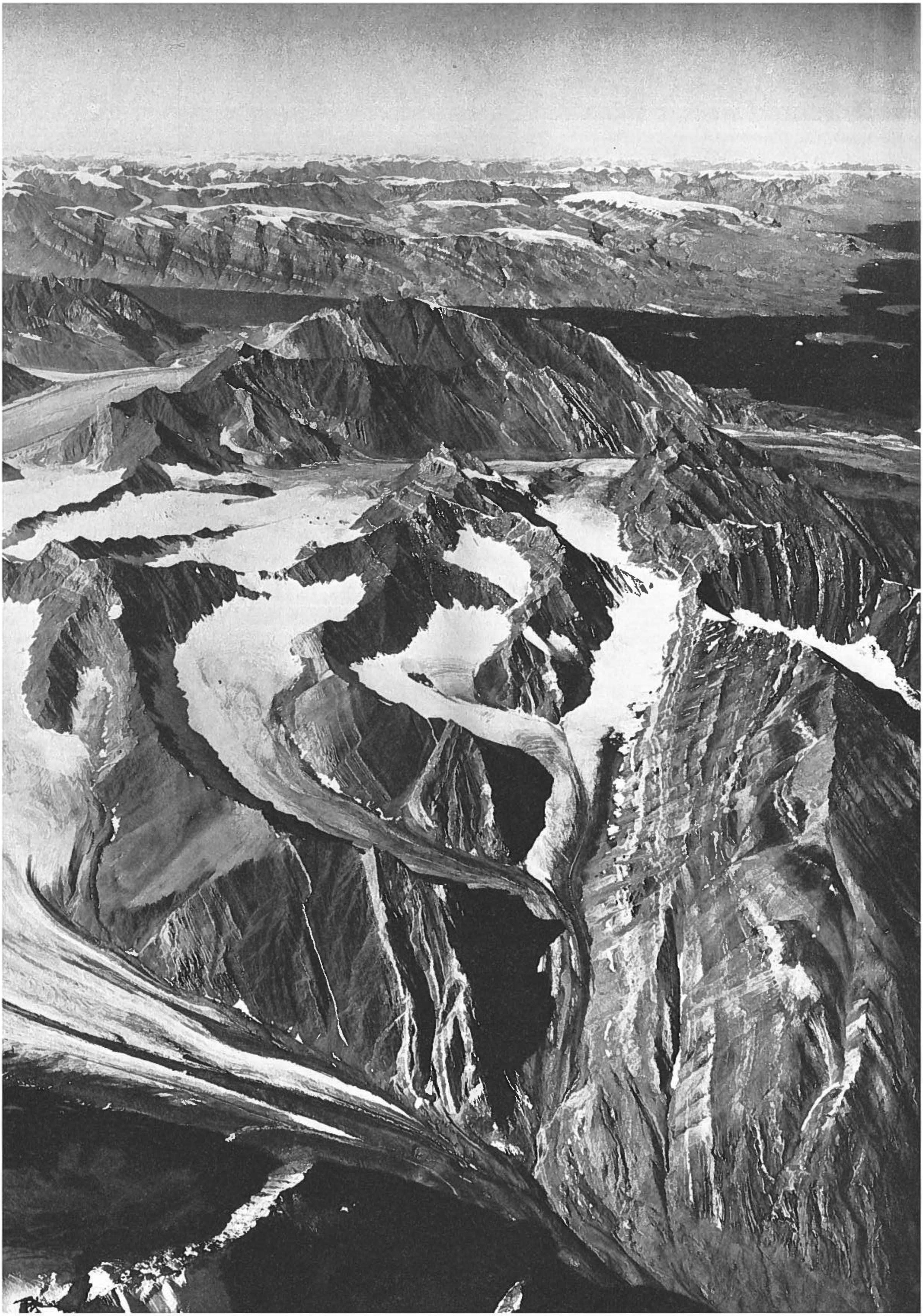


East Greenland Caledonian fold belt

Niels Henriksen

A. K. Higgins

Fig. 171. Steep eastward dipping strata of the upper Eleonore Bay Group in the northernmost Stauning Alper, mainly units of the Multicoloured 'series' and the Limestone-Dolomite 'series'. Dips decrease north of the fjord in Lyell Land. Minor N–S trending faults are common, and a major fault runs parallel to the right edge of the figure. Route 653 G-NV no. 09516. Copyright Geodetic Institute.

Introduction

The East Greenland fold belt is part of a major Caledonian structure which occurs on both sides of the North Atlantic Ocean (fig. 172). It extends from latitudes 70° to 82° N in East Greenland (fig. 173), occupying most of the wide strip of land between the coast and the Inland Ice.

Metamorphic crystalline complexes dominate the fold belt throughout most of its length; these comprise gneisses, migmatites, granites and high grade supracrustal rocks, of a variety of ages. In central East Greenland the metamorphic complexes are bordered to the east and west, and partially overlain, by low grade or non-metamorphic late Precambrian and Lower Palaeozoic sediments of considerable thickness. Caledonian orogenic activity can be traced throughout the region.

Continental clastic deposits of Devonian and Carboniferous to Lower Permian age were laid down in central East Greenland on Caledonian folded units, locally in great thicknesses. They are succeeded by Upper Permian and Mesozoic mainly marine sediments exposed only in the outer fjord zone and coastal region (Birkelund & Perch-Nielsen, this volume). Tertiary basalts bury and hide the southern continuation of the fold belt at 70° N, and occur locally as a partial cover to the Mesozoic sediments between latitudes 73° to 76° N.

Our present knowledge of the East Greenland fold belt stems largely from the series of expeditions led by Lauge Koch between 1926 and 1958, although significant contributions were also made by British, Norwegian and American expeditions mainly in the 1930s. Geological maps at a scale of 1:250 000 covering central East Greenland from 72° to 76°

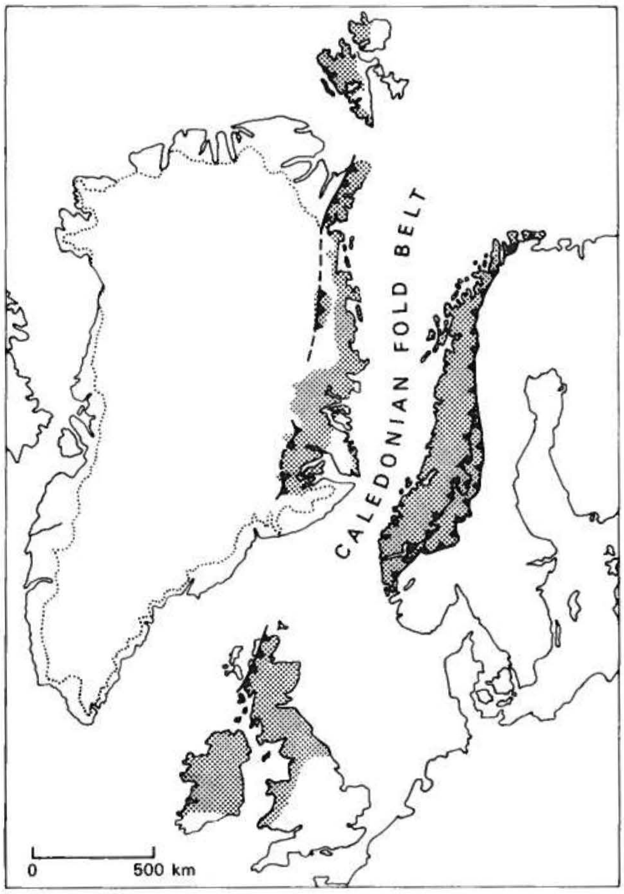
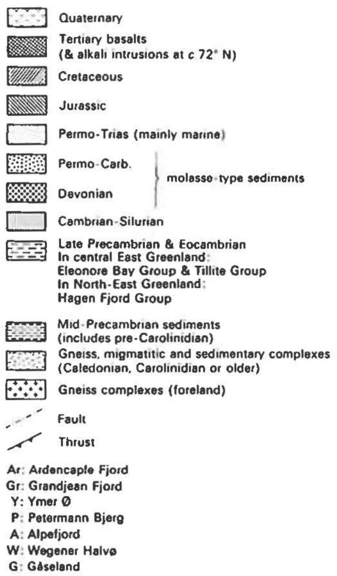


Fig. 172. Relation of the Greenland, Scandinavian and British Caledonides in a pre-drift configuration.



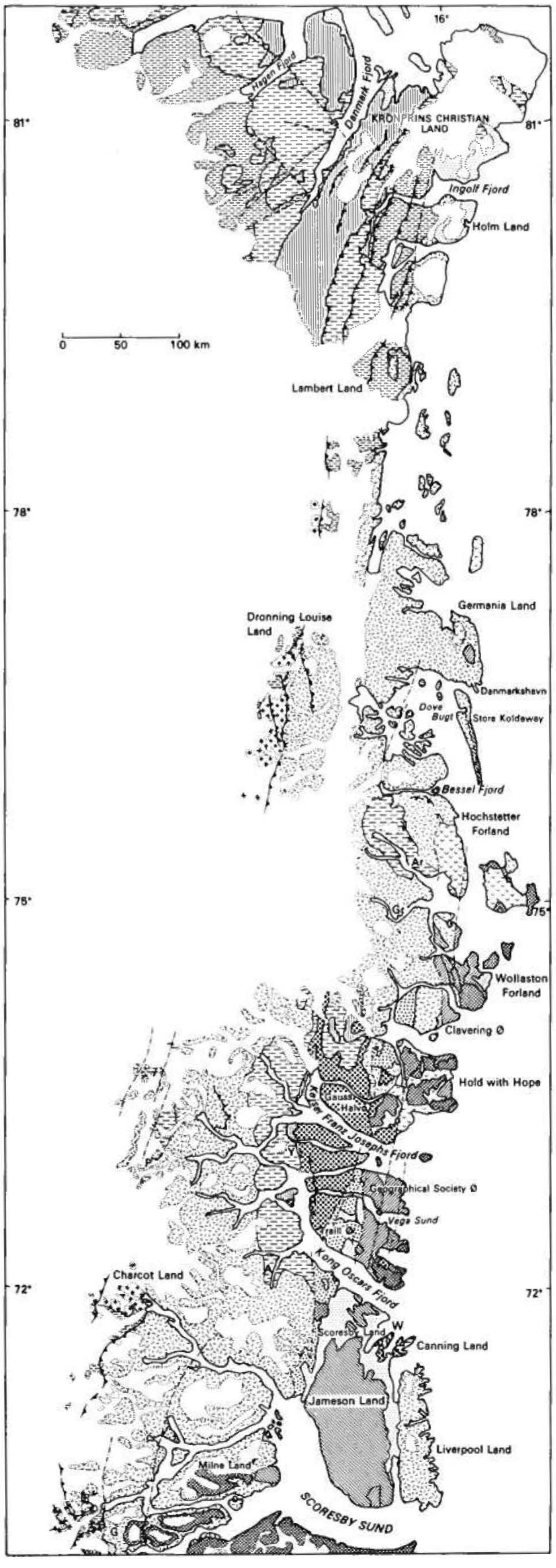


Fig. 173. Main geological divisions of the East Greenland Caledonian fold belt and the post-Caledonian formations.

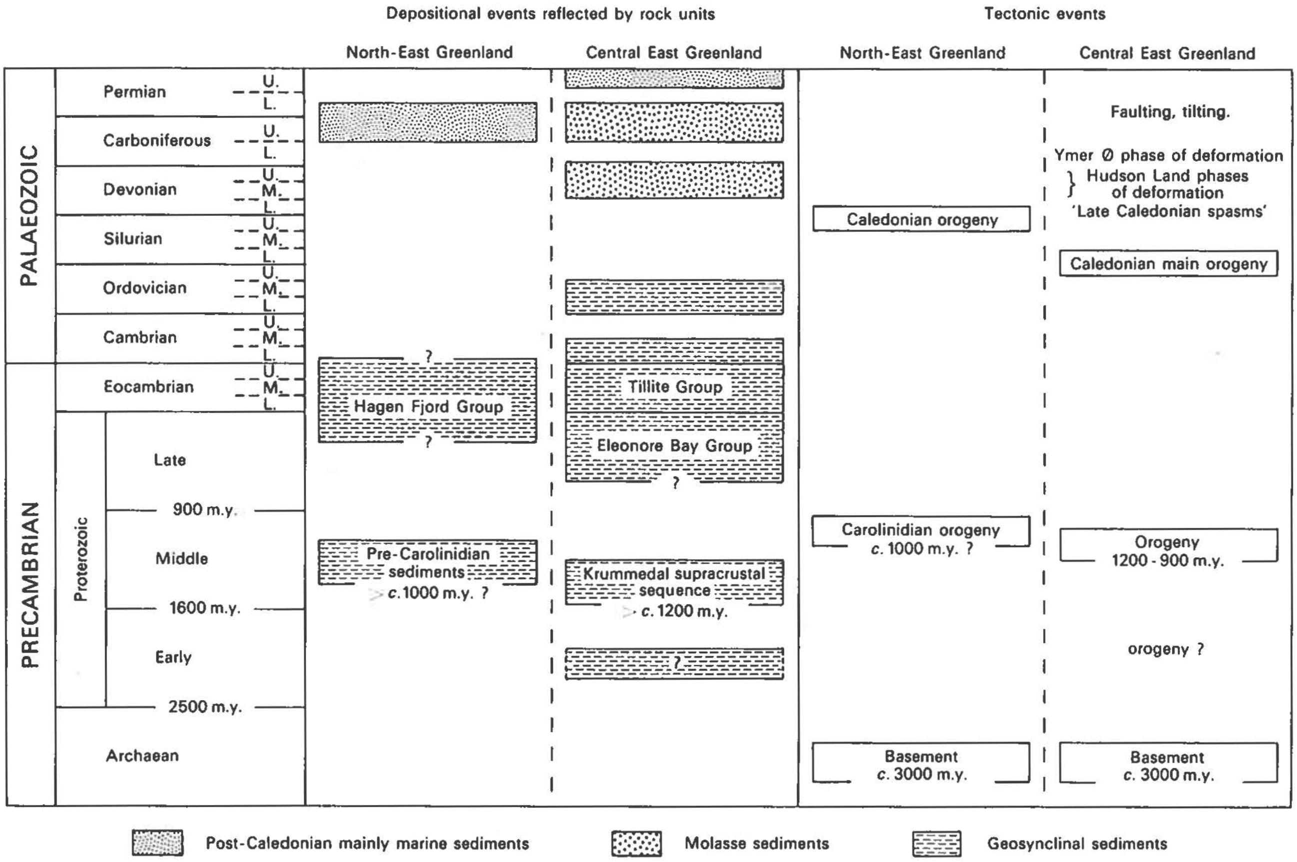


Fig. 174. Provisional chronological scheme of deposition and orogenic events represented in the East Greenland fold belt.

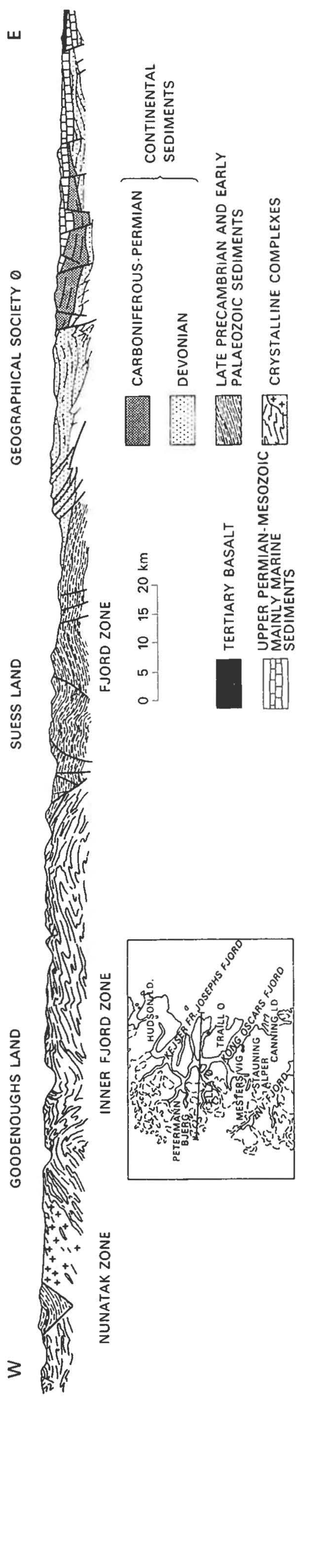
N have been published by Koch & Haller (1971). The Survey has recently completed a 5-year programme of regional mapping in the southernmost section of the fold belt (70°–72° N).

The most comprehensive accounts of the fold belt are those of Haller (1970, 1971), which are based largely on the results of Koch's expeditions including Haller's own extensive field mapping and wide-ranging aerial reconnaissance. With regard to the region south of latitude 76° N, these accounts, and many of the detailed descriptions of this part of the fold belt, are linked to a particular interpretation of the metamorphic complexes as being the deep-seated mobile infrastructure of the Caledonian fold belt. The characteristics of the complexes are regarded as being essentially Caledonian in origin, and the associated high grade metasedimentary rocks are viewed as parts of the late Precambrian sedimentary accumulations metamorphosed during the Caledonian orogenic event. The existence of areas of pre-Caledonian basement rocks within the complexes was recorded by Haller & Kulp (1962), although these were considered largely Caledonian remobilised.

Recent Survey work in the Scoresby Sund region (70°–72° N), and in particular an associated programme of radiometric dating, suggests that the conventional interpretation of the southern part of the fold belt is an over-simplification. Areas of pre-Caledonian basement rocks are apparently more widely distributed and less affected by Caledonian orogenesis than had been supposed. The new work indicates that the metamorphic complexes of the Scoresby Sund region retain characteristics of several pre-Caledonian orogenic events, and that some high grade metasediments were metamorphosed in pre-Caledonian time. Similarities with metamorphic complexes in regions to the north suggest a comparable pattern of events may be widespread.

In fig. 174 the apparent chronological succession of events in the East Greenland fold belt is summarised according to present knowledge. There are many uncertainties, and the scheme should be viewed with some reservation.

In this account the metamorphic crystalline rocks are described from region to region, using as far as possible established subdivisions of the various complexes (figs 193, 197). In many cases the proportion and distribution of Caledonian and pre-Caledo-



nian elements is an open question, and correlation of lithologies and events between the complexes is speculative.

Several areas of infracrustal and supracrustal rocks which may be viewed as autochthonous or parautochthonous parts of the Greenland shield occur along the margin of the Inland Ice west of, or below, major thrusts. These complexes have similarities with some of the units within the fold belt and are described individually.

In North-East Greenland the Carolinidian orogenic complex was described and established by Haller (1961). Its status as a distinct orogenic phase is reviewed here.

Major developments of late Precambrian and early Palaeozoic sediments are found in North-East Greenland and central East Greenland. The successions in the two regions are developed in different ways, but both reflect accumulations of geosynclinal proportions which later became involved in Caledonian deformation and metamorphism. In central East Greenland the outcrops occur mainly in the fjord zone between 72° and 76° N. The cumulative thickness reaches in some areas 17 000 m comprising the Eleonore Bay Group, Tillite Group and Cambro-Ordovician sediments. The age of the Eleonore Bay Group is presumed to be late Precambrian. The lower part of the sequence often appears to merge into high grade metamorphic sediments of the metamorphic complexes, a phenomenon which led to early controversy. No true base to the sequence is known, even today. In North-East Greenland the late Precambrian (post-Carolinidian) successions have been collectively termed the Hagen Fjord Group, and comprise up to 5000 m of sediments of a geosynclinal facies which are correlated with lesser thicknesses on the foreland.

Caledonian orogenic activity brought this sedimentation to a close. The Caledonian orogeny is considered to be much less intense than usually envisaged, but it is generally extremely difficult to make precise statements as to the age of development of various structures, and time of emplacement of plutonic bodies. In this account an attempt is made to isolate the definite Caledonian structures and intrusions from those of questionable or unknown age. The dominant structural pattern seems likely to be Caledonian, and in this sense the East Greenland fold belt is the Caledonian fold belt, but presumed pre-Caledonian structural trends survive in all the metamorphic complexes.

Fig. 175. Generalised cross-section across the fold belt at about latitude 73° N.

Continental deposits ranging from Devonian to Lower Permian in age form thick accumulations in central East Greenland and comprise weathering detritus derived from the Caledonian mountains. There are several cycles of deposition interrupted by minor deformational episodes. The Upper Devonian sequence is noted for its vertebrate fossils (Bendix-Almgreen, this volume), while the Carboniferous to Lower Permian sediments contain an extensive flora (Raunsgaard Pedersen, this volume). Continental deposition was brought to a close by the transgression of the Upper Permian (Zechstein) sea.

In this treatment of the East Greenland fold belt the late Precambrian and early Palaeozoic sedimentary sequences are described first. The Caledonian deformation and plutonism are next outlined, followed by the related late Palaeozoic continental deposition and deformation. The more problematical metamorphic complexes of the fold belt are described individually in the last section.

Late Precambrian and early Palaeozoic sediments: central East Greenland

The great accumulations of late Precambrian and Lower Palaeozoic rocks are one of the most spectacular features of the fold belt. The most complete sections are found in the outer fjord zone of central East Greenland where cumulative thicknesses of up to 17 000 m have been recorded; incomplete sections up to 7000 m thick occur in the nunatak zone. General dips are eastwards and westwards respectively on either side of the central metamorphic complex (fig. 175), while folding is of moderate intensity. The succession is exclusively sedimentary and comprises very shallow water deposits characteristic of shelf-type conditions with frequent sub-continental incursions; sub-tidal facies are indicated by stromatolithic biostromes. Three main divisions are recognised: Eleonore Bay Group, Tillite Group and Cambro-Ordovician. In North-East Greenland late Precambrian sediments are represented by the up to 5000 m thick Hagen Fjord Group, preserved in several thrust sheets within the Caledonian fold belt.

Eleonore Bay Group: late Precambrian

Non-metamorphic or weakly metamorphosed outcrops of the Eleonore Bay Group outcrop between Canning Land (71° 40′ N) and Bessel Fjord (76° 00′ N) (fig. 176). The sequences preserved suggest a grossly similar lithological development over a re-

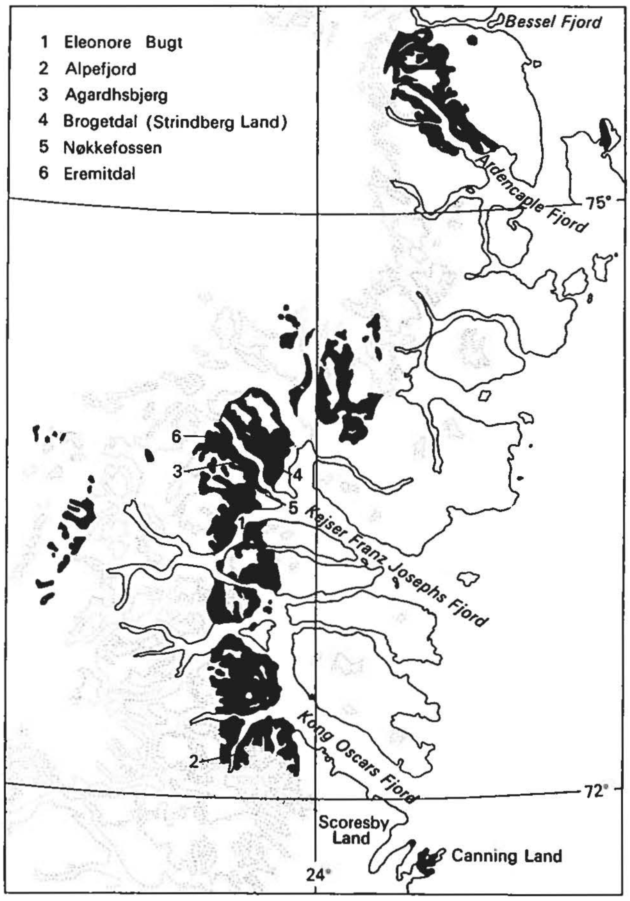


Fig. 176. Eleonore Bay Group outcrops in central East Greenland (71°40′–76°00′ N).

gion 450 km from north to south and 200 km from east to west. Generally simple Caledonian fold structures and faults deform and displace the succession. Metamorphic equivalents are developed in transition zones to the infracrustal complexes and the true base to the sequence is not known. The subdivisions, nomenclature and lithology are summarised in fig. 177, and the distribution of the Lower and Upper Eleonore Bay Group are shown in figs 199 and 214.

Nomenclature

The spectacular and variously coloured strata of the Eleonore Bay Group were first described by Nathorst (1901) and included in his 'Silurian'. Subsequently Wordie (1927) placed them within his 'Franz Josef Beds'. Koch (1929), Backlund (1930) and Teichert (1933) established the present stratigraphic nomenclature, substantiated and elaborated in subsequent papers by Fränkl (1953a, b), Haller (1953, 1955, 1958, 1971) and Katz (1952a, b, 1954, 1961).

Two independant sets of nomenclature have been proposed for the Eleonore Bay Group (fig. 177). Katz's (1961) terminology was applied only to the sediments of the fjord zone between 72°–74° N, and represents a revision based on the principles set out by the American Commission on Stratigraphic Nomenclature (1956). Haller's (1971) nomen-

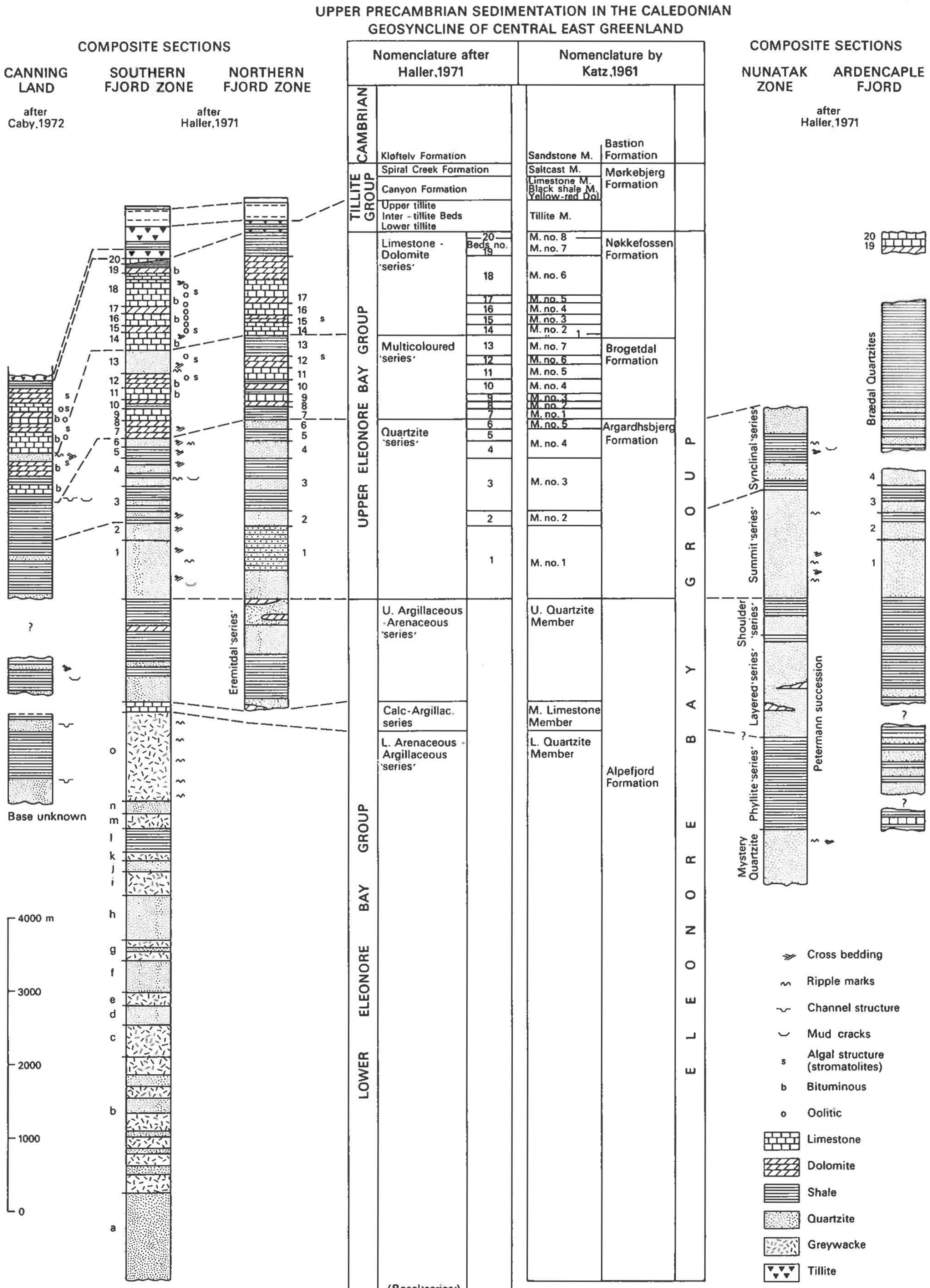

UPPER PRECAMBRIAN SEDIMENTATION IN THE CALEDONIAN GEOSYNCLINE OF CENTRAL EAST GREENLAND
COMPOSITE SECTIONS
CANNING LAND
after Caby,1972
SOUTHERN FJORD ZONE
NORTHERN FJORD ZONE
after Haller,1971
Nomenclature after Haller,1971
Nomenclature by Katz,1961
CAMBRIAN
Kløftelv Formation
TILLITE GROUP
Spiral Creek Formation
Canyon Formation
Upper tillite
Inter - tillite Beds
Lower tillite
UPPER ELEONORE BAY GROUP
Limestone - Dolomite 'series'
Beds no.
Multicoloured 'series'
Quartzite 'series'
U. Argillaceous -Arenaceous 'series'
Calc-Argillac. series
L. Arenaceous - Argillaceous 'series'
LOWER ELEONORE BAY GROUP
(Basal 'series')
Sandstone M.
Bastion Formation
Saltcast M.
Limestone M.
Black shale M.
Yellow-red Dol.
Mørkebjerg Formation
Tillite M.
Nøkkefossen Formation
Brogetdal Formation
Argardhsbjerg Formation
U. Quartzite Member
M. Limestone Member
L. Quartzite Member
Alpefjord Formation
ELEONORE BAY GROUP
Eremitdal 'series'
Base unknown
4000 m
3000
2000
1000
0
COMPOSITE SECTIONS
NUNATAK ZONE
ARDENCAPLE FJORD
after Haller,1971
Synclinal 'series'
Summit 'series'
Shoulder 'series'
Layered 'series'
Phyllite 'series'
Mystery Quartzite
Petermann succession
Brædal Quartzites
Cross bedding
Ripple marks
Channel structure
Mud cracks
Algal structure (stromatolites)
Bituminous
Oolitic
Limestone
Dolomite
Shale
Quartzite
Greywacke
Tillite

Fig. 178. Cross-bedding in well-bedded sandstones of the Lower Eleonore Bay Group on the west side of Alpefjord.

clature, which was also applied to the various isolated successions, corresponds to that used in the majority of published descriptions and for this reason is also employed in the present account. Both Katz and Haller define the Eleonore Bay Group as comprising the sedimentary successions below the basal beds of the Tillite Group, although Haller includes supposed high grade metamorphic equivalents forming part of the metamorphic complexes.

Problem of the 'Basal Series'

The 'Basal Series', postulated by Haller (1971) as the lowest unit of the Eleonore Bay Group, occurs mainly in scattered locations of the nutatak zone between Gåseland (70° 15′ N) and Arnold Escher Land (74° N) and is characterised by a marble-greenschist association. Haller's 'Basal Series' includes the Marble-Phyllite Series of Gåseland (70° N: Wenk, 1961), the Charcot Land supracrustal sequence (71°45′ N: Steck, 1971), the Eleonore Sø 'series' in Arnold Escher Land (74° N: Katz, 1952b) and the succession at Målebjerg in western Andrée Land (73°35′ N: Haller, 1971).

Recent investigations have shown that parts of the 'greenschist' sequence in Gåseland are mylonitic developments and not of volcanic origin as earlier supposed, whereas associated marbles and local tillites may be uppermost Precambrian to Cambrian in age.

The Charcot Land sequence is veined by a granite which has given a date of 1900 m.y. and this seems to preclude any relationship with the Eleonore Bay Group.

The Eleonore Sø 'series', which occurs in a fault block surrounded by gneisses and schists, comprises a thick sequence of sandstones, mudstones, calcareous shales and dolomites (1000 m) overlain by ophiolitic greenstones (1000 m) and a thrust unit of quartzite (1000 m: Katz, 1952b). Katz compared the succession with parts of the Upper Eleonore Bay Group and suggested the ophiolites were formed at the same time as the tillites in the central fjord zone, whereas Wenk (1961) correlated the ophiolites with the supposed volcanic greenschists of Gåseland and the basic volcanics of the Charcot Land sequence. The true age of the Eleonore Sø 'series' is at present unknown.

The succession at Målebjerg (Andrée Land) was at first correlated with the upper part of the Lower Eleonore Bay Group (Haller, 1953), but later reinterpreted as representing the 'Basal Series' (Haller, 1971). This view is probably based on similarities with other occurrences of the supposed 'Basal Series', and is thus inconclusive.

In view of the uncertainty as to the stratigraphic position of the rocks which have been referred to as the 'Basal Series' the term is disregarded in this account.

Lower Eleonore Bay Group: fjord zone

The bulk of the Lower Eleonore Bay Group has a simple lithology of alternating argillaceous and arenaceous layers. There are indications of considerable lateral facies changes, but no detailed investigations have been carried out. The general stratigraphy and lithology outlined below, and on fig. 177, are those established in the southern part of the fjord zone where the greatest thicknesses are developed.

Lower Arenaceous-Argillaceous 'series'

The sequence has been described in the Alpefjord area (72°15′ N) by Fränkl (1951), while Haller's (1971) account also takes into consideration investigations by B. Evans in the same area. The series reaches about 8000 m in thickness in the Alpefjord area and consists of alternating thick units of pure quartzites and fine-grained greywackes.

←——

Fig. 177. Stratigraphical and lithological divisions of the Eleonore Bay Group and Tillite Group.

Sedimentary structures are abundantly developed, quartzites often showing current bedding (fig. 178), and the greywackes small-scale grading, ripple bedding, or load structures and breccia developments.

The lowest exposed part of the succession is only found in a slightly metamorphic state in contact with an intrusive granite. The original base of the succession therefore cannot be defined, but both Fränkl (1953b) and Haller (1971) regard a 1000–2000 m thick sequence of epimetamorphic sedimentary rocks in the crystalline complex adjacent to Alpefjord as an even lower unit of the Eleonore Bay Group.

Calc-Argillaceous 'series'

A 150 m sequence of alternating siliceous limestones, shales, and a few thin-bedded quartzites make up the Calc-Argillaceous 'series' in the Alpefjord area. The series is largely restricted to the southern part of the fjord zone. At one time Haller (1953, 1955) regarded the series as a marker correlatable with marble bands within the infracrustal complexes, but this interpretation is no longer maintained (Haller, 1971).

The shales are frequently rusty weathering. The limestones are often black due to an iron sulphide content, and have an ochre coloured weathering.

Upper Argillaceous-Arenaceous 'series'

This sequence was first described by Fränkl (1953a) from Eremitdal (73°50′ N) as the Eremitdal Series. Later it was correlated with similar successions in other parts of the fjord zone and acquired the present name. It consists mainly of thin-bedded quartzites, slates and shales with a total thickness of 1200–1400 m. In the upper part some horizons contain dolomite lenses, and the quartzite bands are generally thicker. The rocks are dark brownish grey and greenish in colour and mostly have a characteristic rusty weathering.

The many measured sections through this series show that the succession is lithologically very variable in detail, implying the existence of lateral facies variations and local influence on the depositional conditions. The overall pelitic to semipelitic nature of the sedimentary sequence, however, reflects the general fine clastic depositional environment for the whole series.

Metamorphic equivalents of these sediments occur in the Isfjord – Ole Rømer Land supracrustal region in the form of chlorite schists, mica schists, siliceous gneisses and quartzites.

Lower Eleonore Bay Group: other areas

Outside the main fjord zone outcrops, supposed Lower Eleonore Bay Group sequences are found in the nunatak zone (Wenk & Haller, 1953), around Ardencaple Fjord (Sommer, 1957b) and in Canning Land (Caby, 1972). There are general similarities with the fjord zone, but facies developments are slightly different and precise correlations are not possible. Developments are summarised in fig. 177. Overlying sequences in each case are correlated with the Upper Eleonore Bay Group.

The Canning Land sequence comprises more than 2000 m of black shales, quartzitic shales and slates (Caby, 1972). Sun cracks, small scale ripple marks and conspicuous minor channel features are recorded, and Caby suggests a sub-continental depositional environment in a shallow basin, on a vast deltaic and sub-tidal shelf.

Upper Eleonore Bay Group: fjord zone

The Upper Eleonore Bay Group is noted for its spectacular and distinctive lithology (fig. 179) and great uniformity of development over an extensive strip of the central fjord zone (72°–74°N). Three main divisions ('series') and many subdivisions (fig. 177) can be traced throughout the region. Detailed accounts are given by Eha (1953), Fränkl (1953a, b), Katz (1952a) and Sommer (1957a).

Quartzite 'series'

The lowest of the three divisions is an 1800–2200 m succession of well-sorted sandstones, quartzites, silty shales and shales. Cross-bedding, ripple marks, mud cracks, grading and rhythmic bedding are common features indicative of shallow water sedimentation. The succession is divided into six numbered beds, reclassified by Katz as five members.

The two lowest beds of this series comprise 1000–1100 m of rather pure quartzites with locally thin shale bands. The boundary with the underlying rusty coloured pelitic rocks of the Upper Argillaceous-Arenaceous 'series' is marked by a thick, massive, white quartzite bed; in detail the boundary is transitional.

Beds 3, 4 and 5 are represented by semipelitic and interbanded pelitic and psammitic rocks with a total thickness of 900–1100 m. The psammitic beds in this sequence range from impure quartzites, arkoses and siltstones to very pure, fine-grained quartzites, generally well sorted but showing a varied degree of roundness. The fine-grained pelitic and semipelitic material is often very well banded and may exhibit conspicuous greenish and reddish colours. Some of the pelitic rocks contain a considerable proportion of carbonate.

The contact between the different beds is often sharp indicating a pronounced change in sedimentation but no direct evidence of disconformities has been found.

The uppermost unit of the Quartzite 'series' (bed no. 6) is a leucocratic quartzitic sandstone with a thickness varying from 40–140 m. Cross-bedding is well developed at some levels. The upper limit is very sharp and well defined, but it is not known whether it reflects a depositional break.

Multicoloured 'series'

The 900–1000 m thick succession comprises alternating bands of variable colours: a very characteristic development. The different lithologies include shales, flaggy mudstones, arenaceous dolomites, limestones, dolomitic shales, sandstones and sandy shales. Bituminous limestones are also recorded. Seven beds or members are recognised, and show a marked consistency in development laterally suggesting deposition on a stable marine shelf. Well developed algal structures, resembling *Collenia*, occur in some of the higher beds, their horizontal distribution indicating subtidal depositional conditions over immense areas from Scoresby Land (72°00′ N) to Strindberg Land (74°00′ N).

The lowest unit of this series (bed no. 7) consists of

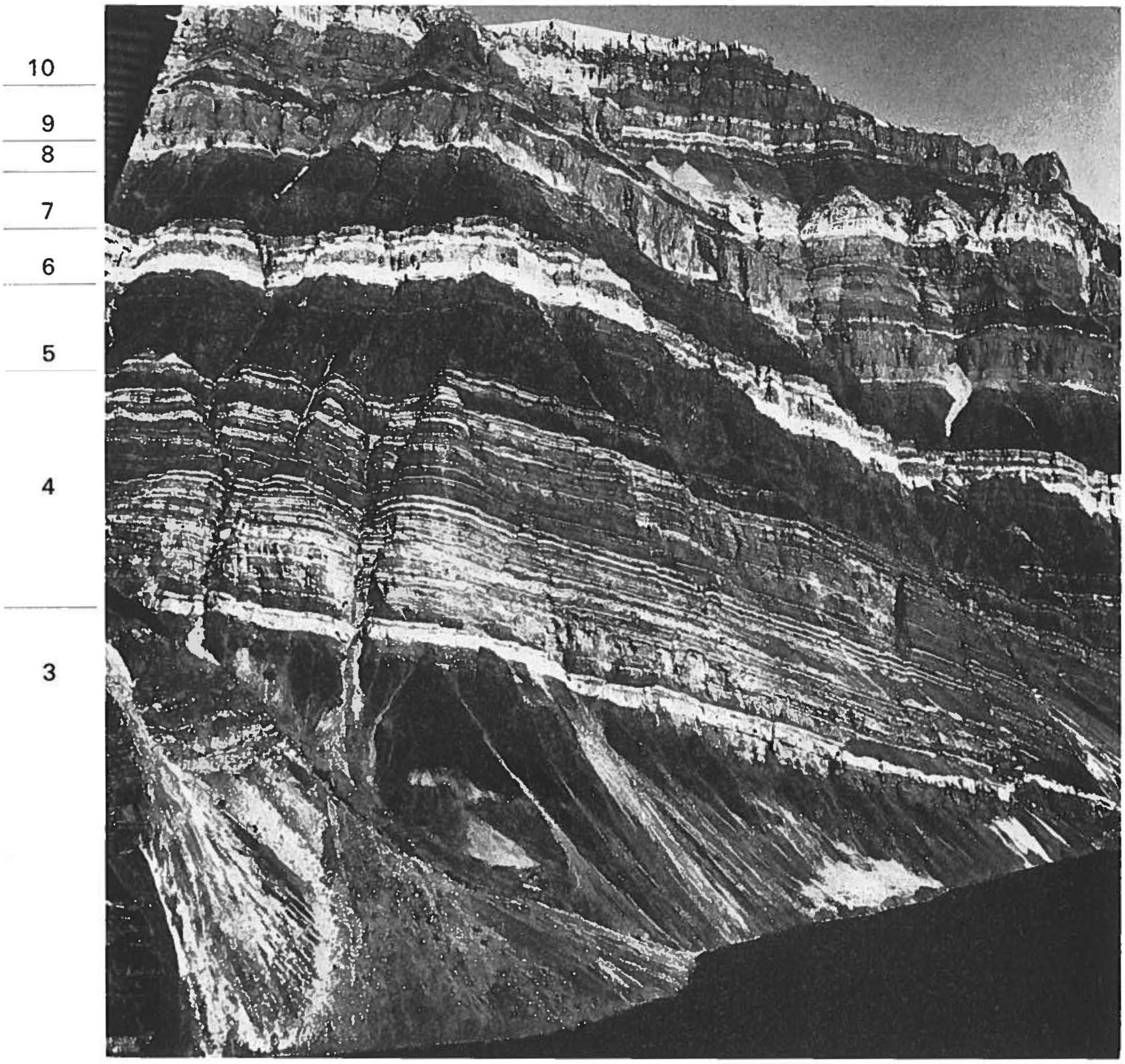


Fig. 179. Part of the Upper Eleonore Bay Group sequence in Berzelius Bjerg, Lyell Land. The numbers correspond to the bed numbers of fig. 177. Section height about 1700 m.

approximately 200 m of brick-red shaly to flaggy laminated mudstones. The individual layers show a graded bedding, arenaceous or dolomitic material at the base gradually passing up into ferruginous shale. Minor slump structures and local disconformities are common and subaqueous erosion is thought to have been important.

The following unit (bed no. 8) is an arenaceous dolomite about 50 m thick which has a transitional boundary to bed no. 7. The overlying bed no. 9 is a well-bedded grey limestone with a very high $CaCO_3$ content (up to 98 %); the thickness is 110–150 m.

The most spectacular unit in the Multicoloured 'series' is bed no. 10, which comprises a strongly coloured sequence of complexly developed strata 100–150 m thick. The lowest 10–15 m comprises green and red flaggy marls and shales interbedded with thin limestone bands. Erosional disconformities and conglomeratic breccias containing reworked fragments from underlying layers are common. In ascending order there follows a sequence of variously coloured limestones, shaly marls and well-bedded limestones, and the uppermost 30 metres is an alternating sequence of red silty pelite and whitish dolomite. The earliest indications of algal structures have also been observed in this unit.

Bed no. 11 is a 100–150 m thick dark grey to blackish bituminous limestone with a sharp contact with the overlying light grey dolomite of bed no. 12. The latter 125–200 m thick sequence is well bedded and contains algal biostromes throughout, though especially well developed in the upper levels.

Bed no. 13 is a 220–300 m thick complex sequence of wide lithological variation. The rocks are mainly well bedded red and greenish sandstones and arenaceous shales, with intercalations of shales, marls, limestones and dolomites. Biostromal dolomites with algal structures occur in the upper part of the sequence, and some dolomites preserve also intra-formational breccias and mud cracks. A polymict conglomerate occurring locally in the uppermost part of this succession together with the abundant intra-formational breccias indicates the onset of a period of unstable deposition, which characterises part of the succeeding Limestone-Dolomite 'series'.

Limestone-Dolomite 'series'

This series comprises predominantly limestones and dolomites, with minor shaly and marly intercalations. The lithologies and thicknesses of the various members are more changeable than in the underlying divisions of the Upper Eleonore Bay Group. Breccias, intra-formational conglomerates, local pebbly conglomerates and occasional erosional disconformities indicate deposition under unstable conditions. The calcareous rocks may be oolitic and pisolitic, and bituminous and carbonaceous material occurs in some members. Algal structures including well preserved stromatolites are characteristic of some beds. The sedimentary features suggest shelf-type marine conditions, and the stromatolithic biostromes imply large areas characterised by conditions of the sub-tidal zone (Caby, 1972). Seven beds (eight members) are traceable throughout the fjord zone.

Bed no. 14 is a darkish limestone about 140–300 m thick. In the lower part it is sometimes bituminous, and at higher levels erosion surfaces, breccias and cross-bedding indicate unstable deposition. The upper limit is a sharp erosional disconformity with bed no. 15, which begins with a transgressional zone of conglomeratic breccia. Bed no. 15 is 50–80 m thick and comprises greyish limestones with numerous breccia horizons in northern parts of the fjord zone, while in the central and southern parts it is dolomitised and whitish in colour. Algal structures and oolites are common.

Bed no. 16 comprises 80–200 m of dark grey to black limestones which are generally bituminous and frequently oolitic. Breccias and conglomerate levels are common. Bed no. 17 is a highly compact white dolomite with abundant breccia horizons and pebbly horizons; it is 60–70 m thick.

Bed no. 18 consists of about 400 m of thick grey and black bituminous, partly oolitic, limestone which in places is strongly dolomitised. Bands of white dolomite are characteristic of certain levels and often contain algal structures.

Bed no. 19 is a thinly bedded composite unit of dolomites, limestones and silty shales 160–210 m thick. The lithology varies considerably and it exhibits a strong colour banding. The boundary with bed no. 20 is transitional. Bed no. 20 is a uniform dark grey limestone, but with a very variable thickness throughout the region varying from 0 to 80 m.

In the central part of the fjord zone there is a gradual transition from bed no. 20 into the lowest parts of the Tillite Group, but in the north there are indications of a slight erosional disconformity surface between the two units.

Upper Eleonore Bay Group: other areas

Outside the fjord zone sequences correlatable with the Upper Eleonore Bay Group have been described from Canning Land (Bütler, 1948; Caby, 1972), the nunatak zone (Wenk & Haller, 1953) and from the Ardencaple Fjord area (Sommer, 1957b). Of the divisions recognisable in the fjord zone the Quartzite 'series' is most uniformly and widely developed and is the basis for correlation in other areas. The other divisions where represented exhibit somewhat different developments. Local successions and divisions have been established in the nunatak zone and in the Ardencaple Fjord area. The lithologies and nomenclature are summarised in fig. 177.

A study of the stromatolites of the calcareous lithofacies of the Upper Eleonore Bay Group in Canning Land (Bertrand-Sarfati & Caby, 1974) has shown that the central East Greenland forms are comparable to those of Spitsbergen, where a Vendian age has been ascribed (600–700 m.y.). It may be inferred that the higher part of the Upper Eleonore Bay Group was deposited in the latest part of Precambrian time.

Tillite Group: latest Precambrian – earliest Cambrian?

The rocks referred to this group can be traced in a narrow belt of the fjord zone from Canning Land (71° 36′ N) to Payer Land (74° 25′ N). There are marked lateral variations in facies. The thickness varies from 300–1300 m, but usually is 500–800 m (fig. 180). Five units are recognised: Lower tillite, Inter-tillite beds, Upper tillite, Canyon Formation and Spiral Creek Formation (Haller, 1971). Both upper and lower contacts of the group are slightly unconformable.

The origin of the tillites has been much debated since their first discovery by C. Poulsen (1930), and it is an open question whether they should be regarded as tillites *sensu stricto* or tilloid deposits. Various parts of the sequence have been described by Fränkl (1953a, b), Huber (1950), Katz (1954), Schaub (1950, 1955), Sommer (1957a) and Caby (1972). Haller (1971) and Katz (1961) have reviewed the lithology and genesis.

Most workers agree in distinguishing two main tillite levels of regional extent, separated by inter-tillite beds: a series of shales and sandstones with frequent cross-bedding and ripple marks. Each of the main tillite beds may comprise several tillitic horizons. In the lower tillites the boulder components seem to be entirely derived from the Limestone-Dolomite 'series' of the underlying Eleonore Bay Group; in size the fragments vary from a few millimetres to several metres and are mainly rounded. The pebble assemblage in the upper tillites, by contrast, includes blocks derived from the Multicoloured 'series' and Quartzite 'series' in the lower levels, while crystalline components are dominant in the higher levels; red granite pebbles are particularly abundant (Huber, 1950). The lower tillite matrix is a calcareous sandstone, whereas that of the upper tillite – sometimes termed the 'red tillite' – comprises hematite-coated quartz and feldspar grains in a calcareous to siliceous cement; the red facies gives way both north and south to a more common grey facies. Fränkl (1953a) suggested that the red colouration and boulder assemblage of the upper tillite might be due to glacial redeposition of continental red sandstones and conglomerates. The tillitic part of the Tillite Group varies from less than 200 m to 600 m in thickness.

The Canyon Formation, 250–300 m thick, is divisible into three parts. The lowest unit comprises dolomites, mudstones and marly shales from which a varve-like rhythmic banding has been described (C. Poulsen, 1930; Schaub, 1950). The middle unit is a sequence of black, marly, silty shales. Limestones and dolomites with local algal structures form the upper unit.

The Spiral Creek Formation is 25–55 m thick, and begins with a gypsiferous limestone breccia which may indicate a break in sedimentation. The lower part of the formation comprises thin, ripple-marked, cross-bedded sandstones with intercalations of silty mudstones preserving mud cracks and halite pseudomorphs. The upper part consists of red thin-bedded mudstones. Katz (1961) who named this formation the 'Salt Cast Member' considered the sequence to be of regressive type.

The Canyon Formation and Spiral Creek Formation are usually referred to the uppermost Precambrian, though Cowie & Spencer (1970) anticipate that both may form part of the lowermost Cambrian.

Outcrops of tillites resting directly on crystalline rocks have been described from Charcot Land and Gåseland in the inner Scoresby Sund region (see below); in both areas the occurrences are found below Caledonian thrusts and may form part of the foreland. There is no definite indication of their age but both may be latest Precambrian.

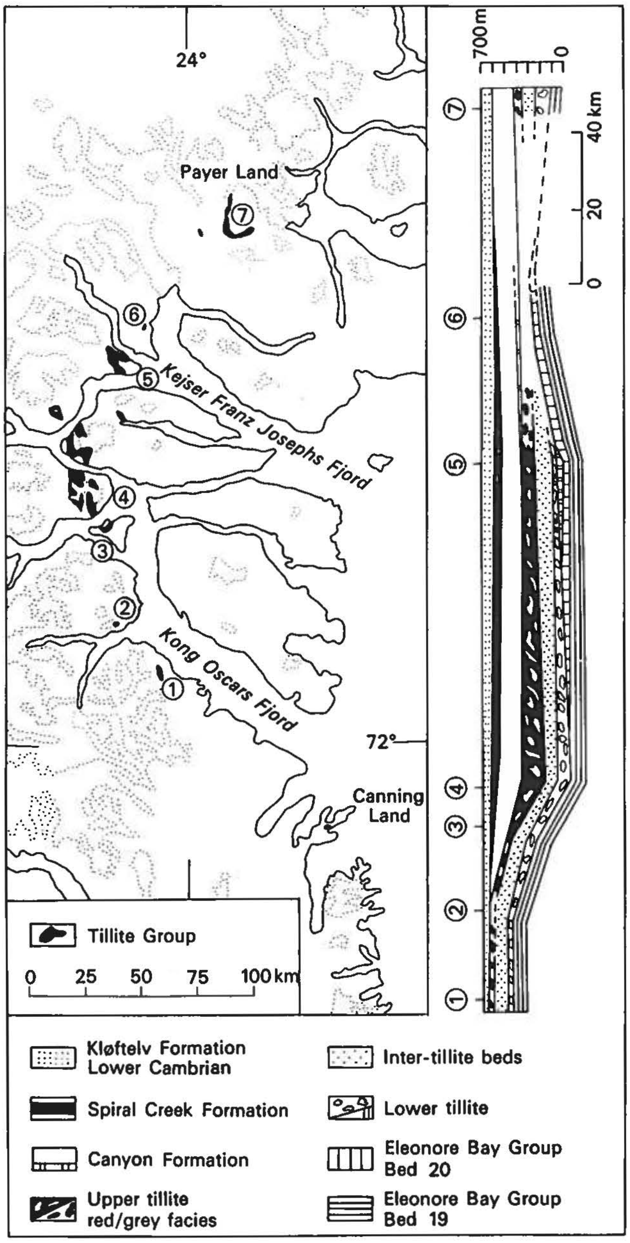


Fig. 180. Distribution and variation in development of the Tillite Group in central East Greenland. After Fränkl (1953a).

Cambro-Ordovician

Lower Palaeozoic rocks ranging in age from Lower Cambrian to Middle (?Upper) Ordovician outcrop in a narrow zone of the fjord region between Canning Land (71° 36′ N) and C. H. Ostenfeld Nunatak (72° 22′ N) (fig. 181). The sequence overlies deposits of the Tillite Group, and is overlain with major unconformity by Devonian red beds.

Details of the stratigraphical succession, which totals *c.* 3070 m, are summarised in fig. 182. There appears to be a major hiatus comprising part of the interval between the Middle Cambrian and lowermost Ordovician, and minor breaks at lower levels. The succession is very uniformly developed and displays little lateral variation in lithology and faunal content. The lower part comprises detrital sediments of shallow marine facies, while in the main part of the succession limestones and dolomites are dominant.

The Cambro-Ordovician of central East Greenland has been studied most extensively by C. Poulsen (1930, 1932, 1937, 1951, 1956), Cowie (1961, 1963) and Cowie & Adams (1957). The papers by Poulsen mainly concern the fauna, and the most comprehensive account of stratigraphy and structure is

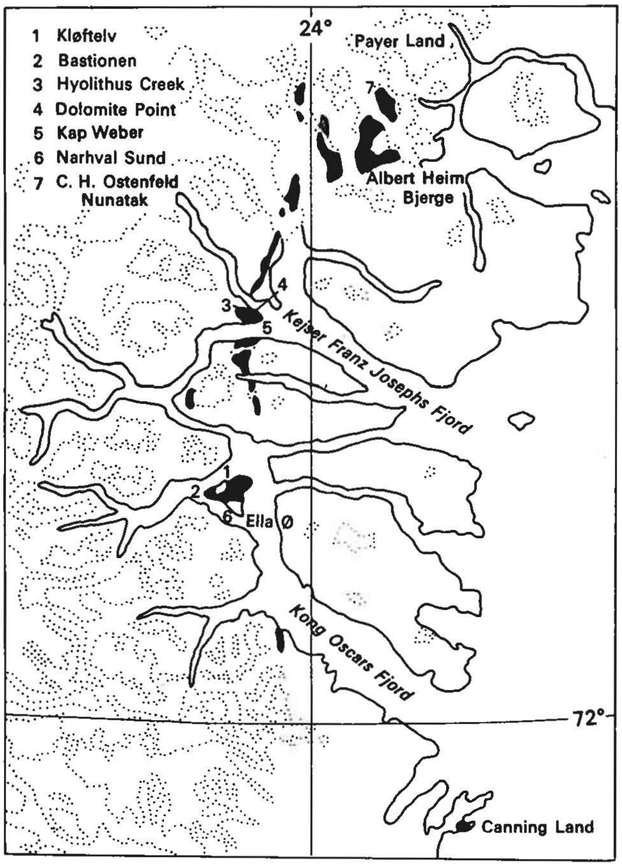


Fig. 181. Cambro-Ordovician outcrops of central East Greenland.

that of Cowie & Adams. Swett & Smit (1972) report on sedimentological investigations, while Cowie & Spencer (1970) describe the trace fossils. The geology has been summarised and aspects of correlation discussed by V. Poulsen (1967). Recently Caby (1972) has reported the presence of previously unknown Cambrian strata in Canning Land.

The first stratigraphical division was proposed by Koch (1929) and modified by C. Poulsen (1930). The present account follows the division and nomenclature of Cowie & Adams (1957), based on two detailed measured sections at Albert Heim Bjerge (74° 07′ N; 23° 20′ W) and Ella Ø (72° 50° N; 25° 15′ W). These two sections fully represent the exposed Cambro-Ordovician successions, but do not include the type localities of all the formations.

The position of the base of the Cambrian remains a point of discussion. Sedimentation was at first believed to be continuous from the upper tillite through a *c.* 400 m thick non-fossiliferous sequence (Canyon Formation, Spiral Creek Formation & Kløftelv Formation) into the fossiliferous Bastion Formation. Later an erosional unconformity was found below the Kløftelv Formation which transgresses the Canyon Formation and Spiral Creek Formation. The lower limit of the Cambrian is now conventionally placed at the base of the Kløftelv Formation, but on the basis of regional correlations and trace fossil studies Cowie & Spencer (1970) anticipate the limit may in the future be pushed back to include part or all of both the Spiral Creek and Canyon Formations.

Kløftelv Formation

The formation comprises an interbanded succession of quartzites and sandstones with worm trails and casts in the lower sandstones, but without body fossils. The main lithology is a massive rock of variable colour with frequent cross-bedding and ripple marks. In composition it is a quartz-arenite to sub-arkose, modal analyses indicating increasing maturity upwards. The sequence is uniformly developed throughout its occurrence. Swett & Smit (1972) indicate from palaeocurrent analysis a general southwards directed palaeoslope, and suggest deposition was by tidal marine processes

Bastion Formation

Glauconitic sandstones and arenaceous shales, generally ferruginous and sometimes micaceous, form the lower part of the formation. A glauconitic conglomerate at the base containing phosphatic collophane bodies may be indicative of a minor hiatus between the Bastion and Kløftelv Formations. Cowie & Spencer (1970) report trace fossils such as arthropod scratch marks, *Scolicia, Planolites* and *Scolithus* from this part of the sequence.

The upper part of the formation begins with the Lower Shell Limestone, a 50 cm glauconitic limestone comprising almost entirely fossil fragments; in places it is conglomeratic with phosphatic pebbles, probably indicating a minor hiatus within the Bastion Formation. The Lower Shell Limestone contains the first Cambrian body fossils. Arenaceous shales and occasional thin bands of limestone, arenaceous limestone and siltstone complete the formation.

The change in facies upwards in the Bastion Formation reflects a diminishing supply of terrigenous sediments.

In the Lower Shell Limestone only olenellid trilobites are recorded, whereas in higher beds olenellid and eodiscid types occur together. On this basis the formation is divided and referred to the lower and upper subzones of the *Olenellus* Zone (fig. 182).

Ella Ø Formation

The formation consists largely of arenaceous limestones with a thin central sequence of shaly beds. The limestones are often cross-bedded, and slumping structures and intraformational conglomerates occur at a number of horizons. The fauna is indicative of a late Lower Cambrian age. Trace fossils from the shaly beds include *Cruziana, Diplichnites, Plagiogmus* and *Scolithus.*

Hyolithus Creek Formation

Massive, stylolithic, dark grey or black dolomites with many horizons of intra-formational conglomerates make up the formation. Only few fossils are known, a mollusc, *Salterella,* which occurs in a few horizons probably being indicative of a Lower Cambrian age.

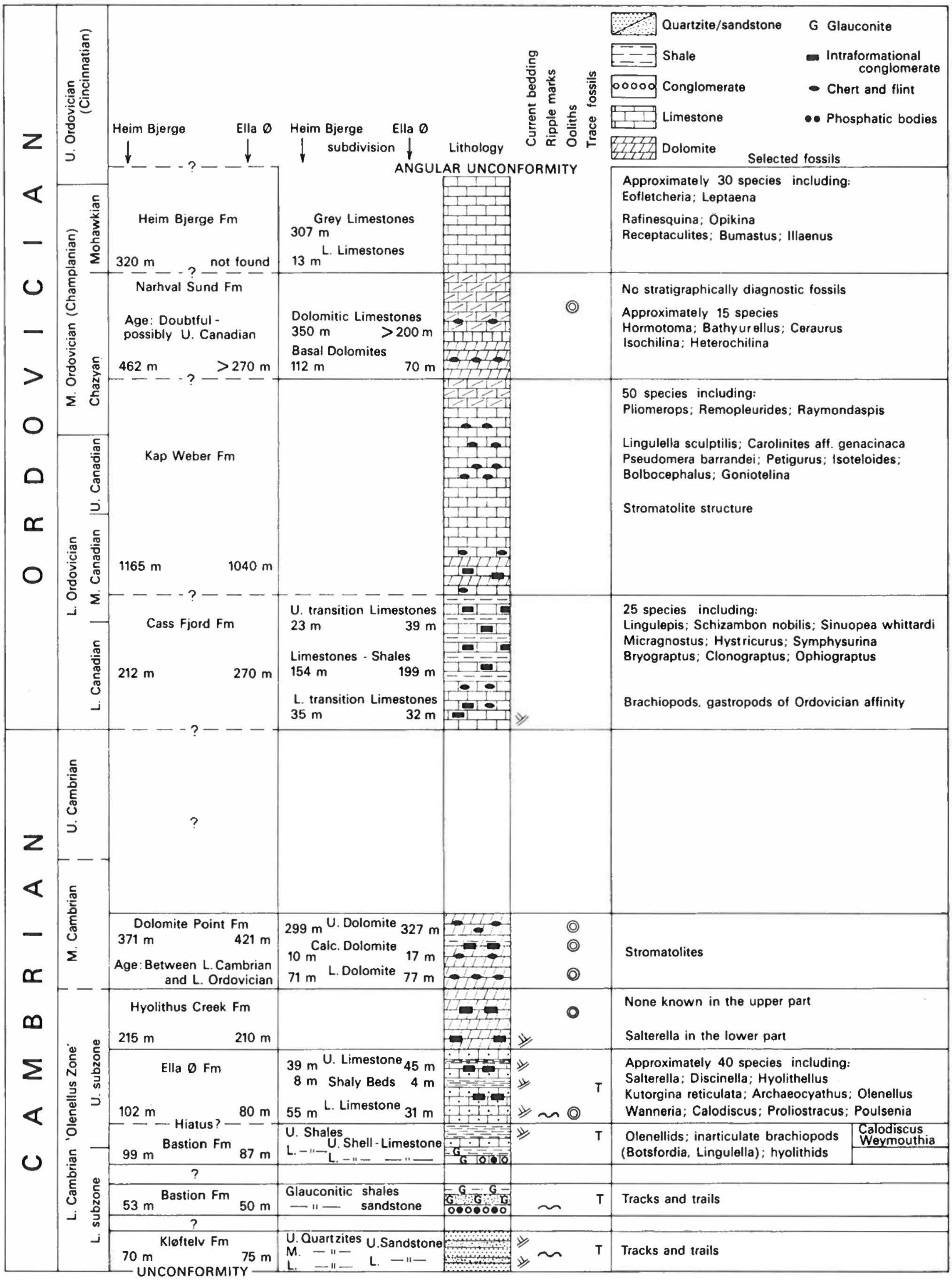


Fig. 182. Stratigraphy, lithology and fauna of the Cambro-Ordovician succession in central East Greenland. Compiled mainly after Cowie & Adams (1957) and Cowie (1961).

Dolomite Point Formation
The dominant lithology is a massive, fine-grained dolomite. Thinly bedded silty dolomites and dolomitic shales also occur, and intra-formational breccias and conglomerates are found at irregular intervals. Chert and flint are widely distributed as small ovoid bodies and lenticles, and flint segregations occasionally assume stromatolithic forms. Stromatolites are the only fossils in the formation.

In the absence of diagnostic fossils the age can only be provisionally indicated as between Lower Cambrian and Lower Canadian. However, since relations with the Hyolithus Creek Formation appear conformable and the two formations are similar lithologically, the Dolomite Point Formation is tentatively regarded as being Middle Cambrian. A major hiatus appears to cover part of Middle Cambrian to Upper Cambrian time in the central East Greenland succession.

Cass Fjord Formation
The formation typically comprises beds of thinly stratified, nodular, muddy limestones with shaly partings, alternating with purer and more homogeneous limestone bands. Intra-formational conglomerates are very common, suggesting deposition in an unstable fairly shallow water environment.

Poorly preserved orthid brachiopods and fragmentary gastropods in the basal beds are of Ordovician affinity. At higher levels trilobites, graptolites, brachiopods and gastropods occur, indicative of a Lower to Middle Canadian age.

The formation name, Cass Fjord, refers to a locality in Washington Land, North Greenland, where deposits similar but not identical to it are found. The nomenclature is in need of revision.

Kap Weber Formation
The lithology of the Kap Weber Formation is extremely uniform and precludes establishment of subdivisions. It comprises a very thick sequence of massive limestones and dolomitic limestones, with occasional lenticular intercalations of thin bedded limestones with shaly partings. There are frequent intra-formational conglomerates. The upper and lower boundaries of the formation are conformable.

Fossils are sparse and concentrated at a few levels; they indicate an Upper Canadian age. Limestones identical to those of the Kap Weber Formation and forming part of a fault block have yielded a fauna that shows affinities with the Middle Ordovician Chazyan stage.

Narhval Sund Formation
A basal group of massive dolomites and calcareous dolomites is overlain by a series of thinly bedded dolomitic limestones and limestones. The fauna includes ostracods, gastropods and bathyurid trilobites, but is not diagnostic. Cowie (1961) proposed a Canadian or Chazyan age, while Yochelsen (1964) suggested a late Canadian age for at least the lower units based on correlation of the gastropod *Ceratopea* opercula.

Heim Bjerge Formation
This formation consists of uniform, massive, well-bedded grey weathering limestones with a finely crystalline granular texture. The extensive fauna is Middle Ordovician, and probably referable to the Mohawkian stage. The fauna from a fault block, possibly of the Heim Bjerge Formation, included fossils of late Mohawkian or even Cincinnatian (Upper Ordovician) affinity.

The Lower Palaeozoic succession in central East Greenland indicates stable shelf conditions from Lower Cambrian to Middle Ordovician, with probable non-deposition in Upper Cambrian time. The lithological variation beginning with sandstone, followed by shale, limestone and dolomite, reflects, according to Swett & Smit (1972), an increasing isolation from detrital sources rather than increasing water depths. The sedimentary and organo-sedimentary structures indicate generally very shallow deposition, and imply that sedimentation and subsidence rates were roughly equal. Stromatolites and oolites suggest a probable tropical to subtropical climate. The absence of angular unconformities within the succession precludes pre-Cincinnatian Palaeozoic folding, but the probable breaks in deposition may reflect minor earth movements.

The Cambro-Ordovician fauna is referable to the Pacific province. The central East Greenland fauna is comparable with that of North-West Scotland and the Appalachian region (C. Poulsen, 1951; Cowie, 1963), and together with similarities in palaeogeographic and depositional environments is in agreement with the hypothesis that these areas were developed on the western margin of a proto-Atlantic basin (Swett & Smit, 1972).

Erratic blocks of *Scolithus* quartzite are abundant along the entire length of the East Greenland fold belt (Haller, 1971, fig. 48), and are presumed to derive from uppermost Precambrian or Lower Cambrian strata laid down on the foreland areas now hidden by the Inland Ice. A non-fossiliferous marble sequence on the foreland in western Gåseland is speculatively interpreted as (?) Cambrian by Phillips *et al.* (1973).

Late Precambrian sediments: North-East Greenland

Hagen Fjord Group: late Precambrian

The late Precambrian (post-Carolinidian) successions of North-East Greenland have been collectively termed the Hagen Fjord Group (Haller, 1971). They comprise a 4000–5000 m sedimentary sequence preserved only in Caledonian thrust sheets between Kronprins Christian Land and Lambert Land, and a partly equivalent but much thinner foreland sequence underlying the Cambro-Silurian deposits in the foreland area. Only the allochthonous sediments are discussed in this account, the foreland sequence being

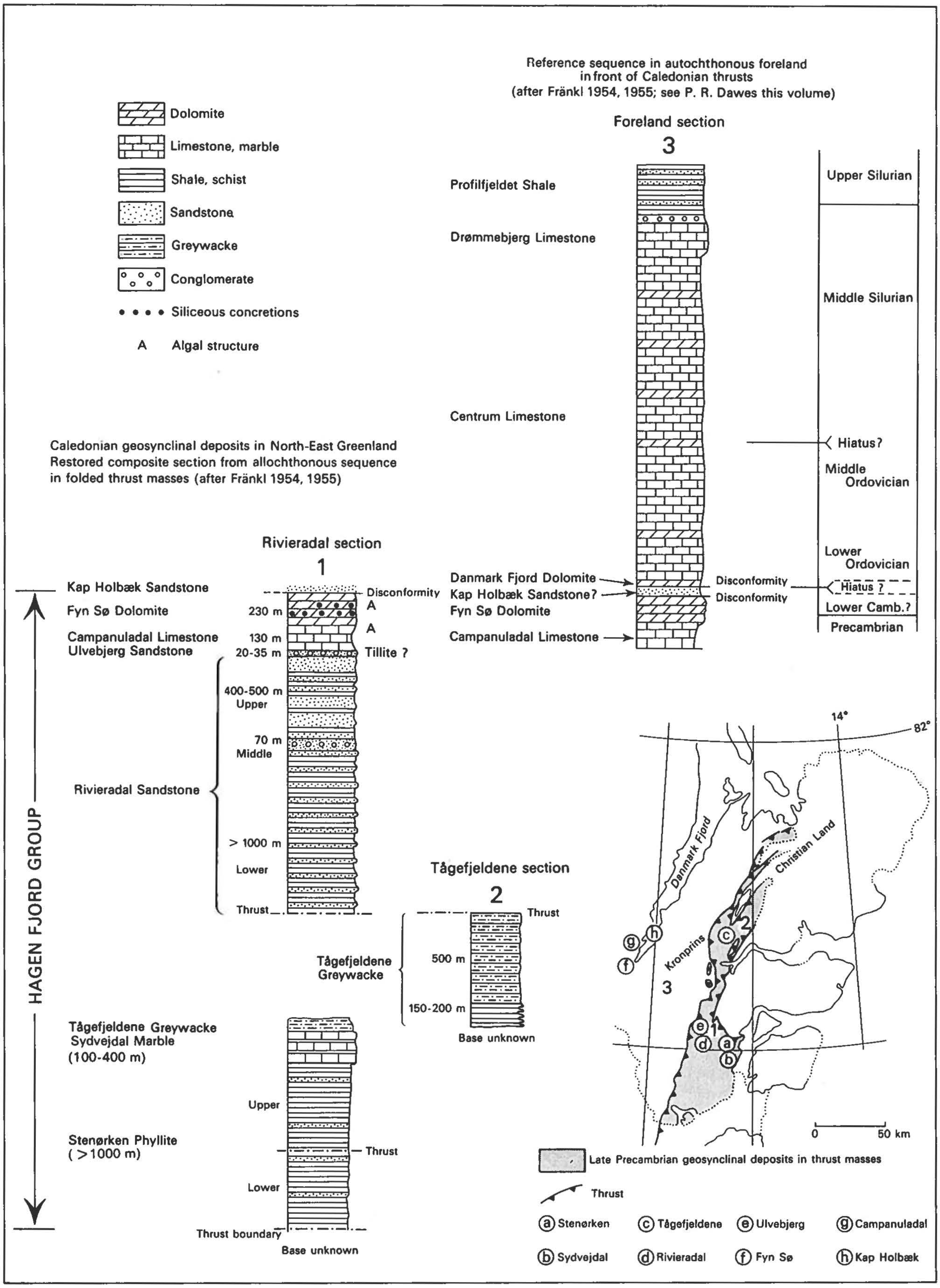


Fig. 183. Stratigraphy and lithology of the late Precambrian geosynclinal deposits of North-East Greenland.

described by P. R. Dawes (this volume). There appears to be a correlation between the uppermost part of the sequence in the fold belt and the lowermost part of the foreland sequence (fig. 183). The allochthonous sediments are considered to have accumulated in a miogeosynclinal trough sited east of the present coast (Haller, 1971).

The successions preserved in the Caledonian fold belt are highly folded and are found in a number of thrust slices. General observations have been made by Fränkl (1954, 1955) but detailed work remains yet to be carried out and the thicknesses quoted should be viewed with some reservation. The base to the succession is unknown.

Fränkl's composite sections have been compiled from different localities in Rivieradal and Tågefjeldene. The lower units occur in thrust nappes and the upper units in a gliding nappe. The succession as a whole can be compared with the thicker late Precambrian developments of the Eleonore Bay Group in central East Greenland, but no correlation is possible.

Stenørkenen Phyllite. This unit comprises more than 1000 m of weakly metamorphosed sericite schists with occasional sandy beds. The base is unknown. A thrust divides the sequence into two parts.

Sydvejdal Marble. Weakly metamorphosed marbles with bands of chlorite schists 100–400 m thick make up this unit.

Taagefjeldene Greywacke. In the northern outcrops of this unit the lower beds are sulphide-bearing alum shales (150–200 m), and are succeeded by 500 m of greywackes, carbonaceous shales and sandstones; the alum shales were deposited under euxenic conditions. The southern outcrops comprise only quartzite and greywacke. The upper boundary is a thrust.

Rivieradal Sandstone. The unit consists of 1000–2000 m of interbanded sandstones and shales with a coarse conglomerate in the middle of the sequence; conglomerate horizons also occur at lower levels.

Ulvebjerg Sandstone (and tillite?). The sandstone sequence is 20–35 m thick but includes a 1 m arkosic sandstone with two distinct psephitic beds 20 cm and 50 cm thick. The psephites contain small quartzite and red porphyry clasts. Fränkl (1954, p. 44) interpreted the psephites as tillites but Haller (1971, p. 74) expresses doubts as to a glacial origin.

Campanuladal Limestone. The sequence of dominantly clastic sediments is abruptly terminated by 130 m of thin-bedded, reddish schistose limestones. Fränkl (1955) correlated the sequence with the 'Campanuladal Limestone' described by Adams & Cowie (1953) from the foreland sequence.

Fyn Sø Dolomite. These dolomites are 230 m thick and contain algal structures and chert concretions. Correlation with the 'Fyn Sø Dolomite' of the foreland sequence (Adams & Cowie, 1953) is generally accepted.

Kap Holbæk Sandstone. A local exposure of quartzite filling fractures in the allochthonous representative of the Fyn Sø Dolomite has been connected by Fränkl (1955, p. 20) with the supposed Lower Cambrian Kap Holbæk Sandstone. This interpretation must be viewed with reservation.

Caledonian orogeny

Caledonian orogenesis influenced the entire East Greenland fold belt to a varying extent. In the metamorphic complexes it is difficult with certainty to separate the older pre-Caledonian and younger Caledonian elements from each other.

According to Wegmann's concept of 'stockwerk' folding elaborated especially by Haller (Wegmann, 1935a, p. 332; see Haller, 1971, p. 144) and supported by most other workers, most of the structures in the metamorphic complexes were formed during the Caledonian orogeny. Disharmonic folding on an immense scale was envisaged with development of a highly mobile infrastructure, and with a superstructural mantle of gently folded sediments; a zone of detachment separated the two levels. Conditions in the infrastructure were considered created by the advance of the migmatite front from below to envelope the original gneiss basement and parts of the overlying sedimentary succession, transforming them into intensely folded granites and migmatites. Vertical movements apparently led to upwelling of migmatitic centres in bulges variously classified as domes, foreheads, sheets and mushrooms (Haller, 1955). The envelope of metamorphic supracrustal schists and gneisses surrounding the migmatitic upwellings was viewed as the transformed equivalent of the Eleonore Bay Group. Movements within the different levels were considered largely synchronous, while lateral shortening was not thought to be of importance.

Haller distinguished three phases of deformation relating to Caledonian orogenic activity. The 'Caledonian main orogeny' was succeeded by 'late Caledonian spasms' thought to be Devonian in age and finally in Carboniferous to Permian time by 'minor succeeding episodes'.

As stated elsewhere at least some of the metamorphosed supracrustals are now known to have suffered a pre-Caledonian metamorphism, and it is now necessary to consider the possibility that most of the structures in the metamorphic complexes might be

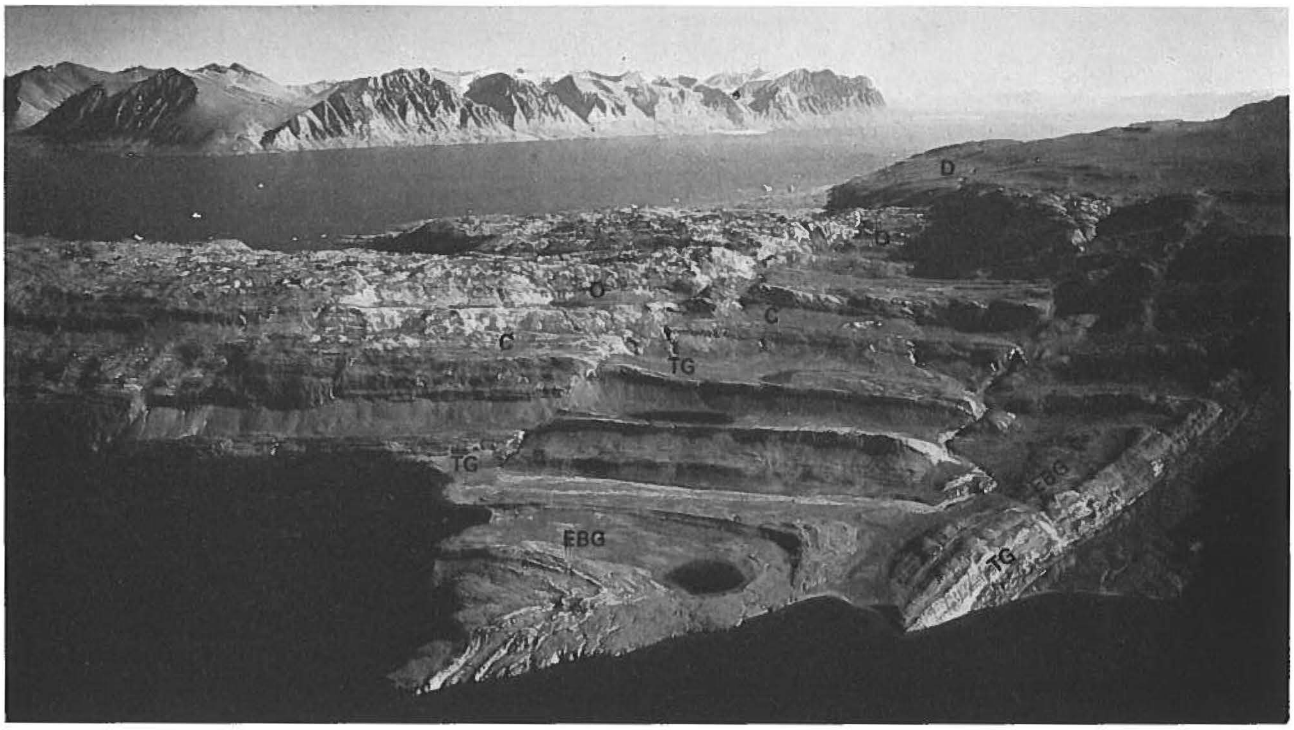


Fig. 184. Oblique aerial photograph of Ella Ø (72°50'N) showing Caledonian large scale folding in the Limestone-Dolomite 'series' of the Eleonore Bay Group (EBG), Tillite Group (TG), Cambrian (C) and Ordovician (O). In the background Devonian strata (D). Route 638 no. 9920. Copyright Geodetic Institute.

pre-Caledonian, with a relatively mild Caledonian overprint.

Deformation can only be specifically attributed to the Caledonian orogeny where the late Precambrian to Cambro-Silurian sedimentary accumulations are involved. In central East Greenland these sediments occur in two N–S trending belts on either side of the central metamorphic complex and in a graben structure around Ardencaple Fjord (figs 173, 176), and in North-East Greenland are found as allochthonous Caledonian thrust masses (figs 183, 186).

Similarly, Caledonian metamorphism and plutonism can be inferred only where the same late Precambrian and lower Palaeozoic sediments are influenced or intruded. On both sides of the central metamorphic complex the sediments show an inwards transition from non-metamorphic rocks to their metamorphic equivalents, but it is uncertain whether all the metasediments in the central metamorphic complex represent equivalents of the Eleonore Bay Group. The highest grade reached in safely identifiable equivalents to the Eleonore Bay Group corresponds approximately to the garnet zone. Kyanite grade supracrustals in the inner part of the central metamorphic complex are of uncertain age, but at least some of them compare closely with the pre-1200 m.y. Krummedal supracrustal sequence known from the Scoresby Sund region. South of latitude 76° N a number of definite late to post-kinematic Caledonian granites have discordant contacts with Eleonore Bay Group sediments. Some similar bodies entirely within the metamorphic complexes may be equivalent to the Caledonian granites, while others can be shown to be pre-Caledonian.

It is more difficult to estimate the degree of Caledonian metamorphism and plutonism in North-East Greenland, where the late Precambrian sequence is described as essentially non-metamorphic and no discordant plutonic bodies have been recorded. A late-tectonic pegmatite from Lambert Land (79° 20' N) has, however, given a K-Ar age on biotite of 405 m.y. (Haller & Kulp, 1962). The infracrustal rocks of the region may have suffered Caledonian metamorphism and plutonism, but its extent cannot be defined or separated from that of earlier developments.

Caledonian deformation: central East Greenland

The thick late Precambrian to Lower Palaeozoic sedimentary developments in the fjord zone between 72°–74° 30' N (fig. 176) have been described by Eha (1953), Fränkl (1953a, 1953b), Katz (1952a) and Sommer (1957a). East–west sections presented by these authors and a structure contour map of

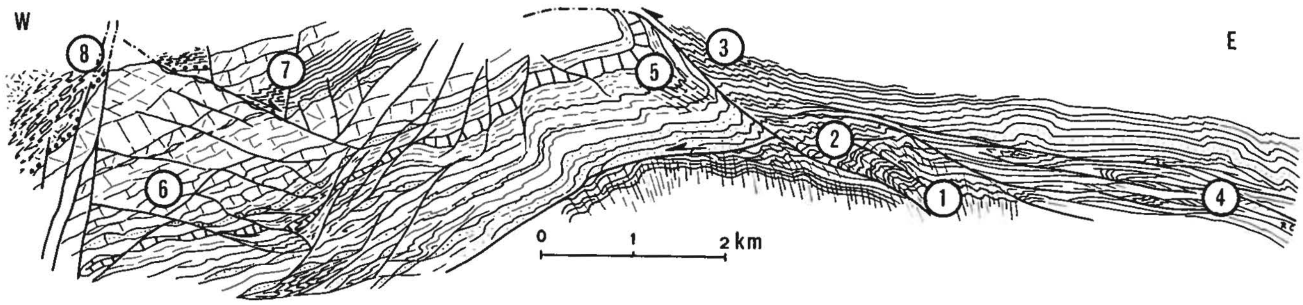


Fig. 185. Diagrammatic section across Canning Land showing various structures developed. Black shales of the Lower Eleonore Bay Group: 1 – harmonic folds and slaty cleavage; 2 – flexural-slip type open folds; 3 – zone of frontal contraction; 4 – mylonitic stratoid zones and lenses. Upper Eleonore Bay Group: 5 – recumbent syncline; 6 – low angle normal faults and boudinage. Lower Cambrian: 7 – recumbent folding along main low-angle normal fault. Devonian: 8 – syn-sedimentary folding, bounded by late Devonian faults. After Caby (1972, fig. 3).

most of the belt by Haller (1971, p. 155) all show a series of rather open folds and flexures with a general N–S trend (figs 184, 199, 210). Where folding is most intense in the central part of the belt Eha estimated a shortening of *c.* 1.3 km in a 25 km section (*c.* 5.3 %), but this figure also includes the influence of Devonian deformation which is considered of most importance. The shortening attributable to the main Caledonian phase is thus very small and, as Caby (1972) has pointed out, may be apparent since Eha did not take into account vertical extension. Fränkl's (1953b) sections of the southern part of the sedimentary belt do not show shortening, indeed swarms of flat-lying tension faults indicate a late E–W widening of possibly as much as 30 %.

In Canning Land Caby (1972) has recorded different types of structures in four zones descending through the Limestone-Dolomite 'series' to shales of the Lower Eleonore Bay Group. There are lateral transitions between the different types of structures and no evidence of polyphase deformation (fig. 185). Caby suggests these structures developed passively in gravity gliding units.

The sediments of the Petermann Bjerg region west of the central metamorphic complex (fig. 210) occupy a prominent N–S trending open syncline, with a parallel open anticline to the east where metamorphism becomes pronounced (Haller, 1955, 1956a; Katz, 1952b; Wenk & Haller, 1953). The west flank of the syncline is cut by an east-dipping normal fault, which brings non-metamorphosed sediments into contact with a western metamorphic complex. The style of structures in the sediments is generally comparable to the fjord zone.

The sediments of the Ardencaple Fjord–Bredefjord graben (figs. 173, 214) exhibit two sets of open folds and associated faults, the older NNE trending and the younger NW trending. Thrusting in a north to NNE direction is associated with the younger phase along the northern boundary of the graben and led to displacements of non-metamorphic Eleonore Bay Group sediments by 5 to 10 km over the adjacent metamorphic rocks (Sommer, 1957b).

Caledonian deformation of the sediments of the fjord zone may well be related to extension and associated gravity gliding processes in connection with an uplift of the central metamorphic complex (Caby, 1972). Major thrust developments of presumed Caledonian age are found in the western parts of the metamorphic complexes in the Scoresby Sund region. Similar major thrusts have not been recognised between latitudes 72° to 76° N, but a thrust system at the west edge of the fold belt is traceable from 76° to 82° N, and in the extreme north is known to be Caledonian (see below). If the thrusts in the western Scoresby Sund region are also Caledonian the major lateral displacements are in interesting contrast to the relatively superficial deformation affecting the late Precambrian and Palaeozoic sediments.

Caledonian deformation: North-East Greenland

In North-East Greenland the late Precambrian sediments are found in a series of thrust sheets and gliding nappes (fig. 186). The nappes partially overlap the foreland sequence which is seen in occasional windows and demonstrates a minimum westward displacement of 40 km (Fränkl, 1955). Fränkl considered the nappes had roots just east of their present exposure, whereas Haller (1971) suggested the sediments were deposited in a trough somewhere east

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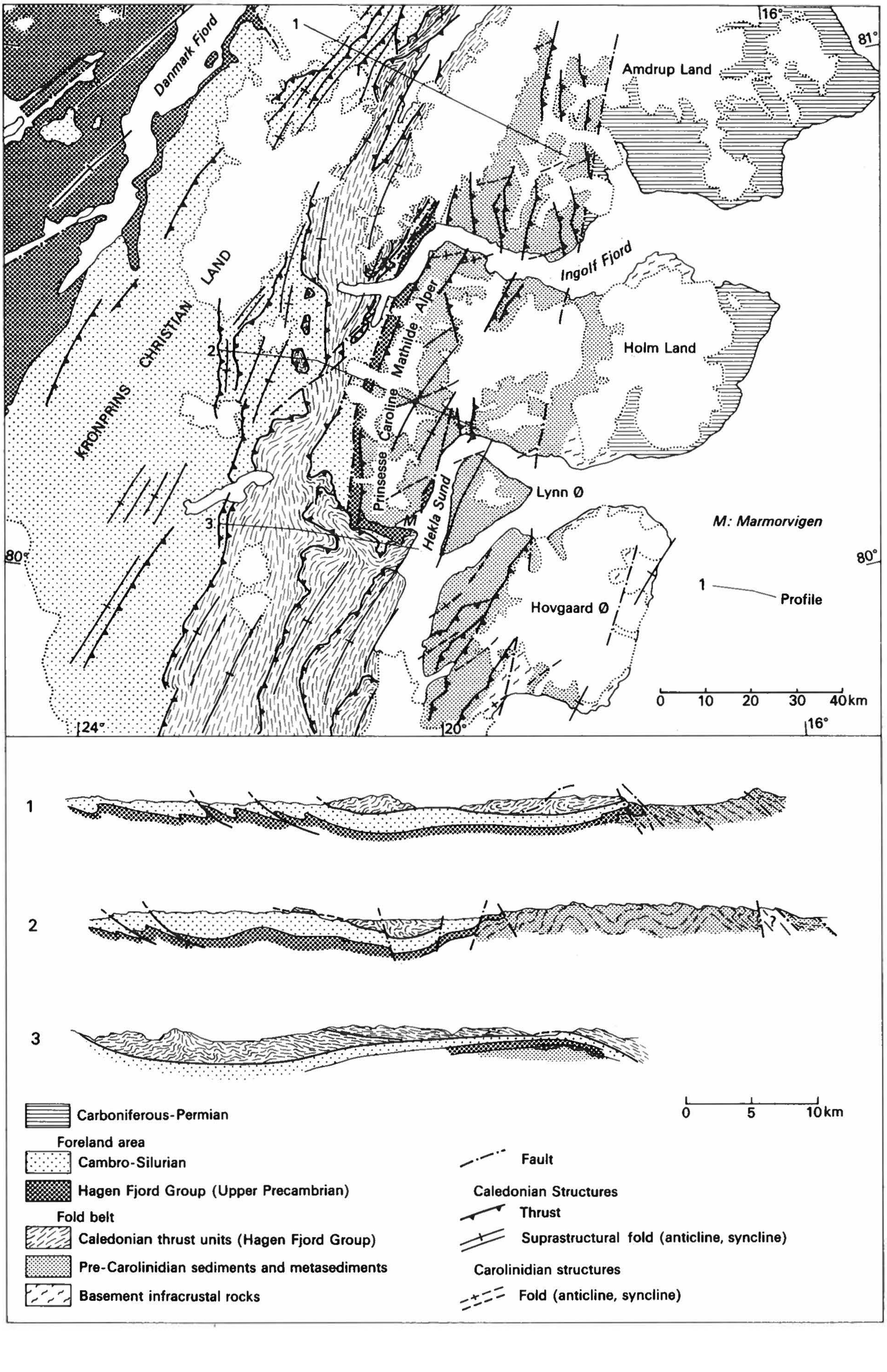
Fig. 186. North-East Greenland (79°40'–81°10'N) showing development of Caledonian structures. Compiled after Haller (1970, 1971).



Danmark Fjord
KRONPRINS CHRISTIAN LAND
Amdrup Land
Ingolf Fjord
Holm Land
Prinsesse Caroline Mathilde Alper
Hekla Sund
Lynn Ø
Hovgaard Ø
M: Marmorvigen
M
1
2
3
1 Profile
0 10 20 30 40km
16°
81°
80°
24°
20°
0 5 10km
Carboniferous-Permian
Foreland area
Cambro-Silurian
Hagen Fjord Group (Upper Precambrian)
Fold belt
Caledonian thrust units (Hagen Fjord Group)
Pre-Carolinidian sediments and metasediments
Basement infracrustal rocks
Fault
Caledonian Structures
Thrust
Suprastructural fold (anticline, syncline)
Carolinidian structures
Fold (anticline, syncline)

of the present coastal area implying thrust displacements of the order of 100 km.

The fold belt in North-East Greenland may be divided into four structural zones from west to east: an autochthonous foreland; a zone of nappes; a central chain of parautochthonous blocks and thrust wedges – mainly Carolinidian folded sediments; and an eastern lowland region of gneissose rocks with a partial cover of unfolded Upper Palaeozoic rocks.

The foreland area comprising sediments of Proterozoic to Upper Silurian age is affected by open folds and minor thrusts increasing in intensity of developments towards the front of the nappe assemblage. The zone of nappes comprises entirely Hagen Fjord Group sediments, and Fränkl (1955) has shown that the southern part of the zone can be divided into an eastern group of thrust sheets and a western group of gliding nappes. The principal discontinuity surface coincides usually with a sequence of alum shales near the base of the Taagefjeldene Greywacke. The Caledonian deformation in the central chain is of moderate intensity, comprising scattered thrusts and some open folds.

Caledonian plutonism

The main Caledonian intrusions, identifiable by their discordant contacts with Eleonore Bay Group rocks, are shown in fig. 187. Two bodies known to be Devonian are described in a later section, and the large number of plutons whose age is less certain are briefly mentioned in the regional descriptions of the metamorphic complexes. The Caledonian bodies include the following.

North Stauning Alper plutonic complex. This extensive complex has been described by Haller (1958) as comprising an older core of migmatitic, foliated biotite granite and a younger mantle of homogeneous granite. While both phases were considered by Haller as Caledonian, the older heterogeneous granite phase often contains metamorphic garnet, sillimanite and cordierite and a partly pre-Caledonian age is now thought likely. The younger intrusions include biotite granodiorites and biotite-muscovite granites, and are late to post-orogenic bodies with sharp irregular boundaries against folded Eleonore Bay Group rocks.

Grejsdalen batholith. The main mass of this 14 by 7 km dome-shaped body is a leucocratic, homogeneous, medium to coarse-grained, two-mica granite (Haller, 1953). The western part is porphyritic. Veins of reddish aplite granite cut the central part of the main body.

Nordenskiöld Gletscher pluton. This post-tectonic intrusion has an outcrop length of 60 km and was emplaced in a NNE–SSW anticlinal structure. It has partly discordant and partly concordant contacts with weakly metamorphic Eleonore Bay Group rocks to the west and the central metamorphic complex to the east (Haller, 1955). The main rock type is a white, homogeneous, two-mica granite.

North-west Louise Boyd Land pluton. No details are known of this remotely situated body which outcrops in scattered nunataks over an area of 10 by 15 km.

Ankerbjerg pluton. This body has a complex composition, comprising granodioritic and monzonitic phases, and two generations of related monzogranite aplite dykes (Stern, 1964). It has tectonic contacts to the south-east and north-west and a roof of Eleonore Bay Group sediments (Dalvesco, 1954).

Kap Wardlaw granite. The main rock type of this 10 km² body is a whitish biotite granite. In contrast to most of the other Caledonian granites it has a pronounced contact metamorphic aureole (Caby, 1972).

Granite plutons in the Ardencaple Fjord – Bredefjord graben There are several stocks and batholiths (Haller, 1971). The 'Knæksø granite stock' is a forcefully intruded porphyritic, two mica granodiorite. The 'Bredefjord granite stock' was apparently emplaced by overhead stoping. A leucocratic granite phase has yielded a K–Ar muscovite age of 394 m.y. (Haller & Kulp, 1962). The 'Ardencaple Fjord batholith' is a complex sheet intrusion with early synkinematic units as well as post-tectonic units.

Age of the Caledonian orogeny

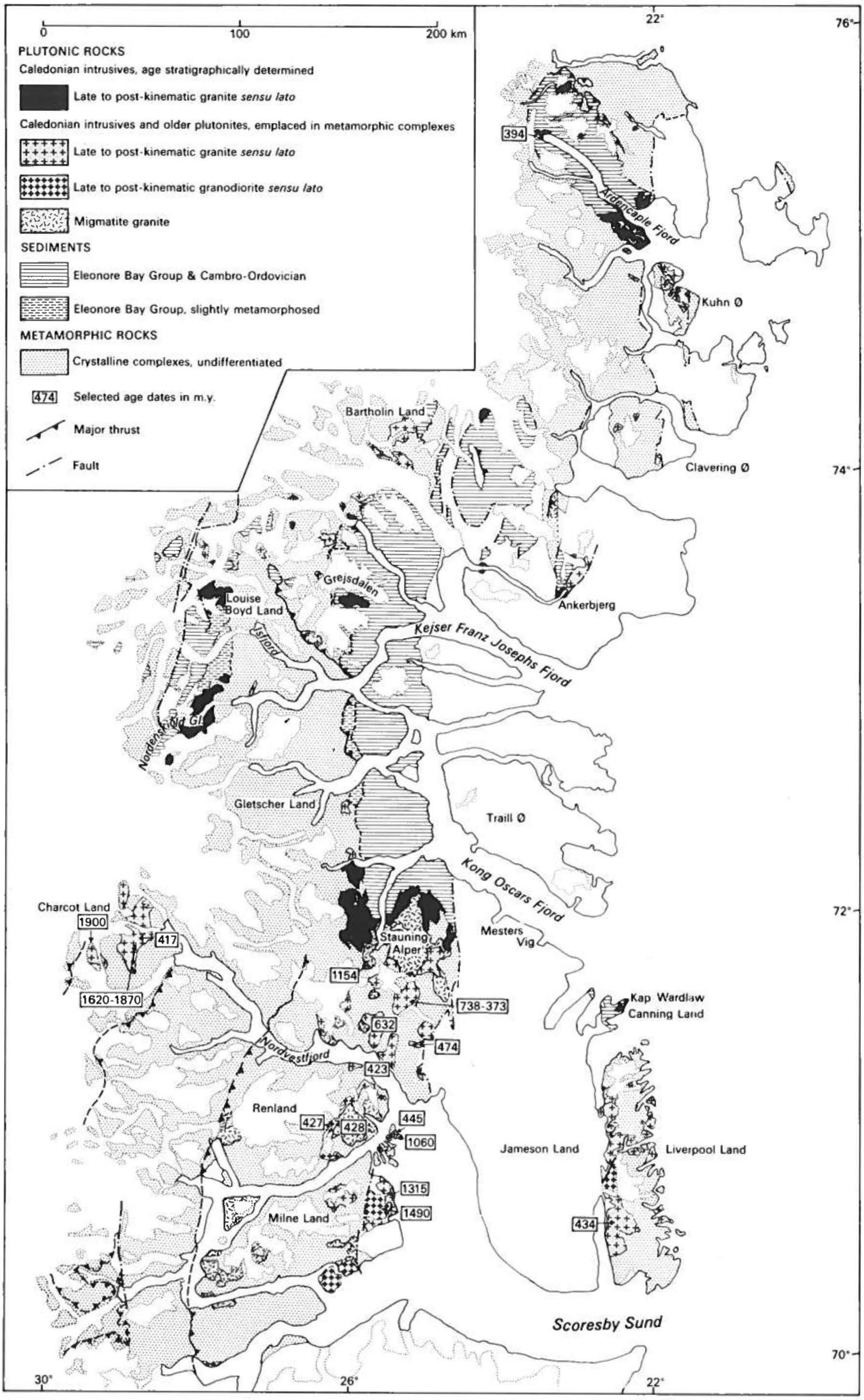
The youngest pre-Caledonian sediments in central East Greenland are rocks of the Heim Bjerge Formation, generally referred to the upper Middle Ordovician – Mohawkian stage. A fault block possibly referable to the same formation has yielded a fauna suggesting a late Mohawkian or even Cincinnatian age, which would raise the sedimentation range to possibly lowermost Upper Ordovician. The oldest post-Caledonian sediments are thick deposits of Devonian molasse which rest unconformably on the folded late Precambrian and lower Palaeozoic strata. The base of the molasse sequence on vertebrate fossil evidence is referred to the lower part of the Givetian stage.

The stratigraphical evidence thus suggests the main phase of the Caledonian orogeny in central East Greenland can be placed in the interval between the upper Middle to lower Upper Ordovician, and the upper Middle Devonian.

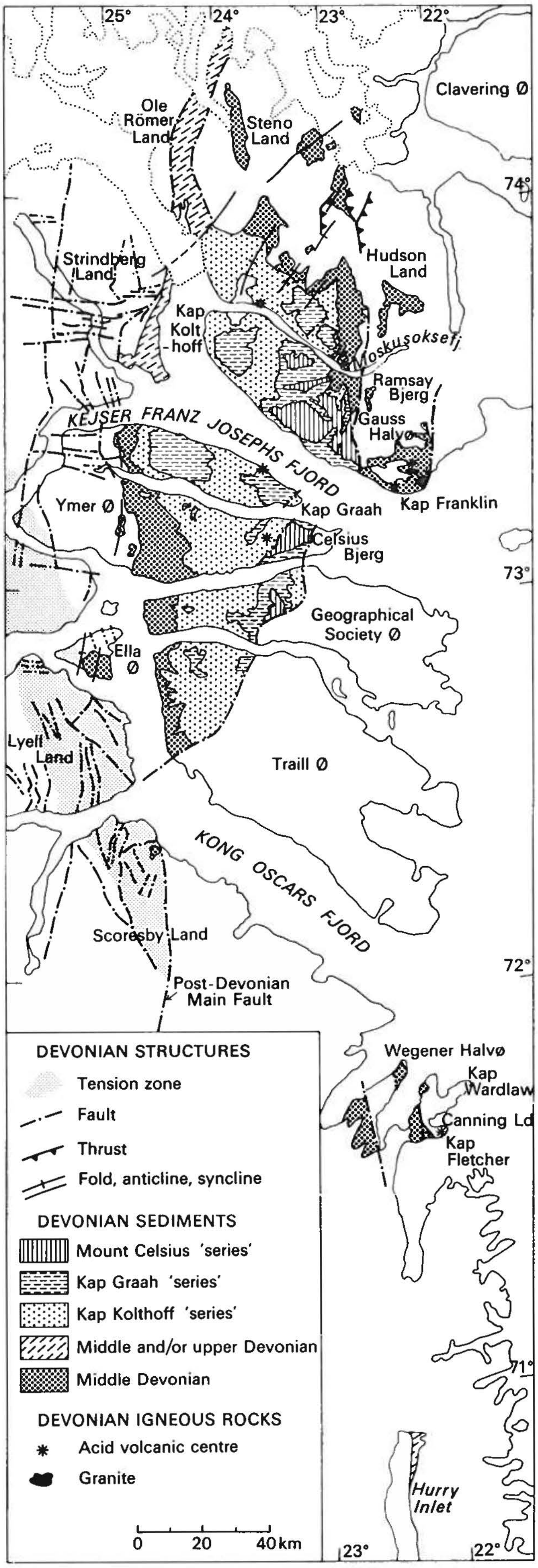
Radiometric age determinations on a variety of reworked pre-Caledonian and Caledonian metamor-

→

Fig. 187. Intrusive bodies cutting the late Precambrian and lower Palaeozoic sediments (Caledonian intrusions) are distinguished from those of uncertain age (pre-Caledonian or Caledonian).



0
100
200 km
PLUTONIC ROCKS
Caledonian intrusives, age stratigraphically determined
Late to post-kinematic granite *sensu lato*
Caledonian intrusives and older plutonites, emplaced in metamorphic complexes
Late to post-kinematic granite *sensu lato*
Late to post-kinematic granodiorite *sensu lato*
Migmatite granite
SEDIMENTS
Eleonore Bay Group & Cambro-Ordovician
Eleonore Bay Group, slightly metamorphosed
METAMORPHIC ROCKS
Crystalline complexes, undifferentiated
474 Selected age dates in m.y.
Major thrust
Fault
22°
76°
394
Ardencaple Fjord
Kuhn Ø
Bartholin Land
Clavering Ø
74°
Greisdalen
Louise Boyd Land
Ankerbjerg
Ymer Fjord
Kejser Franz Josephs Fjord
Nordenskiöld Gl.
Gletscher Land
Traill Ø
Kong Oscars Fjord
Charcot Land
1900
417
72°
Mesters Vig
Stauning Alper
1154
1620-1870
738-373
Kap Wardlaw
Canning Land
632
474
Nordvestfjord
423
Renland
427
428
445
1060
Jameson Land
Liverpool Land
1315
1490
Milne Land
434
Scoresby Sund
70°
30°
26°
22°



phic rocks from central East Greenland show a concentration of ages in the range 400–470 m.y., of which many fall between 405 and 425 m.y.; they are largely Rb-Sr and K-Ar mineral ages (see below and figs 198, 199). A U-Pb age on monazite from a post-kinematic granite dyke has given 445 m.y. (Oberli & Steiger, 1973). While the evidence is limited the available dates can be taken to give minimum metamorphic ages, and it is a plausible assumption that the main orogeny occurred shortly after deposition of the youngest pre-Caledonian sediments; i. e. in latest Ordovician to earliest Silurian time.

In North-East Greenland there are indications that the main Caledonian deformation is somewhat younger. The youngest sediments in the foreland sequence overridden by Caledonian thrust sheets are the Profilfjeldet Shales, of which graptolites in the lower part indicate a Niagaran age while the upper non-fossiliferous part may be Cayugan (fig. 183). A reliable lower age limit for the Caledonian event is thus Middle to Upper Silurian. An upper age limit is given by a post-folding sequence of plant-bearing sandstones found in Holm Land and Amdrup Land, considered Lower Carboniferous by Nathorst (1911) but more likely to be Upper Carboniferous by V. Poulsen (1967). A single K-Ar biotite age from a late-tectonic pegmatite in Lambert Land (79° 20′ N) has given 405 m.y. (Haller & Kulp, 1962). Caledonian diastrophism in North-East Greenland thus probably occurred in uppermost Silurian to lowermost Devonian time.

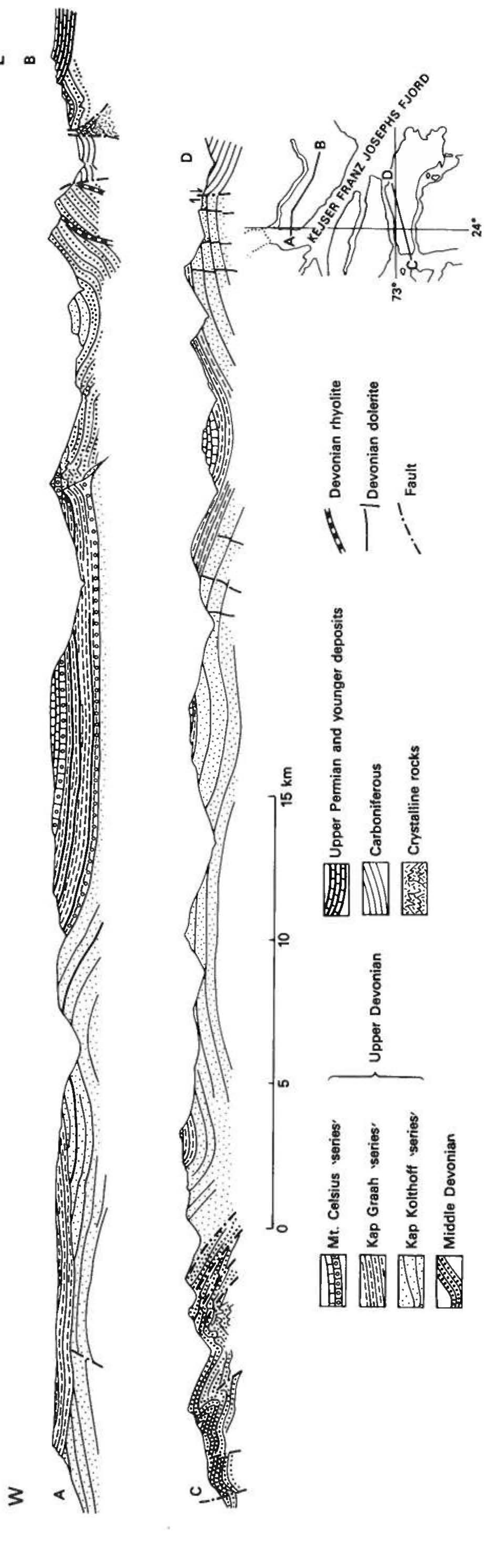
These observations should be viewed with reservations, but there are clear indications that the main Caledonian event was diachronous in East Greenland.

Late Palaeozoic continental deposits and late Caledonian deformation

Devonian – Old Red Sandstone basin

After the main Caledonian orogenic phase an intermontane molasse basin was formed in East Greenland between latitudes 71° 30′ N and 74° 30′ N. Non-marine, red-coloured clastic sediments with a cumulative thickness of more than 7000 m were deposited, dated by their vertebrate fauna to the Middle and Upper Devonian (Jarvik, 1961; see also

Fig. 188. Devonian sediments, igneous rocks and structures in the outer fjord zone of central East Greenland. Compiled after Haller (1971). Only igneous rocks of stratigraphically established Devonian age are shown.



Bendix-Almgreen, this volume). Lava flows and tuffs within the sequence witness to intermittent, mainly acid, volcanism.

Late Caledonian folding, thrusting and uplift is reflected by disturbances of the Devonian sedimentation in the northern part of the molasse basin. The folding affected not only the Devonian sequence but also the pre-Devonian pavement, and according to Haller (1971) also caused reactivation of certain older Caledonian structures.

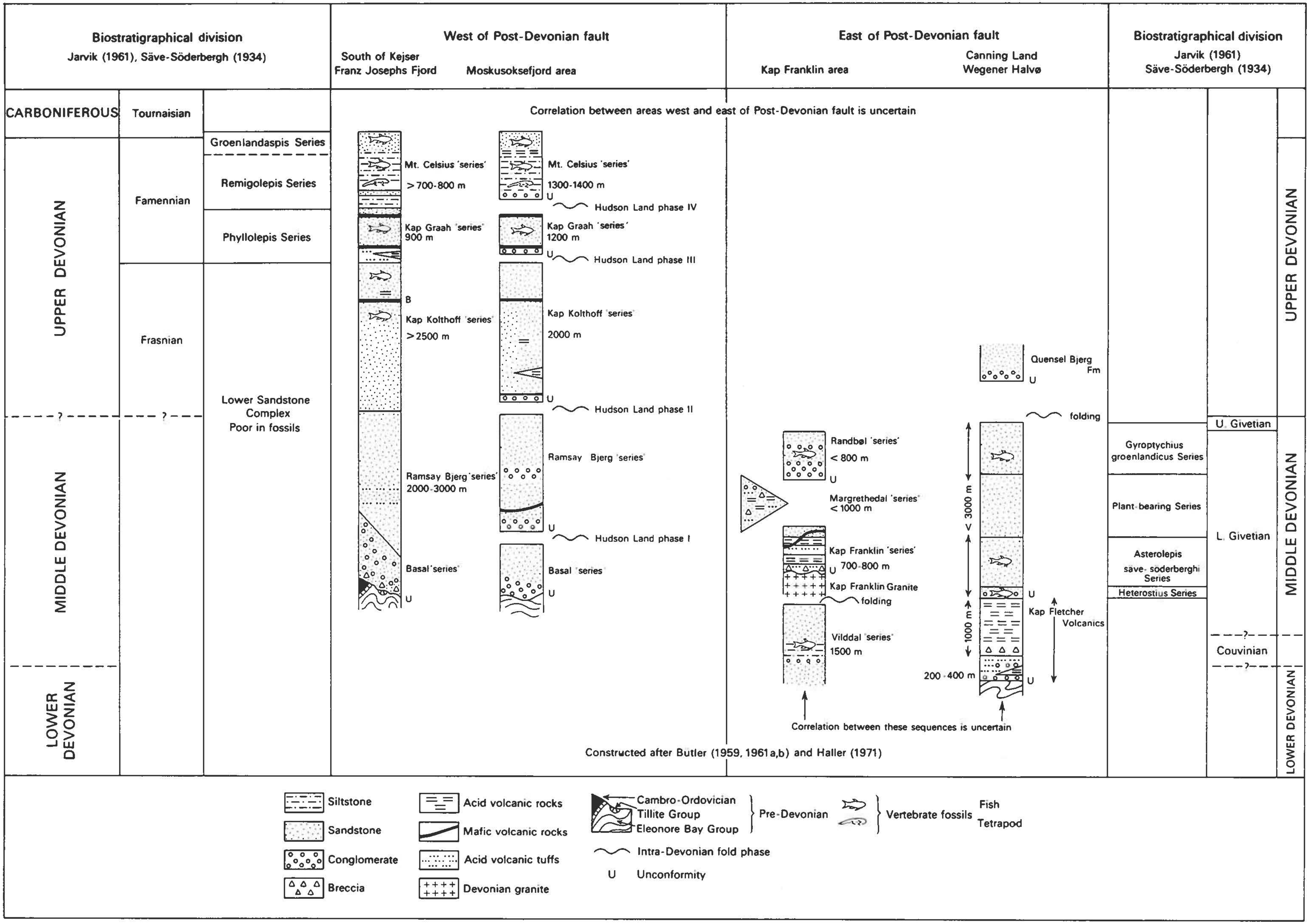
Reviews of Devonian geology with special reference to lithostratigraphy and tectonics have been given by Bütler (1959, 1961a), and Jarvik (1961) has presented a mixed litho- and bio-stratigraphical division. Recent investigations (1968–1970) by geologists from the Scott Polar Research Institute, Cambridge, indicate that some revision of the existing stratigraphy will be necessary (P. Friend, personal communication, 1973).

Devonian sediments outcrop over 5600 km² of a zone 400 km from north to south and 80 km in width in central East Greenland (fig. 188). The principal outcrops lie west of the structure known as the 'Post-Devonian Main Fault' in the region between Kong Oscars Fjord and Steno Land. East of the main fault there are a number of isolated outcrops, but most of the deposits can be assumed hidden in subsided blocks beneath younger strata. The successions on either side of the main fault are not directly correlatable.

The sedimentary rocks are exclusively continental, comprising coarse and fine-grained red and grey sandstones, conglomerates and breccias. Feldspar and mica are abundant in the sandstones, and the coarser clastics often have a carbonate matrix. Cross-bedding, current and wave ripples and other characteristics of fluviatile deposits are abundant. Limnic marly pelites and calcareous beds occur particularly in the upper parts of the succession. In general the Devonian sequence comprises a very uniform facies type, a repetitive sequence in a vertical sense but laterally showing some variation. The lack of reliable lithological markers and the absence of fossils in thick sequences means there is a degree of uncertainty in the present stratigraphical divisions.

On a lithological-tectonic basis Bütler (1961a) has proposed a stratigraphic division of the sequences of the main area, and suggested a correlation with those on the east side of the main fault (fig. 190). Jarvik (1961) has established a biostratigraphic division and shown that the upper third of the main

Fig. 189. Cross-sections of the Devonian molasse basin. After Haller (1971) based on original sections by H. Bütler.


Biostratigraphical division
Jarvik (1961), Säve-Söderbergh (1934)
West of Post-Devonian fault
South of Kejser Franz Josephs Fjord
Moskusoksefjord area
East of Post-Devonian fault
Kap Franklin area
Canning Land Wegener Halvø
Biostratigraphical division
Jarvik (1961)
Säve-Söderbergh (1934)
CARBONIFEROUS
Tournaisian
UPPER DEVONIAN
Famennian
Frasnian
MIDDLE DEVONIAN
LOWER DEVONIAN
Groenlandaspis Series
Remigolepis Series
Phyllolepis Series
Lower Sandstone Complex
Poor in fossils
Correlation between areas west and east of Post-Devonian fault is uncertain
Mt. Celsius 'series'
>700-800 m
Kap Graah 'series'
900 m
B
Kap Kolthoff 'series'
>2500 m
Ramsay Bjerg 'series'
2000-3000 m
Basal 'series'
U
Mt. Celsius 'series'
1300-1400 m
Hudson Land phase IV
Kap Graah 'series'
1200 m
Hudson Land phase III
Kap Kolthoff 'series'
2000 m
Hudson Land phase II
Ramsay Bjerg 'series'
Hudson Land phase I
Basal 'series'
Quensel Bjerg Fm
folding
Randbøl 'series'
< 800 m
Margrethedal 'series'
< 1000 m
Kap Franklin 'series'
700-800 m
Kap Franklin Granite
folding
Vilddal 'series'
1500 m
< 3000 m
1000 m
200-400 m
Kap Fletcher Volcanics
Correlation between these sequences is uncertain
Constructed after Butler (1959, 1961a,b) and Haller (1971)
Gyroptychius groenlandicus Series
Plant-bearing Series
Asterolepis save-soderberghi Series
Heterostius Series
U. Givetian
L. Givetian
Couvinian
Siltstone
Sandstone
Conglomerate
Breccia
Acid volcanic rocks
Mafic volcanic rocks
Acid volcanic tuffs
Devonian granite
Cambro-Ordovician
Tillite Group
Eleonore Bay Group
Pre-Devonian
Intra-Devonian fold phase
U Unconformity
Vertebrate fossils
Fish
Tetrapod

area sequence is Upper Devonian on the basis of the fish fauna. In isolated areas of Canning Land and Kap Franklin east of the 'Post-Devonian Main Fault' the fish faunas give a Middle Devonian age (see also Bendix-Almgreen, this volume).

Around Moskusoksefjord and areas farther north successive episodes of intra-Devonian deformation, the four 'Hudson Land fold phases' of Bütler (1959), have resulted in conspicuous angular unconformities and basal conglomerates in the Devonian succession. The deformation cannot be traced south of Kejser Franz Josephs Fjord where continuous deposition is assumed, and where stratigraphic division can only be carried out by comparison of broad features with the northern areas.

Devonian sediments west of the 'Post-Devonian Main Fault'

Bütler (1959) distinguishes a sequence of Middle and Upper Devonian sediments in the area between Kong Oscars Fjord and Steno Land, divisible into five 'series' separated by episodes of deformation. Under modern nomenclature rules Bütler's 'series' should strictly rank as groups or formations.

The Basal 'series' (Middle Devonian). The lowest part of the sequence occurs at the western edge of the Devonian outcrop overlying Caledonian folded rocks with a major unconformity. The basal conglomerates and breccias rest in contact with members of the Eleonore Bay Group, Tillite Group and Cambro-Ordovician, indicating that deposition took place subsequent to the main Caledonian folding. The basal unconformity is traceable over more than a hundred kilometres with a general dip towards the centre of the basin. In the northern part of the area the lowest part of the sequence is now only preserved in graben-like structures. In the west part of the basin there is evidence of westwards transgression, such that the lowest beds at the west margin are younger than the lowest levels in the interior of the basin.

The Basal 'series' begins with breccias of very coarse local debris of the underlying rocks. Coarse conglomerates follow, comprising pebbles of Caledonian folded sedimentary rocks but without crystalline components. The succeeding sandstones, and in places thick conglomerates, represent deltaic cones with sources in the west.

Ramsay Bjerg 'series' (Middle Devonian). This series is in northern areas a 2000–3000 m thick sequence of mainly grey and grey-green sandstones, with thick conglomerate beds in the central and lower parts. In the southern areas it is an alternating sequence of grey, grey-green, red and white sandstones. Westwards it passes into marginal conglomerates. The series is prominently exposed in the higher parts of Hudson Land, while in the south it is seen in limited exposures beneath the succeeding Kap Kolthoff 'series'.

Kap Kolthoff 'series' (Upper Devonian). This is the most widely exposed of the Devonian units. In the Moskusoksefjord area it comprises a 2000–2500 m thick sequence of banded red-brown and grey sandstones, sharply delimited at top and bottom by angular unconformities, and with a basal conglomerate. Vertebrate fossils in the uppermost levels are not diagnostic but suggest an Upper Devonian age.

Kap Graah 'series' (Upper Devonian). The main part of the series consists of a coarse-grained indurated sandstone with an intense brick red colour. Thicknesses can only be measured in a few places, and give totals of 900–1200 m with apparently a general decrease southwards. In the Moskusoksefjord area there is a coarse basal breccia representing the beginning of deposition after the dying out of the third of the 'Hudson Land fold phases'. The fish fauna in this series was used by Säve-Söderbergh (1934) as the basis for his biostratigraphical division the *Phyllolepis* Series.

Mount Celsius 'series' (Upper Devonian). The lower part of this unit, which has been termed the *Remigolepis* Series, begins with coarse-grained, partly conglomeratic sandstones which are overlain by fine-grained calcareous shales. These represent deposits in a shallow basin which periodically dried out. They are succeeded by limnic marly beds alternating with fine to medium-grained fluviatile sandstones. The *Groenlandaspis* Series, the upper part of the unit, is mainly coarse-grained to conglomeratic sandstone whose period of deposition may extend into the Carboniferous. The total preserved thickness of the Mount Celsius 'series' is 1300–1400 m with a lateral thickening westwards towards the margins of the basin. The upper boundary is not known. The series is well known for its fish and tetrapod faunas.

Devonian sediments east of the 'Post-Devonian Main Fault'

East of the main fault there are two widely separated main areas of Middle Devonian sequences, the Kap Franklin area (73° 15′ N) and the Canning Land – Wegener Halvø area (71° 50′ N). There are also smaller and less well known sequences at the head of Hurry Inlet (70° 50′ N) and north of the head of Moskusoksefjord (73° 45′ N). General biostratigraphic correlation of the Kap Franklin and Canning Land areas seems justified, but detailed correlation is a matter of discussion.

Kap Franklin area

The continental deposits in the Kap Franklin area were divided by Bütler (1959) into four units or series separated by unconformities or gaps in sedimentation. The sequence is not uniformly developed, and a sequence in one area may correspond to a period of non-deposition in another area.

←

Fig. 190. Devonian stratigraphical and lithological divisions.

Vilddal 'series' (Middle Devonian). This 1500 m sequence may be divided into a lower part of dark grey micaceous sandstone, and an upper part of grey-green, fine-grained sediments with red bands. Conglomerate levels occur in both parts. The fish fauna includes *Gyroptychius groenlandicus* which indicates a Middle Devonian age. Folded Vilddal 'series' sediments were intruded by the Kap Franklin granite and both were subjected to erosion prior to deposition of the Kap Franklin 'series'.

Kap Franklin 'series'. The 700–800 m thick sequence comprises a variable mixture of acid volcanics and coarse-grained fluviatile clastic sediments. Basal breccias include volcanic fragments and some derived from the underlying series. No fossils are recorded.

Margrethedal 'series'. Red sandstones, rhyolitic breccias, volcanic tuffs and fluviatile conglomerates make up this 1000 m thick sequence. It appears to be in part equivalent to the upper part of the Kap Franklin 'series', and includes deposits represented by a hiatus elsewhere.

Randbøl 'series' (Middle Devonian). This sequence mainly comprises coarse conglomerates passing upwards into sandstones with pebbly horizons and is up to 800 m thick. The upper contact is an erosion surface. The Middle Devonian fauna in the lower part includes *Coccosteus* and *Asterolepis* (Jarvik, 1961).

Canning Land area

On Canning Land and adjacent Wegener Halvø the sequence begins with the presumed Lower to Middle Devonian Kap Fletcher volcanics, overlain unconformably by a thick sequence of Middle Devonian red beds containing vertebrate fossils (Bütler, 1948, 1959). The nearly 3000 m sedimentary sequence comprises conglomerates, arkoses, sandstones and silty shales, which in Canning Land have been divided into the four biostratigraphical divisions given below (Säve-Söderbergh, 1937):

Heterostius Series: 50 m of grey-white arkose beginning with a coarse conglomerate containing pebbles of the underlying volcanics.

Asterolepis säve-söderberghi Series: reddish to grey-green banded sandstones.

Plant-bearing Series: with a poorly preserved flora.

Gyroptychius groenlandicus Series: grey and red streaked sandstones and arkoses with bands of dark-grey to black partly bituminous shales.

At Quensel Bjerg in the south-west part of Wegener Halvø the gently folded Middle Devonian strata are overlain by a flat-lying sequence of pale red coloured conglomerates and brown sandstones. A preliminary Upper Devonian age is suggested by the presence of scales of *Holoptychius* (Säve-Söderbergh, 1937).

Devonian volcanism

Acid and basic volcanic rocks are encountered at several stratigraphic levels in the Devonian and at a number of localities (fig. 188).

Basic intrusions and extrusions have a wider occurrence and a broader time span than their acid counterparts. Dykes and sills are most important, tuffs and lava horizons being uncommon. At least four intrusive events can be recognised in the Middle and Upper Devonian (Bütler, 1959).

Acid volcanism was of local nature, and the three main occurrences are of three different ages. Each includes flows and pyroclastics. They are described in order of stratigraphic age below.

Kap Fletcher volcanics (uppermost Lower Devonian or Middle Devonian). This sequence in the Canning Land area has been described by Noe-Nygaard (1936, 1937), Bütler (1948) and Caby (1972). A thin sedimentary unit occurs beneath the main volcanic sequence, locally with a basal unconformity preserved. The first volcanics are tuffs interlayered with subvolcanic rhyolite, and these are succeeded by the main flows of red and green porphyries, with some rhyodacites and latites. The thickness reaches about 1000 m. Many generations of lamprophyre dykes cut the lavas; their association with microgranite forerunners of the Kap Wardlaw granite (see above) suggests that acid volcanism preceded its intrusion (Caby, 1972, p. 28).

Kap Franklin volcanics (Middle Devonian). A mixed suite of sedimentary and volcanic rocks is found in the Kap Franklin area (73°15′ N), with unconformable contacts with the Vilddal 'series' and Kap Franklin granite below and the Randbøl 'series' above. The volcanics are mainly alkali rhyolitic brown and red porphyries with quartz and sanidine phenocrysts. They are largely found as flows and sills, the flows frequently overlain by tuffs (Backlund & Malmqvist, 1935; Graeter, 1957).

Moskusoksefjord – Ymer Ø volcanics (Upper Devonian). Local occurrences of volcanic and subvolcanic rocks are found in these areas, spanning lower Upper Devonian to upper Upper Devonian time (Backlund, 1932; Rittmann, 1940). Rhyolitic flows and pyroclastics are common, with occasional dyke and sheet formed intrusions.

Devonian granites

Only two relatively small plutons can be shown to be of Devonian age on stratigraphical evidence. These are the Kap Franklin granite (Middle Devonian) and the Högboms Bjerg intrusion (Middle or Upper Devonian).

The Kap Franklin granite is a stock formed intrusion about 3 km by 5 km in outcrop (Bütler, 1954). It cuts discordantly the slightly folded Vilddal 'series', containing near its margins baked sedimentary inclusions, and is unconformably overlain by the Kap Franklin 'series'. A K-Ar biotite-muscovite age on a homogeneous coarse-grained, albiteperthite, alkali granite phase gave 393 m.y. (Haller & Kulp, 1962), which is not in complete agreement with the stratigraphic Middle Devonian age (360–370 m.y.).

The Högboms Bjerg intrusion is a laccolith-shaped complex emplaced in the Middle Devonian lower Ramsay Bjerg 'series'. The centre part of the body is an aplite granite, while the outer part is an alkali rhyolite porphyry (Haller, 1971). The hyperbyssal character of the complex makes it likely that it is related to the rhyolitic volcanoes of Upper Devonian age in the same area, just north of the inner part of Moskusoksefjord (fig. 188).

Devonian structures

Deposition of the molasse-like Old Red Sandstone succession was interrupted by intermittant tensional and compressional events, and the entire Devonian period was apparently characterised by tectonic instability. While most easily discernable in the areas of Devonian deposits, systems of faulting, folding and thrusting of wider occurrence are believed also to be of Devonian age. The tectonics of the Old Red Sandstone basin and its vicinity have been very instructively reviewed in a series of sketch maps and profiles by Haller (1971, p. 293–312). A brief summary is given below.

Structures affecting Devonian sediments

Mention has been made already of the four intra-Devonian 'Hudson Land fold phases' established by Bütler (1959) in the region around Moskusoksefjord, each phase succeeding a period of deposition and thus being stratigraphically datable. During the earliest fold phase, Hudson Land phase I, a thrust wedge of crystalline rocks known as the Moskusoksefjord inlier was emplaced into the overlying supracrustals including the basal Devonian sediments. The Ramsay Bjerg 'series' was subsequently deposited, tilted during phase II, and overlain with angular unconformity by the Kap Kolthoff 'series'. Phase III was the most intense deformation phase, and produced structures with general NNE trends. In the northern part of the area crystalline thrust wedges were displaced westwards over the autochthonous Devonian sediments. Hudson Land phase IV was marked by local folding and thrusting in the north-east part of the area.

Intra-Devonian faulting in the Old Red Sandstone basin was most pronounced along the north-west boundary of the outcrop where a major N–S trending graben was developed, corresponding in age to Hudson Land phase III.

Structures in areas beyond the Devonian basin

In areas west of the Devonian outcrops it is possible to distinguish a succession of tectonic events which are later than the Caledonian folding of the late Precambrian and early Palaeozoic sediments and the main deformation in the metamorphic complexes. While the age of these events is in some cases uncertain, comparison with structures in the northern part of the Old Red Sandstone basin suggests they may be Middle and Upper Devonian (Haller, 1971 p. 299). Haller terms these events 'late Caledonian spasms' and distinguishes an older NNW system of folds and thrusts and a younger NE system of warps and very open folds cutting across the north-west nunatak zone between 73° 30′ and 74° 30′ N.

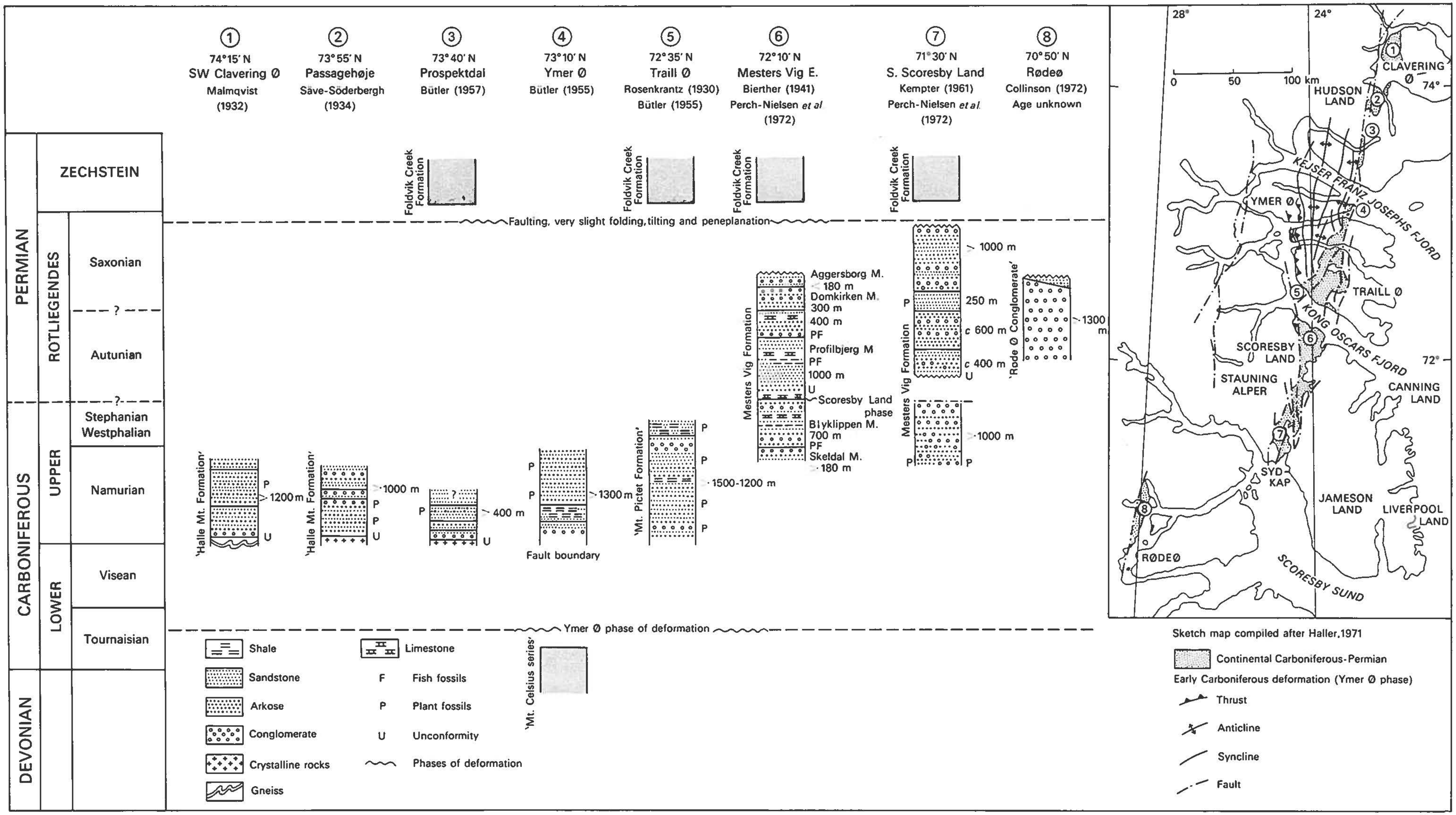
In the late Precambrian and early Palaeozoic sediments the Devonian structures comprise low angle tension faults concentrated in three NNW-trending zones. Fränkl (1953b) estimated a tensional widening of 30 % for the southern part of the central zone. It has been suggested that the Old Red Sandstone basin formed as a major depression related to these zones, as the main Devonian outcrops are concentrated between the south-east continuation of two of the tension zones (Haller, 1971 p. 297).

Systems of E–W and N–S trending steep normal faults are common in the vicinity of the west border of the Devonian outcrops. There were several phases of displacement and throws of more than 1000 m are recorded on certain faults. Graben structures of both trends developed. N–S faulting resulted in a step-like pattern with increasing downthrow eastwards and in some cases it can be shown that the fault movements started furthest west and migrated eastwards later. Step-like fault systems of possibly similar age have been recorded in the crystalline complexes of the Scoresby Sund region (Chadwick, 1971) where a cumulative throw of 1000–1500 m has been estimated.

At the west margin of the Old Red Sandstone basin Middle Devonian deformation has locally caused an accentuation of the fold pattern in neighbouring sediments, the age being inferred from a tilting of the lowest Devonian sediments (Haller, 1971 p. 302).

Carboniferous to Lower Permian in central East Greenland

Continental Upper Carboniferous to Lower Permian deposits with a cumulative thickness of 4000–5000 m are preserved in two narrow belts in central East Greenland between 70° and 74° N (fig. 191). They represent remnants of the last almost continuous phase



1 74°15′ N SW Clavering Ø Malmqvist (1932)
2 73°55′ N Passagehøje Säve-Söderbergh (1934)
3 73°40′ N Prospektdal Bütler (1957)
4 73°10′ N Ymer Ø Bütler (1955)
5 72°35′ N Traill Ø Rosenkrantz (1930) Bütler (1955)
6 72°10′ N Mesters Vig E. Bierther (1941) Perch-Nielsen et al (1972)
7 71°30′ N S. Scoresby Land Kempter (1961) Perch-Nielsen et al. (1972)
8 70°50′ N Rødeø Collinson (1972) Age unknown
PERMIAN
ZECHSTEIN
ROTLIEGENDES
Saxonian
Autunian
CARBONIFEROUS
UPPER
Stephanian Westphalian
Namurian
LOWER
Visean
Tournaisian
DEVONIAN
Foldvik Creek Formation
Faulting, very slight folding, tilting and peneplanation
Aggersborg M.
180 m
Domkirken M.
300 m
400 m
PF
Profilbjerg M
PF
1000 m
U
Scoresby Land phase
Blyklippen M.
700 m
PF
Skeldal M.
180 m
Mesters Vig Formation
1000 m
250 m
c 600 m
c 400 m
'Rode Ø Conglomerate'
1300 m
'Halle Mt. Formation'
1200 m
1000 m
400 m
1300 m
Fault boundary
'Mt. Pictet Formation'
1500-1200 m
Ymer Ø phase of deformation
'Mt. Celsius series'
Shale
Sandstone
Arkose
Conglomerate
Crystalline rocks
Gneiss
Limestone
F Fish fossils
P Plant fossils
U Unconformity
Phases of deformation
28°
24°
0 50 100 km
CLAVERING Ø
74°
HUDSON LAND
KEJSER FRANZ JOSEPHS FJORD
YMER Ø
TRAILL Ø
KONG OSCARS FJORD
SCORESBY LAND
STAUNING ALPER
72°
CANNING LAND
SYD KAP
JAMESON LAND
LIVERPOOL LAND
RØDEØ
SCORESBY SUND
Sketch map compiled after Haller, 1971
Continental Carboniferous-Permian
Early Carboniferous deformation (Ymer Ø phase)
Thrust
Anticline
Syncline
Fault

of molasse deposition, part of the successive phases of continental deposition and deformation which brought the Caledonian orogenic period to a close. A deformation phase in Lower Carboniferous time divides the Devonian molasse from the Carboniferous accumulations. A regional marine transgression in Upper Permian time marked the beginning of an entirely cratogenic period: the marine Foldvik Creek Formation was deposited over wide areas. In North-East Greenland the earliest post-orogenic marine sediments are of Upper Carboniferous age (see Dawes, this volume).

The continental Carboniferous–Lower Permian succession has been extensively studied by members of Lauge Koch's expeditions, their work being reviewed by Bütler (1961b) and Haller (1971). A general correlation scheme for the region between 70° and 72° N has been presented by Perch-Nielsen *et al.* (1972) and incorporates results of the new Survey mapping.

The succession comprises almost entirely clastic sediments, mainly conglomerates and coarse to fine-grained arkoses and sandstones. There are strong lateral facies variations reflecting the numerous centres of accumulation and a decrease in grain size away from a western highland. There are no reliable marker horizons and correlation from area to area is difficult, though a preliminary division has been suggested for the southern part of the region.

The plant fossils have been studied especially by Halle (1931) and Witzig (1951, 1954). At first the oldest deposits were considered to be Lower Carboniferous (Dinantian), but the earliest flora associations are now thought more likely to indicate a Lower Namurian age. Pollen and spores suggest a Lower Permian (Saxonian) age for the youngest deposits. These are found in the Ødemarksdal Member (Kempter, 1961 p. 35), which may be equivalent to the Domkirken Member (Perch-Nielsen *et al.*, 1972, p. 44). Non-fossiliferous sequences at both extremes of the succession may extend the depositional time range.

The Carboniferous–Permian flora is treated in a special phytopalaeontological section (Raunsgaard Pedersen, this volume).

Lower Carboniferous

The *Groenlandaspis* Series of the Upper Devonian Mount Celsius 'series' contains vertebrate and plant fossils indicative of an age at the Devonian–Carboniferous boundary (Bütler, 1961a, p. 194), and it can be assumed that the highest beds extend into the lower Tournaisian.

The early Carboniferous so-called Ymer Ø phase of deformation led to the development of N–S trending generally gentle folds and thrusts in the Devonian deposits. Deformation was most intense in the south-west part of the Devonian molasse basin where a system of imbricate thrust slices formed, individual slices often being strongly folded. Northwards deformation was less pronounced and the folds die out in southern Hudson Land. The age of the folding on stratigraphic grounds can be placed between the lower Tournaisian and lowermost Namurian, corresponding to the gap in sedimentation.

Denudation accompanying or associated with the folding and faulting was of some significance, the Upper Carboniferous deposits being laid down unconformably on folded Middle and Upper Devonian rocks, on the Eleonore Bay Group, and also on crystalline rocks.

Upper Carboniferous – Lower Permian

The main Carboniferous–Permian succession occurs in a 370 km long belt between Sydkap (71° 15′ N) and Clavering Ø (74° 25′ N). Only Upper Carboniferous deposits occur in the northern section, but southwards progressively younger beds appear; south of Kong Oscars Fjord Lower Permian deposits are also found (fig. 191).

Namurian deposits are described from the northern part of the belt. On Clavering Ø the 'Halle Mountain Formation', a sequence of green, red and yellow arkoses and sandstones with occasional conglomerate layers, has been described by Malmqvist (1932). It has been compared with the deposits on Passagehøje (Säve-Söderbergh, 1934), and probably corresponds to the lower part of the 'Mount Pictet Formation' (Rosenkrantz, 1930). The latter consists of light coloured sandstones and arkoses, locally with coarse conglomerates and plant-bearing dark shales; the flora of south Traill Ø shows a passage from Namurian to Westphalian (Witzig, 1951).

South of Kong Oscars Fjord strata underlying Lower Permian deposits are referred to the Upper Carboniferous; these are the two lowest members of the Mesters Vig Formation (Perch-Nielsen *et al.*, 1972). The Skeldal Member comprises arkoses alternating with silty and carbonaceous layers containing fish remains. The succeeding Blyklippen Member is a sequence of conglomerates, breccias and sandstones, with intercalations of siltstones and carbonaceous shales containing plant and fish remains of Westphalian age (Bierther, 1941; Witzig, 1954).

←

Fig. 191. Diagrammatic representation of the Carboniferous – Middle Permian succession. There is no detailed correlation between individual sections and the exact stratigraphic position is often uncertain.

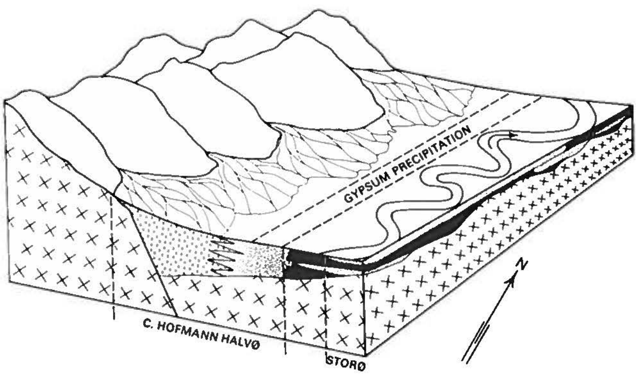
A normal fault everywhere forms the western boundary to the Carboniferous; its cumulative eastward downthrow may reach several thousand metres. The eastern boundary is also often fault bounded, though in the northern part of the region deposits are found in a series of westward tilted fault blocks so that the west boundary is a fault and the east boundary a line of erosion. North of Kong Oscars Fjord the western fault cuts abruptly through the Carboniferous succession suggesting that deposits once continued further to the west. Possible eastward extensions of the sequence may be hidden beneath younger deposits.

Lower Permian deposits south of Kong Oscars Fjord rest with slight unconformity on Upper Carboniferous strata (Witzig, 1954), the minor episode of local folding being referred to as the Scoresby Land phase. A NE–SW trending structure is recorded west of Mesters Vig.

Of the five members of the Mesters Vig Formation the upper three are referred to the Lower Permian, and make up most of the molasse sequence south of 72° in the Scoresby Land area. The deposits here appear to have accumulated at the foot of a mountain range now represented by the crystalline rocks of the Stauning Alper. The present western fault boundary probably largely corresponds to the original west limit of the deposits. Outcrops of continental Carboniferous deposits preserved in fault blocks on Wegener Halvø and Canning Land imply that the deposits continue beneath the Mesozoic sediments of Scoresby Land and north Jameson Land, and that the original basin of accumulation was 80 km or more in width.

The Profilbjerg Member, the lowest of the three Permian members, comprises well-bedded arkoses, coarse sandstones, siltstones, thin conglomerates, and pelitic intercalations with plant and fish fossils. The fossils and palynological evidence suggest an Autunian age. The Domkirken Member consists of arkosic red beds and conglomerates and lacks fossils; it has been compared with the New Red Sandstone and a Saxonian? age assumed. The Aggersborg Member comprises arkosic sandstones and siltstones, with silty and carbonaceous shale intercalations.

Fig. 192. Environmental situation envisaged for deposition of the Røde Ø Conglomerate. Schematic block diagram after Collinson (1972, fig. 24).



Faulting, slight folding, tilting and peneplanation preceded transgression by the Upper Permian Zechstein Sea and deposition of the marine Foldvik Creek Formation (see Birkelund & Perch-Nielsen, this volume).

In the inner part of the Scoresby Sund region a formation of red sandstones and conglomerates, the Røde Ø Conglomerate, outcrops within a region of high grade metamorphic rocks (Collinson, 1972). The west boundary is a normal fault, while in the east the sediments rest unconformably on the migmatites. Four lithofacies are recognised with lateral gradations. The westernmost facies is a coarse conglomerate association deposited probably as alluvial fans east of a rapidly rising block west of the fault. This facies passes eastwards into a sandstone association, which in turn grades into a gypsiferous sandstone. Farthest to the east cross-bedded fluviatile sandstones are found. The environmental situation envisaged is depicted in fig. 192. There is no direct evidence for the age of the Røde Ø Conglomerate but comparisons with the Lower Permian sequence of south Scoresby Land suggest similarities in structural environment and possibly also of age (Collinson, 1972).

Metamorphic crystalline complexes

A considerable proportion of the East Greenland fold belt comprises crystalline infracrustal gneisses and granites, and metamorphosed supracrustals. These may be conveniently divided into a number of metamorphic complexes, each with a characteristic lithological and structural composition. Some of the complexes preserve both pre-Caledonian and Caledonian orogenic features reflecting a composite origin for the East Greenland fold belt. As correlation between the various complexes is generally speculative they are described individually region by region, using as far as possible established subdivisions (fig. 193).

Parkinson & Whittard (1931) initially distinguished western, central and eastern metamorphic complexes in the southern part of the fold belt. These main groupings are retained here for the region south of latitude 76° N. For convenience the areas of the Gåseland and Charcot Land windows are grouped with the original western complex, the three areas all lying at the western edge of the fold belt. In the northern part of the central metamorphic complex Haller's (1955) subdivisions are used, while in the southern part divisions are based on the results of new Survey mapping (fig. 197). Liverpool Land and the Grandjean Fjord metamorphic complex make up widely separated parts of the eastern complex. North of latitude 76° N there are two main geographical divisions, both of a composite nature. The large nunatak of Dronning Louise Land comprises a probably autochthonous foreland to the fold belt in the west, and an allochthonous thrust mass in the east. In the coastal region between 76° and 81° N two units are distinguishable: the Bessel Fjord – Ingolf Fjord metamorphic complex of largely infracrustal rocks and the Carolinidian orogenic complex which contains the remnants of a supposed middle Proterozoic fold belt.

Western complexes

The three western complexes all lie at the extreme western edge of the fold belt. The Gåseland and Charcot Land exposures are both tectonic windows through westward directed thrust sheets and may represent an autochthonous or parautochthonous foreland to the Caledonian fold belt. The structural position of the western nunatak zone further north between 72° 45′ and 74° N is uncertain.

Gåseland window

The presumed foreland outcrops are found in a tectonic window in the extreme western part of Gåseland and in Paul Stern Land (fig. 194). They consist of an infracrustal basement complex overlain with a major unconformity by a thin sequence of weakly metamorphosed sediments. A unit of sericitic quartzites and chloritic schists above the autochthonous metasediments was earlier referred to the autochthonous sequence (Wenk, 1961) but is now interpreted as highly tectonised gneisses (Phillips *et al.*, 1973). Above these sheared basement gneisses occur thick thrust masses of high grade metasediments forming part of the Vestfjord – Hinks Land gneiss and schist zone (see figs 197, 198).

The infracrustal basement rocks are commonly grey hornblende-biotite gneisses intruded by early basic sheets which have been subjected to migmatisation, amphibolite facies metamorphism and intense

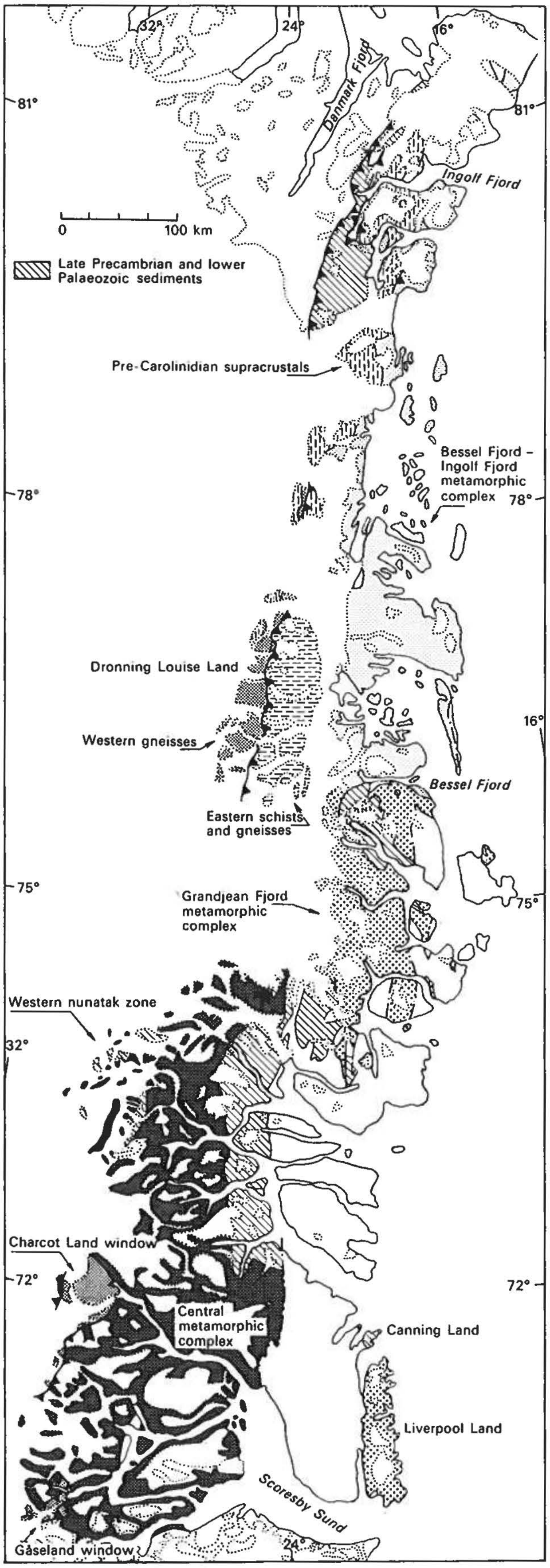


Fig. 193. The divisions of the metamorphic complexes of central East Greenland and North-East Greenland as used in the text.

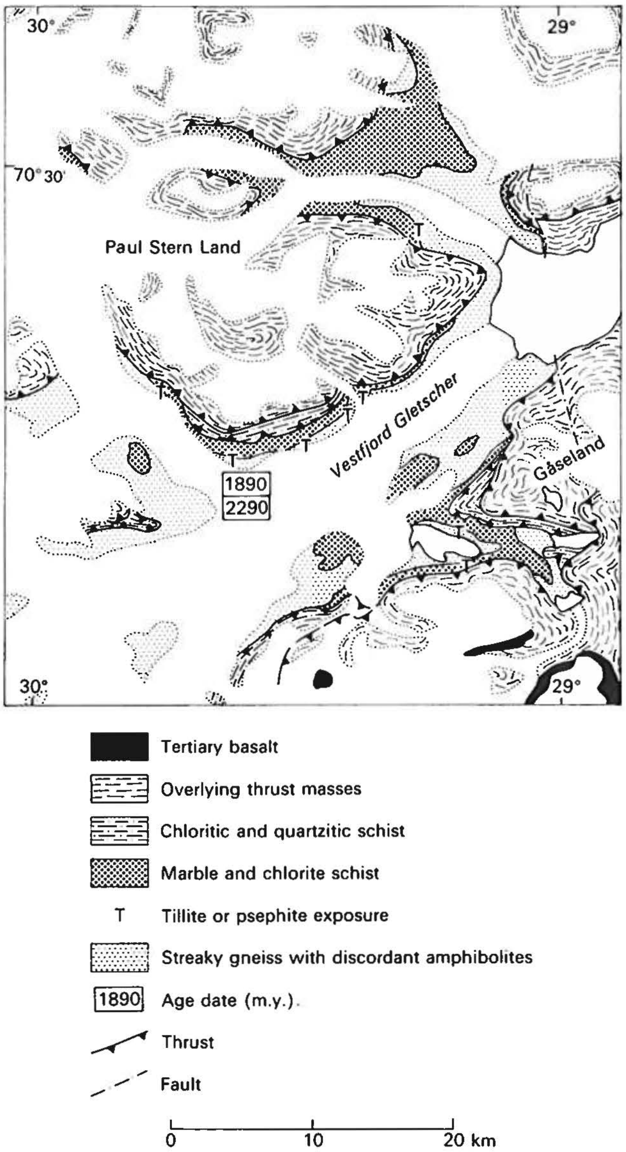


Fig. 194. The foreland window of western Gåseland and Paul Stern Land. After Phillips *et al.* (1973).

folding. The migmatitic granite phase occurs in net-veined, agmatitic or nebulitic forms, and sometimes in discrete bodies. A later phase of augen granite or augen gneiss is found in places. Discordant basic dykes dissect this gneiss and granite complex and have been metamorphosed under amphibolite facies conditions. Mineral age dates of 1890 and 2290 m.y. suggest an interpretation of the basement as Archaean (Haller & Kulp, 1962). An unconformity at the base of the supracrustals post-dates all these events (Wenk, 1961; Phillips *et al.*, 1973).

The autochthonous supracrustal sequence consists mainly of a cream-coloured marble with local psephitic, quartzitic and tillitic developments at the base.

The tillitic and psephitic lenses preserved in pockets in the basement below the marbles were first recognised by Eduard Wenk and Paul Stern and a number of new localities have been discovered subsequently (fig. 194). In the thickest development (*c.* 40 m) there are two psephite levels which contain clasts up to 40 cm in diameter, and purple and green siltstones which preserve 'dropped-in' features suggestive of a glacial origin for the deposit.

The marbles are well laminated with many wedge-shaped sheets of quartz-sericite schists and chlorite-carbonate schists. The demonstrable maximum thickness is 300 m, but there are numerous isoclinal folds and planes of dislocation related to the main thrust zone so the original thickness is uncertain.

The Gåseland window became well known as the first example of the western edge of the fold belt south of Dronning Louise Land (76° N), and as a locality for the occurrence of the base of the Eleonore Bay Group (Wenk, 1961). It was presumed that the weakly metamorphosed sediments resting unconformably on the basement complex represented a 'Basal Series' of the Eleonore Bay Group, but the recent Survey work does not confirm this view and their age is open to discussion. Phillips *et al.* (1973) point out similarities between the Gåseland tillites and the Eocambrian tillites of central East Greenland implying that the Gåseland marble sequence might correspond to part of the Cambro-Ordovician carbonate succession. While there is no *in situ* fossil evidence to support this view, the widespread occurrence along the entire fold belt of erratic blocks of *Scolithus* quartzite has long given rise to speculation that Lower Palaeozoic rocks are hidden beneath the Inland Ice (see Haller, 1971, fig. 48).

Charcot Land window

The rock units outcropping over most of Charcot Land, in western Hinks Land and in adjacent nunataks occur in a tectonic window below an arch-formed major thrust with a westward displacement of at least 40 km. They comprise: (1) an infracrustal complex of gneisses and granites; (2) the Charcot Land supracrustal sequence; (3) late to post-kinematic granites; and (4) a small occurrence of tillite resting unconformably on a granite (fig. 195).

The infracrustal rocks are mainly banded gneisses, augen gneisses and rusty weathering amphibolites. The infracrustal basement is conformably overlain by the Charcot Land supracrustal sequence which is at least 2000 m thick (Steck, 1971), though the basement and cover are deformed together to the extent that a possible original unconformity is no longer discernable. The lowest part of the supracrustal sequence includes prominent marble and greenschist or amphibolite units. Semipelitic and quartzitic units are widespread, and the Royston Nunatakker comprise largely basic extrusives. Pillow structures have been noted at several localities. There is a pronounced lateral variation in development of the various supracrustal units. A number of hornblende gabbro intrusions found in the supracrustals in southern Charcot Land are considered to be comagmatic with the basic extrusions (Steck, 1971).

The southern areas of supracrustals are characterised by a low greenschist facies metamorphic grade, in sharp contrast to the high grade rocks of the overlying thrust sheet. Northwards there is a pronounced progressive increase in metamorphic grade, and high amphibolite facies is reached in the supracrustals in north-east Charcot Land. The phenomenon is described in detail by Steck (1971) who considered the metamorphic episode to be Caledonian. Earlier investigators, E. Wenk and P. Vogt, viewed the supracrustals as representing the basal part of the Eleonore Bay Group (Vogt, 1965).

Two late to post-kinematic intrusions outcrop in Charcot Land. The smaller body occupies most of Tillit Nunatak and is mainly a hornblende-biotite quartz diorite. Generally it exhibits slight alteration attributed to retrogressive metamorphism. It is emplaced largely in the infracrustal basement unit, but also veins the supracrustal sequence. The larger intrusive body is a very prominent coarse-grained to pegmatitic, leucocratic muscovite granite which outcrops over an area of 25 by 10 kilometres. A marginal network of pegmatite veins and dykes cuts the infracrustal gneisses and the supracrustals. This body has been previously interpreted as a post-kinematic Caledonian granite (Haller, 1971, p. 286).

Isotopic ages reveal a complex situation. The quartz diorite has given a zircon age of 1900 m.y. (Steiger & Henriksen, 1972), while the muscovite granite has given several mineral ages in the range 1600–1800 m.y. (Hansen *et al.*, 1972; 1973b) as well as Caledonian ages (417 m.y.: Hansen *et al.*, 1973a). The Charcot Land supracrustal sequence may thus be of great antiquity, though the only direct dates are mineral ages of 632 m.y. (K-Ar: hornblende) and 411 m.y. (Rb-Sr: biotite) on an amphibolite from the highest zone of regional metamorphism (Hansen *et al.*, 1973a, b). The latter age reflects a Caledonian event, but the former a partially reset older age.

The tillite of Tillit Nunatak is several hundred metres thick, occupies an area of 500 by 1500 m

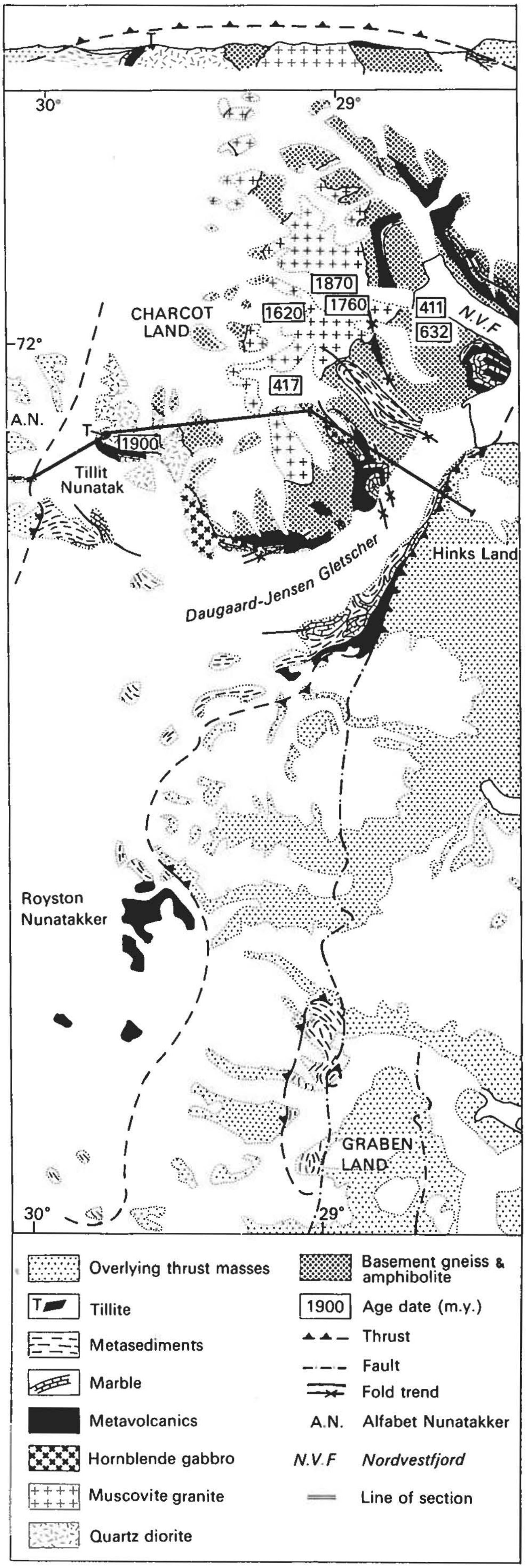


Fig. 195. The foreland window of Charcot Land and its continuation southwards in the nunatak region.

Fig. 196. The tillite of Tillit Nunatak showing scattered crystalline blocks in a pelitic matrix with local varve-like banding. The vertical cleavage and tension veins may relate to the proximity of the overriding thrust sheet.

and rests unconformably on the quartz diorite intrusion. The rock components vary from a few millimetres to 2 m in diameter and are largely of local derivation, dominantly from the quartz diorite and the infracrustal gneiss complex, but also including representatives of the supracrustals. The groundmass is a dark grey or black arenaceous to arkosic rock with semipelitic and pelitic layers exhibiting repetitive graded bedding reminiscent of varves (fig. 196). 'Dropped-in' structures have been noted.

There is no clear evidence for the age of the tillite though it has been regarded as Eocambrian (Steck, 1971). Like the Gåseland tillite, which may be the same age, it rests directly on crystalline rocks. It is of interest to note the apparent absence of the thick late Precambrian successions which underlie the tillites of the outer fjord zone.

Western nunatak zone (72° 45'–74° N)

A broad zone of migmatites, gneisses and metasediments, originally described as the western metamorphic complex, occurs west of the unmetamorphosed Eleonore Bay Group rocks of the Petermann Bjerg region (fig. 199). The contact between the two areas is a prominent N–S trending normal fault, the Eleonore Bay Group sediments (Petermann 'series') being downthrown to the east. Ground traverses are limited to areas in the north and south and there is some supplementary information derived from aerial observations.

Haller (1956a) distinguishes a unit of synorogenic granites and migmatites with bands of schistose biotite gneisses, and a second unit of metasedimentary rocks mainly comprising quartzitic schists and siliceous gneisses (fig. 199). The infracrustal unit has conformable contacts with the metasedimentary unit, and the metasedimentary rocks may grade upwards into non-metamorphic, possibly Eleonore Bay Group sediments. NW-trending tight to isoclinal folds with flat-lying axial planes characterise the infracrustal rocks, but are absent from the metasediments. All rock units, however, exhibit NNE-trending gentle open folding or warping with steep axial planes.

The known lithology of the western nunatak zone has similarities with the various units of the central metamorphic complex, and Haller accordingly has interpreted the infracrustal rocks as the Caledonian granitised and migmatised equivalents of the Eleonore Bay Group. Alternatively, the extreme westward location of the complex suggests that it might be a part of the Greenland shield of the foreland region. The gently folded metasediments and non-metamorphosed sediments might in the latter instance represent either autochthonous foreland sediments, or perhaps remnants of westward directed thrust sheets.

Central metamorphic complex

The central metamorphic complex has played a significant role in the development of ideas concerning the genesis of the Caledonian fold belt. A number of early workers considered this broad region to be an essentially Precambrian massif (e. g. Wordie, 1927; Odell, 1944; Teichert, 1933), whereas others claimed that the Eleonore Bay Group stratigraphy could be traced into and throughout the complex and that it must therefore be a manifestation of Caledonian orogenesis and mobilisation (e. g. Backlund, 1930; Wegmann, 1935b). Detailed work by members of Koch's expeditions over many years seemed to support the latter interpretation (e. g. Haller, 1956a; Wenk & Haller, 1953). However, recent Survey mapping in the Scoresby Sund region indicates that a compromise between the two extreme viewpoints is most likely.

The six structural-lithological subdivisions of the central metamorphic complex (fig. 197) are described from south to north, beginning with the two southern zones from which much new information is available (Henriksen & Higgins, 1969, 1970, 1971, 1973).

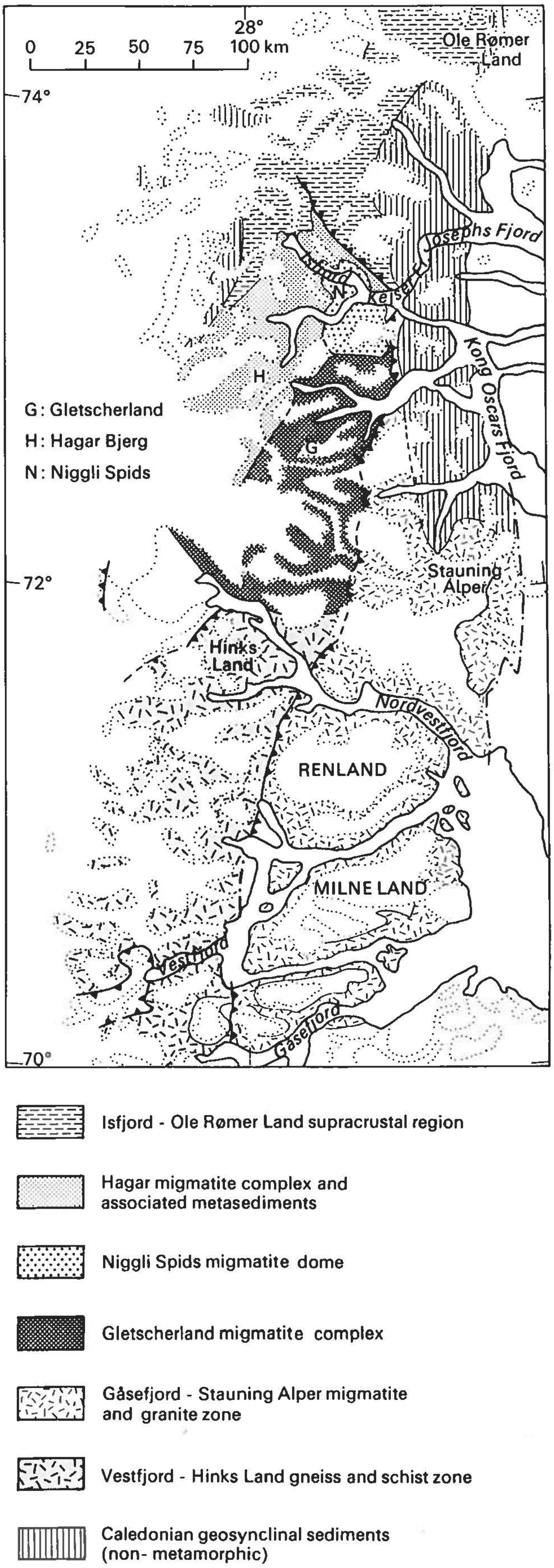


Fig. 197. Subdivisions of the central metamorphic complex as used in the text.

Vestfjord – Hinks Land gneiss and schist zone

In the Scoresby Sund region the western part of the fold belt in the inner fjord zone is formed by a broad zone of distinctive gneisses and schists (fig. 198) extending from south of Vestfjord to Hinks Land. This zone is separated from a region of essentially migmatitic character to the east by a prominent east dipping thrust or reverse fault running from central Nordvestfjord via Rødefjord to Gåsefjord. Westwards the zone extends to the margin of the Inland Ice except for several foreland windows preserved beneath prominent, assumed Caledonian, flat-lying thrusts (fig. 198). Parts of the gneiss and schist zone were mapped and described by Wenk (1961) and Vogt (1965), but this account is largely based on the recent regional mapping by the Survey (Henriksen & Higgins, 1969, 1971; Phillips *et al.*, 1973; Homewood, 1973; Higgins, 1974). Two principal lithological units are recognised: the Flyverfjord infracrustal complex and the Krummedal supracrustal sequence.

Flyverfjord infracrustal complex

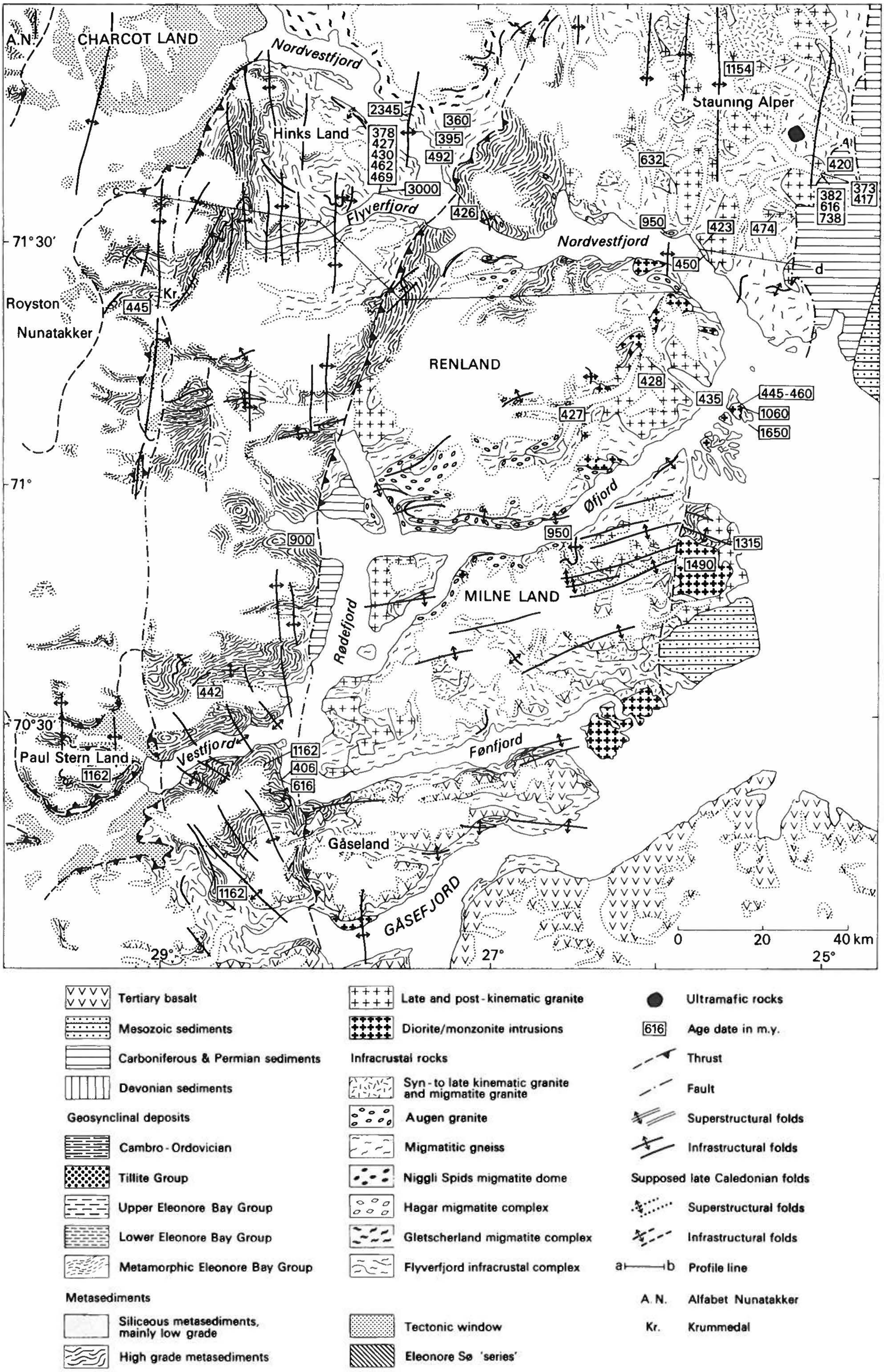
The complex occurs throughout the zone, but the most extensive outcrops are found around Flyverfjord and inner Nordvestfjord where the generally leucocratic gneisses clearly form a basement to the contrasting overlying red-brown schists of the Krummedal sequence. To the north of Nordvestfjord the Flyverfjord infracrustal complex has an apparently transitional boundary with the Gletscherland migmatite complex (see below).

In the northern part of the zone the Flyverfjord complex comprises a variety of biotite or hornblende bearing banded to veined gneisses, as well as abundant and persistant amphibolite bands, ultrabasic lenses and occasional granitic masses. Amphibolite bands can sometimes be used as markers, and assist in defining major recumbent folds, dome-shaped structures, and on a mesoscopic scale fold interference patterns (fig. 202). A conspicuous feature of many areas are swarms of folded, discordant, amphibolite dykes 5–10 m, rarely 50 m, in width. They post-date at least two phases of deformation and subsequently suffered a further episode of deformation and metamorphism. Three isotopic age determinations, a Rb-Sr isochron on biotite gneisses with

→

Fig. 198. Geological map of the inner Scoresby Sund region (70°–72°N) showing main rock units, structures and age dates.

Fig. 199. Geological map of the inner fjord zone from 72° to 74°30'N showing main rock units, structures and age dates. Legend as on fig. 198. Compiled after Koch & Haller (1971) and Haller (1970).



A.N.
CHARCOT LAND
Nordvestfjord
Hinks Land
Stauning Alper
2345
378
427
430
462
469
360
395
492
3000
1154
632
420
382
616
738
373
417
Flyverfjord
426
950
423
474
Nordvestfjord
450
71°30′
c
d
Royston
Nunatakker
Kr.
445
RENLAND
428
435
427
445-460
1060
1650
71°
Øfjord
950
900
1315
1490
MILNE LAND
Rødefjord
442
70°30′
Paul Stern Land
1162
Vestfjord
1162
406
616
Fønfjord
Gåseland
1162
GÅSEFJORD
29°
27°
25°
0
20
40 km
Tertiary basalt
Mesozoic sediments
Carboniferous & Permian sediments
Devonian sediments
Geosynclinal deposits
Cambro-Ordovician
Tillite Group
Upper Eleonore Bay Group
Lower Eleonore Bay Group
Metamorphic Eleonore Bay Group
Metasediments
Siliceous metasediments, mainly low grade
High grade metasediments
Late and post-kinematic granite
Diorite/monzonite intrusions
Infracrustal rocks
Syn- to late kinematic granite and migmatite granite
Augen granite
Migmatitic gneiss
Niggli Spids migmatite dome
Hagar migmatite complex
Gletscherland migmatite complex
Flyverfjord infracrustal complex
Tectonic window
Eleonore Sø 'series'
Ultramafic rocks
616 Age date in m.y.
Thrust
Fault
Superstructural folds
Infrastructural folds
Supposed late Caledonian folds
Superstructural folds
Infrastructural folds
a b Profile line
A.N. Alfabet Nunatakker
Kr. Krummedal

Fig. 198.


F. : Furesø
M. : Målebjerg
B. : Bartholin Land
N.S. : Niggli Spids
J.D. : Junction Dal
K.M. : Kap Madeleine
E.S. : Eleonore Sø
E.B. : Eleonore Bugt
0
20
40 km
30°
28°
26°
24°
74°
72°
WALTERSHAUSEN GLETSCHER
Ole Rømer Land
Escher Land
Strindberg Land
Eremitdal
Gerard de Geer Gl.
ANDREE LAND
Isfjord
395
402
410
412
425
KEJSER FRANZ JOSEPH FJORD
Petermann Bjerg
a
b
SUESS LAND
Hagar Bjerg
Ella Ø
KONG OSCARS FJORD
GLETSCHERLAND
Forsblads Fjord
Alpefjord
NATHORST LAND
Stauning Alper
Charcot Land

Fig. 199.

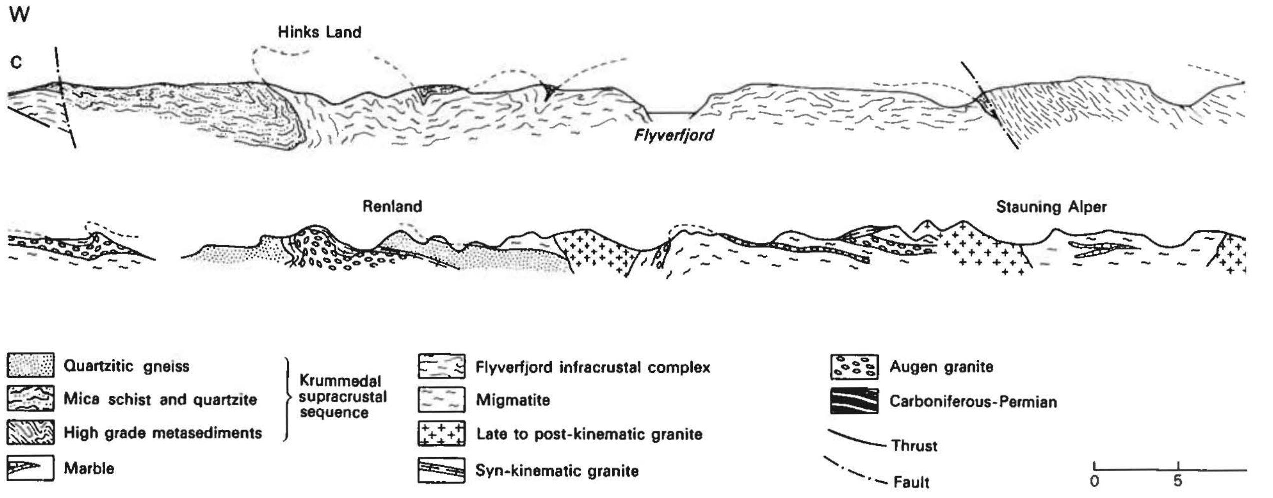


Fig. 200. East–west profile across the inner Scoresby Sund region, through the Vestfjord – Hinks Land gneiss and schist zone and Gåsefjord – Stauning Alper migmatite and granite zone.

amphibolite bands and pods (*c*. 3000 m.y.: Rex & Gledhill, 1974), a K-Ar age on one of the amphibolitic dykes (2525 m.y.: Hansen *et al*., 1973b), and a zircon age on foliated granite (2345 m.y.: Steiger & Henriksen, 1972), indicate that the main development of the complex extends well back into the Archaean.

In the southern and central parts of the zone the infracrustal complex and the Krummedal supracrustal sequence are intensely folded together producing a marked flattening, and largely obliterating the original structural pattern in the infracrustals which now comprise banded leucocratic and veined gneisses with abundant concordant amphibolites. This deformation episode probably coincided with the middle Proterozoic high grade metamorphism in the Krummedal sequence (see below).

Further modification of the infracrustal gneisses took place locally in the vicinity of the major thrusts, assumed Caledonian, where thick mylonite units were formed.

Krummedal supracrustal sequence

The rusty brown pelitic and psammitic sediments of the zone have been informally distinguished as the Krummedal supracrustal sequence, after the spectacular sections in the steep walls of the valley Krummedal (fig. 201).

In the northern part of the zone the succession locally begins with a marble and amphibolite development up to 150 m thick. In the southern part of the zone the sequence starts in places with layers and lenses up to 200 m thick of amphibolites with impure quartzites, and at other localities lenticular outcrops of breccias, agglomerates, gabbros and l are found.

In the northern parts of the zone the successic formed mostly by an alternating sequence of qu zite and mica schist bands each up to several mc thick. Thicker pelitic or psammitic units occur cally, and at a high level of the exposed succes

Fig. 201. Characteristic alternating quartzite and schist bands in the Krummedal sequence at the mout Krummedal. Moderate folding on gently inclined planes. Section height about 600 m.

Fig. 202. Complex fold interference patterns in banded leucocratic and hornblende gneisses of the Flyverfjord infracrustal complex, Hinks Land.

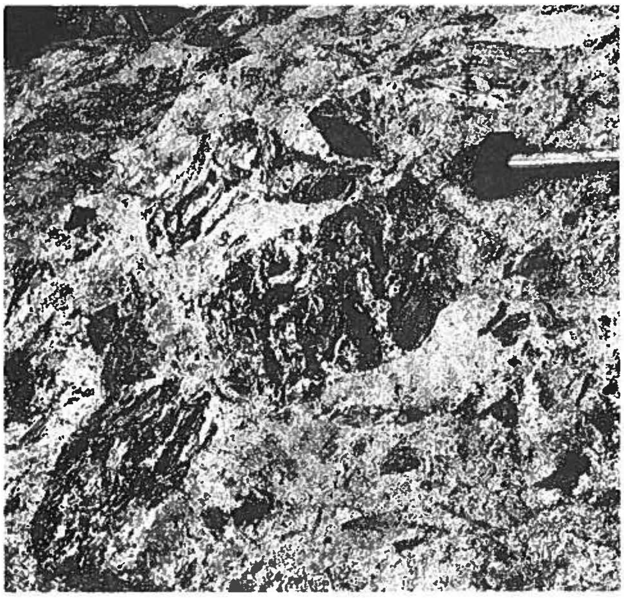
the rusty brown colouration usually changes to a black-grey, and the lithology is generally semi-pelitic with occasional siliceous divisions. The total thickness reaches about 2500 m in these northern areas but no formal subdivision has been attempted (Higgins, 1974). In central and southern parts of the zone a monotonous mica schist development is widespread with occasional psammitic and calc-silicate layers. There are tectonic complications but thicknesses of *c.* 1400 m have been recorded.

Throughout the zone kyanite and garnet are the common metamorphic minerals in the pelitic rocks, occurring as static growths for the most part; staurolite is recorded locally. Augen deformation around the garnet porphyroblasts, retrogressive textures, late static muscovite and new, small garnets represent a late, assumed Caledonian, metamorphic event; muscovite and locally garnet overprint textures in the mylonites associated with the main thrusts. There seems often to be an increase in the main metamorphic grade upwards, pelitic schists becoming more gneissic with increase in feldspar grain size and formation of quartzo-feldspathic layers and lenses.

Fig. 203. Banded gneisses, amphibolites and ultrabasic layers of the Flyverfjord infracrustal complex on the north wall of Flyverfjord. Krummedal sequence rocks occur in the tightly pinched core of the synform near the top of the 2000 m high cliff. The well banded 'conformable' nature of the Flyverfjord infracrustals near the core of the fold is a tectonic modification of more massive gneisses below.

More or less migmatitic developments occur at a high structural level mainly as outliers apparently representing parts of an extensive thrust sheet. They comprise rusty or reddish migmatitic gneiss with thin granitic sheets; locally kyanite and sillimanite are recorded. They resemble most closely parts of the migmatite region to the east from which the postulated thrust sheet may have been derived (Homewood, 1973).

Fig. 204. Migmatite with abundant neosome, closely approaching the migmatite granites in appearence. South Stauning Alper.



The folding of the Krummedal sequence to a large extent involved also modification of the underlying basement (fig. 203). There are at least two phases of tight to isoclinal recumbent folds usually with E–W or NE–SW axial trends. Later more open structures have N–S or NNW-trending axes. Linear structures are dominantly E–W.

A recent Rb-Sr isochron on Krummedal sequence schists of 1162 m.y. (Hansen *et al.*, 1974) is interpreted as the date of the main metamorphic event, and deposition of the sequence is thus inferred as taking place earlier in the Proterozoic. Mineral ages between 406 and 616 m.y. (Larsen, 1969; Hansen *et al.* 1973a, 1974) testify to a significant Caledonian overprinting and up-dating.

Gåsefjord – Stauning Alper migmatite and granite zone

A zone of dominantly migmatitic and granitic rocks can be traced in the inner fjord zone from 70° to 72° 45′ N between, to the west, the Vestfjord – Hinks Land gneiss and schist zone and Gletscherland migmatite complex and, to the east, a variety of sedimentary rocks (fig. 198). The west contact is a major thrust or reverse fault. The east contact with late Palaeozoic and Mesozoic rocks is partly fault modified, and north of 72° N a somewhat irregular contact with the late Precambrian Eleonore Bay

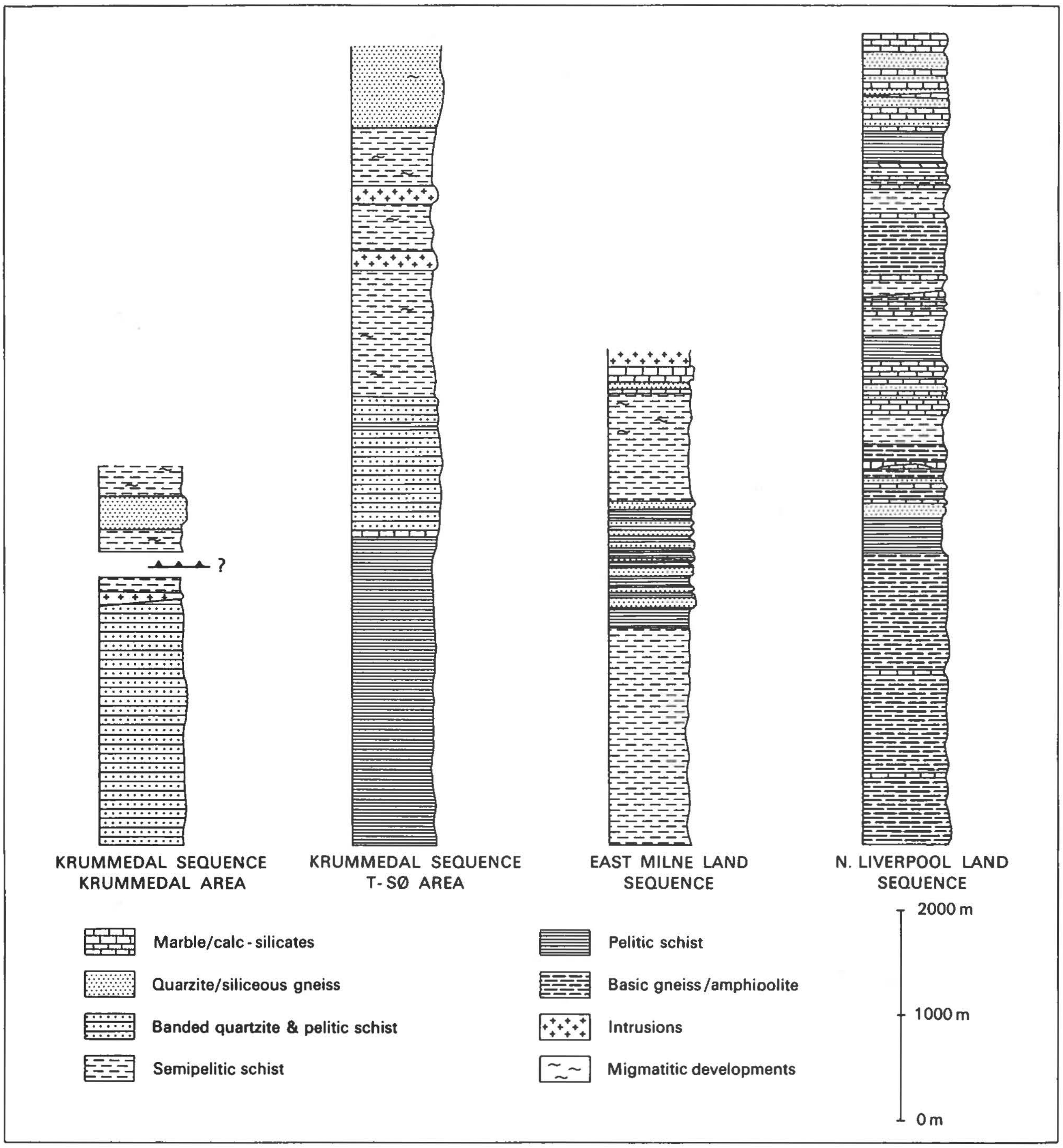


Fig. 205. Schematic development of some of the presumed early Proterozoic supracrustal sequences in the Scoresby Sund region.

Group is partly obscured by granite intrusions as well as faults.

Main rock groups

The dominant rock types are migmatitic gneisses which grade with increasing neosome proportion into migmatite granites (fig. 204). The paleosome proportion is largely of metasedimentary origin, comprising pelitic and quartzitic gneiss. The neosome is a fine to medium-grained, garnet-biotite granite developed as schlieren, thin sheets, or a diffuse network of permeating veins. Some of the migmatites have a regular, banded 'stromatite' structure, others are veined or nebulitic with abundant 'schollen'. Garnet and sillimanite are ubiquitous, and throughout the eastern part of the zone cordierite and locally andalusite occur; the two last named possibly formed at a later metamorphic stage and imply a relatively

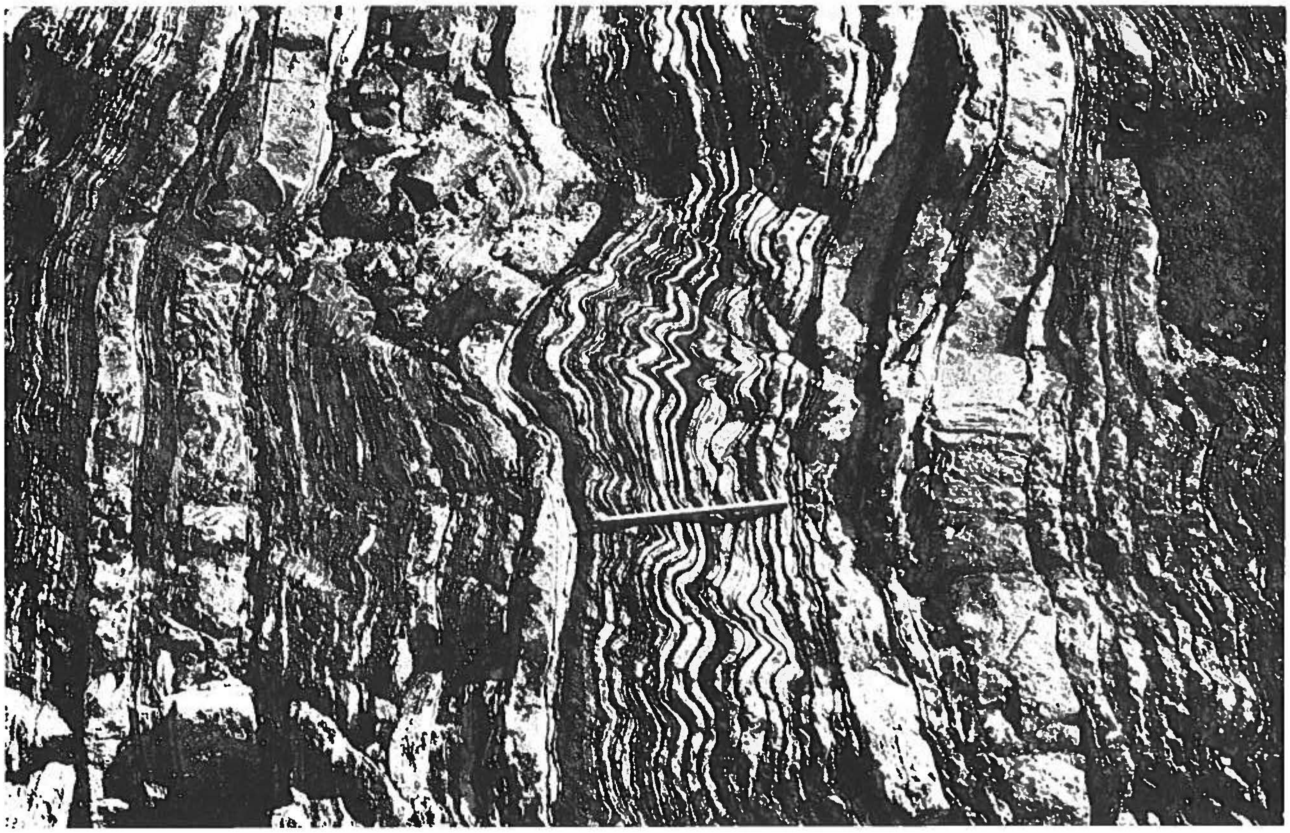


Fig. 206. Finely banded quartzite and mica schist layers in the eastern Milne Land supracrustal sequence.

lower pressure. Granulite facies conditions are reported locally in the eastern areas.

In places sizeable areas of only slightly migmatised metasediments survive in which some primary sequence is traceable. The main areas of these supracrustals occur at or near the west margin of the zone, and an isolated sequence is found in eastern Milne Land. A series of lenses and bands of marbles and calc-silicates is traceable throughout the eastern part of the migmatite zone.

The metasedimentary sequence around the T-Sø area has a preserved thickness of at least 8 km (fig. 205). The main divisions include pelitic to semipelitic gneissic schists, well bedded alternations of reddish weathered quartzites and mica schists, and siliceous gneisses, disrupted at several levels by augen granite sheets. The eastern Milne Land sequence, totalling about 5 km in thickness (fig. 205) includes very well banded units on both major and minor scales (fig. 206). These and other metasedimentary areas in the migmatite and granite zone are now usually compared with the Krummedal supracrustal sequence, though a lateral transition into Eleonore Bay Group sediments has previously been presumed in northern parts of the zone (e. g. Zweifel, 1959; Haller, 1958).

Locally, abundant amphibolite inclusions occur in the migmatites, as in a large area of south-west Milne Land, and locally in parts of Renland and Gåseland. Amphibolites are generally rare as paleosome components and it is likely that they are derived from a characteristic level of the migmatised original sequence, possibly a basement gneiss and amphibolite complex.

Extensive sheets and massive bodies of foliated garnet augen granite are a conspicuous feature of Renland and adjacent areas. They appear to have been emplaced at an early stage of migmatisation at a deep orogenic level (Chadwick, 1971) and became involved in subsequent major isoclinal folding. Some of the sheets reach 1000 m in thickness. The conspicuous feldspar augen reach up to 10 cm across; other minerals present include garnet, biotite and sillimanite. Most bodies are well foliated with a gneissic texture and a prominent, generally E–W, lineation (Chadwick, 1971, 1975).

The so-called migmatite granites occur as small and large bodies, up to 5 by 25 km in outcrop, with diffuse and irregular borders to the gneissic migmatites; characteristically they contain scattered paleosome schollen. They correspond to the older granite generation of the Stauning Alper (Haller,

1958) which is described as arising by *in situ* granitisation and progressive assimilation of gneisses by anatectic processes under high metamorphic temperatures.

There are a number of major dioritic bodies as well as scattered small sheets and dykes. In composition they include diorites *sensu stricto*, quartz diorites, quartz monzonites and adamellites. In Renland a 500 m thick hypersthene monzonite sheet appears to separate two phases of migmatisation (Chadwick, 1975). Major sheet-formed bodies of biotite-hornblende quartz diorite more than 500 m in thickness occur in eastern Milne Land, Danmark Ø and southern Gåseland. Foliation may be conspicuous especially at the margins and mafic diorite inclusions are present in variable concentrations.

Major and minor granitic sheets and plutons occur throughout the migmatite and granite zone featuring very prominently in eastern Milne Land, the Stauning Alper and the northern extreme of the zone. Most are late to post-kinematic intrusions whose composition varies from body to body, and also within single plutons. Porphyritic biotite granites are most widespread and form the major part of many of the larger bodies. Fine-grained, homogeneous biotite granites and leucocratic biotite-muscovite granites are also important. Some bodies have hornblende syenite cores. Sheets of mafic pegmatitic biotite granite, biotite aplite granite and garnet-biotite granite are prominent capping the mountains of Milne Land and Renland; most are clearly discordant, but some have somewhat diffuse boundaries to the migmatites. Biotite and biotite-muscovite granites in the north Stauning Alper and west of Alpefjord which cut or vein the Eleonore Bay Group are described above. A number of the other intrusive bodies within the migmatite and granite zone may be Caledonian, but the age data discussed below show that many are older.

There are at least two phases of recumbent, often isoclinal, folds which may be of nappe-like proportions. They are seen notably in the metasediments and migmatites, and deforming the augen granite sheets. A later phase of more superficial ENE-trending structures is prominent in Milne Land, perhaps corresponding to E–W trending folds in Gåseland. Several large scale major warps in the Stauning Alper with a N–S trend probably correspond to the N–S Caledonian structures recorded north of 72° N (Haller, 1970); (fig. 207). Most faults are more or less N–S trending, while a few are E–W. In age they appear to relate partly to Caledonian, partly to post-Caledonian time. The major thrust movements are presumed to be Caledonian.

Isotopic ages

The majority of isotopic ages now available from the migmatite and granite zone are Rb-Sr and K-Ar mineral ages on plutonic bodies; there are also a few zircon and monazite ages (Larsen, 1969; Hansen & Steiger, 1971; Hansen *et al.*, 1972, 1973a,b, 1974; Steiger & Henriksen, 1972; Oberli & Steiger, 1973). Zircon ages on two augen granite bodies, one in Øfjord and one in Nordvestfjord, both give 950 m.y.,

Fig. 207. Major overturned folding in migmatites at the right of the photograph capped and cut by a late-kinematic leucocratic granite; north-west Milne Land in the Gåsefjord – Stauning Alper migmatite and granite zone. On the far side of Øfjord, on the left of the photograph, north–south trending Caledonian folding is thought responsible for the dome-like structure occupied by one of the synkinematic augen granites. Plateau altitudes reach 1900 m.

which implies that the closely related migmatisation and deformation episodes may relate to a pre-Caledonian orogenic episode. A preliminary 4-point isochron from a granodiorite in the northern Bjørneøer of 1060 m.y. and the spread of Rb-Sr mineral ages in the Stauning Alper from *c.* 1150 to *c.* 450 m.y. strongly support this view, though the younger ages presumably indicate Caledonian up-dating. The east Milne Land plutons gave unexpectedly old ages (1490 & 1315 m.y.) and reinforce the impression that the migmatite and granite zone is essentially a product of one or more Precambrian orogenic episodes. The youngest pegmatites give 380 m.y., a clear late Caledonian age. There remain diverse opinions as to the manner in which these mainly mineral ages should be interpreted, and some workers view the older ages as due to contamination and retain the more traditional viewpoint that the Caledonian orogenic episode is largely responsible for the character of the region.

Summary

Based on present knowledge the following somewhat speculative sequence of events can be suggested for the Gåsefjord – Stauning Alper migmatite and granite zone:

(1) Formation of an amphibolite rich gneissic basement, known only at scattered localities at the present level of exposure. This basement may be equivalent to the Flyverfjord infracrustal complex.

(2) Deposition of a very thick supracrustal succession widely represented as paleosome inclusions in the migmatites, and as high grade less migmatised sequences in some western areas of the zone and possibly eastern Milne Land. The succession probably corresponds to the Krummedal supracrustal sequence.

(3) First phase of migmatisation and granitisation, emplacement of large augen granite sheets, formation of major recumbent folds and regional sillimanite grade metamorphism. The ages of 950 m.y. for the augen granites probably give a minimum age for these events.

(4) Emplacement of a number of intermediate plutonic bodies, and a related high grade metamorphism reaching granulite facies conditions locally in the east.

(5) A second phase of migmatisation and granisation recognisable only in the eastern part of the complex. It may have been accompanied by the low pressure type of amphibolite facies regional metamorphism.

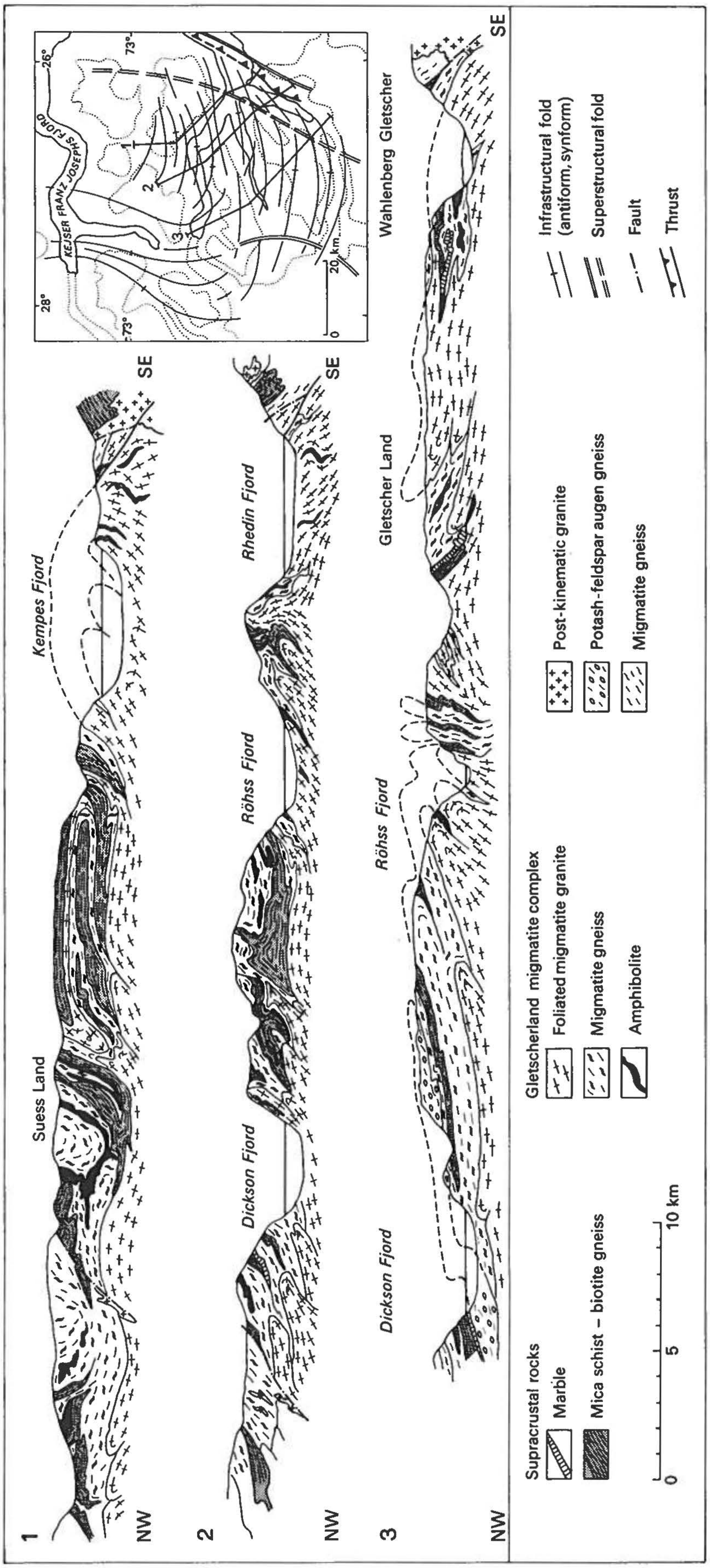
(6) Emplacement of late to post-kinematic granites, and low grade metamorphism retrogressing and up-dating older rocks to give mixed mineral ages as well as Caledonian ages in the range 400–450 m.y.

Gletscherland migmatite complex

A complex of migmatitic banded and veined gneisses, and foliated and nebulitic migmatitic granites occupies the southern part of Suess Land, Gletscherland and continues into Nathorst Land (figs. 197, 199). These mainly granitic to granodioritic rocks contain abundant amphibolite and mafic hornblende gneiss bands, and in some areas folded discordant amphibolite dykes occur. Characteristic associations of

Fig. 208. The east wall of the innermost branch of Nordvestfjord. The conspicuous marble and amphibolite bands are typical components of the Gletscherland migmatite complex. Very similar rock types of the Charcot Land window occur in the opposite fjord wall. Profile height *c.* 1700 m.

Fig. 209. Profiles through the Gletscherland migmatite complex. Redrawn after Haller (1955, 1970).



marbles and amphibolites in units often several hundred metres thick are common (fig. 208). Mica schists, biotite gneisses and siliceous paragneisses are also found. Haller (1955) distinguished this unit as the Gletscherland migmatite complex.

To the east the complex is bounded by a major N–S to NNE–SSW trending thrust and fault zone, and to the north and west it is separated from the adjacent complexes by conformable zones of supracrustal rocks. The main structures within the complex are in the northern part a system of E–W trending nappe-like, southward-facing folds, and in the south a cluster of E–W trending overturned tight to recumbent folds (fig. 209). The south margin of the complex is an arbitrary line placed roughly at the limit of the marble and amphibolite occurrences, though in the south-west very similar units occur in the presumed foreland window of Charcot Land. These two regions are separated by a fjord arm a few kilometres wide (fig. 208) and their relationship is uncertain since the northward continuation of the Hinks Land thrust is unknown, but may pass between them.

Discordant amphibolite dykes characterise the northern part of the Flyverfjord infracrustal complex and are also present in the Gletscherland migmatite complex. At the head of Forsblads Fjord an E–W trending swarm of biotite-hornblende dykes cutting the folded gneisses have been described as 'older lamprophyres' (Haller, 1958, p. 102–110), and have been interpreted as late kinematic with respect to the Caledonian orogeny. However, the similar dykes in the Flyverfjord infracrustal complex are regarded as emplaced post-kinematic to an Archaean orogenic period, and one has given a K-Ar date of 2525 m.y.

In the Gletscherland migmatite complex a few open N–S trending structures are superimposed on the older dominant E–W fold pattern and create a row of axial depressions and culminations. They are conformable with the general N–S trends of the Caledonian folds in the non-metamorphic supracrustals which sweep around the northern end of the central metamorphic complex, and are presumed like them to be Caledonian.

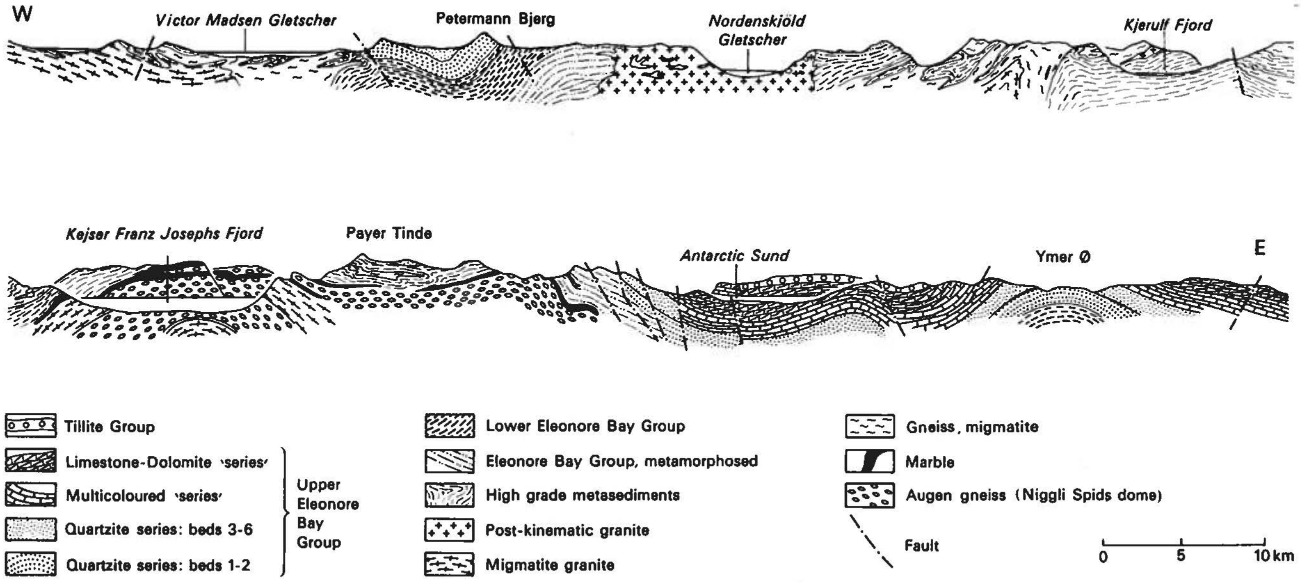
If the similarities with either the Charcot Land region or the Flyverfjord infracrustal complex of the Vestfjord – Hinks Land region are a valid basis for correlation, the older E–W fold pattern might be viewed as pre-Caledonian. Haller (1971) has described these as Caledonian but with their direction inherited from a pre-Caledonian basement.

Niggli Spids migmatite dome

A dome-like migmatite complex occurs in the region of Niggli Spids at the entrance to Isfjord (figs. 197, 199, 210). It is formed by a culmination of two adjacent antiforms and a tightly compressed synform, and is capped by supracrustal rocks in the form of a nearly continuous marble horizon with overlying kyanite-garnet mica schists (fig. 211).

The core of the dome comprises 800 m of homogeneous, leucocratic adamellitic granite with bands and schlieren of gneisses. This is overlain by a 50 m band of amphibolite, hornblendite and biotite-hornblende gneiss, interpreted as a basic front (Haller, 1953). The main higher rock units of the dome

Fig. 210. East–west section through the northern part of the central metamorphic complex and the bordering Eleonore Bay Group sediments. Redrawn after Haller (1971).



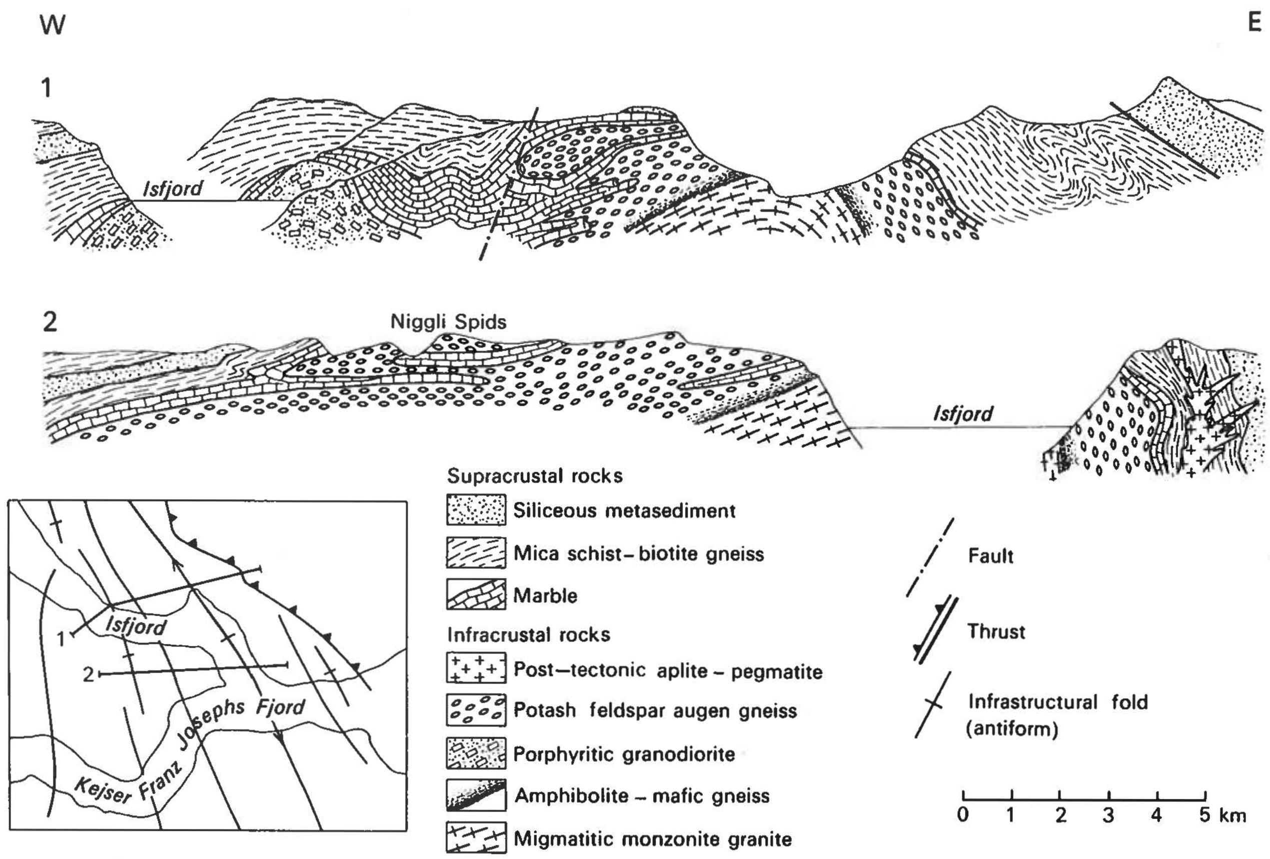


Fig. 211. Two east–west profiles through the Niggli Spids migmatite dome. Redrawn after Haller (1953, 1970).

are a thick succession of K-feldspar augen gneisses, generally schistose in character and including melanocratic and leucocratic types. Idioblastic feldspars several centimetres across appear to have grown under static conditions after deformation of the groundmass.

At Kap Madeleine in the core of the western of the two antiforms an intrusive complex comprising mainly porphyritic granodiorite, with lenses of hornblende-biotite schist, is found. The granodiorite is considered to be of synkinematic replacive origin; it is dissected by post-tectonic pegmatites and aplites.

The augen gneisses making up the Niggli Spids migmatite dome form a series of recumbent folds, some outlined by the marble horizon. The cores of individual folds are massive and coarse-grained, but towards the contacts they become more schistose and porphyroblasts are of smaller size.

The supracrustal rocks which form the enveloping cover were at first assumed to represent the upper part of the lower Eleonore Bay Group (Haller, 1953, p. 28), but later were thought more likely to represent the 'Basal series' (Haller, 1971, p. 86). A third alternative is that they might be equivalent to part of the Krummedal supracrustal sequence (described above), to which they have lithological similarities.

The only radiometric age of 402 m.y. (K-Ar phlogopite: Haller & Kulp, 1962) on a hornblende-mica schist can be interpreted as representing the withdrawal of the Caledonian thermal effect.

Hagar migmatite sheet and associated metasediments

The Hagar migmatite sheet and an interfolded thick sequence of sedimentary rocks occupy a zone through the heads of Kejser Franz Josephs Fjord and Isfjord, and bounded to the east by the Niggli Spids dome and the Gletscherland migmatite complex (figs 197, 199).

The Hagar migmatite sheet is deformed into a series of NNE-trending recumbent and nappe-like structures, which to the south-east are superimposed on the E–W folds characterising the Gletscherland migmatite complex. In the southern part of the sheet a conjugate set of recumbent structures occurs, closing to both east and west with a central root zone of steeply inclined folds; towards the north these structures have a general easterly vergence. The migmatites with a thick envelope of mica schists

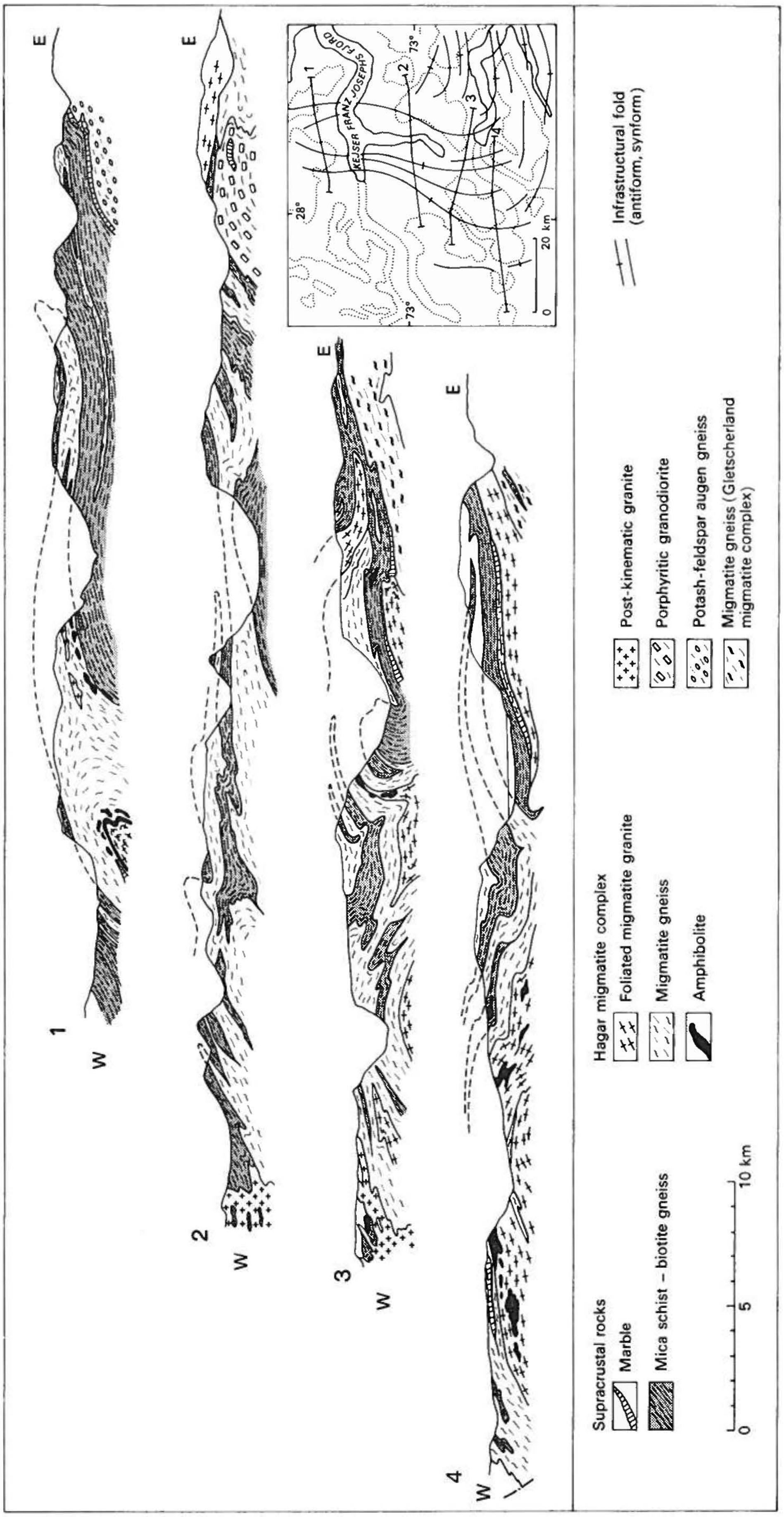


Fig. 212. East–west profiles through the Hagar migmatite complex and the associated, interfolded supracrustal rocks. Redrawn after Haller (1955, 1970).

form a composite nappe-like structure with a 20 km eastward overlap (fig. 212).

The migmatite sheet is made up of leucocratic banded and veined gneisses, and foliated migmatite granites with occasional amphibolite bands. Tightly infolded bands of mica schists and biotite gneisses are related to the envelope of supracrustal rocks.

The main areas of supracrustals occur around innermost Kejser Franz Josephs Fjord and inner Isfjord. They consist of a thick sequence of mica schists and siliceous schists, often well banded and having a rusty brown weathering; they locally grade into gneissose rock types. Odell (1944) and Wenk & Haller (1953) both describe a west to east cross-section from the non-metamorphic Petermann succession (Eleonore Bay Group, see fig. 177) through the metasedimentary sequence to the core of the Hagar migmatite sheet. There is a progressive increase in metamorphic grade eastwards through a chlorite zone, biotite zone and garnet zone, to a zone where the mica schists contain staurolite and kyanite; zone boundaries cut obliquely through the sequence and clearly post-date the fold formation.

North of inner Kejser Franz Josephs Fjord supracrustals on the reverse limb of the nappe-like structure of the Hagar migmatite sheet exhibit an upwards increase in metamorphic grade, from garnet phyllites at sea level to kyanite mica schists adjacent to the migmatite sheet. This type of feature led Haller to suggest that metamorphism was generated as a metamorphic aureole surrounding the migmatite nappe sheet (Haller, 1971, p. 191). Odell (1944, p. 242) described the metamorphic conditions as being the products of regional metamorphism.

Although they are usually regarded as of Caledonian generation, the lithological and structural characters of the Hagar migmatite sheet and surrounding metasediments have marked similarities with those of the pre-Caledonian Vestfjord – Hinks Land gneiss and schist zone, described in an earlier section.

The gradational transition from the Petermann succession into the high grade metasediments strongly suggests the view of Caledonian deformation and metamorphism. However, there is at least a possibility that the critical section is a composite one, and that the non-metamorphic Petermann succession rests disconformably on an older, already metamorphosed supracrustal sequence, which in turn forms an envelope around a still older migmatite gneiss complex. A relatively weak, Caledonian metamorphism and folding may be superimposed.

Isfjord – Ole Rømer Land supracrustal region

A broad region of generally low-metamorphic supracrustal rocks extends from the vicinity of Isfjord to Ole Rømer Land, forming the northern boundary zone of the central metamorphic complex (figs 197, 199). At two localities the metasediments are overlain by non-metamorphic or slightly metamorphosed recognisable Eleonore Bay Group rocks. Haller (1953) distinguished in the metasediments a lower unit (the Maalebjerg series and the Marble series) which he correlated with the 'Basal series', and a higher unit (the Eremitdal series) which he considered equivalent to the upper part of the lower Eleonore Bay Group (fig. 177).

The lower unit is exposed only around the head of Isfjord. It comprises *c.* 800 m of sericite-chlorite schists and augen gneisses, overlain by 200 m of white quartzites and up to 400 m of marbles and calcareous-chlorite schists. The upper unit, the Eremitdal series, is widespread throughout the region and consists of 1400–3000 m of banded pelitic and psammitic metasediments; there are considerable lateral facies variations. It is overlain by the low grade metamorphic equivalents of the lowest part of the Quartzite 'series' of the Eleonore Bay Group. Eastwards and westwards contacts with non-metamorphic Eleonore Bay Group rocks are gradational.

A few inliers of migmatitic rocks beneath the metasediments are found in deep valley sections north of Isfjord, and interfolded migmatites, mica schists and paragneisses occur in the nunatak zone even further north. These fragmentary exposures of infracrustal rocks may be compared to the more extensive gneissic complexes further south.

NNW-trending major open folds are dominant in the region; the axial planes are generally steep or vertical and the fold axes have very gentle plunges. A younger coaxial set of mesoscopic overturned to recumbent folds deforms the sediments and also a series of younger granitic intrusions. The granites are sheet-formed and Haller views them as syntectonic, i. e. emplaced simultaneously with the younger phase of deformation. A syntectonic origin is also suggested for a number of sheet-formed granite intrusions emplaced into local thrust zones in the northern part of Andrée Land. This granitic activity has been correlated with supposed early Devonian late orogenic plutons elsewhere, and the younger fold set affecting them is thus regarded as part of Haller's (1970) 'late Caledonian spasms'.

A zone of mainly sheet-formed, occasionally stock-shaped, late to post-kinematic granite intrusions occurs in southern Andrée Land, immediately north of the prominent NNW-trending thrust zone (Haller, 1953). Contacts with the adjacent schists and paragneisses are clearly discordant. The main rock type is a white, homogeneous two mica granite.

The post-tectonic granite intrusions in Bartholin Land were emplaced into a supracrustal sequence of mainly mica schists and biotite gneisses, with associated minor occurrences of migmatite gneiss. The northern body is an irregularly shaped complex sheet, while the southern body has the form of a NW–SE trending double cupola more than 30 km in length (Haller, 1971; Koch & Haller, 1971).

Numerous local thrusts with NW–SE trends accompanied the younger folding. A major thrust-fault (the Junction Dal fault) is traceable for more than 60 km from Kejser Franz Josephs Fjord to north of Gerard de Geer Gletscher. Pronounced mylonitisation and shearing are associated with this NW-trending prominent feature which forms an important boundary between low metamorphic terrain to the north, and infracrustals and high metamorphic supracrustals to the south. It may be continued further south as the N–S fault-thrust line bounding the east side of the Niggli Spids migmatite dome and the Gletscherland migmatite complex.

Eastern complexes

The eastern complexes comprise the Liverpool Land region and the Grandjean Fjord mountain belt which are widely separated and exhibit no features in common that can be correlated.

Liverpool Land

Liverpool Land consists of a strongly deformed crystalline complex, including gneisses, migmatites, marbles and other metasediments, and granitic and amphibolitic rocks of igneous origin. A series of synkinematic to post-kinematic igneous rocks is abundantly developed.

The crystalline complex was initially regarded as Archaean. Koch (1929), however, suggested the region represented a deep-seated level of the Caledonian fold belt, a view supported by Kranck (1935). Following recent survey mapping (fig. 213) a programme of isotopic dating has been commenced; provisional results suggest the recrystallisation of at least a part of the gneiss complexes was a Precambrian event (1183 m.y. and 1124 m.y.: Hansen *et al.*, 1973b), though one granite gives a Caledonian age (434 m.y.: Hansen & Steiger, 1971).

Metamorphic rocks

In south Liverpool Land four subdivisions of the gneisses are recognised (Coe & Cheeney, 1972). Foliation dips are low and generally northwards so that the lowest structural group occurs in the southeast. There are only a few large folds which produce broad basin and swell flexures. The three lower groups seem largely to be derived from metasediments, and marbles are locally conspicuous. The highest group is a granodioritic gneiss which splits the metasedimentary gneisses locally, and also has transitional relationships with the granodiorite intrusion on the east coast.

In east central Liverpool Land a sequence of coarsely banded gneisses occurs forming a broad domal structure centred on Kap Greg. It is cut off northwards by a thrust. The gneisses are mainly of granitic composition, but with psammitic and calcareous horizons, and numerous amphibolite sheets up to 150 m thick. The sequence is at least 2500 m thick.

North Liverpool Land comprises a thick metasedimentary sequence possibly approaching 11 000 m in total (fig. 205), but duplication and inversion of parts of the succession are likely to have occurred. The strike is mainly north–south with moderate to high dips. The lower group of monotonous, hornblende-biotite gneisses outcropping in the east is succeeded by a very varied group of metasedimentary rocks including quartzites, rusty mica schists and thick marble units. Towards the south and west the sequence is intensely migmatised; marble, amphibolite and banded quartzite inclusions locally survive in the migmatites.

The relationships between these three supracrustal and gneiss areas is uncertain, and there are no obvious correlations with metasedimentary sequences elsewhere. Kyanite and garnet occur in schists in the southern areas, and sillimanite is abundant in the north.

Plutonic rocks

The intrusive rocks post-dating the formation of the gneiss complexes can be divided on the basis of age into four groups (Coe & Cheeney, 1972).

The oldest group is represented by an inhomogeneous hornblende granodiorite around Åge Nielsen Gletscher. The next oldest group is represented by three intrusions, all of them cross-cutting the gneisses: the big feldspar granite at Kap Jones, the Sandbach Halvø quartz monzonite and the Hodal–Storefjord quartz monzodiorite. A younger group comprises the often porphyritic hornblende-biotite granite of Storefjord. The largest and youngest of the intrusions is

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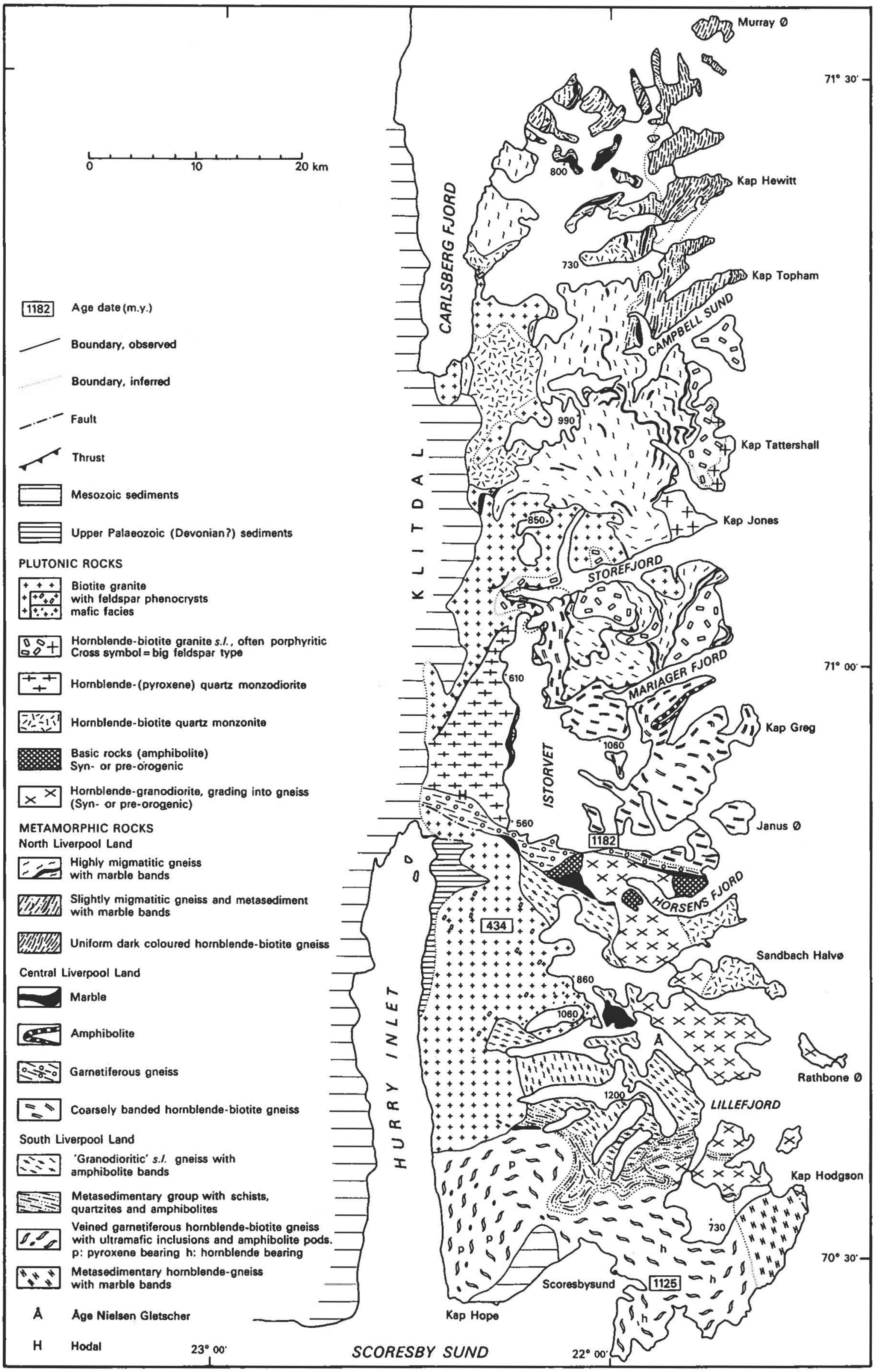
Fig. 213. Geological map of Liverpool Land. After Coe & Cheeney (1972).


0
10
20 km
1182 Age date (m.y.)
Boundary, observed
Boundary, inferred
Fault
Thrust
Mesozoic sediments
Upper Palaeozoic (Devonian?) sediments
PLUTONIC ROCKS
Biotite granite
with feldspar phenocrysts
mafic facies
Hornblende-biotite granite s.l., often porphyritic
Cross symbol = big feldspar type
Hornblende-(pyroxene) quartz monzodiorite
Hornblende-biotite quartz monzonite
Basic rocks (amphibolite)
Syn- or pre-orogenic
Hornblende-granodiorite, grading into gneiss
(Syn- or pre-orogenic)
METAMORPHIC ROCKS
North Liverpool Land
Highly migmatitic gneiss
with marble bands
Slightly migmatitic gneiss and metasediment
with marble bands
Uniform dark coloured hornblende-biotite gneiss
Central Liverpool Land
Marble
Amphibolite
Garnetiferous gneiss
Coarsely banded hornblende-biotite gneiss
South Liverpool Land
'Granodioritic' s.l. gneiss with
amphibolite bands
Metasedimentary group with schists,
quartzites and amphibolites
Veined garnetiferous hornblende-biotite gneiss
with ultramafic inclusions and amphibolite pods.
p: pyroxene bearing h: hornblende bearing
Metasedimentary hornblende-gneiss
with marble bands
Å Åge Nielsen Gletscher
H Hodal
Murray Ø
71° 30'
Kap Hewitt
800
CARLSBERG FJORD
730
Kap Topham
CAMPBELL SUND
990
Kap Tattershall
KLITDAL
850
Kap Jones
STOREFJORD
71° 00'
610
MARIAGER FJORD
Kap Greg
1060
ISTORVET
Janus Ø
560
1182
HORSENS FJORD
434
Sandbach Halvø
860
1060
A
HURRY INLET
Rathbone Ø
1200
LILLEFJORD
Kap Hodgson
730
70° 30'
Scoresbysund
1125
Kap Hope
23° 00'
SCORESBY SUND
22° 00'

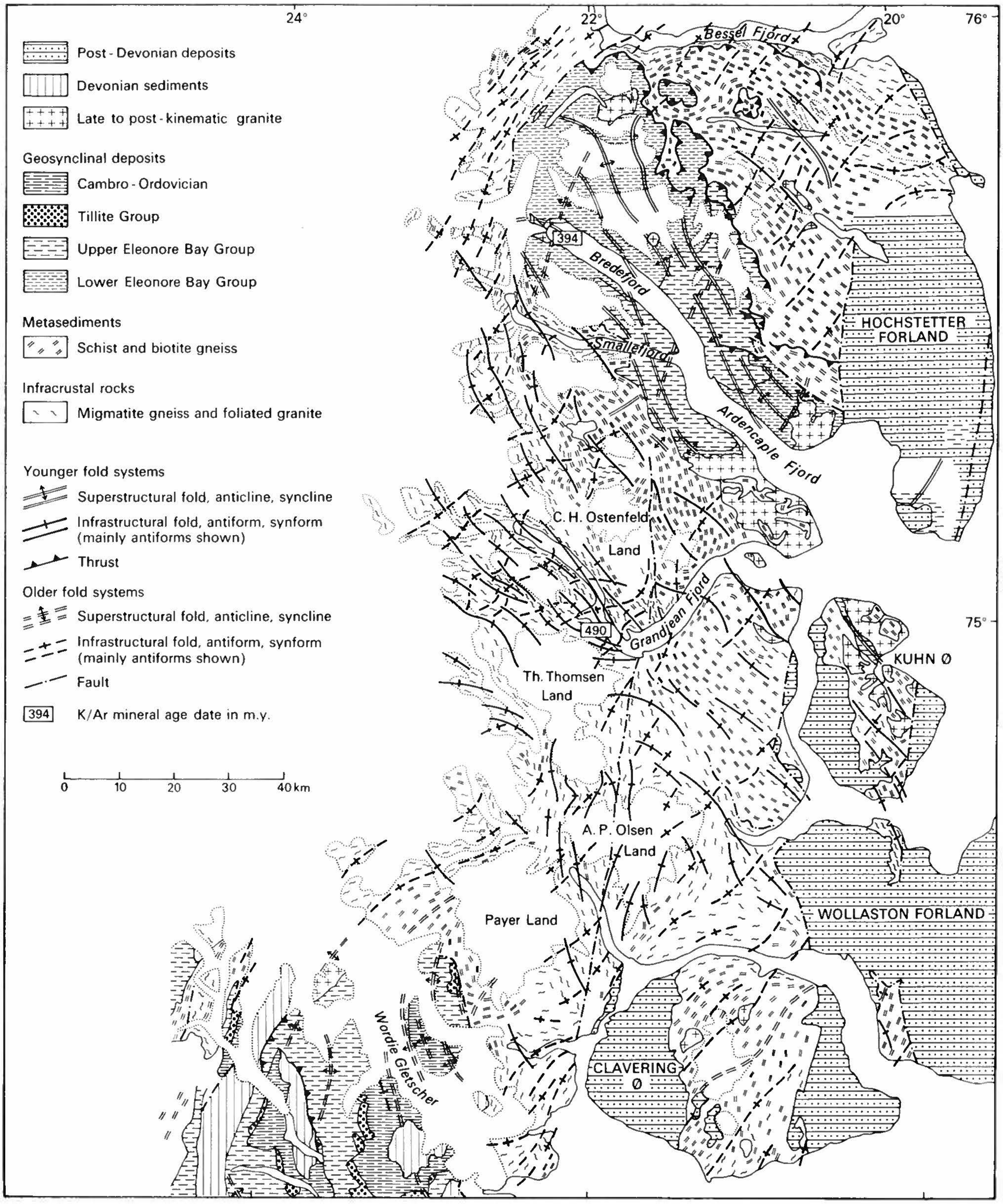


Fig. 214. Geological map of the Grandjean Fjord metamorphic complex (74°–76°N). After Haller (1970, 1971).

the Hurry Inlet granite, a clearly post-tectonic body which has given a Caledonian age (fig. 213).

Grandjean Fjord metamorphic complex

The region between latitudes 74° and 76° N has been termed the Grandjean Fjord metamorphic complex. It comprises a metamorphic complex of infracrustal and supracrustal rocks, occurring on both sides of the graben structure centred on Ardencaple Fjord and Bredefjord, and which contains thick Eleonore Bay Group sequences (fig. 214).

The infracrustal rocks of the metamorphic complex mainly occur in the inland region between Payer Land and Smallefjord, and south and west of the graben. They include migmatitic gneisses and migmatitic foliated granites containing bands of amphibolite, schists and various gneisses. The metamorphosed supracrustals occur mainly in the outer fjord zone between Clavering Ø and Bessel Fjord and comprise garnet mica schists, biotite paragneisses and various siliceous gneisses and schists.

In the southern part of the Grandjean Fjord metamorphic complex both Leedal (1952) and Mittelholzer (1941) distinguished an older pre-Caledonian basement and a younger Caledonian metamorphic complex. The basement is described as largely hornblende and hornblende-biotite orthogneisses, amphibolites, and subordinate metasediments. The younger complex consists of psammitic and pelitic schists, with some calcareous schists and limestones.

The various metamorphosed supracrustals have all been interpreted as equivalents of the Eleonore Bay Group sequence, largely on grounds of lithological similarity as no transition can be demonstrated. The contacts separating the non-metamorphosed sediments of the graben from the metamorphosed rocks outside the graben are entirely tectonic. It is possible that the assumed correlation is correct in part, but it is also possible that some supracrustals are of greater antiquity and were metamorphosed in pre-Caledonian time. Descriptions of the sequence in some areas suggest a similarity to the Krummedal supracrustal sequence of the Vestfjord – Hinks Land gneiss and schist zone (70°–72° N; fig. 198).

Within the Grandjean Fjord metamorphic complex Haller (1970, 1971) distinguished an older set of NNE-trending folds and a younger NNW set. The former are referred to the 'Caledonian main orogeny' and the latter to the 'late Caledonian spasms', because of their relationship to the non-metamorphic Eleonore Bay Group sequence of the Ardencaple – Bredefjord graben. The border zone between sediments and crystalline rocks is towards the north-east often formed by minor thrusts on which north-east movements of 5–10 km are recorded.

The age of deformation of the sediments in the graben is stratigraphically limited by the youngest units represented, which are referred to the Upper Eleonore Bay Group (fig. 177), and by the intrusion of post-tectonic granites which have yielded a K-Ar age of 394 m.y. (Haller & Kulp, 1962); the latter indicates a minimum age near the Silurian –Devonian boundary. Both sets of folds in the sediments of the graben must therefore be considered Caledonian, but their distinction as 'main orogenic' and 'late orogenic' cannot be easily verified.

Two fold sets in the adjacent metamorphic complex have trends parallel to those in the graben, and have been correlated by Haller, the implication being that they are Caledonian.

In the metamorphic complex the interference of younger NW folds with the older NNE structures is most intense in the inner Grandjean Fjord area (Haller, 1956b, 1970, 1971). Here significant migmatisation was associated with both phases. The NW system has been traced through much of the metamorphic complex between 74°–75° N, declining in intensity on either side of Grandjean Fjord. They have not been found in the inner nunatak zone north-west of Bredefjord, and the western limit of the NW structures is apparently marked by a prominent NNE-trending lineament traceable along the margin of the Inland Ice from latitudes 74° to 77° N.

Migmatisation was mainly concentrated in the west part of the region between Clavering Ø and Smallefjord. The supracrustal schists and gneisses are pervaded and injected by granitic material and have lateral transitions to coarsely crystalline migmatitic gneisses. Leedal (1952) records sillimanite in the migmatitic areas and almandine in non-migmatitic schist zones.

In the Grandjean Fjord metamorphic complex (74°–76° N) the ages of the rock units and structures of the fold belt have been deduced from a number of assumed lithological and structural correlations. A vital factor in these interpretations is the assumption that the metamorphosed supracrustals are transformed Eleonore Bay Group rocks. Definitive evidence for or against this assumption is lacking at present. The K-Ar age of 490 m.y. from a migmatite in central Grandjean Fjord (Haller & Kulp, 1962) probably does not date a late Caledonian migmatite event, but seems more likely to represent a Caledonian partial up-dating of an older rock.

Northern complexes

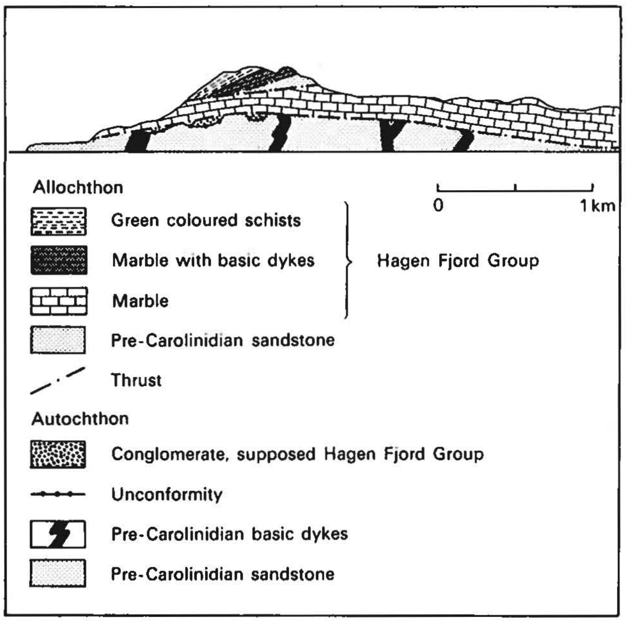
The metamorphic complexes lying north of latitude 76° N can be conveniently divided on a geographical basis into the Dronning Louise Land region and the Bessel Fjord – Ingolf Fjord region. Both regions have a composite development and preserve traces of at least three orogenic episodes. An Archaean or early Proterozoic age is assumed for the crystalline rocks of western Dronning Louise Land, which represent a foreland to the East Greenland fold belt, and furthermore relic basement areas of probably similar antiquity occur within the fold belt. The Carolinidian orogenic complex can be traced throughout the fold belt from 76° to 81° N, and represents a supposed middle Proterozoic sequence of events which are in places superimposed on the earlier basement. The youngest orogenic events are Caledonian, and are represented by folding, partial reactivation of the earlier rocks and development of prominent westward directed thrusts.

It should be recorded that the region north of 76° N is only sketchily known and the present geological status should be viewed with reservations.

Carolinidian orogenic complex

The establishment of the Carolinidian orogenic episode and a pre-Carolinidian sedimentary sequence in North-East Greenland (Haller, 1961) is based on stratigraphical observations at two key localities, and aerial observations. The sedimentary sequence is of geosynclinal proportions where preserved in the Caledonian fold belt, and is correlated with much thinner sequences in the platform area to the west.

Fig. 215. Profile of Marmorvigen (80°10'N) showing unconformity between pre-Carolinidian sandstone and basic dyke complex and conglomerate lenses of presumed Hagen Fjord Group beneath the thrust units. Modified after Fränkl (1954).



Sediments and intrusions

West of Kronprins Christian Land a platform sequence of unfolded psammitic rocks invaded by swarms of Precambrian dolerite dykes and sills occurs; they have been described as the Norsemandal Sandstone (Adams & Cowie, 1953, p. 9) and the Inuiteq Sø Formation (Jepsen, 1971, p. 26). At both type localities uppermost Precambrian sediments (Dawes, this volume) rest with erosional unconformity on the psammites. Fränkl (1954, p. 56) correlated the psammites and sills of the foreland with a similar, folded and weakly metamorphosed sequence inside the north part of the Caledonian fold belt. At Marmorvigen he describes a section in which psammites with dykes have been subjected to certain movements (p. 72) and overlain unconformably by pockets of conglomerate and younger thrust rocks (fig. 215); this inconclusive observation is taken as evidence of an episode of deformation and erosion prior to renewed sedimentation (Haller, 1961).

In western Dronning Louise Land (77° N) a sequence of up to 510 m of non-metamorphosed psammitic rocks cut by dolerite dykes has been described by Peacock (1956, 1958) as the Trekant 'series'. This series rests unconformably on gneissic basement (fig. 216) and is almost flat-lying in the south but folded in the north. The Zebra 'series', a younger 100 m thick quartzitic sequence, overlies the Trekant 'series' unconformably or disconformably; a deformational episode is envisaged separating deposition of the two series. On lithological grounds the Trekant 'series' is correlated with the Norsemandal Sandstone and Inuiteq Sø Formation (Haller, 1971; Jepsen, 1971), whereas the Zebra 'series' is considered representative of late Precambrian sedimentation.

The descriptions of Marmorvigen and western Dronning Louise Land are the only published evidence for the existence of an older sedimentary sequence subjected to Carolinidian deformation, prior to deposition of a younger sedimentary sequence.

Although ground control is limited basic dykes and sills seem to be a ubiquitous feature of both foreland and geosynclinal pre-Carolinidian sediments, and the characteristic association of sandstones and dykes can be interpreted with some degree of confidence from the air.

The supposed pre-Carolinidian sediments, inside

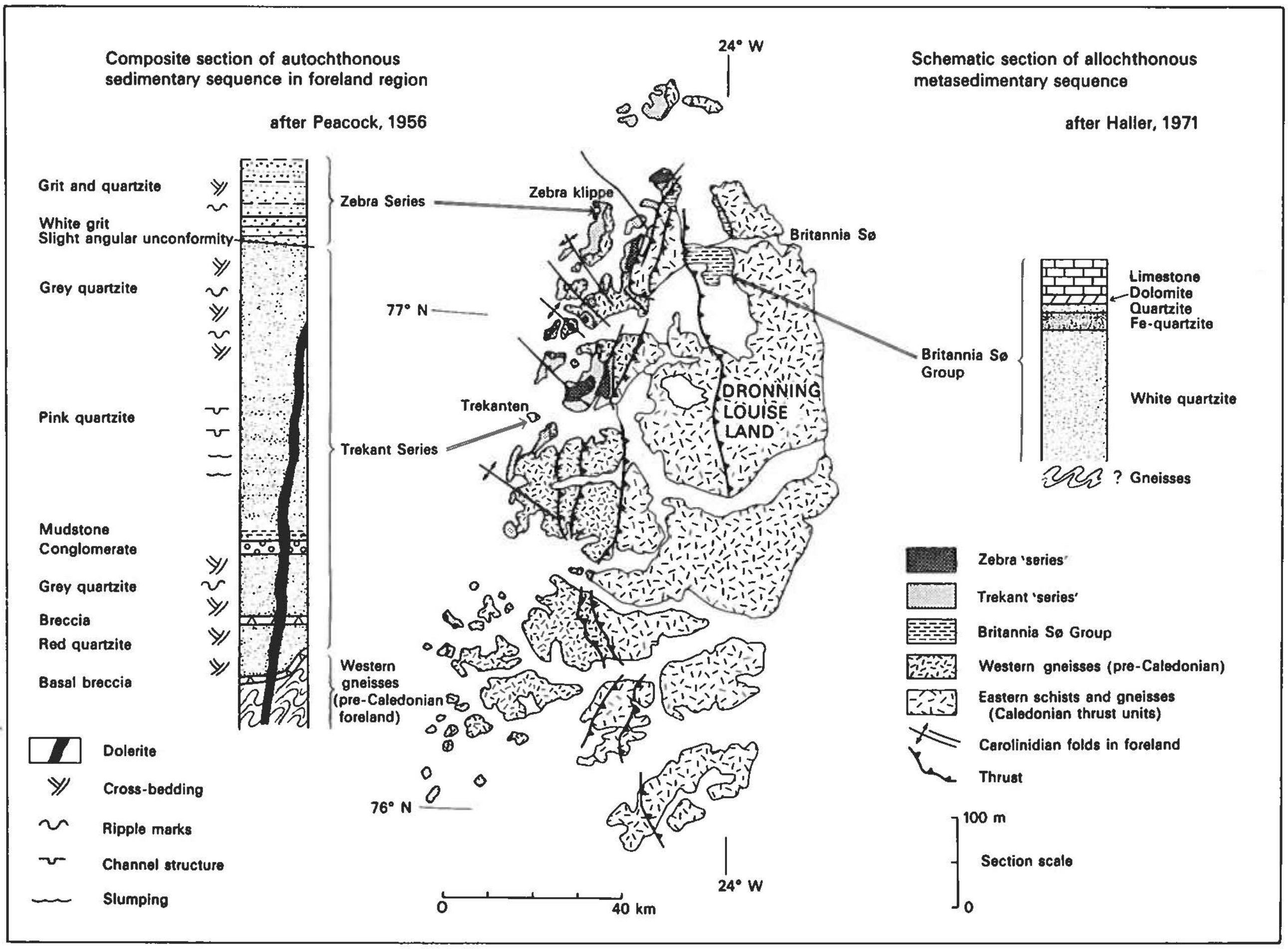


Fig. 216. The sedimentary developments of Dronning Louise Land.

and outside the fold belt, have been collectively grouped and described as the 'Thule Group' (Fränkl, 1954; Haller, 1971). However, in this volume the name 'Thule Group' is restricted to the clastic platform sequence outcropping at Thule in North-West Greenland (Dawes, this volume).

The geosynclinal pre-Carolinidian sequence outcrops mainly in the northern part of the fold belt in a NNE-trending zone between Caledonian nappes to the west, and gneisses and post-Caledonian sediments to the east. The bulk of the pre-Carolinidian sediments are considered autochthonous-parautochthonous with respect to the Caledonian structures (Fränkl, 1955). According to Haller (1971) the sequence comprises: basal quartzite–limestone, 200–300 m; semipelites, 2000–3000 m; and psammites, 3000 m. Two generations of basic dykes and sills are widespread, one prior and one subsequent to Carolinidian deformation.

Basal quartzite–limestone

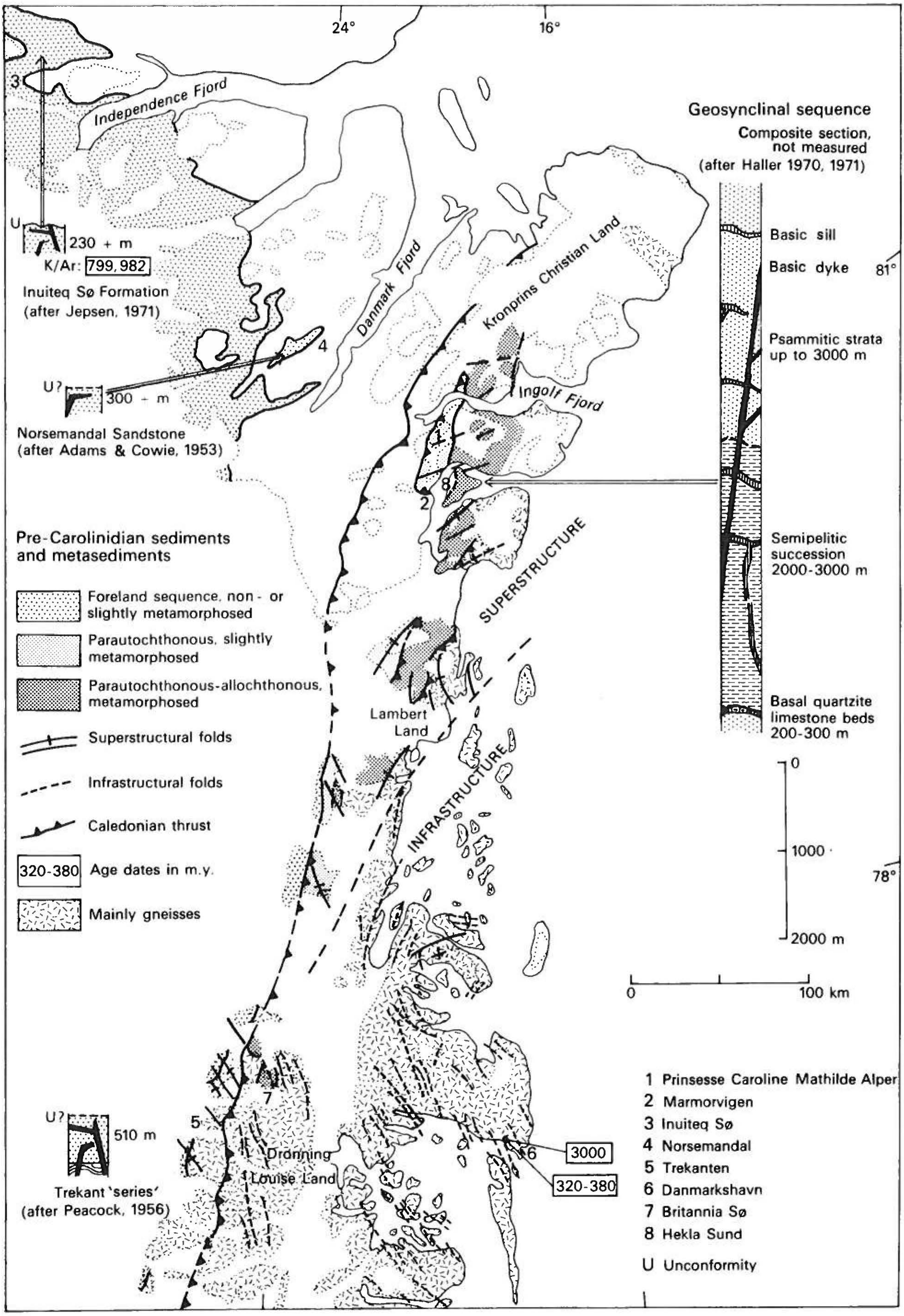
In northern Dronning Louise Land Peacock (1956, 1958) distinguished the Britannia Sø Group (fig. 216), a sequence of metasediments folded together with the surrounding gneisses; the stratigraphic relations to the gneisses are unknown. Peacock compared the Britannia Sø Group to the Zebra 'series', whereas Haller (1971) considered it to be related to the older Trekant 'series'. According to Haller the association of quartzites and marbles, characteristic of the Britannia Sø Group, is widely distributed between Dronning Louise Land (76°30′ N) and Kronprins Christian Land (81° N) (fig. 217), and it is considered that pre-Carolinidian sedimentation "began with a limestone–(dolomite)–quartzite association, showing the characteristics of a normal foreland sequence (miogeosynclinal)" (Haller, 1971, p. 56).

Semipelites

The semipelite succession is best preserved in the coastal mountains of Kronprins Christian Land. It comprises mainly shaly sediments, sandy shales and greywackes, about which published petrological or stratigraphical details are lacking.

Psammites

No detailed descriptions of the psammitic strata of the geosynclinal region are available, and several authors have inferred their characteristics by reference to the supposed equivalent strata of the foreland region (Trekant 'series' and Norsemandal Sandstone). A short description of three


24°
16°
81°
78°
Independence Fjord
Danmark Fjord
Kronprins Christian Land
Ingolf Fjord
Lambert Land
Dronning Louise Land
SUPERSTRUCTURE
INFRASTRUCTURE
U
230 + m
K/Ar: 799, 982
Inuiteq Sø Formation
(after Jepsen, 1971)
U?
300 + m
Norsemandal Sandstone
(after Adams & Cowie, 1953)
U?
510 m
Trekant 'series'
(after Peacock, 1956)
Geosynclinal sequence
Composite section, not measured
(after Haller 1970, 1971)
Basic sill
Basic dyke
Psammitic strata up to 3000 m
Semipelitic succession 2000-3000 m
Basal quartzite limestone beds 200-300 m
0
1000
2000 m
0
100 km
3000
320-380
Pre-Carolinidian sediments and metasediments
Foreland sequence, non- or slightly metamorphosed
Parautochthonous, slightly metamorphosed
Parautochthonous-allochthonous, metamorphosed
Superstructural folds
Infrastructural folds
Caledonian thrust
320-380 Age dates in m.y.
Mainly gneisses
1 Prinsesse Caroline Mathilde Alper
2 Marmorvigen
3 Inuiteq Sø
4 Norsemandal
5 Trekanten
6 Danmarkshavn
7 Britannia Sø
8 Hekla Sund
U Unconformity

samples from the Hekla Sund area has, however, been provided by Fränkl (1954, p. 34); they are non-metamorphic arkoses and quartzites. Haller (1971, p. 54) describes the entire sequence of psammitic strata as being of dominantly non-marine character, including red bed facies and non-red sandy facies.

Dykes and sills

Fränkl (1954, p. 36) has briefly described two albite dolerites from Kronprins Christian Land containing pyroxene, actinolite and epidote, but most descriptions of the pre-Carolinidian basic rocks are of the supposed equivalents in the foreland region. Those of Dronning Louise Land have been studied by Peacock (1958) and those further north by Jepsen (1971).

In south Peary Land (*c.* 82° N, 37° W) Jepsen (1971) has shown that the basic intrusions are cut off by an erosion surface upon which the tillite-bearing Moræneso Formation was deposited (Dawes, this volume). The intrusions include dolerites and quartz dolerites which have yielded K-Ar ages of 982 and 799 m.y. (Henriksen & Jepsen, 1970). In Dronning Louise Land Peacock (1956) noted that the basement gneisses, Trekant 'series', and possibly also the Zebra 'series', were traversed by dykes and sometimes sills of quartz gabbro. Petrological details are given by Peacock (1958).

Haller distinguished a set of pre-orogenic basic intrusions, mainly sills, and a post-orogenic set of mainly dykes in the pre-Carolonidian sediments, based on observations in Kronprins Christian Land and Lambert Land (Haller, 1971, p. 65). The dykes are up to 400 m wide (fig. 218). No details of the distribution and petrology of these basic intrusions have been published.

Carolinidian orogeny

A fold pattern attributed to Carolinidian orogenesis is traceable from 76° to 81° N according to Haller (1970). These folds affect the pre-Carolinidian sediments and are also noted in widely distributed outcrops of the pre-Carolinidian gneissic basement (Haller, 1971, fig. 15a). In the north and west folding is of simple or superficial nature and the metamorphic grade is low (fig. 217). Farther south the fold style is of a more deep-seated type in the infracrustal rocks and metamorphism is higher grade. The region between 76°–78° N has been widely affected by intense migmatisation and Haller (1971, p. 64) indicates that it represents the deep-seated central zone of the Carolinidian fold belt.

Traces of the Carolinidian fold belt are preserved in three types of environment: areas which have not been affected by the Caledonian orogeny; segments transported westwards on Caledonian thrusts; and isolated areas involved in the migmatitic central zone of the Caledonian fold belt.

←

Fig. 217. The Carolinidian fold belt and the distribution of pre-Carolinidian supracrustal rocks in North-East Greenland.

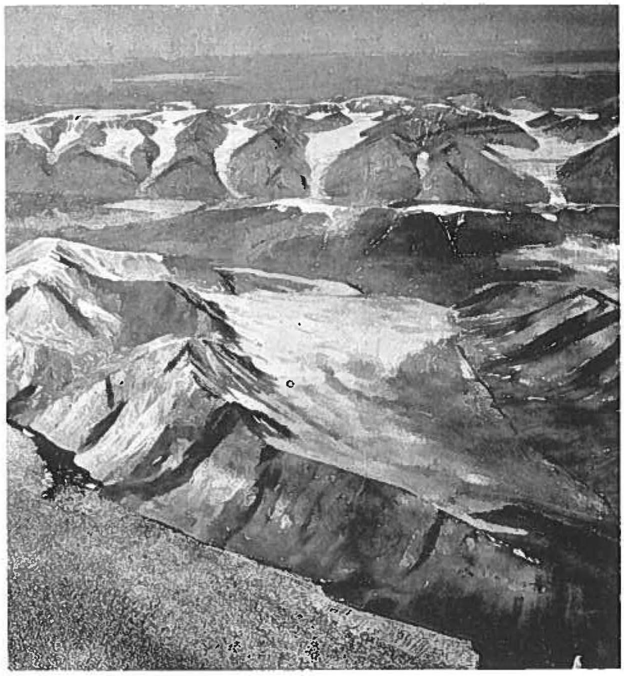


Fig. 218. Pre-Carolinidian sediments cut by basic dykes. Aerial photograph from south side of Lynn Ø (80°10'N). Route 663A–V, no. 10234. Copyright Geodetic Institute.

Areas unaffected by Caledonian orogenesis

In north-west Dronning Louise Land the basement gneisses and the Trekant 'series' sediments were deformed by NW–SE trending open folds prior to deposition of the Zebra 'series'. The structures have therefore been given a Carolinidian age. However, since comparable structures are not recorded in south-west Dronning Louise Land the region is presumed to represent the border zone of the Carolinidian fold belt.

Based on studies of aerial photographs Haller (1971, p. 61) traced a series of very open E–W trending folds at the head of Independence Fjord (82° N) which he took to be the north-west continuation of the Carolinidian border zone; this would indicate that the fold belt had a general NW–SE trend. A correlation with the metamorphic 'Cape Columbia Complex' of north Ellesmere Island was further suggested by Haller & Kulp (1962, p. 29); this complex has yielded a K-Ar age of 545 m.y. However, during mapping west of the head of Independence Fjord Jepsen (1971, p. 34) found no evidence of E–W folding, and there seems to be little real evidence for the north-west projection of the Carolinidian fold belt or any correlation with Ellesmere Island.

Segments within Caledonian thrust sheets

Carolinidian folds have been traced in the infracrustal rocks of the thrust units of east Dronning

Louise Land, and as open style folds in the supracrustals north of 78° 00′ N. The curving trend of the Carolinidian structures in places is attributed to Caledonian refolding. In the northern areas the NE–SW trend is considered to be unaffected by Caledonian deformation. A Precambrian (Carolinidian) age for the fold pattern is inferred from the occurrence of pre-orogenic and post-orogenic dykes which fail to penetrate the post-Carolinidian sediments of the Hagen Fjord Group.

While the age of the Carolinidian orogeny is uncertain, K-Ar age determinations on the dykes in the foreland show that the sediments were deposited more than 1000 m.y. ago (Henriksen & Jepsen, 1970). It is concluded on this indirect evidence that the orogeny may belong to the major orogenic epoch which has yielded K-Ar ages of the order of 1000 m.y.

Isolated areas within the Caledonian migmatitic zone

The coastal region between 76°–78° 30′ N consists of intricately folded gneisses and migmatites which according to Haller (1956b, 1971) assumed their present character during at least three successive orogenic phases. They include areas of pre-Carolinidian basement gneisses, Carolinidian gneisses and migmatites, and Caledonian gneisses and migmatites. Two major fold systems have been distinguished: an older Carolinidian NNW–SSE system which northwards swings to a NNE–SSW trend, and a younger Caledonian NNE–SSW system (Haller, 1970). In the south (76°–77° N) the older set is preserved in resistant blocks 10 m to 10 km across bordered by zones in which the younger folds dominate. Farther north both sets are preserved over large areas, though the Caledonian structures are more prominent.

As the region has not been mapped in detail the distinction of particular structures as being of Caledonian, Carolinidian or pre-Carolinidian age is a difficult undertaking, and Haller's (1970) interpretation should be regarded as provisional. An elaborate age determination programme on supposed Carolinidian gneisses at Danmarkshavn (76° 50′ N) (R. H. Steiger, personal communication) indicates that they were apparently formed, or suffered their last major metamorphism, *c.* 3000 m.y. ago; the NNW-trending structures and other early folds in the banded gneisses and other rocks in the region must be of similar age. Haller has interpreted these structures as Carolinidian, but unless this orogeny is of considerably greater antiquity than generally supposed they are best re-interpreted as basement structures. Isotopic work also revealed an absence of significant thermal activity affecting the gneisses until a partial reactivation giving mineral ages in the range 320–380 m.y.

As has been indicated there is a good deal of uncertainty with respect to the present concept and extent of Carolinidian orogenesis, and no firm conclusions can be drawn before this little-known and relatively inaccessible region of North-East Greenland has been investigated in more detail.

Dronning Louise Land

A major north-south trending and east dipping thrust zone separates Dronning Louise Land into a western group of gneisses and an eastern group of schists and gneisses (fig. 219). The western gneisses are widely regarded as part of the autochthonous Precambrian shield in the foreland region west of the East Greenland fold belt. The eastern schists and gneisses represent Caledonian thrust units. The amount of displacement is unknown, though figures of the order of 50 km have been quoted.

Western gneisses

The western gneisses were investigated by Peacock (1956, 1958) who carried out a number of east–west traverses and studies in the western border zone. Haller (1956b, 1970, 1971) has reported results obtained from reconnaissance flights over the area, and has presented a structural interpretation of his own and Peacock's data.

The western gneisses comprise a complex of banded granitic gneiss, augen gneiss, some basic gneiss, and various granitic bodies. Rarely quartzite and schists occur. This complex is overlain unconformably by two sedimentary sequences, of which the older Trekant 'series' has been correlated with pre-Carolinidian sediments regarded as at least 1000 m.y. old.

Within the gneisses there is evidence for an early period of high grade metamorphism, a phase of late to post-kinematic plutonic activity, and a younger low grade metamorphism. The plutonic rocks include granites and granodiorites, possibly representing two periods of intrusion. Basic augite-hornblende-plagioclase gneisses occur as lenticular bodies in the acid gneisses, or as larger masses in the plutons; they may be derived from basic intrusives.

Little is known of the structure within the gneisses. A zone with eastward dips was noted in the south by Peacock while Haller observed a few uniform NNE-trending large scale folds.

The gneisses, and also the overlying Trekant 'series', are cut by quartz dolerite dykes and sills. These intrusions were influenced only by the later of the

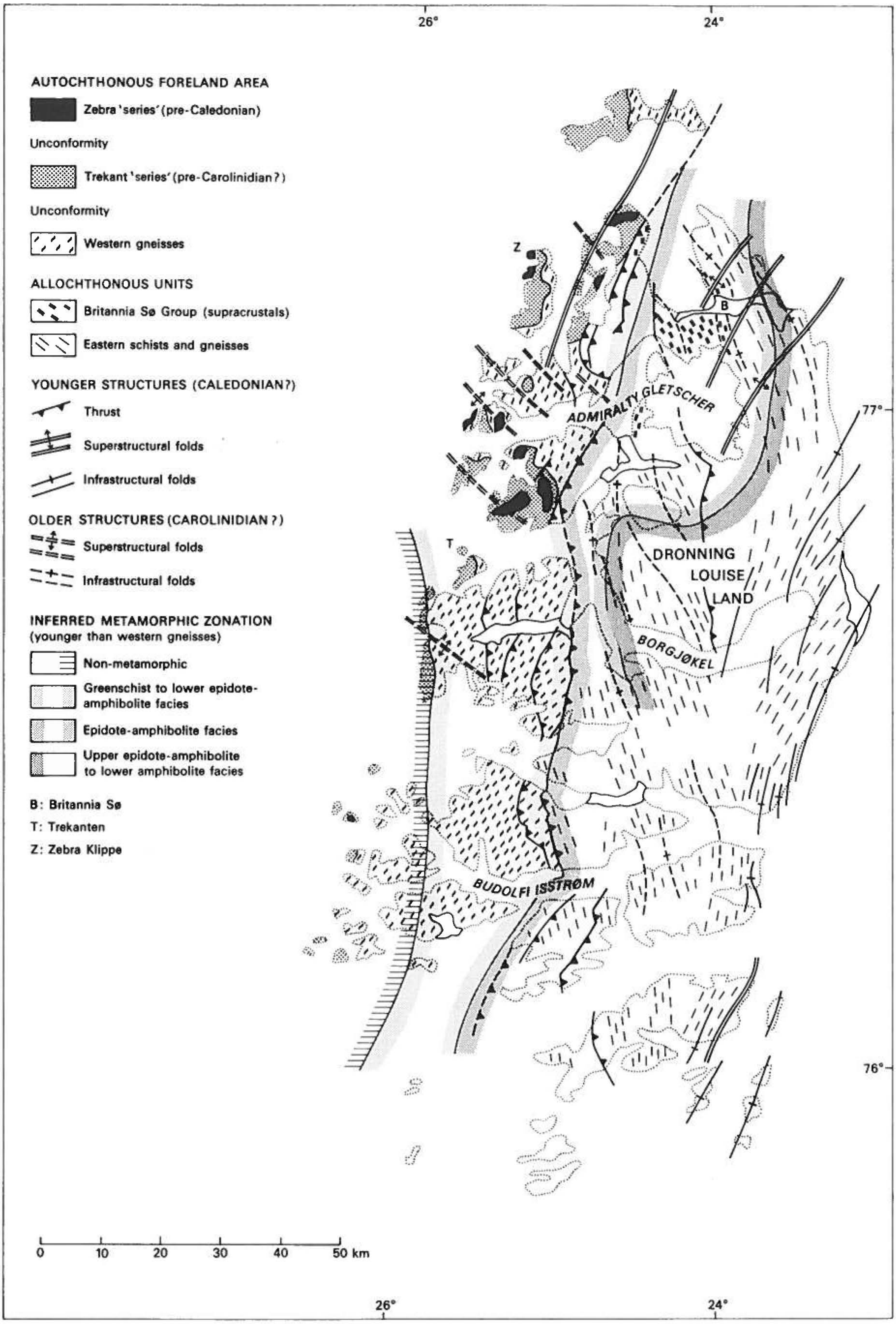


Fig. 219. Geological map of Dronning Louise Land. Compiled after Haller (1956b, 1970) and Peacock (1958).

two metamorphic episodes, whose effects increase eastwards and which is considered to be of Caledonian age. Extensive N–S trending crush belts characterised by cataclastic metamorphism, the development of augen gneisses, and retrogression of the former high grade mineral assemblages also reflect a Caledonian influence.

Eastern schists and gneisses

The eastern half of Dronning Louise Land comprises a complex of paragneisses and paraschists distinguished by Peacock (1956, 1958) as the 'Eastern Schists and Gneisses'. Haller's structural interpretation of the region is based on Peacock's work and his own aerial observations.

The dominant rock types are monotonous, grey, banded quartz-biotite schists, with subordinate calcareous schists and occasional quartz-muscovite schists and quartzites. These schists are interbedded with gneisses and locally in the eastern outcrops there is granite veining and development of porphyroblastic gneisses. Metasedimentary rocks, the Britannia Sø Group, outcrop in the north and have conformable contacts with the adjacent schists. They comprise quartzites, magnetite quartzites and metamorphosed limestones. Peacock correlated the Britannia Sø Group with the Zebra 'series' of the foreland, whereas Haller (1971) prefers to link them with the older Trekant 'series'.

A series of metagabbro to amphibolite dykes cutting the eastern schists and gneisses can possibly be correlated with the basic sills and dykes cutting the foreland gneisses and overlying sediments of western Dronning Louise Land. This would imply that parts of the eastern schists and gneisses were formed more than 1000 m.y. ago and would support Haller's view of the composite nature of the region. He envisages the existence of a possible pre-Carolinidian basement, though more or less reworked, and a Carolinidian central crystalline zone. The Britannia Sø Group is presumed to have been deposited prior to Carolinidian deformation, and the entire area later subjected to Caledonian metamorphism. However, confirmatory field evidence for some of these assumptions is lacking.

Peacock (1958) in a description of rocks collected on his traverses distinguishes only one phase of metamorphism in the eastern schists and gneisses; it ranges from greenschist facies in the west to amphibolite facies in the east. This metamorphic epi-

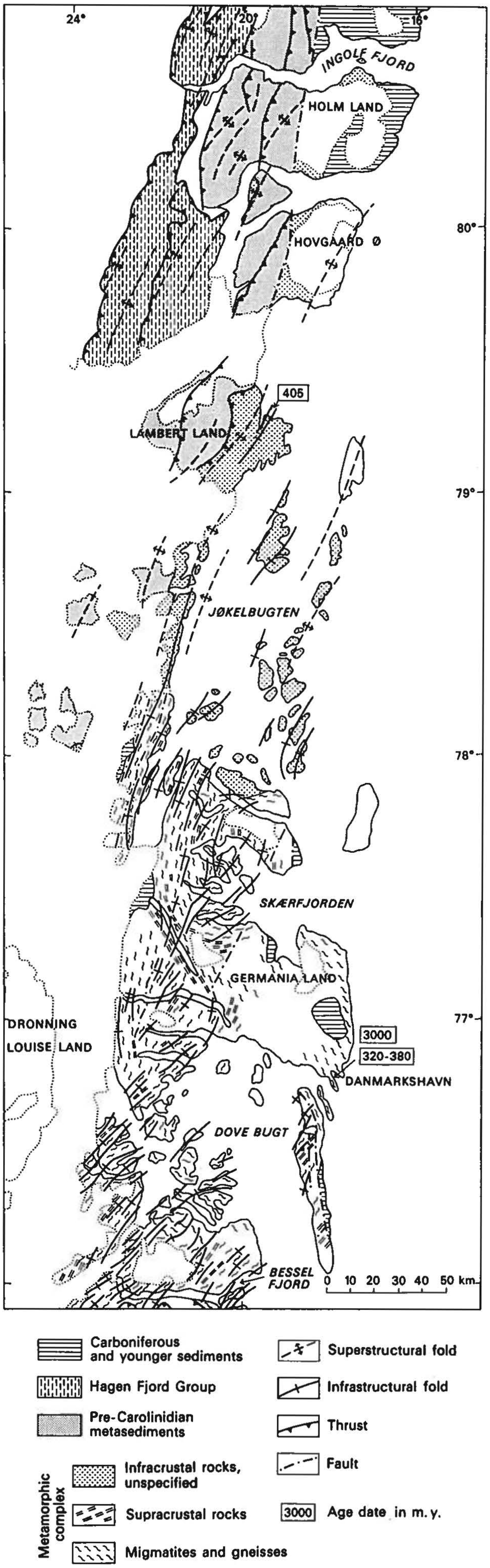


Fig. 220. Geological map of the Bessel Fjord – Ingolf Fjord metamorphic complex. Compiled after Haller (1956b, 1970, 1971).

sode which affects schists, gneisses and dykes is considered to be Caledonian.

Two fold sets are recognisable in east Dronning Louise Land. Broad open NNW-trending folds occur in the west and NNE-trending structures occur in the east. The relationships between the two sets are not absolutely clear though Haller (1971) considers the former to be Carolinidian and the latter to be Caledonian. Haller's view is based on observations in the foreland of north-west Dronning Louise Land where he distinguishes an older NW-trending open fold system separating the Trekant and Zebra 'series', as well as younger NNE folds affecting both series (Haller, 1970); Peacock recognised only the latter set.

The major north–south trending thrust zone and a number of parallel thrusts form an imbricate structure which is generally accepted as being Caledonian. Thrusts separate units of different metamorphic grade, and movements evidently post-dated or outlasted metamorphism. The main thrust is interpreted as the west margin of the East Greenland fold belt.

Bessel Fjord – Ingolf Fjord metamorphic complex

The metamorphic complex between Bessel Fjord (76° N) and Ingolf Fjord (80° 40′ N) consists for the most part of migmatites and gneisses, with occasional bands of supracrustals. To the north-west it is bordered by a wide zone of pre-Carolinidian sediments and metasediments. Two sets of structures affect the complex and the pre-Carolinidian sediments, of which the older set is referred to as Carolinidian. The younger NNE-trending structures (fig. 220) are assumed to be Caledonian as they are parallel to Caledonian structures in the Hagen Fjord Group (Haller, 1971).

No systematic regional mapping has been carried out. Haller (1956b) has presented a sketch map extending to 78° N based on scattered ground observations, aerial observations and a study of aerial photographs, while Wyllie (1957) has recorded the results of a reconnaissance traverse in Germania Land. The region north of 78° N is known in equivalent sketchy detail, and conclusions should be viewed with some reservations.

In the north the NNE-trending Caledonian structures are of superficial simple type associated with a weak retrogressive metamorphism of the older infracrustal rocks. However, in the south it is envisaged that pre-Caledonian infracrustal rocks were subjected to semi-plastic to rigid Caledonian shearing together with selective metamorphism and migmatisation. Various types of structural relations are recorded between the younger deformation and the older crystalline elements of the complex.

In Dove Bugt parts of the old crystalline complex occur in resistant masses 10 m to 10 km across which have been reactivated and refolded around their margins. The younger migmatisation and granitisation is selectively associated with the NNE-trending zones of deformation, such that an old general NNW trend is still traceable in the relict resistant blocks.

In Germania Land early NNW-trending structures predominate, but westwards there is a continuous transition into rocks overprinted by the younger deformation. Wyllie (1957) reports granitic gneiss and migmatites with paragneiss bands from the western part of Germania Land metamorphosed under upper amphibolite or lower granulite facies conditions. In the eastern part of Germania Land amphibolite facies rocks have suffered slight retrogression.

Isotopic work indicates that the NNW structures to be found around Danmarkshavn and possibly other pre-Caledonian structures in the Dove Bugt – Germania Land region were formed about 3000 m.y. ago (R. H. Steiger, personal communication).

In Skærfjorden the older structures form a dome-like pattern about 60 km in diameter. They have only locally been obliterated by migmatisation and granitisation associated with the younger NNE structures.

The gneisses of the southern part of Jøkelbugten are characterised by steep-sided structures, sometimes isoclinal and overturned westwards, with NNE–SSW trends. A younger and older set have the same trend. Broad transition zones occur between intact islands of older complexes and younger belts of deformation.

Little is known of the gneiss areas north of Jøkelbugten. NNE-trending 'up-folds' are recorded by Haller (1971, p. 206) from Lambert Land and adjacent areas, but the degree of associated reactivation is uncertain. A K-Ar age of 405 m.y. is recorded from a late tectonic biotite pegmatite which intrudes biotite schists in north-east Lambert Land.

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