Precambrian to Tertiary of northern Greenland

Peter R. Dawes

Fig. 221. Lower Palaeozoic platform strata in northern Washington Land with Petermann Gletscher in the foreground, Nares Strait and Ellesmere Island in the distance. Aerial photograph 545 E–Y, no. 5670, Copyright Geodetic Institute.

Introduction

This paper describes the bedrock geology of the northern part of Greenland from Melville Bugt (75°00′N) on the west coast to Kronprins Christian Land (80°00′N) on the east coast. The region corresponds to the geographical divisions North-West and North Greenland as used by the Survey. The larger part of this region is ice covered, either by the northern part of the Inland Ice or by smaller ice caps. About 125 000 km² is ice free. The majority of the coast is ice locked throughout the year making logistics and field work difficult.

The essential features of the structure and stratigraphy of northern Greenland were described by Lauge Koch (1920, 1925, 1929a) from sledge exploration carried out between 1916 and 1923. Subsequent work by others has been mainly reconnaissance with but few detailed mapping and stratigraphic studies. This report results in considerable part from field work of the last two decades, but also depends heavily on accounts by the early explorers. Problems can arise, however, with the older documentation, the collections and data for which were often obtained under extremely unfavourable conditions. For example many fossil collections were made from loose or even erratic material. Perhaps more attention than usual is needed for confirmation of parts of the stratigraphic scheme, which at first may appear to be a well established one.

New data from field projects being carried out at the present time and from other unpublished sources have been included where relevant. This includes important information from Greenarctic Consortium, a commercial organisation which carried out field work across northern Greenland between 1969 and 1973.

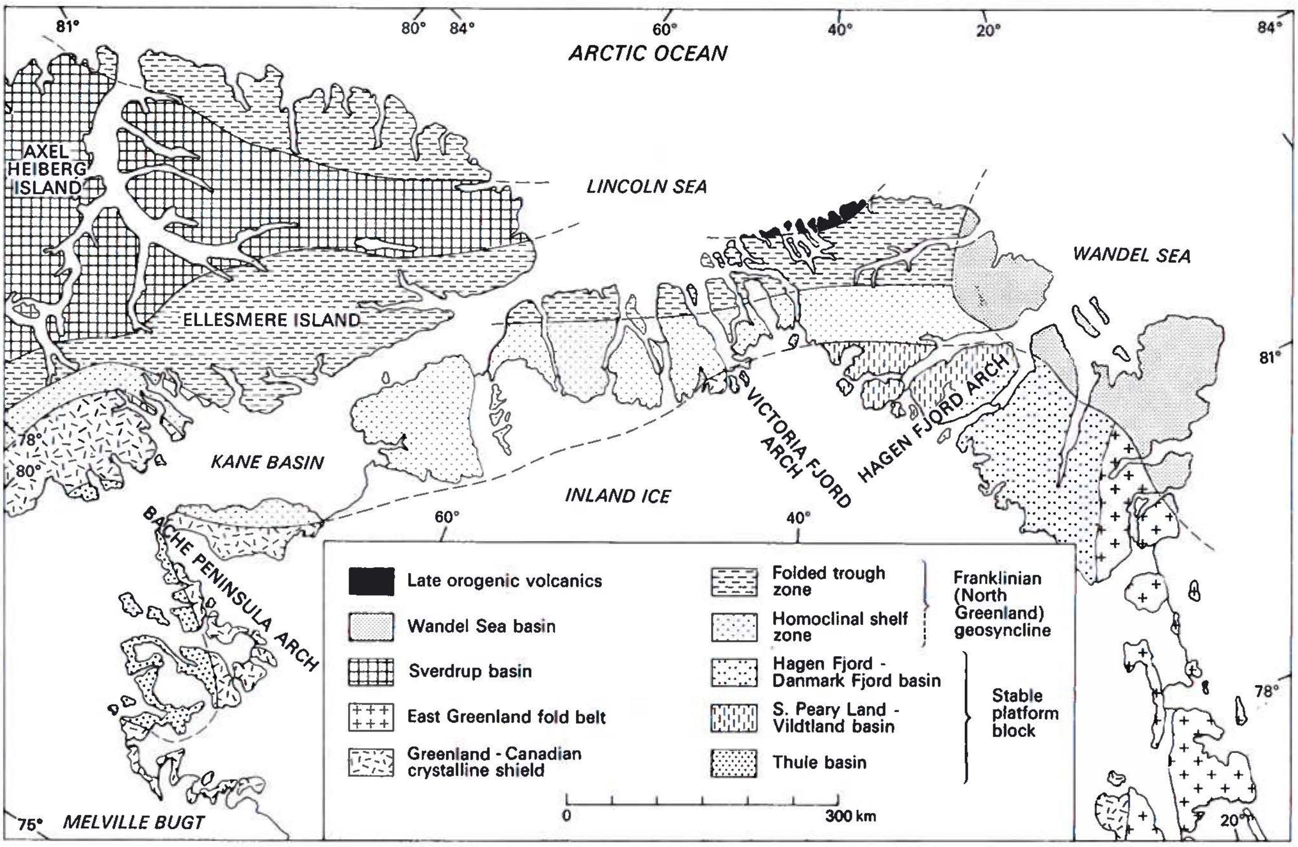

Fig. 222. Map showing the main structural–stratigraphical units of northern Greenland and adjacent Arctic Canada (modified from Dawes & Soper, 1973).

Regional geological framework

Northern Greenland is made up of three main geological provinces (fig. 222): a platform region in the south in which Proterozoic and Lower Palaeozoic rocks overlie crystalline basement rocks, an east–west trending orogenic belt of Phanerozoic rocks in the north called the North Greenland fold belt and a north–south trending orogenic belt of Precambrian and Phanerozoic rocks on the east coast. This latter orogenic belt – the East Greenland Caledonian fold belt – is described elsewhere in this volume (Henriksen & Higgins). A sub-province in eastern North Greenland, the Wandel Sea basin of Upper Palaeozoic to Tertiary rocks, overlies the junction between the older orogenic belts.

The crystalline basement rocks north of Melville Bugt are continuous with the Rinkian complex of northern West Greenland (Escher & Pulvertaft, this volume). The lowest part of the Proterozoic to Palaeozoic platform sequence is continuous with the foreland rocks of the East Greenland fold belt, and all of the basement, platform and northern folded provinces are continuous with similar regions of the Arctic Islands of Canada.

The crystalline basement, exposed mainly adjacent to the Inland Ice, is overlain with profound unconformity by non-metamorphosed Proterozoic, mainly clastic rocks. The Proterozoic section varies in thickness from over 4500 m in the west to no more than 200 m in the central part in south-eastern Wulff Land. Disconformably overlying the Proterozoic rocks are Eocambrian or Cambrian, Ordovician and Silurian clastic and carbonate rocks of platform and shelf facies, a section which reaches 3500 m in thickness. The platform rocks are preserved as down-faulted blocks in the Thule region, as outliers in Inglefield Land and as extensive north dipping homoclinal areas across northernmost Greenland. Several widely separated structural 'highs' or arches transgress the platform region. The sedimentary rocks between

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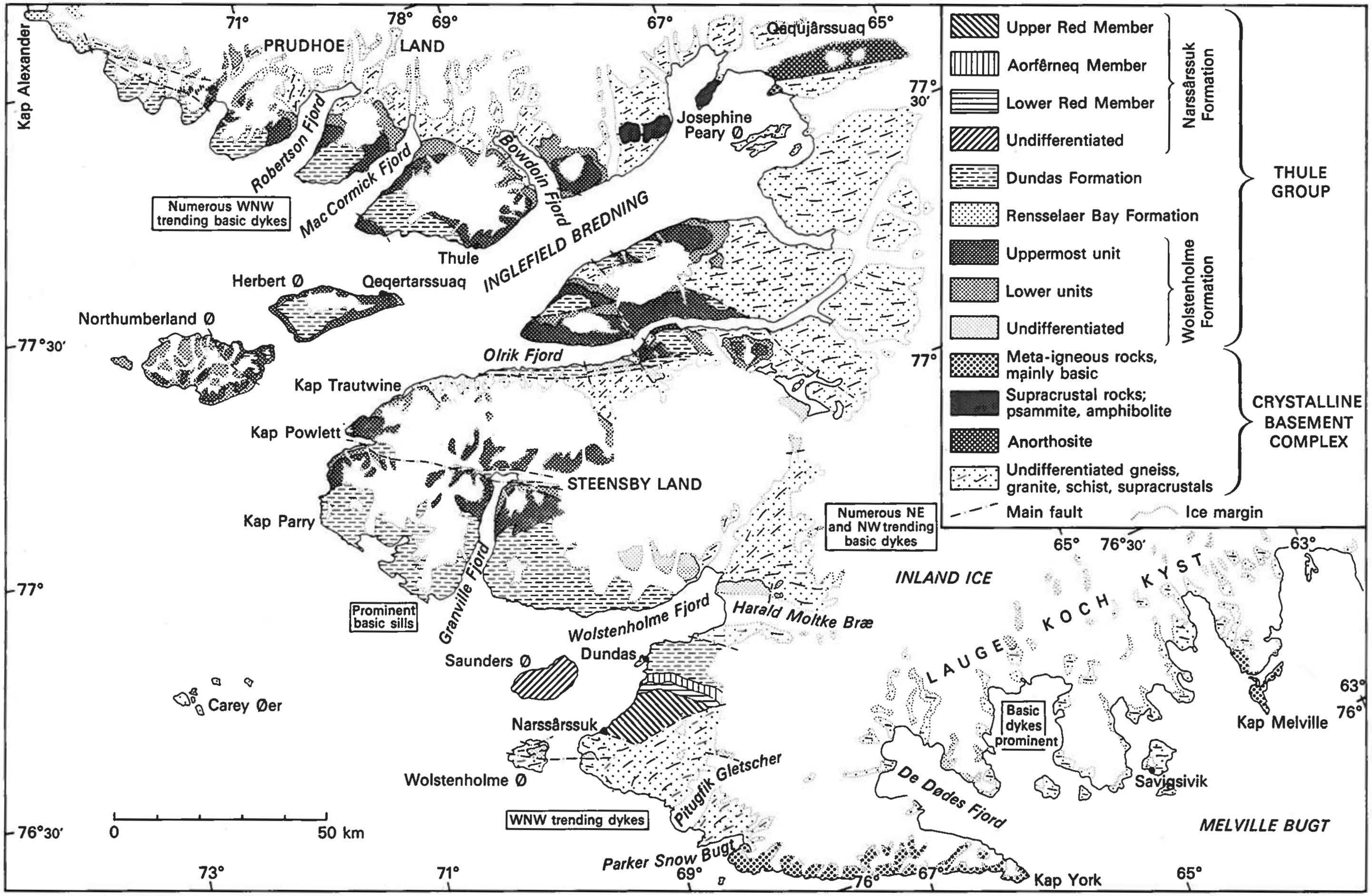
Fig. 223. Geological map of the Thule district from Melville Bugt to Inglefield Land compiled from maps by Koch (1920, 1926), Davies *et al.* (1963), Fernald & Horowitz (1964) Dawes (1972, 1975) and from the author's field and photogeological work. Basic sills and dykes, which form prominent outcrop features in some areas, are not shown.


Upper Red Member
Aorfêrneq Member
Lower Red Member
Undifferentiated
Narssârssuk Formation
Dundas Formation
Rensselaer Bay Formation
Uppermost unit
Lower units
Undifferentiated
Wolstenholme Formation
THULE GROUP
Meta-igneous rocks, mainly basic
Supracrustal rocks; psammite, amphibolite
Anorthosite
Undifferentiated gneiss, granite, schist, supracrustals
CRYSTALLINE BASEMENT COMPLEX
Main fault
Ice margin
Kap Alexander
PRUDHOE LAND
Qáqujârssuaq
Robertson Fjord
MacCormick Fjord
Bowdoin Fjord
Josephine Peary Ø
Numerous WNW trending basic dykes
Thule
INGLEFIELD BREDNING
Herbert Ø
Qeqertarssuaq
Northumberland Ø
Olrik Fjord
Kap Trautwine
Kap Powlett
STEENSBY LAND
Kap Parry
Numerous NE and NW trending basic dykes
INLAND ICE
Prominent basic sills
Granville Fjord
Wolstenholme Fjord
Harald Moltke Bræ
LAUGE KOCH KYST
Saunders Ø
Dundas
Carey Øer
Narssârssuk
Wolstenholme Ø
Basic dykes prominent
Pitugfik Gletscher
De Dødes Fjord
Savigsivik
Kap Melville
WNW trending dykes
MELVILLE BUGT
Parker Snow Bugt
Kap York
0
50 km
71°
78°
69°
67°
65°
77° 30′
77°
76°30′
63°
76°
73°

or flanking the highs form structural basins which probably were also basinal during sedimentation.

The undeformed strata of the platform pass northward into the thicker folded rocks of the North Greenland geosyncline, where the sedimentary record extends into the Devonian. The North Greenland geosyncline is an eastern extension of the Franklinian geosyncline of the Canadian Arctic Islands.

The North Greenland fold belt trends eastward from Hall Land to eastern Peary Land, a distance of 600 km. Folding within the belt conforms to the regional trend. The junction between the platform and the fold belt is transitional: homoclines of the platform pass northward into broad open folds that, farther north, pass into the main fold structures. Asymmetrical folds, mainly overturned to the north, dominate the fold belt. The folding is thus directed away from the platform which acted as a hinterland, not a foreland.

The North Greenland fold belt is an orogenic complex. A long history of structural and metamorphic events, culminating in Devonian time, resulted in polyphase deformation and metamorphic grades as high as amphibolite facies. Calc-alkaline volcanic rocks and major thrust faults younger than the main diastrophism form a late orogenic, possibly Cretaceous–Tertiary, suite on the north coast.

Carboniferous, Permian, Triassic, Jurassic, Cretaceous and Tertiary mainly marine rocks comprise a 3000 m thick section in the Wandel Sea basin in eastern North Greenland. This basin has been deformed by late Phanerozoic movements culminating in Tertiary time and the rocks now form a northwest trending tectonic belt.

Precambrian crystalline basement

Precambrian crystalline rocks are widely exposed between Melville Bugt and Inglefield Land (figs 223, 224). Small areas of exposure are also known in south-eastern Wulff Land and on certain nunataks at the head of Victoria Fjord (fig. 267).

Melville Bugt to Inglefield Land

The basement rocks of the large Melville Bugt – Inglefield Land region have been explored sufficiently to allow tentative subdivision into six main lithological units, the regional extent and relative ages of some of which, however, are not known. The units are: (a) gneiss, schist and granite; (b) anorthosite; (c) psammite and amphibolite; (d) marble, pelite and calc-silicate rocks; (e) gabbroic to granitoid rocks; (f) variable gneiss, melanocratic to quartz-rich.

(a) Gneiss, schist and granite

This unit forms much of the basement terrain between Melville Bugt and Prudhoe Land and includes the rocks described in the Wolstenholme Fjord area (Davies *et al.*, 1963; Fernald & Horowitz, 1964) and on the Carey Øer (Bendix-Almgreen *et al.*, 1967). Grey to pink, biotite and hornblende-bearing, veined to banded gniesses of mainly granodioritic composition are the dominant rock types. Areas of porphyroblastic and augen gneiss occur, and transitions to granitic gneiss and granite are common. The gneisses are commonly melanocratic, have a typically reddish brown weathering and are characteristically contorted into complex structures (fig. 225). Some masses of medium-grained leucocratic granite have sharp contacts with the gneisses and are probably of intrusive origin.

Tracts of biotite-garnet schists, mica-chlorite-talc schists, quartz-mica-magnetite rocks as well as areas of quartzites and metasedimentary quartz-rich garnet gneiss are associated with the granodioritic gneisses.

Various types of basic and ultrabasic rocks occur in the gneisses mostly as discontinuous, often fragmented, concordant layers, as well as isolated masses, lenses and schlieren. Main types are dark grey to black biotite-bearing amphibolites and schists with or without garnet and pyroxene, green hornblendites with or without pyroxene, and lighter coloured chlorite-amphibole-talc schists. Agmatitic veining is common and in places mobility of gneiss material has produced discordant contacts. Some thicker units contain a varied and conformable sequence of rocks and in one such unit at Uvdle in Wolstenholme Fjord structures in the rocks suggest a metavolcanic origin.

Following the main migmatisation and deformation of the gneisses grey to pink granite sheets, dykes and small irregular bodies were intruded, as well as late pegmatites and aplites (fig. 225). Folded discordant amphibolite dykes post-date at least one episode of granite emplacement but pre-date the main pegmatisation.

(b) Anorthosite

Anorthosite forms a tabular body over 3 km thick and with an exposed area of about 180 km² at the

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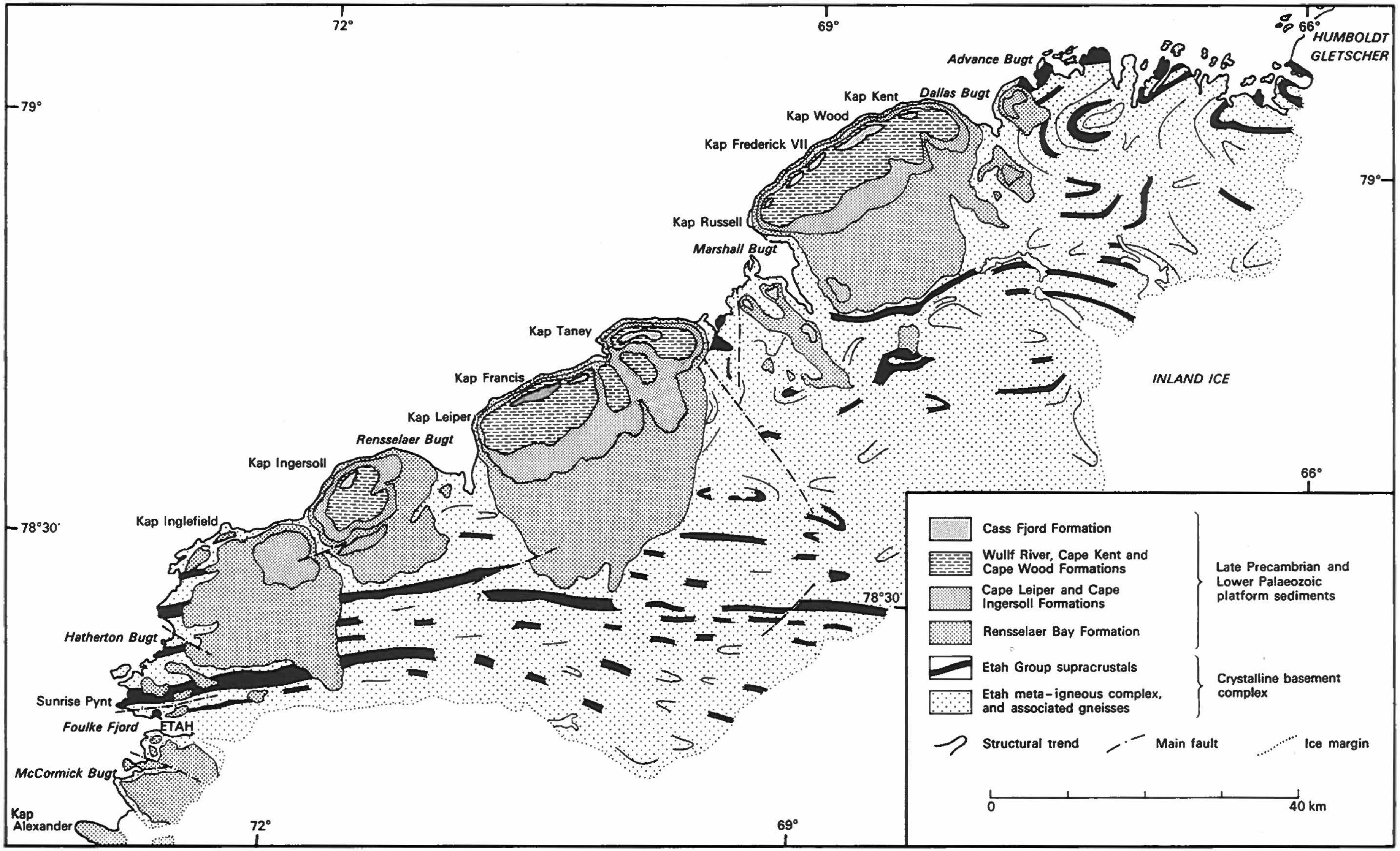
Fig. 224. Geological map of Inglefield Land compiled from maps by Koch (1933), Cowie (1961a), Dawes (1972) and from the author's field and photogeological work. Basic sills in the lower part of the sedimentary sequence, west of Rensselaer Bugt, and basic dykes, are not shown.


72°
69°
66°
79°
78°30′
HUMBOLDT GLETSCHER
Advance Bugt
Dallas Bugt
Kap Kent
Kap Wood
Kap Frederick VII
Kap Russell
Marshall Bugt
Kap Taney
Kap Francis
Kap Leiper
Rensselaer Bugt
Kap Ingersoll
Kap Inglefield
Hatherton Bugt
Sunrise Pynt
Foulke Fjord
ETAH
McCormick Bugt
Kap Alexander
INLAND ICE
Cass Fjord Formation
Wulff River, Cape Kent and Cape Wood Formations
Cape Leiper and Cape Ingersoll Formations
Rensselaer Bay Formation
Late Precambrian and Lower Palaeozoic platform sediments
Etah Group supracrustals
Etah meta-igneous complex, and associated gneisses
Crystalline basement complex
Structural trend
Main fault
Ice margin
0
40 km

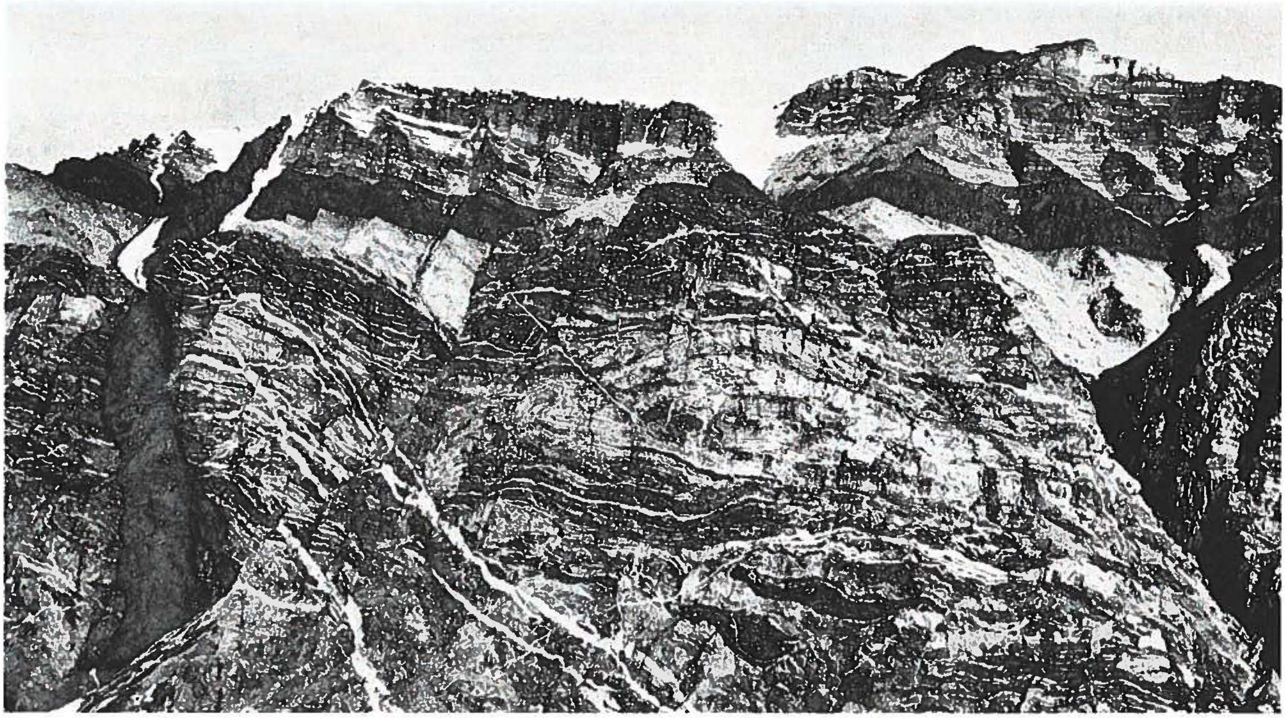


Fig. 225. The major unconformity at the base of the Thule Group. A basement of severely folded gneisses and amphibolites veined by acid veins overlain by the non-metamorphosed clastic rocks of the Wolstenholme Formation. Dark dolerite sills are cut by a WNW–ESE trending dolerite dyke. Kap Trautwine. Height of the cliffs is approximately 750 m.

head of Inglefield Bredning (fig. 226). The body has been referred to earlier as the Qaqujârssuaq anorthosite (Dawes, 1972). The anorthosite lies with sharp and conformable contacts against the underlying garnet-biotite gneiss of unit (a).

The typical anorthosite is medium grained, equigranular and marked by mafic, mainly amphibole-rich schlieren and a foliation with a general east–west trend. On a small scale, schlieren and foliation display irregular contortions and relict folds and these are cut by locally numerous, altered basic dykes (fig. 227). The majority of these dykes are thin, less than 2 m, but the largest dyke noted is about 45 m thick. The dykes are generally subconcordant to the foliation of the anorthosite. The dyke rock varies from metadolerite to amphibolite–schist and the dykes are in places deformed into stringers and schlieren. Metagabbro, probably of similar age to the basic dykes, forms an area in contact with gneisses of unit (a) south of the main anorthosite body.

(c) Psammite and amphibolite

A mixed unit of brown to orange weathering supracrustal rocks at the head of Inglefield Bredning comprises mainly layered quartzite, quartzitic schist, garnet-mica quartz-rich gneiss and sillimanite-garnet-muscovite-biotite schist with frequent garnetiferous amphibolites as concordant layers and boudins (fig. 226). This unit appears to be a metamorphosed sedimentary sequence with contained altered igneous rocks. The stratigraphic thickness of the succession is estimated at about 800 m but so far only the lower part has been examined. The contact with adjacent, structurally underlying darker gneisses of unit (a) is sharp and layering in the two units is concordant.

Other amphibolitic successions with similar relationships to gneisses occur in the Melville Bugt region.

(d) Marble, pelite and calc-silicate rocks

Light coloured crystalline limestone, variable calc-silicate rocks, pelitic schists and minor psammitic rocks of the Etah region were named the Etah Group by Dawes (1972). Distinct belts of these rocks up to 2 km wide have been studied in south-west Inglefield Land (fig. 228), and are thought from aerial photographic evidence, to be present throughout the region (fig. 224). Layering in the supracrustal rocks is steeply inclined to vertical, and the unit is intimately intruded by gabbroic to granitoid rocks of unit (e). Contact metamorphic mineral assemblages containing wollastonite, tremolite, diopside and spinel developed in the marbles which in many places show irregular internal structures indicating appreciable rock mobility.

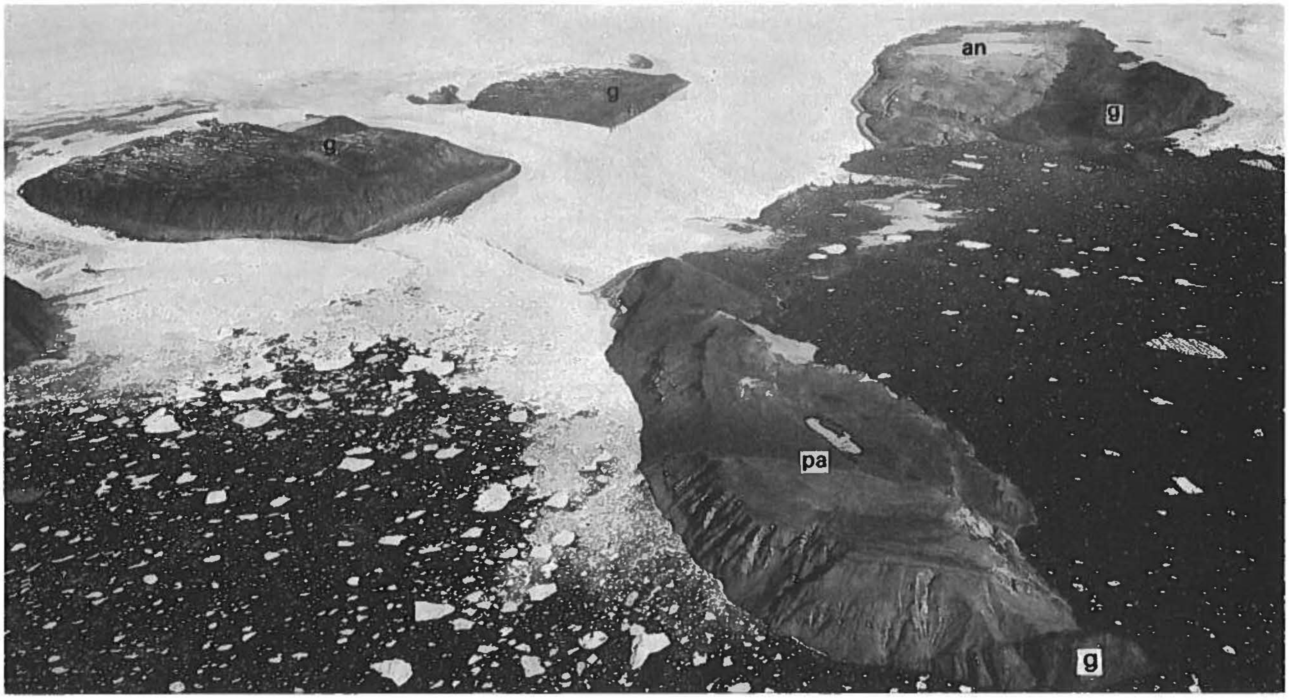


Fig. 226. View north-eastwards of Josephine Peary Ø, the Inland Ice and nunataks at the head of Inglefield Bredning in the Thule district (fig. 223). Rocks of the psammite and amphibolite (pa), Qaqujârssuaq anorthosite (an), and gneiss–schist–granite (g) units are visible. The supracrustal psammite–amphibolite rocks form a broad synform on the island and conformably overlie gneiss (g). Aerial photograph 543 M-Ø, no. 1426. Copyright Geodetic Institute.

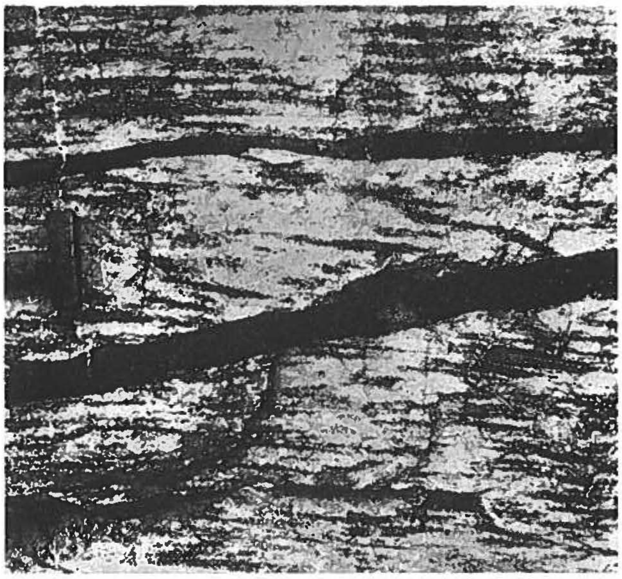
(e) Gabbroic to granitoid rocks

Igneous rocks of a variety of compositions form large outcrops in two regions: in Inglefield Land where they have been grouped together as the Etah meta-igneous complex (Dawes, 1972), and in the Parker Snow Bugt – Melville Bugt region – the Kap York meta-igneous complex (Dawes, 1975).

The Etah meta-igneous complex is particularly prominent in south-west Inglefield Land where it intrudes the Etah Group (fig. 228). The rocks vary from black, dark grey and brown gabbro through diorite, quartz norite, quartz diorite and hypersthene tonalite to pink and red granodiorite and granite. Also, certain plagioclase-rich rocks resemble anorthosites. Orthopyroxene is commonly present. There is a gradation from these rocks of igneous aspect to folded, veined gneisses of varying composition. In many places severely folded and fragmented isolated sheets and veins of intrusive material occur within rocks of the Etah Group, but despite such intensive deformation, transgressive contacts between the igneous suite and the rocks of the Etah Group have been preserved.

The Kap York meta-igneous complex comprises a similar suite of rocks although there appears to be a predominance of gabbroic and doleritic material. The complex also displays gradations to banded gneissic rocks and in places feldspathisation has resulted in porphyroblastic basic and granitoid rocks. The complex has sharp contacts with the gneisses of unit (a). Little known intrusive rocks elsewhere in northern Melville Bugt (Koch, 1920) are possible age equivalents to the Kap York complex (fig. 223).

Fig. 227. The Qaqujârssuaq anorthosite showing mafic foliation cut by two thin discordant amphibolite dykes. North-west Qaqujârssuaq, Inglefield Bredning.



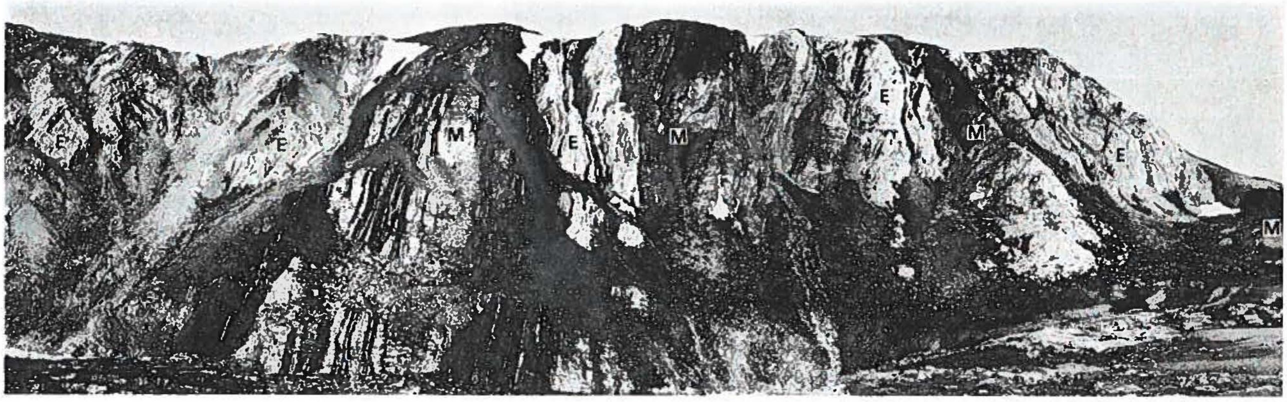


Fig. 228. Cliff section, about 1 km long and 350 m high, of Precambrian basement rocks at Sunrise Pynt, south-west Inglefield Land. The view is eastwards along the regional strike and shows steeply inclined beds of the Etah Group (E) intruded by rocks of the Etah meta-igneous complex (M). Light coloured crystalline limestone and darker pelitic schists are intercalated with granite and diorite.

(f) Variable gneisses: melanocratic to quartz-rich

Certain gneisses and schists in southern Inglefield Land and northern Prudhoe Land are interpreted from gradational contact relationships as being derived from rocks of the Etah Group and the Etah meta-igneous complex (fig. 229). Such rocks are here referred to as variable gneisses. Although variable in composition from amphibolitic and pyribolitic to quartzose gneiss and schists, the gneisses commonly contain both plagioclase and potash feldspar, orthopyroxene, biotite and hornblende. Garnet, cordierite and sillimanite may be present.

It seems probable that hypersthene-bearing granitic to schistose gneisses described as making up a large part of Inglefield Land (Callisen, 1929; Koch, 1933) may correspond to the variable gneisses described above.

Wulff Land and Th. Pedersen Land

Crystalline rocks at the head of Victoria Fjord (figs 222, 267) are mainly biotite and amphibole bearing, veined gneissose and schistose rocks, with associated amphibolites cut by aplite and pegmatite

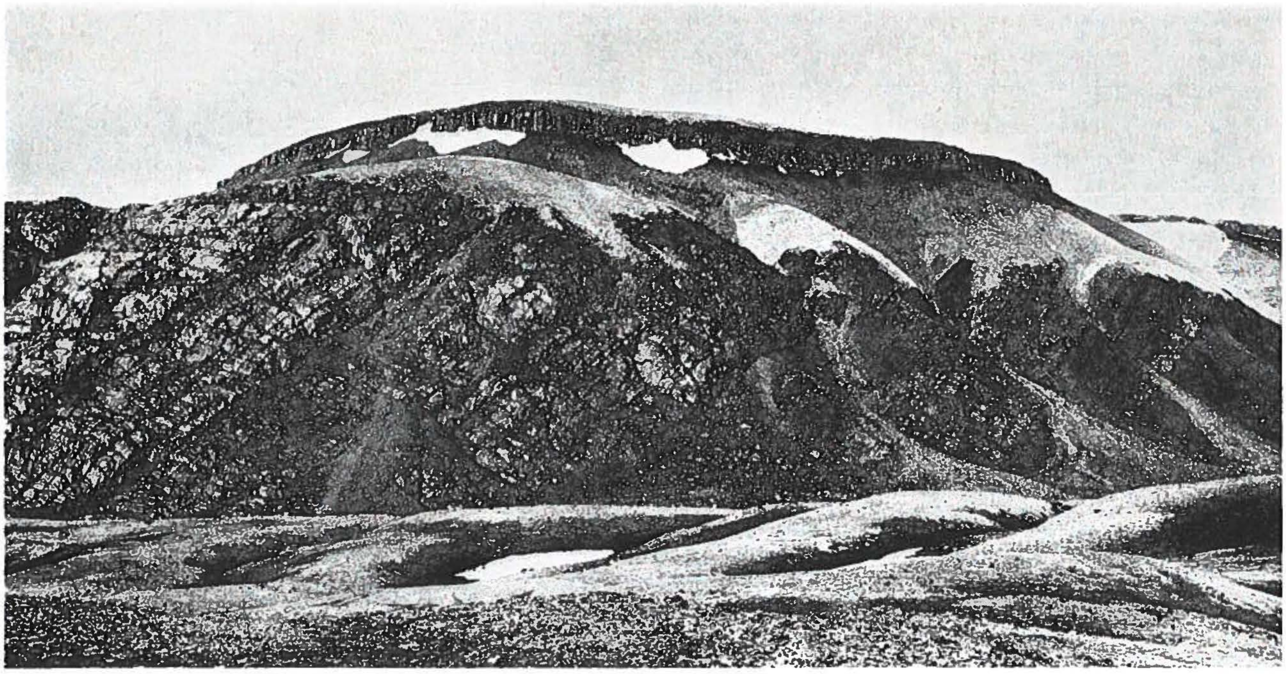


Fig. 229. Precambrian basement of steeply inclined variable gneisses, with some Etah Group metasedimentary layers to the right, overlain by the Proterozoic Rensselaer Bay Formation. A dolerite sill separates the mainly scree covered Hatherton Member from a thin veneer of the Sverdrup Member which forms the top of the hill. Height of the section above the foreground moraine is approximately 350 m. Hatherton Bugt, south-west Inglefield Land.

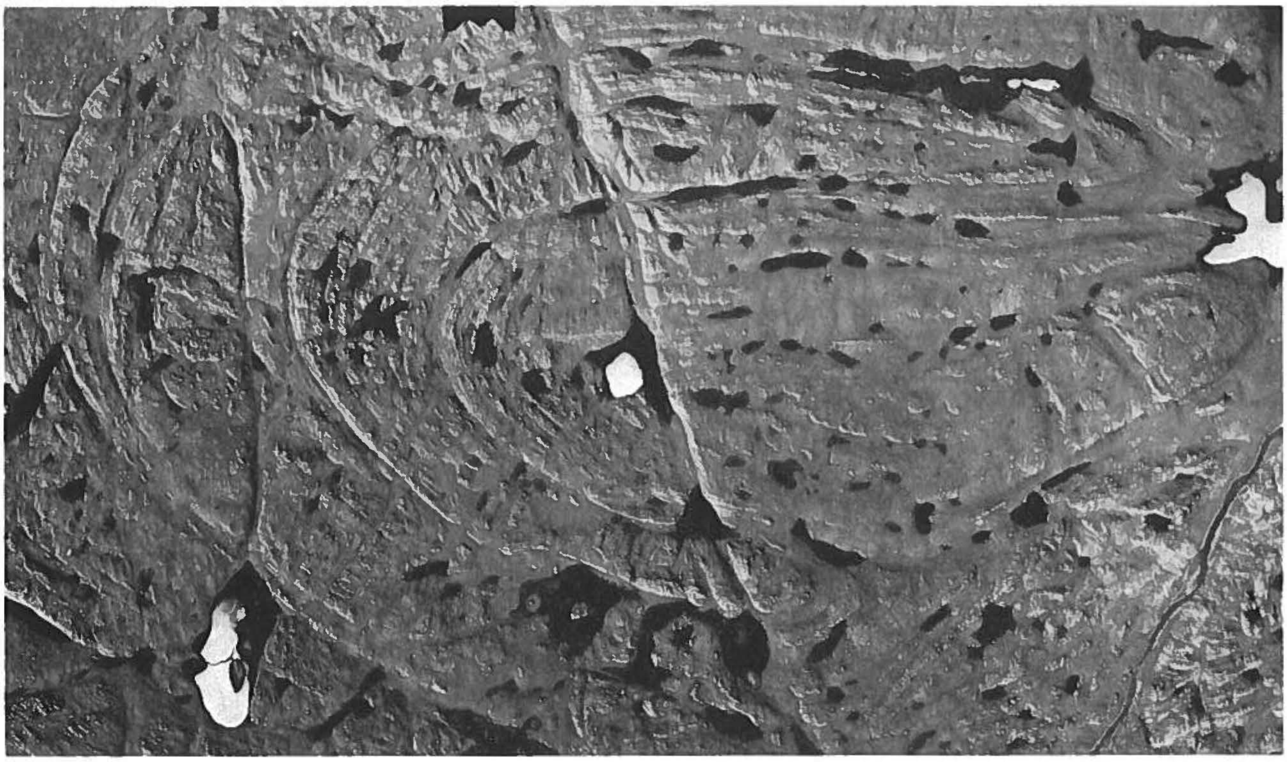


Fig. 230. A large isoclinally refolded structure in gneisses and supracrustal rocks of the Precambrian crystalline basement of northern Inglefield Land. The structure is about 10 km across. Aerial photograph 239 C, no. 79. Copyright Geodetic Institute.

veins. The foliation in the gneisses and schists is generally flat lying, or nearly so, and many leucocratic veins conform to this structure. The basement complex is cut by a number of undeformed, mainly east–west trending, basic dykes of unknown composition. The dykes have not been observed in unconformably overlying, Proterozoic sedimentary beds.

The crystalline rocks in south-east Wulff Land and adjacent nunataks form the Victoria Fjord arch (Dawes & Soper, 1973). Overlying undisturbed Proterozoic strata thicken eastwards away from the arch. The gentle arching during the late Precambrian was followed by stable platform conditions.

Structure

Regional foliation trends of the crystalline rocks in North-West Greenland are generally easterly to north-easterly, with variations to north-westerly in some areas. Much of the basement rock has undergone polyphase deformation and metamorphism producing complex fold patterns. A large isoclinally refolded structure in northern Inglefield Land is an example of the interference patterns resulting from such deformation (figs 224, 230).

The structural relationships between a few of the described rock units are known: (1) rocks of the gneiss, schist and granite unit form a basement to the supracrustal psammite and amphibolite unit; (2) the Qaqujârssuaq anorthosite is associated with the gneiss, schist and granite unit; (3) the Etah meta-igneous complex is younger than the Etah Group but is intimately associated with it in later events; (4) a major group of gneisses, described here as the variable gneiss unit, is younger than the Etah meta-igneous complex. No basement to the Etah Group has yet been recognised.

Age

K-Ar mineral dates on gneisses, schists and basic rocks from the gneiss, schist and granite unit, the Qaqujârssuaq anorthosite, the psammitic and amphibolite supracrustal unit and the Etah meta-igneous complex – geographically spaced from Carey Øer to south-west Inglefield Land – show a range from 1881 m.y. to 1610 m.y. (Larsen & Møller, 1968; Larsen & Dawes, 1974). This suggests that plutonic activity of Hudsonian age was of regional significance and probably affected the entire crystalline complex in northern Greenland.

A K-Ar whole-rock age determination on an undeformed basic dyke from a north-west trending swarm cutting the psammite and amphibolite supracrustal unit has given an age of 1563 ± 60 m.y. (Dawes *et al.*, 1973) suggesting that the regional thermal front had withdrawn by about 1500 m.y.

Rb-Sr whole rock analyses on a suite of samples from the Etah meta-igneous complex define an isochron corresponding to an age of 1960 m.y. interpreted as the age of the metamorphism of the complex (Larsen & Dawes, 1974). Some samples containing higher initial isotopic strontium ratios suggest that much older material is involved in the meta-igneous complex.

Evolution

Structural and age relationships between most rock units are still unknown or uncertain. However a tentative outline of history can be proposed, as follows. Granodioritic gneisses and schists were intruded by basic and ultramafic rocks and underwent polyphase deformation and metamorphism after which granites and pegmatites were emplaced. Psammitic supracrustal sediments were deposited and intruded by basic material and both the basement and the cover were subsequently deformed and metamorphosed. Basic dykes were then emplaced. The Etah Group may be a northern equivalent of the psammite and amphibolite unit to the south. In any case, following some metamorphism of the Etah Group, the Etah meta-igneous complex was emplaced, and both sediments and igneous rocks were subjected to severe, polyphase deformation and metamorphism leading to the formation of the variable gneiss unit.

North Greenland geosyncline and platform

The Proterozoic to middle Palaeozoic sedimentary rocks of northern Greenland were deposited over broad areas of contrasting tectonic character: in the south, relatively thin sequences of clastic and carbonate rocks in a stable platform region; to the north, thick sequences of argillaceous limestone and clastic sediments in a geosynclinal environment. The platform region lies peripheral to the present Inland Ice, and the geosynclinal region is now the North Greenland fold belt. The platform sediments of the hinterland pass without break into the geosynclinal fill of the orogenic belt to the north, the two sedimentary areas being separated by a shelf zone of carbonate rocks with reefs and off-reefal shales. Boundaries between these depositional sites are not precise. To the east the platform strata of the hinterland become the foreland deposits of the East Greenland fold belt.

'Platform' in this paper includes all hinterland regions of unfolded strata. 'Shelf' rocks marginal to the North Greenland geosyncline are included in the platform association, and the term 'miogeosyncline' is not used. The North Greenland geosyncline is the north-eastern part of the Franklinian geosyncline (Schuchert, 1923) of northern Canada and Greenland (fig. 222).

The youngest fossiliferous beds so far recognised in the platform are of Upper Silurian age, whereas in the geosyncline early Devonian beds are known. It seems probable that Devonian sediments extended across at least part of the platform but have been reduced or removed by erosion.

Proterozoic to Silurian rocks of the platform

Sedimentary rocks on the edge of the Greenland Shield range in age from middle Proterozoic to Silurian. Unconformities and glacial deposits mark the Proterozoic sedimentary sequence and while overlying Palaeozoic beds form a conformable sequence, certain breaks are suspected within the column. The Proterozoic units characteristically vary in thickness, or are discontinuous from west to east, while the Palaeozoic beds form a broad, continuous belt across northern Greenland. The greatest recorded thickness of Proterozoic rocks, in the Thule basin, is over 4500 m; the Cambrian to Silurian section is at least 3500 m thick in the middle platform region.

In the following an attempt has been made to describe separately the Proterozoic (including the Eocambrian), Cambrian, Ordovician and Silurian sections despite the fact that boundaries between the systems can only be indicated approximately in many areas.

Proterozoic and Eocambrian

The oldest sediments of the platform, middle Proterozoic in age, overlie the crystalline basement with profound unconformity (figs 225, 229). These sediments occur as widespread, generally homoclinal areas west and north of the margin of the Inland Ice. Tectonically high areas, or arches, divide the Proterozoic rocks into sedimentary basins. Three of these arches have been named: the Bache Peninsula arch, the Victoria Fjord arch and the Hagen Fjord arch. The first two expose Precambrian crystalline rocks, the third is evidently a much weaker structure (fig. 222).

The Bache Peninsula arch separates the Thule basin, containing a thick sedimentary and igneous sequence in the west, from a broad, north-dipping homocline region in which Proterozoic rocks are relatively thin. The Victoria Fjord arch has also had a significant effect on sedimentation and it penetrates northwards into the North Greenland geosyncline separating the thin sequence on the North Greenland homocline from a thicker succession in Peary Land to the east. The Hagen Fjord arch separates the Peary Land – Vildtland basin from an area described as a 'basin-and-swell region' characterised by repeated shift of basin axis during sedimentation (Haller, 1970). This region constitutes the Hagen Fjord – Danmark Fjord basin of this paper where sedimentation borders on the East Greenland geosyncline.

Any discussion of the older sediments of northern Greenland requires an assessment of the term 'Eocambrian', a name well established in the literature (Troelsen, 1949, 1950a, 1956; Jepsen, 1971b). Eocambrian has been applied to strata at many localities in the past but in this paper will be retained only for certain tillite-bearing rocks in Peary Land that can be compared with the classical 'Sparagmites' of Scandinavia.

New fossil finds in recent years have moved the Lower Cambrian boundary downward in Greenland sections, and it is here presumed that much of the so-called Eocambrian is part of the Cambrian system. However, because of the association of Eocambrian and Proterozoic rocks in the field and in the literature, the Eocambrian rocks will be described and discussed in this paper with the Proterozoic.

Thule basin

A thick section of Proterozoic strata – the Thule Group – is preserved in the Thule basin. Koch (1929a) suggested that the sediments of the Kap York – Prudhoe Land region had been laid down in a discrete basin south of the geosyncline. Troelsen (1956) recognised a 'structural high' separating the basin from Inglefield Land and Bache Peninsula to the north. Kerr (1967a) introduced the names Thule basin and Bache Peninsula arch for these structures.

The Thule Group is preserved mainly in down-faulted blocks on the crystalline basement (fig. 231) and reaches a composite thickness of over 4500 m (fig. 232). The rocks are horizontal or gently inclined with broad flexures; local tilting and drag folding occurs in association with major faults. The top of the succession is not seen and apart from stromatolites in some dolomites and trace fossils in some sandstones (Dawes & Bromley, 1975), the rocks are unfossiliferous.

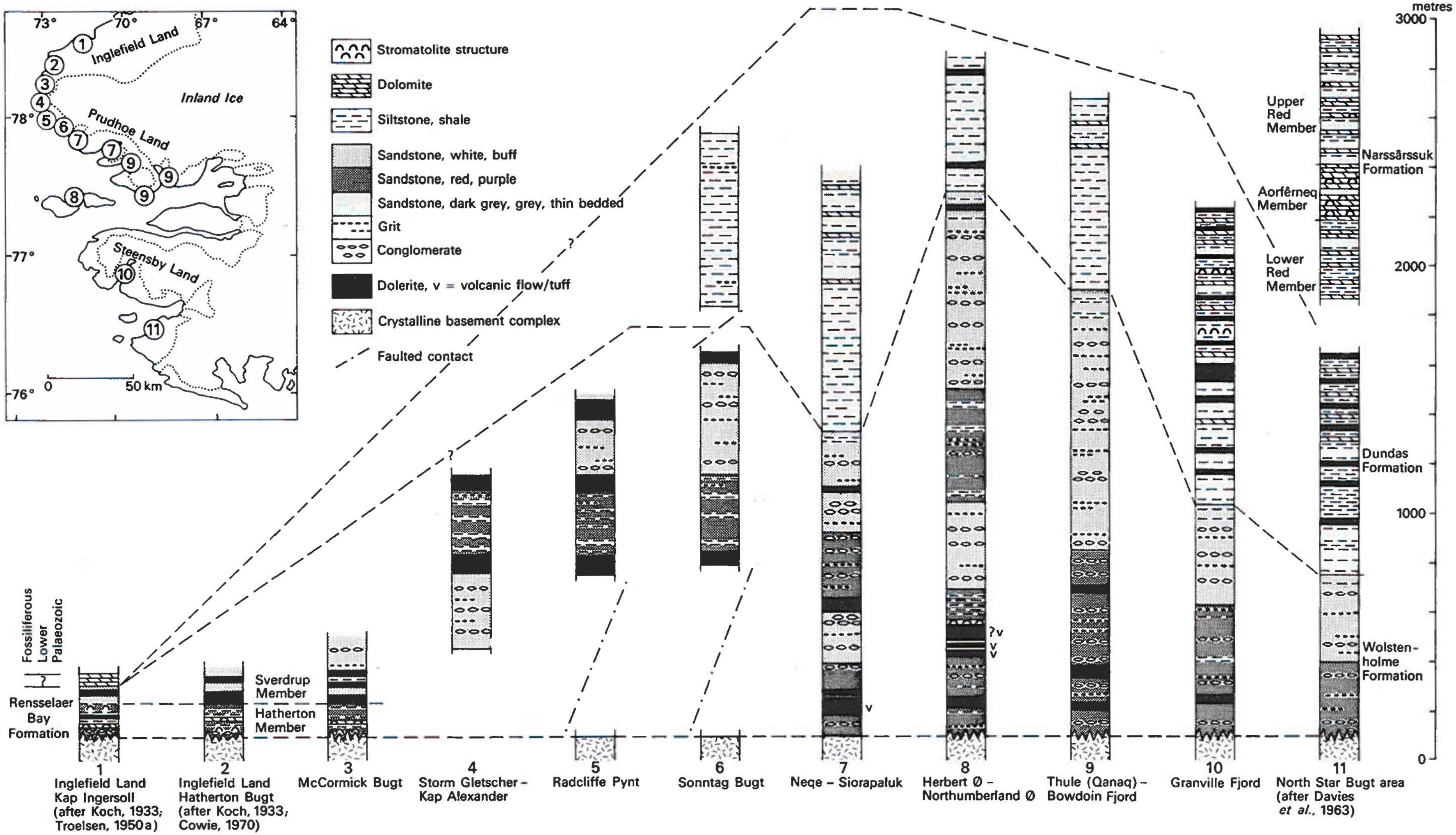
Fig. 231. A view westwards of the east–west fault line on the south coast of Olrik Fjord in the Thule basin; Precambrian basement on the left under the Inland Ice in juxtaposition with siltstones and shales of the Dundas Formation. On the north side of the fjord sandstones and conglomerates of the Wolstenholme Formation. Aerial photograph 543 L–V, no. 1351. Copyright Geodetic Institute.

Three formations constitute the Thule Group (Kurtz & Wales, 1951; Davies *et al.*, 1963).

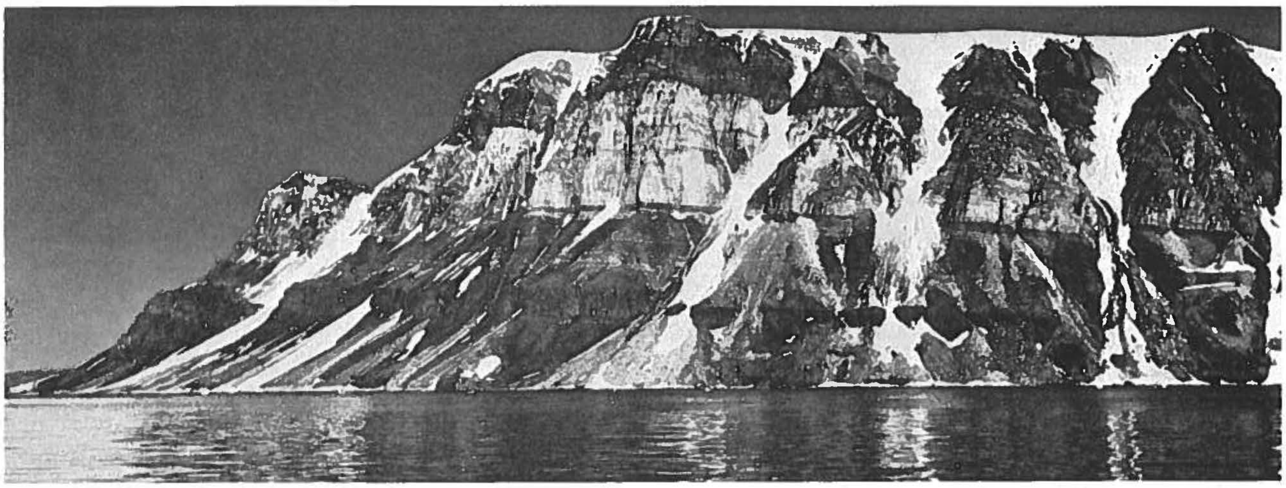
The *Wolstenholme Formation* (500–2000 m) at the base, is divided into four units (Dawes, 1975): a basal multicoloured unit of mainly ferruginous sandstone and shale with basic volcanic rocks and dolerite sills; a white to pink unit of mainly massive quartzite with conglomerate; a red to purple unit of ferruginous sandstone, siltstone, shale and conglomerate; and a buff to yellow unit of sandstone, quartzite and quartz pebble conglomerate. Cross-bedding and ripple marks are common in the sandstones. The most complete sections are in Prudhoe Land and on Northumberland Ø (fig. 233); to the south in the type area of Wolstenholme Ø and to the east in Inglefield Bredning the formation thins out and in places the lower two units are missing.

The *Dundas Formation*, a dark weathering, thin bedded sequence at least 1000 m thick, overlies the Wolstenholme Formation with gradational contact. The lower part of the formation is composed of alternating shale and fine-grained sandstone; upwards these rocks are interbedded with calcareous shale and dolomite. The grey and bluish grey, yellow to brown weathering, dolomites are often sulphide bearing and have a massive to platy lithology. Stromatolites and small reefs occur in places. The proportion of dolomite decreases northwards.

The youngest formation of the Thule Group, the *Narssârssuk Formation* (*c.* 1000 m), is composed of a sequence of multicoloured carbonate–clastic cyclic deposits (fig. 234). The formation has been recognised only in the southern part of the Thule basin where the contact with the Dundas



73°
70°
67°
64°
78°
77°
76°
Inglefield Land
Inland Ice
Prudhoe Land
Steensby Land
0
50 km
Stromatolite structure
Dolomite
Siltstone, shale
Sandstone, white, buff
Sandstone, red, purple
Sandstone, dark grey, grey, thin bedded
Grit
Conglomerate
Dolerite, v = volcanic flow/tuff
Crystalline basement complex
Faulted contact
metres
3000
2000
1000
0
Fossiliferous Lower Palaeozoic
Rensselaer Bay Formation
Sverdrup Member
Hatherton Member
Upper Red Member
Aorfêrneq Member
Lower Red Member
Narssârssuk Formation
Dundas Formation
Wolstenholme Formation
1 Inglefield Land Kap Ingersoll (after Koch, 1933; Troelsen, 1950a)
2 Inglefield Land Hatherton Bugt (after Koch, 1933; Cowie, 1970)
3 McCormick Bugt
4 Storm Gletscher - Kap Alexander
5 Radcliffe Pynt
6 Sonntag Bugt
7 Neqe - Siorapaluk
8 Herbert Ø - Northumberland Ø
9 Thule (Qanaq) - Bowdoin Fjord
10 Granville Fjord
11 North Star Bugt area (after Davies et al., 1963)



← Fig. 232. Generalised stratigraphical correlation chart of the late Precambrian successions (Thule Group) of Inglefield Land and the Thule basin. Positions of conglomerate units in the Wolstenholme Formation are diagrammatically indicated.

↑ Fig. 233. The lower part of the Wolstenholme Formation at Josephine Headland, western Northumberland Ø. A white quartzite unit in the middle of the section separates ferruginous lower and upper units. Volcanic rocks and dolerite sills form the dark resistant part of the lower unit. Height of the cliff approximately 900 m.

Formation is not exposed. There are three members: a basal Lower Red Member of grey and green dolomite, shale, sandstone and red siltstone, passing gradually upwards into the Aorfêrneq Dolomite Member of grey dolomite with some limestone and gypsum layers but lacking the red beds. Irregular bedding surfaces with stromatolites and stylolite structures are frequent in the dolomite. The Upper Red Member forms the top of the formation and has a similar lithology to the lower member.

Dolerite sills and dykes occur throughout the Thule basin and, where cross-cutting relationships can be interpreted, the dykes are invariably the younger. The sills vary in thickness from a few metres to about 100 m. Many are between 10 and 30 m thick and in some areas, as in southern Steensby Land and Wolstenholme Fjord, a sill system of 12 or more sills dominates the landscape. The dykes are mainly

Fig. 234. Cliff section on the south side of Saunders Ø, Thule district, illustrating the regular banding of the Narssârssuk Formation. Darkest layers are red siltstones marking the top of individual sedimentary cycles. Height of the cliff is approximately 300 m.

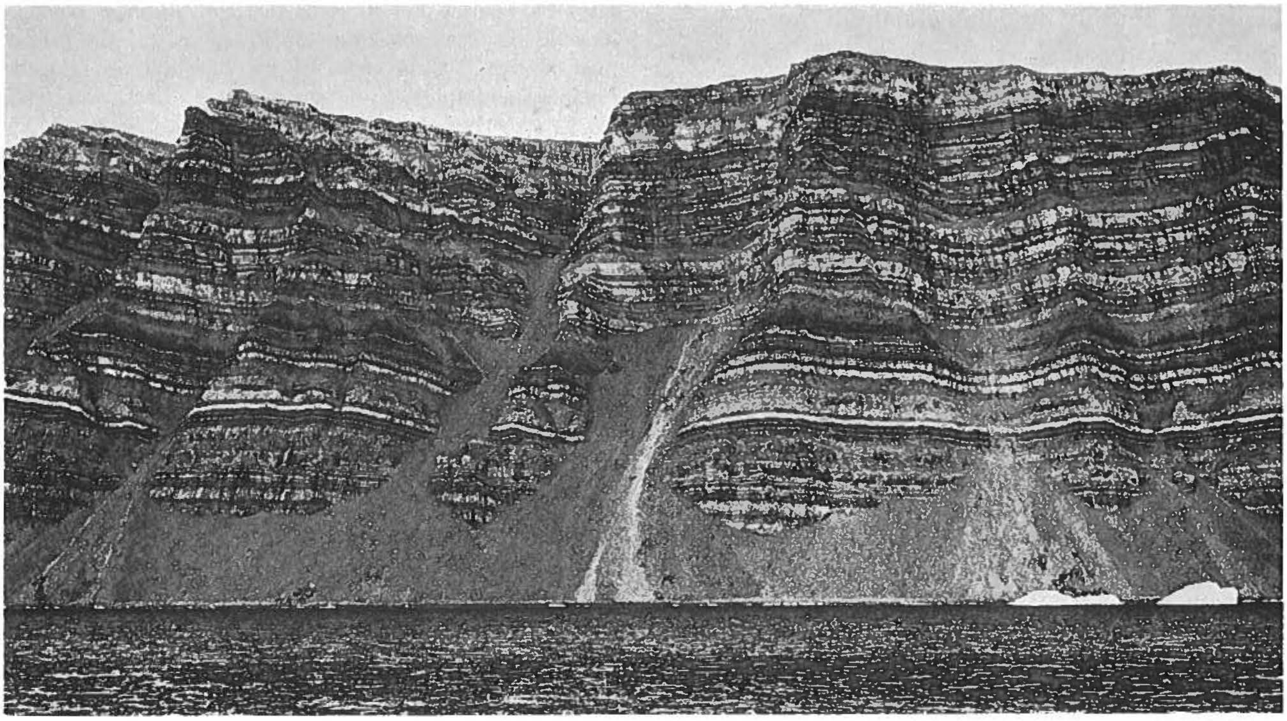


Fig. 235. Proterozoic to Lower Palaeozoic platform strata overlying the peneplained Precambrian basement surface at Marshall Bugt, Inglefield Land. Ellesmere Island in the distance. Aerial photograph 544 C-N, no. 11829. Copyright Geodetic Institute.

tens of metres thick, the largest reaching about 80 m. They form a prominent swarm with a general WNW–ESE trend in both basement and Proterozoic terrain and occur throughout the Thule basin.

In the southern part of the Thule basin the sills intrude, and evidently are restricted to, the Dundas Formation, but to the north in Prudhoe Land they are found only in the stratigraphically lower Wolstenholme Formation. Although no sills have been found in the Narssârssuk Formation, this unit is intruded by dykes of the WNW–ESE trending swarm.

Isotopic age determinations on dolerite sills suggest that the Wolstenholme Formation is at least 1200 m.y. old (Dawes *et al.*, 1973). An isotopic age of 676 ± 25 m.y. has been obtained from a dyke of the WNW–ESE trending swarm cutting the Dundas Formation. Assuming that this is a minimum age and representative of the swarm, the determination indicates that the entire Thule Group is of Precambrian age.

Thus, from the distribution of intrusions and from their ages, it appears that while the basal beds of the Thule basin are relatively old i.e. middle Proterozoic, it is possible that the highest part of the Thule Group *sensu stricto* is of latest Precambrian age.

North Greenland homocline

A relatively thin succession of Proterozoic rocks characterises the North Greenland homocline in the two areas where crystalline basement is exposed, namely Inglefield Land and the Victoria Fjord arch (fig. 232).

In Inglefield Land a 200 m section of sandstone and dolomite is overlain by fossiliferous Lower Palaeozoic rocks (Koch, 1933; Troelsen, 1950a). These rocks have a persistent shallow northerly dip and form outliers on the crystalline basement peneplain (fig. 235).

At the base of the section the *Rensselaer Bay Formation* (140 m thick at Rensselaer Bugt) is divisible into a lower *Hatherton Member* of red to purple ferruginous sandstones and coloured shales, as well as some dolomitic rocks bearing stromatolites, and an upper *Sverdrup Member* of cream, buff and yellow sandstones with siltstones (fig. 229). Ripple marks and cross-bedding characterise both members. East of Kap Inglefield the Rensselaer Bay Formation is overlain by grey to yellow, medium to fine grained dolomites of uncertain age, divisible into the *Cape Leiper Formation* (*c.* 40 m) below, and the *Cape Ingersoll Formation* (*c.* 10 m) above (fig. 240). The contact between the two dolomites is an ordinary diastem. Apart from stromatolites (Koch, 1929a) the section is unfossiliferous.

The *Wulff River Formation*, containing Lower Cambrian fossils, overlies this sequence disconformably (Troelsen, 1950a). In south-west Inglefield Land the Cape Leiper and Cape Ingersoll Formations, and the overlying Cambrian, are not present (probably due to erosion rather than to non-deposition) and the Rensselaer Bay Formation alone can be traced southwards to McCormick Bugt where a thickness of at least 280 m of sediment has been preserved. The stratigraphical conditions around Kap Alexander are complicated by faulting but it seems that the Sverdrup Member increases in thickness from about 160 m at McCormick Bugt to over 300 m south of the cape and in northern Prudhoe Land (fig. 232).

In south-western Inglefield Land the Rensselaer Bay Formation contains dolerite sills, the largest of which reaches about 60 m thickness. Two sills are traceable over a long distance, but at Rensselaer Bugt, and to the north-east, no igneous material has been seen in the section, apart from a single dolerite dyke within the Rensselaer Bay Formation in the vicinity of Kap Leiper (Koch, 1933). The highest stratigraphic position reached by an igneous sill is evidently the boundary between the Rensselaer Bay Formation and the overlying dolomite (Cowie, 1961a). Isotopic age determinations on the sill rocks imply a middle Proterozoic age for the sediments (Dawes *et al.*, 1973). Whether the highest sill was in part intruded along the contact or whether the Cape Leiper Formation was deposited on a stripped and eroded surface of the sill is uncertain. Thus, while little or

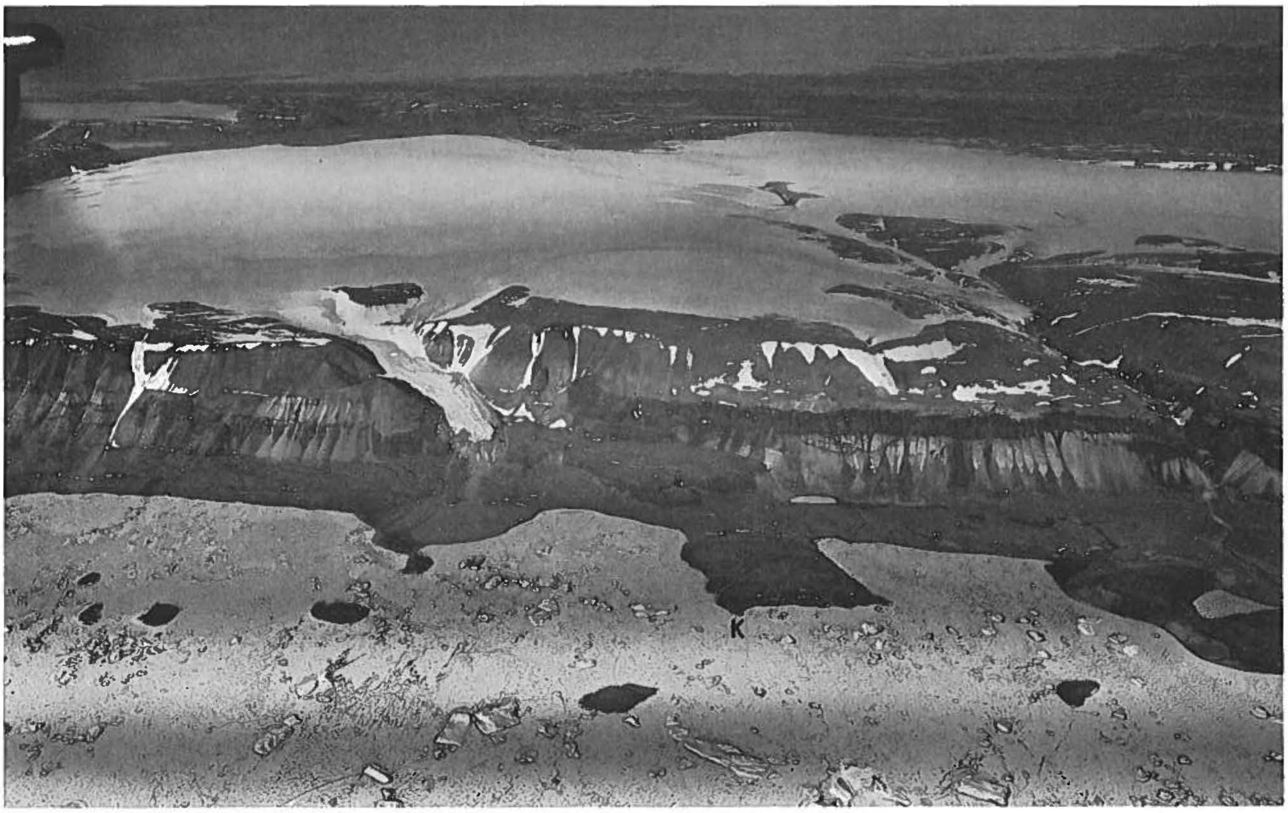


Fig. 236. Dolerite sills and dykes cutting the Inuiteq Sø Formation, southern coast of Heilprin Land, at the head of Independence Fjord. Kap Ejnar Mikkelsen (K) and other promontories and islands are of dolerite. View is north-west towards Hans Tavsens Iskappe with the mountains of the North Greenland fold belt in the right distant background. Aerial photograph 548 D-N, no. 1118. Copyright Geodetic Institute.

no doubt remains that the entire Rensselaer Bay Formation, including its uppermost part, the Sverdrup Member, is Proterozoic, the age of the two overlying dolomite units is uncertain. This uncertainty remains because, although Lower Cambrian beds rest upon the dolomite, no diagnostic fossils have been found in either of the dolomite units.

Proterozoic rocks over the Victoria Fjord arch, if present, are relatively thin (fig. 240). The basement is cut by undeformed basic dykes which are unconformably overlain by a shallow northerly dipping, light coloured sedimentary sequence. In south-eastern Wulff Land a *c.* 200 m section composed mainly of quartzites and sandstones with conglomerate at the base is overlain by shales and limestones which have yielded Lower Cambrian fossils (Greenarctic Consortium, personal communication). Basic intrusions of the type characteristic of other Proterozoic rocks throughout North Greenland appear to be absent, and it seems possible that the lower parts of the section also contain Cambrian elements; the structural level of the arch led to sporadic and slow deposition or accelerated erosion of Proterozoic rocks.

South Peary Land – Vildtland basin

A section of Proterozoic, Eocambrian and fossiliferous Lower Cambrian rocks occurs in southern Peary Land (fig. 240; Koch, 1923, 1929a; Troelsen,

Fig. 237. A view in southern Peary Land showing sandstones of the Inuiteq Sø Formation (I) and at the top of the cliff banded dolomites of the Portfjeld Formation (P). The intervening Moræneso Formation is only 10 m thick at this locality and is not easily seen in the photograph. The Inuiteq Sø Formation is intruded by dolerite sills and dykes; the intrusions are truncated by the unconformity at the top of the Inuiteq Sø Formation. The cliffs are about 800 m high.

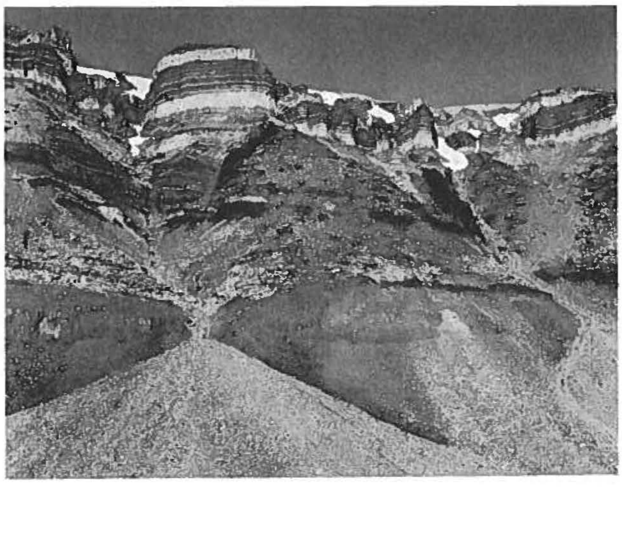


Fig. 238. Tillite of the Moraenesø Formation at Moraenesø, southern Peary Land. Boulders are quartzite and quartz dolerite. Length of the hammer is 45 cm.

1949, 1956; Jepsen, 1971a,b). The base of the sedimentary pile is not exposed. The strata thin towards the Victoria Fjord arch and southwards towards the Inland Ice. The eastern limit of the basin is less well defined at the Hagen Fjord arch over which the stratigraphy is essentially continuous.

The rocks of the basin have a shallow northerly dip of a few degrees. Some steeper dips are associated with certain steeply inclined faults.

The *Inuiteq Sø Formation*, the oldest exposed part of the sequence, is composed of white, yellow and brown cross-bedded and ripple-marked feldspathic sandstone, grit and conglomerate with some minor shale and dolomite units. According to Koch (1923) effusive beds of basic to acidic composition occur in the sequence in the vicinity of Independence Fjord. The formation is at least 900 m thick and is everywhere penetrated by dolerite dykes and sills (figs 236, 237) and by some acidic intrusions.

The formation and the intrusions are unconformably overlain by the *Moraenesø Formation*, a unit up to 130 m thick, composed of a basal brownish quartzite and sandstone breccia, overlain by a dark reddish brown, thick bedded tillite. The tillite varies in thickness from 0 to 100 m and has a fine to medium-grained feldspathic greywacke matrix with a clay fraction of over 30 per cent. Carbonate and hematite occur as cementing material. The blocks range up to about 1 m in diameter and form up to 20 per cent of the rock (fig. 238). They are composed of locally derived sandstone and quartz dolerite as well as granitic gneiss and folded quartzite. Some blocks are marked by glacial striae. The tillite is overlain by fine-grained dolomite containing large stromatolites of *Cryptozoon* type (fig. 239) and an upper thin conglomeratic quartzite unit.

The Inuiteq Sø Formation and the associated basic intrusions were eroded prior to the deposition of the tillite; a glaciation correlated by Troelsen (1956) with the Varangian of Scandinavia. Isotopic age determinations on two dolerite samples from the Inuiteq Sø Formation have given K-Ar ages of 799 ± 68 m.y. and 982 ± 19 m.y. An $^{40}Ar/^{39}Ar$ spectrum analysis gave 988 ± 20 m.y. for the latter confirming the date and indicating that these dates are minimum ages for the intrusions (Henriksen & Jepsen, 1970). These dates prove that the Inuiteq Sø Formation is at least 1000 m.y. old, i.e. middle Proterozoic.

An important period of erosion followed the deposition of the Moraenesø Formation and in places the complete thickness of this unit was removed prior to the deposition of overlying carbonate rocks.

Fig. 239. Large stromatolite structures in dolomites of the Moraenesø Formation at Moraenesø, southern Peary Land.

Thus the Portfjeld Formation, about 206 m thick in the Jørgen Brønlund Fjord area (Jepsen, 1971b), transgresses over both the Inuiteq Sø Formation and the Moræneso Formation.

The *Portfjeld Formation* is composed essentially of fine-grained, thick to thin bedded dolomite with a single quartzite band. The dolomite is in places silicified and contains some black chert lenses and layers. Intraformational conglomerates are frequent. Stromatolites of the *Collenia* type characterise some dolomite units while the cherts have yielded microfossils showing distinct affinities to the thread-like *Eomycetopsis* and the globular form *Myxococcoides* known from a late Precambrian microflora in Australia (Pedersen, 1970).

To the south of Jørgen Brønlund Fjord both the Morænesø and Portfjeld Formations thin and peter out.

Hagen Fjord – Danmark Fjord basin

The stratigraphy of the Hagen Fjord – Danmark Fjord basin is similar to that in southern Peary Land: a middle to late Proterozoic clastic sequence cut by igneous dykes and sills is unconformably overlain by a mixed succession lacking such intrusions (fig. 240). The oldest Proterozoic rocks at the base are mainly flat lying but towards the east in central Kronprins Christian Land rocks are involved in the Carolinidian orogenesis (Haller, 1961). The Carolinidian fold belt, reviewed in some detail in this volume (Henriksen & Higgins), forms the eastern boundary of the Hagen Fjord – Danmark Fjord basin as described here. The youngest rocks of the basin are equivalent to the Eocambrian rocks of southern Peary Land and are part of the Hagen Fjord Group of Haller (1970). This group is represented by a thick sedimentary sequence in the East Greenland fold belt.

Stratigraphical dips are flat or gently northerly in the western part of the basin, and easterly in the eastern part where the strata become part of the foreland of the East Greenland fold belt. Folds, thrusts and faults in the western part of Kronprins Christian Land and Valdemar Glückstadt Land are the marginal structures of this orogenic belt.

The basal unit, the *Norsemandal Formation* (Adams & Cowie, 1953), is present throughout the basin and reaches over 1000 m thick. It is composed of red sandstone and grey to white quartzites with grit and conglomerate beds. Ripple marks and cross-bedding are present. Effusive rocks of acid to basic composition occur in the clastic succession (Koch, 1923) as well as the dolerite sills and dykes referred to above. These volcanic rocks are now known to include bedded units up to 200 m thick composed of amygdaloidal basalt and porphyrite displaying well developed flow structures, possible agglomerates, tuffs and intercalated sills (Greenarctic Consortium, personal communication).

A major unconformity separates the Norsemandal Formation with intrusions from the overlying sandstones and limestones, the thickness of which varies in different parts of the basin (fig. 240). In the Danmark Fjord area the section consists of: a basal unit at least 200 m thick of light coloured sandstone and conglomerate with shale; 150 m of green, glauconitic sandstone and shale and 100 m of reddish brown limestone with stromatolites which make up the *Campanuladal Formation* (Adams & Cowie, 1953); and conformably overlying light grey, stromatolitic dolomite about 330 m thick, the *Fyns Sø Formation*. The succession is unconformably overlain by strata of presumed Lower Cambrian age.

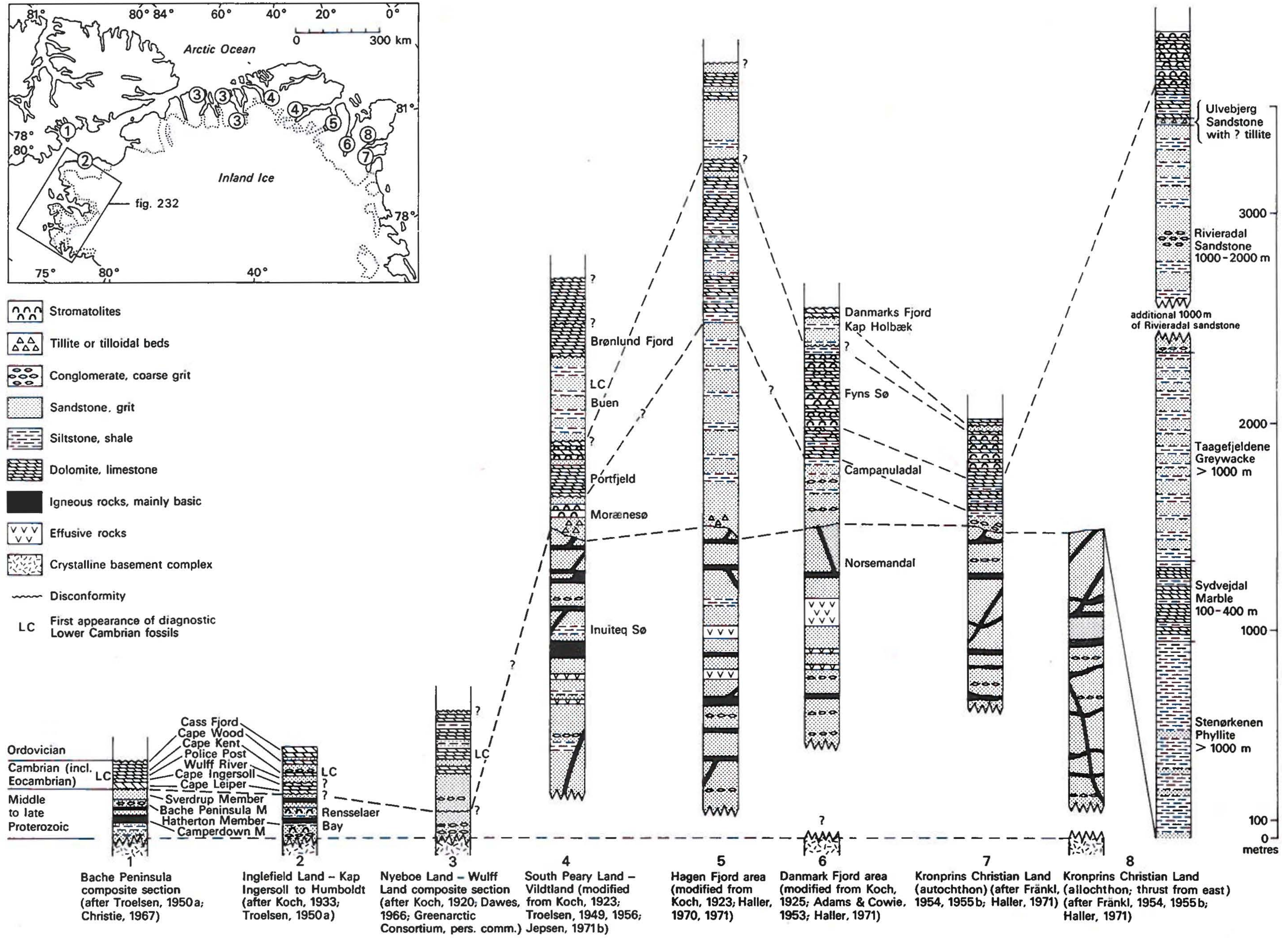
To the west in Hagen Fjord the section overlying the Proterozoic clastic and igneous rocks is apparently thicker. According to Haller (1971) it consists of 1000 m of light coloured clastics, 400 m of reddish brown shaly-sand to limy-shale strata, 350 m of grey dolomite, and capping it, 200 m of presumed Lower Cambrian red sandstones.

To the east within the East Greenland fold belt (Henriksen & Higgins, this volume) the Hagen Fjord Group forms a 4000–5000 m sedimentary sequence preserved in westerly directed thrust slices, as well as a much thinner autochthon section showing clear similarities to the succession in the Hagen Fjord – Danmark Fjord basin (fig. 240). The allochthon sequence is described as containing possible tillite horizons in its upper part (Fränkl, 1954; Haller, 1971).

Correlation of Proterozoic and Eocambrian rocks

Late Precambrian strata of northern Greenland have generally been correlated by means of their position beneath fossiliferous Cambrian beds, and by matching stratigraphy, including unconformities and the presence of basic sills. Thus Koch (1929a) suggested that the sandstone–dolomite section in Inglefield Land (which underlies Cambrian beds) could be correlated with his Thule Formation in the Wolstenholme Fjord area on the basis of similar lithology and presence of sills.

On a regional scale, Koch envisaged the presence of a late Precambrian sedimentary series that had been invaded by igneous material, eroded, and unconformably overlain by strata free of intrusions. Such relationships occur widely, and Haller (1970) used the name Thule Group for lower, dolerite intruded beds in the East Greenland fold belt that he regarded as older than the Carolonidian orogeny. However, the age of the uppermost beds of the Thule Group *sensu stricto* is not known, but may be of late Precambrian, post-Carolinidian age. For this reason, the name Thule Group is restricted in this paper to



81°
80° 84°
60°
40°
20°
0°
0
300 km
Arctic Ocean
78°
80°
81°
78°
Inland Ice
fig. 232
75°
80°
40°
Stromatolites
Tillite or tilloidal beds
Conglomerate, coarse grit
Sandstone, grit
Siltstone, shale
Dolomite, limestone
Igneous rocks, mainly basic
Effusive rocks
Crystalline basement complex
Disconformity
LC First appearance of diagnostic Lower Cambrian fossils
Ordovician
Cambrian (incl. Eocambrian)
Middle to late Proterozoic
LC
Cass Fjord
Cape Wood
Cape Kent
Police Post
Wulff River
Cape Ingersoll
Cape Leiper
Sverdrup Member
Bache Peninsula M
Hatherton Member
Camperdown M
LC
Rensselaer Bay
Brønlund Fjord
LC
Buen
Portfjeld
Moræneso
Inuiteq Sø
Danmarks Fjord
Kap Holbæk
Fyns Sø
Campanuladal
Norsemandal
Ulvebjerg Sandstone with ? tillite
Rivieradal Sandstone 1000-2000 m
additional 1000 m of Rivieradal sandstone
Taagefjeldene Greywacke > 1000 m
Sydvejdal Marble 100-400 m
Stenørkenen Phyllite > 1000 m
3000
2000
1000
100
0
metres
1
Bache Peninsula composite section (after Troelsen, 1950a; Christie, 1967)
2
Inglefield Land – Kap Ingersoll to Humboldt (after Koch, 1933; Troelsen, 1950a)
3
Nyeboe Land – Wulff Land composite section (after Koch, 1920; Dawes, 1966; Greenarctic Consortium, pers. comm.)
4
South Peary Land – Vildtland (modified from Koch, 1923; Troelsen, 1949, 1956; Jepsen, 1971b)
5
Hagen Fjord area (modified from Koch, 1923; Haller, 1970, 1971)
6
Danmark Fjord area (modified from Koch, 1925; Adams & Cowie, 1953; Haller, 1971)
7
Kronprins Christian Land (autochthon) (after Fränkl, 1954, 1955b; Haller, 1971)
8
Kronprins Christian Land (allochthon; thrust from east) (after Fränkl, 1954, 1955b; Haller, 1971)

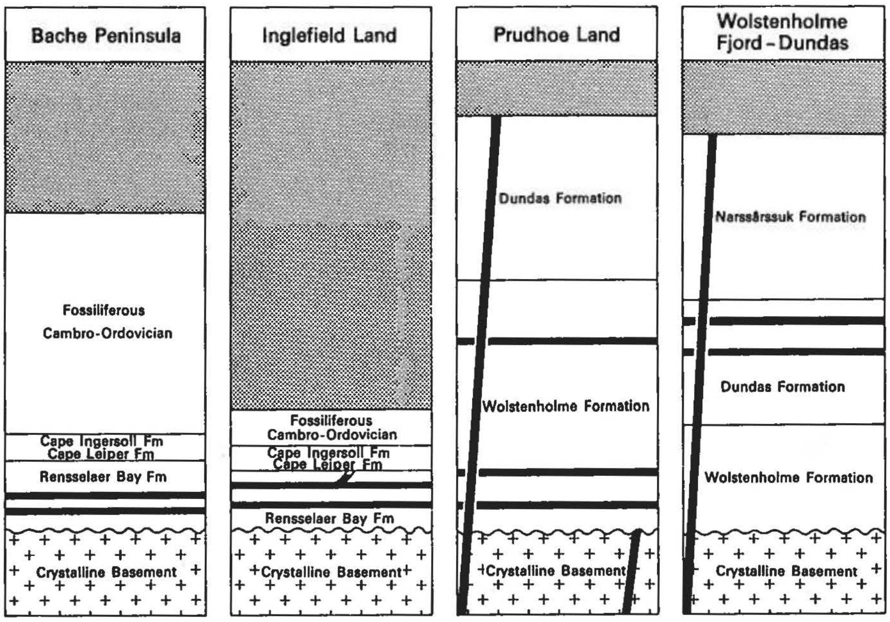


Fig. 241. Diagram of Proterozoic and younger sedimentary units, and basic intrusions, of North-West Greenland and adjacent Ellesmere Island. Approximate relative thicknesses are shown. From Dawes *et al.* (1973) with additions.

beds in the type area and to certain correlatable strata in adjacent Inglefield Land.

From isotopic age determinations it is almost certain that the entire Thule Group is Precambrian. It is also clear that the lower part of the Thule Group (the Wolstenholme Formation) is correlatable with the Rensselaer Bay Formation of Inglefield Land. Age determinations from a sill in the Rensselaer Bay Formation confirm a Proterozoic age for that unit (Dawes *et al.*, 1973). The age of the overlying Cape Leiper and Cape Ingersoll Formations remains uncertain, although from stratigraphical considerations the comparable succession in Bache Peninsula in Ellesmere Island (figs 240, 241) has been assigned to the Lower Cambrian (Christie, 1967; Kerr, 1967a, b; Cowie, 1968). However, evidence is not conclusive and the dolomites could be entirely or in part Proterozoic in which case correlation with the Narssârssuk Formation of the Thule basin, as envisaged by Koch (1929a), could still be achieved.

No tillite has been found in the Proterozoic beds of North-West Greenland and, lacking other equally distinctive features, no reliable correlation can be made with the rocks east of the Victoria Fjord arch.

The unconformity above the Norsemandal Formation in eastern North Greenland can be compared with that above the Inuiteq Sø Formation in Peary Land, a discontinuity that is observable as far west as the Victoria Fjord arch. Few or no effects of the East Greenland Carolinidian orogeny, other than this possible regional unconformity, can be detected across northern Greenland.

Tillite or possible tillite has been identified at similar stratigraphic positions in southern Peary Land (Troelsen, 1956; Jepsen, 1971b) and in Kronprins Christian Land within the East Greenland fold belt (Fränkl, 1954; Haller, 1971) in each case associated with sandstone and overlain by limestone and dolomite (fig. 240). A marked unconformity separates the Moræneso Formation, with its tillite, and the overlying Portfjeld Formation of southern Peary Land. Although no such break in sedimentation has been recognised in the Hagen Fjord – Danmark Fjord basin or in Kronprins Christian Land (that is below the Fyns Sø Formation) it remains possible that the erosion which removed the Moræneso Formation in places in Peary Land also obliterated evidence of glaciation in the Hagen Fjord – Danmark Fjord basin.

Cambrian

Cambrian rocks outcrop in a narrow belt trending north-eastward from Inglefield Land to southern Peary Land. Presumed Cambrian beds also are present in the Hagen Fjord – Danmark Fjord basin. Sections in Inglefield Land and in Peary Land are the best known.

←

Fig. 240. Generalised stratigraphical correlation chart of middle Proterozoic to Cambrian successions across North Greenland and to Bache Peninsula in Canada. Carolinidian orogenic distortion of sills and undeformed intrusions of post-Carolinidian age in Kronprins Christian Land are shown diagrammatically in sections 7 and 8.

Inglefield Land

Known Lower and Middle Cambrian units in Inglefield Land contain limestone with sandstone and conglomerate. Upper Cambrian is not known but may prove to be present. The position of the base of the Cambrian is uncertain, but may lie as low as the base of the unfossiliferous dolomites beneath the Wulff River Formation (fig. 240).

The **Lower Cambrian** *Wulff River Formation* overlies the unfossiliferous Cape Ingersoll Formation disconformably (Troelsen, 1950a). The formation is 35 m thick near the type locality and is composed of a basal conglomerate overlain by dense grey limestone with subordinate thin glauconitic sandstone and conglomerate layers which are more frequent in the upper part. Conglomerates decrease in abundance southwards and in the Kap Ingersoll area the formation is composed of less than 5 m of glauconitic sandstone and siltstone (Cowie, 1961a). The conglomerates contain well rounded sandstone, quartz and dolerite pebbles and according to Koch (1929a) the fossils *Paterina* and *Acrothele(?)* in certain pebbles indicate Cambrian sedimentation earlier than deposition of the Wulff River Formation.

A moderately rich fauna includes the olenellid trilobites *Wanneria, Olenellus, Holmia, Callavia(?), Paedeumias,* as well as *Bonnia* and *Strenuaeva*, brachiopods *Kutorgina* and *Botsfordia*, and *Salterella expansa*, indicative of a middle to late Lower Cambrian age (Poulsen, 1927, 1958).

The *Cape Kent Formation*, a rather pure, yellow to cream oolitic limestone 10–20 m thick and of uniform character, follows on conformably with a sharp boundary. At Kap Ingersoll the formation is represented by about 8 m of unfossiliferous dolomite and glauconitic sandstone and shale (Cowie, 1961a).

The fauna from north-eastern Inglefield Land includes the olenellid trilobites *Bristolia* and *Olenellus* and a distinctive suite including *Inglefieldia, Poulsenia, Dolichometopsis* and *Kochiella*, as well as *Hyolithes*, indicative of a late Lower Cambrian age (Poulsen, 1927). However, the presence of *Inglefieldia, Kochiella* and *Dolichometopsis* in supposed Middle Cambrian rocks in northern Canada (Cowie, 1970) suggests a possible extension of the Cape Kent Formation into the early Middle Cambrian.

The **Middle Cambrian** is represented by the *Cape Wood Formation* of Poulsen (1946) and Troelsen (1950a) which includes the Cape Wood, Cape Frederick VII and the Pemmican River Formations of Poulsen (1927) and Koch (1929a). The formation varies considerably in lithology both laterally and vertically. A basal conglomerate resting on the eroded Cape Kent Formation passes upwards into glauconitic sandstone, argillaceous and arenaceous limestone, dolomite and conglomerate, constituting the *Cape Russell Member* (45–90 m). At Kap Ingersoll the member contains much intraformational conglomerate and breccia. The overlying *Blomsterbæk Member* (2–5 m) contains a thin basal conglomerate overlain by thin bedded, fine-grained limestone and dolomite; in places it is composed of massive grey limestone.

Fossils from the Cape Wood Formation indicate a middle Middle Cambrian age (Poulsen, 1964). The Cape Russell Member is correlatable with the Pacific standard zone of *Glossopleura* with a trilobite fauna containing *Glossopleura Clavaspidella, Polypleuraspis, Poulseniella* and *Prosymphysurus*, in which both the *Glossopleura* and *Clavaspidella* faunules can be distinguished. The Blomsterbæk Member has yielded trilobites including *Blainiopsis, Elrathiella, Glyphaspis* and *Acrocephalops* and is correlatable with the younger *Bathyuriscus–Elrathina* Zone, more precisely the *Blainiopsis* faunule. An assemblage containing *Fieldaspis, Amecephalus* and *Kochaspis(?)* from loose conglomeratic material suggests the presence of the *Plagiura–Poliella* Zone of early Middle Cambrian age either as *in situ* beds or as components in conglomerates.

Washington Land

Cambrian rocks outcrop in a belt adjacent to the Humboldt Gletscher and contain at least some of the formations recognised in Inglefield Land. The succession is composed of limestone and dolomite with frequent intraformational conglomerate and breccia. Middle Cambrian and possibly Lower Cambrian strata are represented. Fossils indicating an Upper Cambrian age have been obtained from dolomites east of Cass Fjord by a field party of Greenarctic Consortium (personal communication). This discovery is of great interest in view of the assumed absence of Upper Cambrian strata in both Greenland and the Canadian Arctic.

This Washington Land fauna includes trilobites among which the early Upper Cambrian (Dresbachian) genera *Cedarina*(?), *Kingstonia* and *Komaspidella*, and the middle Upper Cambrian (Franconian) genus *Sulcocephalus* are the most important; the brachiopod *Linnarssonella*, monoplacophorans *Sinuella* and *Scenella*, and the late Upper Cambrian – Lower Ordovician (Tremadocian) gastropod *Chepultapecia*(?), as well as *Hyolithes*, also occur. The assemblages suggest a large vertical range of Upper Cambrian strata from the early *Cedaria* Zone to the *Prosaukia* and *Saukia* Zones on the North American standard scale and suggest a transition into the Lower Ordovician.

Wulff Land

A section containing Lower Cambrian fossils overlies clastic rocks of probable Proterozoic age in south-eastern Wulff Land on the west side of the Victoria Fjord arch (Greenarctic Consortium, personal communication). Glauconitic sandstone, shale and limestone, with some conglomerate, probably represent the basal Cambrian beds; this section passes upwards into limestone and dolomite that have yielded the trilobites *Olenellus* and *Callavia* and the brachiopods *Wimanella* and *Botsfordia*. Younger Cambrian beds are most probably present in this section which is overlain by fossiliferous Ordovician carbonates.

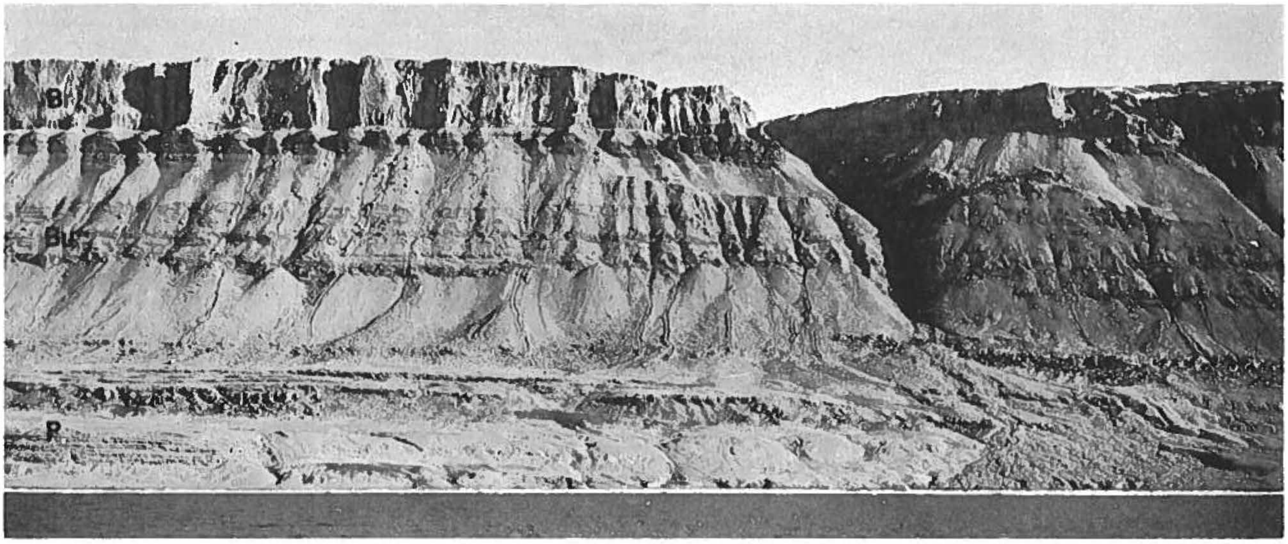


Fig. 242. Cambrian section in the cliffs at Buen on the northern side of Jørgen Brønlund Fjord, southern Peary Land. Height of the section from the fjord is about 700 m. Portfjeld Formation (P, ?Cambrian) at the base is overlain by the recessive Buen Formation (Bu, Lower Cambrian) with the Brønlund Fjord Formation (Br, Lower Cambrian and ?younger) forming the top of the section.

Peary Land

Lower and Middle Cambrian strata are known from Peary Land but the range both upwards and downwards of Cambrian beds is uncertain.

The *Buen Formation* (fig. 242), about 425 m of alternating sandstone, shale and greywacke, is evidently a turbidite sequence. It is overlain abruptly by the *Brønlund Fjord Formation*, about 150 m of massive cliff forming dolomite and intraformational dolomitic conglomerate (Troelsen, 1949; Jepsen, 1971b). *Holmia hyperborea*, indicative of a middle Lower Cambrian age, occurs near the top of the Buen Formation (V. Poulsen, 1974). Olenellid trilobite fragments and *Bonnia*, brachiopods including *Obolella* and *Botsfordia* as well as *Salterella*, hyolithids, gastropods and *Chancelloria* from the basal part of the Brønlund Fjord Formation, indicate a Lower Cambrian age (Troelsen, 1956; Peel *et al.*, 1974; Peel & Christie, 1975).

The Brønlund Fjord Formation in the east is overlain by Lower Ordovician carbonate beds, and the age of the middle and upper parts of the formation is uncertain. In the west a succession of dolomite and oolitic limestone at least 200 m thick occurs between the Brønlund Fjord Formation and strata of Lower Ordovician age. A fauna from the lower part includes the trilobite *Peronopsis* and the gastropod *Helcionella* (J. S. Peel, personal communication) indicative of a Middle Cambrian age. Downwards the Buen Formation conformably overlies the ?Cambrian Portfjeld Formation and the Eocambrian Moræsnesø Formation. The Buen Formation transgresses the latter units, which thin and peter out southwards, and in Heilprin Land it rests on the Proterozoic Inuiteq Sø Formation (Jepsen, 1971a).

Danmark Fjord region

The presence of Cambrian beds in Valdemar Glückstadt Land and western Kronprins Christian Land (figs 240, 243) is suspected from imperfect *Skolithus* in the *Kap Holbæk Formation* (Cowie, 1961a). The lithologies and stratigraphic positions of this and adjacent units compare plausibly with formations in southern Peary Land. Thus, the Fyns Sø Formation and the Campanuladal Formation contain stromatolites and occupy a position similar to that of the Portfjeld Formation. Overlying it with a slight erosional unconformity is the Kap Holbæk Formation, about 135 m thick, composed of three sandstone and two quartzite units. Disconformably overlying this is the *Danmarks Fjord Formation,* a dolomite 10 to 30 m thick, which could be a correlative of the Brønlund Fjord Formation.

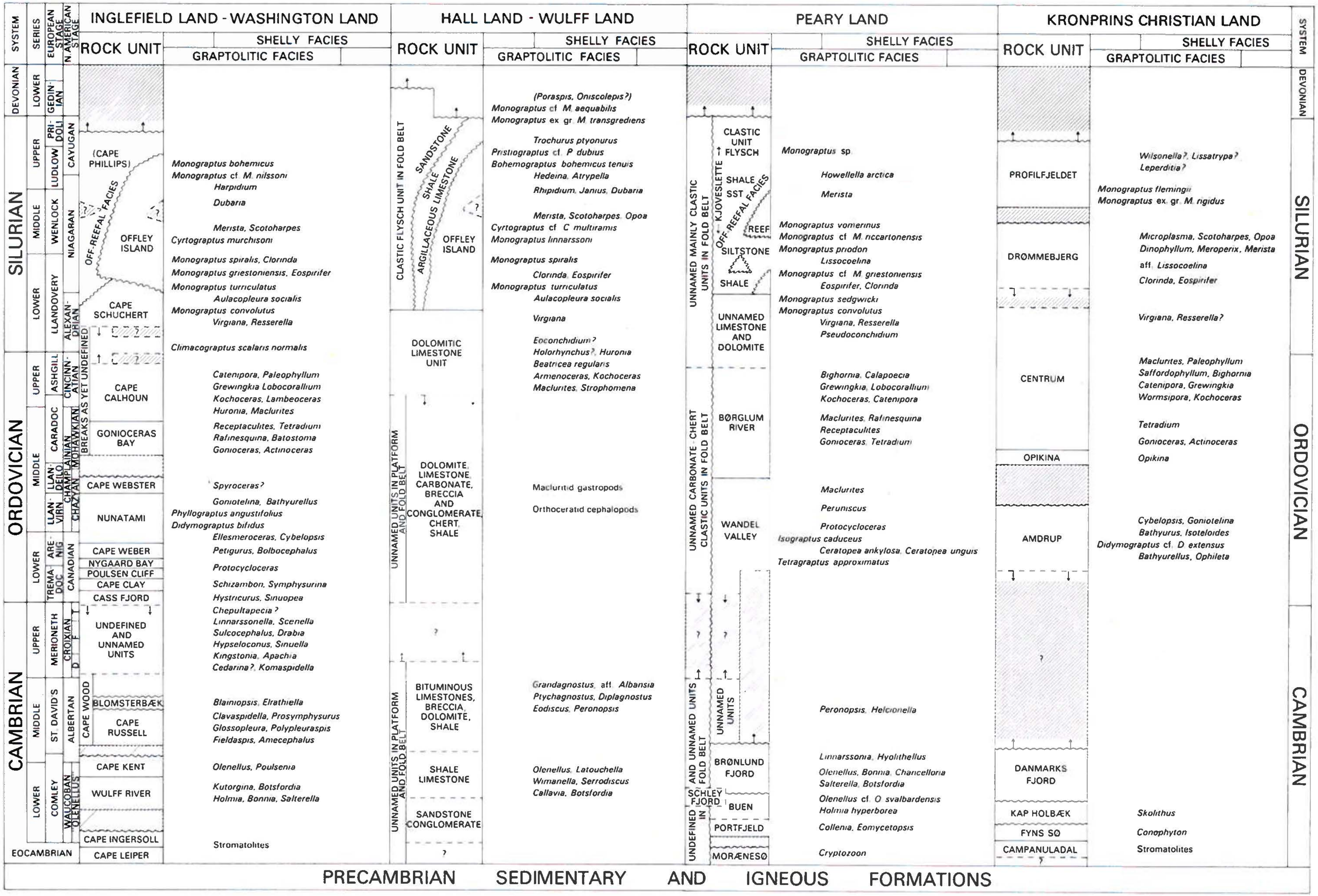
Ordovician

Ordovician strata of the platform outcrop in a relatively broad belt across northern Greenland, adjacent to and north of the Cambrian belt (fig. 267). The Ordovician beds are dominantly limestone and dolomite characterised by the presence of intraformational breccias and conglomerates.

Washington Land

Units in Washington Land span the Lower, Middle and Upper Ordovician (Poulsen, 1927; Koch, 1929b; Troelsen, 1950a).

The *Cass Fjord Formation* is composed of thick bedded limestone with alternating thin bedded argillaceous limestone and shale and abundant intraformational conglomerate. The unit is at least 400 m thick in Cass Fjord but elsewhere


SYSTEM
SERIES
EUROPEAN STAGE
N AMERICAN STAGE
INGLEFIELD LAND - WASHINGTON LAND
HALL LAND - WULFF LAND
PEARY LAND
KRONPRINS CHRISTIAN LAND
ROCK UNIT
SHELLY FACIES
GRAPTOLITIC FACIES
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
LOWER
UPPER
MIDDLE
GEDINNIAN
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
ASHGILL
CARADOC
LLANDEILO
LLANVIRN
ARENIG
TREMADOC
MERIONETH
ST. DAVID'S
COMLEY
CAYUGAN
NIAGARAN
ALEXANDRIAN
CINCINNATIAN
MOHAWKIAN
CHAMPLAINIAN
CHAZYAN
CANADIAN
CROIXIAN
ALBERTAN
WAUCOBAN
OLENELLUS
EOCAMBRIAN
(CAPE PHILLIPS)
OFF-REEFAL FACIES
OFFLEY ISLAND
CAPE SCHUCHERT
CAPE CALHOUN
GONIOCERAS BAY
CAPE WEBSTER
NUNATAMI
CAPE WEBER
NYGAARD BAY
POULSEN CLIFF
CAPE CLAY
CASS FJORD
UNDEFINED AND UNNAMED UNITS
BREAKS AS YET UNDEFINED
CAPE WOOD
BLOMSTERBÆK
CAPE RUSSELL
CAPE KENT
WULFF RIVER
CAPE INGERSOLL
CAPE LEIPER
Monograptus bohemicus
Monograptus cf. M. nilssoni
Harpidium
Dubaria
Merista, Scotoharpes
Cyrtograptus murchisoni
Monograptus spiralis, Clorinda
Monograptus griestoniensis, Eospirifer
Monograptus turriculatus
Aulacopleura socialis
Monograptus convolutus
Virgiana, Resserella
Climacograptus scalaris normalis
Catenipora, Paleophyllum
Grewingkia Lobocorallium
Kochoceras, Lambeoceras
Huronia, Maclurites
Receptaculites, Tetradium
Rafinesquina, Batostoma
Gonioceras, Actinoceras
Spyroceras?
Goniotelina, Bathyurellus
Phyllograptus angustifolius
Didymograptus bifidus
Ellesmeroceras, Cybelopsis
Petigurus, Bolbocephalus
Protocycloceras
Schizambon, Symphysurina
Hystricurus, Sinuopea
Chepultapecia?
Linnarssonella, Scenella
Sulcocephalus, Drabia
Hypseloconus, Sinuella
Kingstonia, Apachia
Cedarina?, Komaspidella
Blainiopsis, Elrathiella
Clavaspidella, Prosymphysurus
Glossopleura, Polypleuraspis
Fieldaspis, Amecephalus
Olenellus, Poulsenia
Kutorgina, Botsfordia
Holmia, Bonnia, Salterella
Stromatolites
CLASTIC FLYSCH UNIT IN FOLD BELT
SANDSTONE
SHALE
ARGILLACEOUS LIMESTONE
DOLOMITIC LIMESTONE UNIT
UNNAMED UNITS IN PLATFORM AND FOLD BELT
DOLOMITE, LIMESTONE, CARBONATE, BRECCIA AND CONGLOMERATE, CHERT, SHALE
BITUMINOUS LIMESTONES, BRECCIA, DOLOMITE, SHALE
SHALE LIMESTONE
SANDSTONE CONGLOMERATE
(Poraspis, Oniscolepis?)
Monograptus cf. M. aequabilis
Monograptus ex gr. M. transgrediens
Trochurus ptyonurus
Pristiograptus cf. P. dubius
Bohemograptus bohemicus tenuis
Hedeina, Atrypella
Rhipidium, Janius, Dubaria
Merista, Scotoharpes, Opoa
Cyrtograptus cf. C. multiramis
Monograptus linnarssoni
Monograptus spiralis
Clorinda, Eospirifer
Monograptus turriculatus
Aulacopleura socialis
Virgiana
Eoconchidium?
Holorhynchus?, Huronia
Beatricea regularis
Armenoceras, Kochoceras
Maclurites, Strophomena
Macluritid gastropods
Orthoceratid cephalopods
Grandagnostus, aff. Albansia
Ptychagnostus, Diplagnostus
Eodiscus, Peronopsis
Olenellus, Latouchella
Wimanella, Serrodiscus
Callavia, Botsfordia
UNNAMED MAINLY CLASTIC UNITS IN FOLD BELT
CLASTIC UNIT
FLYSCH
KJOVESLETTE
SHALE
SST
OFF-REEFAL FACIES
REEF
SILTSTONE
UNNAMED LIMESTONE AND DOLOMITE
UNNAMED CARBONATE - CHERT CLASTIC UNITS IN FOLD BELT
BØRGLUM RIVER
WANDEL VALLEY
UNDEFINED AND UNNAMED UNITS IN FOLD BELT
UNNAMED UNITS
BRØNLUND FJORD
SCHLEY FJORD
BUEN
PORTFJELD
MORÆNESØ
Monograptus sp.
Howellella arctica
Merista
Monograptus vomerinus
Monograptus cf. M. riccartonensis
Monograptus priodon
Lissocoelina
Monograptus cf. M. griestoniensis
Eospirifer, Clorinda
Monograptus sedgwicki
Monograptus convolutus
Virgiana, Resserella
Pseudoconchidium
Bighornia, Calapoecia
Grewingkia, Lobocorallium
Kochoceras, Catenipora
Maclurites, Rafinesquina
Receptaculites
Gonioceras, Tetradium
Maclurites
Peruniscus
Protocycloceras
Isograptus caduceus
Ceratopea ankylosa, Ceratopea unguis
Tetragraptus approximatus
Peronopsis, Helcionella
Linnarssonia, Hyolithellus
Olenellus, Bonnia, Chancelloria
Salterella, Botsfordia
Olenellus cf. O. svalbardensis
Holmia hyperborea
Collenia, Eomycetopsis
Cryptozoon
PROFILFJELDET
DRØMMEBJERG
CENTRUM
OPIKINA
AMDRUP
DANMARKS FJORD
KAP HOLBÆK
FYNS SO
CAMPANULADAL
Wilsonella?, Lissatrypa?
Leperditia?
Monograptus flemingii
Monograptus ex. gr. M. rigidus
Microplasma, Scotoharpes, Opoa
Dinophyllum, Meroperix, Merista
aff. Lissocoelina
Clorinda, Eospirifer
Virgiana, Resserella?
Maclurites, Paleophyllum
Saffordophyllum, Bighornia
Catenipora, Grewingkia
Wormsipora, Kochoceras
Tetradium
Gonioceras, Actinoceras
Opikina
Cybelopsis, Goniotelina
Bathyurus, Isoteloides
Didymograptus cf. D. extensus
Bathyurellus, Ophileta
Skolithus
Conophyton
Stromatolites
PRECAMBRIAN SEDIMENTARY AND IGNEOUS FORMATIONS

is thinner. The brachiopods *Finkelnburgia(?)* and *Lingulepis(?)*, the gastropod *Sinuopea*, and the trilobite *Hystricurus* indicate an early Ordovician age, but the formation extends down into the Cambrian (fig. 243).

The overlying *Cape Clay Formation* (50–60 m) of compact limestone with limestone conglomerate and a thicker overlying unnamed formation of limestone, dolomite and sandstone is early Lower Ordovician, the age indicated by a shelly fauna that includes the gastropods *Ophileta* and *Helicotoma*, the brachiopods *Finkelnburgia(?)* and *Schizambon* and the trilobites *Symphysurina* and *Hystricurus*. The *Poulsen Cliff Formation* (> 130 m) of dominantly grey gypsiferous shales and the *Nygaard Bay Formation* (*c.* 10 m) of dark grey limestone with argillaceous and silicified limestone follow and are dated by the Lower Ordovician (Canadian) cephalopod *Protocycloceras*. The *Cape Weber Formation* (*c.* 10 m) composed of grey or brownish, thick bedded limestone containing lenses of dolomite overlies the Nygaard Bay Formation. The trilobite fauna includes *Bolbocephalus*, *Petigurus* and *Bathyurellus* of late Lower Ordovician (late Canadian) age. These forms are common in the Cape Weber Formation at the type locality in central East Greenland where the formation is much thicker and has an age range of late Canadian to early Middle Ordovician (Chazyan).

The *Nunatami Formation* (*c.* 140 m) follows conformably and is composed mainly of limestone, frequently containing intraformational conglomerate, with some shales. Limestone–shale making up the lower 50 m has yielded the graptolite *Didymograptus bifidus* – a zone fossil of the early Middle Ordovician corresponding to the early Llanvirn on the British standard scale. The overlying 40 m of limestone has yielded *Phyllograptus angustifolius* giving support for this early Middle Ordovician age.

However, a rich shelly fauna includes the trilobites *Goniotelina*, *Cybelopsis*, *Bolbocephalus*, *Isoteloides* and *Pseudomera*, brachiopods *'Syntrophia'* and *Pomatotrema*, gastropods *Raphistomina*, *Turritoma* and *Hormotoma*, the primitive cephalopod *Ellesmeroceras* and the ostracod *Isochilina*; an assemblage indicating strata of Upper Canadian (late Lower Ordovician) age (Poulsen, 1927).

The Nunatami Formation passes, with gradational contact into the *Cape Webster Formation* (c. 290 m) of light grey, thin bedded limestone, shale and mudstone. Fossil crinoids, ostracods and the cephalopod *Spyroceras(?)* have been collected.

A thick series of limestones, probably over 400 m thick, disconformably overlies the Nunatami Formation. The *Gonioceras Bay Formation* (*c.* 100 m thick) at the base is mainly thick bedded, reddish brown to dark grey, dense fossiliferous limestone. At the top the limestone becomes thin bedded and flaggy and the colour changes to light to medium grey. The *Cape Calhoun Formation* overlies these flaggy limestones and is composed of at least 250 m of grey, massive limestones at the base, in places rich in corals, and passing vertically and in places laterally into argillaceous thin bedded limestone and shale.

The majority of fossils so far available from the Gonioceras Bay and Cape Calhoun Formations are of uncertain stratigraphic position (Troedsson, 1926, 1928; Koch, 1929b; Troelsen, 1950a) but indicate the presence of both Middle and Upper Ordovician strata. The age limits of the two formations are uncertain.

A rich shelly fauna from the Gonioceras Bay Formation includes the corals *Tetradium* and *Labyrinthites*, the brachiopods *Strophemena*, *Sowerbyella* and *Rafinesquina*, the bryozoan *Batostoma*, the trilobites *Bumastus*, *Illaenus*, *Thaleops*, *Isotelus* and *Ceraurus*, the gastropods *Maclurites* and *Trochonema*, the cephalopods *Gonioceras*, and *Actinoceras* and the alga *Receptaculites* – an assemblage indicative of strata of late Middle Ordovician age. The cephalopods *Gonioceras* and *Actinoceras* indicate strong affinities to the Black River fauna of the Mohawkian Stage of North America.

The rich fauna of the Cape Calhoun Formation includes receptaculitids, ostracods, echinoderms, bryozoans, the corals *Catenipora*, *Grewingkia*, *Calapoecia*, *Foerstephyllum*, *Labyrinthites*, *Lobocorallium*, *Paleophyllum*, *Saffordophyllum*, the trilobites *Encrinurus*, *Proetus*, *Flexicalymene*, *Illaenus*, the gastropods *Maclurites*, *Hormotoma*, the brachiopods *Leptaena*, *Plectambonites*, *Strophomena* and *Dalmanella* and the cephalopods *Huronia*, *Kochoceras*, *Lambeoceras* and *Armenoceras* – a fauna showing affinities to the Red River and Richmond (Cincinnatian) in the North American standard.

Field work by Greenarctic Consortium (personal communication) has shown the presence of evaporites as extensive units in Lower and Middle Ordovician rocks of southern and central Washington Land. The thickest units of gypsum and anhydrite are part of the recessive Poulsen Cliff Formation (J. S. Peel, personal communication).

Hall Land – Wulff Land

Ordovician rocks outcropping near the Inland Ice between Hall Land and the Victoria Fjord arch are at least 700 m thick. The Lower and Middle Ordovician overlying Cambrian rocks in the arch are composed of well bedded, buff weathering, grey limestones and dolomites with some shale intercalations. A poorly known fauna contains macluritid gastropods and orthocerated cephalopods. The Upper Ordovician is characterised by a dense, dark grey to bluish grey dolomite, often brecciated and mottled, which passes upwards without break into Silurian limestone and dolomite of similar lithology (fig. 244).

The fauna includes the corals *Favosites* and *Labyrinthites*, the gastropods *Maclurites*, *Salpingostoma*, *Phragmolites* and *Trochonema*, the brachiopod *Strophomena*, the cephalopods *Huronia* and *Armenoceras*, and *Receptaculites* (J. S. Peel, personal communication). This assemblage is of Cape Calhoun aspect, although the presence of *Favosites* (not recorded from the Cape Calhoun Formation of Washington Land) possibly indicates the presence of strata of slightly later Ordovician age.

←

Fig. 243. Stratigraphical correlation chart of Lower Palaeozoic strata across North Greenland. The successions for Hall Land – Wulff Land and Peary Land include both platform and fold belt strata (except for the exclusion of the metamorphic strata in the Roosevelt Fjelde). Some diagnostic pelagic and benthonic faunas are given. Compiled from the sources referred to in the text, and unpublished faunal identifications by Greenarctic Consortium, Arthur J. Boucot and John S. Peel.

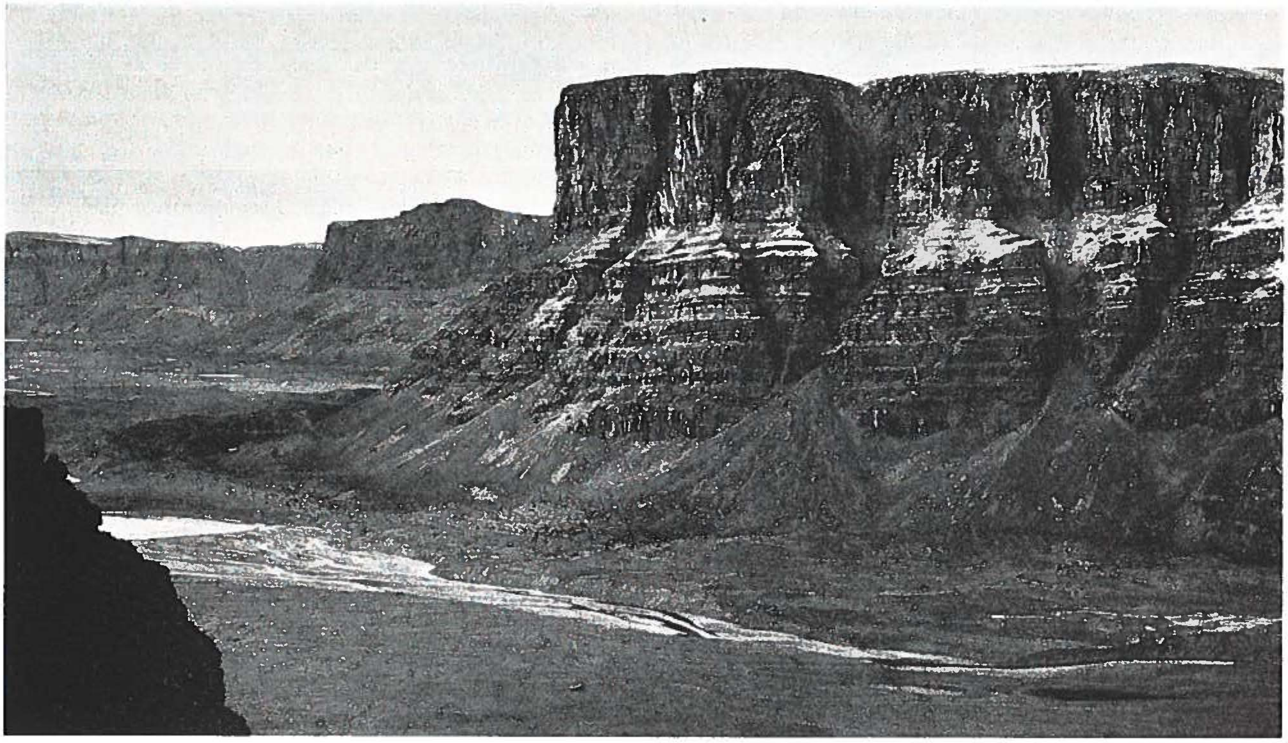
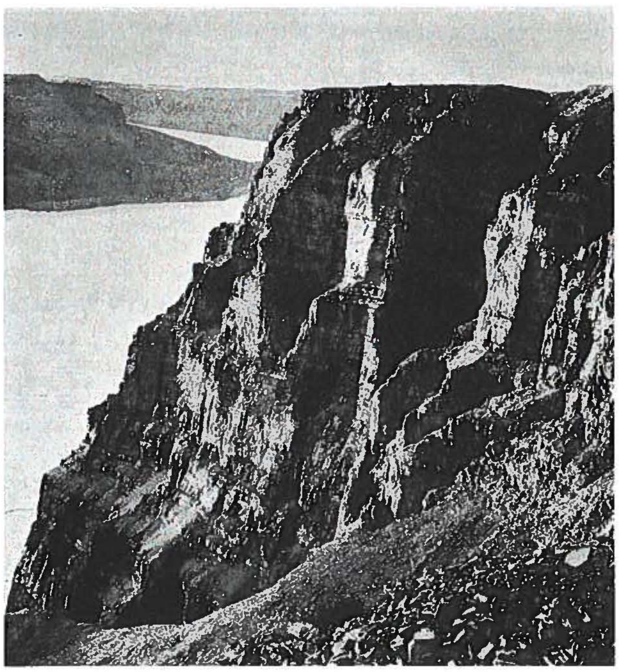


Fig. 244. Shallow dipping Ordovician–Silurian platform limestones on the east side of Store Canyon, Nyeboe Land. Height of the section about 550 m.

Fig. 245. Ordovician dolomites of the Wandel Valley Formation at the head of J. P. Koch Fjord, south-western Peary Land. Thickness of the section shown is about 130 m.



Peary Land

The Ordovician of southern Peary Land is at least 750 m thick (possibly reaching 1000 m), characterised by massive, cliff forming limestones and dolomites. The two lower units are named the Wandel Valley and the Børglum River Formations, *c.* 320 m and *c.* 430 m thick respectively; these are conformably overlain by about 150 m of unnamed limestones and dolomites of uncertain age (Troelsen, 1949; Peel & Christie, 1975).

The *Wandel Valley Formation* is light coloured, thin to medium bedded dolomitic limestone, dolomite, and conglomerate with some dark bands (fig. 245); the *Børglum River Formation* is thick bedded, variously mottled, dark grey silicified limestone and dolomitic limestone. The contact between the two formations is without apparent break. Towards the north the Ordovician contains more argillaceous and clastic material; a facies transitional to the basinal rocks of the North Greenland geosyncline.

The Wandel Valley Formation has yielded crincid plates, ostracods, pelecypods, gastropods (*Maclurites, Ceratopea, Pagodispira, Trochonema*) and the cephalopod *Protocycloceras*. The presence of *Ceratopea ankylosa* and *C. unguis* indicate a correlation with the Cotter and Smithville Formations of the Ozark area of late Canadian (late Lower Ordovician) age (Yochelson & Peel, 1975). However, the formation possibly extends into the Middle Ordovician.

The Børglum River Formation has yielded bryozoans, the coral *Catenipora*, the cephalopod *Gonioceras*, the gastropod *Maclurites* as well as *Receptaculites*. *Gonioceras* is confined to the Black Riverian interval (lower Mohawkian) in North

America and proves the presence of Middle Ordovician strata, while *Catenipora* indicates a younger, late Middle to Upper Ordovician age. Richly fossiliferous beds in the upper part yielded *Lobocorallium, Kochoceras, Calapoecia,* favositid and halysitid corals, indicative of a late Ordovician age (Peel & Christie, 1975).

Kronprins Christian Land

Ordovician rocks in western Kronprins Christian Land are of the same facies as those in southern Peary Land: grey limestone and dolomitic limestone with intraformational conglomerates. These beds, about 2500 m thick, are divided into the Amdrup, *'Opikina'* and Centrum Formations. The entire Ordovician–Silurian carbonate sequence was originally referred to as the 'Centrum Limestone' (Adams & Cowie, 1953); in revised nomenclature this name has been restricted to the major part of the sequence with Ordovician and Silurian units being separated from the lower and upper parts (Cowie, 1970; Scrutton, 1975).

The basal *Amdrup Formation* of grey limestones and intraformational conglomerates (*c.* 190 m thick) overlies the possibly Cambrian, Danmarks Fjord Formation disconformably and is itself disconformably overlain by the *'Opikina Limestone'* (*c.* 50 m thick) of thin bedded limestone with some shaly partings. These rocks pass directly into the *Centrum Formation* (*c.* 2250 m thick) of rather monotonous carbonate lithology composed of grey to dark grey, well bedded, generally brown weathering limestone with occasional dolomite and chert beds which are overlain by the Drømmebjerg Formation of Silurian age.

The fauna of the Amdrup Formation includes the trilobites *Bathyurellus, Benthamaspis, Bathyurus, Cybelopsis, Goniotelus* and *Isoteloides,* the gastropod *Hormotoma,* orthid brachiopods and *Didymograptus* cf. *extensus,* an assemblage indicative of a Lower to Middle Ordovician age. The *'Opikina* Limestone' contains the trilobites *Calliops* and *Isotelus(?)* and the brachiopods *Opikina* and *Plectorthis(?),* suggestive of a Middle Ordovician age. The lower 50 m of the Centrum Formation has yielded a Middle Ordovician fauna including the coral *Tetradium tubifer* and the cephalopods *Gonioceras* and *Actinoceras,* forms known from the Gonioceras Bay Formation in Washington Land. A rich coral fauna from the middle and upper parts of the formation includes *Catenipora, Streptelasma, Helicelasma, Cyathophylloides, Calapoecia, Wormsipora, Favosites, Saffordophyllum, Paleophyllum, Paleofavosites* and *Foerstephyllum(?),* and suggests an Upper Ordovician (Cincinnatian) age (Scrutton, 1975). The upper age limit of the formation is uncertain; a trilobite fauna said to originate from the uppermost 100 m and below horizons with Upper Ordovician corals mentioned above, is identical to that in the overlying Silurian Drømmebjerg Formation (Lane, 1972).

Silurian

Silurian rocks form a broad belt across northern Greenland, parallel with and north of the Cambrian and Ordovician areas (fig. 267). The Silurian belt is about 80 km wide at its broadest part in Washington Land and Nyeboe Land, and forms a large part of these regions. The Silurian reaches a thickness of at least 1500 m on the platform.

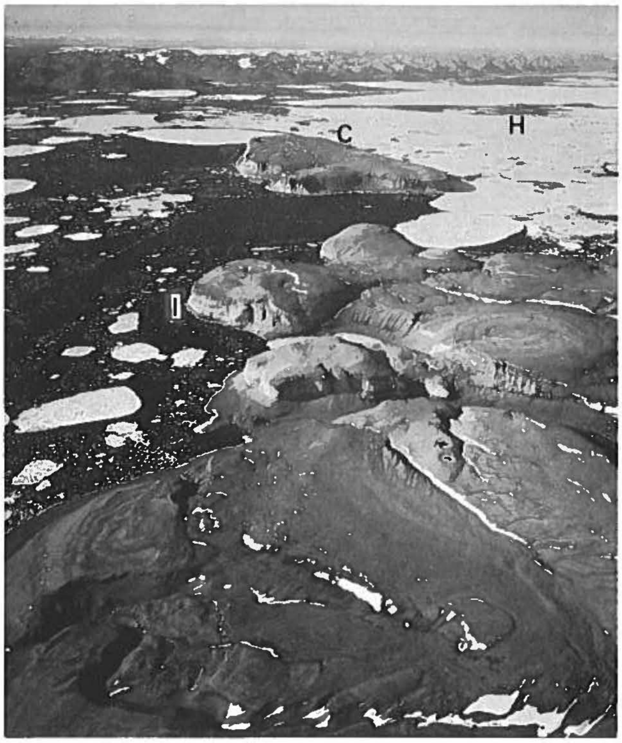


Fig. 246. Silurian reef complex in Washington Land looking northwards across the Nares Strait to the coastal fold mountains in Ellesmere Island, Canada. Large, light coloured bioherms form rounded hills up to 500 m high and bold coastal cliffs as at Kap Independence (I) and on Crozier Ø (C); darker argillaceous, often graptolitic, off-reefal strata flank bioherms and form large parts of the coast northeast and south-west of the reef concentration. Hans Ø (H). Aerial photograph 545 H-N, no. 11802. Copyright Geodetic Institute.

The entire length of the Silurian belt was evidently a transitional zone between a southern platform sedimentary environment and a northern trough environment. Thick bedded limestones of the platform pass northward into platy limestones, then sandstone and shale of the basinal facies. The Silurian platform–marginal zone is characterised by the presence of reefs and associated or related sedimentary facies showing intricate facies changes. The reefs range in scale from small patch reefs of relatively limited horizontal and vertical extent to large reef complexes that extend for tens of kilometres.

Reefs or biohermal rocks make up a substantial part of the Silurian belt between Washington Land and the Victoria Fjord arch; in Peary Land exhumed reefs are present on a relatively small scale. This biohermal zone traceable across northern Greenland

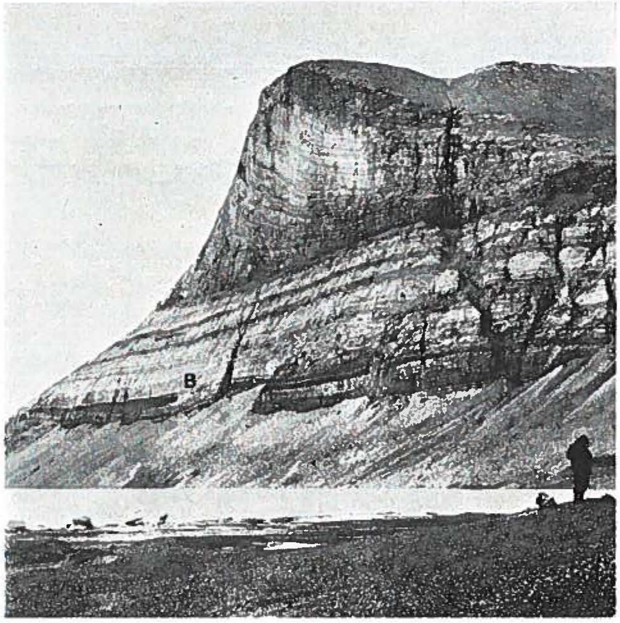


Fig. 247. The Kap Tyson reef in the western face of Kap Tyson, Hall Land. Summit of the cape is about 775 m above the sea-ice. Lower part of the cliff is composed of flat lying biostromal limestone with associated conglomerates in which breaks in banding (e. g. at position B) are due to small bioherms. The main reef forms the upper part of the cliff. Note the depositional dips, and the gradation southwards (to the right) into thinner, darker limestones.

is a continuation of a similar one recognised in the Canadian Arctic (Kerr, 1967a; Norford, 1972).

In the southern part of the Silurian belt the basal Silurian rocks, grey to dark grey limestones and dolomitic limestones, often mottled and silicified, conformably overlie late Ordovician carbonates of similar lithology. The basal limestones pass upwards into light coloured limestones which in many places form the substratum for the reefs and associated limestone conglomerate and argillaceous rocks.

Washington Land – Wulff Land

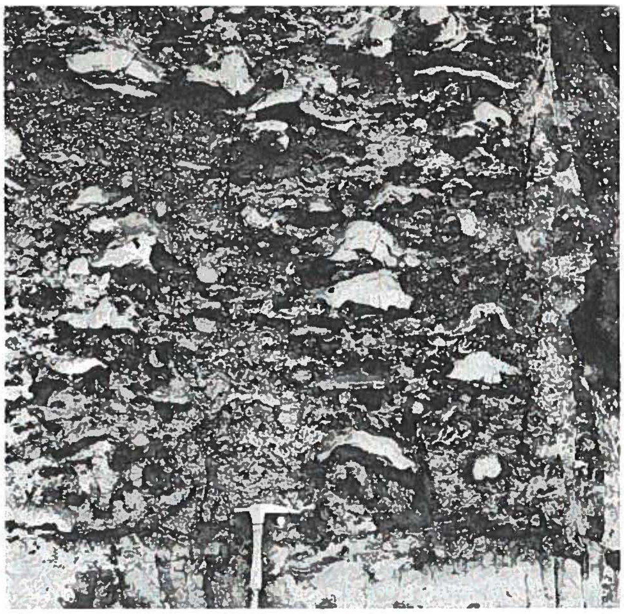
In this region the reef complex is well exposed. The bioherms are light coloured and contrast with the surrounding darker off-reefal argillaceous limestones and shales. Structures such as intertonguing reefal and basinal facies, layered reefs, and pinnacle reefs are well exposed in the coastal and fjord-wall cliffs. Main bioherms form prominent capes at the coast (fig. 246), and in Hall Land the Kap Tyson Reef (fig. 247) forms an east–west trending range of hills, the Hauge Bjerge, and continues as high ground across Nyeboe Land and into Wulff Land.

From numerous collections of shelly fossils and graptolites a wide range of strata from Lower to Upper Silurian age is known to be present (fig. 243). However, lack of a diagnostic Middle Silurian (middle to late Wenlock) graptolitic fauna may indicate an important stratigraphical break. Certain abrupt lithological changes, earlier described as unconformities separating formations of different ages (Koch, 1929a; Poulsen, 1934) are now interpreted as facies boundaries associated with reefs (Kerr, 1967a; Dawes, 1971; Norford, 1972).

The Cape Schuchert and the Offley Island Formations, originally named by Koch (1929a), are in part facies equivalents of each other (Norford, 1972). Each contains reefal and off-reefal strata which are often intricately associated and can be interlayered. In Washington Land, the *Cape Schuchert Formation* is predominantly composed of grey to dark grey and black limestones and argillaceous limestones, dark shales, often bituminous and graptolitic, with lesser amounts of biohermal and biostromal limestones and some cherts. Koch (1929a) mentions conglomerates in the basal part. In contrast the *Offley Island Formation* contains more rocks of the reef facies, and biohermal and biostromal limestones predominate and are associated with calcarenites and limestone conglomerates, argillaceous limestone and graptolitic shale. Norford (1972) has assigned the off-reefal graptolitic facies, including shales, mudstones, chert and argillaceous limestone, as well as some associated bioherms and biostromes to a third unit, the *Cape Phillips Formation* of Arctic Canada.

Reef limestones are characteristically coarse grained with good porosity, with colonial corals, stromatoporoids and algae forming the bulk of the reef cores (fig. 248). Brachiopods and solitary corals, and to a lesser extent echinoderms, trilobites, bryozoans, molluscs and ostracods occur mixed with the reef formers, often in rich concentrations. Petrographically many of the associated limestones are bioclastic

Fig. 248. Biostromal limestone of the Offley Island Formation. The rock consists mainly of stromatoporoid colonies with some corals, brachiopods and gastropods. Hall Land, south of Hauge Bjerge.



and pelletoidal, and contain shell fragments of variable sizes. Shell debris can form coquinoidal limestones. Grey to black shales and mudstones farther away from the bioherms contain graptolites and some shelly debris.

Graptolite and shelly faunas indicate that the reef complex spans Lower Silurian (lower Llandovery) through to at least Upper Silurian (middle Ludlovian) time. The presence of the graptolite *Climacograptus scalaris normalis* at Kap Schuchert (Poulsen, 1934) indicates the presence of early Silurian (lower Llandovery) strata. A fauna including *Monograptus convolutus, M. leptotheca, M. lobiferus* and *Rastrites peregrinus* (Poulsen, 1934) from the Cape Schuchert Formation indicates off-reefal beds of middle Llandovery age. Graptolites in Washington Land and in the Kap Tyson Reef in Hall Land indicate a continuous off-reefal sequence of essentially late Lower Silurian (upper Llandovery) age (Norford, 1972). This fauna includes *Monograptus turriculatus, M. decipiens, M. spiralis, M.* cf. *M. linnarssoni, M. greistoniensis, Cyrtograptus lapworthi and C.* aff. *C. canadensis.* The presence of *Cyrtograptus* cf. *C. multiramis, Retiolites geinitzianus* and *C. murchisoni* indicates a continuation of the section into the Middle Silurian (Wenlock) (Poulsen, 1934).

A brachiopod fauna from Nyeboe Land includes *Eoplectodonta(?), Virgiana, Eoconchidium, Leptaena 'rhomboidalis'* and *Dicaelosia*, an assemblage according to A. J. Boucot (personal communication) of lower to middle Llandovery age. The rich shelly faunas known from Poulsen (1934, 1941, 1943) and others, include the trilobites *Aulacopleura, Encrinurus, Cheirurus, Pseudoproteus, Scotoharpes, Phacops, Bumastus, Scutellum, Illaenus* and *Sphaerexochus*, the brachiopods *Eospirifer, Clorinda, Homeospira, Howellella, Leptaena, Resserella, Merista, Pentamerus, Sowerbyella* and *Platystrophia*, the corals *'Amplexus', Favosites, Halysites, Cystiphyllum*, and the stromatoporoids *Stromatopora* and *Rosenella*. This composite assemblage is of upper Llandovery and Wenlock age.

Upper Silurian (Ludlow) strata are known from the upper part of the Kap Tyson Reef from where a brachiopod fauna includes *Conchidium, Janius, Skenidioides, Drummockina, Strophonella, Atrypella prunum, 'Atrypella phoca'*, a short-lobed *Dicaelosia, Hedeina, Rhipidium(?)* and *Gracianella(?)* (A. J. Boucot, personal communication). A graptolite fauna from off-reefal argillaceous limestone and shale in Nyeboe Land includes *Bohemograptus bohemicus tenuis, Pristiograptus* cf. *P. dubius, Monoclimacis* sp., *Saetograptus fritschi* and *Monograptus ?colonus*, an assemblage of early to middle Ludlow age (Berry *et al.*, 1974).

Peary Land

A Silurian section about 1500 m thick, is present in central Peary Land overlying, apparently conformably, Ordovician carbonate rocks (Peel & Christie, 1975). The basal strata, variable grey and dark grey limestones and dolomites that are often mottled and show a varying degree of silicification, pass upwards into argillaceous limestones and black shales, and an upper thick, poorly fossiliferous, flysch-type unit of interbedded calcareous greywacke, shale, siltstone and some conglomerate (fig. 249). This upper unit contains well preserved sedimentary structures (sole markings, slumps, ripple drift bedding) and is a turbidite sequence. A few small bioherms are exposed in the lower and middle parts of the section associated with shale. The stratigraphically highest reefs are surrounded by the flysch-type clastics which lap onto and over the reefs.

This sequence shows close similarity to the Silurian of the Washington Land – Wulff Land region to the west. The flysch-type unit is correlatable with the Silurian to Devonian sequence in the fold belt, and conglomerate from the upper part of the Peary Land sequence is identical with the late Silurian Hendrik conglomerate known from Nyeboe Land and Hendrik Ø (Dawes, 1966). The sequence in Peary Land probably extends into the Devonian.

Graptolites from argillaceous limestones and shales include *Monograptus* cf. *M. concinnus, M. convolutus, M. leptotheca, M.* cf. *M. pandus* and *M. sedgwicki* (Greenarctic Consortium, personal communication) indicating strata of Lower Silurian (middle to late Llandovery) age in the lower part of the sequence. An assemblage containing *Monograptus* cf. *M. griestonensis, M.* cf. *M. marri* and *Retiolites geinitzianus(?)* is of upper Llandovery age. *Monograptus priodon* known from loose material indicates upper Llandovery to Wenlock strata (Koch, 1923; Peel *et al.*, 1974).

Kronprins Christian Land

In western Kronprins Christian Land the Silurian is of similar facies to that in central Peary Land. Light grey dolomitic limestone of possible Silurian age at the top of the Centrum Formation (described previously) is overlain by the Drømmebjerg Formation, about 200 m thick of well bedded, light grey limestone, and by the Profilfjeldet Formation, about 400 m thick (Cowie, 1961b). A basal boulder conglomerate of the Profilfjeldet unit rests on an eroded surface of the Drømmebjerg Formation; the remainder of the unit is grey, red and brown, marly to sandy shales.

The shelly faunas from Kronprins Christian Land show similarities to the Silurian faunas of western North Greenland. The presence of the zone fossil *Virgiana*, probably from strata equivalent to the Centrum Formation (Greenarctic Consortium, personal communication) indicates the presence of middle Llandovery strata. The brachiopods *Merista, Howellella, Streptis, Clorinda, Leptaena* and a pentamerid with affinity to *Lissocoelina*, as well as the trilobites *Scotoharpes, Opoa* and *Meroperix* (Lane, 1972) known from western North Greenland indicate a Lower Silurian (upper Llandovery) to Middle Silurian (Wenlock) age range. Graptolites collected about 50 m above the base of the Profilfjeldet Formation include *Cyrtograptus* of the *C. rigidus* group and *Monograptus flemingii(?)* (Strachan *in* Lane, 1972), indicating strata of Middle Silurian (late Wenlock) age. Provisional identifications of the brachiopods *Wilsonella(?)* and *Lissatrypa(?)* (Greenarctic Consortium, personal communication) suggest a continuation of the section into the Upper Silurian.

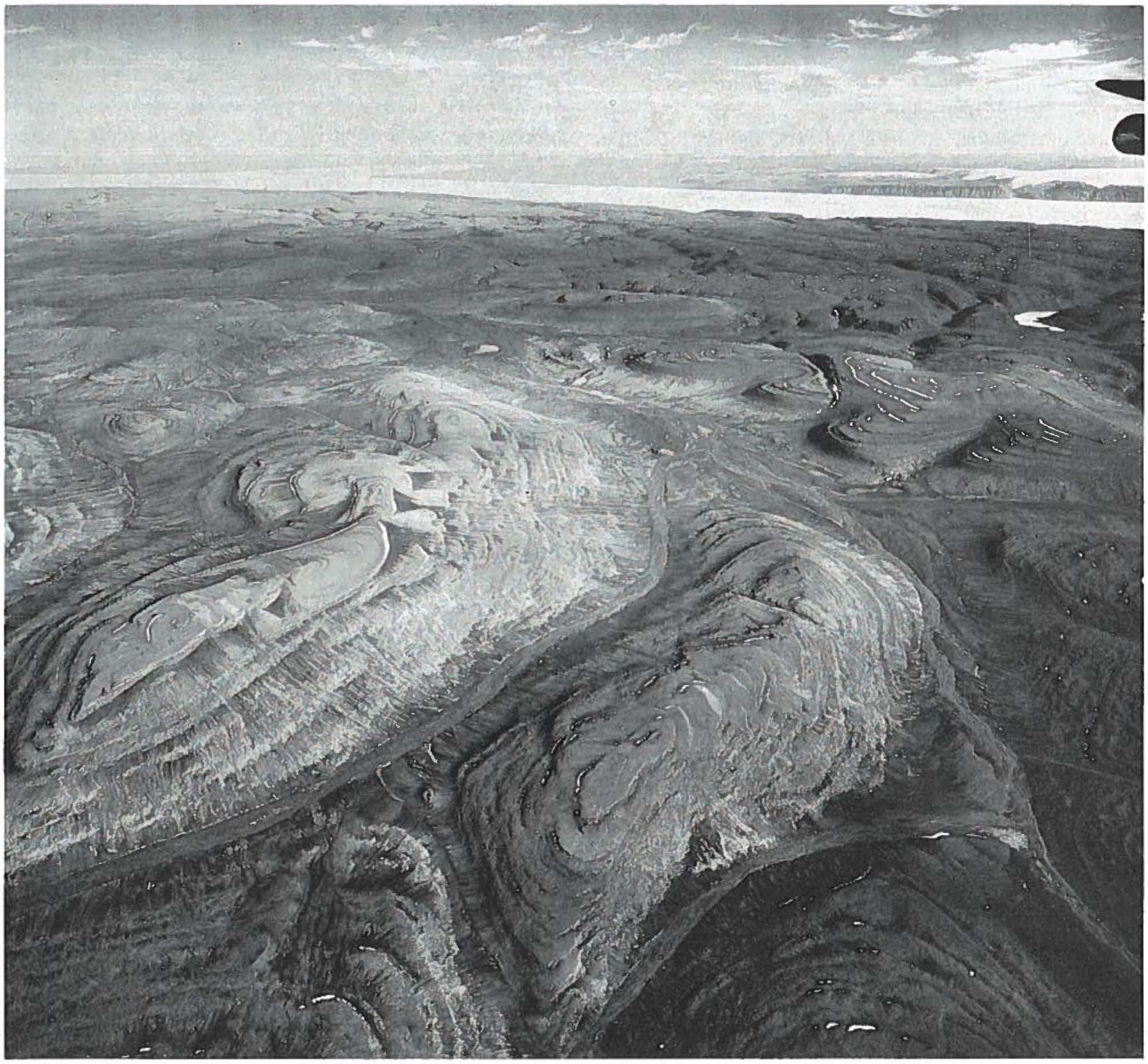


Fig. 249. Terraced hills produced by the alternating resistent and less resistent beds of the Silurian flysch-type sequence in central Peary Land. View looking southwards towards Independence Fjord. Aerial photograph 548 C-S, no. 1954. Copyright Geodetic Institute.

Proterozoic to Devonian rocks of the North Greenland geosyncline

Sedimentary rocks of the North Greenland geosyncline form a relatively thick (probably over 5000 m), apparently conformable sequence, now folded and in places subsequently metamorphosed. Cambrian, Ordovician, Silurian and Devonian fossils have been collected, but the ages and correlation, and even thicknesses, of much of the composite section are uncertain due to structural complexity and a general paucity of fossils. The stratigraphic framework for much of the trough region has been obtained from the nearby and better known parts of the platform.

The geosyncline contains a mixed sequence of rocks characterised by a predominance of clastic material but with important carbonate, chert and graptolitic shale. In the Silurian and Devonian the clastics are developed as a flysch facies.

Proterozoic

Two areas of unfossiliferous clastic rocks, one in Wulff Land and another in eastern Peary Land, are considered as possibly of Proterozoic age because of lithological similarity to known or suspected Proterozoic beds.

Wulff Land

A sequence of sandstone, conglomerate and carbonate rocks, at least 250 m thick, in the core of an anticline in northern Wulff Land and Stephenson Ø are of unknown age, but are tentatively correlated with the Proterozoic(?) and Cambrian beds overlying crystalline basement in the Victoria Fjord arch to the south. The sequence in Wulff Land can be divided into three units: lower light coloured sandstone, grit and conglomerate; light grey dolomite and limestone; and interbedded limestone, calcareous sandstone, arkosic quartzite and quartz-pebble conglomerate. Pisolithic stromatolites of *Pycnostroma* type up to 5 mm in diameter are present in limestone of the middle unit.

Peary Land

Light coloured sandstone and conglomerate which in places contain dolerite intrusions, mainly as dykes, occur in a block faulted region between Frederick E. Hyde Fjord and G. B. Schley Fjord in eastern Peary Land. Lower Cambrian beds are known to occur in the same region (Troelsen, 1956) which lends weight to the possibility that some of the clastic beds may be Proterozoic in age.

Cambrian

Cambrian fossils have been found at two widely separated localities in the fold belt: at G. B. Schley Fjord in eastern Peary Land and in northern Nyeboe Land. A third locality, that in northern Wulff Land (the section described above, under Proterozoic), is thought to be one in which Cambrian beds are present. Cambrian rocks almost certainly form part of the metamorphosed succession in northern Peary Land which is described later in the Ordovician, Silurian, Devonian section.

From the number of fossiliferous localities described below, the Cambrian succession might indeed seem sparse. From the continuity of Cambrian formations in the adjacent platform region, however, it is most probable that Cambrian deposits are well represented in the geosyncline.

Nyeboe Land

An uplifted block in northern Nyeboe Land exposes a sequence of well bedded limestone, dolomite, shale and slate, the upper part of which contains intraformational breccias and bituminous rocks. At least 350 m of strata are exposed and the sequence is overlain by Ordovician carbonate rocks. Lower and Middle Cambrian beds are known to be present in this sequence.

Dark limestones and slates have yielded a poor Lower Cambrian fauna of olenellid trilobites and *Latouchella* (Peel, 1974) together with *Serrodiscus* and *Calodiscus*. A Middle Cambrian trilobite–brachiopod fauna from rocks of similar lithology contains agnostid, paradoxidid and ptychopariid trilobites of the Atlantic province (V. Poulsen, 1969) and includes a faunule containing *Eodiscus, Diplagnostus, Peronopsis*, and the zone fossil *Ptychagnostus punctuosus*, as well as a younger faunule containing *Grandagnostus* and a form similar to *Albansia*. These assemblages correspond to the upper part of the *Paradoxides paradoxissimus* Zone and in part to the *Paradoxides forchhammeri* Zone in eastern North America and thus the fauna appears to be slightly younger than the Pacific Middle Cambrian fauna known from the platform of Inglefield Land.

Peary Land

A succession of dark coloured sandstone and shale, green to brown shale with *Olenellus*, and grey dolomite occurs at G. B. Schley Fjord. The middle, shale unit, 100 m or less thick, is named the Schley Fjord Formation (Troelsen, 1956) and contains fragments of *Olenellus* cf. *O. svalbardensis* indicative of Lower Cambrian age (V. Poulsen, 1974). Both underlying and overlying units are considered to be possibly Cambrian in age.

Ordovician, Silurian, Devonian

Fossiliferous sedimentary sections of Ordovician and Silurian age form an east–west trending belt across northern Greenland and are present in the Hall Land – Nyeboe Land area, in the Frederick E. Hyde Fjord area and in the G. B. Schley Fjord area in eastern Peary Land. Devonian rocks have only been dated from fossil evidence in Hall Land (Berry *et al.*, 1974) but are considered to occur at the top of the trough sequence to the east. All of the trough sequences are of considerable thickness and are generally well exposed, but only rather few, mainly reconnaissance data are available.

In Peary Land to the north of the fossiliferous belt is a zone of more or less metamorphosed rocks, including slates, marbles, phyllites and schists. The suite is considered to be Lower Palaeozoic and Devonian by correlation with fossiliferous, less altered areas to the south, but the ages of the individual stratigraphic units are unknown. This metamorphic succession is described for convenience in this section although the sequence most probably contains Cambrian or even older rocks (fig. 250).

The fossiliferous basinal rocks form a conformable

	NE Ellesmere Island (Trettin, 1971)	Hall Land - Wulff Land (Dawes, 1971)	Northern Peary Land (Dawes & Soper, 1973)		
			Frederick E. Hyde Fjord	Roosevelt Fjelde	
				Group	Formation
DEV.	Cape Rawson Group (Kerr, 1967a)	Clastic unit (greywacke, flysch facies, some limestone)	?	?	
SILURIAN	Marvin Formation (limestone)		Clastic unit (greywacke, flysch facies, some limestone)	Sydgletscher	Sydgletscher Sandstone Upper Sydgletscher Shales Sydgletscher Quartzite Lower Sydgletscher Shales Nysne Gletscher Mudstones
	Imina Formation (greywacke, siltstone, shale)	Limestone unit		Polkorridoren	Polkorridoren Psammite Rusty, green quartz phyllite
ORDOVICIAN	Hazen Formation (limestone, shale, chert, breccia)	Limestone, shale, breccia, chert	Sandstone, siltstone, chert, shale, limestone, breccia	Paradisfjeld	Yellow limestone Green calcareous phyllite Dark grey limestone Graphitic and calcareous phyllite
CAMBRIAN	Grant Land Formation (clastic rocks, limestone)	? Limestone, shale, dolomite, sandstone	? Sandstone, shale Schley Fjord Formation	?	Ulvebakkerne Marble Kap Morris Jesup Quartz Phyllite

Fig. 250. Tentative correlation chart of Lower Palaeozoic geosynclinal successions in the western and eastern parts of the North Greenland fold belt and in adjacent Canada.

sequence at least 4000 m thick and probably considerably thicker. In the lower part dolomite and limestone grade laterally, that is northwards into the deeper trough, and upwards, into a mixed sequence containing clastic rocks with chert, limestone, breccia, argillaceous limestone and graptolitic shale. The upper part of the sequence is a thick, sparsely fossiliferous, clastic flysch-type sequence of monotonous lithology.

Hall Land – Wulff Land

Ordovician to Devonian rocks form a well exposed sequence, at least 2000 m thick, in the Hall Land – Wulff Land region. In the uplifted fault block in Nyeboe Land, light weathering dolomite and limestone characterised by intraformational breccias and conglomerate (fig. 251) with some shales and siltstone, have yielded indeterminate crinoids, brachiopods and corals of probable Ordovician age. Late Ordovician carbonate rocks in a coastal cliff section in Hall Land are overlain by carbonate rocks of Silurian age and by a thick, darker sequence of Silurian to Devonian clastic rocks (fig. 252).

The carbonate unit at the base of the Hall Land section is about 550 m thick. In ascending order, four formations are recognised: about 150 m of thick bedded, fine-grained dark mottled and brecciated dolomitic limestone, with some beds of light grey, compact limestone in the upper part; about 65 m of light grey, massive limestone containing a 15 – 20 m black brecciated dolomitic layer and at the base a conspicuous 1 m thick crinoid-rich bed; about 120 m of a dark, brecciated and mottled limestone; and about 160 m of light grey to brown weathering, massive limestone containing some platy limestone and slate, and in the upper part thin layers of dark limestone and black flint.

Fossil identifications indicate a range of strata from Upper Ordovician to Lower or Middle Silurian age (J. S. Peel and A. J. Boucot, personal communications). A fauna from the upper 80 m of the lowest formation includes the corals, *Paleophyllum*, *Catenipora* cf. *C. robusta*, the stromatoporoid *Beatricea regularis*, the cephalopods *Huronia*, *Armenoceras*, *Kochoceras* and the gastropod *Trochonema*, an assemblage indicative of an Upper Ordovician age. The next formation upwards includes the corals *Paleofavosites* cf. *P. nodosus* and *Rosenella* cf. *R. irregularis*, the brachiopod *Holorhynchus(?)* and the cephalopod *Huronia*, an assemblage which is probably of Lower Silurian (early Llandovery) age. The third formation from the base contains the brachiopod *Eoconchidium(?)* which suggests a lower or middle Llandovery age. Poorly preserved fossils of Silurian age are present in the uppermost formation.

The overlying clastic unit in Hall Land can be traced as a broad belt across Nyeboe Land and into Wulff Land, Nares Land and Peary Land. The rocks have been referred by the author (Dawes, 1971) to the *Cape Rawson Group*, a unit which includes similar rocks in the Canadian Arctic (Feilden & De Rance, 1878; Christie, 1964; Kerr, 1967a). The sequence is composed of well bedded alternating sandstone, siltstone and shale, with some grits, conglomerate and carbonate beds. Petrologically, the sandstones are calcareous greywacke. To the east of Hall Land conglomerate forms conspicuous, mainly darker units alternating with greywacke and siltstone, and a thick unit on Hendrik Ø has been informally named the Hendrik conglomerate (Dawes, 1966). The conglomerates consist of mainly rounded multicoloured chert and quartzite pebbles with occasional crystalline gneiss and granite set in a calcareous greywacke matrix identical with that of the greywacke units (fig. 253). The clastic sequence displays a variety of well developed sedimentary structures including current sole marking, load casts, contorted bedding, ripple marks, cross stratification and graded bedding (fig. 254). The rocks represent a flysch facies in which turbidity currents have played an important role.

In Hall Land the clastic unit is at least 1200 m thick and is divided into four subunits. In ascending order these are: dark platy limestone, about 45 m thick, with some beds of light compact limestone and occasional thin layers of dark grey to black chert; about 65 m of grey shale and slate with alternating greywacke, in the upper part shales pass into compact mudstones; grey, thin bedded greywacke, about 190 m thick, containing intercalations of shale, in beds up to 5 m thick, and some light coloured pure quartzite layers; rhythmically bedded greywacke, siltstone and shale, in which each rock type can predominate. The uppermost subunit is at least 800 m thick but could be considerably thicker. Towards the top some thin fragmental limestone beds occur and to the east of Hall Land there are conglomeratic intercalations.

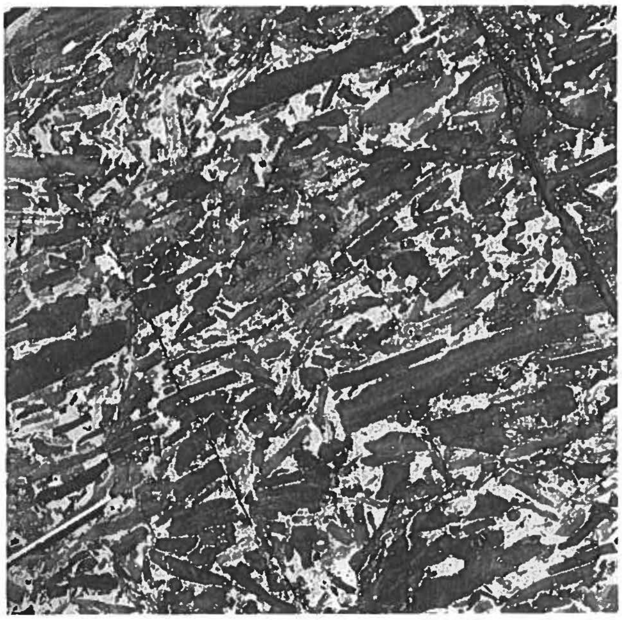


Fig. 251. Ordovician intraformational carbonate breccia composed of laths and plates of fine-grained limestone and dolomite in a yellow-weathering carbonate matrix. Marked orientation of the clasts is parallel to bedding in adjacent undisturbed beds. Northern Nyeboe Land.

Fig. 252. Ordovician–Devonian stratigraphy in the North Greenland fold belt on the northern coast of Hall Land: a light coloured Ordovician–Silurian limestone unit is overlain by a Silurian-Devonian clastic unit. To the south, a line of hills, the Hauge Bjerge, stretching from Newman Bugt (left) to Petermann Fjord (right) represent the Silurian reef front. Height of the cliffs to the left is approximately 900 m. Aerial photograph 546 K, no. 2190. Copyright Geodetic Institute.

Fig. 253. Late Silurian conglomerate composed of rounded pebbles of mainly coloured chert and quartzite set in a greywacke matrix. Hendrik conglomerate, Hendrik Ø. Lens cap is 4 cm across.

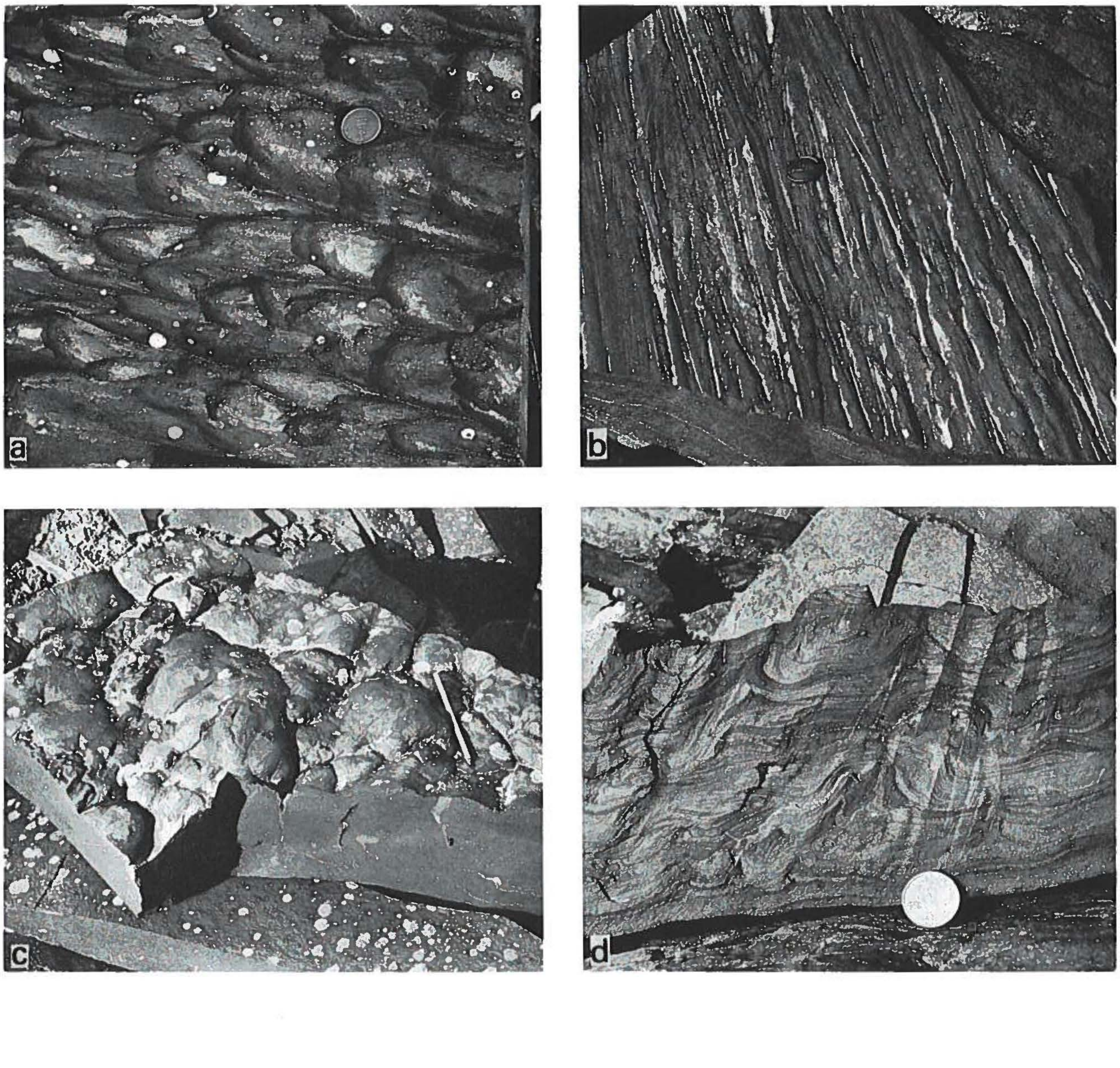


Fig. 254. Sedimentary structures in Silurian–Devonian flysch facies, Nyeboe Land. A, B & C are bottom surfaces of greywacke beds, and D is a siltstone section perpendicular to bedding. A: Elongate to bulbous flute casts, current direction left to right; B: Groove casts with some flat flute casts at bottom right, current direction from top to bottom; C: Bulbous load casts; D: Convolute lamination with some cross stratification. Lens cap is 4 cm across.

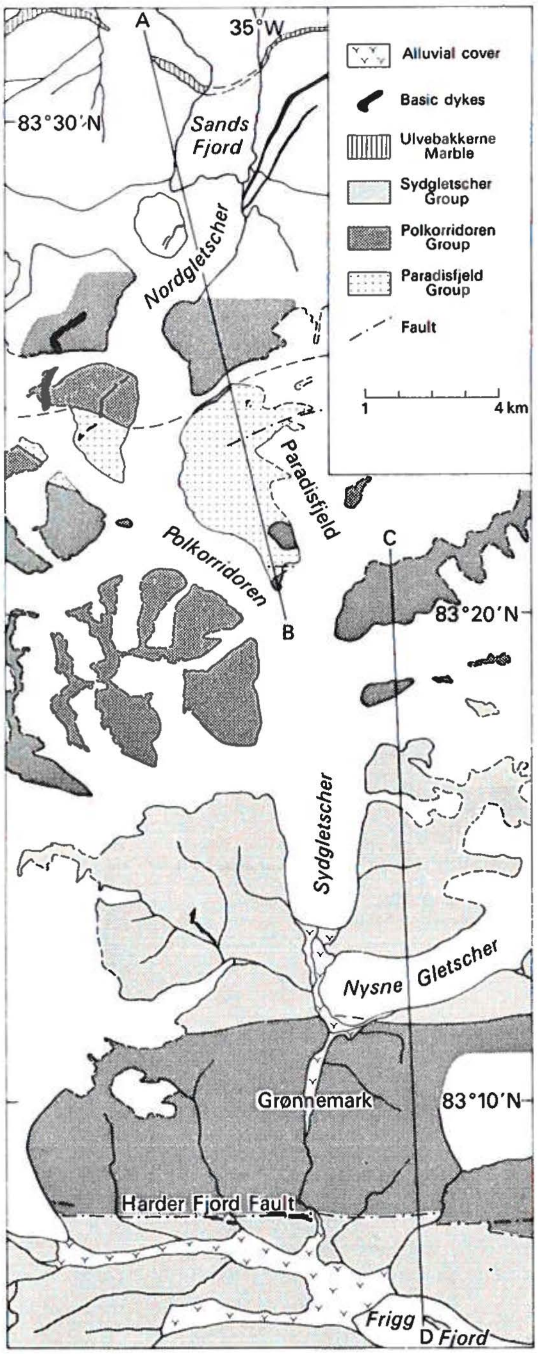
Fig. 255. Strike section of folded Ordovician strata in the North Greenland fold belt: a lower dark unit of mainly siltstones and silicified shales overlain by a unit of calcareous sandstone. South side of O. B. Bøggild Fjord, Peary Land. Height of the profile above the sea-ice is about 900 m.

The clastic unit is sparsely fossiliferous and the main part of the sequence is not accurately datable within the Silurian. The two lower subunits have a poor fauna of favositid corals, crinoids, gastropods and cephalopods of possible Lower Silurian age. Upper Silurian strata are present in the uppermost unit. Shales from that unit on Hendrik Ø have yielded a graptolite fauna including *Bohemograptus bohemicus tenuis(?)*, *Pristiograptus* sp. and *Saetograptus fritschi*, an assemblage of early Ludlow age (Berry *et al.*, 1974). The presence of the trilobite *Trochurus ptyonurus* in a locally derived calcareous sandstone boulder from the Newman Bugt area (C. Poulsen, 1974) suggests middle or late Ludlow strata in the clastic unit. In Hall Land near the top of the sequence, a graptolite fauna including *Monograptus* cf. *M. aequabilis* and monograptids of the *M. transgrediens* type indicates strata of latest Silurian (Pridoli) to Lower Devonian age (Berry *et al.*, 1974). A marine fauna from stratigraphically higher, thin carbonate beds contains a vertebrate assemblage of thelodonts, heterostracans and acanthodians similar to the fauna of the Peel Sound Formation of the Canadian Arctic (Bendix-Almgreen & Peel, 1974), and is provisionally referred to the Lower Devonian.

Peary Land

The Ordovician and Silurian of Peary Land is of unknown, but undoubtedly great thickness. In the east in the G. B. Schley Fjord area, the Ordovician is composed of grey, dark grey and black limestone and dolomite with cherts, similar to the platform carbonate rocks in southern Peary Land. Units referable to the Wandel Valley and Børglum River Formations can be recognised (J. C. Troelsen, personal communication). Towards the trough zone in the north a facies change takes place and more clastic material occurs in the succession. Thus in the Frederick E. Hyde Fjord region, the Ordovician is composed of a well bedded sequence of siltstones and shales containing frequent psammite and grit beds that show graded and cross-bedding. In places arenaceous material predominates and here light coloured impure quartzites are locally common. Many argillaceous units contain dark grey to black chert layers and some units are exclusively composed of silicified siltstones and shales. Within this succession light coloured intraformational carbonate breccias occur in discrete units up to 25 m thick, composed of chert, carbonate and siltstone fragments in a yellow weathering matrix (cf. fig. 251). Gradations from banded limestone into carbonate breccias are common.

The contact between Ordovician and Silurian has not been determined but the sequence described above becomes more sandy upwards and dark grey to black shales and calcareous siltstones pass into a thick mainly arenaceous unit of Silurian age. Where examined in Frederick E. Hyde Fjord (Dawes & Soper, 1970) these rocks are brown weathering calcareous greywacke with shales, siltstones and some grits, and the sequence is characterised by graded beds. Limestone, and limestone breccia and conglomerate units occur in the lower part. To the south of



a

Frederick E. Hyde Fjord these clastics are continuous with the flysch-type sequence forming the upper part of the platform section already described (fig. 249), and which may reach into the Devonian.

Few fossils have been collected from the section described above and these are from scattered localities (Dawes & Soper, 1970). The material indicates strata of Lower Ordovician and Lower Silurian ages but a much wider age range of rocks undoubtedly forms the sequence.

A Lower Ordovician graptolite fauna can be referred to two graptolite zones, viz. the *Tetragraptus approximatus* Zone (early Arenig) and the *Isograptus caduceus* Zone (uppermost Arenig) (Bjerreskov & Poulsen, 1973).

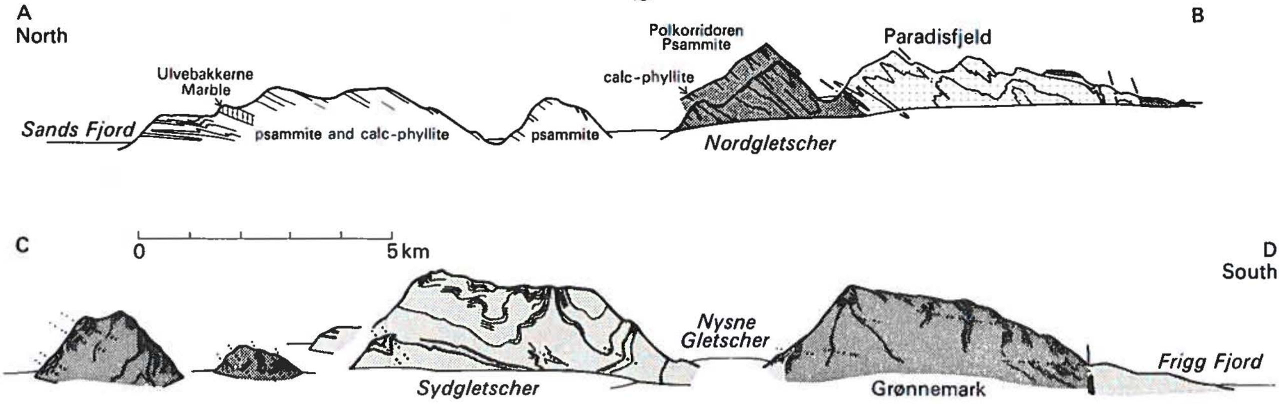
A shelly fauna from limestone in the upper arenaceous unit includes an assemblage known in part from the Cape Schuchert Formation of the platform region in western North Greenland and suggesting strata of early to middle Llandovery age (Bjerreskov & Poulsen, 1973). The brachiopod *Pseudoconchidium* is previously known only from the lower Llandovery of the northern Urals, while the presence of *Eospirifer(?)* may suggest the occurrence of strata as young as late Llandovery (A. J. Boucot, personal communication).

Stratigraphic data from the metamorphic belt in northern Peary Land are available from two regions, Nansen Land in the west (Ellitsgaard-Rasmussen, 1955) and the Roosevelt Fjelde in the east (Fränkl, 1955a; Dawes & Soper, 1970, 1973).

In Nansen Land a dark brown weathering clastic sequence of unknown, but obviously large thickness, outcrops over large areas. The rocks form a monotonous, well bedded succession of grey to dark grey, fine to coarse-grained sandstone and greywacke with

Fig. 256. *a*. Simplified geological map of the central Roosevelt Fjelde, northern Peary Land, showing the location lines of the cross-sections. Unornamented ground around Sands Fjord makes up high-grade equivalents of units recognised in the south.
b. Cross-sections through the central Roosevelt Fjelde, northern Peary Land. Modified from Dawes & Soper (1973).

b



some grits, alternating with grey to black shale and slate beds. In places psammitic rocks are dominant, elsewhere dark shales form thick units with smaller sandstone intercalations. Intraformational breccia and conglomerate composed of dark slate fragments, often rounded, situated in a sandstone matrix are frequent in some beds. Despite severe dynamic metamorphism graded bedding and cross-bedding are commonly preserved. No fossils are known from the sequence, but the rocks are at least in part equivalent to the Silurian to Devonian clastic succession known in the western part of the fold belt in the Hall Land – Wulff Land region and in folded and platform areas in southern Peary Land.

The Roosevelt Fjelde are formed of a thick series of psammitic, pelitic and calcareous rocks which have been metamorphosed and deformed to varying degrees to produce a folded series of rocks that increase in metamorphic grade towards the north. In the central region between Frigg Fjord and Sands Fjord the sequence is divided into three apparently stratigraphically conformable groups (figs 250, 256). These groups are considered to be the equivalents of less metamorphosed rocks to the south in the Frederick E. Hyde Fjord region. Other units defined in the higher grade terrain bordering the Arctic Ocean are, at least in part, high-grade equivalents of rocks in this tripartite sequence (Dawes & Soper, 1973).

The oldest group, the *Paradisfjeld Group*, is composed of four formations of unknown thickness. In ascending order these are: graphitic and calcareous phyllites with subsidiary dark grey limestone and calcareous siltstone; dark grey limestone typically rubbly in appearance, characterised by much quartz-carbonate veining and containing rusty weathering, quartz-sericite phyllite and thin bands of yellow limestone; thin green banded calcareous phyllite; and yellow limestone with graphitic calcareous phyllite and thin quartzite horizons in the upper part.

The *Polkorridoren Group*, composed predominantly of arkosic rocks, conformably overlies the Paradisfjeld Group. Two formations are recognised; a lower of rusty or green weathering quartz phyllite, and an upper, the Polkorridoren Psammite, of unknown but clearly large thickness of graded grit to shale units (fig. 257).

The *Sydgletscher Group* outcropping north of Frigg Fjord almost certainly overlies the Polkorridoren Group. It is composed of five formations which in ascending order are: Nysne Gletscher Mudstones of unknown thickness composed of purple, green and grey mudstones with rare arenaceous beds; Lower Sydgletscher Shales (*c.* 250 m) composed of interbedded dark calcareous and graphitic shales some layers of which are silicified, banded grey to dark grey limestones, thin brown weathering calcareous siltstones with ripple drift bedding, and particularly in the uppermost part, thin beds of quartz grit; Sydgletcher Quartzite (*c.* 100 m) composed of black shales containing two conspicuous bands of fine grained black quartzite each about 30 m thick and thinning southwards; Upper Sydgletscher Shales (*c.* 300 m) of similar lithology to the Lower Sydgletscher Shales and becoming more arenaceous upwards; and Sydgletscher Sandstone, (*c.* 300 m) composed of buff to brown weathering, well bedded, calcareous sandstones.

Fig. 257. Asymmetrical, northerly overturned syncline in the Polkorridoren Psammite, Mary Peary Tinder, eastern Roosevelt Fjelde, Peary Land, viewed from the west. Height of 1600 m summit above the glacier level is approximately 600 m.

The age of the sequence can only be inferred from correlation with units of known age elsewhere in the fold belt (fig. 250). The base of the succession is not seen and the only fossils known are crinoid remains and unidentifiable graptolite and brachiopod fragments in the Sydgletscher Group.

In the high-grade terrain outcropping to the north of the sequence five metamorphic units have been named (Fränkl, 1955a). From south to north these are: Sortevæg Marbles and Phyllites (rusty weathering phyllites with layers of dark marbles); Nunatak Quartzitic Slates (fine-grained, arenaceous slates); Sands Fjord Quartz Phyllites (slaty, micaceous quartzites and sandy mica schist); Ulvebakkerne Marble (grey to buff coloured impure marbles and limestone and rusty weathering calcareous phyllites); and the Kap Morris Jesup Quartz Phyllites (arenaceous mica-garnet schists, with argillaceous psammite, pelite and thin quartzite bands).

The southerly three units are almost certainly high-grade equivalents of rock units recognised to the south. The Kap Morris Jesup Quartz Phyllites are conformably overlain by the Ulvebakkerne Marble. The age relationship of these two mappable units to the three groups recognised to the south is less certain but from structural considerations they could underlie the Paradisfjeld Group and represent the oldest rocks of the metamorphic terrain (fig. 250).

Post-orogenic acid volcanic suite

A suite of acid volcanic rocks known as the Kap Washington Group is found on the northern coast of Peary Land (fig. 267). They structurally underlie the older metasediments which have been thrust northwards over the volcanic rocks on the southerly-inclined Kap Cannon thrust.

The volcanics are known in the region between Kap Cannon and Lockwood Ø (Dawes & Soper, 1970) but from aerial photographs are interpreted to continue westwards to the north coast of Nansen Land (fig. 267). They cover more than 600 km² on land and an unknown extent under the Arctic Ocean. In the immediate offshore region a positive magnetic anomaly could reflect a large submarine extension of the group (Dawes, 1973).

Around the type locality at Kap Washington the group is composed of at least 1500 m of lavas and tuffs which dip generally southwards, parallel to the overlying thrust. The sequence is of variable character containing homogeneous, flinty, vesicular and banded, fine to medium-grained volcanic rocks, some of them porphyritic and others autobrecciated. Some units may be ignimbritic and there are also air-fall tuffs, occasionally with accretionary lapilli. In other areas the succession contains arkose and conglomerate with light coloured granophyre as intrusives.

The suite appears to be essentially calc-alkaline in character; many of the effusives are rhyolitic with SiO_2 generally in excess of 70 per cent.

The effusive rocks are non-metamorphic though local tuffs are cleaved and some open folds affect the volcanic pile. They are younger than the adjacent Lower Palaeozoic metasediments of the fold belt and the main folding and metamorphism that affected them, i.e. Devonian or younger.

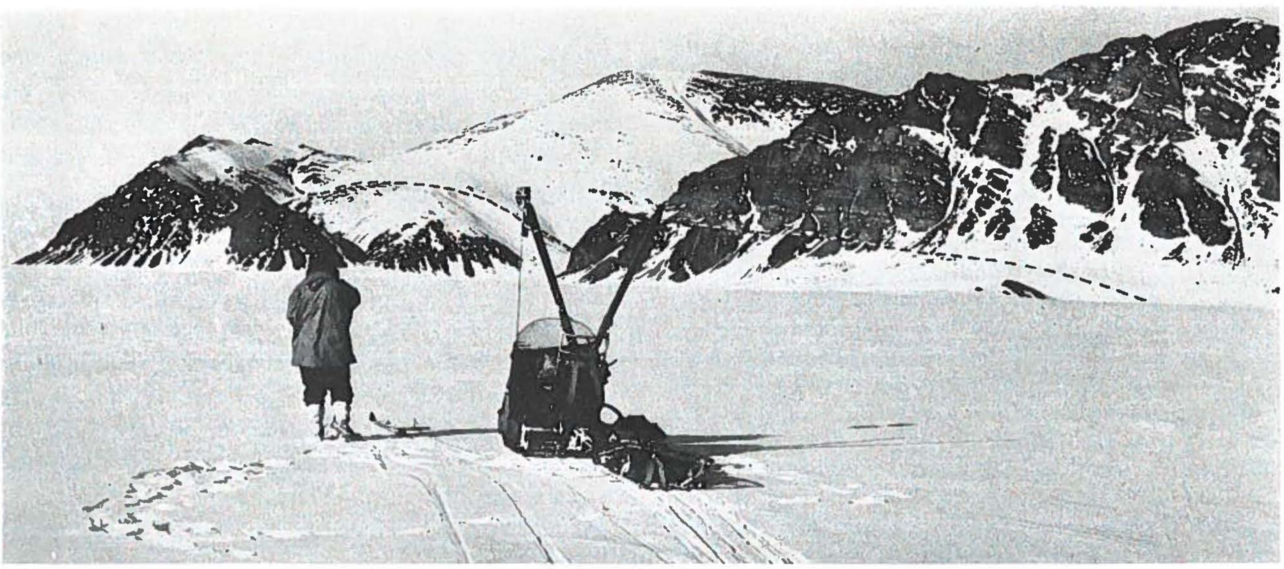
The Kap Washington Group pre-dates the Kap Cannon thrust which is considered to be of mid-Tertiary age. K-Ar whole rock age determinations of two lava samples have given 34.9 ± 3.5 m.y. and 32.3 ± 3.2 m.y. These dates could be close to the intrusion and general cooling age of the volcanic pile, but since the rocks are strongly sheared in the vicinity of the thrust zone, there is a possibility of argon loss and the dates must be regarded as minima for the age of volcanism.

Wandel Sea basin

Slightly deformed sedimentary rocks, Carboniferous to Tertiary in age, are exposed as scattered outliers in the North and East Greenland fold belt terrain in Peary Land and Kronprins Christian Land and on islands and headlands around Danmark Fjord. The same rocks are assumed to underlie parts of the continental shelf of the Wandel and Greenland Seas. A sedimentary basin, the Wandel Sea basin (Dawes & Soper, 1973), evidently underlies this region, which extends about 400 km from south-east to north-west (figs 222, 267).

The basal beds of the Wandel Sea basin overlie the folded and eroded rocks of both the North Green-

Fig. 258. The Kap Cannon thrust separating the Kap Washington Group of volcanic rocks from the overlying, older metasedimentary phyllites. Dark amphibolite layers are visible in the phyllites. Height of the snow-covered cliff behind Kap Cannon is approximately 500 m.



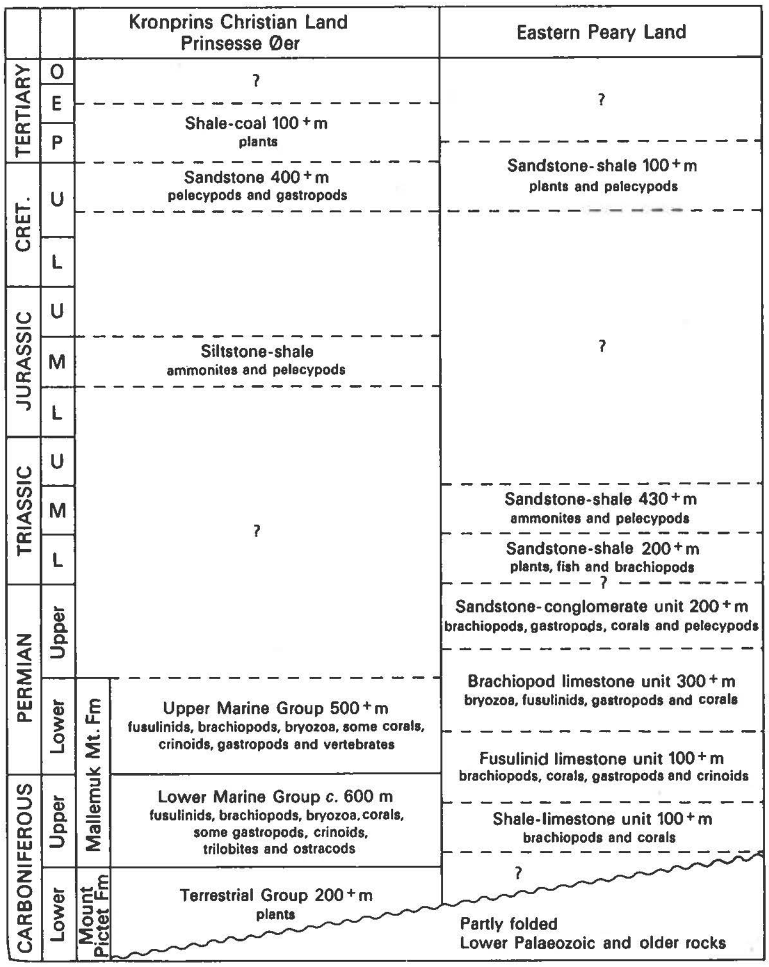


Fig. 259. Composite stratigraphical chart of the Upper Palaeozoic–Mesozoic–Tertiary strata of the Wandel Sea basin.

land and the East Greenland geosynclines with major angular unconformity. The basinal beds are flat lying to shallow dipping but steep dips occur locally, due to folding and faulting.

Strata of the Wandel Sea basin are well exposed in coastal cliffs in Kronprins Christian Land, but in eastern Peary Land mainly underlie low-lying ground and are hidden by a heavy cover of Quaternary deposits.

The Wandel Sea succession begins with Lower Carboniferous terrestrial sandstone, conglomerate and shale, and these pass within a few hundred metres into Permo-Carboniferous marine limestone, sandstone and shale. The marine beds form about the lower half of the composite sedimentary section. The upper half is mainly Mesozoic rocks of mixed marine and deltaic association. Several hundred metres of Tertiary, and probably Cretaceous, beds of coal and plant-bearing sandstone and shale form the topmost units. Nowhere is a complete section exposed, and only scattered stratigraphic data are available; however, from present data, a composite section totals nearly 3000 m (fig. 259).

Permo-Carboniferous

The Permo-Carboniferous is perhaps the best known part of the Wandel Sea basin sequence. Sections have been studied in Amdrup Land and Holm Land of eastern Kronprins Christian Land (Dunbar *et al.*, 1962) and in eastern Peary Land (J. C. Troelsen, personal communication; Peel *et al.*, 1974), where at least 1300 m and 700 m respectively of strata have been measured (fig. 259) Other outcrops are known in north-western Kronprins Christian Land around Station Nord.

Kronprins Christian Land

The sections in Amdrup Land and Holm Land were initially described by Grönwall (1916) and given the names 'Terrestrial, Lower Marine, and Upper Marine groups' (fig. 260).

The terrestrial rocks at the base of the sequence have only been recorded at the south-western edge of the basin on the southern coast of Holm Land, west of Mallemukfjeld. The rccks are dark coloured, plant-bearing sandstone and conglomerate with some

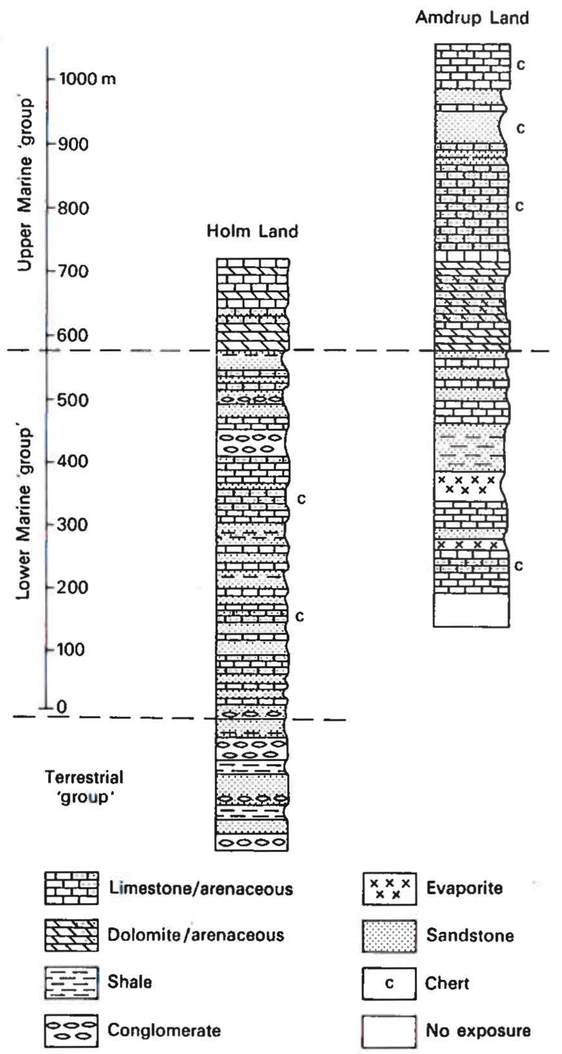


Fig. 260. Sections of Permo-Carboniferous rocks in the southern part of the Wandel Sea basin in Kronprins Christian Land. For ages of strata see figure 259. Modified from Dunbar *et al.* (1962).

alternating sandy and micaceous shales as well as some poor quality coal seams less than a metre thick. At least 200 m of rock is exposed but according to Grönwall (1916, p. 556) the total "thickness probably amounts to about 500 m, or possibly more".

The flora of these terrestrial rocks includes species of *Telangium (Calymmatotheca), Asterocalamites, Spenophyllum, Stigmaria, Lepidophyllum* and *Lepidodendron*: an assemblage showing similarities to faunas from Spitsbergen and suggesting a Lower Carboniferous (Dinantian) age (Nathorst, 1911).

The marine succession is more than 1300 m thick. The *Lower Marine 'group'* exposed in both Holm Land and Amdrup Land, is nearly 600 m thick. A 10 m thick basal conglomerate overlies, evidently disconformably, the terrestrial unit and passes up into a sequence of alternating limestone and sandstone beds with some marl and shale. Many limestones, marls and shales are bituminous. Small bank and patch reefs mainly composed of the coral *Chaetetes* occur in the limestones. Some of the sandstones are reddish in colour, several are characterised by cross-bedding and some have yielded plant remains. In Amdrup Land a 35 m gypsum–anhydrite bed is present in the middle of the section. In Holm Land the upper part of the section contains a conspicuous conglomerate bed composed of quartzite and igneous pebbles.

Studies of the brachiopods (Grönwall, 1916; Frebold, 1942, 1950; Dunbar, 1962), fusulinids (Ross & Dunbar, 1962) and bryozoans (Ross & Ross, 1962) date the Lower Marine 'group' as Upper Carboniferous in age. The group contains two important fusulinid zones with genera known from the Moscovian (middle Upper Carboniferous) series of Russia.

The *Upper Marine 'group'* disconformably overlies the Lower Marine 'group' and in Amdrup Land it is about 500 m thick. The sequence is characterised by alternating limestone and dolomite beds with some siliceous rocks. Many of the limestones in the middle part of the section are arenaceous and in the upper part some sandstone beds come in.

The Upper Marine 'group' is of Lower Permian age. Fusulinids from the basal 100 m of the sequence suggest strata of early Permian age (Asselian of Russia; Wolfcampian of North America). The bryozoan fauna from the upper 150 m of the sequence contains species which show affinities to species from the Sakmarian and Artinskian Stages of Russia (middle Lower Permian) while a rich brachiopod fauna in the upper part of the sequence includes species known from the Brachiopod Cherts of Spitsbergen suggesting that the Lower Marine 'group' reaches the late Lower Permian (Kungurian of Russia). A small vertebrate fauna (see Bendix-Almgreen, this volume) also supports this age assignment for the upper part of the group.

The Permo-Carboniferous around Station Nord is composed of grey to buff, thin bedded limestone, in places richly fossiliferous, and often silicified, as well as calcareous and sandy shale and some sandstone. Main outcrops are separated by faults, and stratigraphic thickness and relationships of carbonate to clastic rocks are uncertain. The limestones contain corals, echinoderms, brachiopods, bryozoa and gastropods. Species of *Fenestrelina, Polypora* and *Lophophyllidium* have been identified indicating at least Permian, possibly Lower Permian strata in the sequence (C. Poulsen, personal communication).

Peary Land

A Permo-Carboniferous section at least 700 m thick outcrops in eastern Peary Land. The sequence is of shale and limestone at the base, fossiliferous limestones in the lower and middle part, and sandstone, grit and conglomerate at the top (fig. 259; Koch, 1925, 1929c; J. C. Troelsen, personal communication, & 1950b; Peel *et al.*, 1974; W. E. Davies, personal communication).

At Herlufsholm Strand the lowest unit, at least 100 m thick, is of dark grey to black shales with intercalated fossiliferous limestone beds up to 1 m thick. To the north in Hellefiskefjord, the fossiliferous limestones are at least 400 m thick and are divided into a lower unit of grey weathering limestone particularly rich in fusulinids, grey and reddish chert, violet shale and shaly limestone and marl, and an upper unit of buff to brown weathering, thin bedded, grey brachiopod-rich limestone with layers of grey chert.

The clastic rocks at the top of the sequence, in the area north-west of Mudderbugten, are at least 200 m thick, and possibly considerably thicker. The rocks are yellow to red weathering, well bedded, brown, red and grey sandstone of varying grain size, grit and pebbly grit, conglomerate and dark brown sandy shales, with minor grey, red and violet limestones. Well rounded pebbles in the conglomerates are of quartzite, vein quartz and basalt and according to Koch (1929c) reach "the size of a walnut".

The Permo-Carboniferous sequence in eastern Peary Land evidently ranges from Upper Carboniferous to Upper Permian in age. The oldest fauna is one of fusulinids from near the base of the section. This includes *Triticites* indicating a middle to late Upper Carboniferous (Pennsylvanian) age (Troelsen, 1950b). A brachiopod fauna from the overlying limestones includes *Cleiothyridina, Septacamera, Thamnosia, Martinia, Licharewia, Spiriferella, Yakovlevia* cf. *Y. greenlandica, Choristites* cf. *C. sederberghi* and *Liosotella spitzbergiana,* an assemblage having a general similarity to the late Lower Permian of Spitsbergen and central East Greenland (F. G. Stehli, personal communication). A fauna from the upper clastic rocks includes the pelecypod *Aviculopecten* and the brachiopods *Muirwoodia* cf. *M. greenlandica, Waagenoconcha* cf. *W. payeri, Streptorhynchus(?), Anidanthus, Spiriferella* cf. *S. keilhavii, Odontospirifer* and *Spirifer striato-paradoxus,* an assemblage of Upper Permian age (W. E. Davies, personal communication).

Triassic

Triassic rocks are known only from eastern Peary Land where at Herlufsholm Strand a section at least 630 m thick contains strata of at least Lower and Middle Triassic age (Kummel, 1953). The stratigraphic relationship of this 630 m sequence to the Permo-Carboniferous already described from the same area is uncertain. The oldest beds in the section are situated about 150 m above sea level and are in probable fault contact with older rocks.

The Triassic sequence is divided into a lower deltaic unit and an upper marine unit. The lower unit, at least 200 m thick, is composed mainly of sandy shale with some fissile shale and micaceous thin bedded sandstone showing cross-bedding. Conformably overlying this, the upper unit, at least 400 m thick, is composed of grey to yellow weathering mainly medium-grained, thin bedded sandstone containing shale layers and partings. Dark brown to black ferruginous nodules, mainly as ammonite casts, characterise a 30 m layer in the middle part of the unit.

The lower unit has yielded a fauna containing plant and fish remains as well as the ammonite *Arctoceras* and the brachiopods *Orbiculoidea* cf. *O. spitsbergensis* and *Terebratula* cf. *T. margaritowi,* forms indicating some relationship to the Lower Triassic of Spitsbergen and northern Russia. The vertebrate fauna contains remains of selachians and palaeoniscoids which show clear affinity to the Scythian fish horizon of Spitsbergen (Nielsen, *in* Kummel, 1953).

The lower 150 m of the upper marine unit has yielded poorly preserved pelecypods and brachiopods as well as an ammonite fauna of Middle Triassic age, including *Pearylandites troelseni, Groenlandites nielseni, Parapopanoceras* cf. *P. tetsa, Beyrichites* cf. *B. affinis* and *Leiophyllites.* The presence of *Parapopanoceras* proves strata of Anisian (early Middle Triassic) age and indicates relationship to strata in Spitsbergen, Siberia and Arctic and Cordilleran North America. The eventual discovery of late Middle and younger Triassic rocks in the overlying 250 m of strata is considered likely, especially in view of the presence of strata of that age in Spitsbergen, with which the Peary Land sequence shows similarity.

Jurassic

The only confirmed occurrence of Jurassic rocks in the Wandel Sea basin is on the eastern side of the Flade Isblink on the semi-nunatak Kilen, Kronprins Christian Land. Here, a series of thin bedded siltstones and black shales of unknown thickness has yielded an ammonite–gastropod–pelecypod fauna indicating strata of at least Middle Jurassic age (Greenarctic Consortium, personal communication).

This fauna includes the pelecypods *Protocardia, Pleuromya, Inoceramus, Entolium, Cucullaea(?)* and *Tancredia(?),* and an ammonite similar to *Cranocephalites vulgaris* Spath suggesting beds of Bathonian age.

Cretaceous to Tertiary

Cretaceous and Tertiary strata are known from three main areas, Kronprins Christian Land, Prinsesse Øer and Peary Land. The outcrops in these areas indicate a composite section over 600 m thick.

A shallow dipping, well bedded section, about 600 m thick, forms Nakkehoved, a semi-nunatak on the northern coast of Kronprins Christian Land. The lower 300 m of this section measured by Nielsen (1941) consists primarily of fine-grained dark sandstones, in beds of 10 to 30 m thick with alternating shales. A poorly preserved pelecypod-gastropod fauna has yielded *Nucula, Yoldia* and *Barbetia* which suggest Cretaceous strata near the base of the sequence. The upper part of the Nakkehoved remains uninvestigated but the presence of Tertiary beds is likely.

A similar but thinner section composed of gently folded grey sandstones and greywackes with thin conglomerate layers, alternating with black shales, outcrops in eastern Peary Land (J. C. Troelsen, personal communication). This section has yielded leaf and stem impressions of deciduous trees as well as fossil wood and is of Cretaceous–Tertiary age.

Tertiary rocks form the bedrock of the low lying Prinsesse Øer. On the western side of Thyra Ø a stream section exposes thin coal seams with alternating sandstones and black shales (Eigil Knuth, personal communication). A flora collected by Greenarctic Consortium (personal communication) from these beds indicates a Paleocene age for at least part of the section and suggests correlation with the Eureka Sound Formation of the Canadian Arctic.

Ages of sills and dykes

Sills and dykes, predominantly of dark grey dolerite, in places quartz or olivine bearing, form a small but significant part of the volume of rock in northern Greenland. The intrusive bodies are emplaced in the crystalline basement complex and in the overlying formations, Proterozoic to Devonian in age. Several periods of intrusion can be surmised from structural and stratigraphical relationships, and in turn the intrusions are, in places, of considerable stratigraphic use, particularly where isotopic age determinations are possible.

Five periods of intrusion can be identified: dykes cutting the basement probably pre-date the middle to late Proterozoic sedimentary formations; sills and dykes intrude late Proterozoic beds but are absent from overlying beds; in the North Greenland fold belt minor intrusions discordant to the Lower Palaeozoic metasediments are deformed and metamorphosed by the mid-Palaeozoic orogeny while in another area, sills similarly intrude Palaeozoic beds but pre-date the unconformably overlying late Palaeozoic formations; a young, probably Cretaceous, period of intrusion of basic dykes.

Early or middle Proterozoic dykes in basement terrain

Undeformed dolerite dykes occur as swarms in the crystalline basement in North-West Greenland; at least some of these are older than the nearby Thule Group (*sensu stricto*). Dykes in the Inglefield Bredning area trend north-west, and an olivine dolerite dyke swarm of this trend in Melville Bugt may be of the same age. North-east trending dykes are present in the Wolstenholme Fjord region, and these are cut by north-west to WNW-trending dykes; dykes of the latter trend also intrude the entire section of the Thule Group (see below). East–west trending basic dykes of unknown composition cut the crystalline basement in central North Greenland in the Victoria Fjord arch.

A K-Ar whole rock age of 1563 ± 60 m.y. was obtained from a north-west trending dolerite dyke in the Inglefield Bredning area (Dawes *et al.*, 1973). The mainly north-west trending dykes in the basement terrain thus appear, from structural and isotopic data, to be of middle Proterozoic age or older.

Middle to late Proterozoic sills and dykes

Basaltic sills and dykes are conspicuous and represent a significant addition of rock to the Proterozoic sedimentary sections throughout northern Greenland (fig. 240). Sills are up to 200 m thick; dykes can be several tens of metres wide. These rocks constitute the 'Algonkian Eruptives' of Koch (1925) and the 'Thulean Intrusives' of Haller (1971). Jepsen (1971b) has used the name 'Midsommersø dolerites' for intrusions of this age in Peary Land. Widespread intrusions of this age also occur in North-East Greenland.

In North-West Greenland in the Thule region the sills and dykes have regular shapes with more or less constant thicknesses but in eastern North Greenland, particularly in the Independence Fjord region, the intrusions display a wide variety of forms. Sills and dykes vary in thickness and merge into each other, and feeding channels, chonoliths, stocks and plugs are exposed in the steep fjord walls.

Basaltic rocks, some quartz bearing, dominate but in certain areas of eastern North Greenland, acidic rocks are common (Koch, 1925). Haller (1971) mentions a NNW–SSE trending swarm of brick-red weathering, acidic dykes near the head of Independence Fjord which can be traced over a distance of 60 km. One of these is evidently a quartz-rich intrusion breccia (Ellitsgaard-Rasmussen, 1950; Jepsen, 1971b).

Reddish brown, porphyrite dykes occur in the Danmark Fjord area (Adams & Cowie, 1953).

In eastern North Greenland from Peary Land to Kronprins Christian Land, the igneous rocks intrude older Proterozoic rocks and are overlain by the younger Hagen Fjord Group. In Peary Land the intrusions pre-date the Eocambrian tillite which has been correlated with the Varangian glaciation of Scandinavia.

In both Kronprins Christian Land and the Thule region periods of basic intrusion can be separated by important regional tectonic events – events which may or may not be of comparable age. In Kronprins Christian Land the Carolinidian folding separates an older period of mainly sill intrusions from a younger period (fig. 240). The younger intrusions are mainly vertical dykes, some of which reach up to 400 m thick (Haller, 1971). Such an age distinction is not possible in regions away from the influence of the Carolinidian orogeny, although in Peary Land at least seven phases of intrusion have been recognised by cross-cutting relationships (Ellitsgaard-Rasmussen, 1950). Isotopic ages of 799, 982 and 988 m.y. on these dolerites in Peary Land, have an uncertain relationship to the Carolinidian orogeny (Henriksen & Jepsen, 1970).

In the Thule region cross-cutting relationships indicate that the regional WNW-trending dyke swarm is younger than the sill intrusions in the Wolstenholme and Dundas Formations of the Thule Group. Furthermore, an important period of faulting occurred in the interval between the emplacement of at least some, may be all, of the sills and the intrusion of the WNW-trending dykes (Dawes, 1975). Eight isotopic K-Ar age determinations of sills and dykes cutting the Thule Group fall into two age groups, those between 532 and 764 m.y. and those between 1070 and 1190 m.y. (Dawes *et al.*, 1973). These isotopic age groups may reflect the approximate ages of the two periods of magmatism deduced from the field relationships.

Older Palaeozoic intrusions in the North Greenland fold belt

A few deformed mafic layers in the metamorphosed terrain of the North Greenland fold belt represent minor intrusions into the geosynclinal sediments. The layers, up to about 15 m thick, are mainly concordant to subconcordant to the lithological banding in the host metasediments, but in places where the layers have a more irregular form, discordant contacts exist. The rock type varies from foliated metadolerite and metagabbro to amphibolite and crystalline schist. The layers have been folded together with the host rocks and schistosity in the layers is mainly parallel to that of the surrounding metasediments.

Where observed along the northern coast of Peary Land, the host rocks are of presumed Lower Palaeozoic age. The intrusions are considered to be either pre-tectonic or syntectonic with respect to the mid-Palaeozoic orogeny (Devonian) of the fold belt.

Younger Palaeozoic sills in the North Greenland fold belt

In the southern margin of the North Greenland fold belt in the G. B. Schley Fjord area of eastern Peary Land a number of greenstone sills cut folded Ordovician–Silurian strata but are overlain by Carboniferous–Permian beds of the Wandel Sea basin (Troelsen, 1950b). The base of this sequence, as described elsewhere, is of Upper Carboniferous (late Pennsylvanian) age. Intrusive activity of similar age is known in northern Ellesmere Island in the Canadian Arctic, where dolerite dykes cut folded Silurian rocks but underlie the unconformity at the base of the Carboniferous strata of the Sverdrup Basin (Trettin, 1969). No dykes of this age have yet been recognised in Greenland but they could be represented in the numerous post-Silurian cross-cutting dykes known in Peary Land and described below under Cretaceous(?) dykes.

Cretaceous(?) dykes

Basic dykes form swarms of several trends in the North Greenland fold belt and some are found also in an adjacent, unfolded area of the platform. Beds of Silurian age, and possibly as young as Devonian, are intruded. The dykes evidently are younger than the mid-Palaeozoic orogeny, but in northern Peary Land some are altered by late Cretaceous–Tertiary diastrophism. K-Ar age determinations suggest a Cretaceous age of intrusion.

Dykes of this group are numerous in the fold belt east of Nares Land and individual dykes can be traced over many kilometres. No dykes have been seen in the westernmost part of the fold belt in Hall Land and Nyeboe Land but Koch (1920) mentions intrusions in nearby northern Wulff Land. Dykes vary in thickness from a few metres to tens of metres but are rarely over 50 m thick. The dykes cut sharply across the folded and metamorphosed rocks and have chilled contacts. Most are vertical to steeply inclined.

Three main trends are present in northern Peary Land (Dawes & Soper, 1970); NE–SW trending dykes form a swarm in the central Roosevelt Fjelde and are particularly conspicuous around Sands Fjord; E–W to WNW-trending dykes form a swarm traceable from eastern Frederick E. Hyde Fjord to J. P. Koch Fjord and Nansen Land. Dykes of this swarm are parallel to, and associated with major faults, i.e. Harder Fjord fault; N–S to NNW-trending dykes form a wide swarm present throughout northern Peary Land with particularly dense concentration in the western Roosevelt Fjelde.

The majority of the dykes are grey to dark grey and occasionally black, often brown weathering, dolerite or olivine dolerite. In Nansen Land various rock types have been recognised and some dykes are composite (Ellitsgaard-Rasmussen, 1950). Some E–W dykes in the Roosevelt Fjelde are lamprophyric with megascopic mica (Dawes & Soper, 1970). In the area between Benedict Fjord and Sands Fjord on the northern coast certain N–S dolorite dykes have sheared contacts and can vary within a single body from ophitic textured dolerite to greenish foliated metadolerite.

Relatively few dykes cut the unfolded platform and all known examples occur to the east of the Victoria Fjord arch. A NW–SE swarm of olivine dolerite dykes, 5 to 50 m thick, cuts the Proterozoic to Silurian sequence in the Midsommersø region (Jepsen, 1971b).

K-Ar ages of 72.9 ± 9 m.y. and 66 ± 6.6 m.y. have been obtained from dolerite dykes from respectively the NW–SE swarm of the platform and the E–W swarm of the fold belt (Henriksen & Jepsen, 1970; Dawes & Soper, 1971). The ages are taken as minima so that a Cretaceous age for these swarms is likely. However, as referred to above, some dykes could be of post-Silurian, pre-late Pennsylvanian age. The alteration of certain dykes in northern Peary Land is connected with the regional metamorphism and tectonism that affected the fold belt in late Cretaceous and Tertiary time.

Structural geology

A geological map of northern Greenland is dominated by north-east to east structural and stratigraphic trends that form a gentle arc from Inglefield Land to Peary Land. North-westerly trends occur, however, in the Thule region, and strong northerly to north-north-easterly structures characterise the East Greenland fold belt in Kronprins Christian Land. The trends noted lie in a sub-rectilinear pattern: the huge and largely unknown mass of the crystalline Greenland Shield forms a core or block that is flanked on three sides by sedimentary basins. These basins are: the Thule basin in the south-west; the North Greenland geosyncline in the north; and the East Greenland geosyncline in the east. The stratigraphic and structural trends in each basin conform to the general coastal configuration of the northern part of the sub-continent.

It is inviting to compare these three basins, each of which contains several thousands of metres of sedimentary rock. The similarities are few, however: the Thule basin consists of mainly undeformed sandstone, dolomite and shale beds and is now a large graben; the North Greenland geosyncline is a deformed trough of mainly clastic and flysch-type sediments in which the direction of tectonic transport is dominantly northward, away from the Precambrian crystalline mass; the East Greenland geosyncline is similarly a deformed trough containing a mixed series of rocks, but the direction of tectonic transport is westward, toward the crystalline mass.

The Wandel Sea basin rests upon the junction between the two geosynclinal fold belts and is deformed into a tectonic zone having mainly north-westerly trending structures.

In the following description the Thule basin, with its cratonic character, is taken to be part of the platform.

Greenland platform

The platform region of northern Greenland comprises the Precambrian crystalline basement and overlying, relatively undisturbed late Precambrian and Palaeozoic sedimentary rocks. The sedimentary rocks form a thin, homoclinal cover over much of the northern platform, but the sedimentary units are vastly thicker in the Thule region, as described earlier, and the remnants of this sedimentary basin are now down-faulted and preserved in a dominantly crystalline terrain.

The platform cover is flat lying to gently northerly dipping up to 10° in most of northern Greenland, but is slightly deformed into broad, open flexures near the North Greenland fold belt.

Structures of the Precambrian crystalline basement were noted earlier, with the description of the basement rocks. There is no evidence that basement rocks have been incorporated, either as elevated blocks or as reworked rocks, into the exposed metamorphic rocks of the North Greenland fold belt.

The platform of North Greenland constitutes hinterland to the North Greenland fold belt, but a foreland to the East Greenland fold belt, the tectonic transport being to the north in the first case and to the west in the second. The surface of the crystalline basement must dip gently northward and eastward beneath the platform sedimentary homoclines. From aerial magnetic profiles of Peary Land it is known that this surface must steepen considerably to accommodate the thick accumulations of basinal sediments (King *et al.*, 1966; E. R. King, personal communication).

Normal faults, vertical to steeply inclined, transgress the platform and are especially prominent in the Thule region, in Peary Land and in eastern North Greenland between Peary Land and the East Greenland fold belt (figs 223, 224, 267). The faults are at least of two ages, Proterozoic, and post-Silurian (probably Tertiary).

As recognised by Koch (1926) the Thule group in North-West Greenland is cut by prominent faults. The main structure of the Thule region is an east–west oriented asymmetrical graben. At the southern edge of the graben, the uppermost strata of the Thule Group are in contact with crystalline basement along the Narssârssuk fault (fig. 223). This juxtaposition suggests a fault displacement of at least 2000 m but the throw could be considerably more. NW–SE trending faults mark the northern edge of the graben near Kap Alexander. In Prudhoe Land the basement – Thule Group unconformity is preserved over large areas and the Thule Group has been tilted southwards with dips up to 40°.

Within the graben the Thule Group is divided up into a number of tilted fault blocks, mainly southerly dipping, some of which expose crystalline basement. Faults have varying trends; many are between E–W and NW–SE, some strike NE–SW. The morphological shapes of many fjords, islands and coastlines developed in the Thule Group are fault controlled (fig. 231). Open folds and broad flexures occur in the Thule Group.

The Thule Group shows evidence of penecontemporaneous faulting (Kurtz & Wales, 1951) and it seems probable that the considerable subsidence indicated by the thick deposits of the Thule basin was also related to movements along early faults.

As noted earlier one important period of Proterozoic fault movement occurred in the interval between the intrusion of dolerite sills and the WNW-trending dolerite dykes. It is probable that faulting of other ages took place, perhaps in Palaeozoic and more probably in Tertiary time.

In Peary Land NE–SW and E–W trending faults occur. An east–west fault in the J. P. Koch Fjord area has a southerly downthrow of about 1 km.

In the region between Peary Land and Kronprins Christian Land, two main fault trends are dominant; a NW–SE set and a NE–SW set (fig. 267). These faults transgress the Proterozoic to Silurian platform strata with a normal displacement of several hundred metres. In Valdemar Glückstadt Land the platform deposits dip eastward at about 5° and in Kronprins Christian Land the foreland of the East Greenland fold belt is deformed by generally northerly trending open folds, faults and thrusts. The Lower Palaeozoic foreland rocks are partially overridden by a series of westerly directed thrust sheets, which form a nappe zone at the margin of the fold belt. This tectonic activity evidently affected the Profilfjeldet Formation which contains beds of probable Upper Silurian age. This gives a lower age limit of the thrusting and associated folding of the foreland.

North Greenland fold belt

The North Greenland fold belt forms a zone of deformed and metamorphic rocks between Hall Land and eastern Peary Land. The fold belt is characterised by a strong east–west trending grain, parallel to the coast and the continental margin. The width on land of the fold belt is about 100 km in Peary Land, and 25 km farther west, but the exposed area must be but a small part of the whole orogenic zone. A northern part presumably underlies the continental shelf, or has been wholly or partially obliterated or removed. From magnetic data (King *et al.*, 1966), it appears that geosynclinal sediments continue northward under the Arctic Ocean, probably to the edge of the continental shelf.

The main sense of tectonic transport in the fold belt is northwards towards the Arctic Ocean. Northerly overturning of fold structures is particularly evident in the northern part where stratigraphical units and structural elements have a conspicuous southerly dip (fig. 261). The fold belt is bounded on the north by the Kap Washington Group of volcanic rocks. Folded metasedimentary rocks have been transported northward over the Kap Cannon thrust so that they tectonically overlie the essentially non-metamorphic volcanic rocks.

The intensity of both deformation and metamorphism increase northwards across the fold belt. Structures attributable to three major episodes of orogenic deformation are recognised (Dawes & Soper, 1973). The major folds of each episode are effectively coaxial and trend east–west over large areas. In a northward traverse through the fold belt from the undeformed hinterland, the 'first' folds appear initially as open structures which intensify northwards and then become refolded by 'second' folds. Further north, with increasing metamorphic grade, these develop an axial planar fabric which in the very north of

Fig. 261. Two views towards the east across the Roosevelt Fjelde illustrating the southerly dipping tectonic fabric of the northern part of the North Greenland fold belt. Thomas Gletscher (T) with a prominent medial moraine appears in both photographs. The Kap Cannon thrust is indicated. Kap Washington (W), Frigg Fjord (F). Aerial photographs 157 M-Ø, no. 1879 & 1805. Copyright Geodetic Institute.

Peary Land is deformed by 'third' structures. These progressive changes enable five tectonic–metamorphic zones to be defined (fig. 262).

Regional tectonic–metamorphic zones

Zone 1. This consists of essentially undeformed, non-metamorphic platform strata in the south (1a) which are affected by weak, often monoclinal warps in the north (1b).

Zone 2. The margin of the fold belt proper is abrupt, but involves no regional dislocations. In the west, in Hall Land and Wulff Land, it is marked by the appearance of east–west trending symmetrical folds and monoclines which in the north become overturned towards the north. Box-folding occurs in some areas (fig. 263) and in Peary Land some southward-facing monoclines occur at the margin.

In Peary Land these 'first' structures become refolded by northward-facing monoclinal 'second' folds which in the north of zone 2 become tighter and develop overturned common limbs (fig. 264). Cleavage occurs locally in the more argillaceous lithologies.

Zone 3. In this zone slaty cleavage is widely developed in the less competent lithologies (fig. 265). It is axial-planar to the northwardly overturned 'second' folds and thus dips south. Most rock types show some degree of recrystallisation with metamorphic muscovite and locally chlorite crudely aligned parallel to the cleavage.

Zone 4. The cleavage is extensively developed in most rock types, congruously with the axial planes of 'second' folds but superimposed obliquely across earlier folds. In the northern part of zone 4 a third set of structures becomes important. Small to medium scale upright 'third' folds deform both the bedding and main cleavage and are themselves accompanied by a crenulation fabric. Muscovite and chlorite are aligned in the main cleavage but are deformed by the crenulation fabric. The thermal peak thus appears to have accompanied the 'second' deformation episode.

Zone 5. The southern boundary of this zone is defined by the incoming of biotite in appropriate lithologies. Within it the metasediments are completely recrystallised and the southerly-inclined schistosity is the dominant fabric of all rock types. The superimposed crenulation cleavage is widely developed, inclined more steeply to the south. Bedding can still be recognised as relict compositional banding.

In the north (zone 5b, fig. 262) amphibolite facies assemblages are developed, with garnet overgrowing the main schistosity, evidently replacing both chlorite and biotite. Well annealed 'static' microfabrics characterise this zone. The thermal maximum in this region appears to post-date the 'second' structures but pre-date the 'third' since retrogressive chlorite is associated with the superimposed crenulation cleavage.

In the highest grade rocks, which are found to the east of Benedict Fjord, garnet is joined in appropriate lithologies by staurolite, andalusite, cordierite and locally sillimanite. Calc-silicate bands contain clinozoisite or amphibole with calcic andesine, while metadolerites develop epidote, amphibole and andesine.

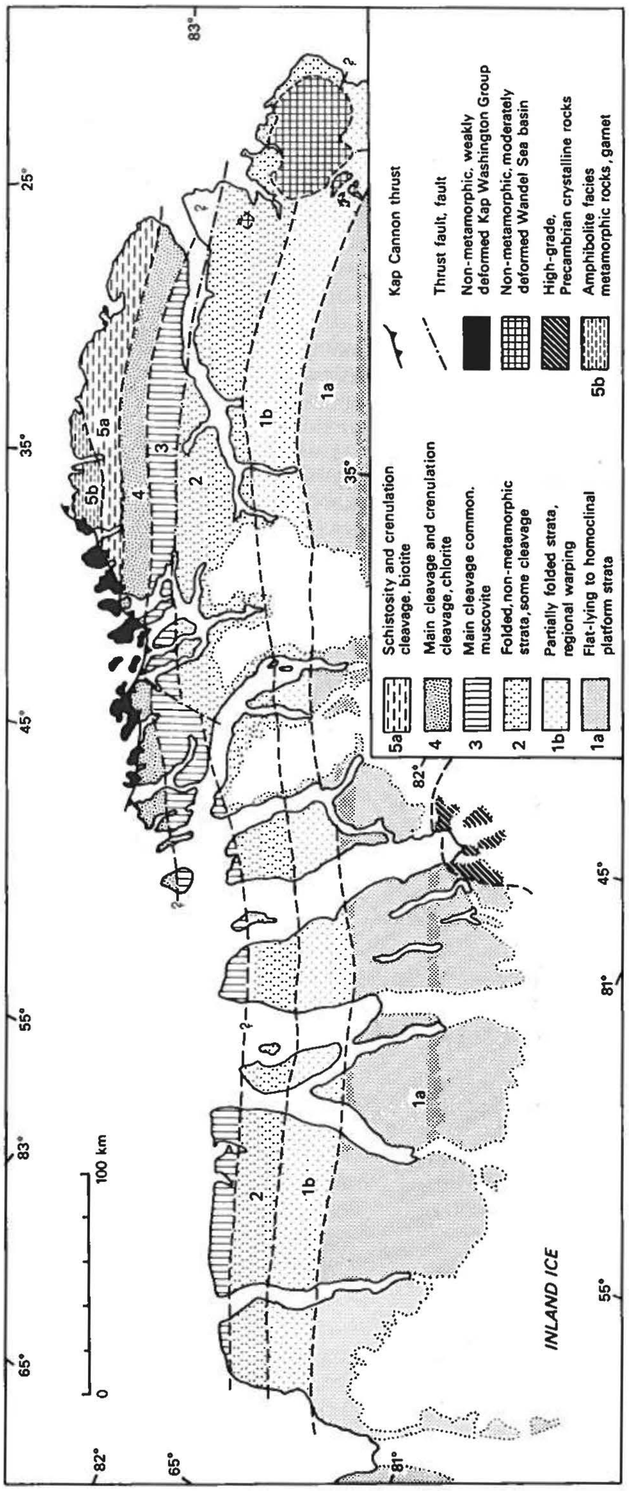


Fig. 262. Map showing the general pattern of tectonic-metamorphic zones across northernmost Greenland. Compiled partly from Dawes & Soper (1973).

Faults

The faults of the fold belt are of three groups: high-angle faults and thrust faults sub-parallel to lithostratigraphical units; NE–SW and NW–SE trending faults; and southerly dipping thrusts.

The high-angle strike faults and thrust faults have mainly southerly dipping fault planes but some have near vertical or northerly dipping planes. Some of the southerly inclined faults occurring on the limbs of northerly overturned folds probably were formed during the main deformation. Others

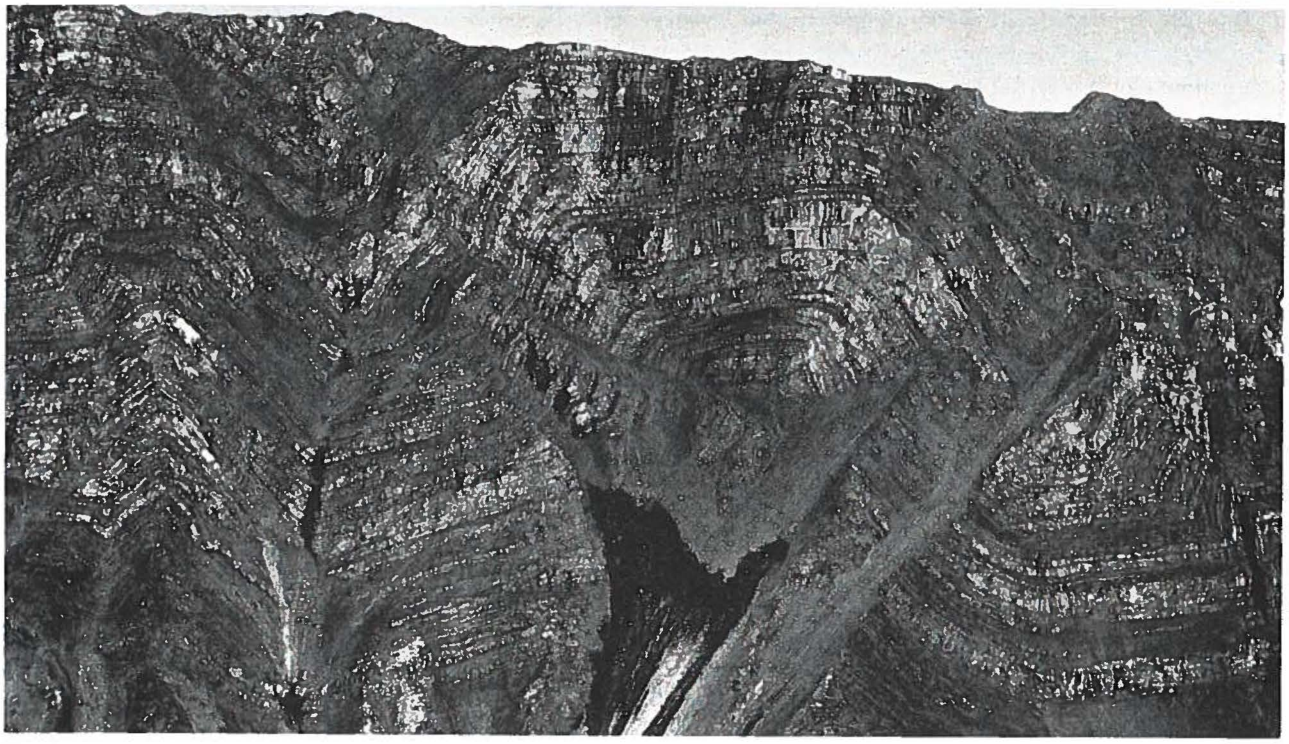
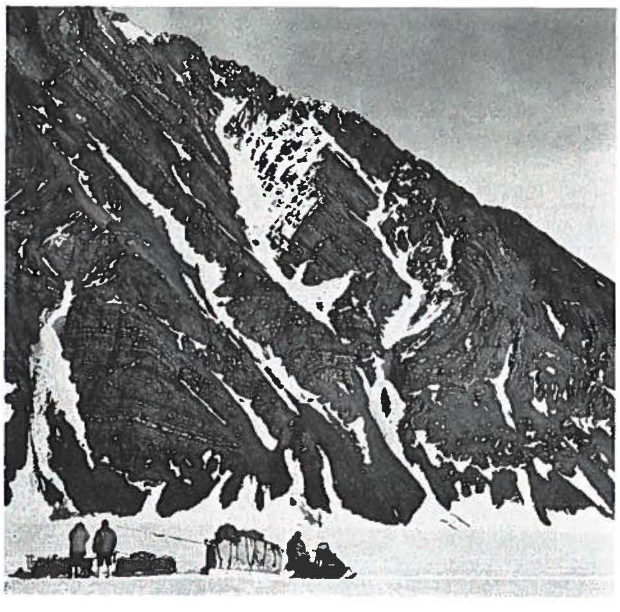


Fig. 263. Box folds in the Silurian–Devonian greywackes on the eastern side of Castle Ø, Sherard Osborne Fjord. Cliff is about 350 m high.

distort the mid-Palaeozoic fold pattern and are post-orogenic, probably Tertiary in age (Haller & Kulp, 1962). A conspicuous, steeply inclined thrust fault of uncertain age in northern Nyeboe Land, separating juxtaposed Cambro-Ordovician carbonates and Silurian-Devonian clastic rocks (fig. 267), shows considerable upwards displacement of the northern block. Drag folds occur in the carbonates adjacent to the fault plane. Similar thrust faults are common in Nansen Land (Ellitsgaard-Rasmussen, 1950).

Fig. 264. Ordovician and ?Silurian siltstone, shale and sandstone in a large-scale northerly overturned fold in the western face of Kap Holger Danske, Peary Land. The lower limb of the structure is the right way up. The height of the section is approximately 350 m.



In northern Peary Land, the Harder Fjord fault and the Kap Bridgman fault, traceable over 200 km and 100 km respectively (fig. 267), are post-orogenic fractures that form distinct topographic features. They flank the alpine mountains of the Roosevelt Fjelde and H. H. Benedict Bjerg, which evidently represent a horst block (Haller & Kulp, 1962; Haller, 1971). The Harder Fjord fault, at least, was in existence before or during the Cretaceous(?) basic dyke intrusion since undeformed dolerite is present in the fault zone. Both faults and probably others in the fold belt were rejuvenated in Tertiary time.

A number of NE–SW and NW–SE trending normal faults, commonly with steeply inclined fault planes, transgress across and displace fold structures in Peary Land. These faults are of post-orogenic, probably Tertiary age. Certain of these in eastern Peary Land affect strata of the Wandel Sea basin.

The third fault group is represented by the Kap Cannon thrust in northern Peary Land. This is slightly oblique to the trend of the fold structures and metamorphic boundaries already described (figs 262, 267). This thrusting is considered to be of mid-Tertiary age. In northern Hall Land northerly thrusting of uncertain age seems to have contributed to the thickening of the Ordovician–Silurian carbonate section (fig. 252). In Peary Land metasediments of the fold belt have overridden the Kap Washington Group of volcanics (fig. 258). The northerly sense of this thrusting has served to accentuate the overturning of the fold structures and, in the metasediments overlying the Kap Cannon thrust, schistosity is of low to almost flat lying dip, fold hinges have been tightened or obliterated, and amphibolite layers are stretched and deformed. The Kap Cannon thrust has caused crushing, mylonitisation and retrogressive greenschist metamorphism of the amphibolite facies metasediments.

The tectonic and metamorphic pattern of the fold belt is thus markedly asymmetric. The progressive northward increase in metamorphic grade was accompanied by increasing deformation and asymmetry of the fold structures, implying tectonic transport towards the north. The true northern margin of the fold belt is unlikely to be represented by the Kap Cannon thrust, since this is much later than the orogenic deformation and developed oblique to the metamorphic zones. The metamorphic belt is thus likely to have an offshore continuation to the north, perhaps with a cover of Kap Washington volcanic rocks.

Age of orogenesis

The orogenic activity of the North Greenland fold belt is dated by the relationships of the structural and metamorphic elements already ascribed to various rock groups and to geological events of known age. The following relationships are significant:

(1) The youngest geosynclinal sediments in the fold belt are of at least Lower Devonian (Gedinnian) age.

(2) Folded Lower Palaeozoic sediments in zones 1 and 2 of the fold belt are unconformably overlain by Carboniferous beds of the Wandel Sea basin.

(3) The main deformation and metamorphism of the fold belt pre-date the cross-cutting basic dykes which are probably of Cretaceous age. These dykes have also suffered a certain amount of metamorphism and shearing.

(4) The Kap Washington Group, which has given a minimum K-Ar age of 35 m.y., post-dates the orogenic deformation and metamorphism, but predates some weak folding, the Kap Cannon thrust and associated greenschist facies metamorphism.

In eastern Peary Land, the unconformity at the base of the Wandel Sea basin lies below rocks at least as old as Upper Carboniferous (late Pennsylvanian), but in Kronprins Christian Land Lower Carboniferous (Dinantian) beds occur in the basal part of the succession. The folds in eastern Peary Land in zones 1 and 2 belong to the main phases of orogenic deformation which is thus placed in the interval between early Devonian and early Carboniferous time.

Isotopic age determinations on the metamorphic rocks of the fold belt have failed to date this mid-Palaeozoic orogenic activity. Four schists from the highest grade rocks (zone 5) have given a Cretaceous to Tertiary K-Ar age; 84.2 m.y. and 75.9 m.y. on biotite, 47.1 m.y. whole rock on a chloritoid-muscovite schist and 42.3 m.y. on muscovite (Dawes & Soper, 1971). These dates indicate that one or more thermal events of regional significance affected

Fig. 265. Typical greywacke–shale lithology of Silurian–Devonian flysch of the North Greenland fold belt showing a well developed slaty cleavage in the argillaceous beds. Some calcite veining. Northern Nyeboe Land.

the North Greenland fold belt in late Phanerozoic time. The dates of 84 and 76 m.y. could refer to the recrystallisation of biotite and garnet grade mineral assemblages during a regional metamorphism of Cretaceous age.

It is uncertain if structural events of comparable age affected the fold belt. Faulting associated with some east–west trending Cretaceous(?) basic dykes is either of Cretaceous age or older, and weak metamorphism and deformation of certain other Cretaceous(?) basic dykes in northern Peary Land is of Cretaceous or Tertiary age. It is not known whether the dates of 47 m.y. and 42 m.y. refer to a separate thermal event of Tertiary age or whether such dates are due to partial argon loss associated with the Kap Cannon thrusting.

Tertiary movements in the fold belt are indicated by the thrusting and slight folding of the Kap Washington Group, regional faulting, and by mylonitisation and greenschist metamorphism associated with the Kap Cannon thrust. The whole rock K-Ar ages of 34.9 m.y. and 32.3 m.y. on volcanic rocks of the Kap Washington Group are interpreted as giving a maximum age for the Kap Cannon thrusting which caused the northward transport of metamorphic rocks over the volcanic pile. The thrusting is thus considered to be of mid-Tertiary age.

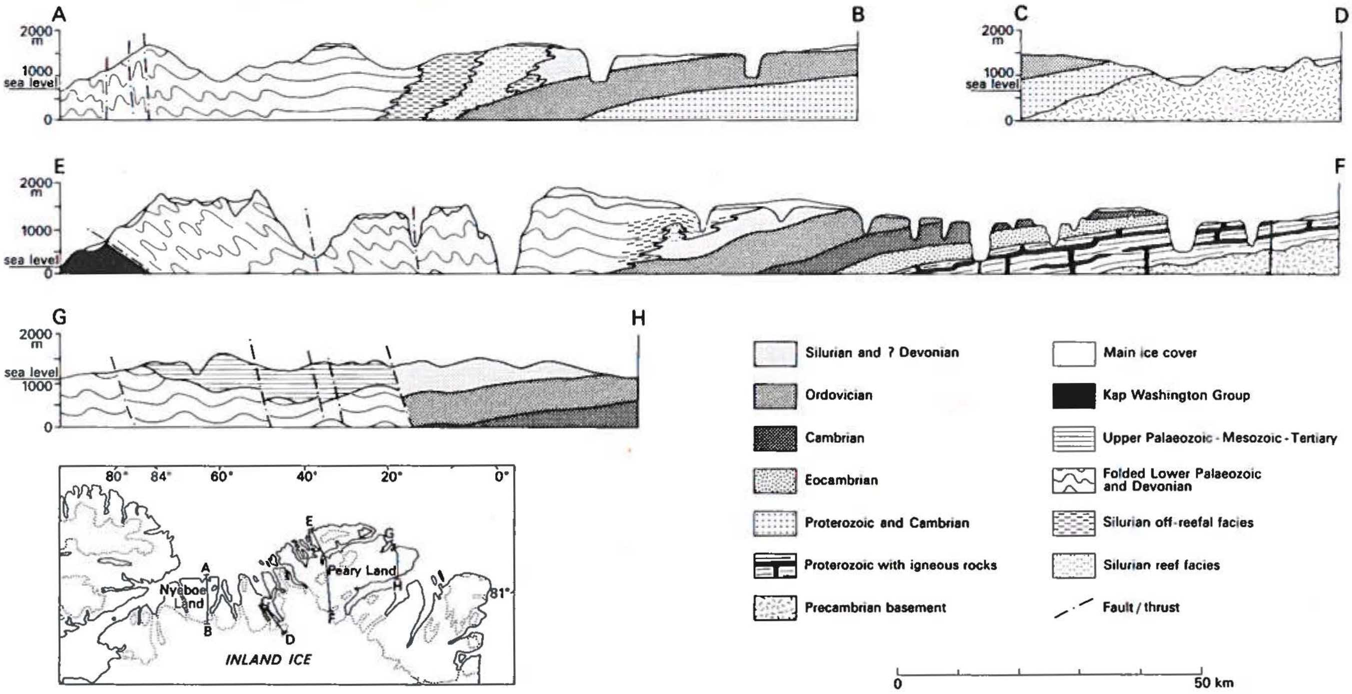


Fig. 266. Simplified cross-sections through North Greenland illustrating the relationships of the main geological units.

Wandel Sea basin

The Wandel Sea basin has been folded and faulted into a tectonic belt having a general north-west to south-east trend. The belt is characterised by broad to medium sized open folds with gentle dips, but locally beds are steeply to vertically inclined in tight folds. Many homoclinal sections represent tilted fault blocks. The rocks are unmetamorphosed. Thus the basin, younger than the main orogenic events that affected northern Greenland, records lesser tectonic activity perhaps beginning in Mesozoic time, and certainly in Tertiary time.

Folds of two main trends are present in eastern Peary Land. A NW–SE trending set of folds is predominant, and in the Herlufsholm Strand region, plant-bearing Cretaceous or Tertiary rocks are folded into open synclines and anticlines (J. C. Troelsen, personal communication). This folding is probably of Tertiary age. Other folds appear to be sub-parallel with structures in the underlying Lower Palaeozoic rocks of the North Greenland fold belt. One large scale E–W to ENE–WSW trending syncline south of G. B. Schley Fjord affects Permo-Carboniferous rocks (J. C. Troelsen, personal communication). The age of this folding is uncertain but since it almost certainly post-dates nearby Triassic strata, it is likely to be of Mesozoic or later age.

Two trends of folds also occur in Kronprins Christian Land where the Permo-Carboniferous is deformed by NW–SE trending folds (Haller, 1971), as well as by weaker folds with NNE axes. Folds of this latter trend affect the strata on Holm Land and Amdrup Land (Nielsen, 1941) and also probably the beds south of Station Nord which may be steeply inclined to the north-east or south-west.

The Wandel Sea basin is crossed by *faults* of two main sets. A NW–SE trending steeply inclined set crosses eastern Peary Land forming some important valleys, and continues into Kronprins Christian Land controlling the NW–SE elongated shape of the Prinsesse Øer where Tertiary beds are exposed. Tertiary fault movements also caused important tilting of strata in eastern Peary Land where a system of NW–SE trending faults cuts Permian and Triassic rocks into a series of south-westerly dipping fault blocks. Faulting of a similar type occurs in western Kronprins Christian Land, south of Station Nord.

A less prominent set of faults striking NNE to NE cuts the Permo-Carboniferous rocks in Kronprins Christian Land (Nielsen, 1941) as well as the Carboniferous to Triassic section in eastern Peary Land. Irregular dips and strikes of the Triassic strata in Peary Land are attributed more to movements along rotated faults than to the folding that affects the Triassic section (J. C. Troelsen, personal communication).

Tectonic history

The Wandel Sea basin contains a Carboniferous to Tertiary sedimentary section. The youngest known rocks are of Paleocene (early Tertiary) age. Thus the

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Fig. 267. Geological map of northernmost Greenland between Humboldt Gletscher and Hovgaard Ø, compiled from maps by Koch (1929b and unpublished colour map of Washington Land, 1931, 1:500.000), Adams & Cowie (1953), Troelsen (1956), Haller (1970, 1971), Jepsen (1971b) and Dawes & Soper (1973), and from the author's field and photogeological work. Igneous intrusions of at least three ages in the region to the east of Victoria Fjord are not shown.

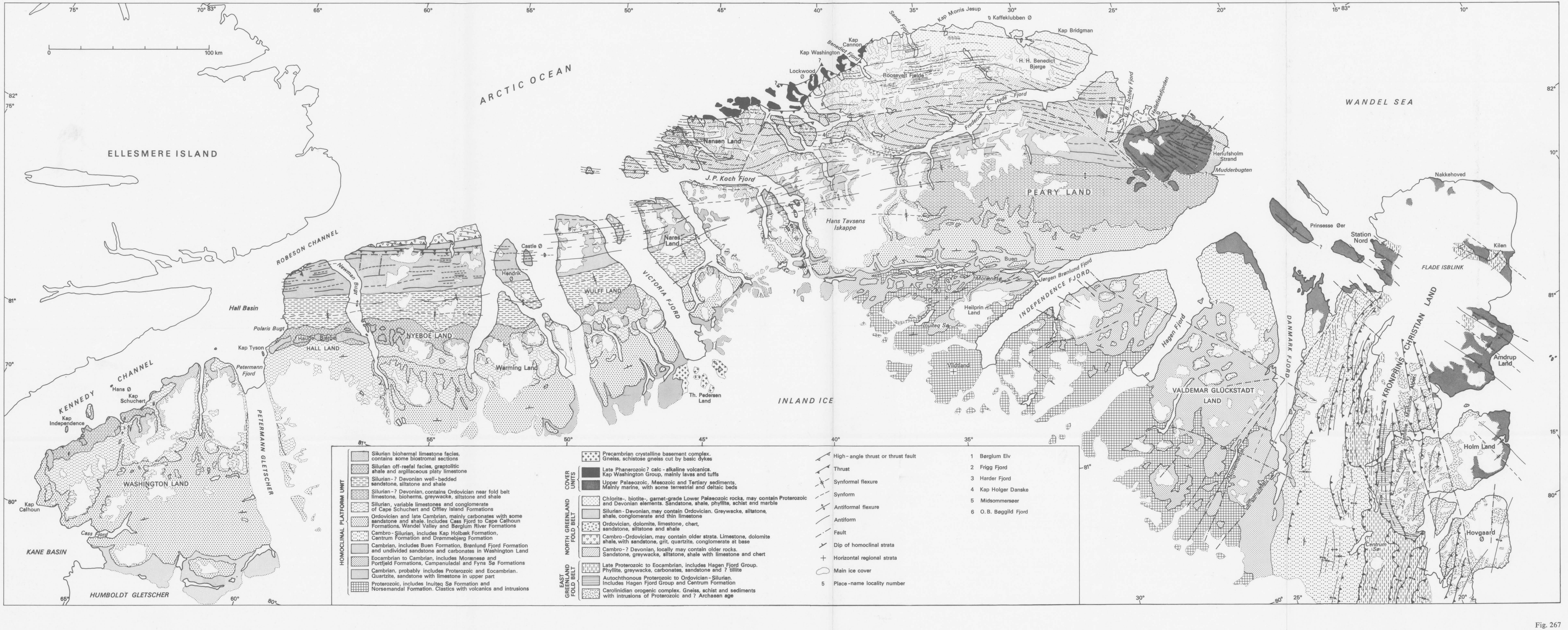
ARCTIC OCEAN
WANDEL SEA
ELLESMERE ISLAND
ROBESON CHANNEL
KENNEDY CHANNEL
Hall Basin
KANE BASIN
HUMBOLDT GLETSCHER
PETERMANN GLETSCHER
INLAND ICE
0
100 km
Kap Morris Jesup
Kaffeklubben Ø
Kap Bridgman
Sands Fjord
Kap Cannon
Kap Washington
Benedict Fjord
H. H. Benedict Bjerge
Lockwood Ø
Roosevelt Fjelde
Frederick E. Hyde Fjord
O. B. Schley Fjord
Nansen Land
J. P. Koch Fjord
Herlufsholm Strand
Mudderbugten
PEARY LAND
Hans Tavsens Iskappe
Nares Land
Castle Ø
Hendrik Ø
Newman Bugt
WULFF LAND
VICTORIA FJORD
NYEBOE LAND
Warming Land
Th. Pedersen Land
Polaris Bugt
Hauge Bjerge
HALL LAND
Kap Tyson
Petermann Fjord
Hans Ø
Kap Schuchert
Kap Independence
WASHINGTON LAND
Kap Calhoun
Cass Fjord
Buen
Moraenesø
Jørgen Brønlund Fjord
INDEPENDENCE FJORD
Heilprin Land
Inuiteq Sø
Vildtland
Hagen Fjord
VALDEMAR GLÜCKSTADT LAND
DANMARK FJORD
Prinsesse Øer
Station Nord
Nakkehoved
Kilen
FLADE ISBLINK
KRONPRINS CHRISTIAN LAND
Amdrup Land
Holm Land
Hovgaard Ø
Centrum Sø
75°
70°
83°
65°
60°
55°
50°
45°
40°
35°
30°
25°
20°
15°
10°
82°
81°
80°
HOMOCLINAL PLATFORM UNIT
Silurian biohermal limestone facies, contains some biostromal sections
Silurian off-reefal facies, graptolitic shale and argillaceous platy limestone
Silurian - ? Devonian well-bedded sandstone, siltstone and shale
Silurian - ? Devonian, contains Ordovician near fold belt limestone, bioherms, greywacke, siltstone and shale
Silurian, variable limestones and conglomerate of Cape Schuchert and Offley Island Formations
Ordovician and late Cambrian, mainly carbonates with some sandstone and shale. Includes Cass Fjord to Cape Calhoun Formations, Wandel Valley and Børglum River Formations
Cambro - Silurian, includes Kap Holbæk Formation, Centrum Formation and Drømmebjerg Formation
Cambrian, includes Buen Formation, Brønlund Fjord Formation and undivided sandstone and carbonates in Washington Land
Eocambrian to Cambrian, includes Moraenesø and Portfjeld Formations, Campanuladal and Fyns Sø Formations
Cambrian, probably includes Proterozoic and Eocambrian. Quartzite, sandstone with limestone in upper part
Proterozoic, includes Inuiteq Sø Formation and Norsemandal Formation. Clastics with volcanics and intrusions
Precambrian crystalline basement complex. Gneiss, schistose gneiss cut by basic dykes
COVER UNITS
Late Phanerozoic ? calc - alkaline volcanics. Kap Washington Group, mainly lavas and tuffs
Upper Palaeozoic, Mesozoic and Tertiary sediments. Mainly marine, with some terrestrial and deltaic beds
NORTH GREENLAND FOLD BELT
Chlorite-, biotite-, garnet-grade Lower Palaeozoic rocks, may contain Proterozoic and Devonian elements. Sandstone, shale, phyllite, schist and marble
Silurian - Devonian, may contain Ordovician. Greywacke, siltstone, shale, conglomerate and thin limestone
Ordovician, dolomite, limestone, chert, sandstone, siltstone and shale
Cambro - Ordovician, may contain older strata. Limestone, dolomite shale, with sandstone, grit, quartzite, conglomerate at base
Cambro - ? Devonian, locally may contain older rocks. Sandstone, greywacke, siltstone, shale with limestone and chert
EAST GREENLAND FOLD BELT
Late Proterozoic to Eocambrian, includes Hagen Fjord Group. Phyllite, greywacke, carbonates, sandstone and ? tillite
Autochthonous Proterozoic to Ordovician - Silurian. Includes Hagen Fjord Group and Centrum Formation
Carolinidian orogenic complex. Gneiss, schist and sediments with intrusions of Proterozoic and ? Archaean age
High - angle thrust or thrust fault
Thrust
Synformal flexure
Synform
Antiformal flexure
Antiform
Fault
Dip of homoclinal strata
Horizontal regional strata
Main ice cover
5 Place - name locality number
1 Børglum Elv
2 Frigg Fjord
3 Harder Fjord
4 Kap Holger Danske
5 Midsommersøer
6 O. B. Bøggild Fjord

Fig. 267

main NW–SE trending folding and faulting which cut the entire succession and produce the NW–SE structural grain of the basin are of post-Paleocene age.

The NNE–SSW and E–W folding and possibly the NNE to NE trending faulting, pre-date this northwest directed tectonism and are either of Tertiary or Mesozoic age. The E–W folding and the NNE to NE trending faulting affected the Permo-Carboniferous and Triassic rocks but the relationships to the Jurassic, Cretaceous and Tertiary rocks are unknown.

The stratigraphic relations of the various rock sections in the basin are not known in detail, but according to Greenarctic Consortium (personal communication) there is evidence of a regional unconformity below Cretaceous and Tertiary strata. Thus the early folding and faulting affecting the lower part of the Wandel Sea basin succession may be of Jurassic (post-Middle Jurassic) to Cretaceous age.

Summary of orogenies in northern Greenland

An undoubtedly long but incompletely known history of sedimentation and orogeny is represented by the Precambrian, crystalline basement rocks of the Greenland Shield. Uplift and profound erosion of the shield preceded subsidence and renewed sedimentation in late Precambrian time. Subsequent tectonism took place at different times in the various basins across northern Greenland: late Precambrian tectonism in the East Greenland fold belt and in the Thule basin; Lower Palaeozoic (Caledonian) orogeny in the East Greenland fold belt and mid-Palaeozoic orogeny in the North Greenland fold belt; and late Mesozoic–Tertiary folding and faulting in the Wandel Sea basin. This latter activity also affected the North Greenland fold belt.

Late Precambrian orogeny

In Kronprins Christian Land within the East Greenland fold belt important folding occurred between the deposition of the middle to late Proterozoic sediments and the overlying Hagen Fjord Group (Haller, 1970). The relationship of basic intrusions to this so-called Carolinidian orogeny has been mentioned elsewhere. To the west of Kronprins Christian Land, the influence of this orogeny peters out, and apart from slight tilting of the platform sediments, in places leading to an angular unconformity above the Inuiteq Sø Formation and possible faulting, no tectonic features of late Precambrian age are recognised in Peary Land. Slight alteration of basic igneous material in the Norsemandal Formation and Inuiteq Sø Formation might be an effect of Carolinidian metamorphism.

The Thule region of North-West Greenland is an important fault zone (Koch, 1926). Faulting probably accompanied the instability and subsidence producing the Thule basin and important fault movements following sedimentation divided the strata up into a number of tilted fault blocks.

Lower Palaeozoic orogeny

The Caledonian orogeny of the East Greenland fold belt is described in detail by Henriksen & Higgins (this volume). However, certain 'Caledonian' structures affect the platform strata described in this paper in Kronprins Christian Land. In central East Greenland the youngest geosynclinal sediments involved in the orogeny are of Middle Ordovician and possibly early Upper Ordovician age being overlain unconformably by Middle Devonian strata. From this stratigraphical evidence and from radiometric age dates the main Caledonian orogeny is assumed to have occurred in latest Ordovician to early Silurian time. However, in Kronprins Christian Land in North Greenland, the platform sequence contains a more or less complete Ordovician section, passing into Upper(?) Silurian. Thus, the folding and thrusting affecting this sequence, and probably also the main nappe zone of the fold belt, can be no older than late Silurian, and and thus movements of Devonian age in Kronprins Christian Land seem likely.

Epeirogenic uplift of the North Greenland platform took place at various times during the Lower Palaeozoic.

Mid-Palaeozoic orogeny

The main orogenic activity of the North Greenland fold belt occurred between early Devonian and early Carboniferous time. The three main deformation phases producing folds and associated planar fabrics, are referred to this mid-Palaeozoic orogenesis although later deformation and metamorphism of Cretaceous to Tertiary age are known to have affected the fold belt.

The North Greenland fold belt is the eastern part of an extensive geosyncline development – the Franklinian geosyncline. In the Canadian part of this province, a more or less complete Devonian sequence of rocks is exposed and this allows various phases of mid-Palaeozoic deformation to be dated stratigraphically. The main deformation was between late Devonian and early Carboniferous (Thorsteinsson & Tozer, 1970) while the earlier movements were of late Silurian to early Devonian, and late Middle (Givetian) to Upper (Frasnian) Devonian ages (Trettin, 1967, 1969). In North Greenland lack of (or failure to recognise) rocks younger than early Devonian prevents a comparable analysis of the deformation phases, but in view of the known orogenic intervals in Canada, it seems likely the mid-Palaeozoic orogenic activity in Greenland was of a similarly long duration.

The mid-Palaeozoic orogeny in Greenland resulted in a northerly directed character of the fold belt which is interpreted as due to a significant southerly movement of material at depth probably under the influence of mantle creep (Dawes & Soper, 1973). This movement may have involved the underthrusting of Palaeozoic ocean floor against the Greenland continental block with the strongly folded and metamorphosed rocks of the north coast being a product of the increased heat flow towards a Benioff zone.

Northerly overturning of fold structures is not characteristic of the western part of the Franklinian geosyncline. This and other differences in the structure of the fold belts in North Greenland and Ellesmere Island have been discussed in relation to the evolution of the Nares Strait and the Arctic Ocean in a separate paper (Dawes, 1973).

Late Mesozoic to Tertiary orogeny

Orogenic activity of Mesozoic to Tertiary age can be summarised as follows: Cretaceous(?) regional metamorphism and deformation, and Tertiary metamorphism, faulting, thrusting, and weak folding in the North Greenland fold belt; folding and faulting of Jurassic to Cretaceous(?) and Tertiary ages in the Wandel Sea basin. The effects of this orogenic activity seem to be concentrated in the north-east corner of Greenland; but Tertiary faulting occurred throughout the North Greenland fold belt, and certain of the NE–SW and NW–SE trending faults cutting the platform are of this age or have been rejuvenated by this orogeny.

In the North Greenland fold belt the effects of the mid-Palaeozoic orogeny have been overprinted to a varying degree by regional metamorphism and important Tertiary thrusting. The volcanicity producing the Kap Washington Group may have been responsible for the regional reheating of the mid-Palaeozoic orogen. Such a heat source acting in connection with Tertiary thrusting could explain the low K-Ar ages on the metamorphic rocks. The Kap Bridgman and Harder Fjord faults evidently post-date this thrusting suggesting tensional conditions in northern Peary Land by late Tertiary time.

Jurassic to present-day 'continental drifting' involving ocean floor tectonics has been postulated in the Arctic – North Atlantic region. The Late Mesozoic to Tertiary structures might thus be related to the compressional forces caused by the interaction of Europe and North America, with periods of tensional effects when spreading rates were slower or had ceased, or when spreading centres changed location.

Furthermore, the late Mesozoic to Tertiary tectonic and metamorphic history of northern Greenland shows close similarities to that of Spitsbergen where the West Spitsbergen orogeny (Harland, 1969) of mid-Tertiary (post-Paleocene, possibly post-early Eocene) age forms a fold belt along the west coast in which thrusting and faulting were important. Recent work in West Spitsbergen indicates the presence of a volcanic sequence of rocks perhaps of the same age as the Kap Washington Group, and suggests that the regional metamorphism accompanied the tectonism (W. T. Horsfield, personal communication). Furthermore there is also evidence in Spitsbergen of late Mesozoic diastrophism with folding and faulting in the late Jurassic – early Cretaceous interval as well as in the late Cretaceous (post-Albian) movements of similar age to those probably affecting the Wandel Sea basin. This close similarity suggests that North Greenland and western Spitsbergen were influenced by the same structural regime which supports a pre-continental drift position geographically much closer than at the present time.

Historical geology

The Greenland crystalline shield was uplifted after the Hudsonian orogenic episode (1800–1600 m.y.) and intense erosion reduced large areas of the basement to a peneplain. Remnants of this are preserved in Inglefield Land and elsewhere (figs 229, 235). Differential subsidence and marine inundation in middle to late Proterozoic time resulted in sedimentary basins separated by structurally high basement areas or arches. Detritus was derived from exposed basement areas and carried northwards in the shallow seas. Thickest sedimentary accumulation in Proterozoic time took place in the Thule basin and in eastern North Greenland (including the East Greenland geosyncline); the Bache Peninsula and Victoria Fjord arches separated these basins from a broad, central platform on which relatively thin sedimentary deposits accumulated.

Much of the middle to late Proterozoic clastic sequences contain red, brown and purple coloured rocks

	Composite stratigraphic section		Geological event	Igneous activity	K/Ar age (m.y.) determination
T	Sandstone, shale with coal units		Faulting Thrusting, faulting, folding, mylonitisation, metamorphism	Calc-alkaline effusives Basic dykes	32.3, 34.9 on lavas 42.3, 47.1 on metasedimentary schists 66.6, 72.9 on dolerite dykes 75.9, 84.2 on metasedimentary schists
C	Sandstone, grit, conglomerate, shale ?		Regional reheating with folding and faulting in Wandel Sea basin		
J	Siltstone, shale		Marine and deltaic sedimentation in Wandel Sea basin (Position and nature of stratigraphical breaks uncertain)		
Tr	Sandstone, shale				
P	Conglomerate, sandstone, grit, sandy shale Dolomite and limestone with some sandstone and siliceous rocks				
C	Limestone and sandstone with shale, conglomerate and evaporites Sandstone, conglomerate, shale with coal units		Major marine transgression Non-marine sedimentation		
	TROUGH	PLATFORM			
D S	Greywacke, shale, siltstone, some conglomerate and limestone	Greywacke, shale, biostromal and biohermal limestones, argillaceous limestone, conglomerate, shale	Major mid-Palaeozoic orogeny-metamorphism and polyphase deformation Marine sedimentation in the North Greenland geosyncline and on the stable platform block. Periods of regional uplift and intermittent erosion (Position and status of stratigraphical breaks vary from region to region)	Basic intrusions	(No mid-Palaeozoic ages due to late Phanerozoic overprinting)
O	Sandstone, shale, chert, limestone, carbonate breccia	Limestone, dolomite, conglomerate, shale, some evaporites			
Є	? Limestone, shale Dolomite, sandstone, shale	Carbonates, shale Limestone, dolomite, some sandstone Dolomite, limestone, sandstone, shale			
EЄ	Sandstone	Dolomite Sandstone, tillite	Marine transgression Glaciation, non-marine deposition	?	Range of 532 to 1190 on post-Thule Group dolerites
PЄ2	Sandstone, quartzite, grit, conglomerate with units of siltstone, shale and dolomite with some evaporites		Faulting and regional uplift, Carolinidian orogeny in east Thick shallow water sedimentation in the Thule basin and in Kronprins Christian Land, thinner on platform Marine transgression	Basic dykes and sills Basic and acidic effusives with sills and dykes	799, 982 on pre-tillite dolerites
PЄ1	High-grade crystalline basement-gneiss, schist, anorthosite, granite with metasedimentary units, limestone, pelite, psammite and igneous intrusions of basic to acidic composition		Regional uplift, faulting Metamorphism and polyphase deformation Complex history with older basement and supracrustal cover	Basic dykes Intrusion of basic to acidic complex	1563 on dolerite dyke 1600 - 1900 + 1960 Rb-Sr isochron on schists and meta-igneous rocks ?

Fig. 268. Chronological summary chart for northern Greenland. No attempt has been made to portray sedimentary unconformities in the Lower Palaeozoic and Upper Palaeozoic – Mesozoic successions.

rich in hematite. This suggests dry climatic conditions and the presence of an iron-rich pedalfer in the source area. Evaporite deposits associated with rhythmically sedimented dolomite, siltstone and shale indicate lagoonal conditions in the later phases of sedimentation in the Thule basin. Widespread conglomerates and grits indicate proximity to the source landmass, and ripple-marked sandstone and mud cracks in shale intercalations indicate shallow water conditions throughout the Proterozoic sedimentation.

Volcanism was widespread towards the end of Precambrian time and effusions both interrupted sedimentation and followed it (fig. 268).

Regional uplift of the Greenland Shield and its Proterozoic sediment and igneous cover occurred and renewed erosion produced an important unconformity, in places angular, above Proterozoic rocks. In Kronprins Christian Land (within what is now the northern part of the East Greenland fold belt) late Proterozoic deformation culminated in the folding and uplift of what has been called the 'Carolinidian mountain chain'.

A subsiding east–west trending zone began to develop in the north in late Proterozoic time and this found full expression in the Lower Palaeozoic as the North Greenland geosyncline. The sea transgressed over the eroded land surface, and regional subsidence and marine sedimentation continued, punctuated by periods of uplift and erosion, into the Devonian. In the beginning of the Palaeozoic sedimentation took place in shallow epicontinental seas adjacent to the uplifted Precambrian craton of the south and in the deeper water trough zone of the north. Sedimentary sources for these deposits varied and it seems most likely that the southerly source was significantly added to in early Palaeozoic time by material derived from a northern landmass. This source area is postulated as a continuation of the Pearya Geanticline (Trettin, 1971); a borderland to the Franklinian geosyncline which shed detritus into the northern part of the trough. Furthermore, additional detritus in the Hagen Fjord – Danmark Fjord basin may have been contributed from denudation of the supposed Carolinidian fold belt in Kronprins Christian Land.

Non-marine tillite-bearing beds were deposited to the east of the Victoria Fjord arch – a glaciation that presumably affected a much larger region than the restricted outcrops now preserved. Following the glaciation, renewed erosion, probably due to uplift, removed in places the entire thickness of the Morænesø Formation. This was followed by a major transgression, the coastline of which ran from Inglefield Land to the Victoria Fjord arch, and from there in an east–west direction across southern Peary Land and Heilprin Land and south-east into the Danmark Fjord region.

The alternating carbonate and clastic rocks of the Eocambrian succession in Peary Land and Kronprins Christian Land suggest an unstable, shallow shelf. This instability continued throughout Cambrian time. In the west the alternating sandstone–carbonate succession of the Wulff River, Cape Kent and Cape Wood Formations containing basal conglomerate, and intraformational conglomerate and breccia indicates shallow water sedimentation, and erosion and redeposition of locally uplifted strata, with a terrestrial source of the sandstones in the south. To the east the thicker clastic units of the Buen Formation and Kap Holbæk Formation indicate a greater subsidence than in the Inglefield Land – Washington Land area with rapidly eroding rivers bringing sand and argillaceous material down from the uplifted Precambrian craton and the Carolinidian 'mountains' to reach the flat shelf zone. Rapid subsidence and turbidite sedimentation is indicated by the greywackes of the Buen Formation. The overlying dolomites are characterised by intraformational conglomerates and indicate deposition near sea level. Late Cambrian time saw marine sedimentation at least in the Washington Land region.

Platform sedimentation with relatively thin widespread units separated by frequent diastems as well as more significant breaks, persisted into the Ordovician when limestone deposition prevailed and shales and particularly sandstones became of much less importance. This suggests that the influence of the southern craton had diminished and throughout much of Ordovician and Silurian time the craton must have been relatively low-lying, producing perhaps only small additions of material to the shelf following uplift and local increased elevation.

The Ordovician succession, particularly the lower part, is characterised by organic-fragmental carbonate rocks alternating with homogeneous limestones and dolomite, argillaceous limestones and shales indicating frequent fluctuations in sea level: strata were deposited, eroded, and then redeposited on renewed submergence. Evaporites in the succession in Washington Land suggest the existence of some closed shallow water basins on the shelf zone.

Sedimentation in late Ordovician and Silurian time took place on a relatively stable platform to produce extensive carbonate beds and reefs. The reefs formed an east–west trending barrier along the edge of the shelf while biostromal limestones were deposited to the south. Periodic erosion of the reefs took place and a main period of emergence may have occurred in Middle Silurian time. Argillaceous rocks were deposited in fore- and back-reef belts and in inter-reef basins. To the north of the reef front deeper water sedimentation took place in the rapidly subsiding geosyncline but in late Silurian or early Devonian time clastic deposition spread southwards stifling the reef banks of the shelf.

The entire geosynclinal sequence in North Greenland appears to be of marine facies and the sediment source for this, particularly for the upper part, was probably entirely from the northern borderland. Thick, chert-pebble conglomerate units in the flysch sequence containing some pebbles of crystalline rocks suggest that this borderland was of appreciable relief, and not too far distant in late Silurian time.

The Lower Palaeozoic sequences in North Greenland illustrate the contrasted depositional environments of the platform and trough zones. A regional north–south facies change is prominent throughout North Greenland grading from the mainly carbonate rocks of the platform to the dominantly clastic rocks of the north. Thus, in Peary Land, massive Ordovician dolomites and limestones pass northwards into siltstone, sandstone, shale and chert, as well as limestone conglomerates representing fragmental material eroded off the platform carbonate sequences. Likewise, the Silurian limestone and reef facies in the south passes northwards into a mixed argillaceous limestone and limy mud facies containing graptolites but lacking the rich benthonic faunas of the reefs. Further to the north the facies itself passes into an unfossiliferous greywacke sequence displaying abundant current markings.

The regional facies relationships indicate that the axis of the North Greenland geosyncline shifted southwards at least during the later stages of geosyncline development. In Upper Ordovician time carbonate rocks of similar lithology were deposited in both northern and southern parts of the Hall Land – Nyeboe Land region indicating a shelf zone somewhere off the present northern coast. In early Silurian time deposition of carbonate rocks decreased, and in the north they were succeeded by clastic beds typical of geosynclinal trough facies, while to the south reef carbonates accumulated. This southerly shift of axis continued into late Silurian and early Devonian time when tongues of clastic material extended southwards over the shelf and platform.

Faunal distribution, characterised by a high proportion of Ordovician and Silurian forms common to both eastern and western North Greenland, indicates that there was free faunal communication during the later stages of Lower Palaeozoic sedimentation. In Cambrian time, although there was evidently some mixture of the Atlantic and Pacific faunal provinces, the faunal distribution suggests a more restricted intercommunication (Poulsen, 1964, 1969).

Sometime in Devonian time the northern borderland ceased shedding detritus southwards and the North Greenland geosyncline was deformed and metamorphosed resulting in an east–west trending mountain chain. Somewhat earlier the extensive geosyncline in East Greenland was deformed into a north–south trending fold belt, and these two orogenic zones converge in the Wandel Sea region. This structural junction evidently controlled in some way the regional subsidence which began in Lower Carboniferous or earlier time to produce the Wandel Sea basin. Erosion of the two fold belts provided detritus for the younger basin.

Plant-bearing terrestrial deposits formed in the Lower Carboniferous in the southern part of the Wandel Sea basin. Marine sedimentation in the Upper Carboniferous transgressed from the north and east across the eroded surface of the North Greenland and East Greenland fold belts and the adjacent unfolded platform. The basin was rather unstable and shallow throughout Carboniferous and Permian time producing a sequence characterised by alternating limestone and sandstone with shale units. Conglomerates indicate proximity to the source area and evaporites indicate some lagoonal conditions. In the Upper Permian coarse conglomerates, grits and sandstones were deposited near the shore, the red colour of these rocks and of parts of the succession below suggesting weathering in the source area in a tropical or sub-tropical climate. At the same time, limestones were laid down offshore.

Subsidence more or less kept pace with sedimentation in Carboniferous and Permian time, but in the early Triassic sandstones with plants and fish were deposited in a deltaic environment. Renewed subsidence in the Middle Triassic led to flooding of the Lower Triassic and older beds, and sandstones bearing ammonites were deposited. Marine sedimentation continued, probably with frequent breaks, into the Jurassic when ammonite-bearing siltstones were laid down. Earth movements probably starting in the late Jurassic caused some uplift and non-deposition but following renewed subsidence late(?) Cretaceous and Tertiary beds were deposited. Sandstones were formed in shallow seas: the source for these rocks was the Palaeozoic mountain ranges and perhaps some uplifted areas within the Wandel Sea basin. The shoreline receded in the Tertiary resulting in accumulation of muds and sands in a deltaic environment and the formation of coal. Deformation and uplift of the Wandel Sea basin occurred in middle to late Tertiary time.

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