Anker Weidick

THE NORTH GREENLAND FOLD BELT AND ENVIRONS

PETER ROBERT DAWES

DAWES, P. R.: The North Greenland fold belt and environs. *Bull. geol. Soc. Denmark,* vol. 20, pp. 197–239. Copenhagen, January, 6th, 1971.

A review of our present knowledge of the North Greenland fold belt and environs is presented.

Precambrian crystalline basement, which is exposed at places adjacent to the Inland Ice and can be expected to form larger areas now covered by its northern extremity, is overlain with marked angular unconformity by a Proterozoic to Lower Palaeozoic sedimentary pile. These sediments dip gently northwards forming a platform and hinterland to the North Greenland fold belt which occupies the extreme northern part of Greenland as a roughly E-W zone of deformation and metamorphism. In Peary Land, where the widest part of the zone occurs, the effects of deformation and metamorphism increase northwards towards the assumed centre of the orogenic belt. In eastern Peary Land, the folded Lower Palaeozoic sediments are unconformably overlain by strata of Pennsylvanian, Permian, Triassic and Cretaceous-Tertiary age. This sequence has been affected by Tertiary earth movements. Field evidence in Greenland, together with evidence from the Innuitian orogenic system in Arctic Canada, suggests that the main Palaeozoic diastrophism affected the sediments of the Greenland part of the Franklinian geosyncline between Late Silurian and Late Devonian time.

Field work since 1965 on both the folded and platform rocks of the fold belt has led to a reinterpretation of the structure and stratigraphy of North Greenland. Important results include: 1) the recognition in the western part of the platform of a Palaeozoic reef complex of regional extent with major facies changes between carbonates, and arenaceous and argillaceous sediments, leading to a criticism of the described Silurian unconformities and to a revision of the established Silurian stratigraphical nomenclature; 2) the lowering of the base of the Cambrian in the platform so that rocks which have been previously regarded as Precambrian or Eocambrian (and part of the so-called Thule Group) are now known to be Palaeozoic in age; 3) recognition that the thick Inuiteq Sø Formation composed of sandstones cut by basic intrusives (which is the oldest unmetamorphosed sedimentary formation in North Greenland) is at least 1000 m. y. old; 4) discovery of both shelly and graptolitic faunas in the folded sediments indicating the presence of Cambrian, Ordovician and Silurian strata in the folded zone; 5) indications that the sediments of the folded zone have passed through a long and complex orogenic history, suffering polyphase deformation and metamorphism—the earlier interpretation of the folded zone as being characterised by intensive superficial thrusting and by nappes and overthrusts of alpine dimensions is refuted; 6) the first isotopic age determinations from the folded zone which suggest a Laramidian thermal episode of regional importance producing Abukuma-type mineral assemblages subsequent to the Palaeozoic metamorphism, and also indicate important Tertiary tectonism; 7) the rediscovery in the folded zone of a bedded volcanic sequence of lavas and tuffs (Kap Washington Group), the effusion of which post-dates the main Palaeozoic diastrophism of the surrounding metasediments but pre-dates Tertiary earth movements.

An extensive bibliography of the main works dealing with the bedrock geology of North Greenland concludes the paper.

It is all but 100 years ago since folded sedimentary rocks were first noted in North Greenland at 81°30′ by men of Capt. C. F. Hall's "Polaris" expedition, 1871–73. 50 years later these rocks in Hall Land were traced by Lauge Koch (Lauge Koch is referred to elsewhere in the text as simply Koch; reference to his uncle I. P. Koch is always made in full) continuously across the northern part of Greenland to eastern Peary Land, in a zone of folding bordered to the south by thick accumulations of unfolded sediments and to the north by the frozen Arctic Ocean. This zone of folding and the adjacent unfolded rocks to the south are referred to here as the North Greenland fold belt.

Geological investigations in the northern part of Greenland have been essentially of a reconnaissance nature, often accomplished under severe conditions. This part of Greenland is particularly remote and suffers extreme weather conditions – a combination of factors which do not produce the most satisfactory working conditions. Since 1965 Grønlands Geologiske Undersøgelse (GGU) has been working north of 80° in certain areas on both the folded and the unfolded rocks. The purpose of this paper is to set out our present knowledge of the North Greenland fold belt and environs giving particular attention to the results of the latest work, as well as giving an outline of the history of geological investigation in this part of Greenland. In essence the content is the same as that of a lecture given to the IX Nordiske Geologiske Vintermøde held in Lyngby, January, 1970.

Place-names mentioned in the text are included on plate 3 and a comprehensive bibliography is included at the end of the paper.

Summary of regional development

The general geology of North Greenland is relatively straightforward and although few areas have been studied in any great detail, the regional pattern of stratigraphical and structural units is known with some degree of certainty.

Precambrian crystalline basement is exposed at places around the edge of the Inland Ice and can be reasonably expected to form larger areas now covered by its northern extremity. Unconformably overlying the basement occurs a succession of Proterozoic to Lower Palaeozoic sediments. These sediments and associated basic intrusive rocks were involved in the diastrophism which affected the North Greenland geosyncline between Ludlovian and Late Devonian time and which produced the east-west belt of folding and metamorphism that now occupies the extreme northern coast of Greenland. Following the Palaeozoic orogenic movements, Upper Palaeozoic and Mesozoic-Tertiary sediments were deposited in a mainly marine environment and a suite of lavas and tuffs of unproven age (?Mesozoic-Tertiary) was emitted. The age relationship of these sediments to the volcanic suite is not known but both groups of rocks were affected by Tertiary earth movements which resulted in folding, faulting and thrusting. A regional thermal episode also affected part of the fold belt in Cretaceous (? and Tertiary) (Laramidian) time.

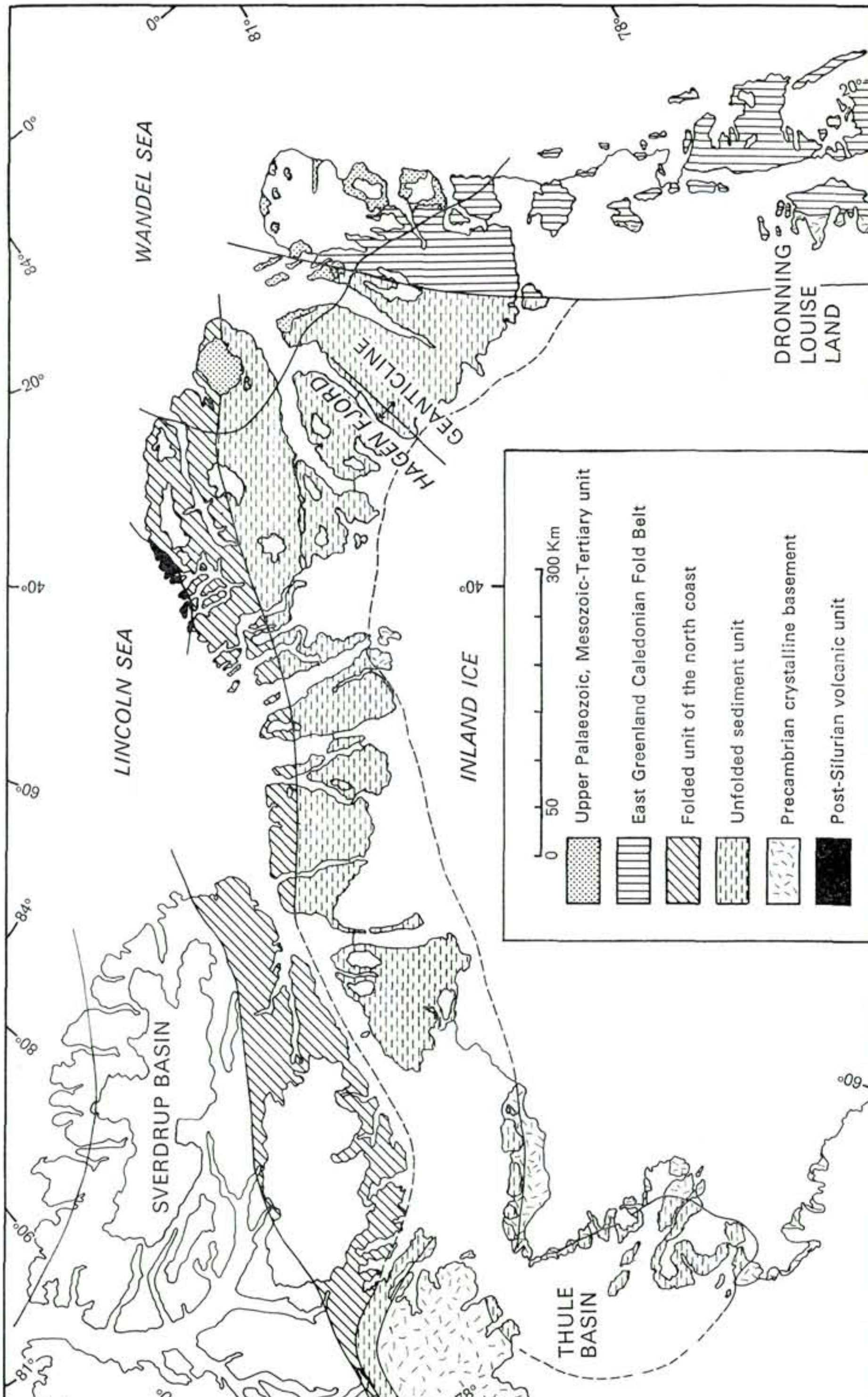
Basic intrusives of Precambrian, Palaeozoic and Mesozoic-Tertiary ages occur in North Greenland.

Figure 1 shows the major geological divisions of northern Greenland; Plate 3 gives the general geology of the North Greenland fold belt and environs; Plate 4 shows two diagrammatic cross-sections across the western and eastern parts of the bold belt; Plate 5 is a general stratigraphical correlation chart covering different parts of the North Greenland geosyncline as well as the Danmark Fjord Basin and the Thule Basin.

Geological divisions of North Greenland

Excluding the Inland Ice, which forms a large percentage of the total area of northern Greenland, six major geological units can be recognised north of 76°N (see fig. 1). These units, which are considered satisfactory divisions for the descriptive purposes of this paper, are given below.

(1) *Precambrian crystalline basement* outcrops mainly in western North Greenland in the Thule – Inglefield Land area as well as further to the north and within the fold belt of East Greenland. In the Thule – Inglefield Land area a variety of gneisses, supracrustal rocks and basic intrusive rocks are known to occur (see Schei, 1903, 1904; Bugge, 1910; Holtedahl, 1917; Koch, 1920, 1933; Callisen, 1929; Davies, 1954; Clebsch, 1954, 1956; Cowie, 1961b; Davies, Krinsley & Nicol, 1963; Fernald & Horowitz, 1954, 1964; Bendix-


WANDEL SEA
LINCOLN SEA
INLAND ICE
SVERDRUP BASIN
THULE BASIN
DRONNING LOUISE LAND
HAGEN FJORD
GEANTICLINE
0 50 300 Km
Upper Palaeozoic, Mesozoic-Tertiary unit
East Greenland Caledonian Fold Belt
Folded unit of the north coast
Unfolded sediment unit
Precambrian crystalline basement
Post-Silurian volcanic unit

Almgreen, Fristrup & Nichols, 1967), but as yet little is known about the small area of basement which outcrops to the north in southern Wulff Land at the head of Victoria Fjord (see Haller, 1961a, p. 156; Koch, 1961, p. 149; Haller & Kulp, 1962, p. 17 and p. 227 this paper). The basement of western North Greenland is considered to be a continuation of the Nagssugtoqidian (Hudsonian) orogenic complex of West Greenland.

According to Koch (1920, p. 28) Ejnar Mikkelsen saw basement gneiss around the head of Danmark Fjord in eastern North Greenland but this observation has not yet been confirmed (see also Nielsen, 1941, p. 26). In parts of Dronning Louise Land in East Greenland crystalline basement rocks are exposed but some of these occurrences have been affected by Carolinidian and Caledonian disturbances (see Peacock, 1956, 1958; Haller 1956, 1961a, 1961b).

A review of the main features of the basement rocks in North and East Greenland has been given by Berthelsen & Noe-Nygaard (1965).

(2) *Unfolded sediment unit* of Proterozoic and Palaeozoic rocks which forms a broad belt from the west to the east coast. Koch (1925) referred to this unit as "the great sediment plain". In the Thule – Inglefield Land area, in Victoria Fjord and in Dronning Louise Land the rocks of this unit overlie with angular unconformity the crystalline basement. In Peary Land and eastern North Greenland the base of the succession is not seen.

(3) *Folded unit of the north coast* which trends approximately E-W and is bordered to the south by unit (2). This zone is 600 km long and reaches over 100 km in its widest part in northern Peary Land. Cambrian, Ordovician and Silurian rocks have been now identified in the zone and the sediments vary in metamorphic grade from unmetamorphosed in the south to chlorite-, muscovite-, biotite-, garnet-, staurolite-, cordierite- and andalusite-bearing schistose rocks in the north.

(4) *Caledonian fold belt of East Greenland* which forms an orogenic zone trending parallel to the east coast. The northernmost structures of the zone occur in Kronprins Christian Land (see Nielsen, 1941; Fränkl, 1954, 1955a, 1956; Haller, 1961a, 1961b, 1970). The thick sediments of unit (2) occupy the foreland and flank the northern part of the fold belt on the west.

(5) *Upper Palaeozoic, Mesozoic-Tertiary sediment unit* which occurs as outliers in eastern Peary Land and in areas to the south bordering the Wandel Sea. The sediments unconformably overlie the rocks of units (3) and (4) and the unfolded rocks of unit (2).

Fig. 1. Map to show the main geological units of Greenland north of 76° N and their counterparts in adjacent Ellesmere Island.

(6) *Post-Silurian volcanic unit* of lavas and tuffs of probable Mesozoic-Tertiary age outcrops on the north coast to the west of Sands Fjord occupying an area of about 250 km².

The context of the paper precludes further discussion of units (1) and (4). The boundary between units (2) and (3) is transitional with unit (2) being arbitrarily limited northwards at the first appearance of small-scale folds. The sediments of the unfolded unit are in part affected by broad folds (see plate 3).

Outline of geological work up to 1965

The earliest geological investigations in North Greenland were incidental observations carried out by expeditions whose main aims were geographical discovery and exploration, and the conquest of the North Pole. Hence as the Smith Sound route was gradually penetrated during the 19th century, the presence in the Thule area of crystalline basement overlain by thick unfossiliferous deposits (the Thule Group), and the presence farther north of unfolded fossiliferous Palaeozoic sediments, became known (see Koch, 1920, for references to early workers). By the turn of the century, when the land adjacent to the Robeson Channel had been visited by the expeditions led by C. F. Hall (Davis, 1876; Bessils, 1879), G. S. Nares, 1875–76 (Nares, 1878, Feilden & De Rance, 1878; De Rance & Feilden 1878; Etheridge, 1878) and A. W. Greely, 1881–84 (Greely, 1886), and the northernmost part of the Greenland coast had been discovered in 1900 by R. E. Peary (Peary, 1907), it was known that in the area of Hall Land and Nyeboe Land folded sandstones, shales and slates occurred as a zone along the north coast while to the south towards the Inland Ice thick unfolded Palaeozoic carbonate rocks existed.

By 1912, when the 1st Thule Expedition led by Knud Rasmussen crossed the Inland Ice from Thule and reported large areas of thick flat-lying sandstones with basic rock intercalations in southern Peary Land around Independence Fjord (see Rasmussen, 1915; Freuchen, 1915; Bøggild, 1915; Koch, 1920), a two-fold division into northern folded, and southern unfolded rocks was apparent in eastern North Greenland. Earlier Peary (1898, vol. 1, p. 335) had noted the flat-lying sandstones around Independence Fjord but failed to comment on them. The folded rocks to the north had been discovered during the Danmark Expedition 1906–08 by I. P. Koch and A. Bertelsen who collected metamorphosed sediments and igneous rocks around Frederick E. Hyde Fjord (I. P. Koch, 1916; Bøggild, 1917; Ellitsgaard-Rasmussen, 1955). Ejnar Mikkelsen (1922) also made some scattered observations in Kronprins Christian Land and the Danmark Fjord area during the Alabama Expedition, 1909–1912.

Such was the scarce geological knowledge of North Greenland when Lauge Koch started his work, first as a member of Knud Rasmussen's 2nd Thule Expedition 1916–18, and later as leader of the Bicentenary Jubilee Expedition 1920–23 (see Rasmussen, 1927; Koch 1926b). Results of Koch's sledge journeys were enormous both from the geological and glaciological, as well as from the cartographical and physiographical sides. Koch was able to draw up the first geological map of North Greenland (Koch, 1920, 1925) as well as more detailed maps of the Thule area and Prudhoe Land (Koch, 1926a), Inglefield Land (Koch, 1933) and southern Washington Land (Koch, 1929b). Complete colour maps of the rest of Washington Land, the North Greenland fold belt and the Thule area, although printed, were never actually published. From the large quantities of collected fossil material which was described in detail by others (see Troedsson, 1926, 1928; Teichert, 1934; C. Poulsen, 1927, 1934, 1941, 1943), Koch was able to construct a stratigraphy for western North Greenland, recognising some 20 formations of Precambrian to Upper Silurian ages (Koch, 1929a). He also gave the first tectonic details about "the folded mountain chain of North Greenland" (Koch, 1920, p. 62, 1923a, 1925, 1929a). Fossils collected in Washington Land by Godfred Hansen during the 3rd Thule Expedition 1919–20 were described by Teichert (1937).

During the Danish Northeast Greenland Expedition 1938–39, led by Eigil Knuth and Ebbe Munck, Eigil Nielsen (1941) reached north of 81° on the east coast of Greenland and made geological observations in Kronprins Christian Land. Frebold (1950) and Dunbar et al. (1962) described the fossils collected.

Nothing was added to Koch's observations on the folded rocks of North Greenland until members of the Danish Peary Land Expedition 1947–50 led by Eigil Knuth visited Peary Land. Troelsen (1949b, 1950a, 1951) provided some information from the folded rocks in eastern Peary Land but the main contribution came in 1950 when Ellitsgaard-Rasmussen (1950, 1955) investigated a section across the fold belt in western Peary Land. In 1953, Erdhart Fränkl and Fritz Müller made another traverse of the folded rocks across northern Peary Land from Frigg Fjord to Kap Morris Jesup during Lauge Koch's East Greenland Expedition 1947–54 (Fränkl, 1955b, 1955c). The only other field work on the folded rocks carried out before 1965 was scattered observations made by Bill Davies during Quaternary studies (W. E. Davies, pers. comm.; Davies, Needleman & Klick, 1959; Davies & Krinsley, 1961).

Since Lauge Koch's investigations, the unfolded rocks of the south have received considerably more treatment than the folded rocks. Munck (1941), Troelsen (1940, 1950b), Kurtz & Wales (1951), Davies, Krinsley & Nicol (1963) and Fernald & Horowitz (1954, 1964) have described the unfolded sediments in the Thule area; Troelsen (1940, 1950b) and Cowie (1961b) have worked on the unfolded Palaeozoic sediments in Inglefield Land, and Troelsen also visited Washington Land. The Cambrian trilobites collected by Troelsen in Inglefield Land have been described by V. Poulsen (1964). To the east, Troelsen (1949a, 1950a, 1956a) and Adams & Cowie (1953) worked on the Proterozoic and Palaeozoic rocks in the Jørgen Brønlund Fjord and Danmark Fjord areas respectively.

Geological field work since 1965

In 1965 and 1966 GGU carried out field work in the western part of the fold belt during the helicopter and fixed-wing supported Operation Grant Land (see Christie, 1966, 1967a). In 1965 J. H. Allaart and the author worked in Hall Land on both folded and unfolded rocks and examined the type localities of Koch's Cape Tyson, Offley Island and Polaris Harbour Formations (Allaart, 1965, 1966). In the following summer the author and Steen Skytte continued the work to the north-east in Nyeboe Land, Hendrik Ø and Wulff Land (Dawes, 1966, 1967) and B. S. Norford of the Geological Survey of Canada made biostratigraphical studies on the unfolded Silurian and examined the type locality of Koch's Cape Schuchert Formation (Norford, 1967).

In 1966 and 1968 Hans Jepsen, as a member of Eigil Knuth's 4th and 5th Peary Land Expeditions, studied the stratigraphy and basic intrusives of the unfolded rocks in southern Peary Land (Jepsen, 1966, 1969a, 1969b, in press) and in 1969 the author and N. J. Soper, as members of the Joint Services Expedition led by J. D. C. Peacock, spent four months on the folded rocks of the Roosevelt Fjelde in north Peary Land (Dawes & Soper, 1970; Soper & Dawes, 1970; Peacock, 1970). In addition, observations have been made by the author during low-level reconnaissance flights over areas in North Greenland which have not been studied on the ground.

1969 also saw the first commercial enterprise in Greenland north of the Inland Ice, when Ponderay Polar Ltd undertook reconnaissance work on the unfolded rocks, as well as studies on the basement of the Thule region.

Unfolded sediment unit

Structure

A number of structural-stratigraphical divisions can be recognised within this unit. Of these the North Greenland geosyncline covers the largest area; the southern shelf zone of this geosyncline extends eastwards from Inglefield Land north of, and partly hidden by, the Inland Ice, into southern Peary Land. The sediments of the Thule – Prudhoe Land area are not considered part of this geosyncline but of the Thule Basin (see Koch, 1929a; Kerr, 1967a) which Koch (op. cit. p. 271) originally recognised as a sedimentary basin structurally distinct from the main geosyncline.

The Proterozoic to Silurian sediments of the unfolded unit are characterised by having a simple tectonic pattern. The sediments of the Thule Basin are preserved in down-faulted or tilted areas and are for the most part shallow-dipping. Broad anticlines and synclines exist and Davies et al. (1963) have described local folds with limbs dipping as much as 45°. Such structures appear to be due to fault tectonics.

The belt of sediments to the north stretching from Inglefield Land to Peary Land in the east is characterised by a shallow but persistent northerly dip so that successively younger rocks outcrop to the north (see plate 3). The average dip is below 5° but locally steeper dips occur. Towards the folded unit in the north, the uniform northerly dip no longer prevails and a zone characterised by broad flexures exists. These unfolded and slightly folded sediments do not strictly form the foreland of the North Greenland fold belt, since the main direction of overturning in the folded unit is towards the north away from the unfolded sediment unit (see p. 218).

In the east in the Hagen Fjord – Danmark Fjord area, the northerly dip of the unfolded sediment unit changes to an easterly one and the rocks form the foreland of the East Greenland fold belt (Adams & Cowie, 1953; Fränkl, 1956). In this area Fränkl (1956) recognised a NW structural feature of regional extent – the "Hagen Fjord Geanticline" – which separates the easterly dipping sediments of the "Danmark Fjord Basin" from the northerly dipping sediments of the "South Peary Land Basin." This latter feature which Fränkl (op. cit., p. 11) describes as "a shallow basin lying in front of the geosyncline", corresponds to the southern part of the North Greenland geosyncline as recognised in this paper.

Proterozoic to Cambrian sediments

Considerable discussion has taken place about the age and stratigraphical relations of the oldest sediments in North Greenland which outcrop in a broad arc from the Thule area to eastern North Greenland. No clear datum line is evident over the whole area limiting the base of the Palaeozoic sediments and it is now known that the previously assumed pre-Palaeozoic Thule Group (Koch, 1929a; Troelsen, 1949a; 1950b) contains rocks which vary from Proterozoic to Cambrian in age. A restricted use of Thule

Group to describe only the succession of the Thule area is favoured (see below, p. 208).

Rocks which have been referred to the Thule Group are known in some detail from four main areas (see plate 5).

Thule area

The Thule Group in its type locality is preserved in down-faulted areas where it overlies with angular unconformity the crystalline basement. The exposed succession is over 2300 m thick. Davies et al. (1963), adopting Kurtz & Wales' (1951) original tripartite division, have described the three formations: a lower Wolstenholme Formation (490 m) of sandstone and quartzite, the Dundas Formation (790 m) of black shale with dolomite, sandstone and basic igneous sills, and an upper Narssârssuk Formation (1040 m) composed of dolomite, siltstone and sandstone. The top of the succession is not seen and no tillite or diagnostic fossils have been recognised.

Inglefield Land

The total thickness of sediments ascribed by Troelsen (1950b) to the Eocambrian Thule Group in Inglefield Land is only 190 m (see also Cowie, 1961b). Three units are recognised. The lower Rensselaer Bay Sandstone (140 m) overlies the crystalline basement with angular unconformity and is overlain by the Cape Leiper Dolomite (40 m) and the Cape Ingersoll Dolomite (10 m). The fossiliferous Lower Cambrian Wulff River Formation limits this succession upwards. Up to now no fossils have been collected from this 190 m succession but by correlation with the rocks of Ellesmere Island (see Kerr, 1967a, 1967b; Christie, 1967b; also below, p. 208), the 190 m succession is considered here as Lower Cambrian in age.

Southern Peary Land

Koch's initial observations (Koch, 1923a, 1925, 1929a) have been added to by Troelsen (1949a, 1950a, 1956a) and recently by Jepsen (1966, 1969a, 1969b, in press). The exposed succession in southern Peary Land is about 1750 m thick and divisible by Jepsen (1969b, in press) into a lower unit of sandstones (1000 m+) veined by basic sills and dykes (the Inuiteq Sø Formation), overlain unconformably by the Moræneső Formation (117 m) containing the tillite and *Cryptozoon* dolomites mentioned by Troelsen (1949a), the Portfjeld Formation of dolomite (206 m), and the clastic Buen Formation (425 m). Erosional unconformities separate the

Portfjeld Formation from the Moræneso Formation, and the Buen Formation from the overlying Lower Cambrian Brønlund Fjord Dolomite. The base of the succession is not exposed. Troelsen (1949a) regarded the rocks now included in Jepsen's Morænesø, Portfjeld and Buen Formations as Eocambrian in age. The Buen Formation is now known to be Cambrian in age (see below, p. 208).

Danmark Fjord area

In the inner part of Danmark Fjord to the south-east of Peary Land, Adams & Cowie (1953) have described a succession over 1000 m thick. The base is not seen and no tillite has been recognised. The succession is divisible into a lower unit of Norsemandal Sandstone which is traversed by basic igneous rocks, and an upper unit of Campanuladal Sandstones and Limestones and the Fyns Sø Dolomite. The overlying Kap Holbæk Sandstone is considered by Cowie (1961b) to be of Lower Cambrian age (see below, p. 210).

Discussion, and age of the Thule Group

Koch (1929a, 1929b, 1933) gave the name Thule Formation to the thick unfossiliferous sediments in the Thule area which overlie the crystalline basement with angular unconformity and which were considered by him to be of Late Algonkian age. He also regarded a much thinner succession on Inglefield Land underlying the fossiliferous Lower Cambrian rocks as part of the Thule Formation, as well as the large areas of flat-lying unfossiliferous sediments in southern Heilprin Land, Vildtland, I. C. Christensen Land, Valdemar Glückstadt Land and Kronprins Christian Land (Koch, 1929a, p. 221). Troelsen (1949a, 1950b) referred to the formation as the Thule Group and, in studying rocks on the Canadian side of the Kane Basin in Bache Peninsula, introduced the name to cover the lower part of the succession there. Troelsen (1949a) also included within the Thule Group the sediments of Jørgen Brønlund Fjord below the Brønlund Fjord Dolomite, sediments which Koch (1923a, 1925, 1929a, 1935a) had referred to the Palaeozoic. Troelsen (1949a, 1950b) preferred to describe the sediments of the Thule Group as Eocambrian since the rocks were said to be separated from the overlying fossiliferous Cambrian by no more than a simple erosional unconformity. The flat-lying sandstones of southern Peary Land, Vildtland and the area south of Independence Fjord, considered as part of the Thule Formation by Koch (1929a), were referred to as Late Precambrian by Troelsen (1956a) and not as part of the Thule Group.

Troelsen (1950b) showed no hesitation in referring the Bache Peninsula succession in Canada to the Thule Group, and he confidently carried the Greenland formational names over to Canada. Recent finds of Cambrian fossils on the Canadian side of the Kane Basin, in rocks which can apparently be correlated with the succession in the Bache Peninsula and thus with the Inglefield Land succession (Kerr, 1967b, p. 8), lead to the conclusion that parts of the Thule Group in Greenland are of Cambrian age. By inference the thin succession in southern Washington Land which was included by Koch (1929b, p. 7) in the Thule Formation and which is correlatable with the dolomites of the Inglefield Land succession also becomes of Cambrian age. Furthermore, J. Stuart Smith (pers. comm., J. C. Sproule and Associates) and H. F. Jepsen (pers. comm., in press) report the presence of olenellid trilobites in the fissile shales at the top of the Buen Formation in southern Peary Land, rocks previously regarded either as Eocambrian (Troelsen, 1949a, 1956a) or tentatively as Lower Cambrian (Cowie, 1961b). These fossil finds prove that the Buen Formation, composed of 425 m of cyclic sedimented sandstones and shales, is of Cambrian age. It becomes also quite possible that the underlying Portfjeld Formation is also of Cambrian age. The nature of the boundary between the Buen Formation and the Portfjeld Formation has not been observed (Jepsen, 1969b, in press).

The succession in the Thule area contrasts markedly with that in Inglefield Land and the sediments appear to be the products of different environments and sedimentary basins. The sediments in each area may well be of completely different age. For this reason, and because the rocks of the Thule area also show little similarity to those of southern Peary Land, the author favours the restriction of the name Thule Group in Greenland (Troelsen, 1949a, 1950b) to Koch's type locality—the Thule area. Christie (1967b) and Kerr (1967a, 1967b) have already refrained from using the name to cover the Bache Peninsula and Inglefield Land successions.

This restricted use of Thule Group is in contrast to the usage of Haller (1961b, 1970) who extends the Thule Group to cover certain Precambrian sediments in East Greenland. Haller bases his Thule Group on the Thule Formation of Koch (1929a), without regard to Troelsen's (1949a, 1950b) original Thule Group. Since Koch's supposed Precambrian Thule Formation in western North Greenland is now known to be in part Cambrian in age, and since the Thule Group in the type locality could in part be of Palaeozoic age, extension of the name Thule Group specifically to cover the pre-Carolinidian sediments of East Greenland (Haller, 1970, p. 48) implies that the sediments of the Thule Group in the Thule area are also part of the pre-Carolinidian cycle. The age of the Thule Group of the Thule area is unknown. Theoretically it may be wholly or in part Proterozoic, Eocambrian or Palaeozoic (Cambrian). No diagnostic fossils have as yet been discovered and no isotopic age determinations are available at the time of writing. The apparent continuation of outcrops from the Thule – Prudhoe Land area into Inglefield Land (see plate 3) suggests that at least part of the sediments in the Thule Basin are of Cambrian age.

Correlation

In North Greenland correlations have been made between successions from widely-spaced areas, and the Thule Group of the Thule area has been correlated with the thin succession in Inglefield Land, as well as with successions as distant as 1000 km in eastern North Greenland (see Adams & Cowie, 1953; Cowie, 1961b; Davies et al. 1963; Berthelsen & Noe-Nygaard, 1965). In the light of the recent discoveries some of these correlations are no longer tenable. The correlation of the Thule Group of the Thule area with the pre-Carolinidian sediments of East Greenland (Haller, 1970) has been mentioned above.

Since the Inglefield Land succession now appears to be Cambrian, any correlations between that succession and the very much thicker sediments of the Thule area (which, as explained, are uncertain), now carry an age connotation. Hence if the previously proposed correlations are at all correct (*e.g.* Davies et al., 1963; Berthelsen & Noe-Nygaard, 1965) then all or much of the Thule Group of the Thule area is of Cambrian age, for which there is little direct evidence. Furthermore, the correlation of the Rensselaer Bay Sandstone of Inglefield Land with the oldest sandstones of southern Peary Land (Jepsen's Inuiteq Sø Formation) and the Norsemandal Sandstones of the Danmark Fjord area (Adams & Cowie, 1953; Cowie, 1961b) can no longer be upheld. Isotopic age determinations indicate that the Inuiteq Sø Formation is at least 1000 m.y. old (see p. 228).

On the other hand the evidence for a thicker Cambrian succession in both Inglefield Land and Peary Land allows closer comparison of the stratigraphies of these two areas, although a difficulty remains with respect to the correlation of the Thule Group, *sensu stricto*, with the sediments of southern Peary Land and the Danmark Fjord area. The Peary Land and the Danmark Fjord successions have some clear similarities which allow tentative correlation. Although no tillite has been recognised in the latter succession, a correlation is suggested since in both areas a two-fold division into a unit containing basic intrusions and an overlying unit lacking such intrusions can be made (see Adams & Cowie, 1953; Cowie, 1961b). In Peary Land, Jepsen (1969a) has clearly demonstrated the discordance between the lower and upper units, but while no angular discordance was observed by Adams & Cowie (1953, p. 10) from Danmark Fjord, those authors put forward with confidence the two-fold division and regard the upper unit as post-dating the basic intrusions in the lower. Whether this two-fold division can be achieved in the Thule area, where part of the succession is typified by conspicuous basic sills, is not as yet known. Davies (Davies et al. 1963, p. 45) suggests that the discordance which separates the Dundas Formation containing the conspicuous basic sills from the overlying Narssârssuk Formation is an unconformity although he regards the field evidence as equivocal. The presence in both areas of the basic rocks prompted correlation even as early as 1912 (see Koch, 1920, p. 28).

In conclusion it can be stated that the thickness of Cambrian strata in North Greenland is greater than earlier thought. As well as the newly-discovered Cambrian strata directly overlying the basement in the Kane Basin area, Cambrian rocks in southern Peary Land have a much thicker extent than envisaged by Troelsen (1949a, 1956a), and not only the Cambrian Buen Formation, but also the Portfjeld Formation, or even rocks lower down in the succession there, might be of Cambrian age. Furthermore, part or much of the Danmark Fjord succession between the Kap Holbæk Sandstone and the Norsemandal Sandstone, and part of the Thule Group in the Thule Basin, may well turn out to be Palaeozoic in age.

Palaeozoic sediments

Cambrian, Ordovician and Silurian rocks are represented in the unfolded unit. The unfolded Devonian suggested initially by Koch (1920, 1923a, 1923c) in the Hall Land – Nares Land area was later referred to the Silurian (Koch, 1925, 1929a). No Devonian rocks have been proved and the youngest pre-orogenic sediments appear to be Upper Wenlockian-Lower Ludlovian (C. Poulsen, 1934, p. 45). The Devonian sediments reported by Kerr (1967a, p. 503) to occur in Washington Land are probably of older age (see p. 217). Koch (1929a, 1929b, 1933) and C. Poulsen (1927, 1934, 1941, 1943) erected a stratigraphy for western North Greenland which was later modified by Troelsen (1950b). The type localities for the formations occur in Inglefield Land, Washington Land and Hall Land. Koch (1929a) and Nielsen (1941) attempted to recognise some of these formations as far east as respectively Peary Land and Kronprins Christian Land.

No Palaeozoic rocks have been identified in the Thule area but in Inglefield Land a sandstone-carbonate succession of Cambrian age (in part the Eocambrian of Troelsen, 1950b, see above, p. 206) and overlying Ordovician limestones, rests with angular unconformity on crystalline basement. Elsewhere, as in Peary Land and the Danmark Fjord area, the identified Palaeozoic rocks lie on older sediments (see plate 5).

In Washington Land the base of the Palaeozoic strata is not exposed but a rather complete succession of Cambrian, Ordovician and Silurian rocks outcrops (Koch, 1929b). In southern Peary Land, Ordovician limestones and dolomites overlie the Brønlund Fjord Dolomite (Troelsen, 1949a). Northwards these rocks are overlain by Silurian carbonates and clastics. In the Danmark Fjord area, the Kap Holbæk Sandstone is overlain by the Cambrian? Danmark Fjord Dolomite and the Ordovician to Silurian Centrum Limestones (Adams & Cowie, 1953; Cowie, 1961a). In the light of the lowering of the base of the Cambrian section in Peary Land (see above, p. 210), part of the succession below the Kap Holbæk Sandstone in the Danmark Fjord area (*i.e.* Fyns Sø Dolomite and part of the Campanuladal Sandstones and Limestones) may well be of Cambrian age.

The Palaeozoic stratigraphy in western North Greenland is characterised by a predominance of carbonate rocks in which stratigraphical breaks are apparently common. The carbonates vary from massive, hard limestones to well-bedded arenaceous and argillaceous limestones and shales. Limestone conglomerates are reported to be common (Koch, 1929a). Some sandstone units occur particularly in the Cambrian part of the succession. In the Inglefield Land – Washington Land area the succession reaches over 2000 m in thickness. In the Nyeboe Land – Wulff Land area the thickness is probably more than this but the lowest part of the stratigraphy adjacent to the crystalline basement is not known in any detail.

A major discovery of the recent field work has been the recognition in the area between Washington Land and Wulff Land of a Palaeozoic reef complex (Allaart, 1965; Norford, 1967). Reefal and off-reefal rocks occur over much of the western part of the unfolded unit and exist as Koch's Cape Schuchert, Offley Island and Cape Tyson Formations. The richly-fossiliferous underlying Ordovician in the Nyeboe Land – Wulff Land area is also reefal in character but elsewhere, for example in Washington Land, the Upper Ordovician Cape Calhoun Formation of Koch (1929a) and the Gonioceras Bay Formation of Troedsson (1926), which have not been restudied, may not be reefal in nature.

At Kap Tyson, Koch's Silurian formation of that name is a biohermal bluff about 400 m thick overlying the banded biostromal limestones of the Offley Island Formation (plate 1). This reef development can be traced eastwards across Hall Land where it forms a ridge of high ground – the Hauge Bjerge. Local bioherms exist north of the main reef. The main reef is well exposed on both sides of Newman Bugt as high bluffs and it continues with an east-west strike across Nyeboe Land and into Warming Land and Wulff Land – always tending to form high ground. Another important accumulation of limestone reef occurs to the south of the Kap Tyson reef and is exposed at places on the west coast of Washington Land. This reef build-up is less continuous than the Kap Tyson reef, and local bioherms are flanked by darker argillaceous shales. Classic bioherm developments are

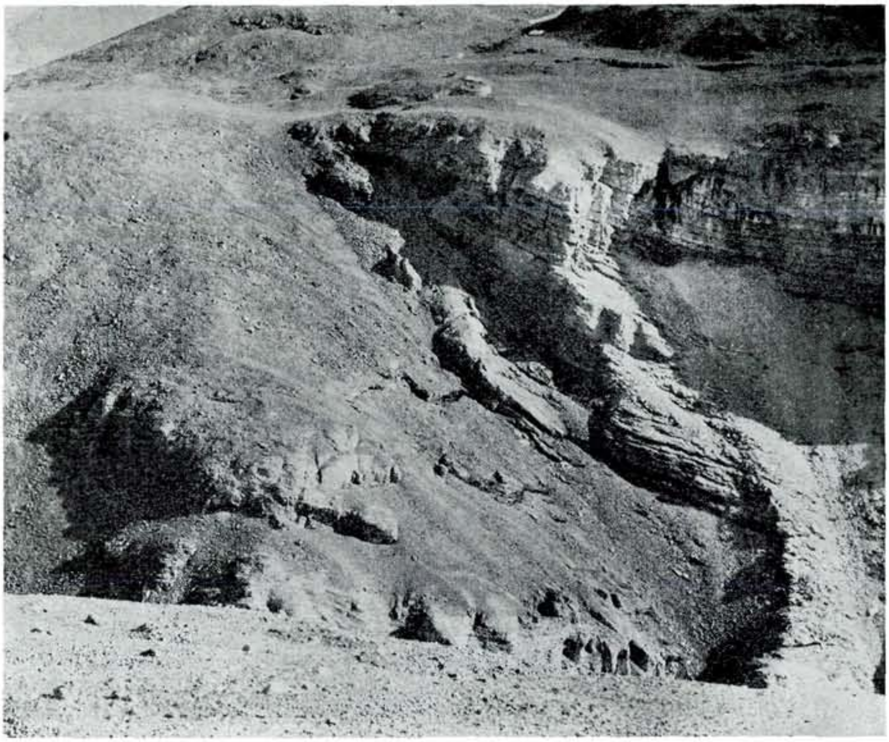


Fig. 2. Facies front at the contact of a reef bioherm (left). Platy limestones, and calcareous and argillaceous shales overlap onto, and grade into, the massive biohermal limestone of the reef. Facies changes in connection with the Kap Tyson reef are abrupt. Height of the section is approximately 100 m. Hauge Bjerge, eastern Hall Land.

Plate 1

Oblique aerial photograph of western Hall Land and the Robeson Channel area viewed northwards towards the Arctic Ocean. Kap Tyson is the cliff in the centre, with Offley Ø in the centre foreground. Offley Ø and the lower part of Kap Tyson is composed of banded biostromal limestones of Koch's (1929a) Offley Island Formation; the upper part of Kap Tyson is a biohermal bluff of the Kap Tyson reef (Koch's Cape Tyson Formation), which stretches across Hall Land and forms the Hauge Bjerge. The mountains of northern Hall Land and Nyeboe Land, composed of folded, mainly clastic rocks of the Cape Rawson Group, are just visible. Ellesmere Island, with the snow-covered United States Range, is visible to the west of the Robeson Channel. 22. July, 1953. Reproduced by permission of the Geodetic Institute, Copenhagen (A316/70). Photograph 546 D-N 11458.

well seen around Kap Constitution and Kap Independence where the bold coastal capes are composed of reef knolls, flanked by off-reefal argillaceous and graptolitic shales (plate 2). Norford (1967) reports similar relations of "reefal, off-reefal, and graptolitic facies" at Kap Schuchert further to the north in Washington Land.

In the Hall Land – Nyeboe Land area where the northern reef development has been studied on the ground, the carbonates of the actual reef bioherm grade northwards into a fore-reef argillaceous facies with graptolitic shales (Allaart, 1965; Dawes, 1966; Allaart & Dawes, in prep.) North of this, the calcareous shales and platy limestones give way to a clastic series composed of alternating sandstone and shale units. Most of these rocks occur in the folded unit and can be referred to the Cape Rawson Group (see p. 217). To the south of the main bioherm, a back-reef facies of argillaceous calcareous shales occurs and this appears to grade into the banded limestones farther south. Lateral facies changes bordering the bioherm can be very abrupt but on a regional scale the Silurian rock pattern is one of interdigitation and intertonguing of biostromal and biohermal carbonates with graptolitic and argillaceous calcareous shales. In many places overlapping of argillaceous beds onto reef bioherm can be seen (fig. 2).

No reef complex has as yet been recognised in Peary Land. Nevertheless there appears to occur in that area, particularly in the Ordovician and Silurian, a gradation from predominantly carbonate rocks of the southern shelf into more arenaceous and argillaceous material towards the folded area – a pattern which simulates that of the area between Hall Land and Wulff Land.

Following the field work in 1965 and 1966 and the recognition of the reef complex with its complicated lateral facies changes, it became clear

---

Plate 2

Oblique aerial photograph, taken looking south-east, of the western coast of Washington Land showing Kap Constitution (left centre) and Kap Independence (right centre). The light-coloured coastal capes are reef knolls, the valleys between them are etched out of off-reefal argillaceous and graptolitic shales of the same age. These off-reefal rocks form the uniformly dipping strata seen forming the coast on both sides of the bioherm development. Compare with figure 57 in Koch, 1929a (p. 278) which shows Kap Constitution viewed from the north, and in which the reef knolls are considered as part of the Offley Island Formation and the surrounding graptolitic shales as belonging to the younger Cape Tyson Formation. Text reference p. 214. 16th July, 1950. Reproduced by permission of the Geodetic Institute, Copenhagen (A 211/70). Photograph 545 K1–SØ 2258.

that Koch's stratigraphy of the Ordovician and Silurian in this part of North Greenland needed critical revision (Dawes, 1966). Koch (1929a) described the Offley Island Formation and the Cape Tyson Formation as both varying markedly in character. The Offley Island Formation was said to be "made up of arenaceous limestone and shales, overlain mostly by massive-bedded, cliff-forming limestone of a light colour and very hard" (Koch, 1929a, p. 238), while the Cape Tyson Formation was formed of massive limestone together with "very fine-grained shales containing graptolites interstratified with thin bands of dark limestone" (Koch, 1929a, p. 240). Koch's unpublished colour map of Washington Land clearly shows that he was able to map out the various rock facies of the Silurian and it becomes apparent that the facies recognised by Koch are the different components of a reef complex of regional extent, so that the graptolitic shales are the lateral facies equivalent of the biostromal and biohermal limestones which as Koch remarks are "cliff-forming".

Koch (1929a, p. 240) also postulated a significant unconformity between the Cape Tyson Formation and the Offley Island Formation and states that the latter formation has been "dissected by valleys several hundred metres deep" which were then filled by the rocks of the Cape Tyson Formation. In Hall Land, where both formations have their type localities, no evidence for this unconformity was found in 1965 and the irregularities in the reef bluff at Kap Tyson are connected to the biohermal nature of the limestones. Furthermore, those cases found where argillaceous limestones and graptolitic shales abut against, or overlap onto, the Kap Tyson reef limestones, the relationship can be explained as reefal and off-reefal rocks of similar age and is not evidence of an unconformity.

It was in western Washington Land that Koch clearly indicated the nature of this unconformity with "islands" of Offley Island Formation surrounded by graptolitic shales of the Cape Tyson Formation (Koch, 1929a, p. 278, *cf.* plate 2). The unconformity in this case is interpreted as the irregular upper surface of the bioherm so that the graptolitic shales are the off-reefal deposits (see also Kerr, 1967a, p. 498). Without having seen more of Koch's localities on the ground it would be audacious to comment further, particularly about the relative ages of the individual units making up the Silurian. The ages of the reefal and off-reefal deposits depend on the nature and rate of growth of the actual bioherm and factors affecting the deposition of the surrounding off-reefal rocks, none of which are as yet known in any detail from North Greenland. However, it is clear that rocks referred by Koch (1929a) to the Offley Island Formation and the Cape Tyson Formation (and most probably the Cape Schuchert Formation studied by Norford, 1967) are in places of the same age and a picture of stratigraphical relationships emerges which is considerably more complicated than one of formations separated by simple unconformities. Thus, since Koch's Offley Island Formation and Cape Tyson Formation have their type localities in precisely the same area (see plate 1), the use of two formational names to describe deposits of essentially the same age is misleading. The present author thus extends the Offley Island Formation to include the limestones and associated rocks of Koch's Cape Tyson Formation, which at Kap Tyson is but the upper part of a limestone reef build-up. As mentioned earlier it is difficult to distinguish rocks of Koch's Cape Tyson Formation from those of the Offley Island Formation away from the type locality (Dawes, 1966, p. 13). On the other hand, the limestones making up Koch's Offley Island Formation form the lower half of the bluff at Kap Tyson, conspicuous tracts in Hall Land and Washington Land, as well as the reef bioherms at Kap Constitution (Koch, 1929a, p. 278). The name Kap Tyson is retained to describe the reef bioherm of the Hall Land – Wulff Land area, a cross-section of which is well exposed at Kap Tyson (plates 1 and 4). The upper Silurian Polaris Harbour Formation, said to consist of coarse sandstones and to overlie the Cape Tyson Formation limestones in the Hall Land – Wulff Land area (Koch, 1929a, 1961), has already been discredited and the use of this term should be discontinued (Dawes, 1966).

Kerr (1967a) has drawn similarities between the Palaeozoic reef developments in Greenland and those to the west of the Nares Strait and has suggested correlation between the Greenland formations with those of Ellesmere Island. Correlation of the Palaeozoic formations across North Greenland must wait until detailed work has been carried out in the ground east of Wulff Land.

Folded unit of the north coast

Stratigraphy

The stratigraphy of the folded unit is not known in any great detail and until recently, the evidence for the age of the folded rocks has been based on the observation that the Proterozoic to Silurian rocks of the unfolded unit pass northwards into the folded unit. Apart from the Silurian fossils reported by Etheridge (1878) from Polaris Bugt and Thank God Harbour, which might have originated from the folded rocks of Hall Land, until 1965 the only direct evidence as to the age of the folded beds was Koch's observation of folded fossiliferous Silurian in northern Hall Land (Koch, 1925, p. 275; 1929a, p. 280) and Troelsen's (1956a, p. 87) recognition of olenellidae in the folded Lower Cambrian Schley Fjord Shale in eastern Peary Land. Since 1965 Ordovician and Silurian shelly and graptolite faunas have been collected from the folded rocks in Hall Land (Allaart, 1965),

Fig. 3. Sedimentary structures in an alternating sandstone-shale sequence of the Cape Rawson Group. Ball-and-pillow structures, due to slumping, characterise the central sandstone layer; load casts and flame structures are present at the base of the upper sandstone unit. Northern Hall Land.

Cambrian carbonate rocks have been discovered in northern Nyeboe Land (Dawes, 1966; V. Poulsen, 1969), and Ordovician-Silurian graptolite and trilobite-brachiopod-coral faunas have been discovered in northern Peary Land (Dawes & Soper, 1970; Soper & Dawes, 1970).

To the west of Peary Land, the oldest rocks in the folded unit occur in the northern part of the Nyeboe Land – Wulff Land area. In Wulff Land a succession of pinkish white Cambrian? quartzite, sandstone, and quartzitic conglomerate outcrops, and in northern Nyeboe Land a succession of grey and yellow limestones and dolomites with alternating dark shales and slates occurs. A mainly agnostid fauna from these limestones prove a Middle Cambrian age for part of the succession (V. Poulsen, 1969). These rocks pass into Ordovician carbonates characterised by intraformational breccias and conglomerates. Upper Ordovician? dolomite also outcrops on the north coast of Hall Land (Allaart, 1965).

The folded Silurian rocks in the Hall Land – Nyeboe Land area are represented by a thick clastic sequence of turbidite sandstones and shales of low metamorphic grade. These rocks display well-preserved sedimentary structures, *e.g.* load casts, flute casts, flame structures, groove casts, slump structures, ripple-drift bedding, graded bedding, etc. (fig. 3). In Hall Land Allaart (1965) describes 1000 m of clastic rocks overlying the supposed Upper Ordovician dolomite. The succession there includes, from base upwards, dark platy limestones with some chert, grey calcareous slates, calcareous sandstone and quartzite, rhythmically bedded sandstones and shales, and mudstones containing intercalated sandstones. Graptolites collected from the top of this succession suggest an Upper Silurian age for the mudstones. On Hendrik Ø, Reef Ø and Castle Ø conglomerate is conspicuous in the succession, where the clasts are mainly composed of quartzite and chert with rare crystalline gneiss.

The whole of the folded clastic and argillaceous succession in northern Hall Land, Nyeboe Land and Hendrik Ø is considered as part of the Cape Rawson Group (Feilden & De Rance, 1878; Christie, 1964). Much discussion has taken place about the age of these rocks (see *e.g.* Koch, 1920, p. 56; Troelsen, 1950b, p. 64). Feilden & De Rance (1878) gave them a possible Huronian age. Koch (1920, 1921) indicated the rocks as Devonian but later, after recognising the presence of Silurian elements in the folded zone (Koch, 1925, 1929a), he considered the folded clastics along the north coast of Greenland as "mostly Gotlandian" (Koch, 1935a, p. 617). Christie (1964, p. 22) regards the Cape Rawson Group in north-eastern Ellesmere Island as Silurian while Kerr (1967a) considers that the group extends into the Devonian both in Ellesmere Island and in Greenland. For instance, in eastern Ellesmere Island Kerr states that the group is "as old as Late Ordovician in the north to probably Middle Devonian in the south" (*op. cit.*, p. 497) while in Washington Land in Greenland he states that the group "can be no older than Middle Silurian, and is probably no older than Early Devonian" (*op. cit.*, p. 503). In North Greenland Devonian sediments have not yet been proved and in Washington Land the arenaceous and argillaceous rocks referred by Kerr *(op. cit.)* to the Cape Rawson Group are most probably of Silurian age being the lateral equivalent of the carbonate rocks of the reef complex (see above, p. 214). Furthermore, since the Silurian fossils reported by Allaart (1965) from the Cape Rawson Group were collected from the youngest rocks of the succession in northern Hall Land, the exposed clastic pile in Greenland may not reach Devonian as it apparently does in eastern Ellesmere Island.

A monotonous sequence of quartzite, sandstone and graywacke rocks alternating with shales and slates characterise Nansen Land in western Peary Land (Ellitsgaard-Rasmussen, 1950, 1955). The age of this succession is unknown but the rocks are similar to the clastics of the Cape Rawson Group to the west, which are on approximately the same strike.

In northern Peary Land, Fränkl (1955b) has described a succession of metasediments composed of marbles, schists, phyllites and slates separated by the Polkorridor Series from a southern succession of unmetamorphosed sandstones, shales and mudstones. Despite the lack of faunal evidence Fränkl gave the units, which together reach a thickness of 3000 m, tentative ages from Precambrian to Upper Silurian. The rocks seen by Fränkl were restudied in 1969 and a revised stratigraphy has been suggested (Soper & Dawes, 1970). Fränkl's unit names have been retained as far as possible but some are discarded, especially in those cases where a revised structural interpretation suggests a single mappable, but highly folded, unit as being equivalent to two or more of Fränkl's stratigraphic-structural units.

The Polkorridor Series of Fränkl was found to be a thick arenaceous unit composed of brown- to buff-weathering, well-bedded psammitic rocks and intercalated shales with grit and conglomerate horizons. The rocks form a turbidite sequence and can be traced from eastern Peary Land into the Roosevelt Fjelde, so that the unit strikes towards the clastic rocks of western Peary Land investigated by Ellitsgaard-Rasmussen (1955).

In the area around Frederick E. Hyde Fjord which was not studied by Fränkl, a succession of rhythmically bedded calcareous sandstones, with siltstone and shale units, occurs, in which there are conspicuous units of yellow-weathering limestones. These frequently contain intraformational breccias and conglomerates. Some dark grey to black chert units and white to cream quartzites occur in the succession. The Ordovician-Silurian fossils from northern Peary Land mentioned above were collected from this succession.

Structure

Lauge Koch, in his initial investigations of the folded rocks, was able to show that the axes of the main structures were approximately east-west striking and parallel to the boundary between folded and unfolded units (Koch, 1920). He also noted that the most severely deformed rocks with the highest metamorphic grade occurred in northern Peary Land (1923a, p. 193; 1925, p. 275).

The style of folding in western Peary Land was shown by Ellitsgaard-Rasmussen (1950, 1955) to be characterised by asymmetrical folds with southerly-dipping axial planes. He concluded (1955, p. 53) that "the folding was caused by a combination of forces with a northward direction" and that "the south foreland, the existence of which has hitherto been assumed, i.e. the unfolded deposits in North Greenland, seems tectonically to have acted as hinterland". This structural pattern was confirmed to be typical of northern Peary Land by Fränkl (1955b, 1955c, 1956) who described folds overturned to the north, in places isoclinal and recumbent, and who interpreted the mountains of northern Peary Land, which reach almost 2000 m in height, in terms of alpinotype structures with northward directed nappes and intense overthrusting. Koch (1923a, p. 193) had suggested earlier that overthrusting occurred in Peary Land. Haller (1961a) has also regarded northern Peary Land as characterised by intense superficial thrusting and has suggested an east-north-east thrust system as typical of the tectonic pattern between Nansen Land and eastern Peary Land (Haller & Kulp, 1962, p. 32).

The presence of such important overthrusts and of associated nappes of alpine dimensions in northern Peary Land is not confirmed by recent field work, and the regional structural pattern can be explained without recourse to nappe and thrust tectonics (Soper & Dawes, 1970; Dawes & Soper, 1970). In some localities where thrust contacts have been said to exist, the disrupted contact zone can be explained by complications due to the interference of different fold phases; elsewhere the stratigraphy is continuous and only broken by minor dislocations and high-angled faults. Earlier Ellitsgaard-Rasmussen (1955, p. 54), commenting on Koch's suggestion about possible overthrusting in Peary land, also concluded that "the structure does not seem to offer any foundation for an assumed overthrusting."

The contact between the folded unit and the unfolded rocks to the south is not a sharp, clear-cut boundary marked by thrusting as is the case for example in the Caledonian fold belt in northern East Greenland, but rather a gradual passage from unfolded to folded rocks. This passage is well seen in Nyeboe Land where, from south to north, gently folded beds (corresponding to the northern fore-reef argillaceous facies of the unfoldede carbonate reef (see p. 213), pass into a zone characterised by monoclines, then asymmetrical folds and further north into isoclinal folds overturned to the north (Dawes, 1966, p. 13). The same pattern exists in Hall Land (Allaart, 1965, p. 10) and in western Peary Land (Ellitsgaard-Rasmussen, 1955, p. 9) and appears to continue in the area of Frederick E. Hyde Fjord. However, in places south of this fjord, this fold geometry is reversed and the first folds north of the gently folded and unfolded rocks are southward facing with northerly-dipping axial planes. Such structures directed towards the platform area of the south are the result of forces different from those responsible for the northward-facing folds present elsewhere.

In northern Peary Land at least three phases of deformation have produced visible folds, the majority of which are overturned towards the north (Soper & Dawes, 1970). The first two deformations produced coaxial folds which become isoclinal in the north. A main southerly-dipping cleavage (S_2) parallel to the axial planes of the F_2 folds post-dates an early cleavage (S_1) and a set of coaxial folds which in the south have axial planes of variable dip. Some southward-facing folds pre-date S_2. In places S_2 is folded into

Fig. 4. Thrust contact on the eastern side of Benedict Fjord between the volcanics of the Kap Washington Group (dark) and the overlying metasedimentary phyllites. The metasediments have been thrust from the south over the volcanics, and mylonites are well developed in the thrust zone. The dark layers in the metasediments are basic igneous sills which show the effects of Tertiary tectonism. Height of the exposed section on the right is approximately 400 m. 16th May, 1969.

F_3 kink-bands and even larger structures. The cleavage-bedding relations are complicated and are not everywhere easily fitted into the regional pattern of folding. The same complex relations also occur in the western part of the fold belt (Allaart & Dawes, in prep.) Despite the polyphase deformational history of the folded rocks, the regional strike is relatively simple. The folds are coaxial and few variations from an east-west regional tectonic grain are present. In the area north of the head of Frederick E. Hyde Fjord, some north-west and even north-south trends occur and these are presumed to be due to the interference of the deformation phases mentioned above.

Both high-angled faults and thrust-faults, as well as low-angled thrusts, occur in the western part of the fold belt and in Peary Land. Some of these appear to have developed in connection with the folding and have mainly southward-dipping dislocation planes while others are clearly later and bear no genetical relationship to the fold structures which they truncate. A conspicuous thrust occurs in northern Hall Land where the direction of the transport appears to have been from the south (*cf.* Haller & Kulp, 1962,

p. 33). In northern Nyeboe Land a set of high-angled thrust-faults occurs parallel to the strike of the folded rocks. These are mainly steeply inclined to the south but some have vertical or steeply northward-dipping fault planes. The main thrust-fault of the set separates the Cape Rawson Group clastics of the south from the Cambro-Ordovician carbonate sequence of the northern coast. The outcrop of these carbonate rocks could be due to the upthrust of the northerly area. High-angled thrust-faults with both southward- and northward-dipping fault planes have been described from western Peary Land (Ellitsgaard-Rasmussen, 1950, 1955).

In the extreme north of Peary Land a conspicuous thrust occurs separating the Kap Washington Group of volcanics from the metasediments of the south (see fig. 4). The metasediments have been thrust from the south over the volcanics along a shallowly-dipping thrust plane, along which mylonites are developed. This thrust is of Tertiary age (see p. 229). Other main east-west striking faults in Peary Land are also of Tertiary age, two of which, the Kap Bridgman Fault and the Harder Fjord Fault border the mountains of northern Peary Land (Roosevelt Fjelde) which are preserved as a tectonic uplifted block (see Haller & Kulp, 1962, p. 32).

Metamorphism

The effects of metamorphism increase from south to north in the folded unit (Koch, 1923a, 1925; Ellitsgaard-Rasmussen, 1950, 1955; Fränkl, 1955b). In the area of Frederick E. Hyde Fjord the visible changes in the sediments are due mainly to dynamic metamorphism (cleavage, crushing, slickensides, etc.). Only in a few places has recrystallisation and the production of a strong cleavage resulted in partial obliteration of the primary structures of the sediments. Similar metamorphic conditions exist in Nansen Land (Ellitsgaard-Rasmussen, 1955). Towards the north increased dynamic metamorphic effects and the appearance of metamorphic minerals occur, so that in places the rocks of the central and northern part of the Roosevelt Fjelde are chlorite-, chloritoid- and muscovite-bearing slates and phyllites. On the north coast at Kap Morris Jesup garnet schists outcrop (Koch, 1923a, 1925; Fränkl, 1955b) and along the coast to the west, pelitic and semi-pelitic schists and phyllites and associated psammitic rocks contain chlorite, biotite, muscovite, andalusite, cordierite, sillimanite, garnet and staurolite. Calc-silicate units contain garnet and amphibole. The rocks are polymetamorphic and the metamorphic isograds in northern Peary Land appear not to be completely parallel to the lithostratigraphical boundaries.

Quartz veins and streaks are common in the rocks of northern Peary Land and they have been formed at various times throughout the deformational history. Only in a few cases does feldspar join quartz in these veins.

Quartz and calcite veins are common in western Peary Land (Ellitsgaard-Ramusssen, 1955).

In the western part of the folded unit the metamorphic state of the rocks corresponds to that in the Frederick E. Hyde Fjord region of Peary Land. Effects of dynamic metamorphism are common and the argillaceous components of the clastic rocks in northern Hall Land and Nyeboe Land can be highly cleaved and in places the rocks are fissile slates. In the northern part of Nyeboe Land the sandstones are clearly indurated and in places have a sheen due to the development of mica (Dawes, 1966).

It can be assumed that metamorphism accompanied the main deformation and that the sediments in the north of the folded unit developed Palaeozoic metamorphic mineral assemblages. Folded biotite and muscovite in some of the pelitic rocks bear witness to this metamorphism. However, the four isotopic age determinations obtained so far from folded schistose rocks (see p. 229) have given Cretaceous-Tertiary ages and it is clear that the Palaeozoic assemblages have been "overprinted" to a certain extent. It is considered likely that a Laramidian regional reheating of part of the fold belt occurred producing (re)crystallisation of mineral assemblages in already folded and metamorphic rocks. The presence of such minerals as cordierite, andalusite, staurolite, sillimanite and muscovite suggests a regional metamorphism of Abukuma-type.

Upper Palaeozoic, Mesozoic-Tertiary sediment unit

Distribution and structure

Carboniferous, Permian, Triassic and Cretaceous-Tertiary sediments form a number of outliers in eastern Peary Land, on the Prinsesse Øer and in the coastal areas of Kronprins Christian Land, south of the Wandel Sea (see plate 3). These sediments are not known in any great detail but the large areal extent of the scattered outcrops in North Greenland signifies an important basin of deposition. However, the suggestions that Upper Palaeozoic sediments form large areas immediately south of Frederick E. Hyde Fjord (Fränkl 1955b, p. 36; Maync, 1961, fig. 1), as well as small exposures north of this fjord (Haller & Kulp, 1961, p. 20), are not confirmed by the recent field work.

The occurrence of Permo-Carboniferous sediments in eastern Kronprins Christian Land has been known since the Danmark Expedition 1906–08 (see Nathorst, 1911; Grönwall, 1916). The Carboniferous outcrops in Peary Land were discovered during the Bicentenary Jubilee Expedition 1920–1923 (Koch, 1923a, 1925). Later, Nielsen (1940, 1941) and Troelsen (1949b, 1950a) examined the successions in Kronprins Christian Land and Peary

Land respectively and examined Mesozoic-Tertiary rocks as well as the Upper Palaeozoic sections. In Kronprins Christian Land the distribution of the Permo-Carboniferous and the Cretaceous-Tertiary beds is reasonably well known but in eastern Peary Land, the outcrop pattern of the sediments is poorly known (see Troelsen, 1956a, pp. 82–83). Little is known about the contact relationships of the different ages of sediments, or the nature of the stratigraphical breaks within the succession.

Koch (1925, p. 282) recognised that the sediments in eastern Peary Land post-date the main diastrophism of the folded unit of the north coast, and he also noted that the Carboniferous strata were in places inclined up to 40°, and that faulting had affected the rocks (Koch, 1929c, p. 93). Troelsen (1950a) observed the actual unconformity between the folded Lower Palaeozoic sediments and the less disturbed Carboniferous strata and also noted that the younger cover was affected by faulting and local folding after the deposition of the Cretaceous-Tertiary sediments. The flexures present in these cover rocks in Peary Land appear to have a general north-west trend and dips of fold limbs of up to 45° have been recorded in some of the Permian sandstones (W. E. Davies, pers. comm.).

Stratigraphy

In 1921, Koch discovered at Herlufsholm Strand in eastern Peary Land, a sequence of dark shales which passed upwards into limestone and shales, and finally into sandstone and conglomerate. The shales and limestones of this succession yielded a Carboniferous fauna of corals, crinoids, brachiopods *(Productus, Spirifer)* and *Fenestella* (Koch, 1923a, p. 193; 1925, p. 282; 1929c, pp. 93–94). Koch referred this succession, which was described as being 700 m thick, to the Upper Carboniferous Mallemuk Mountain Formation of northern East Greenland (Koch, 1929b, p. 245). Troelsen (1950a) was able to show that the oldest rocks in the succession in eastern Peary Land were marine fusulinid-bearing strata of Pennsylvanian *(Triticites)* age.

Permian rocks in eastern Peary Land were also noted but not described by Troelsen but in 1961, W. E. Davies (pers. comm.) identified a grey to brown sandstone sequence which weathers to a brilliant red colour and which contains Upper Permian fossils. This sandstone is possibly equivalent to that forming the top of Koch's succession. Dark grey to buff-coloured fossiliferous limestones outcrop to the south of Station Nord. The fauna of these limestones (corals, polyzoans, echinoderms, brachiopods) has been identified as Permian in age (Christian Poulsen, pers. comm.).

The greater part of the Upper Palaeozoic in North Greenland developed in the marine facies although along the coast of Kronprins Christian Land plant-bearing Lower Carboniferous continental beds occur (Nathorst, 1911;

Nielsen, 1941). These beds, which are mainly sandstones and shales, in places with coal units up to half a metre thick, are overlain by a marine section over 1000 m thick composed of Upper Carboniferous and Lower Permian limestone, dolomite, shale and sandstone. Grönwall (1916), Frebold (1950) and Dunbar et al. (1962) have described the fauna of these marine rocks. Coal beds, with dark shales, also outcrop on the Prinsesse Øer.

Troelsen (see Kummel, 1953) described from Herlufsholm Strand in eastern Peary Land a 630 m section of Triassic sandstones, marls and shales. The relationship of this succession to Koch's original 700 m section is not known. Eigil Nielsen identified the lowest 200 m of Troelsen's section as Lower Triassic on account of the fish fauna which has clear similarities to the Scythian fish horizon of Spitsbergen. The upper part of the section was referred by Kummel (1953) to the Middle Triassic on the basis of ammonites of Anisian age. The Triassic marine sediments of Peary Land show affinities with the Triassic of Arctic and Cordilleran North America, Spitsbergen and Siberia.

No Jurassic rocks have been recorded from Peary Land or Kronprins Christian Land. Plant-bearing shales and marine beds of Cretaceous-Tertiary age have been recorded by Troelsen (1950a) from eastern Peary Land, and Nielsen (1941) has described a 300 m section of marine sandstones of similar age from Nakkehoved to the east of Station Nord. The relationship between these rocks and the Triassic deposits of Peary Land is not known.

Post-Silurian volcanic unit

A volcanic suite of lavas and tuffs outcrops on the north coast from the east side of Benedict Fjord to De Long Fjord in the west. Koch (1920, p. 74) initially indicated areas of "eruptive" rocks in the area of De Long Fjord and, after revisiting the coast in 1921, mentioned the presence of associated "effusives" in the area east of De Long Fjord (Koch, 1923a, p. 193; 1923b, p. 65). Koch regarded the "effusives" as contemporaneous with a set of cross-cutting dykes, veins and intrusions, some of which are composed of "diabase", others of "porphyry", and which post-date the main folding of the surrounding metasediments (Koch, 1918, p. 506; 1920, pp. 74–75; 1923a, p. 193).

The lavas and tuffs, to which the name Kap Washington Group has been given (Soper & Dawes, 1970), make up a volcanic province of which an aerial extent of about 250 km² is now exposed. How far the province extends under the Arctic Ocean is not known. In the Kap Washington area, the volcanics form a well-bedded succession at least 1500 m thick which contains a varied suite of rocks. Many of the volcanics are rhyolitic in type being homogeneous, flinty, vesicular or banded, others are red and black basaltic or andesitic types, some of which are porphyritic, others breccias. Zeolite-bearing lavas occur. Some tuffaceous rocks resemble ignimbrites while some rock units are characterised by concentric pisolitic structures which resemble "bird's-eye tuffs" or chalazoidites. Arkose and conglomerate also occur in the succession.

The lavas and tuffs are non-metamorphic in a regional metamorphic sense. Primary volcanic textures are generally well preserved but the sequence has suffered dynamic and dislocation metamorphism. Crushing and mylonitisation have altered the textures of some rocks and some samples have developed a directive fabric. The suite appears to be of calc-alkaline type and a member of the orogenic basalt-andesite-rhyolite kindred.

The volcanic rocks are flat-lying to southward dipping and in places, folded. To the north the rocks reach the Arctic Ocean and to the south the succession is limited by a thrust along which metasediments have been transported from the south over the volcanics (see fig. 4). Mylonites are well developed in this thrust zone which dips shallowly to the south.

The age of the volcanic suite is as yet unknown and the only contact with the surrounding metasediments so far seen is the tectonic boundary mentioned above. The volcanics are considered to be younger than the metasediments and to post-date the main Palaeozoic diastrophism of the fold belt. The volcanics are only locally folded. This is in contrast to the metasediments which reach amphibolite facies in grade and show polyphase folding.

Theoretically the volcanics might be of Upper Palaeozoic, Mesozoic or Tertiary age. Two isotopic age determinations on mylonitised volcanic rocks have given Tertiary ages and, although these dates are interpreted as indicating important mid-Tertiary thrust movements (see p. 229), it is possible that the ages are not far removed from the actual time of the volcanicity. Two points support this. Firstly, if Koch's (1918, 1923a, 1923b) suggestions about the contemporaneity of the lavas and the cross-cutting dykes in the De Long Fjord area are correct, then the lavas are of probable Cretaceous-Tertiary age. One of the cross-cutting dykes has given such an isotopic age (see p. 229). During the recent field work in the area to the east of De Long Fjord, however, no further information was gathered about the relationship between the swarms of basic dykes cutting the folded metasediments, and the bedded lavas and tuffs. Secondly, the volcanic rocks do not appear to bear the full effects of the regional metamorphism which probably affected the surrounding metasediments in Cretaceous (? and Tertiary) time (see p. 229). This might be taken as evidence indicating that the extrusion of the volcanic rocks post-dated the climax of this metamorphic episode.

Correlation between the folded and unfolded units

It has long been known that strata of the unfolded unit pass northwards into rocks which become involved in the folding, but until recently nothing definite was known about stratigraphical correlation between the two tectonic units. Fränkl (1955b) suggested correlation between some of the folded strata in northern Peary Land and Koch's unfolded Cape Tyson Formation and Polaris Harbour Formation in western North Greenland, correlations made over long distances where the rocks were mainly unknown or only known in poor detail. Such correlations are misleading and are clearly based on insufficient evidence.

Koch (1925, p. 275; 1929a, p. 280) remarked that in the western part of the fold belt, in contrast to Peary Land, it is possible to recognise the limestones and graptolitic shales of the Offley Island Formation and the Cape Tyson Formation. Since 1965 it has been known that the clastic rocks of northern Hall Land and Nyeboe Land are the lateral equivalent of the unfolded Silurian carbonates outcropping to the south (Allaart, 1965; Dawes 1966). The folded Upper Ordovician? dolomite outcropping on the northern coast of Hall Land was recognised in the southern part of Nyeboe Land (Dawes, 1966). Furthermore the pinkish white sandstones and quartzites of northern Wulff Land are probably correlatable with the sandstones which underly the Ordovician-Silurian limestones in southern Warming Land (see Koch, 1920, p. 27; 1921, p. 302), and which also occur in southern Wulff Land and Nyeboe Land overlying the crystalline basement.

In Peary Land little can yet be stated about exact strata correlations, despite the recognition of fossiliferous Cambrian, Ordovician and Silurian rocks in both unfolded and folded units. The folded Lower Cambrian Schley Fjord Shale of eastern Peary Land, remarked on by Troelsen (1956a, p. 87) as being "so different from the Brönlund Fjord Dolomite", can be correlated with the Buen Formation of southern Peary Land. Both have yielded an olenellid fauna. Intraformational breccias and conglomerates characterise the folded Cambrian? and Ordovician carbonate units of the Frederick E. Hyde Fjord region of northern Peary Land – a feature which is typical of the Cambro-Ordovician dolomites of southern Peary Land.

Basic igneous intrusions

A number of episodes of basic intrusion of Precambrian to Cretaceous-Tertiary age can be recognised in North Greenland. At least four, and probably five, different episodes can be distinguished.

1. The oldest intrusions belong to the Precambrian basement of western North Greenland. Bugge (1910, pp. 6–8) mentions hypersthene-quartz diorite and gabbro from the Foulke Fjord – Etah area and Koch (1929a, p. 219; 1933, p. 12) describes gabbro, diorite and hypersthene-bearing diorites invading the crystalline gneisses and associated metasediments of Inglefield Land. W. E. Davies (pers. comm.) also reports basic igneous rocks, some of them hypersthene-bearing, associated with the crystalline basement of the Thule area.

2. Dolerite sills and dykes of Precambrian age which post-date the deposition of the Inuiteq Sø Formation of southern Peary Land (Jepsen, in press) and the Norsemandal Sandstone of eastern North Greenland (Adams & Cowie, 1953), but which pre-date the deposition of the tillite (of presumed Varangian age) of Peary Land. The conspicuous sills characterising part of the Thule Group in the Thule area, and some, or all, of the basic dykes of that area might be of similar age. Basic dykes which clearly cut the crystalline basement in southern Wulff Land, but which from the aerial photographs appear not to penetrate the overlying Proterozoic? and Palaeozoic sediments, may be also of this age.

3. Dolerite sills which post-date the Rensselaer Bay Sandstone and possibly the Cape Leiper Dolomite of Inglefield Land but whose upper age limit is not known with certainty. These igneous rocks were regarded by Koch as Precambrian in age in view of the fact that diabase pebbles were found in the overlying conglomerates of Lower Cambrian age (Koch, 1933, p. 21). Since the sediments penetrated by the sills are now considered to be Cambrian (see p. 206), the intrusions are thus of Phanerozoic age. If the pebbles of diabase in the conglomerate truly originate from the sills in question then the sills are of Cambrian age, if not (and this seems highly possible since the pebbles could originate from earlier Precambrian basic rocks), then the sills could be of post-Cambrian age.

4. Basic sills which are post-Silurian but pre-Pennsylvanian in age. Troelsen (1949b, 1950a) recognised a number of sills in eastern Peary Land which do not penetrate the Upper Palaeozoic and Mesozoic-Tertiary cover rocks but which cut the folded Ordovician-Silurian strata. The sills in southwestern Inglefield Land mentioned above in group 3 could theoretically be of similar age. No dykes of this age have yet been recognised in North Greenland but basic dykes of similar age occur in northern Ellesmere Island where they cut structures in Silurian rocks but are overlain by Carboniferous strata (Trettin, 1969b, p. 49).

5. Basic dykes which are later than the main diastrophism of North Greenland and which are of Cretaceous-Tertiary age. The age of the NW dolerite swarm crossing southern Peary Land and that of an E-W swarm of biotite-bearing dolerites in northern Peary Land has been determined by isotopic age

determination (see below). Other N-S and NNE trending basic dykes in northern Peary Land are also most probably of similar age. All dykes which cut the folded rocks of northern Peary Land need not necessarily be of this age – some could be of post-Silurian, pre-Pennsylvanian age. Straight dolerite dykes post-dating the Thule Group in the Thule area, which have been regarded as Precambrian (*e.g.* Fernald & Horowitz, 1964), could theoretically be of this age or Palaeozoic.

In northern Peary Land two ages of metamorphosed basic intrusions have been distinguished. The oldest group has been recognised as discordant folded layers in the metasediments of the north coast and these appear to predate the F_2 folds. The rocks vary from metadolerite to highly altered schists.

The second group occurs as sills and dykes which are younger than the main diastrophism of the area but which have suffered some alteration (see fig. 4). The basic rocks display varying characters, and within a single dyke there can exist a gradation from ophitic-textured dolerite to foliated and even schistose metadolerite. The dykes and sills may be of Mesozoic-Tertiary age being pre- or syn-tectonic intrusions with regard to the Tertiary disturbances. Theoretically they may be the same age as the "diabase" and "porphyry" identified by Koch (1920) and contemporaneous with the volcanic suite of lavas and tuffs which also bear the signs of the Tertiary deformation (see p. 225).

Isotopic age determinations

Apart from two age dates from the crystalline basement of western North Greenland, one of which is a K/Ar date of 1740±30 m.y. (Larsen & Møller, 1968) and the other a zircon date of 1090 m.y. (Jaffe et al., 1959), ten isotopic dates are now available from Peary Land.

Three dates are available from the basic rocks within the unfolded rocks of southern Peary Land (Jepsen, 1969a; Henriksen & Jepsen, 1970). The oldest determinations are from dolerites within the Inuiteq Sø Formation (group 2 above) which give K/Ar ages of 799 ± 68 m.y. and 982 ± 19 m.y. An Ar^{40}/Ar^{39} spectrum analysis gave 988 ± 20 m.y. for the latter confirming the date and indicating that these dates are minimum ages for the dolerite intrusions. According to Henriksen & Jepsen (*op. cit.*) the dates could perhaps reflect the Carolinidian activity known from East Greenland (see Haller, 1961b; 1970).

A K/Ar determination on a cross-cutting dolerite dyke, which post-dates the unfolded Palaeozoic strata of southern Peary Land, gives 72.9 ± 9 m.y. This date is interpreted as a minimum age for the intrusion (Jepsen, 1969b;

Henriksen & Jepsen, 1970) and the dyke is classified as a member of group 5 above.

From the folded unit of northern Peary Land, seven results are so far available, each date being the average of three conventional K/Ar determinations.

An E-W cross-cutting olivine-biotite dolerite dyke (GGU 53487) has given a total rock date of 66 ± 6.6 m.y. This age is taken as being close to the minimum age for the intrusion, and the dyke is considered as a member of the Cretaceous-Tertiary suite of group 5 above.

Two total rock determinations on volcanic lavas from the Kap Washington Group have given 34.9 ± 3.5 m.y. (GGU 53443) and 32.3 ± 3.2 m.y. (GGU 53452). Both samples are mylonitised to a certain extent and the ages must be interpreted as giving a reasonably accurate estimate of the age of this mylonitisation. Hence the thrust, which deforms the volcanics and limits the succession to the south, is considered to be of mid-Tertiary age. However the ages may not be too far removed from the actual time of volcanicity (see p. 225).

Four K/Ar determinations from schistose rocks from the north coast area to the west and south-west of Kap Morris Jesup have given Cretaceous to Tertiary ages. The dates are: 84.2 ± 4.2 m.y. (GGU 53441) on biotite from a staurolite-andalusite-cordierite-muscovite-biotite-garnet schist from the west of Kap Christian IV; 75.9 ± 3.6 m.y. (GGU 53422) on biotite from a metasedimentary muscovite-biotite schist from the south-west of Kap Morris Jesup; 47.1 ± 2.4 m.y. (GGU 100624), a total rock age of a metasedimentary chloritoid-muscovite schist from the east of the head of Benedict Fjord, and 42.3 ± 4.2 m.y. (GGU 53427) on muscovite from a metasedimentary muscovite-biotite schist from Kap Christian IV. Since the rocks have been "overprinted" to a variable extent and it is known that a main diastrophism affected the rocks in pre-Pennsylvanian time (see p. 230), the true significance of these age dates is difficult to state categorically, particularly without supporting Ar^{40}/Ar^{39} age spectra. The micas and feldspars of GGU 53427 have been altered and the possibility of argon loss cannot be ignored. However the total rock age of GGU 100624 and the biotite age of GGU 53441, rocks which are apparently fresh, might be accepted as giving a reasonable minimum age for the recrystallisation of the mineral assemblages. Hence the dates are tentatively considered to be indicative of a Laramidian thermal event(s) of regional importance.

Age of the diastrophism in North Greenland

Considerable discussion has taken place about the age of the diastrophism in North Greenland and adjacent Ellesmere Island (Feilden & De Rance, 1878; Schei, 1903, 1904; Holtedahl, 1917, 1920; Koch, 1920, 1929a, 1961; Schuchert, 1923; Frebold, 1934, 1942a; Teichert, 1939; Bentham, 1941; Nielsen, 1941; Troelsen, 1940, 1950b, 1951; Ellitsgaard-Rasmussen, 1955; Fränkl, 1955b, 1956; Haller, 1961a; Haller & Kulp, 1962; Kerr, 1967a). Koch (1920), Ellitsgaard-Rasmussen (1955) and Fränkl (1956), who apart from Feilden and Troelsen, are the only workers referred to above to have seen folded rocks in North Greenland in the field, regarded the North Greenland fold belt as Caledonian in age. Haller (1961a) while maintaining that the main diastrophism was Caledonian, *sensu lato*, also indicated (see Haller & Kulp, 1962) the importance of Cenozoic movements which had earlier been noted in Peary Land by Troelsen (1949b, 1950a). The fold belt is part of the Innuitian orogenic system which is characterised by strongly deformed Lower Palaeozoic rocks and less-severely deformed Upper Palaeozoic and younger strata, and which extends from the Beaufort Sea, through the Queen Elizabeth Islands of Arctic Canada, into North Greenland (Fortier, McNair, & Thorsteinsson, 1954, p. 2087; Haller & Kulp, 1962, p. 31).

The only direct evidence of the age of the Palaeozoic folding in North Greenland shows that the main deformation post-dates the deposition of the clastic rocks of northern Hall Land and Nyeboe Land (Cape Rawson Group), the upper part of which is at least as young as Lower Ludlovian, and pre-dates the Pennsylvanian beds of eastern Peary Land. Koch (1920, p. 72) considered the age of the folding as "Devonian, presumably the first half of this period, perhaps beginning in the uppermost Silurian" (see also Koch, 1923d, p. 58; 1934, pp. 154, 159; 1935a, p. 619), while Fränkl (1956, p. 34) regards the main orogeny to have taken place "in the Upper Silurian (Ardennian phase) or in the lowermost Devonian (Erian phase)". Haller (1961a, p. 171) remarks that "the orogenic climax is assumed to be late Silurian" and regards the distinct transgressions recognised by Koch (1929a) within the Silurian, as indicative of epeirogenic movements prior to the main orogenic activity. Since theoretically, folding could have occurred as late as the Carboniferous, the fold belt has sometimes been recorded as being Hercynian (*e.g.* Carey, 1958; Beloussov, 1962).

The North Greenland geosyncline is the eastern extension of the Franklinian (Schuchert, 1923) or Smith Sound (Koch, 1929a) geosyncline which has an extensive development in Arctic Canada where Caledonian, Hercynian and Cenozoic earth movements have all been recognised (Thorsteinsson & Tozer, 1960). From northern Ellesmere Island, Trettin (1969a, p. 145) gives evidence for a "Middle Ordovician or somewhat earlier orogeny". In northern Axel Heiberg Island an angular unconformity occurs between Late Wenlockian beds, and Lower and Middle Devonian sediments and volcanics (Trettin, 1968, p. 695). The rocks of the Sverdrup Basin, the oldest sediments of which in northern Axel Heiberg Island and northern Ellesmere Island are of Mississippian age (Kerr & Trettin, 1962; Christie, 1964; Trettin, 1969b), overlie with angular unconformity the folded Ordovician and Silurian rocks in north-eastern Ellesmere Island (Christie, 1964, pp. 67–68; Trettin, 1969a, p. 145). In southern Ellesmere Island an angular unconformity exists between Pennsylvanian and folded Late Devonian rocks (McLaren, 1963) indicating a Late Devonian (Frasnian or later) folding there, and Trettin (1969b) describes a Middle Devonian to Mississippian orogeny from Axel Heiberg Island and northern Ellesmere Island. The youngest rocks of the Sverdrup Basin (Tertiary) are affected by Cenozoic disturbances (Thorsteinsson & Tozer, 1960).

Clearly, with evidence for Ordovician, Late Silurian to Early Devonian (*i.e.* the "early Palaeozoic movements" of Thorsteinsson & Tozer, 1960) and Late Devonian to Mississippian (*i.e.* the "mid-Palaeozoic movements" of Thorsteinsson & Tozer, 1960) folding in adjacent Arctic Canada, it is difficult to infer accurately the date of the Palaeozoic folding in North Greenland. However, the one angular unconformity recognised in North Greenland, that between Pennsylvanian and folded Silurian, involves rocks of the same age as the main unconformity in north-eastern Ellesmere Island (Christie, 1964), where away from the axial trough of the Sverdrup Basin, Mississippian rocks are apparently absent. The apparent absence of Mississippian deposits in eastern Peary Land is probably not due to a major diastrophism of that age (Lower Carboniferous rocks are present in Kronprins Christian Land to the south), and the present author regards the main Palaeozoic diastrophism in North Greenland to have occurred between Late Silurian and Late Devonian time. The metasediments of the fold belt have undergone polyphase deformation and it is quite possible that phases of deformation occurred at different times between the Late Silurian and Late Devonian, as apparently was the case in the Canadian part of the Franklinian geosyncline. If the upper age of the Cape Rawson Group in Greenland, or the age of the youngest pre-Pennsylvanian folded strata in Peary Land could be discovered, the time span in which the main deformation could have taken place may be narrowed.

The Kap Washington Group of northern Peary Land and the Upper Palaeozoic, Mesozoic-Tertiary sediment unit of eastern Peary Land are both affected by Tertiary earth movements. Folding, faulting and thrusting all occurred (see pp. 223, 225). The Upper Palaeozoic, Mesozoic-Tertiary sediments in eastern Peary Land are non-metamorphic and the effect of the Laramidian regional metamorphism (see p. 229) appears to have been restricted to that part of Peary Land that was an orogenic zone in Palaeozoic time. The tectonic history of the fold belt is complex and the metasediments are polymetamorphic. It has hitherto been assumed that the regional metamorphism affecting the sediments in northern Peary Land is of Palaeozoic age and associated to the main diastrophism (Fränkl, 1955b). The time relations between metamorphism and deformation are not yet known in detail, but in view of the persistence of the Laramidian ages for the schistose rocks suggesting the crystallisation of Abukuma-type metamorphic mineral assemblages (see p. 222), it seems that the distribution of the metamorphic isograds in northern Peary Land, is a product of two distinct metamorphic episodes. How far the apparent increase in metamorphic grade from the south to the north across the fold belt has been superimposed upon, or controlled by, the younger of these episodes is difficult to assess at present.

Acknowledgements. This paper is published by the permission of the Director of the Geological Survey of Greenland, mag. scient. K. Ellitsgaard-Rasmussen. My thanks are due to all those workers with whom I have discussed geological aspects of North Greenland during the past six years, as well as to T. C. R. Pulvertaft for critically reading the first draft of this paper.

Dansk sammendrag

Der gives en oversigt over vort nuværende kendskab til det nordgrønlandske foldningsområde, ledsaget af et resumé over den historiske udvikling i de geologiske undersøgelser i denne del af Grønland. Til slut gives en udførlig litteraturfortegnelse, som omfatter de relevante beskrivelser af prækvartæret i Nordgrønland.

I Nordgrønland findes en bjergartsserie, som omfatter det prækambriske krystallinske basement, som overlejres af proterozoiske, nedre og øvre palæozoiske, mesozoiske og tertiære lagserier. Det krystallinske underlag, som kommer til syne langs med indlandsisens nordlige begrænsning, overlejres diskordant af en proterozoisk og nedre palæozoisk sedimentserie. Sedimenterne har en svag nordlig hældning og udgør en platform syd for det foldede område. Foldningsområdet strækker sig over den nordligste del af Grønland og udgør en næsten stik øst-vestlig metamorfoseret deformationszone. Grænsen for det foldede område kan følges over en afstand på 600 km fra Hall Land i vest helt ned til det østlige Peary Land. I den bredeste del af foldningsområdet i Peary Land, tiltager deformationsgraden og metamorfosen i nordlig retning ind imod hvad der må antages at være orogenets centrale område. De mest højmetamorfe foldebjergarter er krystalliniske skifre som indeholder granat, biotit, muscovit, staurolit, cordierit og andalusit. Disse skifre findes på nordkysten vest for Kap Morris Jesup. I det østlige Peary Land er de foldede nedre palæozoiske sedimenter diskordant overlejret af en lagserie af Pennsylvanian, Perm, Trias og Kridt-Tertiær alder. Lagserien har været underkastet tertiære bevægelser.

Feltobservationer fra Nordgrønland, sat i relation til vidnesbyrd fra det Innuitiane orogen i Arktisk Canada, antyder at hovedfasen i den palæozoiske diastrophisme indvirker på sedimenterne i den grønlandske del af den frankliniske geosynklinal, og falder mellem Øvre Silur og Øvre Devon.

De siden 1965 udførte feltundersøgelser, såvel i de foldede bjergarter som i platformens sedimenter, har ført til en ny fortolkning af det strukturelle billede af nordgrønlandske bjergartsserier og deres stratigrafi. De vigtigste resultater er: 1) Fastlæggelse af udstrækningen af et palæozoisk koralrev-system i den vestlige del af platform-

området. De vekslende facies mellem kalksten, sandsten og lerskifer har givet anledning til en kritisk vurdering af de tidligere beskrevne siluriske diskordanser, samt til en revision af den hidtidig anvendte stratigrafiske nomenklatur for det nordgrønlandske Silur. 2) En videre nedrykning af Kambriets nedre grænse i platformens lagserie, hvorved sedimenter som tidligere er blevet beskrevet som prækambriske eller eo-kambriske (en del af den såkaldte Thule Group) nu må betragtes for at værende palæozoiske i alder. 3) Den mere end 1000 m mægtige Inuiteq Sø Formation, den ældste kendte lagserie i Nordgrønland, som består af sandsten, gennemsat af baskiske intrusiver, er mindst 1000 millioner år gammel. 4) Fund af såvel brachiopod-, cephalopod-, trilobit-, gastropod-, koral- og graptolit-faunaer i de foldede sedimenter. Herved fastslås at kambro-ordoviciske og siluriske lagserier indgår i foldekæden. 5) Antydning af at sedimenterne i foldningszonen har gennemgået en langvarig og sammensat orogenese, som omfatter såvel polyfase deformation som metamorfose. Den tidligere tolkning af foldekædens struktur, som værende forårsaget af intensive og mindre dybtgående forskydninger og dannelse af napper og overskydninger af alpin karakter afvises. 6) K-Ar aldersbestemmelser for bjergarter fra foldekæden antyder, at den palæozoiske metamorfose efterfølges af termale hændelser af regional udstrækning og af laramidisk alder, hvorved der frembringes mineralparageneser af Abukuma-type. Der er også vidnesbyrd om gennemgribende tertiære tektoniske bevægelser. 7) Genkendelse i foldekæden af en lagdelt vulkansk serie bestående af lavaer og tuffer (Kap Washington Group). Disse effusiver er yngre end hovedfasen i den palæozoiske diastrophisme i de omgivende metasedimenter, men ældre end de tertiære bevægelser.

Grønlands Geologiske Undersøgelse
Østervoldgade 10, DK-1350 København K.
March 25th 1970

Bibliography

Adams, P. J. & Cowie, J. W. 1953: A geological reconnaissance of the region around the inner part of Danmarks Fjord, Northeast Greenland. *Meddr Grønland* **111** (7), 24 pp.

Allaart, J. H. 1965: The Lower Paleozoic sediments of Hall Land, North Greenland. Unpubl. rep., Grønlands geol. Unders., 11 pp.

Allaart, J. H. 1966: Hall Land, Northwest Greenland. *In* Jenness, S. E. (editor): Report of activities, May to October, 1965. *Pap. geol. Surv. Can.* **66–1,** 4 only.

Allaart, J. H. & Dawes, P. R. in prep: Geological reconnaissance of the Hall Land-Nyeboe Land area, North Greenland. *Rapp. Grønlands geol. Unders.*

Beloussov, V. V. 1962: Tectonic map of the world. *In* Beloussov, V. V.: *Basic problems in Geotectonics,* 809 pp. New York: McGraw-Hill.

Bendix-Almgreen, S. E., Fristrup, B. & Nichols, R. L. 1967: Notes on the geology and geomorphology of the Carey Øer, North-west Greenland. *Meddr Grønland* **164** (8), 19 pp.

Bentham, R. 1936: Appendix 1: Geology. *In* Humphreys, N., Shackleton, E. & Moore, A. W.: Oxford University Ellesmere Land Expedition. *Geogr. J.* **87,** 427–431.

Bentham, R. 1941: Structure and glaciers of southern Ellesmere Island. *Geogr. J.* **97,** 36–45.

Berthelsen, A. & Noe-Nygaard, A. 1965: The Precambrian of Greenland. *In* Rankama, K. (editor): *The Precambrian* **2,** 113–262. London: Interscience Publishers.

Bessils, E. 1879: *Die Amerikanische Nordpol-expedition.* 647 pp. Leipzig: Von Wilhelm Engelmann.

Bugge, C. 1910: Petrographische Resultate der 2ten Fram-Expedition. *Rep. 2nd Norweg. Arctic Exp. Fram 1892–1902,* **3** (22), 38 pp. Kristiania: Vidensk. Selsk.

Bøggild, O. B. 1915: Examination of some rocks from North-Greenland, collected by Knud Rasmussen and P. Freuchen in the year 1913. *Meddr Grønland* **51** (10), 383–386.

Bøggild, O. B. 1917: Grönland. *In* Steinmann, G. & Wilckens, O. (editors): *Handbuch der Regionalen Geologie,* Bd. **4,** (2a), Hf. 21, 38 pp. Heidelberg: Carl Winter.

Callisen, K. 1929: Petrographische Untersuchung einiger Gesteine von Nordgrönland. *Meddr Grønland* **71** (4), 217–255.

Carey, S. W. 1958: The tectonic approach to continental drift. *In* Carey, S. W. (convener): Continental drift. *Symp. geol. Dept. Univ. Tasmania, 1956.* Hobart: Univ. Tasmania.

Christie, R. L. 1964: Geological reconnaissance of northeastern Ellesmere Island, District of Franklin. *Mem. geol. Surv. Can.* **331,** 79 pp.

Christie, R. L. 1966: Operation Grant Land. *In* Jenness, S. E. (editor): Report of Activities, May to October, 1965. *Pap. geol. Surv. Can.* **66–1,** 3–4.

Christie, R. L. 1967a: Operation Grant Land (1966), northern Ellesmere Island. *In* Jenness, S. E. (editor): Report of Activities, part A: May to October, 1966. *Pap. geol. Surv. Can.* **67–1,** pt. A, 2–3.

Christie, R. L. 1967b: Bache Peninsula, Ellesmere Island, Arctic Archipelago. *Mem. geol. Surv. Can.* **347,** 63 pp.

Clebsch, A. 1954: The bedrock geology of Inglefield Land. *In* Prelim. rep., *Program Operation Ice Cap 1953, SRI Project 828.* Stanford Res. Inst. Calif.

Clebsch, A. 1956: The bedrock of the SE corner of Inglefield Land. Unpubl. Ms., U. S. geol. Surv.

Cowie, J. W. 1961a: The Lower Palaeozoic geology of Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1,** 160–169. Toronto U. P.

Cowie, J. W. 1961b: Contributions to the geology of North Greenland. *Meddr Grønland* **164** (3), 47 pp.

Davies, W. E. 1954: Bedrock geology of the greater Thule area. *In* Final rep., *Operation Ice Cap 1953,* 441–442. Stanford Res. Inst. Calif.

Davies, W. E. & Krinsley, D. B. 1961: Evaluation of arctic ice-free land sites Kronprins Christian Land and Peary Land, North Greenland 1960. *U. S. Air Force Surv. Geophy.* **135,** 51 pp.

Davies, W. E., Krinsley, D. B. & Nicol, A. H. 1963: Geology of the North Star Bugt area, Northwest Greenland. *Meddr Grønland* **162** (12), 68 pp.

Davies, W. E., Needleman, S. M. & Klick, D. W. 1959: *Report on Operation Groundhog (1958) North Greenland. Investigation of ice-free sites for aircraft landings, Polaris Promontory, North Greenland.* 45 pp. Bedford: U. S. Air Force Cambridge Res. Centre.

Davis, C. H. 1876: *Narrative of the North Polar Expedition. U. S. Ship Polaris, Captain Charles Francis Hall commanding.* 696 pp. Washington: Gov. Printing Off.

Dawes, P. R. 1966: Lower Palaeozoic geology of the western part of the North Greenland fold belt. *Rapp. Grønlands geol. Unders.* **11,** 11–15.

Dawes, P. R. 1967: Lower Palaeozoic rocks, western part of the North Greenland fold belt. *In* Jenness, S. E. (editor): Report of Activities, part A: May to October, 1966. *Pap. geol. Surv. Can.* **67–1,** pt. A, 4–6.

Dawes, P. R. & Soper, N. J. 1970: Geological investigations in northern Peary Land. *Rapp. Grønlands geol. Unders.* **28,** 9–15.

De Rance, C. E. & Feilden, H. W. 1878: On the geological structure of the coasts of Grinnell Land and Hall Basin visited by the British Arctic expedition 1875–6. *In* Nares, G. S.: *Narrative of a voyage to the Polar sea during 1875–6 in H. M. Ships 'Alert' and 'Discovery'*, vol. **2**, 327–345. London: Sampson Low, Marston, Searle and Rivington.

Dunbar, C. O., Troelsen, J. [C.], Ross, C. [A.], Ross, J. P. & Norford, B. [S.] 1962: Faunas and correlation of the Late Paleozoic rocks of Northeast Greenland. Part I–IV. *Meddr Grønland* **167** (4–7), 150 pp.

Etheridge, R. 1878: Palaeontology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R. N., K. C. B., F. R. S. *Quart. Jl geol. Soc. Lond.* **34**, 568–574.

Ellitsgaard-Rasmussen, K. 1950: Preliminary report on the geological field work carried out by the Danish Peary Land Expedition in the year 1949–50. *Meddr dansk geol. Foren.* **11**, 589–595.

Ellitsgaard-Rasmussen, K. 1951: Træk af den nordgrønlandske foldekædes opbygning. *Meddr dansk geol. Foren.* **12**, 163 only.

Ellitsgaard-Rasmussen, K. 1955: Features of the geology of the folding range of Peary Land North Greenland. *Meddr Grønland* **127** (7), 56 pp.

Feilden, H. W. & De Rance, C. E. 1878: Geology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R. N., K. C. B., F. R. S. *Quart. Jl. geol. Soc. Lond.* **34**, 556–567.

Fernald, A. T. & Horowitz, A. S. 1954: Bedrock geology of the Nunatarssuak area. *In* Final rep., *Operation Ice Cap 1953*, 11–25. Stanford Res. Inst. Calif.

Fernald, A. T. & Horowitz, A. S. 1964: Bedrock geology of the Nunatarssuaq area, Northwest Greenland. *Meddr Grønland* **172** (6), 44 pp.

Fortier, Y. O., McNair, A. H. & Thorsteinsson, R. 1954: Geology and petroleum possibilities in Canadian Arctic Islands. *Bull. Am. Ass. Petrol. Geol.* **38**, 2075–2109.

Fränkl, E. 1954: Vorläufige Mitteilung über die Geologie von Kronprins Christians Land (NE-Grönland, zwischen 80–81° N und 19–23° W). *Meddr Grønland* **116** (2), 85 pp.

Fränkl, E. 1955a: Weitere Beiträge zur Geologie von Kronprins Christians Land (NE-Grönland, zwischen 80° und 80°30′ N). *Meddr Grønland* **103** (7), 35 pp.

Fränkl, E. 1955b: Rapport über Die Durchquerung von Nord Peary Land (Nordgrönland) im Sommer 1953. *Meddr Grønland* **103** (8), 61 pp.

Fränkl, E. 1955c: Crossing North Peary Land in summer 1953. *Arctic* **8**, 158–165.

Fränkl, E. 1956: Some general remarks on the Caledonian chain of East Greenland. *Meddr Grønland* **103** (11), 43 pp.

Frebold, H. 1934: Tatsachen und Deutungen zur Geologie der Arktis. *Meddr dansk geol. Foren.* **8**, 301–326.

Frebold, H. 1942a: Die Arktis. *Geologische Jahresberichte* **4B**, 1–34.

Frebold, H. 1942b: Über die Productiden des Brachiopodenkalkes und der Mallemukformation des nördlichen Ostgrönland und die Altersfrage einiger jungpaläozoischer Bildungen der Arktis. *Norges Svalbard og Ishavs Unders., Skrifter* **84**, 68 pp. Oslo.

Frebold, H. 1950: Stratigraphie und Brachiopodenfauna des marinen Jungpalaeozoikums von Holms und Amdrups Land (Nordostgrönland). *Meddr Grønland* **126** (3), 97 pp.

Freuchen, P. 1915: General observations as to natural conditions in the country traversed by the Expedition. *Meddr Grønland* **51** (9), 341–370.

Greely, A. W., 1886: *Three Years of Arctic Service. An Account of the Lady Franklin*

Bay Expedition of 1881–84 and the Attainment of the Farthest North. Vol. **1**, 428 pp., Vol. **2**, 444 pp. London: Richard Bentley & Son.

Grönwall, K. A. 1916: The marine Carboniferous of North-east Greenland and its brachiopod fauna. *Meddr Grønland* **43** (20), 509–618.

Haller, J. 1956: Die Strukturelemente Ostgrönlands zwischen 74° und 78° N. *Meddr Grønland* **154** (2), 27 pp.

Haller, J. 1961a: An account of Caledonian orogeny in Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1**, 170–187. Toronto U. P.

Haller, J. 1961b: The Carolinides: An orogenic belt of Late Precambrian age in North-east Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1**, 155–159. Toronto U. P.

Haller, J. 1970: Tectonic map of East Greenland (1:500,000). An account of tectonism, plutonism, and volcanism in East Greenland. *Meddr Grønland* **171** (5), 286 pp.

Haller, J. & Kulp, J. L. 1962: Absolute age determinations in East Greenland. *Meddr Grønland* **171** (1), 77 pp.

Henriksen, N. & Jepsen, H. F. 1970: K/Ar age determinations on dolerites from southern Peary Land, North Greenland. *Rapp. Grønlands geol. Unders.* **28**, 55–58.

Holtedahl, O. 1917: Summary of geological results. *Rep. 2nd Norweg. Arctic Exp. Fram 1892–1902*, **4** (36), 27 pp. Kristiania: Vidensk. Selsk.

Holtedahl, O. 1920: Paleogeography and Diastrophism in the Atlantic-Arctic Region during Paleozoic Time. *Am. J. Sci.*, 4th Ser. **49**, 1–25.

Jackson, D. E. & Etherington, J. R. 1969: New cyrtograptid graptolites from north-western Canada and northern Greenland. *J. Paleont.* **43**, 1114–1121.

Jaffe, H. W., Gottfried, D., Waring, C. L. & Worthing, H. W. 1959: Lead-alpha age determinations of accessory minerals of igneous rocks (1953–1957). *Bull. geol. Surv. U. S.* **1097–B**, 65–148.

Jepsen, H. F. 1966: Intrusive rocks of the Midsommersø area, southern Peary Land and their stratigraphical position. *Rapp. Grønlands geol. Unders.* **11**, 8–10.

Jepsen, H. F. 1969a: Preliminary report on the stratigraphy of the Precambrian and Eocambrian sediments in the Jørgen Brønlund Fjord – Midsommersø area, southern Peary Land. *Rapp. Grønlands geol. Unders.* **19**, 11–14.

Jepsen, H. F. 1969b: Basiske intrusiver i det sydlige Pearyland og deres geologiske milieu. Unpubl. Diss. Univ. Aarhus, 66 pp.

Jepsen, H. F. in press: The Precambrian, Eocambrian and Early Palaeozoic stratigraphy of the Jørgen Brønlund Fjord area, Peary Land, North Greenland. *Meddr Grønland* **192** (2).

Kerr, J. W. 1967a: Nares submarine rift valley and the relative rotation of North Greenland. *Bull. Can. Petrol. Geol.* **15**, 483–520.

Kerr, J. W. 1967b: Stratigraphy of central and eastern Ellesmere Island, Arctic Canada. Part 1. Proterozoic and Cambrian. *Pap. geol. Surv. Can.* **67–27**, pt. 1, 63 pp.

Kerr, J. W. & Trettin, H. P. 1962: Mississippian rocks and the mid-Palaeozoic earth movements in the Canadian Arctic Archipelago. *J. Alberta Soc. Petrol. Geol.* **10**, 247–256.

Koch, I. P. 1916: Survey of Northeast Greenland. *Meddr Grønland* **46** (2), 79–468.

Koch, L. 1918: Oversigt over II Thuleekspeditions videnskabelige Resultater. *Naturens Verden*, Copen. Aarg. **2**, 494–509.

Koch, L. 1919: De geologiske Resultaten af den andra Thuleexpeditionen till Grönland. *Geol. Fören. Stock. Förh.* **41**, 109–112.

Koch, L. 1920: Stratigraphy of Northwest Greenland. *Meddr dansk geol. Foren.* **5** (17), 78 pp.

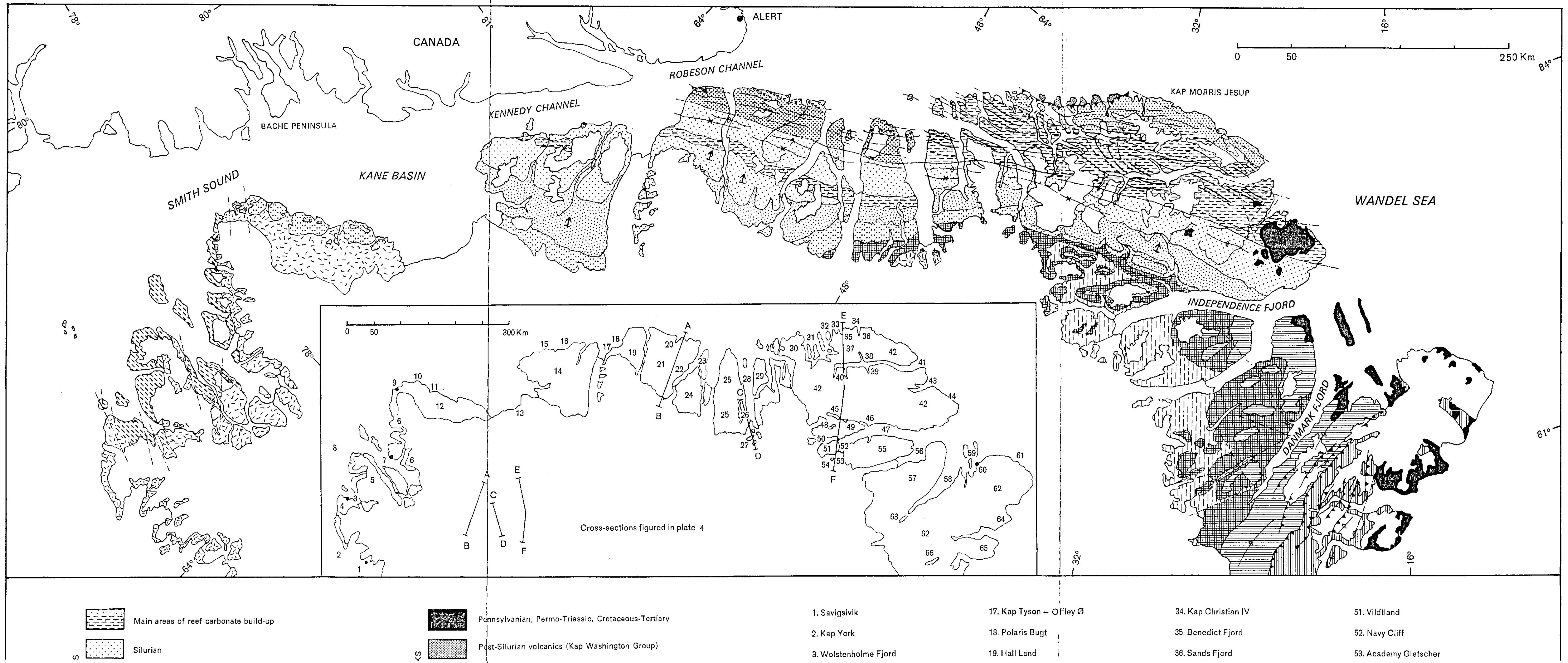


Plate 3

Geological map of the North Greenland fold belt and environs, together with an *inset* map giving the localities of the place-names mentioned in the text, as well as the position of the geological cross-sections shown in plate 4.

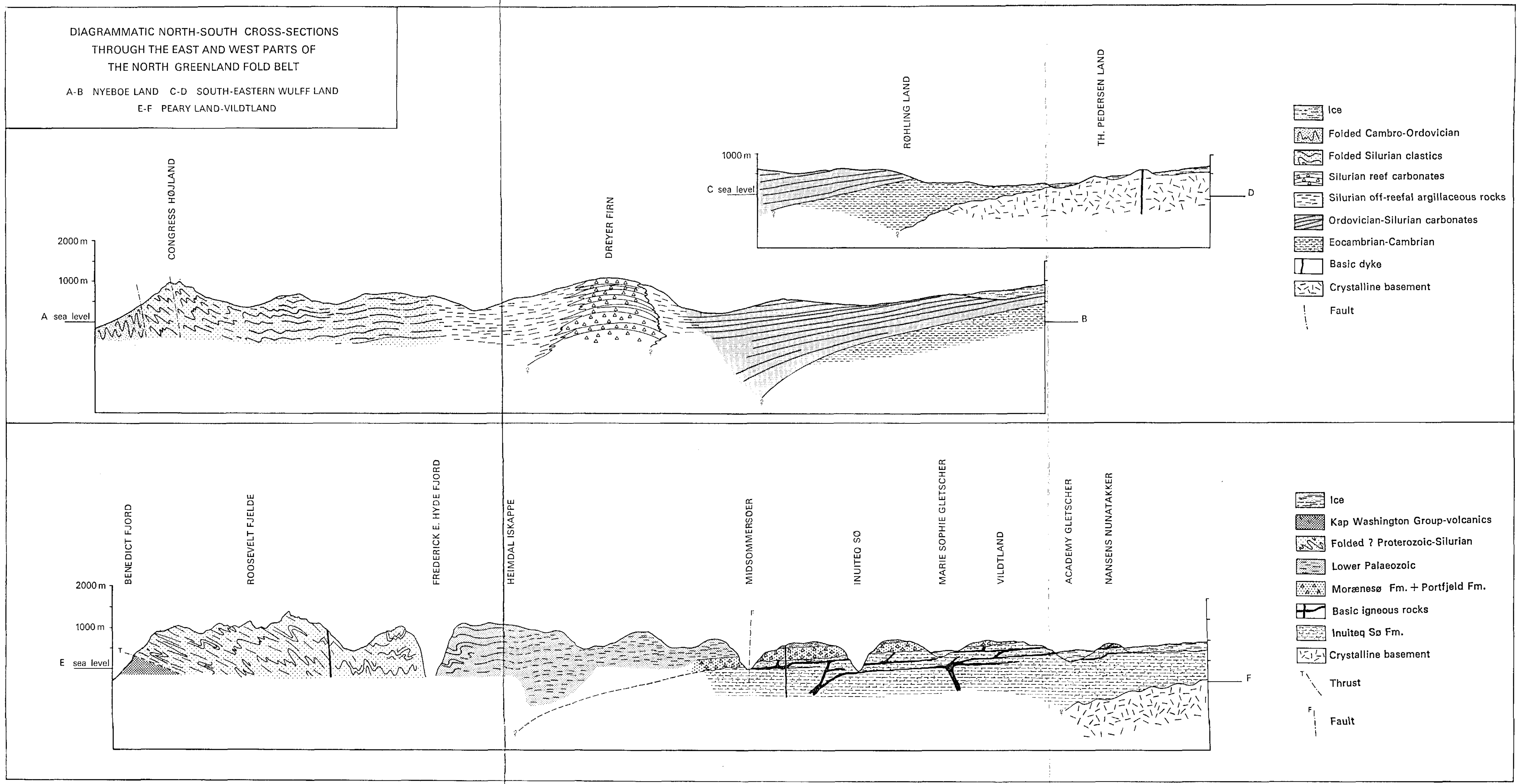


Plate 4

Diagrammatic cross-sections across the western and eastern parts of the North Greenland fold belt. The lines of the sections are indicated on plate 3. Vertical scale is exaggerated to such an extent that the unfolded, homoclinal stratigraphical units of the platform are shown to be dipping too steeply.

		THULE BASIN	NORTH GREENLAND GEOSYNCLINE					DANMARK FJORD BASIN
		THULE-PRUDHOE LAND AREA	INGLEFIELD LAND	WASHINGTON LAND	HALL-NYEBOE-WULFF LAND AREA	NORTH AND EAST PEARY LAND	CENTRAL AND SOUTH PEARY LAND	KRONPRINS CHRISTIAN LAND-DANMARK FJORD
DEVONIAN					?	?	?	
SILURIAN	UPPER			ARGILLACEOUS LIMESTONE AND SHALE BIO-STROMAL AND BIOHERMAL LIMESTONE	CAPE RAWSON GROUP CAPE TYSON BIOHERMAL LIMESTONES AND SHALES	SANDSTONE, ARKOSE, SHALE, WITH SOME CARBONATE	SANDSTONE, CALCAREOUS SANDSTONE, SHALE *	PROFILFJELDET SHALES Hiatus
SILURIAN	MIDDLE				OFFLEY ISLAND BIOSTROMAL LIMESTONE			DRØMMEBJERG LIMESTONE CENTRUM LIMESTONE
SILURIAN	LOWER			CAPE SCHUCHERT FORMATION ? Hiatus	?			?
ORDOVICIAN	UPPER			CAPE CALHOUN FORMATION Hiatus	DOLOMITE, LIMESTONE, CARBONATE BRECCIA AND CONGLOMERATE, SHALE	LIMESTONE, CARBONATE BRECCIAS, GRAPTOLITIC SHALE	BØRGLUM RIVER LIMESTONE	CENTRUM LIMESTONE
ORDOVICIAN	MIDDLE			GONIOCERAS BAY FORMATION Hiatus				
ORDOVICIAN	LOWER		CASS FJORD FORMATION	CAPE WEBSTER FORMATION NUNATAMI FORMATION CAPE WEBER FORMATION NYGAARD BAY LIMESTONE POULSEN CLIFF SHALE CAPE CLAY FORMATION CASS FJORD FORMATION			WANDEL VALLEY LIMESTONE	?
CAMBRIAN	UPPER		? NOT PRESENT Hiatus	?	?	CARBONATES, SANDSTONE *		
CAMBRIAN	MIDDLE		CAPE WOOD FORMATION Hiatus	CAPE WOOD FORMATION Hiatus	LIMESTONE, DOLOMITE, SHALE		? Hiatus	?
CAMBRIAN	LOWER	?	CAPE KENT LIMESTONE WULFF RIVER FORMATION ? Hiatus CAPE INGERSOLL DOLOMITE CAPE LEIPER DOLOMITE RENSSELAER BAY SANDSTONE	(probably present) (probably present) CAPE INGERSOLL DOLOMITE CAPE LEIPER DOLOMITE (probably present)	SANDSTONE, QUARTZITE, QUARTZITIC CONGLOMERATE *	SCHLEY FJORD SHALE	BRØNLUND FJORD DOLOMITE Hiatus BUEN FORMATION PORTFJELD FORMATION *	DANMARKS FJORD DOLOMITE * Hiatus KAP HOLBÆK SANDSTONE * Hiatus FYNS SØ DOLOMITE *
	EOCAMBRIAN	NARSSÂRSSUK FORMATION * ? Hiatus ?					Hiatus MORÆNESØ FORMATION * Hiatus	CAMPANULADAL SANDSTONES AND LIMESTONES * Hiatus
PRECAMBRIAN	PROTEROZOIC	DUNDAS FORMATION * (incl. basic intrusions) WOLSTENHOLME FORMATION *	NOT PRESENT		?	?	INUITEQ SØ FORMATION * (incl. basic intrusions)	NORSEMANDAL SANDSTONE * (incl. basic intrusions)
PRECAMBRIAN	ARCHEAN	CRYSTALLINE BASEMENT	CRYSTALLINE BASEMENT	NOT EXPOSED	CRYSTALLINE BASEMENT			? CRYSTALLINE BASEMENT

Plate 5

Precambrian and Lower Palaeozoic stratigraphical correlation chart between localities in the North Greenland geosyncline, the Thule Basin and the Danmark Fjord Basin. The age of the rock units marked by an asterisk is based on stratigraphical evidence or on isotopic age determinations. The ages of the other rock units are based on faunal evidence from Greenland, except in the case of the Rensselaer Bay Sandstone, the Cape Leiper Dolomite and the Cape Ingersoll Dolomite where the ages of the formations are based on faunal evidence in correlatable strata in Ellesmere Island. Full, vertical, arrowed lines indicate the known age extent of the exposed rock unit(s); broken, vertical, arrowed lines indicate the possible age extent of the exposed rock unit(s). The formational names Fyns Sø Dolomite and Danmarks Fjord Dolomite are given in their original forms, whereas in the text the corresponding place-names are given as Fyn Sø and Danmark Fjord, which are the present official spellings.

Koch, L. 1921: Geological observations. *In* Rasmussen, K.: *Greenland by the Polar sea. The story of the Thule Expedition from Melville Bay to Cape Morris Jesup,* 301–311. London: Heinemann.

Koch, L. 1923a: Preliminary report upon the geology of Peary Land, Arctic Greenland. *Am. J. Sci.,* 5th Ser. **5,** 189–199.

Koch, L. 1923b: Resultaterne af Jubilæumsekspeditionen Nord om Grønland i 1921. *Naturens Verden,* Copen. Aarg. **7,** 49–74.

Koch, L. 1923c: Preliminary report on the results of the Danish Bicentenary Expedition to North Greenland. *Geogr. J.* **62,** 103–117.

Koch, L. 1923d: Some new features in the physiography and geology of Greenland. *J. Geol.* **31,** 42–65.

Koch, L. 1924: De videnskabelige Resultater af Jubilæumsekspeditionen Nord om Grønland. Rapport 1: Kartografi og geologi. *Geogr. Tidsskr.* **27,** 208–218.

Koch, L. 1925: The geology of North Greenland. *Am. J. Sci.,* 5th Ser. **9,** 271–285.

Koch, L. 1926a: A new fault zone in Northwest Greenland. *Am. J. Sci.,* 5th Ser. **12,** 301–310.

Koch, L. 1926b: Report on the Danish Bicentenary Jubilee Expedition North of Greenland 1920–23. *Meddr Grønland* **70,** 1 Afd. (1), 1–232.

Koch, L. 1929a: Stratigraphy of Greenland. *Meddr Grønland* **73,** 2 Afd. (2), 205–320.

Koch, L. 1929b: The geology of the south coast of Washington Land. *Meddr Grønland* **73,** 1 Afd. (1), 39 pp.

Koch, L. 1929c: The geology of East Greenland. *Meddr Grønland* **73,** 2 Afd. (1), 204 pp.

Koch, L. 1933: The geology of Inglefield Land. *Meddr Grønland* **73,** 1 Afd. (2), 38 pp.

Koch, L. 1934: Some new main features in the geological development of Greenland. *In* Arctowski, H. (editor): Zbiór Prac (collected papers), *Towarzystwo Geogr. Lwowie (Geogr. Soc. Lvov), Eugenjuszowi Romerowi Vol,* 149–159.

Koch, L. 1935a: A day in North Greenland. *Geogr. Ann., Sven Hedin Bd.,* 609–620.

Koch, L. 1935b: Geologie von Grönland. *In* Krenkel, E. (editor): *Geologie der Erde,* 159 pp. Berlin: Gebrüder Bornträger.

Koch, L. 1961: Precambrian and Early Palaeozoic structural elements and sedimentation: North and East Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1,** 148–154. Toronto U. P.

Kummel, B. 1953: Middle Triassic ammonites from Peary Land. *Meddr Grønland* **127** (1), 21 pp.

Kurtz, V. E., McNair, A. H. & Wales, D. B. 1952: Stratigraphy of the Dundas Harbour area, Devon Island, Arctic Archipelago. *Am. J. Sci.* **250,** 636–655.

Kurtz, V. E. & Wales, D. B. 1951: Geology of the Thule area, Greenland. *Proc. Okla. Acad. Sci.* **31** (1950), 83–92.

Larsen, O. & Møller, J. 1968: K/Ar age determinations from western Greenland I. Reconnaissance programme. *Rapp. Grønlands geol. Unders.* **15,** 82–86.

Maync, W. 1961: The Permian of Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1,** 214–223. Toronto U. P.

McLaren, D. J. 1963: Southwestern Ellesmere Island between Goose Fjord and Bjorne Peninsula. *In* Fortier, Y. O. et al.: Geology of the North-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). *Mem. geol. Surv. Can.* **320,** 310–338.

Mikkelsen, E. 1922: Report on the Expedition. *In* Alabama-Expeditionen til Grønlands Nordøstkyst 1909–1912 under ledelse af Ejnar Mikkelsen. *Meddr Grønland* **52** (1), 142 pp.

Munck, S. 1941: Geological observations from the Thule District in the summer of 1936. *Meddr Grønland* **124** (4), 38 pp.

Nares, G. S. 1878: *Narrative of a voyage to the Polar sea during 1875–6 in H. M. Ships* 'Alert' and *'Discovery'*. Vol. **1**, 395 pp., Vol. **2**, 378 pp. London: Sampson Low, Marston, Searle & Rivington.

Nathorst, A. G. 1911: Contributions to the Carboniferous flora of North-eastern Greenland. *Meddr Grønland* **43** (12), 337–346.

Nielsen, E. 1940: En geologisk Undersøgelsesrejse i Nordøstgrønland. *Meddr dansk geol. Foren.* **9**, 651–652.

Nielsen, E. 1941: Remarks on the map and the geology of Kronprins Christians Land. *Meddr Grønland* **126** (2), 34 pp.

Norford, B. S. 1967: Biostratigraphic studies, northeast Ellesmere Island and adjacent Greenland. *In* Jenness, S. E. (editor): Report of activities, part A: May to October, 1966. *Pap. geol. Surv. Can.* **67–1**, pt. A, 12 only.

Peacock, J. D. 1956: The geology of Dronning Louise Land N. E. Greenland. *Meddr Grønland* **137** (7), 38 pp.

Peacock, J. D. 1958: Some investigations into the geology and petrography of Dronning Louise Land, N. E. Greenland. *Meddr Grønland* **157** (4), 139 pp.

Peacock, J. D. C. 1970: Joint Services Expedition to north Peary Land, 1969. *Polar Rec.* **15**, 54–55.

Peary, R. E. 1898: *Northward over the Great Ice. A narrative of life and work along the shores and upon the interior of Ice-cap of Northern Greenland in the years 1886 and 1891–1897.* Vol. **1**, 521 pp., Vol. **2**, 625 pp. London: Methuen & Co.

Peary, R. E. 1907: *Nearest the Pole. A narrative of the Polar Expedition of the Peary Arctic Club in the S. S. Roosevelt, 1905–1906.* 410 pp. London: Hutchinson & Co.

Poulsen, C. 1927: The Cambrian, Ozarkian and Canadian faunas of Northwest Greenland. *Meddr Grønland* **70,** 1 Afd. (2), 233–343.

Poulsen, C. 1934: The Silurian faunas of North Greenland. I. The fauna of the Cape Schuchert Formation. *Meddr Grønland* **72,** 2 Afd. (1), 46 pp.

Poulsen, C. 1941: The Silurian faunas of North Greenland. II. The fauna of the Offley Island Formation. Part I Coelenterata. *Meddr Grønland* **72,** 2 Afd. (2), 28 pp.

Poulsen, C. 1943: The Silurian faunas of North Greenland. II. The fauna of the Offley Island Formation. Part II Brachiopoda. *Meddr Grønland* **72,** 2 Afd. (3), 60 pp.

Poulsen, C. 1946: Notes on Cambro-Ordovician fossils collected by the Oxford University Ellesmere Land Expedition 1934–5. *Quart. Jl geol. Soc. Lond.* **102,** 299–337.

Poulsen, V. 1964: Contribution to the Lower and Middle Cambrian Paleontology and Stratigraphy of Northwest Greenland. *Meddr Grønland* **164** (6), 105 pp.

Poulsen, V. 1969: An Atlantic Middle Cambrian fauna from North Greenland. *Lethaia* **2,** 1–14.

Rasmussen, K. 1915: Report of the First Thule Expedition 1912. *Meddr Grønland* **51** (8), 283–340.

Rasmussen, K. 1927: Report on the II. Thule-Expedition for the Exploration of Greenland from Melville Bay to De Long Fjord, 1916–1918. *Meddr Grønland* **65** (1), 1–180.

Schei, P. 1903: Summary of geological results. The Second Norwegian Polar Expedition in the 'Fram'. *Geogr. J.* **22,** 56–65.

Schei, P. 1904: Preliminary account of the geological investigations made during the Second Norwegian Polar Expedition in the 'Fram'. *In* Sverdrup, O.: *New Land.*

Four years in the Arctic regions, vol. **2**, 455–466. London: Longmans, Green & Co.

Schuchert, C. 1923: Sites and Nature of the North American Geosynclines. *Bull. geol. Soc. Am.* **34**, 151–230.

Smirnow, L. P. 1953: *Geology and oil possibilities of northern Greenland and Canadian Islands.* New York: Photosat./World GR-NY 35, 93 pp.

Soper, N. J. & Dawes, P. R. 1970: A section through the north Peary Land fold belt. *Proc. geol. Soc. Lond.* **1662,** 60–61.

Teichert, C. 1934: Untersuchungen an Actinoceroiden Cephalopoden aus Nordgrönland. *Meddr Grønland* **92** (10), 48 pp.

Teichert, C. 1937: A new Ordovician fauna from Washington Land, North Greenland. *Meddr Grønland* **119** (1), 65 pp.

Teichert, C. 1939: Geology of Greenland. *In* Ruedemann R, & Balk, R. (editors): *Geology of North America* **1,** 100–175. Geologie der Erde. Berlin: Gebrüder Bornträger.

Thorsteinsson, R. & Tozer, E. T. 1960: Summary account of structural history of the Canadian Arctic Archipelago since Precambrian time. *Pap. geol. Surv. Can.* **60–7,** 25 pp.

Trettin, H. P. 1968: Devonian of the Fran[k]linian eugeosyncline. *In* Oswald, D. H. (editor): *Proc. intern. Symp. Devonian System, 1967,* **1,** 693–701. Calgary: Alberta Soc. Petrol. Geol.

Trettin, H. P. 1969a: A Paleozoic-Tertiary fold belt in northernmost Ellesmere Island aligned with the Lomonosov Ridge. *Bull. geol. Soc. Am.* **80,** 143–148.

Trettin, H. P. 1969b: Pre-Mississippian geology of northern Axel Heiberg and northwestern Ellesmere Islands, Arctic Archipelago. *Bull. geol. Surv. Can.* **171,** 82 pp.

Troedsson, G. T. 1926: On the Middle and Upper Ordovician faunas of northern Greenland. I. Cephalopods. *Meddr Grønland* **71** (1), 1–157.

Troedsson, G. T. 1928: On the Middle and Upper Ordovician faunas of northern Greenland. Part II. *Meddr Grønland* **72,** 1 Afd. (1), 197 pp.

Troelsen, J. [C.] 1940: Foreløbig Meddelelse om Resultater af Mag. scient. J. Troelsen's geologiske Undersøgelser i Inglefield Land, Grinnell Land og Ellesmere Land. *Meddr dansk geol. Foren.* **9,** 638–641.

Troelsen, J. C. 1949a: Contributions to the geology of the area round Jørgen Brønlunds Fjord, Peary Land, North Greenland. *Meddr Grønland* **149** (2), 29 pp.

Troelsen, J. C. 1949b: Geologiske undersøgelser i Peary Land 1948–49. *Meddr dansk geol. Foren.* **11,** 501 only.

Troelsen, J. [C.] 1950a: Geology. *In* Winther, P. C. et al.: A preliminary account of the Danish Pearyland Expedition, 1948–9. *Arctic* **3,** 6–8.

Troelsen, J. C. 1950b: Contributions to the geology of Northwest Greenland, Ellesmere Island and Axel Heiberg Island. *Meddr Grønland* **149** (7), 86 pp.

Troelsen, J. C. 1951: Den frankliniske (Nordgrønlandske) geosynklinals udvikling i ældre Palæozoisk tid. *Meddr dansk geol. Foren.* **12,** 162 only.

Troelsen, J. C. 1956a: The Cambrian of North Greenland and Ellesmere Island. *In* El sistema Cámbrico, su paleogeografía y el problema de su base. *20 Congr. geol. intern. Mêxico.* Symp. **3,** t. 1, 71–90.

Troelsen, J. C. 1956b: *Groenland. In* Lexique Stratigraphique International **1** (1a), 116 pp. Paris.

Trümpy, R. 1961: Triassic of East Greenland. *In* Raasch, G. O. (editor): *Geology of the Arctic* **1,** 248–273. Toronto U. P.

Wordie, J. M. 1938: An expedition to Northwest Greenland and the Canadian Arctic in 1937. *Geogr. J.* **92,** 385–421.