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Precambrian metamorphic complexes in the East Greenland Caledonides (72°–74°N) – their relationships to the Eleonore Bay Group, and Caledonian orogenesis

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Abstract

Results are presented of regional geological reconnaissance and local detailed studies. The new field work, together with isotopic studies, has made possible a provisional reassignment of metamorphic, plutonic and deformational events recorded in the different rock units to Archaean and Proterozoic, as well as Caledonian, orogenic episodes. The infracrustal elements of the 'central metamorphic complex' are considered to be essentially Archaean – early Proterozoic basement gneiss complexes, and are overlain by middle Proterozoic metasedimentary sequences. The late Proterozoic and Lower Palaeozoic sediments have a restricted outcrop at present levels of exposure. During the Caledonian orogeny the late Proterozoic cover sequences appear to have become detatched from their older metamorphic 'basement' along a décollement surface, but the nature of this contact is usually obscured by Caledonian metamorphic effects. The main characteristics of the different rock units are described.

Detailed relationships are illustrated by studies of four areas: Nunatakgletscher–Eremitdal, Knækdalen and adjacent areas, Kap Hedlund, and Tærskeldal–Forsblads Fjord–Randenæs.

Introduction

In the summers of 1975 to 1978 the writers undertook geological reconnaissance studies mainly within the metamorphic complexes of the East Greenland Caledonian fold belt between latitudes 72°–74°N. This was a natural extension of the regional mapping by the Survey in the Scoresby Sund region (70°–72°N) which, apart from production of a series of 1:100 000 map sheets, had also led to significant modification of the classic interpretation of the East Greenland Caledonides (Haller, 1971). The revised view of the fold belt (Henriksen & Higgins, 1976; Higgins, 1976; Higgins & Phillips, 1979) based on the new field work and associated isotopic investigations, emphasises the importance of the pre-Caledonian history of the infracrustal complexes and some of the supracrustal sequences, but also confirms important Caledonian metamorphism, deformation and granite emplacement.

Since 1:250 000 geological maps of the region 72°–76°N were already in existence (Koch & Haller, 1971), as well as many areal descriptions, the new investigations were aimed at specific problems, the main geological results being the subject of this report; preliminary results have been given by Friderichsen & Higgins (1976), Higgins *et al.* (1977) and Higgins & Friderichsen (1979). Regional metamorphic studies are the special interest of the third author (Thyrsted, 1978). In cooperation with the Department of Earth Sciences, University of Leeds, collecting was undertaken for detailed isotopic studies (Rex *et al.*, 1976, 1977; Higgins *et al.*, 1978; Rex & Gledhill, this report), and these provide the framework for the geological interpretations. Related investigations carried out by other workers include

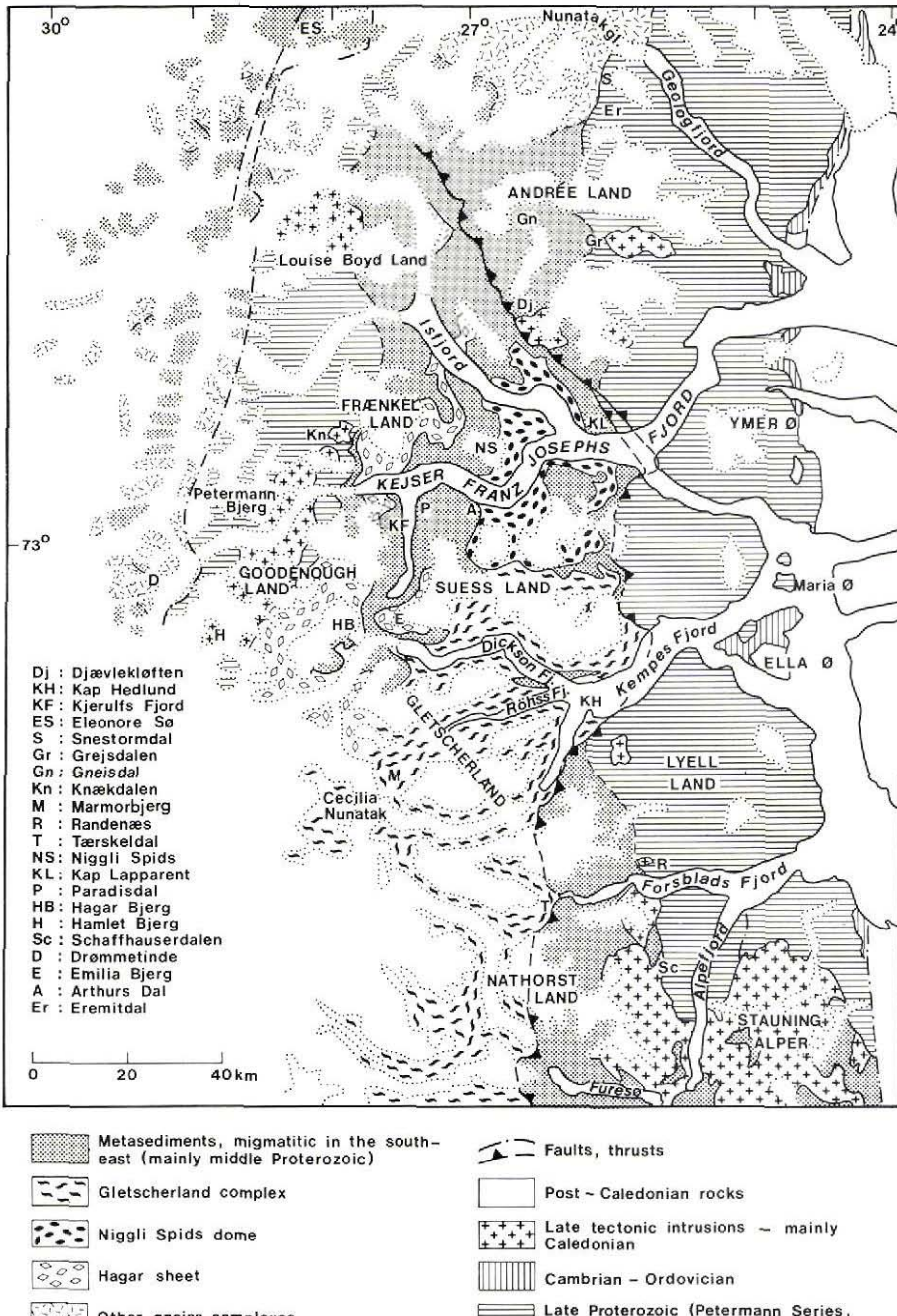


Fig. 1. Geological map of the region 72–74°N showing distribution of the principal litho-structural units.

stratigraphic and stuctural studies in the Lower Eleonore Bay Group (Caby, 1976a), and the Lower Palaeozoic succession (Frykman, 1979).

Earlier work had already established the existence and extent of the principal gneiss complexes and rock sequences (see e.g. Koch & Haller, 1971; Haller, 1971), and the main results of the new field work and isotopic studies have been a provisional reassignment of metamorphic, plutonic and deformational events recorded in the different rock units to Archaean and Proterozoic, as well as Caledonian, orogenic episodes. The ages assigned to the different rock units in this account refer to the period when each is believed to have acquired its essential petrological and structural character, though in adopting this approach it is emphasized that the older units have suffered some degree of reworking in one or more subsequent orogenic episodes. For descriptive purposes the following distinctions are made (fig. 1):

A. Archaean – early Proterozoic basement gneiss complexes. These are represented by the three infracrustal elements of the 'central metamorphic complex' (Gletscherland complex, Hagar sheet, Niggli Spids dome), together with less precisely defined areas in northern Andrée Land and the nunatak region in the west.

B. Middle Proterozoic metasediments, migmatites and granites. Metasediments are widespread. In the northern half of the region and in the nunataks in the west they overlie and are interfolded with the older gneiss complexes. In the south-east they are mainly migmatitic and are invaded by middle Proterozoic as well as Caledonian granites. A and B together make up the 'central metamorphic complex' and 'western metamorphic complex' of early workers (see e.g. Haller, 1971).

C. Late Proterozoic and Lower Palaeozoic sediments. The former include the Petermann Series in the west and Eleonore Bay Group and Tillite Group in the east, in both areas outcropping in N–S trending zones. Lower Palaeozoic sediments overlie the Tillite Group.

D. Caledonian orogenesis. Deformation, metamorphism and plutonism were widespread in the region during the Caledonian orogeny, but in our view less intense and deep-seated than in the classic interpretation (Haller, 1971).

This report presents an account of regional observations based on reconnaissance work followed by more detailed local studies of critical areas.

Regional Geology

Archaean – early Proterozoic gneiss complexes

The earliest visitors to the region 72°–74°N assumed a 'primitive' or Archaean age for crystalline rocks of the inner parts of the fjords (Nathorst, 1901; Nordenskjöld, 1907), as did later British and American expeditions who drew comparisons with the Lewisian gneisses of Scotland (Wordie, 1927; Parkinson & Whittard, 1931; Odell, 1939, 1944). However, geologists working with Lauge Koch's expeditions drew attention to the involvement of all rock units in the Caledonian orogeny (Backlund, 1930, 1932; Wegmann, 1935). An excellent summary of the evolving viewpoints is given by Haller (1971). By the time Lauge Koch's nearly 30 years of geological expeditions were brought to a close in 1958, more or less detailed geological maps and descriptions of the infracrustal complexes had been published, and the concept of a Caledonian 'stockwerke' model of development apparently firmly established. This classic concept, most clearly presented by Haller (1971), envisaged

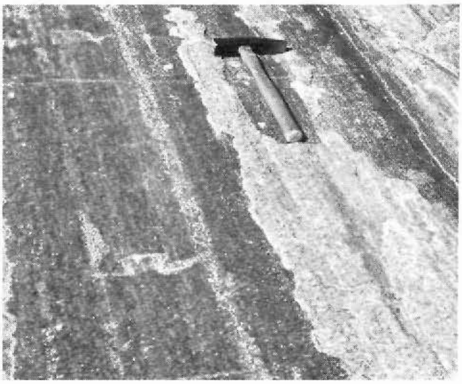


Fig. 2. Strongly lineated foliation plane of augen gneiss in central Suess Land.

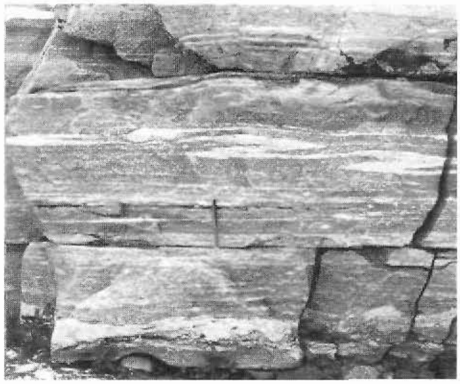


Fig. 3. Cross-section of foliated augen gneisses in central Suess Land showing isoclinal folding of leucocratic veins; the fold axes are parallel to the lineation of fig. 2.

the spectacular involuted nappe, dome and mushroom shapes of the infracrustal complexes to have been created during the ascent of highly mobile Caledonian fronts of migmatisation into the surrounding sediments. Thus the infracrustal complexes were regarded as essentially younger (not older) than their sedimentary cover, though it was allowed that major parts represented 'transformed' pre-Caledonian basement rocks (Haller & Kulp, 1962, fig. 3) and that some of the transverse fold trends were 'inherited' from the old basement (Wegmann, 1935; Haller, 1971).

Isotopic studies in the Scoresby Sund region (70°–72°N) have yielded Rb-Sr whole rock and zircon ages in the range 2935–2300 m.y. (Rex & Gledhill, 1974; Steiger & Henriksen, 1972; Steiger *et al.*, 1979) in the southern extension of the 'central metamorphic complex'. In the region 72°–74°N essentially similar rock types have mainly yielded early Proterozoic Rb-Sr whole rock ages (see below), and the writers conclude that the essential petrological and structural character of the infracrustal complexes is largely a reflection of pre-Caledonian orogenic events; however, they have certainly suffered appreciable metamorphism, deformation, and in part remobilisation, during the Caledonian orogeny. The Gletscherland complex, Hagar sheet and Niggli Spids dome are three well-established infracrustal units in the region 72°–74°N (see e.g. Haller, 1971), and the names are retained here for descriptive purposes although a fundamental difference in origin and development from that originally proposed is assumed.

Gletscherland complex

The Gletscherland complex extends over most of Gletscherland, the southern half of Suess Land, and continues southwards into Nathorst Land. Its principal geological features have been described by Haller (1955, 1971) and Zweifel (1959). The eastern border from Tærskeldal to Kap Hedlund (fig. 1) is a prominent late thrust or fault, which separates the infracrustal complex from younger migmatitic sediments to the east.

The Tærskeldal area at the west end of Forsblads Fjord is considered later in more detail. The rocks represented include banded hornblende gneiss, homogeneous granitic gneiss and plentiful amphibolite, which are cut by amphibolite dykes. The gneisses have yielded an approximate isotopic 'age' of 2450 m.y. (Rex *et al.*, 1976).

Dickson Fjord, the longest of the fjords dissecting the Gletscherland complex, exhibits a great variety of well-banded, biotite gneiss, hornblende gneiss, mica schist, amphibolite and granitic layers and lenses. Major E–W trending folds dominate the fjord, and are spectacular in the cliffs of Suess Land.

Röhss Fjord and Rhedin Fjord exhibit comparable fold trends and rock types. Hornblende gneisses and amphibolites are very common in Röhss Fjord, and a major dioritic body outcrops on the south side of the outer part of the fjord. Diorites and gneisses from Kap Hedlund have yielded Rb-Sr isochron ages of 1705 and 1830 m.y. (Rex *et al.*, 1976).

The north side of Kempes Fjord is dominated by outcrops of massive augen gneiss, grading westwards into banded and veined gneisses at the mouth of Dickson Fjord. In central Suess Land the same features are seen, foliated and strongly lineated augen gneiss units (figs 2 & 3) alternating with biotite and hornblende gneisses and amphibolites. East–west trending folds and lineations dominate (fig. 4).

Discordant amphibolite dykes, a common and characteristic feature of many old gneiss terrains, are most conspicuous in the Tærskeldal region. Notable examples also occur at Kap Hedlund, and on both sides of inner Röhss Fjord.

East–west trending major and minor structures dominate the Gletscherland complex (fig. 4) and form the transverse structural trends of Wegmann (1935) and Haller (1955, 1971), which, because they conflicted with the regional N–S Caledonian trends were interpreted as 'inherited' from the old basement (presumed transformed). We view the structures as an early Proterozoic deformation pattern within an intact region of old gneiss basement. Wegmann (1935, p. 26) admitted the possibility of this interpretation, but with the provisor that this could hardly be so because of the relics of sedimentary rocks within the complex which he, and many subsequent workers, believed to be representatives of the Lower Eleonore Bay Group.

A variety of metasedimentary rock units are found within the Gletscherland complex, notably marble bands and mica schist units, but these are considered to be parts of a sedimentary sequence considerably older than the Eleonore Bay Group. Some of the numerous bands of 'biotite gneiss' and 'mica schist' shown on published maps of the complex (Haller, 1955; Koch & Haller, 1971), are rusty coloured, sheared gneisses.

Hagar sheet

The Hagar sheet extends from western Gletscherland, where it adjoins the Gletscherland complex, northwards through Goodenough Land, part of Suess Land and into Frænkel Land (fig. 1). It has the general form of an extensive nappe of infracrustal rocks (Haller, 1955; Wenk & Haller, 1953), overturned eastwards and enveloped by supracrustal rocks with which it is frequently intricately folded.

Near Marmorbjerg in western Gletscherland the Hagar sheet comprises banded biotite and hornblende gneisses, nebulitic veined gneisses, granitic gneisses and foliated granites. Several small periodotite bodies have also been noted. The gneisses are intensely folded,

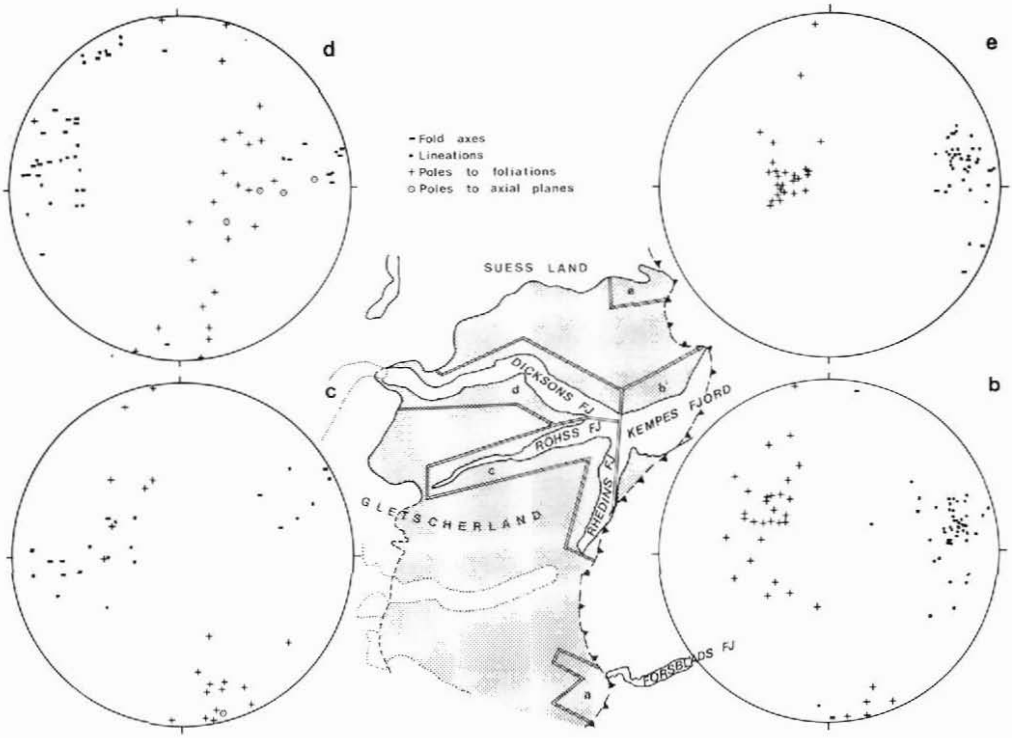


Fig. 4. Stereograms (equal area, lower hemisphere plots) of planar and linear structures in the Gletscherland complex. Plots of subarea a (Tærskeldal) are given in fig. 30.

three distinct fold phases occurring in some areas, and trends of fold axes and lineations are variable. Numerous semiconcordant to markedly discordant amphibolite dykes cut the gneisses, post-dating some of the folding, but themselves being folded; however, many dykes still preserve chilled margins, relic ophitic textures and feldspar xenocrysts.

North and east of Hagar Bjerg, the same variety of rock types occur, though here the infracrustal rocks are tightly folded with the overlying supracrustal rocks. A discordance between banded gneisses and rusty quartzites and schists is locally preserved. Emilia Bjerg (fig. 5) is formed by a major body of strongly foliated and lineated granitic gneiss, which has yielded two Rb-Sr isochron ages of *c.* 1900 m.y. (Rex & Gledhill, this report). Amphibolite dykes are conspicuous in the granite locally, and up to 15 m thick. Lineations in the region have a general NW to NNW trend.

The Hagar sheet is well exposed in the inner part of Kejser Franz Josephs Fjord, where it consists of a variety of gneisses, amphibolite units and discordant amphibolite dykes (described in detail in a later section). A granitic gneiss body at the east margin of the sheet, closely resembling the Emilia Bjerg body, has yielded a very similar Rb-Sr isochron age (Higgins *et al.*, 1978). Lineations and fold axes are dominantly N–S trending.

The five Rb-Sr whole rock isochron ages so far obtained from Hagar sheet rock units range from 1980–1725 m.y. (Higgins *et al.*, 1978; Rex & Gledhill, this report), and suggest significant early Proterozoic orogenic activity. The interfolding of basement and cover

Fig. 5. The Emilia Bjerg granitic gneiss on the north side of Dickson Fjord with Hisinger Gletscher in the foreground. The nappe-like body of foliated granitic gneiss is cut by several dark amphibolite dykes, and is part of the Hagar sheet infracrustal unit. The sample collections used in the isotopic work which gave ages of *c.* 1900 m.y. (Rex & Gledhill, this report) came from the valley beyond the left edge of the photograph, and the slopes at the right. Mountain summits reach *c.* 2000 m.

Fig. 6. View from Frænkel Land eastwards across Kejser Franz Josephs Fjord to Payer Tinde (2320 m) in Suess Land. The light-coloured, well-foliated, granitic gneisses and augen gneisses of the Niggli Spids dome are conformably overlain by dark-coloured metasediments.

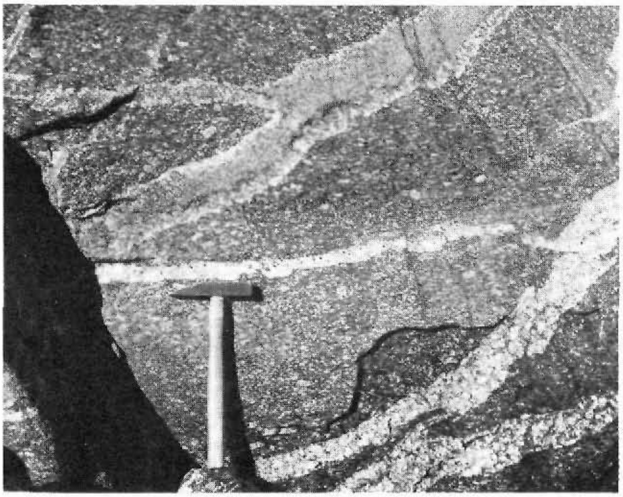


Fig. 7. Augen gneisses of the Niggli Spids dome at the north coast of Kejser Franz Josephs Fjord, cut by several generations of granitic veins.

lithologies may reflect a middle Proterozoic deformation event, but if so it has not been recorded in the Rb-Sr whole rock systems of the basement units. However, mineral ages on all rock units are Caledonian, reflecting a regional Caledonian metamorphic overprint (D. C. Rex, personal communication).

Niggli Spids dome

A dome-shaped mass of mainly granitic gneisses outcrops in northern Suess Land, eastern Frænkel Land including Niggli Spids, and in part of south-west Andrée Land (fig. 1). Its structure and petrology have been described by Haller (1953, 1955, 1971).

The dominant rock types are homogeneous, well-foliated granitic gneiss, augen gneiss and porphyritic granodioritic gneiss. They form spectacular outcrops on steep fjord walls (fig. 6), exhibiting a large scale banding of lighter and darker units. All the rock types appear to have been derived from plutonic rocks, and have now variable textures and complex relative age relationships. In some outcrops granitic gneiss sheets cut the augen gneisses, but all rock types are dissected by a variety of granitic and pegmatitic veins (fig. 7). Amphibolite bands and hornblende-rich gneisses are of minor importance, but are well-foliated and concordant to the regional banding.

The general structure is superficially simple, notably in the steep cliff sections of Kejser Franz Josephs Fjord (fig. 6). The metasediments dip off the dome of gneisses to the north, east and west, while in the south the augen gneisses merge with the Gletscherland complex in central Suess Land. Lineations trend between N–S and NE–SW, parallel to the axes of occasional mesoscopic folds. Haller (1971) distinguishes a number of major N–S trending folds.

The Niggli Spids dome is assumed to be an infracrustal basement unit, older than the overlying metasediments, and possibly of the same age of formation as the Gletscherland complex or Hagar sheet. Isotopic studies have not, however, yet confirmed this assumed age (Rex & Gledhill, this report).

Northern Andrée Land

A zone of infracrustal rocks occurs west of the Eleonore Bay Group outcrop in northern Andrée Land, mainly in Snestormdal and parts of Eremitdal, though the western limits of the zone are not well defined. The principal rock units are gneisses, amphibolites, granite and granitic augen gneisses; they are described in more detail in a later section. The augen gneisses resemble very closely those of the Niggli Spids dome, and it seems most probable that the zone of infracrustal rocks is part of another basement gneiss complex of much the same age as those described above.

Nunatak zone

Infracrustal rocks are known in several parts of the nunatak zone between latitudes 72°50′ and 74°N, and have been denoted on Koch & Haller's (1971) maps as migmatite gneiss and synorogenic granite, and described by Haller (1956). Some of these areas have been revisited by the writers, and a few observations are given below. Only K-Ar mineral ages are so far available from these locations, and testify to involvement in the Caledonian orogeny. The rock types encountered and their geological history, however, most closely resemble those of the Archaean – early Proterozoic basement gneiss complexes further east and south-east.

South-west and west of Petermann Bjerg several areas of infracrustal rocks were visited. One locality proved to comprise regularly banded granitic gneisses with occasional thin amphibolites. Rock units from Drømmertinde have previously been described as fine to medium-grained, migmatite granite (Haller, 1956), and where examined at a col east of the summit the most conspicuous rock was a very coarse-grained, granitic, augen gneiss.

North-west of Eleonore Sø (*c.* 74°N; fig. 1), Katz (1952a) described a white to red, two-mica, foliated granite. At one locality visited banded gneisses with occasional layers of foliated amphibolite were encountered.

Middle Proterozoic metasediments, migmatites and granites

Metasedimentary sequences overlie and are interfolded with the infracrustal complexes throughout the region (fig. 1), occurring most extensively in the nunatak region, around Kejser Franz Josephs Fjord and Isfjord, in Andrée Land, Lyell Land and eastern Nathorst Land. These supracrustal rocks were at one time considered the metamorphic representatives of the late Precambrian Eleonore Bay Group, but an increasing amount of isotopic evidence points to their having been involved in middle Proterozoic orogenic activity. This implies not only that sedimentary sequences older than the Eleonore Bay Group are widespread, but that some of the orogenic activity attributed to the Caledonian epoch is of earlier date.

Comparable relationships were first proposed in the Scoresby Sund region (70°–72°N), where in the west, Archaean gneiss complexes are overlain by several thousand metres of psammitic and pelitic metasediments (Krummedal supracrustal sequence) which have yielded Rb-Sr whole rock isochron and monazite ages suggesting a metamorphic event *c.* 1100 m.y. ago (Hansen *et al.*, 1978). In the eastern part of the inner Scoresby Sund region the Krummedal supracrustal sequence is extensively migmatised and invaded by granites, an early suite of augen granites isoclinally folded with the migmatites having yielded Rb-Sr whole rock and zircon ages of 987 and 1053 m.y. respectively (Steiger *et al.*, 1979). This migmatitic zone is 90 km wide in the Scoresby Sund region, but north of latitude 72°N the outcrop narrows between the Eleonore Bay Group in the east and a prominent thrust in the west (fig. 1), and it pinches out at Kap Hedlund (Plate 1c). The zone may reappear in Andrée Land, in a less migmatitic state. This middle Proterozoic orogenic activity corresponds in time with the Grenville-Sveco-Norwegian events of North America and Europe.

Attempts to date the metasediments between 72°–74°N isotopically have met with limited success, but a main metamorphic event at *c.* 1000 m.y. is suggested (Rex & Gledhill, this report). Unpublished K-Ar mineral ages are mainly Caledonian with a number of older ages, reflecting possibly excess argon (D. C. Rex, personal communication).

The present intricate dome and nappe-like forms of the infracrustal complexes, enveloped by middle Proterozoic metasedimentary sequences, may have developed during the middle Proterozoic orogenic event. In many ways the forms they assume resemble classic mantled gneiss domes (Eskola, 1949), for which a conduction/convection mode of genesis has been suggested. Talbot (1979) has presented a thermal convection model specifically for the infrastructural upwellings in East Greenland which could explain the intricate forms assumed by the old basement complexes.

The main features of the middle Proterozoic sedimentary sequences in different areas are given below.

Isfjord, Kejser Franz Josephs Fjord, Kjerulfs Fjord

The fjord walls of inner Kejser Franz Josephs Fjord, Isfjord and Kjerulfs Fjord preserve excellent sections in the metasediments overlying and interfolded with the infracrustal complexes.

While usually appearing to be concordant, the metasediment-basement gneiss contact is occasionally markedly discordant. The clearest discordant contacts were seen near Hagar Bjerg, in Knækdalen (see later section), and in Gemmedal (fig. 8).

Calcareous schists and yellow to orange-weathering marbles are commonly the basal units of the metasedimentary sequence around the margins of the Niggli Spids dome. In Gemmedal a red, yellow or white-weathering quartzite is the basal unit, succeeded by a sequence of homogeneous calcareous schists, and a well-bedded group of marbles (fig. 8).

The major part of the metasedimentary sequence comprises quartzitic, semipelitic and pelitic rocks with an overall brown to rusty brown weathering colour. Alternating quartzitic and pelitic units are common, and often exhibit conspicuous zigzag folding (fig. 9). Some massive quartzite units reach 50 m in thickness. Brown calc-silicate lenses are locally common in quartzite beds. Thick lenses and horizons of amphibolite are conspicuous in lower levels of the succession near the mouth of Knækdalen and the mouth of Kjerulfs Fjord, and at Kap Lapparent east of the mouth of Isfjord (Haller, 1971, phot. 28).

The metamorphic grade is generally low, sometimes high amphibolite facies. Garnet is seen everywhere, and kyanite occurs at the eastern and western margins of the region. The sediments are rarely migmatitic in this region, with the exceptions of areas on the west side of Kjerulfs Fjord and the south side of inner Kejser Franz Josephs Fjord near the mouth of Kjerulfs Fjord.

Mesoscopic folding is commonly seen, developed usually on inclined axial planes with a

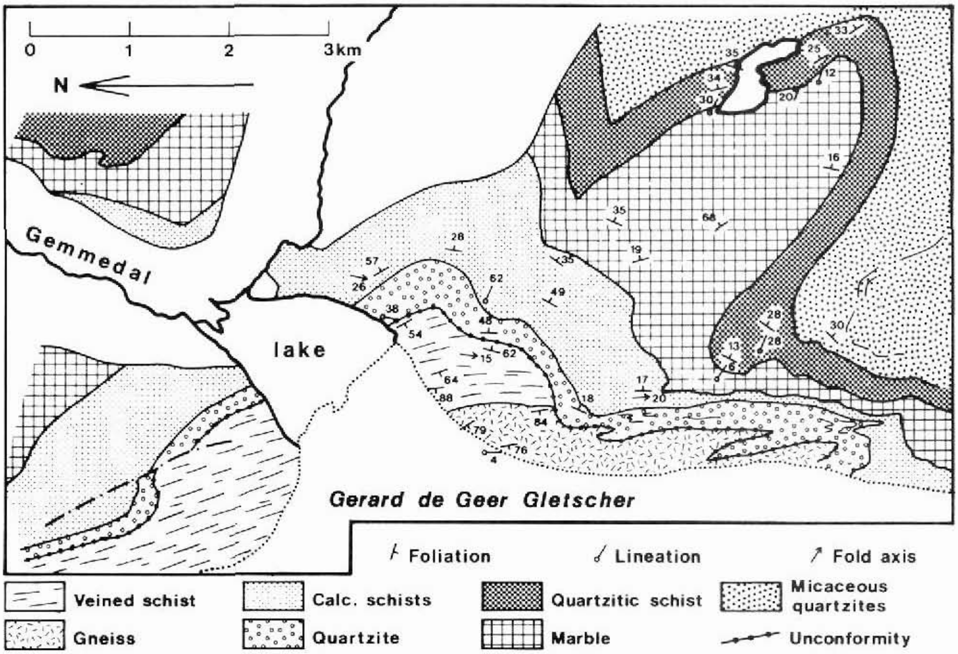


Fig. 8. Geological map of the Gemmedal–Målebjerg area in west Andrée Land showing basal units of the middle Proterozoic metasediments uncomformably overlying veined schists and gneisses of the basement complex.

sense of overturning either eastwards (fig. 9) or westwards; fold axes and lineations have a general N–S to NW–SE trend.

Nunatak region

The nunatak region between latitudes 72°45′–74°N, west of Petermann Bjerg and Louise Boyd Land, is not well known. Koch & Haller's (1971) map is based largely on aerial observations with little ground control. The writers' visits to the region by a series of helicopter flights have improved the ground control, but were of too short duration to make any detailed observations.

Thick sequences of generally flat-lying metasediments are present, though the apparent structural simplicity is misleading, several major recumbent folds having been observed. Generally the rocks are brown or rusty brown in colour, though often with a few leucocratic bands of massive quartzite or granite. In the field the rocks encountered have been described as thickly-bedded quartzites with coarse-grained, micaceous horizons, mica quartzites, quartzitic schists and garnet-bearing pelitic gneisses; quartzo-feldspathic veins and sweats are locally prominent. The metasediments in general overlie basement gneiss complexes, and the general structure of the region is probably much the same as the 'central metamorphic complex' to the east. The areas in the nunatak region shown as metasediments on fig. 1 may include some representatives of the Eleonore Bay Group (cf. Koch & Haller, 1971).

Fig. 9. Assymetrical folding in metasediments on north side of *Kejser Franz Josephs* Fjord east of Knækdalen. Folds are overturned eastwards. Thin mica schist layers between the quartzite beds are deeply weathered.

Western Lyell Land and eastern Nathorst Land

High grade metasedimentary rocks and migmatitic metasediments are widely exposed in western Lyell Land and eastern Nathorst Land between a prominent thrust in the west and the Eleonore Bay Group outcrops in the east, occupying a wedge-shaped zone 25 km broad at Furesø, 20 km broad in Forsblads Fjord and pinching out just south of Kap Hedlund (fig. 1). The best sections occur in Forsblads Fjord, which is the subject of a later section. Caledonian granites are particularly common in and above the eastern contact zone, notably in the region west of Alpefjord. Haller (1958) and Zweifel (1959) have previously described the principal rock types of the region.

Rb-Sr isotopic studies in Forsblads Fjord have given middle Proterozoic ages on metasediments, and Caledonian and intermediate ages on granites in the magmatites (Rex & Gledhill, this report). The significance of these ages is discussed in a later section.

Andrée Land

Extensive areas of Andrée Land west of the Eleonore Bay Group outcrop are dominated by metasedimentary rocks. A prominent NW–SE trending thrust system divides the metasedimentary rocks (fig. 1). Those beneath the thrust to the west are continuous with the metasediments surrounding the Hagar sheet and Niggli Spids dome and have already been described above. The metasediments east of the thrust correspond in part to the metamorphosed 'Eremitdal Series' of Haller (1953), and are described here. A more detailed description of the Nunatakgletscher–Eremitdal area is given later.

The metasediments form thick, well-bedded sequences, dark or rusty weathering in colour, in some areas mainly pelitic and semipelitic, in other areas mainly quartzitic. No formal lithostratigraphic division has been made, though some indication of the variation in lithology is given by Haller (1953). In much of the region the metasediments are flat lying or gently inclined. Semiconcordant granitic or pegmatitic sheets, veins and lenses are common, and outcrops can often be described as migmatitic, though the intensity of migmatisation is much less than in western Lyell Land and eastern Nathorst Land.

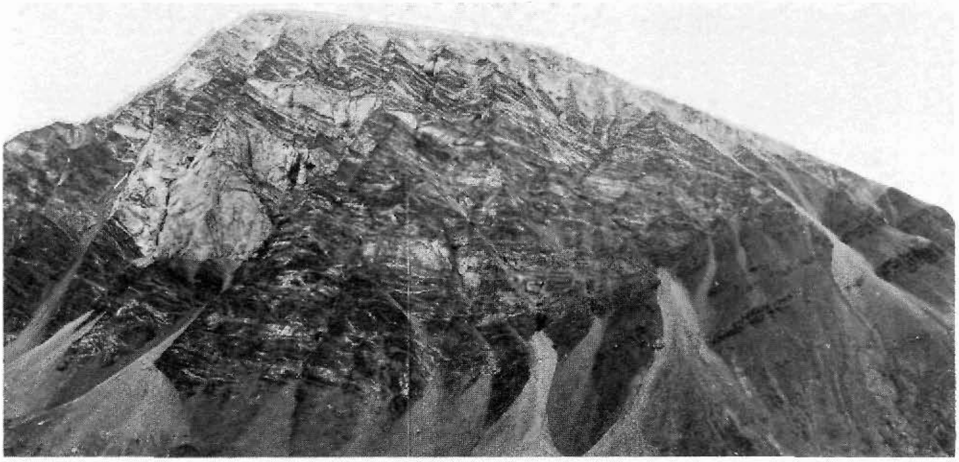


Fig. 10. South side of Djævelkløften near its confluence with Rendalen. Metasediments, invaded by numerous minor and major granite sheets, are cut by a late Caledonian east dipping thrust and fault system on the right side of the photograph. The dark metasediments beneath the thrust show the effects of shearing several hundred metres below the contact. Samples of granite collected from the screes at the left side of the photograph have yielded a Caledonian isotopic age (Rex & Gledhill, this report). Profile about 1000 m high.

The thicker granite sheets include normal, medium-grained, leucocratic granites and gneissic granites with irregular veined textures. Several sheets are involved in spectacular major folds (Haller, 1971, phot. 104). Two granite sheets have given Rb-Sr isochron ages of *c.* 1000 m.y. (Rex & Gledhill, this report); one is a folded sheet in the east wall of Eremitdal and the second a similar body in Gneisdal. Caledonian Rb-Sr whole rock ages have been obtained on several other granites (Rex & Gledhill, this report). One of the Caledonian granites is post-dated by a thrust (fig. 10).

The general metamorphic grade is amphibolite facies; sillimanite and kyanite have been recorded from several localitities in the eastern part of the region, while garnet is always present. Fold axes and lineations have a general NW–SE orientation.

Late Proterozoic and Lower Palaeozoic sediments

Late Proterozoic sediments are represented by the Petermann Series in the west and the Eleonore Bay Group and Tillite Group on the east side of the metamorphic complexes (fig. 1). Lower Palaeozoic sediments overlie the Tillite Group. The reassignment of most of the supposed metamorphic equivalents of these series to middle Proterozoic or older sequences has had consequences for the standard Eleonore Bay Group statigraphy. Thus the basal psephites (tillites) reported from the 'basal series' of the Eleonore Bay Group in west Gåseland and Paul Stern Land (Wenk, 1961), are now thought most likely to be Vendian (Phillips *et al.*, 1973; Phillips & Friderichsen, 1981), and the ophiolitic developments thought to be associated with the Lower Eleonore Bay Group (Haller, 1971, pp. 91–93) now seem to be of mixed origin (Archaean and early Proterozoic amphibolites, middle Proterozoic basic rocks, and Caledonian dioritic instrusions).

Fig. 11. Asymetrical folding in the Upper Eleonore Bay Group on the coast of Ymer Ø south-west of *Blomster Bugt. Numbers 7–12 refer to the bed groups of the standard stratigraphy (Haller, 1971).* Height of cliff about 1000 m.

The thickest developments of the Lower Eleonore Bay Group occur in the Alpefjord region and exceed 8000 m. The most recent studies by Caby (1976a) indicate a sequence of mainly quartzites and shales interpreted as the shallow water deposits of a subsiding and fluctuating deltaic zone, with periodic fluvial, tidal, evaporitic and lacustrine environments. Flysch or greywacke sediments of the classical geosynclinal type are noticeably absent.

The Petermann Series consists of more than 6000 m of psammitic and pelitic sediments including several strikingly coloured units, and was regarded by Wenk & Haller (1953) as equivalent to the upper part of the Lower Eleonore Bay Group and the lowest levels of the Upper Eleonore Bay Group. Additional features of the sequence are given in a later section.

The Upper Eleonore Bay Group is noted for its spectacular and destinctive sequence of quartzites, limey sandstones, limestones and dolomites (fig. 11), uniformly developed over extensive distances from north to south, and with a thickness of *c.* 4000 m. Bertrand-Sarfati & Caby (1976) suggest a Vendian age for the upper levels based on stromatolite studies, while Vidal (1976, 1979) indicates a range in age from late Riphean to very late Riphean from studies of acritarchs.

The writers have made only few observations in the Eleonore Bay Group sequence, including new geological maps of parts of northern Andrée Land (Plate 1a) and Maria Ø (fig. 12). Computations of bed group thicknesses indicate some variation from published figures: beds 8–11 and 13–14 on Maria Ø are in the normal range of thicknesses, while bed 12 is thinner and beds 15–17 considerable thicker than previously recorded (Eha, 1953; Haller, 1971).

The Tillite Group is a 500–800 m sequence of shales, limestones and mudstones with two main tillite units, each of which may comprise several tillite members. It overlies the Upper Eleonore Bay Group slightly unconformably, the latter unit evidently being exposed to erosion in other areas as it is the source of the boulder assemblage of limestones and

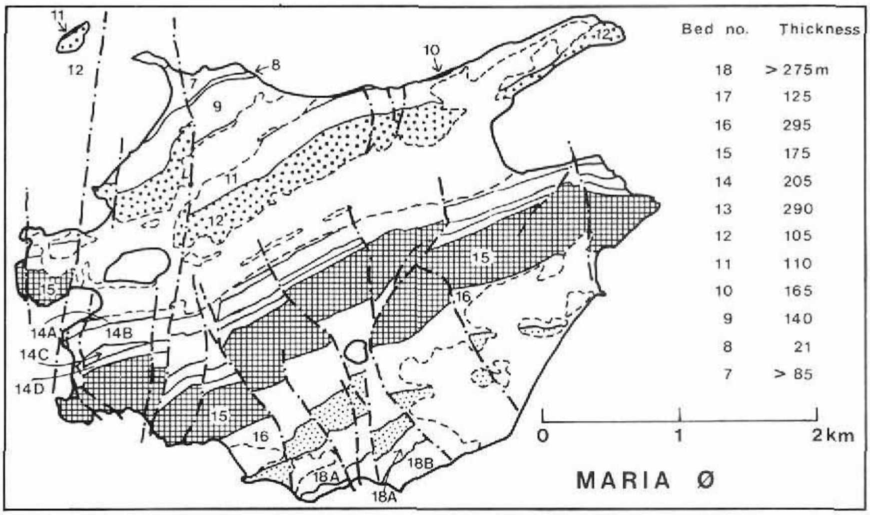


Fig. 12. Geological map of Maria Ø. Dip of bedding is SSE at 28°–58°. Numbers refer to the bed groups of the Upper Eleonore Bay Group. The mainly N–S trending faults show downthrow to both east and west.

dolomites in the Lower Tillite. The Upper Tillite contains a more varied boulder assemblage including quartzite and crystalline components, the latter presumed derived from the basement beneath the Eleonore Bay Group. Acritarch studies (Vidal, 1979) indicate a Vendian age for the Tillite Group with significant hiatuses at base and top.

Lower Palaeozoic rocks ranging from Lower Cambrian to Middle Ordovician (possibly lowermost Upper Ordovician) in age overlie the Tillite Group, and are overlain with major unconformity by Devonian red-beds (fig. 13). They comprise a uniformly developed 3000 m thick succession of mainly limestones and dolomites with a fauna referable to the Pacific province. Observations by Frykman (1979) show the uppermost formation of the Ordovician sequence to be considerably thicker on C. H. Ostenfeld Nunatak (74°18′N, 22°55′W) than known elsewhere, and include the youngest known Lower Palaeozoic rocks (deposited before the Caledonian deformation) in East Greenland.

Erratic blocks of Scolithus quartzite are common along the length of the Caledonian fold belt, and are presumed to be derived from Lower Cambrian deposits laid down in the foreland areas now beneath the Inland Ice (Haller, 1971, fig. 48). Wegmann (1935, p. 14) also reported limestone erratics containing poorly preserved gastropods on Cecilia Nunatak (72°30′N), and limestone boulders recently collected by the writers from the same locality have yielded Middle Ordovician conodonts (J. S. Peel, personal communication).

Caledonian orogenesis

Caledonian deformation, metamorphism and plutonism influence the entire region, and overprint the features developed during Archaean, early Proterozoic and Middle Pro-

Fig. 13. Anticlinalbugt on the south-east coast of Ella Ø. Folded Lower Palaeozoic sediments are unconformably overlain by Devonian conglomerates (D). Cliff is 700 m high.

terozoic orogenic episodes such that it is often difficult to separate older pre-Caledonian and younger Caledonian events from each other.

Caledonian regional metamorphism was characterised by extensive greenschist facies conditions and smaller areas of amphibolite facies (Thyrsted, 1978). In the metamorphic complexes its effects are seen as a retrogression of earlier higher grade assemblages and recrystallisation, which has everywhere been sufficient to reset the K-Ar mineral isotopic systems. K-Ar biotite, muscovite and hornblende ages from all rock types lie mainly in the range 380–440 m.y. (D. C. Rex, personal communication). Pre-Caledonian Rb-Sr whole rock isotopic systems were not reset by Caledonian metamorphism. Comparable behaviour of the isotopic systems in parallel geological settings has been recorded in the Scandinavian Caledonides (Bryhni *et al.*, 1971; Skjerlie & Pringle, 1978), and in the Pennine nappe cores of the Alps (Hänny *et al.*, 1975).

The Eleonore Bay Group and Petermann Series bordering the metamorphic complexes exhibit a systematic and rapid decrease in metamorphic grade stratigraphically upwards, and only the lower parts of the two series are affected. Amphibolite facies was reached in the Lower Eleonore Bay Group in parts of Andrée Land, Lyell Land and eastern Nathorst Land (Caby, 1976a; Thyrsted, 1978), all areas where Caledonian granites are particularly common; the high grade may locally be of contact metamorphic origin.

Caledonian deformation takes the form of a series of major folds and flexures in the late Proterozoic and Lower Palaeozoic sediments with N–S axial trends (figs 11 & 13); the fold systems have been well described and illustrated by Haller (1970, 1971). In different areas, and notably in the lower levels of the sedimentary succession, it is possible to establish two or three fold phases – though they are usually coaxial, while at higher stratigraphic levels there are large regions dominated by fault tectonics rather than folding.

In Schaffhauserdalen, west of Alpefjord, Caby (1976a) described a major recumbent anticline facing eastwards in the lowermost levels of the Eleonore Bay Group; it is veined by Caledonian granites. A comparable and equally remarkable recumbent anticline has also been observed in the lowest levels of the Petermann Series in Louise Boyd Land (figs 18 & 24). Both these major structures occur in close proximity to décollement zones at the contact with the crystalline complexes; it is possible that they formed as a consequence of gliding of the late Proterozoic – Lower Palaeozoic cover respectively eastwards and westwards off an uplifted central region of basement crystalline rocks (cf. Caby, 1976b).

The intensity of Caledonian deformation within the basement gneiss complexes and middle Proterozoic metasediments remains a major uncertainty. The revision of the 'stockwerke' model for the Caledonian fold belt carried with it an assumption that the complex structural pattern was essentially pre-Caledonian, and only broad N–S trending structures were thought likely to be Caledonian (Henriksen & Higgins, 1976; Higgins, 1976). While it is possibly a correct assumption, it must be admitted that the evidence is ambiguous and the age of specific structures within the older rocks should be left open. Talbot's (1979) model for the development of the infracrustal domes and upwellings by processes of thermal convection, if it is in fact applicable, could conceivably have occurred during the Caledonian epoch though the writers are inclined to a middle Proterozoic orogenic setting. The process of formation envisaged differs from the classic 'stockwerke' model in that the infracrustal complexes are seen as deformed *old* basement units rather than *new* active migmatitic upwellings.

Caledonian plutonic rocks are mainly late orogenic leucocratic granites, dated by their cross-cutting relationships with the Eleonore Bay Group or isotopically. They appear to have been emplaced mainly in zones along the margins of the metamorphic complexes, and range in size from modest sheets and dykes to major plutons. They are mainly medium-grained, homogeneous, biotite-muscovite granites, though aplitic, porphyritic and pegmatitic phases are often present. A few are monzonites rather than strict granites, but there is a marked general uniformity in composition compared to the Scoresby Sund region (70°–72°N) where Caledonian plutonic bodies at presumed deeper orogenic levels include quartz monzonites, hypersthene monzonites and granodiorites as well as normal granites. The Caledonian granites in the region 72°–74°N dated by Rb-Sr whole rock isochrons range in age from 560–377 m.y. (Rex & Gledhill, this report). Most granites post-date folding, though there are indications of overlap of granite emplacement and deformation (fig. 17); many are displaced by late faults and thrusts.

Faults and thrusts affect the entire region, the most important structures having already been shown on the maps of Koch & Haller (1971) and Haller (1970, 1971). One of the more important N–S trending structures, marked on fig. 1 as an east-dipping thrust, can be traced throughout the region through Nathorst Land, Lyell Land, Suess Land and Andrée Land (fig. 1); south of latitude 72°N it continues a further 200 km through the Scoresby Sund region. In general this structure separates the principal Archaean and early Proterozoic gneiss complexes and their metasedimentary cover in the west, from the middle Proterozoic migmatite and granite region to the east. However, it is a complex structure which has periodically been reactivated by normal or reverse faulting. The northern part of the structure in Andrée Land corresponds to a belt of en échelon tension faults distinguished by Haller (1971, fig. 125). There are extensive mylonite developments everywhere along the line of this structure. In this report it is generally referred to as a thrust or thrust zone.

The higher levels of the Eleonore Bay Group and the Lower Palaeozoic succession are affected by an intense pattern of N–S, NNE–SSW and E–W trending faults (Haller, 1971 pp. 294–299). Movements are believed to extend over a long period of time and many are attributed to tensional movements (see also Caby, 1976b). The pattern of faults on Maria Ø is shown in fig. 12.

Fig. 14. The contact zone in southern Snestormdal. Bed 1 is just visible in the right summits. Most of the cliff comprises dark-coloured Lower Eleonore Bay Group sediments with a few white sheets of Caledonian granite, resting apparently conformably on banded gneisses invaded by concordant pegmatite and granite veins. Granitic augen gneisses at lower extreme left. Height of cliff about 1500 m.

The interrelation of deformation, metamorphism and plutonism in the East Greenland Caledonides has not been described in anything like the detail of other parts of the Caledonide orogen (e.g. Scotland or Scandinavia). Most geological descriptions are based on mapping at scales of 1:250 000 and 1:100 000, and in the Scoresby Sund region at 1:50 000. Published modern detailed studies include those of Chadwick (1971, 1975), Homewood (1973), Steck (1971), Bucher-Nurminen (1979), Coe (1975) and Caby (1972, 1976b). Detailed studies by the writers in selected areas follow below.

Detailed studies

Four areas were the subject of more detailed investigations (Plate 1). These areas were selected because they exposed good sections across the contacts of lithological divisions thought to be of fundamentally different age of formation, and because they included the sites of many of the sample collections made for isotopic studies. In the north of the region the Nunatakgletscher–Eremitdal area spans the contact between the Eleonore Bay Group and the east margin of the 'central metamorphic complex'. The Knækdalen area covers the equivalent contact with the Petermann Series on the west side of the 'central metamorphic complex'. Near Kap Hedlund a zone of migmatitic sediments wedges out against an important thrust line. The Tærskeldal–Forsblads Fjord–Randenæs area covers the width of the migmatitic zone, including the thrust contact to the west with the Gletscherland complex and the contact with the Eleonore Bay Group to the east.

Nunatakgletscher–Eremitdal

The contact between the Eleonore Bay Group and older crystalline rocks is well exposed in northern Andrée Land between Nunatakgletscher and Eremitdal (Plate 1a). The line of the contact runs along the axis of Snestormdal. The best previous observations and maps are those of Fränkl (1953), while Odell (1939), Huber (1950) and Haller (1953) have contributed observations on some rock units and geological relationships.

Older crystalline rocks

A complex of crystalline rocks outcrops in Snestormdal and part of Eremitdal and includes augen gneisses, amphibolites, a variety of gneisses, and a few bands of mica schists. The extension of this crystalline region to the west and south-west is uncertain. Granite bodies cutting overlying metasedimentary rocks in Eremitdal, a few kilometres south of the map boundary, and in Gneisdal in central Andrée Land have yielded *c.* 1000 m.y. ages (Rex & Gledhill, this report). The crystalline rocks are therefore presumed to be part of an Archaean – early Proterozoic basement complex similar to the infracrustal rocks of the 'central metamorphic complex'.

Augen gneisses outcrop extensively on both sides of Snestormdal (Plate 1a), and beyond the map area continue north-westwards to Nunatakgletscher. While contacts with other gneisses are essentially conformable, strips of gneiss and amphibolite occur as inclusions within the augen gneisses. The extremely homogeneous nature of the augen gneisses suggests they were emplaced as granite bodies, though they have subsequently been modified by deformation. The conspicuous features of the rock are the feldspar phenocrysts, occasionally preserving rectangular outlines, but mostly deformed into lensoid augen in a well-foliated host. In thin section, textures are fresh, the augen are microcline (often perthitic), and the other minerals include plentiful biotite in large flakes, scattered garnets, and quartz. The augen gneisses are frequently cut by aplitic and pegmatitic veins. Superficially this rock type strongly resembles the augen gneisses comprising the Niggle Spids dome (Haller, 1971).

Well-banded units of biotite and siliceous gneisses occur beside Nunatakgletscher. Amphibolite is common everywhere within the gneiss sequence as bands and lenses, and may form extensive bodies locally. Most rock types are fine to medium-grained, and in thin section comprise fresh textures of quartz, plagioclase, microcline, biotite, hornblende and epidote. A conspicuous pattern of concordant and discordant granite and pegmatite veins invades the augen gneisses and gneisses on the east side of Snestormdal below the contact with the Eleonore Bay Group (fig. 14). Most of the granitic veins are pink to white in colour; they comprise mainly quartz, plagioclase and microcline, with accessory muscovite, biotite and small garnets.

Mica schist units occur occasionally within the gneisses, and also locally at the contact with the Eleonore Bay Group where they have been the location of significant planes of movement. The mica schists are medium-grained and conspicuously rich in muscovite. In thin section they comprise fresh textures of biotite, muscovite, garnet, kyanite and fibrolitic sillimanite.

Foliation trends in the crystalline rocks have a general NE–SW strike and dip generally south-east at angles of 20–35° (fig. 15a). A few tight minor folds with NNE or SW trending fold axes have been observed, but the most conspicuous linear structure is a SE trending lineation accompanied in some cases by similarly trending minor fold axes.

Contact zone

The contact between the crystalline rocks and the Eleonore Bay Group is clearly traceable from Eremitdal through Snestormdal to Nunatakgletscher (Plate 1a), and is also recognised as a geological boundary on Fränkl's (1953) and Koch & Haller's (1971) geological maps.

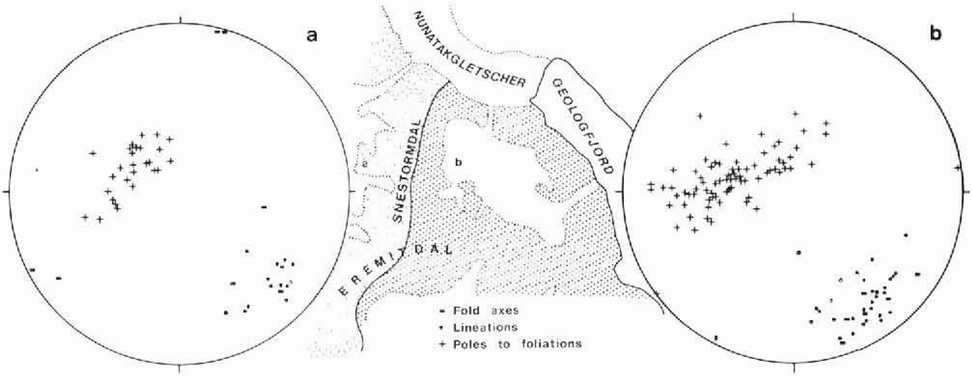


Fig. 15. Stereograms of planar and linear elements in the Snestormdal–Eremitdal area of northern Andrée Land (lower hemisphere, equal area projections). (a) crystalline rocks; (b) Eleonore Bay Group.

Beside Nunatakgletscher the contact is well exposed, well-bedded quartzites with calc-silicate lenses (Lower Eleonore Bay Group) resting more or less concordantly on a thick sequence of kyanite-mica schists. Within the schists, foliation is sometimes irregular and pinkish granite veins may show shearing in zones of dislocation which appear to have accomodated movements of the cover sequence relative to the basement crystalline rocks.

In Snestormdal a gulley section across the contact is marked by several movement planes located along schistose horizons and involving several slices or lenses of gneisses and Eleonore Bay Group lithologies. The Eleonore Bay Group above the contact comprises well-bedded, grey quartzites dipping eastwards at 28°, while below the contact banded gneisses, hornblende gneisses and amphibolites cut by granitic veins and sheets dip eastwards at 45°. Even in inaccessible cliffs in Snestormdal the contrast in rock types clearly marks the line of the contact (fig. 14). In the Eremitdal river section the contact is a series of movement or shear planes; above the contact zone the Eleonore Bay Group comprises well-bedded quartzites with calc-silicate lenses and rare pelitic interbeds, and a number of mainly concordant pegmatite and aplitic horizons; below the contact occur massive mica schist zones and gneisses.

The prominent feature of the contact zone is the contrast in lithologies on either side. The Eleonore Bay Group comprises a relatively superficially deformed, sedimentary succession of mainly psammitic rocks, slightly metamorphosed in the lower levels, but of lower grade than the mica schist parageneses below the contact. Amphibolites are only found in the crystalline rocks. Caledonian granites occur on both sides of the contact, although seem preferentially to be emplaced as sheets into the lower part of the Eleonore Bay Group succession. The most important granitic rocks of the crystalline complex are the augen gneisses, which have evidently suffered pronounced penetrative deformation of an intensity not recorded anywhere in the Eleonore Bay Group sequence.

Eleonore Bay Group

At least 2000 m of the Lower Eleonore Bay Group and bed groups 1 to 5 of the Upper Eleonore Bay Group are represented (Plate 1a). The former sequence was initially distinguished by Katz (1952b) as the 'Eremitdal Quartzite', and by Fränkl (1953) and Haller (1953) as the 'Eremitdal Series'.

Fränkl (1953) estimated a thickness of 1200–1500 m for the 'Eremitdal Series' which he divided into five units (Fränkl *in* Haller, 1953 pp. 39–41; Haller, 1971). His divisions are not readily recognisable in the field, but the choice of boundaries is perhaps arbitrary due to a general uniformity of lithologies, and tends to depend on incidental variations in weathering colour. The following composite sequence has been determined from outcrops in Snestormdal and beside Nunatakgletscher (top to bottom):

(f) *c.* 100 m Dark quartzites with pelitic interbeds; one or two conspicuous white quartzite beds near base.

(e) *c.* 500 m Generally dark well-bedded quartzites, with many lighter and darker weathering zones and a few prominent levels of light quartzites.

(d) *c.* 150 m Pale grey thinly-bedded quartzites.

(c) *c.* 400 m Conspicuous well-bedded, generally leucocratic, quartzites. Massive quartzite beds with brown-weathering calc-silicate layers and lenses alternate with thin semipelitic and pelitic beds. Cross-bedding conspicuous.

(b) *c.* 150 m Brown weathering, massive pelitic beds.

(a) *c.* 300 m Rusty pelitic and semipelitic beds, and occasional quartzites.

The composite sequence a-f totals *c.* 1600 m. The equivalent sequence in parts of Snestormdal and Eremitdal is as little as 1100–1250 m, and in the core of the anticlinal box-fold in the Eremitdal and Nunatakgletscher sections, at least 2000 m (see cross-sections in Plate 1a). The differences are attributed mainly to discordance at the plane of décollement with the crystalline rocks. Fränkl (1953, fig. 34) also noted a variable thickness for this part of the sedimentary sequence, though it was attributed to a differential rise of the Caledonian migmatite front.

No significant new observations were made on the lithological development of the Upper Eleonore Bay Group, except that new thickness computations have been made using photogrammetric methods at the mouth of Eremitdal. These are as follows (Fränkl's estimates in brackets): bed 1 – 900–1000 m (800 m); bed 2 – 340 m (220–240 m); bed 3 – 650 m (500 m); bed 4 – 350 m (350 m).

Metamorphism and structures

The increase in metamorphic grade of the Eleonore Bay Group sediments traced stratigraphically downwards and westwards towards the crystalline basement has traditionally been associated with the occurrence of late Caledonian granites and the assumed ascent of a Caledonian front of migmatisation (Fränkl, 1953; Haller, 1953, 1971). In this account it is ascribed to Caledonian regional metamorphism, which in the older crystalline rocks overprinted the textures produced by pre-Caledonian metamorphic events.

At the mouth of Eremitdal the rocks are essentially non-metamorphic. Westwards the grade increases through a chlorite and biotite zone to a garnet zone. Close to the contact with the crystalline rocks, the Eleonore Bay Group sediments are still generally fine-grained, micas showing a strong lamination parallel to the bedding, occasionally with discernable lineation of biotite laths. Textures are fresh, though biotite and muscovite are sometimes distorted by late kink bands. In pelitic rocks garnets up to 1.5 mm in diameter occur, often nearly euhedral, sometimes with rounded or slightly irregular outlines; inclusions are small and arranged in straight trails, occasionally in curved trails, while garnet rims in some cases are inclusion-free.

In the crystalline rocks below the contact zone only mica schist units preserve useful metamorphic minerals. They exhibit fresh medium-grained textures of quartz, biotite, muscovite, numerous garnets, kyanite, and rarely staurolite and fibrolitic sillimanite. The garnets reach 4 mm in diameter and are often rounded or with ragged outline, sometimes lens-shaped and apparently flattened; they may have many or few inclusions, occasionally in trails, though margins of garnets may be inclusion-free. Kyanite occurs as small stubby prisms in some sections, and as elongated prisms in others; in some outcrops it is also found as abundant, conspicuous blue crystals in leucocratic veins and sweats. These medium to high grade amphibolite facies assemblages are believed largely to reflect the pre-Caledonian metamorphic episode, though in view of the Caledonian recrystallisation of the adjacent Eleonore Bay Group sediments, some Caledonian retrograde modification and recrystallisation is assumed.

The major N–S trending Caledonian structures deforming the Eleonore Bay Group on a regional scale can be traced throughout eastern Andrée Land (Fränkl, 1953, fig. 21) and have been linked with comparable structures deforming the Eleonore Bay Group farther south (Haller, 1971, figs 58 & 60). Within the mapped area the folds sometimes have classic box fold profiles (fig. 16), described by Fränkl as 'Kofferfaltenstruktur' (Fränkl, 1953, fig 24 & plate 3). In other areas farther south and at higher stratigraphic levels, the folds have usually more normal profile shapes, although they are not infrequently assymetrical and modified by faulting; overturning of limbs, both eastwards and westwards, has been recorded, and attributed to accentuation by lateral forces in Middle Devonian time (Haller 1971, phot. 31 & 35).

The main structure in the Eleonore Bay Group of the area mapped is an anticlinal box fold with a flat crest and widely spaced steep limbs. The west limb is overturned in the Nunatakgletscher section (Plate 1a, sections A–B, C–D) and exhibits pronounced folding in banded quartzites; farther south in the Eremitdal section (Plate 1a, section G–H) the same fold limb is vertical where it involves the thick competent quartzites of bed group 1. The east limb of the same anticline is also overturned with prolific development of mesoscopic folds beside Nunatakgletscher, but these die away laterally eastwards (Plate 1a, section C–D).

The syncline running across the mouth of Eremitdal also has a pronounced box fold profile, particularly well seen in the contorted bed group 4 in the core of the structure exposed in cliff sections on both sides of the mouth of Eremitdal (fig. 16).

The major fold structures trend almost exactly N–S, axes plunging at low angles southwards. They are envisaged as having developed as a consequence of Caledonian E–W movements leading to slip of the sedimentary cover over the crystalline basement. The décollement zone may have coincided more or less with the original basement–cover contact, and variations in the exposed thickness of the Lower Eleonore Group may be largely accomodation to the folding. There are no conspicuous faults in the mapped area, in contrast

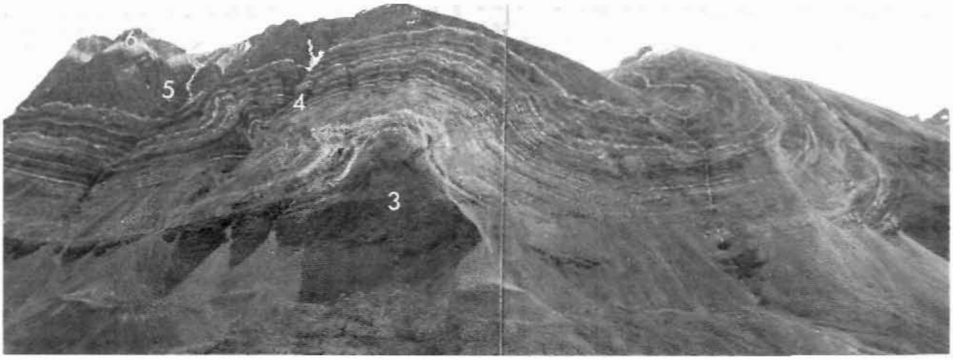


Fig. 16. Spectacular box-fold structures in the lower part of the Upper Eleonore Bay Group at the mouth of Eremitdal. Numbers refer to the bed groups of the standard stratigraphy. Dark and light-coloured quartzites of bed group 4 dominate.

to the association of folds and faults at higher stratigraphical levels a few kilometres southeast along Geologfjord. This possibly reflects a ductility contrast between the lower levels of the Eleonore Bay Group subjected to low grade Caledonian metamorphism, and the non-metamorphic higher levels. The maximum E–W shortening estimated for the base of bed 1 between Geologfjord and Snestormdal (Plate 1a, section G–H) is of the order of 15 per cent.

Lineations measured in the Lower Eleonore Bay Group and in the crystalline rocks in the outcrops beside Nunatakgletscher show a very consistent SE trending plunge in both levels (fig. 15). Massive quartzite beds exhibit a pronounced ribbing lineation simulating ripple marks, due to intense minor folding. In both levels a parallel orientation of biotite flakes is apparent. Nearly all measurements were made within a restricted zone of well-exposed outcrop beside Nunatakgletscher, and the divergence from the regional N–S structural trend could be viewed as a local variation, or as a distinct deformation phase. The presence of parallel structural features suggests that basement and cover shared the same deformation and recrystallisation events in the Caledonian orogeny, despite fundamental differences in age and lithological development.

Caledonian granites

Thin sheets and occasional larger bodies of mainly medium-grained, leucocratic, Caledonian granite invade the lower levels of the Eleonore Bay Group. They correspond to the late tectonic Caledonian or marginal granites known along both margins of the metamorphic complexes. Observations on those in northern Andrée Land have previously been made by Odell (1939), Huber (1950) and Fränkl (1953).

The largest body occurs beside Nunatakgletscher near Geologfjord, where related pegmatitic veins were described by Odell (1939) and Huber (1950). Further west beside Nunatakgletscher thick and thin sheets are common in the complexly folded core zone of the anticline. Many are emplaced as concordant sills, while others cut across the folded bedding.

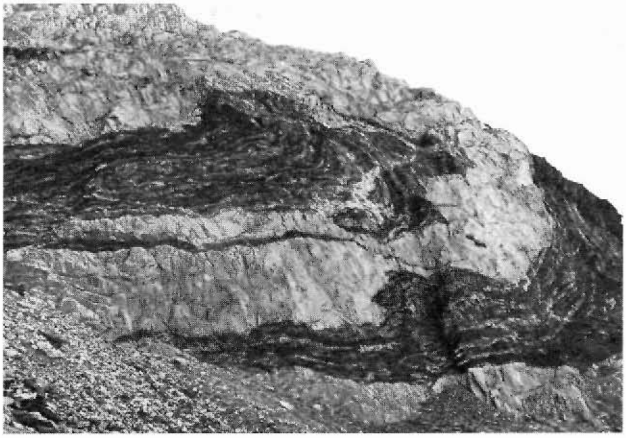


Fig. 17. Caledonian granite sheets emplaced into the Lower Eleonore Bay Group and apparently involved in the folding; locality beside Nunatakgletscher. Outcrop height about 50 m.

The relationship to the folds is not always clear. Some very thin sheets are tightly folded in a ptygmatic style; other larger sheets and lenses appear to be folded (fig. 17), and at the contacts may exhibit the same pronounced SE trending lineation seen in the sediments.

In Snestormdal scattered pegmatites and granite veins occur near the contact zone in the north, while in central and southern parts of the valley a series of sheets have been emplaced at a level about 350 m above the contact with the crystalline rocks.

In thin section the Caledonian granites comprise fresh, medium-grained textures of quartz, microcline, plagioclase, and small amounts of muscovite and biotite. The feldspars are often slightly altered, and occasionally biotite may be chloritised. The occasional pegmatites show the same mineral associations.

Only one granite body from the region, near Nunatakgletscher, has been dated isotopically; it yielded a rather old Caledonian age, but with a large error (550 ± 180 m.y.: Rex & Gledhill, this report).

Knækdalen and adjacent areas

Along the margin of the Inland Ice between latitudes 72°50′–73°40′N, the Petermann Series (the assumed western equivalent of the late Precambrian Eleonore Bay Group) outcrops at the western border of the 'central metamorphic complex' (fig. 18). The best section across the contact zone is in Knækdalen (Odell, 1939, 1944; Huber, 1950; Wenk & Haller, 1953), and this has been reexamined together with an equivalent section in Louise Boyd Land to the north. The new field work and isotopic investigations suggest that the apparently transitional contact can be resolved into a basement gneiss complex, a sequence of middle Proterozoic metasediments, and the Petermann Series (fig. 18, Plate 1b).

Basement gneiss complex – Hagar sheet

The basement gneiss complex of innermost Kejser Franz Josephs Fjord forms a broad north–south trending zone between two broad zones of metasediments. The principal rock types are gneisses of variable type, amphibolite and diorite, granite, and bands of mica

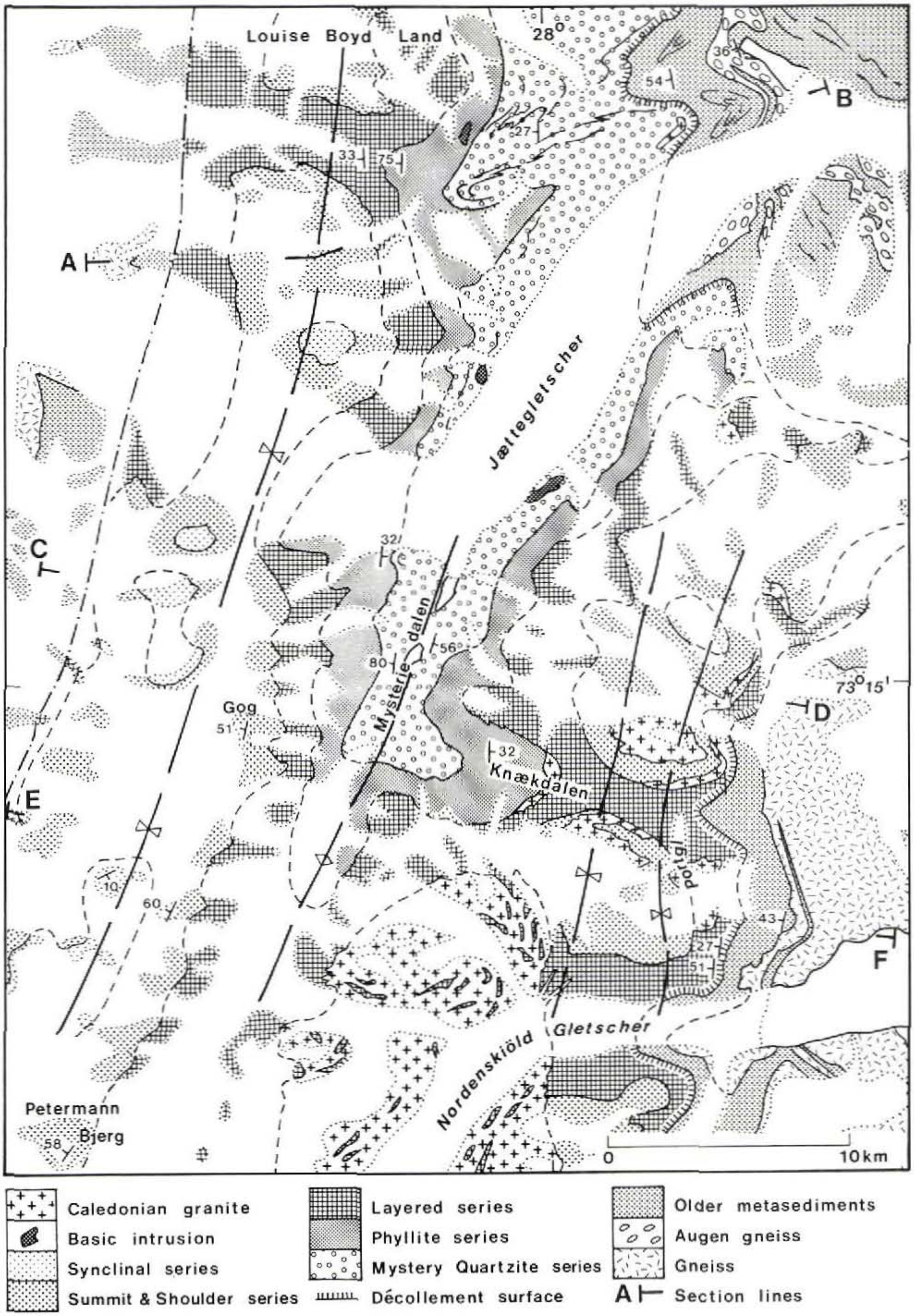


Fig. 18a. Geological map of the Petermann Series in the Knækdalen region. Partly after Wenk & Haller (1953) and Koch & Haller (1971).

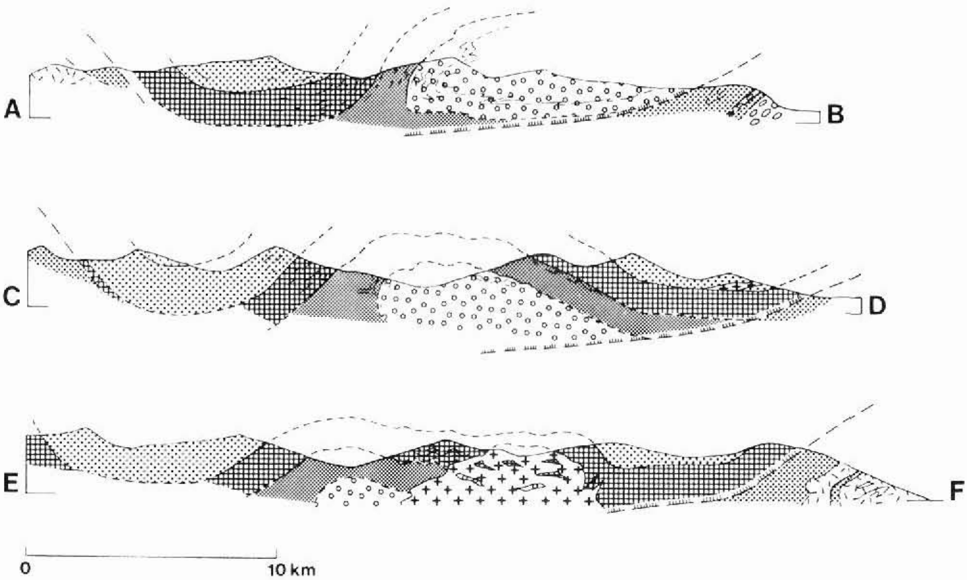


Fig. 18b. Cross-sections of the Petermann Series in the Knækdalen region. See Fig. 18a for section lines and legend.

schist. Isotopic evidence for the age of the complex comes from Rb-Sr whole rock isochrons on siliceous biotite gneisses at the west margin of the complex in Knækdalen (two isochrons of 1725 and 1980 m.y.), and for a leucocratic biotite-muscovite granite at the east margin of the complex on the north side of Kejser Franz Josephs Fjord (1950 m.y.); mineral ages on the same rocks were Caledonian (Higgins *et al.*, 1978; Rex & Gledhill, this report).

The common gneiss types are well-foliated and banded biotite and hornblende bearing gneisses. There are often thin granitic or aplitic veins, usually rather irregular and sometimes giving a migmatitic appearance to the rock. Occasionally there is a tendency to development of feldspathic augen. Amphibolite is common, usually as concordant thin bands and layers. Discordant amphibolite dykes and sheets are also common, and have been observed notably at the bend of Knækdalen (fig. 19), near the east margin of the gneiss complex south of Kejser Franz Josephs Fjord, and on the north side of the fjord cutting foliated granite. Many of these discordant amphibolites are conspicuously folded, sometimes isoclinally.

Mica schist zones sometimes occur enclosed within the gneisses, and it is not clear whether they should be regarded as infolded enclaves of the middle Proterozoic metasediments, or remnants of even older sequences. The most prominent such zone is traceable for several kilometres in the west wall of the outer part of Knækdalen, and probably continues also in the steep walls on the south side of Kejser Franz Josephs Fjord. At the bend of Knækdalen it is a finely layered, massive mica schist unit, with numerous quartzo-feldspathic sweats. Large lenses of garnet amphibolite occur near the upper (west) margin, and thinner lenses at lower levels.

The isotopically dated early Proterozoic biotite-muscovite granite at the eastern margin of the gneiss complex has a fresh appearance, variable texture and is foliated in the marginal parts. It has been involved in major folding together with a marginal zone of foliated dioritic rocks (Plate 1b, section C–D), and is cut by several conspicuous amphibolite dykes. Both

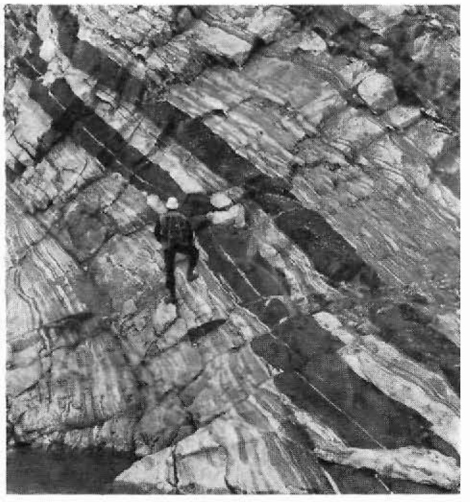


Fig. 19. Well-banded biotite and hornblende bearing gneisses of the Hagar sheet at the bend of Knækdalen. Two almost concordant amphibolite bands, metamorphosed basic intrusions, are prominent. Quartzo-feldspathic material forms thin, mainly concordant, sheets and one vein cuts the lower amphibolite discordantly.

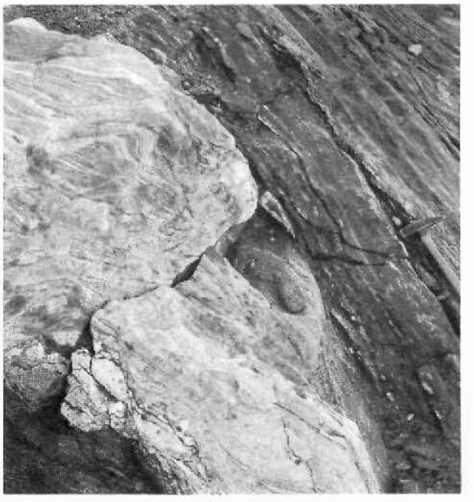


Fig. 20. Middle Proterozoic (older) metasediments on right unconformably overlying veined, siliceous gneisses of the Hagar sheet. It is these gneisses, situated at the bend of Knækdalen, which have yielded Rb-Sr isochron ages of 1725 and 1980 m.y. (Higgins *et al.*, 1978; Rex & Gledhill, this report).

granite and diorite are cut by leucocratic veins which, in the foliated diorite, are sometimes muscovite-rich pegmatites. The diorite is very homogeneous and medium to coarse-grained. On both north and south sides of the fjord granitic, leucocratic gneisses, cut by amphibolite dykes, occur at the margins of the gneiss complex and may represent gneissic varieties of the dated granite; however, here the dioritic border zones are not continuously present.

Middle Proterozoic metasediments

The middle Proterozoic metasediments outcrop in broad belts on both sides of the Hagar sheet of basement gneisses (Plate 1b). The eastern zone occurs partly beneath the overturned limb of the Hagar sheet nappe and extends eastwards to cap the augen gneisses of the Niggli Spids dome (fig. 6). The western zone is sandwiched between the Hagar sheet and the Petermann Series.

The eastern zone comprises a thick succession of banded quartzites and mica schists, the former often in beds up to 1 m thick. Near to the contact with the Hagar gneisses on the north side of Kejser Franz Josephs Fjord, lenses and layers of dark amphibolite are common. The intense minor (fig. 10) and major folding (Plate 1b, section C–D) renders thickness estimates uncertain, but the succession must total at least 1000 m, and possibly 2000–3000 m in thickness. The rocks have a deep rusty brown colour and are rather deeply weathered.

The western zone comprises 1000–1200 m of mica schists, massive semipelitic gneiss, well-bedded micaceous gneiss, a few amphibolite bands and siliceous schists. In Knækdalen this sequence rests with clear discordance on veined Hagar sheet gneisses (fig. 20). A

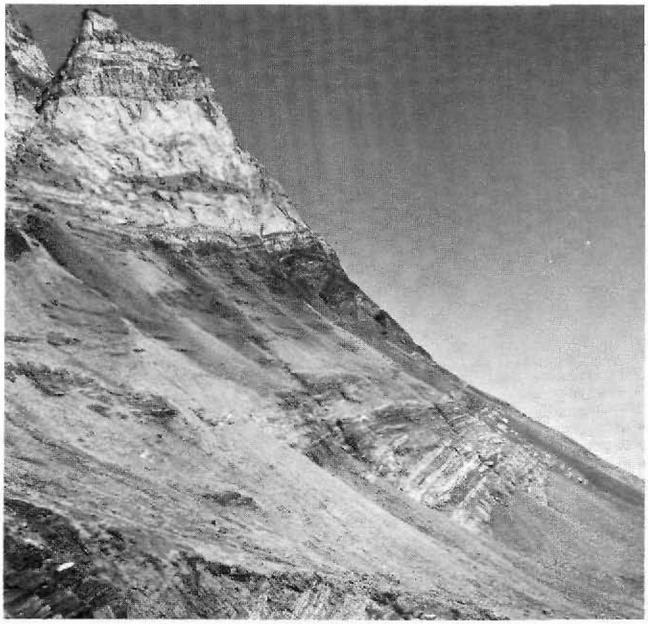


Fig. 21. The north wall of Knækdalen showing the contact zone of the Petermann Series and older (middle Proterozoic) metasediments. At top left the steep cliffs rising to 1800 m comprise thick sub-horizontal Caledonian granite sheets emplaced in the 'Summit quartzite series' and 'Shoulder quartzite-slate series'. These overlie the dark coloured 'Layered quartzite-slate-dolomite series'. Downwards the dip increases from very shallow westward dips, to dips of about 45°, such that the contact with the older metasediments, here light-coloured due to numerous concordant granitic and pegmatitic veins, appears only slightly unconformable. There are marked shear zones at the contact, and the dark 'layered series' appears to thin eastwards (to right side of photograph).

conspicuous feature of the sequence is the periodic development within broad lenticular zones of numerous, leucocratic, granitic and muscovite pegmatite sheets, which impart a clear migmatitic appearance. Several such zones occur in the walls above Nordenskiöld Gletscher, and another is well exposed in the gorge east of Portgletscher (fig. 21). The latter occurrence contributes to the appearance of a 'transitional' contact with the Hagar sheet gneisses reported by Wenk & Haller (1953).

Contact zone

The contact between the middle Proterozoic metasediments and the Petermann Series is a slightly discordant décollement zone traceable throughout the region (fig. 18, Plate 1b).

In Knækdalen the contact occurs east of Portgletscher between well-bedded garnetiferous quartzites of the 'Layered quartzite-slate-dolomite series' and mica schists and semipelitic gneisses invaded by granitic and pegmatitic veins (older metasediments) (fig. 21). Wenk & Haller (1953) viewed the latter as the metamorphic equivalents of their 'Phyllite series', which is a distinctive sequence of greenish-grey to silver-grey garnet phyllites at the west end of Knækdalen; this interpretation would necessitate lateral variations in facies, and also thickness of different parts of the Petermann Series. In fact the 'Phyllite series' and 'Mystery quartzite series' seem to be cut out at the east end of Knækdalen (fig. 18b, section C–D). East of Portgletscher there are several planes of shear or dislocation, and there is apparent interleaving of Petermann Series quartzites and the older metasediments.

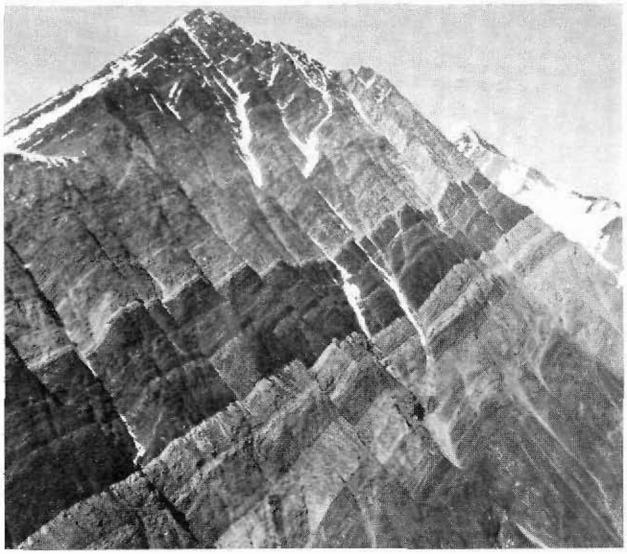


Fig. 22. Strikingly banded Petermann Series in the cliffs on the west side of Nordenskiöld Gletscher. The peak on the right skyline is Petermann Bjerg. The upper light-coloured unit is the 'Summit quartzite series', the dark and light-coloured units below it the 'Shoulder quartzite-slate series', and the lower dark unit the 'Layered quartzite-slate-dolomite series'.

North of Nordenskiöld Gletscher the contact is a clearly marked line between well-bedded quartzites ('Layered series') and rusty brown pelitic and semipelitic rocks (older metasediments). The former exhibit angular and conjugate style folding locally close to the contact.

In Louise Boyd Land the décollement surface coincides with the reverse limb of a major recumbent fold developed in the 'Mystery quartzite series' (fig. 18b, section A-B).

Petermann Series

The Petermann Series (fig. 22) was originally compared in general terms to the Eleonore Bay Group on the east side of the metamorphic complexes (Wordie, 1930). All subsequent workers made similar comparisons, and Wenk & Haller (1953) who established the first reasonably detailed lithological division, suggested a correlation with the highest levels of the Lower Eleonore Bay Group and lowest levels of the Upper Eleonore Bay Group. A few samples from high levels treated for microfossils proved barren (G. Vidal, personal communication).

The lithostratigraphical divisions of Wenk & Haller (1953) have been retained in this account, though with some modification of their assumed distribution in the vicinity of the décollement zone. It has already been mentioned that the 'Mystery quartzite series' and 'Phyllite series' are cut out at the east end of Knækdalen, and the 'Layered quartzite-slate-dolomite series' is also reduced in thickness here from its normal 1400 m to about 300 m. The 'Mystery quartzite series' is widespread in southern Louise Boyd Land and at least 2000 m thick; the base is not seen. It is well-bedded with abundant ripple marks and mud cracks. There are several major dioritic instrusions on both sides of Jættegletscher within the 'Phyllite series' and 'Mystery quartzite series'.

Metamorphism, structures and Caledonian granites

The eastward increase in metamorphic grade within the Petermann Series has been described by Odell (1939), Huber (1950), Wenk & Haller (1953) and Wenk (1954), although the highest grades recorded are within the middle Proterozoic metasediments of this account. The present metamorphic zonation is the combination of Caledonian regional metamorphism overprinting and retrograding older metamorphic events.

Samples from near the summit of Gog, the highest stratigraphic level examined, exhibit non-metamorphic detrital textures in thin section. Nearly 4000 m stratigraphically lower, spotted phyllites from the 'Phyllite series' in Mysteriedalen contain a few partly chloritised garnets, biotite laths and plentiful opaque minerals. A few kilometres farther east in western Knækdalen the same stratigraphic level exhibits large idioblastic garnets and biotite laths overgrowing fine-grained textures of muscovite and quartz, and a strain slip cleavage. In the 'Layered quartzite-slate-dolomite series' near Portgletscher coarse-grained textures of quartz, muscovite, biotite, and idioblastic and poikilitic garnets are found.

Pelitic and semipelitic lithologies in the middle Proterozoic metasediments show coarse-grained metamorphic textures of biotite, muscovite, quartz and garnet. Garnets range up to 6 mm in diameter, occasionally much larger, with few, or numerous, inclusions arranged in helicitic trails or producing a skeletal outline. Kyanite and staurolite have been recorded in the western zone of metasediments. Biotite may show alteration to chlorite.

The structures within the Hagar sheet gneisses include major tight and isoclinal folding, strong foliation and banding, and are reflections of their long history extending back to at least the early Proterozoic. Granites and basic dykes emplaced into the gneisses are also strongly foliated and folded. The middle Proterozoic metasediments exhibit pronounced tight folding, notably beneath the reverse limb of the Hagar sheet nappe (Plate 1b, section C–D), which is a major eastward facing structure.

The structures deforming the Petermann Series are by comparison mainly simple, comprising broadly spaced anticlines and synclines similar in style to the Caledonian structures affecting the Eleonore Bay Group. Wenk & Haller (1953) distinguished three major N–S to NNE–SSW trending folds: Petermann syncline, Gregory anticline and Knækdalen syncline. The Knækdalen syncline has a broad flat bottom in Knækdalen and two troughs (Wenk & Haller, 1953), resembling a large scale box fold; the western trough is well exposed on the north side of Nordenskiöld Gletscher where it exhibits a variable intensity of development (fig. 23).

The most spectacular structure is the major westward facing recumbent fold developed in the 'Mystery quartzite series' (fig. 24), which has a limb length of at least 12 km in Louise Boyd Land (fig. 18b, section A–B). The nose of the fold is enveloped by the 'Phyllite series' without great complications or major dislocation, presumably due to accomodation by the imcompetent strata of the 'Phyllite series'. This recumbent structure is equivalent to the Mystery Valley (Mysteriedalen) overfold of Odell (1939), at which locality it is less completely exposed and was interpreted by Huber (1950) and Wenk & Haller (1953) as part of the complicated core region of the Gregory anticline.

Planar and linear structures of the different structural levels are shown in fig. 25. The middle Proterozoic metasediments and Hagar sheet gneisses have regional westward dipping foliation and bedding, while the Petermann Series dips both east and west. Lineations and fold axes have a general similarity in the different levels, though with a broader range of

Fig. 23. Western of the two hinge zones of the Knækdalen syncline in the north wall of Nordenskiöld Gletscher. Note that the fold tightens downwards, and that dykes of Caledonian granite have been emplaced along the axial plane foliation surfaces. The light upper units are competent quartzites of the 'Summit' and 'Shoulder series'.

variation in the older rocks. Wenk & Haller (1953) viewed the close similarity of structural trends in different units in Knækdalen as evidence supporting the classic 'stockwerke' interpretation, but this feature may equally well be the result of Caledonian deformation of both younger and older rock units.

The most extensive outcrops of Caledonian granites occur on both sides of Nordenskiöld Gletscher (fig. 18); a major sheet intrusion extends as far as Knækdalen. The spectacular

Fig. 24. Nose of recumbent anticlinal fold in Louise Boyd Land developed in the 'Mystery quartzite series'. At the right the quartzites have a concordant contact with the 'Phyllite series'.

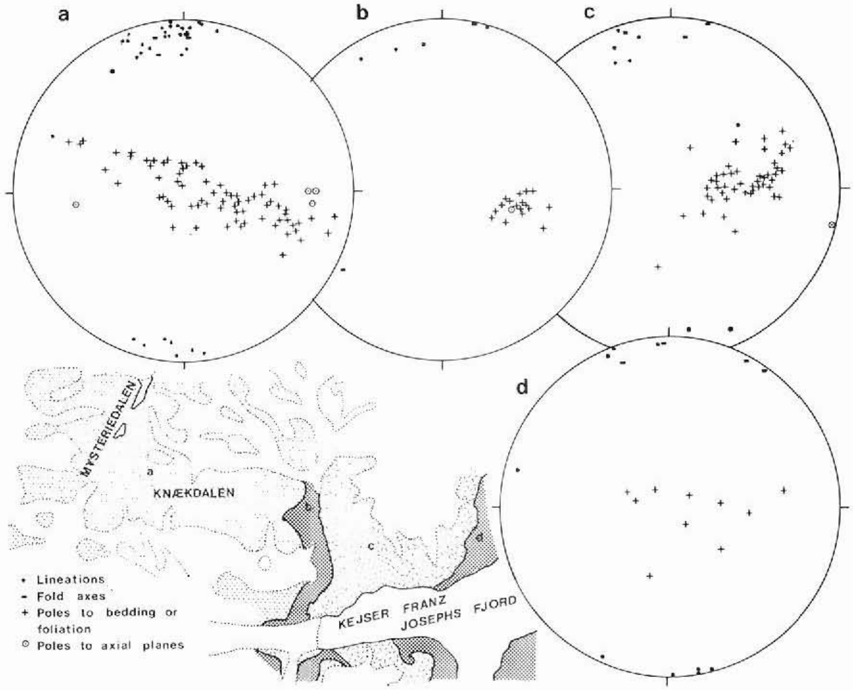


Fig. 25. Stereograms of planar and linear elements in the Knækdalen region (lower hemisphere, equal area projections). (a) Petermann Series; (b) middle Proterozoic metasediments between Petermann Series and Hagar sheet; (c) early Proterozoic Hagar sheet gneisses; (d) middle Proterozoic metasediments beneath Hagar sheet.

contacts with the Petermann Series have been described and illustrated by earlier workers. Odell (1939) notes that they have taken part in the latest folding, while Wenk & Haller (1953) describe them as late to post-tectonic. The granite sheets of fig. 23 have been emplaced along the axial plane cleavage of the west trough of the Knækdalen syncline. Like the leucocratic Caledonian granites of other areas, they are medium to coarse-grained, muscovite-biotite granites; muscovite dominates over biotite, and microcline over oligoclase. Whittard (1930) noted porphyritic varieties on the south-east side of Nordenskiöld Gletscher with large orthoclase phenocrysts, and more biotite than muscovite.

Kap Hedlund

Three main geological units meet at Kap Hedlund (Plate 1c), which lies at the confluence of four fjords (fig. 1). The peninsula itself is formed largely by basement gneisses of the Gletscherland complex. A prominent south-east dipping thrust zone with extensive associated zones of shearing separates these gneisses from migmatitic, middle Proterozoic metasediments and late Proterozoic Eleonore Bay Group sediments which occupy the high ground south-east of Kap Hedlund.

Basement gneisses – Gletscherland complex

A variety of gneisses are present, most commonly banded biotite gneisses with varying amounts of amphibolite layers and lenses, a few peridotitic ultrabasic lenses, and scattered calc-silicate inclusions. Homogeneous, grey, foliated and lineated hornblende gneisses also form extensive areas; they are of quartz monzodiorite composition and were probably derived from igneous rocks. Amphibolite forms several major horizons, though the proportion of amphibole is somewhat variable, and rock types vary from hornblendite through to hornblende gneiss. Discordant amphibolite dykes are very common cutting the gneisses at and around Kap Hedlund, in some cases showing cross-cutting of the gneiss banding, and in other cases being strongly sheared. Several horizons of mica schists and micaceous quartzites occur within the gneiss sequence, but as is the case elsewhere in the Gletscherland complex, it is not clear whether these are integral parts of the gneiss sequence or infolded strips of the middle Proterozoic metasediments. Kyanite, fibrolitic sillimanite and garnets have been recorded in the mica schists.

Two Rb-Sr isochron ages have been obtained on rock units of the Gletscherland complex at Kap Hedlund (Rex *et al.*, 1976; Rex & Gledhill, this report). An age of 1705 m.y. was obtained for a collection of samples from a dioritic amphibolite band east of Kap Hedlund, and an age of 1830 m.y. for biotite and hornblende gneisses collected in the same region. These suggest a minimum early Proterozoic age for the complex.

Thrust zone

A south-east dipping thrust zone forms the eastern border of the Gletscherland complex. It runs through the steep cliffs along the east side of Rhedin Fjord, striking north-east to the south of Kap Hedlund, where it marks the break in slope below steep cliffs of migmatites and the Eleonore Bay Group; the thrust enters Kempes Fjord about 4 km east of Kap Hedlund (Plate 1c). There are several prominent movement planes associated with extensive mylonitic developments. Above the thrust, along the coast of Kempes Fjord, Caledonian granite sheets emplaced into the Eleonore Bay Group show considerable shearing.

This thrust zone is a northward continuation of the similar structure at the west end of Forsblads Fjord (fig. 1). At Kap Hedlund the strike of the thrust zone swings from N–S to NE–SW, and cuts across the strike of the migmatite zone and the high levels of the Lower Eleonore Bay Group. On the north side of Kempes Fjord (fig. 1) basement rocks are in thrust or fault contact with low levels of the Upper Eleonore Bay Group; at this locality a zone of en échelon tension faults (Haller, 1971, fig. 125) may overprint the, apparently older, thrust system.

Migmatitic metasediments and the Eleonore Bay Group

The migmatitic metasediments south of Kap Hedlund are the northernmost extremity of a middle Proterozoic migmatitic zone traceable southwards continuously for at least 250 km. Forsblads Fjord cuts through this zone where it is approximately 20 km wide (see below, and Plate 1d).

The migmatites, where examined, are typically developed as highly veined, neosome-rich rocks, with quartizitic bands and lenses of paleosome material. They are rich in fibrolitic sillimanite.

The contact with the Eleonore Bay Group outcrops in high cliff sections, which were not visited, and meets the thrust zone in an area covered by extensive Quaternary deposits.

Numerous granite sheets occur in the Eleonore Bay Group sediments near the contact with the migmatites. The precise stratigraphical level is not certain as the sedimentary sequence is generally monotonous, but is believed to be fairly high up in the Lower Eleonore Bay Group. Metamorphic grade reaches amphibolite facies close to the contact, with development of staurolite and garnet, but decreases rapidly eastwards and stratigraphically upwards.

Tærskeldal – Forsblads Fjord – Randenæs

Forsblads Fjord exposes an excellent east–west section through a 20 km wide zone of migmatites, migmatitic granites and metasediments. This zone is clearly a northward extension of the broad migmatite zone traceable throughout the Scoresby Sund region to the south, where isotopic investigations suggest the main migmatite development to be middle Proterozoic (Steiger *et al.*, 1979), but with significant emplacement of granitic material in Caledonian time. At the west end of Forsblads Fjord the migmatite zone is in thrust contact with the older Gletscherland complex, well exposed in Tærskeldal. In the east near Randenæs there is an apparently transitional contact between migmatites and the Lower Eleonore Bay Group. The area has previously been described by Haller (1958), while more recent investigations are briefly described by Caby (1976a). A new geological map is given in Plate 1d.

Gletscherland complex in Tærskeldal

The broad valley bottom of Tærskeldal exposes a great variety of gneisses and amphibolites, cut by swarms of discordant amphibolitic dykes. Rex *et al.* (1977) undertook Rb–Sr whole rock studies on collections from the south margin of Tærskelsø, a few kilometres west of the map boundary of Plate 1d, and obtained a linear plot about a 2450 m.y. reference line suggestive of an Archaean age of development.

Hornblende and hornblende-biotite gneisses are common. They are usually well-banded, sometimes with thin bands of pure amphibolite, and may exhibit several phases of tight or isoclinal folding. Leucocratic gneisses are important, and are later than the banded gneisses which they envelope and invade, producing migmatitic and agmatitic structures. The leucocratic gneisses can be very homogeneous and almost granitic, but are usually well-foliated and may exhibit isoclinal folding; they form extensive areas on the north side of Tærskeldal where Haller (1958) mapped them as synorogenic granites.

Amphibolites are common as thin bands in the various gneisses, and also form major bodies. Several major lens-like amphibolite bodies occur in the eastern part of Tærskeldal. Some are medium-grained dioritic bodies with relic igneous textures and structures, while others are purple-brown to rusty-coloured, schistose, hornblende-biotite rocks. They may enclose strips of gneiss and are cut locally by NNE trending pegmatites. Ultrabasic layers and lenses occur locally; they include hornblendites and peridotites.

Swarms of amphibolitic dykes cut all rock units; they correspond to the older dioritic 'lamprophyre' generation of Haller (1958). They post-date at least one episode of isoclinal folding, and have themselves been strongly deformed producing folding, foliation, and pinch

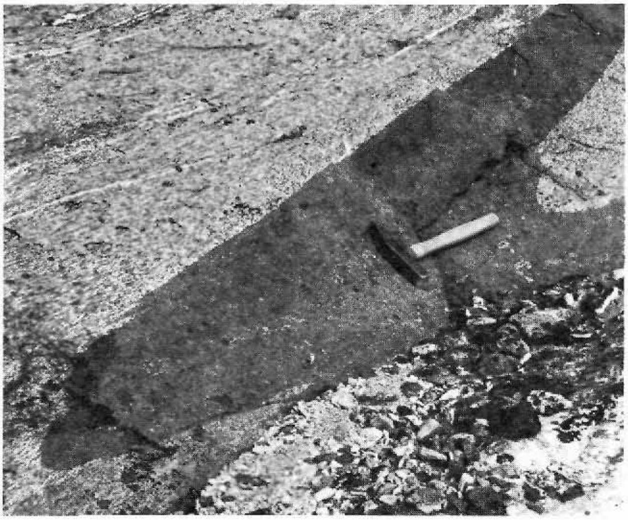


Fig. 26. Folded discordant amphibolite dyke in the Tærskeldal area. The foliation in the hornblende gneisses is parallel to the axial plane of the fold.

and swell structures (fig. 26). However, they still locally preserve chilled margins, relic igneous textures and apophyses. On the north side of the valley it is possible to distinguish two amphibolite dyke generations (Haller, 1958 p. 102); an older E–W trending set of brown dykes up to 30 m wide is cut by a set of NE–SW purplish-brown dykes. Young, unmetamorphosed lamprophyre dykes also occur sporadically.

Regional dips of banding and foliation are to the south-east at moderate angles, while well-developed lineations plunge eastwards at low angles (fig. 30).

Thrust zone

A network of lineaments follows the south-east side of Tærskeldal, marking a system of faults and thrusts. The main eastward dipping thrust follows the contact between the gneiss complex to the west and metasediments to the east, and crosses from Tærskeldal across the extreme west end of Forsblads Fjord and up into Højedal. Splays run off the main thrust line on both sides. Interleaved wedges of gneissic and metasedimentary lithologies occur along the main thrust.

Mylonites are extensively developed along all the lineaments, notably in the lower slopes of Tærskeldal and in Højedal. They are typically strongly foliated, dark grey or green, schistose or cherty rocks, with angular or rounded feldspathic porphyroblasts. Thin sections show fine-grained cataclastic textures with new growths of strongly orientated minute biotite and chlorite laths.

The thrust zone has a regional N–S trend, and can be linked up with a major thrust system running through the crystalline rocks of the Scoresby Sund region to the south, and also continuing to the north passing close to Kap Hedlund (fig. 1).

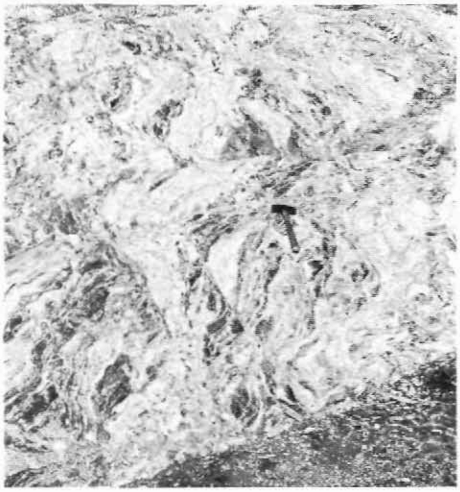


Fig. 27. Migmatites in Forsblads Fjord, dominated by several generations of neosome veins, the paleosome surviving as dark lenses and schlieren of biotite-sillimanite rich psammitic gneiss.

Metasediments and migmatites of Forsblads Fjord

The metasediments and migmatitic metasediments occupying most of Forsblads Fjord are in the writers' opinion of middle Proterozoic age. However, it deserves mention that Caby (1976a, and unpublished GGU report) from his recent investigations in the same region, argues that they are, in fact metamorphosed Lower Eleonore Bay Group as Wegmann (1935) and Haller (1958) had earlier maintained.

At the west end of Forsblads Fjord, east of the thrust zone, extensive outcrops of metasediments (rusty schistose gneiss, garnetiferous gneissic schist, siliceous gneiss, grey quartzite) form high dark-coloured cliffs. A few thick units of foliated garnet-biotite granite relieve the generally monotonous sequence of metasediments.

Fig. 28. Large inclusion of banded psammitic gneiss in coarse-grained granular neosome, or migmatite granite. South side of Forsblads Fjord, west of Caledoniaø.

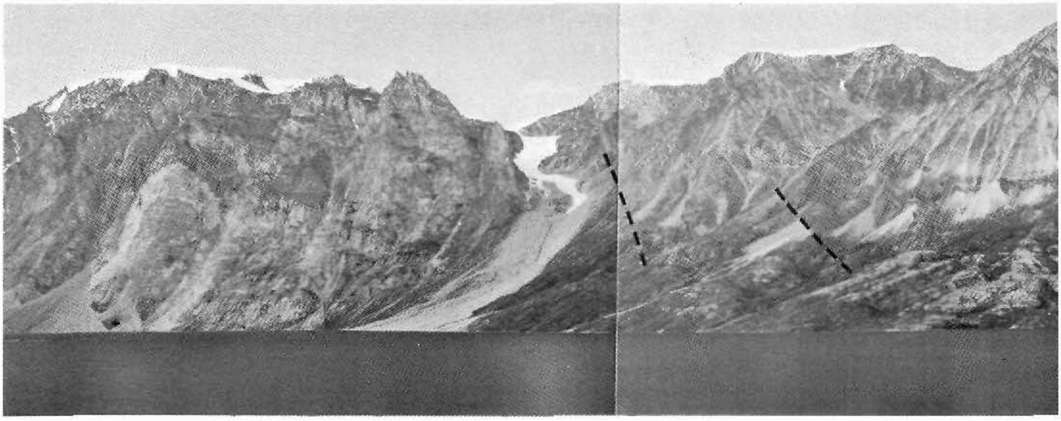


Fig. 29. Panorama across the contact zone between the Eleonore Bay Group and the middle Proterozoic migmatites on the north side of Forsblads Fjord. To the right (east) the unfolded Eleonore Bay Group dips eastwards at moderate angles, and in the centre of the photograph, at Randenæs, is invaded

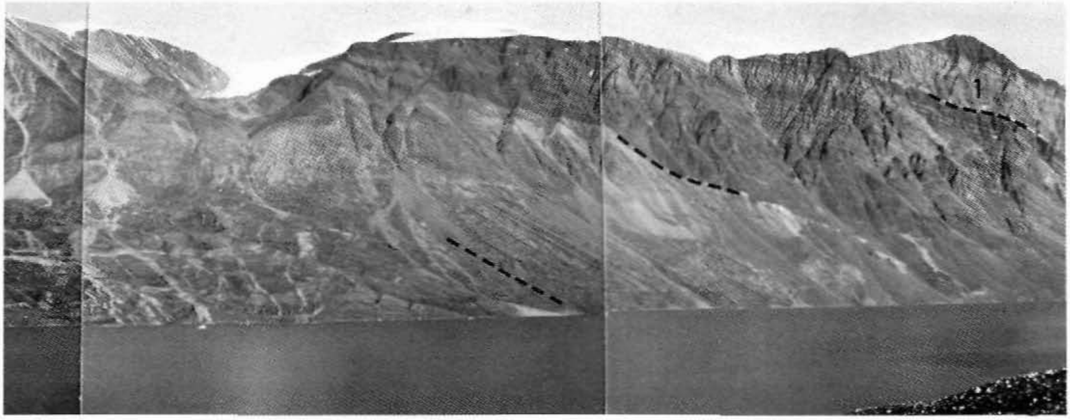
Kyanite and sillimanite occur together in the metasediments of the west part of the fjord, but eastwards kyanite disappears and the proportion of sillimanite increases as the metasediments are invaded by increasing amounts of veins and lenses of granitic neosome which transform them into migmatites. Migmatites, migmatitic granites and granites of diverse character extend along both sides of Forsblads Fjord as far as the Eleonore Bay Group outcrop at Randenæs. There are several generations of neosome (fig. 27), early phases being folded prior to injection of later phases. The paleosome includes obvious fragmented bands and lenses of quartzites (fig. 28), while pelitic material survives as strongly modified lenses and schlieren of biotite schists or gneisses. The migmatites are generally well-banded and foliated. Several major fold closures can be distinguished. The regional strike is N–S with steep inclinations, and fold axes and mineral lineations have a clear N–S trend (fig. 30).

The south side of Forsblads Fjord is more granitic than the north side, and largely comprises granitic migmatite or migmatite granite in which the granitic neosome component is overwhelmingly dominant. There are also many distinct bodies of late leucocratic granite, some of them folded, some of them with small amounts of garnet and sillimanite, and others without metamorphic minerals.

Thin sections of samples of the migmatites and metasediments show in general fresh textures, except near the west end of the fjord where chloritisation is common, probably due to the proximity of the thrust zone. Many pelitic gneisses contain abundant sillimanite in seams of prismatic crystals or fibrolite. A band of granitic augen gneiss on the north side of the fjord contains elongate patches of fibrolite within the large feldspar augen. Garnet is very common as small and large, often poikiloblastic, crystals.

Within the migmatites occasional bands and bodies of amphibolite occur. They are particularly common in an area of veined gneisses about 5 km from the west end of the fjord on the north side, as thin bands, and lines of amphibolite pods deformed into rootless intrafolial folds.

Whole rock Rb-Sr isotopic studies from collections in the Forsblads Fjord migmatite zone



by a network of Caledonian granite and pegmatite sheets and veins. At extreme left migmatites show major folding. Contacts of the main lithological units shown in Plate 1d are marked. The peaks rise to 2400 m, and the width of the section is about 15 km.

have yielded three errorchron 'ages' (Rex & Gledhill, this report). Gneissic quartzites from near the west end of the fjord gave an age of *c.* 1245 m.y., biotite-bearing migmatite granite neosome material from south of Caledoniaø gave a somewhat anomalous age of *c.* 750 m.y., while dykes of sillimanite-bearing granite from the north side of the fjord gave a Caledonian age of *c.* 430 m.y.

Contact zone

The contact between the Eleonore Bay Group sediments and the east edge of the migmatite zone on the north side of Forsblads Fjord shows all appearances of being transitional (fig. 29). However, the isotopic evidence from the migmatite zone would seem to indicate that the apparent transition results from progressive Caledonian metamorphism and emplacement of granite sheets obscuring the nature of the original contact. Backlund (1930) appears to have been especially impressed by the apparently transitional contact, and Caby (1976a) reached the same conclusion during his recent investigations of the Lower Eleonore Bay Group.

A major Caledonian granite body (445 m.y.: Rex *et al.*, 1976) obscures the contact zone on the south side of the fjord. Farther south, in Schaffhauserdalen on the west side of Alpefjord, Caby (1976a) has described a major recumbent anticline facing eastwards in the Eleonore Bay Group at the margin of the migmatite zone. The fold is traceable for more than 12 km, and occurs above a large scale detachment zone developed within and below the inverted limb.

The original contact may have been a basement–cover unconformity, but this is no longer apparent due to décollement along the contact, and superimposed Caledonian metamorphism and granite emplacement.

On the north side of the fjord west of Randenæs the contact can be defined within narrow limits. Above the contact, high grade Eleonore Bay Group quartzite beds alternate with thin concordant sheets of Caledonian granite. Below the contact, granitic neosome material in

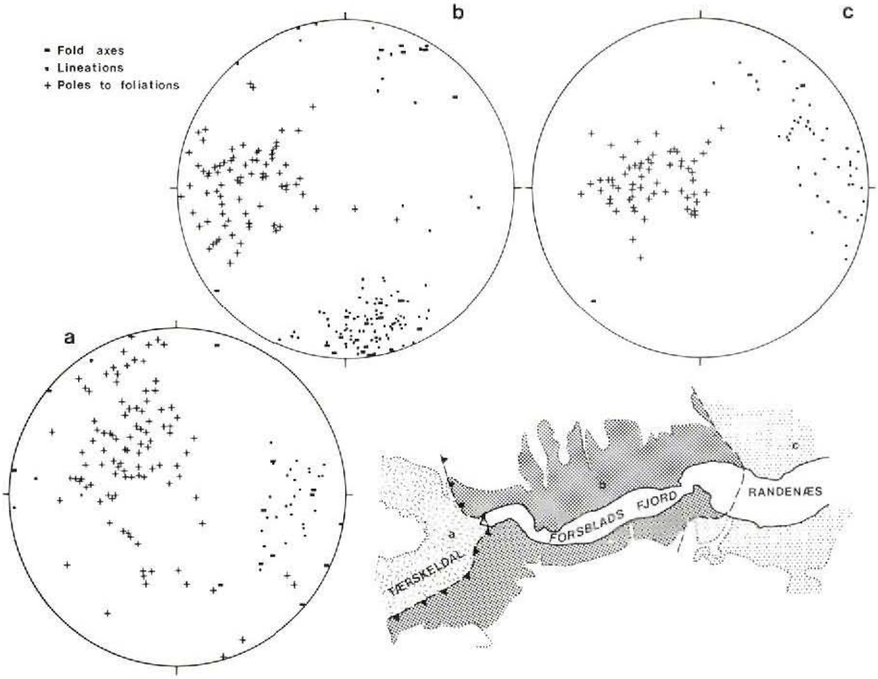


Fig. 30. Stereograms of planar and linear elements in the Forsblads Fjord region (lower hemisphere, equal area projections). (a) Archaean – early Proterozoic gneisses; (b) Middle Proterozoic metasediments and migmatites; (c) Eleonore Bay Group.

the migmatites has a diffuse, variable texture and the older metasedimentary rocks occur as disrupted and disorientated remnants.

Eleonore Bay Group

Caby (1976a) confirms the presence of an 8000 m Lower Eleonore Bay Group sequence in the Alpefjord region, but thicknesses are considerably less in the Randenæs section on the north side of Forsblads Fjord (*c.* 4800 m); parts of the sequence may be cut out along an east dipping low angle fault above and east of Randenæs (fig. 29), or along the suggested décollement plane at the base of the sequence.

The Lower Bay Group sequence can be divided into four parts (fig. 29, Plate 1d). The highest part, between the light-coloured bed group 1 of the Upper Eleonore Bay Group and a low angle fault, is composed of uniform, generally dark-coloured, well-banded quartzites and shales which are virtually non-metamorphosed (*c.* 1300 m). The fault line follows a conspicuous, but impersistent, yellow quartzite. The lower three units are: massive, well-bedded, light-coloured quartzites with a few semipelitic horizons (*c.* 800 m); well-bedded alternations of quartzitic, semipelitic and pelitic beds with cross-bedding common, ripple marks, occasional slump structures, and frequent calc-silicate lenses in quartzite beds (*c.* 1200 m); and grey to orange-grey quartzites (*c.* 1500 m). The conspicuous network of cross-cutting granite and pegmatite dykes and sheets at Randenæs mainly affects the lower two units.

Metamorphic affects increase systematically from east to west in the Lower Eleonore Bay Group at Randenæs. Garnet, biotite and staurolite are common in the semipelitic and pelitic parts of the sequence, in thin section forming large poikiloblastic crystals in a fine-grained detrital matrix. At the top of the lowest siliceous group Caby (unpublished GGU report) recorded sillimanite in nodular developments. These take the form of white nodules or cylindrical developments 1–2 cm in diameter. In thin section the quartz grains within the nodules are impregnated and enveloped by fans of minute fibrolitic sillimanite.

The regional dip is eastwards at 20°–30° east of Randenæs, very shallow at Randenæs itself, and west of Randenæs dips steeply eastwards at up to 70°. Sedimentary structures show the succession is all right way up, the changes in dip reflecting large scale simple folding. Mineral lineations are commonly developed with a general eastward trend, and NE and sometimes NNE trends in the steeply inclined beds in the west (fig. 30).

Caledonian granites

A very large granite pluton largely obscures the contact between the Eleonore Bay Group and the migmatite zone on the south side of Forsblads Fjord. It is a medium to coarse-grained biotite granite, in some places with porphyritic microcline. In its western parts close to the migmatite it contains thick wedges of metasediments. This granite has yielded a Caledonian Rb-Sr isochron age of 445 m.y. (Rex *et al.*, 1976). Many similar bodies occur to the south in Schaffhauserdalen and to the south-east in the Stauning Alper (Haller, 1958). The related network of granite and pegmatite dykes at Randenæs are mainly emplaced along joint planes with trends of 150–170° and eastward dips of 50–70°; a few major and many minor sills emplaced parallel to the flat-lying bedding contribute to the complex net vein outcrop pattern. Westwards, towards the migmatite contact, the number of granite dykes appears to increase, most being concordant to the steeply inclined bedding.

Most granites are medium-grained biotite granites. In thin section the biotite is pleochroic to a very deep brown; a little muscovite is usually also present. Slight alteration of biotite, and cloudiness of feldspars is common.

Some of the late, lencocratic granite sheets within the older migmatitic sediments are Caledonian; one has been dated isotopically (Rex & Gledhill, this report).

Concluding remarks

The investigations reported on here represent the conclusions of a preliminary stage of reinvestigation of the metamorphic complexes between 72°–74°N. The closely associated isotopic studies which provide a framework for the geological interpretations are reported on by Rex & Gledhill (this report). There is still, however, a great need for detailed investigations of many kinds in this part of the East Greenland Caledonides.

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