GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 86

THE STRATIGRAPHY AND DEFORMATION OF THE PRECAMBRIAN ROCKS OF THE GRÆNSELAND AREA, SOUTH-WEST GREENLAND

BY

ERLING BONDESEN

WITH 69 FIGURES AND 18 TABLES IN THE TEXT,
AND 14 PLATES

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
1970

GRØNLANDS GEOLOGISKE UNDERSØGELSE
The Geological Survey of Greenland
Østervoldgade 10, DK-1350 København K
Denmark

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(published in association with the series *Meddelelser om Grønland*)

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Abstract

The Grænseland area exhibits a middle Precambrian (Ketilidian) succession of unusually well preserved sediments, basic volcanics, and intrusives. A Ketilidian type lithostratigraphy is established and the evolution of the sedimentary basins is reconstructed.

The sedimentation began on a weathered gneiss surface with residual gravel and arkoses. An early carbonate sedimentation led to a severe alteration of the gneiss substratum.

Varved pelites and a magnetite-conglomerate with chert pebbles transgressed the earlier deposited sediments and the gneiss substratum; orthoquartzites were thereafter deposited in two basin structures.

The deposition of dolomitic shales and pelites appears to indicate progressively increasing depth. Large amounts of graded greywackes, interpreted as turbitides, bear witness of unstable tectonic conditions and a subaqueous tallus indicates nearby fault activity. Filled with greywackes the basins appear to have stabilized, and a comparatively uniform euxenic facies of carbonaceous shales and dolomites with preserved organic remnants prevailed independent of the earlier basins in a period of tectonic quiescence. A considerable thickness of pillow lavas then appears to have been extruded under conditions of quiet subsidence during the euxenic conditions shown by the existence of an anthracite-carbonaceous shale layer and the local facies relations on top of the pillow lavas. A new phase of sedimentation appears to have taken place under conditions of tectonic activity and explosive volcanism.

The total thickness of the Ketilidian strata in Grænseland is approximately 4400 m. This succession is compared with other areas of Ketilidian deposits in South-West Greenland.

The Ketilidian deposits were deformed in two periods of folding, accompanied by thrusting and metamorphism under low greenshist facies conditions. The first deformation is a local drag in incompetent horizons and is possibly related to the tilting and twisting of the basement surface. The second deformation is of regional importance but of very different development depending on the material affected and its position in relation to the sedimentary basins and earlier formed structures. Some areas are virtually undeformed. The basement reacted to the deformations by brecciation and faulting. An analysis of lineations in a thrust zone indicates that the initially formed lineations were twisted and bent towards the direction of tectonic transport.

A correlation, based on deformation of metadykes, is attempted with other areas of Ketilidian activity and it is suggested that the second deformation occurred close to 1635 m.y. and corresponds thus to the Sanerutian plutonic episode.

The Ketilidian (1800 m.y.? — 1500 m.y.) is envisaged as an orogenic cycle of deposition, folding and metamorphism beginning at and ending with major uncomformities. The basement gneisses are shown to contain evidence for two older (pre-Ketilidian) orogenic cycles.

CONTENTS

PREFACE

This paper is a description of an area of migmatitic basement gneisses unconformably overlain by well preserved Precambrian sediments and volcanics. The depositional and structural history of the rocks is presented and evidence is provided of the conditions prevailing during early Ketilidian time *i.e.* probably between 1700 m.y. and 2000 m.y. ago.

The area described is situated along the margin of the Inland Ice in the Ivigtut region (fig. 1) of South-West Greenland, and has been named Grænseland ("border land").

The field work was carried out as a part of the systematic mapping of the Ivigtut region (Ivigtut sheet 1:100 000 from 61°00′ N to 61°30′ N) by the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse – GGU). This mapping was begun in 1953, but the mapping of Grænseland was postponed because of the lack of maps until 1960, when excellent aerial photographs became available. Previous investigations of the area have been restricted to short traverses. The intention of the 1960 work was to make a reconnaissance map suitable for final publication on a scale of 1:100 000 and was carried out by A. Berthelsen (the region between Lappesø and Foselv) and the author. The results, however, were of such importance that further investigations were carried out by the author in the summer of 1961. Because of transport difficulties, the work of this summer was restricted to the area between Grænsesø and Foselv, and thus not all parts of the area have been mapped in the same degree of detail.

The areas immediately to the west of Grænseland have been mapped by L. F. Bonnard and his field maps have been of great assistance, especially in the southern part of the region. Parts of Grænseland were mapped in detail in 1961 by O. Larsen and J. Hansen (the area just north of Lappesø, part of the basement gneisses and an area near Vallen) and their results have been of great value in the preparation of this work.

Much of the material forming this paper has previously been presented as a prize dissertation at the University of Copenhagen (Bondesen, 1962). A brief review of the geology of Grænseland with a description of organic remnants and the isotopic composition of carbonaceous material has been published (Bondesen, Pedersen and Jørgensen, 1967). Fur-

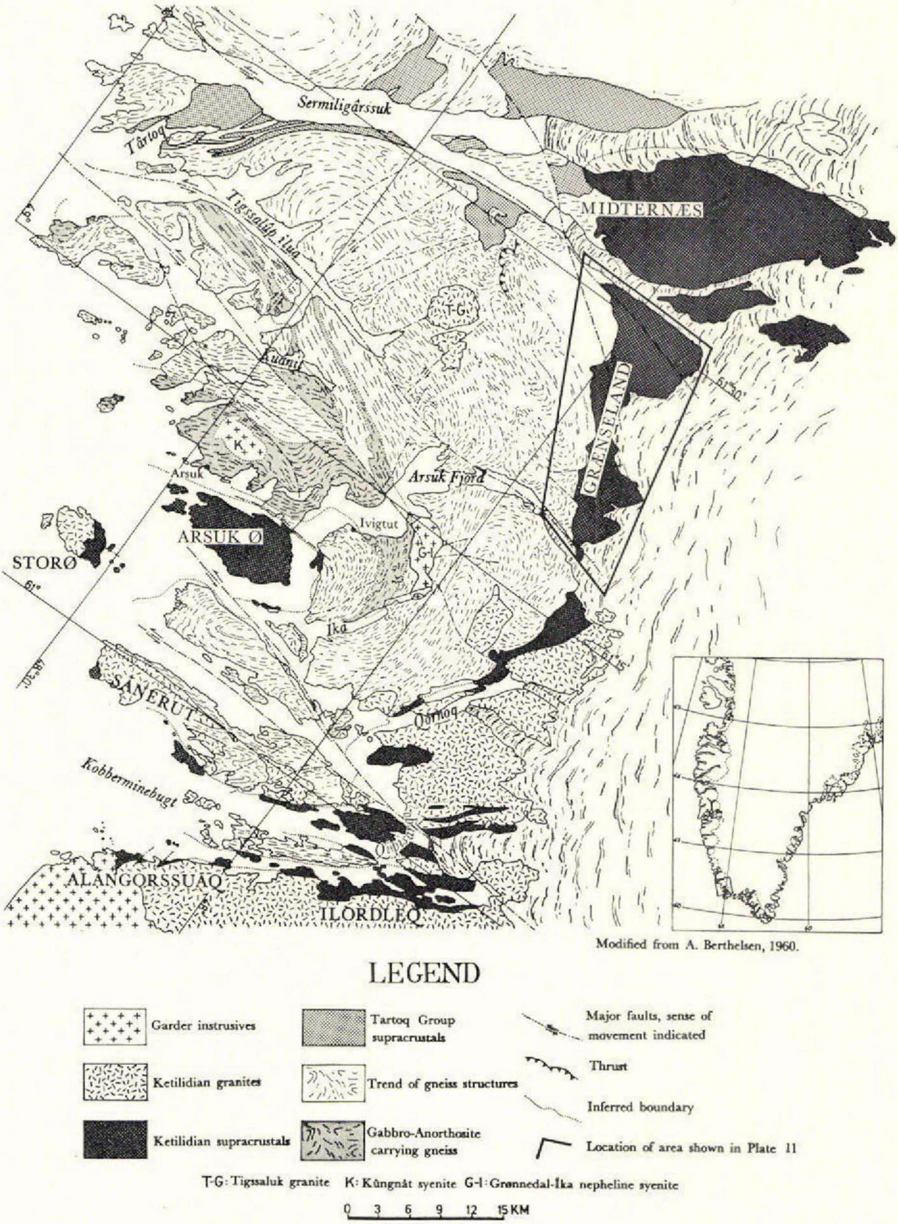


Fig. 1. Geological map of the Ivigtut region.

ther work on the organic material has been carried out by RAUNSGAARD PEDERSEN both regarding renewed collection in the field (PEDERSEN, 1966, p. 40; 1967; 1968, p. 51) and laboratory work (PEDERSEN and LAM, 1968; LAM and PEDERSEN, 1968).

An occurrence of axinite (Bondesen and Petersen, 1965) and some small sand volcanoes (Bondesen, 1966) have been described. Reviews on the geology of Grænseland have also been presented in accounts of various aspects of the geology of South-West Greenland (Berthelsen, 1965; Windley et al., 1966; Higgins and Bondesen, 1966).

The following description will fall in three main parts:

1) a brief account on the basement rocks, their structure and development,
2) a description of the stratigraphy of the Ketilidian and a discussion of the conditions during the Ketilidian sedimentation,
3) an analysis of the deformations during the Ketilidian orogenesis together with a short account on the metamorphism and a general synthesis of the Ketilidian events.

Finally a brief supplementary description of the geology of the Gardar period and the Quaternary in the area is presented.

INTRODUCTION

The area

The situation of the Grænseland area is shown in figs. 1 and 2.

The area between the fjords Arsuk Fjord and Sermiligârssuk is an uneven plateau deeply dissected by valleys. The summits of the plateau are in the coastal region about 400 to 600 metres above sea level, and gradually attain a higher level towards the east. Much of the plateau area is characterized by the occurrence of numerous lakes, and of comparatively small glacially eroded hills whose summits are rarely more than 300 m above the surrounding terrain. Exceptions to this general rule are the peaks of the Kûngnât massif and the Tigssaluk granite, which rise to altitudes of 1300 to 1400 metres.

In the Grænseland area the mean altitude is in the order of 900 metres above sea level, with the summits in the area near the Inland Ice reaching an altitude of 1000 to 1100 metres, about the same altitude as the fringe of the ice cap. However, the area differs in some respects from the general topographical pattern, partly because of its different geology.

The gneiss country to the west of Grænseland rises from below a sedimentary lowland to form a barrier with an altitude of 900 to 1000 metres, which is deeply dissected by a few canyons by which melt water torrents from the Inland Ice make their way to the lake depressions of the plateau and eventually to the sea. The gneiss barrier dams a row of north-south elongate lakes: Grænsesø (= border lake), Vallen (= the whey, named because of its turbid melt water) and Lappesø. From Lappesø a broad valley narrows to the south, receives the Foselv river from the east and deepens out to an imposing canyon as the river approaches the sea. Around and between the lakes, in comparatively low country, sedimentary rocks are exposed.

An escarpment 100 to 200 metres in height runs from north to south throughout Grænseland, to the east of the lakes and the sedimentary lowland. This feature can be followed beneath Blåisen (the blue ice) as a marked change in the ice topography, and outcrops as a small nunatak south-south-west of Vallen. The escarpment marks the beginning of the high eastern plateaus of Fønland and the area of upper Foselv, which are made up of massive volcanic rocks. In the southern part of Grænseland

Fig. 2. Oblique aerial photograph looking south over Grænseland. To the right (west) basement gneisses with amphibolite zones form ridges which project into the lakes as peninsulas. In the foreground is Vallen, north and south of which the bedding in graded greywackes is easily discernable. The south-west corner of the Fønland pillow lava area is seen in the lower left foreground. A large Gardar dolerite dyke is seen in the middle foreground. Note also the moraine ridge bordering the Inland Ice. The high mountainous region of the eastern Julianehåb district 200 km south-east of Grænseland is discernable on the horizon. (Reproduced by permission of the Geodætisk Institut, Copenhagen.

two "peninsulas" reach into the Inland Ice and are separated by Sortisen (the black ice). This country differs from Fønland in the several small narrow north-south valleys, *e.g.* Rendestenen, which are determined by tectonic features.

The southern and northern limits of the area are determined by steep cliff faces which drop to the Arsuk glacier and Sioralik glacier respectively. The glaciers themselves descend rapidly from approximately 800 metres altitude to sea-level. Grænseland is thus difficult to approach from either fjord, and the numerous melt water torrents from the ice cap restrict free movement within the area.

The area is extremely well exposed with extensive ice-polished surfaces but early in the summer large snow fans cover parts of the area. Moraine cover and vegetation is scarce; however, the sedimentary country commonly exhibits a surprisingly rich and abundant flora considering the extreme climatic conditions.

Regional geology and development of research

The first modern account on the geology of South Greenland was given by WEGMANN (1938, 1948), and this has formed the basis for the work carried out by members of GGU since 1953. As the mapping of the Ivigtut sheet progressed BERTHELSEN, in 1960, outlined the results in a general synthesis. The mapping of the Grænseland and the Midternæs areas, however, necessitated some modifications of this picture and of the earlier chronology. The revised chronology and a brief review of the previous work has been presented by HIGGINS and BONDESEN (1966).

The Ivigtut region (fig. 1) extends from Sermiligârssuk in the north to Kobberminebugt in the south. A belt of supracrustals – greenshists with pillow structures and metasediments – with migmatitic relations to the surrounding gneisses (AYRTON, 1963; WIEDMANN, 1964; WINDLEY et al., 1966) is found in the northernmost regions around Sermiligarssuk fjord.

These supracrustals – *the Târtoq Group* – are in Midternæs unconformably overlain by younger *Ketilidian* sediments (HIGGINS and BONDESEN, 1966). The Ketilidian supracrustals can be traced from Midternæs through Grænseland to Qôrnoq, to Qipisarqo and Kobberminebugt; they are also found in the Arsuk Ø – Storø area. The border relations between the Ketilidian supracrustals and the basement gneisses and migmatites grade from autochthonous in the north to allochthonous, tectonized, gneissified and granitized contacts in the south. The intensity of deformation, metamorphism and reactivation of the basement increases from north to south (WINDLEY et al., 1966).

The gneisses and migmatites of the central Ivigtut region – referred to the *pre-Ketilidian* (including the Târtoq Group) — are composed of a varied lithological sequence of gneisses, amphibolites and mica schists forming major gneiss divisions (BONDESEN and HENRIKSEN 1965, p. 7), one of the which is characterized by inclusions of hornblende-plagioclase rocks (gabbro-anorthosites). (BERTHELSEN, 1960 a, p. 46).

These gneiss divisions outline complicated fold structures which can be followed as a broad arch from a general east-west trending strike in the northern part, to north-south and again to an east-west trend in the southern part. The history of the structural development of the migmatites and gneisses seems to be that three phases of folding affected the material, of which the second was the major phase during which the main migmatitic structures were formed. Between the second and third phase of folding consolidation took place and ultrabasic bodies were emplaced. The third deformation was of a semiplastic nature and was accompanied by some migmatitization and granitization (BERTHELSEN, 1960 a, 1961; AYRTON, 1963; WEIDMANN, 1964).

The relations between the Târtoq Group supracrustals and the pre-Ketilidian gneisses and migmatites are uncertain. The third deformation in the northern part of the region affected both groups of rocks. Until the period of consolidation between the second and third deformation and the role of the ultrabasics occurring in close connection to the Târtoq Group have been further elucidated, it cannot be excluded that parts of the Ivigtut region belong to orogenic cycles older than that in which the Târtoq Group supracrustals were deposited and deformed.

The evolution of the Ivigtut gneiss complex was succeeded by the intrusion of basic dykes of several generations with various trends (BONDESEN and HENRIKSEN, 1965). Some of these cut the Târtoq Group supracrustals and some also the Ketilidian (see p. 180). The metamorphism and deformation of these dykes coincided largely with the increasing deformation and metamorphism of the Ketilidian supracrustals. In the southern part of the region synkinematic granites and augen gneisses were emplaced, and in the central part of the region a granite plug was intruded (EMELEUS, 1963).

In the Ilordleq area, south of Kobberminebugt, relations between Ketilidian granites, basic metadykes and the reactivation of granites justify the establishment of a late Ketilidian phase of plutonism – the *Sanerutian plutonic episode* (WATTERSON, 1965) – dating from 1650 m.y. to 1500 m.y., Farther to the south in the extensive Julianehåb granite area a complex chronological development of intrusive, metasomatic and reactivated granites, with inclusions and enclaves of supposed Ketilidian supracrustals and possible pre-Ketilidian rocks, occurs (ALLAART, 1964, 1967). South of this region supracrustals, referred to as Ketilidian, again outcrop in a NE-SW trending belt around Søndre Sermilik fjord (ESCHER, 1966).

In the *Gardar* period the whole of South Greenland was subjected to faulting and dyking, and plutonic complexes were emplaced. One of these, the well known Ilímaussaq batholith cuts through deeply dissected Julianehåb granite and Gardar continental sandstones and lavas. In the Ivigtut region the Kûngnât syenite complex (Upton, 1960), the Grønnedal nepheline syenites (Emeleus, 1964) and the Ivigtut granite and cryolite ore (Berthelsen, 1962) are some of the larger intrusive bodies, which with numerous dyke generations present a complex chronological pattern. Fault movements along major wrench faults reached the scale of several kilometres (Henriksen, 1960).

A young post-Gardar dyke swarm along the coast may be of Mesozoic age (Walton, 1966; Larsen, 1966).

The regional chronology of South-West Greenland has been under current discussion among GGU geologists for the last decade. Lately Allart (1967, p. 128) has reviewed this discussion and presented a chronological nomenclature, which takes into consideration also the material discussed in this paper.

An evaluation of isotopic age determinations from the region was presented by Bridgwater (1965), who also discussed the chronological possibilities. The ages determined range from 3520 m.y., which is a lead age from the central Ivigtut region, to 1012 m.y., which is a young Gardar alkali intrusion. The general chronological concept with isotopic ages and possible ages, modified from Bridgwater (1965), Larsen (1966, p. 57), Larsen and Møller (1968, p. 82), Jørgensen (1968, p. 87) is as follows:

Post-Gardar	164 m.y.
Gardar	1020–1275 m.y.
Ketilidian	1500–2000 m.y. ?
Târtoq Group	? 2500–2700 m.y. ?
Pre-Târtoq Group ?	>3000 m.y.

The main structural divisions

As an introduction to the geology of Grænseland a short description of the main structural divisions (fig. 3) will be presented.

The main structural divisions are:

1) The basement gneisses
2) The sedimentary division
3) The pillow lava division
4) The eastern thrust complex.

The boundaries between these main units are either original sedimentary contacts or tectonically modified contacts as is indicated on fig. 3:

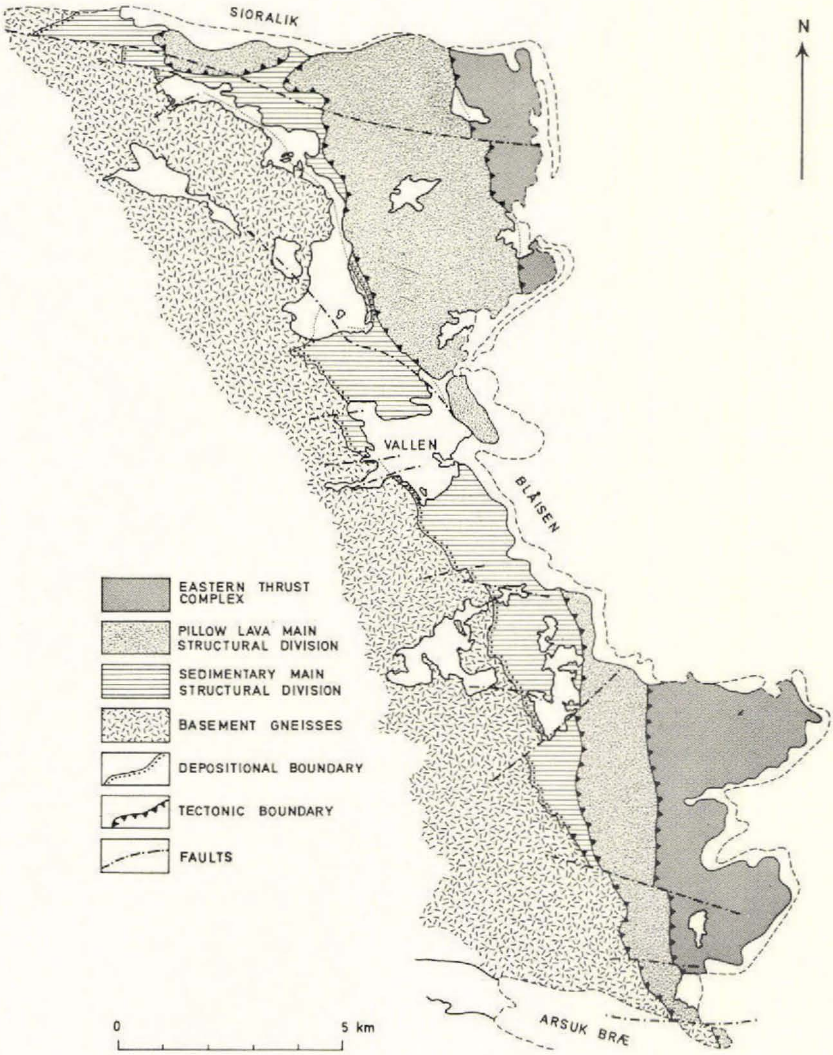


Fig. 3. The main structural divisions of the Grænseland area.

1) **The basement gneisses** outcrop throughout western Grænseland. They are bordered to the east by the unconformity at the base of the sedimentary division and to the west they grade into the gneisses of the central Ivigtut region. They vary from homogeneous nebulitic gneisses to streaky and banded biotite gneisses, and also include zones of banded amphibolites. They are older than the sediments and are referred to the pre-Ketilidian.

2) **The sedimentary division** rests unconformably on the basement gneisses and is referred to the Ketilidian. The original sedimen-

tary contact is preserved over the major part of the area. The sedimentary sequence has developed in two sedimentary basins and consists of dolomites, shales, quartzites and pelites, and in the upper part of graded greywackes which are cut off on various levels by an eastward-dipping transgressive thrust at the base of the pillow lava division.

3) **The pillow lava division** is in its lowest part characterized by dolomites, shales, and cherts, but the major part of the sequence consists of very slightly deformed pillow lavas which have been intruded by numerous sills. Within the pillow lavas local bands of sediments and pyroclastics occur.

4) **The eastern thrust complex** consists of several minor thrust units and is separated from the pillow lava division by a major eastward dipping thrust. The lower part is characterized by dolomites, pelites and thick pyroclastic deposits and the upper part by pelites and greywackes. The succession is intruded by several thick basic bodies.

The basement gneisses have a long history of development prior to the formation of the three main supracrustal structural divisions, and they are therefore treated separately in the next section.

THE BASEMENT GNEISSES

The material

The basement gneisses have been mapped in a sector along the border of the Grænseland supracrustals, as indicated on the geological map (plate 11). In the following pages the field relations and also some microscopic characteristics of the gneisses and related rock types will be described.

In general the rocks can be devided on a regional basis into three groups:

1) a northern area of mainly uniform gneisses extending from the Sioralik glacier to the area west of Vallen,
2) an area west of Zigzagland composed of homogeneous, streaky and banded gneisses grading into amphibolites,
3) an area from the west of Lappesø to the Arsuk glacier consisting mainly of banded rocks.

As can be seen from the geological map (plate 11) the rocks of area 3 are a direct continuation along the strike of those of area 2. The abovementioned division have thus no relation to the structures and is only established for practical reasons.

In accordance with the migmatite terminology proposed by Berthelsen (in Sørensen, 1961) and in general use among GGU geologists the uniform gneisses may be described as homogeneous gneisses. Other structural descriptive terms used in this section are in accordance with the same scheme.

1. The northern area

In the northern part of the area near the Sioralik glacier homogeneous granodioritic to granitic gneisses occur. The same rocks also outcrop to the west and as far as the southern end of Grænsesø. The rocks are massive, white or locally pink in colour, generally fine- to medium-grained and rarely coarse-grained. The most commonly seen structural elements are lenticles of platy quartz, which may show a linear arrangement. Measurements of the orientations of the platy quartz did not show any clear structural pattern on a macroscopic scale.

The monotony of the homogeneous gneisses is rarely interrupted by darker lenses and bands comparatively rich in mafic minerals so that nebulitic gneisses appear. At three localities dark bands were observed to be discordant to the quartz foliation of the homogeneous gneisses and in one case 'en bayonet' characters and apophyses were noted (53086)[1]. These bands are clearly the remnants of metadykes. The dykes are in places almost obliterated and are locally completely absorbed within the gneisses. They clearly predate the metadyke generations described on p. 180.

A common feature of the homogeneous and nebulitic gneisses in the area of the southern part of Grænsesø is the occurrence of small patches of quartzo-feldspathic rocks with a micrographic texture. This phenomenon is also encountered near recrystallized movement zones, similar to the plasto-mylonites described by Berthelsen (1950, p. 561; 1960 b, p. 186).

Along the east coast of Bæversø a belt of folded chloritized amphibolite can be followed for some hundreds of metres. The rocks seem to be extremely basic, locally with actinolite and talc and magnetite concentrated in bands. The strongly altered amphibolite is schistose and the schistosity is folded.

Pegmatites and veins are very infrequent. A few thin aplitic veins occur in the southern part of the area, and appear to become more common towards the south.

A few quartz veins, up to 1 m wide, occur in a NNW-striking joint system, and close to the border of the Grænseland supracrustals two small quartz-tourmaline-muscovite pegmatites have been observed. A vein development, connected to fissures, consisting almost exclusively of tourmaline (20876) and accompanied by strong bleaching of the country rock has also been found close to the border of the supracrustals. Quartz veins with a peculiar breccia structure have been found three kilometres west of the border (20916). These veins and pegmatites are believed to be related to the Ketilidian (see p. 20 and p. 32).

The gneisses south-west of Grænsesø and west of Vallen are still generally homogeneous, but are somewhat richer in veins and locally in dark minerals. Streaky gneiss types gradually become prevalent, especially in the western part of the area. Locally banded gneisses occur and these may contain inclusions of talc-chlorite-calcite rocks (20863) arranged concordantly to the gneiss structures.

The thin sections of a series of homogeneous gneisses and nebulitic gneisses (53009, 53010, 53013, 20869, 52976, 52965) all show the same general relations although the quantitative mineral composition varies.

Thus specimen 52965 is a quartz-dioritic gneiss, specimen 53010 is of granitic composition with microcline as the dominant feldspar, whilst most of the remainder

[1]) The numbering is GGU sample numbers.

of the samples are classified as of granodioritic composition. The proportion of quartz varies from 15% (53010) to 40% (52976). Quartz occurs generally in large composite grains with undulatory extinction, often arranged in elongated groups corresponding to the mesoscopic rock texture. Plagioclase is generally the most common mineral, sometimes well preserved with good twinning (An_{28} to An_{35}), but most often strongly saussuritized and sericitized and the composition is difficult to determine. In one sample of granitic composition (53010) plagioclase of An_4 to An_{12} was observed. The large primary plagioclase grains are usually recrystallized along their borders and along cleavage and twin-planes to small droplets of untwinned feldspar of low refractive index, possibly albite. Microcline occurs in large primary as well as smaller interstitial grains. Patch perthites are common.

Of the minor constituents muscovite is the most common, occuring in large and smaller flakes, and may make up as much as 15% of the rock. It also occurs as a secondary alteration product after biotite. Biotite is usually found as relic crystals strongly altered to muscovite and chlorite. Chlorite occurs as feebly pleochroic flakes with anomalous interference colours. Large grains of carbonate are common. Opaque ore minerals occasionally occur in irregular grains and a reddish pigmentation, possibly secondary after ore minerals, is widespread.

Apatite, tourmaline, pyrite and sphene occur in accessory amounts. Rounded and prismatic zircons occur enclosed in biotite and quartz crystals.

A thin section of a dark grey discordant band (metadyke) (53086) showed a heterogranoblastic texture with strongly altered plagioclase, quartz, muscovite, chlorite (yellowish to grass-green pleochroism and blue anomalous interference colours), a carbonate mineral and biotite with feeble brownish pleochroism. The textures of the chlorite suggest that it is secondary, possibly after hornblende.

A thin section (20873) of a talc-chlorite-carbonate lens from the area south-west of Græznsesø also revealed tremolite ($c \wedge z$ approximately 10°) and altered and unaltered plagioclase with inclusions of quartz and ore. The lenses are transected by pegmatite and quartz veins.

Sample No. 20876 of a vein of almost exclusively tourmaline also showed very minor amounts of quartz, plagioclase (albite) and muscovite. The veins are accompanied by a bleaching of the country rock, but the thin section of this rock did not show any difference from the surrounding rock apart from stronger alterations of the mafics. Tourmaline is also associated with a quartz vein with a breccia-like structure. The grain shape and the texture of this rock (20916) suggest a sedimentary origin for some of the quartz grains and it is thought that this may be related to Ketilidian sedimentation.

2) The area west of Zigzagland

The gneisses in the area west of Zigzagland exhibit a regular repetition, in broad zones, of several oriented rock types. The general strike is between 160° and 180° with only minor variations, and the dip is generally steep to vertical.

Homogeneous gneisses occur close to the border of the Ketilidian supracrustals. South-westwards the gneisses gradually become streaky and eventually banded. An approximately 100 m wide zone of banded gneisses is succeeded by banded amphibolites which grade into more massive amphibolite. The banded zones can be strongly folded (fig. 4). To the south-west of the massive amphibolite a similar zoning is apparent

Fig. 4. Small-scale folds in banded biotite gneiss. Some of the bands exhibit a grading and an internal fine-scale banding, which suggests that they may be of sedimentary origin. The strong plastic deformation has the character of drag folding. From the banded zones south-west of Vallen. (O. LARSEN phot.)

as the amphibolitic rock gives way to banded gneisses, streaky gneisses and then to a broad zone of homogeneous gneisses or very homogeneous streaky nebulites. In the extreme western part of the area a similar repetition of a very broad zone of amphibolites and banded rocks occurs. Thus two zones of banded rocks can be followed towards the north with a gradual disappearance of their banded nature, and towards the south increasing in width. The westernmost belt occupies most of the area from south-west of Lappesø to Arsuk Fjord.

The zones of homogeneous gneisses in the area west of Zigzagland are very similar in nature to the rocks of the northern Grænseland area described above. A few melanocratic and isolated inclusions occur. In an area close to the south-west shore of lake Vallen dark interconnected and angular patches up to 50 cm wide occur in the homogeneous gneisses.

The patches seem to be arranged in a few metres wide lenticular zone subparallel to the general strike of the banded rocks found farther to the south-west. These trains of dark patches are not agmatites but resemble more a breccia of the light homogeneous gneiss in a dark matrix.

The samples 53023, 53024 and 53035 are light homogeneous gneisses without any visible orientation. The thin sections show a heterogranoblastic texture dominated by quartz and altered, sericitized plagioclase (An_{32}). A few small grains of albitic plagioclase have been seen. Chlorite, muscovite, epidote and carbonate minerals are common. The chlorite appears to be mainly secondary after biotite. Very little microcline is apparent. The composition is thus quartz-dioritic, apart from sample 53023 which is granodioritic. Rounded small zircons enclosed in quartz are quite common in sample 53023, which also contains tourmaline. Apatite and ore are accessories.

The streakly gneisses are microscopically very similar to the homogeneous gneisses, apart from a larger content of mafics, containing biotite altered to chlorite and epidote-chlorite patches apparently secondary after amphiboles.

The banded gneisses, which grade into amphibolites, show an increase in mafic minerals relative to the streaky gneisses and the nebulites. The light quartzo-feldspathic bands (20848) contain quartz (dominating), sericitized and saussuritized plagioclase (An_{26}), a little biotite, altered amphibole (yellowish to greenish pleochroism), epidote and apatite. The dark bands (20849) have quartz and plagioclase in proportions 2 to 1, chloritized biotite, amphiboles (hornblende with strong green pleochroism) and ore; however, the mafics may make up to 30% of the bulk.

The banded amphibolites (20842, 20843, 20844, 20845 and 20846) contain 10–20% quartz, 30% of altered plagioclase (An_{30}), a recrystallized unaltered albitic plagioclase, and approximately 50% of mafics. The mafics are mainly amphiboles (hornblende and actinolite), chlorite, biotite, carbonate, sphene, ore, a few rounded zircons and apatite. The central part of the banded amphibolite zone is strongly sheared, and characterized by the occurence of chlorite and carbonate minerals, as well as fillings with a yellow carbonate rock (see p. 35). The shear zone, possibly an old rejuvenated fault line, is clearly visible on aerial photographs (fig. 2) (see p. 24).

The banded and streaky gneisses and homogeneous gneisses, which divide the two banded zones, show microscopically better preserved minerals, although some alteration is apparent. Sample 53076 is a quartz- and microcline-rich gneiss from the intermediate zone. The plagioclases have sutured margins and patch perthite is prominent. Large idiomorphic epidote-allanite grains, biotite strongly altered to chlorite, muscovite and carbonates, are the remaining sparsely represented minerals. A banded gneiss (53175) also showing heterogranoblastic texture, contains quartz, altered plagioclase, biotite of yellow-brown pleochroism, muscovite, pale green pleochroic chlorite, epidote-allanite, sphene and apatite. Small rounded zircons in biotite with pleochroic haloes have been observed. Some of the mafics appear to be secondary after amphiboles.

Samples from the amphibolites (53169, 53170, 53171, 53173) all show a similar mineral content of varying proportions. Altered plagioclase, which in one case has been determined to be of a composition of An_{37}, is locally recrystallized to small grains of low refractive index, which are possibly albite. Hornblende, pleochroic from yellow to pale green, green and in some cases brown, dominates. It may be altered to non-pleochroic amphibole, biotite, chlorite and epidote. Primary biotite is well preserved. Quartz, calcite, sphene, ore, apatite and muscovite are minor constituents. The texture of the rocks is dominated by the amphiboles and in sample 53171 it can be described as lepidoblastic.

Locally a feldspathic augen texture is developed in these amphibolites and the coarser textured rocks may bear a superficial resemblance to the gabbro-anorthosites (Berthelsen, 1960 a; Ayrton, 1963, p. 21) which are found elsewhere in the Ivigtut region. The specimen 53173 is, however, too much altered to permit any petrographical comparisons with the gabbro-anorthosites. The plagioclases are strongly altered to minerals of the epidote group which suggest that the plagioclases had a high anorthite content. Quartz, hornblende, biotite, chlorite and sphene are also present.

3) The southern area

In the area north of Lappesø basic inclusions, arranged in rows and related to gneisses and schists of a banded "metasedimentary" appearance, occur within the more or less homogeneous quartzo-feldspathic gneisses. The lenses are strongly deformed. Samples from the lenses (20838, 20839 and 20840) are composed of chlorite, carbonate, some biotite and a little quartz. The specimen 20838 also contains talc. The almost ultramafic inclusions consist of a fine asbestos mass of tremolite and chlorite with accessory amounts of quartz and feldspar (20847).

West of Lappesø the rocks from the western part of the area west of Zigzagland can be traced into the area of the Arsuk glacier. The zone of banded gneisses and amphibolites is here comparatively wider and massive amphibolite bands are more prominent. The amphibolites are ore-bearing and carry bands and streaks of solid magnetite. The rock succession of "metasedimentary" appearance is also more conspicuous and the inclusions of ultrabasics are larger and more frequent. The ultramafic bodies vary from hornblendites to pure tremolite rocks and soapstones. The soapstones consist more or less entirely of talc (26328) with only very little ore. A regular porphyroblastic growth of a carbonate mineral is common in these soapstones.

Although the banded amphibolites are dominant, banded biotite gneisses and streaky gneiss types are fairly common. The proportion of homogeneous gneisses and nebulites is reduced to a narrow band along the west coast of Lappesø. The general steep orientation of the rocks from further north still prevails, but more and more varied orientations are encountered and parts of larger fold structures can be mapped. West of the banded succession less banded and foliated gneisses occur.

The structures

The general structure of the basement gneisses is shown on the geological map of plate 11.

In the northern part of the area only vague linear structures are apparent and these do not appear to be related to any macroscopic fold structures. A general directional pattern first becomes established near Bæversø.

Towards the south planar structures become more common and reach their greatest development in the two well foliated banded groups with a zonal arrangement of less well foliated rocks on either side. These bands can be traced throughout the area to the Arsuk glacier or to where they disappear beneath the Ketilidian supracrustals. The fold structures in the bands are on too small a scale to be shown on the map. In the southern part of the area the steep orientation locally varies and outlines parts of large possibly isoclinal structures, and also monoclines.

West of Grænseland WIEDMANN (1964) and BONNARD (1963) have mapped large open anticlines and steep tight synclines in gneisses which form the direct continuation of the rocks here described. In the area near Bikuben WEIDMANN has mapped a thrust zone where the homogeneous gneisses of the northern part of the area are thrusted over banded migmatites and agmatites. This thrust zone is not found in Grænseland, but it is possible that it grades into a steep narrow shear zone which outcrops in the eastern amphibolite group west of Zigzagland, a proposal put forward by BERTHELSEN (1962, p. 7). The thrust movements have been dated by WEIDMANN (1964, p. 120) as later than the migmatization of the gneisses and prior to the emplacement of metadykes, and the same chronology appears to hold for the steep fault in Grænseland.

Small-scale structures of the type illustrated in fig. 4 and 5 are common in the banded zones. Many of the folds are isolated relic structures with larger pegmatite veins or new banded structures imposed upon their flanks. Zones of strong drag folding are also common (fig. 4).

A lineation in the amphibolites is generally sub-horizontal and is parallel to the axes of mesoscopic isoclinal folds (fig. 5). The axes plunge generally to the south, and the angle of plunge never exceeds 25°. The mesoscopic isoclines have been observed to be deformed by a folding about steeply plunging axes which produced double fold interference patterns and also deformed the amphibolite lineations. Both sets of folds are of regional distribution and have apparently been formed in a highly mobile stage accompanied by the development of migmatitic veins; they are therefore considered to be associated with the plutonic development of the basement gneisses.

The small-scale structures do not give any definite clue to the position and existence of large-scale regional structures. However, it is possible that the structures in the gneiss area mapped may represent open anticlines and tight synclines similar to those found further west and northwest in the Stabelland area (WEIDMANN, 1964, p. 110–113). The homogeneous gneisses may occupy anticlinal fold scores and correspond to the strongest degree of granitization. The banded and basic rocks might, as locally indicated by drag fold orientation, occupy compressed synclinal structures, as has also been suggested by AYRTON (1963, p. 56) and WEID-

Fig. 5. Mesoscopic fold in banded amphibolite related to the first phase of folding in the basement gneisses. A large pegmatite bounds the fold on the right of the photograph. The irregular fracturing of the amphibolite is thought to be partly the reaction of the basement to the first phase of the Ketilidian deformation (see p. 116). Locality in the eastern amphibolite zone in Zigzagland.

MANN (1964, p. 113). However, it is also possible that the homogeneous cores of the culminating structures could represent structures of a still older cycle, since from a petrographic point of view these rocks have been through a much more complex development than the oriented and more basic rocks. The areas of the homogeneous gneisses also represent the lowest structural level as the axial plunge of the main structures in the area is towards the south (BERTHELSEN, 1960, fig. 1), and to the north in the Stabelland area the plunge is to the north-west (WEIDMANN, 1964, fig. 51, plate 6).

Faults older than the sub-Ketilidian surface transect the gneiss structures. One fault parallel to the south-west coast of Vallen with a trend of 150° can be traced to the border of the Ketilidian but does not displace the sediments. This fault is parallel to the shear zone already mentioned in the eastern amphibolite band, and also to faults in the southern part of the area which predate metadykes. There is also a striking parallelism to the major Bæversø fault (plate 12) which although displacing the Ketilidian sediments and Gardar dykes may also have moved during sedimentation, and may have originated at an earlier date (see p. 133).

A joint pattern can be shown to have existed in the gneisses prior to Ketilidian sedimentation (see p. 34).

Petrogenetic considerations and metamorphism

It seems probable that some of the material which makes up the basement rocks was originally sedimentary. The existence of rounded zircons in the nebulitic division as well as in the banded rocks supports this suggestion, as does the occurrence of graded banded structures, and gneisses and schists of a "metasedimentary" appearance. The amphibolitic rocks may have originally been basic volcanics or calcareous sediments. Granitized relics of basic dykes have been noted.

The lenses of ultrabasic rocks could originally have been serpentinites. A detailed study by Weidmann (1964) in the area west of Grænseland has shown that serpentinites were intruded prior as well as subsequent to the main episode of migmatitization and deformation. The ultramafic rocks may represent the transformed relics of original subconcordant sills.

The plutonic activity which occured during the main deformation of the basement gneisses resulted in a concentration of quartzo-feldspatic material and the formation of the migmatites. Sub-concordant pegmatite veins were developed during a late phase of this activity.

The varied composition of the homogeneous gneisses suggests that they were of varied composition prior to homogenization. The homogenization (granitization) occurred both prior and subsequent to the intrusion of dykes in an intervening period of consolidation. Secondary microcline and perthites are the traces of a late episode of plutonic activity which could be termed granitization.

The platy quartz structures were developed before the late granitization and earlier than the dyke intrusion.

The pressure/temperature conditions under which the gneisses were metamorphosed correspond to amphibolite facies, to judge from the composition of the plagioclase and hornblende. Later these minerals became unstable during a retrogressive phase of metamorphism. The new equilibrium conditions in the northern part of the area correspond to low greenschist facies, and in the southern part of the area, where chlorite and biotite were stable, to high greenschist facies. The metamorphic conditions of the rocks correspond to the facies relations found in the supracrustals (see fig. 66), and it is therefore possible that this diaphthoresis took place in the Ketilidian period. However, it cannot be excluded that retrogressive metamorphism occured both in pre-Ketilidian and in Ketilidian time.

The metamorphism related to Ketilidian deformation will be discussed in a later section (p. 171).

The development of the basement rocks

The development of the basement rocks of the Grænseland area cannot be regarded in isolation, but must be considered in relation to the development of the large gneiss-migmatite complex of the central Ivigtut region. The general development of this region has been outlined on page 13.

It has already been mentioned that the nebulitic gneisses of the northern part of the area grade into the banded gneisses of the two zones of Zigzagland farther to the south (plate 11). These banded rocks also seem to grade continuosly into the gneisses and migmatites farther west. With respect to the northern part of the area there is also the possibility that the homogeneous gneisses containing the banded zones may be a thrust wedge as they are bounded to the west by an eastward-dipping thrust (WEIDMANN, 1964) .The thrust overrides migmatites which were derived from Târtoq Group supracrustals.

The Târtoq Group supracrustals have migmatitic border relations to the adjacent rocks (WIEDMANN, 1964; AYRTON, 1963; WINDLEY et al., 1966). It also seems probable that there is a general structural conformity between migmatites below the Târtoq Group supracrustals and the migmatites and gneisses in the central Ivigtut area (BERTHELSEN, 1960a, fig. 1), although some contrasting and disharmonic structures are known, especially in the northern and north-western part of the area. It would therefore be tempting to regard the whole Ivigtut gneiss-migmatite complex as of an age similar to that of the Târtoq Group and to have developed during three phases of deformation and migmatitization (BERTHELSEN, 1960; HIGGINS and BONDESEN, 1966). This would be more or less in accordance with previous views except that these phases would be events of the pre-Ketilidian and not the Ketilidian as originally described by several authors (AYRTON, 1963; WEIDMANN, 1964; BERTHELSEN, 1960 and 1961; BONDESEN, 1964).

However, some doubts remain, and there is a possibility that the migmatites formed from the Târtoq Group have a limited extension and that a still older basement exist in the Ivigtut region (HIGGINS and BONDESEN, 1966). The main doubts concern the significance of the existence of a period of consolidation after the main migmatitic phase of the central Ivigtut gneisses and before the folding and migmatization of the Târtoq Group supracrustals a period during which ultrabasics (dunites and serpentinites) were emplaced (BONDESEN, 1964, p. 31).

Table 1.

	Alternative A	Alternative B
Ketilidian	deposition	deposition
	—— sub-Ketilidian surface ——	
	faulting (NNW) folding and migmatization (granitization)	faulting (NNW) folding and migmatization (granitization)
	consolidation and intrusion of ultrabasics	deposition – ultrabasics related to initial volcanism – Târtoq supracrustals.
pre-Ketilidian	folding and migmatization (granitization)	—— consolidation – erosion ——
	deposition (Târtoq Group supracrustals)	folding and migmatization (granitization)
	(older cycle?)	deposition (? emplacement of gabbro-anorthosites?)
		(older cycle?)

Also the structural complications in the northern and north-western part of the Ivigtut area (BERTHELSEN, 1960, fig. 2), where the lithological units of the central Ivigtut gneisses (including the gabbro-anorthosite carrying gneisses) converge to the trend of the Târtoq Group supracrustal and their conformable migmatites, may be considered in respect to the existence of an old pre-Târtoq Group basement. To this may be added the evidence from the nebulites of Grænseland, which were granitized twice, and the occurrence of ghostly metadykes which most likely have been emplaced in solid rocks.

As limited information is available from the basement rocks of Grænseland, and the chronological relations of the gneisses in the central Ivigtut region, to which the Grænseland rocks seem to be closest related, are uncertain, it is preferred to refer the basement rock of the area as a whole to the pre-Ketilidian. In this pre-Ketilidian epoch a development such as either of those listed in table 1 A and B, could be considered.

THE KETILIDIAN

Definition and subdivision

The Ketilidian period was defined by WEGMANN (1938, p. 13) as the period of the Precambrian orogenic cycle which involved the sedimentation of the Sermilik group, the extrusion of the Arsuk group volcanics, and the folding, granitization and migmatization of this and also older pre-Ketilidian material. The Sermilik group was established at Sermilik fjord 250 km south-west of Grænseland and the Arsuk group on Arsuk Ø which is situated 45 km west of Grænseland.

In this paper the Ketilidian is regarded as a period of deposition, folding and metamorphism. It extends from the time of deposition of the first local pockets of sediment on the old sub-Ketilidian surface, to the formation of the next important erosion surface known in south Greenland – the sub-Gardar peneplain. It thus includes all the events comprising Wegmann's Ketilidian cycle. However, it is used in a wider sense than the term Ketilidian as employed by BERTHELSEN (1961) and WATTERSON (1965) who recognized two periods, the Kuanitic and the Sanerutian, between the close of the Ketilidian and the beginning of the Gardar. The term Ketilidian is used in the same sense as used by ALLAART (1967, p. 8), who abandons the terms Kuanitic and Sanerutian and includes these periods in the Ketilidian.

In the definition stated above the author follows the general practice of using major unconformities as the main time markers which must also be the basis of division of the Precambrian, rather than plutonic episodes (SIDORENKO, 1963; SUTTON, 1965).

In the light of the more complete and better known Ketilidian succession found in Grænseland this area has been chosen as the type area (BERTHELSEN, 1965, p. 120) and two major lithostratigraphic units have been established:

1) *The Vallen Group* – named after the lake Vallen, and composed of the sedimentary succession from the basal unconformity to the first appearance of volcanics.
2) *The Sortis Group* – named after the glacier tongue Sortisen (the black ice) and composed principally of volcanics and sediments.

The top is unknown in Grænseland, but may be taken as the base Qipisarqo Group (BERTHELSEN, 1965).

In the Kobbermine bugt region (fig. 1) a thick supracrustal succession occurs structurally higher than the Vallen Group and the Sortis Group. These supracrustals are divided into the Qipisarqo Group (BERTHELSEN, 1965), composed mainly of sediments, and the Ilordleq Group (ALLAART et al., in press), composed of sediments and volcanics, and are regarded as stratigraphical units higher than the Sortis Group (see also p. 136).

The Vallen Group and the Sortis Group, which here are preferred as formal units, correspond roughly to the Sermilik group and the Arsuk group of WEGMANN. The further stratigraphic subdivision of the new major units is given in the section on the stratigraphy of the Ketilidian (p. 35).

As an introduction to this section a chapter dealing with the phenomena associated with the sub-Ketilidian sedimentary surface is presented.

The sub-Ketilidian surface

The sub-Ketilidian surface has been observed at intervals all along the sedimentary border. It can be studied in the northern part of the area north of Grænsesø and on two small peninsulas in the middle of Grænsesø. It is also exposed in the area between Grænsesø and Vallen, and from Vallen to a point approximately 2 km south of Lappesø.

In the Grænsesø region the sub-Ketilidian surface dips towards the east at angles between 10° and 20°, with locally steeper dips near the fault north of Grænsesø. For most of the exposed distance between Grænsesø and Lappesø the eastward-inclined surface dips at about 20° to 30°. South of Lappesø the angle of inclination increases to about 45°. Over the distance exposed only a narrow sector of the sub-Ketilidian surface can be reconstructed (fig. 6).

On a large scale the plane shows a varying degree of curvature, of which the major bulge near southern Grænsesø coincides with stratigraphical thinning and seems to be of significance with respect to the development of sedimentary basins (see p. 131). A minor mappable unevenness of the plane corresponds closely to the plunge of the axes of the Ketilidian second phase folds. Generally, the plane of the sub-Ketilidian surface seems to be more steeply inclined in the southern part of the area and this is also evident in the general attitude of the bedding planes of the lowest Ketilidian sediments. Correcting for the varied inclinations it would appear that the surface was generally even on a large scale, and may have been part of a peneplain.

On a mesoscopic scale the detailed topography of the sub-Ketilidian surface shows many minor irregularities, but these generally have rounded outlines and never rise more than a few metres above the general level of the surface.

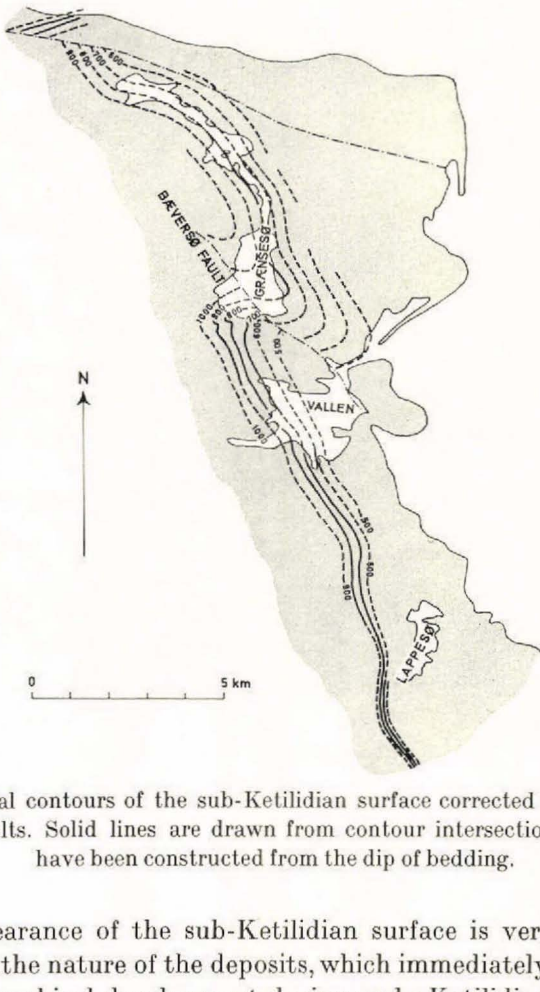


Fig. 6. Structural contours of the sub-Ketilidian surface corrected for displacement along minor faults. Solid lines are drawn from contour intersections. Dashed lines have been constructed from the dip of bedding.

The appearance of the sub-Ketilidian surface is very variable depending upon the nature of the deposits, which immediately overlie it, and the paleogeographical development during early Ketilidian deposition.

In the area south of the Sioralik glacier quartzites were deposited directly on top of the gneisses. In a narrow zone 10–30 cm thick the gneisses are altered to a grey-black rock of fine-grained material (sericite and chlorite) with quartz preserved and reflecting the original texture of the homogeneous gneiss. Along the west side of Grænsesø scattered patches of a similar grey altered gneiss are seen, although no overlying sediments are apparent here. The whole eastern slope of the homogeneous gneisses west of Grænsesø possibly more or less corresponds to the sub-Ketilidian plain. Further evidence pointing towards the close proximity of the sub-

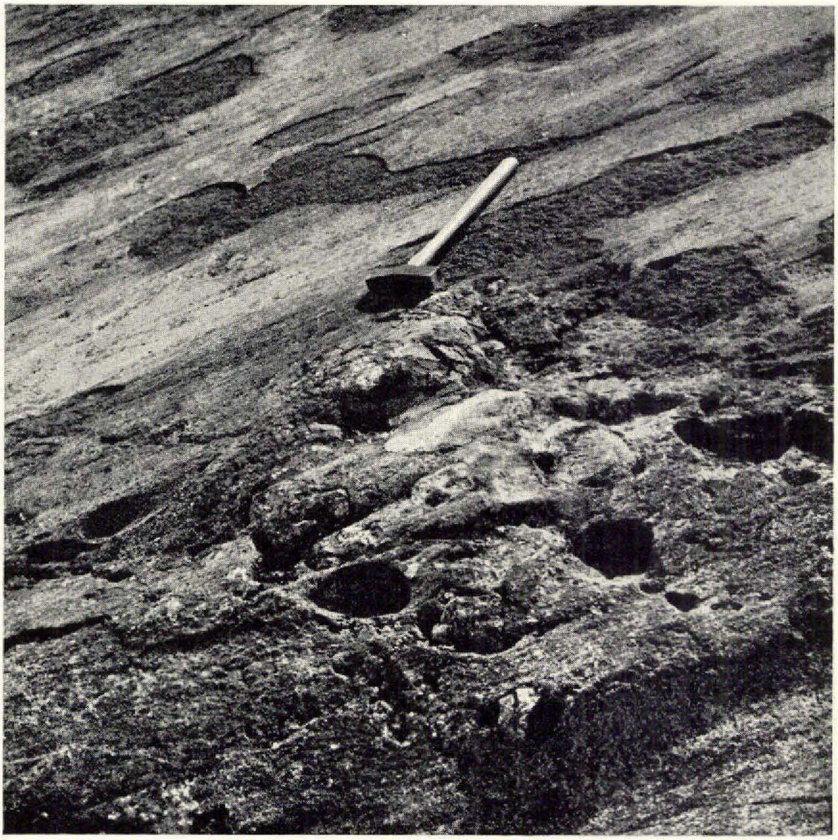


Fig. 7. Casts of boulders and boulders of cherty quartzite resting in coarse uncarbonatized arkose of the Lower Zigzagland Formation immediately south-west of Grænsesø. The boulders possibly represent the lower part of the Ore-Conglomerate Member of the Upper Zigzagland Formation. The arkose has an exfoliation mantle bearing strong recent glacial striations.

Ketilidian surface in the gneisses west of Grænsesø is seen in the occurrence of a quartz vein containing tourmaline and quartz grains of probable sedimentary origin, on the summit 1094 m west of the southern part of Grænsesø (20916, p. 19). It is suggested that the vein may originally have been an open fissure on the sub-Ketilidian plain which was filled in by sedimentary of material colour.

Between Grænsesø and Vallen the gneisses are overlain by the conglomeratic member at the base of the Upper Zigzagland Formation (the lowest formation of the Vallen Group). Here small basins with preserved arkose deposits and rounded gneiss boulders are occasionally seen between the transgressive conglomerate and the gneiss basement (fig. 7). Beneath the conglomerate the gneiss surface is black in colour and below the arkose deposits of a rusty red colour.

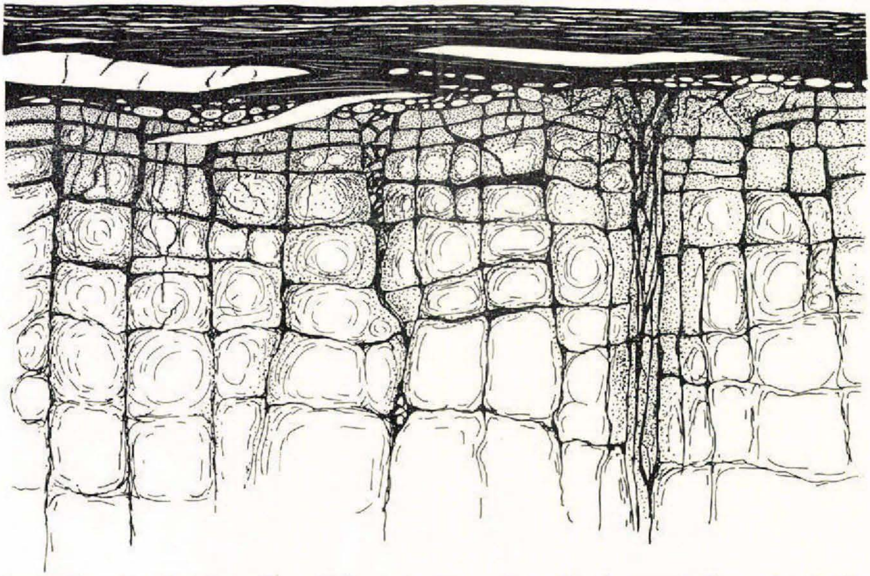


Fig. 8. Drawing to show the relations in the carbonatized zone in Zigzagland. The drawing shows a profile through the lowest Ketilidian deposits of dolomite (black), conglomerates and arkose. The white lensoid bodies represent chert. The structure of the carbonatized gneisses below the sub-Ketilidian surface is indicated by dolomite veins filling joint fissures but also in the upper part cutting through the joint blocks. Breccia structures are related to open fissure systems. The concentric "onion" structure of the joint blocks is indicated. The vertical section represents approximately 15 m. The joint blocks are thus not drawn on scale.

The altered gneiss area extends from the gneiss surface to a depth of 1–10 m. In thin section (52108 and 52976) the gneiss shows strongly or completely altered feldspars, with chlorite and non-pleochroic micas (muscovite or sericite) as alteration products, and with quartz, carbonate and some disseminated secondary ore grains. The gneissic texture of the rock is however still preserved (plate 2a).

Along the west shore and to the south of Vallen the Lower Zigzagland Formation always comprises calcareous rocks in its lowest part. Below these sediments the gneisses are strongly altered with carbonate minerals (carbonatized) as are local deposits of polymictic conglomerates which rest directly on the sub-Ketilidian surface. The intensity of the alteration (carbonatization) decreases downwards into the gneisses, and also decreases towards the northern part of the Vallen region where the sedimentary carbonate member is thinner and eventually disappears.

A schematic representation of the relations in the carbonatized zone of the gneisses below the sub-Ketilidian surface in Zigzagland is given in fig. 8. In the upper part a network of carbonate veins penetrates the carbonatized gneisses and the conglomerate. The network of veins resembles

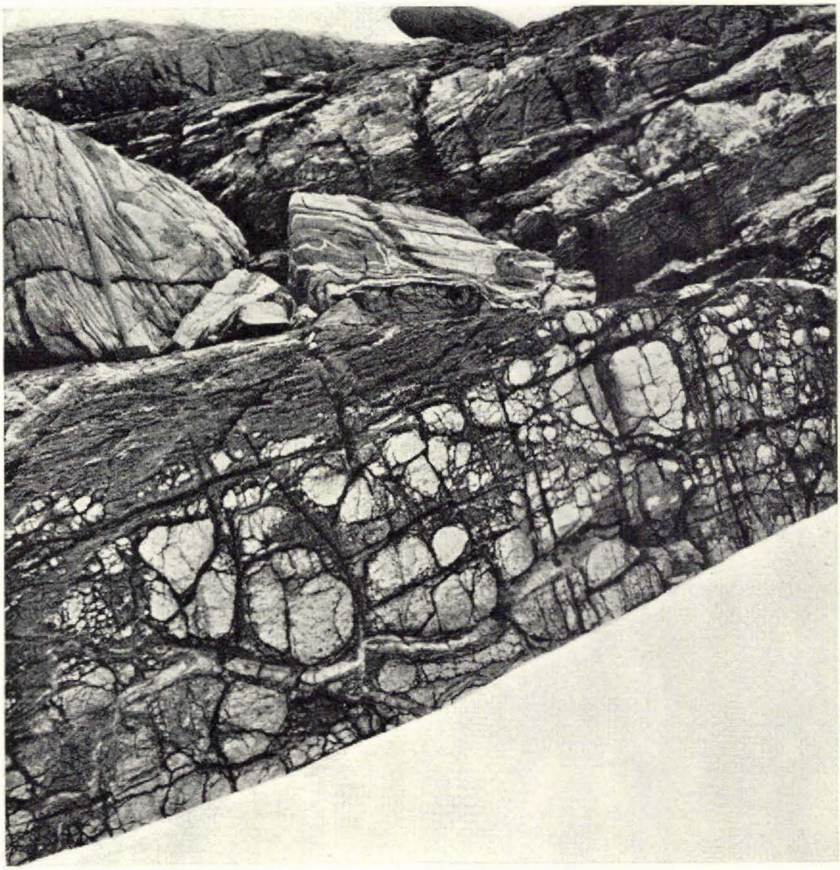


Fig. 9. The photograph shows the structure of the carbonatized gneisses below the sub-Ketilidian surface in Zigzagland. Unaffected remnants of gneiss are set in a network of carbonatized gneiss, which at a higher level possesses parallel planar orientation possibly due to compression. In the background occur completely carbonatized gneisses with lenses and veins of pure dolomite. The disintegration of the gneiss has preferably followed pre-existing joints leaving ball-shaped bodies of gneiss intact. The sub-Ketilidian surface is at the top of the exposure in the background.

the structure of an original joint pattern. The largest and dominant veins occur sub-parallel to the sedimentation surface and resemble a release sheeting pattern.

The gneisses appear to have been completely carbonatized in a 3–10 m thick zone. Of the original minerals only quartz remains in its original textural position although rarely feldspars or traces of feldspar structures have been encountered, and locally large muscovite grains secondary after biotite are found. The gneiss structure as well as pegmatite structures are preserved in the carbonatized rock. Where mafic rocks, presumably amphibolites, have been carbonatized chlorite, pyrite and magnetite have developed. The dominant carbonate mineral in all rock types is dolomite.

Below the completely carbonatized zone a 10–20 m thick zone of ellipsoidal gneiss blocks occurs (fig. 8 and fig. 9). There is a transition from the zone above. The original joint pattern is frequently apparent, from which the carbonatization decreases inwards leaving rounded crumbling rusty gneiss blocks with an onion-like structure.

Still deeper in the gneiss the partially carbonatized zone is replaced by a carbonate vein system restricted to joint fissures, which fades out downwards into barren rusty joints coated with rust and chlorite. The gneisses here do not show any appreciable alteration.

Locally the carbonate veins are found in the gneisses some distance west of the sedimentary border. It is estimated that they extend up to 100 m below the plane of the original sedimentary surface. They are also found in the fault zone connected to the eastern amphibolite band (see p. 22).

Elongated breccia structures occur near the sedimentary surface (fig. 8) and are apparently related to the carbonatized zone. The breccias consist of angular gneiss fragments, carbonatized to a varying degree, in a matrix of carbonate minerals and quartz. These features are widest at the top and grade downwards into closely spaced joint systems or fissure zones. They seem to be open fracture zones filled by a debris of gneissose rocks.

Characteristic of the carbonatized zone are beds or flat lenticular bodies (app. 0.5 m thick) of dense cherty quartzite, often of a yellowish rusty colour. In thin section the chert consists almost exclusively of eugranoblastic quartz of 0.01 mm grain size. The grains exhibit curved amoeboid to sutured mutual boundaries. Muscovite, ore and apatite occur in accessory amounts.

The chert bodies occur at several levels, both in the carbonatized gneisses and in the overlying calcareous sediments, and they transgress from one level to another.

Euhedral magnetite and pyrite crystals are commonly developed in the carbonatized zone.

The stratigraphy of the Ketilidian

The stratigraphy of the Ketilidian rocks can only be established on lithostratigraphical grounds. Although organic remnants are present and in one instance even of stratigraphic significance (Bondesen et al., 1967), and good chronological markers such as pyroclastics are also found, the information is too scattered to permit either biostratigraphical or chronostratigraphical divisions to be made.

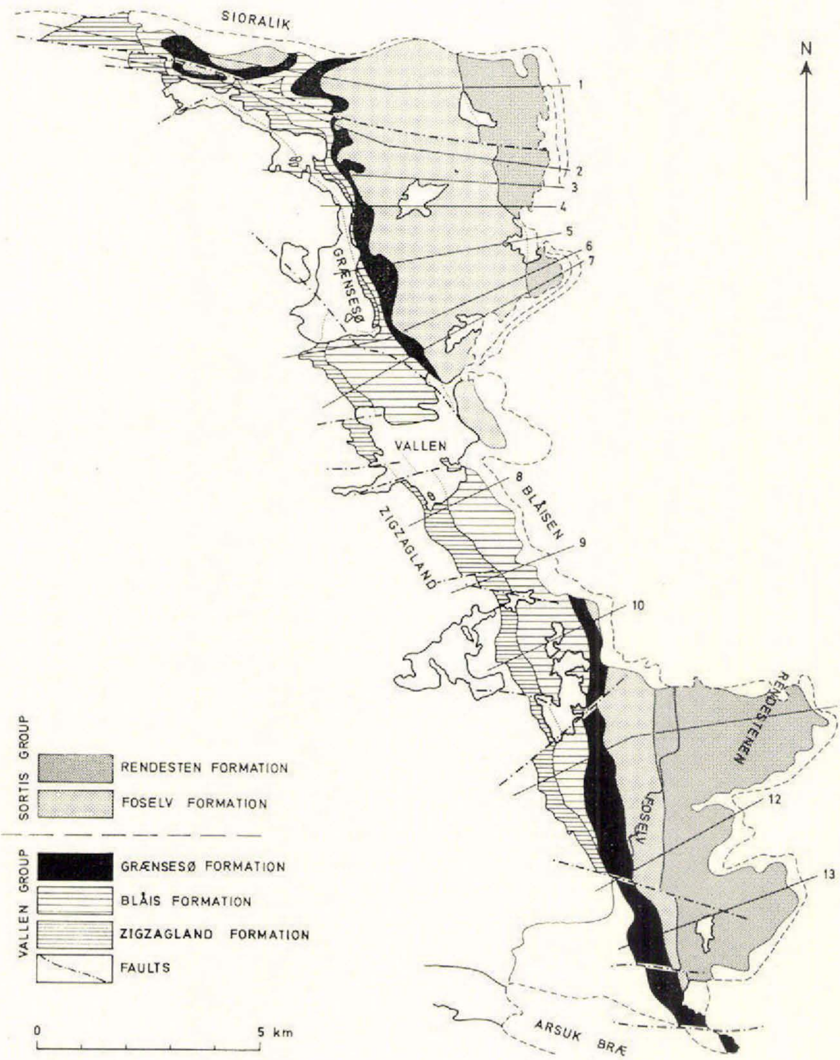


Fig. 10. Distribution of the stratigraphic units in Grænseland. The location of the profiles 1–13, shown in fig. 11, is indicated.

It is considered, however, that lithostratigraphical methods combined with paleogeographical studies would form a possible basis for correlation of the Ketilidian rocks in south-west Greenland, at least on the formation level.

To date the only locations where the base of the Ketilidian succession is exposed are in the Grænseland area and the neighbouring area to the north, the Midternæs area. It is also in these areas that the most complete successions are preserved. It is therefore proposed to establish a type section in Grænseland which can serve as a basis for comparisons and correlations with other areas. Hence a major part of this paper is in the form of a detailed lithostratigraphical description of the Ketilidian supracrustals.

A brief outline of the principal subdivisions of the Ketilidian follows. The map of fig. 10 shows the distribution of the different stratigraphic units and the general stratigraphy is given in fig. 11. The stratigraphical terminology employed is in accordance with the American Commision on Stratigraphic Nomenclature (1961). This brief outline is followed by more detailed descriptions which include sedimentological and petrographic data.

Although the rocks have been metamorphosed it is preferred to use exclusively sedimentary terminology as primary structures dominate while metamorphic features are usually only seen on microscopic scale. Terms such as mica schists, phyllites and even the prefix "meta-" have therefore been avoided, although the use of these terms would have been justified in certain minor areas.

The Vallen Group

The Vallen Group is divided onto three formations which by their contrasting sedimentological and petrological development portray the evolution of the sedimentary basins both laterally and vertically:

3) *Grænsesø Formation*
2) *Blåis Formation*
1) *Zigzagland Formation*

The lowest formation – *the Zigzagland Formation* – named after the area between Vallen and Lappesø where it is most typically developed outcrops between the Sioralik glacier in the north and Foselv in the south. It possibly also occurs south of Foselv (Pedersen, 1968). It rests directly on top of the sub-Ketilidian surface. The formation is divided into a lower and upper division.

The *Lower Zigzagland Formation* is characterized by the following members:

D. *The Rusty Dolomite Member*
C. *The Varved Shale Member*
B. *The Lower Dolomite Member*
A. *Residual deposits on the sub-Ketilidian surface*

These stratigraphic units are best developed in a basin to the south of Grænsesø and the Rusty Dolomite Member only in the southern part of this basin. The thicknesses vary from place to place. North of Vallen the Lower Zigzagland Formation is absent, or represented only by limited local arkose basins as in the area between Vallen and Grænsesø.

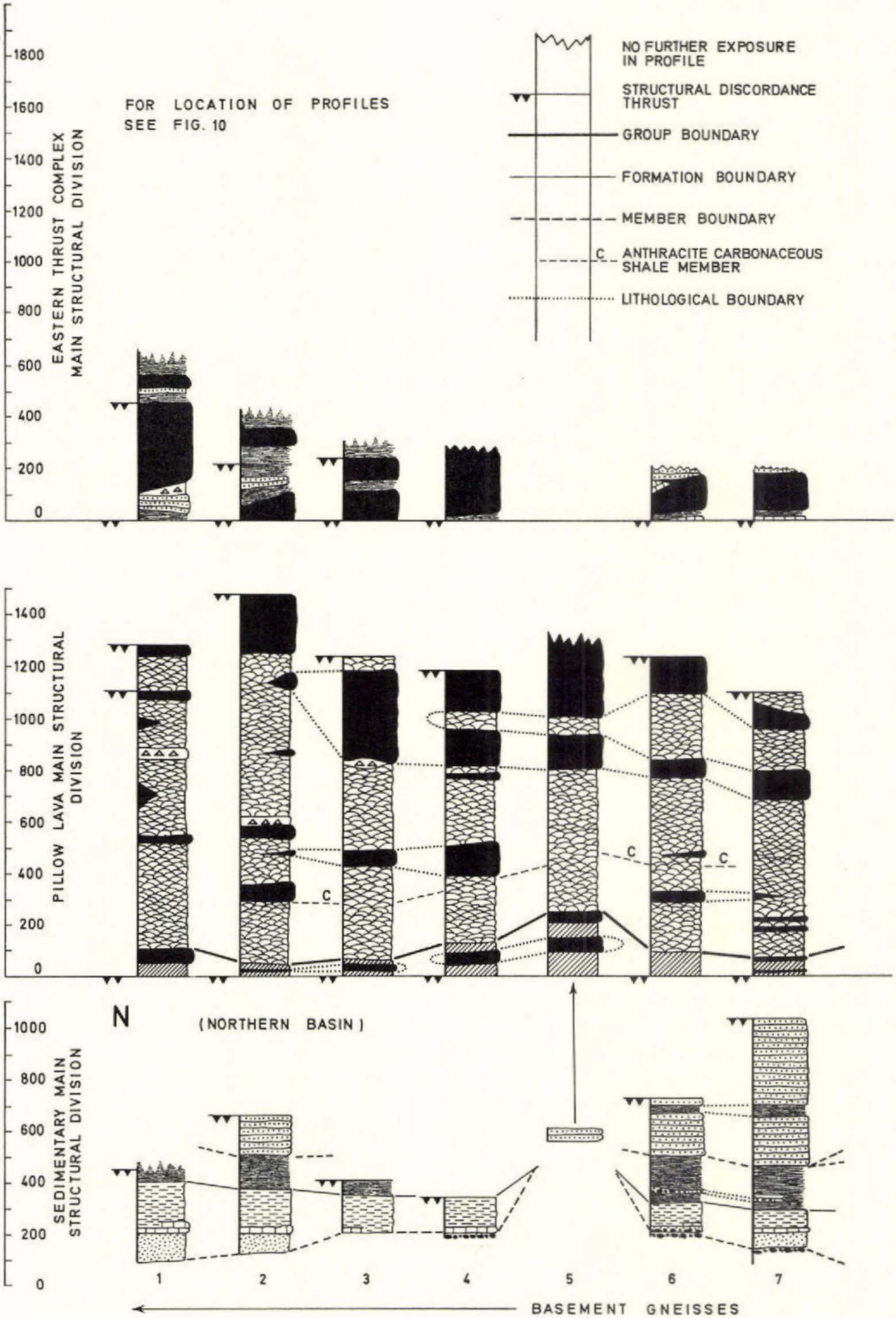

NO FURTHER EXPOSURE IN PROFILE
STRUCTURAL DISCORDANCE THRUST
GROUP BOUNDARY
FORMATION BOUNDARY
MEMBER BOUNDARY
C ANTHRACITE CARBONACEOUS SHALE MEMBER
LITHOLOGICAL BOUNDARY
FOR LOCATION OF PROFILES SEE FIG. 10
EASTERN THRUST COMPLEX MAIN STRUCTURAL DIVISION
1800
1600
1400
1200
1000
800
600
400
200
0
PILLOW LAVA MAIN STRUCTURAL DIVISION
1400
1200
1000
800
600
400
200
0
C
C
C
N
(NORTHERN BASIN)
SEDIMENTARY MAIN STRUCTURAL DIVISION
1000
800
600
400
200
0
1
2
3
4
5
6
7
BASEMENT GNEISSES

Fig. 11 a.

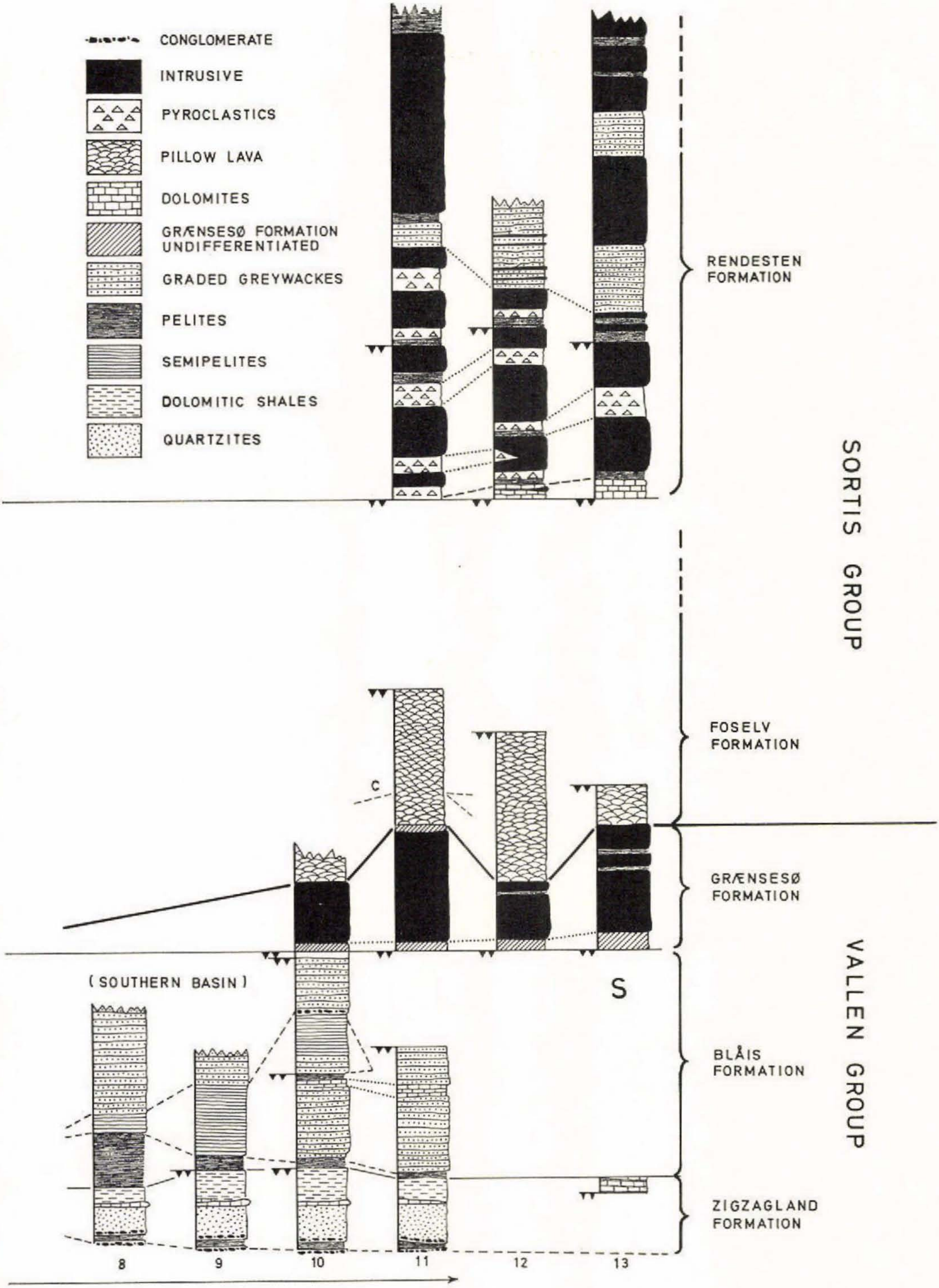

CONGLOMERATE
INTRUSIVE
PYROCLASTICS
PILLOW LAVA
DOLOMITES
GRÆNSESØ FORMATION UNDIFFERENTIATED
GRADED GREYWACKES
PELITES
SEMIPELITES
DOLOMITIC SHALES
QUARTZITES
RENDESTEN FORMATION
SORTIS GROUP
FOSELV FORMATION
C
GRÆNSESØ FORMATION
(SOUTHERN BASIN)
S
BLÅIS FORMATION
VALLEN GROUP
ZIGZAGLAND FORMATION
8
9
10
11
12
13

Fig. 11b.

The *Upper Zigzagland Formation* is characterized by coarser clastic sediments and a transgressive character relative to the Lower Zigzagland Formation; it is composed of the following members:

C. *Dolomite Shale Member*
B. *Banded Quartzite Member*
A. *Ore-Conglomerate Member*

The Blåis Formation (named after the glacier tongue Blåisen) follows concordantly on top of the Zigzagland Formation and is characterized by pelites, banded and mixed semipelites, and thick graded greywackes. The sedimentary facies varies from area to area and subdivisions are therefore made on a regional basis. In the northern part of the area pelites form the lower part of the formation, whereas graded greywackes with interstratified calcareous bands are found in the southern part of the area. These greywackes were provisionally regarded as a separate formation – the Lappesø Formation (BONDESEN, 1962; BERTHELSEN, 1965) – but in this paper this rock suite is included in the Blåis Formation as it is considered as most probably a facies development.

At the base of the main structural division, the pillow lava thrust sheet, there occurs a comparatively thin series of highly varied sediments which comprise *the Græsensø Formation* (named after the lake Græsensø). The sediments (limestones, dolomites, shales, pyritic shales and cherts – all carbonaceous) are intruded by a large sill, a persistent feature througout the area. In the northern part of the area this sill forms the upper border of the formation, but in the southern part of the area pyritic shales are found above the sill.

The base of the pillow lavas is taken as the base of the Sortis Group.

The Sortis Group

The Sortis Group is divided into two formations:

2) *Rendesten Formation*
1) *Foselv Formation*

The border between these two formations is tectonic and corresponds to the thrust border between two main structural divisions: the pillow lava thrust sheet and the eastern thrust complex.

The lower formation, *the Foselv Formation* (named after the river Foselv in the southern part of the area) can be devided into the *Lower Pillow Member* and the *Upper Pillow Member* separated by an *Anthracite-Carbonaceous Shale Member.* Other minor occurrences of sediments may occur. The Foselv Formation is everywhere intruded by small and large basic sills. Pyroclastics occur in a few places.

The upper formation of the Sortis Group, the *Rendesten Formation*, *is* characterized by pyroclastic deposits and a varied sedimentary succession of pelites, semipelites and psammites. Calcareous rocks occur at the base. This formation is also intruded by numerous sills of basic composition. The top of the Rendesten Formation is unexposed in Grænseland, but is defined as the base of the Qernetoq Formation found on a nunatak north-east of Fønland (Higgins, 1970).

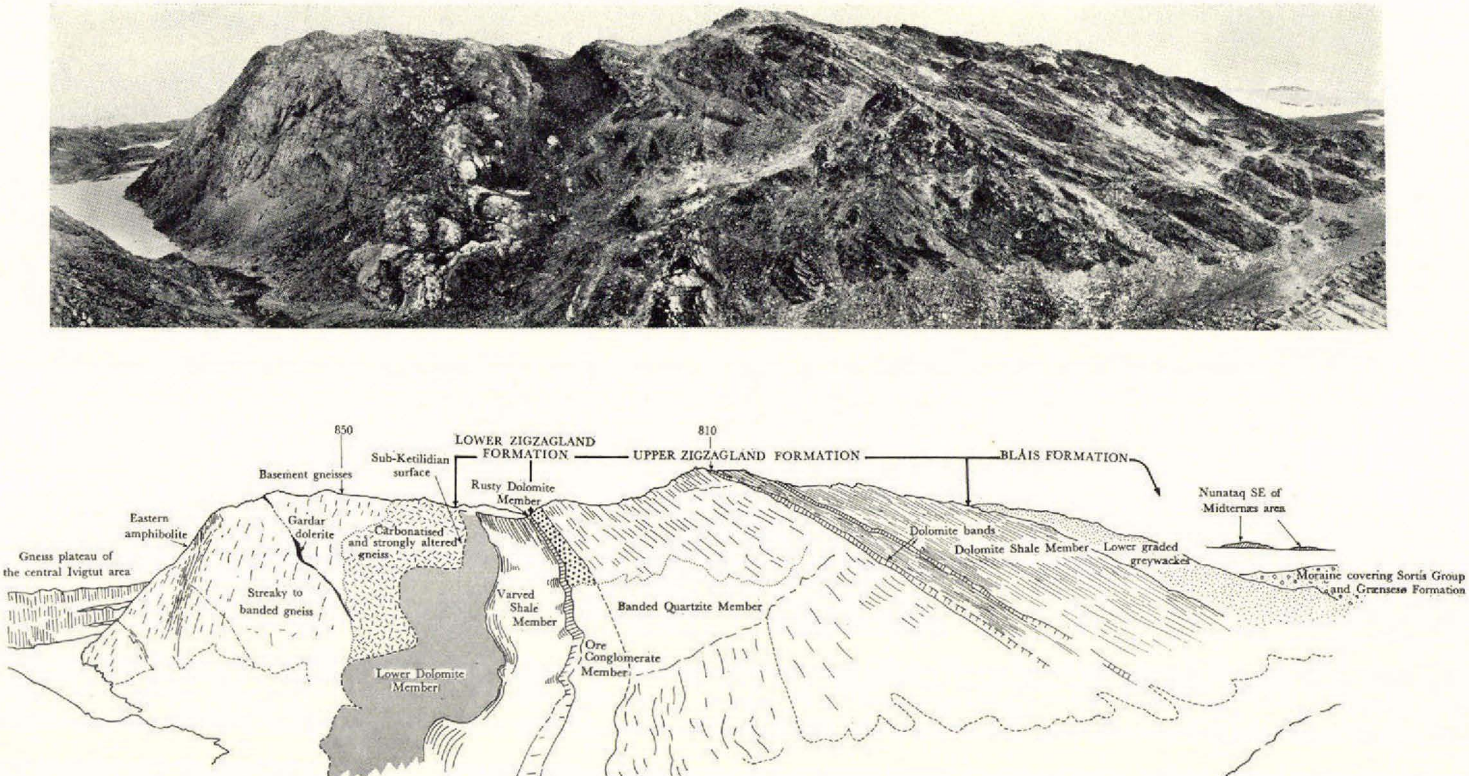


Fig. 12. Panorama of the hillside 850–810 (see plate 11) in the area immediately west of Lappesø.

THE VALLEN GROUP

The Zigzagland Formation

The Zigzagland Formation is exposed for a distance of 24 km along the border between the Ketilidian and the basement gneisses in Grænseland. As the type area for this formation the northern part of Zigzagland, i.e. the area immediately south of lake Vallen, was chosen. Here the Zigzagland Formation is found in its most complete development and almost non-tectonized. The lower boundary is the unconformity with the basement and the upper boundary is the contact with the black pelites of the Blåis Formation. The thickness in the type area is approximately 230 m. Fig. 12 shows the Zigzagland Formation in the southern part of Zigzagland south of the type area.

In the northern part of Grænseland close to the Sioralik glacier very local thrusting affects the otherwise autochthonous boundary (WINDLEY et al., 1966). To the south of Grænsesø and for the next 13 km further south the boundary is autochthonous. About two kilometres north of Foselv the boundary between the basement gneisses and the Zigzagland Formation is affected by strong movements and southwards successively higher stratigraphic levels of the formation rest on gneiss. Thin Zigzagland Formation deposits possibly exist south of Foselv as far as Arsuk glacier (PEDERSEN, 1968).

The Lower Zigzagland Formation

A. Residual deposits on the sub-Ketilidian surface

The area north of Vallen

North of Vallen and south of Grænsesø the Ore-Conglomerate Member of the Upper Zigzagland Formation overlaps the gneisses. Below the conglomerate small flat depressions of an extension of a few dozens of metres and filled with arkosic material occur.

The arkose is generally difficult to distinguish from the basement nebulites of the area as it has the same rusty-red white colour and a similar grain size and mineralogical composition. However, the texture and the occurrence of scattered cobbles and boulders of gneiss and blackish dense chert often provide distinguishing features. The chert also occurs as angular to sub-rounded clastic grains. No stratification or sedimentary structures have been observed in the arkose.

In thin sections the arkose exhibits broken grains of altered feldspar (plagioclase and microcline) and up to 80 % of angular quartz grains with undulate extinction. The matrix is of chlorite and fine-grained sericite, and a few ore grains and some small chert and sphene fragments have been observed.

The area south of Vallen

The area south of Vallen is characterized by the carbonatization of the sub-Ketilidian surface described on page 33.

The sediments resting directly on the sub-Ketilidian surface consist of local carbonatized conglomerates with pebbles and cobbles of basement rocks (gneisses and amphibolites) and sedimentary rocks (fig. 13).

Some material is composed of angular or sub-rounded quartz grains randomly distributed in a carbonate matrix with sericite and muscovite. The rock thus resembles a carbonatized gneiss, except that the quartz occurs in grains instead of the lenses as usual with the gneisses. It seems likely that these deposits are the carbonatized equivalents of the arkose deposits described from the area north of Vallen.

The conglomerates and arkoses are not continuous but occur in small depressions, and occasionally in trenches and open fissures in the gneisses (figs. 13 and 8). The thickness is variable but never exceeds a few metres.

The conglomerates are polymict. The boulders found are of carbonatized gneisses, orthoquartzites, vein quartz, and white and dark varieties of chert. Chlorite schists, recognizable amphibolites (now chloritic rocks), and various types of silicified calcareous rocks, which originally may have been calcareous sediments, are also found as boulder material.

The size of the boulders ranges from less than 1 cm to about 25 cm along their longest axes. The deposits are poorly sorted, but a vague layering is sometimes apparent. The shapes of the boulders are often perfect ellipsoids, but angular and sub-rounded particles also occur. Some boulders posses a faceting, which could have been caused by wind action, but no definite winderoded "dreikanters" have been found.

At many places the gneiss surface is covered by a few centimetres of unsorted gravel, and at such localities it is possible to see the gneiss surface actually in contact with the Lower Dolomite Member of the Zigzagland Formation. These gravel deposits overlie rocks which have the appearance of conglomerates, but in section the "boulders" can be seen to be the result of a rounded "onion" exfoliation of joint blocks of the gneiss.

Residual deposits have been found wherever the sedimentary border has been exposed. They are well preserved even where the Vallen Group is comparatively strongly deformed as it is south of Lappesø. However,

Fig. 13. Carbonatized unsorted conglomerate on top of carbonatized arkose veined by dolomite. Locality in Zigzagland just south of Vallen. In this carbonatized state the arkose is very difficult to distinguish from carbonatized gneiss (see fig. 9) unless small pebbles, such as those which occur just under the hammer head, are present.

carbonatization tends to obscure their relations and it is often difficult to trace their extension.

Microscopic characteristics

Petrologically the residual deposits are closely comparable to the carbonatized gneisses. The only completely preserved mineral is quartz, and the main constituent is carbonate minerals. The minor constituents are muscovite, chlorite, apatite, magnetite, pyrite and sphene. Generally the cobbles and boulders are mantled by a layer of fine-grained siliceous carbonate material. This layer has evidently protected the boulders to some extent from the carbonatization process as some gneiss and arkose boulders have partly preserved feldspars.

Widely distributed in the sediments connected to the sub-Ketilidian surface are small magnetite octahedra of about 1 mm in size, and also idiomorphic pyrite.

A specific rock type associated with these lowest deposits is a yellowish dolomite (53021, 53038, 53183) with dark purple and violet angular to sub-rounded spots, often oriented and with a vague layering. The sample 53038 is composed of 31.2% insoluble material (silicates), 48.1% $MgCa(CO_3)_2$, 8.8% $CaCO_3$ and possibly some $FeCO_3$ (for the method of this and other analyses, see p. 199). The sample 53183 shows dolomite-calcite in a 10:1 ratio as revealed by X-ray diffraction. Thin sections of this rock exhibit carbonate minerals, quartz, plagioclase (albite in simple twins), muscovite and chlorite. These minerals form a heterogranoblastic matrix with large 1–2 mm patches of homogranoblastic quartz and finely disseminated opaque material, small (less than 0.002 mm) orange to deep reddish coloured anisotropic? droplets of high refractive index (n = approx. 1.8) and euhedral magnetite and apatite (plate 2 b). In addition to these patches, which correspond to the coloured spots in the hand specimen, there are also other patches of presumed strongly altered plagioclase and of pure chlorite.

The two types of patches are interpreted as clastic grains, and the eugranoblastic quartz as chert fragments (possibly iron chert with organic material (see p. 129).

Summary and character

The lowest deposits of the Zigzagland Formation are regarded as residual gravels and accumulations of locally transported material. The occurrence of well rounded but badly sorted particles suggests deposition from small streams. The presence of boulders of rock types comprising the sub-Ketilidian surface in the immediate surroundings, and also pebbles and boulders of sediments and metamorphosed supracrustals (chlorite schists), implies a complex history of erosion and transportation. Thus Târtoq Group supracrustals (HIGGINS and BONDESEN, 1966) besides quartzitic and calcareous sediments of unknown source may have contributed material. Boulders of arkose show that consolidated, possibly continental, deposits have been exposed to erosion. Attention is also drawn to the iron chert, which found in this situation is likely to be related to the sub-Ketilidian surface. On the other hand the large chert lenses without finely dispersed ore have possibly been formed in situ as a result of carbonatization, and might contain the excess silica from the alteration of the feldspars.

The arkoses found north of Vallen are regarded as equivalent in age to the carbonatized deposits south of Vallen. These better preserved rocks seem to be made up of weathered locally transported material which accumulated in small depressions.

The comparatively good to perfect rounding of the coarsest material and the low maturity of the fine-grained material show that only short transportation took place (PETTIJOHN, 1957, p. 548).

B. The Lower Dolomite Member

Occurrence

Everywhere along the sedimentary border where carbonatized gneisses and residual deposits are found, the Lower Zigzagland Formation includes

Fig. 14. The Lower Dolomite Member with planar arranged pyrite nodules. Location at a lake 2 km south of Vallen in Zigzagland. The exposed face represents a bedding plane.

an up to 3 m thick, white to tan coloured, hard dolomite layer. The weathering colour is a pale orange-yellow. The lower part of the layer consists of alternating bands of pure dolomite and a white siliceous carbonate-rich rock. The upper part of the layer appears to be a silicified carbonate-rock. In places it contains planar arranged pyrite nodules (fig. 14).

The large chert lenses described on p. 35 also also associated with these rocks.

The Lower Dolomite Member is often transected by a network of calcareous veins frequently producing breccia-like structures. In places other types of breccias seem to be associated with the deposition of this member, as they do not affect the layers deposited immediately above.

The latest veins in the Lower Dolomite Member are barren quartz veins which in the northern part of the area are small and rare and in the southern part are up to 1 m thick. These veins are thought to be related to Ketilidian deformation.

Globular structures which might be of organic origin are found in the lower dolomite just to the south of Vallen (BONDESEN et al., 1966., p. 28 and plate 12, fig. 2). Irregular tube-formed fossils of a diameter of up to 10 mm and up to 40 mm long have since been found at right angles to the bedding at the same localities (PEDERSEN, 1966, p. 40).

On top of the Lower Dolomite Member occurs a talc-bearing quartzite about 1 m in thickness. This is the only level which shows signs of intense plastic deformation in connection with the Ketilidian phases of folding. In this talc quartzite cubes of pyrite (up to 3 cm across) and deformed pyrite exhibiting rhombohedral forms and glide planes are found. A light green chlorite is associated with calcareous layers.

Microscopic characteristics

Microscopically the dolomite (53143, 53184) and the siliceous carbonate rocks (53018) show a dominance of carbonate minerals (about 80%). Quartz in a saccharoidal texture together with plagioclase (albite in polysynthetic and single twins) are the other main components together with a little muscovite. In one of the samples (53184) a seam (stylolithic) of opaque material was observed in the microscope.

The talc quartzite (53053) shows microfolded talc which has been strained in the folds and shows undulatory extinction, unfolded muscovite and quartz. Accessory albite and a little ore are seen.

The tan-coloured layers have (in sample 53184) 55.9% $MgCa(CO_3)_2$ and 6.9% $CaCO_3$ (calculated, see p. 200), besides 31% insoluble material, and contain some Fe judging from the colour of the solution. Sample 53173 is composed of 58.8% $MgCa(CO_3)_2$, 11.9% $CaCO_3$ and 25.1% insoluble material. The clear solution suggests that little or no iron is present.

The white siliceous carbonate rock is of similar composition with 32.6% insoluble material, 55.9% $MgCa(CO_3)_2$ and 9.1% $CaCO_3$ (sample 53184).

Summary and character

The Lower Dolomite Member appears to have been deposited under conditions of strong chemical activity as the carbonatization of the gneisses below is closely related to the distribution of the member in the section exposed. This member may thus be largely a chemical precipitate from water of high CO_2 content having conditions supporting replacement of silicates by carbonates in the substratum immediately below. Organisms have been present but it is unlikely that they have been rock-forming to a large extent. The sedimentary structures observed suggest that some consolidation took place just after deposition so that brecciation and formation of fissures was possible. It has not been possible to show whether these processes were related to a temporary regression. It could also be suggested that the movements leading to the structures in question were related to volume changes associated with the chemical activity in the substratum.

Fig. 15. Mud cracks in the Varved Shale Member of the Lower Zigzagland Formation. The face shown is not the very fractured surface, but a cast of the cracks in a thin covering layer of pelitic sediment. Location at the south-west corner of Vallen.

C. The Varved Shale Member

Occurrence

The dominant and most conspicuous member of the Lower Zigzagland Formation comprises a sequence of brownish shales which exhibit a graded bedding very similar to that in Quaternary varves. They are therefore here termed the varved shales to emphasize the cyclic nature of their sedimentation, but no relation to glacial conditions of formation is implied.

The Varved Shale Member has a thickness varying from a few to more than 20 m. There are compositional variations both vertically and horizontally. In their lower part the rocks are strongly pelitic and dark brown in colour. In places silty or even fine-grained reddish sandstone layers occur. Apart from the variation in grain size due to the rhythmic layering there is also a variation from base to top of the sequence, the top being more sandy. As the grain size increases, the colour tends to become more reddish. In the coarser-grained part the rock cleaves easily along bedding planes, whereas the cleavage in the strongly pelitic parts is less pronounced, and where present it is often a transgressive cleavage of tectonic origin.

Unfortunately the sequence is rather badly exposed because of vegetation cover and the ease with which erosion breaks down the soft schistose rocks. The typical relief across the strike, shown in fig. 12, also reveals that there is a relative concentration of rock debris and talus from the overlying Upper Zigzagland Formation in the area of outcrop of the shales.

The sedimentary structures exhibited by this member are dominantly a graded bedding very similar to that in glacial varves. The single units vary between 2 and 10 cm in thickness. Within the larger units minor units on the scale of a few millimetres can be distinguished (plate 3a). The base of the larger units is always fairly sharp.

Other sedimentary structures found in the sequence are mud cracks (fig. 15) and small-scale fold structures apparently caused by slumping under load.

In the area from Vallen to a point 3 km south of Vallen the upper part of the varved shales is developed as a sandstone with a large proportion of magnetite concentrated in bands and lenses. These ore-bearing horizons show a grading upwards due to grain size variation and content of ore. This feature is similar to that in concentrations of heavy ore sand in recent beach sands in Denmark (CHRISTENSEN and LARSEN, 1961).

Microscopic characteristics

Microscopically the pelitic sediments (53041) show graded layers 1 cm thick with small subordinate layers and bands less than 1 mm in thickness. The grain size is usually less than 0.01 mm. The mineral content is muscovite (40%), quartz (30%), ore (20%), with carbonate (siderite ?), limonite, and chlorite in accessory amounts. The muscovites show a strong orientation (plate 3a) parallel to the bedding as well as oblique to this, following cleavage planes in the rock. Ore, carbonate and limonite are concentrated layers parallel to the sedimentary banding. A polished sample from the varved shales shows magnetite and ilmenite in small flakes.

In a red silty shale (53036) the same minerals are present but quartz is dominant and the maximum grain size is about 0.06 mm. This sample also shows a syntectonic recrystallization of the muscovite.

Two sections (53192 A and B) of a sample of the banded ore sandstone in the upper part of the sequence contain quartz and magnetite as the main components. The quartz occurs in both rounded and recrystallized grains and has a saccharoidal texture. The magnetite is mainly euhedral, although it may show subangular and, in a few cases, rounded shapes. Associated with the magnetite is strongly pleochroic brown to black biotite in large grains and composing up to 25% of the rock. Other minerals present are albite (An_7), limonite, zircon, and apatite in small irregular grains and patches. In sample 53192 B chlorite of light yellow to green pleochroism and some small needles of possibly actinolite have also been found. Characteristic of both 53192 A and B are disseminated grains of opaque material in a fine homogranoblastic quartz matrix which resembles the iron chert mentioned on p. 46.

Summary and character

The Varved Shale Member appears to have been deposited in limited basins to judge from the variation in thickness along the strike. However, the lateral variations in grain size cannot be related to the supposed basins, and it may be that the variations in thickness are partly caused by the differential compression of pelitic and more semipelitic material. The rhythmic nature of the sediment suggests variations in the velocity of the sedimentation perhaps due to seasonal variations in the water supply to the basins. These considerations are supported by the occurrence of mud cracks, which indicate that parts of the basin(s) were temporarily dry. The ore-bearing sandstone could be interpreted as a black sand deposit, as rounded clastic quartz and ore grains occur. An important part of the ore-bearing clastic material may have been iron chert. The strongest evidence of the origin of the sediment as a black sand is the mesoscopic structure of the sediment.

The interpretation of stratigraphic relations in the upper part of the Lower Zigzagland Formation presents some difficulties as the lithology shows gradual changes. As previously mentioned the Varved Shale Member contains an increasing amount of silt and sand upwards and terminates in a conglomerate – the Ore-Conglomerate Member – which is the lowermost member of the Upper Zigzagland Formation. The matrix of the Ore-Conglomerate Member can be regarded as the upward continuation of the ore-bearing sandstone.

In the southern part of the area the Rusty Dolomite Member occurs at the base of the conglomerate and can thus be distinguished as the uppermost member of the Lower Zigzagland Formation. Towards the north this member wedges out. At a locality 1.5 km south of Vallen the Rusty Dolomite Member is found as a 20 cm thick bed in the ore-bearing sandstone and 1.2 m below the base of the conglomerate. Part of the ore-bearing sandstone above the rusty dolomite in the northern part of the area has been included in the varved shale sequence, although it is possibly equivalent to the Rusty Dolomite Member in the southern part of the area. Although it may be diachronous the rusty dolomite sequence is maintained as a separate member because of its distinctive lithology.

D. The Rusty Dolomite Member

Occurrence

The stratigraphic relations of the Rusty Dolomite Member have been outlined above, and as mentioned it occurs as a 20 cm thick calcareous layer 1.5 km south of Vallen. About 3 km south of Vallen it has a thickness of 0.5 to 1 m, and farther south it has a thickness varying between 0.5 and 3 m. It seems never to be lacking south of Vallen.

From the top of the ridge 850–810 north-west of Lappesø (fig. 12) the Rusty Dolomite Member is exposed as a mappable unit with a true thickness of 3.5 m. At the river leading from Lappesø the member thins out to 0.5 m, but thickens again along the west coast of Lappesø and farther south attains a fairly constant thickness of about 8 m.

As the Rusty Dolomite Member occurs outside the type area of the Zigzagland Formation, the south-west corner of Lappesø is chosen as type area for this member.

Farther north the Rusty Dolomite Member shows a vague bedding, which is not apparent in the southern part of the area where the layer is more compact, although often disjointed by irregular fissures. The dolomite is strongly silicified. It contains pyrite, the weathering of which gives it its rusty colour, and which is especially abundant in the southern part of the area.

It is uncertain whether or not the variations in thickness of the Rusty Dolomite Member are due to deposition in a basin. The variations appear to correspond to the variations found in the Varved Shale Member.

The Upper Zigzagland Formation

A. The Ore-Conglomerate Member

The Ore-Conglomerate Member is extremely well exposed in section and on bedding surfaces throughout the area of its occurrence; it is only found south of Grænsesø.

The member varies in thickness from 1 to 2 m north of Vallen to a fairly constant thickness of 8 to 10 m south of Vallen. Its appearance varies from area to area partly due to depositional conditions, and also, in the south, to the effects of deformation. For the purpose of this paper its development is described in three areas:

1) the area north of Vallen
2) the area between Vallen and northern Lappesø
3) the area south of the northern part of Lappesø

The name, the Ore-Conglomerate Member, is applied with reference to the development in the type area south of Vallen where the matrix of the conglomerate is a magnetite ore.

The area north of Vallen

In the area north of Vallen the Ore-Conglomerate Member rests directly on top of the gneisses, or on the thin non-carbonatized arkose deposits, described on p. 32.

Fig. 16. Large boulders resting directly on the sub-Ketilidian surface in the area between Vallen and Grænsesø. The surrounding sediment is a banded dark grey ore-bearing quartzite with some silty and pelitic bands following the outline of the boulders. Note the sub-rounded shape and the polygonal outline of the boulder to the right. The length of the hammer is 45 cm.

The member is here 1 to 2 m thick and consists of large boulders whose longest axes may reach 2 m and the shortest axes 1 m in length. The shapes of the boulders vary to some degree but they may generally be described as rounded to sub-rounded and with axes of more or less the same relative proportions (fig. 16). Often the boulders show a polygonal outline possibly reflecting an original joint pattern.

The boulders are rusty coloured and often have a 10 cm thick rusty spallating mantle. Below this mantle the boulders consist of a porous quartzitic rock stained with elongated red spots. It has not been possible to examine the cross of the largest boulders.

The majority of the large boulders rest as far as can be seen directly on the gneiss without any appreciable amount of sediment below. Smaller boulders are usually enclosed in a sedimentary matrix. Where the arkose deposits occur no relations to the larger boulders have been observed, but the smaller boulders and cobbles have been seen resting directly on the arkose (fig. 7).

The matrix material between the boulders is a dark grey to black finely laminated sediment of medium to fine sand with layers of silt. The layering in the sediment sweeps round the large boulders which often can be recognized as a doming of the layering.

In thin section the sedimentary matrix (52977 A and 20865) is seen to be composed mainly of rounded and sub-rounded quartz grains. Some quartz seems to be recrystallized. Iron chert is also present as clastic grains. Other minerals are plagioclase (albite and altered clastic plagioclase), sphene, carbonate, epidote and ore. In the finer matrix muscovite and chlorite are found. Limonite seems to play an important role. The thin section 20865 shows large epidote crystals arranged in star-shaped aggregates but these may owe their presence to pyrometamorphism due to the large Gardar dolerite intruded close to the sample locality.

The thin section, 52977 B, is one of the smaller boulders and shows the rock to be a fine cherty quartzite with limonite.

The area south of Vallen

On the west coast of Vallen the Ore-Conglomerate Member differs in character from its appearance north of Vallen. Its thickness is here about 6 m and increases to up to 10 m farther south. It has a fairly constant thickness of around 8 m as far as the southern part of the area, where the thickness again decreases to about 5 m.

As the thickness of the member increases southwards the boulder size decreases; the longest axes of the largest boulders measure about 40 cm. In the southernmost localities only cobble-size components are found. There is no appreciable variation in the boulder size vertically.

The conglomerate is oligomict and the boulders are almost exclusively of grey or white cherty quartzites. Occasionally rusty spotted porous boulders occur which resemble the interior of the boulders found north of Vallen.

The shapes of the boulders (fig. 17) are generally similar to those found north of Vallen, but more perfectly ellipsoidal and also flatter shapes are encountered.

As previously mentioned (p. 51) the matrix of the conglomerate could be regarded as an upward continuation of the ore-bearing sandstone immediately below. The ore content can be very high in the lower part of the conglomerate and seems to decrease upwards.

Banding occurs in the Ore-Conglomerate and is expressed by more densely packed boulders at some levels and a higher proportion of matrix at others. In some cases bands without boulders occur.

The ore proportion of matrix varies vertically, being greatest at the base (up to 70 $^0/_0$), decreasing upwards and amounting to 50 $^0/_0$ about 3 m from the top. Generally the top metre is without ore.

Fig. 17. Oilgomict conglomerate – the Ore-Conglomerate Member – at the base of the Upper Zigzagland Formation. The boulders are cherty quartzites, which here in the upper part of the member are set in a quartzitic matrix. The exposed face is a bedding plane. Locality in the south-west corner of Vallen.

Variations in the ore content also occur laterally. There is a decrease in ore content towards both north and south, the highest concentration being found in the vicinity of the lake 3 km south of Vallen. From this lake and southwards the central part of the Ore-Conglomerate Member has the appearance of a fine jasper quartzite often with flattened cobbles. The ore is concentrated in pure magnetite bands. In this area it becomes more and more common to find that the ore has migrated into secondary fissures in boulders and into joints. In places a brecciation of chert-like quartzite with an ore matrix is found. The same tendency for the ore to migrate into fissures is apparent under the microscope.

Provisional examinations of 110 polished samples of ore-rich conglomerate matrix show that magnetite is the dominating ore mineral. Pyrite, hematite and occasional ilmenite are minor constituents. The matrix thin section 53042 contains in volume

34.6% quartz, 60.4% ore, 3.0% biotite and 2.0% of other constituents; the last include plagioclase (An_{10-12}), limonite, carbonate and a large number of small anhedral grains of apatite.

The magnetite is usually euhedral and twinned, and occasionally subhedral. In a few cases rounded magnetite grains have been observed. The quartz is generally recrystallized but rounded grains also occur. Chert grains with finely dissiminated ore have been found.

A thin section of a boulder contains 98% quartz with a fine saccharoidal texture (chert), a little muscovite and ore.

The area south of north Lappesø

Approximately 1.5 km north of the river leading from Lappesø the nature of the Ore-Conglomerate Member gradually changes. The conglomeratic character persists towards the south as does the thickness, although it has an average thickness of only 5 m south of Lappesø. The main differences occur in the matrix, which gradually becomes a rusty, often porous, quartzite usually containing pyrite. South of Lappesø the conglomerate matrix is sometimes a pyrite ore.

The character of a matrix of the Ore-Conglomerate Member in the southern part of the area is regarded as a continuation of the tendency of the ore to migrate as described on p. 55. Gradations from local activation and mobilization to a more complete mobilization can be observed. The gradations take place over a distance of little less than 100 metres. The mobilization coincides with a stronger deformation of the overlying rocks and it is a notable feature that widespread hematite and pyrite mineralizations occur in joints and fissures over the whole southern part of the area, especially in the greywackes of the Blåis Formation. Therefore it is suggested that ore was originally present in the Ore-Conglomerate Member in the southern part of the area, and that it had migrated away from this level into fissures and joints of the overlying rocks leaving a rusty, porous occasionally pyrite-bearing matrix.

Summary and character

The Ore-Conglomerate Member is one of the most conspicuous and peculiar sediments of the Vallen Group. Equivalents to this member are not known from other areas of Ketilidian sedimentation, except for the Midternæs area, north of Grænseland, where a conglomerate with little ore appears in the same stratigraphic position (HIGGINS and BONDESEN, 1966). The Ore-Conglomerate Member exhibits a specific sedimentary facies apparently closely connected to surface relations in the immediate surroundings of the basin. Deposits of siliceous chert from which the majority of the boulders were derived may be presumed to have existed close to the basin. The large boulders found north of Vallen have probably not been transported very far, and may even have been residual. The smaller boulders on top of older sediments have evidently been transported, but possibly only by surf action along a coastline. The distribution of the Ore-Conglomerate Member shows that its deposition was related to a considerable northward expansion of the sedimentary basin.

It has been mentioned that the matrix of the sediment shows a gradational development from the upper part of the underlying sediments and also grades into the overlying sequence of banded quartzites. The matrix of the upper part of the Ore-Conglomerate Member is a quartzite and the lower part of the Banded Quartzite Member contains several thin conglomeratic units (see plate 14).

B. The Banded Quartzite Member

The Banded Quartzite Member occurs south of Grænsesø above the Ore-Conglomerate Member and in a basin structure expressed by the increasing thickness of the member towards the south, as illustrated by the five measured profiles shown in plate 14. The principal variations in the lithology and the sedimentary structures of the banded quartzites are also indicated in the profiles.

The Banded Quartzite Member is also found in the area north of Grænsesø, between Grænsesø and the Sioralik glacier, in a basin structure of which the continuation is found north of the glacier in the Midternæs area (Higgins and Bondesen, 1966, fig. 3). South of the Sioralik glacier the quartzites are found beneath the same Dolomite Shale Member as that which occurs to the south of Grænsesø, and it is on this basis that these quartzites are regarded as part of the same lithostratigraphic unit. However, there are local differences and the two areas are thus described separately: 1) the area north of Grænsesø, 2) the area south of Grænsesø.

The area north of Grænsesø

The Banded Quartzite Member in the area north of Grænsesø has a low easterly dip and rests directly on the homogeneous basement gneisses. The Lower Zigzagland Formation and the Ore-Conglomerate Member of the Upper Zigzagland Formation are lacking, and no basal conglomerate is developed. The border between the quartzites and the gneisses is in a narrow zone locally mylonitized, apparently by thrust movements. The rocks are otherwise practically unaffected by deformation.

South of the large sinistral fault (plate 11), where the beds dip at a very low angle, medium- to coarse-grained very homogeneous white quartzites are found in direct contact with the gneiss surface. The quartzites are here autochthonous. The whole region is thus regarded as autochthonous to parautochthonous, with only little or local movements along the border.

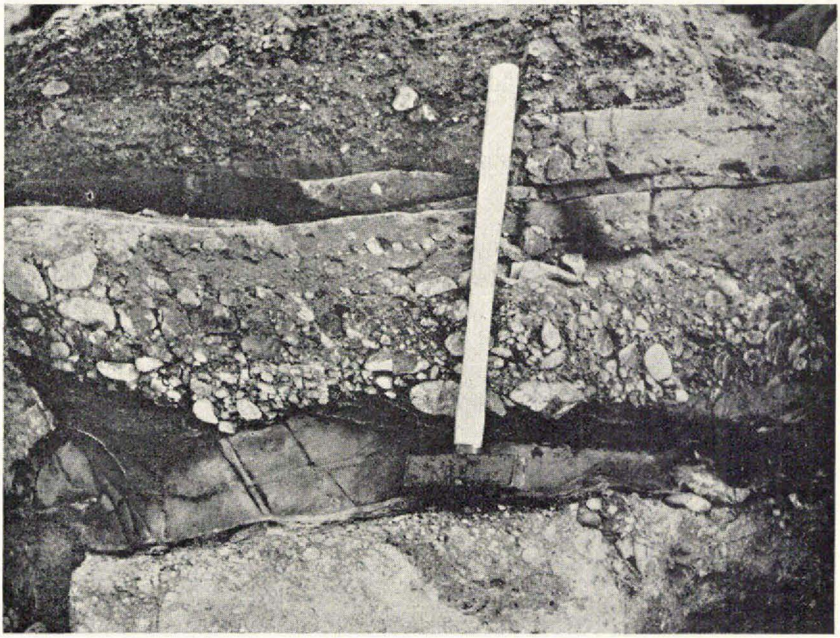


Fig. 18. Graded oligomict conglomerate units in the lower part of the Banded Quartzite Member of the Upper Zigzagland Formation. At the head of the hammer occurs a weathered calcareous sandstone intercalation. The conglomerate unit in the centre exhibits a vague imbricate structure. Locality about 1.5 km south of Vallen.

The thickness of the quartzites varies from approximately 50 m at the shore of Grænsesø to more than 140 m near to the Sioralik glacier.

The sedimentation began in the latter area with a pure white quartzite without banding or pronounced bedding. Some fissility seems to be parallel to the original sedimentary surface. Higher in the succession, approximately 30 to 50 m above the base, banded sedimentary structures due to compositional and grain size variations occur and greyer quartzite is abundant. The thickness of this banded division is generally about 20 m. Above this occurs at least 30 m of pure white quartzites with abundant ripple marks, which give way upwards to about 20 m of quartzites, often coarse-grained and blackish.

The area south of Grænsesø

The Banded Quartzite Member south of Grænsesø indicates a basin structure which is expressed by an increase in the thickness from 3 m at the shore of Grænsesø to 40 m on a small peninsula on the west shore of Vallen. South of Vallen the thickness approaches 100 m (plate 14).

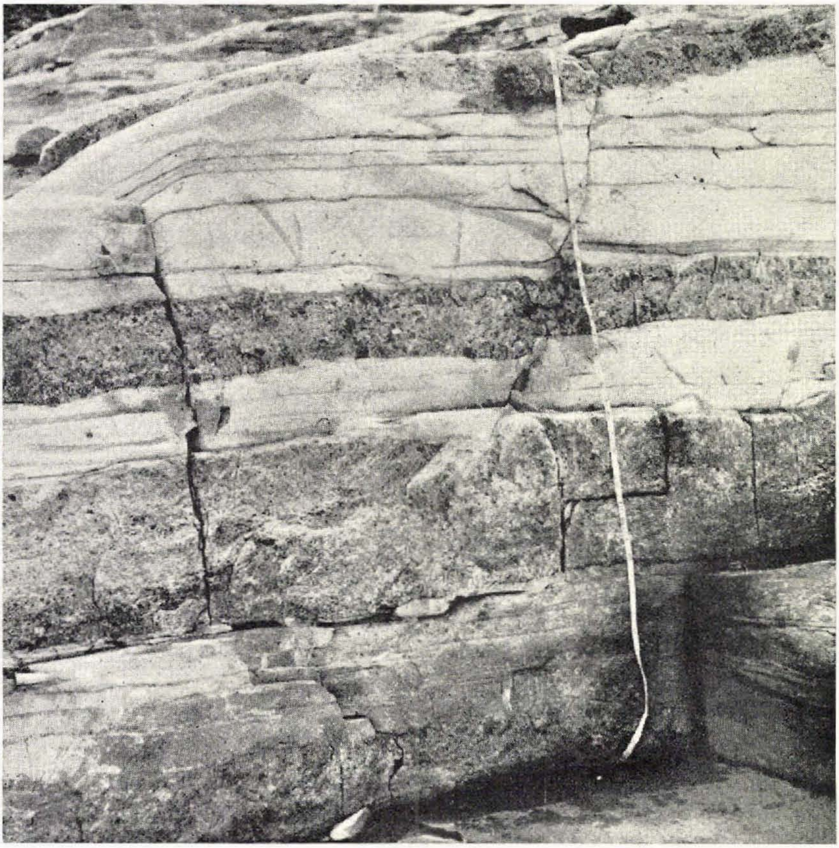


Fig. 19. Light fine-grained facies of the Banded Quartzite Member of the Zigzagland Formation. Badly sorted conglomerate units, with sharp borders to the surrounding sediments, are also seen. The part of the measuring tape seen measures 2.1 m. Locality in the south-west corner of Vallen.

South of Lappesø a decrease in thickness seems to take place, but it is not certain whether this is a sedimentary feature or a result of tectonic thinning or both.

North of Vallen only thin bedded and laminated quartzites occur.

At Vallen conglomerates appear in the lower part of this succession together with coarse-grained grey quartzites. These conglomerates are usually graded (fig. 18).

A special development is found near Vallen (fig. 19). The conglomerates here lack grading and occur in sharply bounded beds up to 40 cm thick. In between fine- to medium-grained quartzites are found.

At certain levels, mainly in the lower part of the sequence, coarse calcareous clastic sediments are present (fig. 18). At higher levels these

Fig. 20. Typical appearance of the middle part of the Banded Quartzite Member of the Zigzagland Formation. The quartzites are here finely laminated with lensoid pockets of contrasting grain size and slump structures. The slumping shown here appears to have taken place under the cover of the overlying sediment. Lenses of coarse quartzite with weathered calcareous matrix are seen at the bottom and the top of the photograph. Locality about 1.5 km south of Vallen. The scale is shown by the pencil in the upper left corner of the photograph.

become less important, although interstitial carbonates are often present, a characteristic difference from the quartzites in the area north of Grænsesø.

The middle part of the quartzite succession, from approximately 20 m above the base to about 30 m below the top, is dominated by banded and laminated quartzites of fine- to medium-grain size. Several levels are silty and some horizons are even pelitic.

In the upper part of the Banded Quartzite Member, marked homogeneous light, medium- to coarse-grained quartzite beds with wavy surfaces similar to sand waves (Potter and Pettijohn, 1963, p. 99) or giant ripples (van Straaten, 1950, p. 76) occur. These beds are found through-

Fig. 21. Strongly distorted banded quartzites from a large slumped unit in the middle part of the Banded Quartzite Member of the Zigzagland Formation. Garland-like structures and, locally, convolute bedding are the dominant structures. Locality about 1 km south-west of Vallen.

out the area in varied thicknesses and numbers. In some cases the beds are seen to bifurcate (plate 14, profile IV). The bases of the giant rippled beds are planar, and the succeeding beds above the crests of the ripples soon become planar (fig. 24).

Black quartzites are found at the top of the member, and are overlain by dolomitic shales of the succeeding member, a feature common to both the areas described.

Sedimentary structures

The Banded Quartzite Member shows a variety of sedimentary structures, some of which already have been noted, and whose position in the vertical succession can be seen from plate 13.

Graded bedding (fig. 18) and other types of bedding (fig. 19), banding and laminations have already been mentioned, and their characteristic appearance is shown in figs. 20 and 24.

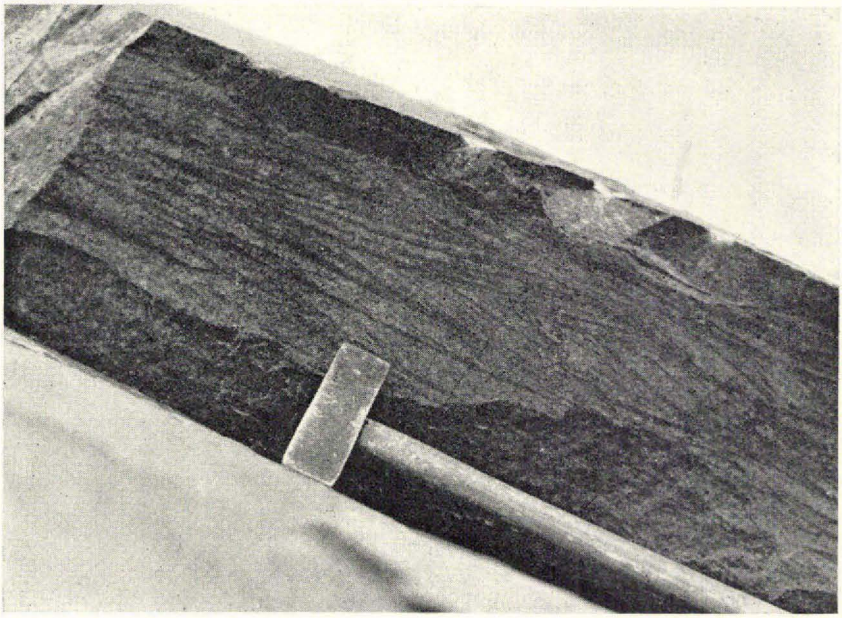


Fig. 22. Isolated occurrence of current bedding in the Banded Quartzite Member of the Zigzagland Formation. The low angle current bedding possesses a complicated pattern which in the sections available yielded several current directions. The structures are limited to the unit shown in the photograph. Locality about 1 km south of Vallen.

Slump structures are very common in the middle banded and laminated parts of the succession. They were all found where a strong variation in grain size from silt to gravel occurs. Clayey layers are also found, but their presence does not seem to be necessary for the formation of the slumps. Some slumping has evidently taken place on the sedimentary surface, as the upper part of some structures has been eroded. However, most of the structures seem to have been produced within the sediment under load. Chaotic convolute bedding of fine-banded light quartzite in darker silty material is shown in fig. 21. Drag features, which seem to have been formed under a sliding mass, are shown in fig. 20. Diapiric structures, formed during the sedimentary stage over small pre-existing culminations, are also encountered. It is noteworthy that no slump structures have been observed in the area north of Grænsesø.

Current bedding is not very prominent and seems always to be at a very low angle (fig. 22). It occurs periodically throughout the succession. The current bedding has perhaps developed locally along small banks or sandbars.

Ripple marks are very common and are of several types. The most common are sinusoidal symmetric varieties, often with the ridge crests

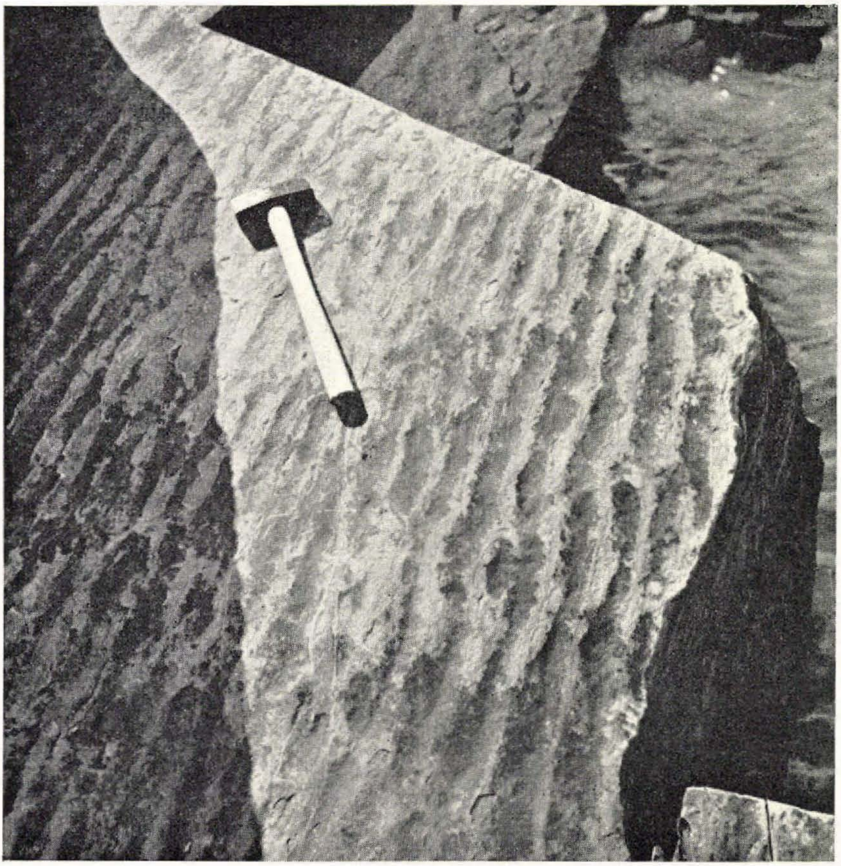


Fig. 23. Ripple marks of a sinusoidal type in the Banded Quartzite Member of the Zigzagland Formation. Locality on the south coast of Vallen.

eroded (fig. 23). Another very common type is symmetric with very sharp ridges and broad open throughs. Asymmetric types are rare. Ripple marks are most common in the middle part of the succession.

Ripple marks are the only sedimentary structures apart from banding which have been observed in the area north of Grænsesø. They are very prominent and generally of asymmetric type with a ratio amplitude-to-wave-length of about 1:11.

The giant ripples are restricted to the upper part of the Banded Quartzite Member. They are perfect sinusoidal with a wave-length up to 1 m and an amplitude of 15 to 25 cm (fig. 24). They are arranged 'en echelon' as long interfingering ridges. Because of inadequate exposure, the length of the ridges could not be established. Vague current bedding dipping to the south on the south side of the ripples, and with the same inclination as the flank, has been observed in several cases. The

Fig. 24. Giant ripples in the upper part of the Banded Quartzite Member of the Zigzagland Formation. The base of the rippled unit is planar and the banded quartzites above the ripples soon reattain a plane-parallel attitude. Locality about 1.5 km south of Vallen.

ripples seem thus to have been formed by possible current action from the north.

Sun-cracks are encountered both in the lower conglomeratic part and in the middle banded part of the sequence, where elongated hexagonal shapes of 20 cm in the longest direction have been found.

Microscopic characteristics

The banded quartzites are highly variable in grain size and composition and the samples examined may therefore not cover the entire range of rock variation in the succession.

Table 2 shows the composition of some of the samples and fig. 25 indicates the grain size variation as revealed from granulometric analyses of suitable thin sections. The methods used are described on page 199.

The size of the sedimentary grains varies from the clay to coarse sand fractions and in the conglomerates from pebbles to cobbles. The sorting within a single band is moderate to good.

The grains are ellipsoidal perfectly rounded or sub-rounded in shape. The heavy minerals always show perfect spherical shapes. Usually the grains are dusty. Recrystal-

Table 2. *Modal composition of quartzites from the Banded Quartzite Member of the Zigzagland Formation*

	53025	53026	53043	53044	53071	53073	52111	53147
	%	%	%	%	%	%	%	%
Quartz	20.1	88.1	74.3	67.2	94.2	87.5	87.8	75.0
Chert	50.4	–	–	–	–	–	–	2.1
Matrix (quartz)	16.2	0.9	5.0	9.3	5.2	2.6	****	11.6
Plagioclase	0.2	3.5	2.8	5.6	0.1	2.3	6.6	–
Microcline		1.1	0.9	0.9	0.1	0.2	4.0	–
Carbonate	–	1.3	10.2*	15.1*	–	2.3	–	1.1
Dark minerals**	3.9	0.4	0.4	1.2	0.2	3.2	0.1	–
Ore	2.3	–	–	0.3	–	–	1.5	0.9
Muscovite	6.9	4.1	2.4	0.4	0.2	1.9	–	6.9
Others***		0.6	–	–	–	–	–	2.1
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*) matrix is carbonate
**) garnet, zircon, sphene, amphibole, pyroxene?, epidote.
***) carbonaceous material and secondary minerals.
****) matrix not specifically counted because of recrystallization.

53025 Quartzite with fragments of chert. Locality south of Vallen.
53026 Fine-grained quartzite. Locality south of Vallen.
53043 Quartzite, 2 km south of Vallen.
53044 Banded quartzite, 2 km south of Vallen.
53073 Black quartzite at the top of the Banded Quartzite Member, north of Grænsesø.
53071 White quartzite with ripple marks. Locality north of Grænsesø.
52111 Light quartzite from bed with giant ripples, south of Vallen.
53147 Matrix of conglomerate, 1 km south of Vallen.

lization of quartz is present, in some samples conspicuous, and cataclastic textures as well as sutured and mosaic textures (Skolnick, 1965) are seen.

The matrix material is generally microcrystalline quartz. In some cases (53044 and 53043 (plate 3b)) carbonates may play an important role. As most secondary minerals, muscovite, epidote and a little chlorite are found in the matrix interstities, it is suggested that a little pelitic material was present in the original sediment.

The clastic grains are dominantly quartz showing undulate extinction and are thus apparently derived from the basement rocks. In some samples (53025, 53035, 53154 and 20835) chert is present among the grains. Among the clastic feldspars, plagioclase dominates over microcline. The plagioclase is always much altered by sericitization and saussuritization. Carbonate might have occurred as original clastic grains now found in the form of large patches of recrystallized carbonate. Accessory minerals are zircon, garnet, sphene, amphibole, epidote and possibly pyroxene (53025). Ore is rarely present and mostly recrystallized. Brown limonite patches and small amounts of dark opaque material (organic remnants?) are also found.

The secondary (metamorphic) minerals are muscovite, chlorite and epidote, with some biotite (in samples 53025 and 20833). Locally single twinned albite crystals occur in the intersticies.

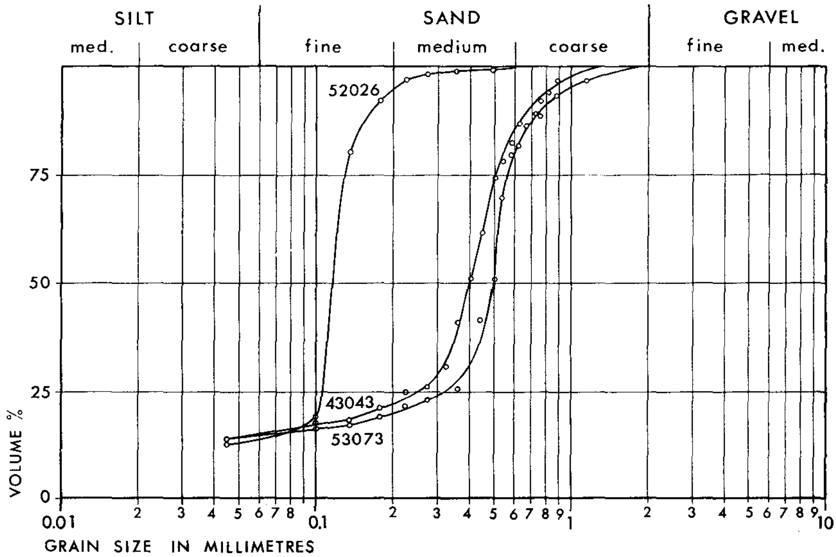


Fig. 25. Grain size cumulative frequency curves of selected quartzites from the Banded Quartzite Member of the Zigzagland Formation.

The quartzites are of varied composition and some may be classed as protoquartzites, others as feldspathic sandstones (PETTIJOHN, 1957). Those with considerable carbonate matrix are calcareous protoquartzites (53043, plate 3b, and 53044), and one (53071) is an orthoquartzite. 53025 has a large matrix proportion besides rock fragments and may thus be termed greywacke (lithic greywacke). The samples 53071 and 53073 are from the northern basin and they are the "most quartzitic" of those examined. This is in agreement with the general impression in the field, that the succession in the northern basin is more uniform and white than the banded succession in the southern basin.

Summary and character

The general impression of the sedimentary succession of the Banded Quartzite Member is a steady change from litoral conditions in the lower part with small graded conglomerates on top of the Ore-Conglomerate Member to shallow water conditions in the middle part with small banks or sand bars which temporarily may have been dry and along which slumping from time to time occurred. Towards the top of the member, sedimentary conditions became more stable and current from a northern direction more constant, as indicated by the mega-ripple structures. This probably corresponds to deeper conditions compared to those which prevailed earlier.

This general deepening, as well as the increase in the thickness in both the southern and the northern basin, corresponds to the transgressive nature of the Zigzagland Formation, already indicated by the Ore-Conglomerate Member.

Of the sedimentary structures graded bedding and ripple marks are indicative of shallow turbulent water, and the rarer occurrences of current bedding are suggestive of deeper water below wave base (PETTIJOHN, 1957, p. 285).

The middle part of the succession, which is strongly banded and frequently slumped, shows that the sediment was highly mobile and suggests that deposition took place relatively rapidly. The slump structures indicate that the sedimentary basin possessed some bottom topography which can be observed on a large scale as a gentle swelling of the layering when viewed from favorable positions along the bedding planes.

A small scale sea bed topography also existed as seen in the culminations mentioned on p. 62, and in the giant ripples.

The source of the material forming the quartzites is dominantly basement gneisses, indicated by the dominance of quartz showing undulate extinction and the character of the feldspars.

The fact there is less microcline than plagioclase suggests that it was nearby basement which acted as a source and it is also consistent with the

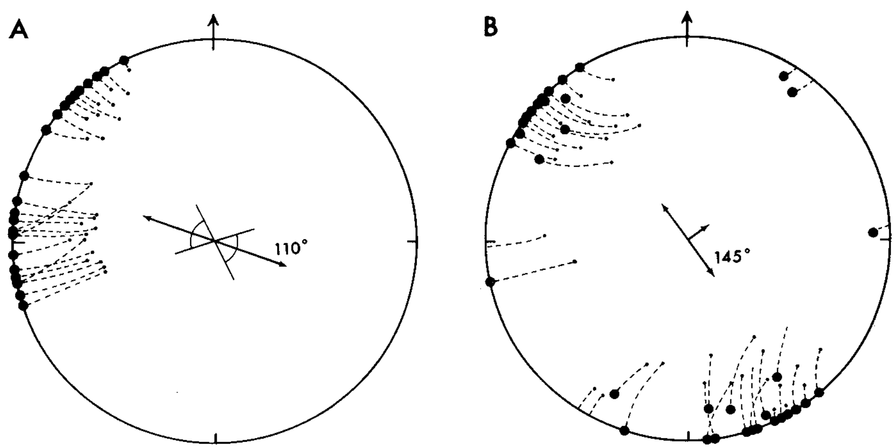


Fig. 26. Orientation of ripple marks (A) and slumping axes (B) from the Banded Quartzite Member of the Zigzagland Formation. The linear structures have been tilted with the bedding plane as indicated by dotted lines. Some slump axes did not coincide with the bedding plane and are thus not horizontal after tilting. The arrows indicate the mean values. Wulff-net angle true projection – upper hemisphere.

fact that quartz-dioritic gneisses are the most widespread in the pre-Ketilidian of the Ivigtut region. Chert has also been exposed for erosion and transport.

The possible direction of the coast line of the basin south of Vallen has tentatively been established by means of the axes of slump structures and ripple marks (fig. 26 A and B). The ripple marks, which if formed by a surf wave action should form a very acute angle to the coast (POTTER and PETTIJOHN, 1963), indicate a coastal direction in the south-eastern quadrant. The slump axes, which give a possible means of finding the average of the slope of the basin floor or the trend of bars and bank structures, indicate a south-east – north-west direction. This direction should be parallel to the coast and parallel to the main current direction; it is more or less consistent with the coastal direction indicated by the ripple marks. However, these suggestions of coastal direction are only average indications as the measurements were made at various stratigraphic levels.

C. The Dolomite Shale Member

Occurrence

The Dolomite Shale Member forms the uppermost stratigraphical unit of the Zigzagland Formation. It is fairly uniformly developed although minor lithological differences are apparent, both horizontally and vertically.

The true thickness of the member is difficult to establish south of Vallen because of deformation. The first phase of folding has more or less exclusively occurred within the lower part of this member (see p. 151). However, the thickness in Zigzagland appears to vary between 135 and 150 m. Between Vallen and Grænsesø the thickness decreases to less than 50 m and in the southern part of Grænsesø the member is absent. On a small peninsula in the middle of Grænsesø the equivalents of the member are seen resting directly on the altered gneiss surface. The lower part is here composed of a thin conglomerate with dolomites immediately above (fig. 28). The thickness is here estimated to be about 20 to 30 m. North of Grænsesø the Dolomite Shale Member is between 100 and 150 m thick.

South of Lappesø the development is similar to that in Zigzagland, although the thickness seem to be less, possibly on account of the deformation. At Foselv the member has what appears to be a tectonic contact with the basement gneisses.

The border with the underlying quartzites is always sharp; the quartzites contrast markedly with the almost pure dolomite which forms the lowest band of the dolomite shales. The upper border is more gradational, as fine clastic material dominates the lower Blåis Formation as well as the upper part of the Dolomite Shale Member. The contact between the two formations is marked by a distinct colour change from greyish green to rusty black. This border is often modified by movements.

The detailed stratigraphy of the Dolomite Shale Member is illustrated by a section in the Zigzagland Formation 2 km south of Vallen (fig. 27). The lowermost unit, about 8 m thick, comprises alternations of a finely banded dolomite shale and pure yellowish dolomite. Then follows 2 m of strongly sheared green chloritic schists with thin dolomite layers and strongly folded quartz veins. This unit is succeeded by about 4 m of unfolded banded dolomite and 12 m of grey-green slates deformed by large drag folds. The bedding of these slates is indicated by bands, furrows and cavities (figs. 54 and 55). The folded zone is bounded above by a strongly tectonized zone of chlorite schists and a further sequence of compact dolomite and banded dolomite shales. The major part of the dolomite shales

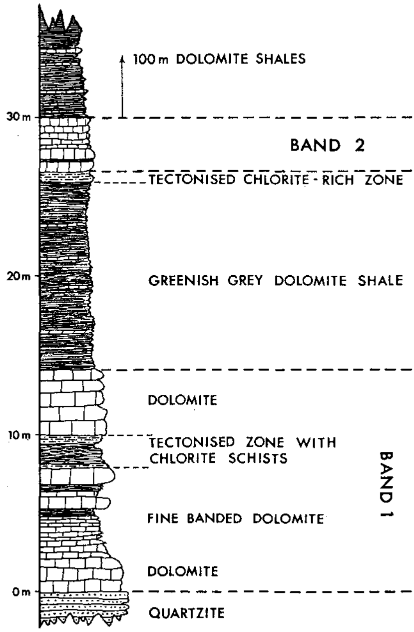


Fig. 27. Section in the lower part of the Dolomite Shale Member of the Zigzagland Formation.

above the upper pure dolomite comprises uniform, greenish, strongly cleaved shales, in some horizons banded, in other cases with thin pure dolomite bands. The content of carbonates appears to vary considerably and is reflected in the degree of weathering of different parts of the shales. The lateral facies variations are from coarse silt and fine sandy material with subordinate thin dolomite bands in the area between Vallen and Grænsesø, towards a higher content of pelitic material in the greenish rocks of the northern part of Grænsesø. However, the general characteristics of the member, with two bands of pure dolomite at the base separated by greyish-green shales, are consistent throughout the whole area.

Special attention is drawn to the two small peninsulas on the west coast of the narrow sound north of the southern basin of Grænsesø. Here the Dolomite Shale Member rests on altered gneisses, on the southern peninsula with a thin 20 cm conglomerate of well rounded pebbles and

Fig. 28. The Dolomite Shale Member of the Zigzagland Formation resting on gneiss. In the lower right corner of the photograph altered gneisses are seen below a small conglomerate of chert and quartzite boulders. Another small conglomerate layer occurs below the hammer head above which is a calcareous sandstone. In the upper left corner fine banded dolomite corresponding to the lower part of the Dolomite Shale Member. The folds seen are F_2 folds. Locality on a little peninsula on the west coast of the middle part of Grænsesø.

cobbles up to 15 cm in diameter at the base (fig. 28), and on the northern peninsula with a banded dolomitic sandstone with rounded quartz grains up to 2 mm in diameter at the base. The dolomite is arenaceous in its lower part, but upwards it becomes a pure banded dolomite (2 to 3 m thick) which grades into grey-green shales. Only one dolomite band seems to occur at these localities which appear to correspond to the whole lower part of the member, shown in fig. 27.

Sedimentary structures, apart from banding and lamination, are rare in the Dolomite Shale Member. The only conspicuous sedimentary structures occur north of Vallen, where contortions of fine pelitic bands in the silty shales, have been observed (fig. 29). The structures are interpreted as

Fig. 29. The Dolomite Shale Member immediately north of Vallen showing the appearance of the layering and a slumped horizon. This horizon is traceable for tens of metres. The incompetent shale in the lower part of the photograph exhibits a fine striation which is the trace of a poorly developed S_2 cleavage. The more calcareous bands are weathered out as furrows.

sedimentary-decollement structures (Pettijohn and Potter, 1964, plate 108 a) and must have been produced under the load of overlying sediment. The structures are generally conjugate fan-folds but are often overturned towards the south in the direction of the basin centre.

Microscopic characteristics

Under the microscope the dolomite shales reveal a varied content of dolomite ranging from more than 90% carbonate (52979 and 53045A) to only a few scattered grains which, however, always seem to be related to original bedding. Analyses of carbonates are shown in table 3. The X-ray diffractometer diagram showed that a little calcite should be present in the rocks.

Thin sections of the samples, classed in the field as "pure" dolomites (52979 from the thin succession just south of Grænsesø and 53045A, 53112 and 53113 from Zigzag-

Table 3. *Analyses of carbonates from the Dolomite Shale Member of the Zigzagland Formation*

	CaO	MgO	Insoluble	$MgCa(CO_3)_2$ calculated	$CaCO_3$ calculated	Total
	%	%	%	%	%	%
52112...	20.5	10.5	31.4	48.5	13.3	90.2*
52113...	30.4	22.9	8.3	95.6	6.4	110.3**
53074...	16.1	10.1	47.0	46.1	3.7	96.8

*) The sample contained high Fe^{+++} concentration, judging from the colour of the solution.

**) Exsolutions during analyses.

land), all exhibit, besides the dominant carbonate, quartz, muscovite, small twinned albites and small needles, possibly of actinolite.

Among the more siliceous rocks, sample 52978 (a greenish grey shale) contains quartz, zoisite, chlorite, a small content of polysynthetic twinned albite, needles of actinolite, carbonate and zircons. A green shale (52973) from the central Grænsesø region contains 70% quartz, 10% muscovite, 5% plagioclase (primary as well as secondary recrystallized albite), 10% chlorite, actinolite?, epidote, carbonate, garnet?, ore and zircon. The siliceous composition is also marked in sample 53045 B, which consists of quartz, carbonate (20%), muscovite and ore, and sample 53045 A which contains quartz, muscovite, epidote (zoisite) and limonite but no carbonate. In the latter case the limonite is thought to be secondary after ferrous carbonate. This is also supported by dissolved samples which, to judge from the colour of the solution, have a fairly high iron content. The rusty weathering of the dolomites may also indicate a fairly high proportion of iron.

In nearly all the samples examined, a fine pigmentation occurs which may be of organic origin; several samples have been shown to contain organic remnants (BONDESEN et al., 1967, p. 13).

In most sections banded or finely laminated structures due to variations in grain size and the occurrence of carbonate are found. These textural relations may locally show a complex pattern which could be due to original organic structures.

The samples 52105 A and B represent matrix and boulder from the basal conglomerate found on the small peninsula in Grænsesø. The matrix (A) is made up of rounded grains (43%) and a few grains of chert and shale embedded in carbonate (36%) and fine quartz (15%). The matrix is finely pigmented and contains furthermore a few percent of secondary muscovite. The boulder (B) is a quartzite (91% quartz) which in its texture shows both rounded grains and sutured intergrowths as characteristic of the most coarse-grained chert. The matrix in the boulder is carbonate (8%). A little muscovite also occurs.

Summary and character

The rocks of the Dolomite Shale Member are, apart from the "pure" dolomite bands, mainly rather siliceous rocks, which possibly originally contained a relatively large proportion of clay minerals and silt. The name dolomite shale (MATHER, 1955), which implies alternating bands of pure carbonate rock and less carbonate rich rock, seems to be valid for most of the succession to judge from the field relationships. Parts of the succession could be termed argillaceous dolomite, and locally the terms dolomitic sandstone or arenaceous dolomite could be applied.

The general stratigraphy and sedimentology of the Dolomite Shale Member shows a marked change from transgressive conditions with the deposition of coarse, clastic material into a milieu of carbonate deposition. The transgressive character still prevails in the Grænsesø region (in the northern basin) as the lower part of the member here transgresses the gneisses. The change in clastic sedimentation from sand in the quartzite to silt and clay in the Dolomite Shale Member, and to clay in the pelites of the Blåis Formation, suggests a general increase in depth, a feature already indicated by the sedimentary structures of the quartzites.

The carbonate material is probably not of clastic origin i.e. resedimented carbonates, *e.g.* from the Lower Zigzagland Formation, as no textural relations is in favour of this origin. It seems far more likely that it is either a precipitate or of biogenic origin. The latter suggestion is only supported by the occurrence of remnants of microorganisms, as no mesoscopic structures which could be interpreted as of organic origin, have been found.

The Blåis Formation

General introduction and division

Above the Zigzagland Formation a thick pile of pelites, semipelites and graded greywackes occur. This sedimentary sequence marks a change in depositional conditions and is distinguished as a new formation – the Blåis Formation, named after the tongue of the Inland Ice, west of Zigzagland, called Blåisen (the blue ice). The top of the Blåis Formation is to the Grænsesø Formation, which is the lowest formation of the pillow lava main structural division.

The thickness of the formation varies; it is at least 300 m north of Grænsesø but only about 40 m in the southern part of Grænsesø. To the south of Vallen the maximum thickness is estimated at 800 m.

The division of the rocks of the Blåis Formation into mappable units is based on the following mesoscopic distinctions: 1) pelites – finely laminated and banded shales and slates; 2) semipelites – banded shales and slates with scattered clastic grains visible in the hand specimen, usually occurring together with pelites and occasionally with greywacke units; 3) graded or banded greywackes – large graded units or banded successions with a dominance of coarse clastic material, usually with minor pelitic or semipelitic intercalations.

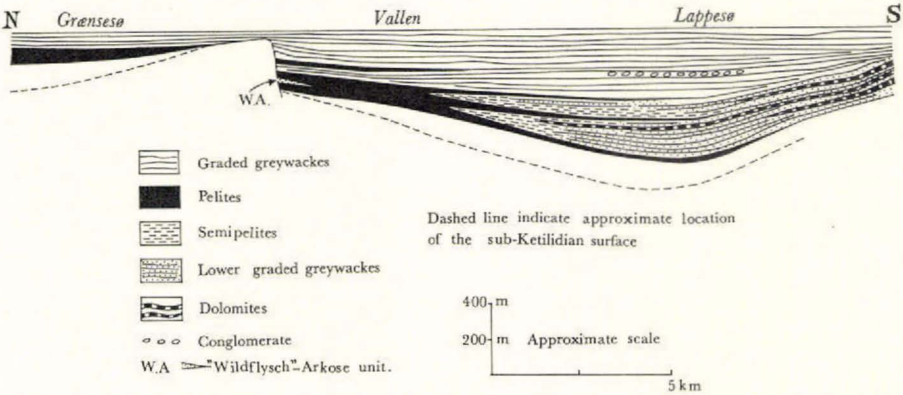


Fig. 30. Tentative reconstruction of the facies relations in the Blåis Formation.

In the southern part of the area the development differs from that farther north. In the vicinity of Lappesø and as far as 3 km to its north, greywackes with dolomitic layers are developed. On top of these occur banded semipelites and coarse graded greywackes. The latter can be followed northwards to Vallen, where they overlie a development of banded greywackes, semipelites and thick black pelites; dolomitic bands are not developed here. Farther north, between Vallen and Grænsesø, black pelites underlie graded greywackes, but there are no distinct occurrences of banded greywackes and semipelites. Along southern Grænsesø graded greywackes, corresponding to a high level in the graded greywackes elsewhere, rest on top of gneisses. In the northern part of the area, black pelites occur below coarse greywackes and above the Zigzagland Formation.

A tentative reconstruction of these facies relationships is given in fig. 30. This reconstruction can only give a rough outline of the situation, as the conditions, especially in the southern part of the area, are obscured by thrusting and folding. However, both thrusts and folds appear to be controlled by the facies changes.

The stratigraphic subdivision of the Blåis Formation into "laminated pelite member", "banded greywacke member" and "rhytmhic greywacke member", earlier published by BERTHELSEN (1965, table 2, p. 124), is not retained in this paper as the Blåis Formation here includes the originally undivided "Lappesø Formation" (see p. 40).

The strong facies variations and lithological gradations make it difficult to define the borders of the different units both laterally and vertically. The single lithostratigraphic members have more the character of rcck units of local development and a formal lithostratigraphic division is therefore of little value in regional correlation. It is therefore preferred to base the following description of the Blåis Formation on a regional subdivision and the local facies development.

The area around Lappesø

The black pelites

On top of the dolomite shales of the Zigzagland Formation north of Lappesø and below the lower greywacke dolomite succession, 20 to 30 m thick black pelites occur. The pelites are strongly sheared and can be traced into the black pelites at Vallen. South of Lappesø thin equivalent black pelites can only locally be seen. Locally graphitic shales have been observed.

The lower greywacke-dolomite succession

The lower greywacke dolomite succession occurs south of Lappesø on top of the Zigzagland Formation with only thin local occurrences of black pelites in between. North of Lappesø the black pelites form the lower boundary of the Blåis Formation.

The major part of the lower greywacke-dolomite succession comprises coarse greywackes, with black quartz grains, in beds less than 1 m thick. The grading is less distinct than in the graded greywackes, but nevertheless yields good indications of way-up in the locally strongly folded succession.

Several bands of dolomite associated with black pelitic slates form good markers and outline folds of an asymmetric to isoclinal style. The greywackes are here affected by a strong cleavage associated with the folding, hence they weather readily and as a result are poorly exposed. The thickness south of Lappesø is possibly more than 300 m.

A good stratigraphical sequence is seen north of Lappesø, where the fold style is more open, and is not associated with the development of a strong cleavage.

The lower greywacke–dolomite succession is here about 250 m thick. The single beds are generally smaller than south of Lappesø, and the whole succession thins northwards over a distance of a few hundred metres towards the lake 2.5 km south of Vallen.

In the upper part of the lower greywacke-dolomite unit there occur two 1 to 3 m thick dolomitic layers in association with black pelites of varying thickness. The folding of these has led to a repetition of the layers. Farther south, close to Lappesø, there seem to be several more of these layers and they appear to correspond to the dolomites in the greywackes south of Lappesø.

The mixed greywacke-semipelite-pelite succession

Eastwards, and at a higher structural as well as stratigraphic level north of Lappesø, there follows a succession of pelites, banded semipelites, units of graded greywackes, and occasionally banded greywackes. The lower boundary of this succession is a strongly tectonized zone – perhaps a thrust zone – which separates the disharmonic folding found below and above. This sequence of mixed rocks cannot be followed south of Lappesø, but might continue northwards to Vallen into the corresponding sequence of banded greywackes. However, except for a few large units of coarse graded greywackes which are traceable into the banded greywackes at Vallen, this cannot be proved in the field because of bad exposures.

This whole mixed greywacke-semipelite-pelite succession occurs within a large recumbent fold.

The graded greywackes

The graded greywackes, which as a sedimentary unit extend from the east coast of Lappesø to the Sioralik glacier, differ in the Lappesø area only slightly from the better preserved graded greywackes farther north. The tectonic conditions in this southern area have imposed a strong schistosity on the rocks in which it is difficult to distinguish sedimentary features, apart from the grain size variations forming the grading.

It is characteristic especially of this area that one, or perhaps two, conglomerate units occur. The two occurrences of conglomerate might represent the two limbs of a fold, of which the closure has been overridden by the main structural division of the pillow lava thrust sheet (see plate 11). The conglomerates are oligomictic, tilloid paraconglomerates (PETTIJOHN, 1957, p. 265), less than 5 m thick, made up of scattered cobbles and boulders up to 30 cm in their longest axis in a matrix of coarse greywacke. All the boulders examined were cherty quartzites, very similar in

Fig. 31. Banded and laminated black pelites in the lower part of the Blåis Formation. Minor slumping occurs in the layer below the lens. An S_2 cleavage intersects the exposed face obliquely. Location immediately south of Vallen.

rock type and in their sub-rounded shapes to the boulders found in the Ore-Conglomerate Member of the Zigzagland Formation. In addition a few units of pebbly greywacke and a unit containing fragments of shales have been found.

Abundant pyrite mineralization is characteristic of the Blåis Formation in this area (see p. 56).

The area around Vallen

The black pelites

The area around Vallen offers the best conditions for detailed studies of the Blåis Formation, as deformation is either absent or very weak.

Just to the north and south of Vallen, black pelites rest conformably on top of the Zigzagland Formation. Farther south this border is obscured by thrusting (see p. 162). The thickness of the black pelites varies from approximately 200 m at Vallen to less than 100 m 3 km to the south, where the lower greywacke-dolomite succession of the southern area begins to thicken.

The lower part of the black pelites is usually rusty due to weathering of pyrite and the shales are often carbonaceous. Higher in the black pelites banded and laminated sedimentary structures with minute laminae less than 1 mm thick make up larger units of lighter or darker colour (fig. 31). These bands often show sedimentary deformation in the form of small-scale folding and convolute bedding. Varved gradations have also been observed. Thin bands of semipelite or even psammitic material occur towards the top of the member.

The banded greywackes

There is a gradual change from the fine-banded division of the black pelites to the banded greywackes with a progressive incoming of fine clastic material and up to 25 cm thick layers of coarser clastic material (silt to medium-grained sand). These clastic layers alternate with the pelites giving rise to a banded sequence. Single bands of this sequence may be very persistent and can be followed for several hundred metres with only slight variations in thickness.

The thickness of the banded greywackes varies from less than 100 m at the south coast of Vallen to nearly 300 m 3 km farther to the south.

Banded greywackes as a mappable unit cannot be established north of Vallen although thin bands, and banded pelites similar to the gradational succession in the upper part of the black pelites, are found.

The banded greywackes may possibly be correlated with the mixed greywacke-semipelite-pelite succession north of Lappesø as has been mentioned on p. 74, since a mappable succession, dominantly of pelites and semipelites with a few minor greywacke units, occurs in the upper part of the banded greywackes.

The graded greywackes

The border between the banded greywackes and the graded greywackes is sharp (fig. 32). The sediment just below the border is a dark banded semipelite with a few minor greywacke units. The graded greywackes then begin with a 2 m thick coarse, light greywacke unit which can be followed for 2 km to the south coast of Vallen. North of Vallen a similar light, coarse greywacke unit forms the base of the graded greywackes overlying the black pelites. The thickness of the graded greywackes north of Vallen is 600 m and the exposed thickness south of Vallen only a little more than 200 m.

The graded greywackes in both northern and southern areas are characterized by the thick units of coarse, clastic material (fig. 33). Often coarse sand or even pebbles occur at the base of a unit and grade into medium sand which is usually dominant. In their upper parts the graded units terminate in fine silty, more rarely pelitic, material.

Fig. 32. The boundary between the semipelites of the banded greywackes (below) and the graded greywackes (above) in the upper part of the Blåis Formation. The light unit at the base of the graded greywackes can be followed to the coast of Vallen. Locality 2.5 km south of Vallen. In the background the terminal moraines of Blåisen can be seen.

Fig. 33. Graded greywackes in the upper part of the Blåis Formation in the south corner of Vallen. The light bands are coarse greywacke and the dark bands the pelitic uppermost part of the units. The units in the foreground are from 1 to 1.5 m thick. In the background outcrop pillow lavas at Blåisen east of Vallen, and in the far background the Fønland pillow lava plateau can be seen.

Locally lenses and streaks of fine material occur in the single units and coarse material can also be found in local concentrations, giving rise to reverse grading and composite layering within a unit.

The thickness of the single units varies from 1 to 3 m. They are of wide horizontal distribution (of the order of kilometres) but are difficult to trace if not followed foot by foot as they are not readily distinguished from each other; only one unit, which contains shale fragments and a few units with pebbles of chert, may be easily traced.

The southern part of Grænsesø

The black pelites

The black pelites just south of Grænsesø rest conformably on the Zigzagland Formation. They are here generally not less than 200 m thick. Although for the most part they are similar to the pelites farther south, a greater number of banded semipelitic intercalations are found. In this area practically no deformation is apparent apart from a few open folds, and the pelites therefore have the appearance more of shales compared to the somewhat slaty character of the equivalent rocks south of Vallen.

Along the east coast of Grænsesø the black pelites are lacking in the southern part, where graded greywackes rest directly on the gneisses, but they reappear 3 km farther north.

The "wildflysch"-arkose unit

Between 50 and 75 m above the base of the black pelites there occurs an important unit of coarse arkose conglomerate, here termed the "wildflysch"-arkose unit because of its apparent genetic connection to movements in the sedimentary basin and its coarse-grained character.

It is 15 m thick at Grænsesø, which is the northernmost occurrence, and it can be followed southwards for approximately 2 km gradually thinning so that close to Vallen it is only 1 m thick.

The "wildflysch"-arkose unit consists of unsorted material ranging from fine pelitic to coarse grains of angular feldspars and quartz, and pebble-size fragments. The unit also contains angular blocks of shales, calcareous rocks, quartzites, gneisses and rounded boulders of dense quartzitic cherty material (fig. 34). The angular blocks of shale, quartzite and calcareous rocks can easily be correlated with corresponding rock types of the sediments of the underlying Zigzagland Formation, and the rounded boulders are of the same character as those found in the basal conglomerate of this part of the area. The gneiss components, in spite of strong disintegration, seem to be of the same varieties as outcrop around southern Grænsesø. Large aggregates of plagioclase feldspar, strongly veined and broken with bent twin-lamellae, are an important constituent in the unit close to Grænsesø; no feldspar rocks of this type are known in situ in the area.

It seems probable that this unit has been formed as a consequence of movements (faulting) in the sedimentary basin, such that all the rocks below the surface of deposition have been exposed to erosion and transport. In most of its characters the unit recalls the olisthostrome deposits of the Mediterranian Mesozoic (Görler and Reutter, 1968, p. 484). A further discussion of the significance of the "wildflysch"-arkose appears on p. 133.

The graded greywackes

As mentioned before, a light graded greywacke unit has a sharp contact with the black pelites. This cannot be definitely correlated with the basal unit south of Vallen.

Fig. 34. The "wildflysch" -arkose unit in the black pelites north of Vallen. The exposure shows the lower part of the unit densely packed with fragments of various sediments of the Zigzagland Formation and gneiss; x) a gneiss boulder, y) a boulder of the same type as found in the Ore-Conglomerate Member, z) angular fragments of the Dolomite Shale Member, w) a quartzitic sediment and q) a large angular gneiss block. The majority of the smaller fragments are gneiss.

There is little difference between these rocks and the graded greywackes at Vallen. However, the general impression given is that the units are thicker (up to 7 m) and that coarse sand and small pebbles play a comparatively larger role. A prominent feature in this area is the occurrence of lensoid (10 to 25 cm long) patches of loose unconsolidated greywackes oriented parallel to the bedding (fig. 36).

A mappable level of pelites and semipelites about 100 m from the base serves as a good guide horizon.

The thickness of the graded greywackes is 225 m just south of Grænsesø. This is probably not the complete thickness, as it is possible that the Bæversø fault traversing the area is responsible for the burial of part of the succession.

On the east coast of the southern part of Grænsesø graded greywackes rest directly on the gneisses. It is uncertain whether this contact is primarily tectonic or sedimentary. There is evidence of some movements but on the small peninsulas a little farther north (see p. 68) the Dolomite Shale Member of the Zigzagland Formation is autochtonous on the gneisses and it seems unlikely that there are major thrusts along the sediment-gneiss border. There is, however, a possibility that transgressive thrusts from higher in the sedimentary series may transgress downwards as far as the border in this region; tectonized zones are fairly frequent at higher stratigraphical levels.

The graded greywackes on the east coast of southern Grænsesø are only 40 to 50 m thick and towards the top there are progressively thicker pelitic intercalations, which are usually strongly sheared. These grade into the pelites of the lower Grænsesø Formation which suggests that the border between the Blåis Formation and the Grænsesø Formation is here parautochthonous to autochthonous; this is in contrast to most other localities in the area, where a structural discordance is apparent between the disharmonically folded sedimentary structural division and the pillow lava structural division (which includes the Grænsesø Formation). This is also the only locality where the upper border of the Blåis Formation appears to exist.

The area around the northern part of Grænsesø

The Blåis Formation is only partly exposed in this area as the pillow lava main structural division in places is in contact with the graded greywackes, and in other places with the black pelites and the upper part of the Zigzagland Formation.

The black pelites

The black pelites are exposed all along the northern part of Grænsesø where they rest conformably on top of the Zigzagland Formation. Their thickness is estimated at about 120 m.

The black pelites are here generally rusty in colour and occasionally banded. In the lower part carbonaceous horizons are present.

The graded greywackes

A strong schistosity associated with the folding dominates the graded greywackes and it is difficult to distinguish the single sedimentary units. However, the general impression is that the units are smaller than at

Vallen and the grain size generally less. The grain size in some units, however, is in the coarse sand and pebble fraction.

A conspicuous feature is that black quartz, as in the southernmost area, again plays an important role. Some units contain pebbles of chert (dominantly black) and others contain well rounded pebbles of a rusty, porous quartzite or chert, similar in appearance to the boulder material in the Ore-Conglomerate Member of the Zigzagland Formation. A few units containing angular fragments of shales have been found.

The greatest thickness of the graded greywackes in this part of the area is approximately 160 m.

Microscopic characteristics

The rocks of the Blåis Formation represent a highly varied sequence, ranging from fine pelites of various types, and dolomites, to coarse greywackes and conglomerates. Although similar in hand specimen, rocks of single layers may differ in respect to mineralogy and quantitative data. Detailed and thorough examinations would therefore require a systematic sampling, a programme which time did not allow. The sampling in the field was therefore designed to secure a representative collection, covering petrological and sedimentological as well as metamorphic and deformational features. The following section is merely a presentation of observations from the collected material, including some quantitative information.

The greywacke samples and other samples from the Blåis Formation show some variation in composition (table 4) and grain size (fig. 35), as the proportions of rock fragments, stable clastic minerals of the sand fraction and the matrix material vary. The rocks point-counted in table 4 and granulometrically examined are mostly coarse-

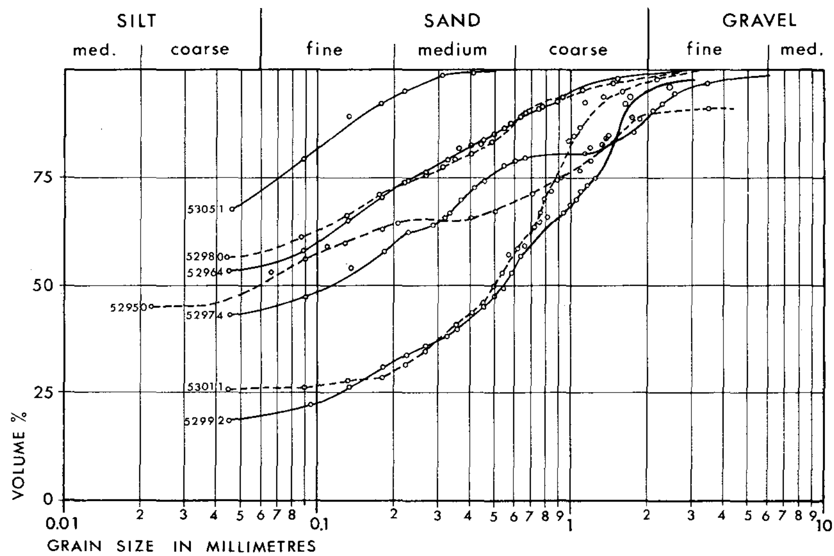


Fig. 35. Grain size cumulative frequency curves of some greywackes from the Blåis Formation.

Table 4. *Modal composition of greywackes from the Blåis Formation*

	20827	52950	52964	52974	52980	52981	52992	53011	53050	53051	53129	51910
Quartz	54.1	8.8	21.6	28.1	26.7	4.5	44.3	53.1	41.7	14.2	35.9	48.0
Plagioclase	0.4	0.5	0.9	2.5	2.0	0.3	2.5	3.1	2.2	0.6	0.7	2.4
Microcline	1.7	2.2	0.3	6.5	1.7	0.5	4.0	–	2.7	0.2	–	2.8
Dark min.	–	–	–	1.3	1.0	0.8	1.0	–	0.9	0.6	–	11.9
Ore	0.4	1.1	4.5	0.8	1.0	1.0	1.0	0.2	0.6	1.0	–	2.6
Chert	–	7.5	6.0	1.0	–	–	–	–	–	–	–	10.5
Carbonate rock	4.5	1.4	–	–	–	–	–	–	–	–	–	2.4
Shale	0.3	26.4	0.5	2.4	–	–	–	–	–	–	–	2.5
Others	8.5	–	–	–	3.5	31.9	17.2	–	8.0	3.9	–	5.6
Matrix	26.6	51.8	57.6	54.7	60.0	59.5	30.0	26.0	30.6	72.3	42.0	51.0
Muscovite	0.2	–	0.2	0.2	–	–	–	–	0.5	–		2.7
Chlorite	–	–	8.4	2.5	0.6	–	–	–	1.8	1.5		3.4
Epidote	–	–			–	–	–	–	–	–		2.6
Actinolite	–	–	–	–	0.2	–	–	–	–	–	21.4	–
Calcite	1.3	0.3	–	–	1.3	1.1	–	16.2	1.3	5.3		–
Biotite	–	–	–	–	0.3	–	–	–	7.8	0.1		2.6
Others	2.0	–	–	–	1.7	0.4	–	1.4	1.9	0.3		–
	100.0	100.01	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Grain curve (fig. 41)		*	*	*	*		*					

grained rocks with well preserved textures. The pelitic and semipelitic samples generally show strain features of tectonic origin under the microscope, and the quantitative data are therefore not comparable.

The grain size distribution analyses show that the sorting in some cases is comparatively good and the matrix proportion below 0.05 mm rather low. However, the matrix proportion is generally high and the calculated cumulative curve flat-lying, which indicates bad sorting. The samples 52950 (plate 4a) and 52954 show a complex cumulative curve trend, which could indicate (as no layering is apparent) that several different fractions are present.

This may be caused by a mixture of already separated grain fractions as would be the case in the conglomerate units where boulders and cobbles form one fraction, coarse to medium sand a second, and matrix a third fraction.

The grain shapes of both mineral and rock fragments range from angular to perfectly spherical.

Among the fine-grained rocks the pelites, (53028 and 53129, table 4) and the semipelites (20826, 20828 and 53051, table 4) exhibit microscopic sedimentary layering (53129 with 0.5 mm between the layers) with syntectonic growth of muscovite oblique to the bedding and corresponding to the S_2 cleavage. The sedimentary lamination is expressed by a concentration of opaque material (ore and carbonaceous matter) and also muscovite and chlorite. Under the microscope the layering is in the form of garland-structures or small folds which are apparently a primary feature pre-dating the growth of the secondary metamorphic minerals.

In the more coarse-grained rocks the textures are dominated by the coarse, clastic grains. In some samples (52981, 53050, plate 5a) syntectonic growth of micas occurred in the matrix and resulted in a lensoid texture around the primary clastic grains; in some cases there has evidently been subsequent rotation of the clastic grains. A possible primary orientation of the clastic minerals has also been observed.

Recrystallization of grain boundaries occurs and the matrix material is generally completely recrystallized. Cataclastic textures are rare.

The primary sedimentary coarse clastic grains are dominantly quartz, showing undulate extinction. Both dusty and clear (mostly angular) quartz grains are found. The feldspars are plagioclase and microcline, with the latter generally dominant (table 4).

The dark minerals found as larger primary grains are amphibole, pyroxene?, epidote, sphene, biotite, ore, zircon? and apatite.

Among the rock fragments chert, shale and carbonate rocks, found as clusters of recrystallized carbonate, are the dominant rock types, but carbonaceous shale and ore-bearing chert have also been observed. No fragments which could be interpreted as igneous have been observed.

The matrix is wholly made up of microcrystalline quartz and secondary metamorphic minerals. The latter are muscovite, chlorite, epidote, needles of actinolite?, biotite (locally), carbonate and finely dessiminated opaque material. Small patches of feldspar ($n < n_{cb}$) and simple twinned albites are also found.

The recognition of greywackes

The term greywacke is, as pointed out by PETTIJOHN (1957), one of the most troublesome in geology. It is widely used with respect to rocks similar to the original Harz greywacke (of Devonian and Carboniferous age), a rock of sub-angular and angular quartz grains, some feldspars and rock fragments in a fine matrix. The term has also been used for coarse, clastic sediments, originating by the disintegration of basic igneous rocks (Twenhofel, 1926), and for the rocks of specific textural (Boswell, 1960) and structural types (McBride, 1962; Packham, 1954; Bouma, 1964) but of variable composition. In this last respect the term becomes useful in the field for banded and graded successions, but difficulties with compositional definition are raised.

Pettijohn regards greywackes as sandstones with 1) more than 15 % matrix (fine-grained chlorite and sericite) and 2) more than 25 % unstable components (rock fragments and feldspars). McBride (1962) proposed a modification, which brought many greywackes so-named in the field within the definition: 1) more than 15 % chlorite-sericite matrix, and 2) more than 10 % unstable, fine-grained rock fragments, and 3) more than 5 % feldspars.

The composition of the "greywackes" examined shows that only two samples out of eleven are greywackes, according to the definition of Pettijohn, and only one according to McBride's modified classification. All the samples fulfil the requirements as to the proportion of matrix and are close to the feldspar content required, but the proportion of rock fragments varies considerably. Taking the large quartz proportion into consideration, many of the rocks could be classed as sub-greywackes or protoquartzites and, in view of the amount of rock fragments, many could be termed lithic greywackes (Pettijohn, 1957, p. 291).

The author has thus encountered the same difficulties as many other geologists, in that the field term for a group of rocks does not strictly correspond to the term defined on composition. Recognition of greywacke in the field was based on textural relations, the occurrence of scattered coarse, clastic grains in a fine matrix, and the structural characteristics. The terms graded, bedded, banded, laminated or homogeneous were used to describe these rocks and also the semipelites and pelites.

Greywackes are a widespread group of sediments, difficult to classify because of their apparent genesis, which fundamentally differs from normal transportation, sorting and sedimentation which provide the primary basis for sedimentary classification. In this respect the same difficulties are encountered with tillite and moraine; these would be impossible to classify on percentage limitations for the different components. Greywackes have been interpreted by several authors as deposited from turbidity currents and, as with moraine and till, they are therefore dependent compositionally on the source material.

Greywackes accordingly have often been termed turbidites. It is preferable, however, to avoid the usage of genetic terms. The classification of sediments in relation to their tectonic environment as syntectonic (flysch) and post-tectonic (molasse) (de Sitter, 1962) is in principle preferable if their setting is sufficiently known, and would include rocks otherwise difficult to classify e.g. the alpine flysch. However, the use of these terms entails a complete analysis of the kinematic evolution of the sedimentary basin and its surroundings and they should be restricted to final and general syntheses. They are therefore of little value in most descriptions and would lead to misunderstanding and misinterpretation when based on small areas.

The author has therefore preferred to employ the term greywacke as defined on textural relations and structural characteristics in accordance with PACKHAM (1954), BOSWELL (1960) and McBRIDE (1962).

Sedimentary structures

The most conspicuous sedimentary structures are lamination, banding and graded structures. Lamination on the scale of millimetres is restricted to the pelites. This minute bedding often exhibits a garland (festoon) structure and minute convolutions apparently caused by consolidation and load (fig. 31). Other load cast and slump phenoma have frequently been observed. Varved structures occur occasionally in the pelites. Grading is a dominant feature of the coarse sediments, and single units may be as large as 7 m which seem to be exceptionally large units (PETTIJOHN, 1957, p. 112). Often the units contain irregular patches and streaks of either coarse or deformed pelitic material. Reverse grading, not so distinct as the normal greading, has been observed within the units.

Slumps, casts and other sedimentary deformations are rare outside the black pelites and have only been observed in a few cases in banded greywackes. It is surprising that substratal sedimentary structures characteristic of the turbidity current deposition of graded sediments are completely unknown in the graded greywackes of the area. An explanation might be that the basal surfaces of the graded units have rarely been observed exposed, since the well preserved units are always right-way-up, and that the cuesta shapes never permit an examination of the bedding planes from below. However, if substratal sedimentary structures existed, deformation of the pelitic top of the unit previously deposited would be expected. As this often shows very fine banding and such deformation therefore would be easily visible in section, it is suggested that substratal sedimentary structures were not developed.

The lensoid patches of unconsolidated greywacke mentioned on p. 82 (fig. 36) range in length from 10 to 25 cm. The sedimentological significance of this phenomenon is uncertain. In one case a shale fragment was observed centrally. It might therefore be possible that it is a secondary solution phenomenon around unstable particles of a chemical composition contrasting to that of the surrounding sediment.

Fig. 36. Lensoid patches of loose badly cemented greywacke in a large greywacke unit. Locality immediately south of Grænsesø.

Summary and interpretation of the greywackes and pelites

The sedimentary variations in the Blåis Formation between pelites semipelites, banded greywackes and graded greywackes seem to represent facies changes both laterally and vertically.

The two basins existing during deposition of the Zigzagland Formation still prevailed, although the dividing ridge in southern Grænsesø was transgressed high up in the graded greywackes and the two basins were thus connected. The general vertical facies changes seem to be the same on both sides of the ridge except in the southern part of the southern basin where the lower greywacke dolomite succession represents an exception. The lateral facies changes in the southern basin tend to show a general increase in the grain size away from the ridge in the lower part of the formation. The upper part, represented by the graded greywackes, seems to have a general decrease in grain size as well as thickness of the units.

The "wildflysch"-arkose unit, and the changes in thickness around the southern part of Grænsesø, show that the sedimentation took place under unstable conditions where paroxysmal movements near the dividing ridge, and possibly also at other localities, influenced the sedimentation. Such conditions would favour the formation of turbidity currents, and it is therefore probable that the graded greywackes represent turbidite units. The existence of grading, the textural relations, the angular grain shapes mixed with more rounded shapes, and the existence of rock fragments and unstable minerals, also suggest a turbidite origin for the graded greywackes. A tilloid paraconglomerate, as found in the Lappesø region, is by PETTIJOHN (1967, p. 266) interpreted as a reliable indication of turbidity flows.

The probable lack of substratal sedimentary structures would be explained if the turbidite suspensions were propagated in water without contact with the sea bed. This would lead to comparatively quiet sedimentation as the speed of the suspended material diminished. This would imply rapid variations in the inclination of the sea bottom for which, however, no direct indications have been found, except for the dividing ridge between the two basins.

The association of greywackes with calcareous rocks is mentioned by PETTIJOHN (1957, p. 312) as a rare phenomenon. This, however, is quite commonplace in the region around Lappesø in the southern basin. The author considers that the explanation may be found in the calcareous rocks being the indigenous sedimentary accumulation in the southern part of the basin, while at intervals turbidity currents brought in external material. The equivalent sediment in the northern part of the basin is represented by the black pelites in very thin and possibly slowly accumulating laminae. This view might explain the gradual increase in number and thickness of the calcareous bands towards the south, and also the alternation between carbonate rocks and pelites, especially prominent in the area north of Lappesø. It should in this connection be mentioned that the black pelites in the area south of Vallen locally include thin calcareous bands, which are the northernmost occurrence of the calcareous facies.

In the source area of the material for the graded greywackes gneissic basement cropped out, from which the grains of strained quartz, plagioclase and microcline are thought to derive. Rounded quartz grains, carbonate, shale and chert fragments, and boulders of chert or quartzite suggest that sediments also provide a source. These could have been consolidated sediments exposed for erosion fault movements or, with respect to rounded grains and loose boulders, unconsolidated material from regions of other sedimentary facies. The wide occurrence of chert seems to be of the same significance as in the quartzites of the Zigzagland Formation (see p. 67 and 129).

The Grænsesø Formation

Occurrence

Throughout the whole area, from the Sioralik glacier to the Arsuk glacier, a thin sequence of strongly varying sediments comprising dolomites, pyritic shales, carbonaceous shales, and cherty quartzites, is found

Fig. 37. The Grænsesø Formation along the east coast of the middle part of Grænsesø. The photograph illustrates well the general condition of exposure. In the foreground the dolomitic shales of the Zigzagland Formation (A) and above the scree lensoid bodies of dolomite in black carbonaceous shales. Large basic sills are indicated (γ) and on the tops of the hills there are pillow lavas of the Foselv Formation.

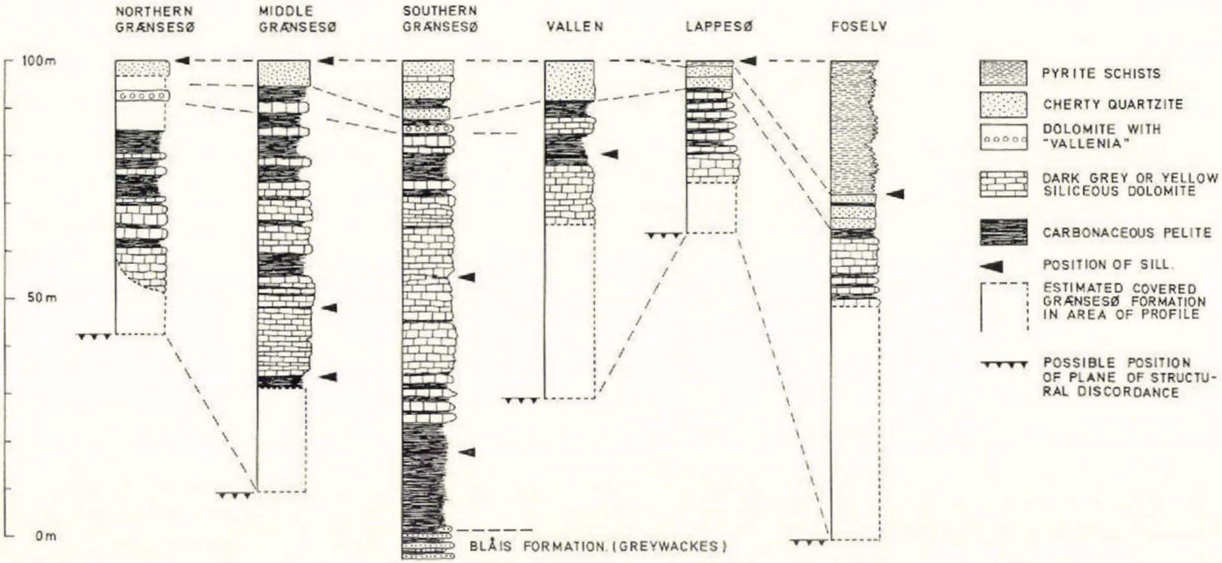


Fig. 38. Tentative presentation of the stratigraphy of the Grænsesø Formation based on field estimations of the thicknesses.

at the base of the main structural division of the pillow lavas. The sediments have partly been mapped collectively and are described under the name of the Grænsesø Formation, after the lake Grænsesø along the eastern shore of which the formation is typically developed and well exposed. The Grænsesø Formation has been intruded by sills.

The sediments are strongly deformed in contrast to the practically undeformed overlying pillow lavas, and they are also in strong structural disharmony with the graded greywackes of the Blåis Formation below. They are nearly always exposed in the escarpment between the high pillow lava plateau and the lowland sedimentary country (fig. 37). As a consequence, the lower part of the Grænsesø Formation is usually obscured by screes.

Good exposures also occur in Fønland in a few open valleys which represent the eroded crests of anticlinal culminations. South of Vallen, the pillow lavas disappear under the Blåisen tongue of the Inland Ice, but the ice topography and a small nunatak indicate the approximate location of the escarpment. From south of Blåisen to Foselv, the Grænsesø Formation is partly exposed in the escarpment and partly in a narrow valley which penetrates the pillow lava plateau.

The region between Foselv and the Arsuk glacier on plate 11, indicated as Grænsesø Formation, has been shown by PEDERSEN (1968) to be not entirely Grænsesø Formation but in its lower part also to include Zigzagland Formation. The Grænsesø Formation in this part of the area may therefore be relatively thin.

In the southern part of Grænsesø, the Grænsesø Formation appears to occupy a parautochthonous position on top of the graded greywackes (p. 83). At other localities it rests in contact with different members of a lower stratigraphical position and is judged to be allochthonous. In the latter cases the actual tectonic contact was usually obscured but the structural discordance is clearly evident from the geological map.

The thickness of the Grænsesø Formation, excluding the major intrusive sills, shows some variations (fig. 38). The thickness of the formation has been estimated in the field from localities with relatively simple folding, but even so there are possibilities of considerable error due to tectonic migration of the incompetent material and boudinage of the more competent layers. Thrusts may also cause variations in that smaller or larger parts of the Grænsesø Formation may locally be lacking.

The Grænsesø Formation seems to be relatively thin in the northern part of the area as a whole, possibly a little more than 50 m thick, but seems to thicken considerably in the immediate vicinity of the Sioralik glacier. In the southern part of Grænsesø, the formation reaches its greatest thickness of 100 m but the thickness again decreases towards

Vallen. South of Blåisen and near Lappesø until Foselv, only 20 to 40 m of sediments are present. As mentioned above, the Grænsesø Formation south of Foselv may be relatively thin.

The detailed stratigraphy of the Grænsesø Formation has proved very difficult to establish. The dolomite bands in the pelitic material are mostly boudinaged and broken, and the pelites have migrated into folds. The best opportunities for stratigraphic studies are afforded by thick dolomite bands as these are often folded in a simple concentric manner.

The lowest known part of the formation at southern Grænsesø comprises black pelites which grade downwards into greywackes (see p. 83). The pelites become carbonaceous and graphitic higher up in the succession where they are also interbanded with thin bands of dolomitic rocks. The dolomitic proportions increase upwards with a development of 20 to 100 cm thick layers, which at a slightly higher level dominate over the graphitic pelite bands and occur as massive dark grey to black dolomites transected by numerous small quartz veins and weathering to a grey or yellow colour. Small siliceous bands indicate the bedding of these otherwise homogeneous dolomites.

In the upper part of the succession the dolomites give way to bands of carbonaceous pelite and pelitic shales again become dominant. Towards the top of the sequence isolated dolomite bands occur and black chert becomes more and more frequent either as 1 cm thick bands in a strongly silicified dolomite, or as thicker massive beds. In this upper part a coarse crystalline dolomite with black spheres of 1 mm diameter has been found in two localities by the author in the northern and southern parts of Grænsesø. The black spheres are organic structures and have been described under the name *Vallenia* by K. RAUNSGAARD PEDERSEN (BONDESEN et al., 1967). K. RAUNSGAARD PEDERSEN in 1966 found a new locality of this fossiliferous dolomite in Grænseland between the two original localities, and A. K. HIGGINS found the same rock in the Midternæs area 22 km north of the type locality which is situated at the south-east corner of Grænsesø in Grænseland. It is thus possible to establish "biostratigraphic" correlations of the upper Grænsesø Formation over a considerable area.

In general a triple division of the Grænsesø Formation can be established: a lower part dominated by carbonaceous pelites, a middle part characterized by massive layers of dolomite, and an upper part of mixed pelite and dolomite, including the *Vallenia* layer, and with cherty quartzites above. In the southern part of the region, however, a new sedimentary unit appears above the cherts, namely a rusty shale layer. This layer is first encountered south of Blåisen above a thick sill and increases in thickness towards the south. At Foselv it is more than 30 m thick. South of Foselv the rusty shales are found in between massive intrusive rocks. The rusty nature of the shales is due to a high content of pyrite and they have therefore been termed the pyritic shales.

Microscopic characteristics

The pelites are exemplified by sample 52971. The rock is very fine-grained black and smearing. No sedimentary structures are visible. It consists of a fine greyish-black semi-opaque mass in which a few quartz grains and some flakes of colourless mica are seen. The black semi-opaque material is carbonaceous.

The dolomites are of black to grey types (20863, 20907, 53069) and consist mainly of carbonate (ca. 90%), quartz (10%), a little plagioclase (albite) exhibiting simple twinning and a colourless mica (muscovite). In samples 20863 and 20907 disseminated black opaque (carbonaceous) material is seen. A few idiomorphic ore grains (pyrite) also occur. Quartz veins and carbonate veins are common. In quartz veins the crystals seem to be oriented perpendicularly to the plane of the vein.

Chemical analysis of a dolomite (52969) from the area north of Grænsesø gave: 22.5% CaO and 13.0% MgO corresponding to a composition of 59.7% $MgCa(CO_3)_2$ and 7.5% $CaCO_3$; 38.4% of the rock was insoluble.

The *Vallenia* rock (plate 5b), of which numerous thin sections have been made (Bondesen et al., 1967), consists dominantly of twinned carbonate minerals in a eugranoblastic saccharoidal texture. The avarage grain size is about 1 mm. The carbonate minerals are in the proportions of approximately 55% $MgCa(CO_3)_2$ and 10% $CaCO_3$ with possibly a little of the $FeCO_3$ molecule in calcite as well as dolomite (as determined by X-ray diffraction methods). Most carbonate grains are pure and have recrystallized across the borders of the globular organic structures. Some carbonate grains contain a dusty pigmentation of opaque material. Small quartz grains occur locally between the carbonates and also in concentric arrangements within the organic structures. A few larger 0.5 mm rounded quartz grains could be of clastic origin. Colourless micas (muscovite) are found randomly scattered and a little nonpleochroic chlorite with brownish anomalous interference colours also occurs. A few plagioclase grains are found.

The opaque material is dominantly carbonaceous but a few idiomorphic pyrites have been observed. Isotopic composition of C_{12}/C_{13} from carbonate as well as carbonaceous matter have been published earlier (Bondesen et al., 1967).

The cherts are exemplified by samples 53060 (plate 6a) and 53114 of which the first is an intraformational breccia consisting of 0.5 to 1.0 cm wide broken black chert layers in a black siliceous dolomite. The chert in both samples is made up of very fine (0.02 mm) eugranoblastic quartz grains, a few scattered ore grains and widely distributed black semi-opaque carbonaceous material.

The pyrite shale from the southern part of the area has not been examined in thin section.

A number of the dolomite samples have been subjected to a varying degree of contact metamorphism against a large Gardar dolerite in the southern part of Grænsesø. The samples 20882, 20902A, B, C, D, generally consist of carbonates, veins of antigorite serpentine, chlorite, quartz and plagioclase. The serpentine may be concentrated in veins, but can generally be seen to have been derived from the carbonates, of which relic corroded grains occur. In sample 53059 from the contact with a large Gardar dolerite north of Grænsesø an undetermined mineral of similar optic properties to olivine has been found in the strongly altered rock.

Summary and character

The Grænsesø Formation is as a whole characterized by the occurrence of carbonaceous material which suggests abundant biological activity during the sedimentation, and the existence of organisms has been demonstrated (Bondesen et al., 1967). Examinations of the content of carbon isotopes (C_{12}/C_{13}) by O. JØRGENSEN (BONDESEN et al., 1967) has shown that the carbonaceous and carbonate material was originally of organic origin. Paraffins have been demonstrated to occur in the carbonaceous material (PEDERSEN and LAM, 1968). Euxenic conditions may therefore have prevailed from time to time as organic substances are preserved.

Despite possible errors of measurement it is the general impression that the Grænsesø Formation developed in different thickness which could correspond to deposition in small basins or depressions. However, the variations could also be due to a form of reef construction if all the dolomite could be regarded as of biogenetic origin. Several of the "boudin" structures are of a curious lensoid shape which might correspond to original colonies of lime-precipitating organisms. Erratics of very local origin with stromatolite structures (BONDESEN et al., 1967, plate 11) have also been found in the Grænsesø Formation.

However, it is likely that a complex sedimentation of biogenic limestones and precipitated limestones in an euxenic milieu, such as found in the Cambrian and Lower Ordivician deposits on the Scandinavian shield, may be responsible for the sedimentological development of the middle part of the Grænsesø Formation.

The appearance of chert in the upper part of the Grænsesø Formation could also be a result of biological activity as the black chert contains numerous threads and filaments of organisms. The occurrence of chert is also consistent with euxenic conditions and so are pyritic shales (PETTIJOHN, 1957). The relations to chert found in other parts of Vallen Group and the role of chert will be discussed later (p. 129).

The larger sills have mainly been intruded along the level of the cherty quartzites.

THE SORTIS GROUP

The Foselv Formation

The Foselv Formation can be divided into three members:

A. The Lower Pillow Member
B. The Anthracite-Carbonaceous Shale Member
C. The Upper Pillow Member

The lower boundary of the Foselv Formation is taken as the appearance of the first pillow lavas. This border is geologically well defined over most of the area, although large sills often intrude at the border and may obscure this otherwise readily traceable feature.

The upper border is marked by a large thrust zone above which pillow lavas have not been found. The trust zone marks the border between the two main eastern structural divisions (see p. 15). The importance of the thrust is unknown, but it is evident from the mapping that the easternmost main structural division south of Foselv transgresses the pillow lavas so that parts of the Foselv Formation may here be hidden. Most of the Foselv Formation outcrops in Fønland where the thickness is estimated at about 1000 m (fig. 11).

A. The Lower Pillow Member

The Lower Pillow Member comprises approximately the lowermost 300 m of the Foselv Formation.

The upper boundary of the member is defined by the occurrence of the Anthracite-Carbonaceous Shale Member which, however, in Fønland in places reaches close down to the upper boundary of the Grænsesø Formation. Considerable variations in thickness are thus apparent.

The pillow lavas are developed in the classic manner and are generally mostly of similar dimensions, viz. from 1 to 1.5 m long (fig. 39). The pillows, which are always well developed and are only occasionally slightly deformed, possess a blackish-green outer crust in which small cooling fissures can be seen. The central part of the pillows is a light green rock generally with tensional cooling fissures, radiating from the lower central part towards, but rarely through, the upper crust. The fissures are

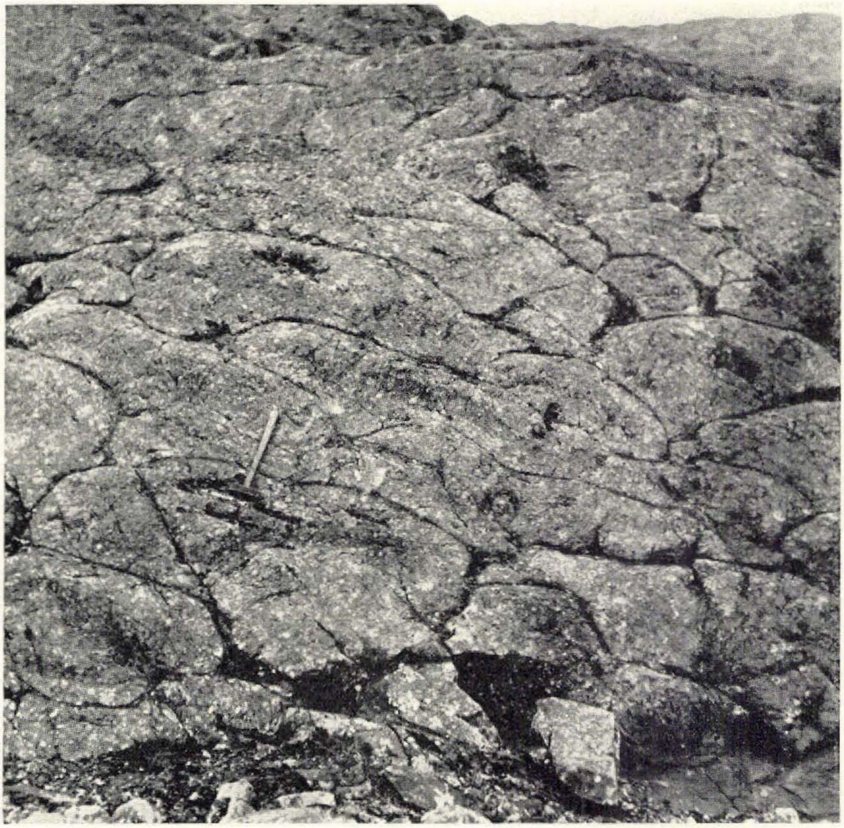


Fig. 39. Typical pillow lava from the Lower Pillow Member of the Foselv Formation. The pillows are closely spaced and only very little interstitial material is found between the pillows. Locality west of Frynsesø in Fønland.

often filled with quartz and calcite but may also be open. In one fissure axinite has been found (Bondesen and Petersen, 1965). The spaces between the pillows are very small, and may be filled in by quartz and carbonate. Occasionally fine debris, apparently of crustal material, occupies the spaces.

Locally in the lower part of the Lower Pillow Member an unusual development of small pillow structures has been encountered (fig. 40). The pillows are situated in a relatively abundant matrix of coarse pyroclastic material. The shapes of these pillows can be irregular and they often possess an open central cavity that is occasionally coated with quartz and calcite crystals. The pillows are made up of extremely fine-grained greenish material and have a dark-coloured crust and a lighter coloured centre.

Besides the pyroclastics no sediments have been observed in the Lower Pillow Member. However, large lensoid sheets of sub-horizontal

Fig. 40. Small amoeboid and irregular pillow lavas from the Lower Pillow Member. The space between the pillows is occupied by pyroclastic material and pillow debris; the proportion of this material increases upwards. Several of the small pillows have a small central cavity. Locality north-west of Frynsesø in Fønland.

white coarse-grained crystalline quartzites are found. They possess open cavities coated with well developed quartz crystals, and show an internal plane-parallel banding of dark fine-grained quartzite. The borders have been observed to transect pillow structures. A sedimentary origin for these quartzites is somewhat doubtful. These quartzites resemble the large cross-cutting vein quartzites which have been found in sediments as well as in lavas and intrusive sills, but may represent original layers of chert activated and recrystallized due to their position in the lava succession.

The petrographic characteristics of the volcanic rocks are described on p. 115.

B. The Anthracite-Carbonaceous Shale Member

A good marker in the otherwise monotonous pillow lava succession is a thin sedimentary unit locally developed as a strongly carbonaceous shale, and locally as coal. This peculiar sedimentary unit has been termed the Anthracite-Carbonaceous Shale Member.

South of Blåisen the member is present as a 1 m thick graphite schist, strongly deformed and disrupted between the two members of pillow lavas.

In Fønland the member is developed as an anthracite coal layer locally 3 m, but generally about 1 m thick. Here it can be followed laterally for about 4 km and it is possible to trace the member to a position close to the upper border of the Grænsesø Formation (PEDERSEN and LAM, 1968). North of Frynsesø a thin carbonaceous horizon has been found, which is possibly equivalent to the coal.

The most interesting occurrence is in south Fønland, east-south-east of Grænsesø. The thick coal layer has here been squeezed locally into a NW-trending shear-zone where it is locally 3 m thick. The coal has also been concentrated parallel to and along a WNW-trending dyke. A 200 m broad NE-trending Gardar dolorite intersects the WNW-trending dyke at the coal occurrence, and the carbonaceous material has here been altered to graphite producing an almost pure graphite.

Where unaffected by the influence of dykes and faults the coal is black, shining and schistose, and contains calcareous and quartzitic nodules.

Four samples have been analysed and the results have together with the isotopic composition of C_{12}/C_{13} been published (BONDESEN et al., 1967, p. 15, table III). Some of the samples were extremely pure with up to 89.8 $^0/_0$ inflammable material. Others were rather impure and contained only 72.5 $^0/_0$ inflammable material. The coal (anthracite) could not be burnt without mixing with easily flammable material and the calory value of the ash-free material was from 7536 to 7671 K-cal/kg (water and ash-free). The alteration of coal to graphite does not seem to involve any isotopic fractionation. Gas chromatograph examinations show that monoterpenoid compounds, normal paraffins and branched paraffins (e.g. pristane, phytane), and methyl esthers are present and indicate that chlorophyl was present (PEDERSEN and LAM, 1968, pp. 11–13).

Altogether it seems probable that the Anthracite-Carbonaceous Shale Member is a further sedimentary development of the Grænsesø Formation. The presence of calcareous nodules and quartzitic material (chert) suggests that some of the material was deposited directly and under euxenic conditions. However, the great quantities of carbonaceous material in some localities suggest that a concentration has already oc-

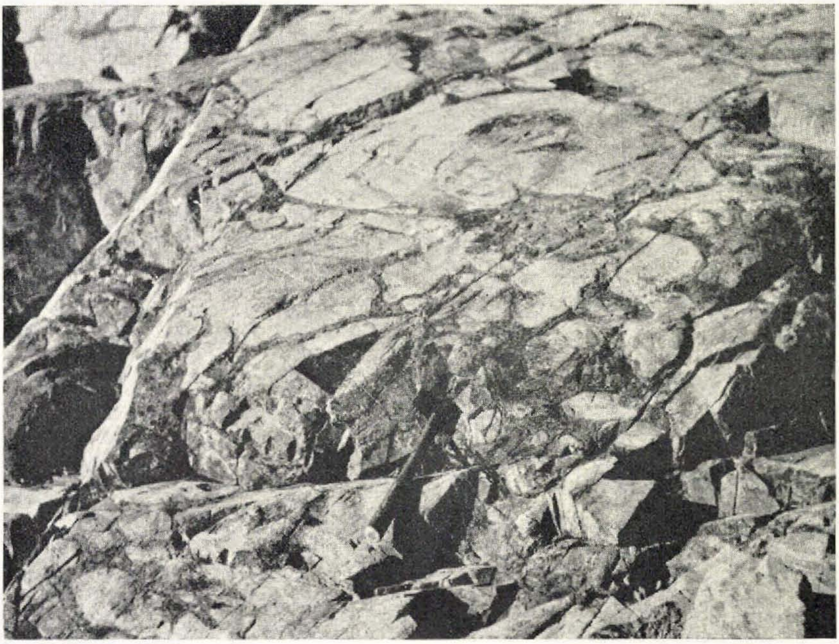


Fig. 41. Typical appearance of the Upper Pillow Member with mixed large and small pillows some of which are of amoeboid shape. Between the pillows pyroclastic material and debris of pillow crusts occur. Locality east of Frynsesø in Fønland.

curred in the sedimentary stage. Current action seems unlikely in combination with euxenic conditions but some movements in water masses or in the unconsolidated sediment might be expected in view of the ex-extrusion of pillow lavas. In any case the significance of the accumulation of large quantities of organic material on the sea floor cannot be too highly stressed.

C. The Upper Pillow Member

Above the Anthracite-Carbonaceous Shale Member, pillow lavas are again found in a pile at least 700 m thick. In general, the Upper Pillow Member differs from the Lower Pillow Member in the development of large irregular pillows intermixed with smaller pillows (fig. 41). However, this is not characteristic of the lower part of this member, and the border between the two pillow members cannot be established in the areas where the Anthracite-Carbonaceous Shale Member is lacking.

The pillows of the Upper Pillow Member, in contrast to those of the lower member, only rarely exhibit tension features developed as a result of cooling. The spaces between the pillows vary, but are relatively larger than those found in the Lower Pillow Member, and are generally filled in with pyroclastic material and debris from the pillows. A further distinguishing feature is the frequent occurrence of breccias of pillows, and agglomerates.

In the area north of Frynsesø, thick pyroclastic deposits ranging from finely banded beds of tuffaceous material to coarse graded beds of lapilli, can be mapped. The characteristics of bedding (a vague current bedding has been observed) suggest that the pyroclastics have been transported subsequent to initial deposition. There does not seem to be any stratigraphical relationship between the different occurrences of pyroclastics.

Both the bedded series of pyroclastics and the pillow lava succession as a whole have been very little influenced by folding.

Most of the intrusive bodies mapped in the Upper Pillow Member are clearly cross-cutting, but some are extremely fine-grained and their intrusive relations are not always very clear. There is a possibility that some of these might therefore be surface flows. Occassionally some of the bodies exhibit a closely spaced sheeting, and agglomeratic structures have been found. It has, however, never been possible to find conclusive evidence of an extrusive origin for any of these bodies.

The petrology and descriptions of thin sections are given on p. 115.

The Rendesten Formation

The Rendesten Formation is a collective name to include all the rocks of the main structural division of the eastern thrust complex. This complex is situated along the Inland Ice in the eastern part of Fønland and outcrops on the two "peninsulas" that extend eastwards into the Inland Ice south of Blåisen and which are divided by the Sortisen glacier tongue. In this southern area – hereafter called the Sortisen area – the Rendesten Formation also outcrops to the west of the "peninsulas".

The Rendesten Formation has only been briefly examined. The following west to east description is an outline of the sequence which, taking the existing fold structures into consideration, probably more or less corresponds to the original order of deposition.

The Rendesten Formation has been strongly folded in some areas, but is also cut up in minor thrust sheets in a form of "schuppen bau". The nature of the top of the formation is not known and there is no apparent break within the limits of exposure convenient for subdivision. The development in the Fønland area differs to some degree from the Sortisen area and the two areas are therefore described separately.

Fig. 42. Strongly folded semipelites and greywacke-like psammites from the Rendesten Formation. Locality north-east of Gabbrosø in Fønland.

The Fønland area

The lower border of the Rendesten Formation in the Fønland area is usually a strongly sheared gneissose mylonitic rock, and the rocks found above this contact vary from place to place.

In the south-eastern part of Fønland black rusty slates, greyish-black dolomites and finely banded pelites occur below a large intrusive body. These sediments are in many respects similar to those of the Grænsesø Formation. Farther north a complex folded sequence of intrusive rocks, finely banded semipelites and rusty shales occurs.

In the northernmost part of Fønland graded, more coarsely banded sediments are found immediately above the thrust zone. The grain size ranges from medium sand to silt. These rocks are very similar to the banded greywackes of the Blåis Formation. In these sediments a sill-like intrusion occurs and south of Gabbrosø a similar body with large xenoliths of graded sediments is found. The xenoliths are to some extent oriented close to the local strike and dip.

Above the sediments a large mass of intrusive rocks occurs which contains elongate lenses of strongly folded banded semipelites. East and south of the intrusion thick beds of pyroclastics occur together with the same sediments. It is of interest that the sediments show no macroscopic mixing or contamination with the neighbouring pyroclastics. The sedi-

Fig. 43. Folded graded pyroclastic deposits from the Rendesten Formation. Layers of scoria and bombs are seen at the head of the hammer and at the top of the shaft. The typical F_2 fold shows some plastic deformation of the fragments in the fold, whereas almost no deformation is visible outside the area of the fold. Locality immediately east of Gabbrosø in Fønland.

ments are mainly composed of medium-grained quartz sand and the pyroclastics apparently exclusively of basic volcanics. The pyroclastics form large graded units with a base of coarse scoria and volcanic bombs. The upper part of each unit is made up of fine lapilli and tuffaceous material (fig. 43).

In the easternmost part of Fønland and southwards along the terminal moraine of the Sioralik glacier a succession of carbonaceous black pelites and banded semipelites intruded by an irregular sill-shaped body occurs. In the southern part of this belt pyroclastics are also found. The lower part of the black pelites is strongly sheared and locally mylonitic rocks have been observed; this suggests that the easternmost sequence may be a separate thrust unit.

The Sortisen area

In the Sortisen area the lower border of the Rendesten Formation is a marked thrust zone extending from the south-west corner of Blåisen

Fig. 44. Finely banded quartzitic rock from the Rendesten Formation at Rendestenen. The single bands are very persistent. Note the irregularities in some beds. The whole structure of the rock is in appearance like a sinter rock.

to Mælkesø. As in the Fønland region mylonitic rocks occur locally exposed along this strongly sheared zone.

In the northern part of the Sortisen area thick piles of pyroclastics, tuffs and lapilli with scattered scoriae and agglomerates are found just over the thrust zone and are intruded by large sills. In these pyroclastics a band of graded semipelites can be followed to the south. The thickness of the single bands decreases and the sediments grade laterally into pelites.

In the southern part of the Sortis area yellow-grey dolomites associated with black pelites are found above the basal thrust zone. The dolomites increase rapidly in thickness towards the south and are close to 100 m thick at Mælkesø. They are intruded by minor sill-like bodies. Higher in the succession above the thrust thick pelites are found between beds of pyroclastics, both being intruded by sills.

At the Rendesten occurs a thick series of flaggy sediments mainly composed of medium-grained quartz sand. The single beds of these psammites can vary between 0.5 and 1 m in thickness. Between the

Fig. 45. Quartzitic slabs in the rusty pelites in the Rendesten Formation south of Sortisen. The slabs occur independent of the fine bedding in the pelite, but seem to be arranged in layers. The deformation of the slabs round a larger quartzitic body in the middle right of the photograph seems to indicate a considerable compression of the sediment.

individual beds occur thin layers of pelitic material and at some levels the pelitic proportion may dominate, giving rise to banded pelites with psammitic layers. In the higher parts of this series the proportion of coarse clastic material gradually decreases giving way to pelites. This succession of mainly bedded psammites in the lower part and banded to fine pelites in the upper part can be followed southwards to the area west of Sortisen, where the succession is complicated by the intrusion of a number of sills and still farther south to the north-east corner of Mælkesø.

On the east side of Rendestenen an unusual very finely banded quartzitic rock occurs (fig. 44). The single bands are extremely persistent and exhibit independent irregularities resembling closely spaced stylolite-like seams. The rock has a superficial resemblance to a mylonite, but on

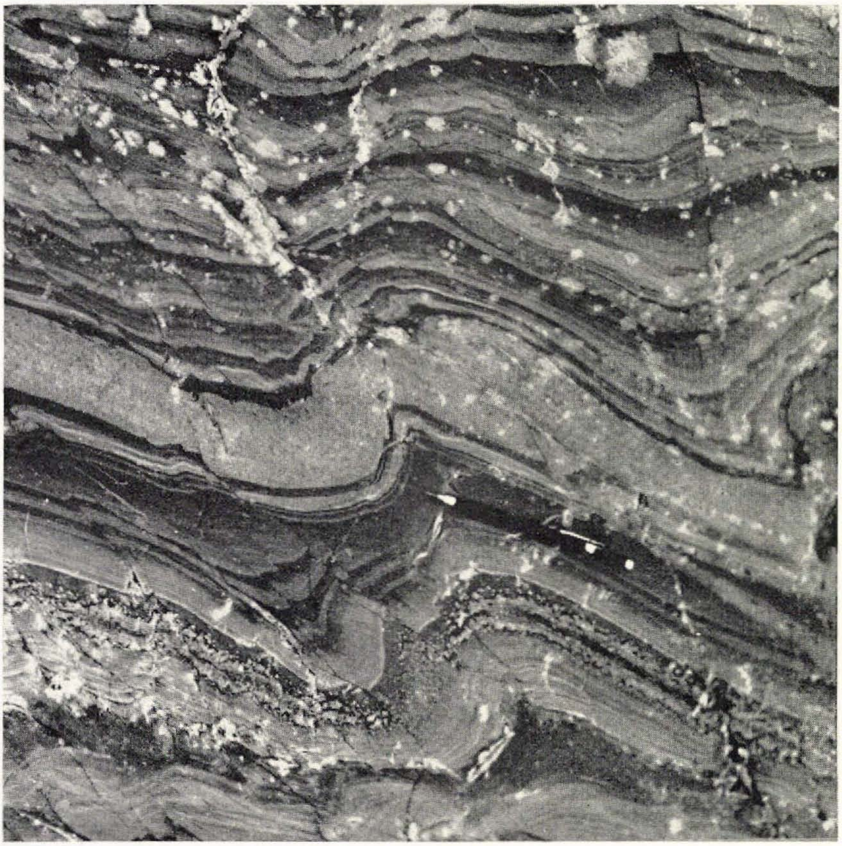


Fig. 46. Strongly differentiated finely banded and varved sediment from the Rendesten Formation south of Sortisen. Above the pencil occurs a homogeneous sandstone layer and below the pencil a thin graded pebble layer. The folds are thought to be F_2 folds, although they here clearly are of S-shape. This discrepancy is believed to be due to the structural position of the layers which at the locality shown in the picture have a strike deviating considerably from the general strike of the bedding.

closer examination and considering its surroundings, shows no signs of severe movements. The appearance and structure of the rock most closely resemble sinter deposits found in the vicinity of hot springs. However, the rock occurs in a limited area and does not seem to be of any stratigraphic importance.

In the Rendesten area extensive lenses of banded pelitic rocks occur in a large mass of coarse-grained intrusive rock. These pelites are also found below and to the east of the intrusive body. In some parts quartzitic slabs and persistent quartzite horizons occur within the pelite sequence. The quartzites are fine-grained and cherty. The slabs seem to be a result of the boudinage of competent quartzitic material originally deposited as a sediment (fig. 45).

In the pelitic succession varved sediments with extremely well preserved sedimentary structures are found. A grading from a coarse-grained light rock to a fine-grained dark rock is occasionally interrupted by thin horizons of quartz pebbles and coarse sand (fig. 46), and units of medium sand. Locally slumps occur.

Microscopic characteristics of the Rendesten Formation sediments

Only a few samples from the strongly varied succession of sediments found in the Rendesten Formation have been examined under the microscope. The bedded psammites and the graded greywackes (52966, 53103, 53109, 53118, 26323) are mainly composed of quartz. The composition of some of the samples is shown in table 5. Samples 52966 and 53103 are from graded units and contain a comparatively large proportion of matrix. Samples 53109 and 53118 from the bedded psammites contain less matrix and may be classed as protoquartzites (Pettijohn, 1957, p. 291). Plagioclase and microcline are present and the occurrence of the latter mineral in particular, as well as strained quartz, suggests that basement rocks could partly be the source of the sediments. Although the sediments are found on top of the pillow lavas and among pyroclastics of basic effusives it is a noteworthy fact that no volcanic fragments have been found in the sedimentary rocks. The secondary minerals are dominantly muscovite, chlorite and carbonate, and in sample 53118 biotite is also found. In general the original sedimentary textures are well preserved in the rocks of the Rendesten Formation. Granulometric analyses of some of the best preserved samples are given in fig. 47.

One sample of pelite (53002) exhibits deformed thin laminae in thin section. A comparatively large proportion of the fine-grained rock is opaque, possibly carbonaceous, material. Small muscovite laths can be detected and are arranged according to a tectonic fabric which does not coincide with the deformed lamination. The laminae may have been deformed as a result of sedimentary deformation. In the pelitic

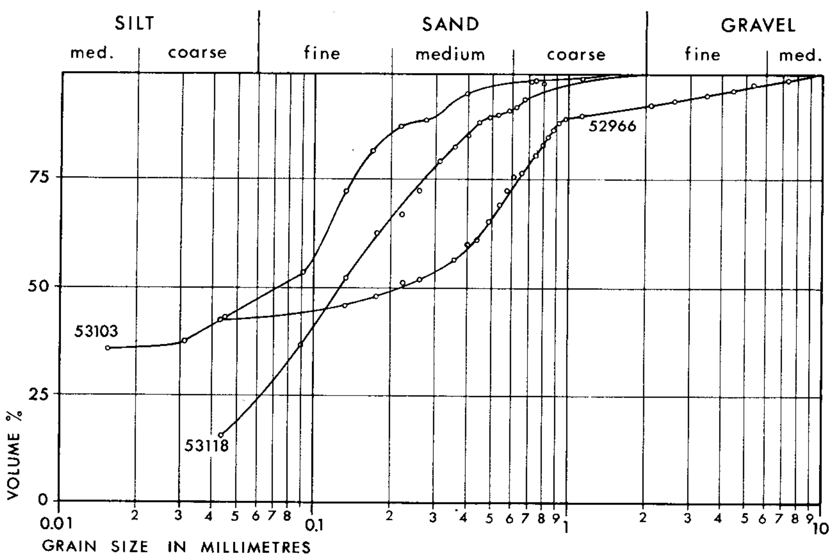


Fig. 47. Grain sixe cumulative frequency curves of some greywackes from the Rendesten Formation.

Table 5. *Modal composition of greywackes and bedded psammites from the Rendesten Formation*

		52966	53103	53109	53118
		%	%	%	%
Primary minerals:	Quartz............	38.1	35.2	90.8	74.5
	Plagioclase........	1.9	3.0	1.6	5.8
	Microcline.........	2.5	0.8	0.5	2.8
	Dark minerals.....	–	0.5	–	–
	Ore..............	0.9	0.5	0.5	4.3
Rock fragments:	Chert.............	4.3	–	–	–
	Shale.............	0.6	0.2	–	–
	Matrix............	46.6	56.5	–	11.1
Secondary minerals:	Muscovite.........	1.7	1.0	2.6	0.4
	Chlorite...........	1.2	–	–	–
	Carbonate.........	2.2	1.8	–	–
	Biotite............	–	–	–	0.7
	Others............	–	0.5	4.0	0.4
	Total.............	100.0	100.0	100.0	100.0
Grain curve (fig. 47)		*	*		*

material scattered minute quartz grains (0.005 mm in diameter) can be seen. Sample 53104 is a pelite showing two deformations (plate 10 b).

The dolomites are fairly fine-grained with seams of coarsely recrystallized carbonate material. Scattered throughout the thin section opaque carbonaceous material and aggregates of quartz occur. Analysis of a dolomite (52985) from the south-eastern part of Fønland revealed 16.7 % MgO and 29.1 % CaO corresponding to 76.7 % $MgCa(CO_3)_2$ and 10.3 % $CaCO_3$; 8.8 % of the rock was insoluble.

The finely banded quartzitic rock (fig. 44 and p. 106) shows in 53105 sharp boundaries between the fine bands which are made up of pigmented and non-pigmented material as well as nearly monomineralic layers of amoeboid quartz, albite and strongly anomalous, blue chlorite. In addition a little carbonate occurs. A comparison of X-ray fluorescence diagrams of this rock and three different samples of recent Icelandic sinter rocks did not reveal any significant similarities.

The petrology of the pyroclastic rocks will be considered in relation to the petrology of the pillow lavas and the instrusive sills which is presented on p. 115.

Summary and character

There is too little information from the Rendesten Formation to permit a reconstruction of the sedimentological and volcanic development. The sedimentary basin, or basins, appear to have been supplied with material from two independent sources: one giving rise to pyroclastics i.e. a volcanic source, and one giving rise to graded, bedded an banded sediments (greywackes, pelites an psammites).

In the lower part of the Rendesten Formation there is a tendency for a continuation of the dolomite-carbonaceous shale sedimentation known from the Anthracite-Carbonaceous Shale Member of the Foselv Formation and in particular from the Grænsesø Formation. Although found just above a thrust zone the outline of a basin of dolomite-shale sedimentation can be traced in the southern part of the area.

Higher in the Rendesten Formation coarse clastic material was supplied to the area of sedimentation possibly by complex mechanisms among which turbidity currents might have played an important role. There is a strong impression of lateral facies changes. To judge from the presence of strained quartz and microcline, basement rocks were probably exposed to erosion somewhere in the source area.

In this milieu of deposition basic volcanism led to the accumulation of pyroclastic material. No pillow lavas or surface flows have been observed with the pyroclastics although the interbedded fine-grained homogeneous igneous sheets could be flows. On the nunataks north-east of Fønland possible equivalents to the Rendesten Formation occur overlain by pillow lavas comprising the Qernetoq Formation (HIGGINS, 1970). The pyroclastics do not form a continuous thick cover but seem to vary in thickness laterally. This could, as may be seen from the geological map (plate 11), correspond to the location of extrusive centres of which one might then be in the northern Fønland and another in the northern part of the Sortisen area. The pyroclastics are badly sorted, although grading is present (fig. 43), and it seems unlikely that the material has been redeposited by water transport as was possibly the case with the pyroclastics of the Foselv Formation.

A provisional stratigraphy for the Rendesten Formation is outlined below:

FØNLAND	SORTISEN
	Banded semipelites and pelites including varved shales and quartzitic slabs (~500 m)
Pelites, semipelites and carbonaceous shales (~100 m)	Bedded psammites with pelites and graded greywackes (~300 m)
Pyroclastics (~200 m)	Pyroclastics (~200 m)
Semipelites and graded greywackes in the north (~200 m)	Pelites and pyroclastics (~400 m)
	Pyroclastics in the north (~1000 m)
Dolomites and pelites in the south (0–15 m)	Dolomites and pelites in the south (0–100 m)

THE IGNEOUS ROCKS

The different bodies of intrusive rocks found in the main structural division of the pillow lavas and the eastern thrust complex have so far been omitted from descriptions. In the following pages their field relations and the structures they exhibit will be described and their petrological characteristics will be treated, together with the petrology of the pyroclastics and of the pillow lavas. They are treated together in this manner since the intrusives apparently are closely related to the extrusives and they together represent interconnected expressions of the magmatic activity of the Ketilidian.

Metadykes found elsewhere in the Grænseland area and metadykes clearly cross-cutting the Sortis Group are discussed in a later section. (p. 117).

Field relations and structures of the basic intrusives

The distribution of the basic intrusive bodies described in this section is shown on the geological map (plate 11). They are restricted to the two main structural divisions in the eastern part of Grænseland. Some of the intrusions are found within the Grænsesø Formation but none occur at lower levels. They were all originally of basic composition, but occur now as slightly metamorphosed "greenstones". As is the case with the pillow lavas their primary structures and original textures are to a great extent preserved due to the week and often only local deformation subsequent to their development. Where deformation is present the rocks appear as greenish or blackish-green schists.

Minor intrusive bodies are found in the Grænsesø Formation in the Grænsesø area. They are mainly sill-shaped but are also found as irregular transgressive bodies. Apophyses and anastomosing features are of frequent occurrence. Unlike the other areas of intrusives to be described they are often sheared and folded.

At the border between the Grænsesø Formation and the Foselv Formation in the Fønland area a large sill-shaped body up to 100 m thick occurs (52995, see p. 117). In the southern part of the area, from north of Lappesø (53047, see p. 117) to the Arsuk glacier, a large intrusive sheet in-

Fig. 48. Texture of an intrusive sill in the Foselv Formation. The body is intruded by a thin dyke which has been disrupted by later deformation. The white straight lines are quartz and possibly original joints. They are cut by the dyke. Locality in south-west Fønland north-east of Vallen.

creasing to 500 m in thickness towards the south is found; it is intruded below the pyritic shales of the Grænsesø Formation. In the southernmost areas extensive bands of rusty shales occurring within homogeneous intrusive rocks suggest a more complex intrusive form or possibly several intrusions. Thus one single large sill complex may extend throughout the whole area at this level, being more compact in the southern part and interfingering and branching towards the north. Large apophyses are seen at Lappesø and north Grænsesø. Its lower part in the Lappesø area shows pods and pillow-like structures locally suggesting perhaps intrusion into wet sediments; the upper part of the sill has produced a contact metamorphic effect against pyritic shales seen as a bleaching.

Numerous intrusive bodies are found in the Fønland region (52961, 53962, 53958, 52957, see p. 117) in the pillow lavas of the Foselv Formation, and only a few and generally smaller bodies are seen in the area south of Blåisen. These bodies, intruded horizontally or sub-horizontally, are sills from 10 to 100 m thick. Their intrusive character can be determined from localities where their contacts clearly transect pillow structures. They often terminate very abruptly without thinning, or irregular intrusive features. In the Upper Pillow Member some of the bodies are very fine-grained and as previously mentioned they may possibly be surface flows.

The original texture of the intrusive rocks in the Foselv Formation is well preserved (fig. 48). The field observations do not suggest that there are any important variations in rock type.

The structural shape of the intrusive bodies in the Rendesten Formation is different from those of the in the Foselv Formation. Although minor regular sills are present in the bedded psammites and the greywackes of the Rendesten Formation the greater part of the intrusives form extremely extensive and complex structures. The rock types vary from fine- to medium-grained to very coarse-grained to almost pegmatitic varieties, which may be darker or lighter in colour. Gradations from melanocratic to leucocratic rocks have been found but no structures such as igneous banding seem to occur.

In the Fønland region a large body of melanocratic rock (53078 and 53081) with medium to coarse igneous textures preserved occurs northeast of Gabbrosø. In the intrusion long bands or zones of homoaxially folded banded pelites and semipelites (fig. 42) can be traced. The sill is conformable to the sedimentary banding and despite the folding, the original textures are preserved to within a few centimetres of the contacts with little or no sign of shearing. A profile of this body on a field sketch is shown in fig. 49.

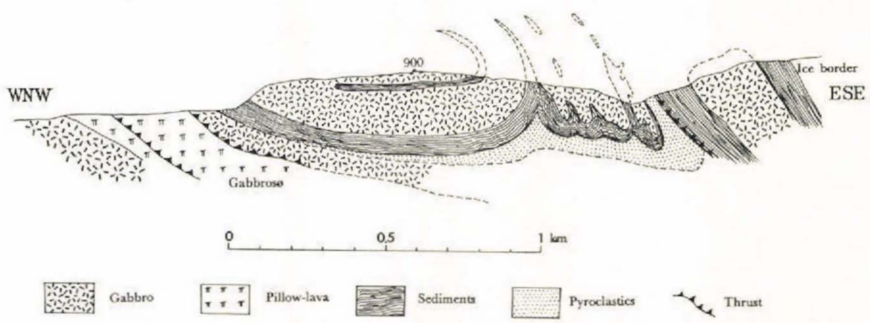


Fig. 49. Profile in large intrusive bodies from Gabbrosø to the ice border in north-east Fønland. The large intrusive masses enclose sediments, which are strongly folded (see fig. 42).

South of Gabbrosø a xenolith-bearing intrusive body with oriented tabular fragments of greywacke occurs and east of Frynsesø large bodies of more or less distinct cross-cutting nature are found in strongly dislocated sediments.

Parallel to the border of the Inland Ice there occurs a large sheet body (53079, see p. 119) above a zone of strongly sheared sediments. This body attains a more massive character (53007, see p. 119) southwards. It is possible that large intrusive masses south of the ice-dammed lake in the south-eastern corner of Fønland are a southwards continuation of this body. In this latter area there is a differentiation into large patchy areas of melanocratic and leucocratic rocks (52986 A, see p. 119) with the original textures very well preserved.

In the Sortisen area numerous smaller regular sill-shaped bodies occur in the bedded psammites, the greywackes and in the pyroclastics.

Most of the two "peninsulas" reaching into the Inland Ice north and south of Sortisen are occupied by large intrusive masses. Long belts of folded sediments with extremely well preserved primary features (fig. 46) can be followed within these masses (see p. 107). These intrusions are structurally as well as petrographically very similar, showing the same grading from melanocratic to leucocratic rocks, and may represent one extensive complex. The western part is composed of comparatively leucocratic medium-grained rocks. Very melanocratic rocks (53120, 53106, 53107, see p. 121) with a sharp western border are found in a broad belt across both "peninsulas"; this border does not exhibit a chilled contact. Towards the east and stratigraphically higher in the sequence the melanocratic rock becomes extremely coarse-grained and almost pegmatitic, with mafic minerals (amphiboles) up to 5 cm in length (53111), and grades into coarse leucocratic rock types (53108 and 53110).

Locally breccia structures and coarse-grained inclusions occur in fine-grained rocks.

To sum up it seems general that the low-level intrusions in the succession are sill-shaped bodies and may be very large. They were intruded prior to deformation and some possibly into wet sediments.

Higher in the succession larger and seemingly more irregularly shaped intrusions occur, but in association with regular and smaller sills. The larger bodies may be laccoliths.

The larger bodies show a differentiation into melanocratic and leucocratic rock types. They may be very coarse-grained and even pegmatitic.

The large eastern intrusions seem to be extensive bulbous structures with elongated zones of the surrounding rocks forming lamellae between minor culminations of the main intrusion, a structure somewhat resembling that of a cauliflower.

It should be mentioned that it was the general impression from the field work that folding, both deviating from and also coinciding with the regional fold pattern, occurred in relation to some of the large eastern intrusive masses. Some relations could indicate that the folding was caused by the intrusions and others that the intrusion occurred at the same time as the regional folding. Unfortunately these problems cannot be solved at present.

Microscopic and petrological characteristics

In the foregoing chapter only field relations of the intrusive igneous rocks have been dealt with and the following chapter will contain microscopic and petrological observations on these rocks and also the effusive volcanic rocks. The samples collected, the pillow lavas, pyroclastics and intrusives, are taken as representatives of the different types. No attempt at systematic collecting has been made and it is therefore not possible here to give any complete and quantitative treatment of these rocks. The data presented on the following pages are merely intended as representative of an extensive volcanic and intrusive complex.

The pillow lavas

20862. The central part of a pillow (25 cm in cross-section) from the Lower Pillow Member, about 2 km north of Lappesø and adjacent to the Inland Ice. The rock is light greyish-green in colour. In thin section it is very fine-grained and dense, with a dusty grey matrix of chlorite and actinolite, and a few larger scattered laths of actinolite. Locally large secondary epidote grains occur. Chemical data for this rock are presented in table 6. The analysis shows rather high CaO which gives rise to an unusual high An content in the normative plagioclase. It may be caused by secondary carbonate.

52987. From the central part of a large pillow from the Lower Pillow Member south-west of Frynsesø. The rock in hand specimen is light green in colour, and in thin section it shows an aphanitic mass of chlorite, actinolite, epidote and carbonate. A few clear albite? grains can be distinguished.

53115. From the Upper Pillow Member, east of Frynsesø. The central part of a large pillow. In section it exhibits a grey dense mass in which randomly oriented laths of amphibole, possibly actinolite, can be seen, and also a few large 1–2 mm laths of strongly altered plagioclase.

The pyroclastics

53058. Tuffite. 400 m north of middle Frynsesø. The rock consists of sharp angular to sub-rounded fragments of lava in which small randomly orientated laths of amphibole, possibly actinolite, occur in a grey dense mass. The matrix between the fragments is composed of dusty irregular grains of epidote and also euhedral epidote group minerals (clinozoisite?), small twinned albite grains, chlorite and a little quartz. This matrix is a minor quantitative proportion of the rock. Chemical data for the rock are given in table 6.

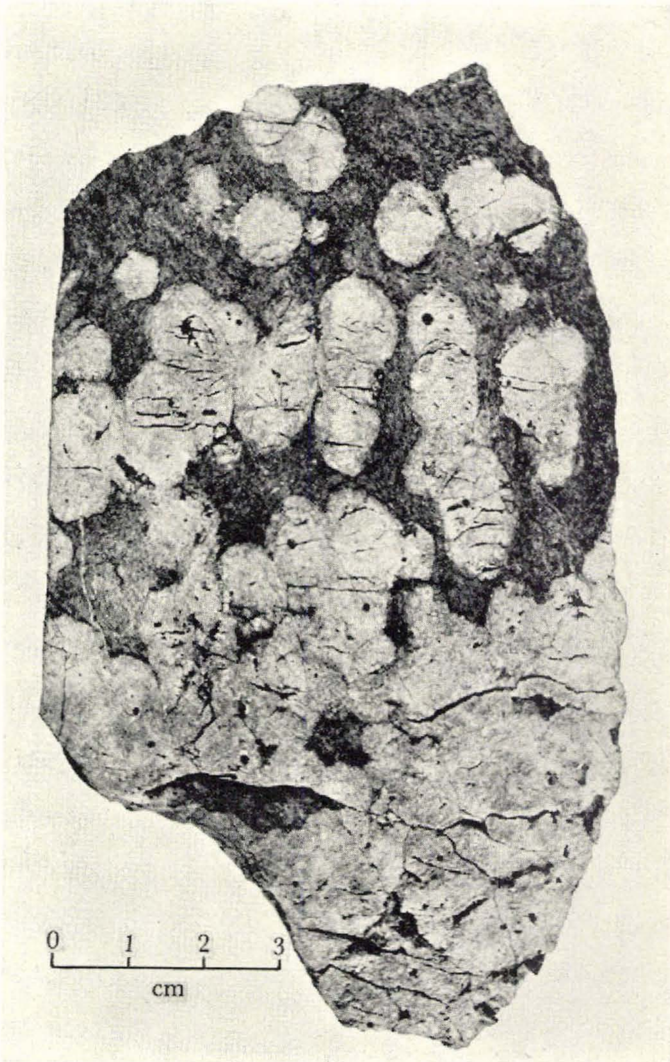


Fig. 50. Pyroclastic rock with small pillows in graded units (sample 53004). The photograph shows densely packed micropillows in the lower part of a graded unit and isolated pillows a little higher in the unit set in a matrix of dark tuffaceous material. Note the tensional fissuring restricted to the small pillows and parallel to the bedding. Locality at the border of the Inland Ice east of Frynsesø in Fønland.

52999. Lapilli tuffite from the Upper Pillow Member east of Frynsesø. The rock consists of very fine-grained lava fragments of sub-angular to amoeboid shape and with a semi-opaque zoning near their borders. Curved belts of fine-grained aphanitic material resembling flow lines surround these grains and contain zones of euhedral epidote, ore, and chlorite of a vague greenish pleochroism and with anomalous brownish interference colours. A few small unstrained quartz grains and feldspars are also seen (plate 6b).

53000. Lapilli tuffite from the upper part of the Upper Pillow Member east of Frynsesø. The rock consists of densely packed lava fragments most of which are surrounded by small round spherulitic particles, small 1 mm phenocrysts of altered plagioclase, and a few small quartz grains. One large feldspar fragment containing clinozoisite may originally have been part of a larger plagioclase phenocryst. Carbonate and chlorite occur between the fragments.

53003. Tuffaceous agglomerate from the south-east corner of Fønland. The rock consists of fragments of fine-grained lava, fragments of primary crystals of a slightly greenish pleochroic hornblende, and pyroxene. In between the fragments occur numerous large grains of epidote-clinozoisite and aggregates of chlorite set in a ground mass of fine semi-opaque dusty material exhibiting curved trails reminiscent of flow structures.

53004. Pyroclastic rock with micropillows in graded units. From the border with the Inland Ice east of Frynsesø. The rock (fig. 50) consists of spheroidal to ellipsoidal altered "drops" of fine-grained igneous texture comprising quartz, feldspar, chlorite and an aphanitic mass, set in a ground mass of fine chlorite and actinolite.

53006. Lapilli tuffite. South-eastern corner of Fønland at the ice border. The rock consists of fragments of crystals and lava set in a fine chloritic ground mass. The crystals are sub-idiomorphic clinopyroxene, small quartz and altered feldspars. The lava fragments are dense fine-grained with phenocrysts of pyroxene and feldspar (plate 7 a).

53122. Lapilli tuffite. North-west of Sortisen. A large (1–2 cm) fragment of fine-grained lava with an original igneous texture bordered by a zone of carbonate minerals is set in a matrix of altered fragments of lava and (hornblende?) crystals. The alteration products are chlorite, epidote and a reddish serpentine.

The intrusives

Two samples (52995 from middle Grænsesø, 53047 from north of Lappesø) are from the large sill complex which occurs in and just above the Grænsesø Formation. The rocks are coarse-grained and greenish in colour. They are moderately to strongly altered although it can be seen that the original texture was ophitic or sub-ophitic. The mafic minerals seem also to have been arranged in large square to rectangular patches which may demonstrate a primary poikilitic structure. Relic primary hornblende is preserved in these zones.

The primary plagioclase is strongly saussuritized and the composition cannot be determined. Secondary albite is present. The secondary mafics are mainly large patches of actinolite ($z \wedge c$ 7°) of irregular outline, feebly pleochroic chlorite, large subhedral epidote, leucoxene, and very little weakly strained quartz which might be primary. The two samples are identical apart from differences in grain size and the quartz which is only found in the coarser-grained sample 53047. The chemical composition of sample 53047 is shown in table 6.

52962. A fine-grained greyish rock from a basic sheet-like body south-east of Frynsesø in Fønland. The original igneous (ophitic?) texture is apparent. The rock consists of non-pleochroic amphibole (actinolite), epidote and feebly pleochroic chlorite. Quartz, carbonate and a little ore are present in accessory amounts.

Three samples (52961, 52957, 52958) all from sheet-like bodies in the Foselv Formation in the Fønland area, are of closely related rock types to judge from their thin sections. The rocks are in hand specimen all relatively coarse-grained (2–5 mm) with dark green spots in a lighter green matrix. They exhibit well preserved primary ophitic textures.

Table 6. *Chemical analyses of basic igneous rocks from the Sortis Group with C. I. P. W.-norms and Niggli-values* (IB SØRENSEN *anal.*).

	20862	53058	53047	52958	53079	53111	53108
SiO_2	48.85	49.98	48.48	48.30	50.21	49.20	47.64
TiO_2	0.76	0.80	0.87	0.87	1.48	1.25	0.43
Al_2O_3	12.21	13.70	14.08	14.95	12.72	10.68	19.64
Fe_2O_3	2.65	1.85	2.02	1.99	2.64	2.30	1.45
FeO	8.56	8.90	9.58	8.78	10.90	13.90	4.31
MnO	0.16	0.18	0.17	0.17	0.21	0.24	0.11
MgO	8.55	9.22	8.26	7.98	5.21	7.14	7.17
CaO	13.00	9.60	10.62	9.90	11.19	9.75	15.35
Na_2O	1.40	2.38	2.62	2.43	2.18	1.47	1.82
K_2O	0.00	0.00	0.09	0.52	0.88	0.04	0.04
P_2O_5	0.08	0.08	0.09	0.08	0.19	0.12	0.06
CO_2	0.09	n.d.	0.00	n.d.	0.00	0.20	0.00
H_2O	3.37	3.40	2.64	3.75	2.16	3.62	2.34
	99.68	100.09	99.52	99.72	99.97	99.91	100.26
C.I.P.W.-norms							
q	2.49	0.06	0.00	0.00	2.61	4.64	0.00
or	0.00	0.00	0.53	3.07	5.19	0.24	0.24
ab	11.83	20.11	22.14	20.54	18.42	12.42	15.38
an	27.01	26.68	26.38	28.33	22.31	22.41	45.00
ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
di	29.99	16.57	20.99	16.50	26.56	20.93	24.59
hy	19.37	28.82	13.34	16.02	15.57	29.43	2.50
ol	0.00	0.00	8.65	6.73	0.00	0.00	7.09
mt	3.85	2.69	2.93	2.89	3.84	3.34	2.11
il	1.44	1.52	1.65	1.65	2.81	2.38	0.82
ap	0.19	0.19	0.21	0.19	0.45	0.28	0.14
Feldspar							
or	0.00	0.0	1.1	5.9	11.3	0.7	0.4
ab	30.6	42.9	45.1	39.6	40.2	35.3	25.4
an	69.4	57.1	53.8	54.5	48.5	64.0	74.2
Niggli-values							
al	16.16	18.60	18.75	20.50	18.19	14.85	25.46
fm	49.50	52.38	49.68	48.57	46.22	57.09	34.22
c	31.29	23.70	25.71	24.68	29.10	24.64	36.36
alk	3.05	5.32	5.87	6.25	6.49	3.42	3.96
k	0.00	0.00	0.02	0.12	0.21	0.02	0.02
si	106	115	110	112	122	116	105

20862 Pillow lava, central part of one pillow from the Lower Pillow Member, about 2 km N of Lappesø.
53058 Tuffite, 400 m N of middle Frynsesø.
53047 Basic intrusive, large sill complex just above the Grænsesø Formation.
52958 Basic intrusive, from sheet-like body in the Foselv Formation.
53079 Coarse-grained mesocratic basic intrusive from large complex east of Rendestenen, Rendesten Formation, eastern Fønland.
53111 Marginal facies of melanocratic basic intrusive from the large complex east of Rendestenen, the Rendesten Formation.
53108 Coarse-grained leucocratic basic intrusive from the large complex east of Rendestenen, the Rendesten Formation.

The plagioclases are saussuritized but were evidently originally strongly zoned. The composition of the best preserved relics varies from An_{26} to An_{31}. The dark minerals mainly comprise a non-pleochroic, possibly iron-poor actinolite ($z \wedge c$ 12–16°) secondary after a primary green pleochroic hornblende preserved as relic crystals, and perhaps also pyroxene. The areas of the actinolite crystals show the outline and also the twinning of the original hornblende. Other secondary minerals are chlorite, euhedral epidote, carbonate and sphene (both euhedral and occurring as leucoxene). Ore is preserved in primary crystals altered to sphene along fissures. Broken apatite needles and quartz (52961) are accessory minerals. The sample 53958 has been analysed and the chemical data and the modal composition are given in table 6 and 7.

The following four samples are coarse-grained mesocratic rocks from the large intrusive bodies of the Rendesten Formation which outcrop in the eastern part of Fønland.

52986A. A light coarse-grained variety of the intrusive mass in the south-east corner of Fønland. Ophitic texture is well displayed. The plagioclase is strongly saussuritized, but the best preserved parts have a refractive index close to that of Canada balsam suggesting an original oligoclase composition. Relic primary hornblende of brown and green pleochroism is abundant but mostly it has been altered to a feebly pleochroic green amphibole with $z \wedge c$ 10–14°. Other secondary alteration products are chlorite and epidote. Ore and leucoxene occur in primary rectilinear intergrowths. Interstitial quartz and micropegmatite (a granophyric intergrowth of quartz and plagioclase) are very conspicuous. The modal composition of the rock is given in table 7.

53007. From a locality 200 m south of the locality of sample 53079; the two rocks are closely similar. The texture is ophitic. The plagioclase is strongly altered but preserved relics have a refractive index close to Canada balsam and are probably oligoclase. Pyroxene has not been observed. Primary brownish hornblende is very conspicuous in large twinned individuals. The section also contains large euhedral epidotes, apatite and reddish-brown fibrous serpentine. The modal composition of both samples is presented in table 7. A microphotograph of 53007 is shown in plate 7b.

53081. From the large intrusive body at Gabbrosø, northeast Fønland. The texture is well preserved and dominated by short prismatic primary hornblendes of feeble greenish-brown pleochroism. The mineral is somewhat altered to non-pleochroic amphibole. The plagioclase is generally saussuritized but a few preserved well twinned individuals yielded a composition of An_{29}. Chlorite, epidote, leucoxene, carbonate and interstitial quartz also occur.

Two groups of rocks appear to be melanocratic and leucocratic derivatives of the basic magma (see p. 114) and are therefore treated seperately in the following descriptions. The sample 53078 is a leucocratic facies of the large mass at Gabbrosø represented by sample 53081. The other rocks are from the Sortisen area where the samples 53106 and 53107 are melanocratic rocks which grade into leucocratic rocks, represented by the samples 53108, 53110, and 53112 (plate 9a). The sample 53111 represents a marginal facies of the melanocratic rocks. All the above samples are from the massif east of Rendestenen. The sample 53120 is an extremely melanocratic type from the area south of Sortisen.

53078. From the large intrusive body at Gabbrosø, northeast Fønland. The rock texture is dominated by short prismatic plagioclase crystals which are strongly altered to a grey dusty mass with epidote and chlorite. In a few cases the twinned plagioclase crystals could be determined to be of a composition of An_{26} to An_{32}. Carbonate is abundant in the rock. The interstitial spaces between the plagioclases are largely occupied by ore, leucoxene and a little chlorite. The rock was perhaps originally more or less exclusively plagioclase.

Table 7. *Modal composition of the intrusive rocks from the Sortis Group*

	52986A	53079	530079	52958	52958*)	53106	53107	53111	53112	53120	53108
	%	%	%	%	%	%	%	%	%	%	%
Plagioclase	37.6	46.0	47.9	39.2	53.1	30.9	21.2	13.9	26.0	14.9	54.3
Quartz and micropegm.	5.6	10.6	6.5	3.1	–	7.6	15.7	8.4	—	2.1	—
Amphibole	44.3	27.8	31.3	30.1	42.3 (amphibole + pyroxene)	33.2	21.4	42.4	47.6	56.2	23.8
Pyroxene	2.0	3.4	5.0	—		6.9	1.8	3.7	+	+	–
Secondary minerals	5.5	8.7	7.0	22.7		11.7	30.8	30.3	17.2	18.7	22.1
Ore and leucoxene	5.0	3.7	2.3	4.9	4.6	9.7	9.1	1.3	9.2	8.1	0.7
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Representative intrusive sills and related rocks					Melanocratic rock types					Leucocratic rock

*) Normative composition, recalculated for comparison (ol+di+hy = amphibole+pyroxene).

Where possible alteration products have been counted as primary minerals. Actinolite has been counted as amphibole, and plagioclase alterations (clinozoisite, chlorite and recrystallized feldspar) have been counted as plagioclase.

53106. A sample representing the melanocratic facies of the large mass east of Rendestenen. The rock is medium-grained and of a dark green colour with the primary igneous textures well displayed. It is characterized by prismatic crystals of mafic minerals in a matrix of what originally may have been feldspars. The mafics are hornblende, strongly pleochroic from green to light-green and brownish but altered to actinolite. Relic pyroxenes are also found which may once have been isolated grains. The secondary minerals are actinolite, epidote, clinozoisite and chlorite. Ore-leucoxene intergrowths are found in primary interstitial textures and quartz occurs in the interstices. The modal composition is seen in table 7.

53107. From the coarse-grained melanocratic facies of the large intrusive body east of Rendestenen. Original ophitic textures are well displayed. The plagioclases are sometimes altered but may also be relatively well preserved, zoned and twinned; the compositions measured were in the andesine range. Widespread intersticial micropegmatitic intergrowths occur. The mafics are dominantly large twinned hornblendes mainly of possibly primary origin and of green and brown pleochroism, but also almost non-pleochroic. A few patches of relic pyroxene are found centrally in some of the hornblendes. Large euhedral epidotes, actinolite, chlorite and clinozoisite occur as secondary alteration products. Reddish-brown serpentine occurs commonly along grain borders, cleavage fractures and twin-planes. Quartz is comparatively common. The modal composition is seen in table 7.

53111. A sample from the marginal part of the melanocratic facies (*cf.* 53107). The rock is similar to the sample 53107 apart from additional apatite and the lack of the reddish-brown serpentine. The plagioclase is more strongly altered. The modal composition is seen in table 7. The apparent large differences in modal composition of the two rocks may be partly due to errors because of the very coarse-grained nature of both rocks. The thin section is illustrated in plate 8a. The chemical composition is seen in table 6.

53120. Very melanocratic facies of the large intrusive body south of Sortisen. The rock is dark green, almost black, and medium-grained. The texture is dominated by short prismatic hornblende crystals of strong green pleochroism in patches and almost completely altered to an actinolite of feeble green pleochroism. The groundmass comprises strongly altered feldspar (chlorite and epidote group minerals) besides quartz and ore altered to leucoxene. The modal composition is seen in table 7.

53108. A sample from the eastern part of the "peninsula" north of Sortisen. The rock is leucocratic, light green and medium-grained. The texture (plate 8b) is dominated by strongly altered prismatic plagioclases in a matrix of actinolite, chlorite and epidote which are alteration products. Relic, presumably primary, hornblende occurs. Leucoxene is also present. The modal composition is seen in table 7 and the chemical composition in table 6.

53110. A sample from the eastern part of the "peninsula" north of Sortisen. The rock is light green and coarse-grained. The texture is dominated by large altered plagioclases ($N \geqslant N_{cbs}$), epidote group minerals and chlorite. The mafics are amphibole (hornblende, $2V_x = 78°$) which is almost non-pleochroic and pyroxene (2V app. 50°, $z \wedge c$ 48°). Apatite, leucoxene-ore intergrowths and abundant quartz are also among the primary minerals. The secondary minerals are actinolite (pale greenish colour, almost non-pleochroic), a green weakly pleochroic chlorite and epidote (plate 9b).

The composition of the igneous rocks and magma type

The composition of the pillow lavas cannot be determined from petrographic data alone. The chemical data (table 6) from one lava

(20862) and one tuffite (53058) suggest that they are of basaltic composition.

The chemical composition of the intrusive rocks (table 6) also shows a basaltic composition although there are variations in the five analyses. The rocks analysed have also been chosen to elucidate the various rock types as established in the field. Thus the rocks 53047 and 52958 represent sill-shaped intrusions low in the succession in the Foselv Formation (see p. 111). The three rocks 53079, 53111 and 53108 represent the large intrusions in the Rendesten Formation and are restricted to the eastern thrust complex. They comprise a mesocratic normal type (53079), a melanocratic type (53111), and a leucocratic type (53108). The character of the last two is also well expressed in the chemistry by high FeO in the melanocratic rock and high Al_2O_3 and CaO in the leucocratic rock.

The intrusive rocks may thus, based on their chemical compositions, be termed gabbros with the additional types of melanogabbros and leucogabbros. The leucocratic rock has been an extremely feldspathic rock, which also can be judged from the thin sections. The basic character (table 6) of the leucocratic rock suggests that it has been anorthositic or gabbro-anorthositic.

The magma type appears to be tholeiitic, judging from the occurrence of quartz and micropegmatite and also the low alkali content, especially K_2O, and relatively high SiO_2 (TURNER and VERHOOGEN, 1960, p. 206; KENNEDY, 1933). The high normative hypersthene is also characteristic of the tholeiitic magma type.

The primary mineralogical composition of the intrusive rocks is somewhat obscured because of metamorphism and possibly also a widespread late magmatic alteration effect. The original ophitic or gabbroic texture is generally easily recognized and strongly suggests the original mineralogical composition of the rocks. All determinations of primary plagioclase are in the oligoclase-andesine range. However, strong zoning can be seen to have been present and it is presumably the more calcic plagioclase which has been altered more easily. The normative plagioclase ranges from An_{52} to An_{73}, the highest being found in the leucogabbro.

Traces of olivine have not been found and olivine was possibly not present at all. Quartz is present in small amounts. The mafics seem dominantly to have been pyroxenes. An interesting feature in the Grænseland rocks is the occurrence of strongly brown and green pleochroic amphiboles (hornblende). These amphiboles are very often prismatic twinned individuals which "fit" the magmatic texture of the rock (fig. 51). They are in most cases a replacement of pyroxenes but single clean primary individuals also occur e.g. in the melanocratic rocks. The formation of the uralitic amphiboles is apparently related to the magmatic history. They are unstable in the present metamorphic rock, where they are altered

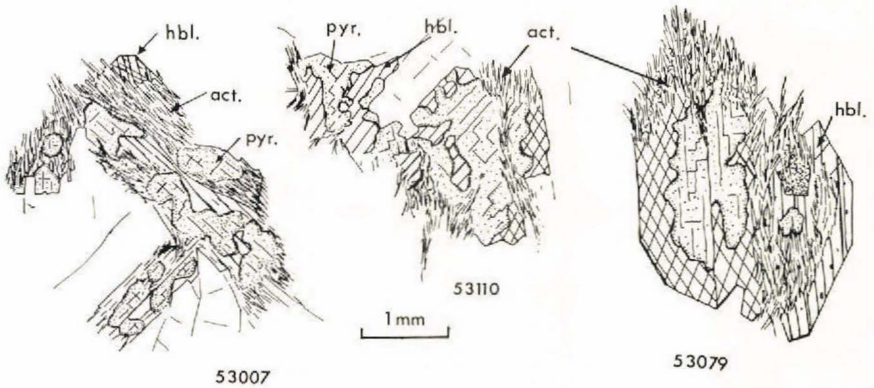


Fig. 51. Relation between pyroxene (pyr.), hornblende (hbl.) and actinolite (act.) in the magmatic texture. Feldspars have been omitted and minor alterations of the hornblende and pyroxene have not been drawn.

to a fibrous mass of actinolite needles, chlorite and epidote minerals. It is therefore suggested that the pleochroic amphiboles are a result of late magmatic alterations or alterations related to a change in the magma during its crystallization. These changes may be addition of water and/or a temperature drop. A reddish-brown serpentine mineral is also believed to be a result of late magmatic alteration as this mineral is formed earlier than the metamorphic minerals and related to the igneous texture.

Among the primary minerals in the intrusive gabbroic rocks have also been ilmenite or titanomagnetite, judging from the widespread occurrence of leucoxene in the original textural position of these minerals. In an interstitial position micropegmatite of primary origin is very common in the most coarse-grained samples and mainly in samples from the large intrusions in the eastern part of the area.

The igneous rocks of Grænseland are in many respects similar to the rocks of the Ahr lake area of the Labrador through (Baragar, 1960). The general geological setting, the occurrence of pillow lavas, the size and shape of the intrusions, the composition of the rocks and the occurrence of melanocratic rocks which grade into leucocratic rocks are all features common for the two areas. In the Ahr lake area a similar degree of regional metamorphism is apparent although unaltered rocks are also found. A slight contact metamorphism around the intrusive bodies is also known in both Grænseland and the Ahr lake area.

The chemistry of the Ahr lake rocks and the present analyses are compared in table 8 where also an average parental tholeiite is shown (Nockolds and Allen, 1956). The silica/alkali diagram fig. 52 shows the Grænseland as well as the Ahr lake rocks in relation to variation trends of the main parental magmas.

Table 8. *Comparison of Grænseland analyses with Ahr lake rocks and average tholeiitic parental magmas (recalculated water-free to 100 %)*

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	50.79	50.07	50.03	50.33	51.32	52.12	49.74	51.21	47.50	48.66	47.90	51.5
TiO_2	0.79	1.32	0.90	0.91	1.52	0.67	1.56	1.30	0.70	0.44	0.39	1.5
Al_2O_3	12.68	14.79	14.53	15.58	13.00	12.83	14.47	11.12	14.56	19.95	23.52	14.8
Fe_2O_3	2.75	1.44	2.09	2.07	2.70	2.45	1.90	2.39	1.16	1.48	1.45	1.6
FeO	8.90	11.69	9.89	9.15	11.14	9.75	12.45	14.46	9.14	4.40	4.32	9.9
MnO	0.16	0.22	0.18	0.18	0.22	0.14	0.25	0.25	0.18	0.11	0.07	–
MgO	8.89	7.55	8.53	8.31	5.33	8.76	6.86	7.43	15.21	7.32	6.75	7.2
CaO	13.51	10.52	10.96	10.32	11.44	9.67	10.20	10.14	9.19	15.68	12.78	11.0
Na_2O	1.45	2.06	2.71	2.53	2.23	2.86	2.20	1.53	2.04	1.86	2.72	2.0
K_2O	–	0.25	0.09	0.54	0.90	0.42	0.22	0.04	0.06	0.04	0.10	0.5
P_2O_5	0.08	0.09	0.09	0.08	0.20	0.14	0.15	0.13	0.26	0.06	tr.	–
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Pillow lava, Grænseland (20862)	Ahr lake basalt	Metagabbro, Grænseland (53047)	Metagabbro, Grænseland (52958)	Metagabbro, Grænseland (53079)	Average metagabbro, Ahr lake area (3 analyses)	Average normal gabbro, Ahr lake area (14 analyses)	Melanocratic metagabbro, Grænseland (53111)	Melanometagabbro, Ahr lake area	Leucocratic metagabbro, Grænseland (53108)	Leucometagabbro, Ahr lake area	Average parental tholeiites

Nos. 1, 3, 4, 5, 8, and 10: IB SØRENSEN anal.
Nos. 2, 6, 7, 9, and 11: From BARAGAR, 1960.
No. 12: Average of six parental tholeiitic magmas after NOCKOLDS and ALLEN, 1956.

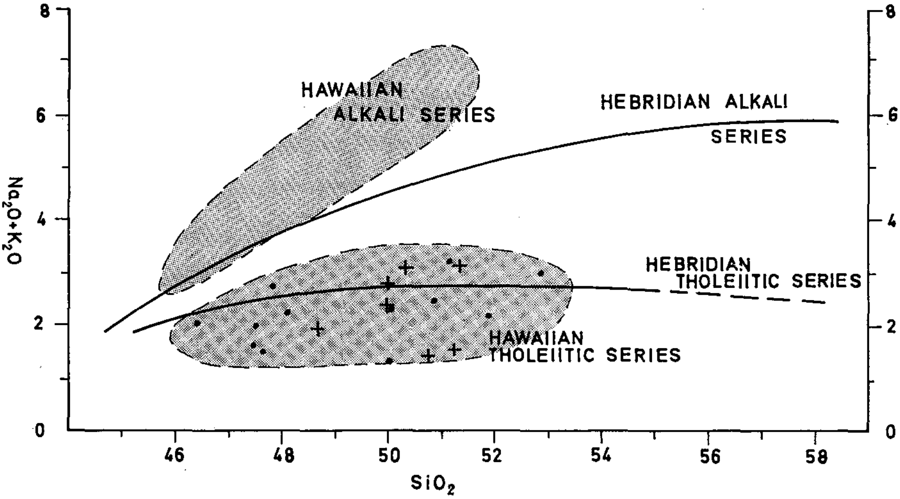


Fig. 52. Silica-alkali diagram with trends of tholeiitic and alkali series. Grænseland analyses (+) and Ahr Lake analyses (•) after BARAGAR (1960) are plotted.

The occurrence of micropegmatite and quartz in the Ahr lake area is shown by BARAGAR (1960, p. 1601) to be related to differentiation in the sills. Gabbro-pegmatite and sub-pegmatitic gabbro (depending on the presence or absence of micropegmatite) are formed in the upper part of the sills whereas porphyritic and ophitic gabbros occur in the lower part. The upper differentiations are shown to make up about 40 $^0/_0$ of the sills. Whether such relations occur in Grænseland cannot be shown from the material available, but as many samples show features relating them to either gabbro-pegmatite or sub-pegmatitic gabbro, it may be deduced that these rocks are abundant in Grænseland.

The leucocratic and melanocratic rock types of Grænseland are very similar to the leucometagabbros and melanometagabbros of the Ahr lake area texturally as well as mineralogically. BARAGAR (1960, p. 1633) concludes that the rocks are not normal differentation products as they show slight or no changes in the minerals across the gradational borders. In Grænseland gradational borders also occur.

CONDITIONS DURING THE EARLY KETILIDIAN, AND GEOSYNCLINAL DEVELOPMENT

Conditions

The sub-Ketilidian surface exposed in the Grænseland area is a remarkable feature of late middle-Precambrian time. The features associated with this old surface provide evidence of the prevailing phsyical conditions. The absolute age of the earliest sedimentation on this surface is still uncertain but may be as old as 2000 m.y. (Bridgwater, 1965) and is earlier than 1700 m.y.

The main features exhibited by the sub-Ketilidian surface and the sediments immediately overlying them provide information on the following:

1) Continental conditions and structures related to subaerial weathering.
2) Subaqueous conditions and structures related to subaqueous weathering.
3) The role of chert.
4) The role of iron-formations.

These main groups of problems will be treated separately in the following pages in so far as they are not mutually dependent.

1) Continental conditions and structures related to subaerial weathering

The small arkose deposits and the badly sorted residual conglomerates found directly upon the sub-Ketilidian surface are referred to the earliest continental stage of the Ketilidian. The arkoses comprise locally transported, badly sorted material, which has been altered to some extent. The alterations take the form of sericitization and possibly the formation of cloudy feldspars. These alterations cannot, however, be directly related to weathering as the subsequent metamorphic processes might also be responsible. A rusty colour characterizes the best preserved arkoses south of Grænsesø. The pre-Ketilidian gneisses below the small pockets of arkose also show a strong rusty staining. The occurrence of rounded cobbles of chert and gneiss in the arkose is a characteristic feature of the deposits.

It is suggested that the arkoses might be a result of local rapid decomposition of the gneisses and that the rounded cobbles represent material resting on the gneiss surface prior to the formation of the arkoses. Although rusty, the arkoses cannot be termed "red beds" as the oxidation appears not to be complete.

The residual conglomerates mainly occur in the area south of Vallen and consist of well rounded, badly sorted particles, some of which are of local origin and some of which could be derived from the Târtoq Group supracrustals and consolidated sediments related to the sub-Ketilidian surface. The latter would appear to have comprised quartzites, chert, dolomites and arkoses. The later carbonatization of the deposits may have masked the true origin of the dolomite cobbles and pebbles, so that it is uncertain whether carbonate deposits did in fact exist prior to carbonatization.

The structure of the residual deposits suggests that they represent the deposits of small streams or outwash fans. In some cases the local conglomerates are concentrated along pre-existing joint systems so the first mentioned possibility seems most likely. Traces of wind action have not been recorded.

The joint pattern preserved in the carbonatized zone below the Lower Dolomite Member south of Vallen suggests that the surface to some extent was controlled by a sheeting. The increasing frequency of joints towards the sub-Ketilidian surface from below and the occurrence of open breccia-filled fractures, which close to the surface contain conglomerates, indicate that release spallation and sheeting were developed.

The general impression of the primary surface is of rapid decomposition, local deposition of coarse material and possibly only a temporary supply of water in the form of small streams. The few sediments related to this surface are cherts, quartzites, arkoses and perhaps dolomites. The weathering was apparently dominantly mechanical. Chemical weathering, however, may have played a role in regions where water accumulated for longer periods, as shown by the superimposed traces of subaqueous conditions on the relationships discussed above.

2) Subaqueous conditions and structures related to subaqueous weathering

The earliest sediments of appreciable lateral extent deposited in water are those comprising the Lower Dolomite Member of the Lower Zigzagland Formation. These sediments control the carbonatization of the gneiss surface south of Vallen, described on page 44. The carbonatization and the lack of clastic material in the dolomite suggest that these sediments were largely precipitates. However, organisms also took part in the deposition as shown by the remnants found by PEDERSEN, (1968).

The carbonatization involves a replacement of feldspars by dolomite and an alteration of dark minerals to chlorites. The excess silica is thought to be found in the large chert lenses found in the lower dolomite and the carbonatized gneisses, and it may also have taken part in the silicification of the dolomite. Excess alumina probably went into hydrophyllosilicates, which later formed muscovite. Alkalies possibly went into solution, and iron to siderite or into the widespread magnetite found in the dolomites. Sulphur possibly also took part in the processes to judge from the widespread occurrence of pyrite (fig. 14).

The water responsible for the carbonatization may have been of high CO_2 concentration, and supplied from both the surface and from chemically highly active ground-water. A basin to which little or no detrital material was transported would be likely to yield these conditions which also might be expected to grade into the conditions of cyclic sedimentation prevailing during deposition of the next member – the Varved Shale Member. An atmosphere comparatively rich in CO_2 provides a high CO_2 vapour pressure and facilitates the carbonatization processes, especially in a closed basin. The occurrence of such an atmosphere is probable in view of HOLLAND's work on a model of atmospheric development (HOLLAND, 1962).

It should be noted that the structures produced by the carbonatization, the ball-shaped joint blocks and the onion-structures in their interior, are similar to structures found in deep kaolinitic weathering of granites and gneisses (WILLIAMS, 1968). A structural zoning similar to that in the weathered Hong Kong granite (RUXTON and BERRY, 1957 and 1959) has developed in the carbonatized gneisses. Although the weathering elsewhere in Grænseland may be kaolonitic, the parallelism with the Hong Kong granite is regarded as a convergence phenomenon as it seems unlikely that the carbonatization was superimposed on kaolinitization of the same order.

Subaqueous weathering, or weathering which may be so regarded because of its close relation to water-laid sediments, is also found below the Ore-Conglomerate Member between Vallen and Grænsesø and below the quartzites and the Dolomite Shale Member in the Grænsesø region. These sediments are younger than the lower dolomites and have developed in a basin of larger dimensions than that in which the Lower Zigzagland Formation was laid down.

Beneath the ore-conglomerate, the quartzites and the dolomite shales, similar relations are found in that the feldspars of the gneisses are altered to a fine mass of micaceous material. The altered zone can be of varying depth with respect to the old surface but appears to be at least 0.5 m under the ore-conglomerate and thickest under the dolomite shales (app. 2–5 m). In the latter case isolated carbonate crystals may occur in the altered zone but the micaceous material dominates. A sub-parallel banding and layering seems to be present in the weathered zone which may be a result of load on the relatively soft material. Similar phenomena have been described from the base of the Karelidian Jatulium in the Suojärvi region by METZGER (1924).

No alteration products which can be directly related to the weathering have been identified in the rocks. The whole mass consists of fine sub-microscopic material and opaque material which may be ore besides quartz in a gneissic texture. The metamorphic products of the fine mass are dominantly muscovite and a little chlorite, and in one sample (53083) large andalusite crystals. This would suggest that the material is strongly aluminous and that the weathering thus may have been kaolinitic. KHARITONOV (1965) mentions a kaolinitization at the base of the Jatulium visible in the same region as described by METZGER (1924).

3) The role of chert

Very fine-grained quartzites or chert in the sense of FOLK and WEAVER (1952) have a widespread occurrence in the sediments of the Vallen Group both as a primary sediment – dominantly in the Grænsesø Formation – and as clastic grains in the coarse sediments of the greywackes and quartzites. Most of the boulders found in the oligomict conglomerates above the residual conglomerates are chert or cherty rocks. In addition, large chert lenses occur related to the deposition of the Lower Dolomite Member and the carbonatization processes.

The chert found is of three types but when it occurs as small clastic grains they are not always distinguishable. 1) One type is a pure siliceous chert composed almost entirely of small eugranoblastic quartz grains in saccharoidal or amoeboid sutured textures. 2) The second variety is a chert associated with euhedral magnetite ore and with relatively hemigranoblastic textures; the magnetite seems mostly to have recrystallized from a finely disseminated ore pigmentation (53038, p. 46). 3) The third type of chert is associated with organic or carbonaceous material, and perhaps also ore.

An important occurrence of chert occurs in connection with the Ore-Conglomerate Member in the lower part of the Upper Zigzagland Formation. It here shows close relationships to iron-formations of Superior type (BLONDEL, 1955), together with the second chert variety mentioned above. The close association of chert with iron-formations is well known and has been emphasized by several authors (SAKAMOTO, 1950; JAMES, 1954; LEPP and GOLDICH, 1964). In Grænseland no direct connection between primary chert and iron-formations can be established, as the ore-conglomerate is possibly a wholly secondary feature which, however, may have its origin in a primary iron-formation. This is indicated by the existence of preserved clastic grains of iron chert.

Secondary deposited chert of all three types is found even in the lowest arkose deposits; it must therefore either have been derived from much older formations or be related to the surface conditions locally. The occurrence of the large boulders in the ore-conglomerate (fig. 16) suggests that the latter may be the case, and the chert lenses in the carbonatized zone also show that the occurrence of chert may be related to weathered zones and/or small closed basins on the sub-Ketilidian surface.

4) The role of iron-formations

Iron-formations have been defined by JAMES (1954, p. 239) as chemically precipitated sediments, often banded, with more than 15 % iron and often, but not always, associated with chert. PETTIJOHN (1957, p 449) uses the term in a much more wide sense.

There are two main hypotheses concerning the origin of iron-formations. One is connected to volcanic processes and an exhalative origin and another connects the origin of silica and iron to weathering processes of various kinds under different conditions. Most iron-formations are connected with early and middle Precambrian successions.

LEPP and GOLDICH (1964, p. 1027) review the different theories for Precambrian iron-formations, their age and their occurrence, and showed that these iron-formations, unlike later iron-formations, contained high proportions of Mn and Si, and low proportions of Al, Ti and P. They concluded that this might be a consequence of lateritic weathering under atmospheric conditions of lower oxygen and higher CO_2 content than the present day, corresponding to the second stage of atmospheric development in HOLLAND's (1962, p. 645) three stage model for the development of the earth's atmosphere. Under these conditions Fe, Mn and Si could be transported whereas Al, Ti and P would be retained in the weathered crust.

The precipitation of iron is regarded by some authors as a result of biological activity (HARDER, 1919; HOERING, 1962; MOORHOUSE and BEALES, 1962; and CLOUD, 1965). LEPP and GOLDICH (op. cit.) point out that many iron-formations are closely associated with carbonaceous material.

The only iron-formation known in the Ketilidian until now is the Ore-Conglomerate Member of the Zigzagland Formation, an iron-formation of a rather specific facies. The occurrence is very local, and the character of a conglomerate, the clastic matrix, and the sediments interpreted as black sand which underlie it, suggest that the ore has been redeposited. The large boulders found in the region north of Vallen do not appear to have been transported any great distance and they may have been residual. The Ore-Conglomerate Member moreover represents a transgressive phase and there is a gradation from the underlying varved shales to ore-bearing sandstone and to the conglomerate.

There is in the ore-bearing rocks no appreciable amount of heavy minerals such as zircon, sphene, amphibole or garnet which would have been derived from the basement rocks. Apatite is very frequent. It is therefore possible that the source material which gave rise to the ore-bearing sediments was a surface cover restricted to the regions subsequently transgressed. This material might either have occurred in the immediate surroundings of the basin of the Lower Zigzagland Formation or be a general feature of surface depressions on the sub-Ketilidian surface, where chemical conditions may have lead to precipitation of iron and silica, for instance in temporary lakes. It is probable that the precipitation took place in close connection with the formation of chert, since clastic chert grains with finely dissiminated ore occur; there may also be some relationship with the third of the chert types found which encloses organic material.

Textures very similar to the aggregates of intergrown magnetite octahedra of the Ore-Conglomerate Member have been described by La Berge (1964) who regards them as due to metamorphism. This may very well be the explanation of the Grænseland textures, since James (1956) and Donovan (1964) both state that iron-formations are very sensitive to metamorphism.

Basin development

The basin development during sedimentation, based on the facies distribution and thicknesses described earlier, is presented as a series of sketch profiles in fig. 53.

From a probably peneplained surface with residual deposits and arkoses (1) a shallow and probably closed basin developed in which the Lower Zigzagland Formation was laid down. The sedimentation possibly began as a precipitate with later the incoming of small amounts of very fine clastic material. The basin was periodically dry and could possibly have been a lake (2).

In the upper part of the Lower Zigzagland Formation coarse clastic very iron-rich material was added and in the southern part of the basin carbonate facies sedimentation prevailed (the Rusty Dolomite Member, described on p. 51).

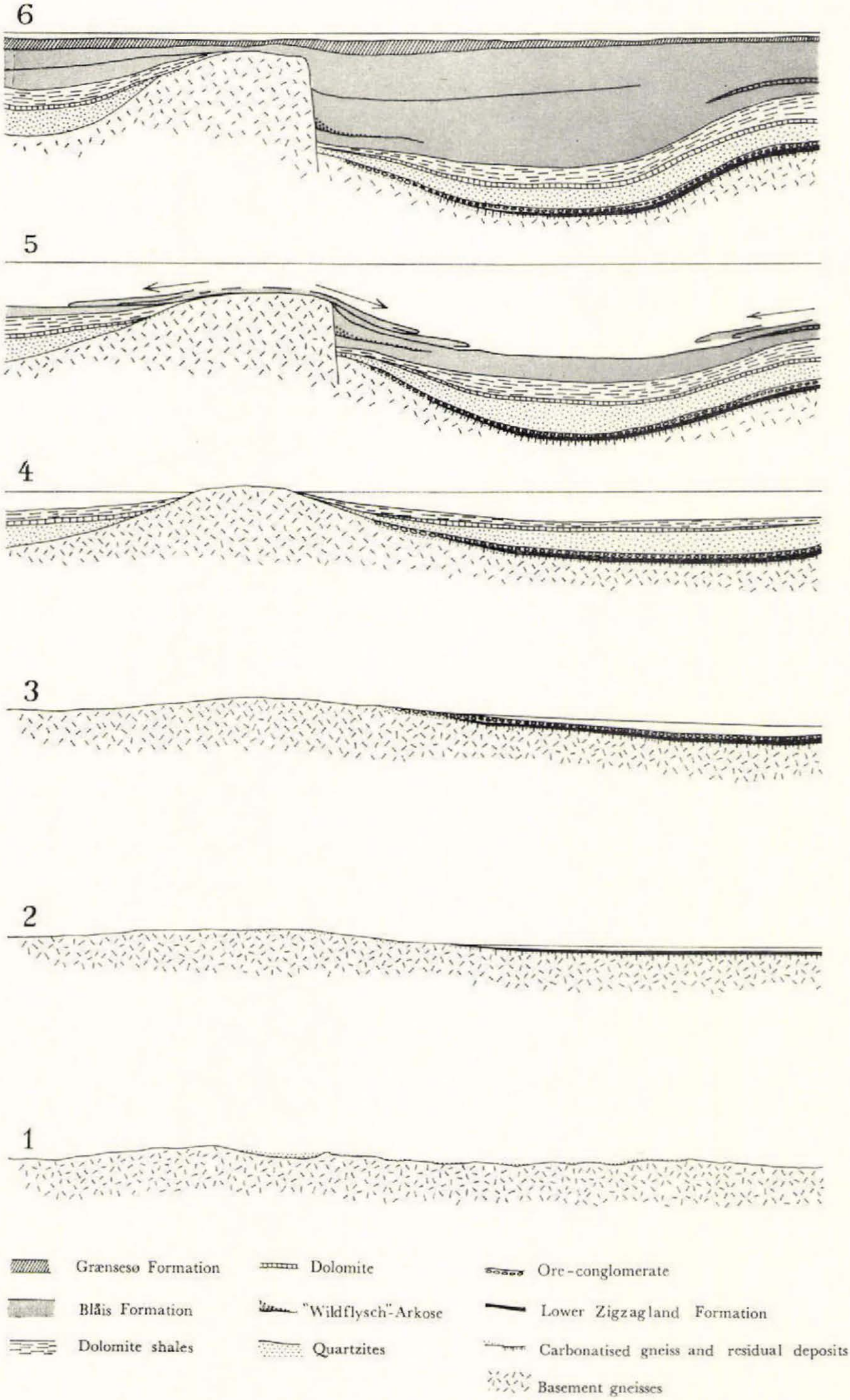


Fig. 53. The development of the sedimentary basins in the Vallen Group. Not on scale and vertical scale exaggerated. For explanation see text pp. 131–134.

With the deposition of the ore-conglomerate the basin appears to have widened northwards (3) and coarse clastic conglomeratic material locally indicates that littoral conditions prevailed during the deposition of the lower part of the Banded Quartzite Member. The middle part of this member seems to have been deposited in a shallow sea with banks and varied current directions. Parts of this sea may temporarily have been dry. The upper parts of the Banded Quartzite Member appear to have been laid down in water with more stable current directions and perhaps in relatively deeper water compared to the conditions which prevailed earlier.

Possibly at the same time as the deposition of the Banded Quartzite Member a second basin of quartzite deposition developed in the northern part of the Grænseland area and extended over parts of the Midternæs area where a third basin is also found (HIGGINS and BONDESEN, 1966). A land area existed in the southern part of Grænsesø, dividing the two southernmost basins.

The Dolomite Shale Member of the Upper Zigzagland Formation implies a return to fine clastic sedimentation commencing with the formation of massive carbonates. During this period the basin north of Grænsesø extended farther to the south (4). Carbonate sedimentation also occurred close to the coast line although here it was associated with coarse clastic material (p. 69). The sedimentation of the Dolomite Shale Member is very uniform and seems to exhibit the same character over large areas.

With the sedimentation of the Blåis Formation the influence of tectonic activity on the sedimentation in the basin may be recognized. The accumulations in the basin were black and dark pelites which dominate the lower part of the formation in the northern part of the area. In the southern part of the area the accumulate was apparently of a carbonate facies. In addition, large amounts of greywackes were brought into the basin, possibly by the action of turbidity currents.

The "wildflysch"-unit provides further evidence of penecontemporaneous movements, since it contains blocks of all the sedimentary members which underlie it and also gneiss. A vertical displacement corresponding to at least the thickness of these sediments ($\sim$200 m) must have taken place prior to the deposition of this unit (5).

This faulting may be a continuation of the Bæversø fault, which during the deposition of the Blåis Formation controlled the ridge dividing the two basins represented in the area. There are no indications as to whether the ridge was land or submerged in lower Blåis Formation time, but in upper Blåis Formation time the ridge was transgressed by graded greywacke deposits.

The facies distribution in the Blåis Formation indicates that coarse greywacke deposition took place early in the southern part of the southern basin suggesting a supply from that direction. Later coarse greywackes were laid down over the whole area and during this time the ridge in the southern part of Grænsesø may have played a role as a centre of tectonic activity, to judge from the facies relations just to its south.

The variations in sedimentary facies vertically in the succession of the Zigzagland Formation and the Blåis Formation suggest an increasing subsidence of the basin floor. During the deposition of the Zigzagland Formation, as far as up to the formation of the Dolomite Shale Member, the sedimentation seems to have been more or less equal to the rate of subsidence. The deposition of the Blåis Formation was, however, accompanied by paroxysmal events which seem to have led to an increase in the rate of subsidence, and the sedimentation probably took place in comparatively deep water. The basin may at this time have been bordered by a comparatively steep submarine topography which would facilitate the formation of turbidity currents.

With the transgression of the ridge in the southern part of Grænsesø by the uppermost part of the Blåis Formation the two basins, which may then have represented only minor depressions in extensive basin structures, were filled in by sediments.

A new phase in the basin development was now opened with the deposition of the contrasting sediments of the Grænsesø Formation (7). Pelites, carbonaceous shales, dolomites, and later cherts and pyritic shales with abundant organic remnants were deposited under quiet, euxenic conditions. This period of deposition may have included an elevation of the basin floor so that the area of sedimentation was a comparatively shallow sea in which precipitation of carbonates and photosynthesis could readily take place (BONDESEN et al., 1967). The two pre-existing basins can no longer be traced at this stage, and the sedimentation is more even over large areas. The variations in thickness of the Grænsesø Formation suggest rather a development of several small depressions.

This phase in the development of the Ketilidian may perhaps be viewed as a period of relaxation and rest at the termination of the Vallen Group sedimentation and prior to the volcanic phase of the Sortis Group. Although there is a strong contrast in the sedimentary development between the Blåis Formation and the Grænsesø Formation, no significant break in the stratigraphy such as e.g. an angular unconformity or hiatus can be seen. The strong structural disharmony between the two formations is, as far as can be judged, purely a tectonic feature.

The first extrusion of pillow lavas may have occurred earlier in the northern part of the area as the pyritic shales of the Grænsesø Formation are apparently developed at a higher stratigraphic level in the southern part of the area. Also the greatest thicknesses of lava are found in the northern part of the area. The sea was probably still relatively shallow and thin sediments, such as the Anthracite-Carbonaceous Shale Member, show that euxenic conditions still prevailed. The lowest part of the Rendesten Formation, which comprises carbonaceous pelites and dolomites, shows that the same facies as shown by the Grænsesø Formation continued until after the termination of the extrusive activity represented by pillow lavas. As the facies relations during the lava extrusion remained the same, a considerable subsidence must have taken place gradually as extrusions occurred.

In the lower part of the Rendesten Formation pelites and semipelites interbedded with a considerable proportion of pyroclastic material grade into a greywacke facies. This implies a return to conditions similar to those prevailing during deposition of the Blåis Formation. The strong lateral facies changes suggest that a rugged submarine topography or a subdivision into several basins may have existed. However, little is known of the stratigraphical relations so that the basin development in this upper part of the whole succession is very schematic.

Organic remnants and their significance

The organic remnants from Grænseland have been provisionally described and discussed by Bondesen et al. (1967), and papers on the organic chemistry of the remnants have been published (Pedersen and Lam, 1968; Lam and Pedersen, 1968). Besides material collected by the author, new and systematic collections have been made by Pedersen (1966 and 1968). The findings comprise macrostructures as well as microstructures.

Macrostructures occur in the succession from the lowermost Zigzagland Formation to the Rendesten Formation. Well preserved macrostructures found in the Lower Dolomite Member of the Zigzagland Formation (Bondesen et al., 1967, plate 12, fig. 2; Pedersen, 1968, p. 51) show that living organisms existed in the limited basin at the time when the deep carbonatization of the substratum occurred. Stromatolite-like structures have been found in loose blocks probably derived from the Grænsesø Formation. From this formation the occurrence of the globular organic structures – *Vallenia* – has already been noted (see p. 94) and the possible "biostratigraphic" value emphasized.

Micro-organisms and/or parts of larger organisms also occur and they seem to have a wide vertical distribution. These remnants are bacteria-like structures, filaments with an irregular cellular structure, irregular lumps of organic material, parts of threads which occasionally branch and "spore"-like microspheres. The remnants occur in almost all formations and rock types but are particularly common in the Grænsesø Formation, in dolomites, shales and chert, and the dolomite shales of the Zigzagland Formation. It seems to be the calcareous rocks and the cherts which contain most of the remnants, and thus secondarily deposited chert may be responsible for the organic remnants in greywackes and quartzites.

An examination of the isotopic composition of the carbonaceous material and the carbonates by Jørgensen (in Bondesen et al., 1967) has shown strong organic affinities. It has also been shown that *Vallenia* may have been photosynthetic. The isotopic composition of the carbonate from the *Vallenia*-bearing rocks suggest that these might have been precipitated in oxygen-poor water, and the composition of the coal from the Foselv Formation indicates that it represents marine organic material accumulated under extreme reducing conditions (Jeffrey et al., 1955). These results suggest that the succession was deposited under euxenic conditions. The results of organo-chemical examinations (Pedersen and Lam, 1968) show that some of the organic material has escaped complete decay. This would also imply reducing euxenic conditions.

The Anthracite-Carbonaceous Shale Member of the Foselv Formation further indicates that large amounts of organic material were able to accumulate. The present thickness of an average 1 m necessitates an original accumulation of a considerable thickness of organic material.

The distribution of organic remnants shows that organic material was present under nearly all conditions. The material has a wide vertical distribution and an extensive horizontal distribution, and organisms have also played an important role quantitatively. This suggests that they may have had an influence on geological processes (formation of chert, carbonaceous sediments and carbonate rocks) in certain regions, especially in lakes and relatively shallow parts of the sea. The organisms appear to have been photosynthetic and thus in this part of the Precambrian may have had a considerable influence on the development of an oxygenic atmosphere (Holland, 1962).

Comparisons and correlations with other regions in South-West Greenland

The Ketilidian sediments and volcanics can be traced as a belt from the Midternæs area throughout Grænseland, from south of Arsuk glacier to Qôrnoq and along the north coast of Kobberminebugt to the area around Storø and Arsuk Ø (fig. 1). Apart from this almost continuous belt in which the degree of deformation and metamorphism increases towards the south (Windley et al., 1966; Henriksen, in press) Ketilidian supracrustals (see p. 144) also occur in the southern part of Kobberminebugt at Ilordleq (Watterson, 1965) and along the north coast of Alangorssuaq (Harry and Oen, 1964). These supracrustals have provisionally been termed the Ilordleq Group (ALLAART, BRIDGWATER and HENRIKSEN, in press).

In the vast granite areas between Kobberminebugt and Igaliko Fjord inclusions and scattered enclaves of sediments of supposed Ketilidian age are found (ALLAART, 1964 and 1967). South of this in Søndre Sermilik extensive areas of thick sediments and volcanics occur in a NE-SW-trending belt (Escher, 1966). These correspond to the Sermilik Group of WEGMANN (1938) and are also regarded as Ketilidian, although WATTERSON (1965, p. 134) has suggested that they could be of Sanerutian age, *i.e.* late Ketilidian in the sence of this paper. Towards the Kap Farvel region the supracrustals are strongly metamorphosed, and intruded by numerous granitic bodies.

Correlations in the Ivigtut region, based on the triple division of the Ketilidian into the Vallen Group, the Sortis Group and the Qipisarqo Group, have earlier been carried out by BERTHELSEN (1965, p. 128). Berthelsen correlated most of the sediments below the pillow lavas south of Arsuk Fjord and in the Arsuk Ø – Storø area (BERTHELSEN op. cit., table 3) with the Grænsesø Formation on the assumption that large parts of the migmatites and gneisses in the Ivigtut region were derived from the Zigzagland Formation and the Blåis Formation. This assumption is not valid (HIGGINS and BONDESEN, 1966), and the correlation must therefore be revised.

From the experience in Grænseland, and also partly in Midternæs, the value for regional correlation purposes of single stratigraphical units may be outlined as follows:

1) The Lower Zigzagland Formation, including the ore-conglomerate, can be expected to have only local distribution.
2) The banded quartzites of the Zigzagland Formation may be of wide horizontal distribution but of varying thickness. They may also be lacking. It is unlikely that they would be mistaken for other members.
3) The Dolomite Shale Member of the Zigzagland Formation, characterized by two (or perhaps more) pure dolomite bands in the lower part and occurring just above the quartzites, seems to have a wide horizontal distribution and may serve as a good marker.
4) The Blåis Formation may vary strongly lithologically and in thickness and may be lacking. The general character of deposition under tectonically active conditions may, however, serve as a means of correlation. The formation may be developed as pelites or calcareous rocks.
5) The Grænsesø Formation may serve as a good marker on the basis of its characteristic occurrences of carbonaceous shales,

dolomites and cherts. The dolomitic character may locally dominate. The *Vallenia* bed might be recognizable close to the top of the formation.

6) The pillow lavas may be usefully employed in large-scale correlations on group level.
7) The Rendesten Formation on account of its varied development may serve as a poor correlating link. The lowest part which comprises dolomites and carbonaceous pelites may be of local value.

On the basis of the above evaluations correlations with the different areas are presented below.

The Midternæs area

Correlations with the Midternæs area, which lies immediately to the north of the Sioralik glacier and where a maximum thickness of about 5000 m of Ketilidian rocks occur, are comparatively easy (HIGGINS,

Table 9

	Grænseland		Midternæs	
Sortis Group	Rendesten Form.		Thick pillow lavas	4800 m with approx. 5 % sediments
			Lavas and sediments including pyroclastics	
	Foselv Formation		Pillow lava (100–900 m) with thin sediments	
Vallen Group	Grænsesø Formation		Principally limestones with interbedded shales and thin quartzites, *Vallenia* bed in NE Midternæs	~ 70–170 m
	Blåis Formation		Shales, semipelites and graded greywackes (includes calcareous bands, cherty quartzites and a 75 m thick arkose)	50–700 m
	Upper Zig-zag-land Form.	Dolomite Shale Member	Calcareous shales, calc-cemented sandstones and thin limestones	up to 35 m
		Banded Qzt. M.	Orthoquartzites and feldspatic sandstones	1–100 m
		Ore-Congl.M.	Conglomerate	0–4 m
	Lower Zigzagland Formation		(Lacking)	
	Unconformity		Unconformity	

1970). The rocks in the Midternæs area are generally less deformed and less metamorphosed than those in Grænseland. A basin development in the Vallen Group similar to that found in Grænseland can be deduced. The northern extension of the basin found in north Grænseland occurs in south Midternæs and another basin appears to be present in north-west Midternæs where a low ridge, perhaps controlled by fault scarps, separates the two basins.

The stratigraphy of the Midternæs area is compared with that of Grænseland in table 9.

In north-east Midternæs calcareous shales, possibly equivalent to the Dolomite Shale Member of the Zigzagland Formation, are found adjacent to the gneisses as is also the case in the central part of the Grænsesø area. The arkose in the greywacke sequence of Midternæs equivalent to the Blåis Formation is possibly also found in Grænseland between Vallen and Grænsesø where a similar rock type has also been sampled; in the area north of Grænsesø, some observations suggest the presence of a similar unit. The thicknesses of the arkose appear to be much greater in Midternæs than in Grænseland (up to 75 m).

The Foselv Formation and the Rendesten Formation are not clearly distinguishable in the central and northern Midternæs area, mainly because lavas are found at the supposed level of the Rendesten Formation. Moreover, it is possible that a higher stratigraphical level is reached in the nunataks, north-east of Grænseland. Here thick pillow lavas occur.

The tectonic history of the Midternæs area is very similar to that of Grænseland. It is noteworthy that the earliest deformation appears to be clearly developed at certain stratigraphic levels in Midternæs as in Grænseland (the lower part of the Dolomite Shale Member).

The area Arsuk Fjord-Qôrnoq-Kobberminebugt

The Ketilidian rocks south of Arsuk Fjord (fig. 1) contrast with those of Grænseland in their stronger deformation and higher degree of metamorphism (WINDLEY et al., 1966). The comparatively wide belt of supracrustals in the north narrows southwards along the strike to Qôrnoq. The lower boundary with migmatites and gneisses is strongly tectonized and the supracrustals are bounded upwards by an extensive complex of augen gneisses. In table 10, the stratigraphy of the area (S. BAK JENSEN, pers.comm.) is compared to that of Grænseland.

The stratigraphic relations in this 75 km long belt of Ketilidian supracrustals are not so well known due to the condition of preservation of the rocks. However, there are some consistent features in that quartzites form the lower boundary for long distances, occasionally with thin calcareous rocks below and often with dolomite bands immediately above associated with mica schists. The quartzites are regarded as equivalents

Table 10

	Grænseland		Arsuk Fjord – Qôrnoq	Kobberminebugt	
Sortis Group	Lacking (?)		Augen gneisses	Semipelites 1200 m	Qipisarqo Group
			Polymict conglomerate with gneiss boulders 0–200 m	app. 190 m	Qipisarqo Group
	Rendesten Formation Foselv Formation		Amphibolites with pillow lava structures (500 m)	Amphibolites with pillow lava structures (200 m)	
Vallen Group	Grænsesø Formation		(Local dolomites)	(Lacking?	
	Blåis Formation		Mica schists 200 m	?	
	Upper Zigzagland Form.	Dolomite Shale Member	Mica schists and dolomites 100–150 m	Mica schists 100 m	
		Banded Quartzite Member	Quartzite 0–50 m	Quartzite 140 m	
	Lower Zigzagland Formation		Mica schists 300 m / Local dolomites	?	
	Basement		Migmatites	Migmatites and Ketilidian granites	

of the Banded Quartzite Member bounded by calcareous rocks which could correspond to the Lower Zigzagland Formation and the Dolomite Shale Member.

On a small island in Qôrnoq fjord, mica schists with dolomite bands resembling the Dolomite Shale Member occur in tectonic contact with granite. In Kobberminebugt quartzites form the lower boundary against migmatites and granites.

Another correlating link is a thick amphibolite sequence with occasional pillow structures. This should correspond to the Foselv Formation. A thick conglomerate overlies the amphibolite and marks the lower border of the Qipisarqo Group (BERTHELSEN, 1965, p. 128) which in Kobberminebugt is largely composed of semipelitic sediments. The possibility that the Qipisarqo Group in part equals the Rendesten Formation can be considered (see p. 145).

Between the amphibolite and the quartzite below occurs a varying sequence of mica schists with dolomite bands. This succession could correspond to the Dolomite Shale Member and the Blåis Formation.

It is possible that no greywacke sedimentation took place in the area between Arsuk glacier and Kobberminebugt as the mica schist succession is dominantly of pelitic nature. It is notable that no equivalents to the carbonaceous sediments of the Grænsesø Formation are apparent, although in the northernmost part of the area at the Arsuk glacier quartzites and dolomites below the amphibolites, and rusty mica schists in the amphibolites, could be considered to be equivalents of the Grænsesø Formation.

An occurrence of 300 m of mica schist below quartzites and above the gneisses, immediately south of the Arsuk glacier, appears to have no equivalent in Grænseland or in other areas.

The Arsuk Ø-Storø area

Arsuk Ø and Storø (fig. 1), the classic area of the Ketilidian supracrustals in the Ivigtut region (WEGMANN, 1938), has been remapped and subjected to detailed stratigraphical analysis by I. MULLER. The rocks, which occur in a major basin structure, are less well preserved than those of Grænseland, but exhibit an interesting tectonic and metamorphic history.

A stratigraphical correlation between Grænseland and the Arsuk Ø – Storø area based on local stratigraphical subdivisions (MULLER, pers. comm., 1966) is given in table 11.

Comparisons with the Arsuk Ø area are primarily based on the border between the pillow lavas and the sediments which is presumed to be equivalent to the border between the Sortis Group and the Vallen Group. Further the orthoquartzites and arkosic quartzites may be correlated with the Banded Quartzite Member. The Issua Formation of Arsuk Ø seems thus directly comparable to the Grænsesø Formation, and it is possible, between the Issua Formation and the quartzites, to distinguish sedimentary sequences corresponding to the Dolomite Shale Member and the Blåis Formation, as a whole. There are clearly many similarities between the stratigraphy of the Arsuk Ø area and Grænseland, but some differences and peculiarities should be remarked:

1) There are volcanic tuffs in the Taylers Havn Formation; these, however, occur at a level which approximates to the level of the "wildflysch"-arkose unit in the Blåis Formation and the appearance of the lower greywacke-dolomite succession south of Lappesø (see p. 75 and p. 133). It may thus be postulated that the tectonic activity which led to the Blåis Formation basin development and the formation of greywackes elsewhere in the region may have been accompanied by volcanism.

2) The rocks of the lower part of the Taylers Havn Formation below the volcanic tuff may be compared with the Dolomite Shale

Table 11

	Grænseland	Arsuk Ø	Storø	
Sortis Group	Rendesten Formation	Pillow lavas including pyroclastics, black pyritic phyllites and chert Amoeboid pillow lavas.		Arsuta Formation
	Foselv Formation	Pillow-lavas and lavas including pyroclastics, black pyritic phyllites and black cherts. Banded chert with intercalated pyritic phyllites and quartzitic slabs (80—20 m). Pillow lavas, breccias of pillows with lavas and/or sills.		
Vallen Group	Grænsesø Formation	Pyritic and graphitic phyllites, cherts. Black banded phyllites (locally pyritic and graphitic). Total 80 m. At the base a large sill.	Bedded sequence of massive quartzites, banded quartzites with slumping, cherts, phyllites (banded black, green and grey) in beds of 1–14 m. Total 70 m including minor sills. Large sill at the base (200 m).	Issua Formation
		? (Sea – unexposed or lacking).	Banded, graded, currentbedded and slumped Quartzites. Banded quartzo-feldspathic phyllites. Arkosic quartzites. Base unknown	"Levant" Formation
	Blåis Formation Black pelites ~ Calcareous facies	Top unknown Graphitic and pyritic schists. Orthoquartzites and arkoses. Dolomite quartzite. Calcareous dolomite. Biotite garnet schists with pyrite and graphite. Granular arkosic schists and quartzitic phyllites with biotite. Volcanic tuff.		Taylers Havn Formation (350–400 m exposed)
	Zigzagland Formation U. Dolomite Shale Memb.	Calcareous dolomite (7 m). Banded quartzo-feldspathic phyllites (50 m). Banded quartzo-feldspathic phyllites. } 80–100 m Dolomitic quartzites.		
	Zigzagland Formation U. Banded Quart. Memb.	Orthoquartzites. } 80–100 m Arkosic quartzites.		
	Zigzagland Formation L.	Banded dolomitic quartzites. } 10–15 m exposed Calcareous dolomitic phyllites.		Evqitsut beds (only exposed on Evqitsut island)
	Unconformity.	Structural discordance at Taylers Havn.		

Member, especially their phyllitic portion. It is of interest that a thick dolomite is found at the top of this sequence.

3) The upper part of the Taylers Havn Formation above the volcanic tuff exhibits an alternating pelite and carbonate facies. If these rocks correspond to the lower part of the Blåis Formation, then the lateral facies changes apparent in Grænseland clearly extend to other areas.

4) The "Levant" Formation, developed in Storø, might correspond to the upper part of the Blåis Formation. The author would here like to indicate the possibility that this formation might thin considerably so that in the narrow sound Ikerassarssuk, between Arsuk Ø and the mainland, there may be little or no representative of the "Levent" Formation. Such a thinning would imply a NE-SW-trending sedimentary basin, which may partly have controlled the present exposed basin structure.

5) The Issua Formation is graphite-bearing on Arsuk Ø without dolomites, and is comparable to the Grænsesø Formation. The Issua Formation on Storø is of a different character.

6) The pillow lavas of the Arsûta Formation differ somewhat from the Foselv Formation and the Rendesten Formation and there is no feature which might correspond to the border between these two formations. The tendency of pyritic shales and chert to occur high in the lava succession is common to south Grænseland and to Arsuk Ø. No clear division of the Sortis Group into the Foselv Formation and the Rendesten Formation, can be recognized in the Arsuk Ø – Storø area.

The Ilordleq area and the southern part of Kobberminebugt

In the Ilordleq area a sequence of 1500 m of sediments, homogeneous basic volcanics, laminated calcareous rocks, banded sediments with pyroclastics and agglomerates, plagioclase porphyries and homogeneous basic volcanics occurs (WATTERSON, 1965, p. 13). It is believed, as BERTHELSEN has also suggested (1965, p. 128), that this sequence – the Ilordleq Group (ALLAART et al., in press) – represents a comparatively high stratigraphic level of the Ketilidian succession above the Qipisarqo conglomerate. This succession can be traced towards the west along the north coast of Alangorssuaq where pillow lavas occur (HARRY and OEN, 1964). However, GHISLER (1968) has drawn attention to the occurrence of copper mineralizations in the Ilordleq Group and on this basis compared the sequence to the pre-Ketilidian Târtoq Group.

Søndre Sermilik

In Søndre Sermilik (ESCHER, 1966) a thick sequence of rocks may be divided into a lower sedimentary division (1500 m thick) and an upper volcanic division (700 m thick) as is also the case in the Ivigtut region. The sediments, which may correspond to the Vallen Group, show no striking similarity to the succession in Grænseland. From below pelitic gneisses ($\sim$500 m), semipelites ($\leqslant$ 500 m), pelitic schists including sulphide- and graphite-bearing layers (450 m) and quartzites ($>$800 m) are the principal units of the sedimentary succession. The base is unknown. It should be mentioned that the Ketilidian age of the sediments and volcanics in these southernmost regions in Greenland is not established with certainty (WATTERSON, 1965 p. 135, ALLAART, 1967 p. 138 ff.).

Ketilidian basins

Although the stratigraphy of the Ketilidian is incompletely known in the Ivigtut region as a whole and there are many uncertainties in correlations, a pattern of Ketilidian sedimentation is apparent from the geology of the supracrustals.

In general, the Vallen Group sedimentation seems to have begun with the deposition of orthoquartzites, a feature which seems to be common to basin sedimentation commencing at major unconformities (PETTIJOHN, 1943).

These sediments and the immediately succeeding deposits of finer clastic material were mainly laid down in at number of limited basins, which gradually widened. Tectonic activity and accompanying greywacke deposition accentuated the basin development as can be shown in both Grænseland and Midternæs (HIGGINS and BONDESEN, 1966). The axes of these basins may possibly have had NE-SW or ENE-WSW trends.

In addition to the three basins known in north-west Midternæs, south Midternæs and north Grænseland, and central Grænseland, a further basin may have existed in the Arsuk Ø – Storø area.

The comparatively thick sequence of sediments immediately to the south of Arsuk glacier may indicate a section in a separate basin of deposition. The comparatively thin Vallen and Sortis Group succession in the Qôrnoq fjord area may be an indication of a major dividing ridge.

The Qipisarqo Group with its thick conglomerate might have its explanation in a later phase of development in the Kobberminebugt area, which may also have had a NE-SW axis. If this later basin development was also controlled by tectonic features, the Qipisarqo Group conglomerate, which contains boulders of gneisses and migmatites, occurs near an area where the Vallen Group and Sortis Group were relatively thin and where basement rocks could most easily be exposed to erosion.

The character of the Rendesten Formation in Grænseland also seems to indicate renewed tectonic activity in the basins, and it would thus be possible on this basis to consider the Rendesten Formation as penecontemporaneous with at least part of the Qipisarqo Group.

The conception of the Qipisarqo Group as a flysch facies, as BERTHELSEN (1965, p. 128) has advocated, would be consistent with these ideas. It must, however, be stressed that the development of a possible Kobberminebugt basin cannot, on present evidence, be related to any phase of deformation. As will be shown later, (p. 186) it is likely that the Qipisarqo Group was already in existence prior to the first phase of Ketilidian deformation recognized.

Comparisons with regions outside Greenland

The attempts to establish a stratigraphic division of the Precambrian (SIDORENKO, 1963; HARPUM, 1960; QUENNELL and HALDEMANN, 1960) have gained much interest. These efforts have mainly been concentrated on the best preserved supracrustal successions in different parts of the world and it is the author's view that the Grænseland sediments and volcanics can be regarded as belonging to these. In the following other occurrences comparable to Grænseland will briefly be mentioned, and it is noted that those which show the closest similarities on purely lithological grounds also are of comparable ages. Regarding comparisons of the geology on both sides of the Davis Strait is referred to ALLAART et al. (in press).

A sedimentary evolution very similar to that found in the Ketilidian occurs in the Labrador trough (1800–1600 m.y.) on the Canadian shield (GASTIL et al., 1960). This, the nearest of the comparable occurrences, has a sedimentary development in its lower part comparable to that seen in the Vallen Group. Iron-formations, however, seem to be much more common both in the sediments and in the upper volcanic division. Organic structures similar to *Vallenia* have been reported (STINCHCOMB et al., 1965).

There are also similarities between the Huronian (1650–1750 m.y., GOLDICH et al., 1961) in the Lake Superior region and the Ketilidian. Again iron-formations are more widespread, but the sedimentary succession with respect to quartzites and dolomites exhibits a similar development. A rich assemblage of organic material has been reported from the Gunflint chert (BARGHORN and TYLER, 1965; CLOUD, 1965) and anthracite coal also occurs in the Michigamme Formation under circumstances very similar to the Grænsesø Formation (TYLER et al., 1957).

On the Scandinavian shield the development of the Karelian (SIMONEN, 1960) may be compared with the Ketilidian. Relations near the basal unconformity of the Jatulian, with the quartzites, dolomites, shales and greywackes which comprise the Ladoga Formation, and the Onega series with carbonaceous material and dolomites, exhibit strong similarities to the development of the Vallen Group. In the Onega series schungite, a coal shale, occurs (KHARITONOV, 1963). The ages of Karelian structures and metamorphism are between 1700 m.y. and 1900 m.y.

THE DEFORMATIONS

General introduction

Subsequent to the deposition of the sediments and volcanics and the emplacement of intrusions in the higher parts of the succession, the whole complex was subjected to plastic and cataclastic deformations. Two main phases of folding can be distinguished in Grænseland. Related to the movements metamorphism and partial recrystallization occurred. New minerals, especially micas, were developed in accordance with the prevailing stress/strain pattern.

The main structural divisions of the Ketilidian (see p. 16) reacted very differently to the deformations according to their competency, which largely seems to have been dependent on the physical properties of the original material, and the tectonic development during previous deformations. The vertical alternation between incompetent and competent material, the position in relation to the major sedimentary basins, and the horizontal facies changes have played an important role in the distribution of the structures.

The establishment of the main phases of folding

The key area for the establishment of the successive phases of folding is the area south of Vallen at the stratigraphic level of the Dolomite Shale Member.

The lower part of the dolomite shales is folded in asymmetric tight folds of similar type (fig. 54). The bedding planes are visible as furrows weathered out because of higher content of carbonates. The folds also occur in close connection with thrusts or reverse faults (fig. 54) and give a clear indication of the relative movement. Thus, folding and thrusting were related to the same movements.

Otherwise the shape of the folds and the existence of a strong cleavage parallel to or very nearly parallel to the axial planes is typical (fig. 55). The folds are generally tight but never quite isoclinal; they are overturned asymmetric folds and their axial planes dip eastwards sub-parallel to the regional dip of the bedding.

A.

B.

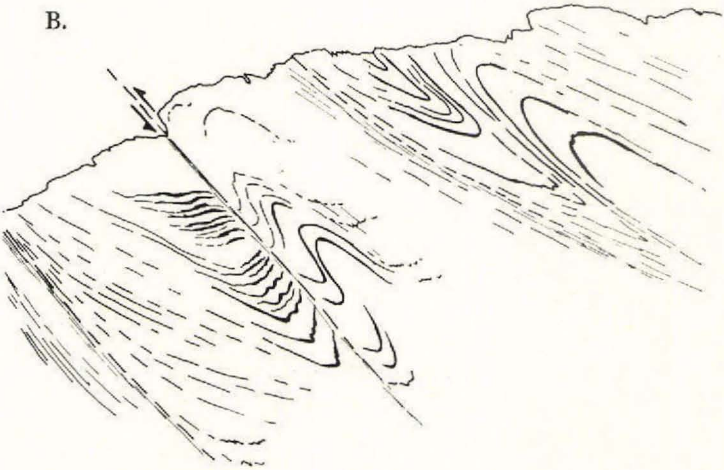


Fig. 54. Asymmetric to isoclinal similar folds (F_1) in the lower part of the Dolomite Shale Member of the Zigzagland Formation. The bedding planes are seen as furrows. A small thrust has developed. The scale is indicated by the hammer in the lowermost synclinal closure below the thrust plane. The drawing (from another photograph) shows the sense of movement and the style of the folding. Locality about 2 km south of Vallen.

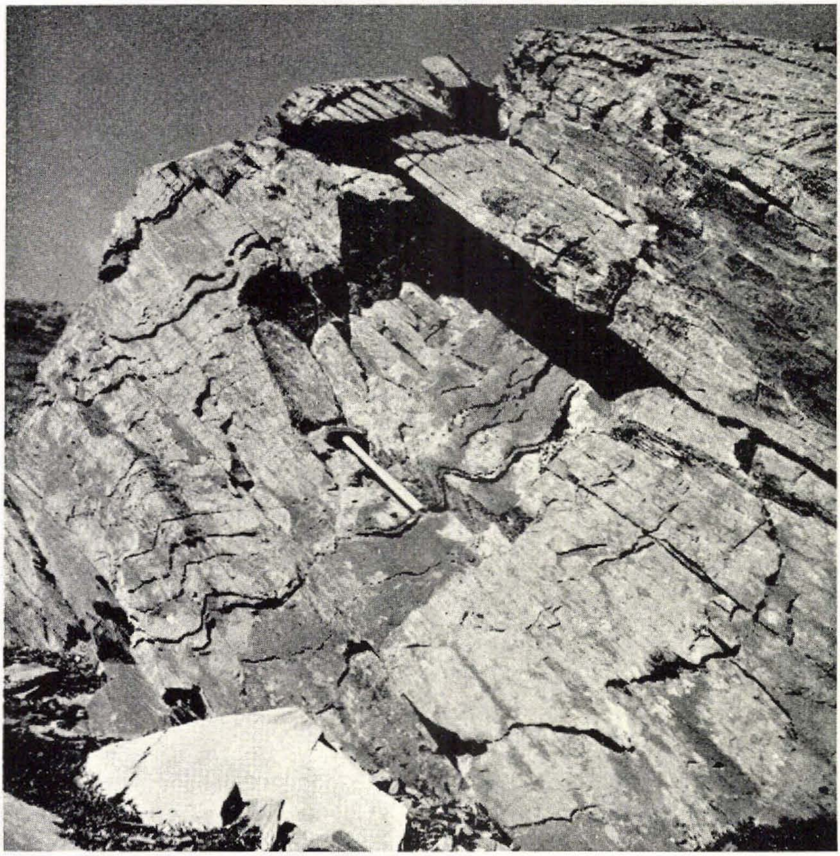


Fig. 55. Closure of a large similar F_1 fold. The bedding planes are apparent as furrows which represent weathered-out carbonate-rich horizons. They have an M-shaped structure characteristic of the closure zone and are cut nearly at right angles by the axial plane cleavage. Locality in the Dolomite Shale Member of the Zigzagland Formation about 2 km south of Vallen.

These folds are the oldest fold structures (F_1) found in the area. Their axial plane cleavage is called S_1, and their fold axes L_1 plunge ESE at angles of 10° to 30°.

The S_1 planes completely dominate the dolomite shales and are, with the bedding, the planes on which the F_2 folds developed (fig. 56).

F_2 folds are generally asymmetric to overturned with an axial plane dipping towards the north-west. L_2 axes plunge ENE at angles af 20° to 40° depending on the position of S_1 or the bedding. As both these planar structures always dip eastwards F_2 folds always have a Z shape when viewed in profile down the plunge. S_2 is generally developed in areas where the folds are formed, but is rarely evident elsewhere; occasionally this plane is seen as a minute fissuring giving the same displacement relations as the F_2 folds.

From the key area, F_2 folds on all scales can be traced throughout the area. They are characterized by a striking parallelism of S_2 as well as the Z shape and the vergence, and are therefore easily recognizable. The dimensions of the F_1 and F_2 folds in the key area such that F_2 is always on a smaller scale than F_1. There is therefore no considerable deflection of

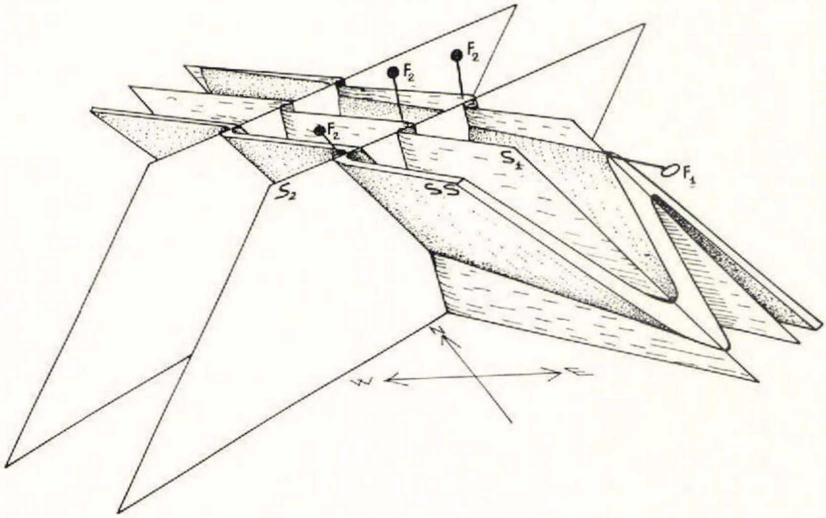


Fig. 56. Relations between the bedding plane (SS), F_1 folds and their axial plane cleavage (S_1), and F_2 folds and the corresponding cleavage (S_2) as can be observed in the lower part of the Dolomite Shale Member south of Vallen.

L_1 by F_2 folding and the lineations L_1 and L_2 group into two clusters when plotted on stereograms (typically shown in No. 12, plate 13). There is very little variation in the amount of plunge of L_2 but some variation in trend. The variation in trend is apparent on some small scale F_2 folds which have a form, close to that of "kink folds" (RAMSAY, 1967).

Locally S_2 planes are seen to be deformed in small open folds which are related to a third phase of folding, F_3. The key area for relationships between the three phases of folding is the peninsula in northern Lappesø. Their relationships are demonstrated on diagram 21 of plate 13, where a cluster of steep L_3 plots is indicated. L_3 plunges NW or NNW, the amount of plunge depending on the position of S_2 or other planes which are folded by F_3. L_3 only shows a consistent direction where it is superposed on S_2 and only in this situation F_3 can be distinguished with certainty; the plunge of L_3 in this case varies between 45° and 70°. S_3 has a steep northeastern dip or may be vertical.

It is only in rare cases that the relation F_1, F_2 and F_3 can be established at the same locality and the distribution of F_3 seems to show that F_3 folding was mainly concentrated in earlier thrust zones or near faults.

The distribution and description of F_1 structures

Folds with similar geometric relations to those of the F_1 folds of the key area have only been found locally in the sediments and are generally confined to incompetent layers, just below or above competent bands. The folds in the key area mostly occur just above the banded quartzites of the Zigzagland Formation.

From the area south of Vallen folds of F_1 type and age can be traced southwards at the same stratigraphic level. In the varved shales F_1 structures have occasionally been observed as minor drag folds (their orientation is seen in diagram 11, plate 13). Strong lineations such as rodding, parallel to L_1, have also been observed in the talc quartzite.

In the area north of Lappesø, F_1 folds also occur at higher stratigraphic levels in the succession in incompetent bands (diagrams 18, 19 and 20, plate 13). The dolomite bands in the higher part of the lower greywackes form mappable structures coincident with F_1 and minor structures related to these correspond to L_1. North-east of Lappesø a few smaller isoclinal folds (F_1?) were observed, refolded around larger F_2 folds.

South of Lappesø, a large isoclinal structure with an axial plane close to S_1 can be mapped by means of dolomite and shale horizons in the graded greywackes (plate 11). Small scale F_1 folds refolded by F_2 have been observed in the vicinity. The true nature of the large structure is, however, somewhat uncertain as the axial relations are not known. It may be a major F_1 fold, in which case it is an isolated phenomenon, or it could be an exceptionally strongly overturned and compressed major F_2 fold. The latter case would be consistent with an increasing intensity of F_2 deformation from north to south (see p. 154).

In the area between Vallen and Grænsesø no structures related to F_1 have been found below the Grænsesø Formation. In the northern part of Grænsesø fold structures of the first phase of deformation have not been detected with certainty. However, the sediments in this area exhibit a strong cleavage sub-parallel to the bedding, corresponding to the regional S_1, and which is folded by F_2.

In the Grænsesø Formation, F_1 folds occur locally, particularly in the parautochthonous area in the southern part of Grænsesø (diagram 6, plate 13) and in the area near Vallen (diagram 7, plate 13). Folds of this phase, or traces of movements related to F_1, appear to be more common in the lower part of the Grænsesø Formation where a strong S_1 cleavage is prominent. However, this part of the formation is often poorly exposed (see p. 93).

In the sediments of the Rendesten Formation, a strong cleavage is widely distributed, folded by F_2 folds, and in some cases it can be seen intersecting the bedding. No folds related to this S_1 cleavage have been observed.

The distribution and description of F_2 structures

Folds related to the second deformation are developed throughout the area and are generally easily distinguished, although they are very often only seen to deform the bedding (SS). The criteria for the identification of F_2 folds, which are empirically valid, are their ENE-trending axes, NNW-dipping axial planes and their Z-shaped profile when viewed down the plunge. There is a general southerly vergence. The dimension of the folds vary from a few centimetres to major mappable structures. Generally an S_2 cleavage is developed.

In the Zigzagland Formation and the Blåis Formation north and north-east of Grænsesø, broad open anticlines with a wavelength of 100 m, and more compressed and smaller synclines occur. The area which divides the outlier of pillow lavas from the main pillow lava area north of the large WNW-ESE fault is a broad open F_2 anticline.

In the Grænsesø Formation in this northern region F_2 folds are very common but of much smaller scale than in the underlying sediments, thus underlining the structural disharmony between the two main structural divisions of the sediments and the pillow lavas.

Larger structures, however, are apparent in the form of culminations, comprising sediments of the Grænsesø Formation with complex internal folds (fig. 57). Above these culminations the lavas and accompanying intrusions form fault bounded anticlines. Such structures are exposed in the valleys where the Grænsesø Formation, as seen on the geological map (plate 11), crops out over fairly large areas. A schematic illustration of these structures is given in fig. 57. It is possible that the relations in the SSE-trending valley 2 km south of Lappesø, where the Grænsesø Formation is exposed, represent a similar feature. This would then be a continuation of the large isoclinal fold structure south of Lappesø, already discussed on p. 151.

In the area between Vallen and Grænsesø (diagrams 8, 9 and 10,

Fig. 57. Culminations in the Grænsesø Formation. The culminating structure seen in the photograph (on the west coast of middle Grænsesø) may be compared to the simplified sketches below. These sketches represent two types of culminations of the Grænsesø Formation in the Grænsesø area. On the photograph the strongly folded middle part of the Grænsesø Formation with dolomite layers and lenses occurs below a large sill. Pillow lavas cap the summits of the hills.

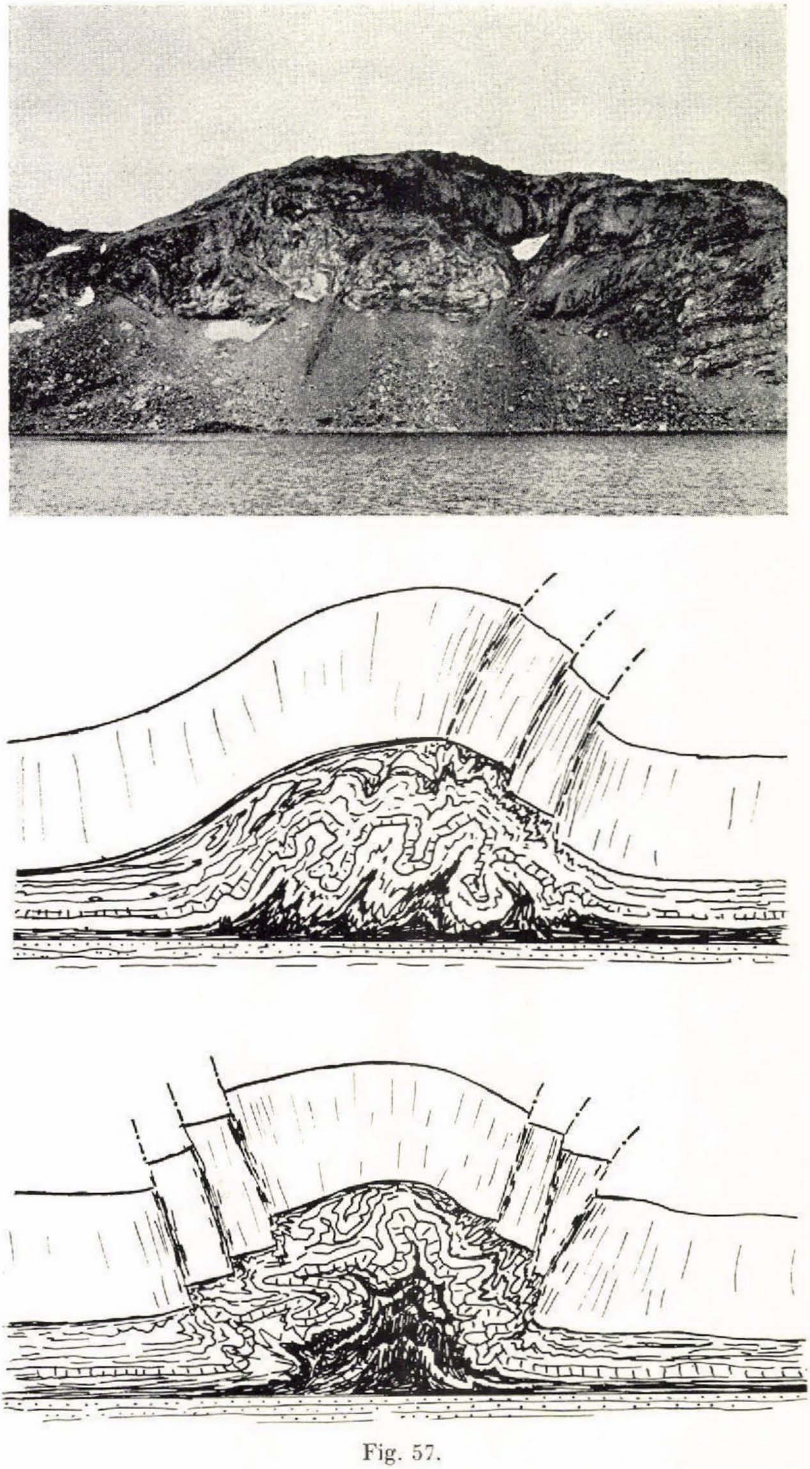


Fig. 57.

plate 13) only comparatively open folds of more or less concentric type occur. Here there appear to be special relationships between numerous small faults in the basement and folds in the immediately overlying sediments; the folds are developed over displaced blocks of basement. The fault planes continue upwards as the axial planes of the folds, at first with a vertical attitude but higher in the succession bending southwards so as to dip north at an angle as low 45°.

The area between Vallen and Grænsesø is the least deformed in the sedimentary main structural division and some small areas are almost undeformed; F_1 is lacking and F_2 is of a very simple type. A weak S_1 cleavage is present (fig. 29). This is thought to be due to the position of the area relative to the old fault-controlled ridge feature which developed during the sedimentation. To judge from the general southerly vergence of F_2 folds the area might be regarded as sheltered behind the ridge.

The Zigzagland Formation in the area between Vallen and Lappesø is only affected by small-scale F_2 folding in the incompetent layers. In the Varved Shale Member numerous small chevron folds occur with a wavelength of about 10 cm and in the Dolomite Shale Member F_2 folds with a wavelength of 5 to 25 cm are developed on SS and S_1 similar to those described from the key area. The quartzites seem to have reacted to F_2 only to the extent of minor faulting but with displacement relations characteristic of F_2.

The Blåis Formation in the area between Vallen and Lappesø exhibits a fold pattern disharmonic to that of the Zigzagland Formation.

The fold pattern has been mapped on aerial photographs on the scale 1:10000, and the results are presented in fig. 58. There is a clear disharmony between the incompetent pelite-semipelite succession and the competent graded greywackes. The latter is in the northern part of the area largely deformed into open folds of a concentric type in contrast to the complicated pattern of similar type folds in the underlying sediments. These folds are especially intensely developed in the vicinity of faults cutting up through the succession from the basement. In addition, there appears to be an increase in the intensity and size of the folds upwards to the base of the graded greywackes.

In the area along the margin of the Inland Ice, large open asymmetric F_2 folds with NW-dipping axial planes can be mapped. The dimensions and intensity of the folding increase towards the south. Between the lakes north of Lappesø, a major tight asymmetric overturned fold occurs. Below this structure several zones of strong shearing with disharmonic folding above and below have been mapped as thrusts.

The large isoclinal fold south of Lappesø, which was described earlier (p. 151), could, as stated, be regarded as a major F_2 fold. While this

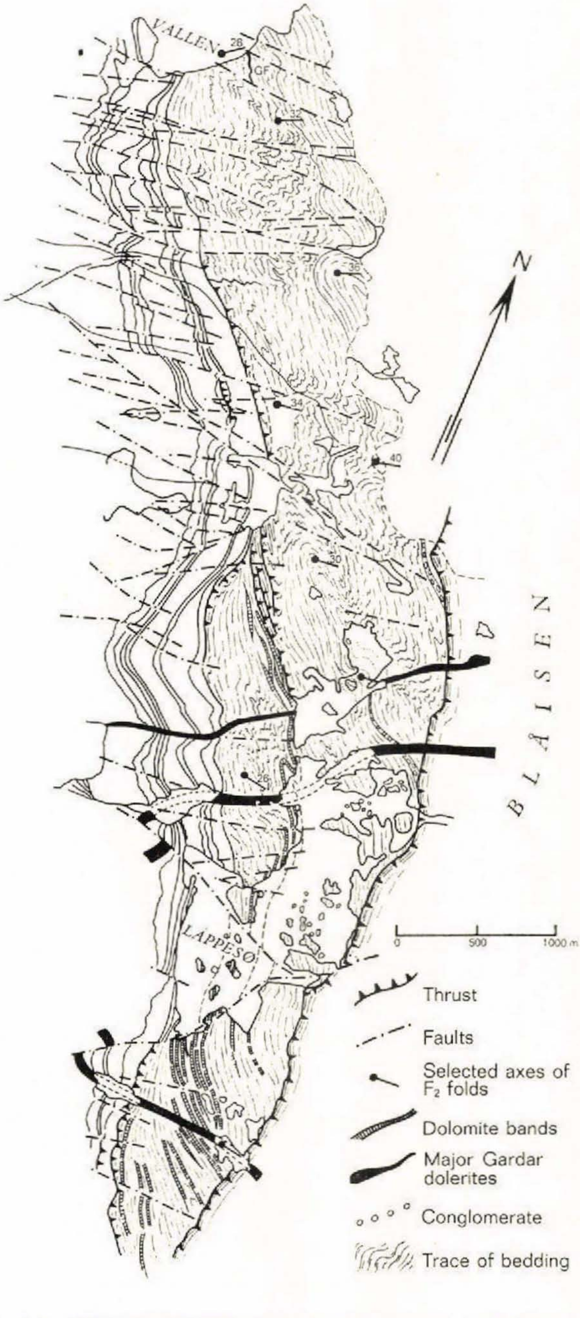


Fig. 58. Trend of bedding in the Blåis Formation south of Vallen illustrating the fold pattern. Mapped on aerial photographs on a scale of 1:10000. The boundaries of members of the Zigzagland Formation are indicated.

would be consistent with the increasing intensity of F_2 deformation towards the south (as shown in fig. 58), it would imply that the axial plane (S_2) had changed its position to a more SE-strike and easterly dip. Such a tendency is in fact already apparent in the diagrams 1, 19 and 20 prepared for the areas north of Lappesø (plate 13). In addition, relations characteristic of F_2 culminating structures in the Grænsesø Formation and in the lavas and intrusives (mentioned on p. 152) seem to be present.

Small-scale structures in the area south of Lappesø (F_1?) have a varied southerly plunge, which may be caused by refolding. The dolomites of the area also exhibit a concentration of folds of uncertain age with axes plunging close to the usual direction of L_2, and other folds with a SSE-dipping axial plane. The latter might belong to a younger deformation, characteristic of the region and not consistent with F_3 as found farther north.

F_2 folds are very common at higher stratigraphic levels especially in the Rendesten Formation. The areas from which the diagrams 26 and 27 (plate 13) have been prepared show a development of folds whose axes are consistent with L_2. Folds in the bedded greywackes are mainly typical concentric types well exposed just west of Sortisen and along the western shore of Rendestenen. In incompetent beds, exhibiting a supposed S_1 cleavage, complicated folding of F_2 age is apparent and in some areas S_2/S_1 intersections have the form of a "pencil shale" lineation. In other areas, and especially on the "peninsula" south of Sortisen, varved shales were apparently deformed only by F_2 structures (fig. 46).

On the southern "peninsula" and partly also on the northern "peninsula" the geological map exhibits a pattern which could be intrepreted as due to folding. Long streaks of rusty shales exhibiting F_2 structures are seen to bend round southwards in a large closure. The shales are included in coarse-grained basic intrusives which show little or no deformation.

Similar relationships are found in the north-eastern part of Fønland (in the area of diagram 3, plate 13). The strongly folded banded semipelites (fig. 42) are homoaxial. As seen from the diagram the position of the axes corresponds more or less to L_2 although the plunge has a NNE-trend.

In the area of diagram 4 (plate 13) a mappable major structure is found between two thrust zones. As apparent from the diagram the minor structures are strongly disordered. Intrusions similar to those in the subareas of diagrams 3 and 26 also occur here, but seem to be of a cross-cutting nature.

The relations of the folded sediments around the large intrusions in the areas mentioned above suggest that the folding is largely F_2. However, the intrusive rocks are astonishingly little influenced by the movements. During the field work this phenomena gave the impression that the intrusions might be synkinematic to F_2. As this hypothesis cannot be convincingly demonstrated it is not discussed further although clearly it may have considerable chronological implications.

The deformation of the pillow lavas and the intrusives

In the two preceding sections the structures described have been restricted almost entirely to the sediments. The lavas and the intrusive bodies are relatively competent and this is illustrated by the type of structures they exhibit.

Plastic deformation of the thick pillow lavas and the intrusive bodies is very rare. The large-scale bending, previously mentioned, which can be detected from the structures of the underlying sediments, cannot be mapped or observed in the lava succession alone. The rare traces of primary planar orientation found show that the whole succession in Fønland has a shallow eastward dip, around 10–30°. In the Foselv area steeper inclinations, around 40–60°, are found.

Traces of deformation are confined to shear zones with small displacements. These zones of crushing may have a pronounced schistosity oblique to the trend of the zone. The general tendency of the schistosity with respect to the extension of the zones has been mapped in the Fønland area, and is shown in plate 13.

The shear zones show a varied and curved trend either NNW-SSE or NE-SW. The NE-SW trending zones are evidently related to the F_2 swellings of the Grænsesø Formation and are especially frequent around these phenomena in the western part of Fønland where they are associated with a second type of shearing; this has the form of broad zones of minute fissures with little displacement, denoting a feebly plastic deformation of the pillow structures. These zones could not readily be mapped because of their diffuse character.

In the areas close to the planes of structural discordance in the Grænsesø Formation (especially in the Foselv region) and below the eastern thrust zones, a strong schistosity comparable to S_1 occurs.

Tensional features are common in the pillow lavas and the intrusive bodies. They occur on a very minor scale and on a major scale, often of metres. The open fissures developed may be filled by quartz. No regional pattern has been distinguished although there is a tendency for the larger quartz veins to be vertical with an E-W trend.

The reaction of the basement

The basement gneisses do not seem to have been folded together with the supracrustals. One possible exception is found in the area between Vallen and Grænsesø where a broad open anticlinal structure is seen to deform the sediments of the Vallen Group. The structure seems to be superimposed on a pre-existing ridge-like culmination formed during the sedimentation. This structure located in the south-west corner of Grænsesø south of the Bæversø fault is apparent on the structural contour map (fig. 6) and the trend of its axis seems to coincide with the axes of F_2 structures.

In the uppermost altered zone of the basement, just below the oldest sediments, small-scale fold structures and schistosity, related to F_2 and perhaps also F_1, may sometimes be seen.

In all other areas the basement rocks react in a brittle manner and are deformed only by rupture.

In the northern part of the area north of Grænsesø, small shear zones are found in the gneisses below the quartzites. These small, local "thrusts" are difficult to relate with any of the phases of folding and might have been moved during both the main phases.

In the area between Vallen and Grænsesø numerous small faults displace the basement-sediment border by amounts of 1 to 2 m. These small faults, which deeper in the gneisses cannot be distinguished from normal jointing, have as previously mentioned a relation to F_2 folds developed in the sediments above (see p. 154).

Closely spaced faults in approximately the same direction (NE) are found south of Vallen (see fig. 58 and plate 11, 12 and 13). These also seem to have some relation to the F_2 folds in the sediments which are particularly common in the vicinity of the faults (fig. 58).

In the southern part of the region shear zones and zones of strong schistosity are found along the border of the Ketilidian supracrustals. The shearing intersects the lithological banding of the gneisses and the metadykes found in that region (see p. 175). The schistosity is locally folded. Although displacement along the shear zones occurs, this is not very prominent.

The shearing can only be related to the deformation of the Ketilidian by its spatial distribution. The fact that the shearing of the dykes mainly occurs on north-east- and eastwards-facing contacts also suggests that the same forces are responsible for both shearing and Ketilidian deformation. The shearing may be related mainly to the first deformation as the shear zones are sub-parallel to the border of the supracrustals and to S_1. The shearing may thus be related to the main F_1 thrusting which is

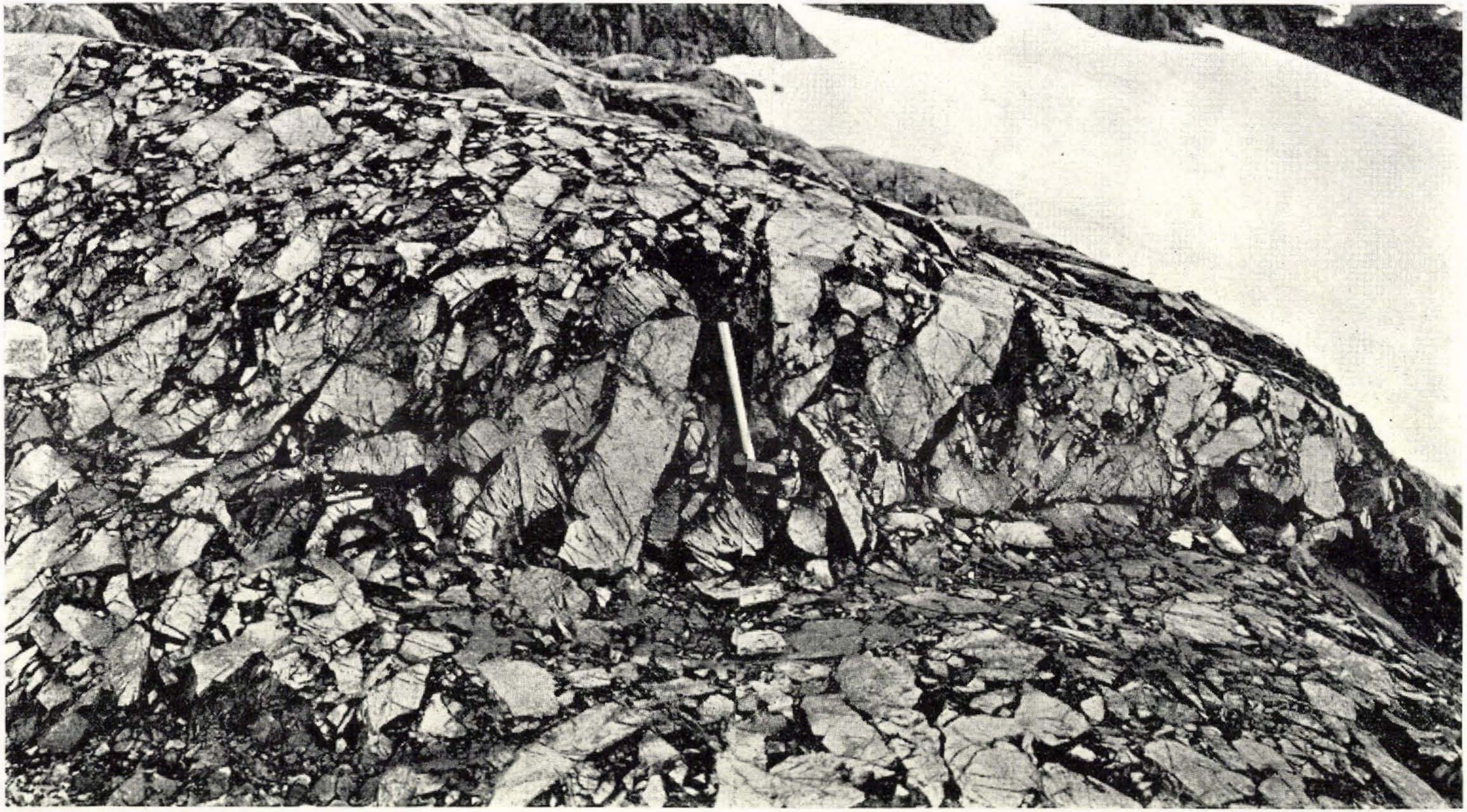


Fig. 59. Large breccia in basement gneisses west of Zigzagland (see plate 1). The fragments are partly oriented in their longest dimensions and are transected by secondary tensional fissures. The border of the breccia (upper left corner) is sharp (see also fig. 61). Although the fragments form a cohesive mass as seen from the ice-polished surface, the spaces between the fragments seem to be empty.

Fig. 60. Minor breccia in the basement gneisses west of Vallen. The rock is crushed with tensional openings and the fragments are only slightly rotated. No matrix is present.

especially prominent in this area (see p. 166). However, it is also apparent that shearing took place during the second deformation.

Breccias are prominent features in the gneisses west of Zigzagland. They occur either as large elongate areas of brecciated and fragmented gneiss rocks (fig. 59) or as smaller local features (fig. 60). The fragments in the breccias are angular and the matrix where present is either of fine crushed gneiss or in some cases composed of carbonates. Usually, as evident in the figures, matrix is lacking. The breccias have sharp borders (fig. 61).

The breccias are doubtless of tectonic origin and have no relation to intrusive activity. Chronologically they are older than the small metadykes (p. 177), which are folded by F_2 folds and cut F_1 folds, as the metadykes intrude such a breccia zone. The breccias are probably younger than carbonatization and sedimentation, as they transect dolomite veins.

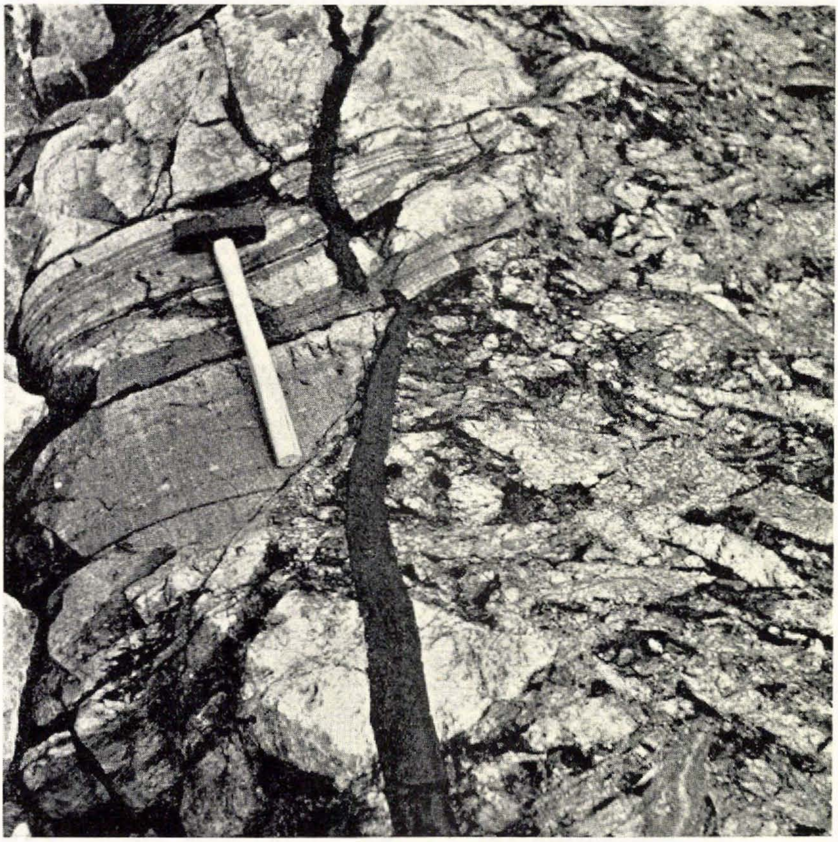


Fig. 61. Border between a breccia and unbrecciated rock in banded gneisses west of Zigzagland. The border is very sharp and the fragments here more disintegrated and fissured than in the central part of the breccia (fig. 59). The banded structures in the gneisses can be traced in the fragments suggesting that no transportation or significant displacement of the fragments has taken place. A small vesicular lamprophyre (Gardar) has intruded the breccia 'en echelon' at the border.

The most likely date for their formation would be that they were formed during the first phase of deformation.

Numerous irregular tensional fissures, often rust-coated, appear to be related to the breccias (fig. 5). Similar structures are also found over large areas of the basement gneisses and also may be the reaction of the basement to the Ketilidian deformation.

The pre-existing joint system in the basement has to a large extent been reactivated and new joints have possibly been formed. The thus strongly jointed terrain has a curious large-scale breccia structure (plate 1) which is thought to have mainly originated during Ketilidian deformation.

The development of thrusts as elucidated from a key area analysis

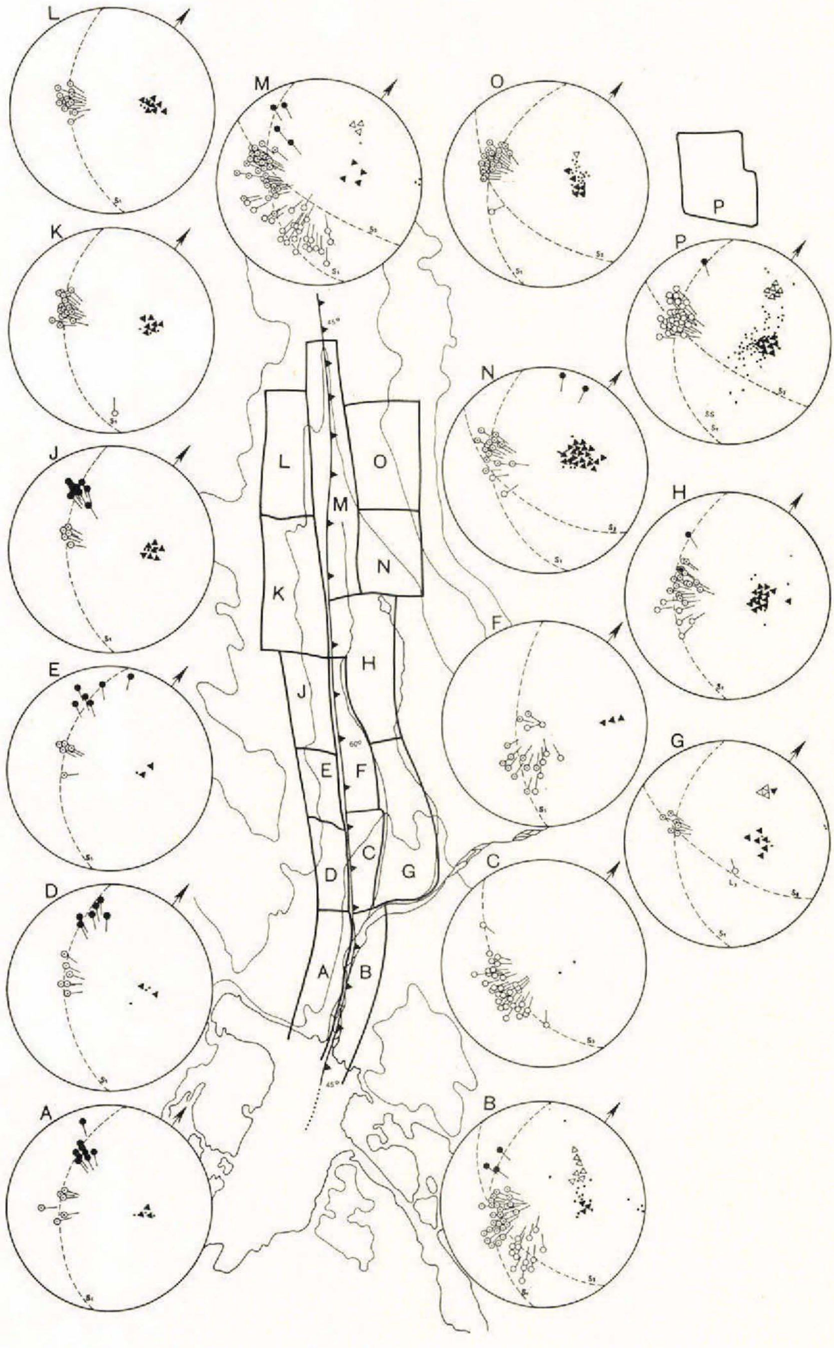
The main structural divisions (see p. 16) are divided by planes of strong structural disharmony, *i.e.* planes below and above which the size and style of folding are entirely different and along which slip apparently has occurred. These and other structural planes have been mapped as thrust planes on the basis of such disharmonious relationships although in some cases these cannot be shown on the scale of the map.

At the base of the thrust units and in the immediate surroundings of the planes of structural disharmony strong shearing is characteristic and mylonitic rocks may occur. In some cases there is an intense folding which to some extent can be related to either F_1 or F_2. Generally there is a concentration of lineations on the stereograms near the regional L_2, but a considerable scatter is also apparent. To examine this scatter and the complex relationships in the thrust zones the border between the Dolomite Shale Member of the Zigzagland Formation and the black pelites of the Blåis Formation in the area south of Vallen was selected.

In this area the relations between F_1 and F_2 are well known and also thrusts related to F_1 folds at the base of the Dolomite Shale Member occur (see p. 147). Another thrust zone at the top of the Dolomite Shale Member can be traced from an area of little or no displacement at the south coast of Vallen into an area of strong dislocation and lateral movement farther south. A small metadyke has been displaced 100 m in a dextral sense along the thrust zone (see p. 178). About 1 km south of Vallen a strong variation in the direction and plunge of the minor folds was found in the thrust zone (fig. 62 and plate 13). The general eastern dip of the zone is from approximately 20° at Vallen to 45° and 60° farther south. The thrust apparently moved as a result of the forces producing the regional F_2 folds and in accordance with the vergence of these folds i.e. towards SSE.

The selected area around the above described thrust zone was divided into sub-areas in three zones. The dolomite shales beneath the thrust contain the sub-areas A, D, E, J, K, and L. The sub-areas B, C, F, and parts of H and M are in the thrust zone itself. The strongly folded, but unfortunately badly exposed black pelites above the thrust zone are divided into the sub-areas G, N, and O, and as a control a further sub-area P was selected 500 m north-north-east of the sub-area O.

Fig. 62. Variations in linear structures around the thrust zone between the Zigzagland Formation and the Blåis Formation. The sub-areas north-west of the thrust are in the Dolomite Shale Member and the sub-areas south-east of the plane are in black pelites. For explanation see text. The location of the map area is shown in plate 13. The stereograms are Wulff-net angle-true upper hemisphere projections.



Fold axis of unknown relations
Axis of F_1 minor fold
Axis of F_2 minor fold
Axis constructed from bedding planes in a single fold
Pole to bedding plane
Pole to S_1 cleavage plane
Pole to S_2 cleavage plane
Approximate position of thrust plane with dip indicated

Fig. 62.

In the sub-areas as many linear features as possible – mainly fold axes – were measured and their interrelationships were noted. The measurements have been plotted in the stereograms of fig. 62.

In the zone below the thrust zone in the sub-areas A, D, E, and J, both L_1 and L_2 could be measured and distinguished. In the sub-areas K and L no lineations corresponding to the position of L_1 were observed and all the measurements group around the position of L_2. The lineations were here observed and measured on both SS and on cleavage planes sub-

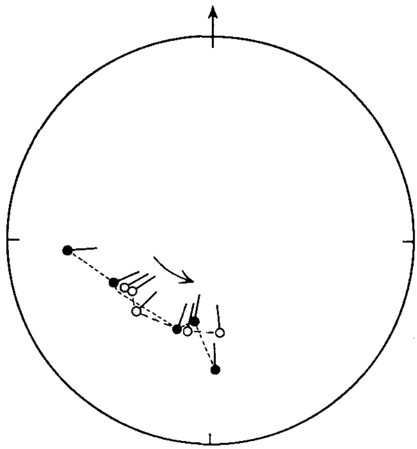


Fig. 63. Variation in small-scale F_2 fold axes related to two bedding planes. The open and black fold axis symbols each represent an individual bedding plane. The arrow indicates the sense of bend in the axes. Wulff-net angle-true upper hemisphere projections.

parallel to the bedding corresponding to S_1. It seems therefore likely that F_1 folds did not develop in the sub-areas K and L although S_1 was produced.

In the zone above the thrust zone represented by the diagrams O, N, G, and P large clusters of lineations group around the position of L_2. These lineations were observed on both SS and S_1. Two lineations on diagram N and one on P correspond to L_1. Apart from the scarcity of L_1 there do not seem to be any important differences between these diagrams and the diagrams of the zone below the thrust plane (A, D, E, J, K, L).

The diagrams representing the sub-areas B, C, F, and parts of H and M, which cover the thrust zone itself, show a considerable scatter of the lineations. They vary from the approximate position of L_2 southwards on the stereograms. The variation in plunge increases with the divergence from the L_2 position.

The diagram of fig. 63 shows two cases of variation of folds, related to the same bedding plane. Although vaguely twisted the plane did not seem to be deformed by any major fold structure. The variation in trend of the fold axes corresponds to the pattern obtained from the sub-areas in the thrust zone.

The explanation of the deflections observed in the field and obtained from the diagrams could be that the L_2 lineations were refolded. This, however, does not seem to be the case as no F_3 folds corresponding to the great circle of the scatter exist. A great circle scatter could be considered in the diagrams B, C, and M, whereas the scatter on diagram F confirms rather a small circle.

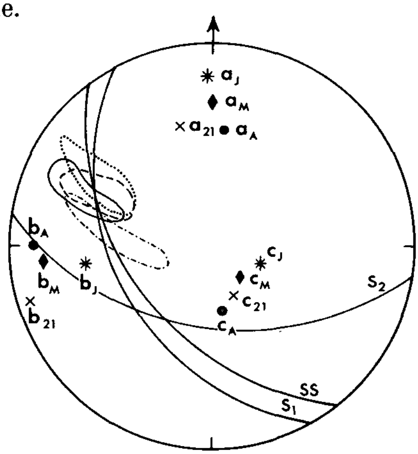


Fig. 64. Orientation of the tectonic axes based on F_1 variations (as indicated by elongated dotted areas). SS, S_1 and S_2 planes are drawn as averages for the thrust zone shown in fig. 62. The poles of the tectonic axes for the sub-areas A, J, and M (fig. 62) and 21 (plate 13) are indicated with appropriate lettering. Wulff-net angle-true upper hemisphere projections.

It could also be considered that the L_2 fold axes were scattered because these lineations were not folded but deflected. This would be possible if the planes which contain the fold axes (*i.e.* SS and S_1) were oblique to the tectonic axes of the F_2 folding.

The tectonic axes in the sence of RAMSAY (1967) for F_2 cannot be reconstructed with any accuracy from the material available, mainly because L_1 only shows a small degree of variation. If F_2 is of similar style, as it appears to be, the deformed F_1 lineations should vary along a great circle and the intersection of the great circle and S_2 should then correspond to the tectonic a-axis (RAMSAY, 1960; WEISS, 1959). The tectonic b-axis is found 90° from the intersection along the S_2 great circle.

The F_2 tectonic axes have been constructed from the diagrams A, J, M, and from diagram 21, plate 13 and are shown in fig. 64. It is seen by comparing the diagrams that the approximate tectonic b-axis is inclined at the low angle to the S_1 and SS planes, the planes which possibly controlled the thrust plane. Under these circumstances it seems most likely that under continued movement a deflection towards the axis of tectonic transport (the a-axis) would take place according to the pattern shown by the diagrams representing the thrust zone (B, C, F, H and M).

The strongly folded slates exhibit in several localities abnormal wrinkles and kinks of Z-type characteristic of F_2. These are rotated in a spiral manner around axes parallel to the regional L_2. If such rotations have led to a twisting of perhaps more than 360°, it would mean that the folds became detached from the thrust plane. The scatter obtained by the rotation should produce a small circle pattern. However, variations in steepness of the spiral would lead to further deviations from a small circle pattern, and thus obscure this pattern.

The existence of spiral folds and twisted S_2 planes offers an explanation of the steep plunges and the fan shaped scatter in the diagrams B, C F, and M (fig. 62). It may also explain the deflection of more than 90° from L_2 which exceeds the angle between L_2 and the tectonic a-axis (diagram M, fig. 62). It is thus possible that the chaotic L_2 lineations producing the scatter in the diagram are a result of both deflection and twisting (rotation) of folds formed in the initial stages of the development of the thrust.

The thrusting

A major thrust is found below the Grænsesø Formation at the base of the pillow lava main structural division and at the base of the eastern thrust complex. The eastern thrust complex may comprise a number of thrust slices controlled by major intrusions.

The displacement of thrusts can only be stated for the one case mentioned in the preceding section. The shift of 100 m dextrally of the small metadyke (fig. 68) is the order of displacement. To judge from the scale of the structures in the main sedimentary structural division, which have been overridden by the higher thrust units, the total thrusting may amount to several hundred metres.

Thrusting from NNW has been shown to have taken place during and in a continuation of F_2 movements. It is, however, also believed that thrusting from NE occurred penecontemporaneously with F_1 deformation, as mentioned on p. 147 and seen from fig. 54.

The only locality where F_1 folds have been found without superimposed F_2 structures of significance, is at the base of the Dolomite Shale Member of the Zigzagland Formation. Here strongly chloritized and tectonized zones (fig. 27) occur, related to the folding. These zones are slip zones or thrusts. The general vergence of F_1 structures and the orientation of S_1 shows a parallelism with the main thrust zones trending from north to south through the area. This parallelism suggests that the thrusts are low angle structures which developed penecontemporaneously with the F_1 folding.

F_1 folds and thrusting possibly occurred in association in the talc quartzite in the Lower Zigzagland Formation. The metamorphism leading to the formation of talc is very local. The siliceous dolomites above and below are possibly of similar chemical composition but are not affected by movements or the metamorphism leading to the formation of talc.

In the large thrust zones below the higher main structural divisions both F_1 and F_2 folds occur with relations similar to those found in the small thrust zone analysed south of Vallen. The scatter of lineations is seen from the diagrams 2, 5, 6, 24, and 25 in plate 13. It is possible that similar complex relations are found in these thrust zones in addition to double fold patterns formed by the interference of F_1 and F_2 folds.

The tilting of the basement

A structural contour map constructed for the gneiss surface (fig. 6) illustrates the present form of this plane. It also partly reflects the sedimentary basins. These basin structures were imposed on a presumable original sub-horizontal plane. The present attitude and twisted shape must therefore be related to later development.

North of the large fault in the area north of Grænsesø, the basement surface is more steeply inclined and differently oriented to that south of the fault. The tilting of the area north of the fault might exclusively be related to the faulting (Gardar, p. 196), but may also be of older date as the quartzites north of the fault exhibit fold structures, apparently related to the fault.

In the Grænsesø area south of the fault, the gneiss surface is only gently inclined eastwards. South of Vallen the eastward dip increases and may reach inclinations of 50° in the Lappesø area. As a whole, the surface seems to have been subjected to a twisting motion.

This twisting of the basement surface and consequently the general dip of the sedimentary bedding and the tilt is a tectonic feature.

There seems to be a connection between the intensity of both F_1 and F_2 fold phases and the degree of tilting. The increase in the amount of tilt appears to correspond largely with the increase in intensity of folding. Also there seems to be some relation to the "degree of structural discordance" between the sedimentary division and the pillow lava thrust sheet, and also to the occurrence of thrusts of F_1 age.

It is the authors' view that there is a possible causal connection between the tilting of the basement and the nature of the first phase of folding and thrusting. The first folding is largely restricted to specific stratigraphic levels as are the thrusts. The small reverse faults in the dolomite shales (fig. 54) show that the upper parts have moved relatively to the

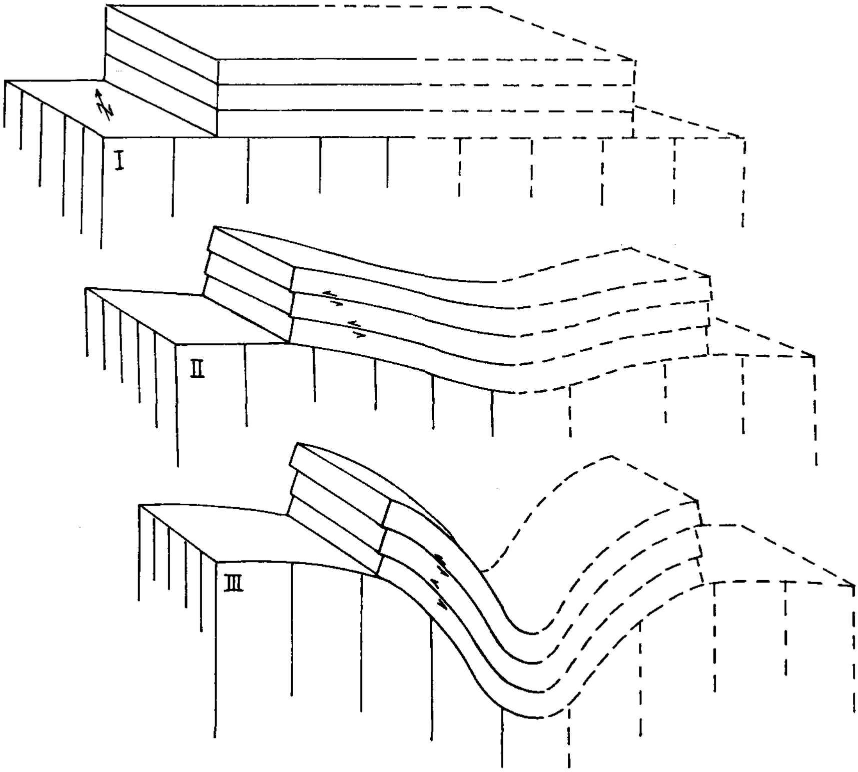


Fig. 65. Model to show thrusting and related F_1-folding as a result of tilting of the basement (vertical-ruled). The mechanism is that of concentric folding. However, the contact between the basement and the sediments lowest block in cover) is kept in its original position i.e. is autochthonous. It is seen that the more the basement is tilted the larger the amount of thrusting which occurs in the cover. The F_1-folding then occurs in the border zone between the blocks. The three blocks drawn in the cover could be thought to represent the three main structural divisions of the Ketilidian. Block II could represent the area around Grænsesø and block III could illustrate the relations in the Lappesø area.

lower part, and it is considered that such a drag is consistent with the general movements of the thrusts.

A simple model for the explanation of the relation between the basement tilting and the thrusts with associated F_1 folding is illustrated in fig. 65. Assuming the pile of deposits is subsiding in one area relative to another (possibly along the main orogenic axis relative to the foreland), the result would not only be a tilt of the basement surface, but also that successively higher units would move relative to the lower units away from the centre of subsidence. This would produce increased movement with increasing tilt which again would be reflected in the size and intensity of the structures. The competent units (*e.g.* the lavas, gabbros, or quartzites) would be thrust over incompetent material (mainly shales). The incompetent units would be able to fold adjacent to the larger competent units. The incompetent material, however, does not necessarily react by folding, and the mechanism could also result in the production of a cleavage only. This is found to be the case in several places in Grænseland (see p. 164 and fig. 29). Apart from the relations found in Grænseland, where increasing size and intensity of the F_1 structures coincide with increasing tilt of the basement surface and also increasing thrusting, it seems to be a common feature (in the Ivigtut region as a whole) that the trend of the axes of the first folds generally conforms to the border between the supracrustals and the underlying gneisses and migmatites. This feature also indicates that the formation of the first folds is related to the disposition of the supracrustal belt.

The large-scale mechanism of the model described above is comparable to that of concentric folding in a syncline (fig. 65). However, all types of complications may be added to this simple scheme. Different thickness of the different units will result in movements of different size along the slip planes, and also the shape of the units will be of great importance. The complex internal structure of the "syncline", which may be sliced up in wedges, also largely modifies the picture

Pre-Gardar faulting

Pre-Gardar faulting is of minor importance in the area. It is possible that the large fault in the northernmost part of the area (see p. 167) has moved prior to the intrusion of the earliest Gardar dykes. Also other faults may have moved in pre-Gardar time, *e.g.* the Bæversø fault (see p. 131); this is, however, difficult to verify as all the larger faults were rejuvenated in Gardar time.

The numerous small faults trending ENE from the basement into the sediments and which seem to be related to the second phase of deformation in the Zigzagland area (see p. 154) also displace the folds in some areas, and are transected by Gardar dykes. The continued movements of the faults may have taken place immediately following folding and need not imply a specific period of faulting. The displacements are all of less than 10 m, with very few exceptions which appear to have been rejuvenated in Gardar time.

Faults trending from 50° to 70° in the southern part of the Fønland area displace NW-trending metadolerites dextrally but are cut by an early Gardar dolerite (BD_0). This faulting is of late Ketilidian age.

General synthesis of the Ketilidian deformations

The Ketilidian sediments, volcanics and intrusives have been deformed by several phases of folding, whose character varies in the different areas depending on the material affected, and their position in relation to the pre-existing sedimentary basin structures.

The first fold phase produced overturned asymmetric to isoclinal folds with ENE-dipping axial planes and ESE-plunging axes. These folds were largely restricted to specific stratigraphic levels of incompetent material. A cleavage parallel or sub-parallel to the bedding was produced. Minor thrusts probably occurred in close connection with the sub-Ketilidian surface. Major thrusts are thought to have developed at the base of the Grænsesø Formation and below the lowest sediments of the Rendesten Formation. The major part of the succession moved as competent material without significant plastic deformation.

The general tilting and twisting of the basement surface is probably related to this fold phase and might, as mentioned on p. 168, be intimately related to the thrusting, as successively higher units moved relatively farther to the south-west with increasing tilt.

The gneiss basement reacted in a brittle manner with the production of breccias. Shearing also occurred in the southern part of the area.

The second fold phase is characterized by generally NW-dipping axial planes striking NE-SW and fold axes which plunge fairly consistently ENE or NE. The type, style and intensity of the folding varies from place to place. In the northern sedimentary basin broad open structures were formed. In the southern basin concentric folding of the competent layers occurred in the area sheltered by the pre-existing ridge between the two basins. Farther out in the basin, towards the south, the size and intensity of folding (mainly of similar style) increases towards higher stratigraphic levels so that large structures in the southern part of the region are pressed towards the tilted basement. Thrusting was developed in connection with disharmonic folding and penecontemporaneous with minor structures which were deflected and rotated during the progressive movements.

The main thrust planes, formed during the first period of deformation, were possibly also moved in the second phase exaggerating the strong structural disharmony. The folding of the Grænsesø Formation led to a migration of material into anticlinal culminations of complex structure, and in the lavas and intrusions simple open folds were formed accompanied by thrusting and faulting. As a whole, the lavas and the intrusions mainly reacted against deformation by the development of shear zones.

Traces of a third deformation are found in the old shear zones and thrust zones where planar elements were suitably exposed to a deformation expressed by minor folds with NNW-trending fold axes.

Faulting occurred in close connection with the second deformation and the major Gardar faults possibly also moved in Ketilidian time. Late Ketilidian dextral NE-faulting also occurred.

REGIONAL METAMORPHISM

The metamorphic zones which can be established in Grænseland fall into a regional pattern of increasing metamorphism from the low greenschist facies in the Midternæs area in the north to amphibolite facies in the Kobberminebugt area in the south (WINDLEY et al., 1966; HENRIKSEN, in press).

In Grænseland metamorphism apparently occurred in relation to both major phases of movements as micas in pelitic rocks have developed both along S_1 and S_2.

Metamorphism related to the first deformation, especially the thrusting, is apparent in the shear zones of the talc quartzite in the Lower Zigzagland Formation and in the chlorite schists associated with the slip zones in the lower part of the Dolomite Shale Member of the Upper Zigzagland Formation (see p. 166).

In most rocks metamorphism cannot be related to any specific phase of movement as the deformations are so feeble that the primary textures are wholly preserved and the growth of the secondary minerals is controlled by these textures. This is for example the case in most of the coarse-grained sediments, the dolomites and particularly the basic igneous rocks and the pyroclastics.

In many rocks it is difficult to distinguish the slight metamorphic effect from diagenetic or hydrothermal alterations. Thus there are large clusters of epidote in the altered gneiss surface rocks and fine sericite-muscovite in the same rock. Small twinned albites commonly occur in the dolomites and strongly resemble diagenetic albite (PETTIJOHN, 1957), and the formation of the reddish brown serpentine as well as amphiboles in some of the gabbroic rocks could be a result of hydrothermal alteration in a late magmatic stage.

A source of error in determining the metamorphic zones may be the influence of late contact metamorphism in the vicinity of large Gardar dykes. Alterations in the sediments near the large Gardar dolerite in the southern part of Vallen seem to have taken the form of albite-epidote-hornfels facies in a zone about 200 m wide, parallel to the dyke, but it seems unlikely that these effects would have any larger regional distribution.

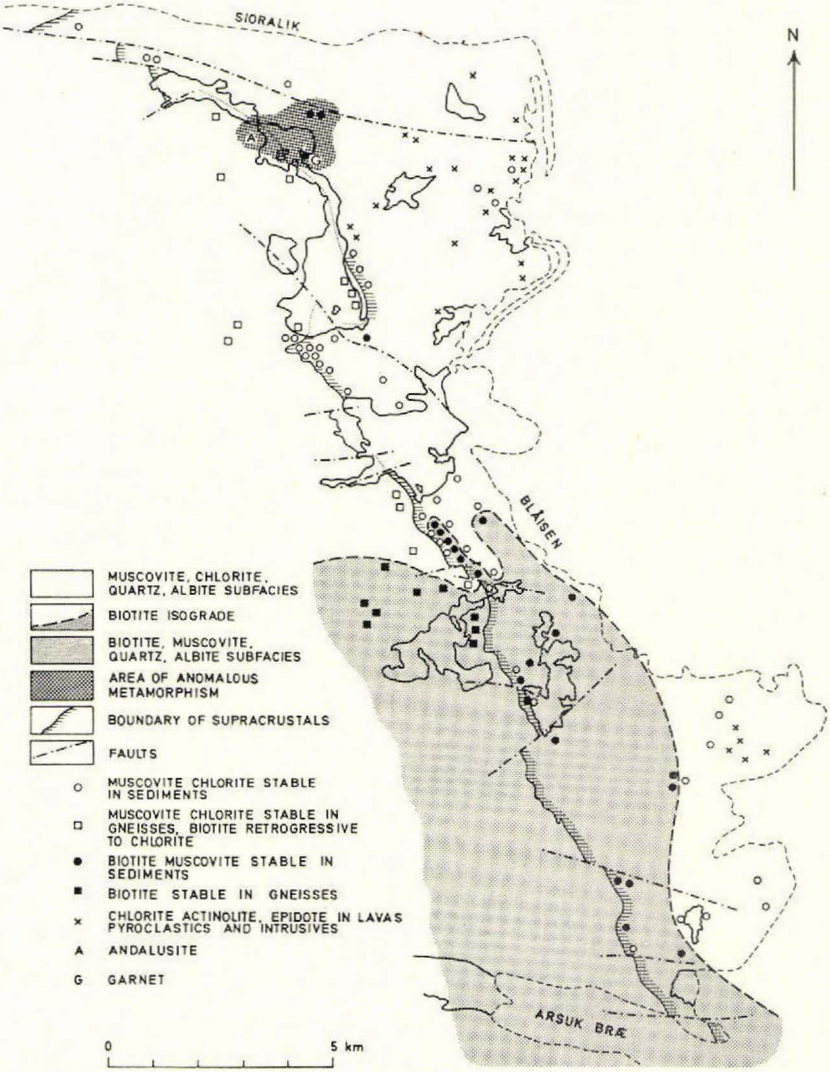


Fig. 66. Map showing the metamorphic facies relations in Grænseland.

The regional metamorphic facies of the Grænseland area can be determined from stable mineral parageneses in rocks of different composition. The abundant occurrence of new recrystallized albite, muscovite, biotite and chlorite restricts the rocks to greenschist facies (TURNER and VERHOOGEN, 1960). In addition to recrystallized albite, primary plagioclase of higher anorthite content also occurs as clastic grains in the coarse-grained sediments and in the igneous rocks. These are clearly unstable, as are hornblende, pyroxene and clastic garnet.

The pressure conditions (Miyashiro, 1961) cannot be clearly determined from the data available. In Grænseland biotite is found retrogressive to chlorite in gneisses and in the same regions albite, muscovite and chlorite occur without spessartite-rich garnet. The Grænseland rocks could thus correspond to the two subfacies of the Barrovian facies series (Winkler, 1965):

1) quartz-albite-muscovite-chlorite subfacies
2) quartz-albite-muscovite-biotite subfacies

However, these two subfacies also exist in the low-pressure facies series – the Abukuma facies series (Miyashiro, 1961). Based on the complete lack of stilpnomelane and on comparisons with the region south of Arsuk Fjord it is more likely that the pressure conditions correspond to the Abukuma facies series or slightly higher pressures (Henriksen, in press).

The distribution of the two subfacies is shown in fig. 66, an approximate biotite isograde indicating their mutual border.

The facies is readily seen in pelitic and semipelitic sediments and greywackes, but is difficult to trace in the basic igneous rocks, where the percentage of aluminium is too low to produce biotite. When both biotite and stilpnomelane are absent, it is impossible to find out which subfacies the metagabbroic rocks belong.

The Ore-Conglomerate Member and the iron-rich sediments around this stratigraphic level contain large amounts of biotite in areas where the surrounding rocks seem to be of the lower subfacies. This seems to be consistent with the relations shown by James (1955), that iron formations are particularly sensitive to low metamorphism.

In the northern part of the area around Grænsesø biotite is locally present in semipelitic rocks. An occurrence of garnet (52973) and andalusite (53083) in the sub-Ketilidian altered gneiss surface, where it has a strongly pelitic nature, is more or less in accordance with the local distribution of biotite. The occurrences of these index minerals may show a local culmination of higher facies in the northern part of the area. The minerals, especially the andalusite, indicate the Abukuma facies series in a subfacies characterized by a quartz-andalusite-plagioclase-chlorite assemblage. This, however, does not quite conform to the temperature conditions as shown by the quartz-albite-muscovite-chlorite subfacies, but indicates higher temperatures. Andalusite – but not biotite – could indicate the presence of albite-epidote-hornfels contact facies, which may be due to the later effects of the three large Gardar dykes trending NE in this area.

The metamorphic facies conditions in the Grænseland area thus seem to be of a low pressure type in the greenschist facies, with the low quartz-albite-muscovite-chlorite subfacies in the northern part of the area and the higher quartz-albite-muscovite-biotite subfacies in the southern part of the area. This also corresponds to the increasing degree of deformation and thrusting towards the south, and the inclination of the basement surface and stronger deformation of the substratum to the Ketilidian rocks. The increasing metamorphism southwards coincides with the general pattern of Ketilidian metamorphism in the Ivigtut region as a whole.

METAMORPHOSED DYKES

Introduction and division

In this section all metamorphosed dykes which predate the Ketilidian phases of deformation and metamorphism and metamorphosed pre-Gardar dykes will be described.

The dykes falling within these limitations can, disregarding their chronological significance and position, be divided into:

1) Swarm of large basic metadykes in the basement south-west of Lappesø.
2) Small basic metadykes in the Zigzagland area.
3) Granophyric dykes and sills.
4) Basic metadykes in the northern part of the area with an ENE-trend.
5) NW-trending metadolerites in the north-eastern part of the area.

In the following sections the field relations and the petrology of the dykes are first described under the above listed divisions, and in the succeeding section the chronology of the dykes is discussed.

1) Swarm of large basic metadykes in the basement south-west of Lappesø

A swarm of large basic metadykes can be followed from the areas around the outer part of Arsuk Fjord (BONDESEN and HENRIKSEN, 1965) to the area south-west of the southern part of Lappesø.[1])

The dykes vary in width from a few metres to one hundred metres and in certain areas, particularly to the west and north-west of Grænseland, exhibit characteristic dyke shapes with en echelon features and apophyses. In other parts of Grænseland they show irregular intrusive shapes similar to characters found in areas farther west (BONDESEN and HENRIKSEN, 1965); the complicated shapes and branching found are clearly shown on the geological map. The dykes are in addition strongly sheared and transected by later Gardar faults, and may show drag phe-

[1]) The dykes in this area were originally mapped in 1957 and 1958 by L. F. BONNARD on an unsatisfactory topographical base (BONNARD, 1963). The author visited the area in 1961 and with BONNARD's field map and new low-altitude aerial photographs on the scale 1:10,000 as a base revised parts of the mapping.

noma. A distortion in the trend from 65° to 100°, and even 130°, is apparent on the maps (plates 11 and 12).

As the dykes approach the border of the Ketilidian supracrustals irregular dyke shapes become pronounced. None of the dykes penetrate the unconformity and none show a sudden stop at the unconformity as if they had been eroded; they all appear to terminate in the gneisses below the unconformity. Some of the dykes show strongly marked irregular features prior to terminating and some attain a position sub-parallel to the tilted border of the Ketilidian. An abrupt termination apparently not

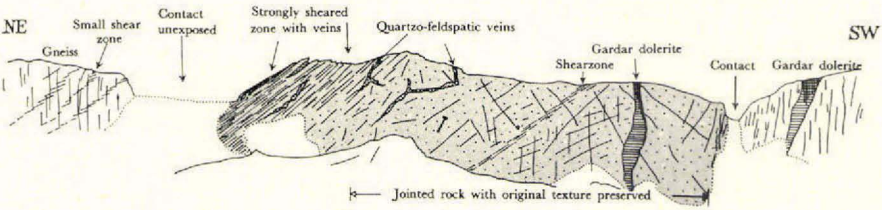


Fig. 67. Field sketch of basic metadyke with shear zones. From the area south-west of Lappesø. The scale is indicated by the hammer.

caused by later faulting or disruption is also characteristic. Many of the dykes in this area are strongly xenolithic.

The dyke swarm possibly comprises several generations, but it proved very difficult to distinguish branching dykes from true intersections.

All the dykes are metamorphosed and are green or black in colour. They are cut by quartz and quartzo-feldspathic veins and are generally in a schistose condition. The trend of the schistosity varies from 150° to 180°. Veins in the dykes as well as the schistosity may be folded, with fold axes plunging steeply NE or E. In flat-lying dykes two trends of axes have been observed related to the same plane of schistosity; one plunges at 20° to 175°, and the second at 45° in a direction of 120°. The schistosity in the dykes is connected with shearing in the gneisses outside the dykes.

Some dykes are schistose on their north-eastern and eastern facing contacts and are homogeneous or less affected by shearing on their south-western contacts (fig. 67) where they exhibit a jointing leaving rhombohedrons, and relic primary textures. This specific jointing is also characteristic of unsheared dykes and similar to the features described from elsewhere in the Ivigtut region.

In the area west of that visited by the author, L. F. BONNARD has observed small intrusive bodies of microgranite and microquartz-diorite displacing the dykes. These bodies are undeformed (BONNARD, 1963). No thin sections from the dykes of this region have been examined by the author.

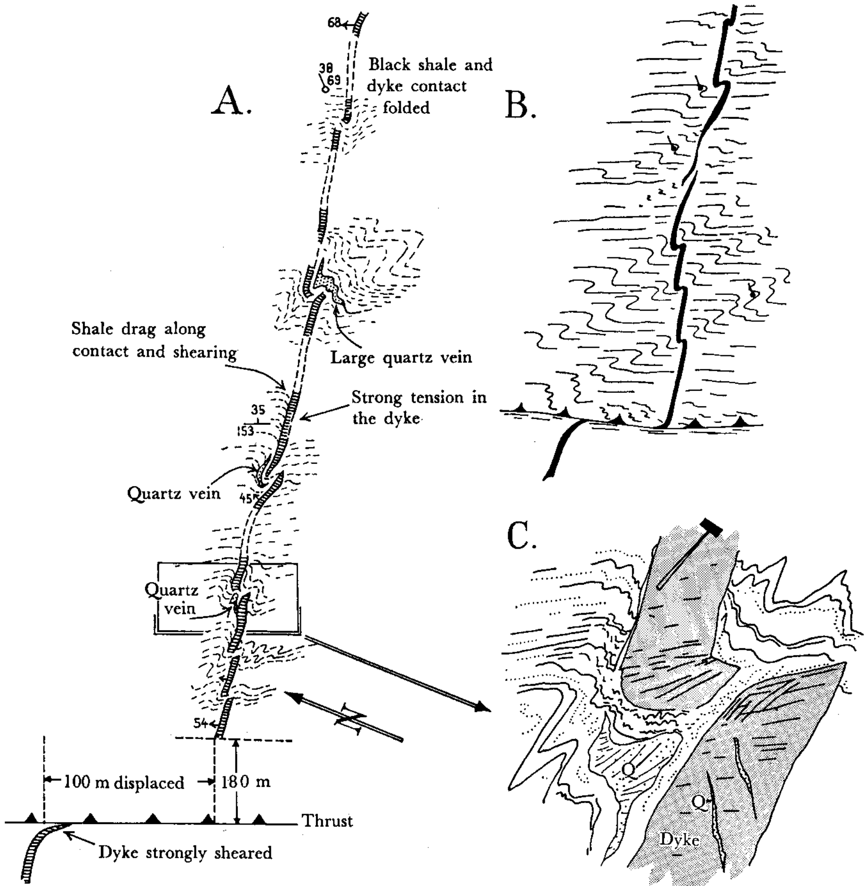


Fig. 68. Dislocation of small basic metadyke in black pelites of the Blåis Formation in Zigzagland (see plate 1). A. Map of the dyke with the fold pattern indicated. The dashed connections indicate larger areas unmapped or unexposed. B. A reconstruction of the folded dyke. C. Detail from A as indicated. Note that the dyke is displaced opposite to the sense of movement of the F_2 folds. This is an apparent displacement due to the angle between the dyke and the direction of the fold axis.

2) Small basic metadykes in the Zigzagland area

In the basement gneisses west of Zigzagland a few 1 to 3 m wide metadykes of apparently the same swarm have been mapped. The dykes transect the basement gneisses and are sinistrally displaced by faults related to the second Ketilidian deformation (see p. 158). They cross the shear zone located centrally in the banded amphibolite without displacement (p. 22).

One of the dykes intersects the breccia structure described on p. 160 and is intruded between the breccia fragments. The dyke is here rather porous and strongly altered. The same narrow dyke continues to the north-east with a trend of 60° and has an 'en echelon' outcrop pattern near the sedimentary border of the Ketilidian, where it shows irregular intrusive features. It crosses the sub-Ketilidian surface again exhibiting 'en echelon' features and can be followed through the Zigzagland Formation without being disrupted by the F_1 slip zone at the base of the Dolomite Shale Member. The dyke crosses this zone approximately at right-angles to the F_1 fold axis. It is then displaced about 100 m along the F_2 thrust zone at the base of the Blåis Formation (see p. 162), and can be traced into the folded black pelites and semipelites of this formation. The dyke is here disrupted and deformed in the hinge zones of F_2 folds as is shown in fig. 68. Plate 1 is an enlarged aerial photograph showing the relations around the small dyke.

The narrow dyke is generally sheared along its contacts and locally throughout its whole width. Besides shearing it may show an irregular block-jointing. Often small quartz veins are apparent perpendicular to the contacts and may represent a relic jointing which resulted from cooling. The dyke rock is light green and locally orange in its weathered state, and green or greenish-black in fresh section.

Six thin sections (53135, 53190, 30857, 20855, 20859, 20851) of this group of small dykes have been examined. The rocks are generally strongly altered and metamorphosed. Only rarely may the relic ophitic relations of feldspars be seen.

Primary plagioclase is preserved in a few cases (20851) but is generally strongly altered. The composition could not be determined.

Some of the plagioclases appear to have been phenocrysts. The alteration products are epidote and a little muscovite. Recrystallization to small blebs of untwinned albite? occurs.

The dark minerals are chlorite and a little actinolite, which together make up about 30% of the bulk. Ore as pyrite and a dark pigmentation is found in addition to leucoxene aggregates. A carbonate mineral, a little quartz and apatite also occur.

One thin section (20859) represents a sample adjacent to one of the displacing minor faults. This section also contains talc concentrated in lenses and surrounded by opaque material.

These small dykes may originally have been doleritic dykes.

3) Granophyric dykes and sills

In the area 1 km north of Vallen three granophyric dykes 3 to 4 m in width have been mapped from the basement gneisses up to and intersecting the sub-Ketilidian surface. Above the quartzites two of the dykes turn gradually into sills. One of the sills can be followed to the north shore of Vallen. South of Vallen a similar 1 m thick sill is found in the banded semipelites of the Blåis Formation (plate 13).

In the area north of Vallen no folding occurs in the area where the sills are apparent, but they are displaced by minor faults (p. 158). The sill

Fig. 69. The contact relations of a granophyric sill south of Vallen. The sill is here intruded into semipelites of the Blåis Formation. The contact seems to be folded by a small F_2 fold and the sill itself exhibits a "fold" although it cuts the bedding. The axial plane cleavage of the F_2 fold cuts the sill body. On a larger scale this has a curved trend consistent with the F_2 fold pattern.

found in the area south of Vallen appears to be deformed by F_2 folds (fig. 69). The sill is transected by fissures which correspond to the S_2 cleavage, but does not follow the single fold structures, instead being disrupted on the inverted or steep flank of the asymmetric F_2 folds. A fissuring parallel to the dyke contacts also occurs.

In the nebulitic gneisses it is difficult to trace the dykes, as they differ from the gneisses only in possessing an irregular jointing. The dykes have been traced for 800 m west of the border of the Ketilidian where they attain an E-W trend.

The dykes are white to pink in colour. They are porphyritic with feldspar and quartz phenocrysts. In the sediments they often contain inclusions of shale fragments.

Table 12. *Chemical analysis of granophyre 53027 from Grænseland* (IB SØRENSEN *anal.*)

	%	C.I.P.W.-norm.	
SiO_2	71.27	q	30.5
TiO_2	0.40	c	3.9
Al_2O_3	15.42	or	14.6
Fe_2O_3	0.66	ab	41.2
FeO	1.15	an	5.2
MnO	0.00	hy	2.8
MgO	0.78	mt	1.1
CaO	1.18	il	0.6
Na_2O	4.50	ap	0.2
K_2O	2.42	Total	100.0
P_2O_5	0.11		
CO_2	0.78		
H_2O	1.50	sum sal	91.5
Sum	100.17	sum fem	8.5

Two thin sections of the dykes and sills treated in this section have been examined (20877 and 53027). The texture of the quartzo-feldspathic groundmass shows occassionally relic graphic intergrowths of quartz and feldspars. The main impression of the texture is that it is granophyric (JOHANNSEN, 1939). The phenocrystic feldspars are twinned oligoclase and microperthite. The quartz phenocrysts are amoeboid to subidiomorphic and show undulatory extinction. Ore (altered to limonitic patches) apatite and fluorite are accessory minerals. The secondary minerals are muscovite and chlorite, the muscovite laths possessing a parallel arrangement. A chemical analysis of 53027 is shown in table 12. In the area north of Grænsesø, a similar dyke, 53054, has been collected.

It appears from the study of thin sections that these granophyres have been strained in addition to being metamorphosed.

4) Basic metadykes in the northern part of the area with an ENE trend

In the northern part of Grænseland, several 1 to 20 m wide metadykes with trends of 50° to 80° have been mapped in the basement nebulites. One of these dykes intersects the sub-Ketilidian surface and is found in the Zigzagland Formation quartzites.

The dykes are green in colour and are intersected by quartz, quartzo-feldspatic and carbonate veins. They are usually strongly sheared. Unsheared examples are traversed by an irregular jointing. Some of the dykes are porphyritic and a few xenolithic. All possess a linear trend, are discordant to the gneiss structures and are displaced by small faults.

Two thin sections (53082 and 20915) show badly preserved relic ophitic? textures of recrystallized feldspar (albite) and a ground mass of muscovite, chlorite, epidote and carbonate in the areas formerly occupied by mafic minerals. Ore, leucoxene and quartz are accessory minerals.

The dyke found in the quartizites (53072) has a better preserved relic texture than the two rocks mentioned above. The primary feldspar is a strongly altered twinned plagioclase ($n > n_{cb}$), in places recrystallized to small albite? ($n < n_{cb}$) grains. Other minerals are chlorite (secondary after biotite) and ore. Chlorite (feebly pleochroic from light yellow to light green and an anomalous blue), carbonate, epidote, quartz and actinolite? are secondary minerals after mafics.

5) NW-trending metadolerites in the north-eastern part of the area

An interesting group of dykes with very constant trend in directions between 120° and 130° is restricted to the northern part of Grænseland to the north-east of the Bæversø fault (marked SD in plate 12). The individual dykes have a fairly constant width between 5 and 15 m. They appear to be part of a swarm of which the north-eastern limit is found in Midternæs (A. K. Higgins, pers. comm.). Some of these dykes intersect the basement in Grænseland whereas the majority are found cutting the Ketilidian supracrustals. They cross folds and thrusts as well as the sub-Ketilidian surface. In the southern part of Fønland they are displaced by small dextral faults trending 50° to 70° which are themselves cut by an early Gardar dolerite (BD_0). 'En echelon' features are common.

The dykes appear to have been subjected to some degree of tectonization. They are strongly sheared close to the Bæversø fault, and a feeble shearing is also found along the margins of the dykes in Fønland where they are also characterized by a specific type of block-jointing.

Some of the dykes are porphyritic. They are all metamorphosed and have a greenish or brownish colour. However, the alterations vary along the same dyke from a rock with nearly unaltered pyroxenes and pseudo-

Table 13. *Modal composition of the best preserved NW-trending metadolerites in Fønland*

	53001	52946	53077
	%	%	%
Plagioclase	56.6	57.0	51.3
Pyroxene	11.0	15.6	16.6
Olivine pseudomorphs	11.0	6.2	4.2
Ore	2.7	3.1	0.2
Biotite	2.6	2.0	–
Apatite	–	0.7	–
Actinolite/serpentine	–	4.3	15.6
Chlorite	16.1	10.0	–
Carbonate	–	1.1	1.6
Other alterations	–	–	10.5
Total	100.0	100.0	100.0

morphs after olivine, to strongly altered rocks with no primary minerals intact. The degree of alteration also appears to change across the dyke with the central parts generally best preserved.

The petrology of the dykes is exemplified by six samples which represent an increasing degree of alteration. The modal composition of the least altered dykes is given in table 13. The dykes were originally olivine dolerites.

Sample 53001 from the south-west corner of Frynsesø represents the least altered dyke of the group. The dyke is porphyritic, 10 m wide, brownish in weathered colour and black in fresh sections. The sample is from the central part of the dyke where the rock is medium-grained. The texture is ophitic.

The thin section shows one large plagioclase phenocryst slightly altered to sericite with a cloudy central portion. The groundmass plagioclase is strongly zoned (An_{40-60}) and slightly sericitized. The phenocrysts and the groundmass plagioclases are transected by fissures with the development of a fibrous serpentine.

The pyroxene is a pink titaniferous augite with optical continuity over large parts of the slide and with a poikilitic relationship to plagioclase.

Perfect pseudomorphs of serpentine after olivine occur. Ore occurs along original fissures and crystal margins. The plagioclase phenocrysts enclose the pseudomorphed olivines. Large ore grains are associated with a biotite of deep reddish-brown to yellow and green to yellow pleochroism, and with accessory amounts of acicular apatite. Between the feldspar laths and locally at the borders of the pyroxenes, aggregates of chlorite, serpentine and actinolite occur.

Sample 52946 is from a 12 m broad dyke, 300 m west of Frynsesø trending 123°. The rock is medium-grained, greyish-brown in colour and exhibits well preserved ophitic texture.

The plagioclase (An_{38-68}) is cloudy, sericitized and strongly zoned. The pyroxene is a pink to colourless augite altered along fissures and grain borders to aggregates of chlorite, actinolite and carbonate. Pseudomorphs of serpentine after olivine are preserved with recognizable grain borders and relic fissures associated with ore. Primary reddish-brown and green pleochroic biotite occurs. Ore, apatite and quartz occur in accessory amounts.

Sample 53077 is from the same dyke as sample 53001 and from a locality 700 m north-west of Frynsesø. Medium-grained ophitic texture is preserved.

The plagioclase (An_{40}) is sericitized and cloudy. The composition could only be determined in a single case. The pyroxene is a pink augite altered along grain borders to actinolite and aggregates of greenish pleochroic chlorite, serpentine and carbonate. The olivine is presumably completely altered as it is not recognizable in pseudomorphs. Primary ore is preserved as rectilinear intergrowths of opaque ore and leucoxene. Secondary ore occurs scattered among the alteration products. Accessories are biotite, quartz and apatite. Secondary minerals are muscovite?, carbonate, chlorite, serpentine and actinolite.

Sample 52948 is from a 8 m wide dyke 1500 m north-north-west of Frynsesø with a trend of 120°.

The primary texture is hardly visible apart from the position of the plagioclase. The plagioclases are strongly pigmented but zoning is recognizable; the composition could not be determined. The mafics are actinolite (secondary after pyroxene), the most abundant mineral next to plagioclase. Aggregates of chlorites, ore and serpentine (possibly former olivines) and sub-idiomorphic ore altered to leucoxene occur. Other secondary minerals are muscovite and small grains of recrystallized albitic? feldspar ($n < n_{cb}$).

Sample 52106 is from a 5 m wide dyke with a trend of 132° in the nebulites on the west coast of the southern part of Grænsesø. The rock is black with a greenish tint. The original ophitic texture is visible from partly recrystallized plagioclase (strongly altered), the areas of alteration products of the mafic minerals and the shape and relations of the ore. The secondary minerals are a greenish pleochroic chlorite, actinolite, epidote and carbonate.

Sample 20915 is from a 1 m wide metadyke south-east of Bæversø. The texture of the fine-grained aggregate seems to show a preferred orientation of the chlorites. The main constituent – about 60% of the bulk – is chlorite of light green pleochroism. In some cases the chlorite replaces biotite of which relics can be occassionally observed. Actinolite occurs in acicular needles. Serpentine and muscovite? occur in association with the chlorites. About 25 % of the thin section comprises calcite and about 10 % is feldspar? and quartz grains showing undulatory extinction.

It is possible that some of the alteration and strain phenomena in this rock are due to the activity of the large Bæversø fault during Gardar time.

The age of the metadykes

The five groups of metadykes, the relations of which have been described in the previous section, must be either of pre-Ketilidian or Ketilidian age.

The first group and the fourth group – the large swarm of metadykes south-west of Lappesø and the ENE-trending dykes of the northern part of the area – are possibly related. These dykes are broadly correlatable with NE- and EW-trending dykes in the Ivigtut region as a whole (formerly called "Kuanitic dykes") (Bondesen and Henriksen, 1965). Several of the largest dykes can be traced far west and the structural pattern fits well into that of the Ivigtut region farther west.

The relationships found in the south-western part of Grænseland indicate that the sub-Ketilidian surface was in existence at the time of the intrusion of the majority of the dykes. It seems reasonable to suppose that the then-existing surface may have controlled the irregular intrusive features and the tendency to form sills. This implies in the author's view that the majority of the dykes are of Ketilidian age. However, the conclusive proof case, and "feeder relations" to the Ketilidian sills and lavas have not been found. No dykes have been observed to be cut off by the sub-Ketilidian unconformity. The large swarm of dykes is possibly older than the first deformation as shearing corresponding to an S_1 cleavage sub-parallel to the border of the supracrustals intersects the dykes. They also seem to have been affected by the tilting of the basement as witnessed by the general distortion of the dykes south-west of Lappesø.

The age of some of the metadykes – as broadly correlated with similar dykes farther west and north-west – is indicated by K/Ar age determinations by Jørgensen (1968), who supposes that the intrusion took place not more than 1900 m.y. ago. Their metamorphism would according to these dates have taken place between 1600 m.y. and 1700 m.y. ago.

The second group of dykes – the small metadykes in the Zigzagland area – were apparently intruded between the first and second phase of Ketilidian deformation (see p. 178 and fig. 68).

The dykes are difficult to distinguish from those of the first group and might therefore be more abundant than has been suggested.

The third group – the granophyric dykes and sills – seems to pre-date the second phase of deformation. Their relation to the first phase of deformation is uncertain, but they appear to be later. The example, shown in fig. 68, could be interpreted as penecontemporaneous with the F_2 folding.

Wiedmann (1964, p. 79) has reported micrognanitic dykes and sheets north-east of the Tigssaluk granite (fig. 1), 13 km west of Vallen, and he connects these hypabyssals with sills cutting the granite and related to the emplacement of this intrusive granite stock. Although the granophyric dykes and sills in Grænseland have not been mapped so far west, only a few kilometres separate the two occurrences. It is therefore tempting also to relate the Grænseland granophyres to the intrusion of the Tigssaluk granite, because no other evidence of intrusive granitic activity is known from this region. The field relations in Grænseland indicate that the granophyres have been intruded earlier or contemporaneous with the second folding, *i.e.* close to 1635 ×40 m.y. (the age of biotite from the Tigssaluk granite; Bridgwater, 1965).

The fifth group – the NW-trending metadolerites in the northern part of the area — post-dates both main fold phases and pre-dates a weak faulting and the earliest Gardar dykes. They are metamorphosed, in some cases less than the altered Gardar dykes and in other cases to the same degree as the earlier metadykes. Their composition is close to that of the Gardar olivine dolerites. Their border relations and their metamorphic state suggest that they have been subjected to later weak movements or have been intruded under conditions of some tectonic activity.

Correlations

In this section a correlation between Grænseland and other areas in south-west Greenland especially with regard to the metadykes and the deformations will be attempted.

The general chronological scheme of the Precambrian of south-west Greenland has been revised by various authors as mapping progressed. The development has been reviewed by Allaart (1967, p. 128) who also gives a general synthesis of the chronology in the vast "Julianehåb granite" region (op.cit., table 4). This region may be regarded as the central part of the Ketilidian mobile belt. In relation to this Grænseland is situated on the foreland to the north-west. The passage from the foreland basement regions to the central mobile belt is unusually instructive (Henriksen, 1968) and shows an increasing deformation and metamorphism of the Ketilidian cover rocks as well as the basement.

The Ilordleq area in the south-eastern part of Kobberminebugt (fig. 1) served as a key area in this passage. The plutonic development in the Ilordleq area has been described by Watterson (1965) and involves deposition of supracrustals, and several periods of dyking, deformation and granite emplacement, which to some extent are correlatable with the regions farther south (Allaart, 1964 and 1967). A correlation between Grænseland and Ilordleq may thus be of value in the regional geology because high-level (or peripheric) Ketilidian events might thus be linked to deep-level episodes of plutonism.

The chronology of the Ilordleq area can be summarized after Watterson (1965):

1) Sediments and volcanics including basic intrusives.

2) a. 1st period (A) of discordant amphibolites.
   b. Deformation along NE–SW axes, the folding being restricted to calcareous rocks; development of a regional foliation parallel to the bedding and the establishment of the present disposition of the rocks.
   c. 1st period (B) of discordant amphibolites.
   d. Granites and migmatization.

3) 2nd period of discordant amphibolites; numerous relatively small basic dykes in several generations, mainly with NE-trends but some with N and a few with NW trends.

4) a. Granite emplacement and reactivation including deformation of the supracrustals along the same planes as established under 2), *i.e.* the lineations are oriented NE–SW. Discordant bodies are shear-folded.
   b. Formation of NNW and ENE conjugate shear fractures.
   c. 3rd period of discordant amphibolites intruded in swarms with NNW trends under compressive forces and under elevated temperatures.

The events listed under (2a) to (2d) are referred by Watterson to the Ketilidian, whereas (4a) represents the Sanerutian plutonic episode. Allaart (1967) presents a chronological scheme for the "Julianehåb granite" area, where the Ketilidian is represented by two episodes of plutonism corresponding to Watterson's (2) and (4). The dykes dividing the two plutonic episodes ((3) in Watterson's chronology) are regarded as intra-orogenic. Although the author agrees with Allaart as to the

Ketilidian (see p. 29) he would like to maintain the term Sanerutian to cover the "2nd episode of plutonism" in the sense of ALLAART, because the term is so well established in the geological literature.

A presumable reliable correlating link to the Ilordleq area[1]) is, as noted on p. 143 and also stated by WATTERSON, the Ketilidian supracrustal belt (WATTERSON op.cit., p. 130). Correlation with Grænseland based on the discordant amphibolites would, strictly speaking, be impossible as 1st and 2nd period dykes in the supracrustals are indistiguishable unless their relation to Ketilidian granite veins are known. However, both periods of granite emplacement in the Ilordleq area are closely related to deformation, and a possible alternative means of comparison would be to correlate the phases of deformation.

The first deformation in the Ilordleq area ((2b) in WATTERSON's chronology) and the first deformation in Grænseland have many features in common such as, for example, the development of a regional foliation and the restriction of the folding to certain lithological environments. One difference is in the trends of the fold structures. However, in Grænseland the F_1 folds and their axial planes conform to the basement surface and they are possibly related to the tilt of this surface. This means that the F_1 folds should conform in trend to the broad bend of the Ketilidian supracrustals between Arsuk Fjord and Kobberminebugt, and this appears to be the case (S. BAK JENSEN pers. comm.). Also WATTERSON notes that the first folding in the Ilordleq area and the disposition of the rocks in their present attitude are chronologically related. It is therefore quite likely, despite the differences in the trend of the fold axes, that the first folding in both areas is of the same age.

The metadykes (or at least some of them) in the Grænseland area – the first and fourth group (p. 173 and p. 180) – may therefore be correlated to the 1st period of discordant amphibolites in the Ilordleq area. They are pre-orogenic dykes, but not necessarily pre-Ketilidian. It should be noted that there is a conspicuous difference in size between the two groups of dykes thus correlated, as the 1st period of discordant amphibolites have never been found to be more than 5 m wide.

The small metadykes in the Zigzagland area (the second group, see p. 177, fig. 68 and plate 1) could be correlated to either the 1st period B or the 2nd period of discordant amphibolites. There is no possibility of distinguishing between these two dyke groups in Grænseland, nor is there any means of establishing a period of crustal tension between the two main plutonic episodes, manifested by the two main phases of folding, except for the fact that the tectonic axes were reserved.

[1]) It is noted that GHISLER (1968) has pointed out that copper mineralizations in the Ilordleq Group are comperable to similar mineralizations in the pre-Ketilidian Târtoq Group.

The second deformation in Grænseland could possibly be compared to the deformation in the Ilordleq area, related to the Sanarutian plutonic episode. The Sanerutian deformation in the Ilordleq area and most of the "Julianehåb granite" area is of a remarkably constant NE trend (Allaart, 1964 and 1968, p. 18) which is coincident with the trend of the second deformation in Grænseland. The main reactivation phase in the "Julianehåb granite" area, including the formation of allochthonous granites, is of this age and the metamorphic zoning in the foreland regions, situated to the north-west, appears to be approximately parallel to the NE trend. The relations in Grænseland also suggest that the second deformation is responsible for the main metamorphism. Biotite age determinations around 1600 m.y. from the north-west Ivigtut region probably reflect Sanerutian reactivation farther south (Jørgensen, 1968, p. 90). To this is to be added the evidence represented by the granophyric sills and dykes in Grænseland and their supposed relation to the Tigssaluk granite (see p. 184). The age of this granite (1635 m.y.) and thus also roughly that of the second deformation corresponds to the Sanerutian plutonic episode.

The NW-trending metadolerites in the north-eastern part of Grænseland (the fifth group, p. 181) have some features in common with the 3rd period discordant amphibolites in the Ilordleq area, and they might correspond to these in a higher crustal level. The NNW and ENE conjugate shear set in Ilordleq has close directional coincidence with the relations in Fønland. The ENE-trending small faults may be related to one direction and the dykes to the other.

However, Allart (1967, p. 20) has recognized a late phase of tholeiitic dyke intrussion in the Julianehåb region. These dykes have the same directional trend, the same narrow variation in width and similar metamorphic alterations as the NW-trending metadolerites in Grænseland. They are later than the 3rd period of discordant amphibolites in the Ilordleq area but earlier than Gardar dykes. The dykes in Grænseland, however, cannot be demonstrated to be of tholeiitic affinity and are, as shown on p. 182, table 13, to be regarded as olivine dolerites. It is nevertheless tempting, as also proposed to correlate the narrow swarm in Grænseland and Midternæs and the regions to the north-west (see p. 181) with the (also narrow) swarm of tholeiitic dykes due south-east of the Inland Ice in the Julianehåb district and farther south-east in the Sydprøven area (Persoz, 1969).

THE CHRONOLOGY OF THE KETILIDIAN

Earlier in this paper the Ketilidian has been defined (p. 29) as a period of deposition and folding bounded by the two major unconformities – the sub-Ketilidian surface and the sub-Gardar peneplain.

With these limitations of the Ketilidian period a conflict is apparently raised with regard to time-stratigraphic usage as such unconformities are not necessarily isochronous surfaces. This conflict extends far into Precambrian chronological and stratigraphic tradition, which is built upon the concept of the geological cycle – in most cases the orogenic cycle – rather than upon a time-division (Stockwell, 1964). The different chronological methods used in the Precambrian, including radiometric dating, require in many respects interpretations which finally depend on the cycle concept. This concept, which has proved applicable for various regions (Quennell and Haldemann, 1960; Harpum, 1960; Magnusson, 1965), was originally applied to the Ketilidian period (Wegmann, 1938; Berthelsen, 1961) or the Ketilidian – Sanerutian orogeny (Walton, 1965). A further employment of the cycle concept to the Ketilidian is the application of the chelogenic cycle (Sutton, 1963) including both the Ketilidian and the Gardar in the Svecofennid chelogenic cycle (Bridgwater and Walton, 1964; Bridgwater, 1965).

It is the author's opinion that the cycle concept regarding Precambrian stratigraphy is justified as a major time-stratigraphic unit because "the resolving power of the existing geologic methods" (Intern. Subcomm. of Strat. Terminology, 1960, p. 12) is sufficiently low to eliminate the errors introduced by using the defined boundaries – the unconformities. It would thus be erroneous to compare the Phanerozoic stratigraphic time-scale and the Precambrian stratigraphic time-scale, as they are of different orders of magnitude and based on entirely different methods. Because of this, it would be desirable to use two different time-stratigraphical terminologies and it is to be hoped that such arrangements will be established on an international basis. At present the author prefers to use the traditional time-stratigraphic terminology.

The subdivision of the Ketilidian period into epochs might be based on various geological relationships. One or several epochs might thus concern deposition, others tectonic phases or plutonic phases (episodes or

Table 14. *Chronology of the Ketilidian in the Ivigtut region and Kobberminebugt based on Grænseland – Ilordleq correlations and regional geology 1968.*

		On the surface	In the basins	Movements: In supracrustals	Movements: In basement	Metamorphism	Hypabyssal activity	Plutonic conditions	Age
Gardar		Volcanics Sandstones		Faulting	Faulting		Basic and alcaline dykes	Plutonic centres	1020 m.y. 1275 m.y.
		unconformity							
Ketilidian	Geosynclinal stage	Erosion.		Elevation Faulting ↑ F_3-folding	Faulting	Slight and selective in dykes.	Basic dykes in WNW-direction	↑	1500 m.y. Sanerutian plutonic episode
				F_2-folding and increasing in intensity towards south	Faulting in north, towards south shearing and folding	Main metamorphism of increasing degree towards south	Granophyric dykes and sills Granite stocks	Activation, granitization and plutonic mobilization in the central part of the orogenic zone	1640 m.y.
							basic dykes (2nd per. DA)	Brittle conditions	
	Orogenic stage	Ilordleq Gr. {Volcanics, Sediments}		F_1-folding – thrusting and subsidence of the central orogenic zone	Tilting of the basement, brecciation	Slight metamorphism in zones of strong movement.		Granites and migmatites in the south	1st plutonic episode 1700 m.y.
		Qipisarqo Gr. {Semipelites, Conglomerate}		↑ Subsidence					
		Sortis Gr. Rendesten F.	Deep basins Shallow basins				Basic dykes (1st per. DA)		
		Sortis Gr. Foselv F.	↑	Even subsidence					
		Vallen Gr. Grænsesø F.	Shallow basins Deep basins	Stable Strong subsidence					
		Vallen Gr. Blåis F.	Shallow basins ? lake ?	Slight subsidence					
		Vallen Gr. Zigzagland F	Continental	Stable					1800 m.y.
		unconformity							
pre-Ketilidian		(see table 1)							

events). At present there is no need to established time-limited epochs as chronological markers of regional importance have not yet been fully elucidated. However, the author whishes to employ the informal time-stratigraphical term "stage" to cover the time of deposition and the time of deformation in the Ketilidian period, and returning to the concept as a cycle consequently regards these two informal stages as the geosynclinal stage and the orogenic stage.

The geosynclinal stage may be sub-divided on the basis of stratigraphical methods as has been attempted in this paper. The lithostratigraphical division established can be used in correlation where used cautiously. The movements leading to the basin development may also be employed in a chronological subdivision but they can only be considered on a regional scale.

The orogenic stage involves tectonic phases and plutonic phases (episodes or events) and includes in this respect the two phases of folding in Grænseland, faulting and dyking. In other regions it forms a complicated succession of plutonic events. It also includes the final uplift and erosion to the sub-Gardar peneplain. It may be possible to introduce a third stage – the epeirogenic stage of the Ketilidian – which WALTON (1965) regards as essentially the Sanerutian plutonic episode.

Based on the principles outlined above, the chronological development of the Ketilidian cycle has been outlined in table 14. The compilation is mainly based on the records from Grænseland and the correlation of these events, and the deformations.

Ketilidian initial volcanism can, based on the interpretations on p. 183, hardly be older than 1900 m.y. and might be as young as 1750 m.y.. An age of about 1800 m.y. would in the opinion of the author be more likely for the early Ketilidian.

Development of orogenic cycles similar to the Ketilidian, also regarding the geosynclinal stage, are known on the Canadian shield (the Hudsonian with ages between 1800 m.y. and 1600 m.y.) and on the Scandianvian shield (the Karelian and the Svecofennian with ages between 1850 m.y. and 1750 m.y.) Karelian initial volcanism has been dated to 1860 m.y. (SIMONEN, 1960).

The age of 1800 m.y. is, however, ascribed to the first Ketilidian plutonic episode (ALLAART et al., in press) in which the main tectonic trends and metamorphic features were established. This does not quite conform to the views of the author, who agrees to the establishment of the main tectonic trends, related to the first phase, but would much rather consider the main metamorphic features, at least regarding the foreland regions, as related to the second phase corresponding to the Sanerutian plutonic episode.

GARDAR

Introduction

The Gardar is characterized as a period of deposition, volcanism and cratogenic tectonics. The deposition comprises sandstones and volcanics Poulsen, 1964) laid down on a major unconformity, the sub-Gardar peneplain. The movements are restricted to major faulting and the formation of tensional fissures along which dykes were periodically intruded. The Gardar igneous activity also comprises emplacement of large intrusive complexes of gabbros, saturated and undersaturated syenites, and granites. The whole of south Greenland as far north as Frederikshåb has been affected by Gardar activity, the age of which ranges from 1250 m.y. to 1020 m.y. (Bridgwater, 1965).

In the Ivigtut area Wiedmann (1964) and Ayrton (1963) have given detailed accounts of the Gardar evolution with particular respect to the dyke chronology. The specific relations around the famous cryolite ore at Ivigtut (of Gardar age, 1160 m.y.) have been treated by Berthelsen (1962). Upton (1960) describes the Kûngnât syenite complex of young Gardar age and Emeleus (1964) have treated the Grønnedal-Ika nepheline syenite complex, which is of early Gardar age (see fig. 1). In Grænseland Gardar is only represented as dykes and faults.

The general GGU field terminology regarding the dykes is employed in the following. According to this scheme dolerites are termed BD (Brown Dykes), lamprophyres LP, and trachytes, microsyenites and related rocks TR; BFD is a specific type of phenocrystic and xenocrystic dyke (Big Feldspar Dykes) (Bridgwater and Harry, 1968).

The map of plate 12 shows the dyke and fault pattern in the northeastern part of the Ivigtut region.

The map shows clearly that two distinct zones have been subjected to dyke intrusion and faulting both in Gardar and earlier time. The intermediate area south-west of Vallen and west of Lappesø around Overløbssø is only traversed by comparatively few and thin dykes, and the faults which occur here have only small displacements. This intermediate zone was apparently comparatively stable from pre-Ketilidian to Gardar time and also nearly coincides with the ridge feature of paleogeographical importance which divided the Ketilidian sedimentary basins.

In the following the tectonic features and the rocks of Gardar age in the Grænseland area described briefly in order to complete the description of the stratigraphy and deformation of the Precambrian in this area.

Cronology and field relations of the dykes

The Gardar dykes in Grænseland comprise lamprophyres and related rocks, syenites and dolerites. Their chronology as revealed from intersections is shown in table 15.

Table 15. *Chronology of Gardar Dykes in Grænseland*

	type	direction
youngest..................	BD_2	50°–45°
	?(LP+TR)?	60°
	BD_1	60°
	?(BFD)?	–
	BD_0	80°
	BFD	80°–90°
oldest....................	LP+TR	120°–80°

LP = lamprophyre
TR = trachyte or microsyenite
BD = dolerite (Brown Dyke)
BFD = phenocrystic dolerite (Big Feldspar Dyke)

The dolerite chronology with the oldest dykes trending nearly E–W and the youngest in a NE direction is consistent with the relations in other parts of the Ivigtut region. The thin lamprophyres and syenite dykes, which can rarely be traced for more than a few hundred metres, have infrequent intersections with dykes of established chronological position; some of them are younger than BD_0 and older than BD_2 dolerite dykes.

The lamprophyres range in thickness from 5 cm (fig. 61) to about 5 m. They are black and porous often with irregular weathered rusty surfaces and internal zoning or banding. They may contain phenocrysts of olivine or biotite, and are occasionally xenolithic.

The microsyenite dykes are also thin, varying in width from 0.5 to 3 m; they are usually very fine-grained. In colour they may be white, grey or brick-red, and more rarely green, crumbly weathering when coarse-grained. Xenoliths and phenocrysts are rare except for the BDF dykes which locally contain densely spaced plagioclase phenocrysts, xenocrysts and xenoliths. These particular dykes are generally less than 10 m wide.

'En echelon' and 'en bajonet' features are common especially among the youngest BD_2 dolerites. Where the dykes cross the border with the Ketilidian supracrustals they commonly exhibit irregular intrusive features in contrast to their linear trend in the basement gneisses. This trait is exemplified by the large BD_1 crossing the south-western corner of Grænsesø, which swells, changes direction and possibly produces 'en echelon' features just in front of the ice border. The dykes are commonly deflected towards faults, and it is a conspicuous feature that the deflections always occur on the north side of the faults. Such deformations have had very little influence on the character of the dyke rocks themselves, at least in the cases of the BD_1 and BD_2 dykes.

Contact metamorphic effects along the margins of the dykes are clearly apparent, especially when the wall rock is a carbonate sediment; In these cases visible alterations (formation of yellow serpentine minerals) can be traced 10 to 15 m from the contacts of the larger dykes. Strong graphitization has occurred where a dyke crosses the Anthracite-Carbonaceous Shale Member of the Foselv Formation (see p. 100). Other rock types may exhibit a baking adjacent to dykes visible as a hardening or bleaching, but there is no conspicuous development of new minerals.

Petrology of the dykes

The microsyenite dykes

The microsyenite dykes generally have a texture of randomly orientated feldspar laths. In the case of the green dykes (53065, 53066, 53055 and 53056), a more or less pronounced trachytic texture is present. All the rocks are more or less altered, especially their feldspars. It has thus proved difficult to obtain optical data for most of the minerals. Table 16 shows the modal composition of the best preserved samples.

Table 16. *Modal composition of microsyenite dykes from Grænseland*

	20898	20917	20918
	%	%	%
Feldspar	56.5	63.5	63.3
Pyroxene	25.5	14.3	21.4
Amphibole	–	0.8	8.3
Analcite	18.0	7.0	2.1
Biotite	–	12.9	4.4
Ore	–	1.5	0.5
Total	100.0	100.0	100.0

The rock types with a trachytic texture have a feldspar/mafic ratio of 85/15, and those with non-trachytic textures a ratio of 60/40.

The potassic feldspar is usually cluody and generally untwinned or exhibits simple twinning. The pyroxenes are either augite (pale yellowish colour, $z \wedge c = 41°$) or strongly pleochroic aegirine ($x \wedge c = 5–8°$). A less pleochroic aegerine-augite? ($z \wedge c = 60–80°$) also occurs. The pyroxene crystals are idiomorphic, needle- or lath-shaped. Other minerals, which occur are analcite, albite? with inclusions of apatite needles, biotite and carbonate. Fluorite, ore and quartz occur in accessory amounts. The secondary alteration products are a strongly pleochroic greenish chlorite after aegirine, and an actinolitic amphibole after augite. Two samples (20903 and 20867) contain strongly altered square-shaped idiomorphic nepheline crystals with cancrinite and analcite. The composition of the dykes suggests classification either as augite microsyenites (trachytes) or aegirine microsyenites (alkali trachytes). Gradations occur between these types as the proportion of the pyroxenes varies. The nepheline-bearing dykes may be regarded as tinguaites.

The lamprophyres

Petrologically the lamprophyres are closely related to the dolerites, and there is a gradation between these two groups of dykes. Thus, one dyke mapped as a BD (53954) has a strong lamprophyric affinity texturally and compositionally, and some dykes mapped as lamprophyres (20896, 20856 and 20852) closely resemble the BD dolerites from a textural point of view.

The lamprophyres are characterized by idiomorphic mafic minerals both as phenocrysts and in the groundmass. The leucocratic minerals are found generally in intersticies. Minerals containing volatile components (carbonate, biotite and apatite) are fairly abundant, whereas primary amphiboles are absent. This is in contrast to the lamprophyres in other parts of the Ivigtut region (AYRTON, 1963; BONDESEN, 1960) Zeolites and feldspars? secondary after zeolites are, however, prominent in the Grænseland dykes.

Table 17. *Modal composition of lamprophyres and related rocks from Grænseland*

	20852	20854	20856	20860	52954	53054
	%	%	%	%	%	%
Feldspars	56.0	12.2	17.8	51.3	13.2	15.1
Pyroxene	9.6	21.8	31.4	2.7	33.2	25.1
Olivine (including pseudom.)	1.0	29.1	6.3	3.4	20.2	12.7
Biotite	–	19.1	7.8	2.0	10.3	18.7
Ore	11.5	9.9	10.4	10.9	4.0	6.1
Carbonate	3.3	1.1	6.7	4.6	19.1	12.3
Alterations	18.6	6.8	19.5	25.1	–	–
Total	100.0	100.0	100.0	100.0	100.0	100.0

Alterations in the lamprophyres are common, especially with respect to olivine and the leucocratic minerals. Some samples are severely altered. Fourteen samples of different dykes have been examined in thin section. The modal composition of the best preserved samples is given in table 17.

The feldspar of the true lamprophyric types is possibly a sodic plagioclase ($n < n_{cb}$), oligoclase or albite. In the types of doleritic affinity they are andesines (ca. An_{35}). In a 5 m broad biotite-rich dyke (53199) analcite and nepheline were observed. Olivine occurs as large phenocrysts and is generally altered to serpentine and ore. Relic olivines have $2V_X$ = 70–75°.

The pyroxene is generally a pink augite found in idiomorphic laths, but a colourless variety also occurs. Biotite is generally reddish-brown and strongly pleochroic, and may occur as phenocrysts. Idiomorphic ore is generally very abundant comprising up to 10 % of the slide. Carbonate minerals may be common as a primary constituent but can rarely be distinguished from secondary carbonates formed, along with other minerals, from the alteration of olivine. Apatite in long idiomorphic needles occurs as a primary mineral in accessory amounts.

Zeolite minerals occur commonly in the intersticies of the slides; they are particularly prominent in some spherulitic dykes. The zeolites are replaced by chlorite, serpentine and also ore, carbonate and an undetermined mineral in brownish aggregates (a serpentine mineral?).

There is a wide compositional variation in the lamphrophyres. One sample (53127) is close to a pyroxenite, and others approach a doleritic composition (20896, 20852, 20860) except that they are characterized by a very high ore proportion (about 18 %). An olivine phenocryst-bearing type, a biotite-rich type and a spherulitic type may be distinguished. Some of the dykes may be classified as biotite spessartites, while one (53199) may be a camptonite (Johannsen, 1937).

The general impression of the lamprophyres is that the composition may vary considerably along and also across the same dyke. This is suggested by the banded and zoned nature of some of the dykes. There is also the impression that the composition may vary from area to area in some sense dependent on the nature of the country rock. The spherulitic dykes appear to be restricted to the shales and greywackes, and olivine phenocrystic types to the basement gneisses. It is thus possible that the magma (or crystal mush of idiomorphic mafics) may have been modified largely at water-rich levels.

The dolerites

The various generations of dolerites are olivine dolerites with the exception of one BD_2, which lacks olivine and contains a surprisingly large proportion of quartz-feldspar micropegmatite intergrowths. In the twenty thin sections of these rocks examined all the primary minerals are generally preserved. The small amounts of alteration products found occur along the grain borders and in the intersticies.

The texture is always distinct with prominent ophitic relations between plagioclase and pyroxene. In the coarse-grained broad dykes textures with more rounded and curved plagioclase and pyroxene crystals are found.

The plagioclase ranges in composition from An_{38} to An_{68} in strongly zoned individuals. The pyroxenes are clear and non-pleochroic, or pink with a faint yellowish pleochroism. The pink colour and $2V_Z$ = 55° correspond to a titaniferous augite. Often there is a poikilitic relation between pyroxene and plagioclase, the pyroxene exhibiting optical continuity over large parts of the slide and enclosing plagioclase laths. In a few cases a beginning of uralitization can be detected.

The olivines ($2V_X$ = 80°) occur as large grains and show exsolution of ore along cracks. Alterations of olivine to carbonate, serpentine, chlorite and ore often in zoned aggregates (53954) occur with carbonate in a central position. Primary ore is often associated with biotite and chlorite. Biotite is very abundant with a strong reddish-brown and green pleochroism. Apatite and carbonate occur in accessory proportions.

The Big Feldspar Dykes (BFD) are the only truly porphyritic dykes. The phenocrysts in one case are oligoclase-andesine at the margins. The centre was indeterminable because of alteration.

An xenolithic dyke (marked XD on plate 13) (20818, 20820, 20821 and 20830) contains strongly altered mafics and quartz in the matrix. The xenoliths have the composition of quartz-monzonite and monzonite containing vaguely greenish pyroxene and biotite.

The modal composition of the best preserved Gardar dolerites is given in table 18.

Table 18. *Modal composition of dolerites from Grænseland*

	BD_0	BD_0	BD_1	BD_1	BD_2	BD_2	BD_2	XD	BFD
	53068	20853	52984	52988	52983	20819	53030	20812	20823–24–25
	%	%	%	%	%	%	2%	%	%
Plagioclase .	71.5	58.6	67.3	60.2	60.0	63.8	62.6	62.0	50
Pyroxene . .	8.0	14.2	14.0	11.0	14.4	19.6	17.8	10.2	10
Olivine	10.7	5.0	14.1	25.6	16.7	4.2	–	–	–
Ore	3.3	13.1	1.9	1.3	3.2	6.4	9.0	6.7	10
Biotite.	2.7	5.7	1.2	1.9	2.5	1.5	1.6	0.2	5
Alterations .	3.8	3.4	1.5	–	3.2	4.5	7.9	17.8	25
Carbonate. .	–	–	–	–	–	–	0.5	0.3	–
Quartz.	–	–	–	–	–	–	0.6	2.8	–
Total.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Faulting

Gardar faulting is restricted to a few large sinistral faults trending in the directions of 90° to 120° and some dextral faults trending in directions of 30° to 45°. One fault, the Bæversø fault, a rejuvenated pre-Gardar fault, deviates from this pattern with a trend of 135° to 140°. All the faults are vertical or nearly vertical.

Displacements have occurred along the faults throughout Gardar time. The large sinistral faults displace BD_2 dykes and there is thus no means of determining the upper limit of the faulting in Grænseland. In other regions major sinistral faults of similar trend are cut by coast-parallel dolerites of Mesozoic age. A detailed analysis of a large sinistral fault in the Ivigtut region – the Laksenæs fault – has been given by HENRIKSEN (1960). The sinistral faults in Grænseland appear to have a very similar history. The displacement along the north-east-trending dextral faults is post-BD_1 and pre-BD_2.

A characteristic feature of the sinistral faults is that their displacements appear to be greater in the western than in the eastern area. This could be due to a flexural development in one of the fault blocks similar to that shown for the Laksenæs fault (HENRIKSEN, op.cit.), or to hinge-like fault movements. A large fault crossing Fønland has a sinistral displacement in the eastern part of the area of 600 m in a horizontal sense with no apparent vertical movement, and in the western part of the area about

1200 m horizontal sinistral movement and 300 to 600 m displacement in a vertical sense. The displacements were determined by considering the dip of bedding and the intersections with vertical dykes. The Bæversø fault shows similar relations; a BD_0 dyke at Vallen is displaced 400 m sinistrally and one at Bæversø about 900 m in the same sense. In the southern part of the area no displacements of the border to the Ketilidian larger than 300 m are apparent, whereas the displacement of the BD_2, 8 kilometres west of the border, reaches as much as 1200 m.

The displacements along the dextral faults are about 450 m in the southern part of the area and about 200 m near the Sioralik glacier.

Only small movements appear to have occurred along the numerous small Ketilidian faults in the Zigzagland area; there are no displacement relationships to the few Gardar dykes in this stable area. In the southern part of the area, however, many of the smaller faults have been rejuvenated in Gardar time and some of the major faults in this area may have developed along original faults of Ketilidian age.

The effects of fault movements on the country rocks are mainly brecciation, crushing and mylonitization. There is also a certain metamorphic effect and recrystallization of some minerals is apparent. A recrystallization of quartz is common. Veining in tensional fractures is also frequent largely as quartz and carbonate fillings.

The Bæversø fault follows a trend abnormal in the Ivigtut region as a whole. The alteration of the surrounding rocks is very marked involving chloritization and microclinization of the country rock in a broad belt more than 150 m wide. From the stratigraphical and structural evidence it is possible that this fault was responsible for the special relations in the development of the Blåis Formation basin, and the paleogeography of very early Ketilidian time. The Bæversø fault is parallel to the pre-Ketilidian faults in the gneisses west of Zigzagland (see p. 25), but these have not been reactivated during Ketilidian and Gardar time as has the Bæversø fault.

APPENDIX

Economic geology

The Ore-Conglomerate Member of the Upper Zigzagland Formation is of possible economic interest especially in the area between Vallen and Lappesø.

The Anthracite-Carbonaceous Shale Member of the Foselv Formation, where contact metamorphosed by large dykes in the Fønland area, has yielded large masses of almost pure graphite. Locally the graphite is tectonically concentrated in faults.

Some pyrite concentrations are found in the southern part of the area in greywackes and shales of the Blåis Formation.

A radiometric survey did not show any noteworthy radioactivity.

The Quaternary

The Grænseland area is to the east, north and south bordered by the Inland Ice, the Sioralik glacier and the Arsuk glacier, respectively. It would therefore be expected that Quaternary deposits such as moraines and glacio-fluvial deposits would be conspicuous, but this is not the case. Although evidence of glaciation in the form of striae, shattermarks, 'roches moutonnées' and scattered erratics are found everywhere in the area, significant deposits are restricted to the actual border of the ice (see plate 11). Here an almost continuous boulder moraine is found resting apparently on top of ice. It is therefore suggested that, to a large extent the moraine may be a shear-moraine (Bishop, 1958).

In front of the moraine, a pro-glacial snow bank occurs in most areas. Sections in this snow bank revealed a marked layering, possibly representing annual accumulation. Up to 58 layers were counted in well exposed sections. The layering was deformed, not only by compression, but apparently also in response to local movements in the bordering ice which locally caused the development of overturned folds.

The boulder material of the moraines is dominated by the same rock types as found in the low-metamorphic complex of the Ketilidian just to the west of the ice i.e. sediments, volcanics and intrusives, and also apparantly Gardar hypabyssals. About 5 % of the boulders comprised red and purple (continental?) sandstones and unmetamorphosed intermediate and basic volcanics of Gardar supracrustal type. In addition to these, single boulders of coarse porphyroblastic granite and hornblende gneisses were found.

Glacio-fluvial plains and deltas are found in the lakes, especially Vallen and in front of Blåisen 2 km south of Vallen (Bondesen, 1966).

Terraces at Vallen and Grænsesø, and in the large open valley leading from Lappesø to Foselv, appear to have originated from ice-dammed stages in the history of the lakes. Those in Grænsesø could hardly have been formed unless the Sioralik glacier was at a very advanced stage corresponding to an altitude of the surface in the Grænsesø region of 800 to 850 m above sea level. Those found at Vallen could only have been formed if Vallen lake itself was occupied by a large glacier tongue, and the valleys to the north in which the terraces occur were ice-dammed lakes. The terraces in the valley south of Lappesø were probably formed in a lake dammed by the Arsuk glacier. This required an advanced stage of the glacier corresponding to a surface altitude of at least 750 m above sea level. This would correspond to an advanced position of the Arsuk and the Sioralik glaciers – the Fjord stage 1 and 2 – equivalent to the Cochrane stage (7500–9500 b.p.) (Weidick, 1968).

The ice border seems largely to have been stationary in recent time. At Vallen (altitude 575 m) a local glacier tongue in the south-eastern corner has left a terminal lobate moraine 200 m from the present ice border (see fig. 39 and plate 1). The two fjord glaciers – the Sioralik glacier and the Arsuk glacier – show a trim line zone which seems to peter out at an altitude of 800 m. The history of retreat of the Arsuk glacier is fairly well known and has been described by Weidick (1959, p. 92). Recently Mælkesø has been drained and a productive tongue now extends into the lake. Between 1960 and 1961 a 50 m deep lake 1400 m south of Vallen was drained. The drainage occurred beneath the ice border towards Vallen. Along this stretch numerous sink holes occur in the moraine-covered ice and the pro-glacial snow banks. The extensive moraine-covered area immediately east of Vallen is largely dead ice with numerous sink holes (fig. 2).

The margins of the Inland Ice shown on the maps attached to this paper correspond to the position in August 1958. The Quaternary geology shown on the map of plate 11 was largely mapped from aerial photographs and checked in the field.

Laboratory methods

Granulometric analyses (figs. 25, 35, and 47) were performed both after the methods of Friedmann (1958) and those of Münzner and

SCHNEIDERHÖHN (1953). As the granulometry of the greywackes presents some difficulties when using Friedmann's method, it was preferred to present the results according to the recommendations of Münzner and Schneiderhöhn. The curves presented are thus mutually comparable, but cannot be compared to those of sieve analyses. For this reason the results have not been recalculated to weight percentages but are given as volume percentages. Although FRIEDMANN has shown the existence of a linear relationship between sieve analyses and thin section measured grain sizes it has not been possible to make the necessary compensations because of the extreme variations in mineral composition of the greywackes.

The statistical demands (200–300 measurements after Friedmann and 1000 after MÜNZNER and SCHNEIDERHÖHN) have been met with in all cases. However, only one section from each sample has been measured and there is thus an error due to possible preferential orientation of the grains. Errors due to layering in the sample have been eliminated unless otherwise stated. Only samples which in thin section seem to be unaffected by tectonization have been measured.

All analyses have been performed by the same technician, so that operator errors, which may be large (GRIFFITS and ROSENFELD, 1954), do not influence the relative results. The linear proportion of matrix was compared to that obtained from modal analyses.

The modal analyses have been made by means of a point-counter. Depending on the relative proportion of constituents between 800 and 3000 points were made. Three operators have been employed in the analyses but generally so that one group of rocks was counted by the same operator.

Mineralogical work has been carried out on a Leitz universal stage. Staining of feldspars has been carried out after the methods of BAYLEY and STEVENS (1960). Carbonates were examined with X-ray diffractometer (MÜLLER, 1964).

Chemical analyses were made by I. SØRENSEN in the Chemical Laboratory of the Geological Survey of Greenland. The methods used have been described by BORGEN (1967) and refined by I. SØRENSEN. Chemical data from carbonate rocks were obtained titrametrically from a HCl-solution of the rock powder. From MgO and CaO proportions stoichiometric $MgCa(CO_3)_2$ have been calculated.

X-ray fluorescense analyses have been made in the Laboratories of the Geological Institute of the University of Copenhagen.

Acknowledgments

The author is greatly indebted to the director of the Geological Survey of Greenland, mag. scient. K. ELLITSGAARD-RASMUSSEN, for permission to publish this paper and for excellent working conditions in Greenland. Also thanks are due to the director of the Mineralogical Museum and the Mineralogical-Geological Institute at the University of Copenhagen, Prof. Dr. A. Noe-Nygaard, for good working conditions during my stay in Copenhagen. Prof. Dr. A. Berthelsen is thanked for his inspiring guidance in the field.

Thanks are directed to the board of the Geological Institute of the University of Aarhus.

All GGU members, past and present, and all colleagues at the Geological Institutes in Copenhagen and Århus are thanked for help and for many valuable discussions. Special thanks in this respect are directed to mag. scient. Niels Henriksen, T. C. R. Pulvertaft B. A., Dr. A. K. Higgins, Dr. F. Kalsbeek, Prof. Dr. H. J. Zwart, cand. mag. Stig Bak Jensen, mag. scient. K. Raunsgaard Pedersen, Dr. W. S. Watt, Dr. D. Bridgwater, and Dr. J. H. Allaart.

Dr. A. K. Higgins kindly corrected the English manuscript.

РУССКОЕ РЕЗЮМЕ

На территории Грэнселанд Юго-Западной Гренландии (фиг. 1) представлена на редкость хорошо сохранившаяся серия осадочных и вулканических отложений среднего докембрия. Эта серия относится к супраструктуре Кетилидского подвижного пояса, насчитывающего 1750—1500 млн. лет, а возрастом главного этапа отложения предположительно считают 1800 млн. лет и более. Кетилидский орогенический комплекс ограничен двумя главными несогласиями: субкетилидским, обнажение которого находится в Грэнселанде, и субгардарским несогласием (WEGMANN, 1938).

Основание кетлидской осадочной толщи в Грэнселанде сложено докетилидскими гнейсами и мигматитами, принадлежащими по меньшей мере к ближайшему из двух предшествующих орогенических циклов. Севернее Грэнселанда, на территории Мидтернэс, кетилидская серия несогласно перекрывает немигматизированные метаосадочные и метавулканические породы тартокской группы (HIGGINS & BONDESEN, 1966). Суб-кетилидское несогласие обнажено более, чем на 15 км. Имеются также следы выветривания и изменения пород, относящиеся к началу осадконакопления. Первые поверхностные отложения представлены маломощными аркозовыми песчаниками и остаточными конгломератами, залегающими в небольших карманах и углублениях на поверхности докетилидских гнейсов. В районах, где первыми водными отложениями являются кварциты и конгломераты, верхняя часть гнейсов, залегающих ниже несогласия, носит пелитовый характер, предполагающий наличие каолинитового выветривания. В центральной части Грэнселанда осадочная серия начинается доломитами, ниже которых происходила глубокая карбонатизация гнейсов и остаточных отложений. Карбонатизация, которая в основном заключается в замещении полевых шпатов карбонатами, проходила по ранее образованной системе трещин. Положение кварца в структуре гнейса осталось неизменным, и текстура самой породы в значительной степени сохранена. Крупные линзы кремня зылегают в измененных гнейсах, а также в доломите.

Литостратиграфически кетилидские отложения можно разделить на группу Валлен (исключительно осадочные породы мощностью около 1100 м.) и группу Сортис (осадочные, основные вуканические и интрузивные породы мощностью 3000 м.) (фиг. 11).

В валленской группе наиболее ранние осадки состоят из маломощных и разбросанных отложений остаточного конгломерата и аркозового песчаника, а в центральной части Грэнселанда они представлены доломитом, сильно пелитовыми ленточными сланцами с трещинами усыхания и ожелезненным доломитом. Эти осадки отлагались в местном, возможно, закрытом бассейне. В центральном Грэнселанде осадочная толща начинается трансгрессивным олигомиктовым конгломератом, цемент которого состоит из магнетита и подчиненного количества кварца и кремневых валунов. Затем следуют полосчатые кварциты с конгломератами; текстурные особенности этих пород указывают на их мелководное происхождение. В настояще время считают, что седиментация на территории Грэнселанд в целом происходила в двух бассейнах, а третий бассейн намечается к северу от нее. Мощный однородный доломит и доломитовые сланцы образуют резкую литологическую границу с кварцитами и намечают дальнейшее расширение этих двух бассейнов. Все вышеотмеченные породы составляют формацию „Зигзагланд" (максимальная мощность 275 м.) валленской группы.

Следующие затем осадочные породы формации „Блоис" (максимальная мощность 800 м.) характеризуются сильными горизонтальными, а также вертикальными фациальными изменениями (фиг. 30), указывающими на заметное изменение условий седиментации. Территория, разделяющая два ранее существовавших бассейна, претерпела трансгрессию. На юге ее однородные черные пелиты вскоре перекрываются мощной толщей сортированных граувакков, или же тонкими пачками полосчатых пелитов и граувакков, характерных для всй остальной площади региона. Верхняя часть формации представляет собой однообразное чередование толстых пачек сортированных граувакков. Нижняя часть блоисской формации содержит конгломерат, называемый „дикий флиш" (аркозовая пачка), который состоит из валунов и обломков различных пород зигзагландской формации, а также гнейсов. Вероятно, этот конгломерат представляет собой подводную осыпь, появившуюся в результате вертикального смещения в порядке 200 метров вдоль разлома, обнаруженного на территории, и который первоначально разделял два бассейна, где формировались зигзагландские отложения. Конгломерат и сортированные граувакки (последние рассматриваются как отложения мутных потоков) свидетельствуют о том, что седиментация происходила в неустойчивой тектонической обстановке.

Самой верхней формацией валленской группы является формация „Грэнсесо" (максимальная мощность 100 м.), которая представляет собой очень характерную осадочную серию. Несмотря на то, что ее нижняя граница скрыта зоной надвига, наблюдения на одном из участков показывают, что эта формация согласно перекрывает формацию „Блоис". Формация „Грэнсесо" состоит из черных углистых сланцев, линзовидных доломитов, черного углистого кремня и, в самой верхней своей части (да и то только на юге территории), из пилитовых сланцев (фиг. 38). Эти сильно углистые осадки свидетельствуют об устойчивой эвксинической обстановке осадконакопления и, возможно, о небольшой глубине бассейна. Содержание углеродных изотопов δC^{13} в доломите, а также наличие углистого материала (Bondesen, Pedersen & Jørgensen, 1967) и содержание углеводородов (Lam & Pedersen, 1968) указывают на биологическую деятельность в период седиментации, что также подтверждается находками организмов сферической формы (*Vallenia*) и многочисленных обломков микроорганизмов.

Группа Сортис в своей нижней части (формация „Фосэльв", мощностью около 1000 м.) представлена мощной толщей подушечных лав, прорванных пластовыми интрузиями основного состава. Количество пирокластического материала очень незначительно, и встречается он только в верхней части формации. Примечательно наличие пласта антрацитового угля, который достигает мощности свыше одного метра. Верхняя часть сортисской группы представлена формацией „Рендестен", низы которой состоят из серии сланцев и доломитов, очень похожих на те же породы формации „Грэнсесо" валленской группы. Отсюда можно заключить, что эвксинические условия осадконакопления преобладали в период выбрасывания подушечных лав фосэльвской формации, и что бассейн в то же время медленно погружался, чем обеспечивалось постоянство условий седиментации. Остальная часть формации „Рендестен" характеризуется мощными пирокластическими отложениями, переслаивающимися с граувакками и сланцами в резких фациальных изменениях. Следует отметить, что граувакки не содержат обломков пород или минералов вулканических отложений. Это дает основание предполагать, что бассейны, или бассейн формации „Рендестен" получал питание из двух различно расположенных источников. Формация „Рендестен" включает большие массивы основных интрузий.

Вулканические породы группы Сортис представлены толеитовыми базальтами (табл. 6), подобными базальтам Лабрадорского прогиба (Baragar, 1960). Интрузивными породами являются габбро толеитового типа, отличающиеся наличием неизмененной первичной роговой обманки и мезостатических микропегматитов. Интрузивные породы встречаются как в меланократовых, так и в лейкократовых разновидностях и местами крайне грубозернисты.

Кетилидская серия на территории Грэнселанд претерпела три последовательных периода деформации и складкообразования. Первый период складкообразования в основном коснулся отдельных стратиграфических горизонтов и сопровождался надвигами. Наклон поверхности основания (фиг. 6) и выход на поверхность кетилидских пород связаны с этим периодом. В это же время произошло образование брекчии в основании комплекса (фиг. 59, 60 и 61). Второй период деформации имел более проникающий характер. Тип и интенсивность складчатости этого времени зависят от податливости испытуемого материала и от занимаемого им положения по отношению к седиментационным бассейнам. Второй период складкообразования также сопровождался надвигами. Третья группа складок обусловлена местным развитием.

Процесс метаморфизма проходил под относительно низким давлением в кварц-альбит-мусковит-хлоритовой и кварц-альбит-мусковит-биотитовой субфациях фации зеленых сланцев (фиг. 66).

На территории встречено несколько генераций метаморфизованных даек. Очень немногие из них пересекают кетилидские отложения. Остальные, хотя и прорывают основание, но не переходят за несогласие; их положение относительно несогласия показывает, что несогласие уже существовало во время внедрения даек. Более поздняя генерация основных даек не претерпела складчатости, но слегка метаморфизована. Многочисленные дайки тингуаитов, микросиенитов и оливиновых долеритов относятся к гардарскому периоду (1000—1200 млн. лет). Образование разрывных нарушений имело место как в кетилидский, так и в гардарский периоды.

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Færdig fra trykkeriet den 30. september 1970

PLATES

Plate 1

Aerial photograph across the border of the Ketilidian supracrustals in Zigzagland. The strongly fissured landscape of the basement gneisses with the eastern amphibolite band on both sides of a pre-Ketilidian fault line covers the lower half of the photograph. Several small dykes are apparent in the gneisses. The small metadyke mentioned on p. 177 is indicated with black. The border of the Ketilidian is seen as a whitish spotted zone (indicated with A), which represents the lower dolomite and the carbonatized gneisses. The zone B is the Varved Shale Member, which is mostly covered in scree from the Ore-Conglomerate Member. The latter is apparent as a dark zone in the lower part of the field C; the rest of this zone is the Banded Quartzite Member. The zone D is the Dolomite Shale Member, whereas E, F and G are the black pelites, the banded greywackes and the graded greywackes respectively. To the right of the fiducial mark at the top of the photograph a large recumbent fold in graded greywackes may be seen (see also fig. 58) and the single units of the greywackes can easily be recognized in the upper left corner.

In the area marked E the thrust zone analysed in fig. 62 and p. 162 is found. Its trend is indicated by the displacement of the small metadyke north-west of the area. Numerous faults which are related to F_2 are seen crossing the border of the Ketilidian and are clearly discernable in the quartzites. These are virtually unfolded. In the upper left corner of the photograph the terminal moraines of Blåisen are seen. Reproduced by permission of the Geodætisk Institute, Copenhagen.

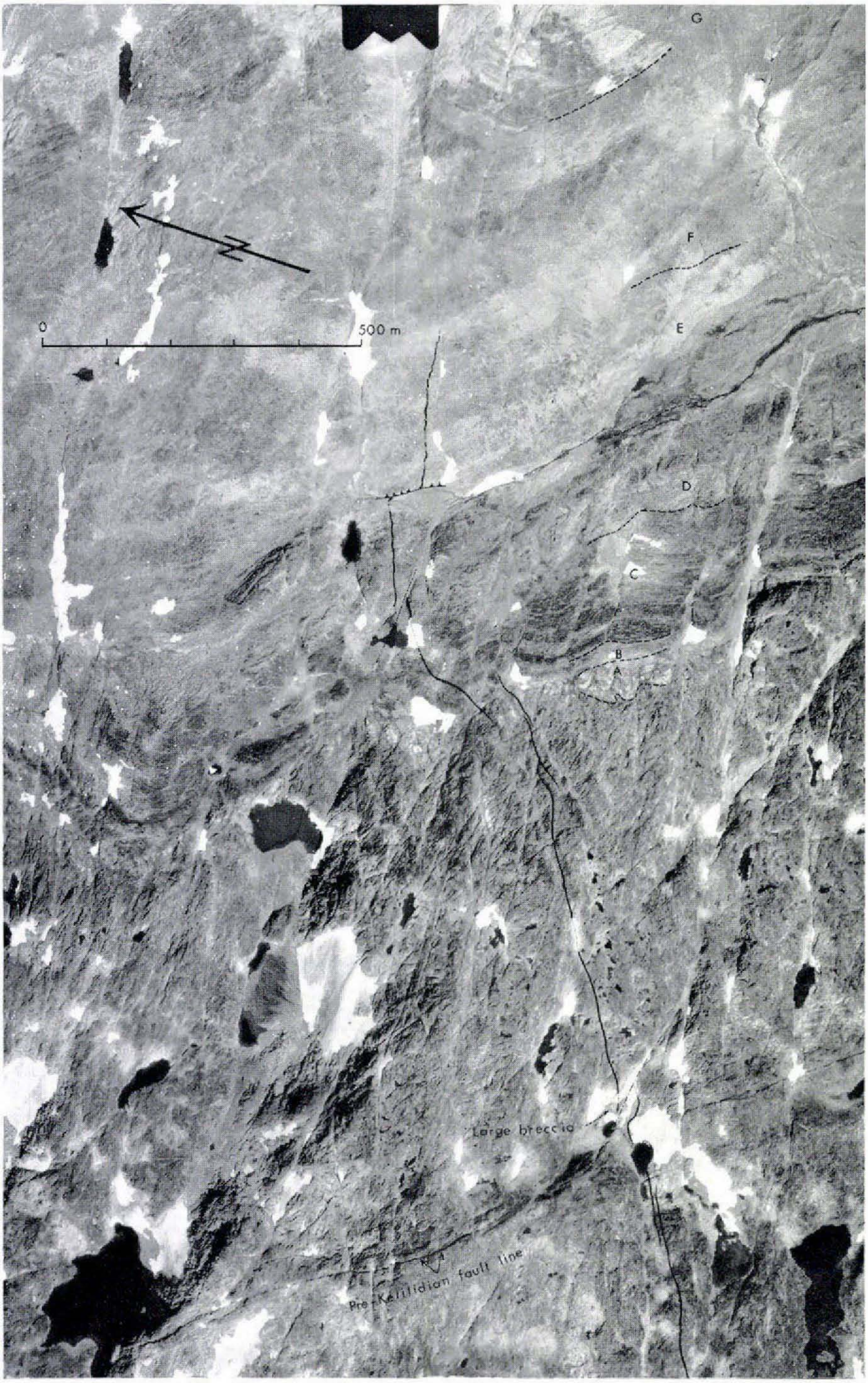

G
F
E
D
C
B
A
0
500 m
Large breccia
Pre-Ketilidian fault line

Plate 2 a

Sample 52976. Nebulitic gneiss. Locality south-west corner of Grænsesø. × 12 – crossed nicols. The specimen is taken a few metres below the sub-Ketilidian surface. The thin section shows quartz in a typical gneiss texture. The feldspars are practically totally altered except for microcline in the centre, and some areas which show vague polysynthetic twinning. The alteration product is fine chlorite-micaceous mass locally containing a little carbonate.

Plate 2 b

Sample 53183. Red-spotted carbonatized arkose. Locality 1 km south of Vallen. × 12 – plane polarized light. The dark grey areas are carbonate minerals enclosing light angular grains of chert finely spotted with opaque material (iron ore) and reddish "drops" (see text p. 46). In some grains idiomorphic magnetite recrystallized from iron chert occurs. In some of the chert grains apatite is found.

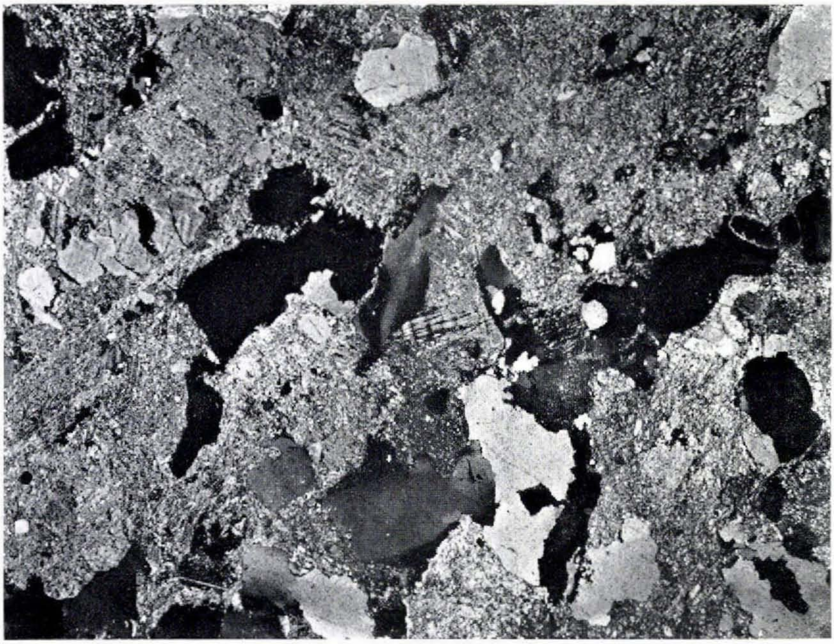


Plate 2 a.

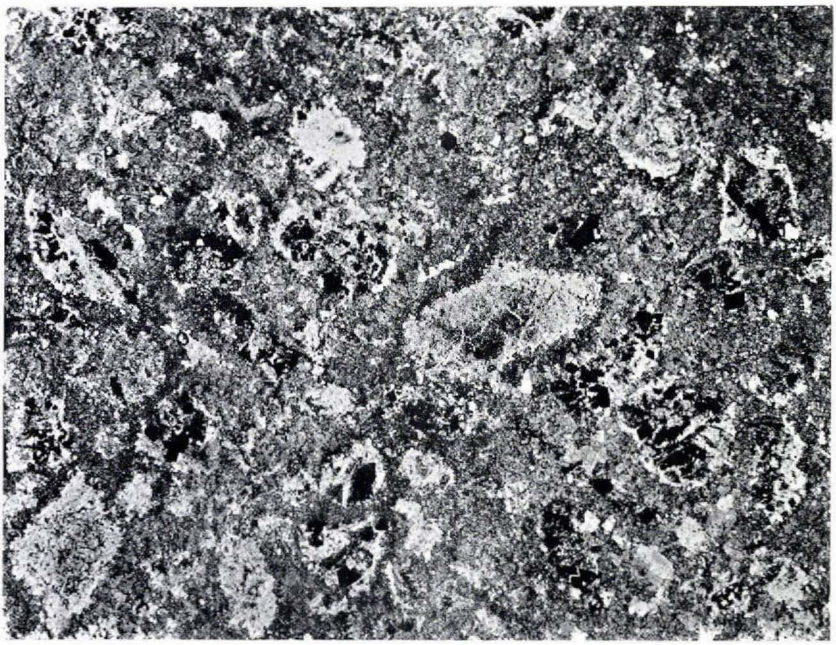


Plate 2 b.

Plate 3 a

Sample 53041. Varved shale from the Varved Shale Member of the Lower Zigzagland Formation. Locality 1.5 km south of Vallen. × 12 – plane polarized light. The photograph shows the minute laminations in a larger graded unit 1.5 cm thick. The pelitic bands (dark grey) show an oriented growth of kink banded mica. The coarser bands (light grey) contain numerous ore grains and only exhibit a very poor cleavage.

Plate 3 b

Sample 53043. Quartzite from the Banded Quartzite Member of the Upper Zigzagland Formation. Locality 2.5 km south of Vallen. × 12 – crossed nicols. The dominance of quartz grains is apparent, but a few microcline and plagioclase grains are also seen. The grains, although slightly recrystallized along their borders, appear to have had rounded shapes. The matrix is dominated by microcrystalline quartz, but carbonate is also present. At the top of the photograph a band of heavy minerals comprising zircon and ore is seen.

Plate 3 a.

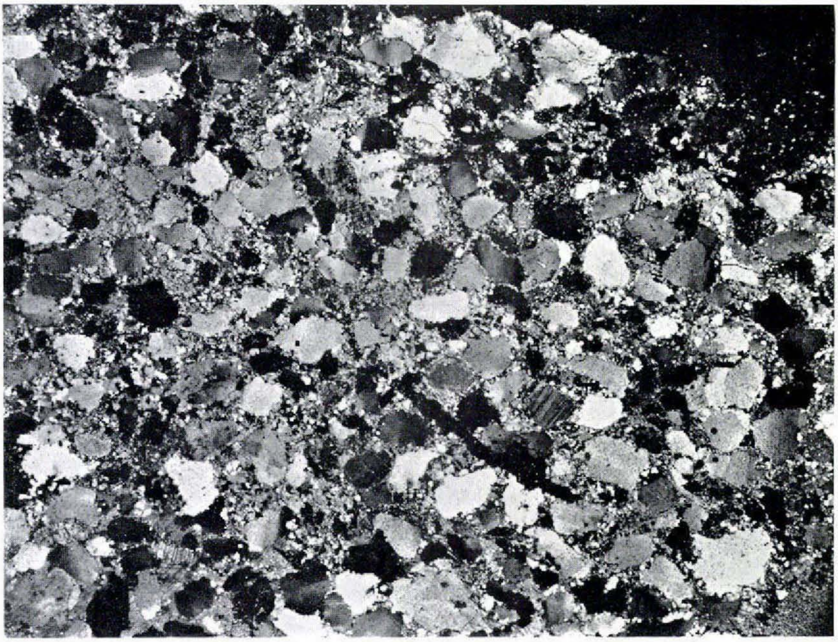


Plate 3 b.

Plate 4 a

Sample 52950. Basal boundary of a graded greywacke unit from the Blåis Formation. Locality immediately south of Grænsesø. × 12 – plane polarized light. The fine top of the preceding unit is dominantly quartz in a fine chlorite-micaceous matrix. The coarse base of the upper unit is composed of densely packed angular, sub-rounded and rounded fragments of various rock types – shale fragments, quartz fragments showing undulatory extinction, plagioclase-microcline aggregates, chert, chert with carbonate, semipelite and feldspar grains. Some of the chert grains are associated with recrystallized ore and opaque material, possibly carbonaceous matter.

Plate 4 b

Sample 52992. Greywacke. Locality at the north coast of Vallen. × 12 – plane polarized light. Unsorted angular and sub-angular fragments are seen closely spaced in a matrix of carbonate, chlorite, mica and microcrystalline quartz. The grains are mainly chert and quartz with undulate extinction.

Plate 4 a.

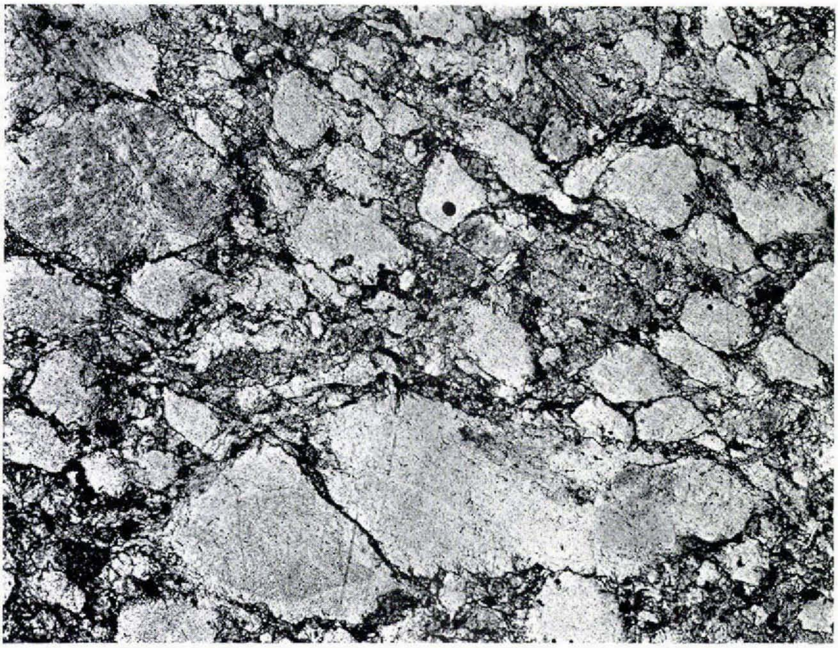


Plate 4 b.

Plate 5a

Sample 53050. Badly sorted fine-grained greywacke from the mixed pelite/semipelite division of the Blåis Formation. Locality 2 km south Vallen. × 12 – crossed nicols. The texture is typical of most greywackes. The large quartz grain in the centre shows undulate extinction and is thus derived from the basement rocks. It has fairly good rounded shapes.

Plate 5b

Sample 53061 – 1. The Vallenia rock. Locality in the Grænsesø Formation north of Grænsesø near the Sioralik glacier. × 12 – plane polarized light. The round fossils are set in a nearly eugranoblastic mass of carbonate grains (dolomite). Opaque carbonaceous material occurs in the fossils and also interstitially in relation to irregular patches. Carbonate also makes up to the fossils. The small white grains and a few larger grains are quartz. For further illustrations of this rock and the fossils see Bondesen et al. (1967), plates 1–6.

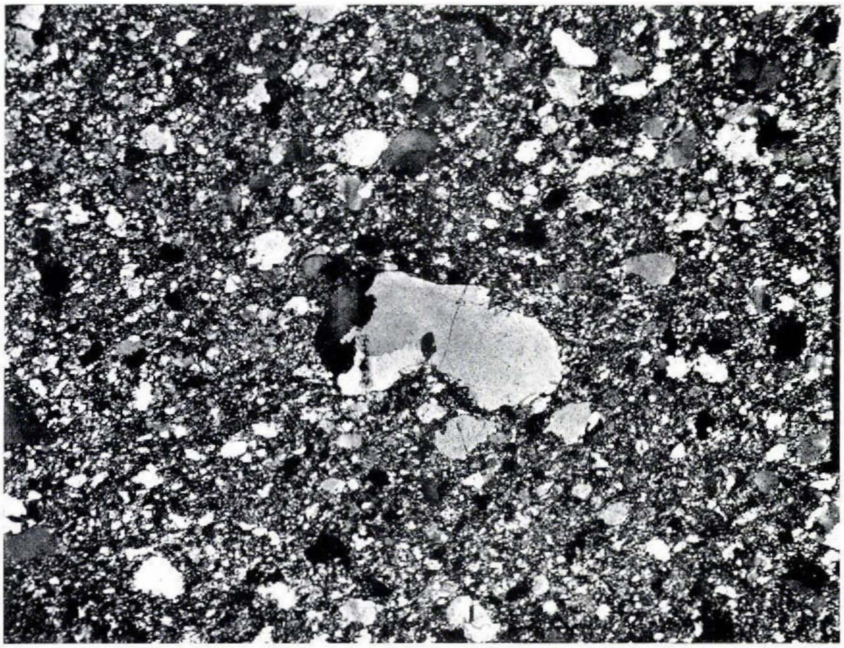


Plate 5 a.

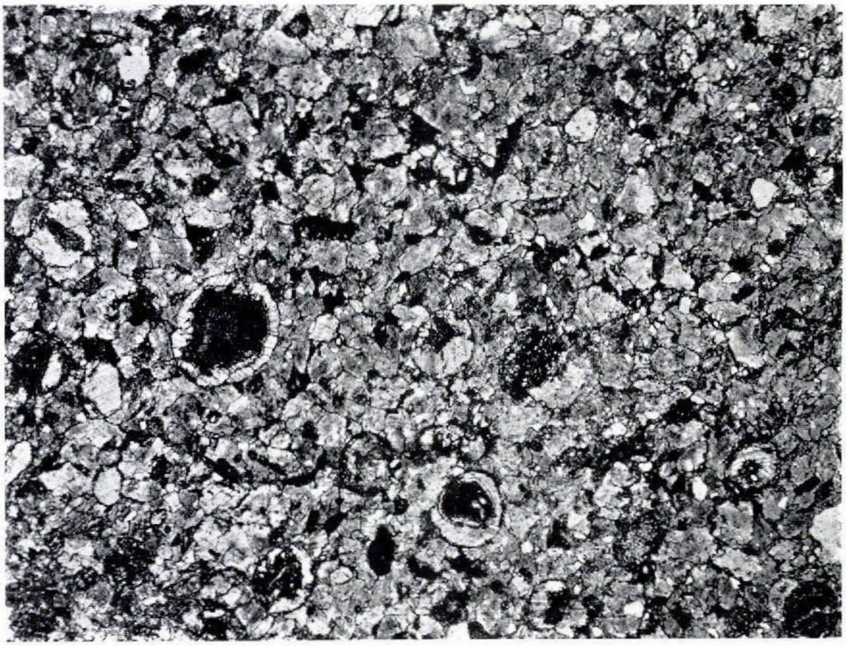


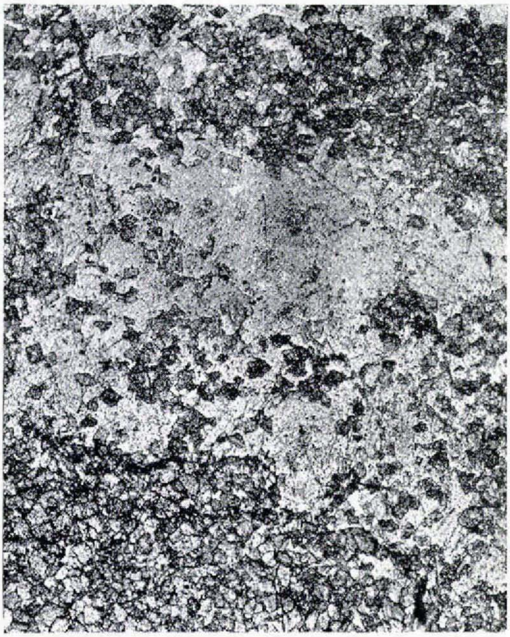
Plate 5 b.

Plate 6 a

Sample 53060. Chert dolomite. Locality in the Grænsesø Formation in the south-east corner of Grænsesø. × 12 – to the right with crossed nicols, to the left with plane polarized light. Two bands of dolomite with chert between them are seen. With the crossed nicols the fine eugranoblastic texture typical of chert is seen.

Plate 6 b

Sample 52999. Lapilli tuffite. Locality 1 km east of Frynsesø in Fønland. × 12 – plane polarized light. The rock shows scattered angular fragments of lava (dark grey) in a mesostasis of oriented fine semi-opaque material, secondary chlorite and epidote crystals. A small fragment below the centre appears to have been rotated in the mesostasis.



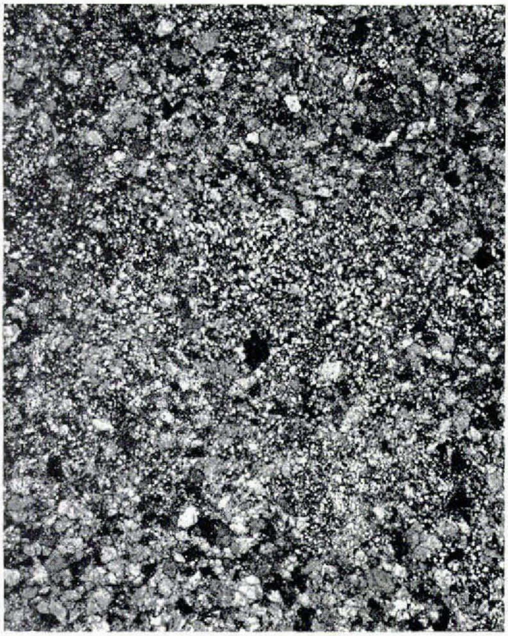


Plate 6 a.

Plate 6 b.

Plate 7 a

Sample 53006. Lapilli tuffite. Locality in the south-east corner of Fønland at the ice border. × 12 – plane polarized light. The rock consists of a dark grey part which possibly represents elongated areas of lava, and a light part, which is a mesostasis of chlorite, quartz, feldspar fragments, carbonate and epidote crystals. Both parts contain large subidiomorphic crystals of pyroxene and lenses of carbonate and chlorite.

Plate 7 b

Sample 53007. Coarse-grained intrusive rock (gabbro). Locality in the south-east corner of Fønland. × 30 – plane polarized light. A large area of late micropegmatite is seen centrally. In the upper right corner a large twinned primary amphibole encloses patches of pyroxene. The twinned individuals show ophitic relations to ore, which locally is altered to leucoxene. The majority of the field in view is altered plagioclase with small idiomorphic clinozoisite crystals and long actinolite needles. In the lower left corner another twinned amphibole individual is evident. The dark border zone to the micropegmatite is mainly chlorite.

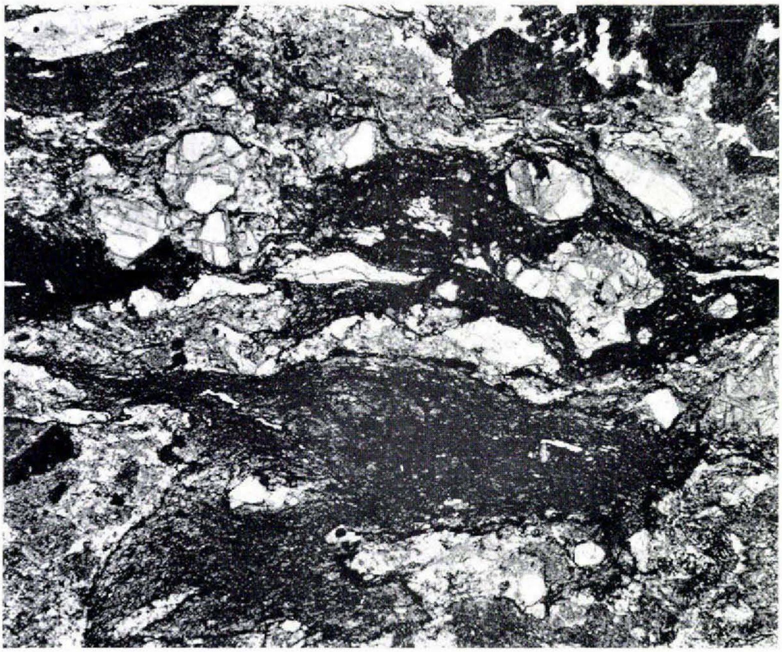


Plate 7 a.

Plate 7 b.

Plate 8 a

Sample 53111. Marginal facies of the melanocratic part of the large intrusive body south-east of Rendestenen. × 12 – plane polarized light. Black areas are ore enclosing small prismatic crystals of a pale greenish pleochroic primary amphibole, of which the cleavage traces may be seen. Grey areas are partly altered amphibole with chlorite and actinolite. White areas are altered feldspar and quartz.

Plate 8 b

Sample 53108. Leucocratic intrusive rock from the large massif east of Rendestenen. × 40 – plane polarized light. The dark grey tabular areas are altered feldspars The light areas are partly altered non-pleochroic amphibole.

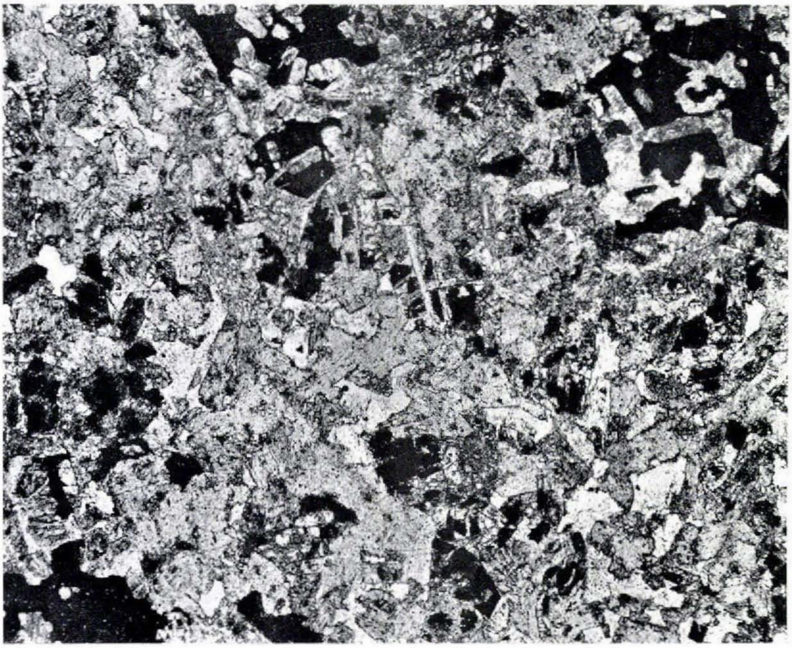


Plate 8 a.

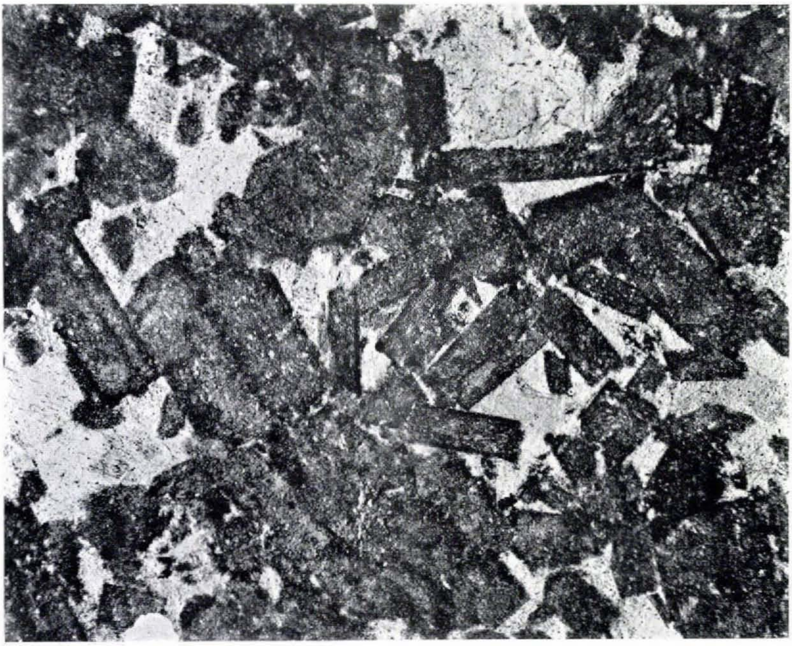


Plate 8 b.

Plate 9 a

Sample 53112. Leucocratic rock from the large intrusion at Rendestenen. × 12 – plane polarized light. The large grains seen are primary amphibole in ophitic relation to areas of altered feldspar. The light grey areas are dominantly chlorite.

Plate 9 b

Sample 53110. From a coarse-grained leocucratic intrusive body south of Rendestenen. × 12 – plane polarized light. A large primary pyroxene encloses strongly altered feldspar exhibiting the ophitic texture of the rock. The pyroxene is locally altered to a fine chlorite-actinolite mass. Ore is seen to enclose quartz.

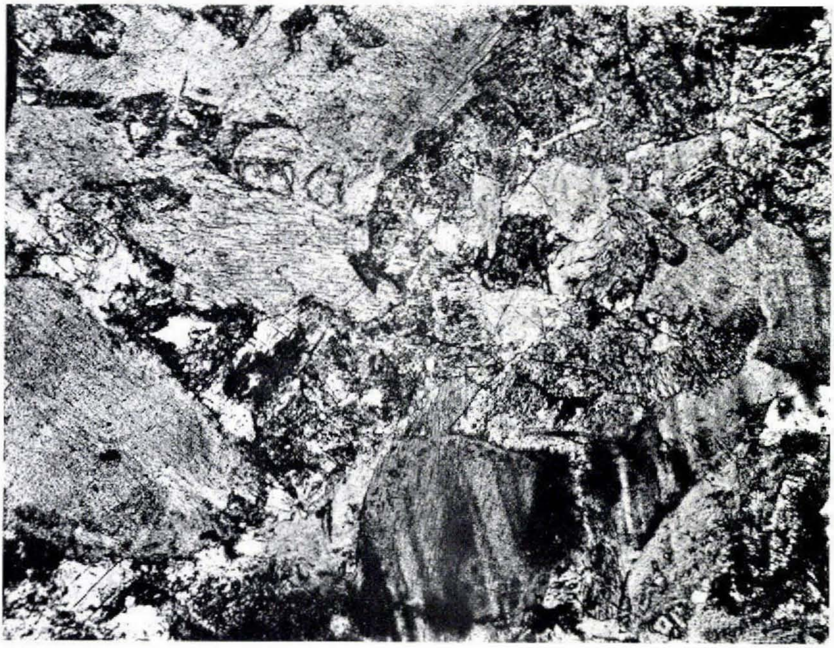


Plate 9 a.

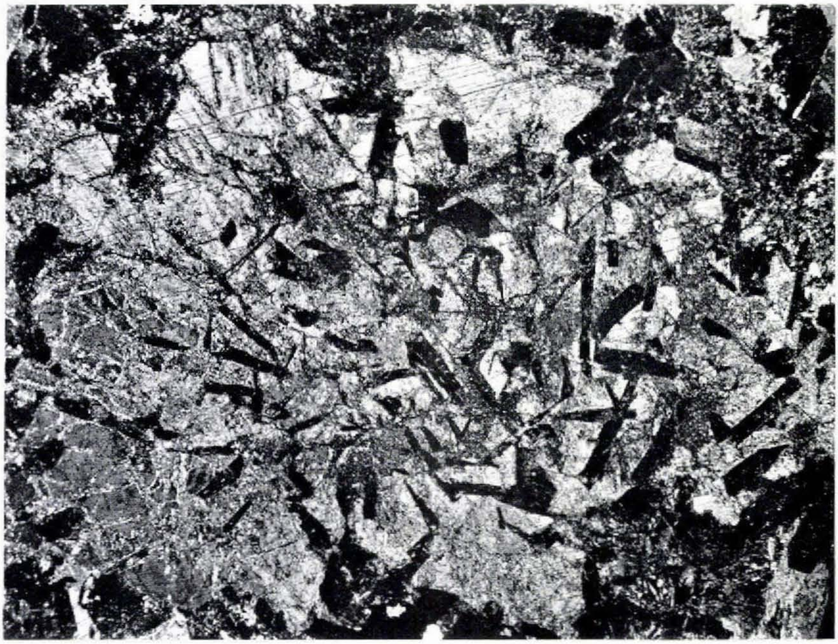


Plate 9 b.

Plate 10 a

Sample 53129. Finely banded semipelite. Locality in the upper part of the Blåis Formation, at the ice border 2 km south of Vallen. × 12 – plane polarized light. The finely banded structure of the rock is clearly seen. Light is mainly quartz and black is partly the pelitic matrix and partly opaque material (ore and carbonaceous matter), which outline a more or less well developed boudin structure of the silty layers.

Plate 10 b

Sample 53104. Varved shale. Locality in the Rendesten Formation immediately west of Rendestenen. × 12 – plane polarized light. The bedding (horizontal) is characterized by a zone of quartz grains in a semi-opaque groundmass. Two diagonal cleavage planes correspond to S_1 and S_2. Small mica flakes are arranged parallel to both planes.

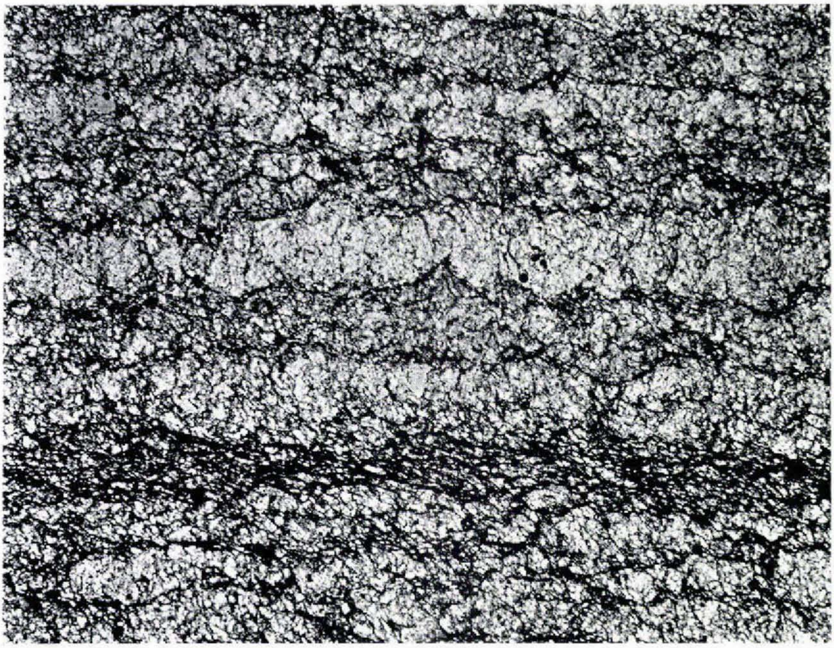


Plate 10 a.

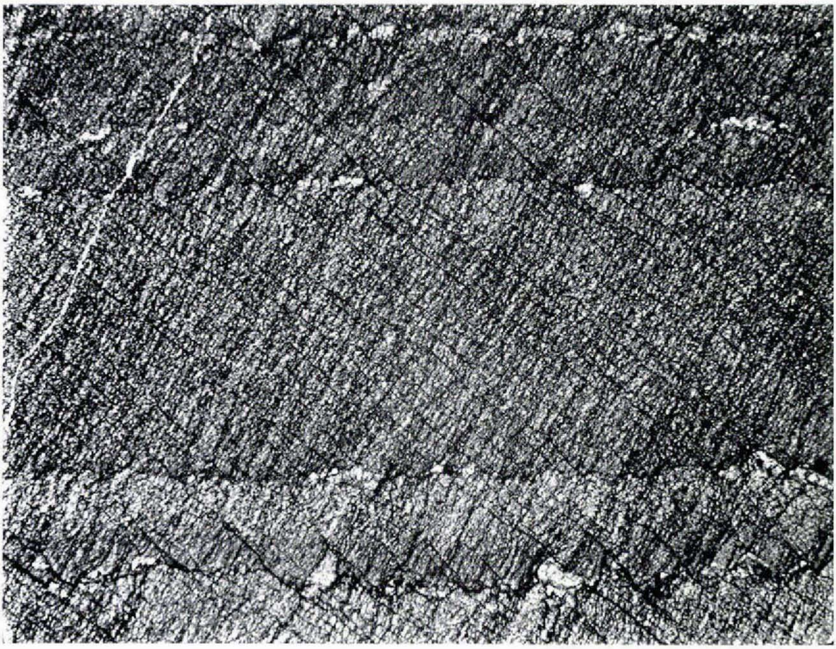
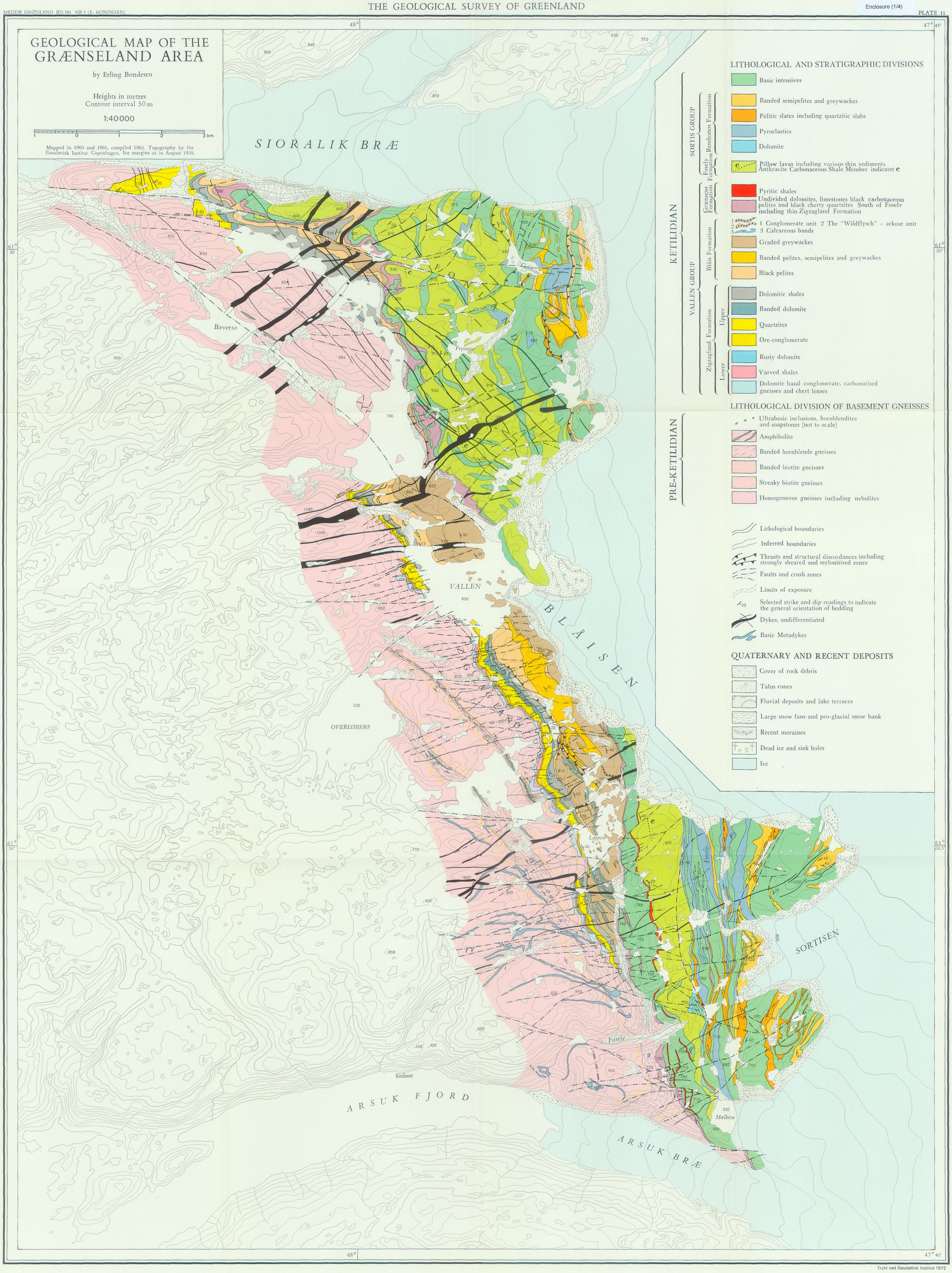


Plate 10 b.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDDR GRØNLAND BD.185 NR.1 (E. BONDESEN)

PLATE 11

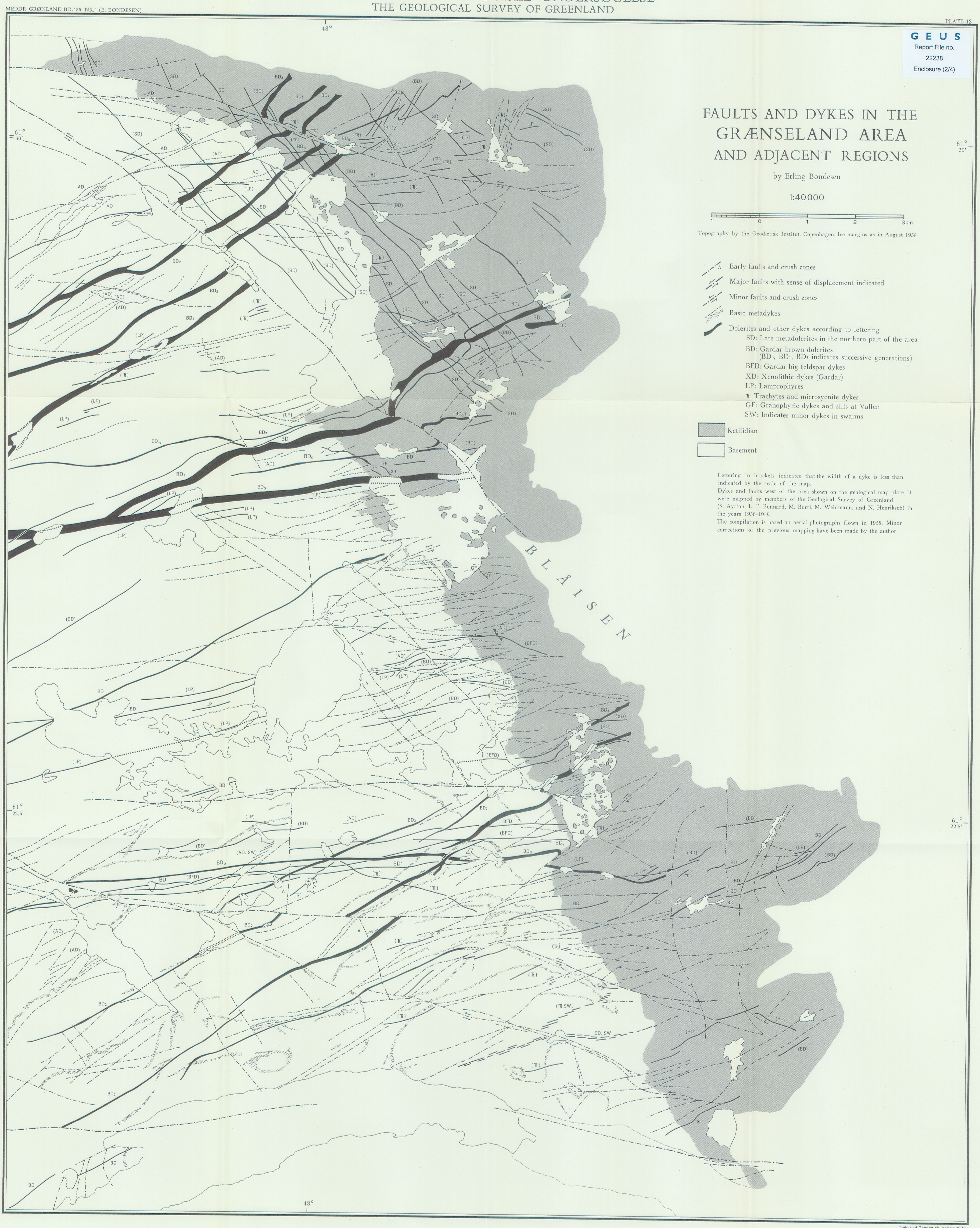


Trykt ved Geodætisk Institut 1972

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND
MEDDR GRØNLAND BD.185 NR.1 (E. BONDESEN)

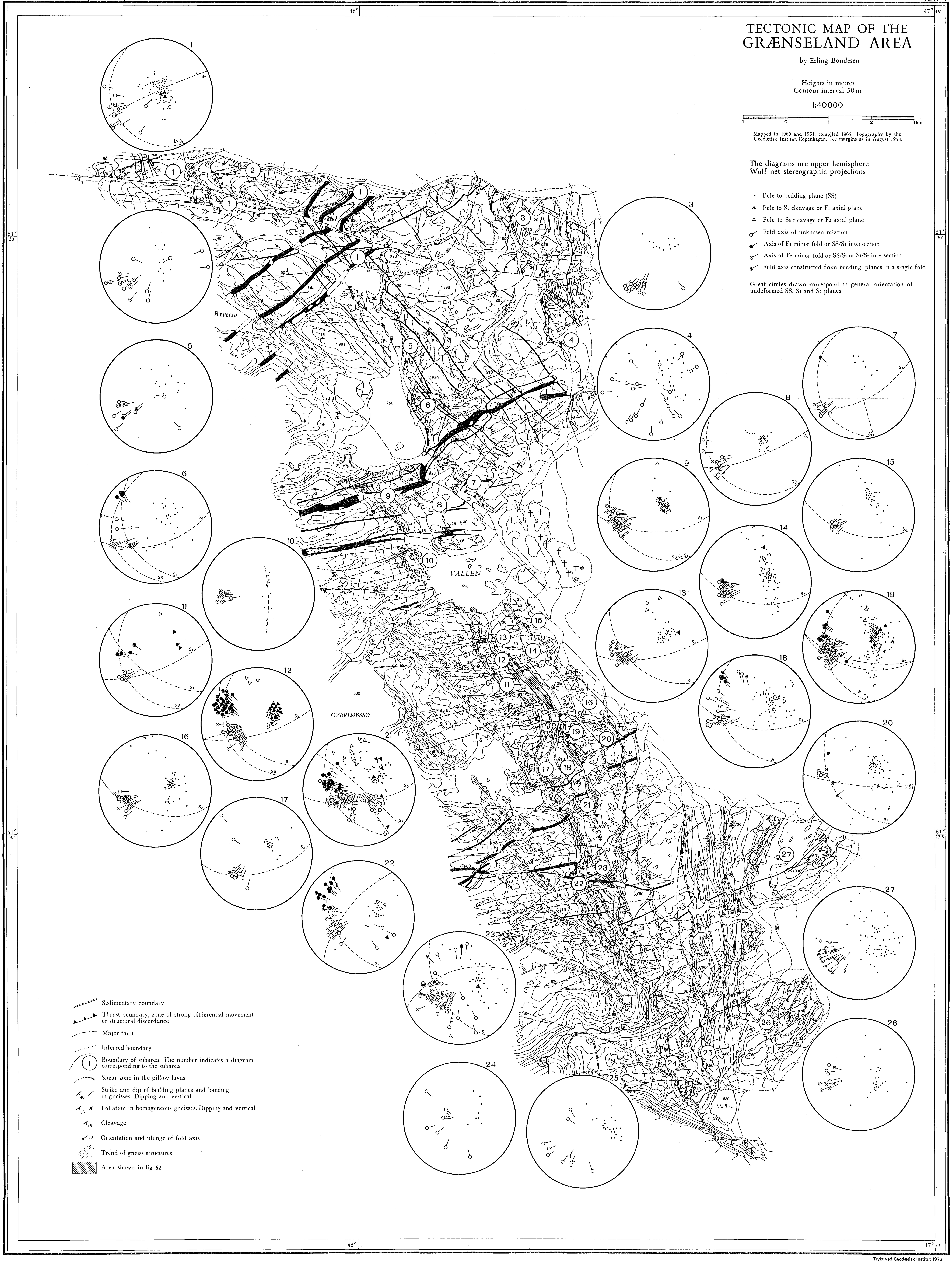
FAULTS AND DYKES IN THE GRÆNSELAND AREA AND ADJACENT REGIONS

by Erling Bondesen



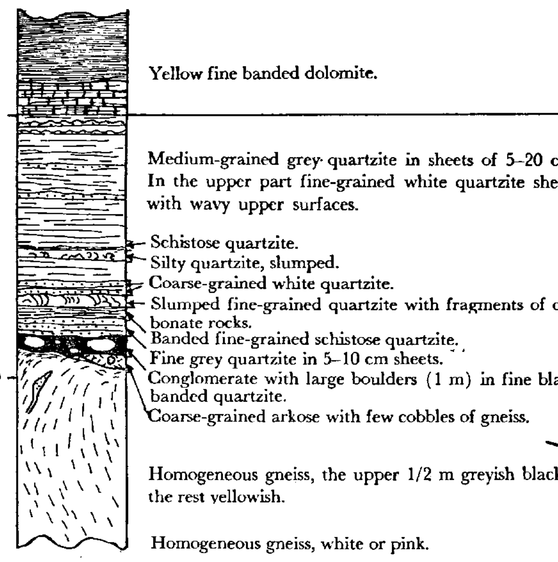
Trykt ved Geodætisk Institut 1972

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

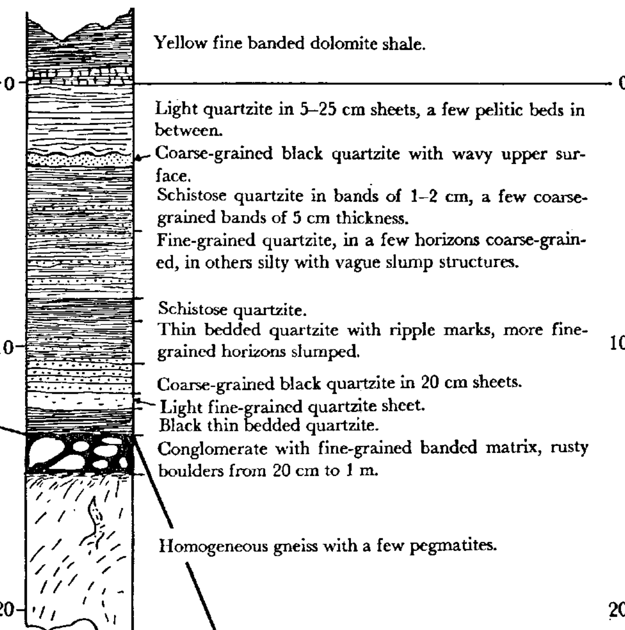


Trykt ved Geodætisk Institut 1972

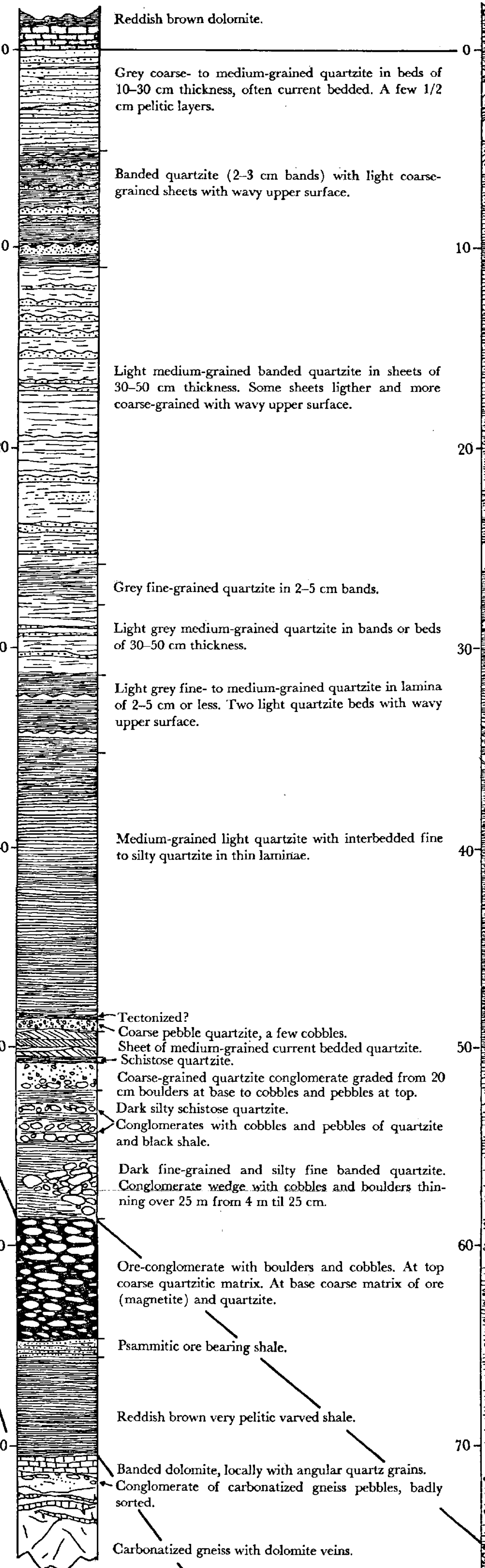
I



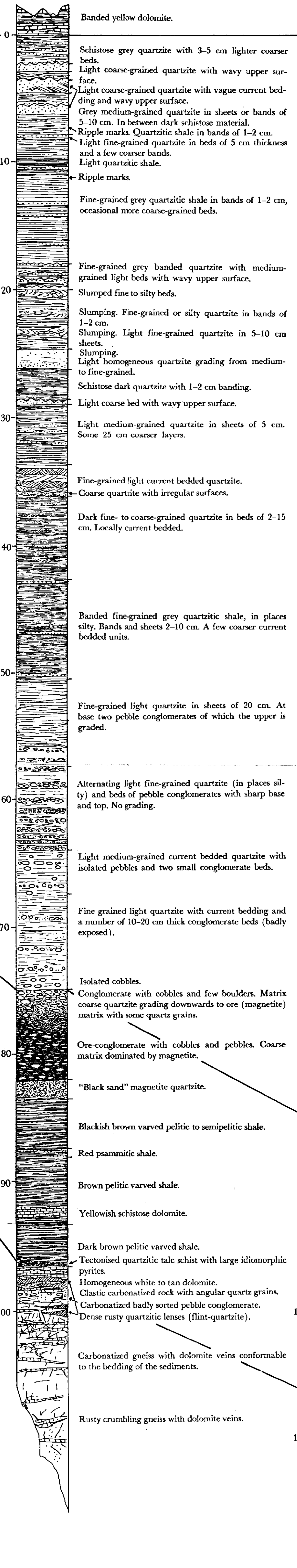
II



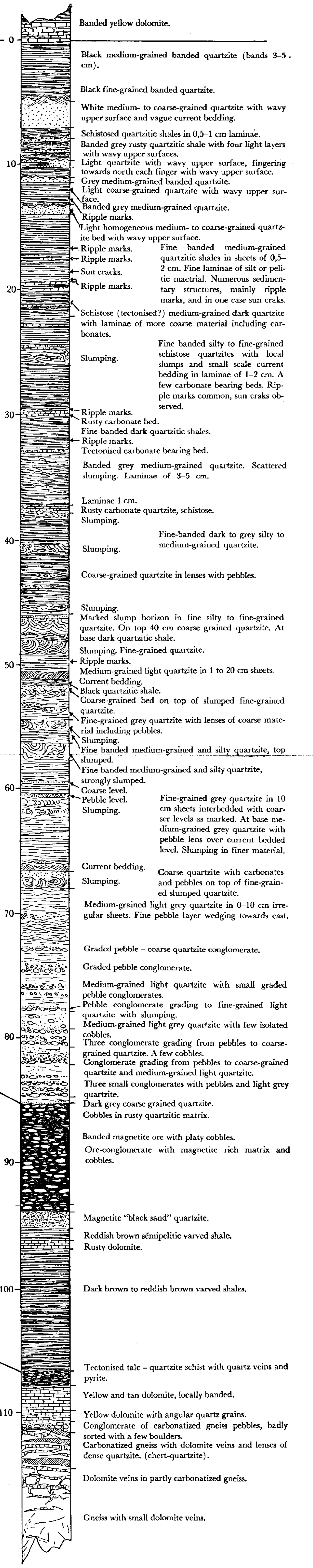
III

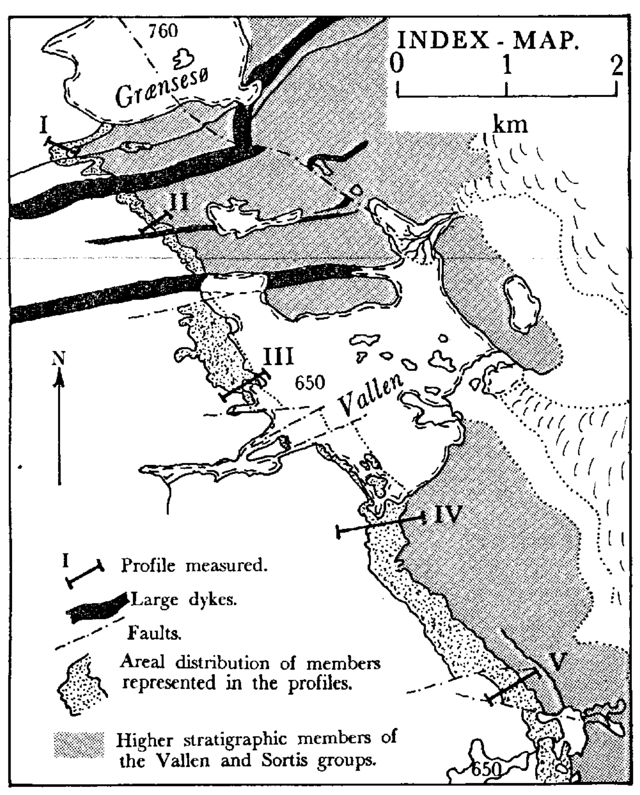


IV



V





Profile I: 8.6 m
– II: 14.6 m
– III: 72.1 m
– IV: 98.4 m
– V: 111.1 m

The profile ornamentation is drawn to illustrate the field appearence of the rocks.

The base of the dolomite shales served as a reference level.

All pebbles and cobbles above varved shales are of quartzite if not otherwise indicated.

FIVE PROFILES in THE ZIGZAGLAND FORMATION