Basin characterisation, limits, development: a summary

Thule Basin: onshore – offshore

The Thule Supergroup defines a depocentre on the northern margin of the North Atlantic craton. The outcrops, forming coastal exposures disappearing under the sea in down-faulted blocks, are the preserved fragments of a large sedimentary and volcanic province. Gravity, magnetic and seismic reflection data indicate the presence offshore of a thick, faulted sedimentary section between south-east Ellesmere Island and North-West Greenland (Keen & Barrett, 1973; Hood & Bower, 1975; Ross & Falconer, 1975; Newman, 1982a; Jackson *et al.*, 1992). A sedimentary section several kilometres thick is interpreted to fill these offshore down-faulted basins; for example from magnetic data between 77º and 78ºN, Hood & Bower (1975) suggest thickness variation between 10 and 20 km.

Farther south, between 74º and 76ºN, reflection seismic data indicate that a thick sedimentary succession is preserved in graben structures in the Melville Bugt – Kap York region, with one small basin south-west of the Carey Øer (Whittaker & Hamann, 1995). The offshore section here is up to 8 km thick.

There is clear correlation between offshore geological features and onland strata and tectonics. Thus the offshore sedimentary tract trending north-west from the Bylot Sund region – the Steensby Basin of Newman (1982a; Fig. 119) – is online with the major graben structure that preserves the Narssârssuk Group with a throw on the southern boundary fault (Narssârssuk Fault) of several kilometres. However, the age of the offshore strata in the North Water and Steensby Land Basins (Fig. 119), as well as in the Melville Bugt basins farther south, is unknown. From comparison with the offshore geology of Baffin Bay (cf. Balkwill *et al.*, 1990), it is predicted that a thick late Phanerozoic (Cretaceous–Tertiary) section is preserved. But it is very conceivable that Proterozoic strata form an important part of the offshore successions although as yet only qualified guesses can be made as to the extent and thickness of Proterozoic versus Phanerozoic rocks.

Also uncertain, is the structure of northern Baffin Bay and Smith Sound; the origin of this seaway, and its continuation northwards as Nares Strait, have been the subject of considerable debate (Dawes & Kerr, 1982). Some authors, working with plate kinematic models, interpret the seaway as the site of a Cenozoic plate boundary: a major suture zone representing a subducted ocean, substantial transcurrent motion, massive crustal shortening with continental collision (e.g. Srivastava & Tapscott, 1986; Jackson *et al.*, 1992). However, the regional geology, including the presence of the intracratonic Thule Basin straddling the seaway, and the overlying undisturbed Palaeozoic strata bordering Smith Sound and Kane Basin, militate against such a dynamic crustal history (e.g. Dawes, 1986; Higgins & Soper, 1989). Clearly, information on the tectonic setting of the offshore strata in the northern Baffin Bay – Smith Sound region must await renewed and more refined geophysical data.

Geological setting

Dominated by continental, littoral and shallow marine sedimentary facies, coupled with continental tholeiitic magmatism, the Thule Supergroup is an expression of the evolution of a rifted continental margin or intracratonic basin. The spatial relationships and thicknesses of the described lithostratigraphic units define two major structural margins: one in the north across Smith Sound, the other in the east and south-east between Inglefield Bredning and Wolstenholme Fjord. Marked thickness changes with the cut-out of basal strata and overlapping of younger Thule strata onto the crystalline shield characterise these margins (Fig. 119, see below). They evince that the Thule Supergroup represents the fill of a restricted or semi-restricted intracratonic basin rather than a one-sided wedge on a shallow continental margin.

Basin geometry

The regional extent of the Thule Basin, from Canada to Greenland and over 300 km in a north–south direction, is defined by the lower Thule Supergroup, viz. the Nares Strait, Smith Sound and Baffin Bay Groups. These groups have preserved sedimentary contacts with the crystalline shield. Overlying strata of the Dundas and Narssârssuk Groups are only preserved in Greenland, and the strata outcrop within the limits of the basin as defined by the older rocks, viz. there is no overlap of upper Thule strata onto the crystalline shield.

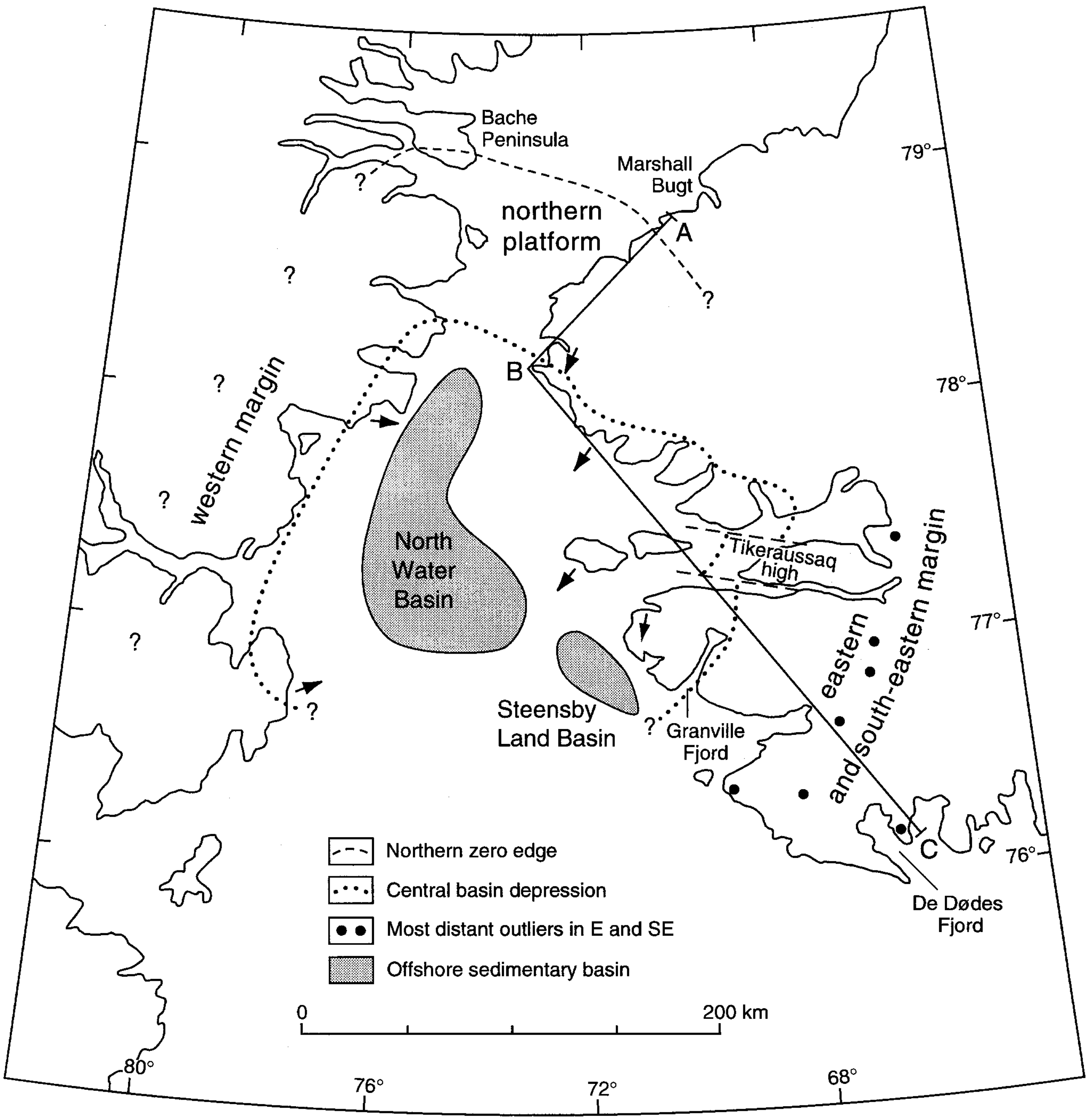

Fig. 119. Map of the northern Baffin Bay – Smith Sound region showing the extent of the central and marginal parts of the Thule Basin in Neohelikian time. This corresponds to the evolution stage shown in the cross-section given in Fig. 120 (line A–B–C). The central basin depression corresponds to the Nares Strait Group and correlative strata of the Smith Sound Group over the northern basin margin. The arrows indicate prominent palaeocurrent directions for the Nares Strait Group and lower strata of the Smith Sound Group mainly from Dawes *et al.* (1982a), Frisch & Christie (1982) and Jackson (1986), as well as unpublished data. The offshore sedimentary basins are based on geophysical data from Newman (1982a). For bedrock outcrops and ice cover, see Fig. 2.

The present limits of the Thule Supergroup on land are defined by both sedimentary and tectonic contacts (Figs 1, 2, 5). The most extensively preserved sedimentary contacts marking the outer limits of the basin occur in Greenland, in the east and south-east between Inglefield Bredning and Wolstenholme Fjord, and in the north in Inglefield Land. In the former region, scattered outliers on the shield show easterly stratal thinning; in the north, a thin platform cover of Smith Sound Group over structurally high shield (Bache Peninsula arch) thins to the north and north-east in Inglefield Land and to the west in Bache Peninsula, finally petering out at the unconformity between the shield and Cambrian strata of the Franklinian Basin (zero-edge in Fig. 119).

The present north-eastern limit in Prudhoe Land is fault-controlled. In the north a major NW-trending block fault system, characterised by down dropping to the south-west, limits Thule strata to the coastal area. The Dodge Gletscher Fault, as the main outer fault of the system, juxtaposes the basal Thule strata (Nares Strait Group) against the shield (Figs 1, 5B, 27, 111). Farther south, the unconformity involving Nares Strait Group, although extensively faulted, marks the basin limits. The Inland Ice hides the geological relationships inland but overlapping of younger strata (Baffin Bay Group) on the basin substratum is not seen. This contrasts with conditions farther south where outliers of the Baffin Bay Group stretch far beyond the faults that limit the Nares Strait Group. The outlier at De Dødes Fjord, representing the most distal strata of the marginal succession, is over 100 km south-east of the central basin limit at Granville Fjord (Figs 13A, 119).

Based on the Greenland sections, the lower Thule Supergroup shows progressive thinning to the north, east and south defining a central depression with a section exceeding a thickness of 2 km, e.g. in the Northumberland Ø area (Figs 12, 120). The Canadian outcrops, although relatively small and isolated, and being truncated by the present erosion surface (apart from the Smith Sound Group at Bache Peninsula in the north), show corresponding thinning to the north and south. Comparison with the Northumberland Ø section suggests an overall westerly thinning, but narrowness of the coastal sections between Clarence Head and Johan Peninsula (Fig. 2) restricts meaningful inferences on regional east–west trends. These outcrops disappear under the ice cap or are in fault contact with crystalline shield. They show no sign of westerly thinning or overlapping of younger strata onto crystalline basement. It should be mentioned here that the overlapping of the crystalline shield by 'Upper beds' shown by Frisch (1988, map 1572A) in western outcrops at Gale Point, is reinterpreted in this bulletin as an unconformity involving basal sandstones (Northumberland Formation, see Fig. 54).

In general terms the palaeocurrent pattern supports the basin geometry devised from the regional thickness variations. In Greenland, lower Thule Supergroup data indicate prominent transport directions to the south and south-west away from the fringing outcrops of crystalline shield (Dawes *et al.*, 1982a), while in Canada easterly transport directions prevail with more local westerly and northerly components (Frisch & Christie, 1982; Jackson, 1986). In terms of the primary basin geometry, the Canadian provenance data are particularly significant since the western boundary is only fragmentarily preserved (compared with the eastern side in Greenland). The data indicate that in Neohelikian time the basin was closed to the west, i.e. a land source area lay in that direction. This is supported by volcanic flow direction where determinable, e.g. the emplacement of a terrestrial basaltic flow at Goding Bay (Cape Combermere Formation) is from the west (Jackson, 1986). How far to the west the original margin of the Thule Basin was situated is conjectural (Fig. 119).

The central fill of the Thule Basin is formed mainly of the Nares Strait Group that in Greenland shows a regional thinning to the north, east and south (Fig. 12). Equivalent strata of the Smith Sound Group (Pandora Havn and Kap Alexander Formations) show overlapping relationships with crystalline shield, tapering and petering out northwards; basal strata of the Nares Strait Group are abruptly cut out by faults (Figs 26, 27, 120). The present expression of this basin margin is as a post-deposition fault zone. Coeval sedimentation may have taken place beyond the central basin depression in shallows on the eroded crystalline shield or in local sags. Such deposition is probably represented by the basal clastic strata of the Smith Sound Group (Cape Camperdown Formation).

The presence of similar marginal faults in the east and south-east limiting the Nares Strait Group can be surmised from outcrops in the Inglefield Bredning area and Steensby Land (see Fig. 95). It is noteworthy that this margin, delimiting the central basin depression and projected to reach the outer coast at Granville Fjord (Fig. 119), is on strike with a major offshore fault deemed by Okulitch & Trettin (1991, fig. 17.12) to have been active during the late Phanerozoic development of Baffin Bay.

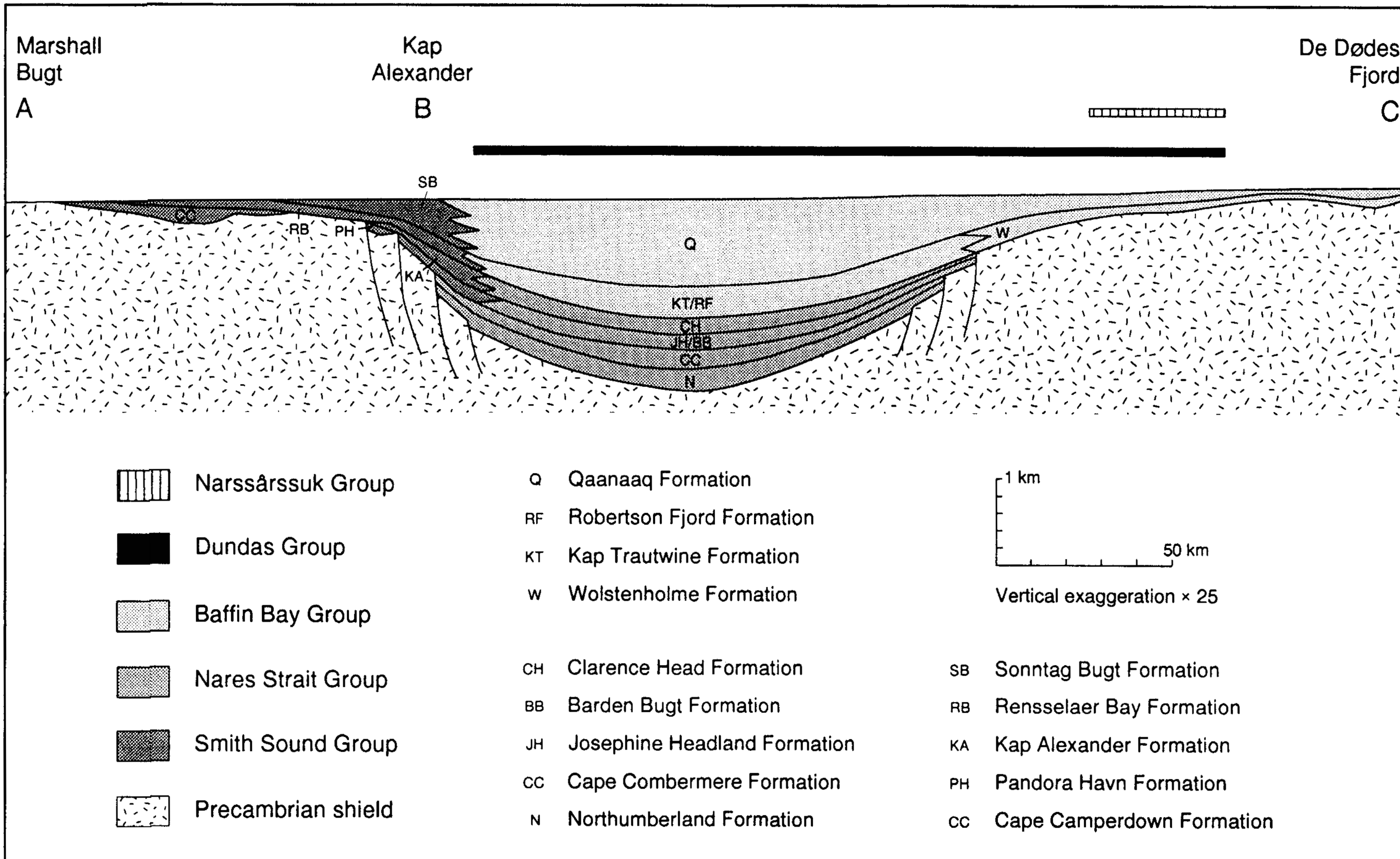

Fig. 120. A cross-section through the Thule Basin with the lower Thule Supergroup as basin fill, showing the relationships of groups and their formations. The spatial relationship of the Dundas and Narssârssuk Groups superimposed on this Neohelikian evolutionary stage is shown by bars. The location of section line A–B–C is shown in Fig. 119.

Major basin expansion is indicated by the Baffin Bay Group and upper strata of the Smith Sound Group with sedimentation across the early basin margin and with overlapping of the crystalline shield beyond. This expansion defines the maximum limits of the Thule Basin as preserved today. As described above, a thinning of both these groups away from the depocentre is evident.

A polyhistory interior fracture basin

The Thule Supergroup is notably lacking in regional or intra-basinal unconformities. Taken on face value this field observation suggests that deposition more or less kept pace with slow and steady subsidence. However, in the absence of more precise biostratigraphical control, any paraconformities in the succession remain undetected. The only major stratigraphic junction that has not been observed is that limiting the Hadrynian Narssârssuk Group and a major unconformity representing an appreciable time gap may exist at this level. On the other hand, the succession does show marked changes in vertical lithologies and depositional environments, for example from continental to shallow marine, and there are pronounced changes in transport directions (e.g. Jackson, 1986); these features suggest that penecontemporaneous faulting may have been important.

The recognition of faulted basin margins delimiting an early central depression (Nares Strait Group) from surrounding marginal areas with thinner successions point to a Neohelikian evolution in which vertical horst and graben faulting played an important role. This early rift development included basaltic magmatism, with outpouring of lavas, injection of sills and some explosive volcanism. This magmatic activity is regarded as indicative of an overall extensional environment (rather than a specific high geothermal gradient) in much the same way as Cox (1970), in the case of the Karoo region of South Africa, viewed the tholeiitic volcanism in association with sedimentary basins and extensional faulting. Rifting of the continental crust is seen as the initiator of basin development with early sediments filling depressions within the block fault system and with contemporaneous volcanism.

Fault blocks can be expected in the central part of the basin; at Thule, however, this segment of the basin is submarine. Predicted fault blocks are not portrayed on the cross-section given here (Fig. 120), although Northumberland Ø, representing today an uplifted block and the most central section of the basin (Fig. 48), may well be flanked by fault depressions with thicker successions. One well-defined fault block – here called the Tikeraussaq High – is preserved in the eastern part of the basin (Figs 95, 119). This is a WNW-trending horst that must have been a positive feature during the deposition of the basal strata of the basin: strata of the Nares Strait Group are present north and south, while the horst is draped by strata of the Baffin Bay Group.

A main stage of basin expansion, heralded by the Baffin Bay Group and coeval strata of the Smith Sound Group, was presumably due to renewed block faulting and foundering of the early basin margin. At that time faults such as that delimiting the Tikeraussaq High were active.

Passage from lower to upper Thule Supergroup – from continental and littoral Baffin Bay Group to more basinal Dundas Group – marks environmental changes indicating accelerated basin subsidence, presumably by increased tensional faulting accompanied by basin sagging. In Canada, transitions in the uppermost Baffin Bay Group towards more basinal lithologies suggest that the Dundas Group may once have had a much wider distribution. On the other hand, nothing can be said about the original extent of the Narssârssuk Group, which is now restricted on land to the Bylot Sund area. In any case, the upper Thule Supergroup signifies consolidation of the previous basin expansion with youngest deposition on the south-east margin of the basin. The answer to the question of whether the Narssârssuk Group represents a local successor basin developed, for example, in a narrow fault-controlled trough or represents a fragment of a larger province, such as a carbonate platform, must await data from the offshore regions.

Dislocations in the Narssârssuk Group provide some evidence for syndepositional faulting which may be responsible for the prominent cyclicity characterising the sedimentation. The strata are preserved in one of several graben structures that cut the Thule Supergroup and that are also known offshore. Many of these faults, including those bounding the Narssârssuk Group, are parallel to a regional swarm of Hadrynian basic dykes that have given K-Ar ages between 645 and 725 Ma (Dawes & Rex, 1986; Figs 70, 105). These dykes are seen as the waning phase of the Franklin magmatism that released appreciable amounts of basaltic material into the basin and produced the sill complex penetrating the Dundas Group in central and south-eastern exposures (Fig. 106).

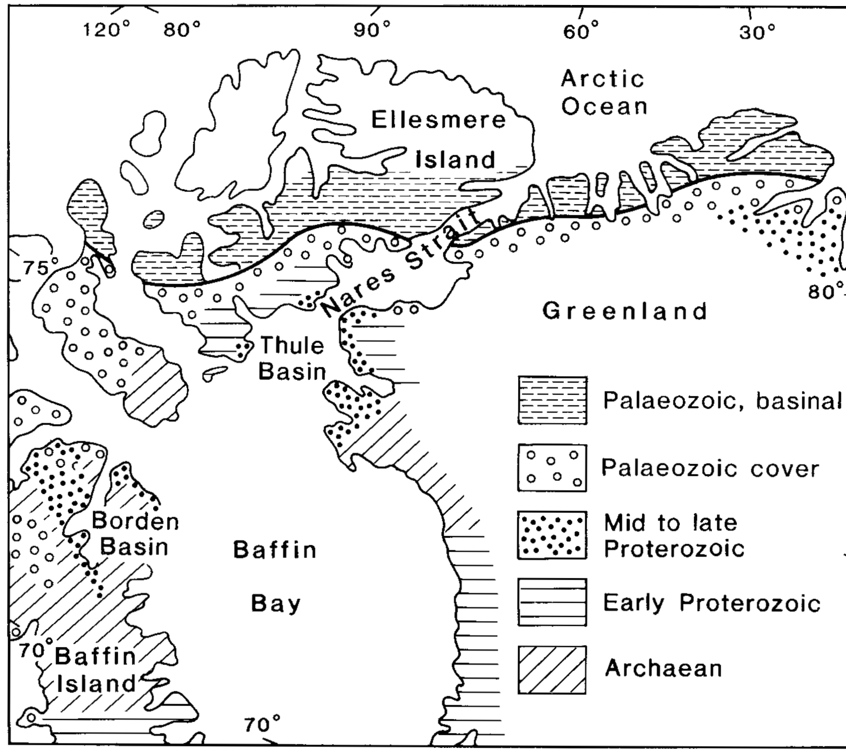

Fig. 121. Simplified geological map of northern Greenland and adjacent part of Canada, showing the locations of the Thule and Borden Basins of northern Baffin Bay. The middle to late Proterozoic strata shown in eastern North Greenland define the Independence Fjord and Hagen Fjord Basins (Sønderholm & Jepsen, 1991). The one geological boundary highlighted corresponds to the southern limit of basinal rocks of the Palaeozoic Franklinian Basin. Shelf carbonates bordering this basin (part of the 'Palaeozoic cover') overlie the northern exposures of the Thule Supergroup in Bache Peninsula, Ellesmere Island, and in Inglefield Land, Greenland (see Fig. 2). Modified from Frisch & Dawes (1994).

Many post-depositional faults that cut the Thule Basin and that are associated with tilting, local folding and broad flexuring, may represent a long Proterozoic history and may have been active during sedimentation. Clearly, an overall extensional environment persisted during the Hadrynian development of the basin, as indicated by the Franklin dykes that follow such faults. (Fig. 70).

The Thule Basin records a long history of sedimentation, magmatism and tectonism possibly spanning as much as 650 Ma. While continuous sedimentation through such a long period of time is improbable, unconformities in the succession have yet to be documented. In terms of global basin classification such as that proposed by Kingston *et al.* (1983), the basin can be categorised as a multicycle, polyhistory, interior fracture basin, characterised by block faulting and subsidence and followed by basin sagging. Divergent plate movements are deemed to be the underlying cause of this type of basin.

Regional comment

The Thule Basin is one of several mid to late Proterozoic depocentres that fringe the northern margin of the Canadian–Greenlandic shield stretching from the western Cordilleran region to East Greenland (Young, 1979). These intracratonic basins were influenced to varying degrees by the Neohelikian Mackenzie, and Hadrynian Franklin, magmatic episodes, and they share many features in stratigraphic sequence and tectonic setting.

The nearest basin to Thule is the Borden Basin of northern Baffin Island (Fig. 121). This basin contains a comparable thickness of shallow water sediments with an interval of Neohelikian volcanics and it has a conspicuous NW tectonic grain (Jackson *et al.*, 1978, 1985; Jackson & Iannelli, 1981, 1988). Faults were active during Neohelikian sedimentation and they reflect a long history from the Paleohelikian to Recent. The parallelism of the main fault trends in the Borden and Thule Basins led Jackson & Iannelli (1981) to propose a tectonic model for the development of both depocentres as rift basins generated during the Neohelikian (1250–1200 Ma) opening of a Proto-Atlantic (Poseidon) Ocean. Impressed by the similar evolution and apparent coevality of the depocentres, Fahrig *et al.* (1981) introduced the name 'Bylot basins' to cover them.

Several authors, searching for geological evidence to support plate tectonic models that predict substantial transcurrent movement along a hypothetical plate boundary in Nares Strait, match the Proterozoic strata of the Thule and Borden regions as separated parts of a single basin (e.g. Newman & Falconer, 1978; McWhae, 1981; Newman, 1982b; Jackson *et al.*, 1992). These reconstructions ignore the certainty that the Neohelikian strata of Ellesmere Island are an intrinsic part of Thule stratigraphy and form the western margin of the Thule Basin.

However, the southern margin of the Thule Basin is not exposed and it remains conjectural whether Proterozoic sedimentation of the depocentres of the Thule and Borden Basins was linked (Dawes *et al.*, 1982a). Jackson & Iannelli (1981) and Jackson (1986) speculate that the two depocentres were interconnected at some stage, the most likely period being during deposition of platform carbonates late in the sedimentary history, viz. the Narssârssuk Group at Thule. These authors also suggest that some displacement of Greenland relative to Canada occurred as early as Neohelikian time (1250–1200 Ma). As suggested in the previous section, the Narssârssuk Group may be a fragment of a regional carbonate-siliciclastic province (parts of which are preserved offshore) and part of a broad, shallow embayment extending far to the south-west.

However, there are also pertinent differences in both sedimentary and tectonic history between the Thule and Borden Basins. For example, the entire fill of the Borden Basin accumulated in Neohelikian time: more precisely, over an 18 million year period starting around 1220 Ma ago (Fahrig *et al.*, 1981; Jackson & Iannelli, 1988). The Thule Supergroup appears to have a much longer depositional history, and although the presence of important paraconformities in the succession cannot be discounted, the Narssârssuk Group appears to have closed the Proterozoic sedimentary record possibly as late as the end of the Hadrynian (Vendian; Fig. 4). This simulates the geological record seen in other Proterozoic basins farther east in northern Greenland (cf. Sønderholm & Jepsen, 1991; Clemmensen & Jepsen, 1992). Tectonically, the Thule Basin is a restricted or semi-restricted 'symmetrical' depocentre that in the Neohelikian was closed to the west. This contrasts with the Borden Basin, which was open to the north-west in the Neohelikian and is thought to have developed as an aulacogen within a 1200 km long, NW-trending fault zone (Jackson & Iannelli, 1981).

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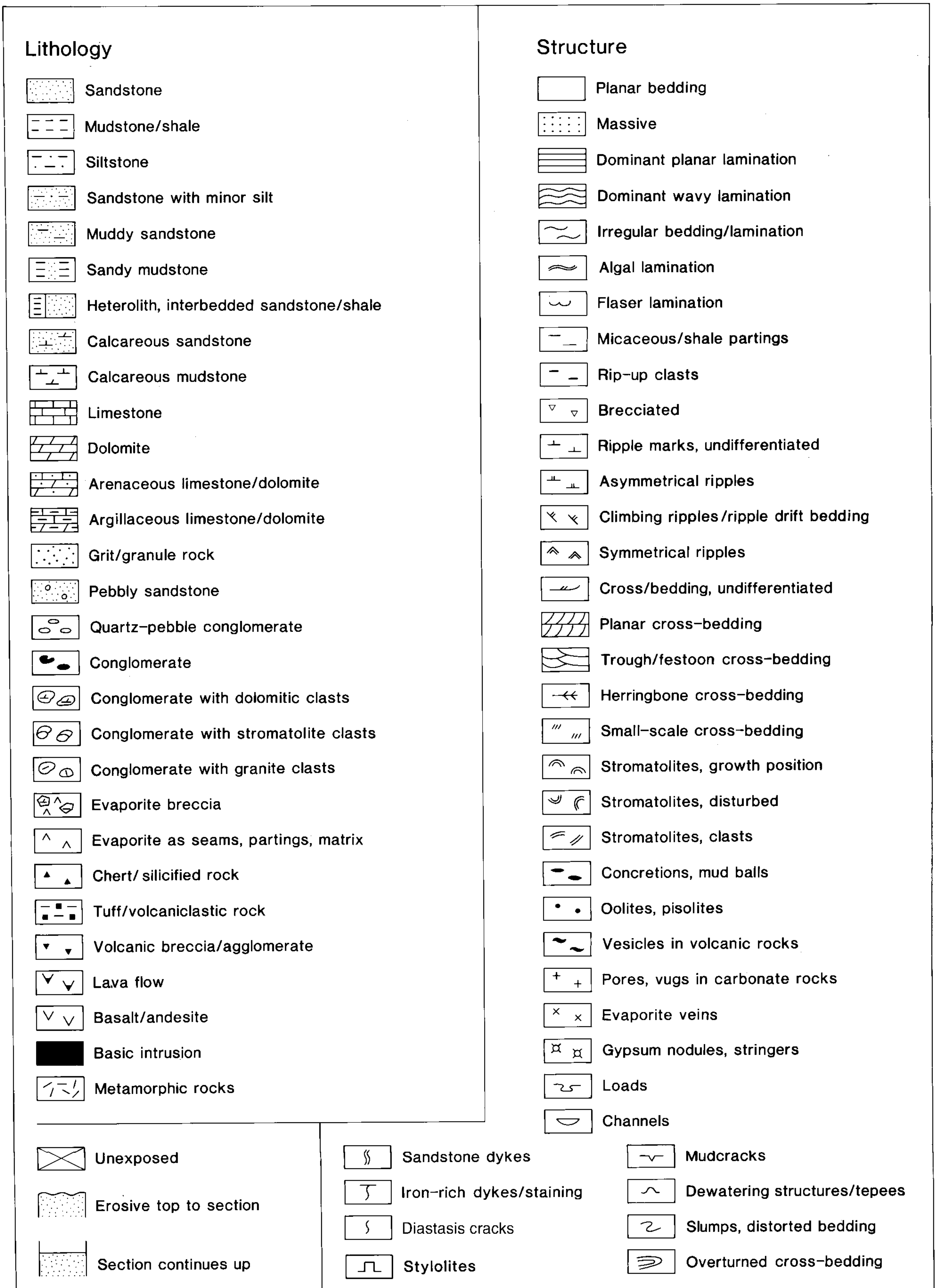

Plate 1. Legend covering all stratigraphic logs and generalised sections for which no other signature is given.

Note added in proof

An important paper on the micropalaeontology of the Thule Basin was published last year by the Geological Survey of Canada (GSC). The paper – Hofmann & Jackson (1996) – is based on samples from sections that are formally redefined in this *Geology of Greenland Survey Bulletin*. Hofmann & Jackson note that the Thule Group is raised to supergroup status by Dawes (in press), and state that since "the new nomenclature awaits publication, we retain the old terminology, referring to Dawes' new nomenclature where appropriate to facilitate comparisons". The citation to "Dawes (in press)" refers to a preprint version of the present Bulletin sent to GSC for critical review in 1994.

As well as mentioning the supergroup terminology in their main text, Hofmann & Jackson (1996) refer to it in an appendix and in their cover illustration. They also cite three figures in Dawes (in press) as the source for sketch maps used in their Fig. 1. Regrettably, Hofmann & Jackson's citations are premature. *Geology of Greenland Survey Bulletin* 174 is a revised version of the 1994 text and there are several important differences. For example, the so-called "new nomenclature" quoted by Hofmann & Jackson does not equate totally with the formal terminology presented in this Bulletin; neither do the figure numbers cited equate with the figures as they appear in this Bulletin.

It needs to be stressed that the formal stratigraphic nomenclature presented in this Bulletin supersedes the supergroup terminology mentioned by Hofmann & Jackson (1996). Corrections have already been made by Hofmann & Jackson in a corrigendum distributed with the GSC Bulletin but for practical reasons the most pertinent differences in stratigraphic terminology are given below.

Cover illustration of Hofmann & Jackson (1996)

View of Paine Bluff, eastern Goding Bay, Canada; these cliffs are also featured in Fig. 81B of this Bulletin. The conspicuous dark coloured unit in the middle part of the cliffs is the Goding Bay Formation of this Bulletin, not the Paine Bluff Member. The middle sub-unit of this formation that yielded microfossils is the Paine Bluff Member.

Appendix in Hofmann & Jackson (1996)

a) The Ekblaw Member does not exist; the unit equates with the Sparks Glacier Member of this Bulletin;
b) The Sparks Glacier Member as used by Hofmann & Jackson is equivalent to the Cape Dunsterville Member of this Bulletin;
c) The Sparks Glacier Member of this Bulletin is part of the Cape Combermere Formation and not part of the Josephine Headland Formation;
d) The Troelsen Member is stated by Hofmann & Jackson to occur at Clarence Head. The Troelsen Member of the Goding Bay Formation of this Bulletin is not recognised at Clarence Head; the strata in question are referred to the Siorapaluk Member of the Robertson Fjord Formation.

Reference

Hofmann, H. J. & Jackson, G. D. 1996: Notes on the geology and micropaleontology of the Proterozoic Thule Group, Ellesmere Island, Canada, and North-West Greenland. *Geological Survey of Canada Bulletin* **495**, 26 pp

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