MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
BD. **189** · NR. **2**

GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 87

THE STRATIGRAPHY AND STRUCTURE OF THE KETILIDIAN ROCKS OF MIDTERNÆS, SOUTH-WEST GREENLAND

BY

A. K. HIGGINS

WITH 40 FIGURES AND 6 TABLES IN THE TEXT
AND 5 PLATES

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
1970

Abstract

The stratigraphy of the Ketilidian rocks of the Midternæs area is described and an account given of the various structures which deform them. Correlations between the Midternæs area and the Ketilidian type area of Grænseland, situated immediately south of Midternæs, are made on group and formation level; the Vallen Group and Sortis Group and their respective formations are each recognised. Lateral variations within the Sortis Group are described and a new formation not exposed in the type area is established. The total thickness of the Ketilidian strata exposed is about 5000 m.

The early deposits of the mainly sedimentary Vallen Group were laid down in restricted basins and are of variable rock type, thickness and distribution. Later deposits were laid down in deeper water and are more uniform in character and have a more widespread distribution.

The mainly volcanic Sortis Group comprises thick sequences of pillow lavas of tholeiitic basalt composition intruded by numerous gabbroic sills derived probably from the same parent magma. Pyroclastics and sediments occur at certain levels. Felsic volcanic breccias suggest that a vent was situated at the southern extremity of the Midternæs area.

A large-scale warping of the sub-Ketilidian surface may have preceded the mesoscopic folding. F_1 folding produced isoclinal, recumbent structures and was accompanied by low-angle thrusting. F_2 folding produced structures with NE-trending, steeply inclined axial planes and often an axial plane cleavage. The minor F_3 folds are of little significance. Kink folds and conjugate folds occur in Ketilidian and in pre-Ketilidian rocks and their development appears to have occurred under stress conditions comparable to those which produced faults. The principal faults are tear faults. A group of WNW faults have consistent sinistral displacements and a group of faults trending between ENE and NNE consistent dextral displacements.

The chronology of the dykes which cut the Ketilidian rocks is briefly discussed. Some WNW dykes may be late Ketilidian, but the major dyke swarm trending between ENE and NNE is probably of Gardar age. It is considered that similar stress conditions influenced both Gardar dyke intrusion and Gardar faulting.

ISBN 87 421 0020 3

CONTENTS

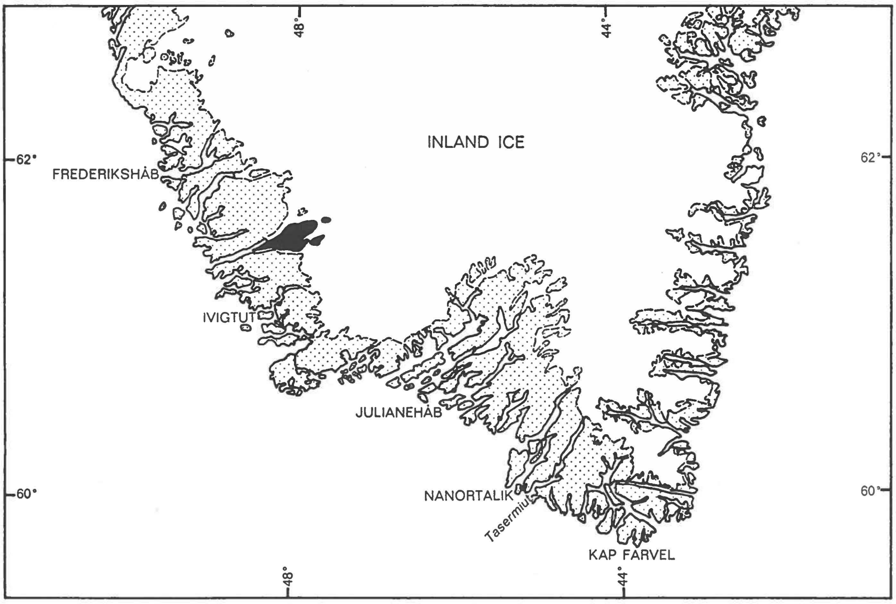


Fig. 1. Sketch-map of South Greenland with the Midternæs area shown in black.

I. INTRODUCTION

1) General

Midternæs is situated about 75 km south-east of Frederikshåb and about 40 km north of Ivigtut in South-West Greenland (Fig. 1). To its north Midternæs is bounded by the fjord Sermiligârssuk and the glacier Sermiligârssuk Bræ and to its south by the fjord Sioralik and the glacier Sioralik Bræ; the Inland Ice forms the eastern boundary (Plate 1). The term 'Midternæs area' as employed in the text is taken to include the nunataks which lie east and south-east of Midternæs.

The Midternæs area was mapped between 1964 and 1966 on a scale of 1:20,000 using topographical maps and vertical aerial photographs supplied by the Geodetic Institute, Copenhagen. The Midternæs area has a land area, including lakes, of about 360 km^2 and ranges in altitude from sea-level to 1787 m. The terrain is well exposed but of a very rugged nature and parts of the area, particularly the cliffs which border many of the main glaciers, are difficult of access. Some outlying small nunataks and the high eastern parts of Nuna qernertoq were mapped on helicopter reconnaissance flights.

The only previous investigations of Midternæs have been by geologists of GGU (Grønlands Geologiske Undersøgelse: Geological Survey of Greenland) and these were largely restricted to the western peninsula. A brief review of their observations is given on p. 9.

2) Outline of regional geology

The geological development of South-West Greenland has been the object of extensive research by GGU geologists since the inception of systematic mapping in 1956. The nomenclature is based on Wegmann's work (Wegmann, 1938, 1939, 1948). A recent review of the general geology has been presented by Allaart, Bridgwater and Henriksen (1969).

A geological sketch-map of the region between Neria and Kobberminebugt is given in Fig. 2. An outline of the history of research leading to the present chronological interpretation of this region has been presented by Higgins and Bondesen (1966). The chronology of the region is given in Table 1 which is adapted from a detailed scheme presented by Allaart *et al.*, (1969).

A large part of the Ivigtut-Frederikshåb region consists of pre-Ketilidian rocks: gneisses, amphibolites and locally greenschists and gabbro-anorthosites. A pre-Ketilidian supracrustal sequence in the Sermiligârssuk-Târtoq-Midternæs area has been distinguished as the Tartoq Group (Higgins and Bondesen, 1966). The pre-Ketilidian strata have undergone migmatisation, metamorphism and repeated deformation in pre-Ketilidian time (Ayrton, 1963; Weidmann, 1964; Kalsbeek, 1967).

Four main sets of basic metadolerite dykes each with a characteristic general trend transect the pre-Ketilidian basement gneisses of the Ivigtut region (Bondesen and Henriksen, 1965) and three sets are found north of Sermiligârssuk (Jensen, 1966). Each set may consist of more than one generation of dykes intruded in the same direction. Their grade of metamorphism increases as they are traced from north to south into the Ketilidian mobile belt; the dykes are almost non-metamorphosed in the Frederikshåb area. It has not proved possible in the field to demonstrate their relationship to Ketilidian strata (Windley *et al.*, 1966). Comparison between the chemical compositions of the metadolerites and Ketilidian metavolcanics (Henriksen, 1969) shows that they are slightly different, and it is concluded that the metadolerites and metavolcanics cannot have been derived at the same time from the same source. The dykes are ascribed by Henriksen to the pre-Ketilidian. The age-date obtained by Jørgensen (1968) in the contact-altered gneiss at the border of a fresh example of one of the dykes suggests a very late pre-Ketilidian or early Ketilidian age.

The Ketilidian rocks which outcrop in most of the Midternæs area are the principal concern of this paper. They form part of a belt of

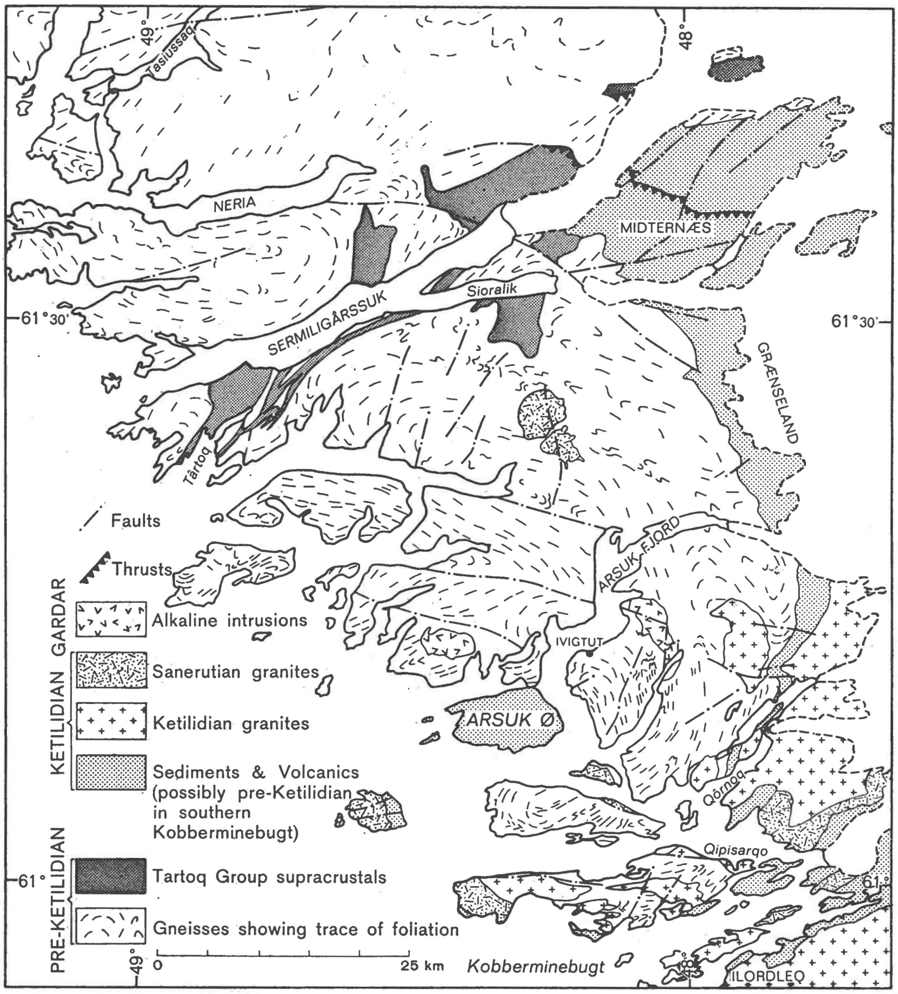


Fig. 2. Geological sketch-map of the area between Kobberminebugt and Neria.

Ketilidian supracrustal rocks which may be traced southwards from Midternæs through Grænseland, and from south of Arsuk Bræ to Qôrnoq and Qipisarqo; further outcrops of Ketilidian rocks occur on Arsuk Ø and along the south coast of Sánerut (Fig. 2). On Midternæs and in Grænseland the Ketilidian rocks rest unconformably on pre-Ketilidian gneisses and schists, but elsewhere the junction is obscured by shearing, granitisation and migmatisation (WINDLEY *et al.*, 1966).

South of the area shown in Fig. 2 inclusions of metasediments, some of which may be derived from Ketilidian supracrustals, are found in the Julianehåb granite. Thick well preserved sediments and volcanics also assigned to the Ketilidian are found in the Tasermiut fjord region about 225 km south-east of Midternæs (WEGMANN, 1938; ESCHER, 1966).

Table 1. *Chronology of the Ivigtut region*

TIME	MAJOR EVENTS		ISOTOPIC AGE (m.y.)
PHANERO-ZOIC	Carbonatite lamprophyre dykes Coast-parallel olivine tholeiitic dykes		164
GARDAR	Faulting Major NE-trending basic dyke swarms Alkaline intrusions		ca. 1200
?	WNW and NW-trending dykes		
KETILIDIAN	Sanerutian plutonic episode	Rapakivi granites Plutonic reactivation of earlier structures and granites	1500–1640
	Minor basic dykes		
	Main Ketilidian plutonic episode	Folding, thrusting, faulting, metamorphism, migmatisation, formation of granites	1700–1750
	(?) Ilordleq Group — volcanics Qipisarqo Group — sediments Sortis Group — mainly volcanics Vallen Group — sediments		
?	Basic dykes — 4 major generations		
PRE-KETILIDIAN	Folding, metamorphism, migmatisation, granitisation Volcanics with some sediments (Tartoq Group) Older (?) basement (parts of regional gneisses)		2500–2700

The excellent exposures of the Ketilidian sequence in Grænseland led to its selection as a new type area. Bondesen's divisions and subdivisions of the Ketilidian of Grænseland have been outlined by Berthelsen and Noe-Nygaard (1965) and presented in detail by Bondesen (1962, and in press).

In the southern part of the Ivigtut region (Fig. 2) and farther south there occur many granitic bodies emplaced during the main Ketilidian and Sanerutian plutonic episodes (Table 1). These two plutonic episodes are regarded as successive phases in the development of the Ketilidian mobile belt (BRIDGWATER and WALTON, 1964; ALLAART *et al.*, 1969).

Swarms of E- to NE-trending basic dykes and a few alkaline intrusions are the only representatives of the Gardar period in the Ivigtut region, but erratic sandstone boulders resembling the Igaliko sandstone of the Julianehåb district are common in the moraines bordering the Inland Ice south of Sioralik Bræ (BONDESEN, in press).

The only Phanerozoic rocks found in South-West Greenland, apart from Quaternary glacial deposits, are a swarm of coast-parallel trap diabase (TD) dykes and a few carbonatite lamprophyre dykes which are of Mesozoic age (WALTON, 1966).

3) Previous geological investigations of Midternæs

Reconnaissance work by GGU geologists in 1954 and 1955 revealed the presence of areas of greenschists on both sides of Sermiligârssuk and on Midternæs. MICHEELSEN (1955) noted from observations from the north side of Sermiligârssuk Bræ and from the air that there appeared to be a thrust plane in Midternæs dipping at 10° to 15° towards the E or ENE. He observed that the greenstones overlying this plane (the Ketilidian rocks of this paper) appeared to be more homogeneous than those underlying the plane (the Tartoq Group schists).

On a provisional sketch map in the GGU archive drawn by A. BERTHELSEN from observations made in 1957 and 1958, Ketilidian supracrustal rocks are recognised over a large part of Midternæs and are broadly divided into two groups. Except in northern west Midternæs where parts of the Tartoq Group schists are included in the Ketilidian, the basic interpretation has been verified by the present work.

Apart from a small area of extreme west Midternæs mapped by BERTHELSEN in 1954 the only detailed mapping prior to the present work was that of OEN ING SOEN in 1960. OEN mapped the west peninsula of Midternæs and areas north and south of Birkesø. OEN's observations are recorded on manuscript maps, in diaries and an unpublished report (OEN ING SOEN, 1960), all in the GGU archives. OEN recognised the presence of many sedimentary rock types in the relatively small area of Ketilidian rocks which he mapped and correctly regarded the massive greenstones comprising much of Midternæs as representing pillow lavas and fine-grained sills. He made many structural observations and recognised refolding in the sediments. A sharp contact was noted between a massive greenstone-slate series (the Ketilidian), and underlying disharmoniously folded greenschists (the Tartoq Group) and gneisses. This contact (the Ketilidian unconformity) was initially considered by Oen (1960) to be a gneissification front, but he has subsequently revised this interpretation (personal communication, 1966).

The preliminary results of the recent mapping by the author which led to the distinction between pre-Ketilidian and Ketilidian supracrustal rocks separated by an unconformity and consequent modification of the regional chronology have been presented in Higgins and Bondesen (1966). An outline of the geology of Midternæs is given below.

4) Outline of Midternæs geology

Pre-Ketilidian rocks outcrop on Midternæs west of Birkesø and in a narrow strip along the northern border of Midternæs. They consist mainly of banded biotite and hornblende gneisses, rather homogeneous quartz gneiss, and two zones of the Tartoq Group hornblende-chlorite-biotite schists (Higgins and Bondesen, 1966), The southern half of Nuna qaqortoq just to the north of Midternæs is also composed of Tartoq Group schists which exhibit deformed pillow structures in some areas and possible blastophitic textures in others (Higgins, 1968).

Metadolerite dykes are uncommon in Midternæs. None have been observed in the vicinity of the Ketilidian unconformity, and it is not therefore possible to demonstrate their age relative to the Ketilidian strata.

The Ketilidian rocks of Midternæs rest unconformably on the pre-Ketilidian gneisses and on Tartoq Group schists. The unconformity is for the most part autochthonous but has been modified locally by minor thrusting and folding. The stratigraphy of the Midternæs Ketilidian rocks and the structures that deform them are described in this paper.

A complex dyke chronology mainly of presumed Gardar age is briefly outlined at the close of the stratigraphy section. Some WNW- and NW-trending dykes which post-date Ketilidian deformation but predate the main Gardar swarms may be of late-Ketilidian age. The coast-parallel swarm of Mesozoic dykes (TDs) cross Sermiligârssuk just west of Midternæs.

The geomorphology of Midternæs reflects the extensive Pleistocene to Recent glaciations. The glaciological features of the area are not described here, but the principal morainic deposits are shown on the geological map (Plate 5).

II. STRATIGRAPHY

1) General

The Ketilidian strata of Midternæs are the northward extension of the strata of the new Ketilidian type area of Grænseland (BONDESEN, in press). They are the northernmost outcrops of Ketilidian rocks in the Ivigtut-Frederikshåb region.

The western and northern limits of the Ketilidian strata on Midternæs are defined by the unconformity with the pre-Ketilidian basement. The regional dip of the Ketilidian rocks is towards the east-north-east in west Midternæs and southwards in north Midternæs, but there are considerable local variations in dip caused by Ketilidian deformation.

The stratigraphy has been established on the basis of lithostratigraphical divisions, and locally well-preserved fossils have proved to be of limited use (PEDERSEN, 1966, 1968). BONDESEN (1962, and in press) has divided the Ketilidian rocks of Grænseland into a lower mainly sedimentary group (the Vallen Group) and an upper mainly volcanic group (the Sortis Group); both these groups and their subdivisions can be clearly distinguished in south-west Midternæs which is separated from Grænseland by the 2 km wide Sioralik Bræ. In other parts of Midternæs BONDESEN's subdivisions are employed where this is compatible with the original definitions, but lateral lithological changes have made it necessary to modify his terminology in central and northern Midternæs.

A summary of the Ketilidian stratigraphy of Midternæs is given in Table 2. The group and formation terminology is after Bondesen except that a new formation of the Sortis Group, the Qernertoq Formation, has been established for a volcanic sequence on Nuna qernertoq which is not represented in Grænseland. The Perledal Volcanic Complex is the lateral equivalent of part of the Rendesten Formation in northern Midternæs. For the purposes of the detailed stratigraphical descriptions the Zigzagland Formation and the Blåis Formation have been divided into members. The names given to these members in Midternæs differ from those used in the type area and they are regarded as of only local application, but many of them are roughly equivalent to members distinguished in the type area. The members are designated according

Table 2. *Ketilidian stratigraphy of Midternæs*

Group	Formation	Unit	Description
			Top unexposed
SORTIS GROUP (4800 m +)	QERNERTOQ FORMATION	Undivided sequence	— very thick pillow lava succession and several important sills (at least 2200 m)
	RENDESTEN FORMATION	Undivided sequence	— banded siltstones, shales, cherts, impure dolomites, thick pyroclastics and many thick sills
		Perledal Volcanic Complex	— pillow lava flows in northern Midternæs interbedded with the Rendesten Formation
			(totals 1100 to 2400 m)
	FOSELV FORMATION	Undivided sequence	— mainly thick pillow lava flows, a few sedimentary bands and several sills (100 to ca. 900 m)
			Thrust contact locally
VALLEN GROUP (120 to 750 m +)	GRÆNSESØ FORMATION	Shale Member	— includes pyritic shales (up to 120 m)
		Dolomite Member	— dolomites and pelitic shales (10 to 70 m)
			sills at several levels (up to 300 m)
		Pelite Member	— black pelitic shales (0 to 50 m)
	BLÅIS FORMATION	Undivided sequence	— massive siltstones, shales, arkose lenses, greywackes, a thin graphite shale and several thin dolomites (50 to ca. 700 m)
	ZIGZAGLAND FORMATION	Calcareous Member	— finely banded calcareous and dolomitic shales (up to 35 m)
		Sandstone Member	— feldspathic sandstones and orthoquartzites (1 to 100 m)
		Conglomerate Member	— ore-bearing matrix (0 to 4 m)
			Unconformity-minor shearing

to their characteristic lithology in the absence of suitable geographical names. The outcrop pattern of the groups and formations of Midternæs and Grænseland is shown in Plate 4.

2) The Vallen Group

The sediments of the Vallen Group rest unconformably on pre-Ketilidian gneisses (Fig. 4), and north of Birkesø on steeply inclined schists of the Tartoq Group (Fig. 3). The general autochthonous nature of the unconformity is modified locally by folding and minor shearing. The level at which volcanic effusives first appear has been defined by BONDESEN (in press) as the upper boundary of the Vallen Group and the lower boundary of the Sortis Group; on Midternæs this level is in some areas the site of a major thrust.

The Vallen Group outcrops in north and west Midternæs as a narrow strip of dark rocks of a dominantly shaly aspect. The minimum thickness of the Vallen Group is about 120 m in northern west Midternæs and the maximum about 750 m in north Midternæs. In west Midternæs the succession can be equated with that of Grænseland, and the Zigzagland, Blåis and Grænsesø Formations can be recognised; in north Midternæs only the Blåis and Grænsesø Formations are clearly represented.

Of the organic remnants found in the Vallen Group, most occur in the Lower Zigzagland Formation of central Grænseland (PEDERSEN, 1966, 1968); this part of the formation is not known in Midternæs. One of the best preserved of the fossils, a globular structure known as *Vallenia*, has been recorded in the Grænsesø Formation at five separate localities in Midternæs and Grænseland (BONDESEN, PEDERSEN and JØRGENSEN, 1967; PEDERSEN, 1968).

A sill has been noted by BONDESEN (1962, and in press) as a persistent feature in the Grænsesø Formation. In Midternæs a sill occurs only locally at the same level, and several thin sills are found at various other levels in the Vallen Group.

In Plate 3 are presented schematic cross-sections, drawn parallel to the strike, of which two show the principal variations in thickness and lithology of the Vallen Group. Comparative profiles of the succession at four different localities are given in Fig. 6. Descriptions of the stratigraphical variations within the three formations of the Vallen Group are given below.

The degree of metamorphism exhibited by the Ketilidian sediments and igneous rocks is so low in Midternæs that they may be described and classified as non-metamorphic rocks. The classification of the sedimentary rocks in this paper follows the usage of PETTIJOHN (1957).

3) The Zigzagland Formation

In west Midternæs the rocks of the Zigzagland Formation can conveniently be divided into three members: a Conglomerate Member, a Sandstone Member and a Calcareous Member. These members have ap-

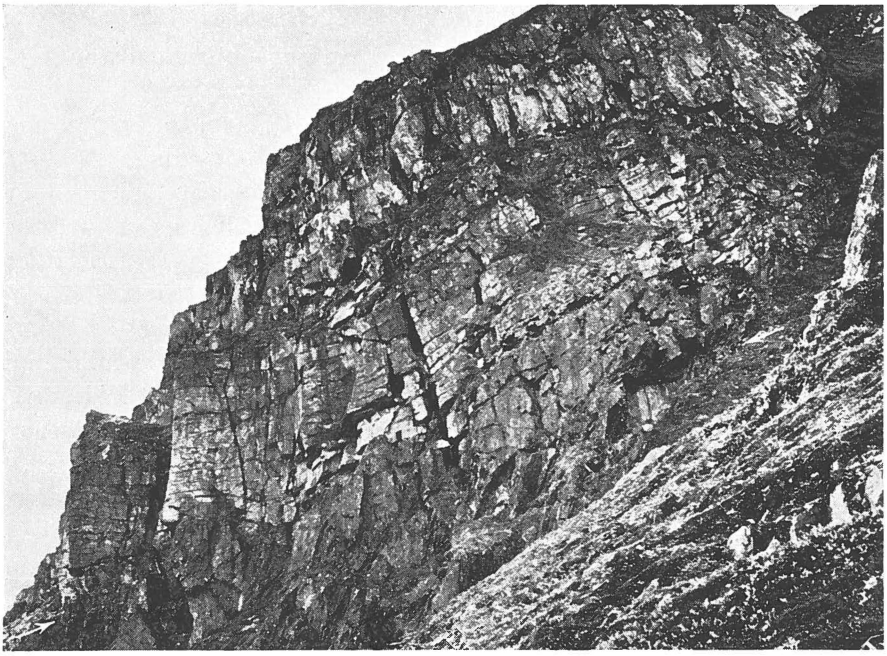


Fig. 3. Well bedded feldspathic sandstone sequence passing downwards into a 4 m non-bedded conglomerate which rests unconformably on steeply inclined Tartoq Group schists. Northern west Midternæs. The position of the unconformity surface is indicated by the white arrows.

proximate counterparts in the Upper Zigzagland Formation of Grænseland. The Lower Zigzagland Formation is not represented in north Grænseland or in Midternæs and the base of the Ketilidian succession is in these areas formed by the Conglomerate Member or the Sandstone Member. Stratigraphical details are given below (see also Plate 3).

The Conglomerate Member in west Midternæs

The Conglomerate Member is found in Midternæs only north of Birkesø between a point on the north edge of the plateau and Sermiligârssuk Bræ. In its traceable outcrop of about 1 km it has a maximum thickness of only 4 m and it often has a red-brown surface discolouration caused probably by the oxidation of an appreciable ore content in the matrix.

The component pebbles of the conglomerate are mainly of quartzitic composition; a few foliated gneiss pebbles and several small black amphibolite pebbles have also been noted. The pebbles are mainly less than 15 cm in diameter, but the largest example observed measured 40 cm by 7 cm in cross-section. The pebbles are not well sorted and are generally poorly rounded. The conglomerate is not bedded except to-

Fig. 4. Massive orthoquartzites resting unconformably on dark hornblendic gneisses and pegmatites. Southern west Midternæs.

wards the top where it passes upwards into the well bedded Sandstone Member (Figs. 3 and 5). The conglomerate rests on an uneven surface of Tartoq Group greenschists. Rolled magnetite grains occur in the matrix sometimes in sufficient quantity to attract a magnet.

The Sandstone Member in west Midternæs

The pale grey to white sandstones of the Sandstone Member are the dominant rock type of the Zigzagland Formation. They reach their maximum thickness of over 100 m on the plateau west of Akuliarutsip timilerssue where they rest directly on a peneplained gneiss surface (Fig. 4) and the sandstones at the base appear locally to fill in small irregularities on the plane of unconformity. There is nowhere any conspicuous discolouration of the gneiss surface. North of Birkesø the Sandstone Member rests partly on peneplained Tartoq Group schists and partly on the thin Conglomerate Member.

The thick sandstone sequence west of Akuliarutsip timilerssue is massive, well bedded and rather uniform. Cross-bedding is fairly common and slump structures and poor examples of graded bedding have been noted. The sandstone decreases in thickness fairly rapidly towards the north to about 15 to 25 m, and maintains this thickness as far as Birkesø.

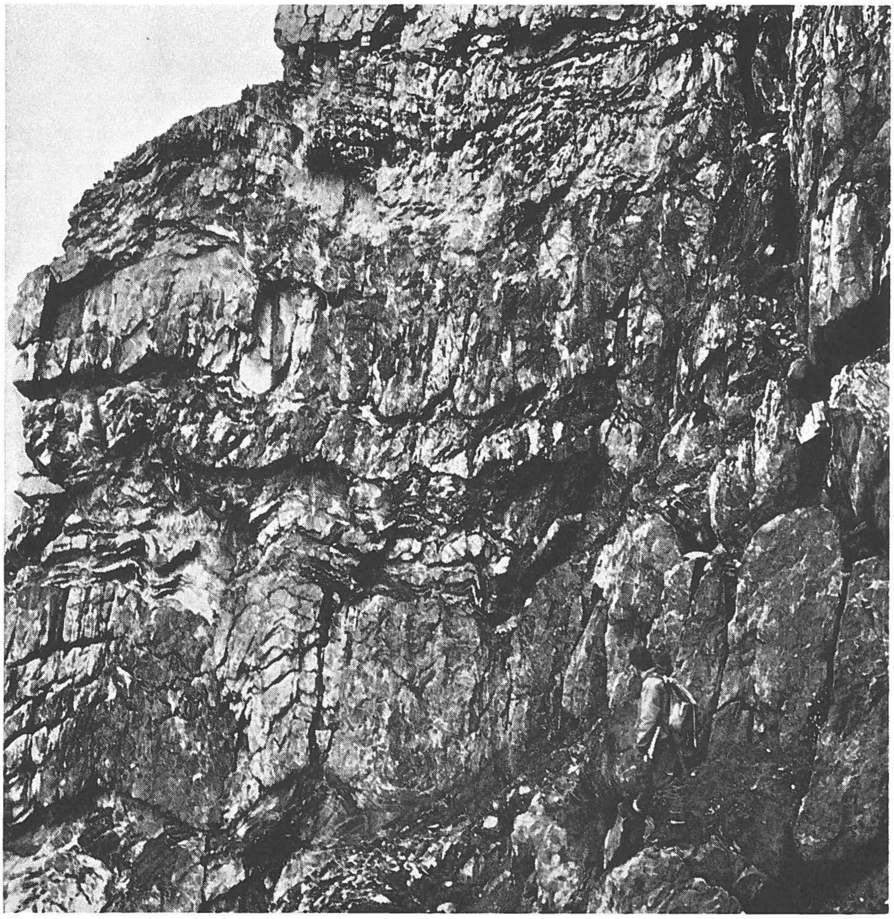


Fig. 5. Graded sandstone sequence deformed by F_2 folds and displaying a vertical F_2 axial plane cleavage. Northern west Midternæs adjacent to Sermiligârssuk Bræ.

In composition the sandstones to the south of Birkesø can mainly be classified as feldspathic sandstones with some orthoquartzites, particularly near the base; a few samples from the upper part of the sequence are best classified as feldspathic greywackes (Pettijohn, 1957 p. 291). The grain size varies from fine sand to very coarse sand, and in shape most grains are subangular to subrounded where they have not been modified by deformation or recrystallization.

To the north of Birkesø the Sandstone Member is about 22 m thick at the south edge of the plateau and consists of massively bedded and thinly bedded feldspathic sandstones. Traced northwards these thin abruptly against a small fault and across the central part of the plateau are not more than 3 m thick. At the north edge of the plateau there is a gradual increase in thickness and about 27 to 30 m of graded bedded sandstones occur at the edge of Sermiligârssuk Bræ.

While they are in part similar in character to the sandstone sequence south of Birkesø, the sandstones which outcrop near Sermiligârssuk Bræ are characterised throughout by exceptionally good examples of graded bedding. In the lower part of the sequence the bottoms of the graded beds are very coarse sand or may be conglomeratic, and the tops of the beds are of fine sand. Higher in the sequence the graded beds are commonly medium sand at their bases and silty or shaly at their tops. The silt or shale layers are usually preferentially weathered (Fig. 5). The individual graded beds are most commonly 5 to 20 cm thick with occasional examples up to 70 cm thick. In composition the rocks are mainly feldspathic sandstones, and in shape the sand grains are rounded to well rounded.

The Calcareous Member in west Midternæs

Throughout west Midternæs the Sandstone Member is succeeded by sediments with a high carbonate content which have a characteristic colour varying from grey-white, to pale yellow, pale orange-brown or pinkish brown. The carbonate-rich rocks which comprise the Calcareous Member have a somewhat variable lithology but their boundaries with the Sandstone Member below and the Blåis Formation above are fairly easily delimited.

South of Akuliarutsip timilerssue the Calcareous Member is intensely deformed but the least deformed outcrops suggest the thickness was originally in the order of 30 to 35 m. The member consists here of finely banded dolomitic and calcareous siltstones and shales with thin dolomite layers, and a few interbedded layers of dark grey and pale silver-grey siltstones and shales. The banded siltstones exhibit a rhythmic layering; individual layers are from 0.1 mm to 1 cm thick generally, rarely reaching 3 cm in thickness (Fig. 28).

Midway between Sioralik Bræ and Birkesø the member consists of about 25 m of thinly bedded calcareous siltstones. These grade towards the north into a similar thickness of calcareous siltstone and calcareous coarse sandstone. The grains of this sandstone are subrounded in shape, up to 7 mm in diameter and occur in graded beds in a carbonate matrix.

At the south edge of the plateau north of Birkesø about 10 m of carbonate-rich siltstone and graded bedded sandstone represent the Calcareous Member. In common with the Sandstone Member the Calcareous Member is very thin over the central part of the plateau; at the north edge of the plateau about 5 m of silty dolomite and dolomitic shales were recorded. These probably continue as far as Sermiligârssuk Bræ but are hidden beneath shaly screes derived from the Blåis Formation.

North Midternæs

The Zigzagland Formation does not exhibit its characteristic development in north Midternæs. The only rocks which might represent this Formation are a few thin calcareous arkoses at the base of the succession in the western part of the Vallen Group outcrop, and a few quartzitic bands in the central part of the outcrop. Most of the rocks near the base of the succession in this area are siltstones and shales apparently forming part of the Blåis Formation.

4) The Blåis Formation

The lower limit of the Blåis Formation is placed at the level at which the pale yellow or orange dolomitic siltstones and shales of the Calcareous Member of the Zigzagland Formation give way to the grey massive siltstones and shales which in Midternæs form the bulk of the Blåis Formation. The upper limit of the Blåis Formation is placed at the base of a black pelite, the lowest member of the Grænsesø Formation in Midternæs and presumed equivalent to the carbonaceous pelites at about this level in Grænseland. Bondesen (1962, and in press) selected the lower boundary of the Grænsesø Formation in Grænseland at the base of the carbonaceous pelites to coincide with a structural discordance at this level. In Midternæs there is a transitional boundary between the Blåis and Grænsesø Formations, but a major thrust does occur in some areas at the top of the Grænsesø Formation. Details of stratigraphical variations in the Blåis Formation are given below.

West Midternæs

The Blåis Formation in west Midternæs varies in thickness from more than 300 m in the southern part of the outcrop to about 50 m north of Birkesø. The schematic cross-section (Plate 3) suggests that marked changes in the thickness of the Blåis Formation take place in the vicinity of two fault lines.

The variations in lithology of the Blåis Formation are not sufficiently distinctive to justify a subdivision into members, and minor thrusts and isoclinal recumbent folds in parts of the area also hinder interpretation.

In southern west Midternæs the lowest part of the formation consists of massive, grey, banded siliceous siltstone; this unit thins northwards and is not present north of Birkesø. The banding of these rocks is often a very conspicuous feature and comprises alternations of grey-white and dark grey layers 1 mm to 3 cm thick. Occasional layers have a small carbonate content. In thin section many of these siltstones are revealed to have compositions which in coarser grained rocks would classify them as feldspathic greywackes.

The remainder of the Blåis Formation in west Midternæs comprises a varied sequence of dark grey shales, greywackes, occasional bands of calcareous shale and dolomite, and a thin layer of graphite shale. Some of these rock types are locally conspicuous.

Between Birkesø and Sioralik Bræ a few bands of dolomite locally reach 2 m in thickness. Their yellow weathering colour contrasts with the dark grey shales and siltstones and this has facilitated the tracing of several recumbent fold structures.

North of Birkesø a pale grey greywacke band from 1 m to 15 m thick occurs in the central part of the Blåis Formation and can be traced laterally for about 2 km. South of Birkesø several greywacke bands have been mapped near the top of the Blåis Formation of which the most important is a 20 m feldspathic greywacke sequence located south of Akuliarutsip timilerssue. This greywacke is composed of quartz, feldspar and rock fragments up to 2 cm in diameter; the rock fragments are of grey shale or siltstone which may have been derived by contemporaneous erosion of perhaps lower levels of the Blåis Formation. Parts of the greywacke sequence are well bedded and good examples of washout structures have been observed.

North Midternæs

In north Midternæs the Blåis Formation varies from about 300 m to about 750 m in thickness (Plate 3), but intense folding prevents reliable estimations of thickness in some parts of the area. The Blåis Formation rests either unconformably on the pre-Ketilidian gneisses or upon a few metres of calcareous arkose or quartzite which may be the only representatives in this area of the Zigzagland Formation. As in west Midternæs lateral lithological changes and a lack of distinctive rock types hinder any useful subdivision into members.

In most parts of the area very massive siliceous siltstones occur near the base of the formation. They have a pale grey weathering colour and are usually banded to some degree, though in some outcrops the banding has the form of irregular white lenses and veins. Ripple marks have been observed at a single locality. Thin shaly and calcareous layers occur within the massive siltstones, and there is a gradual transition upwards into more shaly sediments.

The Blåis Formation has an essentially shaly aspect in most outcrops. Dark grey flaggy shales and black pelitic shales are common. In some areas the monotonous nature of the sequence is broken by the occurrence of thin bands of white, yellow and orange dolomites, bands of calcareous shale, grey cherty rocks, arkoses and greywackes.

An arkose sequence of the order of 75 m thick outcrops on the lower north-facing slopes of Palisaden in the central Blåis Formation. It is traceable laterally for about 3.5 km but does not apparently extend northwards beyond the line of a major NE fault. At the best exposures in the eastern part of the outcrop the arkose sequence is seen to vary in grain size from medium-grained in the lower and upper parts to very coarse-grained in the central part which is also well bedded and exhibits grading. Modal analyses of three specimens taken at three levels between the base and central part of the arkose sequence show an increase in quartz and decrease in feldspar percentages with increasing grain size; the quartz/feldspar modal percentages for these three specimens are 40/52, 53/39 and 65/24. There are no rock fragments apart from occasional chert grains; small amounts of mica and ore occur and there is little or no matrix. The feldspar is microcline and a little plagioclase and its source is most probably the pre-Ketilidian gneisses. The arkose bears a superficial resemblance to feldspathic greywackes found at a slightly higher stratigraphical level in southern west Midternæs (Fig. 6 and Plate 3).

5) The Grænsesø Formation

The Grænsesø Formation may be divided conveniently into a Pelite Member, a Dolomite Member and a Shale Member; the division is comparable to that made by BONDESEN (in press) in the type area. The Pelite Member forms the lowest part of the Grænsesø Formation and is only well developed in west Midternæs where it contrasts with the more flaggy shales and siltstones of the Blåis Formation below and the conspicuous dolomites of the Dolomite Member above. The boundary between the Grænsesø Formation and the overlying Sortis Group is often a structural discordance and locally the Shale Member and the Dolomite Member are cut out. Details of the lithological variations are given below (see also Fig. 6 and Plate 3).

The Pelite Member

The Pelite Member is best exposed between Birkesø and Sioralik Bræ where it consists of a uniform sequence of black pelitic shales about 40 to 50 m thick. Just south of Birkesø a thick sill has been intruded at or near the base of the Pelite Member.

North of Birkesø, where the Vallen Group has its minimum development, the Pelite Member is not clearly discernible as the main dolomites rest on a variegated sequence of grey semipelitic shales which cannot be distinguished from the uppermost part of the Blåis Formation.

In north Midternæs the boundary between the Blåis and Grænsesø Formations is transitional; it is not possible to distinguish pelites as a distinct unit except locally in the extreme western part of the outcrop.

The Dolomite Member in west Midternæs

The Dolomite Member in southern west Midternæs consists of a sequence of five main dolomite bands with black pelitic shale bands between them and has a total thickness of about 70 m. The lowest and thickest of the dolomite bands measures 8 to 10 m. Traced north-east along their strike a marked discordance between the Dolomite Member and the Sortis Group is seen south of the fault which follows the south margin of the ridge Akuliarutsip timilerssue. North of this fault the Dolomite Member is absent locally.

The member reappears about 2 km south of Birkesø as a mainly dolomite sequence with thin bands of dark grey and purple shales and some grey chert. It may be traced continuously northwards to Birkesø, and is well exposed in the cliffs north of Birkesø. Farther north on the plateau the Dolomite Member has a total thickness of between 25 and 60 m, and comprises principally dolomites with thin layers of calcareous shales, dark grey cherts and a few black graphitic and pyritic shales.

The dolomites of west Midternæs vary in weathering colour from grey, to pale yellow or deep orange, but are all pale grey on fresh surfaces. Their composition varies to some degree although those few analysed (Table 3) can all be classed as calcitic dolomites. BONDESEN gives similar types of analyses for 9 samples of dolomites and dolomitic shales from different stratigraphical levels of the Ketilidian of Grænseland (BONDESEN, in press). All BONDESEN's samples are dolomitic, but in PETTIJOHN's evaluation (1957, p. 417) 6 would be classified as calcitic dolomites and 3 as dolomites. Both the Midternæs and Grænseland samples contain an important proportion of insoluble material, mainly silica; from 8.4 % to 47 % was recorded in the Grænseland samples.

Table 3. *Analyses of Grænsesø Formation dolomites*

GGU. No.	Insol. %	CaO %	MgO %	CO_2 %	Ca as* $CaCO_3$	Mg as* $MgCO_3$
71242	10.9	29.2	16.1	38	52.0	33.6
71269	24.9	24.9	13.4	34	44.4	28.0
71380	18.5	26.0	14.7	41	46.4	30.8

Analyst: IB SØRENSEN. * Calculated.

The grain size of the dolomites shows variation from compact fine-grained examples to medium-grained examples with a sugary texture. Many of the dolomite bands are cut by a network of thin quartz veins or calcite veins.

The Dolomite Member in north Midternæs

In the western part of the outcrop the Dolomite Member is composed mainly of thick dolomite bands alternating with bands of purple shales and occasional chert horizons. A main group of dolomites can usually be recognised and thin dolomite bands occur at higher and lower levels. Boundaries with the members above and below are transitional and the limits of the Dolomite Member are somewhat arbitrary. At the base of the main dolomites there occur several metres of dolomite breccia; numerous angular fragments of pale yellow dolomite are embedded in a matrix of grey-yellow dolomite and small black chert grains. At a higher level in the main dolomites dark grey chert occurs in lenses and bands, some of which are arranged oblique to the bedding.

Traced towards the east the main dolomite sequence thins until it is scarcely more prominent than some of the thin dolomite bands below it in the Blåis Formation, and since the Pelite Member is not developed in north Midternæs it is difficult to place a boundary between the Blåis and Grænsesø Formations.

The main dolomite sequence thickens again eastwards and in the area where it is displaced by a major NE fault and a very thick Gardar dyke the Dolomite Member has its usual appearance of a sequence of thick dolomite bands interbedded with shales.

The entire Dolomite Member wedges out abruptly at a point about 5 km west-north-west of Palisaden and for an outcrop distance of about 3 km is absent and was either not deposited or has been thrust out. The member reappears abruptly on the lower north-west slopes of Palisaden, immediately on the south side of a major NE fault, as a 70 m sequence of dolomites interbedded with shales and black and grey cherts. The member again thins eastwards and eventually wedges out, perhaps due to non-deposition, or it may be that the thrust at the base of the Sortis Group has here cut downwards into the succession.

The Dolomite Member north of Palisaden is of particular interest in that a 1 m pale yellow dolomite in the central part of the sequence contains numerous small spherical structures up to about 1 mm diameter of organic origin which have been given the name *Vallenia* (Bondesen *et al.*, 1967). These fossils are found at four other localities in dolomites of the Grænsesø Formation in Grænseland (Pedersen, 1966, 1968).

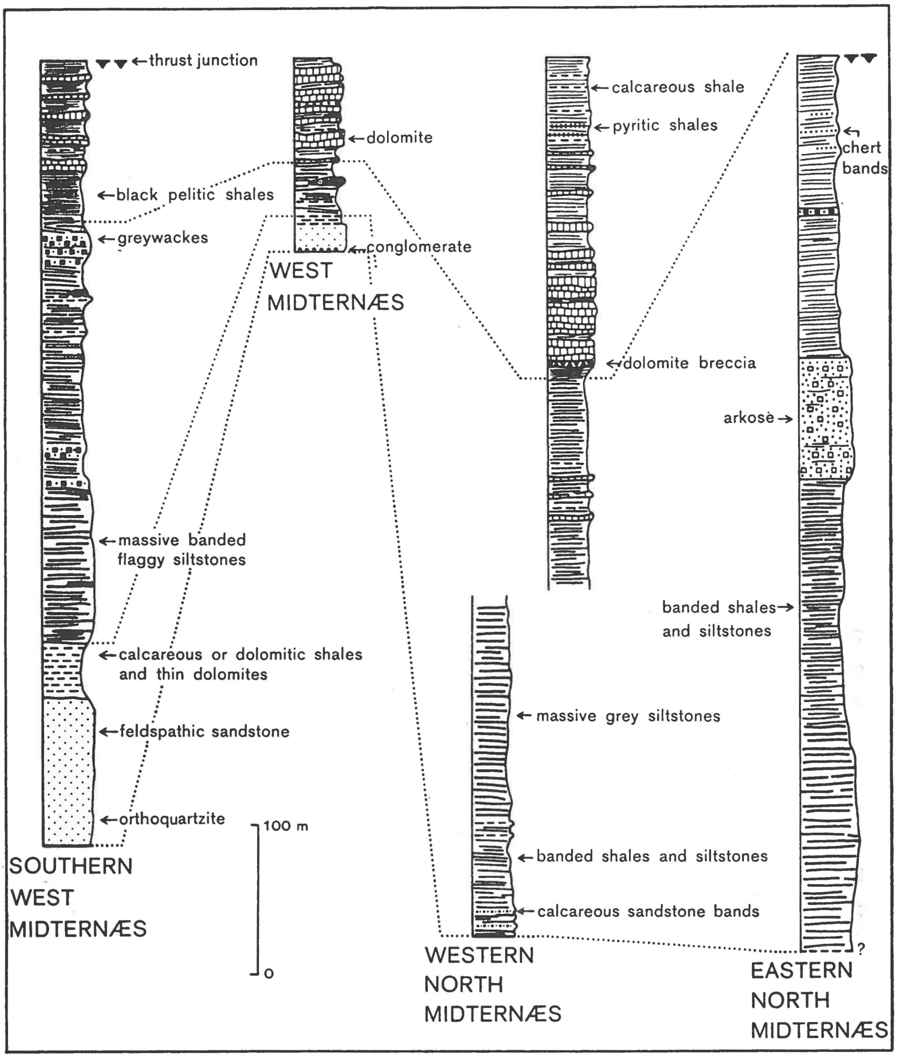


Fig. 6. The Vallen Group sequence at various localities in Midternæs.

The Shale Member

The Shale Member comprises those sediments between the last mappable dolomite which marks the top of the Dolomite Member and the base of the Sortis Group. It is not certain that the member is anywhere completely represented; it is often thin and in some areas absent due to thrusting.

In southern west Midternæs a few metres of dark shales are the only representatives of the Shale Member. About 2 km south of Birkesø it has a more varied development and includes cherty quartzites, calcareous shales, pelitic shales, and red-stained shales containing lenses and nodules of pyrite. North of Birkesø up to 15 m of rather sheared shales make up the Member.

The Shale Member is best developed in the western outcrops of north Midternæs where it may be as much as 120 m thick. Here it comprises a sequence of mainly semipelitic shales with a few thin calcareous shale bands and very thin dolomite layers. Of particular note is the occurrence of red-stained bands of pyritic shales at several levels. The pyrite occurs concentrated in lenses and layers parallel to the bedding. Thin talc-bearing shales were noted near the top of the sequence.

In other parts of north Midternæs the Shale Member is mainly composed of grey semipelitic shales, occasional bands of massive flaggy shales, a few thin calcareous bands and occasional rusty-coloured bands of pyritic shales. North of Palisaden the member is largely cut out by the thrust, but where present it includes black shales, pyrite-bearing cherty bands and red-stained pyritic shales.

6) Petrography of representative Vallen Group rocks

Zigzagland Formation rocks

Ore conglomerate (71320). West Midternæs.

Collected from the base of the 4 m Conglomerate Member north of Birkesø.

The rock is composed of subrounded quartz pebbles up to 14 cm in length and small quartz grains in a dark coloured silt matrix. In thin section the clastic quartz grains and pebbles comprise mosaics of several crystals which always exhibit undulose extinction, but the angular to subrounded shapes of the original grains are usually clearly marked. The matrix consists mainly of silt sized quartz grains, disseminated fibres of chlorite and rounded grains of magnetite. With the exception of the magnetite grains, which are often fractured with the fragments drawn apart from each other, the matrix appears to be more or less recrystallised. The chlorite has a tendency to occur in lenses of matted fibres surrounding the magnetite grains.

Orthoquartzite (71262). West Midternæs.

From near the base of the thick sandstone succession in southern west Midternæs (Fig. 4).

The specimen is a grey-white quartzite with no apparent trace of bedding or of the individual quartz grains. In thin section the rock is seen to be composed entirely of quartz with the exception of a few scattered sericite laths. The original textures and grain boundaries are discernable but have been much modified by shearing and partial recrystallisation. A mosaic of large quartz grains exhibiting undulose extinction is present, but the grains have borders of, or are partly replaced by, small crystals of unstrained quartz. Small sericite laths occur disseminated throughout the slide and in a few instances outline the larger grains of quartz.

Feldspathic sandstone (71236). West Midternæs.

Collected near the base of the Sandstone Member about 2 km south of Birkesø.

The rock comprises large clastic grains 3 mm to 5 mm in diameter set in a whitish matrix. There is a poor parting parallel to the bedding. In thin section subrounded clastic grains of quartz (ca. 85–90 %) and feldspar (ca. 5–10 % of microline and oligoclase) are clearly defined but their shapes are slightly modified by shearing and are elongate in section. The matrix comprises small clastic quartz and feldspar grains in a meshwork of sericite, but there has been partial recrystallisation of some of the quartz to form mosaics of unstrained grains.

Calcareous siltstone (71480). West Midternæs.

From the Calcareous Member in southern west Midternæs.

On fresh surfaces the rock exhibits a sequence of thin light and dark grey layers which are cut by a fine secondary cleavage which is the primary plane of fissility. In thin section the dark layers are of finer grain size (0.02 to 0.08 mm) than the light layers (0.02 to 0.2 mm). The composition of both layers is the same and consists of a mosaic of small carbonate grains (ca. 65 %), quartz (ca. 30 %), a very few feldspar grains and minute disseminated sericite laths. The texture appears to be largely an original sedimentary one but there has been some recrystallisation.

Blåis Formation rocks

Flaggy siltstone (71493). West Midternæs.

A specimen from the massive flaggy sequence at the base of the Blåis Formation in southern west Midternæs.

It is a dark grey rock with a good parting parallel to the bedding. In thin section it comprises small grains of detrital quartz and a little feldspar in a fine meshwork of sericite laths. The bedding is accentuated by small amounts of carbonaceous material. The grain size of the various components is mainly in the coarse silt fraction (about 0.01 to 0.06 mm) but a few large grains reach a size of about 0.2 mm. The composition approximates to that of a greywacke.

Dark grey shale (71237). West Midternæs.

From the upper part of the Blåis Formation south of Birkesø.

A fine bedding lamination slightly distorted by small scale folding is visible in the specimen and in the thin section. The bedding is accentuated by the alignment of considerable amounts of carbonaceous material and microscopic chlorite laths. Small grains of quartz of silt grain size occur scattered throughout the section. A few laths of chlorite recrystallised parallel to the bedding occur in some parts of the slide.

Feldspathic greywacke (71391). North Midternæs.

Collected from a greywacke band in a shaly sequence of the central Blåis Formation in eastern north Midternæs.

The specimen is dark grey in colour and contains mainly glassy detrital grains up to 3 mm in diameter. In thin section a mosaic of quartz and feldspar grains is revealed, many of which preserve their original angular to subrounded outlines. Sutured boundaries developed by recrystallisation or solution are apparent in some parts of the slide. The feldspar (albite-oligoclase) which comprises about 20 % of the large grains is partly sericitised. The large grains are set in a matrix of small detrital grains of quartz, microscopic sericite fibres and a little carbonate.

Arkose (71400). North Midternæs.

A coarse-grained example from the thick arkose which outcrops on the north slopes of Palisaden.

It is composed of large grains of quartz (ca. 70 %) and feldspar (ca. 25 %) up to 6 mm in diameter many of which have subrounded shapes; some of the feldspars have rectangular or lath shaped sections. In thin section the feldspar is seen to be mainly rather altered microcline. Both quartz and feldspar show indications of strain and many crystals are fractured; some of the quartz grains have been recrystallised to mosaics of unstrained crystals. The matrix (ca. 5 %) consists of small fragments of quartz and feldspar, and irregular aggregates of yellow-brown to red-brown secondary amphibole mainly in veins.

Grænsesø Formation rocks

Black pelitic shale (71241). West Midternæs.

From the Pelite Member about 2 km south of Birkesø.

A finely laminated specimen in which the bedding is distorted by minor folding and the development of an incipient axial plane cleavage. In thin section almost opaque layers comprising abundant carbonaceous material alternate with layers of microscopic quartz and abundant sericite. The bedding is in places compacted about a few quartz grains of fine sand grain size. The sericite has been recrystallised in slender laths parallel to the bedding and is responsible for the faint sheen on the bedding surfaces of parts of the hand specimen

Calcitic dolomite (71269). West Midternæs.

Collected from the dolomite sequence in southern west Midternæs.

The fine-grained specimen is orange-brown on weathered and grey on fresh surfaces. In thin section it consists of a fine-grained mosaic of calcite and dolomite (analysis Table 3) and scattered small grains of quartz. A faint bedding is discernible from the alignment of quartz grains.

Dolomite breccia matrix (24323). North Midternæs.

The specimen was taken from the matrix of the intraformational breccia which is found locally at the base of the main dolomite sequence in western north Midternæs.

It is composed of small fragments of black chert and fragments of yellow-weathered calcitic dolomite in a greyish-yellow groundmass. The yellow dolomite fragments appear to be the same composition as the large dolomite components comprising the bulk of the breccia and the non-brecciated calcitic dolomite beds in the same succession. The chert fragments are mainly angular and in thin section are composed of structureless or faintly laminated microcrystalline quartz. The groundmass to the fragments is a mosaic of calcite, dolomite and a little quartz. Both groundmass and chert fragments are cut by a later network of thin veins of quartz and carbonate minerals.

Pyritic shale (25714). North Midternæs.

Collected from a high level of the Shale Member in western north Midternæs.

The rock is a well foliated shale which contains pyrite in concentrations of small cubes in lenses and layers parallel to the bedding. A little pyrite also occurs in a network of thin cross-cutting veins. The shale in thin section consists in the pyrite-poor part of the section of a few detrital quartz grains of fine silt grain size in a matrix of microscopic quartz, sericite and scattered ore grains. The pyrite-rich layers contain numerous well shaped pyrite crystals with square cross-sections and a few crystals with somewhat rounded cross-sections. Between some of the adjacent larger pyrite crystals the quartz and sericite is slightly coarser grained suggesting strain-shadow recrystallisation. Sericite laths are sporadically distributed in the pyrite-rich layers but in the pyrite-poor layers exhibit a strong preferential alignment parallel to the bedding.

7) Conditions of deposition of the Vallen Group

A brief review of the probable depositional conditions of the sediments of the Vallen Group of Grænseland and Midternæs has been presented by Higgins and Bondesen (1966). Further brief mention has also been made by Bondesen *et al.* (1967) and a more detailed analysis of Grænseland conditions is given by Bondesen (in press). The short account which follows is with special reference to the Midternæs sediments.

The surface on which the earliest Ketilidian sediments were laid down was composed of roughly peneplained pre-Ketilidian gneisses and schists. Residual gravels which accumulated on this surface may be represented by the Conglomerate Member of northern west Midternæs. The Conglomerate Member is unsorted at the base, but the appearance of bedding near its top suggests that it was partly reworked in early Ketilidian time.

The probable uneven nature of the peneplained sub-Ketilidian surface is suggested by the distribution of the earliest Ketilidian sediments. Sedimentation appears to have been restricted at first to shallow basins of limited extent and it has been suggested that three probably initially separate sedimentary basins can be traced in Midternæs and Grænseland (Higgins and Bondesen, 1966). The Lower Zigzagland Formation is only represented in the southernmost of these three basins, in central Grænseland, and a carbonatisation of the sub-Ketilidian surface associated with dolomite deposition is restricted to this basin, as are certain fossiliferous horizons (Pedersen, 1966).

In Upper Zigzagland Formation time the Ketilidian sea became apparently gradually more extensive and the successive deposits in north Grænseland in the central of the three basins are of a transgressive nature. In west Midternæs, where the northern part of the same basin is found, orthoquartzites, suggesting slow initial deposition, occur and are succeeded by feldspathic sandstones. The sandstones show considerable variation in thickness and appear to thin out north of Birkesø against what may have been the northern limit of the basin. About 2 km to the north near Sermiligârssuk Bræ 30 m of sandstones with distinctive graded bedding are found (Fig. 5). This is the possible site of the southern extremity of the third and most northern of the sedimentary basins recognised; it was probably initially separated by dry land from the second basin.

The abrupt changes in thickness of the Sandstone Member in Midternæs which take place in the vicinity of ENE- or NE-trending faults give a clue to the nature of the topography of the Ketilidian sea floor (Plate 3). It seems probable that fault scarps may have formed cliff-like features, and strongly influenced depositional conditions. In Grænseland the boundary between the central and southernmost of the three basins recognised was apparently a major fault scarp (Higgins and Bondesen, 1966, fig. 3).

The occasional occurrence of cross-bedding in the sandstones suggests the sea was relatively shallow in Zigzagland Formation time and sun cracks recorded in Grænseland imply that parts of the basins were periodically dry. From the orientation of ripple marks and slump axes in the Grænseland sandstones Bondesen (in press) has calculated that the coastline had a trend of 110° to 145°.

An expansion and deepening of the Ketilidian sea appears to have begun in late Zigzagland Formation time and to have continued into Blåis Formation time. The distinction between the three basins of deposition became less pronounced and similar sequences of sediments occurred in both Midternæs and Grænseland.

In west Midternæs the Calcareous Member succeeds the Sandstone Member. The dominantly argillaceous sediments of the Blåis Formation are found both in north and west Midternæs, and it seems likely that at the time of deposition the sea was fairly deep and the shore line some distance from the Midternæs area.

The thickness of the sediments which accumulated during Blåis Formation time in different areas may be taken to reflect local variations in the supply of detritus. Northern west Midternæs with only 50 m of sediments was perhaps relatively elevated with respect to southern west Midternæs and north Midternæs in which up to 300 m and 750 m respectively of sediments seem to have accumulated during the same period.

In Grænseland the Blåis Formation, also of variable thickness, is represented by from 40 m to 800 m of pelites, semipelites and greywackes. The greywacke proportion is dominant, coarser-grained, and of far more importance than in Midternæs where banded siltstones dominate and greywackes are found in bands of limited thickness. Bondesen considers the greywackes to be turbidites whose deposition is related to fault movements in the vicinity (Bondesen, in press). Direct evidence for tectonic activity is seen in the lower part of the Blåis Formation of central Grænseland in the form of a "wild flysch" unit containing boulders and fragments of all the underlying members and the basement gneisses.

In Midternæs there is also evidence for instability of the sea floor in Blåis Formation time. In north Midternæs a 80 m thick arkose is found only on the south side of a major NE fault line, and in southern west Midternæs a feldspathic greywacke unit containing perhaps locally derived shale and siltstone fragments occurs only on the south side of an ENE-trending fault line. It seems possible that these deposits may owe their existence to movements on the nearby faults. Fault movements may have continued into Grænsesø Formation time; an infraformational dolomite breccia several metres thick at the base of the main dolomite sequence in western north Midternæs occurs in the immediate vicinity of a NE-trending fault line.

The thin dolomites interbedded with the siltstones and greywackes of the Blåis Formation probably represent chemical precipitates which accumulated during temporary failure of the supply of clastic material. The thicker dolomite accumulations of the Grænsesø Formation presumably represent a more prolonged period of similar conditions. It is notable that there is little or no coarse clastic material represented in the Grænsesø Formation, but a pronounced accumulation of pelitic material is apparent in the Pelite Member of west Midternæs and the rather pelitic shales interbedded with the dolomites of the Dolomite Member.

Accumulation of dominantly argillaceous material continued into late Grænsesø Formation time and is represented by the Shale Member. The pyrite in some shales probably formed originally during sedimentation under anaerobic reducing conditions, and recrystallised along bedding places and locally in cross-cutting veins during diagenesis.

In Midternæs a thrust sometimes occurs at the top of the exposed Vallen Group sequence and parts of the succession are missing locally.

In general terms the dominant siltstone deposition in north and southern west Midternæs, and the wedge-shaped arkosic deposits in both areas, are fairly characteristic of the sedimentary associations in intracratonic basins (auto- or zeugogeosynclines) (Dapples, Krumbein and Sloss, 1948). Thinner equivalents of the same types of deposit such as occur in northern west Midternæs, may be considered typical of shelf conditions bordering the intracratonic basins. Sedimentary successions including extensive greywacke sequences appropriate to geosynclinal troughs (orthogeosynclines) occur only in central and southern Grænseland. The Vallen Group cannot be traced continuously farther south than the fjord Qôrnoq in the eastern part of the Ivigtut region.

Further discussion on the environment of deposition of the Ketilidian succession as a whole is found at the close of the section on the depositional conditions of the Sortis Group (see p. 61).

8) The Sortis Group

The Sortis Group is composed largely of volcanic rocks and sills and its lower boundary is placed at the level at which volcanic effusives first appear. The upper boundary of the group is not seen in Midternæs, but the exposed part of the group is about 4800 m thick. The Sortis Group overlies the Vallen Group but in several areas a thrust is developed along their mutual contact and parts of the Vallen Group succession are locally missing; it is possible, but it is difficult to demonstrate, that part of the lower Sortis Group may be lacking in some areas.

Stratigraphical correlations of a general nature can be made for the Sortis Group between Midternæs and the type area (Grænseland), but it is only in the southern part of Midternæs that the relationships can be clearly demonstrated; this area is described first.

South of Akuliarutsip timilerssue and on the nunatak south of Tordensø the regional dip of the Sortis Group is ENE at angles of about 25° to 45°, but as in other parts of Midternæs, high anomalous dips in various directions have been produced locally by folding and the intrusion of lenticular sills. In this part of Midternæs the Sortis Group succession can be divided into three distinct parts: a lower pillow lava sequence, an intermediate sequence of sediments, pyroclastics and intrusive sills, and an upper pillow lava sequence. The lower two sequences can be easily correlated across the narrow Sioralik Bræ with the Foselv and Rendesten Formations of the Grænseland type succession (BONDESEN, in press). The lower sequence comprising lavas and a few thin sedimentary bands is equivalent to the Foselv Formation, and the intermediate sequence is characterised by the same rock types as occur in the Rendesten Formation.

The Rendesten Formation on Midternæs is well exposed to the north-west of Tordensø, on the large nunatak south of Tordensø and along the north-west and west margins of Nuna qernertoq. On Nuna qernertoq the Rendesten Formation sediments, pyroclastics and sills are succeeded by a very thick succession of pillow lavas. These upper lavas are not represented in Grænseland, and it would seem logical to place the upper limit of the Rendesten Formation (not defined in Grænseland) at the base of these thick lavas. It is proposed that this upper pillow lava sequence with its sills be assigned to a new formation of the Sortis Group termed the *Qernertoq Formation.* The Qernertoq Formation on Nuna qernertoq is about 2200 m thick; its upper boundary is hidden by the Inland Ice and cannot be defined.

The ENE-trending fault line at the south boundary of the ridge Akuliarutsip timilerssue appears to mark an important boundary between contrasting lithological developments of the Sortis Group. North of the fault line a lower pillow lava sequence corresponding to the Foselv Formation can be distinguished, but the Rendesten Formation sediments and pyroclastics are only conspicuously developed north and north-east of Birkesø and in the Palisaden area. Between these areas the sediments and pyroclastics thin laterally between flows of pillow lava. An alternating sequence of sediments and lava flows is seen in some areas, and in the northern Perledal area an almost uninterrupted pillow lava sequence occurs. It would appear that contemporaneous with the accumulation of sedimentary and pyroclastic rocks in the southern Midternæs area pillow lavas were outpoured in Midternæs north of the Akuliarutsip timilerssue fault line. Pillow lavas have not been recorded in the Rendesten Formation of the type area (Grænseland) and although important in north Midternæs they might be considered as atypical of the Rendesten Formation as a whole. It is therefore proposed to distinguish the pillow lavas of north Midternæs which appear to be contemporaneous with the deposition of the Rendesten Formation as the *Perledal Volcanic Complex*, after the good exposures in the northern part of Perledal.

In the Palisaden area sediments and pyroclastics of the Rendesten Formation, which alternate with thin lava flows of the Perledal Volcanic Complex, are overlain by a thick sequence of lavas and several thick sills which are best correlated with the Qernertoq Formation.

The thickness and stratigraphical variations of the Sortis Group are difficult to establish with certainty because of the repeated succession of identical rock types, the scarcity of good marker horizons, the variability of the dip caused by the numerous intrusive sills and subsequent folding. A schematic interpretation of variations in the stratigraphy is given in Plate 3. A map showing the outcrop of the Sortis Group Formations is presented as Plate 4.

Since the main rock types of the Sortis Group are represented in all three formations but in varying proportions, brief stratigraphical descriptions of the three formations are given first in the following pages, and the characteristic forms and petrography of the main rock types are presented subsequently.

9) The Foselv Formation

The lowest formation of the Sortis Group, the Foselv Formation, may not be complete everywhere in Midternæs since in several areas its base is a thrust plane. The Foselv Formation is composed principally of pillow lavas, a few intrusive sills and several thin sedimentary bands, and its upper limit is taken as the level at which lavas give way, characteristically, to a sedimentary and pyroclastic sequence. This upper limit is easily determined south of Akuliarutsip timilerssue, north of

Birkesø and Perledal, and in the Palisaden area. In the northern Perledal area and south of Birkesø where the Perledal Volcanic Complex is well developed the approximate limit of the Foselv Formation can usually only be determined by lateral extrapolation from adjacent areas.

The Foselv Formation appears to consist of up to three main lava sequences which are separated by thin and usually impersistent sedimentary bands. The number of individual lava flows which may be represented in each lava sequence is impossible to determine. Each lava sequence is at least partly made up of pillow lavas and in some areas the entire sequence is pillow lava. A few massive intrusive sills occur at some localities.

The total thickness of the Foselv Formation varies considerably from area to area. It is approximately 300 m thick south of Akuliarutsip timilerssue, about 800 m south of Birkesø and about 500 to 600 m north of Birkesø. In western north Midternæs the thickness is in the order of 900 m decreasing eastwards to about 500 m in the west Palisaden area and apparently to less than 150 m in the east Palisaden area. Some of these extreme thickness variations may be partly a consequence of the thrusting at the base of the formation, but most appear to be original variations related probably to differential outflow of lava.

The accumulation of unequal thicknesses of lava flows would give rise to an undulating area floor topography and it may be significant that the thickest sedimentary accumulations of the succeeding Rendesten Formation occur in those areas where the Foselv Formation is at its thinnest.

10) The Rendesten Formation and Perledal Volcanic Complex

The lower boundary of the Rendesten Formation is placed at the level at which the lavas of the Foselv Formation give way to a predominantly sedimentary and pyroclastic sequence, except where the Perledal Volcanic Complex is developed. With the same proviso the upper limit of the Rendesten Formation is placed at the level at which the sediments and pyroclastics are overlain by the very thick lava sequences of the Qernertoq Formation.

The sediments of the Rendesten Formation are mainly banded siltstones which are sometimes indurated and very massive, but usually weather easily to form shaly screes. Cherts and cherty quartzites are locally important. Some distinctive rock types are found in several areas, but at various levels, and none can be employed as reliable marker horizons.

Pyroclastic deposits varying in type from very fine tuffs to agglomerates and volcanic breccias are found at several levels; the characters of the various rock types are described in a separate section below. The most important deposits occur at intermediate to high levels of the Rendesten Formation and are represented at many different localities in Midternæs. South of Tordensø the main pyroclastic sequence exceeds 250 m in thickness.

Sills are very important in the Rendesten Formation and appear to be particularly abundant in those areas in which the greatest thicknesses of sediments accumulated.

South and south-east of Akuliarutsip timilerssue only an estimated 900 m of the 2400 m thick Rendesten Formation are sediments and pyroclastics and the remaining thickness is made up by the numerous sills. Even so, this thickness of sediments and pyroclastics is not approached at any other locality in Midternæs. At the only other locality where the total thickness of the Rendesten Formation can be estimated with any degree of reliability, in the Palisaden area, the sediments and pyroclastics are about 500 m thick; about 350 m of sills, and 250 m of lavas of the Perledal Volcanic Complex, made up the remainder of the estimated 1100 m total thickness.

Sediments are notably thin in the areas between Birkesø and Akuliarutsip timilerssue and between Perledal and Palisaden. In the latter area the Rendesten Formation is represented mainly by the Perledal Volcanic Complex, an almost unbroken pillow lava sequence, and only a few thin sedimentary bands. The principal sedimentary developments east and west of this area thin and in many cases wedge out completely between lava flows as they are traced inwards.

The interpretation of the complex stratigraphy of the Rendesten Formation is perhaps best appreciated from Plate 3. It is suggested that the lava flows comprising the Perledal Volcanic Complex were extruded periodically in parts of central and north Midternæs contemporaneous with accumulation of sediments and pyroclastics elsewhere. These lavas appear to have a limited lateral extent and were perhaps restricted in their distribution to the immediate vicinity of a volcanic vent or vents; none of the actual vents have been observed in the field. Lavas have not been recorded at this level in Grænseland (Bondesen, in press).

The absence of lava flows and the extreme thickness of the sedimentary accumulations in the area south of Akuliarutsip timilerssue might point to the existence of some type of barrier in the vicinity of the ENE-trending fault line along the south margin of Akuliarutsip timilerssue. It has been noted previously that this fault may have influenced deposition of the Vallen Group, and during that period the sedimentary accumulations were also greater on the south side of the fault line.

11) The Qernertoq Formation

The Qernertoq Formation outcrops on Nuna qernertoq, north of Andesø and south of Palisaden. It is at least 2200 m thick and its upper limit is not exposed.

The major part of the Qernertoq Formation is composed of well developed pillow lavas. Near the base, and at several other levels, lavas lacking pillow structures but exhibiting a poor to good columnar jointing occur. East of the large lake on Nuna qernertoq alternations of columnar jointed probable lavas, and sequences of pillow lavas are conspicuous.

Thick intrusive sills are prominent in the lower part of the formation north of Andesø. On eastern Nuna qernertoq and the nunataks to its east massive igneous rocks lacking pillow structures were interpreted as intrusive sills during a low-level helicopter reconnaissance but this diagnosis could not be verified as landings were prevented by turbulence.

The occurrence of sediments is restricted to a few thin bands of red-stained shaly siltstones and two 10 to 15 m thick chert lenses, all in the lower part of the formation.

12) Lavas

Occurrence and character

Lavas are the dominant rock type of the Sortis Group. Most of the lavas exhibit pillow structures implying subaqueous extrusion and it is not uncommon for pillow lavas to occur in unbroken successions several hundred metres thick. Some lava flows are devoid of pillow structures and may be columnarly jointed; others may exhibit poorly developed pillow structure in occasional bands or may be characterised by an irregular arrangement of small fractures.

The pillow structures in the lavas vary considerably in shape and dimension although most examples approximate to the classic pillow or bolster shape (Fig. 7). In section the pillows are commonly 20 cm to 1 m across in their shortest diameter and about 2 or 3 times this amount in their largest diameter. Rarely smaller examples occur and exceptionally large examples up to 10 m by 2 m in section have been observed in a few localities. At any one locality the pillows are usually of similar dimensions but extreme variations in size also occur. Bolster-shaped pillows appear to exhibit a general preferential alignment of their long axes in some areas, and most usually this direction is between NNE and ENE. Crescentic pillow shapes have been observed on Nuna qernertoq (Fig. 8). In most pillow lavas the pillows are distinct and separate entities. However, there occur in some parts of Nuna qernertoq sequences of apparently interconnected pillows. They occur as sheets of lava 1 m to

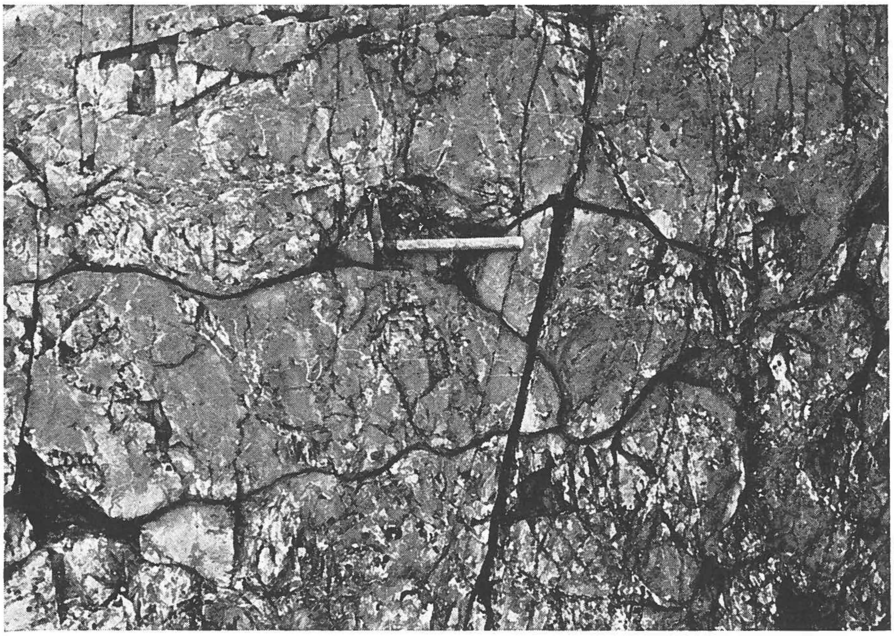


Fig. 7. Section through closely packed pillow lavas. North east of Perledal.

Fig. 8. Pillows weathered-out in three dimensions. Nuna qernertoq.

2 m thick with chilled pillow-form upper surfaces. These interconnected pillow sheets might be compared to a succession of thin surface lava flows of pahoehoe type (*cf.* Macdonald, 1953) but their association in Midternæs with thick sequences of pillow lavas suggests that they are subaqueous phenomena in this instance.

The pillows are nearly always closely moulded upon each other and there are commonly no, or very few and very small, cavities between pillows. The occasional cavities may be filled in by black cherty material, or sometimes by white quartz in association with calcite. In a very few areas cherty lenses between pillows are common and conspicuous. Brecciated lava fragments have been noted between pillows on rare occasions. At the base of some flows the underlying sedimentary material has been forced upwards between the pillows of perhaps the lower 5 to 10 m of the lava pile. A chert band at the base of one such flow was noted to be closely moulded to the shape of the pillows.

Thick pillow lava sequences frequently appear to be arranged in beds, and it has sometimes been possible to estimate the dip of pillow bedding planes. Their orientation is generally in agreement with the regional sedimentary bedding (Fig. 23).

Most pillows preserve good chilled margins usually darker in colour than the pillow interiors and of the order of 5 mm thick; the outer part of the chilled margin may be glassy and concentrically laminated. Concentric jointing or layering of pillows is rather uncommon (Fig. 9) and good radial columnar jointing has been observed only in a few very large pillows; most pillows are not conspicuously jointed. The outer surfaces of pillows are usually smooth and rounded and in some cases preserve a delicate ribbing or wrinkling suggestive of flow in a plastic state.

Lensoid cavities are in some areas common in the centres of pillows but may be totally absent in other areas. The margins of the cavities are glassy and may be empty, or filled in by chert, quartz, and occasionally calcite and epidote (Fig. 9). In some localities up to seven cavities occur arranged one above the other in a single pillow and separated by thin layers of lava. Pillows with multiple cavities do not occur very frequently but at one locality in western north Midternæs were present in an estimated 2 % of the observed pillows.

At two widely separated localities within thick pillow lava successions there have been noted alternations of thin lava sheets about 5 cm thick and slightly thinner cherty layers. Although on a smaller scale there is a strong similarity between the structure of these rocks and that of the layered lava pods described by Snyder and Fraser (1963) which they considered to have developed by a mechanism of laminar flow.

Within a thick pillow lava sequence in north Midternæs was noted the occurrence of spectacular pillow breccias (*cf.* Henderson, 1953;

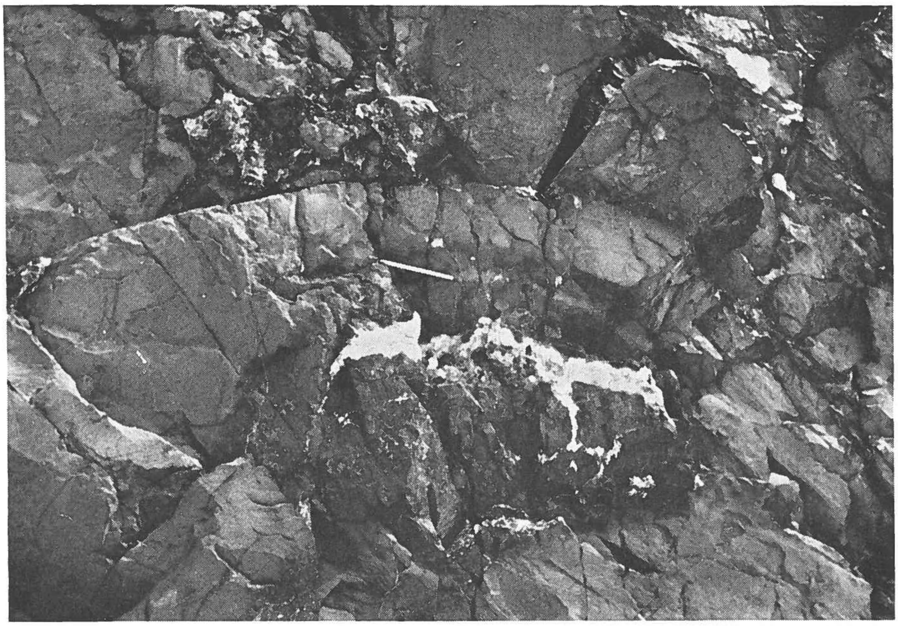


Fig. 9. Section of a concentrically layered pillow with a calcite filled central cavity. North of Andesø.

CARLISLE, 1963) within a zone about 150 m thick and traceable for about 1 km. These breccias can be traced laterally into normal pillow lavas and there is an irregular but sharp junction between the two rock types. The pillow breccia comprises numerous small pillows of very irregular shape, usually less than 50 cm in their greatest dimension, together with fragments of broken pillows which are embedded in a tuffaceous matrix (Figs. 10 and 11). There was complete intermingling of zones with mainly broken pillows and zones with mainly whole pillows. The matrix consists of angular shards, globules and multiple globular structures which are embedded in a fine-grained groundmass. The globular or aquagene tuff is thought to develop by globulation from a highly fluid magma under considerable internal pressure (CARLISLE, 1963). The formation of pillows in such a tuff is apparently facilitated by a very small density contrast between pillow and tuff (SOLOMON, 1966). Once formed the pillows cooling slowly in a medium of hot water and hot granulating glass were able to deform appreciably during even relatively gentle flowage of the pillow matrix (CARLISLE, *op. cit.*) or due to accumulating overburden (SOLOMON, *op, cit.*). The rupture and disaggregation of pillows is variously attributed to slumping and sliding of pillows and matrix (CARLISLE, *op. cit.*; BAILEY and HALLIDAY, 1963) or to brecciation due to the increase in volume accompanying late-pelagonitisation (FRANCE, 1967).

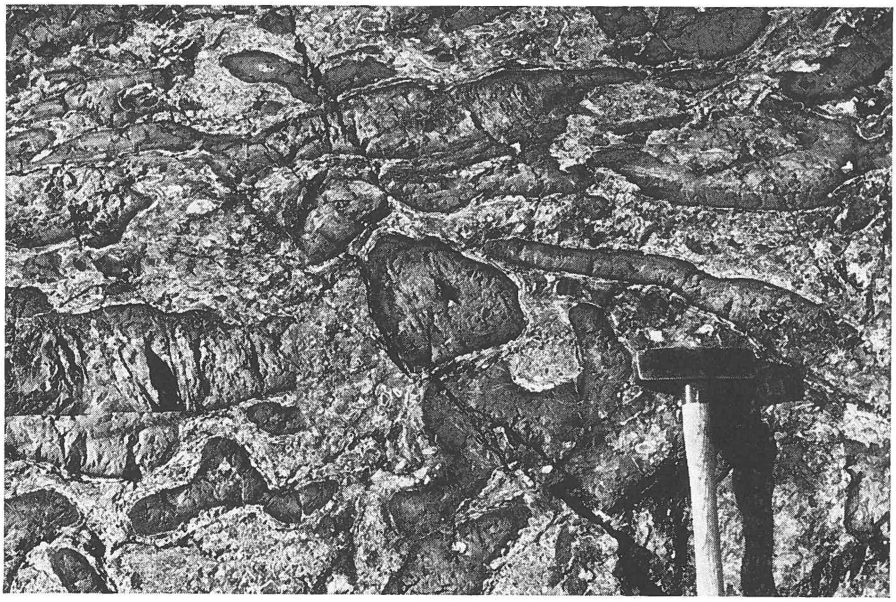


Fig. 10. Pillow breccia comprising mainly entire pillows in a tuff matrix. North Midternæs.

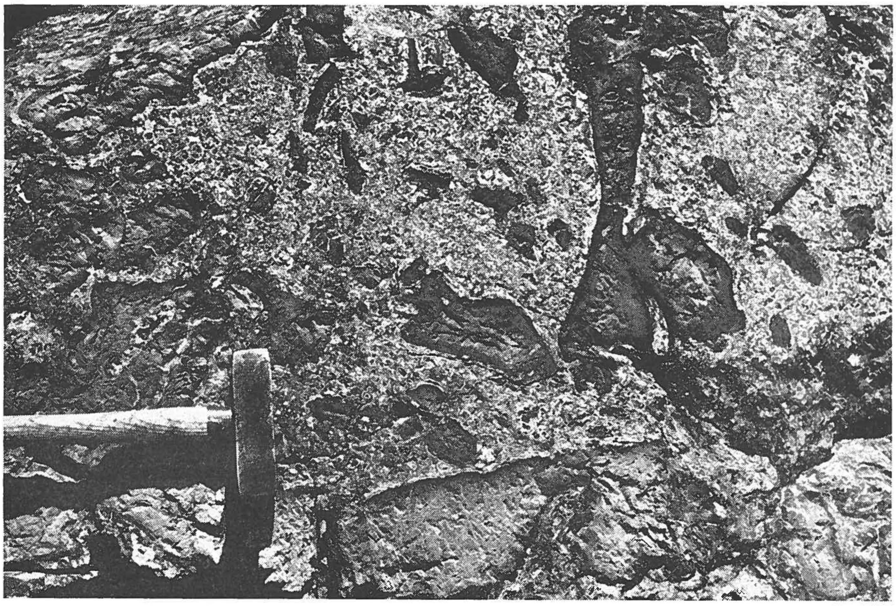


Fig. 11. Pillow breccia containing many broken fragments of pillows chilled only on one margin. The globular nature of the tuff matrix is apparent. North Midternæs.

Boundaries between successive lava flows are difficult to determine in areas where conditions did not permit the intermediate accumulation of sedimentary material. Breccias of angular lava fragments in a glassy mesostasis encountered in several thick lava sequences on Midternæs may represent flow boundaries.

Interbedded with the pillow lavas there occur occasionally thick conformable massive lava flows. Massive flows occur mainly in the Perledal Volcanic Complex in northern Midternæs and near the base of the Qernertoq Formation. The association with extensive sequences of pillow lavas suggests they were of subaqueous eruption rather than surface flows. It may be that such massive flows represent parts of subaqueous eruptions of considerable volume which did not come into intimate contact with water (Wilson, 1960).

On the geological map (Plate 5) all Ketilidian igneous rocks have been indicated as either sills or lavas, but difficulty was in fact occasionally experienced during mapping in distinguishing between some non-pillowy lavas and fine-grained sills. In those areas where doubt as to the mode of emplacement of the rocks exists the boundaries between lavas and sills have been indicated as arbitrary, but since both rock types have virtually identical compositions any misinterpretations are considered to be of little consequence.

The shape and sizes of pillows in the other Ketilidian volcanic sequences of the Ivigtut region are similar to those of Midternæs in many respects. Wegmann (1938) has recorded pillows on Arsuk Ø up to 10 m in length and Muller (in prep.) in the same area has observed examples 5 m by 50 cm in cross-section. Muller has observed central vesicular portions in many pillows of Arsuk Ø, both concentric and radial jointing, and pillows with multiple quartz and calcite-filled cavities identical to those of Midternæs. Pillow breccias in the Foselv Formation of Grænseland have been figured by Bondesen (1962, fig. 84), and examples from Arsuk Ø, where they form important sequences at several levels, are described by Muller (in prep.).

Petrography and chemical analyses

Thin section analysis provides little clue to the composition of the lavas, most of which are aphanitic. Petrographic descriptions of a few examples are given below:

Pillow lava (71285). Southern Midternæs.

From the chilled margin of a pillow in a flow of the Perledal Volcanic Complex.

Within the chilled margin which is preserved in the specimen the lava is aphanitic, pale grey in colour and cut by several thin irregular veinlets. The thin section is composed mainly of densely packed brownish patches which may represent devitrified glass. The variolitic groundmass appears to be composed of plagioclase and perhaps some pyroxene, and small euhedral clinopyroxenes are also present as scattered phenocrysts.

Pillow lava (25791). Nuna qernertoq.

From the centre of a 30 cm pillow in the Qernertoq Formation lavas.

The specimen is grey in colour and comprises scattered small pale coloured phenocrysts in an aphanitic matrix. The thin section shows the matrix to comprise prismatic plagioclase microlites, euhedral and subhedral clinopyroxene and scattered grains of ore. The plagioclase is mainly andesine. The phenocrysts of the hand specimen seem to be slightly coarser grained aggregates of pyroxene and plagioclase notable only in that the plagioclase is more altered than in the groundmass and occurs as brownish laths.

Globular pillow breccia matrix (25719). Northern Midternæs. Analysis Table 4.

Collected from the Foselv Formation localities illustrated in Figs. 10 and 11.

The main features of the specimen are the discrete and composite globules from 1 mm to 6 cm in diameter which have an extremely varied form and texture. They are set in a greyish tuffaceous matrix which is red on weathered surfaces. The interior parts of the globules in thin section are very complex but appear to represent devitrified chloritised volcanic glass; perlitic structures are often preserved. The most consistent feature of the globules is the zoned border comprising usually a bleached inner zone, a thin opaque ferruginous layer and an outer brownish zone of probably palagonite. The matrix between the globules comprises shards, lithic fragments and other tuffaceous debris in a mesostasis of chlorite, actinolite and silica whose texture in places is suggestive of flow (*cf.* detailed petrology of these rock types by Carlisle, 1963).

Five analyses and two partial analyses of lavas and an analysis of pillow breccia matrix are presented in Table 4. The CIPW norms with normative olivine and hypersthene for all five lava analyses imply that the lavas are just saturated olivine tholeiites. The affinity with tholeites is brought out in Fig. 14 where Na_2O plus K_2O for the lavas (and sills) is plotted against SiO_2 and compared with the Hawaiian tholeiite suite field. The comparison of the average of the five Midternæs lavas with the average Hawaiian tholeiite (Macdonald and Katsura, 1964) is favorable in many respects, if the high H_2O in the Midternæs analyses is allowed for (Table 4); the Midternæs rocks contain somewhat lower proportions of TiO_2, Fe_2O_3 and K_2O.

Of the five lava analyses, four are of pillow lavas and one is from a massive lava band, but all are thought to be subaqueous extrusive rocks. It may be noted that they show none of the characteristics of spilitic rocks with the exception of low K_2O. The percentage of Na_2O is about average for basalts and in only one analysis exceeds 4 %.

Each of the pairs of analyses 3–4 and 5–6, and the partial analyses 7–8, were collected from the margin and core of pillows at three different localities. Since the selvedges, or outer chills, of the marginal pillow samples were not included in the analyses these pairs of analyses are not

Table 4. *Analyses of lavas*

	1	2	3	4	5	6	7	8	9	10
	25719	25781	71463	71464	24358	24357	25790	25791	Average of 2–6	Average Hawaiian tholeiite
SiO_2	50.64	48.89	50.89	47.43	47.14	47.56	–	–	48.38	49.36
TiO_2	0.87	1.57	0.75	0.84	0.79	0.83	–	–	0.96	2.50
Al_2O_3	13.92	12.76	13.43	12.92	15.23	14.25	–	–	13.72	13.94
Fe_2O_3	1.45	2.64	1.29	1.12	1.42	1.65	–	–	1.62	3.03
FeO	10.49	11.70	10.42	9.93	9.84	9.72	–	–	11.32	8.53
MnO	0.13	0.21	0.05	0.21	0.27	0.20	–	–	0.19	0.16
MgO	9.64	5.96	7.01	6.92	8.11	8.14	–	–	7.23	8.44
CaO	4.96	8.45	9.20	13.77	10.30	11.36	5.58	12.12	10.62	10.30
Na_2O	0.21	3.22	4.13	1.90	2.30	2.01	2.90	2.98	2.71	2.13
K_2O	0.19	0.19	0.19	0.25	0.25	0.24	0.10	0.20	0.22	0.38
P_2O_5	0.28	0.22	0.19	0.00	0.23	0.13	–	–	0.15	0.26
CO_2	–	Tr.	–	1.00	–	–	–	–	–	–
H_2O^+	7.18	3.29	2.78	3.73	4.35	3.41	–	–	3.51	†
H_2O^-	*	*	*	*	*	*	*	*	–	†
Total	99.96	99.10	100.33	100.02	100.23	99.50	–	–	–	–

* Analysis on sample dried at 110°C for 2 hours. † Not given.

CIPW Norms

	1	2	3	4	5	6
q	16.70	–	–	–	–	–
c..............	5.02	–	–	–	–	–
or..............	1.12	1.12	1.12	1.48	1.48	1.42
ab	1.77	27.21	34.91	16.06	19.44	16.99
an	22.76	19.79	17.54	25.97	30.47	29.13
di..............	–	17.16	22.15	29.68	15.65	21.57
hy	40.98	22.25	2.85	13.69	13.79	15.57
ol..............	–	0.90	15.19	3.87	10.91	7.09
mt	2.11	3.84	1.87	1.63	2.06	2.40
il	1.65	2.98	1.42	1.60	1.50	1.58
ap	0.66	0.52	0.45	–	0.54	0.31
cc..............	–	–	–	2.41	–	–

Analysed samples:

Analysis no:

1 Globular tuff matrix of pillow breccia (Figs. 10 & 11). Foselv Formation, north Midternæs.
2 Massive lava flow. Near base of Qernertoq Formation, Nuna qernertoq.
3 Pillow 0.5 cm to 2 cm from margin. Perledal Volcanic Complex, western north Midternæs.
4 Core of pillow of analysis 3.
5 Pillow 0.5 to 2 cm from margin. Foselv Formation, north Midternæs.
6 Core of pillow of analysis 5.
7 Pillow 0.5 to 2 cm from margin (partial analysis). Qernertoq Formation, Nuna qernertoq.
8 Core of pillow of analysis 7 (partial analysis).
9 Average of analyses 2 to 6.
1964, p. 124).
10 Average of 181 tholeiites and olivine tholeiites (MacDonald and Katsura,

in all particulars comparable to those presented by Bailey and McCallien (1960), Vallance (1965) and others. However, certain chemical variations may be observed. In the samples 3–4 the core sample is relatively depleted in Si, Al and Na and notably enriched in Ca. The core sample of the analyses 7–8 shows also marked enrichment in Ca and slight depletion of Al. A slightly lower Na content and slightly higher Ca content is found in the core sample of the analyses 5–6 (*cf.* Table 4 and Fig. 15b). While comparable changes of composition within pillows have been recorded in analyses quoted in Bailey and McCallien (1960), variations in the opposite sense have been noted by Vallance (1965).

The pillow breccia matrix analysed largely comprises chilled basaltic lava and has similarities with the analyses of chilled selvedges of pillows (Vallance, 1965). In contrast to the normal pillows these chilled rocks exhibit an extreme depletion of Na, relative depletion of Ca, higher Mg and markedly higher H_2O. A depletion in Si characteristic of selvedges is not, however, found in the pillow breccia matrix. The very high water content of the pillow breccia matrix may be viewed as a consequence of the quenching of basalt glass in reaction with water, and similarly the high water of all five lava analyses suggests mineral adjustments in a wet environment.

Further consideration of the analyses of both lavas and sills follows at the close of the following section on sills (p. 48).

13) Sills

Occurrence and character

Basic sills make up 30 to 40 % of the Sortis Group; a few examples also occur at a high level of the Vallen Group. The intrusive nature of the sills is most clearly apparent in the Tordensø area and to the north and north-east of Birkesø where they intersect thick sedimentary sequences of the Rendesten Formation. The sills in these areas have a rather irregular outcrop pattern. They vary considerably in size and shape and many small sills occur as isolated pods with no apparent connection with adjacent sills. Individual sills vary from a few metres to several hundred metres in thickness. The thicker sills are usually aligned concordant to the regional bedding but minor discordances can often be observed. Laterally some sills may be extremely extensive. Many have characteristic blunt or rounded terminations. Intrusion into the sediments appears to have caused the local development of minor folds unrelated to the subsequent regional deformations, as well as giving rise to anomalous dip readings. Most of the sills which have been in-

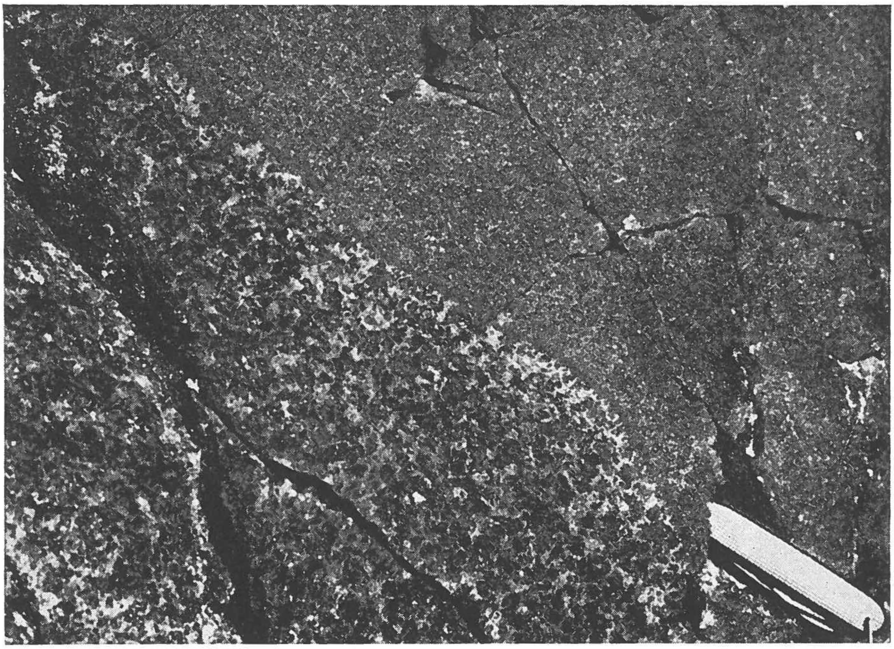


Fig. 12. Contact between coarse- and medium-grained gabbro in the upper part of a thick sill. Central Midternæs. Photo: NIELS Ø. OLESEN.

truded into dominantly lava sequences appear to be more extensive and generally thicker than those which have been intruded into sedimentary successions.

Sills up to about 10 m thick tend to be fine-grained throughout and those up to about 100 m thick have usually a medium-grained central portion and fine-grained margins. It is generally only in sills greater than 100 m thick that coarsegrain sizes are reached. The coarse-grained zones often have very irregular and sharp boundaries with the medium-grained zones (Fig. 12).

Nearly all sills are mesocratic with a colour index of 30 to 50. The upper part of some sills and zones in the uppermost third of some thick sills consist of deeply weathered melanogabbro. A thin altered sill west of Perledal is entirely melanocratic. Some apparently leucocratic and melanocratic parts of sills proved on close examination to be normal rock types with a surface discolouration.

Columnar jointing is sporadically developed in the sills. The dimensions of columns varies from about 15 cm to 2 m (Fig. 13).

Examples of differential lithological layering have only been recorded in a few thick sills and take varying forms. Developments of red spherulitic patches up to 1 cm in diameter occur in some of the thicker sills, particularly near the base and more rarely at the top. At

Fig. 13. Crude columnar jointing in a thick sill on the north slopes of Palisaden. The larger columns are up to 2 m in diameter.

the base of a sill in central Midternæs the patches are concentrated in thin layers at intervals of 4 to 7 cm. In the upper part of a very extensive sill 2.5 km north-west of Andesø apparent concentrations of ferro-magnesium minerals occur at repeated intervals of about 3 m. The upper part of a sill at the east side of the lake on Nuna qernertoq contains several melanocratic layers 5 to 10 cm thick containing conspicuous amounts of ore. An intrusion in western Nuna qernertoq contains near the top a 40 cm thick amphibole segregation (Table 5, sample 33904). On a small nunatak 3 km south-east of Palisaden a sequence of leucocratic bands 5 to 40 cm thick and extending laterally for several tens of metres was observed; the successive layers are separated from each other by several metres of normal mesocratic rock (Table 5, samples 25747 a and 25747 b).

The sills of some areas are cut by leucocratic veins which appear to be confined to the body of the sill and do not extend into the surrounding rocks. The best examples of the veins are seen on the nunatak south of Tordensø where they exceptionally reach thicknesses of 1 to 2 m. Mineralogically the veins are composed chiefly of quartz, calcite or clino-zoisite usually with one mineral dominant; epidote and ore occasionally occur as accessories. Most of the veins appear to be secondary accumulations in open joints but some may be deuteric phenomena related to the late stages of cooling of the sills.

Petrography and chemical analyses

The modal compositions of 25 samples from several sills as determined by thin section analysis are given in Table 5. The main mineral constituents are plagioclase, pyroxene and amphibole, with ore in ac-

Table 5. *Modal analyses of sills*

GGU No.	Plag.	Pyrox.	Am-phib.	Ore.	Alter-ation	Locality and level		
25747a	53.4	28.8	15.2	1.4	1.2	Mesocratic layer	SE Midt	QERNERTOQ FORM.
25747b	68.8	22.8	3.8	1.6	3.4	Leucocratic layer	SE Midt	QERNERTOQ FORM.
33907......	50.6	28.8	13.6	1.2	5.8	0.2 m from top	Western Nuna qernertoq	RENDESTEN FORMATION
33906......	52.3	21.1	15.1	2.0	9.3	5 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
33905......	46.8	32.5	10.6	1.3	9.1	16.7 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
33904......	1.8	0.1	83.9	8.0	6.2	17 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
33903......	45.2	28.1	12.3	3.4	11.0	17.3 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
33902......	51.6	27.6	9.4	2.5	10.3	20 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
33901......	55.3	34.6	2.8	1.6	5.7	35 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
25800......	55.6	32.5	2.5	1.6	7.8	50 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
25799......	62.3	33.0	1.2	0.6	3.0	65 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
25798......	67.7	21.6	4.5	1.4	4.8	90 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
25797......	57.1	32.8	1.5	0.8	7.8	125 m – –	Western Nuna qernertoq	RENDESTEN FORMATION
71286......	44.6	42.0	0.0	3.2	10.2	3 km WNW of Andesø		RENDESTEN FORMATION
71409......	55.4	35.7	0.0	3.9	5.0	3 km W of Andesø		RENDESTEN FORMATION
71397......	58.5	21.5	0.4	4.6	7.2	Palisaden		RENDESTEN FORMATION
71402......	46.4	27.5	3.7	4.8	17.6	5 km W of Palisaden		RENDESTEN FORMATION
24390......	55.2	26.6	0.6	2.2	15.2	4 m from top	Western north Midternæs	FOSELV FORMATION
24389......	52.4	33.7	3.0	4.2	6.7	29 m – –	Western north Midternæs	FOSELV FORMATION
24387......	58.3	27.5	4.6	1.6	8.0	44 m – –	Western north Midternæs	FOSELV FORMATION
24386......	56.3	33.3	3.2	1.6	5.6	79 m – –	Western north Midternæs	FOSELV FORMATION
24385......	49.1	33.3	5.6	1.9	10.1	109 m – –	Western north Midternæs	FOSELV FORMATION
24384......	54.3	30.5	6.2	2.1	7.0	144 m – – / 5 m – base	Western north Midternæs	FOSELV FORMATION
71238......	45.0	0.0	43.5	3.0	8.5	West Midternæs		BLÅIS FORM.
71239......	51.0	0.0	40.7	1.2	7.1	West Midternæs		BLÅIS FORM.

cessory amounts. Alteration is marked in all specimens, reaching in exceptional cases 17 % of the modal totals.

The samples listed in Table 5 were collected from 8 sills, the lowest of which is in the Blåis Formation and the highest in the Qernertoq Formation. Six samples were collected from successive levels of a 150 m sill (samples 24384–24387, 24389 and 24390) but the modes show no systematic variations in mineral proportions. Eleven other samples were collected at successive levels of the upper 125 m of a sill whose base was not exposed (samples 25797–25800 and 33901–33907). With the exception of sample 33904 which was taken from an amphibole segregation band, these modes show a general decrease in plagioclase content upwards together with an increase in amphibole content; the pyroxene percentage fluctuates.

The plagioclase in most samples is andesine (An 30–45 %) and in only a few samples has a lime-poor labradorite (An 54 %) been recorded. The plagioclase occurs in prisms and laths often in ophitic relationship with pyroxene and less commonly with amphibole. Occasional micrographic intergrowths of feldspar and quartz have been recorded. Albite twinning is common, and pericline and baveno twinning also occur. Zoning is rare. The plagioclase is always affected to some degree by sericitisation and saussuritisation and in some cases alteration is so advanced as to prevent composition determinations.

The pyroxene is a colourless to pale brown common augite which occurs in small subhedral prisms, or large anhedral crystals enclosing plagioclase laths in ophitic relationship. Simple twinning is common. Alteration is not pronounced but some pyroxenes may be fringed by a narrow border of secondary fibrous actinolite.

The primary amphibole commonly found is green and usually strongly pleochroic. It occurs in large prismatic crystals or as clusters of crystals which may enclose plagioclase in ophitic relationship. Amphibole rimming pyroxene with the same optical orientation or crystals with small relic pyroxene cores also appear to be primary. Most of the amphibole is hornblende.

Ore is always present in small amounts, occasionally as euhedral crystals, but most often as irregular or skeletal grains.

The principal secondary minerals are chlorite, actinolite or uralite, apatite, zoisite and quartz, and in some cases a little stilpnomelane.

In the thin section descriptions of specimens of sills given below the plagioclase compositions suggest classification as diorites or meladiorites. This is, however, inconsistent with the chemical analyses, given in Table 6 and discussed further below, which show that the sills have a gabbroic composition.

Hornblende 'gabbro' (71238). West Midternæs. Mode Table 5.

From the upper part of a thick sill in the Grænsesø Formation.

A mesocratic medium-grained rock, the specimen exhibits on weathered surfaces a conspicuous network of dark amphibole laths up to 3 mm in length in a pale feldspar matrix. In thin section the texture is hypautomorphic-granular. The amphibole is a markedly pleochroic greenish-brown hornblende. The longitudinal sections mostly seen in the section often show twinning and a few cross-sections give the typical amphibole cleavages. The hornblende is often partly chloritised and in addition the borders and terminations of the laths may be fringed by fibrous actinolite. Plagioclase occurs in equidimensional aggregates intergrown with the hornblende. The plagioclase appears to be andesine, but identification is often uncertain due to turbidity caused by extensive saussuritisation. Rare micrographic intergrowths of feldspar and quartz have been noted. Secondary chlorite and actinolite occur in radiating clusters.

Pyroxene 'gabbro' (71374). West of Andesø.

Collected from the margin of a sill in the Rendesten Formation.

The hand specimen is mesocratic and fine-grained, but is conspicuous for the occurrence of scattered red-weathered spherical 'phenocrysts'; on fresh surfaces the 'phenocrysts' are grey in colour and aphanitic. The texture of the thin section is hypautomorphic-granular with a tendency to ophitic. The essential components are plagioclase and pyroxene. The plagioclase is partly saussuritised but albite twinning is clearly apparent and suggests a composition of andesine. The pyroxene is a colourless augite which commonly has narrow fringes of brownish hornblende in parallel position and apparently primary. Fibrous secondary amphibole also occurs. The alteration of the plagioclase into cloudy laths has a patchy distribution on the slide and it is in these areas that clusters of chlorite fibres are common. Ore is an accessory. The spherical 'phenocrysts', which have not uncommonly been observed at the margins of sills, consist in thin section mainly of a dense meshwork of plagioclase and chlorite microlites.

Pyroxene 'gabbro' (33902).Nuna qernertoq. Mode Table 5.

From a thick sill in the uppermost part of the Rendesten Formation.

The specimen is a mesocratic medium-grained rock with dark irregular phenocrysts more than 1 cm in diameter. The phenocrysts are pale brown augites which enclose laths of saussuritised plagioclase in ophitic relationship. Wedge-shaped areas in the pyroxenes are composed of pale brown slightly pleochroic amphibole with the same optical orientation and may be primary. The amphibole occurs in some cases intimately intergrown with the pyroxene, as well as independently in lath-shaped crystals. Micrographic intergrowths of quartz and feldspar and myrmekite-like intergrowths of plagioclase and pyroxene have been recorded. Ore is accessory and forms skeletal grains. Among the secondary minerals are chlorite, which forms radiating aggregates, and quartz.

'Melanogabbro' (78889). North of Tordensø. Analysis Table 6.

From a deeply weathered band in a sill of the Rendesten Formation.

The weathered zone from which this specimen derives can be traced for several kilometres. The specimen is melanocratic; it is a dark greenish-brown colour on the cut surface. The most conspicuous feature of the thin section is the proportion of alteration products of which red-brown to golden brown disseminated fibres of stilpnomelane are the most abundant. The stilpnomelane occurs also as thin irregular

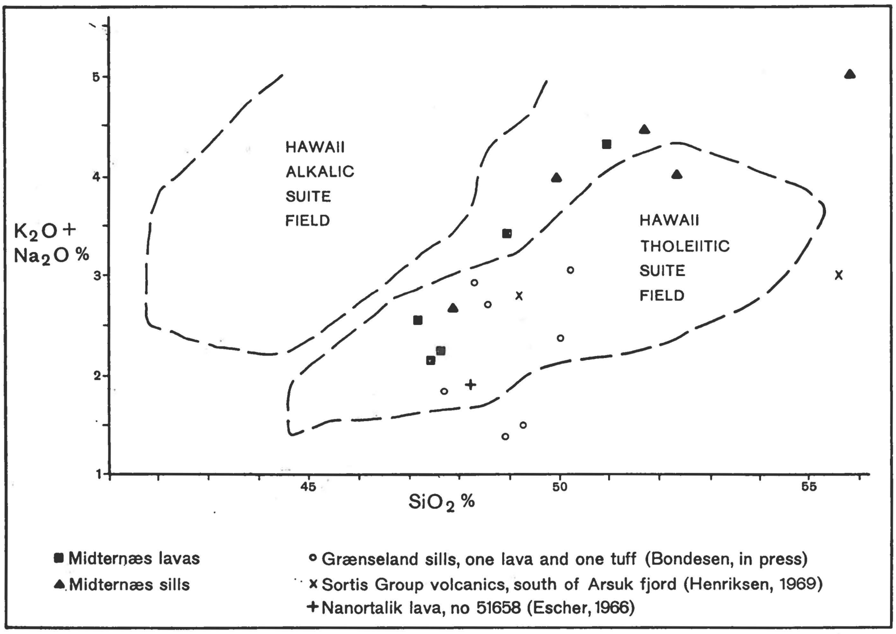


Fig. 14. Plot of Na_2O plus K_2O against SiO_2 for Ketilidian igneous rocks compared to the fields of occurrence of the Hawaiian alkalic and tholeiitic suites adapted from Macdonald and Katsura (1964).

veins in other minerals and in some cases as patches of matted fibres pseudomorphic after pyroxene and preserving ophitic textures towards plagioclase. The plagioclase occurs as large and small laths of andesitic composition. Micrographic intergrowths of quartz and feldspar are widespread. Scattered laths of pale green primary hornblende also occur. Conspicuous among the secondary minerals are apatite in hexagonal and prismatic sections, zoisite, chlorite, and sphene associated with ore.

Analyses of five specimens of sill rocks are presented in Table 6. Four of these are of normal sills of which the modes are given in Table 5; the fifth sample (78889) is from a melanocratic zone within a normal sill. The norms suggest that the sills are of slightly more variable composition than the lavas, ranging from oversaturated to undersaturated tholeiites; one sample with relatively low silica (analysis 3) contains a very little normative nepheline. In the plot of Fig. 14, which includes sills and lavas of Midternæs, Grænseland and other areas, the general affinity of Ketilidian igneous rocks with the tholeiitic suite is evident.

Comparison of the average Midternæs sill (Table 6, no. 6) with the average Midternæs lava (Table 4, no. 9) shows broad similarities, with only Si and Na slightly higher in the sills and total Fe slightly lower. Very low Ti and K and high H_2O are features common to both sills and lavas and are in line with the view that both intrusions and extrusions

Table 6. *Analyses of sills*

	1 78889	2 71238	3 24386	4 33901	5 33907	6 Average 2–5
SiO_2	55.73	52.26	47.84	51.62	49.83	50.39
TiO_2	1.96	1.79	0.57	0.52	0.75	0.91
Al_2O_3	10.83	11.57	15.62	15.28	13.84	14.08
Fe_2O_3	8.29	2.20	2.23	2.16	0.92	1.88
FeO	8.91	12.47	5.96	5.04	9.14	8.15
MnO	0.28	0.17	0.81	0.16	0.17	0.33
MgO	1.78	4.31	8.05	7.87	8.60	7.21
CaO	4.09	8.36	14.31	10.13	7.99	10.20
Na_2O	3.93	3.58	2.10	4.26	3.60	3.38
K_2O	1.25	0.45	0.57	0.20	0.40	0.40
P_2O_5	0.62	0.15	0.08	0.06	0.10	0.10
CO_2	–	–	–	–	1.05	–
H_2O^+	2.81	2.40	2.16	2.80	3.80	2.79
H_2O^-	*	*	*	*	*	–
Total	100.48	99.71	100.30	100.10	100.19	–

* Analysis on sample dried at 110°C for 2 hours.

C I P W Norms

	1	2	3	4	5
q	17.05	3.05	–	–	–
or	7.38	2.66	3.36	1.18	2.36
ab	33.21	30.26	15.51	36.00	30.43
an	8.22	14.17	31.49	21.97	20.41
ne	–	–	1.21	–	–
di	6.72	22.14	31.44	22.32	9.73
hy	7.88	18.06	–	0.27	17.71
ol	–	–	10.56	11.23	10.32
mt	12.04	3.20	3.24	3.14	1.34
il	3.72	3.40	1.08	0.99	1.42
ap	1.47	0.35	0.19	0.14	0.24
cc	–	–	–	–	2.53

Analysed samples:

Analysis
no:

1 From a melanocratic zone in a sill in the Rendesten Formation north of Tordensø.
2 Hornblende gabbro sill in the Grænsesø Formation of west Midternæs.
3 Gabbro sill in the Foselv Formation of western north Midternæs.
4 Gabbro sill in the Rendesten Formation of western Nuna qernertoq.
5 Chilled gabbro of same sill as analysis 4.
6 Average of analyses 2–5.

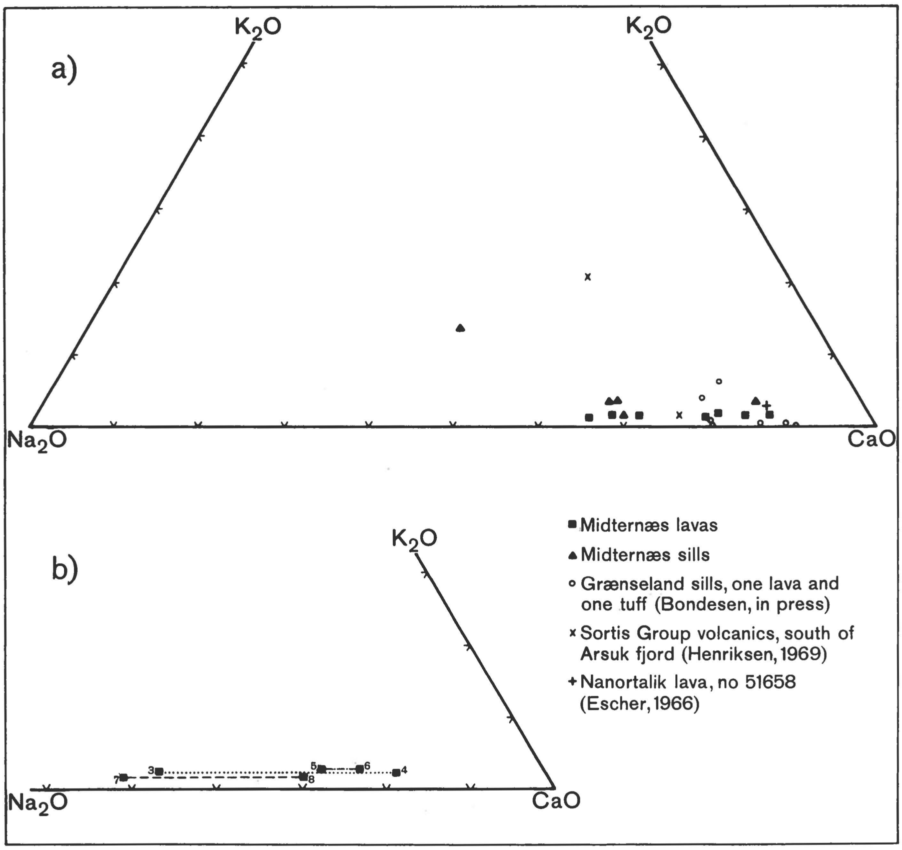


Fig. 15. $K_2O/Na_2O/CaO$ variation diagram. a) Analyses of all Ketilidian igneous rocks. b) Midternæs pillow lavas showing variations between centres and margins of pillows. The numbers refer to the analyses in Table 4.

were derived from the same magma chamber. The equivalent Grænseland analyses (Bondesen, in press) show the same characteristics. The K_2O-Na_2O-CaO plot of Fig. 15 and the plot of normative Or-Ab-An in Fig. 16 both emphasize the marked K depletion in the Ketilidian igneous rocks. There is growing evidence according to Barager (1968) that potash-poor magma may be characteristic of Precambrian geosynclinal volcanism; the Noranda volcanic belt, the Yellowknife volcanic belt, the Labrador trough and several other geosynclinal belts in the Canadian Shield are noted to contain volcanic rocks with a low potash content.

The high water content of the Midternæs sills and lavas may be indicative of an original rather wet magma, or may reflect the environment of accumulation as submarine lavas and shallow intrusions into wet sediments. Sedimentary rocks were considered by Barager (1960)

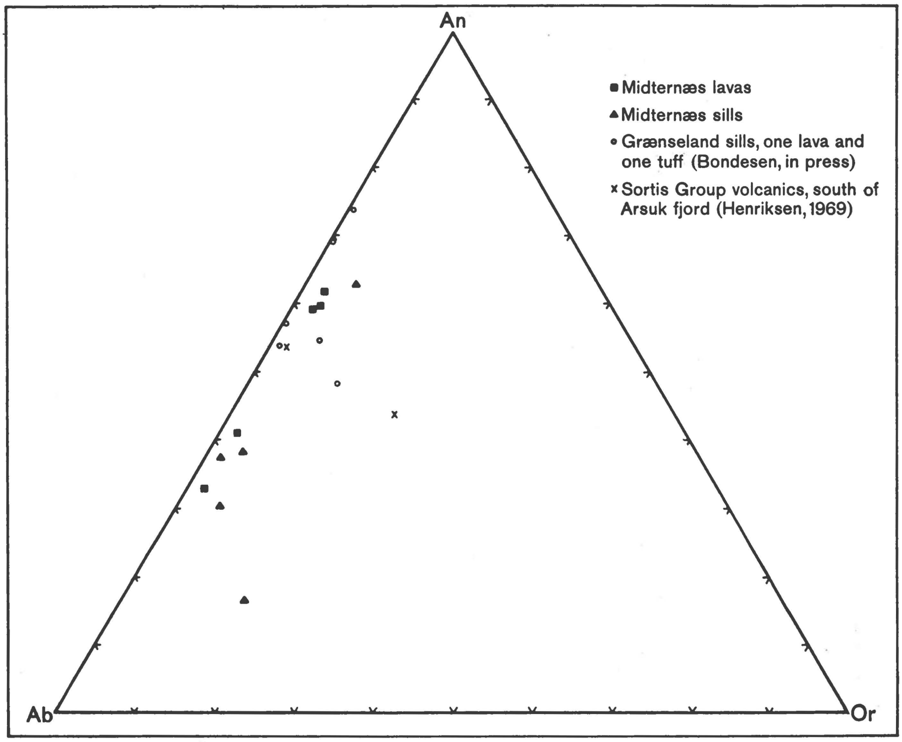


Fig. 16. Variation diagram of normative An/Ab/Or.

as the source of a high water content in the sills of the Ahr Lake area of the Labrador trough.

There is some indication of differentiation in some of the sills (see Table 5) but on the evidence available it is not pronounced. The melanocratic zones encountered in some of the sills, usually at high levels, and represented by one analysis (Table 6, no. 1), might be regarded as late differentiates. In the sample analysed Si and total Fe are greater than in the normal sills and Mg and Ca are relatively depleted. The melanocratic gabbro analysis, and one of the lava analyses from south of Arsuk fjord (HENRIKSEN, 1969), fall outside the main group of plots on the variation diagrams (Figs. 14, 15 and 16).

14) Pyroclastic rocks

Pyroclastic deposits occur only in the Rendesten Formation. Thick sequences are exposed in the area south of Tordensø, north of Birkesø and Perledal, and on the west slopes of Palisaden. Many of these sequences occur at approximately similar levels of the Rendesten Forma-

Fig. 17. Volcanic breccia south of Tordensø. Traces of bedding may be seen in some of the large blocks of tuff. Photo: Stig Bak Jensen.

tion succession but it is likely that they represent several eruptive phases. The various deposits cannot and be traced continuously along their strike and many of them have a lenticular form.

The pyroclastic sequence south of Tordensø has a thickness of at least 250 m; it outcrops for more than 2 km traced along the strike and at both extremities of the outcrop is bounded by the Inland Ice. It begins with 20 to 30 m of well bedded tuffs and lapilli tuffs, which rest on a thick sequence of banded shales, and continues with a 50 m thick unit of spectacular volcanic breccias and agglomerates. The latter unit consists principally of angular to subrounded pebbles and boulders, up to 30 cm in diameter, of several textural varieties of andesite, numerous white aphanitic fragments of perhaps trachytic or rhyolitic composition, and small and large angular and rectangular blocks of bedded tuffs

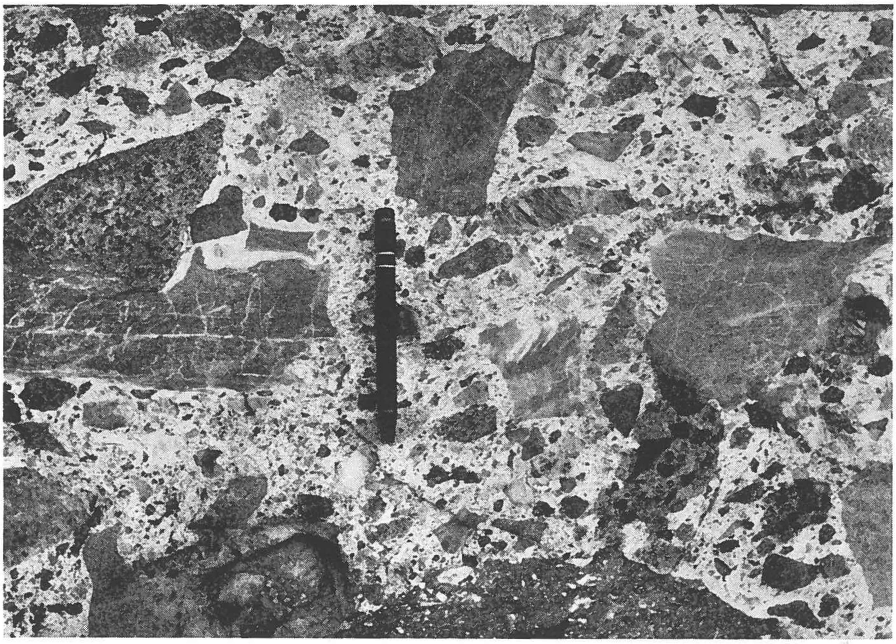


Fig. 18. Detail of volcanic breccia. Fragments of bedded tuff and andesite are set in a vitric tuff matrix.

which may be up to 2 m by 50 cm in cross-section. These components are embedded in a fine-grained pale grey tuffaceous matrix (Figs. 17 and 18). The remainder of this pyroclastic sequence comprises alternations of well bedded tuffs and lapilli tuffs, agglomerates and breccia-agglomerate units. The dimensions of some of the components of this sequence indicate highly explosive activity and imply that the site of accumulation was probably adjacent to an eruptive vent. Much of the pyroclastic material in this sequence is of intermediate or acid composition.

North of Birkesø occurs a pyroclastic sequence at least 50 m thick, its upper limit being concealed by a thick sill. At the base of the sequence occurs a 1 m thick agglomerate comprising volcanic bombs of homogeneous and slightly vesicular lava, angular fragments of bedded tuffs up to 20 cm in length, shale fragments up to 7 cm by 2 cm in cross-section and several dolomite pebbles. These components occur in a non-bedded lapilli tuff matrix partly cemented by carbonate. The agglomerate is overlain by mostly well bedded tuffs and lapilli tuffs which exhibit locally examples of cross-bedding. The lapilli tuffs contain subrounded fragments of pale grey rhyolitic material, often concentrated in layers and embedded in a fine-grained tuff matrix.

Between Perledal and Sermiligârssuk Bræ there outcrop several thick bands of dolomitic lapilli tuffs and agglomerates. They comprise rounded and angular fragments of glassy or fine-grained vesicular material, mainly less than 3 cm in diameter, set in a carbonate matrix. A few shale fragments have been noted in some bands. Bedding is not pronounced in these bands but a poor sorting is sometimes apparent.

A 75 to 100 m thick unit of tuffs and lapilli tuffs associated with cherty quartzites and shales outcrops on the west slopes of Palisaden. In its lower part the unit is non-bedded, but bedding is very pronounced in the upper part. The tuffs throughout the unit comprise dark glassy shards and scattered pale grey rhyolitic fragments. In part of the sequence there occur curious lens-like accumulations of coarse pyroclastic material in a sequence of finer pyroclastic material, and in the same area sedimentary lenses also occur mixed in with the pyroclastics.

All the pyroclastic deposits are associated with or interbedded with sedimentary rocks. However, their widespread occurrence and the occurrence of volcanic bombs suggests subaerial distribution and implies that the sea was of shallow or only moderate depth in the vicinity of the volcanic vents. A volcanic vent appears to have existed in the near vicinity of the felsic pyroclastic deposits south of Tordensø.

Of the main pyroclastic sequences many are partly unsorted and non-bedded, usually in the lower part, and these may represent primary pyroclastic accumulations. The well bedded parts of the sequences presumably represent reworked pyroclastic material which may be partly derived from adjacent areas. Contemporaneous erosion of loosely accumulated pyroclastic material may account for the scattered distribution of the preserved sequences.

The nature of the pyroclastics varies considerably from area to area. Petrographic descriptions of some rock samples are given below.

Volcanic breccia (25742). South-west of Tordensø.

Collected in a sequence of the type illustrated in Fig. 18, and in the same general area.

The hand specimen consists of several rounded to subangular fragments of porphyritic andesites with variable textures which are set in a pale grey-white porcelaneous matrix. In thin section the andesite fragments comprise phenocrysts of clinopyroxene and probably plagioclase, now more or less completely altered to chlorite, epidote, calcite and secondary albite, in a groundmass of microlitic plagioclase. The tuff matrix between the andesite components is very fine-grained and contains an abundance of microlites.

Lapilli tuff (25739). South-west of Tordensø.

From a large boulder in the volcanic breccia sequence partly shown in Fig. 17.

The specimen consists of numerous grey-white rounded to angular, often rectangular, rock fragments up to 1 cm in diameter in a dark grey matrix. Some of the fragments show banding but most have a uniform texture. In thin section the grey-white components consist of an abundance of microlites and it is possible that some of the components are acid aphanitic igneous rocks. However, the banding in some fragments suggests that some of them may be derived from tuffs deposited earlier. The dark grey matrix is revealed in thin section as a complex meshwork of microlites, pyroxene and plagioclase phenocrysts, and very numerous crescentic and spicule-like shards which are opaque or nearly so and consist of devitrified volcanic glass.

Tuff (71379). West slopes of Palisaden.

Collected in the upper well bedded part of the thick tuff sequence.

A bedding lamination is not conspicuous in the hand specimen but the numerous small angular lithic and other fragments do exhibit a preferential alignment. In thin section the rock is seen to comprise a closely compressed network of devitrified glass shards and scattered lithic fragments. The lithic components consist of abundant microlites and numerous opaque particles. Secondary carbonate, sericite, chlorite and quartz are common products of alteration.

Dolomitic lapilli tuff (71461). North-west of Perledal.

Collected from an extensive dolomitic sequence of which pyroclastic rocks are the most important part.

The rock consists of closely packed dark grey lithic fragments up to 3 cm in length which may be angular or rounded; most of the small fragments are fairly well rounded. The matrix is carbonate. In the thin section it is apparent that the whole rock is thoroughly indurated by carbonate and some of the lithic components are only preserved in outline. A few of the lithic components preserve a banding which suggests they may be derived from a tuff. The best preserved of the rock fragments contain abundant opaque material and under high power plagioclase laths and sericite can be discerned.

15) Sedimentary rocks of the Sortis Group

Sedimentary rocks form important sequences in the Sortis Group in the Palisaden, Birkesø and Tordensø areas. They are most abundant at the level of the Rendesten Formation where they are associated with pyroclastic rocks, but thin bands are also present at various levels of the Foselv and Qernertoq Formations. The most common sedimentary rock types represented are banded shales and siltstones, quartzites, cherts, calcareous shales and thin impure dolomites. A few restricted rock types are sufficiently distinctive locally as to be of some use stratigraphically.

Banded shales and siltstones (Fig. 19) are the most common of the Sortis Group sediments and make up very thick sequences. In colour they are usually dark grey or black, but some examples weather red-brown or red. For the most part they possess either a good bedding fissility or a secondary cleavage, sometimes both, along which they weather readily to form shaly screes which often obscure details of stratigraphical variations. The banding of the rocks varies from a fine layering on the scale of a few millimetres to bands each 20 cm or more in thickness, which reflect small rhythmic variations in grain size and

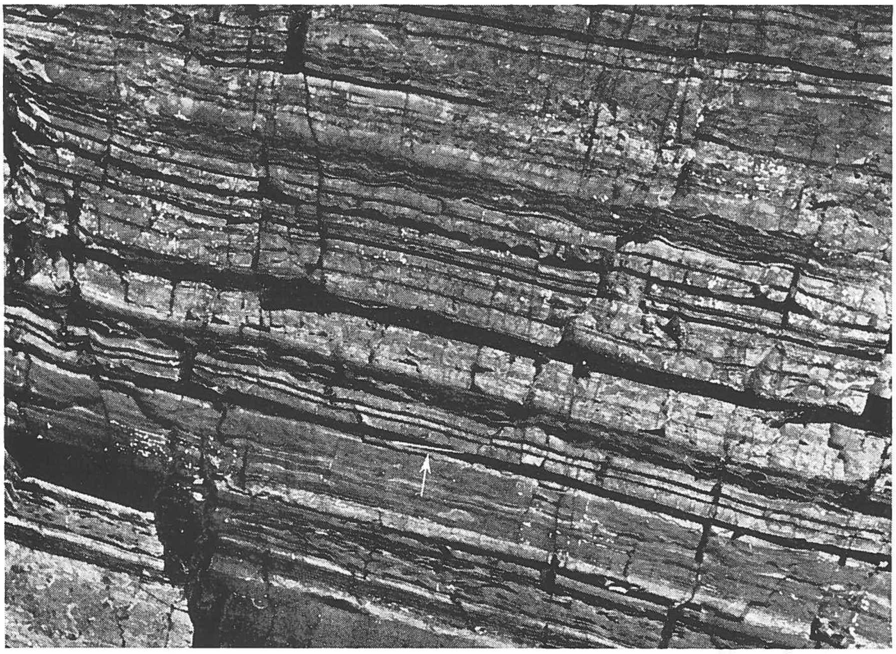


Fig. 19. Finely laminated shales and siltstones. Thin carbonate layers are weathered out. Pencil (arrowed) is scale.

composition. Rarely slumping and cross-bedding have been recorded. Microscopic examination has revealed that much of the banding comprises alternations of layers of fine silt and coarse silt grain size, and that the fine silt layers are normally the thicker of the two layers. In some rocks the grain size of the coarser layers may reach that of fine sand.

Along the southern edge of the nunatak south of Tordensø there outcrops a distinct variety of banded siltstone characterised by the large scale of the banding (Fig. 20). Bands of coarse siltstone up to 40 cm and rarely 1 m thick alternate with finer-grained siltstone bands. The latter are normally darker in colour and weathered preferentially. Very similar rock types but with less pronounced banding occur in the Rendesten Formation of northern Midternæs. Rocks of identical appearance have been recorded by BONDESEN (1962; in press) in the Rendesten Formation of north Grænseland.

Impure orange-brown dolomites have been noted at various levels of the Sortis Group but are usually thin and impersistent. Dolomite cemented pyroclastics have been observed north of Perledal, and occasional carbonate-bearing layers have also been noted in some banded shale sequences where they may weather out preferentially (Fig. 19).

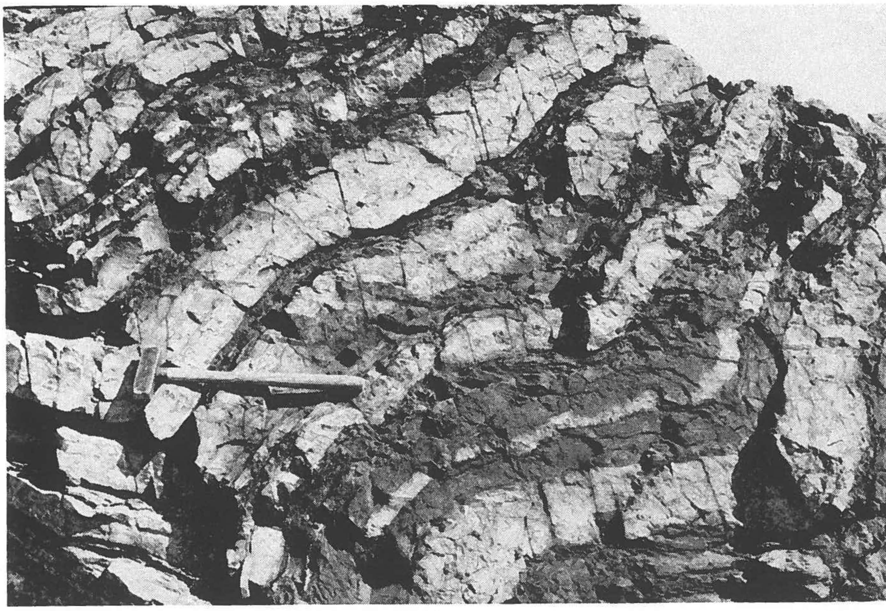


Fig. 20. Banded siltstones. South of Tordensø.

Quartzites and cherts are locally of importance. Chert beds several metres thick and locally of mappable proportions occur particularly at the top of certain thick lava flows, the best examples outcropping in western north Midternæs. Two 10 to 15 m thick chert and jasper lenses several hundred metres in extent have also been noted in the otherwise monotonous pillow lava successions on Nuna qernertoq. Thick cherty quartzites occur interbedded with shales and pyroclastics in western Palisaden, and in the northern cliffs a chert band was noted containing appreciable ore, 17.33 % Fe_2O_3 and 4.00 % FeO by weight (analysis Ib Sørensen). Within the thick pillow lava sequences chert frequently occurs in spaces between adjacent pillows, and may also occupy the cavities within some pillows.

A distinctive development of chert lenses and layers in a deeply stained blue-black pelitic matrix has been observed at several levels of the Rendesten Formation east of Tordensø and in western Nuna qernertoq (Fig. 21). An identical rock type has been noted by Bondesen (1962, Fig. 115) in the Rendesten Formation of Grænseland. The lens development appears to be an original sedimentary feature although Bondesen considers they may have developed from the boudinage of competent quartzitic layers.

Most of the sedimentary rock types of the Sortis Group are represented also in the Vallen Group described earlier; only a few petrographic descriptions of Sortis Group sediments are therefore given here.

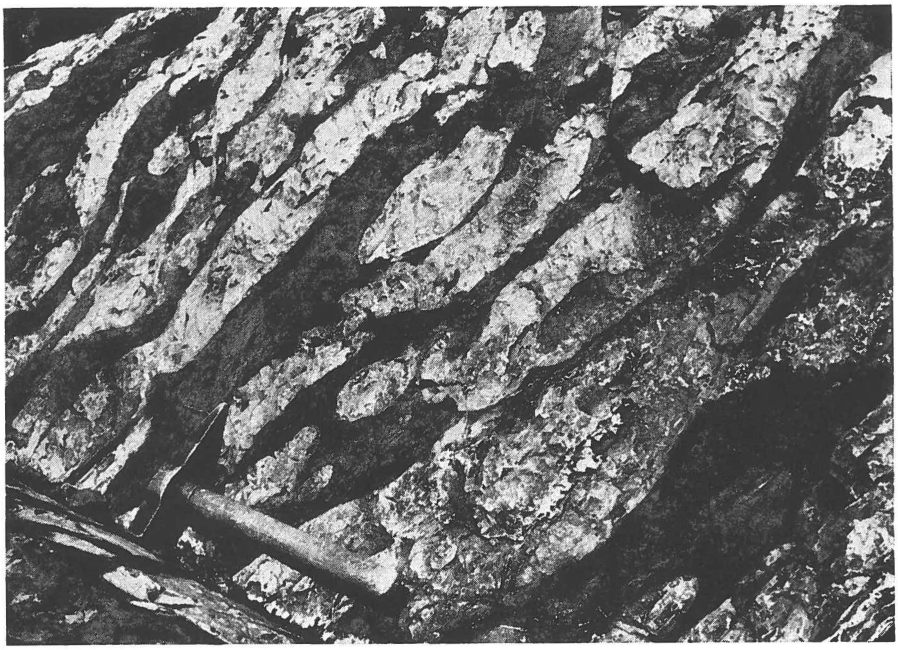


Fig. 21. Chert lenses in a shale matrix. South of Tordensø. Photo: Stig Bak Jensen.

Banded siltstone (78892). Nunatak south of Tordensø.

From a coarse siltstone band of the banded siltstones (Fig. 20) at the south margin of the nunatak.

The hand specimen consists of grey-white and orange-grey layers of which the latter are finely bedded. In thin section the rock consists of a closely packed mosaic of quartz and feldspar grains in proportions of approximately 2:1. In parts of the slide the grains are rimmed by a meshwork of fine sericite shreds, but more commonly the boundaries between adjacent grains are sutured as a consequence of recrystallisation or solution. The feldspar is mainly albitic plagioclase. The grain sizes vary between those of coarse silt and fine sand, most grains being between 0.02 mm and 0.1 mm diameter.

Quartzite (78894). Southern west Midternæs.

From a thick quartzitic sequence at the base of the Rendesten Formation.

The hand specimen is pale grey in colour and the detrital grains are clearly visible on fresh surfaces. In the thin section a mosaic of quartz grains and an occasional feldspar grain occur in a matrix of fine sericite fibres, microcrystalline quartz and a little calcite. The grains are mainly between 0.1 mm and 1.0 mm in diameter and they all exhibit undulose extinction due to strain.

Spotted shale (71270). Southern Midternæs.

Collected from an area of banded shales and siltstones in which dark spots were conspicuous.

Dark ovoid spots up to 3 mm in diameter occur throughout the specimen and obscure the bedding which is only discernable on the sectioned surface. In thin section the material between the spots is revealed under high power as a very fine-grained network of sericite fibres and submicroscopic quartz, disseminated carbonaceous material and scattered silt-sized quartz grains. The larger quartz grains and clots of carbonaceous material occur as inclusions within the spots whose optical properties are insufficiently distinctive for identification purposes. The spots are individually roughly oval in section but several spots frequently coalesce. A dark rim of carbonaceous material or a border of microscopic quartz, or both, may surround the spots. NIELS OLESEN (personal communication, 1968) has examined similar material collected from the same locality and observed traces of twinning in some of the spots which he identifies as strongly sericitised cordierites.

Purple shale (71384). Palisaden, northern Midternæs.

Collected from a sequence of banded shales, siltstones and pyroclastics on the north-west slopes of Palisaden.

The hand specimen is a finely foliated shale, purple in colour on weathered and fresh surfaces. In the thin section considerable amounts of opaque carbonaceous material are apparent and accentuate a very fine layering. Submicroscopic quartz grains and sericite fibres form thin lenses and layers, and silt-sized quartz grains occur disseminated through the slide. Recrystallised sericite laths occur mainly parallel to but also across the layering.

Dolomite (78838). North-west of Perledal.

From a dolomitic sequence which includes important pyroclastic deposits cemented by dolomite.

The specimen is orange-brown on the weathered surface and grey on fresh surfaces. It appears to consist of numerous fragments of dolomitic rock cemented together by carbonate, and contains a number of spherical objects up to 8 mm in diameter which may be of organic origin. In thin section the boundaries of the component fragments and the internal structures of the spherical objects have been masked by recrystallisation. The slide consists of a mosaic of carbonate minerals, disseminated carbonaceous material, a few lenses of microscopic quartz and scattered grains of ore.

16) Conditions of deposition of the Sortis Group

The Sortis Group in Midternæs has a total thickness of the order of 4800 m. Of its three formations the first and third are composed mainly of lavas and intrusive sills, and the second, while largely sedimentary, includes important felsic pyroclastic rocks and numerous thick sills.

The Foselv Formation can be taken to represent the initial extrusive phase and consists largely of thick pillow lava flows. The thickness of the formation varies quite considerably from area to area and may total between 150 m and 900 m. The extreme thickness variations are presumably a consequence of disparity in the distribution of volcanic vents and the volume of lava extruded from them. The total thickness of the flows implies either that the sea was very deep, or more probably that subsidence of the sea floor kept pace with the rate of lava accumulation. Sedimentary rocks are restricted to a few thin bands between pillow lava sequences and presumably were deposited in the intervals between the extrusion of successive flows.

The Rendesten Formation composed in some areas of very thick sedimentary sequences can be regarded as representative of a relatively quiescent phase of the volcanic episode, although intermittent extrusion of some significance appears to have continued in areas such as northern and central Midternæs where the Perledal Volcanic Complex is found. The very varied thicknesses of sedimentary rocks in different areas may be related to an undulating sea floor topography at the time of deposition and it has been noted that the thickest development of the Rendesten Formation occurs in those areas where the Foselv Formation is thinnest. The sedimentary rocks are for the most part finely banded shales and siltstones whose original source is uncertain; it is possible that the sedimentary material was brought in by turbidity currents as has been proposed by Bondesen (in press). The wide occurrence of pyroclastic material and the occurrence of volcanic bombs suggests that the material was partly distributed subaerially, and that the sea was therefore of only moderate depth in the vicinity of the volcanic vents. Much of the Midternæs pyroclastic deposits have been reworked by current action and exhibit bedding and sometimes cross-bedding, suggestive again of moderate sea-depths, but the basal part of some pyroclastic sequences is unsorted and non-bedded and these may represent primary accumulations.

The dimensions of the felsic pyroclastic material south of Tordensø are indicative of explosive volcanic activity and suggest close proximity to the eruptive vent. The eruption of acid to intermediate volcanic rocks in this area more or less synchronous with the eruption of basic rocks in the Perledal area might indicate that the source magma chamber was tapped at several different levels.

The Qernertoq Formation may be taken to represent a second major basic extrusive phase of the Sortis Group volcanic episode. The proportion of sedimentary material is negligible and about 75 $^0/_0$ of the more than 2200 m thick formation on Nuna qernertoq is composed of pillow lavas. Unbroken pillow lava sequences hundreds of metres thick imply that subsidence of the sea floor again kept pace with lava accumulation.

Basic sills are an important constituent of the Sortis Group and occur at all levels; they are particularly conspicuous in thick sedimentary sequences. These intrusions are for the most part fine- to medium-grained, suggesting fairly rapid cooling. Their very irregular form in the sedimentary sequences together with the grain size might be taken to indicate intrusion under inconsiderable confining pressure at perhaps a very shallow depth. The chemical analyses of lavas and sills are in general accordance with a derivation from the same parent magma, and it seems most probable that both extrusion and intrusion of basic rocks took place concurrently, the sills being injected into the already deposited lavas and sediments at a shallow depth perhaps as further lavas were extruded at a somewhat higher level. It is of interest that few intrusions occur in the Vallen Group, whose sediments might be considered to have attained a degree of compaction prior to the onset of Sortis Group volcanic activity.

In the Ivigtut region Vallen Group sediments succeeded by Sortis Group volcanic rocks are known in Grænseland (Bondesen, in press) and a similar approximately equivalent sequence is known on Arsuk Ø (Muller, in prep.).

Towards the south the Vallen Group and Sortis Group thin and at Qipisarqo are overlain by a new succession of sediments and volcanics. The next well preserved sequence of Ketilidian sediments and volcanics is found in the Tasermiut fjord region 150 km to the south-east (Escher, 1966).

The Ketilidian supracrustal rocks are generally thought to represent the geosynclinal stage of the Ketilidian orogenic cycle, but Allaart *et al.* (1969) have observed that their present known areal extent is so limited that the term "geosynclinal" should be viewed with some reservation.

The Ketilidian succession is similar in many respects to volcano-sedimentary assemblages described from several areas of the Canadian Shield (Barager, 1960; Goodwin and Shklanka, 1967) and their conditions of accumulation may be comparable. Goodwin and Shklanka develop the concept of volcano-tectonic basins in which a tectonically controlled distribution of felsic eruptive centres with associated differential subsidence leading to basin development is viewed as the prime cause of interrelated mafic to felsic volcanic and sedimentary facies. The tectonic influence on the Ketilidian sedimentary environment is evident in the deposits of the Vallen Group and the Rendesten Formation. It is not certain but it is possible that the subsidence of the Ketilidian sea-floor during Sortis Group time was directly linked to the eruption of large quantities of magma with consequent withdrawal of crustal support leading to regional subsidence. However, it may be noted that Ketilidian felsic pyroclastic rocks are known only in a restricted area in Midternæs in contrast to their widespread occurrence as pyroclastics and lava flows in the areas described by Goodwin and Shklanka.

17) Metamorphism of the Ketilidian rocks

The Ketilidian strata of Midternæs have suffered a weak regional metamorphism but retain for the most part their original sedimentary or igneous characters and textures.

New mineral growth in the siltstones and shales is evident in the recrystallisation of disseminated sericite to form small muscovite laths usually arranged parallel to the bedding and in a very few cases oriented in irregular patches parallel to a secondary schistosity. Secondary growth of the component crystals of some feldspathic sandstones, quartzites and dolomites, resulting in some cases in sutured margins between grains, is probably largely a consequence of regional metamorphism.

The igneous Ketilidian rocks, notably the sills, show mineral alterations which may be partly deuteritic but are probably mainly of metamorphic origin. The most common alterations are the sericitisation and saussuritisation of the feldspars and the partial breakdown of pyroxene to fibrous actinolite; fibrous chloritic patches also occur in many thin sections of sill rocks. Small amounts of probably stilpnomelane occur in some arkoses and siltstones and larger amounts are found in some melanocratic sill rocks.

On the basis of the petrographic observations the Ketilidian strata of Midternæs can be regarded on the whole as regionally metamorphosed under low greenschist facies conditions.

Southwards from Midternæs, as has been illustrated by WINDLEY *et al.* (1966, p. 33), the grade of regional metamorphism of the Ketilidian rocks increases rapidly, reaching high greenschist facies in South Grænseland and almandine amphibolite facies (WINKLER, 1967) between Arsuk Fjord and Qôrnoq. The increase in metamorphic grade is accompanied by an increase in the degree of deformation of the border zone between the Ketilidian strata and the underlying gneisses.

At the contact with some thick Sortis Group sills the sediments often have a compact flinty appearance, and relative to sediments elsewhere are more resistant to weathering. Other evidence of contact metamorphism is lacking, perhaps as a consequence of rapid cooling of the sills and the nearby counting rocks under the low confining pressures which are thought to have existed at the time of intrusion.

Some of the most noticeable effects of metamorphism are in fact those apparent in the immediate vicinity of some of the larger post-Ketilidian dolerite dykes where contact metamorphism has resulted in the formation of serpentine, actinolite and other minerals in dolomites of the Vallen Group. In banded siltstones adjacent to dykes dark ovoid spots which are probably cordierite (see p. 58) may be conspicuous.

The spots are up to 3 mm in diameter and postdate a cleavage in the siltstones: the axial plane cleavage of second phase folds.

18) Correlation with Ketilidian rocks of other areas

Ketilidian supracrustal rocks are found in two main regions in South-West Greenland: the Ivigtut region and the Tasermiut fjord region. No strict correlation between these two regions, which are separated by 150 km of granite and gneiss, is possible although there are basic similarities in the successions. In this section only correlations within the Ivigtut region are considered.

The Ketilidian rocks of the Ivigtut region outcrop in a belt along the margin of the Inland Ice, in Kobberminebugten and on Arsuk Ø (Fig. 2). They are considered by ALLAART *et al.* (1969) to have a fourfold succession, sediments-volcanics-sediments-volcanics, of which the lowest part comprising the Vallen and Sortis Groups and their lateral equivalents is preserved in the northern part of the belt and on Arsuk Ø. Towards the south the Vallen and Sortis Groups apparently thin, and at Qipisarqo near Kobberminebugt seem to have a total thickness of less than 1000 m. At Qipisarqo they are apparently overlain by a further succession of sediments and volcanics traceable along the south margin of Kobberminebugt comprising the Qipisarqo and Ilordleq Groups with an estimated total thickness of 5000 m (ALLAART *et al.*, 1969; WATTERSON, 1965). Recent observations by GHISLER (1968, p. 48) have, however, raised the possibility that the Ilordleq Group may be of pre-Ketilidian age.

The general Ketilidian successions in Grænseland, Arsuk Ø and Midternæs and the most likely correlations between the areas are shown in Fig. 22.

The general good correlations between Midternæs and Grænseland have been previously noted by HIGGINS and BONDESEN (1966). In this paper correlations with the type area of Grænseland have been made on formation level, and a new formation, overlying the Rendesten Formation and not represented in the type area, has been established and named the Qernertoq Formation. In north Midternæs a lateral variant of part of the Rendesten Formation comprising lava flows, a rock type not apparent in the type area, has been distinguished as the Perledal Volcanic Complex. The distribution of the formations of Midternæs and Grænseland are indicated in Plate 4.

There are many similarities between the successions of Midternæs and Grænseland and that of Arsuk Ø (Fig. 22). MULLER's lower group comprising largely sediments can be correlated with the Vallen Group and his volcanic group is equivalent to the Sortis Group. Correlations

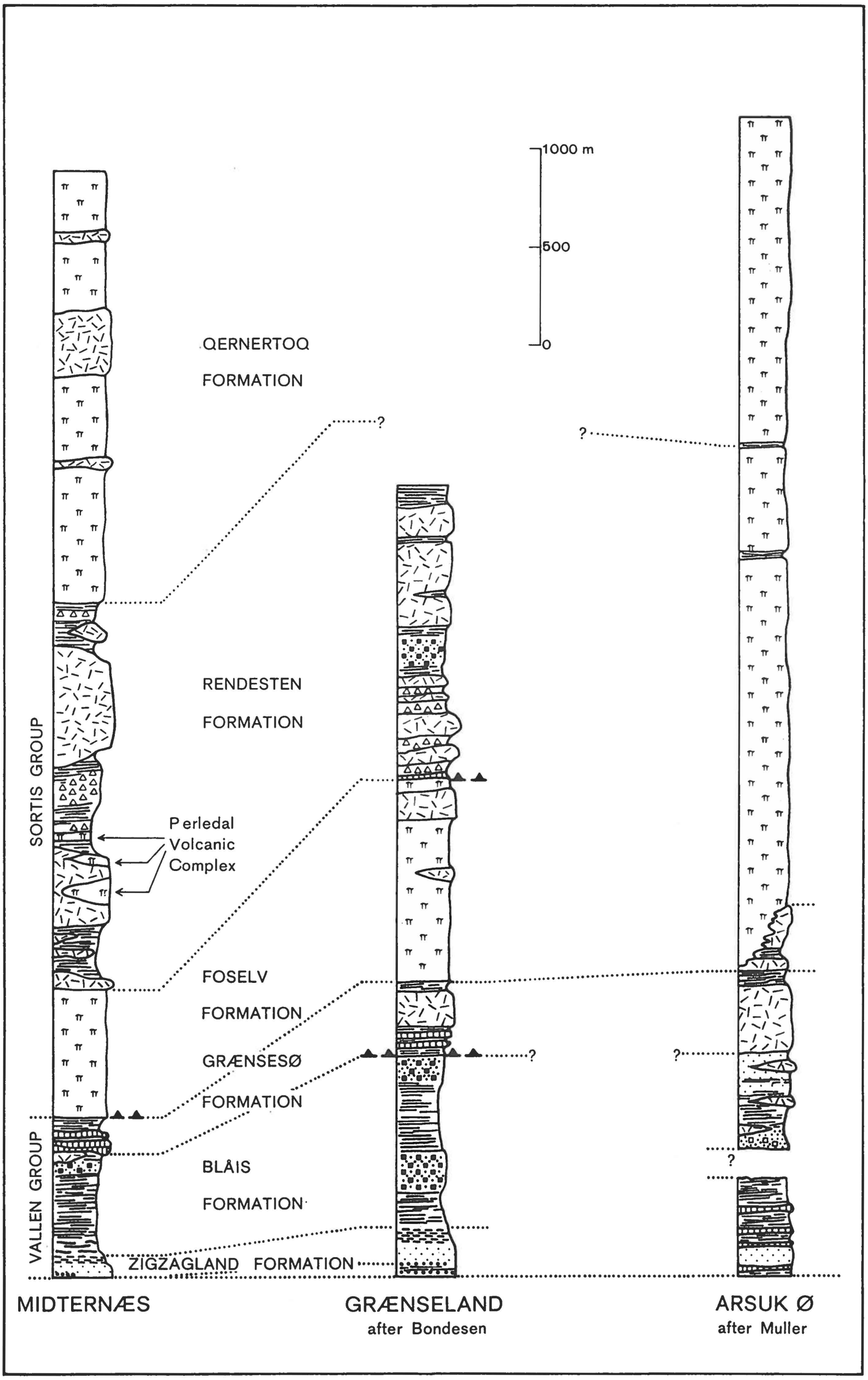


Fig. 22. Suggested correlations between the Ketilidian successions of Midternæs, Grænseland (Bondesen, in press) and Arsuk Ø (Muller, in prep.). The key to the rock types is as Plate 3.

on formation level are less certain because of breaks in the succession of the lower group and the general uniformity of the upper group; there is no apparent equivalent of the pyroclastic-sedimentary development of the Rendesten Formation on Arsuk Ø. The volcanic succession on Arsuk Ø has, however, a total thickness similar to that of the Sortis Group succession on Midternæs. It may be that in Rendesten Formation time lavas were extruded in the areas represented by Arsuk Ø and northern Midternæs, and the Perledal Volcanic Complex might have an equivalent in the middle part of the volcanic group on Arsuk Ø.

The lateral variability in lithology of the formations of the Vallen and Sortis Groups, particularly of the Rendesten Formation, opens the possibility that the Qipisarqo Group at Qipisarqo may not overlie the Sortis Group, but might be a lateral variant of the Rendesten Formation and overlie the equivalent of the Foselv Formation. This possibility has also been put forward by BONDESEN (in press). Such a hypothesis overcomes any difficulty of explaining the dramatic reduction in thickness of the Vallen and Sortis Groups from a total of at least 5000 m in Midternæs to less than 1000 m at Qipisarqo 110 km to the south but involves instead explanation of considerable variations in facies. The thick and extensive conglomerates of the Qipisarqo Group are considered by ALLAART *et al.* (1969) as indicative of a sharp change of conditions of deposition together with considerable changes in the relief of the surrounding area; no deposits comparable to the Qipisarqo conglomerates are known in the Rendesten Formation of Midternæs or Grænseland.

The possibilities and problems of correlations between South-West Greenland and the Canadian Shield are reviewed by ALLAART *et al.* (1969).

19) Dykes

The Ketilidian rocks of Midternæs are cut by a large number of dykes most of which are presumed to be representative of the Gardar swarms which are widely distributed in South Greenland between Kap Farvel and Frederikshåbs Isblink (BERTHELSEN and NOE-NYGAARD, 1965). A complex network of intersections between dykes particularly in northern Midternæs has permitted a detailed dyke chronology to be established. The principal dykes and intersections are shown on the geological map (Plate 5); the dominant dyke trends and the sequence of intrusion are also depicted in Plate 2.

The characteristic features of the main phases of dyke intrusion are briefly outlined below, but no petrological details are given.

Metadolerites (MDs)

A few NW-trending metadolerites cut the pre-Ketilidian rocks of the west peninsula of Midternæs, but none occur in the vicinity of the Ketilidian unconformity and their age relative to the Ketilidian strata cannot be demonstrated.

Porphyritic '120' dykes

Between 25 and 30 dykes cross western Midternæs in a well defined swarm about 9 km broad. Their strike varies locally but is generally in the range 105° to 130°. Most of the dyke individuals are between 5 m and 15 m wide; one example is locally 40 m thick. The dykes are generally dark coloured dolerites characterised by conspicuous plagioclase phenocrysts which are sometimes arranged in stellate clusters; a few non-porphyritic dykes are also known.

The '120' dykes are the earliest of the dykes which can be shown to cut Ketilidian strata. They were first recorded in Grænseland by Bondesen (1962; in press) and recent mapping has shown that the swarm continues north-westwards for at least 100 km to the vicinity of Frederikshåb town. These dykes are not metamorphosed in Midternæs or areas farther north but are recorded by Bondesen (in press) as weakly metamorphosed in Grænseland where they may also have suffered weak shear movements.

'140' dykes

Examples of grey to grey-black dykes up to 8 m wide and with rather variable trends between 100° and 150° outcrop in parts of eastern Midternæs and on the two large nunataks south-east of Midternæs. There are many intersections between the '140' dykes and the later "BDs", but the relative age of the '140' and '120' dykes is unknown. A few scattered examples of dykes of similar trend and age relations to those of the '140' dykes are found in areas north of Midternæs.

Lamprophyres, brown dolerite dykes and a few trachyte dykes all of presumed Gardar age postdate the '120' and '140' dykes. All the Gardar dykes have NNE to E–W trends which are in marked contrast to the general NW trends of the '120' and '140' dykes. Recent paleomagnetic work on the Midternæs dykes (Bullock, 1967) gives consistent results for the presumed Gardar dykes, but the earlier dykes in common with Ketilidian lava flows are characterised by low susceptibility, intensity and stability. The '120' and '140' dykes may have been affected by the weak Ketilidian metamorphism.

Lamprophyres

Dark coloured lamprophyric dykes up to 5 m wide occur throughout Midternæs. They are often rendered conspicuous by the presence of calcite-filled vesicles. The trends of the lamprophyre dykes vary between 35° and 100°, but most examples have trends within the limits 55° to 75°.

It is not certain that all the Midternæs lamprophyres are representative of the same phase of intrusion since the relative age of only a proportion of the dykes can be determined from intersections. However, several lamprophyres cut examples of the '120' and '140' dykes and others have been noted as being displaced by the earliest of the 'brown dyke' intrusive phases. It would appear that a proportion of the lamprophyres represent the earliest manifestation of the NE-trending Gardar dyke swarm in the Midternæs area.

Brown dykes (BDs)

Brown weathering doleritic dykes are the most conspicuous and most abundant of the Gardar dykes and are common in South-West Greenland south of Frederikshåb. In the Ivigtut area regional mapping has led to the distinction of three or four successive phases of BD intrusion (Berthelsen, 1958; Ayrton, 1963; Weidmann, 1964; Bondesen, in press).

In north Midternæs a local chronology of seven successive phases of BD intrusion has been established from intersections (Plate 2). Of the seven BD phases only three are of importance; of the others, three phases are represented by only a single dyke, and one phase probably by two dykes. Detailed correlations between the Midternæs BDs and those of adjacent areas have not been made but the succession of three important phases is comparable to the general chronology of the Ivigtut area.

The principal trends of the Midternæs BDs are summarised in the rose diagram of Plate 2, but the three peaks in NNE, NE and ENE directions do not correspond to the three main BD phases. Dykes of the same intrusive phase tend to be parallel to each other, but there is also parallelism between dykes of different phases; the dykes of phases 1, 3 and 4 have similar trends and the two dykes representing phases 2 and 6 are parallel. It may also be noted that some dykes have been diverted for distances of up to 2 km along pre-existing fault planes, and that the irregularities in trend of the thickest phase 5 dyke in northeast Midternæs are due to local diversions along the junction between Vallen Group sediments and Sortis Group lavas.

The main characteristics of the seven BD phases of Midternæs are summarised below:

BD
Phase 1: three examples up to 60 m wide with trends of 78° to 80°.
Phase 2: one dyke up to 70 m thick with a trend of 52°.

Phase 3: three or four examples up to 60 m wide with trends of about 80°; usually grey in colour and more resistent to weathering than any of the other BD phases.
Phase 4: one or two grey-brown dykes up to 30 m wide and with trends of 85°.
Phase 5: at least four examples up to 150 m in width and with trends of 65° to 70°.
Phase 6: one known example, possibly several others, up to 20 m wide and with trends of about 52°.
Phase 7: one dyke up to 70 m wide with a trend of 42°.

Phenocrysts and xenocrysts of anorthositic composition are conspicuous in many of the Gardar dykes of South-West Greenland (Bridgwater and Harry, 1968). In Midternæs they have been observed in several dykes of phase 1 and 5 age, usually concentrated along one or both margins.

Trachytes

A number of trachytic dykes varying in colour between grey and pink have been observed in various parts of Midternæs. These dykes are up to 3 m wide and have trends of between 50° and 70°. Intersections with other dykes are insufficiently numerous to define their chronological position, but one of the trachyte dykes post-dates a phase 4 BD.

Kimberlites

A few thin kimberlite sills containing lherzolite nodules occur in southern west Midternæs. They have been observed to cut two dykes of probable Gardar age. Andrews (1969) has investigated a similar kimberlite occurring as a dyke in the eastern part of the Frederikshåb district and found that the nodules were of deep-seated origin.

III. STRUCTURE

1) General

The Ketilidian strata of Midternæs have undergone mild folding accompanied by very little internal deformation; the pillow lavas and the spherical fossil *Vallenia*, except very locally, exhibit no modifications in shape. Southwards from Midternæs there is an increase in the intensity of deformation accompanying the increase in metamorphic grade (WINDLEY *et al.*, 1966).

Major and minor folds, thrusts and faults affect the Ketilidian rocks of Midternæs. Most fold structures have been observed in the sedimentary rocks and a consideration of their style, geometrical properties and relationships to one another has permitted the distinction of several phases of folding.

Phase 1 (F_1) folds are close to isoclinal recumbent folds and phase 2 (F_2) folds are open to tight structures with ENE-trending steeply inclined axial planes. Both are considered to be of Ketilidian age. The age of the comparatively unimportant phase 3 (F_3) folds is uncertain.

An ESE–WNW trending zone of south dipping thrusts, the Andesø thrust zone, is cut by the '120', '140' and brown dykes. Its age is probably Ketilidian.

Most of the faults can be referred to a conjugate system. Some of the faults moved during Ketilidian deposition, and further movements took place on various faults during and after intrusion of the Gardar dykes. Minor conjugate folds and kink folds appear to bear some relationship to faulting and their period of formation could be as extensive as that of the fault movements.

The major change in strike of the Ketilidian strata from NW–SE in west Midternæs to E–W in north Midternæs is difficult to interpret solely in terms of the folding and thrusting described in the following pages, although clearly these structures have influenced the outcrop pattern. It seems probable that very large scale regional warping of the Ketilidian rocks and the underlying pre-Ketilidian basement preceded the development of mesoscopic folds in the Ketilidian strata. The warping might be a consequence of unequal subsidence of the Ketilidian sea floor during the accumulation of the Ketilidian rocks.

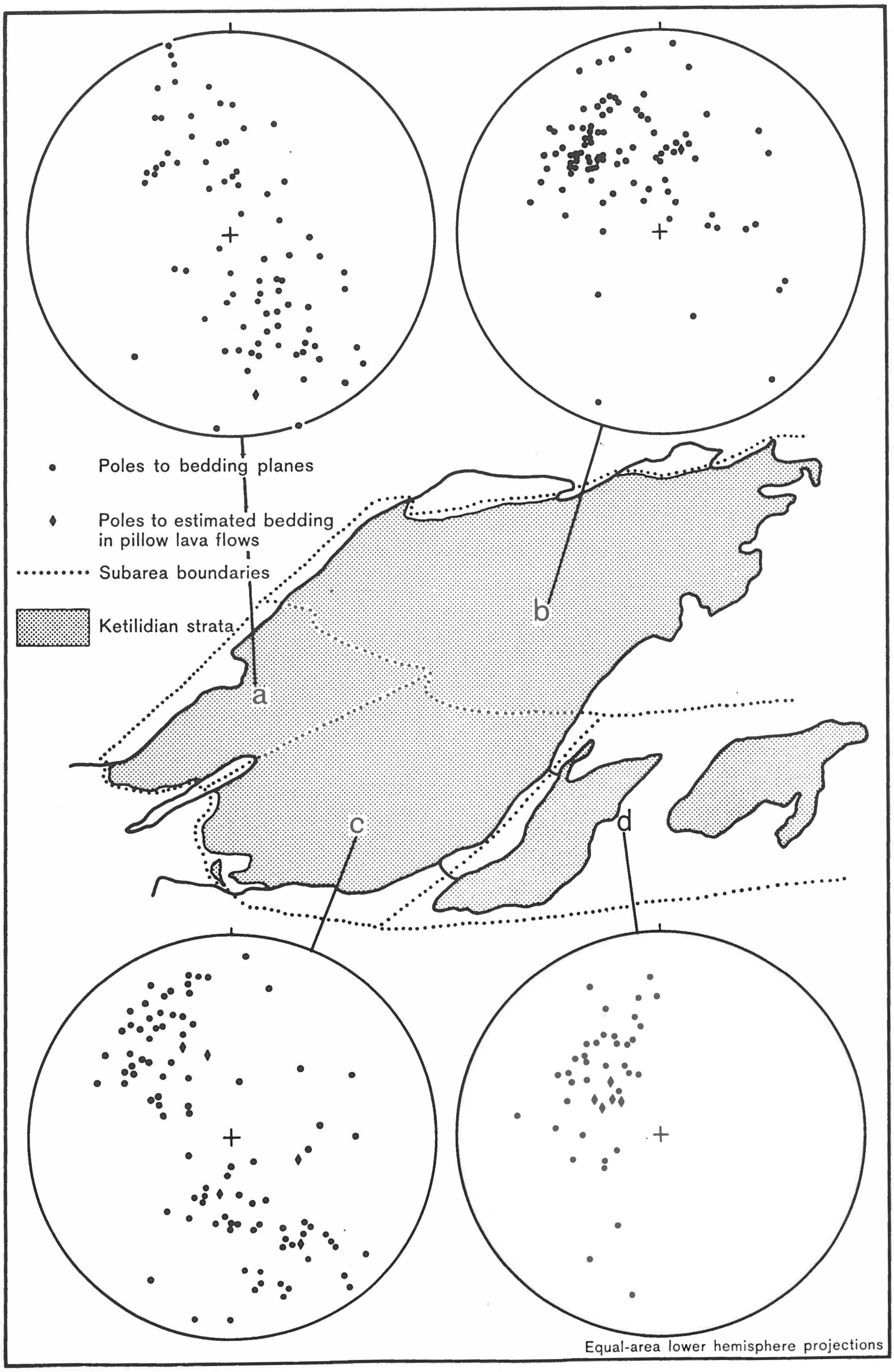


Fig. 23. Analysis of bedding plane measurements.

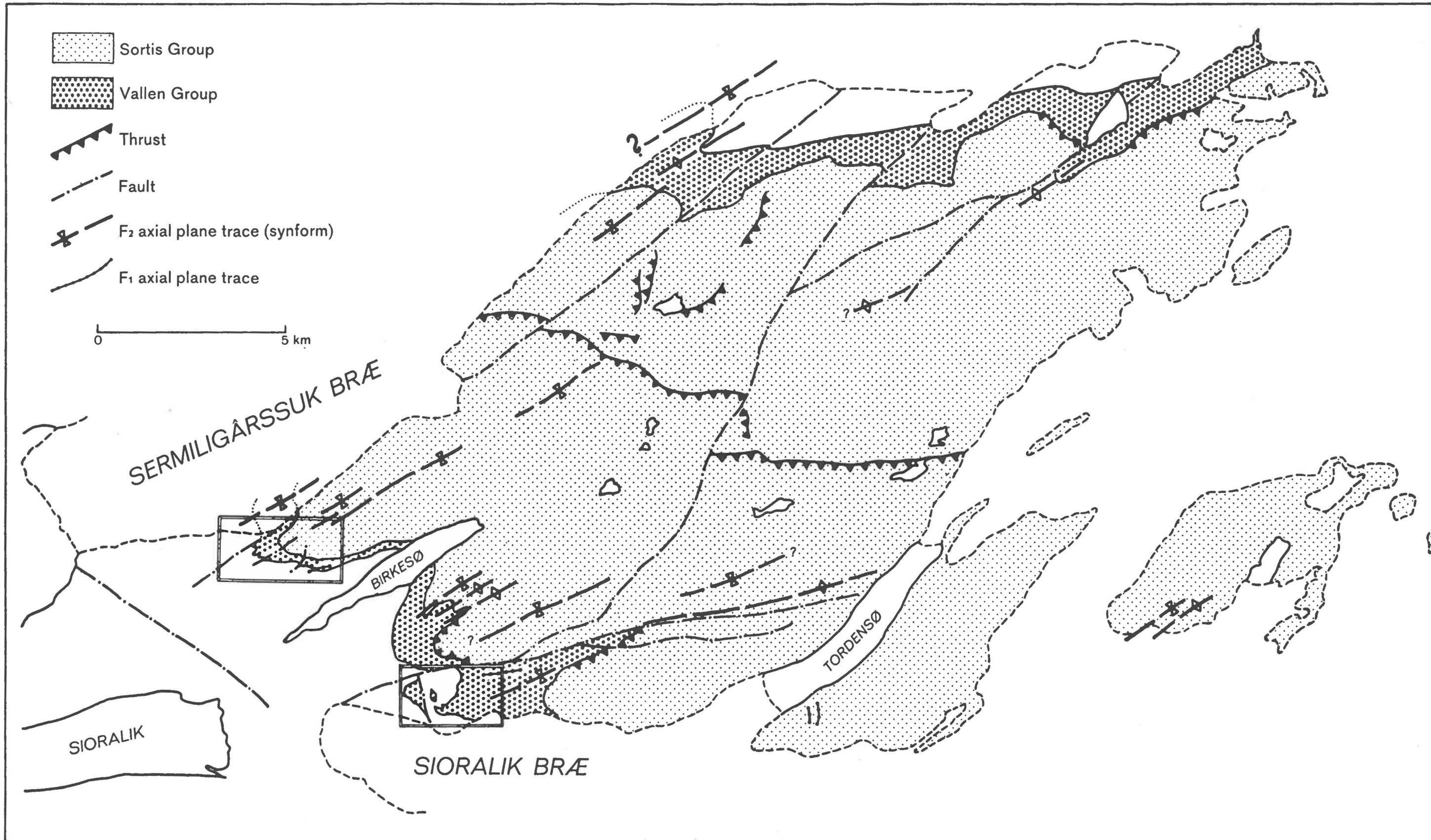


Fig. 24. The location of the main Ketilidian fold structures in Midternæs. The structures in the outlined areas are shown in Figs. 27 and 31.

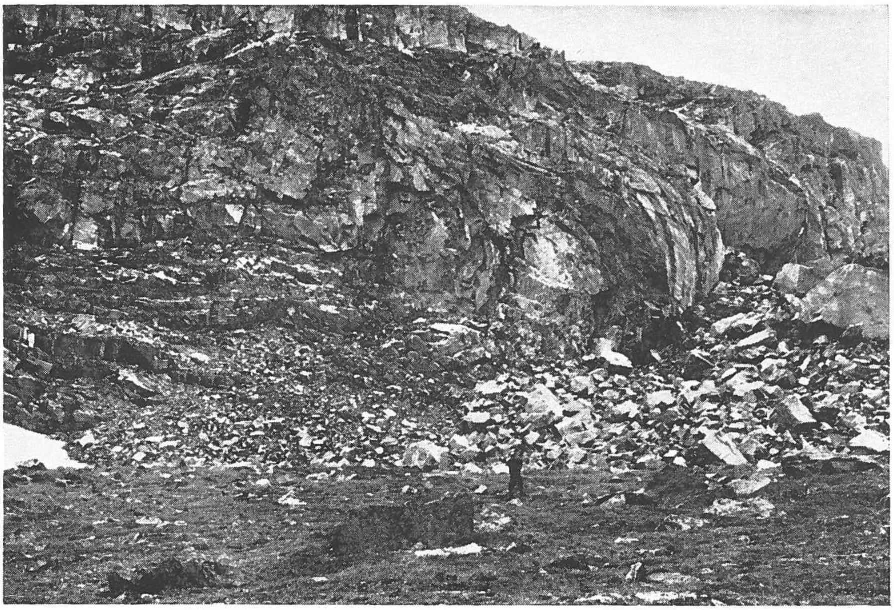


Fig. 25. Large scale recumbent F_1 fold in massive quartzites south-west of Akuliarutsip timilerssue. The fold axis of the structure dips at a low angle in a NE direction.

Bedding plane measurements are analysed in Fig. 23; from this the major swing in strike described above may be appreciated. The wide spread of plots in each subarea may be attributed to a number of factors, including inconsistencies in orientation introduced by the intrusion of lenticular sills, distortion due to F_1 deformation and, most noticeably, the influence of major F_2 ENE folding (Fig. 23, subareas a & c).

The axial plane traces of the main Ketilidian fold structures which have been recognised are shown in Figs. 24, 27 and 31.

It should be mentioned that in his preliminary investigations of Midternæs Oen Ing Soen (1960) had already recognised refolding in the sediments (the interference of F_1 and F_2 of this paper). He also observed open NE–SW trending folds (F_2) and noted an ENE-trending vertical cleavage in the sediments and locally in the lavas (the F_2 axial plane cleavage).

2) First phase folds and thrusts

The folds in the Ketilidian strata distinguished as first phase structures are close to isoclinal shear folds. They are most commonly observed as minor folds but major folds of about 100 m amplitude are also known (Fig. 25). These F_1 structures are not uniformly developed. They have not been recognised in the lavas and sills of the Sortis Group and their

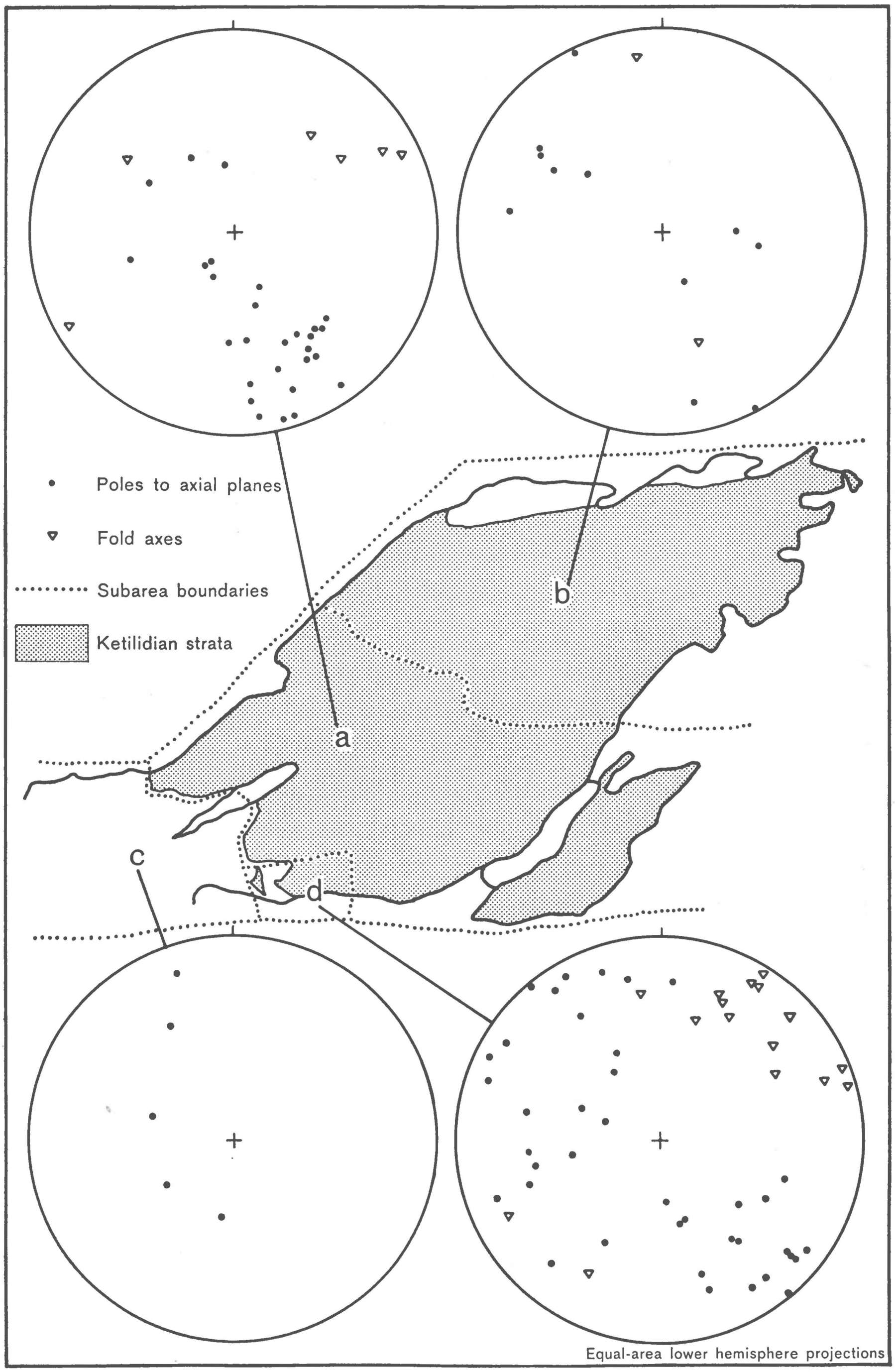


Fig. 26. Analysis of F_1 structural data.

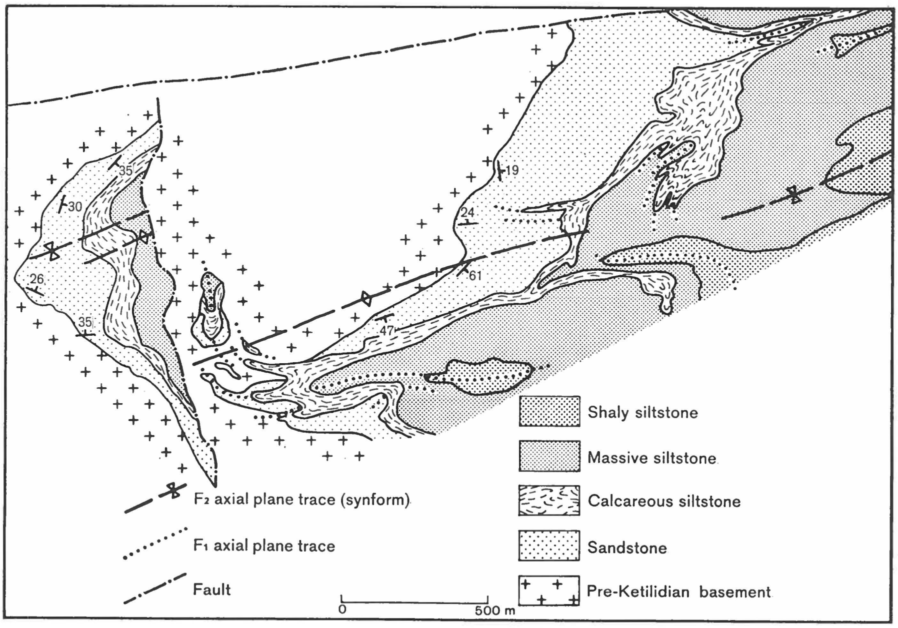


Fig. 27. Structural interpretation of a complex area south-west of Akuliarutsip timilerssue.

distribution in the sedimentary rocks varies widely from area to area. The majority of folds observed appeared to be overturned towards the south, but exceptions to this general rule have also been recorded.

The F_1 structural data are analysed in Fig. 26. The wide variation in the plots of axial plane poles can be largely attributed to F_2 refolding; the initial axial plane orientation was probably flat lying and subparallel to the bedding. Of the F_1 fold axes which could be measured most plunge at low angles between NNE and ENE. Where F_2 folding is well developed F_1 structures are difficult to recognise, but a streaky lineation possibly of F_1 age has occasionally been traced over the crests of F_2 minor folds.

F_1 folding is particularly strongly developed on the plateau area west of Akuliarutsip timilerssue (Fig. 26, subarea d and Fig. 27). Isoclinal minor folds are conspicuous in the Calcareous Member here and a number of major folds can be distinguished. In this area the plane of unconformity has been deformed and sheared and pre-Ketilidian gneisses form the cores of several tight major F_1 anticlines (Fig. 27). In this zone of intense disturbance the basal Ketilidian succession is locally incomplete, the Sandstone Member being either tectonically reduced in thickness or absent.

North of Birkesø shearing has been observed locally at the plane of unconformity and extends to a depth of about 2 m into the Tartoq

Group schists beneath the unconformity. The shearing is quite probably of F_1 age. Shearing along the plane of unconformity is a common feature in Grænseland (BONDESEN, in press), and farther south the unconformity becomes progressively more deformed (WINDLEY *et al.*, 1966).

F_1 folds are less common in the Sortis Group than in the Vallen Group but have been noted in the thicker sedimentary sequences, particularly in the area south of Tordensø. In the relatively competent sequences of pillow lavas and sills folding is absent, but F_1 stresses appear to have been accomodated by movements along low angle thrust planes at several levels. The occasional sills in the Vallen Group have for the most part behaved as competent bodies, but some thin sills have suffered intense shearing. The thrust plane between the Vallen and Sortis Groups in some parts of Midternæs, which locally transgresses and cuts out part of the Grænsesø Formation, may be of F_1 age.

3) Second phase folds

The main folding of the Ketilidian rocks of Midternæs is of phase 2 age. F_2 folds occur commonly on both a major and minor scale; they are shear folds with steeply inclined ENE-trending axial planes with a degree of closure varying between open and tight. The axial plane traces of major F_2 folds are shown in Fig. 24.

Minor F_2 folds are usually only observable in the sedimentary rocks, particularly in sequences of banded siltstones and calcareous shales (Figs. 5 and 28). An F_2 axial plane cleavage is often visible and may be a stronger parting plane than the bedding (Fig. 29). The cleavage is particularly pronounced in southern Midternæs, where it is also apparent in the immediately adjacent pre-Ketilidian gneisses. The analysis of structural data from F_2 minor folds appears in Fig. 30. In all subareas plots of poles to axial planes indicate a consistent steep dip and a strike generally between 50° and 70°. In subarea b minor fold axes plunge either NE or SW at low angles, but in the other subareas a low NE plunge is prevalent; the variations in plunge direction partly reflect the variations in regional bedding orientation viz. a southerly inclination in northern Midternæs and a north-east inclination in western Midternæs.

The best examples of major F_2 folds occur north of Birkesø where, between the plateau area and Sermiligârssuk Bræ the unconformity is clearly deformed (Fig. 31). It is clear that the Tartoq Group schists which occupy the F_2 anticlinal fold cores have accomodated F_2 deformation but only a few minor folds of definite F_2 age have been recorded from these schists, or from the adjacent areas of gneisses (Fig. 30, subarea c).

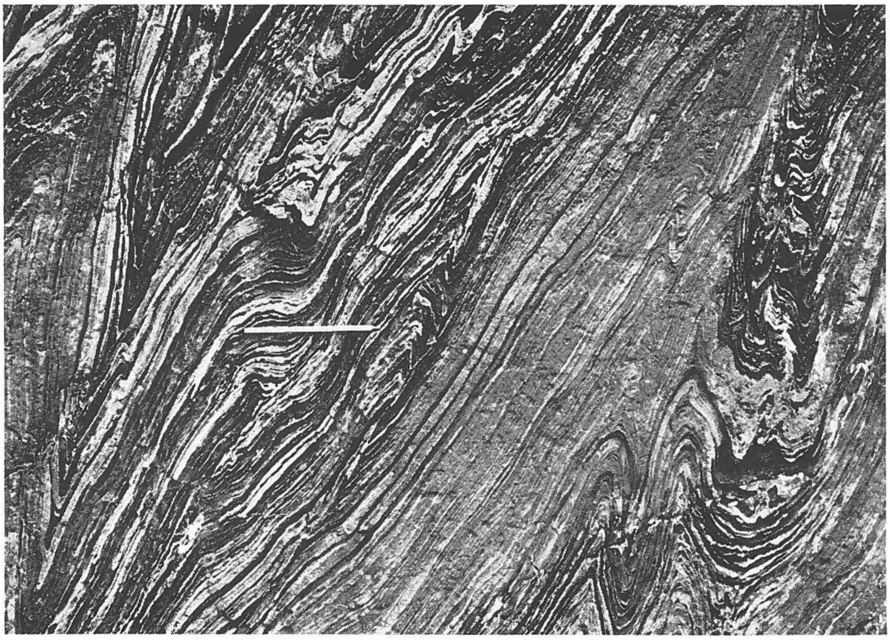


Fig. 28. Well developed F_2 folding in calcareous shales. South of Akuliarutsip timilerssue.

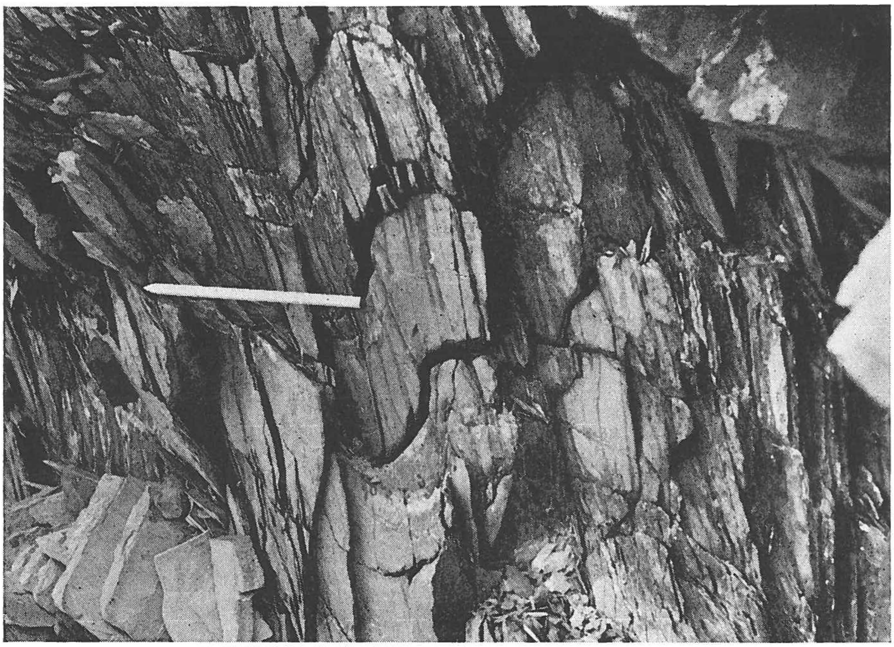


Fig. 29. Banded shale with F_2 folding and a strong axial plane cleavage. North-west of Perledal.

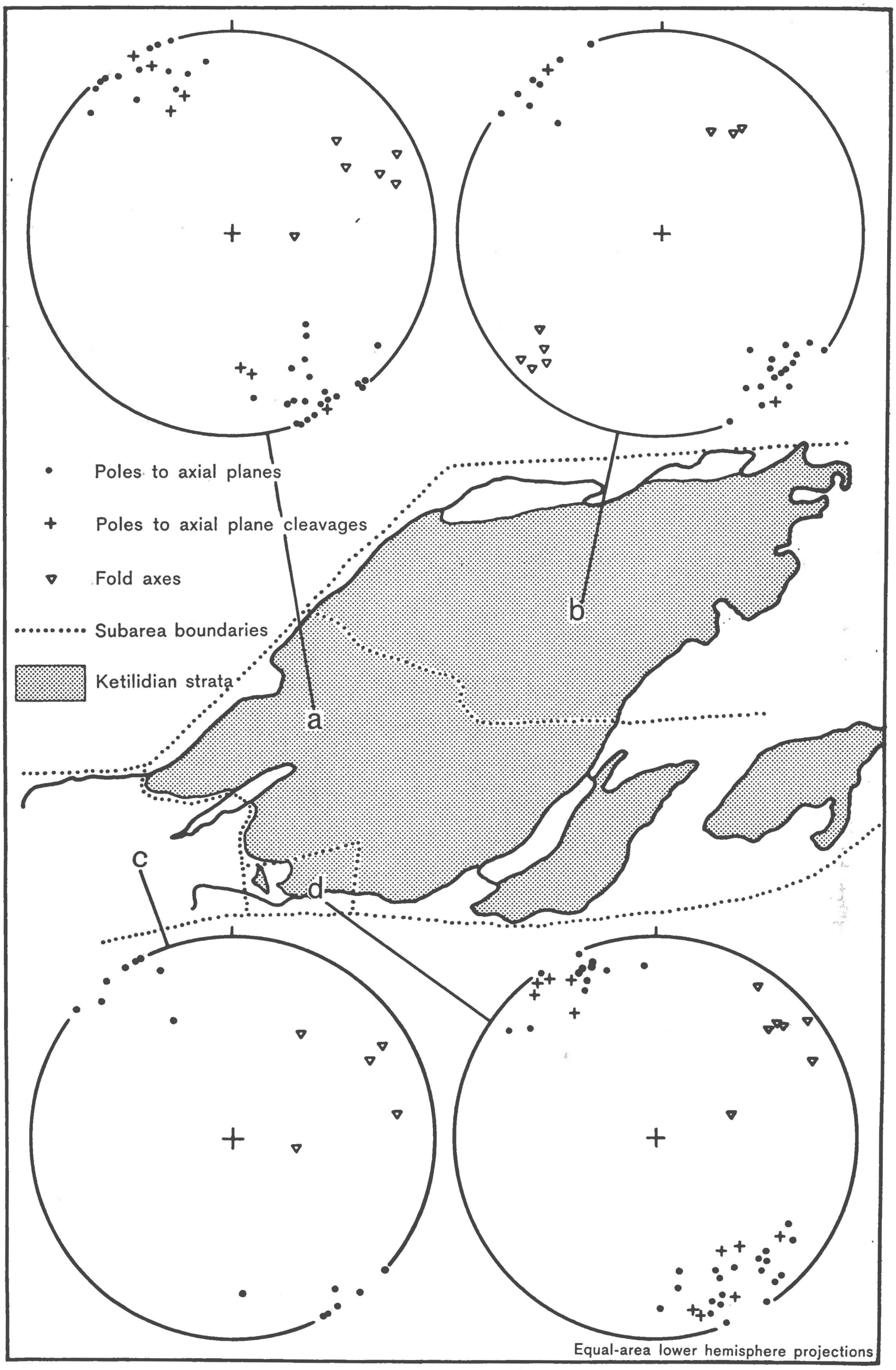


Fig. 30. Analysis of F_2 structural data.

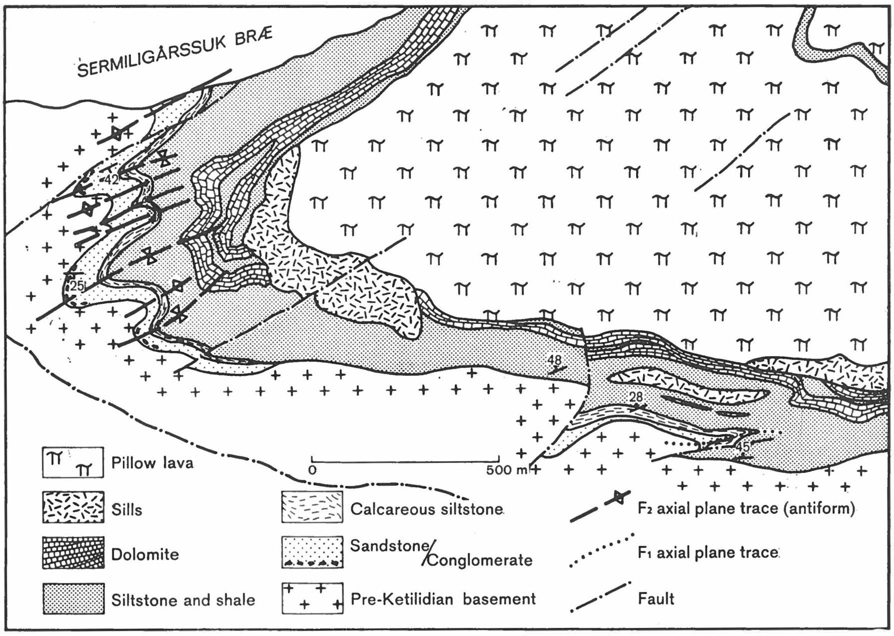


Fig. 31. Structural interpretation of part of the area between Birkesø and Sermiligârssuk Bræ.

A number of major F_2 folds have been recognised in the Sortis Group (Fig. 24) but in general the complex outcrop pattern and the distortion of bedding orientation caused by the lenticular intrusive bodies considerably hinders interpretation. Occasional shear zones parallel to the F_2 axial plane orientation have been observed in several areas, in particular north of Birkesø. A steep axial plane cleavage with associated F_2 folds can be observed not uncommonly in the Sortis Group sediments, and a similarly oriented weak cleavage may occasionally be noted in pillow lava sequences. The shapes of pillows appear to be generally unaffected by deformation (Figs. 7 and 8).

4) Third phase folds

Between Birkesø and Tordensø it proved possible to distinguish a set of minor folds with consistently gently inclined axial planes. They have a brittle appearance often with fractures parallel to the axial planes (Fig. 32) and have been distinguished as F_3 structures. Compared to the F_1 and F_2 structures they are of little importance. The few measurements of F_3 structures are given in Fig. 33.

The F_3 folds may be representative of but one of several phases of minor folding which affect the Ketilidian rocks. Other minor folds are

Fig. 32. Weak F_3 folding with a low-angle axial plane cleavage. South-east of Akuliarutsip timilerssue.

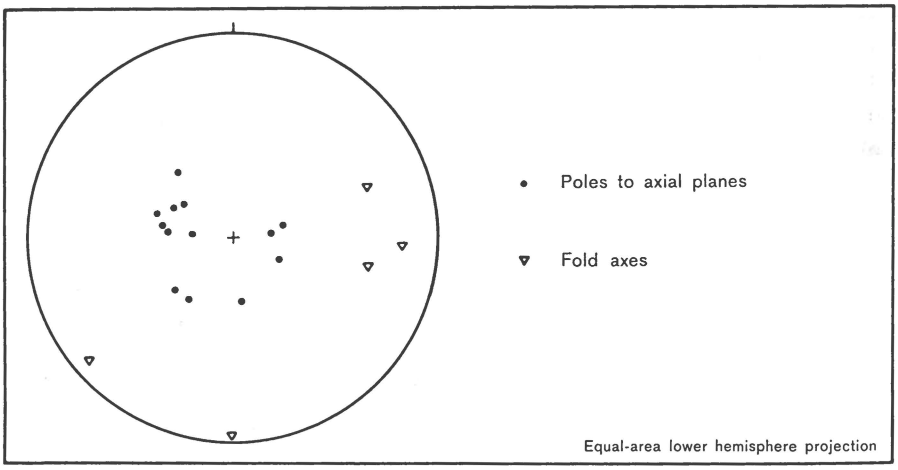


Fig. 33. F_3 structural data.

considered in a later section together with conjugate fold structures. The age of the F_3 minor folds is difficult to assess. Their brittle appearance suggests they may have developed towards the end of orogenic deformation.

5) The Andesø thrust zone

A zone of southward-dipping thrusts may be traced across Midternæs from east to west. The zone is conspicuous near Andesø in eastern Midternæs and westwards is displaced dextrally by two major NE faults before reaching Sermiligârssuk Bræ (Fig. 24).

In Midternæs the thrust zone may comprise a single thrust plane, or as on the north side of Perledal a large number of related, branching thrust planes. The individual planes of movement are inclined at usually 40° to 60° southwards but occasional higher and lower dips have been noted. The thrust planes are marked by mylonite zones which may be several metres broad and have a shaly consistency. Layers and lenses of secondary chert may occur in the mylonites. West of Perledal the line of individual thrusts is sometimes difficult to define since they frequently follow the natural boundaries between sedimentary layers and sills or lava flows.

The degree of movement on the thrust zone is not easy to compute due to the difficulties of correlating the successions on either side of the zone but it appears to be considerable. It can be said that the rocks south of the thrust zone have been thrust over the rocks to the north.

The line of the thrust approximately separates an area of Ketilidian strata to its south with a regional NW–SE strike from an area to its north with a regional E–W strike. The change in strike direction may be a consequence of large scale regional warping as has already been noted, but movements on the thrust appear to have accentuated the differences. Near Andesø a high level of the Qernertoq Formation lies in thrust contact with an intermediate level of the Rendesten Formation (Plate 4). The movements on the thrust must here total some hundreds of metres and may exceed the movements at the west end of the thrust zone near Sermiligârssuk Bræ; the thrust may have had an overall scissor-like movement.

The thrust movements predate the major NE faults and also the dykes; '140' dykes cross the fault zone without displacement near Andesø. Although it appears as a thrust in Midternæs, traced northwards it passes into an E–W fault. It is possible that it bears some relationship to the group of E–W to WNW-trending sinistral faults which affect much of South Greenland and moved at several different periods between pre-Ketilidian and post Gardar time (Henriksen, 1960).

6) Kink bands and conjugate folds

Angular minor folds or kink bands apparently unrelated to the main phases of Ketilidian folding are quite common in the Ketilidian

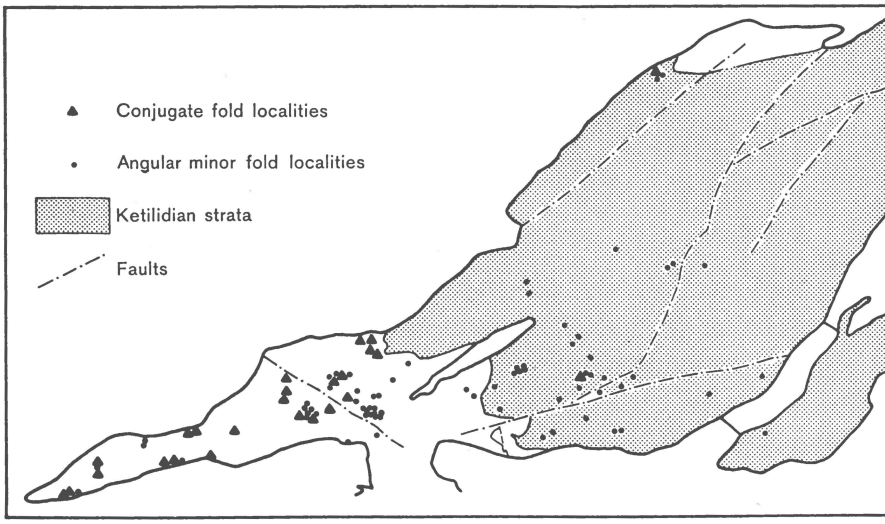


Fig. 34. Location of congugate fold and kink band observations.

sediments, particularly in western Midternæs. Folds of this type but distinguished by having flat-lying axial planes have been described above as phase 3 folds. Most of the angular minor folds have, however, steeply inclined axial planes with somewhat variable strike directions. Folds with WNW-striking axial planes and Z-shaped profiles were most

Fig. 35. Kink bands of the WNW trending set in Tartoq Group schists.

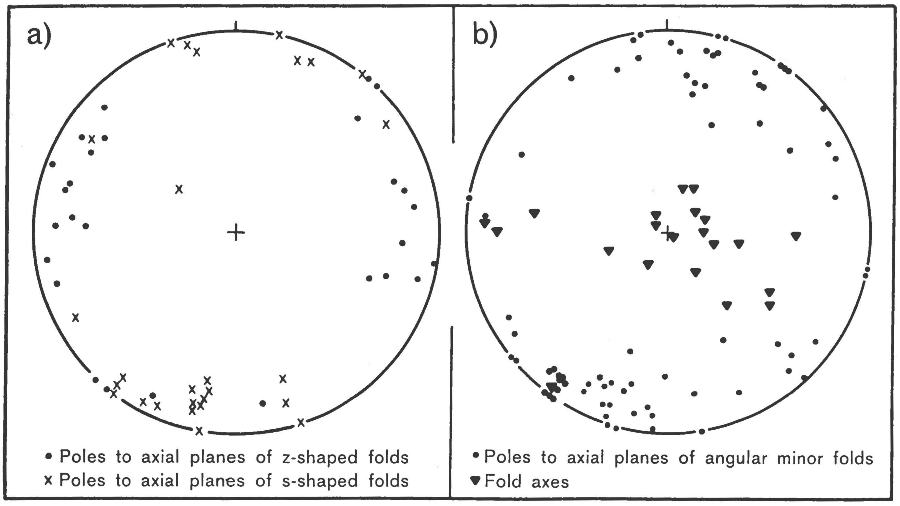


Fig. 36. Analysis of conjugate fold and kink band structural data.

often encountered, and where they have developed in pelitic rocks a strain-slip cleavage is often apparent.

Angular Z-shaped folds with WNW-trending axial planes also occur in the pre-Ketilidian gneisses and schists. It has also been observed in a number of instances, mainly in the pre-Ketilidian rocks, that two sets of angular folds, one set with S-shaped profiles and the other with Z-shaped profiles, occur in association, forming the structures known as conjugate folds (Johnson, 1956; Ramsay, 1962).

The locations of observations of conjugate folds and also minor angular folds are shown in Fig. 34. Observations are particularly abundant in the vicinity of the major WNW–ESE fault which traverses the pre-Ketilidian rocks of west Midternæs, where some major folds appear to be related to movements on the fault. Fig. 35 shows some well developed WNW trending kink bands.

The orientations of axial planes of 25 conjugate fold observations are plotted in Fig. 36a, distinction being made between component parts of the fold with S-shaped or Z-shaped profiles. The data for kink bands not observed to form parts of conjugate folds are plotted in Fig. 36b; many of them have similar orientations to the conjugate fold plots although some are apparently unrelated. Diffuse maxima corresponding to the WNW-trending folds are apparent in both diagrams.

Assuming that the two axial planes of a conjugate fold are symmetrically disposed to the applied stresses under which they develop, then the axes of the stress system may be determined from the intersection of the two axial planes in the manner proposed by Ramsay (1962). The results of these computations for the Midternæs conjugate folds

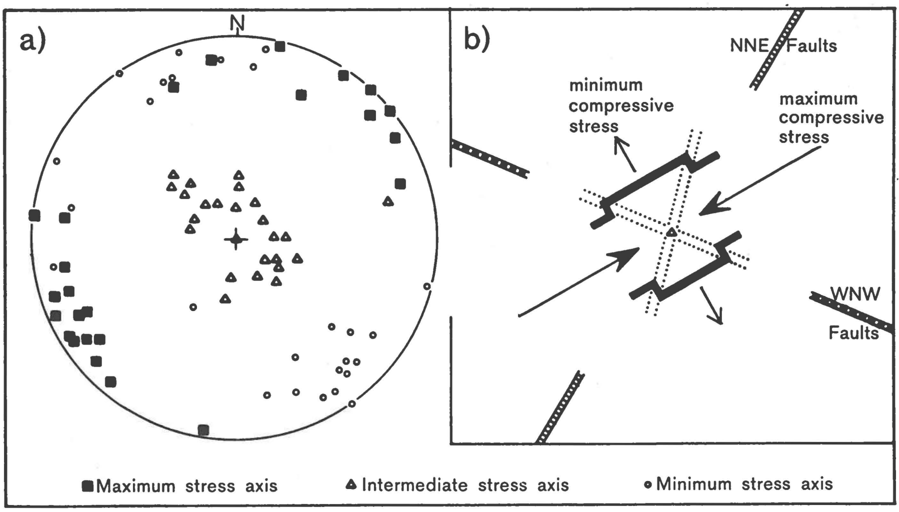


Fig. 37. Conjugate fold stress axes.

are given in Fig. 37a and are fairly consistent. The majority of the conjugate folds would appear to have developed under a stress system whose maximum compressive stress was horizontal and directed NE–SW.

The mean of the computed stress axes is compared in Fig. 37b with the trends of a group of WNW sinistral faults and a group of NNE dextral faults. While the sense of displacement on these two fault trends and the conjugate folds is consistent with development under similarly oriented stress systems their period of formation was not necessarily synchronous. Furthermore, as is described in a later section, there are several other important directions of faulting.

7) Quartz and calcite veining

In the competent sills of the Sortis Group there occur locally vertical or steeply inclined veins of quartz and/or calcite, rarely with small amounts of epidote, pyrite or clinozoisite. The veins have not been observed in sediments adjacent to the sills and have only in isolated cases been observed in neighbouring lavas. The veining is most conspicuous in the area south of Tordensø where quartz veins exceptionally reach thicknesses of 1 to 2 m.

The strike of the veins is variable, although it tends to be fairly consistent within small areas. The stereogram plot of Fig. 38 suggests a dominant ENE strike, but nearly all observations of this strike were noted south of Tordensø or on Nuna qernertoq.

The origin and age of the veining is uncertain. Some veins may be derived from residual siliceous solutions related to the late stages of

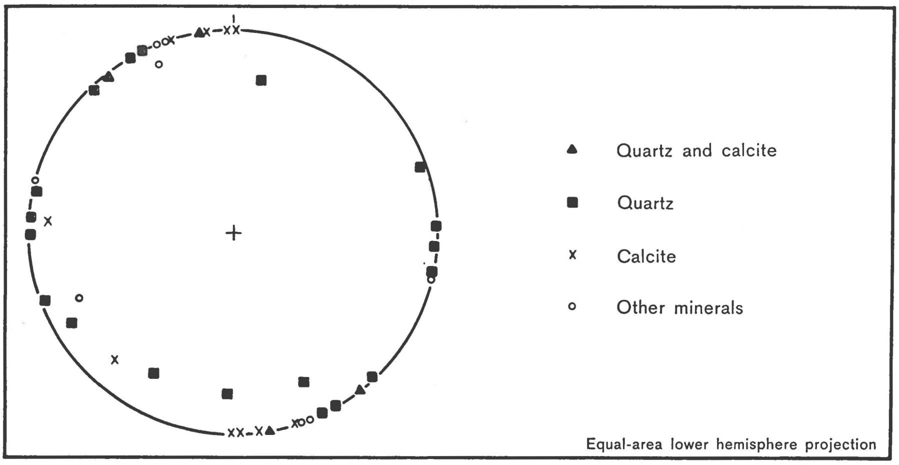


Fig. 38. Stereogram plot of poles to quartz and calcite veins.

crystallisation of the sills. However, many of the veins probably result from the secondary filling of fissures and joints which developed during Ketilidian deformation of the relatively competent sills. A few calcareous veins clearly occupy shear zones. North of Birkesø a 5 m wide '120' dyke clearly cuts several thick quartzitic veins, but it is itself cut by a later thin vein.

There is no associated mineralisation of economic significance.

8) Faults

The location of the main faults and thrusts of Midternæs are indicated in Fig. 39. Most of the thrusts are low angle and probably are related to phase 1 folds. The Andesø thrust zone has been described separately. Some of the faults have a long history and may be shown to have moved on several separate occasions. Many faults displace Gardar dykes.

Analysis of the fault trends indicates three prevalent directions, NNE, NE and ENE and a less common WNW trend; in adjacent areas the WNW faults are of major importance. The Midternæs faults exhibit in some cases variations in trend, or branch into several faults with different trends. The principal movements on the faults appear to be lateral and are detectable from the displacement usually of dykes. It is thought likely that there is at least some vertical component of displacement on many faults, but this is difficult to demonstrate due to the absence of suitable marker bands.

In Fig. 39 the principal faults of interest are each indicated by a letter corresponding to its main trend, and a number for ease of reference.

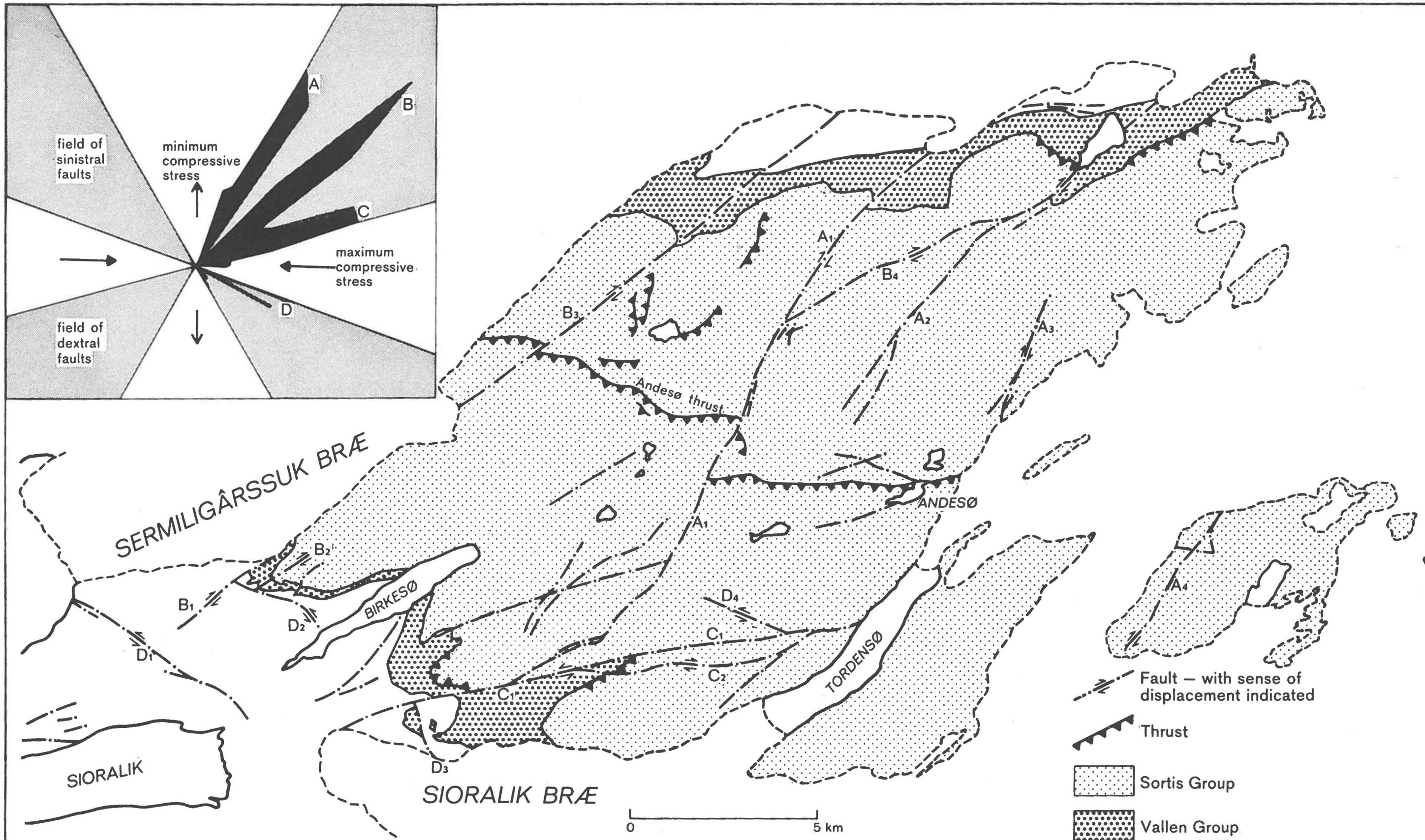


Fig. 39. Map of the main faults and thrusts of Midternæs with sense of displacement, where known, indicated. The inset rose-diagram summarises the principal fault trends.

In the descriptions of the stratigraphy it was suggested that movements on the faults C_1 and B_4 during Vallen Group deposition might have some bearing on the occurrence of feldspathic greywacke and arkose sequences, which in both instances occur on the south side of the faults. It was further noted that the fault C_1 appears to be the location of a major topographic feature influencing the type and particularly thickness of deposition of the Rendesten Formation. It has also been observed that the thick dolomite sequence of the Grænsesø Formation found on the south side of the fault B_4 is totally lacking in the area just north of the fault.

The C_1 fault line separates areas with marked differences of bedding inclination. The fault plane may be coincident with a phase 2 anticline (Fig. 24) and there may have been movements on the fault in phase 2 time. The faults B_1 and B_2 also appear to exhibit some phase 2 axial plane movement.

The fault A_2 appears to displace a phase 1 BD about 800 m in a sinistral direction (Plate 5), but more probably the dyke has been diverted along the fault plane as faults of this trend are usually dextral. The A_4 fault displaces a '140' dyke dextrally, but a later BD is not displaced although its course is deflected for about 1 km. Dykes are also deflected along the faults C_1 and C_2; the C faults appear not to have moved in Gardar time.

Many faults are late-Gardar or post Gardar in age (A_1, A_3, B_3, B_4, D_1) and cut most or all BDs. The only example of a phase 7 BD is intruded partly in the mylonite zone of the A_1 fault.

The fault lines are marked by the obvious displacements of geological features and may be traced as mylonite zones, or quite often several parallel, closely spaced mylonites. The mylonites are of a shaly consistency, usually weathering to a rusty red colour, and may be associated with bands of secondary grey chert. Nearly all fault lines can be traced as minor topographic features.

The WNW-trending faults D_1, D_2 and D_4 all have sinistral displacements, of about 4.5 km, 80 m and 50 m respectively, and most of the NNE- to ENE-trending faults have dextral displacements, ranging from a few metres to 400 m. Although the various faults have moved at different periods the consistent sense of displacement of each fault trend is noteworthy and suggestive of consistently oriented stress conditions over an extensive period of time. An interpretation of the mean direction of this stress field is given in the inset in Fig. 39 and may be compared with that deduced from the analysis of conjugate folds (Fig. 37).

In the region south of Midternæs two main systems of wrench faulting are recorded, a dextral mainly NNE system and a sinistral mainly WNW system (Ayrton, 1963; Weidmann, 1964; Bondesen, in press). Major faulting with the same general trends is found over a large part of South-West Greenland (Berthelsen, 1961). While other fault directions of lesser importance occur in all areas there are grounds for concluding the existence of consistent regional stress conditions.

During Gardar time important swarms of dykes were intruded, and it has been suggested that throughout a vast region tensional conditions during which the dykes were intruded alternated with compressional conditions during which movements on the major wrench faults took place (Berthelsen, 1962; Ayrton, 1963; Weidmann, 1964; Berthelsen and Noe-Nygaard, 1965). However, Henriksen in an unpublished report (1961) has put forward the attractive alternative that Gardar dyking and faulting were coexistent phenomena. In an analysis of the Gardar faults in an area 40 km south-west of Midternæs Henriksen deduced that they had developed under two similarly oriented stress systems whose maximum compressive stresses were respectively in ENE and NNE directions. Henriksen suggested that the Gardar dykes in his area were emplaced under the same stress conditions as produced the faults, in tensional joints parallel to the largest principal stress and normal to the smallest principal stress with trends of between 030° and 080°.

9) Joints

Jointing is conspicuous in the Ketilidian strata, particularly in the sills and to a lesser extent in the lavas. In the field it proved very difficult to estimate which of the abundant joints were of most importance, but on vertical aerial photographs of the area the main vertical joint trends may often be easily picked out.

Analysis of a number of aerial photographs has shown that the same principal directions of jointing are common to different parts of the area. The main trends of vertical joints are in directions of 045°, 080°, 110° and 165°. Fig. 40 shows the joint pattern in an area in which all four directions of jointing are apparent, but in other areas one or more of these joint trends may not be represented; in some areas a single joint trend is locally dominant. There also occur everywhere a number of joints whose trends do not quite correspond with any of the principal joint directions, as well as joints which are subhorizontal or moderately inclined.

There is a close similarity between the main vertical joint trends and the trends of faults (Fig. 39) as perhaps might be expected; the 045° joints are approximately parallel to the NE faults, the 080° joints to the ENE faults and the 110° joints to the WNW faults.

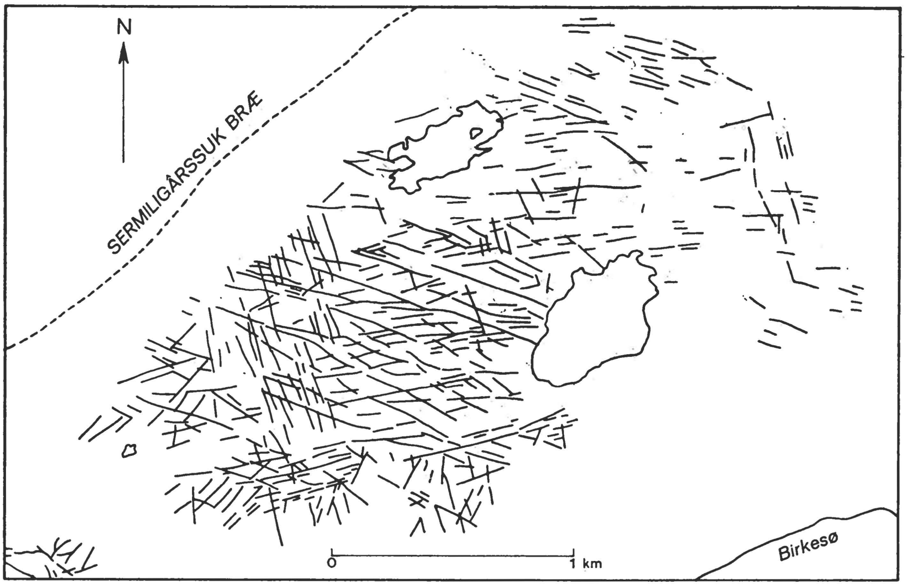


Fig. 40. The joint pattern in gabbroic sills north of Birkesø. Prepared from aerial photographs.

The Gardar dyke directions (Plate 2) do not appear to be related to the joint pattern although it may be noted that dykes have been intruded parallel to the 045° and 080° joint trends.

The calcite and quartz veining discussed above is preferentially found in the 080° joints in parts of southern Midternæs. At least some of the jointing of this trend may have had a tensional origin.

It has been observed that in the field an F_2 axial plane cleavage is locally pronounced; much of the 045° jointing could be of F_2 age.

10) Summary of structures

The deposition of the Ketilidian succession was influenced to some degree by movements along several fault lines. The type and thickness of some sedimentary units was affected. Unequal subsidence of the sea floor during deposition may have led to large scale warping.

Phase 1 folding produced minor and major, tight to isoclinal recumbent folds, usually overturned southwards, in the sediments. Low angle thrusts appear to have developed in place of folds in the relatively competent lava and sill sequences. F_1 folds in pre-Ketilidian rocks were only locally produced, but there was occasionally minor shearing at the plane of unconformity.

Phase 2 folding produced minor and major NE-trending fold structures. A steeply inclined axial plane cleavage was often developed, and locally fault movements took place parallel to this plane. The unconformity was folded in some areas with the underlying pre-Ketilidian rocks, but F_2 minor folds were rarely observed in the gneisses and Tartoq Group schists.

Flat-lying phase 3 minor folds were developed locally; their age relative to other post phase 2 structures is uncertain.

Movements on the major Andesø thrust zone appear to have accentuated the differences in dip and strike of the areas on either side; there may have been a scissor-like movement.

Quartz and calcite veins of several ages fill fissures and joints in the competent sills.

Kink bands and conjugate folds occur in the sediments, and minor folds of the same trend occur also in the pre-Ketilidian rocks.

Several main trends of faults dissect the Ketilidian rocks and were active intermittently between Ketilidian and post-Gardar time. The majority are wrench faults, a generally NE-trending set having dextral displacements and a WNW-trending set sinistral displacements. The computed axes of stress are similar to those deduced for the conjugate folds.

Gardar faulting and dyke emplacement may have taken place concurrently under the influence of the same regional stress conditions.

11) Comparisons with the Ketilidian fold chronology of other areas

The Grænseland area

In Grænseland, which lies due south of Midternæs, Bondesen (1962; in press) has distinguished a succession of three fold phases. His phase 1 structures are tight to isoclinal overturned assymetric folds with axial planes subparallel to the local bedding and dipping eastwards. An F_1 axial plane cleavage is dominant in some rock types. Major low angle thrusts may be contemporaneous with phase 1. Phase 2 folds have axes plunging ENE at 20° to 40°, they have a Z-shaped profile and southwards apparently become overturned and may be isoclinal. In some areas F_2 structures have a diapiric style. The pre-Ketilidian basement exhibits broad anticlinal F_2 folding, but also a brittle reaction with the development of closely spaced small faults parallel to F_2 axial planes. The phase 3 structures occur only locally and have steep NNW plunges of 45° to 70° and axial planes dipping steeply to the NE. They appear to be mainly concentrated in earlier thrust zones or near faults.

The general correlation of the fold phases 1 and 2 of Midternæs and Grænseland has been recorded previously (HIGGINS and BONDESEN, 1966; BONDESEN, in press). It may be noted that an F_1 axial plane cleavage is not conspicuous in Midternæs, and that faulting parallel to F_2 axial planes is much more pronounced in Grænseland. A general increase in intensity of deformation southwards accompanied by an increase in grade of regional metamorphism in the Ketilidian supracrustal rocks of this region has been described by WINDLEY *et al.* (1966). The Grænseland phase 3 structures associated with faults are probably equivalent to the WNW-trending kink bands of Midternæs.

The Arsuk Ø area

In his description of the Ketilidian structures of Arsuk Ø WEGMANN (1938) described the major SW-plunging synformal structure of the Arsuk basin as refolding earlier large scale tight folds.

MULLER (in prep.) in a detailed structural analysis of Arsuk Ø distinguishes two main Ketilidian fold phases. An early tight phase produced major folds and a contemporaneous schistosity in the sedimentary rocks; the fold axes probably originally had a N–S trend. The second fold phase governed the synclinal form of the Arsuk basin. In the volcanic succession the phase 2 fold axes have a NE to ENE trend, but two axial trends are recorded in the underlying sediments, one E–W and the other N–S. The two rock groups are separated by a zone of disharmony. MULLER also notes that the different fold phases are difficult to distinguish in the pre-Ketilidian gneisses.

There is a strong resemblance between the phase 1 and phase 2 structures of Arsuk Ø, Midternæs and Grænseland and it is likely that they are more or less equivalent. The F_1 axial plane schistocity is common to Arsuk Ø and Grænseland. The two F_2 axial trends noted by MULLER have not been recorded elsewhere.

The Nanortalik area

ESCHER (1966) distinguished three fold phases in the supracrustal Ketilidian rocks of the Nanortalik area, which is in the Tasermiut fjord region. The first phase was characterised by isoclinal often recumbent folds, originally with NNE axes, and was accompanied by thrust-faulting. A second phase produced large and small scale open folds with NW-trending axes, and a third phase very large structures trending NE to NNE associated with major faulting and a fracture cleavage.

A tentative correlation of the Ketilidian fold phases in the region between Julianehåb and Frederiksdal has been prepared by WINDLEY

(1966). Four fold phases are distinguished, which correspond to those of ESCHER but with the addition of an earlier phase represented only by minor intrafolial folds and probably pre-Ketilidian.

The distance between the Ketilidian supracrustals of the Tasermiut fjord region and those of the Ivigtut region prohibits correlation of individual fold phases. However, the general development of folding in the two regions shows some similarities.

Acknowledgements

This paper is published by kind permission of the director of Grønlands Geologiske Undersøgelse, mag. scient. K. ELLITSGAARD-RASMUSSEN.

I am very grateful to my colleagues at the survey for their advice and criticism, and especially to IB SØRENSEN who made the chemical analyses, E. KIRSBO who arranged the CIPW norm computer programme and A. DEMIN who translated the Russian résumé.

РЕЗЮМЕ

Кетилидские супракрустальные, надкоровые породы выходят на поверхность в Юго-Западной Гренландии. Они слагают структурный пояс, который прослеживается от района Мидтернэс к югу, через территорию Грэнселанд кетилидского типа (Bondesen, в печати), до района Кобберминбугт (фиг. 2). Осадочные и вулканические породы, также относимые к кетилидской серии, обнажаются в районе фьорда Тасермиут в 225 км юго-восточнее района Мидтернэс (фиг. 1).

В настоящей работе описана стратиграфия и даны сведения о различных деформационных структурах кетилидских пород района Мидтернэс (табл. 2). Корреляция между территорией Мидтернэс и примыкающей к ней с юга территорией Грэнселанд проведена по групповым и формационным признакам пород (фиг. 22 и прил. 4). В описываемом районе выделяются группы Валлен и Сортис и соответствующие им формации. Общая мощность кетилидских отложений, выходящих на поверхность, сосотавляет около 5000 м.

Преимущественно осадочные отложения валленской группы несогласно залегают на докетилидских гнейсах и зеленых сланцах (фиг. 3 и 4). Наиболее ранние осадки, состоящие из маломощных конгломератов, кварцитов и известковых алевритов, отлагались в замкнутых, ограниченных бассейнах, и их мощность и распространенность непостоянны (прил. 3). Последующие осадки носят более глубоководный характер, а также имеют более широкое распространение. Они состоят преимущественно из алевритов с клиновидными включениями аркозовых песчаников. Такая седиментационная ассоциация является довольно характерной для внутрикратонных бассейнов. В то же время на территории Грэнселанд продолжительные серии граувакков, скорее характеризующих геосинклинальные прогибы, залегают на том же самом уровне валленской группы. Верхняя часть валленской группы представлена доломитами с включениями сферических структур органического происхождения, найденными на пяти участках в районах Мидтернэс и Грэнселанд.

Группа Сортис в основном сложена мощной толщей подушечных лав состава толеитовых базальтов с многочисленными инъекциями пластовых интрузий, которые формировались, возможно, из одной и той же материнской магмы. Анализы лав и интрузий характеризуются низким содержанием Ti и K и высоким содержанием H_2O (табл. 4 и 6). Осадочные и пирокластические породы играют важную роль на некоторых уровнях разреза, особенно в центральной части сортисской группы. Наличие фельзической вулканической брекчии (фиг. 17) дает основание предполагать, что кратер вулкана располагался в пределах южного окончания района Мидтернэс. Наличие вулканических бомб, возможно, указывает на то, что глубина моря только по временам была умеренной; но так как непрерывная толща подушечных лав мощностью во много сотен метров представляет обычное явление, то можно

предположить, что опускание морского дна происходило равномерно по мере накопления лавы.

Петрографические наблюдения показывают, что кетилидская серия в районе Мидтернэс претерпела региональный метаморфизм режима фации зеленых сланцев. К югу от Мидтернэс степень регионального метеморфизма быстро возрастает и в 50 км к югу от района достигает альмандин-амфиболитовых фаций. Возрастание степени метаморфизма сопровождается возрастанием интенсивности деформации.

Обширное смещение суб-кетилидской поверхности, возникшее, по-видимому, благодаря опусканию морского дна, сопровождавшему накопление лавы, предварило мезоскопическое складкообразование. В первую фазу складкообразования сформировались изоклинальные опрокинутые структуры; процесс сопровождался слабо наклонными надвигами. Во вторую фазу образовались очень распространенные структуры СВ простирания (фиг. 24). Более поздние складки имеют небольшое значение.

Главным типом нарушений являются разрывные нарушения. Большинство нарушений ЗСЗ направления имеют левостороннее смещение, а нарушения ВСВ-ССВ направления — правостороннее смещение (фиг. 39).

Сложный комплекс даек пересекает кетилидские породы в районе Мидтернэс. Некоторые из даек ЗСЗ направления могут быть поздне-кетилидскими, но главный поток даек с простираниями от ВСВ до ССВ, вероятно, относится к гардарскому периоду (прил. 2).

REFERENCES

ALLAART, J. H., BRIDGWATER, D. and HENRIKSEN, N. (1969) The pre-Quaternary geology of South-West Greenland and its bearing on problems of correlation in the North Atlantic. Mem. Am. Ass. Petrol. Geol., No. 12, 859–882.

ANDREWS, J. R. (1969) A kimberlite dyke in the Nigerdlikasik area, Frederikshåb district. Rapp. Grønlands geol. Unders., Nr. 19, 35–37.

AYRTON, S. N. (1963) A contribution to the geological investigations in the region of Ivigtut, SW Greenland. Bull. Grønlands geol. Unders., No. 37 (*also* Meddr Grønland, Bd. 167, Nr. 3).

BAILEY, D. K. and HALLIDAY, A. L. (1963) Pillow-lava breccias and submarine sliding of pillow lavas. Spec. Pap. geol. Soc. Am., No. 73, 107 only.

BAILEY, E. B. and MCCALLIEN, W. J. (1960) Some aspects of the Steinman trinity: mainly chemical. Q. Jl geol. Soc. Lond., Vol. 116, 365–395.

BARAGAR, W. R. A. (1960) Petrology of basaltic rocks in part of the Labrador Trough. Bull. geol. Soc. Am., Vol. 71, 1589–1644.

— (1968) Major-element geochemistry of the Noranda volcanic belt, Quebec-Ontario. Can. J. Earth Sci., Vol. 5, 773–790.

BERTHELSEN, A. (1958) On the chronology of the Ivigtut district, a compilation. Unpublished report, Grønlands geol. Unders.

— (1961) On the chronology of the Precambrian of western Greenland. *In* Raasch, G. O. (edit.) Geology of the Arctic, Vol. 1, 329–338. Toronto U. P.

— (1962) On the geology of the country around Ivigtut, SW-Greenland. Geol. Rdsch., Bd. 52, 269–280.

BERTHELSEN, A. and NOE-NYGAARD, A. (1965) The Precambrian of Greenland. *In* Rankama, K. (edit.) The Precambrian. Vol. 2. 113–262. London & New York: Interscience Publ.

BONDESEN, E. (1962) Grænseland kompleksets geologi. Unpublished prize dissertation, Univ. Copenhagen.

— (in press) The stratigraphy and deformation of the Precambrian rocks of the Grænseland area, South-West Greenland. Bull. Grønlands geol. Unders., (*also* Meddr Grønland, Bd. 185, Nr. 1).

BONDESEN, E. and HENRIKSEN, N. (1965) On some pre-Cambrian metadolerites from the central Ivigtut region SW Greenland. Bull. Grønlands geol. Unders., No. 52 (*also* Meddr Grønland, Bd. 179, Nr. 2).

BONDESEN, E., PEDERSEN, K. R. and JØRGENSEN, O. (1967) Precambrian organisms and the isotopic composition of organic remains in the Ketilidian of South-West Greenland. Bull. Grønlands geol. Unders., No. 67 (*also* Meddr Grønland, Bd. 164, Nr. 4).

BRIDGWATER, D. and HARRY, W. T. (1968) Anorthosite xenoliths and plagioclase megacrysts in Precambrian intrusions of South Greenland. Bull. Grønlands geol. Unders., No. 76 (*also* Meddr Grønland, Bd. 185, Nr. 2).

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

BULLOCK, P. W. B. (1967) Palaeomagnetism and its application to geological problems in South West Greenland. Unpublished dissertation for Master of Science, Univ. Newcastle upon Tyne.

CARLISLE, D. (1963) Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia. J. Geol., Vol. 71, 48–71.

DAPPLES, E. C., KRUMBEIN, W. C. and SLOSS, L. L. (1948) Tectonic control of lithologic associations. Bull. Am. Ass. Petrol. Geol., Vol. 32, 1924–1947.

ESCHER, A. (1966) The deformation and granitisation of Ketilidian rocks in the Nanortalik area, S. Greenland. Bull. Grønlands geol. Unders., No. 59 (*also* Meddr Grønland, Bd. 172, Nr. 9).

FRANCE, D. S. (1967) The geology of Ordovician rocks at Balbriggan, County Dublin, Eire. Geol. J., Vol. 5, 291–304.

GHISLER, M. (1968) The geological setting and mineralizations west of Lilianmine, South Greenland. Rapp. Grønlands geol. Unders., Nr. 16.

GOODWIN, A. M. and SHKLANKA, R. (1967) Archean volcano-tectonic basins: form and pattern. Can. J. Earth Sci., Vol. 4, 777–795.

HENDERSON, J. F. (1953) On the formation of pillow lavas and breccias. Trans. R. Soc. Can. 3rd Ser., Sect. 4, Vol. 47, 23–32.

HENRIKSEN, N. (1960) Structural analysis of a fault in South-West Greenland. Bull. Grønlands geol. Unders., No. 26 (*also* Meddr Grønland, Bd. 162, Nr. 9, 15–41).

— (1961) En geologisk beskrivelse af et område mellem Arsuk Fjord og Tigssalukfjord, SW-Grønland. Unpublished dissertation, Univ. Copenhagen.

— (1969) Chemical relations between metabasaltic lavas and metadolerites in the Ivigtut area, South-West Greenland. Meddr dansk geol. Foren., Bd. 19, 27–50.

HIGGINS, A. K. (1968) The Tartoq Group on Nuna qaqortoq and in the Iterdlak area, South-West Greenland. Rapp. Grønlands geol. Unders., Nr. 17.

HIGGINS, A. K. and BONDESEN, E. (1966) Supracrustals of pre-Ketilidian age (the Tartoq Group) and their relationships with Ketilidian supracrustals in the Ivigtut region, South-West Greenland. Rapp. Grønlands geol. Unders., Nr. 8.

JENSEN, S. B. (1966) Field work in the Frederikshåb area. Rapp. Grønlands geol. Unders., Nr. 11, 32–35.

JOHNSON, M. R. W. (1956) Conjugate fold systems in the Moine Thrust Zone in the Lochcarron and Coulin Forest areas of Wester Ross. Geol. Mag., Vol. 93, 345–350.

JØRGENSEN, O. (1968) K/Ar age determinations from western Greenland II. The Ivigtut region. Rapp. Grønlands geol. Unders., Nr. 15, 78–91.

KALSBEEK, F. (1967) The pattern of folding in an area of migmatites between Neria and Qasigialik fjords. South-West Greenland. Bull. Grønlands geol. Unders., No. 65 (*also* Meddr Grønland, Bd. 175, Nr. 4).

MACDONALD, G. A. (1953) Pahoehoe, aa, and block lava. Amer. J. Sci., 251, 169–191.

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

MICHEELSEN, H. (1955) Rapport over det geologiske feltarbejde i Sermiligarssuk i sommeren 1955. Unpublished report, Grønlands geol. Unders.

MULLER, J. (in prep.) Geologie et petrographie de la baignoire d'Arsuk et de ses formations ophiolitiques, chaîne des Ketilides, Groenland méridional. Meddr Grønland.

OEN ING SOEN (1960) Field report on geological investigations in Midternæs, Sermiligârssuk fjord, Southwest Greenland. Unpublished report, Grønlands geol. Unders.

PEDERSEN, K. R. (1966) Precambrian fossils from the Ketilidian of South-West Greenland. Rapp. Grønlands geol. Unders., Nr. 11, 40–41.

— (1968) Fossils of Precambrian age from South-West Greenland. Rapp. Grønlands geol. Unders., Nr. 15, 51–53.

PETTIJOHN, F. J. (1957) Sedimentary rocks. (2nd ed.) New York: Harper & Brothers.

RAMSAY, J. G. (1962) The geometry of conjugate fold systems. Geol. Mag., Vol. 99, 516–526.

SNYDER, G. L. and FRASER, G. D. (1963) Pillowed lavas, I: Intrusive layered lava pods and pillowed lavas Unalaska Island, Alaska. Prof. Pap. U.S. geol. Surv., 454-B.

SOLOMON, M. (1966) Origin of pillow structure in lavas. Nature, Lond., Vol. 211, 399 only.

VALLANCE, T. G. (1965) On the chemistry of pillow lavas and the origin of spilites. Mineralog. Mag., Vol. 34, 471–481.

WALTON, B. (1966) Carbonatite-lamprophyre dykes of Mesozoic age. Rapp. Grønlands geol. Unders., Nr. 11, 37–38.

WATTERSON, J. (1965) Plutonic development of the Ilordleq area, South Greenland. Part I. Chronology, and the occurrence and recognition of metamorphosed basic dykes. Bull. Grønlands geol. Unders., No. 51 (*also* Meddr Grønland, Bd. 172, Nr. 7).

WEGMANN, C. E. (1938) Geological investigations in southern Greenland. Part I. On the structural divisions of southern Greenland. Meddr Grønland, Bd. 113, Nr. 2.

— (1939) Übersicht über die Geologie Südgrönlands. Mitt. naturf. Ges. Schaffhausen, Bd. 16, (Jahrgang 1940) 188–212.

— (1948) Note sur la chronologie des formations précambriennes du Groenland méridional. Ecl. geol. Helv., Vol. 40, 7–14.

WEIDMANN, M. (1964) Géologie de la région située entre Tigssaluk fjord et Sermiligârssuk fjord (partie médiane), SW-Groenland. Bull. Grønlands geol. Unders., No. 40 (*also* Meddr Grønland, Bd. 169, Nr. 5).

WILSON, M. E. (1960) Origin of pillow structures in the early Precambrian lavas of western Quebec. J. Geol., Vol. 68, 97–102.

WINDLEY, B. F. (1966) Superposed deformations of the Ketilidian gneisses in the Sârdloq area, South Greenland. Bull. Grønlands geol. Unders., No. 64 (*also* Meddr Grønland, Bd. 179, Nr. 3).

WINDLEY, B. F., HENRIKSEN, N., HIGGINS, A. K., BONDESEN, E. and JENSEN, S. B. (1966) Some border relations between supracrustal and infracrustal rocks in South-West Greenland. Rapp. Grønlands geol. Unders., Nr. 9.

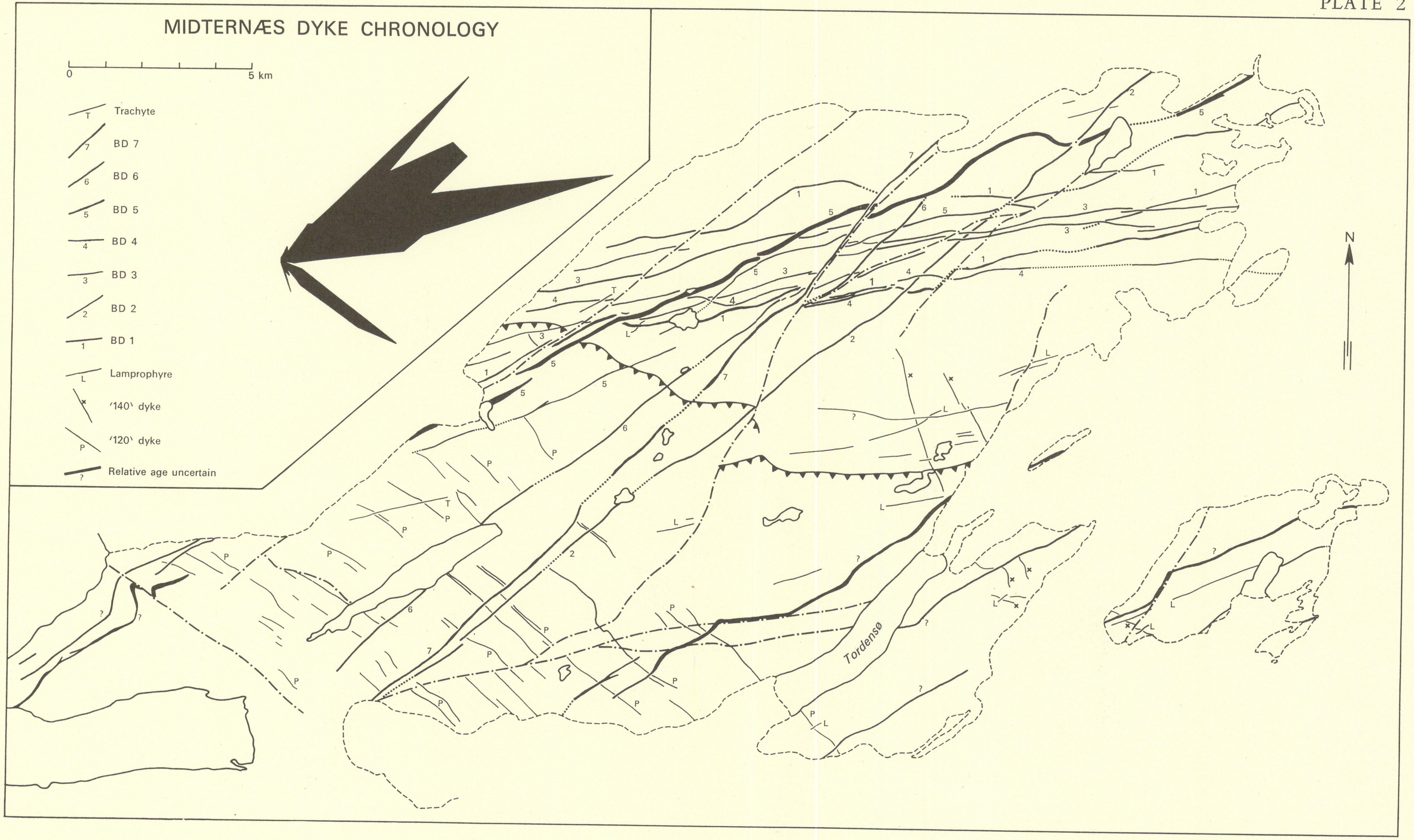
WINKLER, H. G. F. (1967) Petrogenesis of Metamorphic rocks. (2nd ed.) Springer-Verlag: New York.

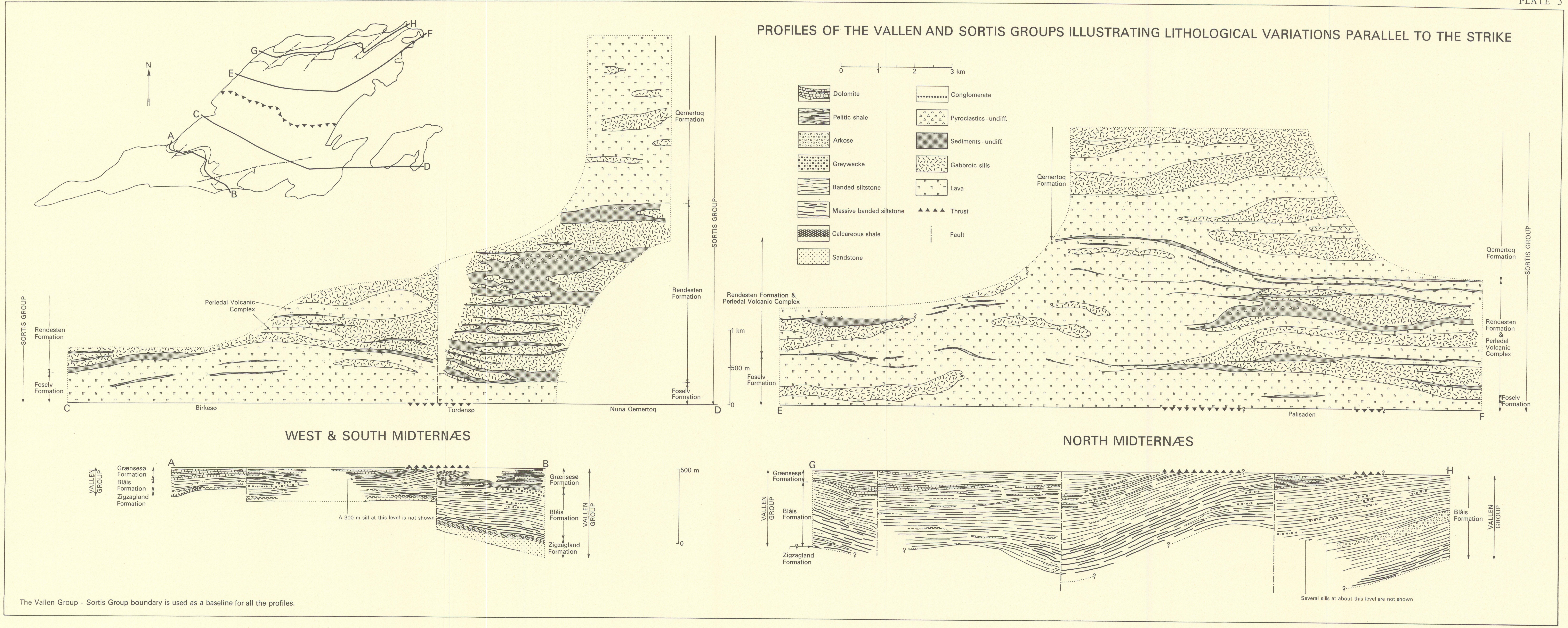
Færdig fra trykkeriet den 28. august 1970.

PLATES

Plate 1

Aerial photograph showing Midternæs and the adjacent nunataks silhouetted against the Inland Ice. North of Midternæs the 4 km wide Sermiligârssuk Bræ runs into the fjord Sermiligârssuk which crosses the photograph diagonally. The fjord in the centre foreground is part of Târtoq. Comparison with the regional geological map of Fig. 2 shows that the well banded rocks in the left foreground belong to the pre-Ketilidian Tartoq Group. The two dark areas on the north side of Sermiligârssuk also comprise Tartoq Group supracrustal rocks. The partly snow covered plateau areas north and south of Sermiligârssuk are mainly made up of pre-Ketilidian gneisses. Reproduced by permission of the Geodetic Institute, Copenhagen.


MIDTERNÆS DYKE CHRONOLOGY
0
5 km
Trachyte
BD 7
BD 6
BD 5
BD 4
BD 3
BD 2
BD 1
Lamprophyre
'140' dyke
'120' dyke
Relative age uncertain
N
Tordensø

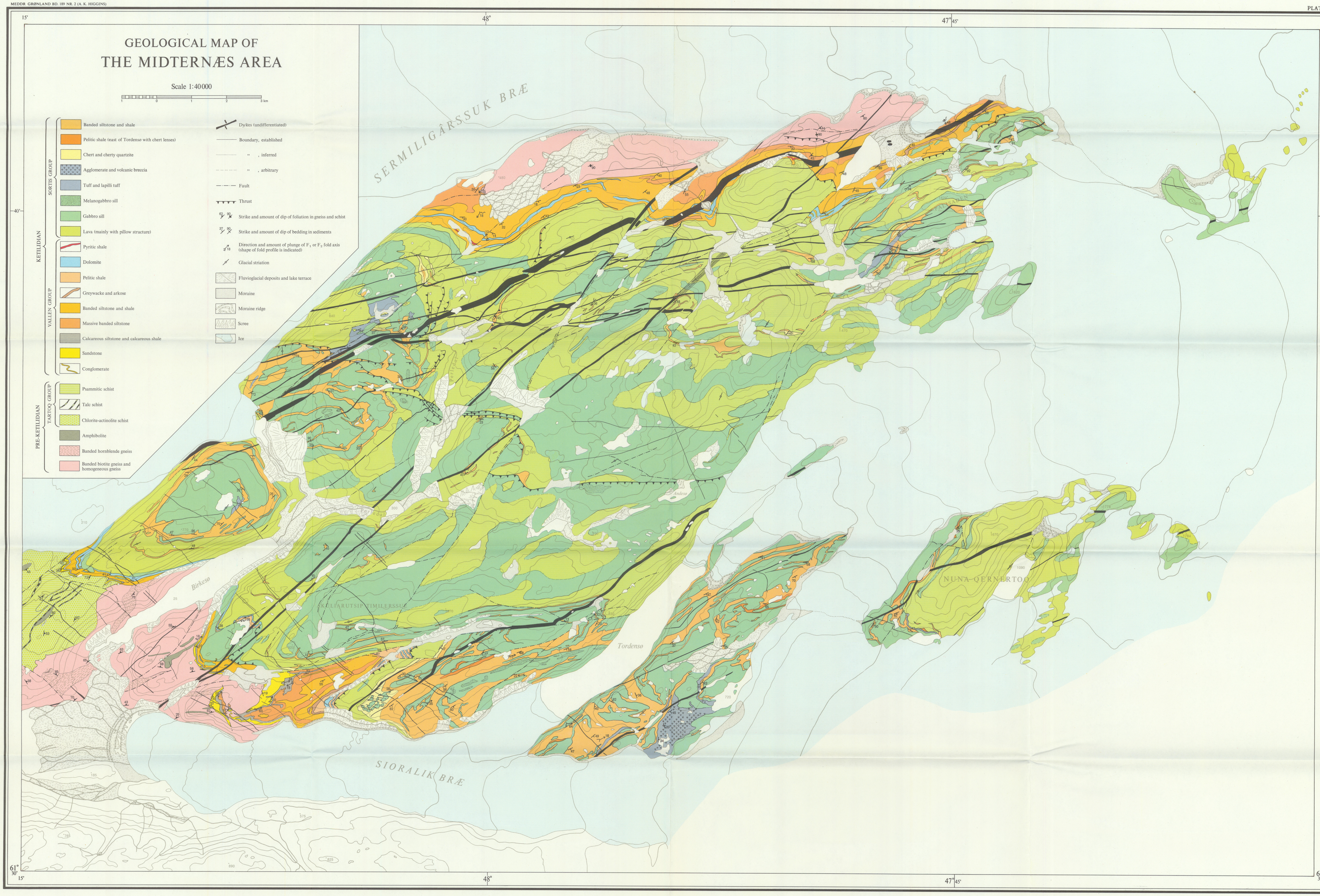

PROFILES OF THE VALLEN AND SORTIS GROUPS ILLUSTRATING LITHOLOGICAL VARIATIONS PARALLEL TO THE STRIKE
N
A
B
C
D
E
F
G
H
0 1 2 3 km
Dolomite
Pelitic shale
Arkose
Greywacke
Banded siltstone
Massive banded siltstone
Calcareous shale
Sandstone
Conglomerate
Pyroclastics - undiff.
Sediments - undiff.
Gabbroic sills
Lava
Thrust
Fault
SORTIS GROUP
Qernertoq Formation
Rendesten Formation
Foselv Formation
Perledal Volcanic Complex
Birkesø
Tordensø
Nuna Qernertoq
1 km
500 m
0
Rendesten Formation & Perledal Volcanic Complex
Palisaden
WEST & SOUTH MIDTERNÆS
NORTH MIDTERNÆS
VALLEN GROUP
Grænsesø Formation
Blåis Formation
Zigzagland Formation
A 300 m sill at this level is not shown
500 m
Several sills at about this level are not shown
The Vallen Group - Sortis Group boundary is used as a baseline for all the profiles.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDR GRØNLAND BD. 189 NR. 2 (A. K. HIGGINS)

PLATE 5.



Trykt ved Geodætisk Institut 1970