly olivine dolerites. Their distribution is shown in plate 7, and their position in the Gardar chronology in table 8.

The brown dykes vary in width from 1 to 200 m, with an average thickness of between 10 and 50 m. A few exceptional examples with thicknesses up to 500 m over a short distance are known. Many of the dykes are very persistant and dykes which can be followed for more than 20 km are quite common; one prominant dyke can be traced for 55 km from the coast to the inland ice.

On estimate the sum of the dyke thicknesses across the region represented by the Ivigtut map sheet reached a figure of 2000 m; this corresponds to a general crustal widening of approximately 3% during the period of intrusion. Due to the strong tendency for the dykes to occur in swarms, local estimates vary widely on either side of this figure.

Chronology

On the basis of a large number of intersections it has been possible to establish three main generations of brown dykes, each generation with a characteristic trend. These, from oldest to youngest, are referred to as BD_0, BD_1 and BD_2 (plate 7). Faults displace some of the generations, but not others, and may facilitate identification.

Some dykes cannot be classified with certainty, and isolated dykes have trends or intersections which place them outside or between the three main generations, thus indicating the existence of at least 7 or 8 intrusion pulses. The variations from the main generations do not appear to be of regional significance.

A group of dykes characterised by their feldspathic inclusions, "big feldspar dykes", is described separately (p. 126) and indicated separately on the map, plate 7, by the symbol XD.

Structural features and field relations

To illustrate the trends of the various brown dykes the Ivigtut region has been divided into subareas and rose diagrams have been prepared (fig. 47a+b). The rose diagrams clearly show that the different generations of brown dykes in all subareas have somewhat varying trends, suggesting variations in the orientation of the stress field during the period of emplacement of each generation.

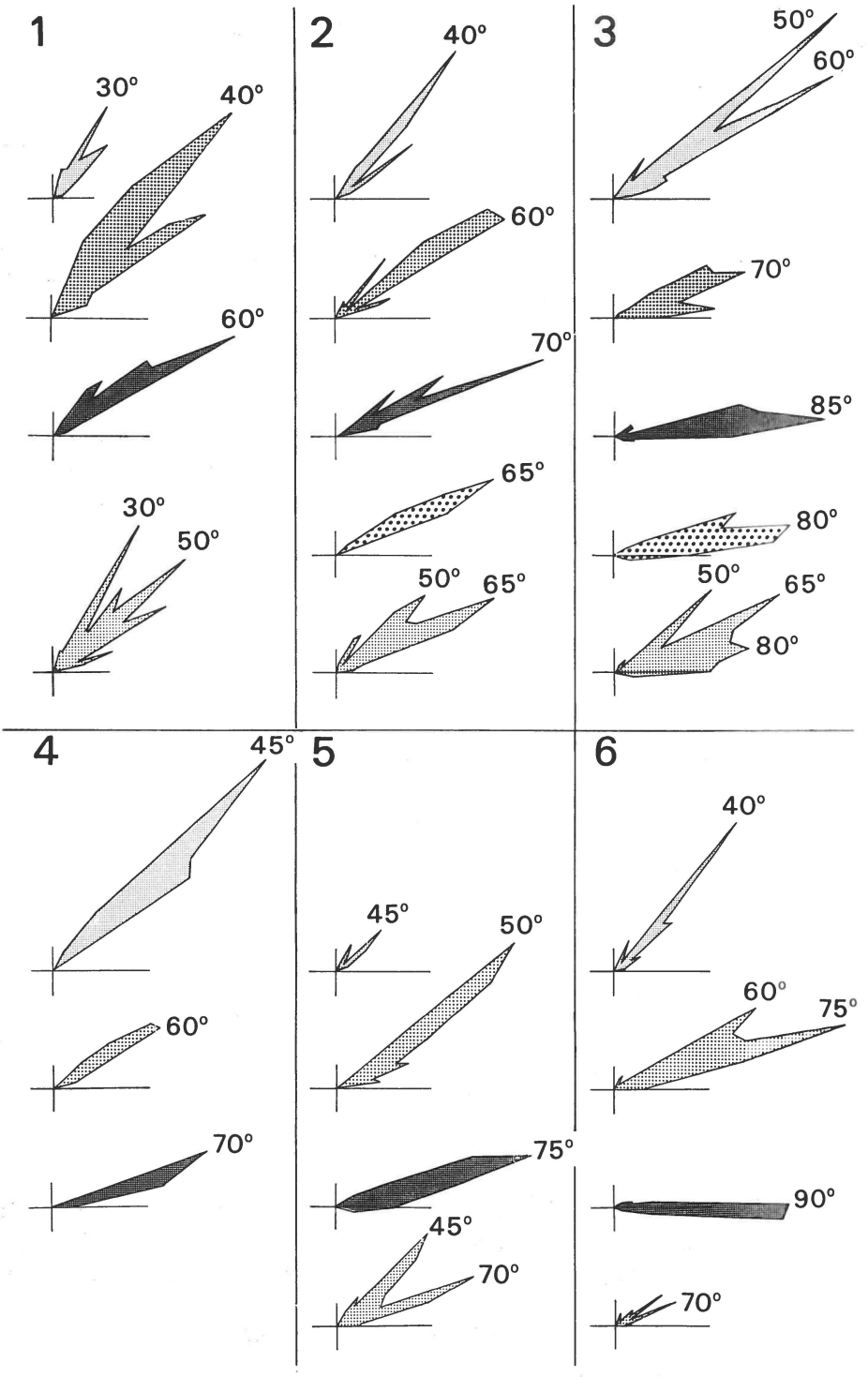
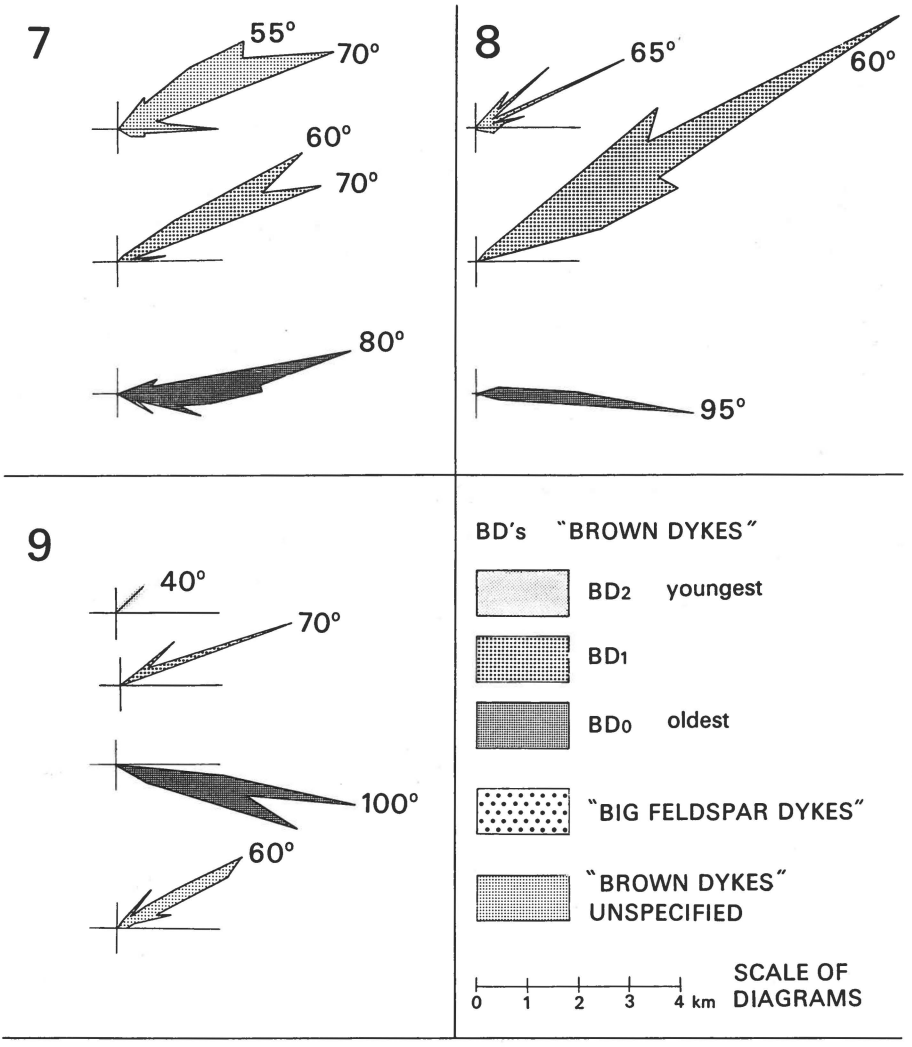
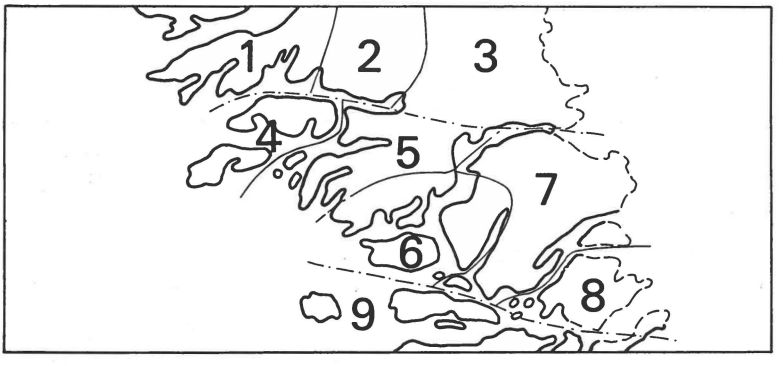


Fig. 47 a, b. Rose diagrams showing





trend of Gardar dolerites in subareas.

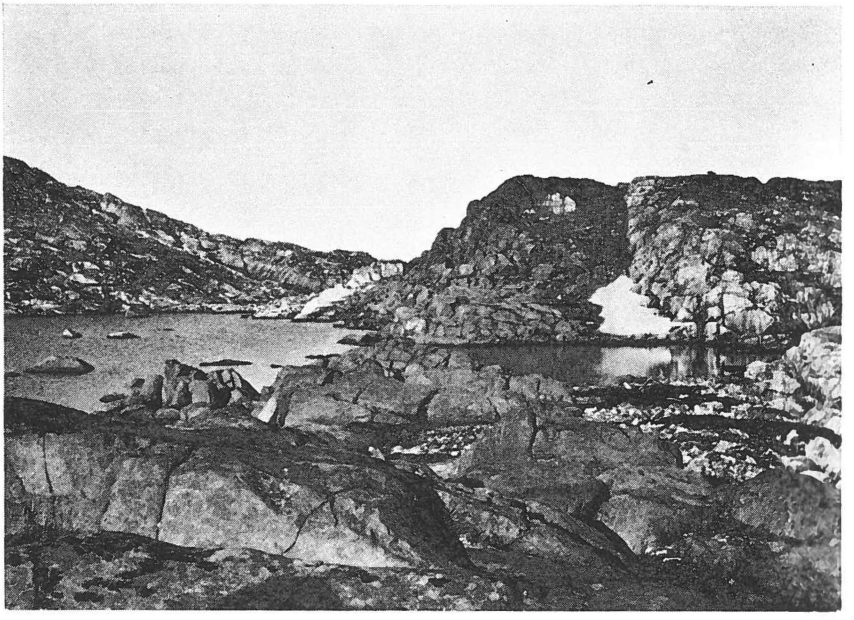


Fig. 48. Gardar dolerite, so-called brown dyke, of oldest generation (BD_0). The dyke is about 15 m wide. Fladland, north side of Arsuk Fjord.

There is a general change in trend from around E–W to ENE in the south-east part of the region, to around NE in the north-west part of the region. This is most pronounced in the BD_0 generation which alters from trends of 100–110° to approximately 60°. The corresponding figures for the BD_1 trend from 60-70° to about 40° and for the BD_2 trend from 60° to 30°.

Characteristically the changes in trend for all generations follow each other in such a way that the different generations maintain their mutual trend relationships in all the subareas. This means that the oldest generation (BD_0) is always the generation which trends in a direction characterised by the greatest angle of bearing measured from true north. Similarly the youngest generation (BD_2) is always the one characterised by the lowest bearing.

The brown dykes are generally regular dyke-formed intrusions (fig. 48) with chilled margins. The outermost 10–20 cm of the dyke are fine grained, the grain size increasing over some metres inwards to medium grain in the centres of the thinner dykes, and coarse grained in the thicker examples. The dykes are nearly all vertical or very steeply inclined; only very occasionally have examples with dips as low as 45° been recorded.

The thicker dykes have a characteristic weathering, the surface usually being covered by loose sandy and gravelly debris of brownish colour; hence the term brown dykes. The thinner dykes usually show

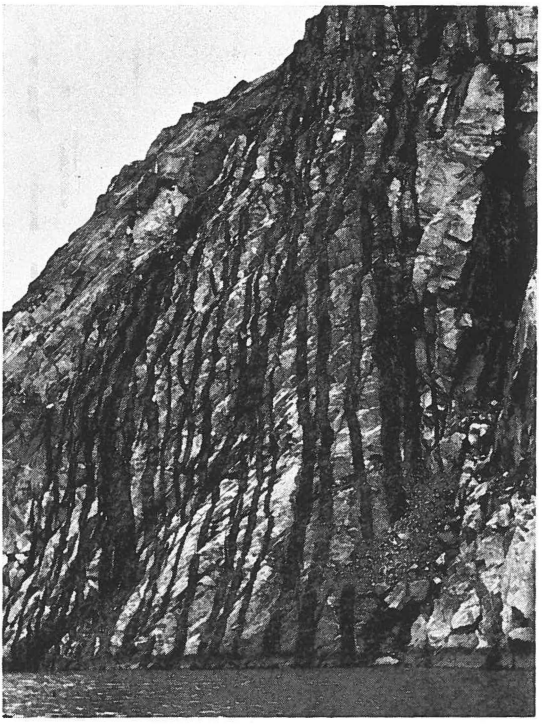


Fig. 49. Swarm of thin Gardar dolerites, each individual up to a few metres wide. South of Søndre Qôrnoq Bræ. Photo: S. B. JENSEN.

block-weathering forms caused by jointing in 3 to 5 prominent directions.

The dykes show in places *en echelon* and *en bajonette* features and apophyses, and often may break up into swarms of thin dykes (fig. 49). Individual dykes may terminate abruptly, thin gradually, or break up into small dyke swarms, and some die out temporarily only to reappear after a short distance.

Special relationships may be found where the brown dykes pass from the infracrustal gneisses up into the Ketilidian metasediments and metavolcanics. Here the brown dykes, otherwise continuous and with constant thickness when traced in the infracrustals, often become suddenly irregular and frequently die out with a short distance. A BD_0 more than 100 m in width which can be traced for more than 50 km in the gneisses projects for less than 2 km into the supracrustals south of Grænsesø in Grænseland. Another very thick BD_1 dyke found south of Arsuk Fjord and traceable for more than 25 km in the infracrustal rocks, also stops near the border with the supracrustal rocks at Skjortesø. This dyke, however, continues on the other side of the supracrustal belt, i.e. in the Ketilidian Qôrnoq augen granite, north of the head of Qôrnoq. Many other features of this nature could be cited. Of the many dykes

which traverse the supracrustal belt, a number have a somewhat irregular course. These features may be due to the contrast in physical properties between the infracrustal and supracrustal rocks, and between different units of the supracrustals.

Dykes of the three main generations are in general chilled against each other indicating that the earlier generation had time enough to completely cool before intrusion of the next generation. However, a few exceptions are recorded in the case of some very thick BD_1 dykes.

On Sermersût a BD_2 dyke cuts a 200–225 m wide BD_1 but only penetrating it for a few tens of metres. The contacts of the BD_2 are medium grained, adjacent to the BD_1, but normally chilled against the country rock, suggesting that the BD_1 was still hot (BONDESEN, 1960). On the Ivigtut peninsula due south of Ivigtut there is again absence of chilling where a 15–20 m BD_2 cuts a BD_1 more than 100 m wide, though further east another BD_2 cutting the same BD_1 is normally chilled at the contact.

It may be concluded that the BD_2 generation was intruded not long after the BD_1 generation. JAEGER (1957) gave some diagrams to show the temperature variations in and around intrusive sheets and based on these it may be assumed that the non-chilled BD_2 dykes intruded a few thousand years after the thick BD_1 dykes.

Contact thermal effects

Contact thermal effects occur adjacent to some of the brown dykes. Along the borders of dykes up to about 50 m in width there are generally no significant signs of alteration. The contact metamorphic effects are primarily seen along certain parts of the broader dykes, those with thicknesses of about 50–100 m. The thermal effects take the form of a bleaching or discolouration of the adjacent rocks, occasional recrystallisation of the wall rock and in many cases rheomorphic effects leading to hybridisation.

The contact metamorphic zone can be several tens of metres wide. In the innermost part of this zone a hybrid rock is sometimes found, formed from a mixture of dolerite and reactivated wall rock material; the latter may also occur as small leucocratic veins which have back-veined the marginal parts of the dyke. In a zone near the dyke contact the wall rock material is sometimes recrystallised (AYRTON, 1963; WEIDMANN, 1964; BONDESEN & HENRIKSEN, 1965). WEIDMANN reports that the gneisses around some of the thick dykes north-west of Gaffelsø are recrystallised between 1 and 10 m from the dykes. In this contact zone the gneisses loose their foliation, become pink in colour and are sometimes transformed into granitic rocks with more or less pronounced

porphyritic texture. Thin sections show that the feldspars are altered, the quartz corroded and recrystallised, and that a micrographic structure is often developed. Bondesen & Henriksen (1965) have reported recrystallisation near a 50 m wide BD_1; here hornblende-hornfels facies conditions have been reached in a discordant amphibolite 5 m from the contact to the brown dyke. A third example of contact metamorphic alteration along the margins of a dyke is described by Emeleus (1964) from the Grønnedal-Îka complex. Here a 40 m wide dyke has metamorphosed a siderite carbonatite rock to form small magnetite deposits (p. 152).

Along some of the thinner dykes (10–40 m) alterations have occasionally been found along the contacts (Ayrton, 1963). These thinner dykes are often xenolith-bearing and it is thought possible that the effects are due to the dykes having a higher gas content than normal.

Internal structures

Internal structures are occasionally found in the brown dykes. The most common type is banding, normally steep or vertical, and consisting of thin alternations of light and dark coloured layers. It generally occurs only in the thicker dykes within a few metres of the borders. Other structures such as flow lines slumping and internal chilling are rare.

Rounded patches of "gabbro pegmatite" commonly occur in all types of brown dykes. The patches up to 50 cm across, though normally smaller, have rather sharp but unchilled boundaries against the surrounding, finer-grained dolerite. The "gabbro pegmatite" patches are generally found exclusively in the inner parts of the dykes and have the same mineral composition as the surrounding rock but with a grain size 5–10 times greater.

Xenoliths of the wall rocks are usually not found in the brown dykes although they do occur occasionally. They may be seen as rare scattered examples, or occasionally as crowds of xenoliths concentrated in a dyke where it crosses a pre-existing crush zone.

Petrology

The brown dykes are olivine dolerites, the olivine content varying from a few per cent to over 25 %. In some cases the ratio of olivine to augite is so great that the rocks are troctolitic in character.

The rocks comprise normally plagioclase, augite, olivine, opaque minerals and biotite. Apatite is the most abundant accessory mineral. Late magmatic and secondary alterations are common and the olivine is usually partly altered to aggregates of secondary minerals. Quartz is

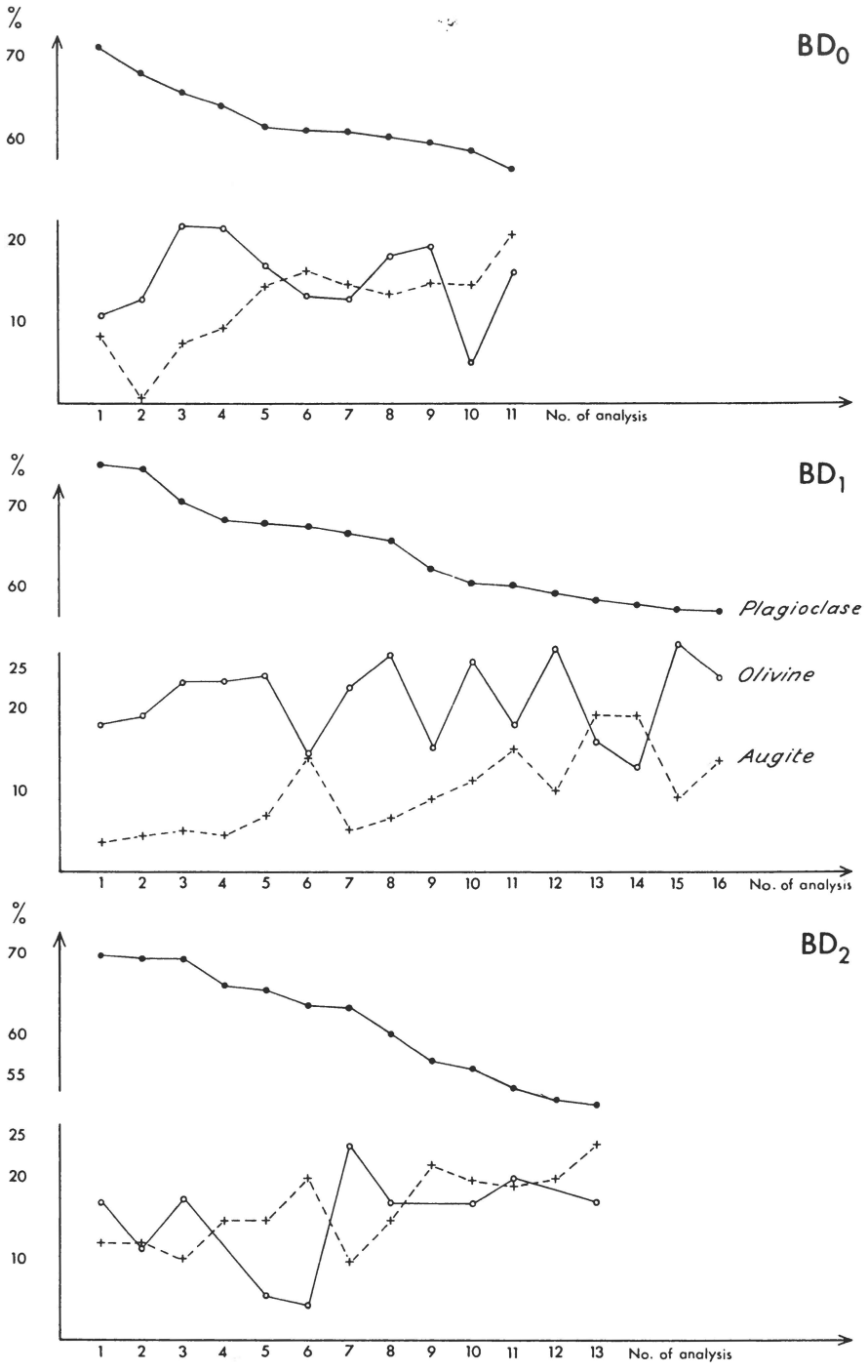


Fig. 50. Modal analyses of major minerals in Gardar dolerites (brown dykes).

rare but can be found in dykes of all three generations. It is most abundant in samples of xenolith bearing dykes.

Modal analyses of unaltered samples from 8 BD_0s, 16 BD_1s and 13 BD_2s representative of the whole map sheet region have been compiled (after AYRTON, 1963; BONDESEN, 1960; BONNARD, 1963; HENRIKSEN, 1961; JENSEN, pers.com. and WEIDMANN, 1964). The variation in content of plagioclase, augite and olivine is shown in fig. 50. The other components in the fresh rocks are *c.* 3–7 % opaque minerals and usually between 0.5 and 2 % of biotite.

Although the number of modal analyses is too small for statistical purpose, the data suggest that the BD_1 generation contains more olivine than either of the other two. The analysed BD_1s also commonly contain more olivine than augite, whereas in the other two generations there may be a surplus of olivine or augite, although often the proportions are roughly equal. These results must be viewed with reservation as AYRTON (1963) has recorded large variations in the modal composition across the width of brown dykes.

The texture in the olivine dolerites is normally sub-ophitic to subdoleritic. Phenocrysts are uncommon, but plagioclase phenocrysts have been found in some of the thinner dykes.

The plagioclase is well twinned and shows a marked normal zoning. Single crystals generally vary between 65 % and 40 % An although the maximum and minimum values recorded are *c.* 75 % An and 25-30 % An. The plagioclase is often sericitised and may also be saussuritised, but is generally less altered than the olivine and augite in the same thin section.

The pyroxene is a pink titaniferrous type with c∧Z of approximately 41–45°. It may be partially or completely replaced by secondary alteration products consisting mainly of uralitic hornblende, chlorite and biotite.

Olivine occurs as rounded grains often in small aggregates and it is often partially or completely altered. Apatite occurs as euhedral crystals in all dykes in accessory amounts (up to 2 % in some cases).

Only three reliable chemical analyses have been made on the brown dykes from the Ivigtut region. These represent a BD_1 and a BD_2, both from the north coast of Sermersût, and the third analysis from an olivine dolerite in the Grønnedal-Íka complex. All three analyses show low silica values (46 to 50 %) and that the olivine dolerites of the Ivigtut region are more alkaline than the average olivine gabbro.

Considering their abundance and the considerable amount of field data available, the petrology and chemistry of the brown dykes have been neglected and would be a very valuable future field of investigation.

"Big feldspar" dykes

In most of South-West Greenland there are a great number of alkaline basic dykes characterised by their content of abundant feldspathic inclusions. The feldspathic inclusions, which may reach several tens of centimetres in size, consist of anorthosite xenoliths and plagioclase megacrysts. They are regarded as products of an early crystallisation in the same Gardar magma that later gave rise to their host. A detailed description of the petrogenesis of these dykes, including those found within the Ivigtut region, is given by BRIDGWATER & HARRY (1968).

Due to the often large size of the feldspathic inclusions the dykes have in the field generally been termed "big feldspar dykes"~BFD. In the Ivigtut region they are found in varying intensity. The most prominent examples are found north and east of the head of Tigssalûp ilua and Puiátoq where a wide swarm of ENE trending big feldspar dykes can be followed towards the inland ice (plate 7). Another but less dense swarm with a similar trend occurs in the south-east corner of the map sheet. Apart from these two swarms big feldspar dykes are found only as single scattered dykes.

The chronological position of these dykes varies. Most of them are older than the oldest brown dykes (BD_0), but they are invariably younger than the lamprophyres. Some big feldspar dykes have been reported as being younger than BD_0s but older than BD_1s. In other cases some BD_1s have been found with local feldspathic inclusions of a type similar to those found in the big feldspar dykes. Dykes belonging to the BD_0 generation only rarely contain big feldspars, and inclusions are not found in the BD_2 generation.

The big feldspar dykes occurring in the Ivigtut region are generally 4–8 m wide and seldom more than 10 m in width. In the swarm north-east of the head of Tigssalûp ilua individual dykes can be followed for several kilometres and some can be traced for up to 10–15 km. The main trend of the dykes varies between ENE and NE.

The general appearance of the dykes, apart from their characteristic content of feldspathic inclusions, is similar to that of the numerous brown dykes found throughout the area. They normally have brownish weathering colour and are dark grey in colour on fresh surfaces; the margins are chilled and the central parts of the dykes are medium grained.

The distribution of feldspathic inclusions within the dykes is somewhat irregular. It seems, however, generally characteristic that the inclusions are concentrated in the central part of the dykes and that the border zones are often free of inclusions (fig. 51). The inclusions may occupy up to 50% of the volume, but the content can vary along the trend of the dyke and in places the megacrysts may be completely ab-

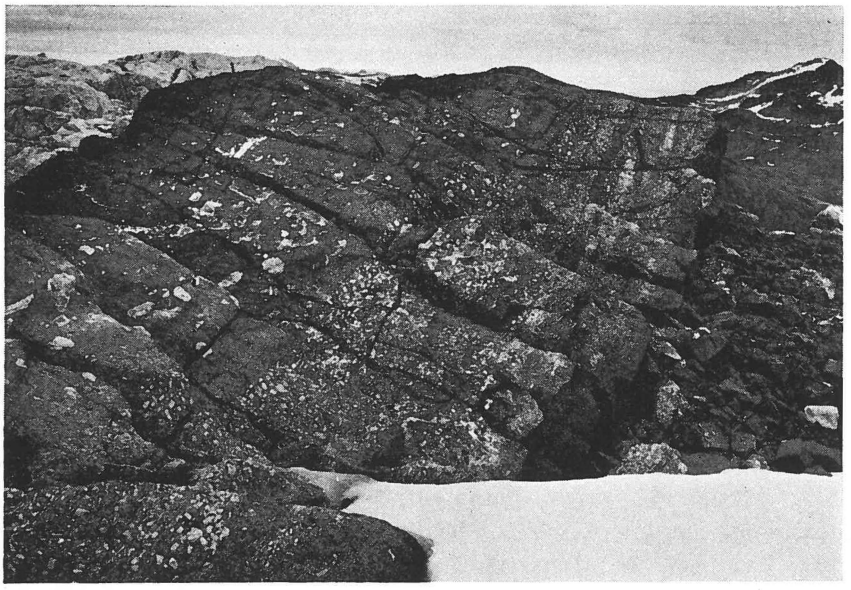


Fig. 51. "Big feldspar" dyke. Gardar dolerite with feldspar megacrysts concentrated in centre of dyke. The right margin of the dyke is eroded away. Plateau south of Puiátoq.

sent. The inclusions are often concentrated in bands parallel to the margins of the dykes. Some of the inclusions are rectangular, with dimensions of up to 5×20 cm, others have rounded forms, and some have sharp irregular edges resembling normal xenocrysts.

According to BRIDGWATER & HARRY (1968) the inclusions in the BFDs consist of anorthosite xenoliths and plagioclase megacrysts. The anorthosite is composed of labradorite, olivine, Fe–Ti oxides and rare ortho- and clinopyroxenes. The plagioclase in the megacrysts ranges generally from labradorite to calcic oligoclase. BRIDGWATER has shown that there exists a relation between type of inclusion and the composition of host rock. The anorthosite xenoliths are generally found in olivine dolerite host rocks, and the plagioclase megacrysts in less basic doleritic host rock.

Miscellaneous basic dykes

A number of small basic dykes, which cannot be assigned to any of the groups so far described, occur scattered throughout the map sheet region. Among these a group of hornblende-bearing dykes and a generation of microporphyritic dykes can be distinguished.

The hornblende-bearing basic dykes are non-metamorphosed and contain primary hornblende as the main mafic constituent. The other

minerals are plagioclase, occasional augite, opaque minerals, chlorite and biotite. Quartz is found in nearly all these dykes (up to 5%). Phenocrysts of a normally zoned plagioclase which ranges in composition from labradorite to low andesine or high oligoclase occur abundantly and may form crystals several centimetres long.

The hornblende-bearing basic dykes are mainly found in the area between Arsuk Fjord and Tôrnârssuk–Sermersût. They generally have trends of 45–80° and are from less than 1 m to 10 m in width. The few intersections between these dykes and other Gardar dykes show one to be younger than a BD_0, and others to be emplaced between intrusion of the lamprophyres and the granophyres. The hornblende-bearing dykes appear not to be a distinct generation, but intruded over a wide time span in the early part of the Gardar period. They may represent water-rich phases of the other types of basic rocks (lamprophyres and dolerites).

A widespread group of thin microporphyritic basaltic dykes, younger than the olivine dolerites but older than the youngest group of alkaline dykes, has been found in the Grønnedal-Íka area (EMELEUS, 1964). Similar dykes occur occasionally throughout the area between Tavdlorutit and Tigssalûp ilua, but they are most abundant in the so-called main fault zone (BERTHELSEN, 1958) between Arsuk Fjord and Íka.

The microporphyritic dykes are very fine grained and are distinguished by the occurrence of abundant mm scale acicular plagioclase phenocrysts, which often collect in stellate aggregates. They are mostly between 25 cm and 2 m wide and occur often in narrow swarms. Their trend is approximately ENE and they tend to be intruded along fault and crush zones, though usually the dykes themselves are not crushed.

The rectangular plagioclase phenocrysts are normally zoned with a core of labradorite and a marginal zone of acid andesine. The groundmass comprises generally granular augite, andesine and opaque minerals. Secondary chlorite, amphibole and sericite are common in some dykes, and calcite, serpentine and epidote occur occasionally. Apatite and biotite are often found in small amounts, and quartz occurs in a few instances. EMELEUS (1964) reports very small amounts of alkali feldspar from one of the dykes in the Grønnedal-Íka area.

It is notable that fresh olivine has not been found and that olivine pseudomorphs are seen only rarely. The microporphyritic dykes are thus probably less basic than the brown dykes.

Alkaline dykes

Alkaline dykes occur over a wide area in the central and eastern parts of the Ivigtut region. They are especially abundant in the 10–12 km wide NE-trending main fault zone south of Arsuk Fjord, where they

occur in a dense swarm. Outside this zone the alkaline dykes are found only in restricted numbers (plate 6).

Based on intersections with other Gardar dykes the alkaline dykes may be divided into two age groups. The earlier group comprises dykes older than the brown dykes but younger than the lamprophyres. The later group is formed by dykes which are younger than the brown dykes and the microporphyritic dolerites, and are cut by the granophyres related to the Ivigtut granite.

The individual members of the two age groups cannot be distinguished from each other in the field except by evidence of intersections. It has therefore only been possible to refer a limited number of the dykes to their respective groups. Examples of a few alkaline dykes supposedly intruded between two generations of brown dykes have been reported from the area north of Arsuk Fjord, but the intersection relationships in these examples are in doubt.

In the field all the alkaline dykes have been called trachytes. They are generally 1 to 5 metres wide, and seldom exceed 10 m. They can usually only be traced several hundreds of metres or at most a few kilometres and often have a somewhat irregular trend. The dykes are all leucocratic, their colour pale, with reddish, brownish, greenish or greyish tinges, although there are also some with darker shades. The colour varies from dyke to dyke, and also along the strike of single dykes, often over a very short distance.

The dyke rocks are fine grained or even aphanitic. They often contain small feldspar phenocrysts and in some mafic minerals and feldspatoids are occasionally also found as phenocrysts. Cavities filled with secondary minerals occur in some dykes and south of Arsuk Fjord fluorite has been found in many of them.

The alkaline dykes vary somewhat in composition. They comprise oversaturated, saturated and undersaturated types, and range from quartz-bearing trachytes and a few quartz-bearing latites, through trachytes, latites and feldspathoid-trachytes, to phonolites (nomenclature according to STRECKEISEN, 1967).

Older group

These occur most abundantly south of the inner part of Arsuk Fjord as a swarm of ENE trending dykes. Many of them are feldspar porphyritic and they are usually sheared near the ENE trending crush zones. The older group also includes a few NW trending dykes in this area, but the age relationships between these two different trending sets of alkaline dykes are not known.

Outside the main fault zone dykes of the older group mainly occur north-west of Arsuk Fjord. They are generally ordinary trachytes, but both quartz- and feldspathoid-bearing varieties are found. The main minerals are alkali feldspar, plagioclase (mainly albite but occasionally oligoclase), augite or aegirine augite, amphibole and brown biotite. In the feldspathoid-bearing varieties nepheline or analcite are found in small amounts and quartz occurs interstitially in quartz-bearing varieties. A more detailed description of some of these dykes can be found in WEIDMANN's (1964) account of the area north of Tigssalûp ilua.

Younger group

The alkaline dykes of this group occur chiefly in the main fault zone south of Arsuk Fjord, and those of the Grønnedal-Íka area have been described by EMELEUS (1964) and GILL (1972). Outside the main fault zone these dykes are found mostly to the north-west of Arsuk Fjord.

In the Grønnedal-Íka area EMELEUS (1964) distinguished 4 generations of closely related alkaline dykes within the younger group.

These generations are from youngest to oldest:

Orthotrachytes with riebeckite, biotite etc.	NE-trending
Phonolites	ENE-NE-trending
Phonolites	NW-trending
Quartz trachytes	NW-trending

South of the inner part of Arsuk Fjord JENSEN (1956) and PULVERTAFT (1957, 1958) have distinguished between two sets of alkaline dykes within the younger group. The oldest of these trends approximately NNW and the younger between NNE and ENE.

According to EMELEUS (1964), who has made a thorough petrographic study of those dykes, the trachytes and the quartz-bearing trachytes are dominated by a perthitic alkali feldspar. The chief mafic mineral is generally a brown mica, often rimmed by riebeckite. Aegerine-augite or aegerine is fairly frequently present in the trachytes, but is not usually found in the quartz-bearing types where the mafic minerals are more commonly brown biotite and/or riebeckite.

The feldspathoid varieties are mainly nepheline-bearing trachytes, nepheline-bearing alkali trachytes and phonolites. They are generally composed of nodule-like crystals of alkali feldspar, aegerine or aegerine-augite with interstitial nepheline, analcite or natrolite. The nepheline is often somewhat altered to cancrinite.

In the Grønnedal-Íka area the quartz-bearing trachytes and the trachytes comprise only about 25% of the alkaline dykes, but outside

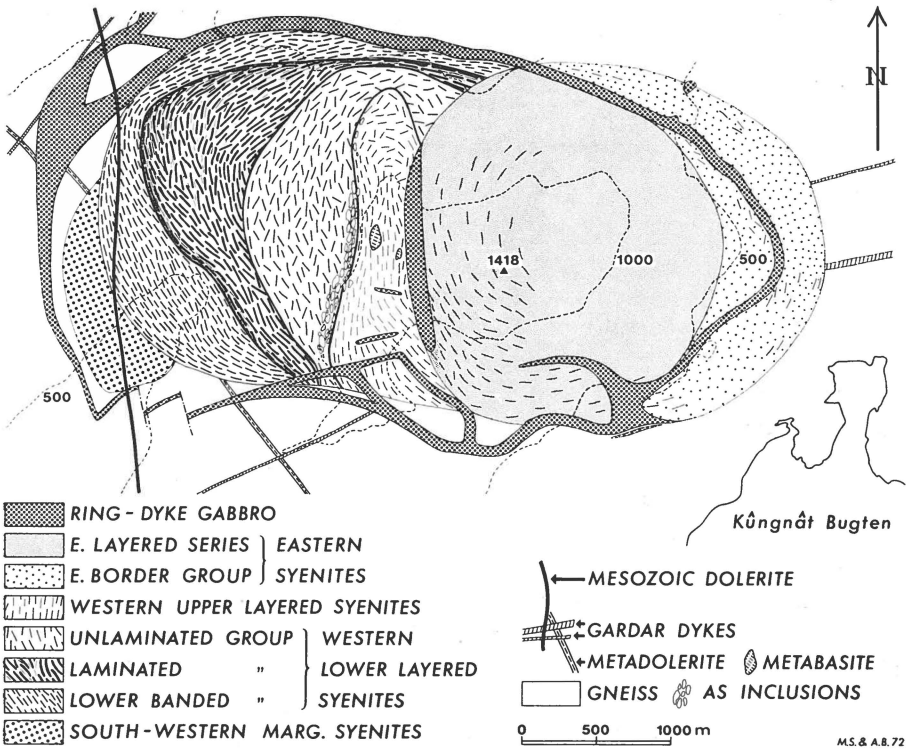


Fig. 52. Geological map of the Kûngnât complex. After Upton (1960).

this area the general impression is that these non-feldspathoid types are the most common. They here occasionally grade into latitic and quartz-bearing latitic types. Hornblende here often forms an important part of the mafic constituents.

Kûngnât complex

The highest point within the Ivigtut sheet area is a spectacular 1418 m mountain north of the small town of Arsuk. This mountain consists mainly of resistent syenitic rocks, which rise 500–800 m above the surrounding gneiss plateau (fig. 60); the syenites make up the late Gardar intrusive Kûngnât complex, a steep-sided oval-shaped complex body approximately 5 × 2.5 km in area.

The Kûngnât alkaline complex has been described in detail by Upton (1960), while Wegmann (1938) had earlier discussed some contact relations and joint patterns within the complex. A recent Rb/Sr whole rock isochron age determination (van Breemen & Upton, 1972) has indicated an age of 1250 ± 15 m.y. for the Kûngnât complex. It is

a late Gardar intrusion, which cuts some of the brown dykes (BD_1s); the relationships with other Gardar dykes are not known. The summary which follows is based on the comprehensive work by UPTON (1960).

The intrusive complex (fig. 52) consists of three steep-sided intrusions of saturated syenites surrounded by a later alkali gabbro ring dyke. These three bodies were emplaced successively with a progressive easterly shift of centre. Each of the intrusions is thought to have formed by ring-faulting and cauldron subsidence.

The earliest of the centres, the south-western marginal syenites, consists of quartz syenite with fayalite and aegirine augite.

The second intrusion is formed by the western layered syenites with inward-dipping rhythmic banding, cryptic layering, feldspar lamination and an overall increase of mafic index from top to bottom. This second intrusion is divided into an upper and a lower series by a raft-like mass of foreign blocks thought to be gneisses. Above this gneiss raft zone are a few dark angular basic rocks, previously regarded as dolerite xenoliths but now thought to be remnants of an original basaltic cover of Gardar supracrustal rocks (UPTON, personal communication). The raft zone is believed to represent a subsided mass of roofing material, differentiation after the subsidence having proceeded separately in the upper and lower magma chambers. In each a bottom accumulation of fayalite, clinopyroxene, high temperature feldspar and other minerals was formed. This resulted in pronounced fractionation and in both series the rocks grade from quartz-free to quartz-bearing types with an ultimate differentiate consisting of soda granites which occur as dykes and sheets.

The third eastern syenite intrusion is also layered. It consists of more basic syenites, but here also *in situ* fractionation has produced quartz-bearing types in the higher parts of the stock.

Through banding found within the layered complex indicates that strong magmatic currents were active during fractionation.

The ring dyke was the last phase. A ring fracture formed and allowed intrusion of an iron- and alkali-rich gabbroic magma (fig. 53). This must have taken place relatively soon after the other intrusions in so far as residual granitic and pegmatitic fluids of the eastern centre were still mobile at that time. The gabbro consists of a rather complex rock suite of feldspars, olivine, Fe-Ti oxides, clinopyroxene, biotite and other minerals.

The four Kûngnât intrusions were apparently intruded in order of increasing basicity. UPTON suggests that the four magma portions were tapped off from successively deeper levels of an already differentiated parental magma.

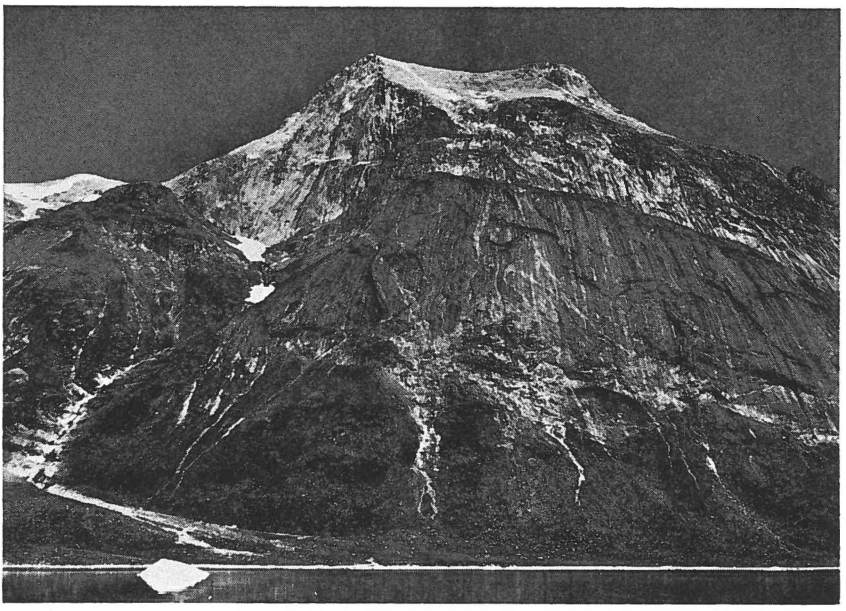


Fig. 53. Kûngnât viewed from Kûngnât Bugten. The peak of the mountain is 1418 m high. The leucocratic rock in the background is syenite, and the darker grey rock crossing the centre of the field of view is the ring dyke.

Ivigtut granite complex

Mode of occurrence and composition

The Ivigtut granite, which surrounds the cryolite ore body, occurs at the south side of Arsuk Fjord. The granite has the form of a stock with a diameter of approximately 300 m where it meets the surface. It is almost entirely surrounded by an intrusion breccia zone up to 60 m wide (fig. 54). At a late stage in the formation of the granite a cryolite mineralisation became trapped in the top central part of the granite and formed the cryolite body and its accompanying formations. The geological setting of the Ivigtut granite has been described by BERTHELSEN (1962).

The petrology of the Ivigtut granite has been briefly treated by CALLISEN (1943). She reports the granite to contain porphyritic quartz and feldspar, the latter being microcline microperthite with considerable amounts of albite. Mafic minerals occur only rarely and comprise biotite, aegirine augite and soda amphibole. In composition it is a soda-rich alkali granite. The micro-granitic intrusion breccia surrounding the granite contains abundant rotated fragments of the wall rock, although no fragments have been found of the gabbro-anorthosite bearing Nordland gneisses which are pierced by the granite at shallow depths. From

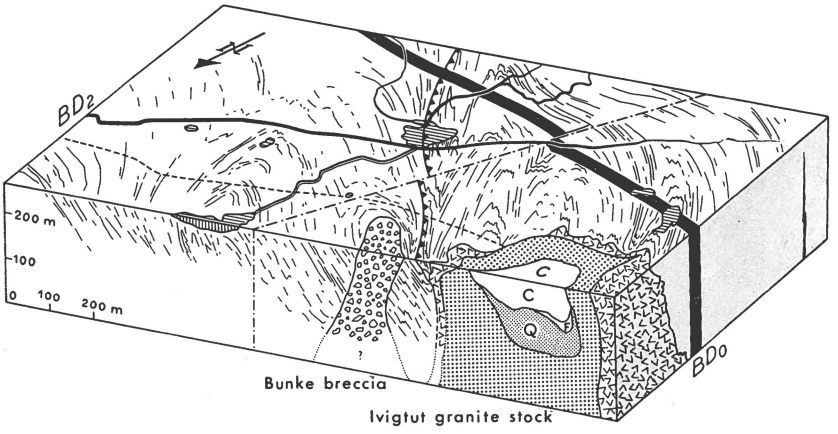


Fig. 54. Block diagram showing the geological relations of the cryolite deposit. The south coast of Arsuk Fjord is situated near the front part of the block. The dolerites shown (BDs) are older than the Ivigtut granite complex. C = Cryolite, Q = Quartz zone, F = Fluorspar.

this evidence BERTHELSEN (1962) concluded that the gneiss xenoliths were derived from above and that the granite was therefore emplaced by overhead stoping.

Immediately to the east of the granite there is another breccia, the "bunkebreccia" of BERTHELSEN (1962), which is separated from the breccia surrounding the Ivigtut granite by a wall of gneiss less than 100 m thick. The eastern breccia is emplaced in gneisses with gabbro-anorthositic enclaves and contains many angular fragments of this gneiss. Its matrix consists entirely of cataclastic wall rock, and the mineral composition reflects the surrounding highly anorthositic gneisses. The matrix material has, however, undergone considerable alteration which affects both feldspars and mafics. BERTHELSEN explained the origin as an effect of gas-drilling closely connected with the formation of the neighbouring granite.

Local related dykes

Detailed investigations of the dykes around Ivigtut by the Cryolite Company (JACOBSEN, 1966a, b) have confirmed and elaborated the dyke chronology established by EMELEUS (1964) for the alkaline rocks in the Grønnedal-Íka area. In addition to the four sets of post-doleritic alkaline dykes described from Grønnedal-Íka, JACOBSEN describes a set of porphyritic kalisyenite dykes and a set of granophyric dykes.

The kalisyenite dykes comprise occasional reddish-grey dykes found in the northern part of the Ivigtut peninsula. They have a general

ENE trend and widths of 0.5 to 2 m. They are often more coarse grained than other, otherwise similar, alkaline dykes. JACOBSEN reports them to contain alkali-feldspar (sometimes perthitic), albite, aegirine, hornblende, riebeckite and biotite. Quartz occurs as 1–3 % of the groundmass. Perthitic alkali feldspar forms porphyric grains but plagioclase grains are also reported as phenocrysts.

The exact chronological position of the kalisyenite dykes is not known as no intersections with other dykes have been found. On lithological evidence, however, JACOBSEN believes that they represent an intermediate stage between the earlier trachytes and the later granophyres described below. He reports a completely gradational lithological transition from biotite-bearing trachytes to porphyritic kalisyenite dykes.

The "bunkebreccia" is cut irregularly by a number of dark porphyritic dykes. These dykes have a groundmass of alkali feldspar, aegirine-augite, biotite, opaque minerals and apatite. The dark minerals form approximately 40 % of the rock and small porphyric grains of plagioclase and augite occur occasionally. The dykes are probably hybrid rocks of an alkaline affinity, but no exact correlation with other dykes has been possible.

Many thin granophyric dykes have been found in the immediate surroundings of the Ivigtut granite. They radiate from the present site of the granite. The granophyric dykes are up to 1 m thick although most of them are less than 0.5 m. The thicker individuals can be traced for several kilometres, whereas the smaller ones are exposed usually only in single outcrops. They comprise quartz and alkali feldspar with albite, muscovite, green biotite and sometimes riebeckite. They sometimes contain megacrysts and granite xenoliths. Opaque minerals and zircon are found as accessories and also, in varying amounts, siderite, ivigtite, cryolite and fluorspar. The occurrence of these last four minerals indicates a genetic relationship between the cryolite ore body and the granitic magma which gave rise to the granophyres and the Ivigtut granite.

Chronological setting

From detailed investigations around the cryolite mine, first BERTHELSEN (1962) and later JACOBSEN (1966a, b) have been able to show that the granophyric dykes cut representatives of all other Gardar dykes in the area. One of the granophyres is cut by Ivigtut granite, which implies that emplacement of the granite is later than the sequence of Gardar dykes known from this area. JACOBSEN shows that thin granophyre dykes cut both the "bunkebreccia" and the dark porphyric dykes found in the breccia. The granophyres, unlike the porphyritic dykes, cut rectilinearly through the breccia and JACOBSEN concludes that the



Fig. 55. Ivigtut and the open pit cryolite mine in 1956. Stockpiles of cryolite ore can be seen in the background.

"bunkebreccia" was formed and consolidated before the intrusion of the granophyres, and thus also before the *mise en place* of the Ivigtut granite.

The cryolite mineralisation

The cryolite deposit formed in the upper part of the Ivigtut granite, originally as an irregular body about 50×115 m in plan and 70 m thick. This deposit has now been exhausted and the mine closed in 1962 after over 100 years of operation. Stockpiles of ore near the mine remain sufficient for commercial demand for a number of years (fig. 55).

The geological setting of the cryolite deposit has recently been described by BERTHELSEN (1962) and PAULY (1960); both publications include references to earlier works. There are, however, no comprehensive accounts of the cryolite deposit and its genetic relations and only a brief summary is given here.

The main part of the cryolite body consists of siderite-cryolite, with about 20% siderite and 1–2% quartz and sulphide minerals. The sulphides are principally sphalerite, galena, chalcopyrite and pyrite. In all 76 minerals have been identified from the deposit. In the western part of the mine cryolite was found in association with fluorite, ivigtite, topaz

and other minerals. At deeper levels sulphide-bearing quartz rocks separate the ore from the underlying granite. According to PAULY (1960) the temperature of the siderite-cryolite rocks at formation can be estimated to lie between 510°C and 590°C.

The granite surrounding the ore body was altered to greisen at the time of emplacement of the ore. Discolouration and bleaching of some alkaline dykes in the surroundings of the granite may be a related phenomenon. The alterations occur in particular adjacent to joints and cracks which also cut the breccia, and are therefore probably younger than both the dyke intrusion and the formation of the breccia.

It is assumed that the formation of the ore took place as a concentration of cryolite mineralisers at the top of the consolidated part of the Ivigtut granite. These mineralisers, probably forming the latest gaseous differentiates of the granitic magma, were locally trapped in the interior of the cupola-shaped granite and thus formed the ore body.

FAULTS

The Ivigtut region, together with most of South-West Greenland, is dissected by a vast number of faults and crush zones. The majority of these formed, or were rejuvenated, during the Gardar period when cratogenic movements were widespread. It is, however, possible to recognise a number of older faults, mainly of Ketilidian age but occasionally also pre-Ketilidian. The distinction between faults of different age groups is best made by comparison with the many sets and generations of dykes. Many faults have been rejuvenated on one or more occasions and show varied displacements on dykes of different ages.

Plate 8 shows the distribution of the main faults and crush zones, and sense of displacement of the faults. The term crush zone is used for those faultlike shear zones along which displacement had not been demonstrated. Rose diagrams have been constructed to show the trends of both faults and crush zones in five subareas (fig. 56a, b).

Principal fault systems

1. Faults and crush zones trending between *c.* 80° and 120° are very pronounced, and displacement along the faults is sinistral. Major wrench-faults of this system, trending ESE and with displacements of several kilometres, divide the Ivigtut region into 4 or 5 large fault blocks, each

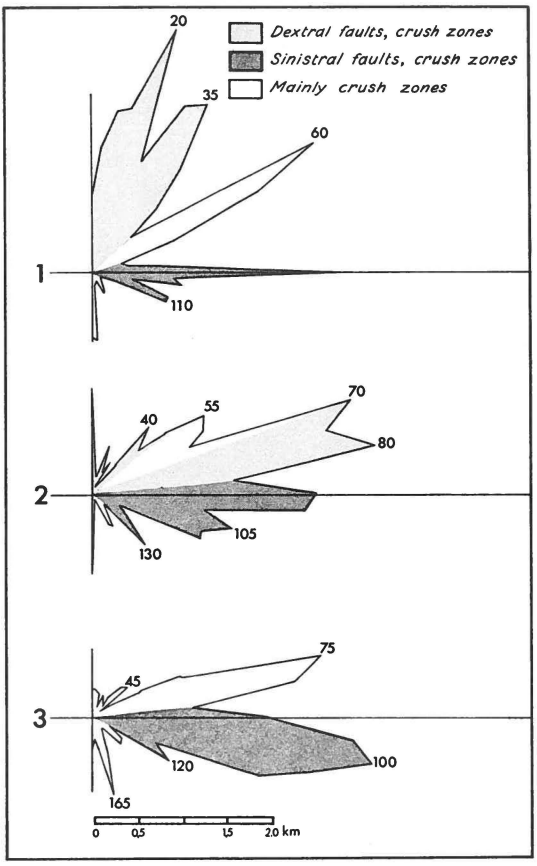


Fig. 56 a, b. Analysis of trends of faults in five subareas as shown on the index map. Numbers on the points indicate degrees from north over east to south.

of which is further dissected by several sets of less important faults and crush zones (plate 8).

2. Faults and crush zones with trends between 60° and 80° are abundant. These directions are dominated by crush zones without displacement, although faults with dextral displacement are common. Sinistral faults with these directions occur less frequently.

3. Faults and crush zones with trends varying from 10° to 50° occur throughout the area, but are most common in the north-west where they dominate other directions. Faults with these trends always show dextral displacements.

4. 160° to 180° trending faults and crush zones occur in relatively restricted numbers and most are crush zones.

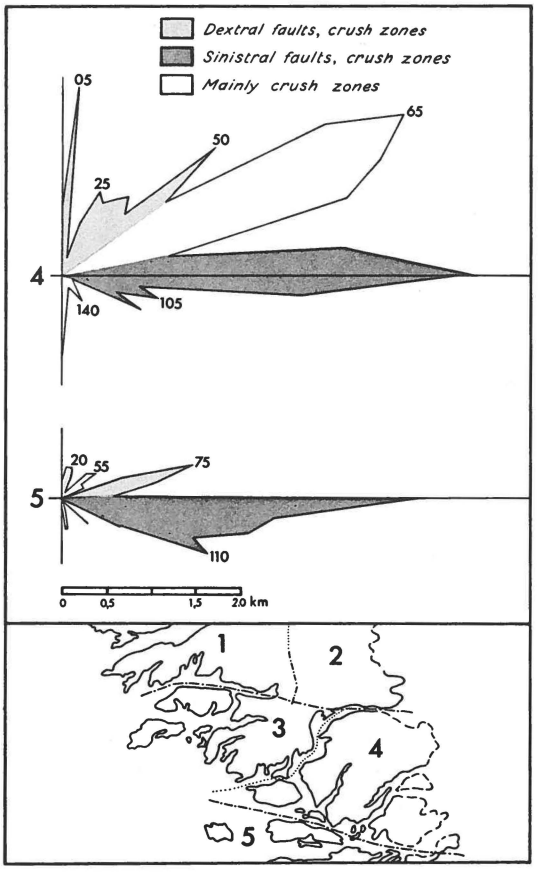


Fig. 56 b.

Chronological development

An analysis of the displacement pattern has shown that faulting activity took place repeatedly over an extended period from pre-Ketilidian to Gardar time. The majority of the faulting and crushing occurred during the cratogenic Gardar period, but many faults can be shown to be of a pre-Gardar origin although they were often reactivated in Gardar. With a few exceptions both pre-Gardar and Gardar faults follow the same trends and have the same displacement directions, and it is therefore not always possible to distinguish between them.

Pre-Gardar faulting

The general chronology of faulting which can be shown to have taken place before intrusion of the earliest Gardar intrusions is shown in table 9.

Table 9. *Chronology of faults older than Gardar intrusions*

	Intrusions	Faulting	
		Major	Minor
Early Gardar	Lamprophyric dykes Grønnedal-Íka complex		
Ketilidian		90–110° SIN;	45–80° dex; 10–40° dex 90–110° sin; 150–170° sin 100–140° dex 60–80° dex et sin
Pre-Ketilidian	Iggavik dykes (set no. indicated) AD_4 AD_3 AD_2 AD_1	90–110° SIN	90–110° sin 10–30° dex

SIN/sin = sinistral; DEX/dex = dextral

Pre-Iggavik dyke faulting

Two examples of fault movements pre-dating the intrusion of the Iggavik dykes can be demonstrated in the Ivigtut region. The most significant is an early sinistral movement of 1.5 km along the ESE trending Laksenæs fault between the fjords Kuánit and Arsuk Fjord (HENRIKSEN, 1960). The second example concerns some 90–110° trending faults around Gaffelsø, north of Tigssalûp ilua. In several cases the Iggavik dykes have been intruded into these pre-existing zones of weakness. The old faults are completely quartz impregnated and were described as "Pegmatite du Gaffelsø" by WEIDMANN (1964).

Inter-Iggavik dyke faulting

In a few cases fault movement can be shown to have taken place between the emplacement of different sets of metadolerites. The examples found indicate that dextral movements along 10–30° trending faults occurred between the emplacement of AD_1 and AD_2 dykes and that sinistral 90–110° trending faults were formed or rejuvenated before the intrusion of the AD_3 set.

Ketilidian, pre-Gardar and "early Gardar" faulting

The Ketilidian deformation of the pre-Ketilidian basement rocks took place as folding, flexuring and shearing in the south-eastern part of

the area, and as faulting and thrusting in the north-west. The boundary between these two tectonically different units approximately follows Arsuk Fjord.

Ketilidian or pre-Gardar faults are recognised by a displacement of Ketilidian or earlier rocks different from that of Gardar rocks, and often also by retrogressive metamorphic alterations. These alterations are most pronounced in the south-east, near Arsuk Fjord, becoming less intense northwards and insignificant north of the outer part of Tigssalûp ilua.

The distinction between Ketilidian and pre-Gardar faults on one side and early Gardar faults on the other side should theoretically be determined by the time at which the Gardar peneplane was formed, this episode indicating the beginning of the Gardar period. It is, however, impossible in practise to refer to this event in the Ivigtut region and thus faults with retrogressive alterations are usually considered as Ketilidian pre-Gardar and those without retrogression as early Gardar—i.e. formed before the intrusion of the early Gardar intrusives. This principle is, however, only partly valid, and it is therefore best to describe the Ketilidian to early Gardar faulting as one unit, mentioning only the more specific age of the faults where this can be satisfactorily established.

Retrogressive alterations occur in and around the crush and fault zones trending 90° around Svampesø; north of Tigssalûp ilua, and along the 110°-trending Laksenæs Fault (plate 8). One of the faults around Svampesø displaces a 2nd set Iggavik dyke sinistrally by approximately 1200 m, and another a swarm of 3rd set Iggavik dykes by approximately 800 m, also sinistrally. Both faults are cut by Gardar dolerites which are unaffected by faulting. Along the Laksenæs Fault a 4th set Iggavik dyke has been displaced sinistrally approximately 1500 m more than the oldest Gardar dolerites; this displacement presumably took place in Ketilidian to early Gardar time. A number of faults with early displacements of up to 50 m are reported from the area north-east of Arsuk Fjord. A few ENE Ketilidian faults with retrogression features also occur.

The retrogression zones often have the character of schistose shear zones where most prominent, and in some muscovite and biotite are recrystallised. They are often cut by semi-concordant quartz veins and the shear zones are internally folded on a small scale. The recrystallisation of muscovite and biotite indicates that elevated temperatures prevailed in the basement block at the time of fault formation.

Ketilidian to early Gardar faults with displacements opposite to the general displacement directions have been recognised in a number of cases. Along some faults it can be shown that the meta-dolerites are displaced either dextrally or sinistrally while all the Gardar dolerites are displaced sinistrally. In other cases both are displaced sinistrally,

but the metadolerites are displaced to a lesser extent than the Gardar dolerites. These irregularities probably indicate a period with somewhat variable crustal stress conditions prior to the main Gardar faulting.

Gardar faulting

The general Gardar chronology presented in table 8 shows formation of intrusions and faulting to have taken place intermittently throughout the Gardar. A conspicuous feature is that repeated movement took place along the same general directions with the same sense of displacement. The faults discussed here are younger than the earliest Gardar dykes.

Older faults

The oldest faults of this category are sinistral faults trending 90–120° and dextral faults trending 10–30°, which displace the BD_0 generation but which are themselves cut by the BD_1 generation. The 90–120° trending faults of this age are concentrated in and along the southern fault block. Those in the central part of the region often show later additional movements. Dextral faults occur on the Ivigtut peninsula (BERTHELSEN, 1962) and a few on Sánerut; these were all rejuvenated.

A somewhat younger set of dextral faults, following trends between 20–60°, was active between the intrusion of the BD_1 and BD_2 generations. Such faults are known on the Ivigtut peninsula, but have not been demonstrated elsewhere.

Faulting and mylonitisation with trends of 60–80° took place prior to the intrusion of microporphyritic dolerites.

In the main fault zone on the south side of Arsuk Fjord a 60–80° trending fracture and fissure system is particularly prominent, and the lines of weakness are loci for many of the later dykes.

Younger faults

In the later part of the Gardar period intensive faulting took place throughout the region. Most faults can be shown to be younger than the brown dykes, and some also displace the younger alkaline dykes.

A detailed chronology for the late Gardar faults has been established for the Grønnedal-Íka area by studying the relationships between faulting and the various sets of younger alkaline dykes (EMELEUS, 1964).

First group

According to EMELEUS the faulting in the later part of the Gardar period began with repeated N to NNE trending dextral faulting which

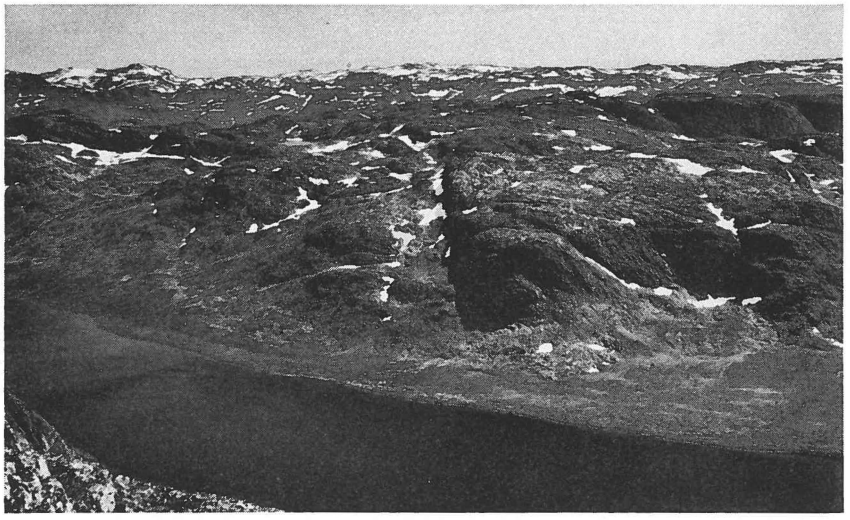


Fig. 57. Trace of the Laksenæs fault crossing Nordland looking east from Christians Havn Sø. Note differential erosion of fault scarp.

took place more or less contemporaneously with the intrusion of the first two NW-trending generations of alkaline dykes (quartz trachytes and first phonolites). Similar NNE-trending faults occur through most of the Ivigtut region, particularly in the fault block to the north of Tigssalûp ilua, and may be of the same age.

It is characteristic of many of these NNE-trending faults that the amount of displacement decreases rapidly towards the north. In the southern part of the area north of Tigssalûp ilua the displacements along the more prominent of these faults are often 500–800 m, whereas further north movements may be less than 50 m. A similar decrease in amount of displacement is seen on a smaller scale along less important faults with the same trend.

Second group

Important sinistral ESE-trending wrench faults make up the second group in the Grønnedal-Íka area. The faulting separates the intrusion of the two sets of phonolite dykes, but some movements also outlasted the intrusion of the second set of dykes.

Displacements of the Gardar dolerites along the ESE-trending faults reached 2–3 km. A structural analysis of one of these major sinistral wrench faults, the Laksenæs Fault (fig. 57). (Henriksen, 1960), showed that the fault had a step-wise development. The amount of displacement decreases eastwards. At the Grønnedal-Íka complex the

movement is only about 1 km, compared with more than 3 km near the fjord Kuánit.

Third group

The youngest movements in the Grønnedal-Íka area are dextral displacements along N-trending faults. These faults post-date the intrusion of the alkaline dykes, and displacements along the more prominent examples reach 700–800 m north of the head of the fjord Íka. These N-trending faults are the only examples in the Ivigtut region younger than the major ESE-trending wrench faults.

Faulting and its relationship to dyke intrusion

Repeated fault movements alternating with the intrusion of dykes during the Gardar period suggest a common origin as a response to prevailing stresses in the crust. The brown dyke swarms have trends varying from E–W to NE, each generation having a progressively more northerly shift in trend. Other Gardar dykes also have NE trends. Their emplacement is indicative of crustal widening in a NW–SE direction of approximately 3% in the Ivigtut region. The general intrusive features of the Gardar dykes and the absence of marginal shearing indicate that they were emplaced under purely tensional conditions.

The chronological and structural analysis of the fault systems shows the dominance of the sinistral E–W to ESE trending faults. The NNE to ENE dextral faults are less important sets. A number of other sets may be explicable as second order faults.

Both dyke emplacement and the widespread faulting during the Gardar period can be considered to have developed under a single regional stress system whose maximum stress axis was oriented approximately E–W, changing with time to NE–SW. The corresponding minimum axis was orientated N–S, changing with time to NW–SE. Primary shear fractures, represented by the two most pronounced principal fault directions, developed at an acute angle to the principal stress. Tensional sites, feasible for dyke intrusions, occurred in planes perpendicular to the minimum stress axes. This simple relationship between Gardar dyking and faulting has previously been outlined by HENRIKSEN (1961) and HIGGINS (1970).

The pre-Gardar cratogenic stress pattern in the Ivigtut region is difficult to evaluate due to the frequent Gardar reactivation of the older faults. Some of the four generations of Iggavik dykes show trends very different from those of the Gardar dykes, but most of the old faults occur with the same trends as the Gardar movements. Metadolerites correspond-

ing to the Iggavik dykes, intruded in shear fractures, have been reported from the Frederikshåb region further north (CHADWICK, 1969), but such relations have not been demonstrated in the Ivigtut region.

MESOZOIC BASIC DYKES AND SILLS

A series of coast-parallel basic dykes and a few thin kimberlitic sheets in the Pyramidefjeld granite complex are regarded as Mesozoic intrusions. Isotopic age determinations gave ages of 164 m.y. (LARSEN, 1966) and 138 m.y. (WATT, 1969) for the dykes, and an age of 225±17 m.y. for a kimberlite (ANDREWS & EMELEUS, 1971). The age of the dykes was obtained on samples from the northwards extension of the dyke swarm near Frederikshåb (WALTON, 1966). The coast-parallel dykes extend both north and south of the Ivigtut region and both the intrusion of these dykes and the kimberlites were probably related to the opening of the Labrador Sea between West Greenland and the Labrador coast in Canada (WATT, 1969).

Coast-parallel basic dykes

Several swarms of thin NNW trending, post-Gardar, dolerites occur in the western part of the Ivigtut region (plate 7). Some of these dykes have a characteristic "step formed" outcrop, formed by jointing, and the dykes have therefore been called "Trappe diabas" (trappe~staircase) or simply abbreviated TD. The dykes represent the youngest cratogenic features in the region; they cut all other dykes and are not displaced by faults. Most of them dip 60–80° towards the west (fig. 58).

Field relations

At least two sets of dykes can be distinguished. One set comprises three to four swarms with trends of 145–150°. Each swarm comprises 3–6 individual dykes which are concentrated in a zone a few kilometres wide. One swarm can be traced across the entire Ivigtut region from Sánerut in the south over eastern Arsuk Ø and eastern Tôrnârssuk to Sermiligârssuk in the north. Other 150° trending swarms can only be traced over the islands and peninsulas in the north-west of the region, or limited distances in the south-east.

The second set comprises dykes with a general trend of 160°–175° forming a swarm or group of swarms, which cross the eastern part of Tôrnârssuk. These may be divided into a group with a general trend of

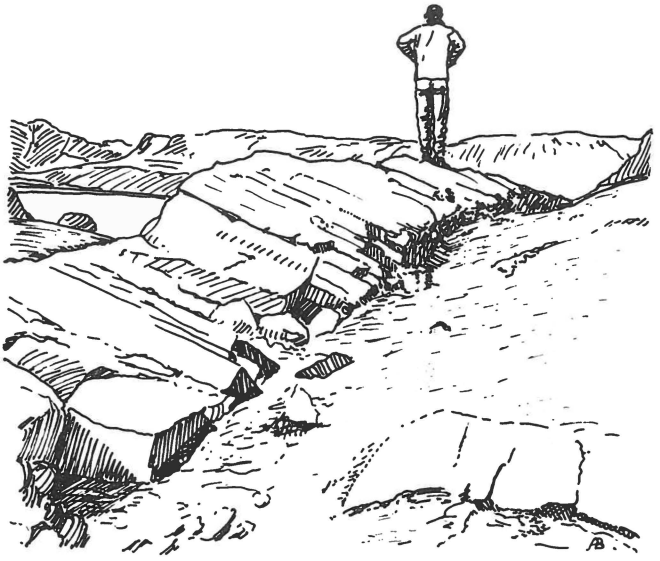


Fig. 58. Sketch of thin north-north-west trending Mesozoic dolerite (TD). Note the characteristic columnar jointing and the dip towards west-south-west. North of Webers Havn, Ivigtut peninsula.

170°–175° and one trending about 160°. Although the majority of the TD dykes occur in the outer coastal region, a single example trending 170° is found north and south of the head of Qôrnoq.

Only three intersections between dykes are known so the chronology is very tentative, but possibly 3 to 4 generations may exist. Some 150° trending dykes appear to be the youngest; the 175° trending dykes may be older and some 160° trending dykes are the oldest (MULLER, 1962).

The TD dykes are easily distinguished from other doleritic dykes in the region by their characteristic NNW trend, their westward dip and their cross-cutting relations. The dykes are generally from 10 to 20 m wide, but many thinner and thicker examples are known. The widest dykes, which are 50–70 m in thickness, are found on Tôrnârssuk. The local trend may often be somewhat irregular or curved, and in places the dykes have taken adventage of pre-existing zones of weakness. Intrusions following the margin of an old dyke (AYRTON, 1963) or an old fault zone are thus known, and under these circumstances the dykes can show local trends, which diverge considerably from the general trend.

Paleomagnetic studies of the coast-parallel dykes in the Ivigtut region show that the dykes have moderately stable remanent magnetism (KETELAAR, 1963). The direction of magnetism is usually in general agreement with the present field, but a few samples show reversed orientation. Based on KETELAAR's results TARLING (1966, 1967) indicated a



Fig. 59. Mesozoic dolerite with late-magmatic granophyric segregation, both are cut by a thin co-genetic dolerite vein with glassy margin. Kangârssûtâ, north of mouth to Sermiligârssuk.

calculated mean declination of 160° and an inclination of 62°. This is similar to results obtained for the Tertiary lavas of East Greenland (TARLING, 1967).

The TDs weather brown or reddish brown. Thin dykes are fine to medium grained. Thicker dykes are coarse grained in the centre and weather easily to form characteristic rounded blocks and gravel. The dyke margins are chilled and may be glassy at the contacts.

Some dykes contain feldspar phenocrysts and at many localities pegmatitic areas occur. Igneous banding and lamination may be locally developed, and some dykes contain thin light coloured longitudinal veins or sweats of granophyric rocks (fig. 59). Small cracks, especially in the marginal zones, have in places been filled with zeolites. Xenoliths are rare.

Petrology

The dykes all have an olivine-tholeiite composition. Typically the texture is ophitic to subophitic. Olivine is found in most thin sections, and forms up to 10% of the rock; in some cases the olivine is completely altered to secondary minerals. Plagioclase, forming approximately half of the bulk, is often fresh, well twinned and zoned varying from labradorite to andesine in composition. The most abundant mafic mineral is a

brownish titaniferous augite, but in some samples an orthorhombic pyroxene is also found (AYRTON, 1963). Brownish biotite and greenish-brown uralitic hornblende occur in small amounts, and opaque minerals form generally 5–10 % of the rock. Quartz is nearly always present, but only in very small amounts (0.5–1 %). It occurs interstitially or in vermicular intergrowths with feldspar. Apatite is a common accessory.

The granophyric leucocratic veins and sweats found in some dykes comprise mainly perthitic orthoclase, some quartz, often in micrographic intergrowths with K-feldspar, and only a little augite, biotite, hornblende and opaque minerals.

Zeolite minerals may be developed on joint planes, fill druses or occur interstitially in the groundmass. Stilbite and mesolite have been identified by X-ray analysis (BONDESEN, 1960; AYRTON, 1963).

Kimberlite sills

A set of carbonate-mica-peridotite sills in the Pyramidefjeld granite complex have been described with other kimberlitic rocks from South-West Greenland by ANDREWS & EMELEUS (1971). Approximately 10–15 sills between 0.1–0.5 m and seldom more than 1 m thick have been found in the granite. The kimberlites often carry nodules of peridotite in which a forsterite-rich olivine predominates. The inclusions are concentrated in the lower part of the sheets. The kimberlites contain porphyritic olivine in a groundmass of diopsidic clinopyroxene, phlogopitic mica, opaque minerals, perovskite, carbonate and serpentine.

According to ANDREWS & EMELEUS (1971) the kimberlites are derived from volatile-rich xenocryst-bearing magmas. The mineralogy of the peridotite nodules suggests they are xenoliths derived from great depths well within the Upper Mantle.

QUATERNARY

Systematic Quaternary investigations were not undertaken during regional mapping of the Ivigtut region. Only the most extensive areas of Quaternary deposits are shown on the map, but the whole region bears witness to a former almost complete ice cover. Only the highest part of the mountains of the outer region, such as the top 400 m of Kûngnât (1418 m), appear to have protruded as nunataks during the maximum of the last glaciation (fig. 60).

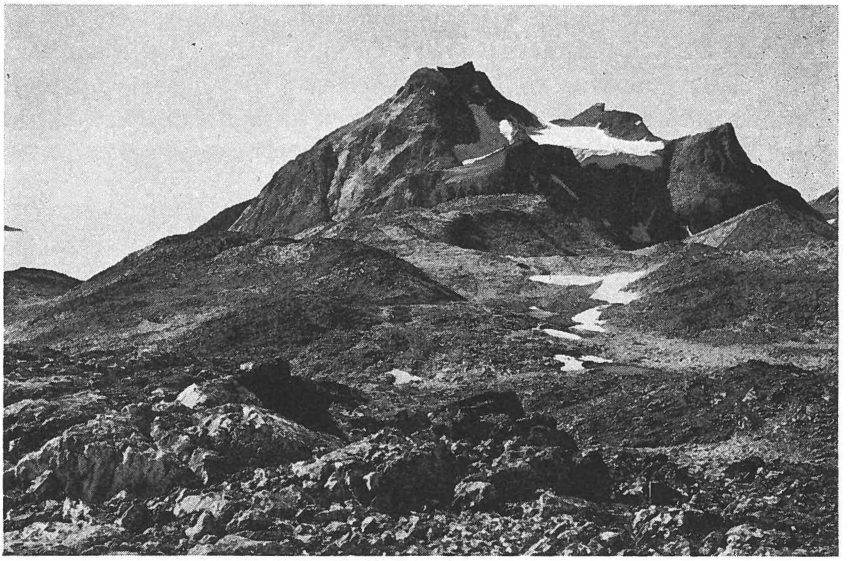


Fig. 60. Kûngnât viewed from the north-north-west. In the foreground the gneiss plateau shows the usual glaciation features. The summit of Kûngnât was a nunatak during the last glaciation.

The plateaus and the valleys are generally covered by ground moraine, thin and sporadic on the plateaus and thicker in the valleys. "Block fields" with autochthonous material are characteristic of many of the plateaus above 700–800 m.

Ice marginal features, formed along the front of the inland ice during the recession, have only been found in a few instances. They are local and no obvious general recession pattern has been established. In historic time, between 1600 and 1900 A.D., a number of ice marginal features developed around most of the local glaciers and along the inland ice. In an account of glacial variations in historic time Weidick (1959) indicates a general retreat of all the glaciers in the Ivigtut region over the last 80–100 years. Søndre Qôrnoq Bræ appears to have retreated up to *c.* 900 m over 75 years, Nordre Qipisarqo Bræ 650 m over 65 years and Arsuk Bræ almost 2000 m over nearly 100 years.

A number of terrace deposits have been found, mainly in the western part of the region near the coast. Most of the terraces have been ascribed to marine environments, but some may be considered kame terraces. Terrace niveaus with a definite marine origin have been found at heights of up to 24 m a.s.l., but it is likely that a 55–60 m niveau found in many places also reflects a former marine level. The origin of a terrace level at 94 m found on Arsuk Ø south of Ikerasârssuk and described by Jessen (1896), Bendixen (1921) and Vogt (1933) remains uncertain.

Concretions containing shells of unknown age have been found in the moraine just in front of Søndre Qôrnoq Bræ. These concretions indicate marine deposits to be present below the present inland ice. Similar concretions found in front of Frederikshåb Isblink were considered to be of interglacial origin (BRYAN, 1954).

ECONOMIC GEOLOGY

Several deposits of possible economic interest have been investigated within the Ivigtut region, but only the cryolite deposit at Ivigtut has been worked. Other deposits of possible interest are: 1. the magnetite-sulphide bearing hornblendic rocks north of Kuánit; 2. the magnetite ore conglomerate in Grænseland; 3. the anthracite-graphite deposits in Grænseland; 4. the magnetite deposits at Jernhat in the Grønnedal-Íka complex; 5. various U and Th mineralisations, especially in the south-eastern part of the region; and 6. miscellaneous mineralisations.

Cryolite deposit at Ivigtut

The occurrence and geological relations of the cryolite deposit have already been described (p. 133). The mining of the cryolite ore began in 1856, when it was used for "soda" production. It first became of importance with the great expansion of the aluminium industry, in which it is used as a catalyst in the electrolytic process of separating aluminium from bauxite and other raw materials. The cryolite mine, an open-cast pit (fig. 55), became exhausted in the autumn of 1962, but substantial amounts of cryolite ore were stockpiled for future use.

The mining was undertaken by the cryolite company, "Kryolitselskabet Øresund A/S", which also explored for other possible deposits near Ivigtut. Several drillings were made in the valley just behind the cryolite deposit and prospecting has been carried out over large areas in the southern part of the Ivigtut region, but no new cryolite deposits have been identified.

Magnetite-sulphides north of Kuánit

The Ikerasak gneiss series comprises north of the head of Kuánit a series of hornblendic and amphibolitic bands about 15–25 m wide. The bands, which contain disseminated ore minerals, occur intermittently in a zone traceable beyond Ikerasak to Tôrnârssuk. Many of the hornblendic bands north of Kuánit are characterised by a rusty weathering

colour, caused by limonitic staining derived from decomposing ore minerals. The hornblendic layers, which are composed of a variety of ultrabasic, amphibolitic and schistose rocks, may contain up to a few percent of ore minerals. According to OEN ING SOEN (1962) magnetite is the most important, but in some hornblendites, pyroxenites and pyroxene-amphibole rocks pyrite, pyrrhotite, chalcopyrite and pentlandite have also been found. Trace element analysis indicates from 100 ppm—3000 ppm Ni and Cr in some samples from the rust zones.

A geophysical team from GGU in 1959 made a geoelectrical survey of the rusty coloured zones but without locating ore of economic significance.

Magnetite ore conglomerate in Grænseland

The ore conglomerate member of the Upper Zigzagland Formation in the Ketilidian supracrustals of Grænseland (BONDESEN, 1970) is a horizon of oligomictic conglomerate with a magnetite bearing matrix up to 10 m thick. The ore conglomerate is best developed between the lakes Vallen and Lappesø, where the thickness is between 6 and 10 m. The ore proportion in the matrix is greatest at the base (up to 70 %) and decreases upwards to around 50 % 3 m from the top; generally the top metres are without ore. South of Lappesø the matrix of the conglomerate is sometimes a pyrite ore.

GGU carried out a detailed magnetometer survey of the ore conglomerate along a 3 km stretch south of Vallen, and a preliminary survey was carried out further south (KETELAAR, 1961). The survey showed anomalies around 4000 γ; a maximum value of 10000 γ was recorded, but not considered of great significance. Preliminary investigations in the southern part of the ore conglomerate horizon showed a total absence of magnetite. The geophysical data indicate that the ore conglomerate horizon is of limited extent. Chemical analyses of samples from the ore-bearing horizon (BONDAM, 1961) gave a Fe content of 20–40 %. A detailed evaluation of the size of the ore body and its tonnage has not been carried out, but it is of limited importance as a potential iron ore.

Anthracite-graphite deposits in Grænseland

Coal, anthracite and graphite are found in a thin sedimentary unit in the Foselv Formation, near the base of the Ketilidian Sortis Group in Grænseland. The 1 to 3 m unit is described as the "Anthracite-Carbonaceous Shale Member" by BONDESEN (1970). In the southern part of Grænseland it is developed as a graphite schist and in the north as an anthracite coal layer. Where contact metamorphosed by basic dykes the

carbonaceous material has been altered to almost pure graphite. The amount of graphite was estimated at 10,000 tons from a total of 4 small concentrations (HANSEN & LARSEN, 1961). The deposits do not appear to have any economic significance.

Magnetite deposits at Jernhat, Grønnedal-Íka complex

A central plug of carbonatite in the Grønnedal-Íka complex described petrographically as sövite is composed primarily of calcite, siderite and magnetite, with minor quantities of apatite, sphalerite, pyrite, strontium-rich baryte and other minerals.

Where the carbonatite is crossed by a 40 m wide olivine dolerite, the contact metamorphic effect resulted in the formation of a small body of magnetite-rich carbonate rock formed from the original siderite-calcite rock. A detailed magnetic survey and drilling programme was carried out during 1948–50 and the workable amount of ore was estimated at 800 000 tons iron ore with 25–30 % Fe (BØGVAD, 1951). The occurrence was not considered an economic proposition.

Various U and Th mineralisations

A regional radiometric survey was carried out as part of the systematic mapping. All field parties were equipped with small portable Geiger-Müller counters, either Phillips PW 4010 or Atomat WR 57 A. The measurements from the rocks were recorded in counts per minute (c.p.m.) and generally the intensity of the background radiation was recorded also. The results of the regional radiometric survey are shown on fig. 61. The values indicated on this compilation represent the reading in c.p.m. on the rock.

A number of zones have conspicuously high readings and some of these, and some other rock complexes, have been subjected to special radiometric surveys.

Radioactivity is high in some mineralised faults and shear zones on the Ivigtut peninsula and east of Íka (fig. 62). An autoradiographic and chemical investigation of some of the mineralised rocks (BUCHWALD *et al.*, 1960) indicated two types of mineralisation. Uranium-bearing veins were found only in small local occurrences, while thorium-bearing veins were much abundant and may contain up to 2.0–3.5 % Th. Trace element analysis shows an Y and La content between 100 ppm and 1 %.

The greisen rock surrounding the Ivigtut granite is relatively strongly radioactive, probably due to a content of thorite or thorogummite? (BUCHWALD *et al.*, 1960). The Ketilidian conglomeratic rocks were par-

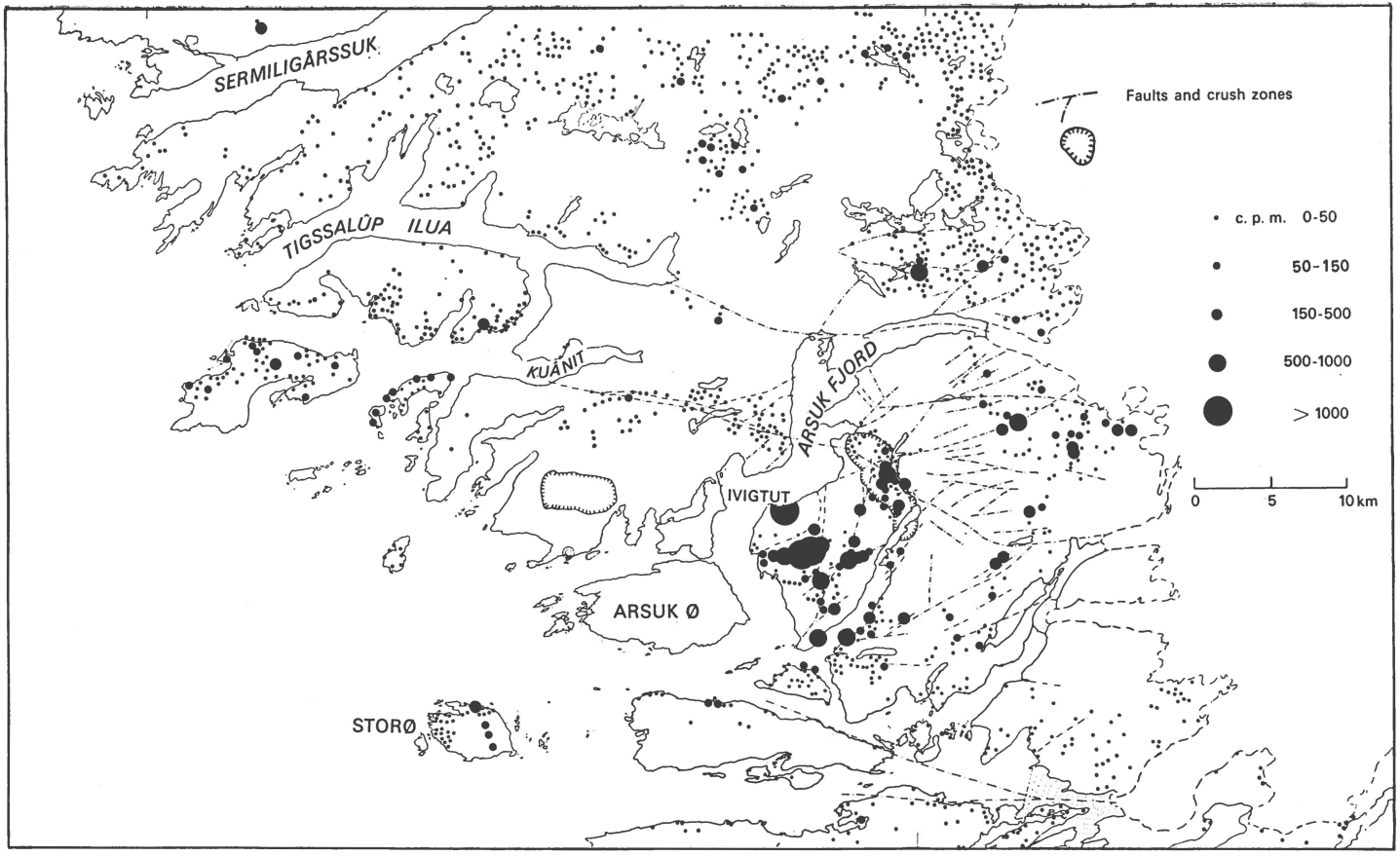


Fig. 61. Geiger-Müller measurements indicated in counts per minute. After a compilation by T. C. R. PULVERTAFT. Hachured areas indicate borders to Gardar intrusions.

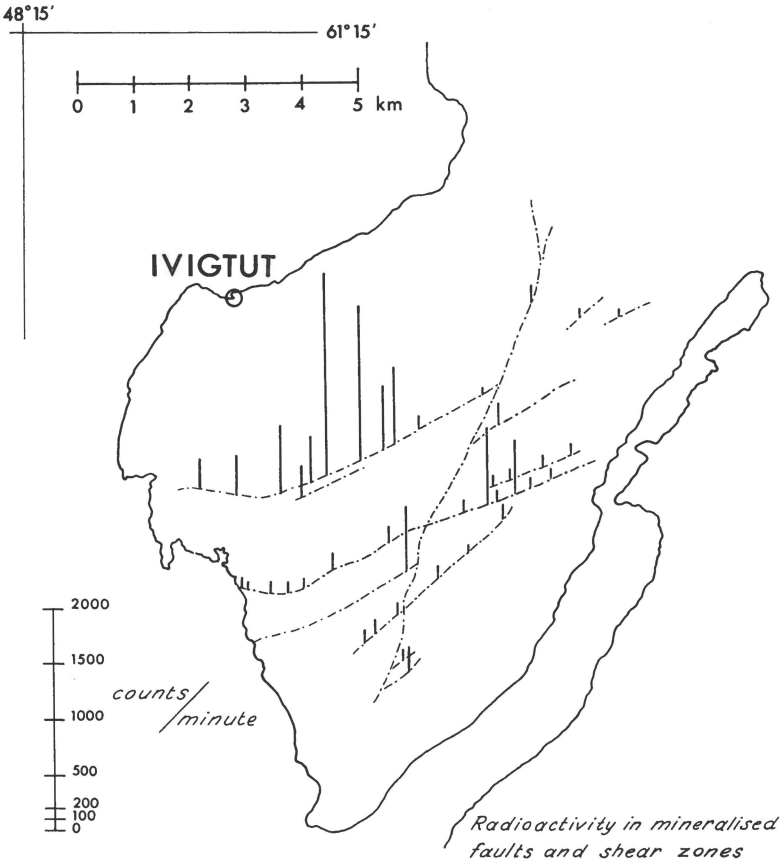


Fig. 62. Geiger-Müller measurements in mineralised faults and shear zones indicated in counts per minute.

ticular subjects of investigation, but neither the Qipisarqo conglomerate nor the ore conglomerate in Grænseland showed any anomalies (BONDESEN, 1961; LARSEN-BADSE, 1959).

A radiometric survey undertaken during exploration of the magnetite deposit at Jernhat in the Grønnedal-Íka complex showed maximum γ-radiation up to 10 times greater than the general background level (BONDAM, pers.comm.). Outside the magnetite mineralisation the carbonatite showed activity levels only slightly greater than the background.

Allanite occurs in pegmatites in the Fladland gneiss series and is especially abundant at Fladland, north of Arsuk Fjord and on the island Isa. Three allanite samples from these localities were investigated by autoradiographic and spectrographic means and showed relatively high track densities and a high content of rare earths (La > 1 % and Y: 300–2000 ppm, NOE-NYGAARD, 1958).

Miscellaneous mineralisations

On the Ivigtut peninsula and in the adjacent areas a variety of mineralisation indications are found in fractures, fissures, mylonites and in association with some lamprophyres and alkaline dykes. The field relations indicate they are related to Gardar magmatic activity. The mineralisations include galena, sphalerite, chalcopyrite, pyrite, iron-oxides, iron carbonates, fluorite, barytes, sodalite and calcite. Trace element analyses indicate that the galena may be silver-bearing and that the Ba and Sr content is often of the order 1000 ppm to 1 %. Co, Ni, Cr, Mo and V occur generally in very low proportions.

Ba and Sr content are also relatively high in the radioactive mineralisations and a genetic relationship with the sulphide mineralisations is possible.

Crocidolite has been reported by Ayrton & Masson (1972) as impregnations or small veins associated with faults and mylonite zones. Such mineralisations occur north of Tigssalûp ilua, on the Ivigtut peninsula, between Îka and Qôrnoq and on Arsuk Ø. These mineralisations have been described as early Gardar (pre-BD) and are considered to be genetically related to the alkaline magmatic activity.

SUMMARY

The general geology of the Ivigtut region is shown on a map sheet at a scale of 1:100000 (plate 1) and the general chronology is indicated on fig. 5.

The region forms the northern boundary zone of the Ketilidian fold belt (*c.* 1800 m.y.) of south Greenland. In the foreland area to the north two pre-Ketilidian orogenic complexes may be distinguished. An older central complex, formed during the Senilian orogeny, is bounded to the north-west by a younger complex, formed during the Maturian orogeny (fig. 6).

Senilian orogeny

The rocks characterising the old Senilian complex are divisible into four lithostructural units comprising gneisses and migmatites as well as layers, bands and inclusions of rocks of distinct sedimentary or igneous origin. The mapped units are:

structurally highest	The Îka gneiss series	
	The Fladland gneiss series	The Ivigtut gneisses
	The Nordland gneiss series	
	The Ikerasak gneiss seriess	
structurally lowest		

The Ivigtut gneisses comprise the main part of the old central complex, but are also known in the later reworked areas to the north and the south. The Íka gneisses are only known with certainty in the areas subsequently reworked during the Ketilidian orogeny.

The Ikerasak gneisses are mainly biotite-bearing banded gneisses which contain a large proportion of amphibolitic bands and lenses, and ultramafic lenses. The series occupies the core of a large nappe and is exposed in a few kilometres wide strip extending from north-western Tôrnârssuk to Christians Havn Sø, west of Arsuk Fjord (see plates 3 & 4).

The Nordland gneisses are characterised by the occurrence of enclaves of gabbro-anorthositic rocks which have been metamorphosed with the enclosing rocks. On the map sheet (plate 1) they are designated as: gneiss with abundant gabbro-anorthositic enclaves. Rocks referred to this gneiss series form extensive exposures in the central part of the Ivigtut region and outline a large refolded nappe structure, the core of which is made up of the Ikerasak gneiss series, and which is enveloped by the Fladland gneiss series. The gneisses of the Nordland series are mainly veined to banded or streaky migmatitic biotite or biotite-hornblende bearing gneisses of generally a granodioritic composition. Amphibolite schlieren and bands and ultramafic lenses occur sporadically. The abundant gabbro-anorthositic enclaves, which can be up to a few metres across, consist mainly of calcic plagioclase and hornblende.

Rocks referred to the Fladland gneiss series (see plates 3 & 4) outcrop in two areas, below and above the nappe. They form a well-defined lithological unit, consisting mainly of quartz diorite and granodioritic light-coloured biotite and garnet-biotite gneisses. Typical of the series are layers of banded amphibolite with ultramafic horizons and thin intercalations of mica schists.

The gneisses in the area north of the fault through Tigssalûp ilua—Puiátoq—Arsuk Fjord may be correlated with the Fladland gneisses. They comprise (1) leucocratic banded biotite gneisses of mainly a quartz dioritic composition, and (2) homogeneous to nebulitic gneisses. The latter are leucocratic, often granodioritic biotite, muscovite bearing rocks.

The various gneiss series mentioned above can structurally be traced into the area south of Arsuk Fjord where similar rock units occur, and form the bulk of the known gneisses in this area.

The Fladland gneiss series is overlain by the Íka gneiss series occurring in a major isocline stretching from Lakseelv, south of Arsuk Fjord, across the head of Íka to central Tavdlorutit (see plates 3 & 4). The Íka gneiss series is developed as a succession of schistose and porphyroblastic gneisses with abundant intercalations of amphibolite, greenschists, mica schists and quartzites, and with bands or lenticles of marble and calc-silicate rocks. The sequence becomes more gneissified towards the south

and in the southern part of the area the supracrustal rocks are only found in scattered lenses. The supracrustals of the Íka gneiss series contrast with the gneisses of the underlying gneiss series and there may or may not have been an original unconformable relationship.

On a regional scale three main deformation episodes represented by large-scale fold structures can be distinguished in the Ivigtut gneisses of the central Senilian complex (table 2, p. 28 and plates 3 & 4). The main structures of this complex are referable to the 2nd episode and greatly influence the outcrop pattern of the various gneiss series. They comprise a number of very large scale overfolds and a major nappe structure, refolded by generally upright folds of the 3rd episode. The 2nd and the 3rd episodes are considered Senilian.

The structures of the 1st episode are tight to isoclinal folds with amplitudes of several kilometres and are indicated by local marker horizons. Relations between structures of the 1st and 2nd episode are particularly well seen in eastern Sermersût where 1st phase isoclines are heteroaxially refolded by recumbent 2nd phase structures (fig. 8).

While there is some evidence to suggest that the 2nd and 3rd deformation episodes may be linked in time, the position of the 1st episode is uncertain due to their scattered occurrence. It may or may not represent a relic of a deformational episode of significantly greater antiquity, which if it could be demonstrated would be defined as pre-Senilian. Two alternative interpretations are therefore presented in the chronological scheme of fig. 5.

A high amphibolite facies metamorphism is the earliest discernable metamorphic event in the Ivigtut region. It has been recognised in Senilian deformed rocks which were unaffected, or only moderately affected, by Maturian and Ketilidian deformations and is therefore interpreted as related to the Senilian orogeny.

Maturian orogeny

The north-west part of the map sheet has been strongly influenced by a 4th main deformation which is attributed to the Maturian orogeny. The outcrop pattern of a supracrustal sequence deposited subsequent to the Senilian orogenic events—the Tartoq Group (fig. 7)—reflects only the influence of the Maturian orogeny. The surrounding gneisses display Senilian structures overprinted to a variable extent by those of the Maturian orogeny. Intense shearing, slicing and thrusting took place along and around the contact between gneisses and supracrustals, and locally the 4th episode structures may be resolved into several phases of folding. The major Maturian structures have an ENE strike which is strongly reflected by the pattern of occurrence of the Tartoq Group

supracrustals which are found in broad or narrow strips in the gneisses. In the Târtoq area the supracrustals occur in a composite Maturian synform overturned to the south-east (figs 9 & 20).

The Tartoq Group comprises mixed metasedimentary and metavolcanic rocks (fig. 24). In the Târtoq area the sequence may be divided into a lower part (*c.* 1000 m) comprising alternating metasedimentary and metavolcanic rocks, and an upper part (1000 m +) consisting almost entirely of metavolcanics. Ultramafic sills intruded this sequence, possibly during the initial phases of the Maturian orogeny.

During the Maturian orogeny the metamorphic facies conditions in the Tartoq Group rocks varied from high greenschist facies to greenschist-amphibolite transition facies in the northern part of the Ivigtut region. The Senilian amphibolite facies gneisses were during this event partially retrogressed in the areas affected by the Maturian orogeny.

Iggavik dykes

Important swarms of basic dykes which cut Senilian and Maturian structures but pre-date Ketilidian deformation occur throughout the region. They are apparently confined to the pre-Ketilidian complexes and are generally believed to have been intruded during cratogenic conditions prior to Ketilidian deposition, though possibly the youngest of them may represent Ketilidian feeders. These swarms were formerly termed the Kuanitic dykes, but the former chronology in which the Kuanitic represented a period of time has been substantially revised. It is therefore proposed to redefine these dyke swarms as the Iggavik dykes.

The distribution of the Iggavik dykes is shown in plate 5. They comprise metamorphosed basic dykes and discordant amphibolites, which may be divided into four main dyke generations of regional distribution.

The Iggavik dykes traced southwards become folded and metamorphosed and may be used as markers of the degree of Ketilidian deformation and reactivation in the Ketilidian foreland area.

Ketilidian supracrustals

Ketilidian sedimentary and volcanic rocks resting on the pre-Ketilidian gneiss complexes occur in two areas: (1) an eastern belt bordering the inland ice stretching from Grænseland southwards to Qipisarqo, and (2) the Arsuk Ø area.

In Grænseland the preserved part of the Ketilidian sequence measures at least 4400 m and in the Arsuk Ø area it is estimated at about 5500 m. In the south-east part of the map sheet area probably younger Ketilidian formations totalling several thousand metres occur.

The development of the Ketilidian supracrustals within the Ivigtut area is summarised in tables 4, 5 & 6, and fig. 31 shows the lower part of the Ketilidian succession in a profile diagram.

In Grænseland the basal part of the Ketilidian metasediments rests with a major unconformity on a sub-Ketilidian peneplane having a weathered surface.

The Ketilidian supracrustal rocks comprise a lower sedimentary sequence (Vallen Group; Ikerasârssuk Group) followed by a higher mainly volcanic sequence (Sortis Group; Arsuk Group). These rock sequences form the majority of the Ketilidian supracrustals in the Ivigtut region. In the southern part of the eastern belt the volcanic sequence is overlain by a younger sedimentary sequence (Qipisarqo Group) which again south of the Ivigtut region may be overlain by a mainly volcanic sequence (Ilordleq Group).

Ketilidian orogeny

Ketilidian supracrustals, the Iggavik dykes and the gneisses of the southern part of the map sheet were deformed during the Ketilidian orogeny (*c.* 1800 m.y.); this effect is referred to as a 5th main deformational episode distinguishable in the Ivigtut region (table 2). Within the Ketilidian supracrustals this 5th episode of deformation may be resolved into several fold phases. The Iggavik dykes traced southwards become folded and metamorphosed as they enter the belt of Ketilidian reactivation and the Senilian gneisses become extensively reworked. The northern boundary of Ketilidian folding of the pre-Ketilidian basement approximately follows Arsuk Fjord. In the area north-west of Arsuk Fjord the Iggavik dykes generally retain their original rectilinear intrusive forms, but south of the fjord the dykes are disrupted, folded and have become semi-conformable with the general gneiss trends. The Ketilidian deformation led to the formation of a large-scale semi-circular flexure in which the general trend of infracrustals, dyke remnants and the eastern belt of Ketilidian supracrustal rocks became semiconformable and took the form of an arch concave to the north-west. Within the infracrustals in this arcuate structure the older Senilian synforms and antiforms and the axes of this older fold system have been deflected within the major flexure so that the traces of the Senilian axial surfaces form also a semicircular pattern in the central and southern part of the Ivigtut region (plates 3 & 4). In the centre of this semicircular structure lies the Arsuk basin in which the Ketilidian supracrustals rest in an axial depression.

Formation of Ketilidian granites is characteristic of the southern part of the Ivigtut region. The granites may be divided into two main groups according to their relations with the surrounding rocks. Autoch-

thonous-parautochthonous granites with synkinematic to late kinematic features are generally found in the border zone between Ketilidian supracrustals and the earlier gneisses, and allochthonous granites form plugs and plutons in the Ketilidian border zone and in the pre-Ketilidian foreland (see fig. 36). The Ketilidian granites in the Ivigtut region were all emplaced subsequent to the main Ketilidian deformation, but many were later partly or completely reactivated by late Ketilidian deformation and were the site of late feldspar porphyroblastesis.

The Ketilidian metamorphism and deformation increases strongly to the south-east. The Ketilidian metamorphic pattern is best reflected by the Ketilidian supracrustals and the Iggavik dykes both of which indicate low greenschist facies conditions in the north, gradually increasing to amphibolite facies condition in the south. Metamorphic alterations in the Iggavik dykes have been recorded for approximately 100 km north of Arsuk Fjord, thus indicating the width of the foreland zone which has been influenced by elevated temperatures and the formation of occasional shear movements related to the Ketilidian orogeny.

The radiometric age determinations on Ketilidian and pre-Ketilidian rocks (table 7, fig. 45) indicate that Ketilidian metamorphism and the subsequent close of the mineral systems with respect to Sr and Ar migration took place between 1800 and 1600 m.y. ago.

Gardar

The cratogenic Gardar period in the Ivigtut region encompasses formation of three intrusive complexes, emplacement of numerous swarms of dykes of various composition and extensive faulting activity. The general Gardar chronology for this region is summarised in table 8, which shows how emplacement of the intrusive rocks and faulting was intermittent. The two youngest Gardar plutons in the Ivigtut region were both emplaced about 1250 m.y. ago.

The oldest Gardar intrusion is the Grønnedal-Îka complex, which was emplaced about 1325 m.y. ago (figs 45 & 46). It comprises two layered and laminated series of foyaitic nepheline syenites which, separated by a gneiss raft, formed an original oval-shaped intrusion with concentric structure dipping 30–70° towards the centre of the complex. The syenites are penetrated by a central plug of carbonatite and breccia.

The oldest Gardar dykes in the Ivigtut region are swarms of thin NE to E–W trending lamprophyres, which occur mainly in the central part of the region. These are followed by swarms of thin trachytic and granophyric dykes also with a predominant NE to ENE trend (plate 6).

Extensive swarms of olivine doleritic dykes occur throughout the Ivigtut region (plate 7). They have generally been designated brown dykes

(BD) and may be divided into three main generations, each generation having a characteristic trend (fig. 47 a, b). These, from oldest to youngest, are referred to as BD_0, BD_1 and BD_2. The brown dykes generally vary in width from 1–200 m, with an average thickness of between 10 and 50 m. One estimate of the sum of the dyke thicknesses across the Ivigtut region reached a figure of *c.* 2000 m corresponding to a crustal widening of approximately 3 % during the period of intrusion.

A group of dykes characterised by their feldspathic inclusions, "big feldspar dykes", are indicated separately on the map (plate 7) by the symbol XD. These dykes are olivine dolerites and the feldspathic inclusions, which may reach several tens of centimetres in size, consist of anorthosite xenoliths and plagioclase megacrysts. A group of miscellaneous basic dykes include hornblende bearing dykes and a generation of thin microporphyritic basaltic dykes, younger than the olivine dolerites.

Alkaline dykes are especially abundant in the 10–12 km wide NE-trending main fault zone south of Arsuk Fjord (plate 6). They may be divided into an early group, older than the brown dykes but later than the lamprophyres, and a later group younger than the basic Gardar dykes. The alkaline dykes are generally 1–5 metres wide and are mainly trachytes, but both quartz and feldspathoid-bearing varieties are found.

The Kûngnât complex is one of the later Gardar intrusions in the Ivigtut region; it cuts some of the brown dykes and has been dated at 1250 m.y. (fig. 45). It is a steep-sided oval-shaped body approximately 5×2.5 km in area, comprising three intrusions of saturated syenites surrounded by a later alkali gabbro ring dyke (fig. 52). The three bodies were emplaced successively with a progressive easterly shift of centre. Each of the intrusions is thought to have formed by a ring faulting and couldron subsidence.

The Ivigtut granite complex (fig. 54), at the south side of Arsuk Fjord, consists of a small stock-formed granite which surrounds a cryolite ore body. The granite is almost entirely surrounded by an intrusion breccia and thin granophyric dykes radiate from the granite and cut through the breccia and the adjacent Gardar dykes, indicating that the Ivigtut granite was emplaced after the sequence of dykes in this area. The cryolite deposit was mined for more than 100 years, but in 1962 the mine closed after large stockpiles of ore had been built up near the mine.

A vast number of faults and crush zones dissect the Ivigtut region (plate 8). The majority of these formed, or were rejuvenated, during the Gardar period when cratogenic movements were widespread (table 8). It is, however, also possible to recognise a number of older faults (table 9). The trend of both faults and crush zones in five subareas are shown in fig. 56 a, b. Major wrench faults trending ESE and with sinistral displacements of several kilometres divide the Ivigtut region into 4 or 5 large

fault blocks, each of which is further dissected by several sets of less important faults. A conspicuous feature is that repeated movements took place along the same general directions with the same sense of displacement, and that the repeated fault movements alternated with the intrusion of dykes during the Gardar period.

Mesozoic basic dykes and sills

A series of NNW-trending coast-parallel olivine tholeiitic dykes, called TDs (plate 7), represents the youngest cratogenic features in the region. They cut all other dykes and are not displaced by faults. Isotopic age determinations (see p. 145) indicate that they are Jurassic.

Kimberlite sills have been described from the Ketilidian Pyramidefjeld granite complex, but an absolute age determination indicates that these basic sills were formed in the early Mesozoic (see p. 145).

The Mesozoic basic intrusions were probably related to the opening of the Labrador Sea between West Greenland and the Labrador coast in Canada.

Quaternary

The whole region was almost completely covered by ice during the Quaternary, but Quaternary deposits only occupy a small proportion of the map sheet area. Systematic investigations of the Quaternary geology were not undertaken.

Economic geology

The Ivigtut region contains a cryolite ($Na_3 AlF_6$) deposit at Ivigtut, which was worked for more than 100 years up to 1962. Other deposits of possible economic interest have been investigated, but have so far not been found economically profitable.

The main part of the known mineralisations are of Gardar origin; the cryolite deposit at Ivigtut, the magnetite deposit at Jernhat, the various U and Th mineralisations and miscellaneous galena-sphalerite indications. Ketilidian mineralisations occur in the form of a magnetite ore conglomerate and an anthracite-graphite deposit known from the supracrustal rocks in Grænseland. Probably pre-Ketilidian magnetite-sulphide bearing mineralisations are known from the central part of the oldest (Senilian) orogenic complex.

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REFERENCES

ALLAART, J. H. 1967: Basic and intermediate igneous activity and its relationships to the evolution of the Julianehåb granite, South Greenland. *Bull. Grønlands geol. Unders.* **69** (also *Meddr Grønland* **175**[1]) 136 pp.

— 1973: Descriptive text to geological map of Greenland 1:100000 Julianehåb. 60 V. 2 Nord. Grønlands geol. Unders. Copenhagen.

ALLAART, J. H., BRIDGWATER, D. & HENRIKSEN, N. 1969: Pre-Quaternary geology of southwest Greenland and its bearing on North Atlantic correlation problems. *Am. Ass. Petrol. Geol. Mem.* **12**, 859–882.

ANDREWS, J. R. & EMELEUS, C. H. 1971: Preliminary account of kimberlite intrusions from the Frederikshåb district, South-West Greenland. *Rapp. Grønlands geol. Unders.* **31**, 26 pp.

AYRTON, S. N. 1963: A contribution to the geological investigations in the region of Ivigtut, SW Greenland. *Bull. Grønlands geol. Unders.* **37** (also *Meddr Grønland* **167**[3]), 139 pp.

AYRTON, S. & MASSON, H. 1972: Les minéralisations en crocidolite de la côte SW du Groenland. Un example de métasomatose sodique. *Bull. Suisse Minér. Petr.* **52**, 277–316.

BARAGER, W. R. A. 1968: Major-element geochemistry of the Noranda volcanic belt, Quebec-Ontario. *Can. J. Earth Sci.* **5**, 773–790.

BENDIXEN, O. 1921: Beskrivelse af Distrikterne i Sydgrønland med historiske Oversigter af Louis Bobé. *Meddr Grønland* **61**[2], 1–559.

BERTHELSEN, A. 1956: Kortfattet rapport over det i sommeren 1956 udførte geologiske feltarbejde i Ivigtutområdet. Grønlands geol. Unders., unpubl. internal report.

— 1958: On the chronology of the Ivigtut district South Greenland, a compilation. Grønlands geol. Unders., unpubl. internal report, 10 pp.

— 1960: An example of a structural approach to the migmatite problem. *Rep. 21st Int. geol. Congr., Norden* **14**, 149–157.

— 1961: Structural classification of gneisses—as used in team work in SW Greenland. *In* SØRENSEN, H. (edit.). Symposium on migmatite nomenclature. *Rep. 21st Int. geol. Congr., Norden* **26**, 69–71.

— 1962: On the geology of the country around Ivigtut, SW-Greenland. *Geol. Rdsch.* **52**, 239–280.

— 1972: Analysen orogener und Kratonischer Strukturen aus der Tiefenzone. *Geol. Rdsch.* **61**, 34–44.

BERTHELSEN, A., BONDESEN, E. & JENSEN, S. B. 1962: On the so-called wildmigmatites. *Krystalinikum* **1**, 31–50.

BERTHELSEN, A. & NOE-NYGAARD, A. 1965: The Precambrian of Greenland. *In* RANKAMA, K. (edit.). *The Precambrian* **2**, 113–262. New York: Interscience Publ.

BONDAM, J. 1954: Ivigtuthalvøen. Grønlands geol. Unders., unpubl. internal report, 6 pp.

— 1955: Feltrapport omhandlende området mellem Íka og Sermiligarssuk. Grønlands geol. Unders., unpubl. internal report.

— 1956: A new occurrence of a calco-alkaline granite intrusion from the Frederikshåb District, South Greenland. *Bull. Grønlands geol. Unders.* **15** (also *Meddr Grønland* **137**[10]) 21 pp.

— 1961: Prøveudtagning i magnetitforekomsten nord for Arsuk Isblink. Grønlands geol. Unders., unpubl. internal report, 6 pp.

BONDESEN, E. 1958: Geologisk rapport: III Timik-Tardlok. Grønlands geol. Unders., unpubl. internal report, 11 pp.

— 1960: Sermersût-Tôrnârsuk områdets geologi: I Kortbladsbeskrivelse. II Petrografi. III Tektonik. Unpubl. thesis Copenhagen University.

— 1961: Geological report on sampling from iron-ore horizon in the lower part of the Vallen-series, "Domaine des schistes verte", Ivigtut area. Grønlands geol. Unders., unpubl. internal report, 5 pp.

— 1962: Grænseland kompleksets geologi. Unpubl. prize dissertation, Copenhagen University. *Review in* Festskrift Københavns Universitet, nov. 1962, 288–294.

— 1964: An intrusion breccia with associated ultrabasics from Sermersût, South-West Greenland. *Bull. Grønlands geol. Unders.* **41** (also *Meddr Grønland* **169**[7]) 36 pp.

— 1970: The stratigraphy and deformation of the Precambrian rocks of the Grænseland area, South-West Greenland. *Bull. Grønlands geol. Unders.* **86** (also *Meddr Grønland* **185**[1]) 210 pp.

BONDESEN, E. & HENRIKSEN N. 1965: On some Pre-Cambrian metadolerites from the central Ivigtut region, SW Greenland. *Bull. Grønlands geol. Unders.* **52** (also *Meddr Grønland* **179**[2]) 42 pp.

BONDESEN, E., PEDERSEN, K. RAUNSGAARD & JØRGENSEN, O. 1967: Precambrian organism and the isotopic composition of organic remains in the Ketilidian of South-West Greenland. *Bull. Grønlands geol. Unders.* **67** (also *Meddr Grønland* **164**[4]), 69 pp.

BONNARD, L. F. 1963: Géologie d'un secteur situé entre les fjords d'Arsuk et de Sermiligârssuk, au N d'Ivigtut (SW du Groenland). Unpublished thèse de doctorat. Université de Lausanne, 1–200.

— 1971: Géologie d'un secteur situé entre les fjords de Sermiligârssuk et Arsuk (SW du Groenland). *Rapp. Grønlands geol. Unders.* **32**, 53 pp.

BREEMEN, O. VAN & UPTON, B. G. J. 1972: The age of some Gardar intrusive complexes, South Greenland. *Bull. geol. Soc. Amer.* **83**, 3381–3390.

BREEMEN, O. VAN, ALLAART, J. H. & AFTALION, M. 1972: Rb/Sr whole rock and U/Pb zircon age studies on granites of the Early Proterozoic mobile belt of South Greenland. *Rapp. Grønlands geol. Unders.* **45**, 45–48.

BRIDGWATER, D. 1959: Field report from the area south of Nordre Qipisarqo Bræ. Grønlands geol. Unders., unpubl. internal report.

— 1965: Isotopic age determinations from South Greenland and their geological setting. *Bull. Grønlands geol. Unders.* **53** (also *Meddr Grønland* **179**[4]), 56 pp.

— 1970: A compilation of K/Ar age determinations on rocks from Greenland carried out in 1969. *Rapp. Grønlands geol. Unders.* **28**, 47–55.

BRIDGWATER, D. & HARRY, W. T. 1968: Anorthosite xenoliths and plagioclase megacrysts in Precambrian intrusions of South Greenland. *Bull. Grønlands geol. Unders.* **77** (also *Meddr Grønland* **185**[2]) 243 pp.

BRYAN, M. 1954: Interglacial pollen spectra from Greenland. *Danmarks geol. Unders.* II Rk, **80**, 65–72.

BUCHWALD, V., SØRENSEN, H., BREVAL, E. & HANSEN, J. 1960: Autoradiografisk undersøgelse af grønlandske bjergartsprøver III. Unpubl. report Min. Geol. Inst., Copenhagen University.

BURRI, M. 1957: Rapport géologique. Grønlands geol. Unders., unpubl. internal report.

— 1957: Aspect général de la tectonique de la région située entre les fjords de Arsuk, Tigssaluk et Sermiligarssuk (SW du Groenland). Grønlands geol. Unders., unpubl. internal report, 15 pp.

BØGVAD, R. 1947: Magnetitforekomsten i Grønnedal ved Ivigtut. *Meddr dansk geol. Foren.* **11**, 240–243.

— 1951: Magnetitjernstenen i Grønnedal ved Ivigtut. Grønlandske Selsk. Årsskr., 16–26.

CALLISEN, K. 1943: Igneous rocks of the Ivigtut region, Greenland. Part I. The nepheline syenites of the Grønne Dal—Ika area. *Meddr Grønland* **131**[8], 74 pp.

CHADWICK, B. 1969: Patterns of fracture and dyke intrusion near Frederikshåb, Southwest Greenland. *Tectonophysics* 8, 247–264.

CROMMELIN, R. D. A. 1937: A sedimentary-petrological investigation of a number of sand samples from the south coast of Greenland between Ivigtut and Frederiksdal. *Meddr Grønland* **113**[1], 32 pp.

DENNIS, J. G. (edit.) 1967: International tectonic dictionary, English terminology (Comm. geol. map of the World). Tulsa. Am. Ass. Petrol. Geol.

EMELEUS, C. H. 1957a: The Tigssalug granite complex. Report on the field work for 1957. Grønlands geol. Unders., unpubl. internal report, 37 pp.

— 1957b: Notes on the visits to Kuiatovfik, Tavdlorutit and Arsuk Storø. Grønlands geol. Unders., unpubl. internal report, 5 pp.

— 1958: The granites of the Tigssalug area, South-West Greenland. Report on field work. Grønlands geol. Unders., unpubl. internal report.

— 1963: Structural and petrographic observations on layered granites from southern Greenland. *Min. Soc. Amer. Spec. Pap*, **1**, 22–29.

— 1964: The Grønnedal-Íka alkaline complex, South Greenland. The structure and geological history of the complex. *Bull. Grønlands geol. Unders.* **45** (also *Meddr Grønland* **172**[3]), 75 pp.

EMELEUS, C. H. & UPTON B. G. J. (in press): The Gardar period in southern Greenland. *In* ESCHER, A. & WATT, W. S. (edit.) *Geology of Greenland.* Copenhagen.

FROIDEVAUX, C. & MULLER, J. 1958: Étude géologique et tectonique d'Arsuk Storø. Grønlands geol. Unders., unpubl. internal report, 28 pp.

GHISLER, M. & WINDLEY, B. F. 1967: The chromite deposits of the Fiskenæsset region, West Greenland. *Rapp. Grønlands geol. Unders.* **12**, 39 pp.

GIESECKE, KARL LUDWIG 1910: Mineralogisches Reisejournal über Grönland. 1806–1813. *Meddr Grønland* **35**[2], 1–478.

GILL, R. C. O. 1972: Chemistry of peralkaline phonolite dykes from the Grønnedal-Íka area, South Greenland. *Contr. Miner. Petrol.* **34**, 87–100.

GULSON, B. L. & KROGH, T. E. 1972: U/Pb zircon studies on the age and origin of post-tectonic intrusions from South Greenland. *Rapp. Grønlands geol. Unders.* **45**, 48–53.

HANSEN, J. & LARSEN, O. 1961: Rapport over feltarbejdet i området mellem Arsukfjorden og Sermilikarsukfjorden. Grønlands geol. Unders., unpubl. internal report.

HARRY, W. T. & PULVERTAFT, T. C. R. 1963: The Nunarssuit intrusive complex, South Greenland. Part I. General description. *Bull. Grønlands geol. Unders.* **36** (also *Meddr Grønland* **169**[1]), 136 pp.

HENRIKSEN, N. 1960: Structural analysis of a fault in South-West Greenland. *Bull. Grønlands geol. Unders.* **26** (also *Meddr Grønland* **162**[9]), 27 pp.

— 1961: En geologisk beskrivelse af et område mellem Arsuk Fjord og Tigssaluk Fjord, SW. Grønland. Unpubl. thesis, Copenhagen University.

— 1963: Rapport om den geologiske kartering af et område mellem Sermiligarssuk og Qasigialik/Neria. Grønlands geol. Unders., unpubl. internal report.

— 1969a: Boundary relations between Precambrian foldbelts in the Ivigtut area, Southwest Greenland. *Geol. Ass. Can. Spec. Pap.* **5**, 143–154.

— 1969b: Chemical relations between metabasaltic lavas and metadolerites in the Ivigtut area, South-West Greenland. *Bull. geol. Soc. Denmark* **19**, 1, 27–50.

HIGGINS, A. K. 1968: The Tartoq Group of Nuna qaqortoq and in the Iterdlak area, South-West Greenland. *Rapp. Grønlands geol. Unders.* **17**, 16 pp.

— 1970: The stratigraphy and structures of the Ketilidian rocks of Midternæs, South-West Greenland. *Bull. Grønlands geol. Unders.* **87** (also *Meddr Grønland* **189**[2]), 96 pp.

HIGGINS, A. K. & 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.* **8**, 21 pp.

JACOBSEN, F. L. 1961: Beskrivelse af en kvartsdioritisering af amfibolitisk grønsten ved N. og S. Kangek N-lige del af Ivigtut kortbladet. Grønlands geol. Unders., unpubl. internal report.

— 1966a: Ivigtuthalvøens gangbjergarter. Report from Kryolitselskabet Øresund.

— 1966b: Gangbjergarterne ved Ivigtut og deres relation til Ivigtutgraniten. Report from Kryolitselskabet Øresund.

JAEGER, J. C. 1957: The temperature in the neighborhood of a cooling intrusive sheet. *Am. J. Sci.* **255**, 306–318.

JENSEN, S. B. 1956: Rapport over de af Stig Bak Jensen foretagne undersøgelser fra det indre Arsuk Fjord mod Kornoq i det sydlige Frederikshaab Distrikt i sommeren 1956. Grønlands geol. Unders., unpubl. internal report, 11 pp.

— 1957: Rapport over de af Stig Bak Jensen foretagne undersøgelser mellem Ika Fjord og Kornoq, på Kuiartorfik og Tavdlorutit i det sydlige Frederikshåb distrikt i sommeren 1957. Grønlands geol. Unders., unpubl. internal report, 15 pp.

— 1958: Rapport over Stig Bak Jensens kartering i sommeren 1958: N-Sanerut, Kinalik, øer i Kornok, N for indre Kornok. Grønlands geol. Unders., unpubl. internal report, 14 pp.

— 1960: Rapport over Stig Bak Jensens kartering i sommeren 1960 på Sanerut, øer i Kobberminebugten og ved Qipisarqo. Grønlands geol. Unders., unpubl. internal report, 16 pp.

JESSEN, A. 1896: Geologiske Iagttagelser. *Meddr Grønland* **16**[2], 123–169.

JOHANNSEN, A. 1939: *A descriptive Petrography of the Igneous rocks. 3 vols.* The University of Chicago Press, Illinois.

JOHNSTRUP, J. F. 1878: *Gieseckes mineralogiske rejse i Grønland.* København.

JØRGENSEN, O. 1968: K/Ar age determinations from western Greenland II. The Ivigtut region. *Rapp. Grønlands geol. Unders.* **15**, 87–91.

KANASEWICH, E. R. & SLAWSON, W. F. 1964: Precision intercomparisons of lead isotope ratios: Ivigtut, Greenland. *Geochim. cosmochim. Acta* **28**, 541–549.

KETELAAR, A. C. R. 1961: The magnetometric survey of a magnetite-bearing conglomerate NE of Ivigtut near the Inland-Ice. Grønlands geol. Unders., unpubl. internal report, 60 pp.

— 1963: The direction of the remanent magnetisation in some TD's in SW Greenland. Grønlands geol. Unders., unpubl. internal report, 8 pp.

KOCH, LAUGE 1935: *Geologie von Gronland.* (*Geologie der Erde*), Berlin.

LAM, J. & PEDERSEN, K. RAUNSGAARD 1968: Precambrian organic compounds from the Ketilidian of South-West Greenland, Part II. *Bull. Grønlands geol. Unders.* **74** (also *Meddr Grønland* **185**[6]), 15 pp.

LARSEN, O. 1966: K/Ar age determinations from western Greenland. *Rapp. Grønlands geol. Unders.* **11**, 57–67.

— 1969: K/Ar age determinations. *Rapp. Grønlands geol. Unders.* **19**, 62–67.

— 1971: Preliminary report on K/Ar dating in the south-eastern part of the Ivigtut region. *Rapp. Grønlands geol. Unders.* **35**, 49–52.

LARSEN, O. & MØLLER, J. 1968a: K/Ar age determinations from western Greenland I. Reconnaissance programme. *Rapp. Grønlands geol. Unders.* **15**, 82–86.

— 1968b: Potassium-Argon age studies in West Greenland. *Can. J. Earth Sci.* **5**, 683–691.

LARSEN-BADSE, 1959: Radiometriske målinger i Sydgrønland 1959. Grønlands geol. Unders., unpubl. internal report.

MOORBATH, S. & PAULY, H. 1962: Rubidium-strontium and lead isotope studies on intrusive rocks from Ivigtut, South Greenland. Tenth Annual Progress Report, Dept. of Geology and Geophysics, Mass. Inst. Tech., 99–102.

MOORBATH, S., WEBSTER, R. K. & MORGAN, J. W. 1960: Absolute age determination in South-West Greenland. *Meddr Grønland* **162**[9] I, 14 pp.

MULLER, J. 1962: Palaeomagnetisme. Grønlands geol. Unders., unpubl. internal report. 5 pp.

— 1974: Géologie et pétrographie des roches sédimentaires et volcaniques kétilidiennes (Protérozoïque inférieur) de la baignoire d'Arsuk, Groenland méridional. *Bull. Grønlands geol. Unders.* **110** (also *Meddr Grønland* **201**[3]) 138 pp.

NOE-NYGAARD, A. 1958: En undersøgelse af prøver af Allanit fra Grønland. Unpubl. report. Min. Geol. Inst. Copenhagen University.

OEN ING SOEN 1962: Hornblendic rocks and their polymetamorphic derivatives in an area NW of Ivigtut, South Greenland. *Bull. Grønlands geol. Unders.* **33** (also *Meddr Grønland* **169**[6]), 84 pp.

PAULY, H. 1960: Paragenetic relations in the main cryolite ore of Ivigtut, South Greenland. *Neues Jb. Miner. Abh.* **94**, 121–139.

PEDERSEN, K. RAUNSGAARD & LAM, J. 1968: Precambrian organic compounds from the Ketilidian of South-West Greenland. Part I. *Bull. Grønlands geol. Unders.* **74** (also *Meddr Grønland* **185**[5]), 16 pp.

POULSEN, V. 1964: The Precambrian sandstone of the Eriksfjord Formation in South Greenland. *Rapp. Grønlands geol. Unders.* **2**. 16 pp.

PULVERTAFT, T. C. R. 1957: Notes on the petrography of some dykes in the Ivigtut region. Grønlands geol. Unders., unpubl. internal report.

— 1958: Report on the area between Høje Laksefjeld and Arsuk Bræ. Grønlands geol. Unders., unpubl. internal report.

REYNOLDS, D. L. & HOLMES, A. 1954: The superposition of Caledonoid folds on an older fold-system in the Dalradians of Malin Head, Co. Donegal. *Geol. Mag.* **91**, 417–444.

SLAWSON, W. F., KANASEWICH, E. R., OSTIC, R. G. & FARQUHAR, R. M. 1963: Age of the North American crust. *Nature, Lond.*, **200**, 413–414.

STRECKEISEN, A. L. 1967: Classification and nomenclature of igneous rocks. *Neues Jb. Miner. Abh.* **107**, 144–240.

SØRENSEN, H. (edit.) 1960: Symposium on migmatite nomenclature. *Rep. 21st Int. geol. Congr., Norden* **26**, 54–78.

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

TARLING D. H. 1967: The palaeomagnetic properties of some Tertiary lavas from East Greenland. *Earth Planet. Sci. Lett.* **3**, 81–88.

TURNER, F. J. 1968: *Metamorphic Petrology.* New York: McGraw-Hill. 403 pp.

ULRYCH, T. J. 1964: The anomalous nature of Ivigtut lead. *Geochim. cosmochim. Acta* **28**, 1389–1396.

UPTON, B. G. J. 1960: The alkaline igneous complex of Kûngnât Fjeld, South Greenland. *Bull. Grønlands geol. Unders.* **27** (also *Meddr Grønland* **123**[4]), 145 pp.

— 1962: Geology of Tugtutôq and neighbouring islands, South Greenland. Part I. *Bull. Grønlands geol. Unders.* **34** (also *Meddr Grønland* **169**[8]), 60 pp.

— 1964: The geology of Tugtutôq and neighbouring islands, South Greenland. Part III. Olivine gabbros, syeno-gabbros and anorthosites. *Bull. Grønlands geol. Unders* **48** (also *Meddr Grønland* **169**[3]), 1–47.

USSING, N. V. 1907–1908: Kryoliten ved Ivigtut. *Geogr. Tidsskr.* **19**, 194–200.

— 1912: Geology of the country around Julianehaab, Greenland. *Meddr Grønland* **38**, 426 pp.

VOGT, TH. 1933: Late-Quaternary oscillations of level in South-East Greenland. *Skr. Svalb. Ishavet* **60**, 44 pp.

WALTON, B. 1966: Carbonatite-lamprophyre dykes of Mesozoic age. *Rapp. Grønlands geol. Unders.* **11**, 37–38.

WATT, W. S. 1966: Chemical analyses from the Gardar igneous province, South Greenland. *Rapp. Grønlands geol. Unders.* **6**, 92 pp.

— 1969: The coast-parallel dike swarm of Southwest Greenland in relation to the opening of the Labrador Sea. *Can. J. Earth Sci.* **6**, 1320–1321.

WATTERSON, J. 1965: Plutonic development of the Ilordleq area, South Greenland. Part I: Chronology, and the occurrence and recognition of metamorphosed basic dykes. *Meddr Grønland* **172**[7], 147 pp.

— 1968: Plutonic development of the Ilordleq area, South Greenland. Part II. Late kinematic basic dykes. *Meddr Grønland* **185**[3], 104 pp.

WEBSTER, NOAH 1904: *Websters Universal Dictionary of the English Language.* Chicago: George W. Ogilvie.

WEGMANN, C. E. 1938: Geological investigations in southern Greenland. Part I. On the structural divisions of southern Greenland. *Meddr Grønland* **113**[2], 1–148.

— 1939: Übersicht über die Geologie Südgrönlands. *Mitt. naturf. Ges. Schaffhausen* **1940**, 188–212.

— 1948: Note sur la chronologie des formations précambriennes du Groenland méridional. *Eclogae geol. Helv.* **40**, 7–14.

WEIDICK, A. 1959: Glacial variations in West Greenland in historical time. Part I. Southwest Greenland. *Bull. Grønlands geol. Unders.* **18** (also *Meddr Grønland* **158**[4]), 196 pp.

WEIDMANN, M. 1964: Géologie de la région située entre Tigssaluk fjord et Sermiligârssuk fjord (partie médiane), SW-Groenland. *Bull. Grønlands geol. Unders.* **40** (also *Meddr Grønland* **169**[5]), 146 pp.

WILKINSON, J. F. G. 1967: The petrology of basaltic rocks. *In* HESS, H. H. & POLDERVAART, A. (edit.) *Basalts* **1**, 163–214. Interscience Publ.

WINDLEY, B. F. 1969a: Anorthosites of southern West Greenland. *Mem. Am. Ass. Petrol. Geol.* **12**, 899–915.

— 1969b: Evolution of the early Precambrian basement complex of southern West Greenland. *Spec. Pap. geol. Ass. Can.* **5**, 155–161.

WINDLEY, B. F. & BRIDGWATER, D. 1971: The evolution of Archaean low- and high-grade terrains. *Spec. Publ. geol. Soc. Australia* **3**, 33–46.

WINDLEY, B. F., HENRIKSEN, N., HIGGINS A. K., BONDESEN, E. & JENSEN, S. B. 1966: Some border relations between supracrustal and infracrustal rocks in South-West Greenland. *Rapp. Grønlands geol. Unders.* **9**, 43 pp.

Færdig fra trykkeriet den 25. juli 1975.

DANMARK
GRØNLAND 1:100000

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

GEOLOGISK KORT OVER GRØNLAND
61 V. 1 SYD IVIGTUT

61 V 1 NORD

61 V 2 NORD

61 V 2 SYD

60 V 1 NORD

49° V. f. Greenwich

Kartografi: Jack E. T. Larsen

Reproduceret ved Geodetisk Institut, København 1968

LEGEND

GARDAR INTRUSIVE ROCKS

- GRANITE. Ivigtut biotite granite.
- SYENITE. Küngnât complex, saturated pyroxene fayalite syenite.
- CARBONATITE in Grønnedal — Íka complex, mainly calcite-rich (sövite).
- NEPHELINE SYENITE. Grønnedal — Íka complex; mainly foyaitic.

DYKES MOSTLY GARDAR

- TRACHYTES, both saturated and undersaturated.
- ACID DYKES, often granophyric; some are pre-Gardar.
- DOLERITES. Dykes and swarms, including dykes with a large content of foreign plagioclase megacrysts, and the ring dyke of the Küngnât complex. NNW trending dykes in coastal region are post-Gardar.
- LAMPROPHYRES, often rich in carbonates.
- METAMORPHIC BASIC INTRUSIVES. Metadolerites and discordant amphibolites.

KETILIDIAN GRANITES

- GRANITE s. l., ALLOCHTHONOUS
  - " biotitic, foliated biotitic
  - " biotite-rich enclaves
  - } Granites of Tigssaluk, Storø, Quiartorfik, Tavdlorutit and Sânerut.
- DIORITE, ALLOCHTHONOUS. Biotite diorite in Tigssaluk granite.
- QUARTZ DIORITE, ALLOCHTHONOUS. Breccia matrix on Sêrmersut.
- GRANITE s. s., AUTOCHTHONOUS-PARAUTOCHTHONOUS. In SE part of Kînâlik and adjacent areas with abundant pelitic schlieren and bands and often with gradational transition to migmatized mica schists.
  - " with pelitic schlieren and bands.
  - " with amphibolitic schlieren and enclaves.
  - " with calc-silicate enclaves.
- GRANITE s. l., AUTOCHTHONOUS-PARAUTOCHTHONOUS, sometimes with ghost remnants.
  - " biotitic, foliated biotitic, with biotite-rich schlieren.
  - " hornblendic.
  - " with pelitic enclaves.
  - " with amphibolitic agmatite.
  - " with ultrabasic lenses.
  - " with augen texture.

The granites are mainly of adamellitic-granodioritic composition

PREDOMINANTLY KETILIDIAN SEDIMENTS AND METAMORPHIC BASIC ROCKS

- CONGLOMERATE, with hornblendic matrix.
- " with gritty quartzitic-greywacke matrix.
- MICA SCHISTS,
- " with amphibolite bands, enclaves.
- DARK PYRITIC SHALES AND SCHISTS. In the Arsuk Ø area with graphite and intercalated quartzitic slabs.
- UNDIFF. SILICEOUS METASEDIMENTS. In Grænseland black schists, dolomitic quartzite and quartzite; on Kînâlik gritty quartzite-greywacke; in the Arsuk Ø area dolomitic quartzites. In the Târtoq region talcose and micaceous quartzites.
- SEMIPELITE. In Grænseland with greywacke bands; on Storø with intercalated pelites, quartzites, pyritic schists, conglomerates and dark schists.
- METAGREYWACKES, with bands of conglomerate, pelite and semipelite.
- CALCAREOUS AND DOLOMITIC METASEDIMENTS AND SCHISTS. In the Târtoq region with a siliceous composition.
- QUARTZITE. South of Arsuk Bræ with some calcareous and pelitic enclaves.
- " Conglomeratic in Grænseland with an ore-conglomerate horizon.
- PELITE. In Grænseland with semipelitic slates and a thin rusty dolomite horizon. In the Arsuk Ø area light and dark banded phyllites.
- CARBONATE ROCKS. In Grænseland dolomite with conglomerate and cherts in basal part.
- BASIC METAVOLCANICS, often with pillow structure and including pyroclastics.
- BASIC INTRUSIVES. Metamorphosed sills and "gabbros".
- BASIC METAMORPHIC ROCKS. In the supracrustal regions metavolcanics mixed with metaintrusives. In the gneisses amphibolite bands.

MAINLY TARTOQ GROUP

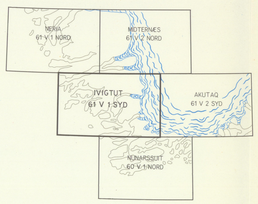
- METAVOLCANIC ROCKS MIXED WITH METASEDIMENTS, (e.g. "green schists"). In the northern part of the sheet belonging to the Tartoq Group.
- QUARTZ DIORITE GNEISS, lithological characteristics as indicated by gneiss symbols.

PREDOMINANTLY PRE-KETILIDIAN ROCKS

- GNEISS, mainly granodioritic - quartz dioritic, occasionally granitic.
- " banded biotitic, with biotitic schlieren, streaks, enclaves.
- " banded hornblendic, with hornblendic schlieren.
- " with amphibolite bands, enclaves, basic agmatite.
- " banded chloritic, with chloritic schlieren, chloritic enclaves, chloritic agmatite.
- " homogeneous - nebulitic with muscovite.
- " with enclaves of calc-silicates.
- " with enclaves of gabbro-anorthosite.
- " with enclaves of ultramafics.
- GNEISS, with abundant gabbro-anorthositic enclaves. Mainly granodioritic-quartz dioritic matrix. Lithological characteristics as indicated by gneiss symbols.
- SILICEOUS GNEISS.
- ULTRAMAFIC METAMORPHITES. Plugs, dykes, horizons.

- MIGMATIZATION.
- PEGMATITES, schematic and mapped bodies.

- QUATERNARY. Ice and perennial snow banks.
- " Undifferentiated deposits.
- " Fluviatile deposits.
- " Deltas.
- " Talus.
- " Historical moraines. Only the most extensive areas of Quaternary are indicated.



1:100000

1 0 5 10 15 Km

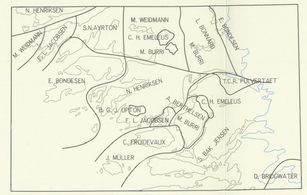
1 0 2 4 6 8 Statute miles

Højdeforskellen mellem kurverne 100 m
Contour interval 100 m

Topography based on preliminary 1:20000 maps prepared photogrammetrically from vertical aerial photographs by the Geodetic Institute, Copenhagen.

Geology based mainly on mapping at 1:20000 carried out during the period 1955-'63. The delimitation of areas mapped by individual geologists is shown in the index map. Compilation by N. Henriksen, 1966.

- BOUNDARY, established.
- " inferred.
- " arbitrary, also used to indicate transitional or migmatitic boundaries.
- STRUCTURAL TREND LINES.
- STRIKE AND DIP of lithological layering of any origin.
- FOLIATION.
- LINEATION.
- FOLD AXIS, measured, constructed.
- MYLONITE AND FAULT.
- THRUST.
- DISCORDANCE.
- BRECCIA (intrusive or tectonic).
- PILLOW STRUCTURE.
- AGGLOMERATE.
- TUFF.
- FELDSPAR MEGACRYSTS.
- GARNET - BEARING.
- MINE, abandoned.



GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDR GRØNLAND BD. 186 NR. 1 (A. BERTHELSEN AND N. HENRIKSEN)

PLATE 2

GEOLOGICAL MAP OF THE IVIGTUT PENINSULA

by Asger Berthelsen 1958.

Mapped by Marcel Burri (1956) and Asger Berthelsen (1956, 1957, 1958). The eastern part includes results from C. H. Emeleus' mapping of the Grønnedal-Íka alkaline complex.

Scale 1:20 000

0,5 0 1 2 km

ARSUK FJORD

IVIGTUT

Bryggerens Elv

Fogtmanns Elv

Randsletten

Hanekammen

Weber's Havn

Inugsuk

Tayler's Havn

Kvartsitnæs

Ikapynt

Blokdalen

Kjerdlene

Sværingen

SYDLOBET

ÍKA

LEGEND

- Ivigtut biotite granite and breccia. I: Intrusion breccia P: Pegmatite C: Cryolite
- Alkaline dykes (trachytes-granophyres).
- Doleritic dykes (BD="Brown dykes", BFD=Feldspar megacryst dykes).
- Lamprophyric dykes.
- Granite (Ketilidian).
- Metagabbro and discordant amphibolite.
- Gneiss with abundant gabbro-anorthositic enclaves.
- Grey banded biotite - hornblende gneiss with hornblenditic enclaves.
- Light-coloured biotite gneiss.
- Boundary, established.
- Boundary, inferred.
- Strike and dip, vertical.
- Fold axis, plunging, horizontal.
- Elongation and mineral lineation.
- Fault, crush zone.
- Thrust.

Trykt ved Geodætisk Institut 1973

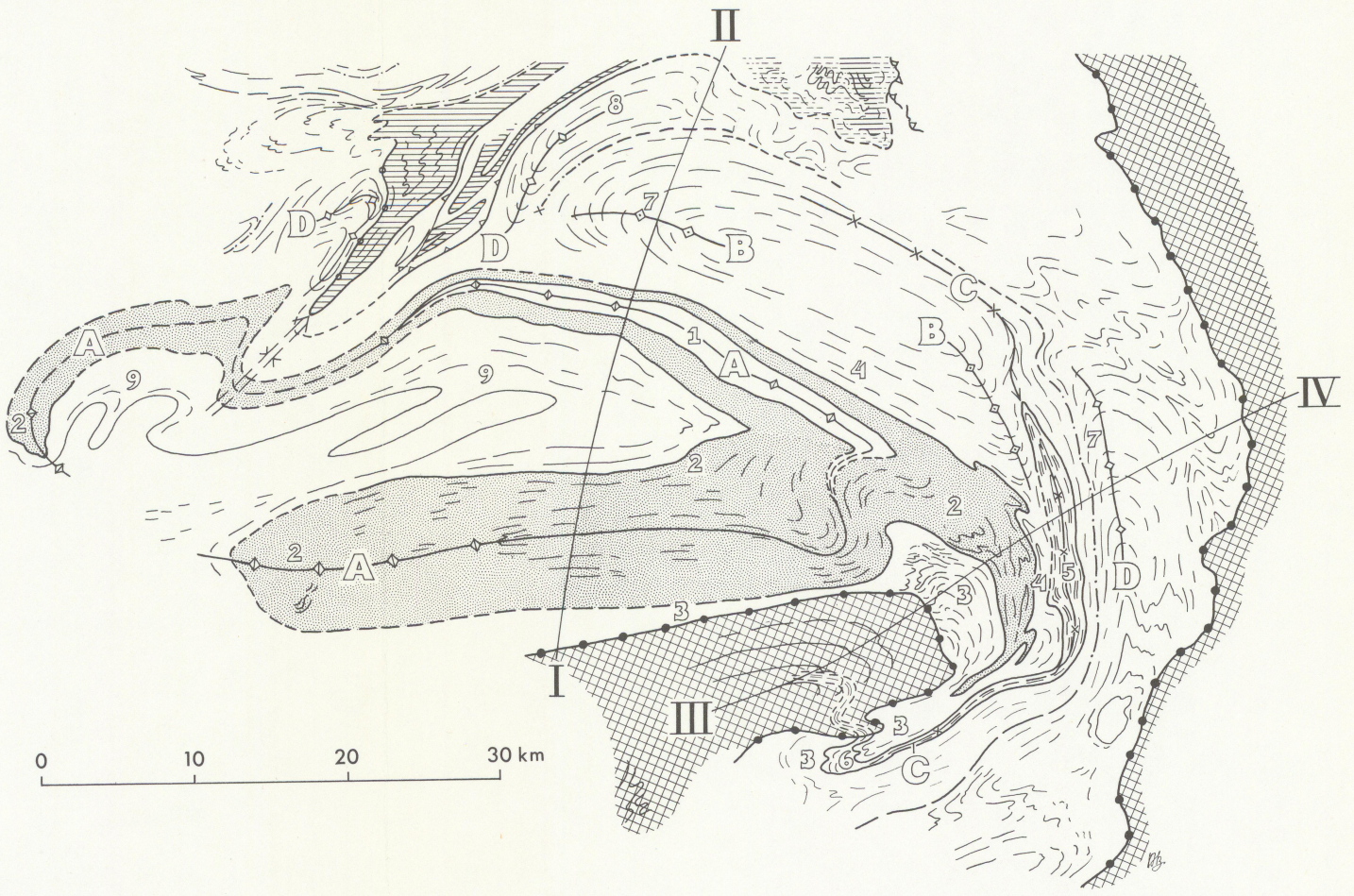
GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

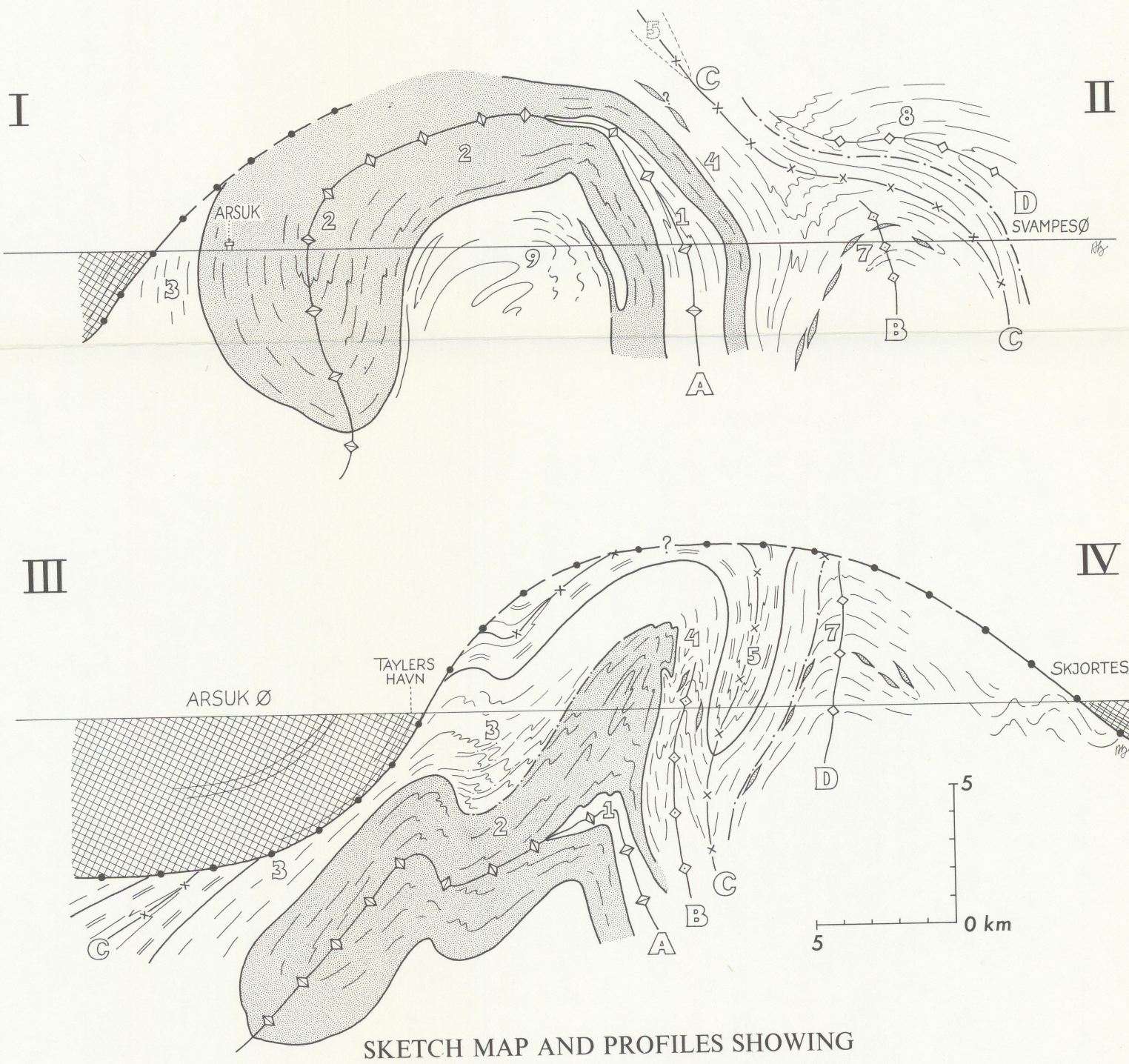
SKETCH MAP OF THE IVIGTUT REGION
SHOWING PRE-KETILIDIAN STRUCTURES

1 0 5 10 15 Km

Tindingen
KANGÂRSSUK
SERMILIGÂRSSUK
Nuluk
Tuapait
Nordre Kangeq
Søndre Kangeq
Tingmiak
Akuliarusinguaq
AKULIARUSSUAQ
Svampesø
Gaffelsø
Pyramidefjeld
Bikuben
Stabelland
PUIÁTOQ FAULT
Puiátoq
TÖRNÂRSSUK
TÖRNÂRSSUKLØB
LAKSENÆS FAULT
Kuánit
SERMERSUT
Isalab
Iggavik
Nunánguit
Arfalik
Fladland
Langenæs
Laksefjeld
Laksepynt
Grønnedal
IVIGTUT
Mellemfjeldene
Taylors Havn
ARSUK Ø
SIMPSON PASSAGE
TAVDLORUTIT
SÂNERUT
Qôrnoq
Ikaslerfjeld
Blæsedalen
Lakseelv
Langesø
Taylors Fjord
Høj Havn
Kløftedal
Nordre Fjord
Nipisarssuk
ARSUK FJORD
STRAIT
BAFFIN SEA

Faults
Ketilidian thrusts
Maturian thrusts
Maturian main synform
Traces of axial surfaces of younger Senilian structures
Traces of axial surfaces of main Senilian structures
Ketilidian supracrustals
Tartoq Group
Structural trend lines
Boundaries between lithostructural gneiss units





SKETCH MAP AND PROFILES SHOWING INTERPRETED MAJOR STRUCTURES

The diagrams indicate the assumed structural pattern prior to the main faulting

Note scale difference between map and profiles

- Ketilidian supracrustals
- Tartoq Group
- Íka gneiss series
- Fladland gneiss series?
- Fladland gneiss series
- Nordland gneiss series
- Ikerasak gneiss series

- A–D — Important structures
- I - II, III - IV — Profile lines
- Proven or assumed unconformity
- Faults
- Maturian thrusts
- Maturian main synform
- Traces of axial surfaces of main Senilian structures

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SKETCH MAP OF THE IVIGTUT REGION
SHOWING THE OCCURRENCE AND RELATION OF METADOLERITES AND AMPHIBOLITIC DYKES

1 0 5 10 15 Km

SERMILIGÂRSSUK

Nordre Kangerd

TIGSSALÛP ILUA

TÔRNÂRSSUK

Iggavik

Kuánit

ARSUK FJORD

Grønnedal

CRYOLITE SENIUM

Ika

SØNDRE LØB

Qôrnoq

TAVDLORUTIT

SÁNERUT

- Quaternary deposits
- Faults
- Thrusts
- Ketilidian granites s.l. Allochthonous, mainly post kinematic
- Ketilidian granites s.l. Autochthonous-parautochthonous, foliated to homogeneous types
- Ketilidian granites s.l. Autochthonous-parautochthonous, foliated types
- Ketilidian supracrustal rocks
- Metadolerites and amphibolitic dykes
- Pre-Ketilidian supracrustals, (Tartoq Group).
- Infracrustal gneisses

In the central and northern part of the area only dykes more than 3-5 m in thickness are generally shown. All dykes between 3 m and 20 m in thickness are shown schematically with the same width on the map. The average dyke width is 10-15 m. A few chronologically significant dykes less than 3 m in thickness have been included.

In the southern part of the area (i.e. south of Qôrnoq and Søndre Løb) the dykes are generally about 1 m wide.

Immediately south of the inner part of Arsuk Fjord and in the granites around the head of Qôrnoq, there are probably more dykes than have been shown on the map. The field mapping in these areas was of a reconnaissance nature only and both small dykes and dyke remnants have not always been recorded.

Gardar intrusions have been omitted on the plate and their widening effect neglected. Only the major faults and thrusts displacing the metadolerites and amphibolitic dykes are shown.

61° 30′ 49° 45′ 30′ 15′ 48° 45′ 30′

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SKETCH MAP OF THE IVIGTUT REGION

SHOWING GARDAR LAMPROPHYRES, GRANOPHYRES AND ALKALINE DYKES

1 0 5 10 15 Km

SERMILIGÂRSSUK

TIGSSALÛP ILUA

TÔRNÂRSSUK

SERMERSÛT

Isalob

Kuánit

GRÆNSELAND

ÂRSUK FJORD

Grønnedal

Ika

Qornoq

61° 30′ 49° 45′ 30′ 15′ 48° 45′ 30′ 61°

Quaternary deposits

Faults

GARDAR DYKES

Alkaline dykes (mainly trachytic and phonolitic types)

Granophyres

Lamprophyres

The majority of the dykes are between 1 and 5 m wide. Dykes wider than 10 m are rare.

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SKETCH MAP OF THE IVIGTUT REGION SHOWING GARDAR AND POST-GARDAR DOLERITES

SERMILIGÅRSSUK
TIGSSALÛP ILUA
TORNÅRSSUK
SARMERSUT
Kuánit
Gaffelso
Grønnesø
GRANSELAD
ARSUK FJORD
Grønnedal
ARSUK Ø
Íka
Qornoq
TAVDLORUTIT
SÅNERUT

Quaternary deposits

TD — Post-Gardar dolerites

Faults

BD_2, BD_1, BD_0 — Gardar dolerites: generation indicated

BD — Gardar dolerites: unspecified

XD — "Big Feldspar Dykes"

Dykes between 3-5 m and 20 m shown with same line thickness
Dykes above 20 m shown to scale
Small faults have been disregarded

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SKETCH MAP OF THE IVIGTUT REGION
SHOWING FAULTS AND CRUSH ZONES

These are mainly Gardar, but include some pre - Gardar movement zones

1 0 5 10 15 Km

SERMILIGÂRSSUK
Svampeso
Gaffelso
TIGSSALÛP ILUA
PUIÁTOQ FAULT
TÔRNÁRSSUKLØB
LAKSENÆS FAULT
Kuánit
FJORD
ÁRSUK
IVIGTUT
Íka
Qôrnoq
SÁNERUT

Quaternary deposits

Major faults - displacements 1-3 km or greater

Faults - displacements ½-1½ km

Faults - displacements up to several hundred metres

Crush zones and faults without determined displacement

Direction of horizontal component of displacement

Where the direction of movement has been reversed during the history of the fault, the direction show is that recorded during the main Gardar phase of faulting.

61° 30′ 49° 45′ 30′ 15′ 48° 45′ 30′ 61° 30′