The Proterozoic Thule Basin of Greenland and Ellesmere Island: importance to the Nares Strait debate

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Onshore geological investigations in the Smith Sound region are now so advanced as to allow correlation between Canada and Greenland to be made with confidence.

The Precambrian Shield is unconformably overlain by unmetamorphosed Proterozoic strata (Thule Group) that are best preserved in Greenland, where they attain a thickness of at least 4.5 km. Less than 1100 m are present in south-eastern Ellesmere Island, but the succession is so similar to the lower part of the Greenland succession that unit to unit correlation of both sedimentary and volcanic rocks is possible. This correlation strongly supports the concept of a single intracratonic basin (Thule Basin) spanning the southernmost part of Nares Strait. In Greenland the basin is well defined and its northern margin is at about 78°15′N. In Ellesmere Island paucity of outcrop provides less definition but the northern margin lies between Baird Inlet (78°30′N) and Bache Peninsula (79°N).

The lithological and thickness correlation of the Proterozoic successions on the opposite shores of the Smith Sound region strongly suggests that any tectonic movement along the Nares Strait lineament has not resulted in major net transcurrent displacement of Greenland and Ellesmere Island.

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Few students of continental drift and plate tectonics of the Arctic have resisted the temptation to accommodate movement between Greenland and North America by transcurrent displacement along the linear channel between Greenland and Ellesmere Island — Nares Strait (Taylor 1910, Wegener 1922, Carey 1958, Wilson 1963, Srivastava 1978). Modern reconstructions, many of which have received wide approval, consider the Labrador Sea and Baffin Bay as oceans formed by sea-floor spreading, with the consequent separation of Greenland and Baffin Island resulting in substantial movement along Nares Strait; in some recent models as much as 300 km or more of sinistral motion has been involved (e.g. Sclater et al. 1977, Srivastava 1978).

In the northernmost Baffin Bay – southern Nares Strait region (herein referred to as the Smith Sound region) the Precambrian Shield forming the northern part of the North American craton is overlain by unmetamorphosed sedimentary and volcanic strata of Proterozoic age (Figs 1 and 2). These strata are extensively developed in coastal North-West Greenland where they have been named the Thule Group. More restricted outcrops in coastal south-eastern Ellesmere Island on the opposite shore of the Smith Sound region correlate with the lower part of the Greenland succession. The Thule Group rocks in Greenland and Ellesmere Island are interpreted as parts of a single sedimentary basin — the Thule Basin. This basin spans the southernmost part of the Nares Strait and as such is of particular relevance in any deliberations about the postulated palaeopositions of the two landmasses on which it outcrops.

The aim of this paper is to summarise the main features of stratigraphical correlation between the Proterozoic sequences of Greenland and Ellesmere Island and to examine the implications of this for the problem of displacement along Nares Strait. The paper is based on field investigations by all three authors; in Greenland by Dawes (1972, 1975, 1976a, 1979) and in Ellesmere Island by Christie (1962a, b, 1967) and Frisch (Frisch et al. 1978). Frisch also carried out comparative studies in Greenland in 1978 and 1980. The most recent regional descriptions of the Thule Group are given in Dawes (1976b) and Frisch & Christie (1982).

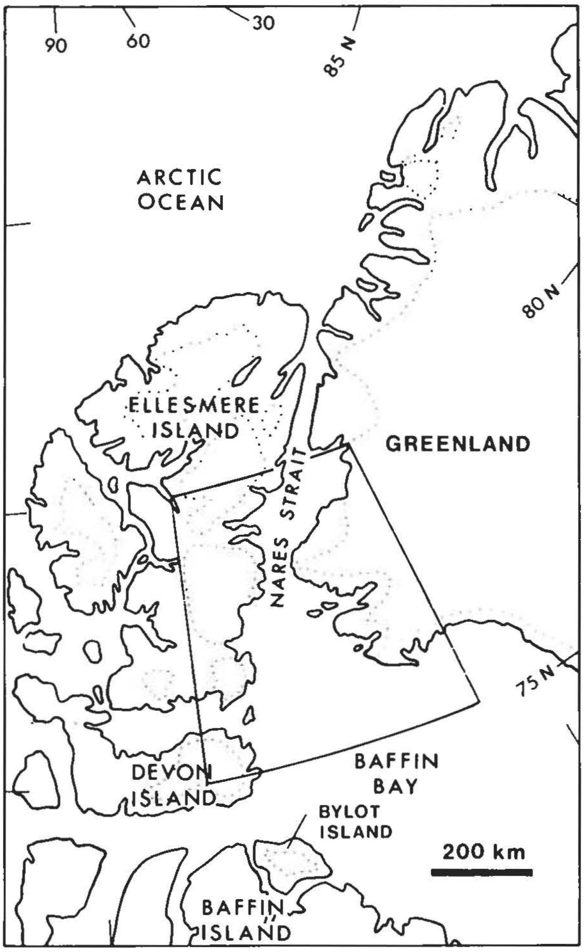

Fig. 1. Index map of the Nares Strait region with frame of the Smith Sound region as shown in Fig. 3. Main ice fields are indicated.

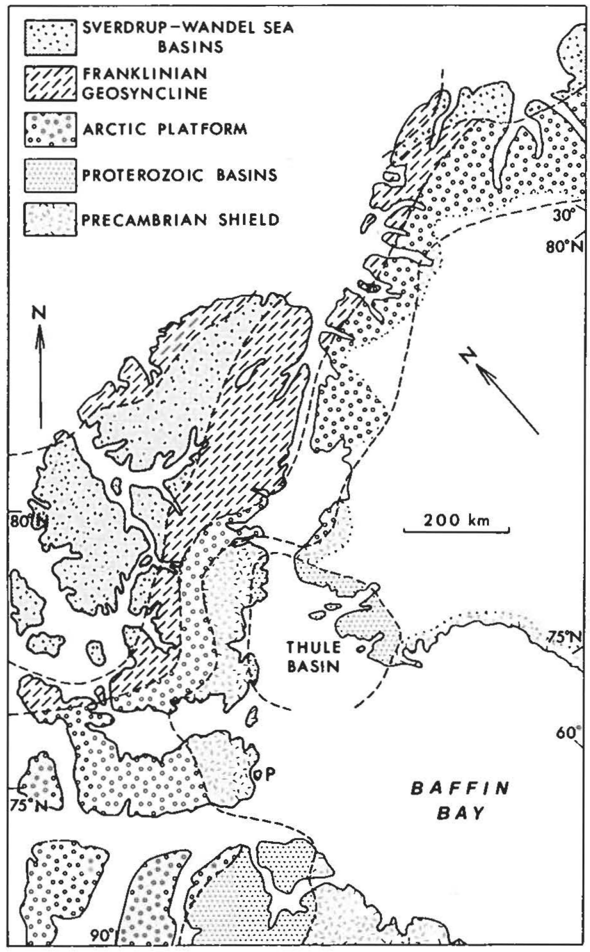

Fig. 2. Main geological provinces of the Nares Strait region showing the setting of the Thule Basin. P = Philpots Island.

The Thule Group – Thule Basin: concept and nomenclature

The unmetamorphosed Proterozoic rocks of the Smith Sound region consist of two geographically separated sequences: a thick southern sequence overlain only by Quaternary accumulations and a conspicuously thinner northern sequence overlain in both Greenland (Inglefield Land) and Ellesmere Island (Bache Peninsula) by Lower Palaeozoic strata. The thick southern sequence forms the Thule Basin (Kerr 1967, Christie 1972), while the thinner sequence (Rensselaer Bay Formation) forms part of the stable platform, south of the Franklinian geosyncline (Fig. 2). The structural high separating the Thule Basin from the platform has been termed the Bache Peninsula arch (Kerr 1967).

In Greenland there is relatively good exposure between the Thule Basin and the thinner platform sequence to the north, and Koch (1929, 1933) used the name Thule Formation to cover both sequences. However, in Ellesmere Island the two sequences are separated and no Thule Group strata are preserved over the Bache Peninsula arch (Fig. 3). This has led to some inconsistencies in stratigraphic nomenclature. Thus, some authors (e.g. Christie 1967, 1972) have restricted the name Thule Group to the thick succession of the Thule Basin, while others (e.g. Troelsen 1950) have included the thin Rensselaer Bay Formation of the platform as part of the Thule Group.

A nomenclatorial revision of the Thule Group based on the type area in Greenland is in preparation by one of us (PRD), but in the present paper the name Thule Group is retained and used to cover all the Proterozoic strata (Thule Basin and adjacent platform deposits) that overlie the Precambrian Shield in the Smith Sound region. The reader is referred to the paper by Peel et al. (this volume) for a description of the platform sequences north of the Thule Basin including a redefinition of the Rensselaer Bay Formation to which the Pro-

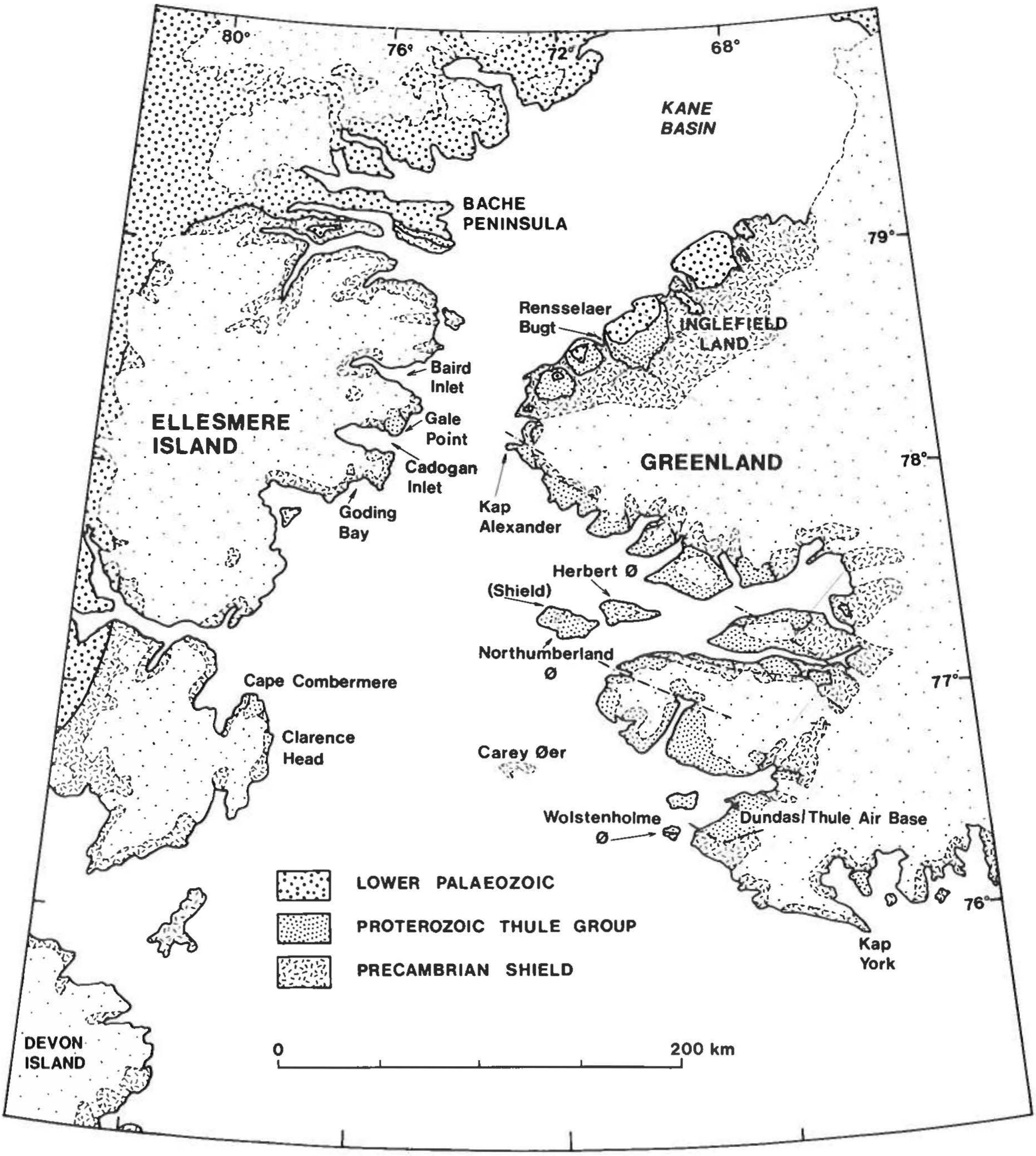

Fig. 3. Simplified geological map of the Smith Sound region.

terozoic strata of Bache Peninsula and Inglefield Land are referable.

Stratigraphy

The main outcrops of the Thule Basin are preserved in Greenland between Wolstenholme Ø (76°30′N) and Kap Alexander (78°10′N), and in Ellesmere Island between Clarence Head (76°45′N) and Cadogan Inlet (78°10′N) (Fig. 3). Lower Thule Group strata occur as an isolated outlier north of Kap York (75°55′N) and as a small patch on Ellesmere Island, north of Baird Inlet (78°30′N).

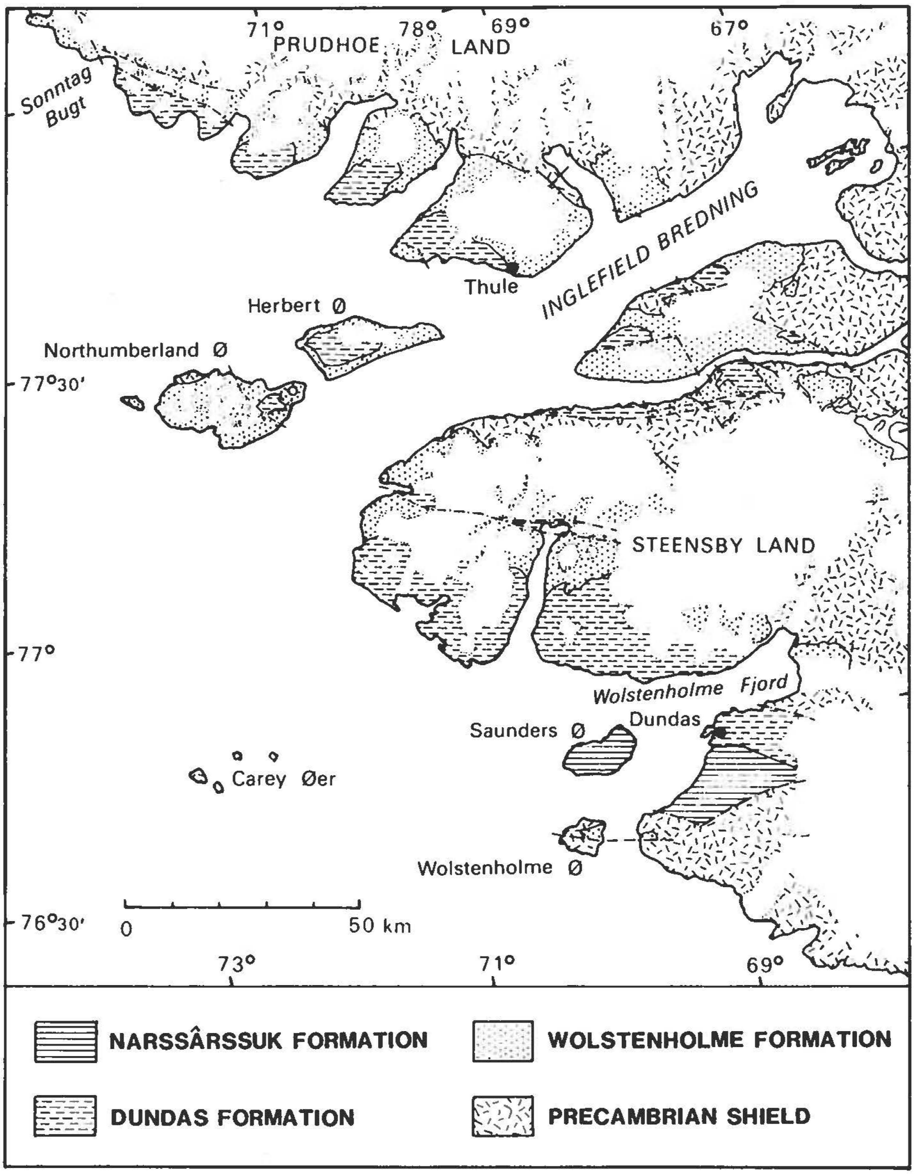

Fig. 4. Geological map of the Thule Basin in North-West Greenland.

The Thule Group has its thickest development in Greenland where the composite section reaches 4500 m. This is presently subdivided into three formations (Davies et al. 1963), i.e. from bottom to top, the *Wolstenholme Formation* (lower Thule Group) of sandstone and conglomerate with basaltic lavas and sills, the *Dundas Formation* of mainly shale and sandstone and the *Narssârssuk Formation* of cyclic carbonate-clastic deposits. The Dundas and Narssârssuk Formations (upper Thule Group) are confined to Greenland where they have restricted occurrences; in particular the Narssârssuk Formation only occurs in the region south of Dundas and on Saunders Ø (Fig. 4).

In south-eastern Ellesmere Island a little less than 1100 m of the Proterozoic sequence is preserved and all strata have been referred to the lower Thule Group or Wolstenholme Formation (Frisch et al. 1978). Hence, the definition of the Thule Basin as a depositional entity spanning southern Nares Strait is based solely on the lower Thule Group and thus only that part of the succession is relevant to the present discussion. However, since some workers (e.g. Newman & Falconer 1978, Newman, this volume) prefer to correlate the Thule Group in Greenland with the Proterozoic succession in northern Baffin Island, 500 km further to the south, a brief summary of the two formations of the upper Thule Group is given below to complete the description of the stratigraphy.

Upper Thule Group

The Dundas Formation of the upper Thule Group conformably overlies the Wolstenholme Formation with a gradational contact. The relationship between the Dundas and Narssârssuk Formations is uncertain although lithological and structural considerations suggest that the latter formation is all, or in part, of younger age (Dawes 1979).

The *Dundas Formation,* at least 1000 m thick, is a dark weathering, thin-bedded sequence of mainly alternating shale, siltstone and sandstone with some thin beds of calcareous shale, dolomite and, in the upper part, minor evaporite, chert and siliceous siltstone. The dolomites are stromatolitic in places and some small carbonate mounds occur. The formation is interpreted as a shallow-water, deltaic to coastal plain deposit.

The *Narssârssuk Formation* is a multicoloured, conspicuously banded, red bed sequence at least 2500 m thick. It is characterised by the cyclic alternation of dolomite, limestone, fine-grained sandstone, siltstone and shale with some thin evaporite, chert and cherty dolomite beds. A variety of stromatolite and algal-mat associations are present. The formation is a shallow-water deposit; its red bed, evaporitic and cyclic nature suggests rather stable lacustrine or lagoonal conditions, perhaps an environment analogous to modern sabkhas.

Both formations are intruded by basic igneous material. K/Ar whole-rock dates on dykes and sills show a range from 532 ± 20 m.y. to 727 ± 30 m.y. (Dawes et al. 1973). Acritarchs suggest a late Riphean age for the main thickness of the Dundas Formation, ranging to Vendian in its uppermost part, while the Narssârssuk Formation is regarded as Vendian in age throughout (Vidal & Dawes 1980).

Lower Thule Group

The lower Thule Group has a composite thickness of over 2000 m, and its distribution is shown in Fig. 5. In both Greenland and Ellesmere Island it includes a wide range of rock types, both sedimentary and igneous. The lithological diversity clearly warrants higher stratigraphical status than that of the single formation accorded it in the literature, i.e. Wolstenholme Formation.

The succession consists essentially of a basal sandstone sequence overlain by basaltic extrusive and hypabyssal rocks which are interbedded with red beds. These are overlain by a much thicker clastic sequence of sandstone and quartz-pebble conglomerate with siltstone and shale. The succession displays lateral lithological and thickness variations which can best be studied in Greenland, where the largest part of the Thule Basin is preserved. However, a regional description of the lower Thule Group is outside the scope of this paper and for convenience the Northumberland Ø sequence is taken as a reference section for comparison with Ellesmere Island. This section is particularly suitable since its lower and upper contacts are preserved and it represents that part of the Greenland succession closest to the area in which the main Ellesmere Island outcrops occur.

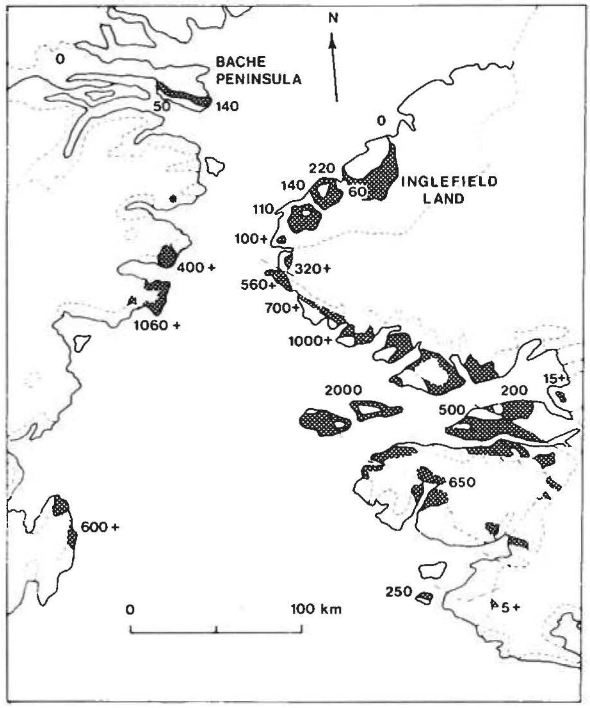

Fig. 5. Map showing the outcrops of the lower Thule Group (including the Rensselaer Bay Formation of Inglefield Land and Bache Peninsula). Asterix north of Baird Inlet represents a small outlier of the Thule Group. Thicknesses are in metres. A positive sign indicates a minimum thickness; either a minimum estimate or a detailed measured section, the upper limit of which is an erosional surface. Thicknesses include basic sills.

Greenland – Northumberland Ø. – A complete sequence of the lower Thule Group is present on Northumberland Ø (Fig. 6). The succession has a tectonically undisturbed, unconformable contact with the crystalline basement on the north-western side of the island (Fig. 7) and it is overlain by the Dundas Formation in a downthrown fault block that forms the eastern end of the island. The succession has been divided into six main units (Dawes 1976a: fig. 8, and Fig. 6).

Unit 1 – Basal sandstone unit. This is composed of a light-weathering, generally medium-bedded, and in places cross-bedded, succession comprising red, purple, orange, brown and buff sandstones that are commonly variegated and mottled. Although generally recessive, some sandstone beds are characteristically cliff-forming (Fig. 7). Some purple and green shales with mud cracks and thin-bedded, fine-grained sandstones occur in the middle part. Basic sills are present in the lower part and

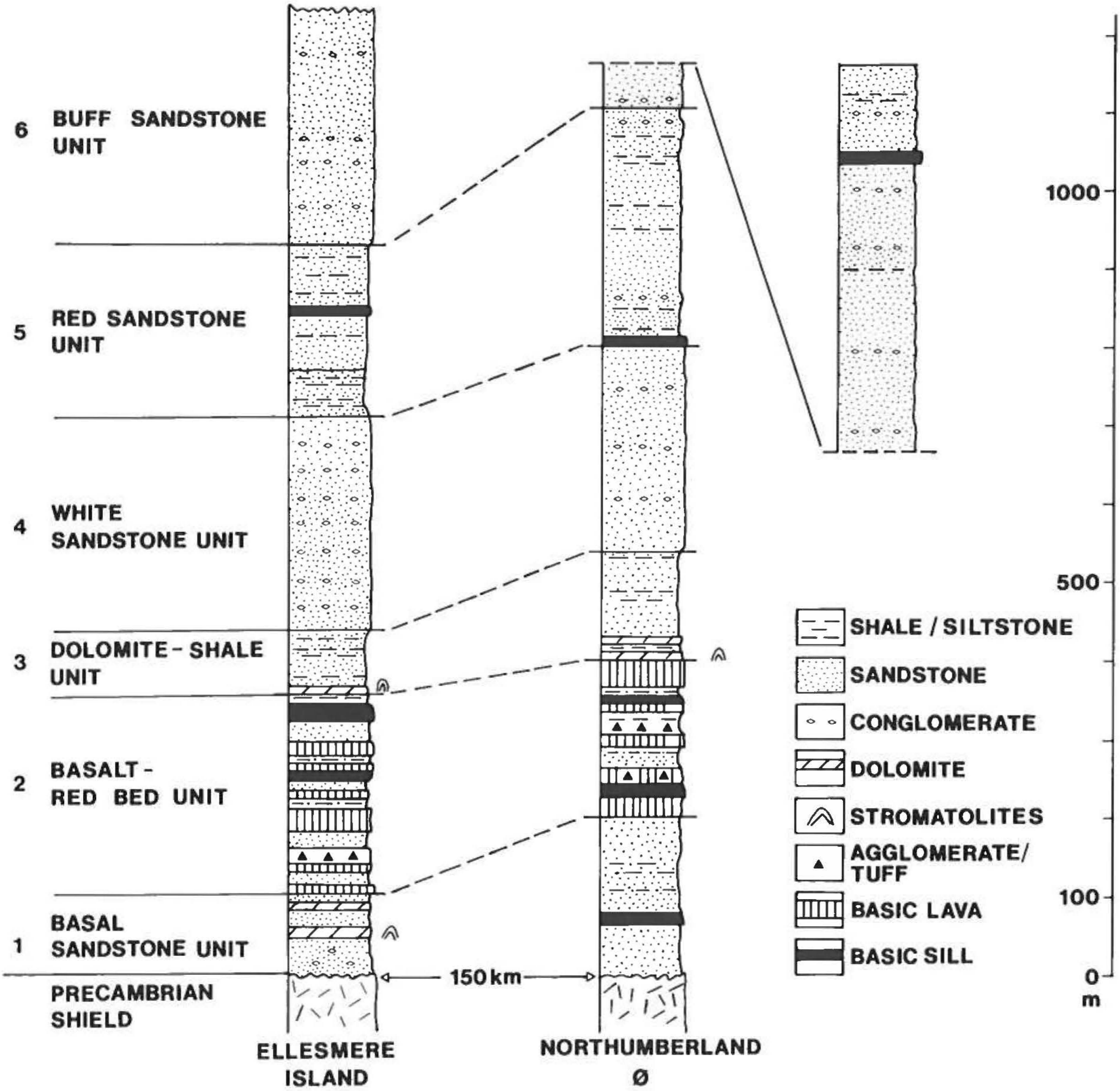

Fig. 6. Simplified stratigraphical correlation chart of the lower Thule Group on Ellesmere Island and Northumberland Ø, Greenland. The Canadian section is a composite of the three main outcrop areas (Clarence Head, Goding Bay and Gale Point) redrawn from Frisch et al. (1978); the Greenland section is modified from Dawes 1976a.

the thickness of the unit, including the sills, reaches 200 m.

Unit 2 – Basalt-Red bed unit. This is a dark-weathering, rather complex sequence of extrusive, hypabyssal, volcaniclastic and red bed rocks which is at least 200 m thick. It shows some lateral variation, but is characterised by having resistant lower and upper parts of basaltic flows and sills, between which is a dominantly recessive sedimentary sequence (Fig. 8). Several of the basaltic members have amygdaloidal tops and a rubbly volcanic appearance, but it is not everywhere apparent whether the igneous members are extrusive flows or intrusive sills.

The sedimentary rocks are thin-bedded and consist of reddish brown to purple tuffs, agglomerates and volcanic breccias which in places are interbedded with red to brown shales, siltstones and fine-grained sandstones.

Unit 3 – Dolomite-Shale unit is a dark-weathering, thin-bedded, recessive unit reaching a thickness of about 140 m (Fig. 8). In the lower part it consists of a variable sequence up to 25 m thick of resistant dolomite and dolomitic limestone, which is partly stromatolitic,

Fig. 7. Contact of the Precambrian Shield and Thule Group on the western side of Robins Gletscher, northwestern Northumberland Ø, Greenland. Basal sandstone unit 1 (about 180 m) is overlain by the basalt-red bed unit 2. The cliff-forming layer forming the top of the section is a lava flow or basic sill.

particularly at the base, with maroon and red shales. These rocks are overlain by multicoloured (red, purple, green, buff), medium- to fine-grained sandstones with some grey green and red shales. The sandstones are cross-bedded and ripple marked. In one locality the middle and upper parts of the unit contain some fine-grained volcaniclastic and extrusive rocks in association with black shales characterised by abundant mud cracks.

Unit 4 – White sandstone unit. This consists of a light-weathering, resistant and cliff-forming sequence up to 260 m thick composed of mainly thick-bedded quartz sandstones or orthoquartzite with frequent quartz-pebble conglomerate beds. The overall colour of

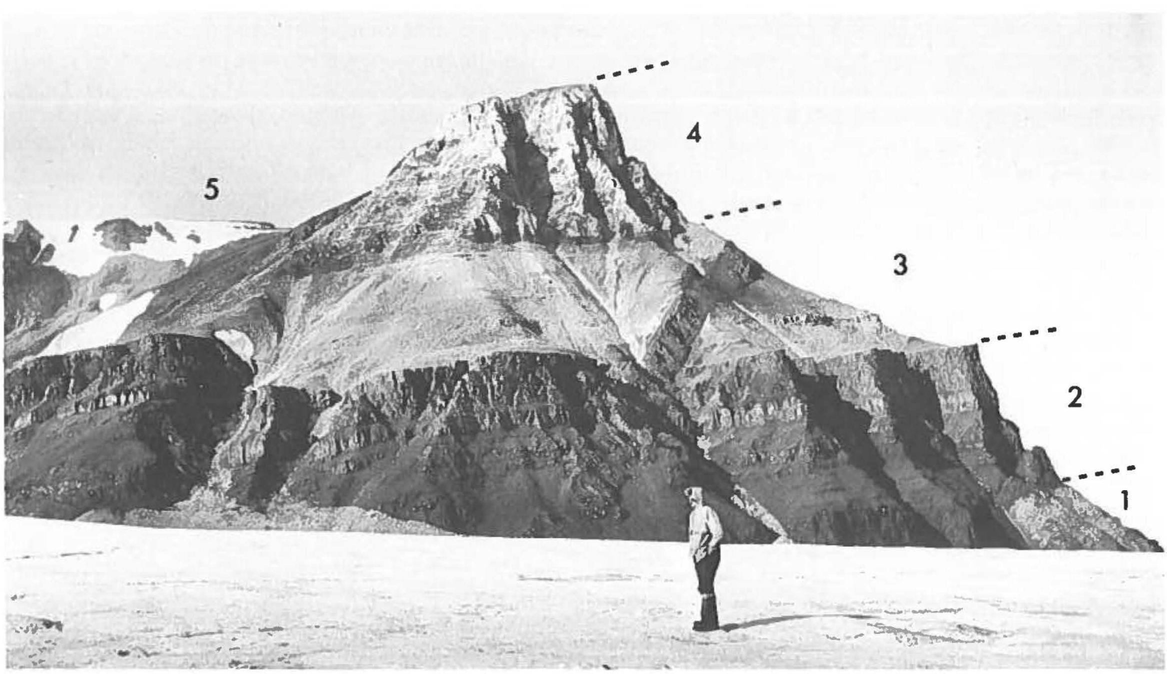

Fig. 8. The lower part of the Thule Group in a cliff section on the west side of Kissel Gletscher, north-western Northumberland Ø, Greenland. The Precambrian Shield is just out of view to the right at sea level. The summit of the headland at approximately 700 m above sea level is at the boundary with unit 5, part of which can be seen at the top of the ridge in the background. The sequence is cut by a late Proterozoic dolerite dyke.

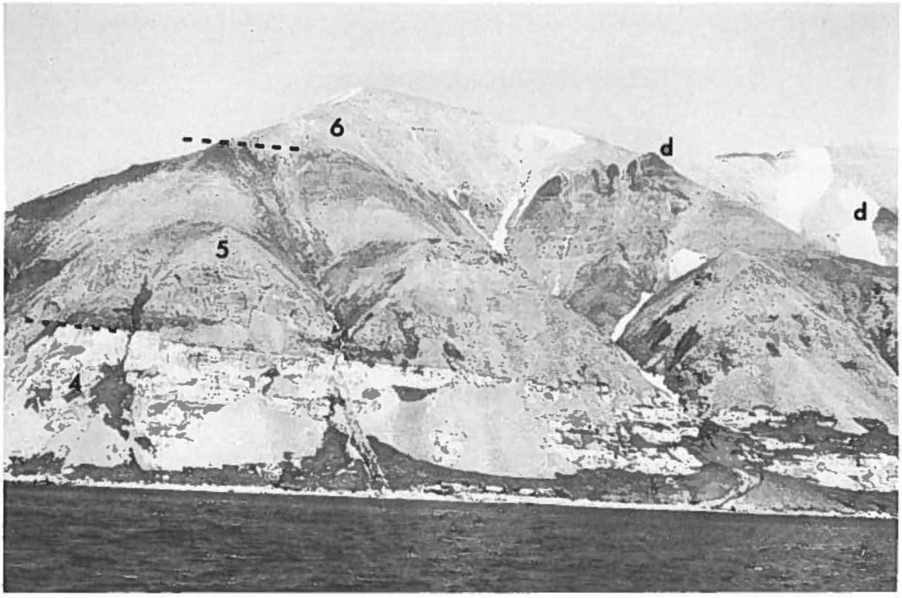

Fig. 9. Part of the southwestern coast of Northumberland Ø in Greenland showing the upper units of the lower Thule Group. Note the sharp boundary between the white orthoquartzites of unit 4 and the red beds of unit 5 and the more transitional boundary between units 5 and 6 — features that also characterise the Clarence Head section on Ellesmere Island (Fig. 10). The dark patches marked (d) are dolerite intrusions. The summit of the mountain is about 650 m above sea level.

the unit is light grey to white (Fig. 8). The sandstones are medium- to coarse-grained, white to pale pink on fresh surfaces and they are characterised throughout by cross-bedding and ripple marks. Some thin purple sandstones occur in the lower part of the unit where a purple and white banding, rather irregular and discordant to bedding, is a common feature.

Unit 5 – Red sandstone-shale unit. This is a variable clastic red bed sequence probably exceeding a thickness of 300 m and having a sharp contact with the underlying unit (Fig. 9). It is composed mainly of multicoloured (purple, red, brown, orange), thin- to medium-bedded and fine- to medium-grained, ferruginous sandstones which commonly show iron staining and liesegang rings. Some pale buff to lilac sandstones are present and pebbly sandstone and quartz-pebble conglomerate beds occur. The sandstones show frequent cross-bedding and ripple marks. At several levels, particularly near the base and the top, siltstones and grey, green and dark shales occur, either in discrete beds or as shaly partings in the sandstones.

Unit 6 – Buff sandstone unit. This is a thick and rather uniform, buff, yellow to pale lilac and pink weathering sequence of quartz sandstones with interbedded quartz-pebble conglomerates. The unit is commonly gradational with the underlying strata of unit 5 (Fig. 9). The sandstones are generally medium-grained and thin-bedded. However, towards the top they are finer-grained and become interbedded with darker siltstones and shales. Cross-bedding and ripple marks in the sandstones and mud cracks in the shales are common.

Unit 6 on Northumberland Ø is several hundred metres thick; the exact thickness is uncertain because of faulting. On neighbouring Herbert Ø the unit is estimated to be about 900 m thick.

Ellesmere Island. – Proterozoic strata comparable to the lower Thule Group of Greenland outcrop in coastal Ellesmere Island in three principal areas: Clarence Head, north of Goding Bay and at Gale Point (Fig. 3).

The thickest section is found on Goding Bay, but the lowermost beds are developed best near Gale Point. In terms of number of units exposed, the Clarence Head section is perhaps the most instructive (Fig. 6). The section given in Fig. 6, being a composite of the three main outcrop areas, is somewhat schematic but is readily applicable to any of the Ellesmere Island sections. As in Greenland, the section is composed of basal sandstones overlain by interbedded basalt and red beds, followed by variegated sandstone, siltstone and shale. All six units of the Northumberland Ø section are clearly recognisable.

The similarities to the strata in Greenland were pointed out by Christie (1962a, b), who subsequently assigned the Ellesmere Island strata to the Thule Basin sequence (Christie 1972). A full description of the Thule Group rocks on Ellesmere Island is given in a separate paper (Frisch & Christie 1982), but the salient features of the succession are enumerated below, with particular reference to the Clarence Head section.

Just south of Clarence Head, 660 m of strata overlie crystalline basement (Fig. 10). The contact appears to be a faulted unconformity and only a few metres of buff sandstone and conglomerate of the basal sandstone unit (unit 1) intervene between basement and a probable lava flow. A series of basalt sills and lavas interbedded

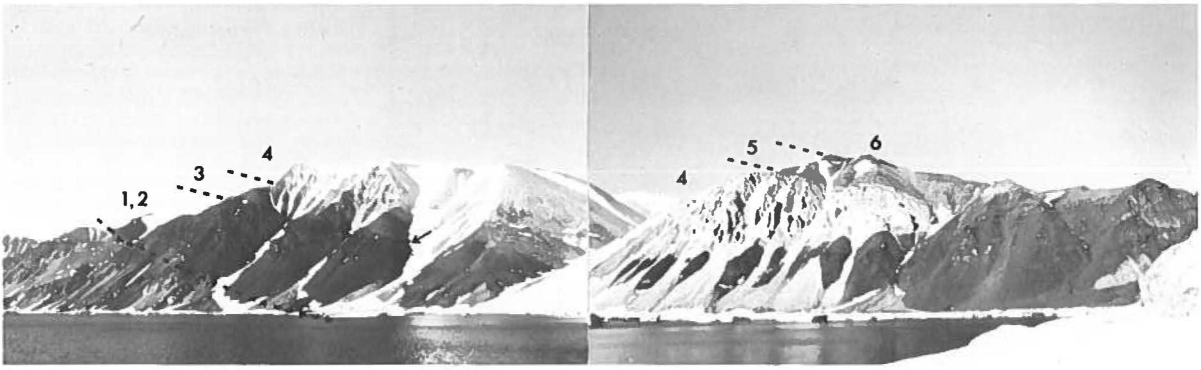

Fig. 10. View of the Clarence Head section, Ellesmere Island, seen from the east. The numbers refer to the six units into which the Thule Group has been divided and which correlate with units in Greenland. In this particular section only small thicknesses of units 1 and 6 are preserved and a basaltic sill has intruded between units 5 and 6. The sill lies about 600 m above sea level. The arrow points to the resistant stromatolitic carbonate bed at the base of unit 3.

with red siltstone or shale and sandstone, and at least one volcaniclastic bed of agglomerate with minor tuff, follow. The entire basalt-red bed unit (unit 2) is estimated to be a little more than 200 m thick.

The basal 13 m of the overlying strata (unit 3) at Clarence Head are stromatolitic dolomite and minor limestone, and these rocks form a resistant marker bed (Fig. 10). Above this lies a 66 m thick, mainly recessive sequence of thin-bedded, varicoloured, quartz-rich sandstone and red shale, interbedded. Lenticular bedding, herringbone cross-bedding, ripple marks and mud cracks are abundantly developed.

Strikingly white orthoquartzite, commonly conglomeratic, forms the next unit (unit 4) which is wedge-shaped, 100–200 m thick at Clarence Head and characteristically cliff forming. The lower beds are banded purple and white and cross-bedding and ripple marks occur throughout.

The overlying unit (unit 5) marks a return to red bed deposition that is marked by a sharp boundary — as it is on Northumberland Ø (Fig. 9). The unit consists of thin-bedded pink quartz sandstone with red micaceous siltstone partings and red shaly siltstone. Bedding surfaces are commonly veneered by specularite. At Clarence Head a basalt sill caps the unit.

The uppermost unit (unit 6) comprises 24 m of very pale pink quartz sandstone with an eroded upper surface.

Each of the units making up the Clarence Head section may be found in the other major exposures farther north on the Ellesmere Island coast, although there are variations. Thus, west of Gale Point (Fig. 11), nearly 50 m of quartz sandstone, conglomerate and several stromatolitic dolomite beds unconformably overlie crystalline basement and underlie the basaltic unit 2 in which sills predominate over lavas, and white orthoquartzite as well as red and green silty rocks occur. Also at this locality a lava flow occurs, capping unit 3. At Goding Bay, 12 m of black shale and thin basalt sills lie at the top of the basal unit 2 and the stromatolitic dolomite of unit 3. At this locality the uppermost buff sandstone unit is more than 300 m thick (top is an erosion surface) representing the unit's thickest preservation in Ellesmere Island.

Age and correlation: Northumberland Ø and Ellesmere Island

The Greenland and Ellesmere Island successions show an obvious similarity both in general lithostratigraphy and thickness, and the disposition of the lithological units and the corresponding red bed sedimentation levels makes a unit to unit correlation possible (Fig. 6). In addition, several specific points of comparison are notable in the Northumberland Ø and Clarence Head sections, e.g. the presence of pyroclastic beds (agglomerate, pisolitic tuffs) in the basalt-red bed unit 2; the stromatolite dolomites overlying the basalt-red bed unit; the intermittent occurrence of volcanic rocks within the dolomite-shale unit 3; and the purple banding in the lower part of the white sandstone unit 4.

Acritarchs from unit 4 on Northumberland Ø suggest a late Riphean age for the upper part of the sequence (Vidal & Dawes 1980). K/Ar ages obtained from the basaltic lavas and sills in Ellesmere Island and from basic sills in equivalent strata in Greenland cluster around 1100–1200 m.y. It is thus concluded that the lower part of the sequence, i.e. units 1 and 2 and probably unit 3, is about 1200 m.y. old, i.e. Helikian in North American terms, while the upper part of the sequence may be as young as late Riphean, i.e. Hadrynian in North American terms.

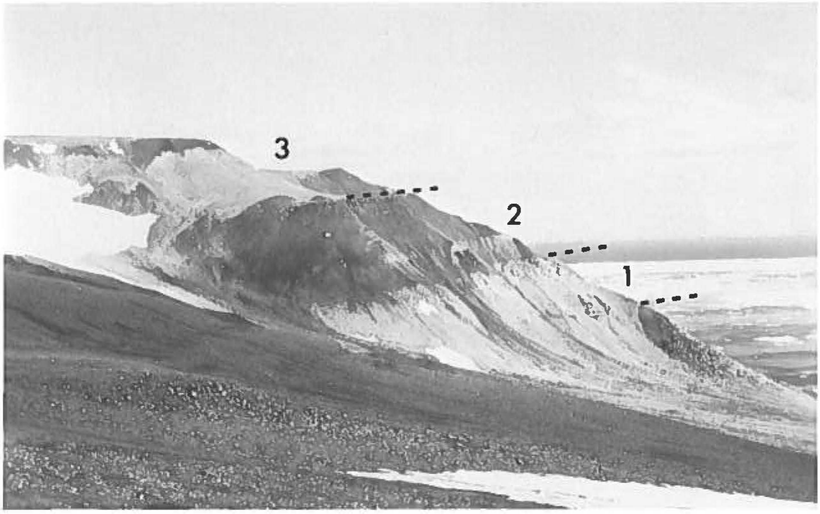

Fig. 11. The lower part of the Thule Group overlying basement rocks at Gale Point, Ellesmere Island, viewed eastwards. The units are designated as in the Clarence Head section (Fig. 10). A lava flow (dark) caps the recessive unit 3 and this is at about 550 m above sea level.

Thule Basin: sedimentary environment, limits and tectonics

The present outline of the Thule Basin is defined by the outcrops of the lower Thule Group in that no overlapping of the Dundas and Narssârssuk Formations (upper Thule Group) on to the Precambrian basement occurs, neither at the borders of the basin nor in uplifted fault blocks within it. The Thule Group strata form flat-lying to gently dipping homoclinal sections and dips greater than 30° are rare. Broad flexures and in some places folds due to fault tectonics occur.

The sedimentary structures of the lower Thule Group in both Greenland and Ellesmere Island indicate it to be a shallow-water, near-shore deposit representing fluvial to tidal environments. The presence of large units of nearly pure sandstone suggests substantial reworking and sorting, while the shale-silt-sand sequences may indicate intermittent more rapid basinal accumulation and migration seaward of the near-shore sites of deposition of the sandy facies. The red colouration could indicate *bona fide* continental oxidising conditions, but it is perhaps more likely to represent diagenetic adjustment of iron contained in the 'normal' clastic sedimentary material. Iron would be derived in abundance from the type of granitoid Archaean and Aphebian crystalline terrain that surrounded and underlay the Thule Basin.

Palaeocurrent directions have not been adequately determined on a systematic regional scale. In Greenland the main transport directions are to the south and south-west, away from the present outcrops of Precambrian basement (B. O'Connor, pers. comm.). However, some variation is present due to syndepositional faulting producing local source areas within the basin and fault blocks with contrasting sequences. A major westward trend characterises the transport direction of the Ellesmere Island sections indicating land somewhere to the east.

The lower Thule Group shows appreciable variation in thickness and lithology, but a correlation has been established throughout the Greenland and Ellesmere Island parts of the Thule Basin (Dawes 1976b: fig. 232, Frisch & Christie 1982: fig. 2). In addition, correlation has also been effected between the Thule Basin deposits in Greenland and the much thinner Rensselaer Bay Formation of Inglefield Land (Dawes 1979, Peel et al., this volume: fig. 3). These correlations establish that on a regional scale the succession in Greenland thins to the north, east and south. Hence, the thickest and also most complete succession of the lower Thule Group occurs in the west, on Northumberland Ø and adjacent Herbert Ø. The lowest units of the Northumberland Ø succession (the basal sandstone, basalt-red bed and the dolomite-shale units) peter out to the east and south where the younger sandstone units overlap on to the crystalline Shield.

In Ellesmere Island the limited extent of the outcrops of the Thule Group isolated in large areas of permanent snow and ice makes regional stratigraphical comparisons difficult. In addition, all the sections end in an erosion surface and the absolute thickness of the Thule Group is unknown. However, judged purely from total thicknesses of sections preserved, there is a stratigraphical thinning to the north and south away from Goding Bay (Fig. 5). Furthermore, contacts with the Precambrian basement in the west are generally covered. There is no evidence of westward thinning and it appears most likely that the Thule Basin is fault bounded to the west. Faults cutting the succession, although numerous, show no preferred orientation.

The Thule Basin in Greenland is cut by prominent faults first reported by Koch (1926). Major sets trend WNW and NW and cut the Thule Group into a number of fault blocks of which several are southerly tilted. A major fault in the south juxtaposes the youngest strata of the Thule Group against crystalline basement and involves a northerly downthrow of several kilometres (Fig. 4). Undisturbed stratigraphic contacts between the lower Thule Group and the Precambrian Shield are preserved south of this fault. Similar contacts are preserved around the entire basin, except in the extreme north, to the south-east of Sonntag Bugt in northern Prudhoe Land (78°N) (Fig. 4). This area is traversed by coast-parallel faults characterised by south-westerly downthrow juxtaposing the lower Thule Group on the seaward side against crystalline rocks.

Fig. 5 shows the measured or estimated thicknesses of the lower Thule Group in Greenland and Ellesmere Island. The southern limit of the Thule Basin is undefined although on Wolstenholme Ø, Greenland, where the lower part of the lower Thule Group is missing, the total thickness of the succession (limited upwards by the Dundas Formation of the upper Thule Group) decreases to a couple of hundred metres. In addition, thin veneers of lower Thule Group occur as scattered outliers on the crystalline basement terrain, perhaps suggesting the southern termination of the basin not far to the south. This parallels the situation along the eastern margin of the basin where the upper part of the lower Thule Group oversteps on to the crystalline basement and is preserved in thin scattered outcrops.

On the Canadian side, the southern limit of the Thule Basin probably lies between Clarence Head (76°48'N), where the southernmost outcrops of Thule Group are preserved, and Philpots Island, off the eastern coast of Devon Island at 75°N (Fig. 2), where Lower Palaeozoic rocks lie directly on crystalline basement (Frisch 1981).

The margin of the Thule Basin is best preserved in the north, although the paucity of outcrop on the Ellesmere Island side prevents precise overall definition. Immediately north of Kap Alexander in Greenland, the lower Thule Group strata thin markedly over a few kilometres from a section approaching a thickness of 600 m, of which the base and top are not exposed, to a sequence of about 300 m. The location of this significant thickness change is now marked by a major fault with downthrow to the south and it is taken to represent the northern margin of the Thule Basin. A general correlation scheme between the Thule Basin succession and the much thinner platform section of Inglefield Land is presented in Fig. 12.

The northernmost occurrence of Thule Basin rocks known in Ellesmere Island lies north of Baird Inlet at 78°32'N where a few tens of metres of sandstone and stromatolitic carbonate rock, very similar to the basal rocks of the Gale Point section (40 km to the south), rest on crystalline basement in a downdropped fault block (Fig. 5). This isolated outcrop is near mid-way between the Gale Point section and Bache Peninsula, a distance of about 90 km. This occurrence, suggesting northward thinning of the lower Thule Group, and the same lithological contrast of the succession to the thinner correlatable strata of Bache Peninsula as seen in Greenland (Figs 5, 12 and 13; see below) indicates that the northern limit of the Thule Basin in Ellesmere Island lies between 78°30'N and 79°N.

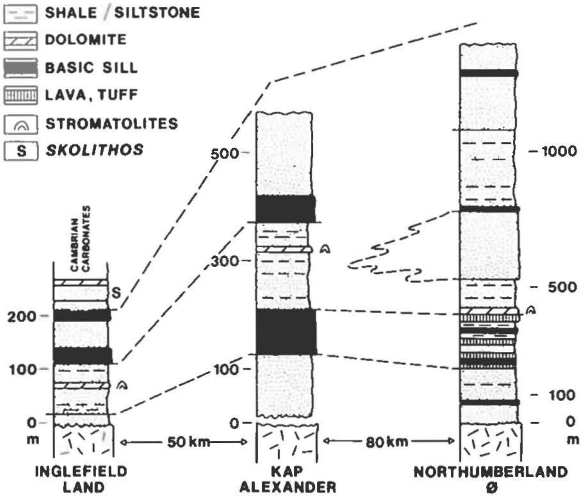

Fig. 12. Stratigraphical correlation scheme of the Proterozoic successions of the Thule Basin (Northumberland Ø and Kap Alexander) and the platform (Inglefield Land). Note the smaller metre scale for the Northumberland Ø section.

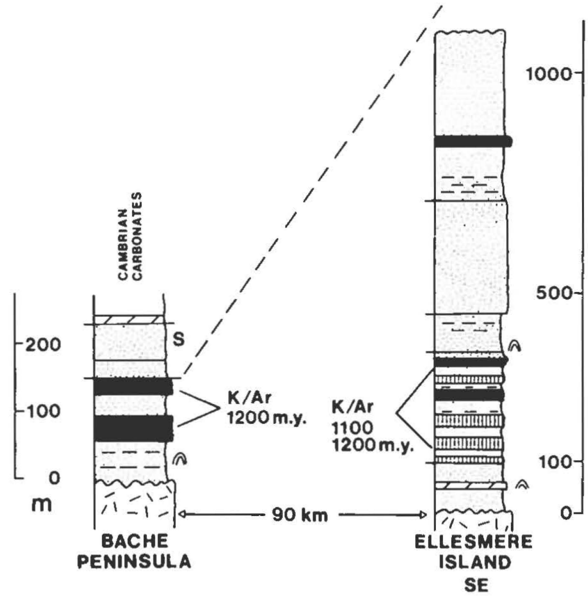

Fig. 13. Stratigraphical correlation scheme between the Proterozoic successions of south-eastern Ellesmere Island and Bache Peninsula. Symbols are explained in Fig. 12.

Inglefield Land – Bache Peninsula correlation

A full description and correlation of the thin platform sequences to the north of the Thule Basin are dealt with elsewhere in this volume (Peel et al.). The close similarities between the Inglefield Land and the Bache Peninsula sections have long been established and Troelsen (1950), who examined both sequences, had no hesitation in correlating and using Greenland formational names for the Ellesmere Island section; a correlation confirmed by all subsequent workers (e.g. Cowie 1961, Christie 1967).

The Precambrian crystalline basement in both regions is overlain with marked angular unconformity by unmetamorphosed red bed clastic rocks with minor shale and dolomite — the redefined Rensselaer Bay Formation (Fig. 14). The Proterozoic age assignment of this 0 to 220 m thick sequence is based on its presence unconformably below early Cambrian sandstone and dolomites and its penetration by basic sills that have yielded Precambrian K/Ar whole-rock ages. In Greenland the available K/Ar dates fall in the range 1073 ± 40 to 1190 ± 40 m.y. (Dawes et al. 1973), strongly suggesting that the sills are products of the same magmatism that affected the Thule Basin. In Bache Peninsula two basalt sills intrude the lower part of the sequence (Christie 1967: plate II). Weathering and frost-shattering have been intense at the igneous contacts and sampling for K/Ar dating was possible only near, but not at, the sill margins. All samples show alteration of one or more of the mafic minerals (olivine and clinopyroxene), but those from the lower sill are fresher. One sample from the latter has given 1197 ± 33 m.y.; determinations on two samples from the upper sill gave 1463 ± 77 m.y. and 1369 ± 66 m.y. The 1197 m.y. date is preferred as being nearest to the time of basic intrusion on Bache Peninsula.

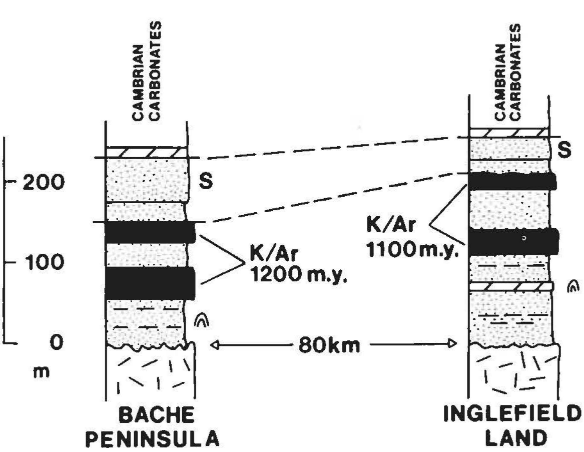

Fig. 14. Stratigraphical correlation scheme of the platform successions of Bache Peninsula and Inglefield Land, showing the Rensselaer Bay Formation overlain by Cambrian clastic and carbonate rocks. Symbols are explained in Fig. 12.

Inferences on Nares Strait

Summary of data

The detailed comparison that can now be drawn between the Proterozoic successions of the Smith Sound region brings out the following main features.

1. The late Proterozoic Thule Group section at Clarence Head in Ellesmere Island can be correlated unit by unit with the lower part of the Thule Group on Northumberland Ø, Greenland.
2. Similarity in physical characteristics between the Greenland and Ellesmere Island sections extends to features, measurable in terms of metres, which occur at the same stratigraphical level in each section.
3. The Northumberland Ø and Clarence Head sections correlate respectively with others to the north, south and east in Greenland and to the north in Ellesmere Island (no Thule Group rocks outcrop to the south of Clarence Head).
4. The lower Thule Group in Greenland is thickest in the Northumberland Ø – Herbert Ø area (77°30′N); in Ellesmere Island around Goding Bay (78°N). In Greenland, based on true thicknesses, and in Ellesmere Island based purely on total thickness of strata preserved, there is stratigraphical thinning north and south of these maxima.
5. K/Ar ages of extrusive and hypabyssal basalts in the lower Thule Group on both sides of northern Baffin Bay are closely comparable (1000 to 1200 m.y.).
6. The late Proterozoic sequences of Inglefield Land (78°–79°N) find their close counterparts on Bache Peninsula in Ellesmere Island (79°N) in lithology, thickness and the presence of 1100–1200 m.y. old basaltic sills.
7. The entire Inglefield Land section intruded by the basic sills can be traced, despite fault complications, over the Bache Peninsula arch to correlate with the lower Thule Group of Northumberland Ø.

The above features strongly suggest that the Proterozoic sequences of the Smith Sound region define a single, sedimentary basin (the Thule Basin) developed in an overall platform environment. This depocentre is intracratonic, and lies on the northern part of the North American craton. To the north it is bordered by the stable sedimentary platform and by the pericratonic orogenic belt of the Franklinian geosyncline (Figs 2 and 15). The northern margin of the Thule Basin lies at about 78°15′N in Greenland and between 78°30′N and 79°N in Ellesmere Island. This margin can be traced with little displacement across Smith Sound and there is

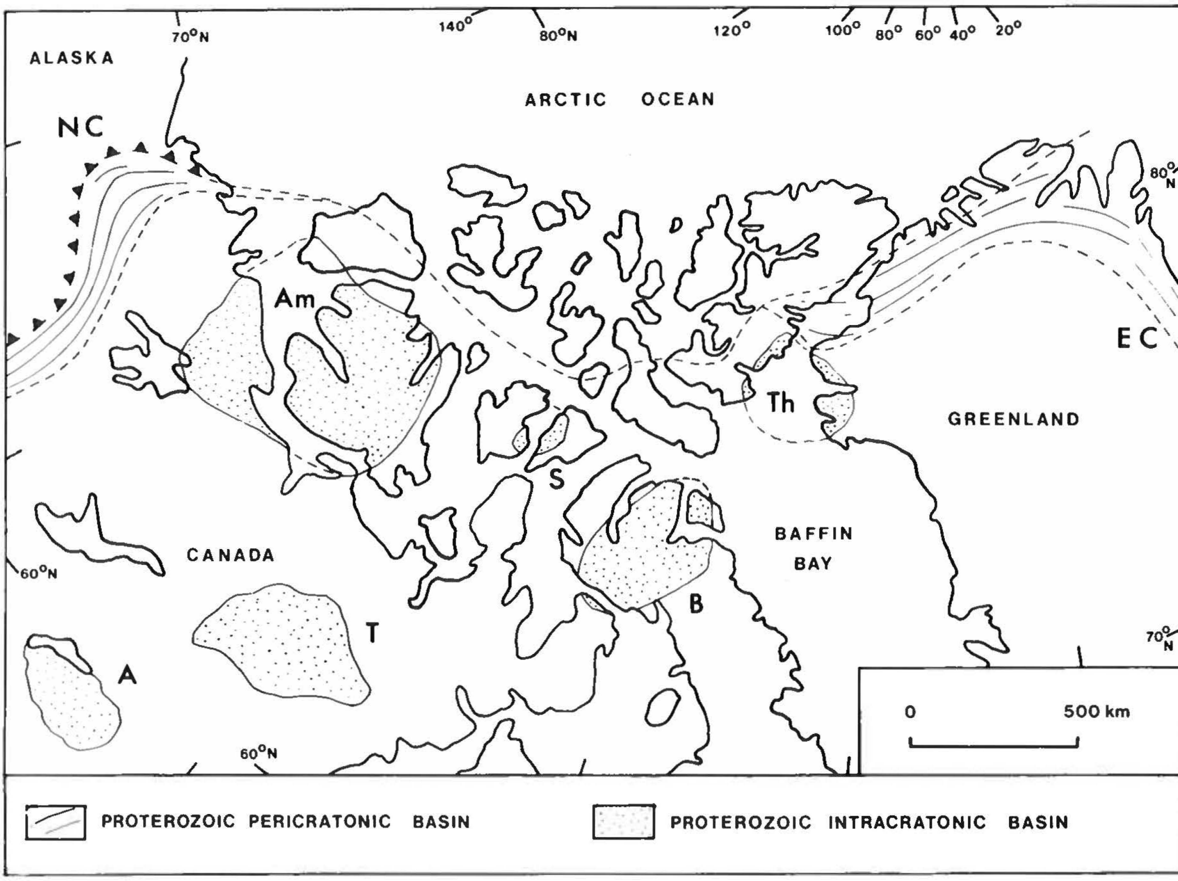

Fig. 15. Map of the northern part of the North American craton showing the distribution of the Proterozoic intracratonic basins and the linear pericratonic orogenic belts. Th = Thule Basin, B = Borden Basin, S = Somerset Basin, Am = Amundsen Basin, T = Thelon Basin, A = Athabasca Basin, NC = Northern Cordillera, EC = East Greenland Caledonides.

clearly no need to envisage any movement along Nares Strait to satisfactorily explain the feature or the thickness and general disposition of the Proterozoic sequences (Figs 5 and 16).

Thule Basin – Borden Basin correlation

A common criticism raised to those studies favouring direct geological continuity from Greenland to Ellesmere Island, as opposed to major offset along Nares Strait, is the value placed on the correlation of homoclinal platform strata. A characteristic of platform successions is that individual units can be traced over large areas and thus there are obvious limitations of correlations based on such units in cases for or against lateral movement between land masses on which the strata are found. However, in the Smith Sound region it is not simply a case of general lithological correlation of layer-cake platform successions. The correlation includes a thick intracratonic basin sequence which is flanked on the north by a thin platform section, both of which can be correlated in detail directly across Nares Strait.

On the other hand, it is surprising that generalised correlations of homoclinal strata have been made in support of the hypotheses that Greenland has moved some 300 km northwards relative to Canada along Nares Strait. Thus, the ~1200 m.y. old sedimentary and igneous rocks of the Borden Basin in northern Baffin Island and Bylot Island (Jackson et al. 1978, see Fig. 2) have been so correlated with the Thule Group of North-West Greenland (Newman 1977, this volume). While it is clear that the Borden Basin succession shows some general similarity to the Thule Group (including strata of similar facies to the upper Thule Group), there is a comparable similarity between both basin successions and the other intracratonic basins along the northern rim of the North American craton (Christie 1972, Young 1979, Fig. 15). In any case, the similarities between the Thule and Borden successions are in no way so close as to permit the unit to unit correlation that exists between Ellesmere Island and Greenland. Fur-

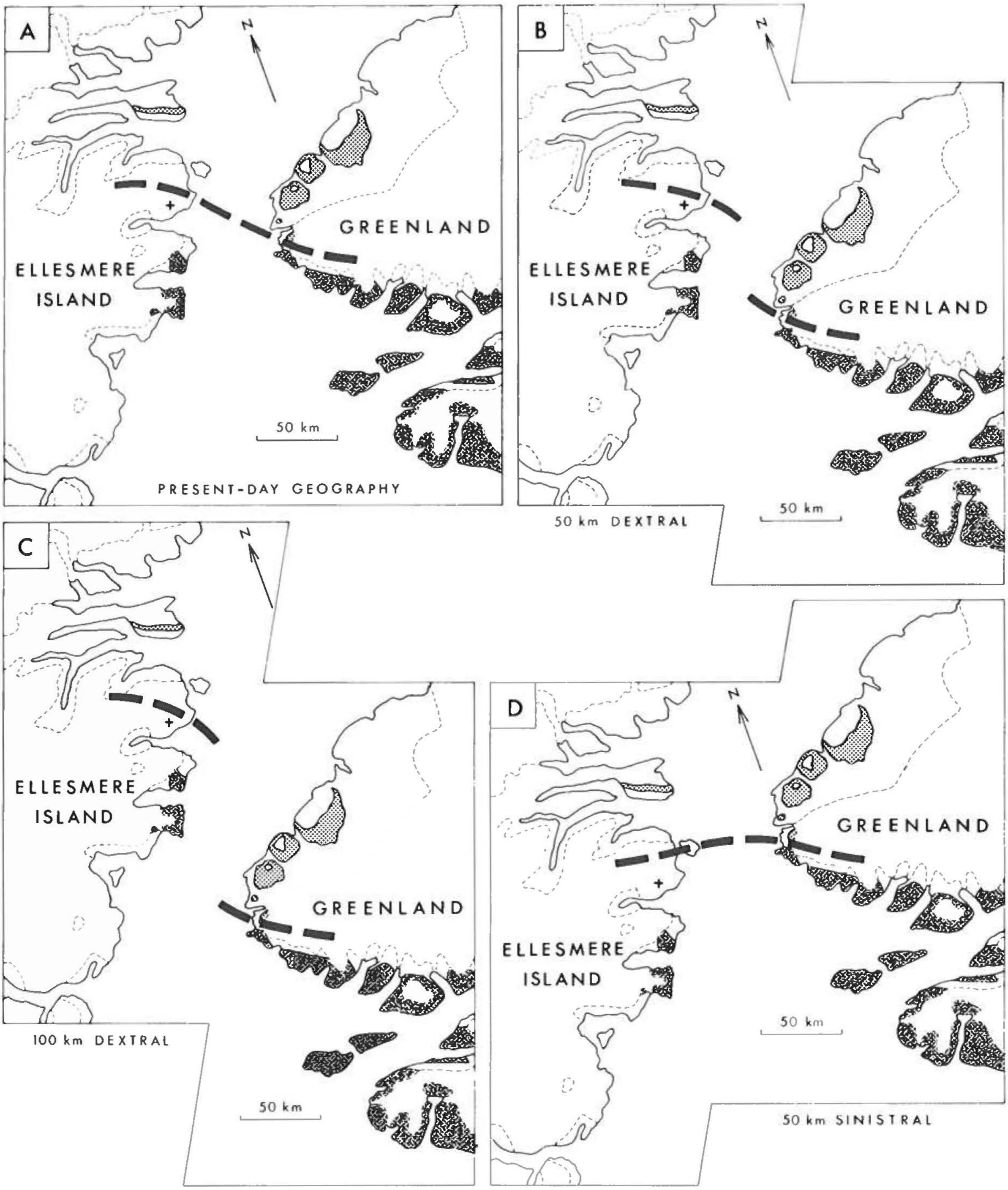

Fig. 16. The present-day position of Greenland and Ellesmere Island compared to reconstructions assuming strike-slip movement along Nares Strait. Shading indicates the outcrop of the Thule Group in the Thule Basin (dark) and the thinner Rensselaer Bay Formation of the platform (light). Cross, north of Baird Inlet, indicates northernmost outcrop of Thule Basin deposits in Ellesmere Island. The heavy broken line represents the northern margin of the Thule Basin. The present-day position (A) or that showing a sinistral movement of 50 km (D) appear to be the best fits with regard to the Proterozoic geology.

thermore, Jackson & Iannelli (1981) regard the Borden and Thule Basins as separate and distinct, albeit coeval, depocentres — an interpretation with which we concur.

The absence of upper Thule Group strata in Ellesmere Island (perhaps seen at first to be a significant point by which to dissociate the Ellesmere Island and Greenland successions) is of little relevance to the discussion, particularly in view of the restricted Proterozoic outcrop preserved in Ellesmere Island and the rather local development of the upper Thule Group in Greenland. However, the southern margin of the Thule Basin is poorly defined and it is to be expected that the Thule Group sedimentation covered a larger area than the southernmost known onshore outcrops, viz. 76°45′N in Ellesmere Island and 76°10′N in Greenland (Fig. 3). Whether the Thule Basin deposits extended so far south as to constitute what would be an extensive Borden–Thule depositional site is unknown.

The long-range correlation of the Proterozoic sequences of the Thule Group and Borden Basin that leads to a 300 km displacement of Greenland to the south relative to Canada is highly speculative and it violates the known Proterozoic geology of the Smith Sound region. Such a correlation indirectly defines the Ellesmere Island Proterozoic sequences as an isolated intracratonic basin–platform system. In such a reconstruction the Precambrian Shield and the small intracratonic basin of Ellesmere Island are placed in juxtaposition against the Silurian shelf and slope limestone and shale deposits of Greenland. Attempts to reconcile this unacceptable arrangement of unassociated geological provinces by suggestions of vertical displacement along Nares Strait, leading to substantial differential erosion of Greenland and Ellesmere Island, are unconvincing. The peneplain surface of the Precambrian crystalline basement on which the Thule Group rests is well developed and in south-west Inglefield Land (Koch 1933, Troelsen 1950, Cowie 1961) and Bache Peninsula (Christie 1967) it has a variable but comparable altitude. Hence, appreciable differential vertical movement of Ellesmere Island and Greenland in the Smith Sound area can be ruled out.

Constraints on strike-slip displacement

We suggest that the correlation of Proterozoic sequences of the Smith Sound region refutes pre-drift reconstructions showing major net strike-slip displacement along Nares Strait. However, an accurate estimate in kilometres of the offset permissible is not possible with the reliability level of the data available. The incomplete sections in Ellesmere Island make it impossible to construct other than crude isopachs of the lower Thule Group across Nares Strait. Thus we choose the northern margin of the Thule Basin as a geological marker and represent this in Fig. 16. A dextral movement of as little as 50 km along Nares Strait produces a significant displacement of this marker (Fig. 16B) and, without evoking an unreasonable shape for the Thule Basin, such reconstructions for the Proterozoic as shown in Fig. 16C can be excluded. Carried one stage further this exercise shows that less stringent controls are present on possible strike-slip displacement when Greenland is offset sinistrally from its present-day position. Thus, a relative position of the two landmasses as shown in Fig. 16D can be accommodated without appreciable disruption of the Proterozoic geological pattern.

Conclusion

The proliferation of plate tectonic models which envisage appreciable amounts of strike-slip displacement along Nares Strait has doubtless been facilitated by the scarcity of published information concerning the geology of Nares Strait and northernmost Baffin Bay. This deficit has been corrected by recent field work in the Smith Sound region, where onshore Proterozoic sequences indicate that the present-day relative positions of Greenland and Ellesmere Island cannot be far removed (if at all) from those present at the time of deposition. In consequence, it is the main conclusion of this paper that there has been little net displacement along Nares Strait — a conclusion supported by other geological studies reported in this volume of the Archaean and Palaeozoic geology of Greenland and Ellesmere Island.

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References

Carey, S. W. 1958. The tectonic approach to continental drift. – In: Carey, S. W. (convener), Continental drift. A symposium: 177–355. – Univ. Tasmania, Hobart.

Christie, R. L. 1962a. Geology, Alexandra Fiord, Ellesmere Island, District of Franklin (map with marginal notes) 1″ to 4 miles. – Map geol. Surv. Can. 9–1962.

Christie, R. L. 1962b. Geology, southeast Ellesmere Island, District of Franklin (map with marginal notes) 1″ to 4 miles. – Map geol. Surv. Can. 12–1962.

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

Christie, R. L. 1972. Central stable region. – In: Christie, R. L., Cook, D. G., Nassichuk, W. W., Trettin, H. P. & Yorath, C. J. (eds), The Canadian Arctic Islands and the Mackenzie region. – 24 Intern. geol. Congr. Montreal, Excurs. guide A66: 40–87.

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

Dawes, P. R. 1972. Precambrian crystalline rocks and younger sediments of the Thule district, North Greenland. – Rapp. Grønlands geol. Unders. 45: 10–15.

Dawes, P. R. 1975. Reconnaissance of the Thule Group and underlying basement rocks between Inglefield Bredning and Melville Bugt, western North Greenland. – Rapp. Grønlands geol. Unders. 75: 34–38.

Dawes, P. R. 1976a. 1: 500 000 mapping of the Thule district, North-West Greenland. – Rapp. Grønlands geol. Unders. 80: 23–28.

Dawes, P. R. 1976b. Precambrian to Tertiary of northern Greenland. – In: Escher, A. & Watt, W. S. (eds), Geology of Greenland: 248–303. – Geol. Surv. Greenland, Copenhagen.

Dawes, P. R. 1979. Field investigations in the Precambrian terrain of the Thule district, North-West Greenland. – Rapp. Grønlands geol. Unders. 95: 14–22.

Dawes, P. R., Rex, D. C. & Jepsen, H. F. 1973. K/Ar whole rock ages of dolerites from the Thule district, western North Greenland. – Rapp. Grønlands geol. Unders. 55: 61–66.

Frisch, T. 1981. Further reconnaissance mapping of the Precambrian Shield on Devon Island, District of Franklin. – Pap. geol. Surv. Can. 81–1A: 31–32.

Frisch, T. & Christie, R. L. 1982. Stratigraphy of the Proterozoic Thule Group, southeastern Ellesmere Island, Arctic Archipelago. – Pap. geol. Surv. Can. 81–19: 13 pp.

Frisch, T., Morgan, W. C. & Dunning, G. R. 1978. Reconnaissance geology of the Precambrian Shield on Ellesmere and Coburg islands, Canadian Arctic Archipelago. – Pap. geol. Surv. Can. 78–1A: 135–138.

Jackson, G. D. & Iannelli, T. R. 1981. Rift-related cyclic sedimentation in the Neohelikian Borden Basin, northern Baffin Island. – In: Campbell, F. H. A. (ed.), Proterozoic basins of Canada. – Pap. geol. Surv. Can. 81–10: 269–302.

Jackson, G. D., Iannelli, T. R., Narbonne, G. M. & Wallace, P. J. 1978. Upper Proterozoic sedimentary and volcanic rocks of northwestern Baffin Island. – Pap. geol. Surv. Can. 78–14: 15 pp.

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

Koch, L. 1926. A new fault zone in northwest Greenland. – Am. J. Sci. 12: 301–310.

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

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

Newman, P. H. 1977. The offshore and onshore geophysics and geology of the Nares Strait region: its tectonic history and significance in regional tectonics. – Unpubl. M. Sc. thesis, Dalhousie Univ., Canada: 153 pp.

Newman, P. H. 1982. A geological case for movement between Canada and Greenland along Nares Strait. – This volume.

Newman, P. H. & Falconer, R. K. H. 1978. Evidence for movement between Greenland and Canada along Nares Strait. – Geol. Soc. Am. Abs. with Prog. 10: 463 only.

Peel, J. S., Dawes, P. R., Collinson, J. D. & Christie, R. L. 1982. Proterozoic – basal Cambrian stratigraphy across Nares Strait: correlation between Inglefield Land and Bache Peninsula. – This volume.

Sclater, J. G., Hellinger, S. & Tapscott, C. 1977. The paleobathymetry of the Atlantic Ocean from the Jurassic to the present. – J. Geol. 85: 509–552.

Srivastava, S. P. 1978. Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic. – Geophys. J. Roy. astr. Soc. 52: 313–357.

Taylor, F. B. 1910. Bearing of the Tertiary mountain belt on the origin of the earth's plan. – Bull. geol. Soc. Am. 21: 179–226.

Troelsen, J. C. 1950. Contributions to the geology of Northwest Greenland, Ellesmere Island and Axel Heiberg Island. – Meddr Grønland 149(7): 85 pp.

Vidal, G. & Dawes, P. R. 1980. Acritarchs from the Proterozoic Thule Group, North-West Greenland. – Rapp. Grønlands geol. Unders. 100: 24–29.

Wegener, A. 1922. Die Entstehung der Kontinente und Ozeane. – Friedr. Vieweg & Sohn, Braunschweig: 144 pp. (3rd revised edit.).

Wilson, J. T. 1963. Continental drift. – Scient. Am. 208(4): 86–100.

Young, G. M. 1979. Correlation of middle and upper Proterozoic strata of the northern rim of the North Atlantic craton. – Trans. Roy. Soc. Edin. 70: 323–336.