Fig. 77. Baffin Bay Group (Kap Trautwine Formation, KT; Robertson Fjord Formation, RF and Qaanaaq Formation, Q) overlying the Nares Strait Group (Cape Combermere Formation, CC; Josephine Headland Formation, JH; Clarence Head Formation, CH) in the cliffs of western Northumberland Ø at Vestgletscher. The cliffs of Josephine Headland on the left are about 900 m high. For map location, see Fig. 48.

Baffin Bay Group

The Baffin Bay Group represents the most widespread strata of the Thule Basin present in the central basin fill and overlapping the Precambrian shield on the south-eastern basin margin (Figs 2, 4, 120). It is subdivided into five formations, viz. the Kap Trautwine, Goding Bay, Robertson Fjord, Wolstenholme and Qaanaaq Formations, in which 6 members are formally recognised.

Baffin Bay Group

new group

Composition. This group composes strata from both the lower red and upper pale sandstone units of the Thule Formation of Koch (1926, 1929a; Dawes & Haller, 1979, plate 1). It includes the lower two sandstone units described by Chamberlain (1895) from Inglefield Bredning, all strata described by Munck (1941) from Siorapaluk, Robertson Fjord, and the lower part of the section examined by her at Uvdle, Wolstenholme Fjord, as well as all strata at the head of that fjord on Nunatarssuaq described by Goldthwait (1954) and Fernald & Horowitz (1964). In the North Star Bugt area the group equates with the Quartzite Series of Davies (1954) and the Wolstenholme Quartzite/Formation as used by Kurtz & Wales (1951), Davies (1957) and Davies *et al.* (1963). Farther north the group corresponds to the upper part of the Wolstenholme Formation, more precisely members (c) and (d) of Dawes (1975) and in Canada to unit V of Frisch *et al.* (1978) and units V and VI of Frisch & Christie (1982). In the 6-unit scheme for both sides of Nares Strait erected by Dawes *et al.* (1982a) and adopted by Jackson (1986) for the section at Goding Bay, the group spans units 5 and 6.

Name. After Baffin Bay, the waterway separating Greenland from south-eastern Ellesmere, Devon and Baffin Islands (Figs 1, 2).

Distribution. The most widespread group of the Thule Supergroup. In Greenland: Prudhoe Land, Herbert Ø, Northumberland Ø, Hakluyt Ø, Inglefield Bredning, Olrik Fjord, Steensby Land, Wolstenholme Fjord, Wolstenholme Ø, with isolated exposures as far south as 76°N at De Dødes Fjord. In Canada: south of Johan Peninsula, viz. Cadogan Inlet, Paget Point, Lyman Glacier, Cape Dunsterville, Goding Bay and Clarence Head (Fig. 2).

Type area. Prudhoe Land, south-east of Morris Jesup Gletscher, Greenland (Fig. 2).

Thickness. In many areas, for example in all outcrops in Ellesmere Island, the group is truncated by the present erosion surface. Where the true thickness is preserved the group ranges from perhaps as much as 1300 m in Prudhoe Land and in the Northumberland Ø – Herbert Ø area to less than 300 m in the inner part

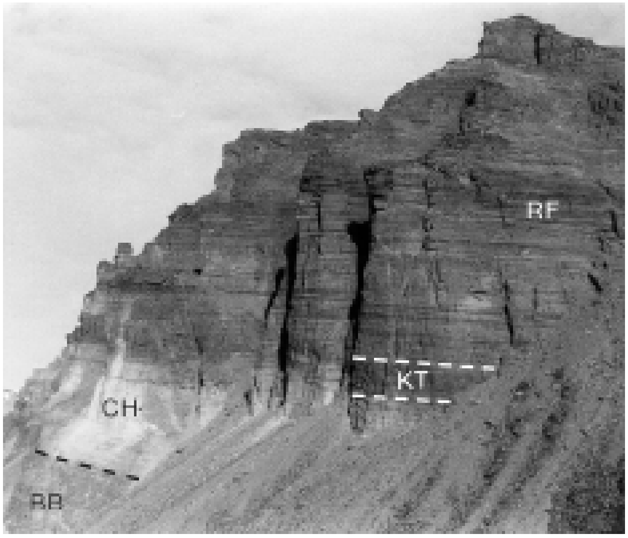

Fig. 78. Contact of Baffin Bay Group (red beds of the Kap Trautwine and Robertson Fjord Formations, KT and RF) and Nares Strait Group (Barden Bugt Formation, BB; Clarence Head Formation, CH) at Castle Cliff, Bowdoin Fjord (Fig. 98). The thin red bed at the top of the Clarence Head Formation suggests some gradation to red bed sedimentation. CH is estimated to be 25 m thick.

of Olrik Fjord (Figs 3, 12, 103). In Ellesmere Island up to about 900 m are preserved in the Goding Bay – Lyman Glacier area.

Dominant lithology. The Baffin Bay Group comprises multicoloured, shallow water siliciclastic strata: quartz arenites, quartz grits, quartz-pebble conglomerates with some subarkoses and important units of varicoloured shale and siltstone (Fig. 3). The siliciclastic rocks vary from highly ferruginous red beds to clean sands. The group shows a gross bipartite subdivision into lower red beds and upper pale weathering sandstones. Basaltic sills occur.

Depositional environment. The Baffin Bay Group is taken to represent mixed continental to marine shoreline environments, with one local interval of possibly deeper water deposition in a prodelta or an offshore basin. The group marks the incoming of red bed sedimentation in an oxidising environment with possible regolith deposits at the base. The many vertical changes in lithology and the supposed abrupt changes in sedimentary environment, may well be indicative of syndepositionary faulting. The uppermost strata indicate a gradually deepening water regime from predominantly alluvial plain deposition to a shallow-shelf tide-dominated environment. This is interpreted as part of a major regional change that continues to the subtidal and basinal deposition of the succeeding strata, the Dundas Group.

Fossils. Organic-walled microfossils (palynomorphs), both acritarchs and tubular forms.

Boundaries and correlation. In Canada and in the main exposures in Greenland, the Baffin Bay Group conformably overlies the Nares Strait Group along a conspicuous and abrupt contact that represents the change to red bed sedimentation (Figs 74, 75, 77). In places the presence of local red beds below and pale weathering sandstones above the boundary suggests some degree of gradation (Figs 78, 82). In some areas, for example at Robertson Fjord, the boundary between the two groups is followed by a basic sill (Fig. 85). In eastern and southern exposures in Greenland the group oversteps onto the crystalline basement. The upper contact in Greenland is conformable and gradational with the Dundas Group; in Canada the present erosion surface limits the group.

Due to lack of exposure the relationship of the Baffin Bay Group to the platform succession in Inglefield Land to the north is unknown, but the group must be a lateral equivalent of at least part of the Smith Sound Group (Figs 3, 4, 120).

Geological age. Neohelikian – ?Early Hadrynian. This assignment is based on radiometric dating of intrusive basaltic rock and on microfossils. The most reliable whole-rock K-Ar age is 978 ± 46 Ma on a sill from the lowest part of the group at Clarence Head (Frisch & Christie, 1982). The microfossils are from the middle and uppermost strata of the group. They are not specifically age-diagnostic, but suggest a general Late Riphean age (see under the Robertson Fjord and Qaanaaq Formations).

Subdivisions. The Baffin Bay Group is subdivided into five formations: the Kap Trautwine, Goding Bay, Robertson Fjord, Wolstenholme and Qaanaaq Formations.

Kap Trautwine Formation

new formation

Composition. This formation corresponds to the basal ferruginous strata of unit 5 and the 'Red sandstone unit', respectively, of Dawes (1976b) and Dawes *et al.* (1982a) from Northumberland Ø and Hakluyt Ø, and to the basal hematitic orthoquartzite of unit V of Frisch & Christie (1982) at Clarence Head.

Name. After Kap Trautwine, the highest part of the prominent cliffed coast on the south side of Hvalsund (Fig. 2).

Distribution. In Greenland: Prudhoe Land, western Steensby Land, Northumberland Ø, and Hakluyt Ø; in Canada: at Clarence Head (Fig. 12).

Geomorphic expression and colour. A very conspicuous dark red to deep purple-weathering unit that at a distance can be readily mistaken for a basic sill. Generally cliff forming but where argillaceous rocks predominate it can be recessive. In Prudhoe Land, and probably on Northumberland Ø, a basic sill forms precipitous benches (Fig. 74).

Type and reference sections. Accessible sections are rare because of the steep exposure. The type section is at the head of Kissel Gletscher, Northumberland Ø (section 37, Figs 48, 79); fairly accessible reference sections are at Morris Jesup Gletscher, west of Kap Trautwine and at Barden Bugt (Figs 71, 91).

Thickness. In Greenland between 15 and 40 m thick (thicker where a basic sill is present); at Clarence Head less than a metre is referred to the formation (Fig. 12).

Lithology. Interbedded, highly ferruginous sandstone, siltstone and shale, which all vary in abundance along strike. The sandstones are quartz arenites, commonly red and maroon; shale and siltstone are red, maroon and green. Conglomerates occur locally. All rock types weather in particularly dark hues.

Strata are thin to medium bedded; mudcracks are common, cross-bedding locally so. The sandstones are fine to medium grained and may be weakly laminated; the shales are recessive and variously silty, and both shales and siltstones are micaceous. Sandstones show wavy, lenticular and nodular bedding, and some shales are lensoid. Siltstones and fine-grained sandstones show loading and channelling into the shales and some beds are characterised by deep desiccation cracks. Liesegang rings and false bedding are common.

In most sections the basal sandstones are particularly ferruginous, with hematite-rich quartz arenites varying in grain size up to grit and granule beds. In places subarkoses occur. Thus at Kap Trautwine dusky red, coarse sandstone has scattered quartz granules up to 6 mm in diameter. The rock is composed of well-rounded quartz grains that have a heavy coating of hematite, occasional quartzite fragments and an isotropic interstitial matrix of hematite dust and detrital mica. At Clarence Head a similar rock type composes the entire formation (Frisch & Christie, 1982).

In Granville Fjord conglomerate beds up to half a metre thick occur near the base of the formation. Clasts, characteristically rounded, are composed of pale well-indurated orthoquartzite set in a sparse sandstone matrix. Clasts are usually pebble to cobble size; some boulders up to 40 cm exist.

Depositional environment. As basal beds of a major red bed sequence, the Kap Trautwine Formation represents the incoming of a strongly oxidising environment. The substantial amounts of hematite suggest fully aerated sedimentation, and some highly ferruginous grits and subarkoses are taken to be regolith products. Frisch & Christie (1982) suggest that rock of this type at Clarence Head represents a palaeosol. Channelling indicates stream action, and the fluvial sands and muds show common desiccation cracks, some of which are deeply penetrative suggesting repeated subaerial exposure.

Fossils. None known.

Boundaries and correlation. The lower boundary is that of the Baffin Bay Group; a distinct conformable contact accentuated by marked colour change to red beds (Figs 77, 78). In places, for example in Prudhoe Land, a basic sill, designated as part of the Kap Trautwine Formation, forms the lower boundary. The formation overlies the Clarence Head Formation and is followed conformably by the Robertson Fjord Formation (Figs 78, 85). Regionally the upper boundary is well demarcated but contact with overlying red beds can be transitional and somewhat arbitrarily placed.

The formation is deemed to be a lateral equivalent to basal beds of the Wolstenholme Formation in Greenland and to be coeval, at least in part, with the Goding Bay Formation of Canada (Figs 11, 12, 79).

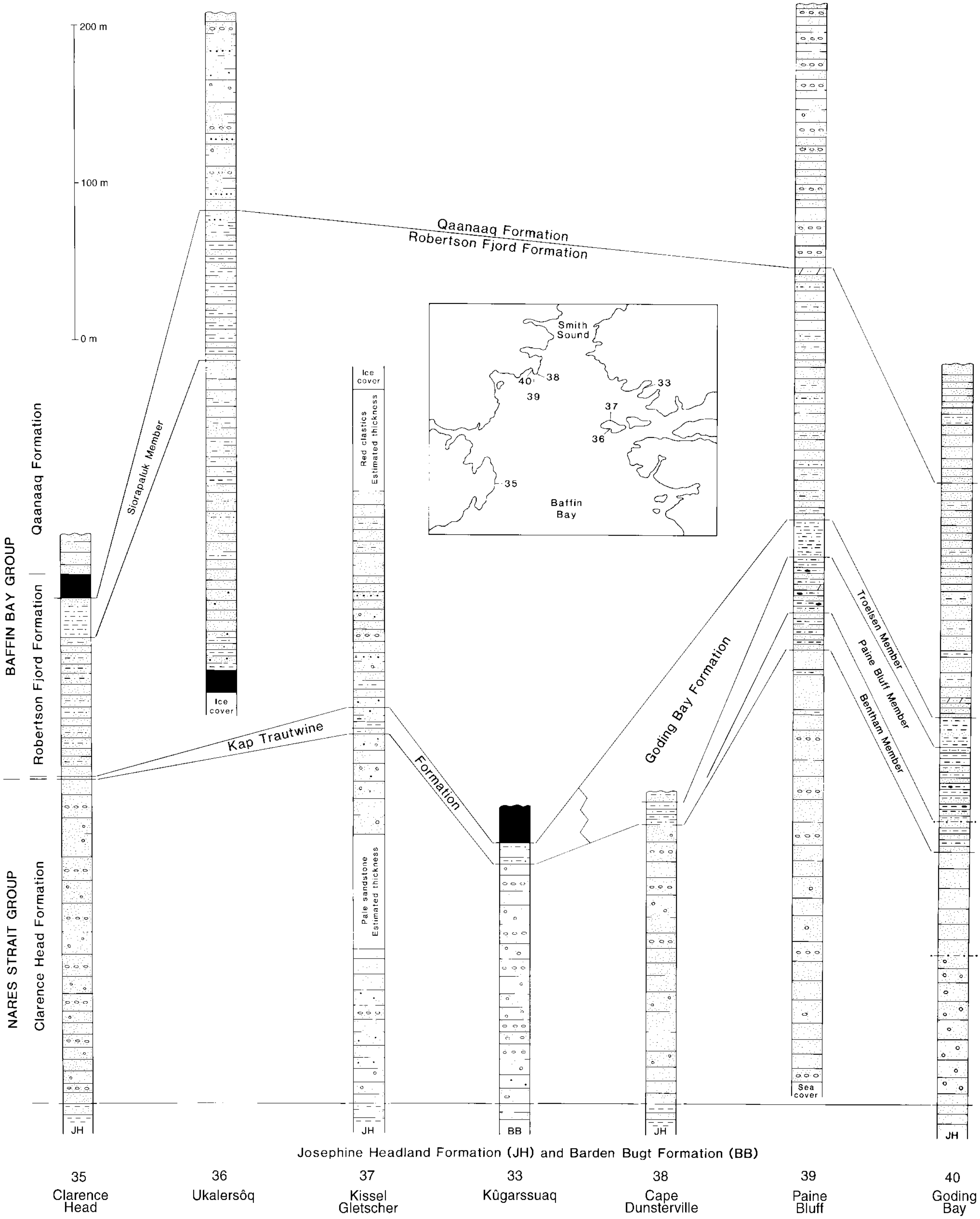

Fig. 79. Generalised sections of Clarence Head Formation of the Nares Strait Group and the Kap Trautwine, Goding Bay, Robertson Fjord and Qaanaaq Formations of the Baffin Bay Group. Canadian geology compiled from the following sources: section 35, Frisch & Christie (1982); section 38, Christie (1975); section 39, Christie (1975) and Frisch & Christie (1982); section 40, Jackson (1986). 37 is a composite section from Kissel Gletscher. Type sections: 35, Clarence Head Formation; 36, Robertson Fjord Formation; 37, Kap Trautwine; 39, Goding Bay Formation. Section locations: 33, Fig. 83; 35, Fig. 75; 36 and 37, Fig. 48; 38, 39 and 40, Fig. 80.

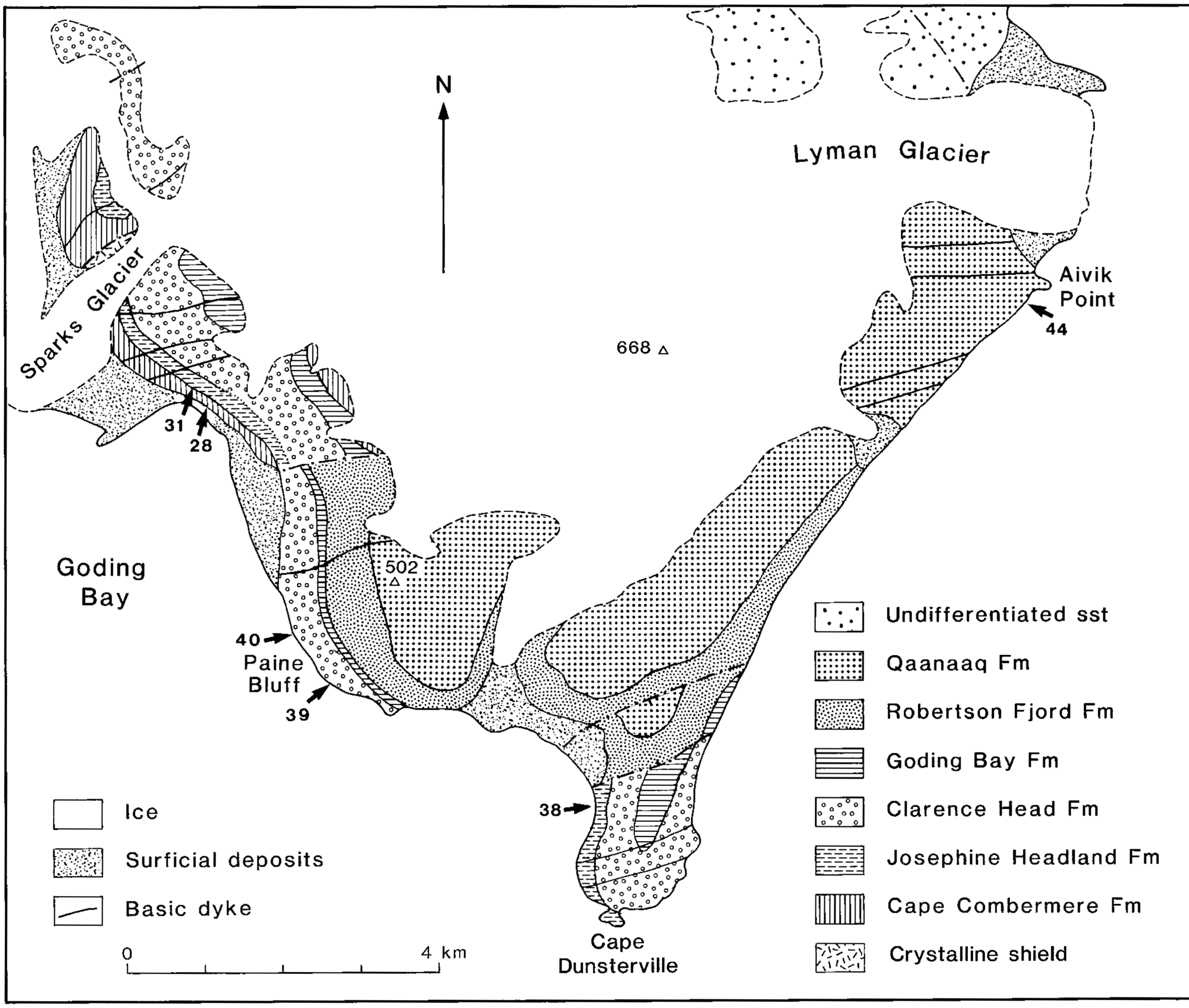

Fig. 80. Geological map of the region between Goding Bay and Lyman Glacier, Canada, showing locations of sections 28, 31, 38, 39, 40 and 44. Map and geology compiled from aerial photographs and based on interpretation of data in Christie (1975), Frisch & Christie (1982) and Frisch (1988). Heights are in metres. For location, see Fig. 2; for photographs of Goding Bay, see Figs 1, 81.

Goding Bay Formation

new formation

Composition. This formation equates with the lower part of unit V of Frisch *et al.* (1978), the 'Green Bed' and the basal part of unit 7 as logged by Christie (1975) at Paine Bluff, and units 4 and 5 of Christie (1975) at Cape Dunsterville. At Goding Bay it equates with all but the lower beds of unit V as defined by Frisch & Christie (1982, p. 8) and the entire thickness of unit 5 of Jackson (1986).

Name. After Goding Bay, the broad and prominent bay west of Cape Dunsterville (Figs 1, 2, 80).

Distribution. As yet only documented in the Goding Bay – Cape Dunsterville region but probably present northwards at least as far as Cadogan Inlet (Fig. 12).

Geomorphic expression and colour. Forms a conspicuous dark band forming steep to moderate slopes (Fig. 81). Dominantly green weathering and fairly resistant, with recessive red beds at the base and top.

Type and reference sections. On the northern slopes of Paine Bluff, eastern Goding Bay (section 39, Figs 79, 81). The sections measured by Christie (1975), Frisch (*in* Frisch & Christie, 1982) and Jackson (1986) are all in the same general area (Fig. 80); a reference section

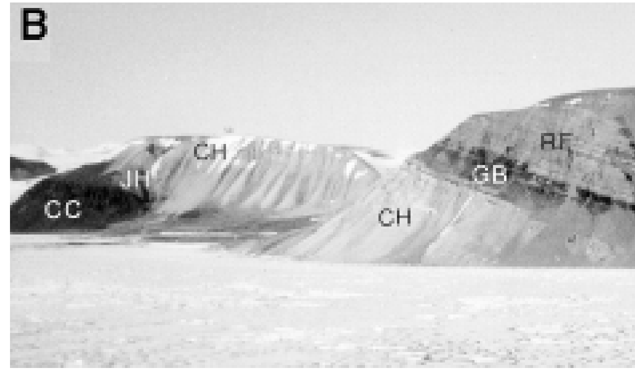

Fig. 81. East side of Goding Bay showing the Goding Bay Formation (GB) as conspicuous dark strata at the base of the Baffin Bay Group and visible even in the poorly exposed coastal slopes. CC = Cape Combermere Formation, JH = Josephine Headland Formation, CH = Clarence Head Formation, RF = Robertson Fjord Formation. **A:** view south-east, photo: R. L. Christie; **B:** view to the north with Paine Bluff in foreground, photo: G. D. Jackson. Relief about 500 m. For regional view of Goding Bay, see Fig. 1.

through the basal part of the formation is on the west side of the Cape Dunsterville peninsula (section 38, Fig. 79).

Thickness. Between 84 and 87 m thick at Paine Bluff, apparently thinning to less than 70 m to the south-east. The thickness of 87 m recorded by Jackson (1986) at Paine Bluff may be tectonically modified by faulting.

Dominant lithology. Multicoloured, interbedded sandstone, siltstone and shale, characterised by a middle unit of greenish strata flanked by red beds. The rocks are variously laminated, planar to lenticular, thin bedded, occasionally lensoid and show abundant ripple marks, cross-bedding and mudcracks, with some units characterised by channel and load structures. Minor carbonate lenses occur. A basic igneous rock (?sill) occurs north of Cape Dunsterville (R. L. Christie, personal communication, 1993).

Depositional environment. Intertidal to supratidal environments are suggested by Frisch & Christie (1982) for this sequence; Jackson (1986) suggests that middle strata are offshore deposits. The tripartite sequence of red-green-red strata is taken to indicate general changes in the oxidation-reduction potential.

Fossils. Microfossils; see under Paine Bluff Member.

Boundaries and correlation. The Goding Bay Formation overlies the Clarence Head Formation along a sharp

Fig. 82. The type section of the Goding Bay Formation (GB) (section 39, Fig. 79) at Paine Bluff showing division into Bentham (B), Paine Bluff (P) and Troelsen (T) Members. CH = Clarence Head Formation, RF = Robertson Fjord Formation. The view is east to the Cape Dunsterville peninsula; for location, see Figs 80, 81. Photo: K. W. Christie.

conformable contact that marks the incoming of a major period of red bed sedimentation. It is overlain, also along a fairly abrupt conformable contact, by the Robertson Fjord Formation (Fig. 81; see under Troelsen Member).

Correlation with the Kap Trautwine Formation is suggested. Both formations are characterised by iron-rich lithologies marking the abrupt onset of red bed sedimentation, and they share the same stratal position separating the Clarence Head and Robertson Fjord Formations (Fig. 79).

Subdivisions. The formation displays a tripartite subdivision well seen in the sea-cliffs of Paine Bluff (Fig. 82). The three units are formally defined from base upwards as the Bentham, Paine Bluff and Troelsen Members.

Bentham Member

new member

Composition. The basal sub-unit of unit IV of Frisch & Christie (1982) and sub-unit 5A of Jackson (1982) from Goding Bay constitute this member.

Name. Named for Robert Bentham (1913–1968), British geologist who, wintering in both Ellesmere Island and Greenland in the 1930's, astutely correlated Thule beds between the two lands (see p. 18).

Distribution. Same as the formation.

Geomorphic expression and colour. Recessive, dark grey to maroon unit that is generally poorly exposed.

Type section. As for the formation.

Thickness. At Paine Bluff the member is between 20 and 24 m thick. Strata that might be referable to this member cannot be recognised in the poorly exposed section logged by Christie (1975) at Cape Dunsterville. It is possible that the member may thin or pinch out to the south-east.

Lithology. The Bentham Member is composed of red to maroon, thin- to medium-bedded, micaceous sandstone, siltstone and lensoid shale. Frisch & Christie (1982) mention shaly siltstone with buff to purplish partings, and Jackson (1986) minor buff to white sandstone in the lower part. Cross-bedding is present in the sandstone. The member shows a change along strike in the sandstone/shale-siltstone ratio.

Depositional environment. The red beds of this member are taken to indicate the regional regression or progradation of the shoreline following the shallow shelf sedimentation of the Clarence Head Formation. Jackson (1986) mentions fluvial deposition as streams readvanced into the basin.

Fossils. None known.

Boundaries. The lower boundary of the Bentham Member is that of the Goding Bay Formation; the upper is drawn at the first incoming of green strata, either siltstone or shale, that characterise the overlying Paine Bluff Member. This boundary is well demarcated and conformable (Fig. 82). Jackson (1986) indicates that in places the sharp contact is a fault.

Paine Bluff Member

new member

Composition. This member corresponds to the middle sub-unit of unit V of Frisch & Christie (1982) and sub-unit 5B of Jackson (1986) from Goding Bay, and unit 4 of Christie (1975) from Cape Dunsterville.

Name. After Paine Bluff, a prominent ice-capped coastal cliff on the east side of Goding Bay (Figs 1, 2, 80).

Distribution. Same as the formation.

Geomorphic expression and colour. A conspicuously dark green-weathering, resistant unit, generally forming steep slopes, but often scree covered. The strata break down into tabular debris.

Type section. As for the formation.

Thickness. Maximum thickness of 48 m thinning to the south-east to 36 m. At Cape Dunsterville the member is estimated at no more than 20 m.

Lithology. Thinly interbedded, green siltstone-shale and paler green to buff to brown fine-grained sandstone, for the most part arranged in fining-upward cycles (Christie, 1975; Jackson, 1986). The rocks are green on fresh and weathered surfaces; lenticular bedding is common in the sandstones, less so in shale beds. The sandstones are predominantly quartz arenites occurring in beds up to 20 cm thick; Frisch & Christie (1982) mention local dolomitic subarkose beds. According to Jackson (1986) sandstone decreases upward through the sequence; in the basal part it forms about 15% occurring in beds more than 1 m apart. The sandstones are massive to variously laminated, characterised by cross-bedding and ripple drift and climbing ripple laminae. They also show a variety of bottom structures in sharp contact with shale: load casts, flutes and channels. Some thin quartz conglomeratic lenses occur, as well as dark green weathering, coarse-grained carbonate lenses and concretions up to 25 cm thick (Jackson, 1986, fig. 65.4).

The siltstones are variously shaly, micaceous and show ripple marks and desiccation cracks. Marcasite nodules up to 2 cm in diameter and malachite staining characterise some beds.

About 3 km north of Cape Dunsterville at the outer coast, a conspicuous dark grey-green unit at least 7 m thick, composed of fractured to highly shattered rock is, on regional considerations, referred to the member. It is taken to be a basaltic or andesitic rock, possibly a sill (R. L. Christie, personal communication, 1993).

Depositional environment. The green colour of the Paine Bluff Member is taken to represent general anaerobic conditions. The quartz arenite beds may have been deposited by turbidity currents (Jackson, 1986); these beds and the marcasite nodules suggest that the member may represent an offshore basin or prodelta deposit.

Fossils. Organic-walled microfossils, including acritarchs and filamentous forms (G. D. Jackson, personal communication, 1993).

Boundaries. The lower boundary, as described earlier, is an abrupt contact with the Bentham Member. The upper contact to the Troelsen Member is equally distinct (Fig. 82), drawn on top of the last green shale bed. North of Cape Dunsterville, an igneous rock occurs at the contact.

Troelsen Member

new member

Composition. This member corresponds to the upper sub-unit of unit V of Frisch & Christie (1982), sub-unit 5C of Jackson (1986) and the basal beds of unit 7 of Christie (1975) from Paine Bluff, and unit 5 of Christie (1975) from Cape Dunsterville.

Name. After Johannes C. Troelsen (1913–1992), Danish geologist who instigated the use of common stratigraphic names to describe the Thule beds and younger strata on both sides of Nares Strait (see p. 18).

Distribution. Same as the formation.

Geomorphic expression and colour. Dark reddish-weathering, very recessive unit.

Type section. As for the formation.

Thickness. At Paine Bluff varies between 19 and 24 m. According to Frisch & Christie (1982) the unit shows an apparent six-fold thickening within a kilometre south-east of the type section – see discussion below under *Boundaries and correlation*. On Cape Dunsterville the present erosion surface caps the section with only about 7 m preserved.

Lithology. A complex sequence of interbedded shale, siltstone and very fine-grained sandstone, which are thinly laminated to very thin bedded. Rocks are red to greyish red on weathered surfaces, brown to mauve when fresh. Some shales are green; hematite-rich beds are deeper red in colour. Beds are generally less than 15 cm thick but some siltstone beds up to 35 cm thick occur near the base. Shales are generally fissile in beds less than 10 cm thick but in the upper strata Jackson (1986) notes green shale and siltstone beds and lenses up to 30 cm thick. Christie (1975) notes ropy and nodular bedding.

Other structures, noted by Frisch & Christie (1982), are ripple marks, cross-bedding and desiccation cracks; Jackson (1986) mentions common load structures, channel fillings and interference ripples, and likens brown siltstone and green shale with channels to rocks of the underlying unit, i.e. Paine Bluff Member.

Depositional environment. The return to red bed sedimentation, shown by the hematite-rich layers, indicates higher oxidation conditions. Mudcracks indicate periodic exposure; other sedimentary structures suggest current action. According to Jackson (1986) the strata may represent an overall delta plain or beach environment.

Fossils. None known.

Boundaries and correlation. As described earlier the lower boundary is a conformable contact to the Paine Bluff Member; the upper boundary corresponds to that of the Goding Bay Formation. This boundary at Paine Bluff is a well demarcated, planar contact seen as an abrupt colour change from dark red strata to the lighter red and purple, more banded rocks of the Robertson Fjord Formation (Fig. 82). This contact is a persistent feature along strike and can be picked out north and south of Paine Bluff even though the coastal section has scree cover (Fig. 81A).

This stratigraphy is difficult to reconcile with the suggestion by Frisch & Christie (1982) that 24 m of strata (Troelsen Member of this paper) thickens within a kilometre in the Paine Bluff area to a 120 m thick sandstone-shale sequence that represents unit 7 as logged by Christie (1975). This proposed thickening is not substantiated by my interpretation of the regional geology, and all but the lower 24 m of Christie's 120 m unit is here referred to the overlying Robertson Fjord Formation.

Robertson Fjord Formation

new formation

Composition. This formation encompasses the bulk of the strata previously referred to as member (c), and subsequently unit 5, of the Wolstenholme Formation as described by Dawes (1975, 1976b) from Northumberland Ø and to the middle part of unit V of Frisch *et al.* (1978) from Ellesmere Island. North of Siorapaluk,

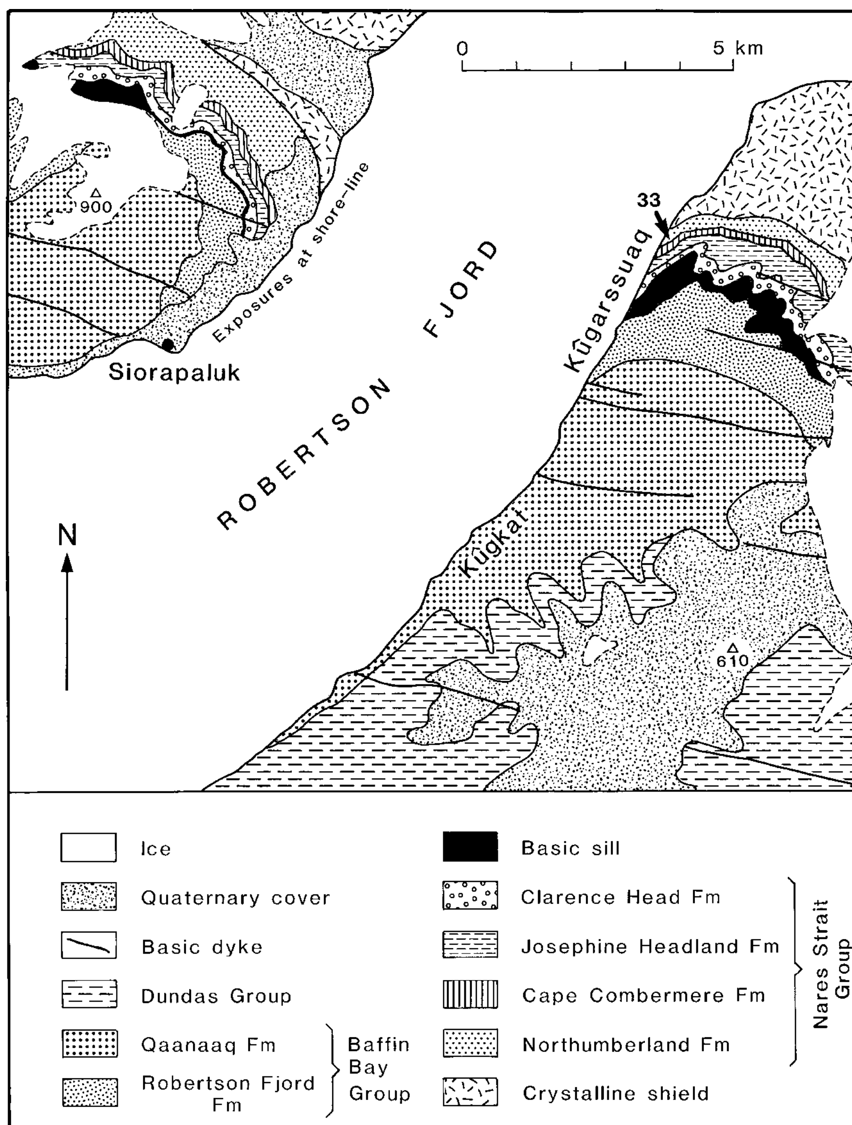

Fig. 83. Geological map of the central part of Robertson Fjord area, Prudhoe Land, Greenland, showing location of section 33 and the settlement of Siorapaluk. The massif Kûgarssuaq is shown in Fig. 74; that north of Siorapaluk in Fig. 85. The Kap Trautwine Formation is not shown but included with the basic sill that occurs at the boundary of the Nares Strait and Baffin Bay Groups. Heights are in metres. For location, see Fig. 2.

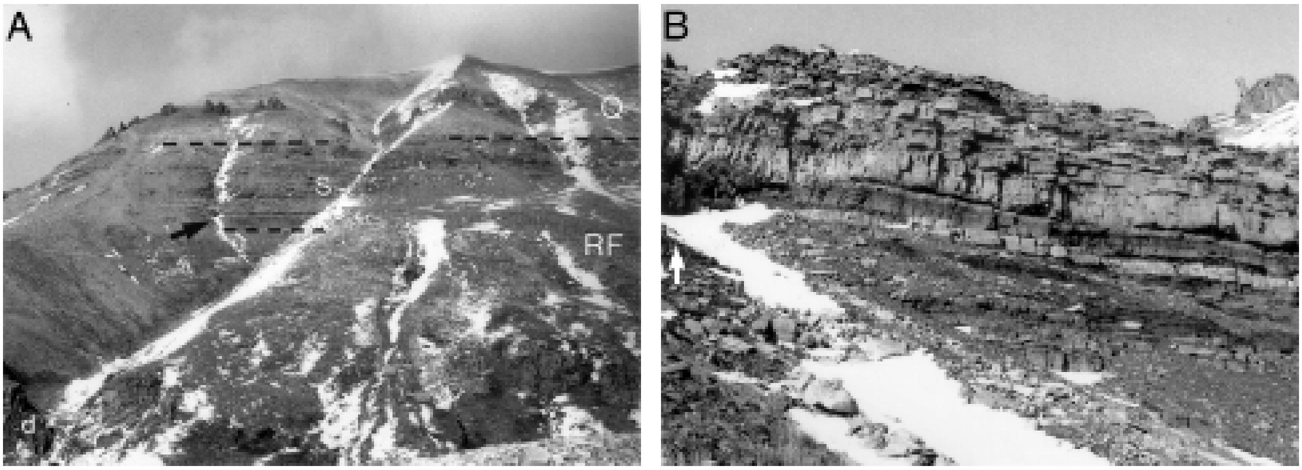

Fig. 84. The type section of the Robertson Fjord Formation (RF), south side of Ukalersôq, Northumberland Ø, overlain by the Qaanaaq Formation (Q) (section 36, Fig. 79). **A:** general view with dolerite (d) at base; **B:** detail of upper part (arrows mark common snow bank) showing interbedded sandstone-shale lithology of the Siorapaluk Member (S).

Robertson Fjord, it includes the lower part of the section examined by Munck (1941); at Goding Bay it corresponds to all but the basal 24 m of unit 7 of Christie (1975), the lower half (161 m) of unit VI of Frisch & Christie (1982) and the lower 151 m of unit 6 of Jackson (1986). At Clarence Head all strata of unit V of Frisch & Christie (1982), except the basal ferruginous bed, are referred to the Robertson Fjord Formation. In the 6-unit scheme pertaining to both sides of Nares Strait (Dawes *et al.*, 1982a), the formation broadly corresponds to the 'Red Sandstone unit' but with the basal beds of that unit being referred to the Kap Trautwine and Goding Bay Formations.

Name. After Robertson Fjord, a major inlet in Prudhoe Land (Figs 2, 83).

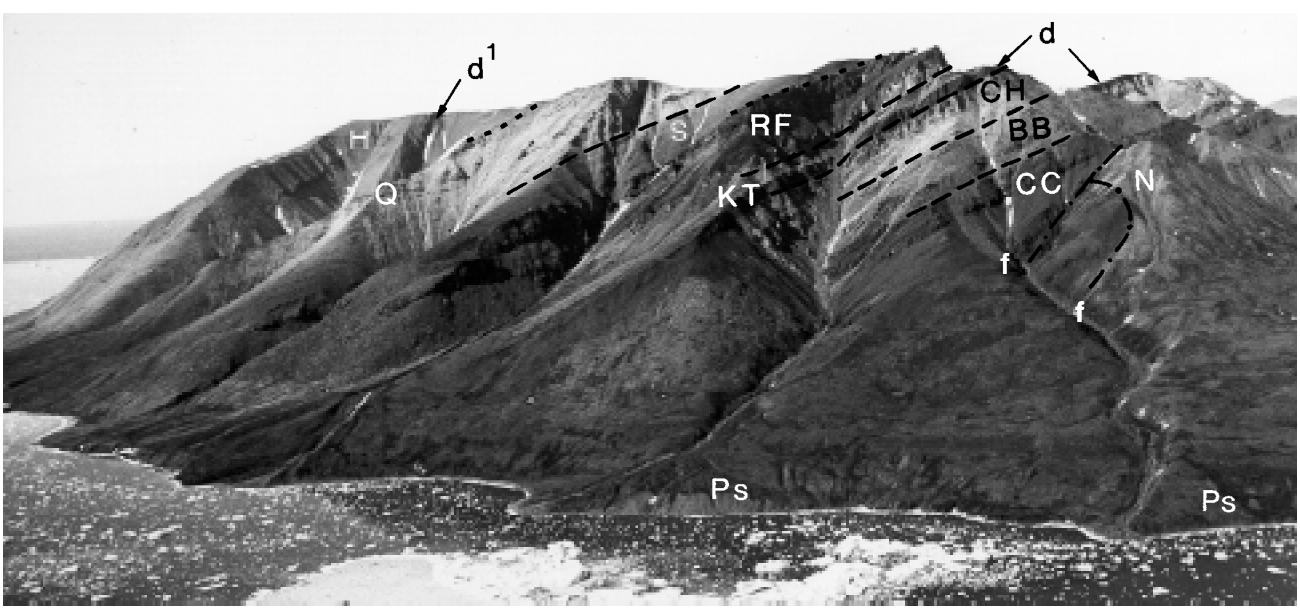

Fig. 85. The massif behind Siorapaluk (settlement just out of view left; located in Fig. 83) showing the Nares Strait and Baffin Bay Groups with a basic sill (d) at the group contact. Northumberland Formation (N), Cape Combermere Formation (CC), Barden Bugt Formation (BB), Clarence Head Formation (CH), Kap Trautwine Formation (KT), Robertson Fjord Formation (RF) composed of cliff-forming and more recessive intervals and with the Siorapaluk Member (S) at the top. Section is completed by the Qaanaaq Formation (Q) with the darker, thinner-bedded Herbert Member (H) forming the youngest strata. The unconformity with the Precambrian shield (Ps) is covered; d[1] = late Hadrynian basic dyke. Relief about 900 m.

Distribution. In Greenland: Prudhoe Land, western Steensby Land, Northumberland Ø and Hakluyt Ø; in Canada: present in main outcrop areas south of Johan Peninsula, viz. between Cadogan Inlet and Goding Bay and at Clarence Head (Fig. 12).

Geomorphic expression and colour. Overall reddish weathering, often banded and generally resistant forming cliffs to steep slopes. Recessive intervals occur and these form medium slopes and may be poorly exposed. One such unit forms the uppermost strata of the formation, viz. the Siorapaluk Member.

Type and reference sections. The section on the south side of Ukalersôq through the upper part of the formation is designated type section (section 36, Figs 79, 84); a better exposed section through the basal part is on the prominent buttress at the head of Kissel Gletscher (section 37, Fig. 79). Main reference sections are on the south side of Morris Jesup Gletscher (section 41, Fig. 89), at Clarence Head and Goding Bay (sections 35, 39, 40, Fig. 79).

Thickness. Ranges from 200 to 400 m in Greenland to between 150 and 160 m at Goding Bay; a little less than 120 m at Clarence Head (Fig. 12).

Lithology. A thick red bed sequence of varicoloured sandstones, siltstones and shales; overall, sandstones dominate but in many areas siltstones and shales predominate in the uppermost part. The sandstones are variously laminated and coloured, mainly red, purple, lilac and pink, with smaller intervals of orange, brown, buff and green rocks; siltstones and shales are mainly dark red, purple, grey and green. On an outcrop scale sandstone and siltstone-shale may be interbedded and this, together with the alternation of red and lighter coloured sandstones, produces a banded appearance typical of many parts of the formation. On a regional scale the formation is composed of units that are variously dominated by sandstone and siltstone-shale and this produces cliff-forming and more recessive intervals, as at Siorapaluk (Fig. 85).

The formation is dominated by thin- to medium-bedded, less commonly thick-bedded, fine- to coarse-grained sandstones that are commonly cross-bedded and ripple marked. Colour banding, striping and mottling are common and some intervals are characterised by liesegang rings. Planar to wavy lamination with ripple-drift lamination characterises some intervals (Fig. 86A). Bedding is usually planar, but it may be irregular with some channelling. Channels up to 2 m deep were noted in a section at Robertson Fjord. Cross-beds are mainly of the planar type with some herringbone stratification (Fig. 86B); ripples are commonly symmetrical with asymmetrical and interference types.

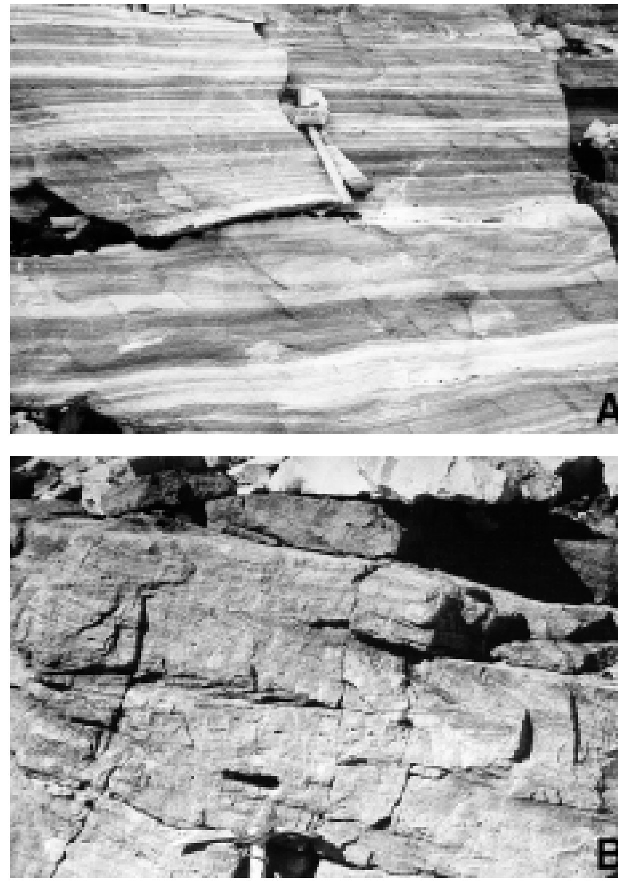

Fig. 86. Bedding characteristics of the Robertson Fjord Formation. **A:** planar- to wavy-bedded, banded sandstones showing beds with ripple-drift lamination. Kissel Gletscher, section 37. **B:** herringbone cross-beds. Paine Bluff, section 39. Ice-axe as scale; photo: R. L. Christie.

A typical feature in south-eastern outcrops is the presence of grits and conglomeratic intervals, either as discrete rudaceous beds or quartz granules and pebbles irregularly scattered and variously concentrated through the sandstone. Quartz pebbles are also concentrated as lag deposits on the truncated surfaces of cross-beds. Red and green shale lamellae and partings characterise some sandstone intervals; others show brecciation of partings and thin beds and some sandstones contain rip-up clasts. Jackson (1986) notes that green shale chips are disseminated throughout the formation at Goding Bay. Mudcracks are common on mud partings.

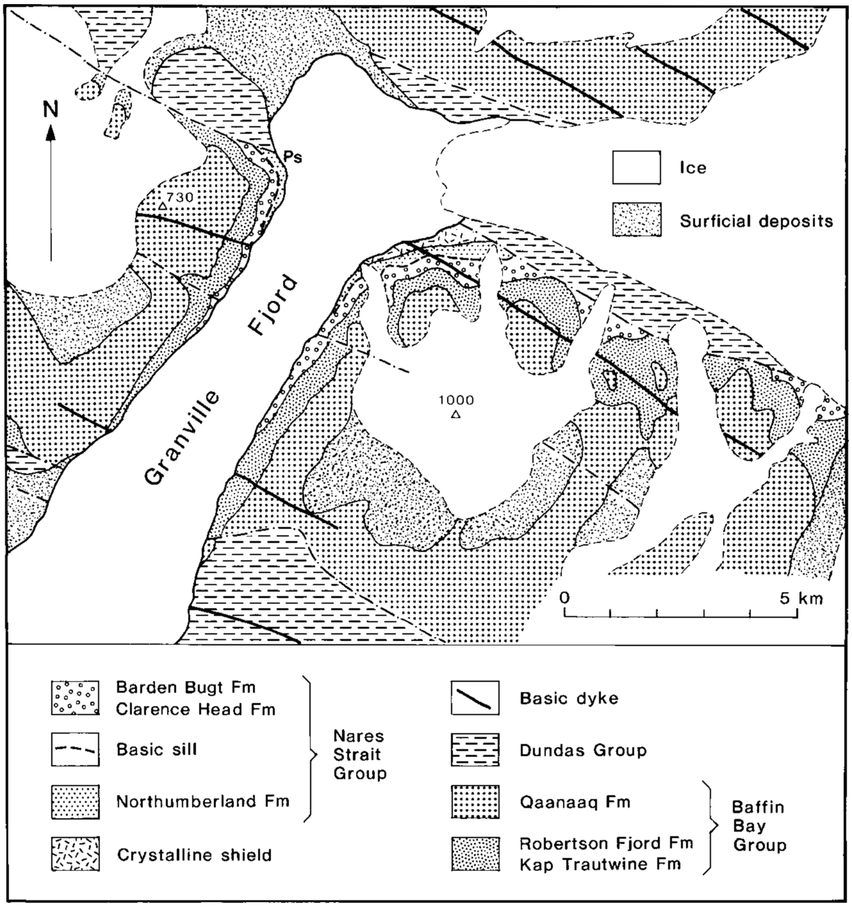

Fig. 87. Geological map of the region around the head of Granville Fjord, Steensby Land, Greenland. Ps = coastal outcrop of Precambrian shield. The Cape Combermere Formation is represented by a basic sheet (?sill). The Dundas Group at the head of the fjord is preserved in a down-faulted block (cf. Fig. 70). The position of the glacier front in Granville Fjord is from 1985. Heights are in metres. For location, see Fig. 2.

The sandstones are quartz arenites, variously ferruginous, with characteristically well-rounded quartz grains that show various amounts of authigenic overgrowth: some beds have typically subangular quartz. Iron oxide coating of quartz grains is common; the iron-rich types have in addition appreciable interstitial oxide (hematite ± limonite) that in places forms a ferruginous cement. Such rocks are typically dusky red to bluish purple and are commonly banded on a millimetre scale. Some rocks contain up to 3 per cent quartzite fragments, mostly rounded. Rock matrix varies from such monomineralic composition to material in which fine hematite is thoroughly disseminated occurring along with detrital sericite. Frisch & Christie (1982) note that the abundance of hematite increases upwards in the formation at Clarence Head where iron oxide is also present as veneers on bedding surfaces and along fractures. The fining-upward beds may grade from pink, medium-grained to dusky red fine-grained sandstone which is thinly coated with mammillary hematite or specularite.

Shale and siltstone occur as thin beds and partings but predominate in the upper part (see Siorapaluk Member). In a section described by Christie (1975) at Goding Bay, red shale is apparently common, occurring interbedded with sandstone throughout a 100 m thick section. From the same area, Jackson (1986) notes a unit of laminated to very thinly bedded shale and siltstone, some 3 m thick, about 40 m above the base.

Calcareous components are restricted to occasional carbonate laminae while carbonate rarely is seen in thin section. A recessive 3 m thick bed of laminated dolomitic subarkose is mentioned by Frisch & Christie (1982).

Depositional environment. The Robertson Fjord Formation is interpreted to represent deposition in terrestrial to shallow intertidal shelf environments. The highly ferruginous nature of some sandstones characterised by dense iron cement, suggests subaerial diagenesis, and aeolian deposition of some sandstones is probable. For the Clarence Head section Frisch & Christie (1982) suggest a gradually deepening littoral environment. In general terms this is applicable to the formation as a whole, with the fine-grained lithologies in the uppermost part (Siorapaluk Member), as well as detrital carbonates, representing supratidal to intertidal deposition. Abundance of cross-bedding, some of which is of herringbone type, suggests tide-dominated environments (Jackson, 1986); however, pebbly sandstone and rudaceous intervals with channels and some fining-upward units common in Greenland sections, particularly towards the south-east, is taken to indicate fluvial deposition.

Fossils. Organic-walled microfossils (acritarchs) – see under Siorapaluk Member.

Boundaries and correlation. The Robertson Fjord Formation rests conformably on the Kap Trautwine and Goding Bay Formations (Figs 77, 82, 85). Contact with the former is usually well demarcated and indicated by a distinct colour change; however, in some places the boundary is gradational and drawn somewhat arbitrarily where dark ferruginous beds give way to lighter-coloured, cross-bedded sandstones. The boundary with the Goding Bay Formation is discussed under the Troelsen Member.

The Robertson Fjord Formation is conformably overlain by the Qaanaaq Formation (e.g. Figs 84, 85). This is usually along a fairly sharp contact which is drawn at the incoming of the buff-weathering quartz arenites which are usually quite distinct from the red beds, particularly from the interbedded sandstone-siltstone-shale lithology (Siorapaluk Member) that in many areas characterises the upper part of the Robertson Fjord Formation. Where that member is missing, the boundary may be gradational and more arbitrarily placed after the last major red sandstone. In sections where there is a gradual colour change from red-purple beds through interbedded purple and lilac sandstone to pink and buff sandstones involving tens of metres of strata, e.g. the high sea-cliffs of western Northumberland Ø, the boundary is arbitrarily defined on regional considerations. At Paine Bluff in Goding Bay, the boundary is placed above a 3 m thick bed of dolomitic subarkose described by Frisch & Christie (1982; section 39, Fig. 79).

Both the lower and upper boundaries of the Robertson Fjord Formation may be followed by a basaltic sill, for example at Kûgarssuaq in Robertson Fjord, Prudhoe Land (lower, Fig. 74) and at Clarence Head, Canada (upper, Figs 75, 79).

In south-eastern exposures the Robertson Fjord Formation interdigitates with the Wolstenholme Formation and the boundary between the two formations can only be defined arbitrarily. Lack of exposure in northern Prudhoe Land prohibits precise knowledge of relations to the Smith Sound Group, but the formation is regarded to be, at least in part, the lateral equivalent of the Rensselaer Bay Formation (Figs 11, 120).

Subdivisions. In Greenland in particular, the Robertson Fjord Formation can be subdivided into a number of readily recognisable units. However, the lithostratigraphy of these has not been studied in detail, and formal definition here is restricted to two members: Granville Fjord and Siorapaluk Members.

Granville Fjord Member

new member

Composition. Shale-siltstone interval of the lower red member of the Wolstenholme Formation at Granville Fjord of Dawes (1976a).

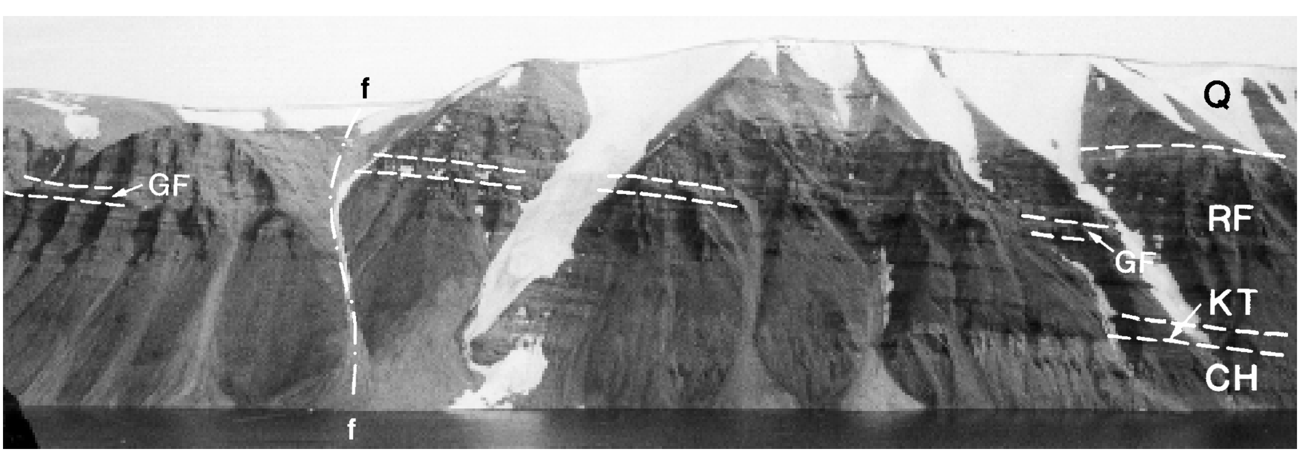

Fig. 88. The Granville Fjord Member (GF) as a dark marker in the middle of the Robertson Fjord Formation (RF) on the eastern side of Granville Fjord, Steensby Land. Down-faulting to the north, see Fig. 87. CH = Clarence Head Formation, KT = Kap Trautwine Formation, Q = Qaanaaq Formation. Cliffs are about 700 m high.

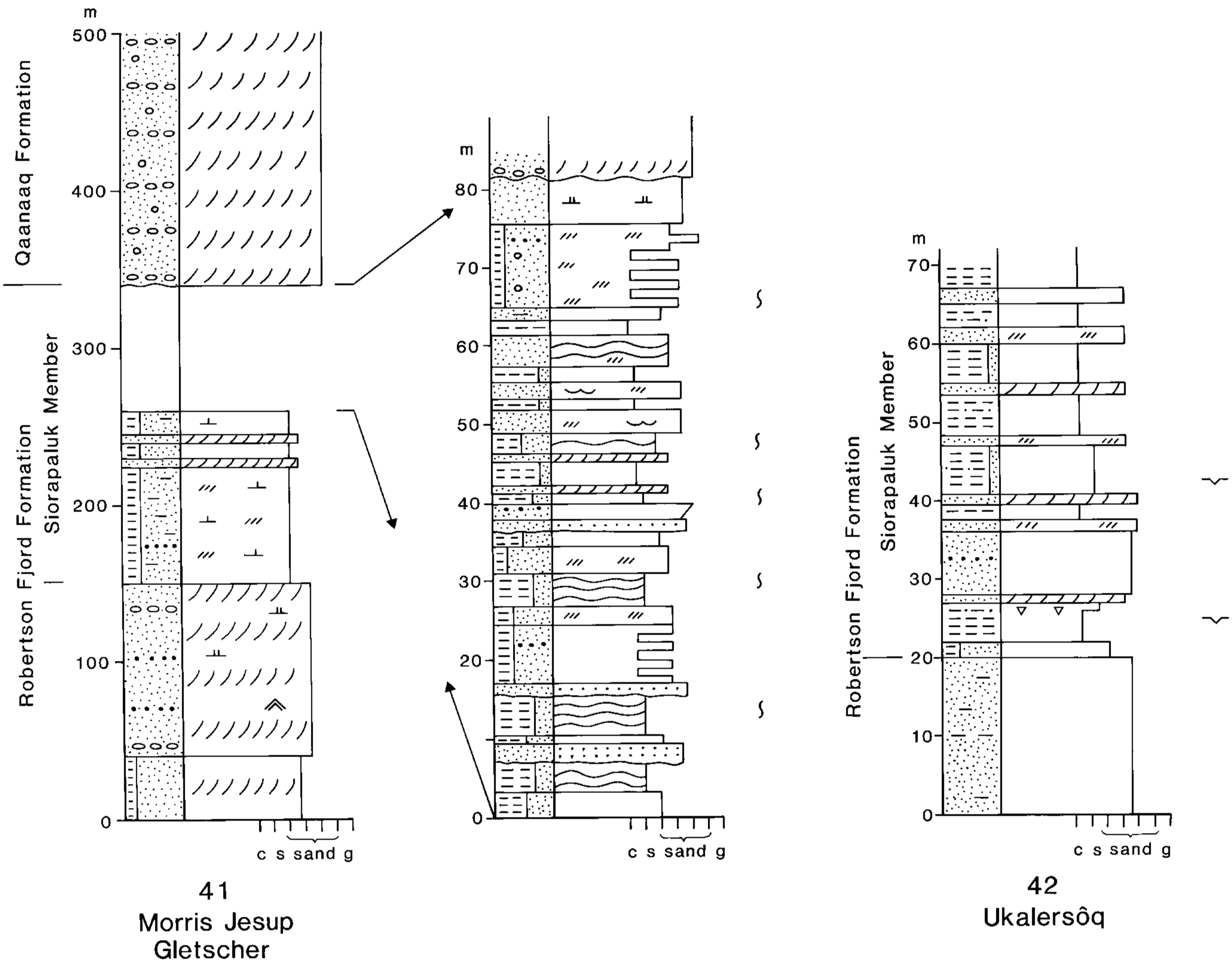

Fig. 89. Stratigraphic logs of the upper part of the Robertson Fjord Formation and basal strata of the Qaanaaq Formation. Section 41 is the type section of the Siorapaluk Member located in Fig. 90; section 42, located in Fig 48, refers to part of the generalised section 36 that is given in Fig. 79.

Name. After Granville Fjord, the main fjord of southern Steensby Land (Figs 2, 87).

Distribution. Steensby Land and south-eastern Prudhoe Land.

Geomorphic expression and colour. A dark purple-weathering, resistant unit that forms a conspicuous regional marker.

Type area and reference section. The type area is the sea-cliffs of Granville Fjord (Fig. 88). The single section examined is on the west side of the fjord at the pronounced break in the cliffs.

Thickness. About 15 m.

Lithology. Thin-bedded, purple, ferruginous sandstone with shale and siltstone interbeds. The sandstones are predominantly fine to medium grained but with some variation to coarse sandstone with quartz grains reaching 1 mm or more in size. The sandstones and siltstones are variously laminated; some have shale partings, others show a well-developed dense planar to wavy lamination. Fining-up cycles occur with the sandstones having sharp contacts to bounding shale-siltstone. Sandstones display cross-bedding and ripple marks, and argillaceous surfaces show mudcracks.

The top of the member is composed of a dark purplish grey to almost black, fine-grained sandstone 10–15 cm thick. The bed has a massive appearance so that at a distance it can easily be mistaken for a basic sill, but where examined the rock contains discontinuous thin micaceous laminae.

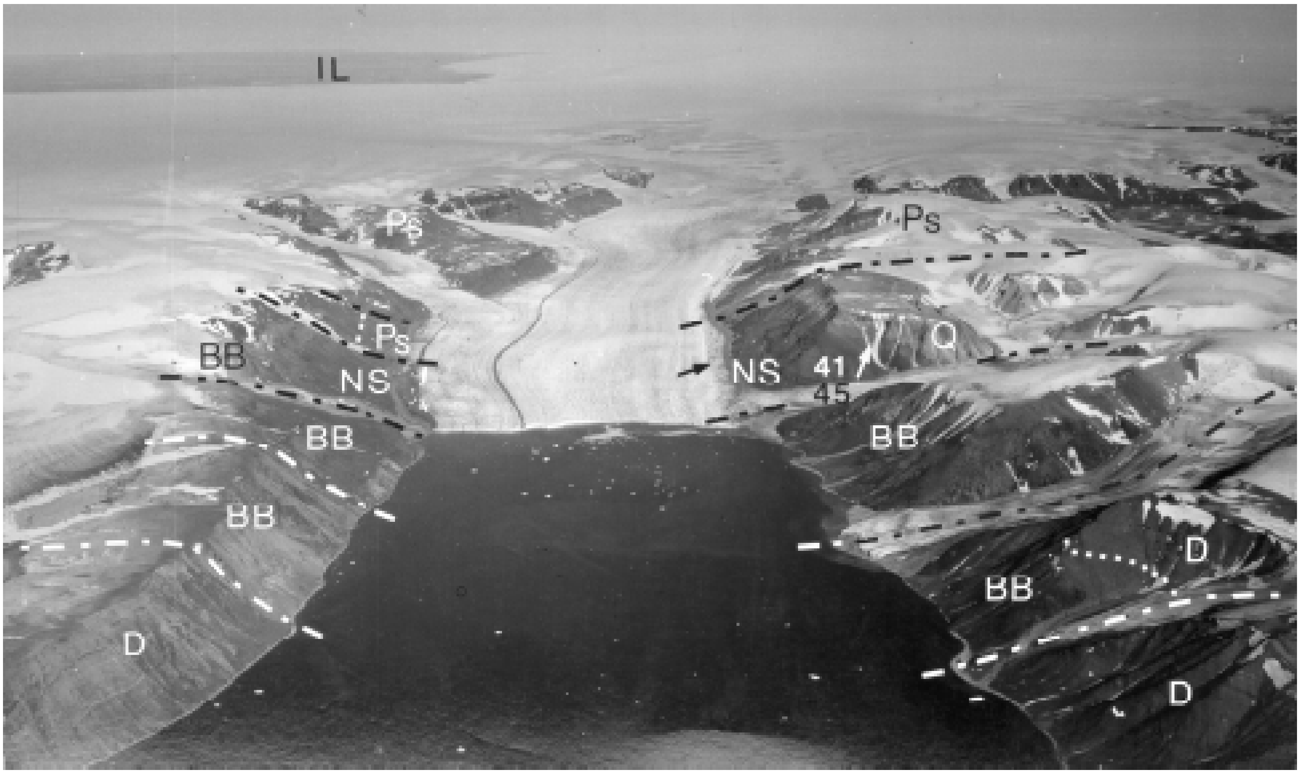

Fig. 90. View north-west up Morris Jesup Gletscher, Prudhoe Land, Greenland, showing fault blocks, and location of sections 41 and 45 that are given in Figs 89 and 99. Arrow on glacier locates view seen in Fig. 91A. Inglefield Land (IL) in the background. Ps = Precambrian shield, NS = Nares Strait Group, BB = Baffin Bay Group, Q = Qaanaaq Formation, D = Dundas Group. Coastal cliffs are about 600 m high. Photo: 543 B-NØ 2738, July 1950; Kort- og Matrikelstyrelsen, Denmark.

Thin sections show a range in quartz mode. Fine-grained arenites and siltstones are characterised by moderately well-sorted subangular to rounded quartz with limited size variation and with interstitial iron oxide, silica cement and mica; coarse types have a pronounced size bimodality with exceptionally well-rounded oxide-coated quartz grains which are set in a fine matrix. Such coarse rocks may be grain or matrix supported, the texture varying within the same rock.

Depositional environment. The member is taken to represent an interval of fluvial deposition in a general oxidising environment. Mudcracks indicate repeated subaerial exposure.

Fossils. None known.

Boundaries. The Granville Fjord Member has conformable lower and upper contacts with unnamed sandstones of the Robertson Fjord Formation. The lower boundary is well demarcated by a colour change to deep purple, but lithologically it is fairly gradational, drawn at the main incoming of shale or siltstone beds. The upper boundary is sharply defined at the top of the thin, dark purplish grey, massive sandstone described above.

Siorapaluk Member

new member

Composition. The member includes the uppermost strata of unit 5 of Dawes (1976b) from Greenland and the uppermost sub-unit of unit V of Frisch & Christie (1982) from Clarence Head.

Name. After Siorapaluk, Robertson Fjord, the northernmost native settlement in Greenland (Figs 2, 83).

Distribution. In Greenland, Prudhoe Land south-east of Diebitsch Gletscher, Northumberland Ø and possibly western Steensby Land; in Canada, at Clarence Head and possibly in the Lyman Gletscher area.

Geomorphic expression and colour. Dark red to deep purple weathering, generally recessive and rather

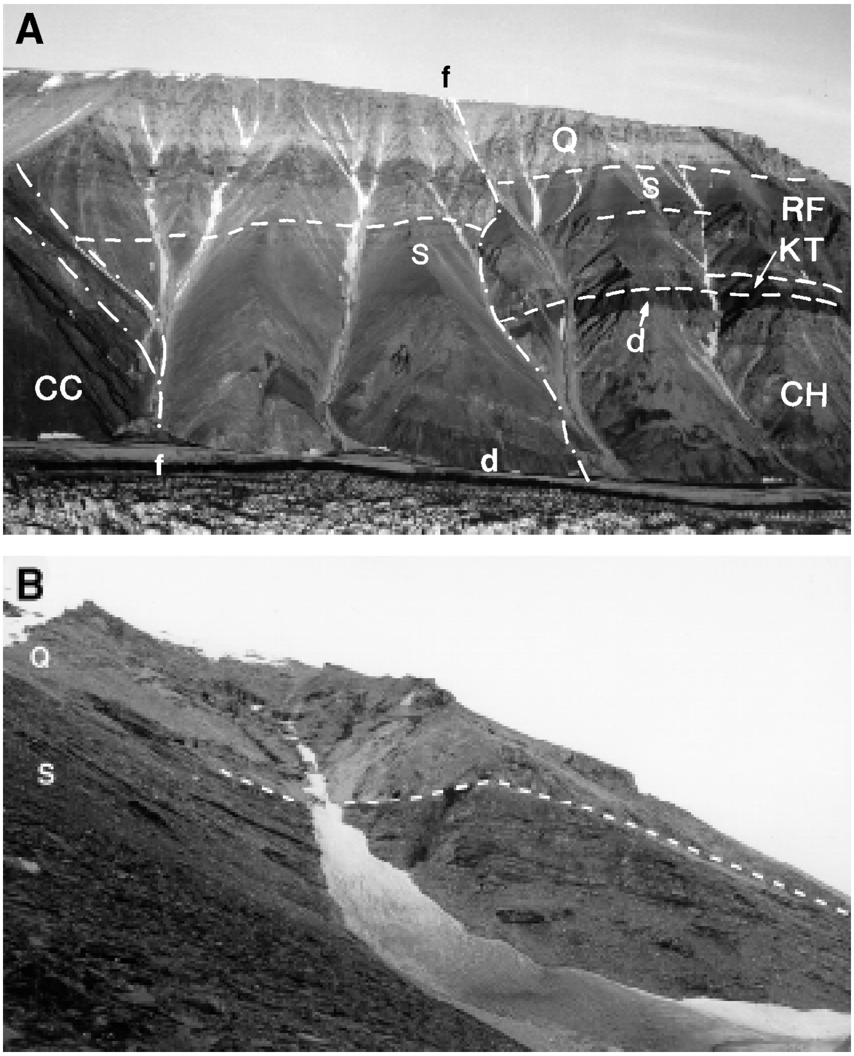

Fig. 91. The Siorapaluk Member (S) of the Robertson Fjord Formation (RF) at Morris Jesup Gletscher, Prudhoe Land. **A:** faulted exposures showing the member as a conspicuous recessive unit overlain by pale sandstones of the Qaanaaq Formation (Q). The division into a lower dark unit and a thinner paler unit is visible. CC = Cape Combermere Formation, CH = Clarence Head Formation, KT = Kap Trautwine Formation, d = dolerite sill. Height of cliff above glacier about 750 m; **B:** the type section; section 41, Fig. 89. Locations are shown in Fig. 90.

poorly exposed. Where the member contains prominent sandstones, medium to steep slopes occur.

Type and reference sections. The type section is on the south-eastern side of Morris Jesup Gletscher, Prudhoe Land (section 41, Figs 89, 90, 91B). Reference sections occur at Ukalersôq, Northumberland Ø (section 36, Fig. 79; section 42, Fig. 89) and at Clarence Head (section 35, Fig. 79).

Thickness. The member reaches a maximum thickness of about 190 m in Prudhoe Land; the thinnest section is at Clarence Head, where the member is 26 m thick.

Lithology. Dark red-purple weathering, thinly to very thinly interbedded sandstone, siltstone and shale. The rocks are varicoloured: sandstones are mainly purple with brown to buff, grey to pale green and greenish white varieties; siltstones and shales are mainly deep purple and green. The ratio of sandstone to siltstone-shale varies both vertically and laterally; in general terms the sandstones coarsen upwards. The type section is divisible into a lower unit of deep purple, fine-grained sandstone, siltstone and shale, and an upper unit in which paler, generally coarser sandstone is intercalated with lower unit lithologies (Fig. 91). Medium-bedded, pale green sandstone forms the uppermost 5 m of the member. At Clarence Head dark laminated hematitic sandstones characterise the top of the member; the bulk of the unit is dark red, shaly siltstone flecked with muscovite (Frisch & Christie, 1982).

The strata are planar to lenticularly bedded. In the type section wavy to irregular bedding surfaces characterise several levels, and thin sandstone beds less than a centimetre thick may be completely disrupted and enveloped by shale. Some of the bedding irregu-

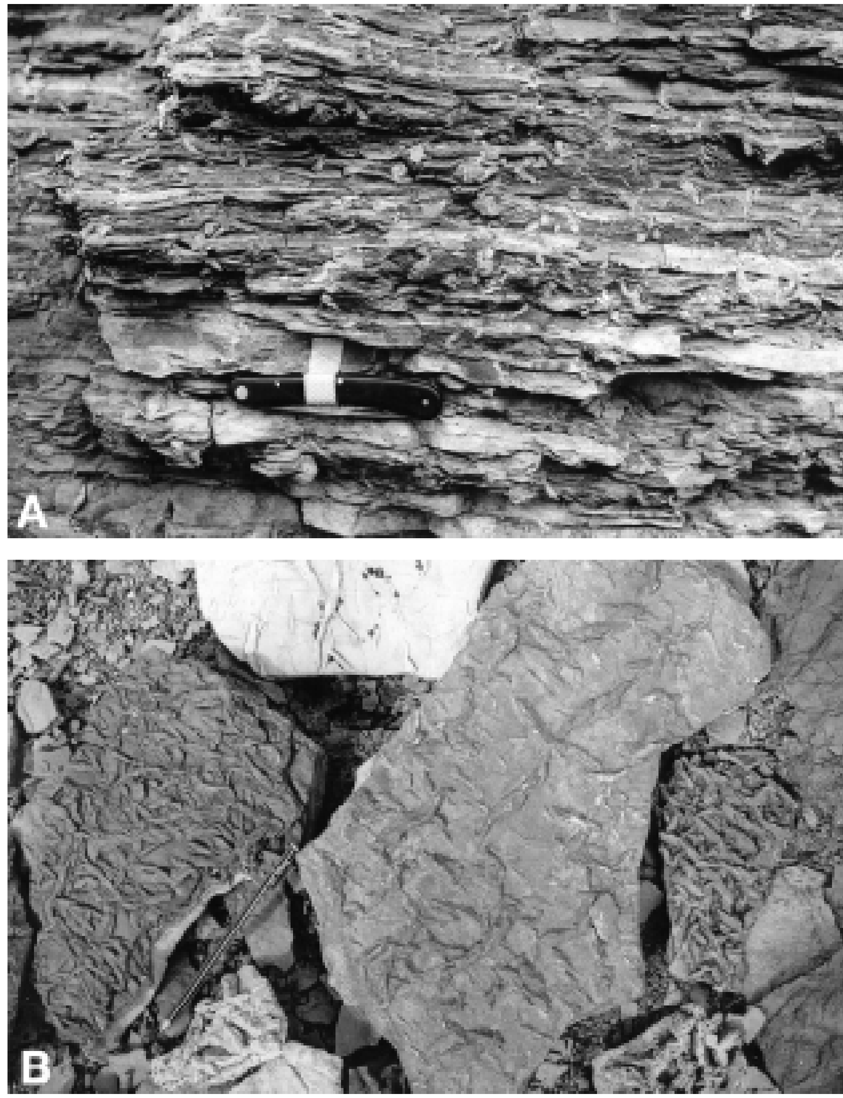

Fig. 92. Thin-bedded sandstone-shale lithology of the Siorapaluk Member of the Robertson Fjord Formation showing prominent mudcracks.
A: irregular sandstone infillings disrupting shale; penknife is 7 cm long;
B: diastasis cracks on bedding planes seen as sinuous to curvilinear structures, pencil as scale. Morris Jesup Gletscher, section 41.

larities seem due to loading or channelling of sandstone into shale, but others are due to diastasis cracks (Fig. 92).

The sandstones are generally fine grained and with the siltstones may be variously laminated. Most sandstones have silty or shaly partings but some thin pale structureless beds also occur; these are of medium to coarse grain size grading into grits with scattered quartz granules up to 2 mm across. Some sandstones show small-scale cross-bedding, ripple marks and in places flaser bedding. Mudcracks occur locally. Dusky red hematite-rich sandstone is present sporadically in beds 10–30 cm thick.

The sandstones are quartz arenites in which quartz varies from rounded to subangular. Fine-grained rocks are generally well sorted with original grain boundaries indistinct; coarser types are mainly grain supported with rounded quartz in an interstitial matrix of hematite and sericite. Some sandstones show bimodal quartz with well-rounded grains set in a much finer-grained subrounded to subangular matrix. Some rocks show appreciable secondary enlargement of well-rounded quartz grains. Glauconite is present in some sandstones, and samples from Northumberland Ø have matrix carbonate. Shales can be fissile, and both shales and siltstones are micaceous.

Depositional environment. The fine interlayering of the sandstones and shales, small-scale cross-beds with flaser and lenticular bedding indicate overall deposition in a low-energy shallow-water environment, such as an intertidal sand flat or a tidal delta plain. White, coarser-grained sand sheets with irregular bases are possibly tidal or subtidal channel sands.

Fossils. Acritarchs from shales on Northumberland Ø and at Morris Jesup Gletscher contain an assemblage of eight species (Vidal & Dawes, 1980). The most age diagnostic taxa are *Leiosphaerida asperata*, *Chuaria circularis* and *Kildinella chagrinata*, all typical Late Riphean forms.

Boundaries and correlation. The Siorapaluk Member has a well-defined and commonly sharp boundary to the underlying cliff-forming sandstones drawn at the base of the first shale-siltstone bed (Fig. 91A). It is often marked by a clear break in slope. The upper limit is the formational boundary, viz. a conformable contact with the buff sandstones of the Qaanaaq Formation (Fig. 91B).

The relationship to the Smith Sound Group in the north is not exposed but there is lithological similarity to the Hatherton Bugt Member of the Rensselaer Bay Formation, which is a possible lateral equivalent.

Wolstenholme Formation

redefined

Composition. Redefinition entails drastic reduction of stratigraphic range and geographical distribution. The redefined Wolstenholme Formation corresponds to the lower red sandstone of Chamberlin (1895) from Inglefield Bredning (Figs 6, 95). It is grossly equivalent to the lower reddish part of the Wolstenholme Quartzite/Formation of Kurtz & Wales (1951), Davies (1957), Davies *et al.* (1963) and Fernald & Horowitz (1964) as described from the North Star Bugt area and environs, as well as the lower red bed member of the formation as illustrated by Dawes (1976a) from south-eastern outcrops of the Thule Basin, viz. Bylot Sund, Steensby Land and south-easternmost Prudhoe Land. It has to be stressed that, as redefined, the formation does not include any strata from Northumberland Ø, Prudhoe Land and Ellesmere Island previously referred to the Wolstenholme Formation by Dawes (1976b, 1979a), Frisch *et al.* (1978), Frisch & Christie (1982), Dawes *et al.* (1982a) and Jackson (1986).

Name. After Wolstenholme Ø, the island forming the western entrance to Bylot Sund (Figs 2, 93).

Distribution. Forms the south-eastern outcrops of the Thule Basin, viz. Wolstenholme Ø and on the opposing mainland at Magnetitbugt, De Dødes Fjord, lands bordering Wolstenholme Fjord, Olrik Fjord and Inglefield Bredning, Nunatarssuaq, with isolated outcrops

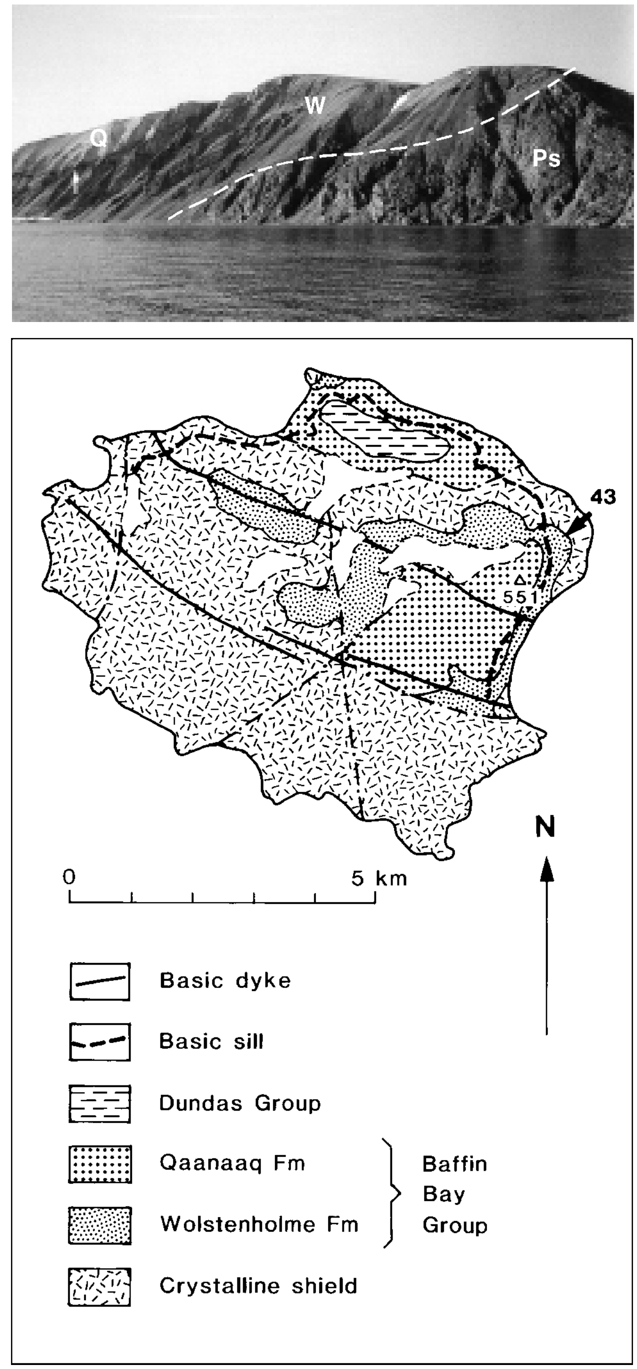

Fig. 93. Geology of Wolstenholme Ø, Greenland, showing the location of section 43. The photographic view is of the north-eastern sea-cliffs (section 43) showing the Wolstenholme Formation (W) overlying the Precambrian shield (Ps). The contact with the Qaanaaq Formation (Q) is partly followed by a basalt sheet (arrowed). Height of 551 is in metres. For location, see Fig. 2.

at Freuchen Nunatak, Dryasbjerg, Rampen and east and west of Academy Bugt (Figs 2, 12).

Geomorphic expression and colour. A dark red to purple weathering resistant unit, commonly banded and generally forming cliff sections and steep coasts. The thin, isolated inland outliers are poorly exposed.

Type and reference sections. The type section is that described by Davies *et al.* (1963) from Wolstenholme Ø (section 43, Figs 93, 94). A well-exposed and accessible reference section, examined but not measured, is at Tikeraussaq on the south side of Inglefield Bredning (Fig. 95); sections in Olrik Fjord are generally poorly exposed (see Fig. 103).

Thickness. The formation has an estimated maximum thickness of about 250 m in the Inglefield Bredning area, thinning to less than 100 m in Wolstenholme Fjord. This regional thinning is thought to continue farther east and south but the isolated outliers forming marginal strata of the Thule Basin, for example at Academy Bugt at the head of Inglefield Bredning, are truncated by the present erosion surface (Fig. 12). If the relationship with pale sandstones of the overlying Qaanaaq Formation at Freuchen Nunatak (Fig. 2) is stratigraphic (rather than tectonic), thinning down to perhaps some tens of metres is demonstrable.

Lithology. A red bed sequence dominated by sandstones with grits, pebbly sandstones and conglomerates (Fig. 96), and minor amounts of siltstone and shale. Where fresh, the sandstones – variously ferruginous quartz arenites – are red-pink to purple-maroon-lilac in colour, weathering in darker hues, but orange, brown and buff varieties also occur. Generally, the rocks are medium to coarse grained with common gradation to granule and conglomeratic beds; a characteristic feature is the very common lateral and vertical variations in grain size.

The sandstones vary from thin- to very thick-bedded, commonly with trough and tabular planar cross-bedding, and ripple marks. Erosive undulose bases to sandstone and conglomerate beds are common locally as are scour-and-fill structures. Oligomict quartz-pebble conglomerates were noted at levels throughout the formation, but in some sections rudaceous rocks are rare or absent. Conglomerates vary in bed size and in density of pebbles. Many conglomerate incursions have diffuse contacts with pebbly sandstone and sandstone; discrete sheets are lenticular to wedge-shaped and up

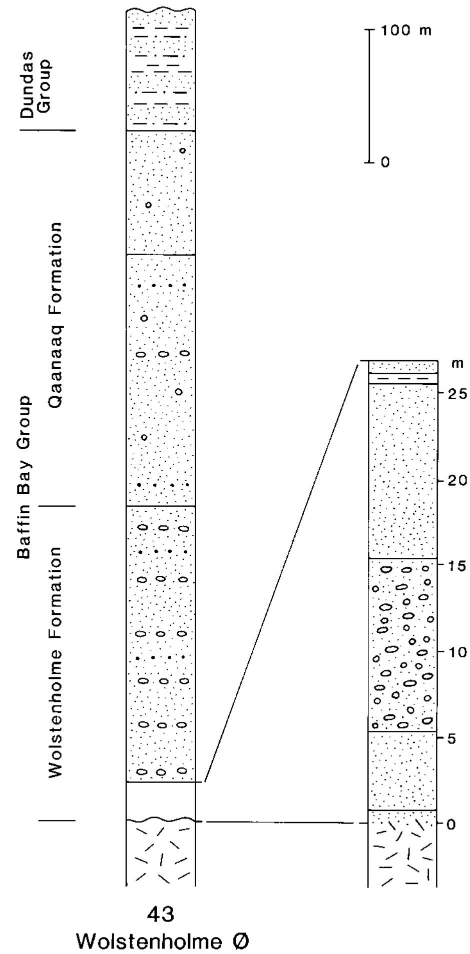

Fig. 94. Generalised sections of the Wolstenholme and Qaanaaq Formations (Baffin Bay Group) on Wolstenholme Ø. Compiled from data in Davies *et al.* (1963). This is the type section of the Wolstenholme Formation; for location, see Fig. 93.

to 2 m thick. Some fining-upward beds from conglomerate to sandstone occur. Typical conglomerates are matrix-supported with pebbles several centimetres long composing up to 70% of the rock (Fig. 96). Sporadic quartz clasts are of cobble dimension and boulders of quartz up to 30 cm were noted by Kurtz & Wales (1951) composing a 5 m thick conglomerate near the base of the formation on Wolstenholme Ø.

True basal conglomerate is inconspicuous. Where the unconformity between the Wolstenholme Formation and crystalline rocks has been examined by this author, for example on the north side of Wolstenholme Fjord (Fig. 97), the basal beds are brownish orange, regularly bedded, medium-grained, ripple-marked sandstones, in places with a basal 0–10 cm thick conglomerate mainly composed of quartz pebbles but with small angular to subrounded fragments of granite. Some

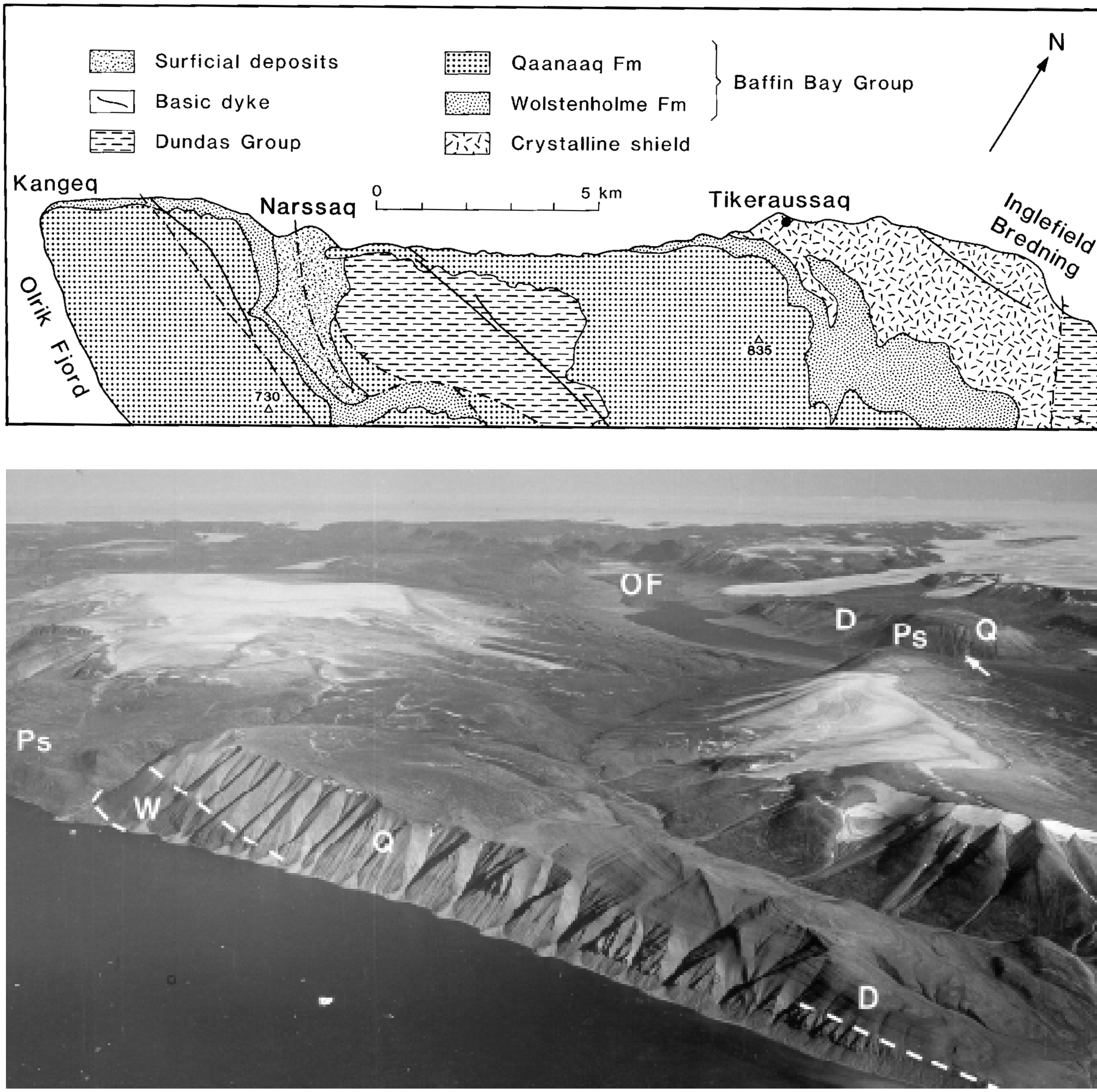

Fig. 95. Geology of the Tikeraussaq area, on the south side of Inglefield Bredning, Greenland, illustrating the westernmost outcrops of the Wolstenholme Formation (W). The photographic view is east to Olrik Fjord (OF) with the Inland Ice in the distance. The Precambrian shield (Ps) forms a basement high (Tikeraussaq High, see Fig. 119) over which the Baffin Bay Group is draped. The nearest exposures to the north around Bowdoin Fjord (Fig. 98) and to the south in Steensby Land (Fig. 87) preserve strata of the Nares Strait Group that farther east are cut out and define the south-eastern margin of the central part of the Thule Basin. The fault block (arrowed), preserving Wolstenholme and Qaanaaq (Q) Formations, is flanked on the east by the Dundas Formation (D). The tripartite division seen at the coast (W, Q and D) corresponds to the three stratigraphic units recognised initially by Chamberlin (1895) and adopted by Koch (1926, 1929a) for the entire Thule district. Heights are in metres. Photo: 543 K1-Ø 2803, July, 1950; Kort- og Matrikelstyrelsen, Denmark. For location, see Fig. 2.

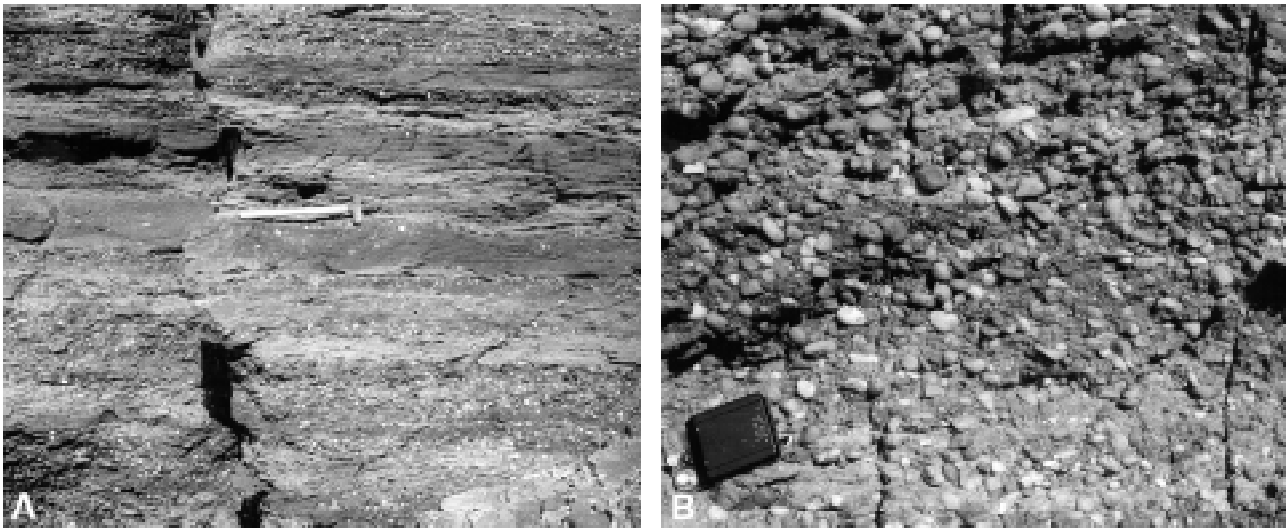

Fig. 96. Bedding characteristics of the Wolstenholme Formation at Kangeq, Inglefield Bredning (Fig. 95). **A:** red sandstone with shallow cross-bedding, pebbly sandstones and quartz-pebble conglomerates; **B:** matrix-supported quartz-pebble conglomerate on bedding plane; the compass is 10 cm long.

beds about 3 m above the contact contain intraformational conglomerate. Sandstone dykes 1 to 3 cm thick occur as joint infillings in the underlying gneiss. The gneiss is lilac to reddish in colour, well jointed and containing extraneous hematite and quartz. A similar contact has been described from Wolstenholme Ø by Kurtz & Wales (1951), who interpreted the basal siltstones as reworked residual soils with scattered pebbles of crystalline rock.

Minor dark purple siltstone and shale occur interbedded with fine-grained sandstones. Shale laminae and partings occur, and some sandstone beds contain rip-up shale chips. Desiccation cracks can be common on the upper surfaces of shale beds and on shale-siltstone partings. On Wolstenholme Ø, Davies *et al.* (1963) report a yellow shale unit 60 cm thick. Argillaceous beds give rise to some of the banding that typifies the formation but other lithological variations causing distinct banding are beds of dark purple to dark bluish grey hematite-rich sandstone. These beds range from a few centimetres thick up to about a metre.

Ferruginous banding occurs on all scales from regular, fine lamination parallel or subparallel to bedding, to liesegang rings and coarser discordant bands. Such banding is often more conspicuous than bedding and can be easily mistaken as such. Three generations of liesegang rings, determined by cross-cutting relationships, have been recorded on one rock slab.

Fig. 97. The unconformity between the Wolstenholme Formation (left) and the Precambrian shield. The basal beds are ripple-marked, cross-bedded sandstone with some grits and conglomerate. Basal sandstone bed (in centre) is *c.* 20 cm thick. North side of Wolstenholme Fjord; location is given in Fig. 107.

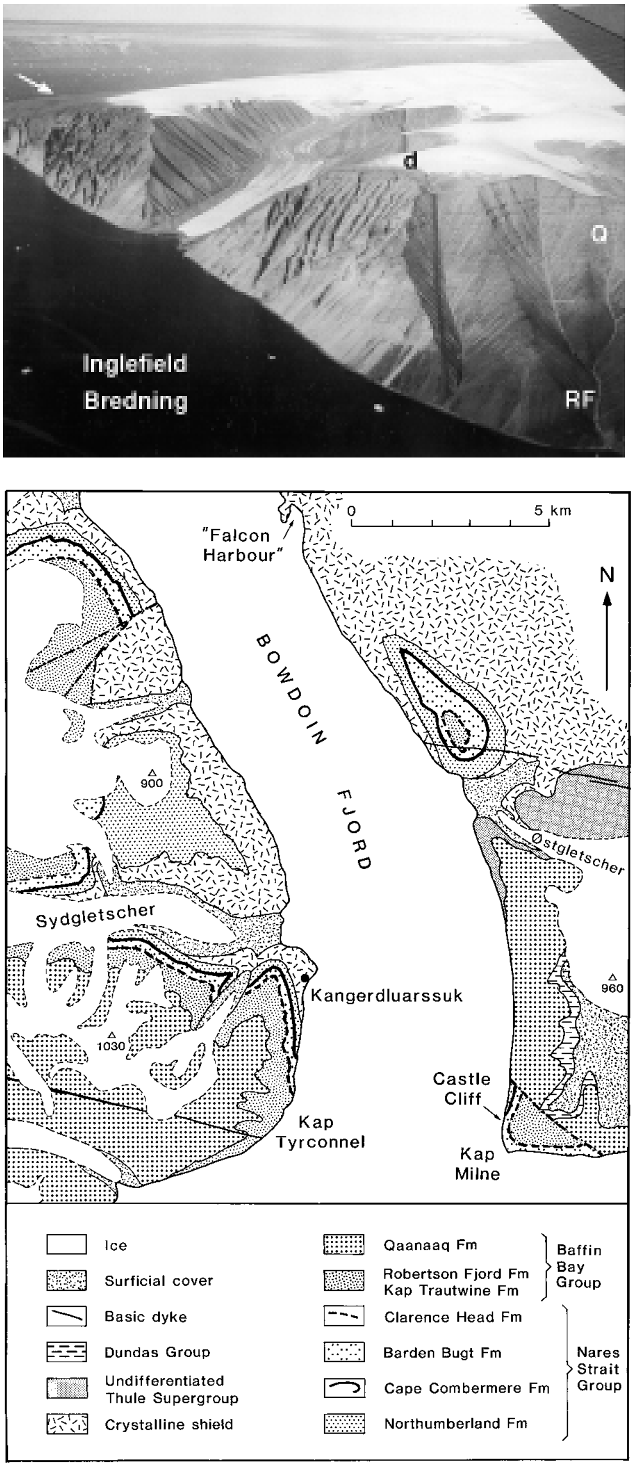

Fig. 98. Geology of the Bowdoin Fjord – Qaanaaq area, southern Prudhoe Land, Greenland. The view of the sea-cliffs, over 800 m high, is to the west over Kap Tyrconnel showing the type area of the Qaanaaq Formation (Q). The basic dyke (d) is shown on the map reaching the coast at Kap Tyrconnel. Qaanaaq town is arrowed and Herbert Ø is visible in the distance. The horst at Castle Cliff exposes the easternmost outcrops of the Nares Strait Group. RF = Robertson Fjord Formation. Heights are in metres. For location, see Fig. 2.

The quartz arenites show limited gradation towards subarkoses, particularly in basal strata, but feldspar content only reaches a few per cent. Main rock types are well sorted with well-rounded quartz grains showing various degrees of authigenic silica outgrowths. Some rocks are hard quartzites with appreciable grain intergrowth and tight silica cementation. Iron compounds, mainly hematite, vary both in abundance and in setting: thin to thick coatings around quartz grains, fine dissemination in the matrix, substantial interstitial concentration, or a ferruginous cement.

Depositional environment. The Wolstenholme Formation is interpreted as an alluvial deposit laid down in an overall oxidising environment. The scarcity of argillaceous material suggests fairly immature reaches of the fluvial system, and the main part of the succession is taken to represent deposition in a braided river system. The lithologies with finer clastic sequences could represent meandering stream channel deposition.

Fossils. None known.

Boundaries and correlation. The Wolstenholme Formation directly overlies the crystalline shield. The upper boundary is a conformable contact to the Qaanaaq Formation and represents a regional marker (Figs 93, 95). The contact is generally well demarcated, with the red beds of the Wolstenholme Formation giving way fairly abruptly to overlying pale sandstones.

In Steensby Land and eastern Inglefield Bredning, the Wolstenholme Formation grades laterally into the Robertson Fjord Formation and probably also into the underlying Kap Trautwine Formation (see Fig. 120). The boundary to the thicker, more basinal Robertson Fjord Formation is somewhat arbitrarily placed but drawn to coincide with the marginal faults that limit the extension of the Nares Strait Group to the south and east. Hence the Wolstenholme Formation directly overlies crystalline basement, while the thicker and more lithologically diverse red bed strata represented by the Kap Trautwine and Robertson Fjord Formations overlie the Nares Strait Group. In some outcrops, for example on Wolstenholme Ø and in eastern Steensby Land, pale sandstones at the base of the Wolstenholme Formation may well be coeval to strata of the Nares Strait Group.

Qaanaaq Formation

new formation

Composition. The Qaanaaq Formation corresponds to the pinkish grey sandstone unit of Chamberlin (1895) from Inglefield Bredning (Figs 6, 95). It is grossly equivalent to the upper light-coloured part of the Wolstenholme Quartzite/Formation as defined in the North Star Bugt area by Kurtz & Wales (1951), Davies (1957) and Davies *et al.* (1963), and member (d), subsequently unit 6, of that formation as described from Northumberland Ø and Herbert Ø by Dawes (1975, 1976b). It includes the upper 100 m of the section at Siorapaluk and about 200 m of strata at Uvdle, Wolstenholme Fjord, examined by Munck (1941). In Canada the formation includes the entire section described by Christie (1975) from south of Lyman Glacier, the upper sub-unit of unit V of Frisch *et al.* (1978), unit VI of Frisch & Christie (1982) as exposed at Clarence Head, and the upper part of unit VI and unit 6 of Frisch & Christie (1982) and Jackson (1986) as defined at Goding Bay. In the scheme erected by Dawes *et al.* (1982a) for both sides of Nares Strait, the Qaanaaq Formation corresponds to the 'Buff Sandstone unit'.

Name. After Qaanaaq, the Greenlandic name for the largest native settlement in North-West Greenland and capital of Avanersuup municipality (bears also the Danish name Thule) (Figs 2, 98).

Distribution. The most widely distributed formation of the Thule Basin. In Greenland it is present from Prudhoe Land in the north to inner Olrik Fjord in the east and to Wolstenholme Ø in the south, and also in the De Dødes Fjord outlier; in Canada the formation is represented in main outcrops south of Cadogan Inlet, from Paget Point to Goding Bay and at Clarence Head (Fig. 12).

Geomorphic expression and colour. A pale-weathering, predominantly buff to light brown, erosion-resistant unit, monotonous to indistinctly banded in general appearance, forming steep slopes and in places precipitous and spectacularly etched cliffed coasts (Fig. 98). Where the upper part contains fine-grained lithologies, medium slopes result and these can be poorly exposed inland.

Type area and reference sections. The type area is the coastal cliffs between Qaanaaq and Bowdoin Fjord (Fig. 98). No type section is designated but good reference

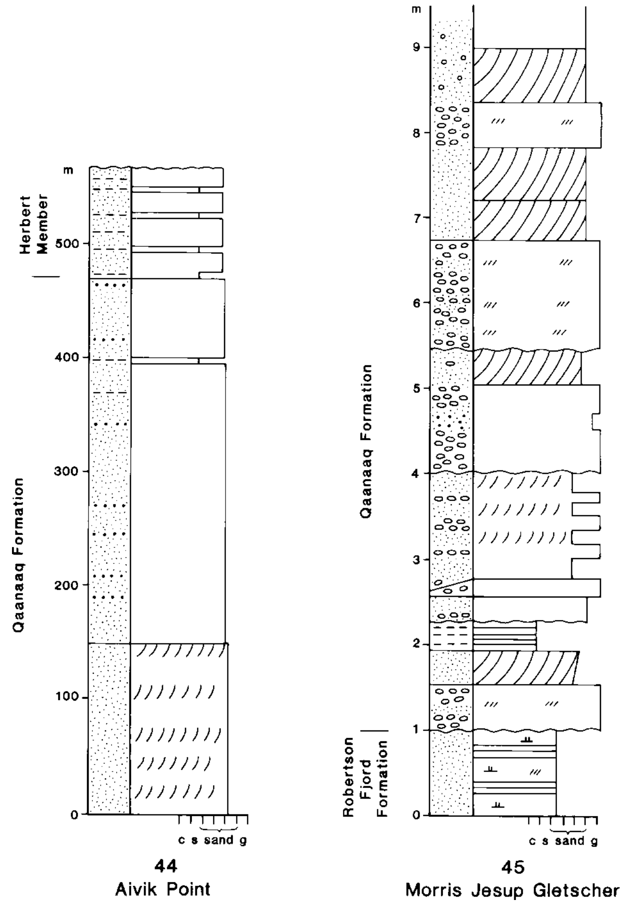

Fig. 99. Reference sections of the Qaanaaq Formation. The generalised section from Aivik Point showing the Herbert Member is compiled from data in Christie (1975) and located in Fig. 80. Stratigraphic log of the basal strata at Morris Jesup Gletscher is located in Fig. 90: it refers to part of the generalised section 41 shown in Fig. 89.

sections are on the south side of Morris Jesup Gletscher in Prudhoe Land, at Aivik Point, south of Lyman Glacier (sections 44, 45, Fig. 99) and at Goding Bay (sections 39, 40, Fig. 79).

Thickness. The formation ranges from less than 200 m in eastern outcrops to an estimated 900 m, perhaps as much as 1000 m, in Prudhoe Land (Fig. 12). In Canada where the formation is truncated by the present erosion surface, minimum thicknesses vary from 25 m at Clarence Head to 550 m at Aivik Point (Figs 79, 99).

Dominant lithology. Pale weathering, rather monotonous, thin- to thick-bedded quartz arenites with in some sections intervals of grit and quartz-pebble conglomerate with minor argillites (Figs 100, 101). The strata are varicoloured but predominantly light grey, buff,

Fig. 100. Medium to thick, planar cross-bedded sandstones of the Qaanaaq Formation. Morris Jesup Gletscher, section 41. One-metre measuring staff (lower centre) as scale.

pale brown, mauve and pink, with occasional darker red beds in the lower part. In the upper part, shale and siltstone beds break up the homogeneity of the sandstone lithology. These more argillaceous strata, which are recognised regionally, are described separately as the Herbert Member (see below).

In general terms the Qaanaaq Formation represents a gross fining-upwards succession. There is also marked lateral lithological variation both on a regional and a local scale. Hence such features as cross-bedding, fining-upwards units and quartz-pebble conglomerates can each characterise intervals of a succession, being elsewhere scarce or absent.

The sandstones are variously ferruginous with iron compounds being in the form of rusty brown spots, bedding surface films, or sandy concretions. Liesegang staining also occurs. In general, beds of darker hues occur in the lower part of the formation, and in places, for example on Herbert Ø and in western Steensby Land, lilac and red beds are interbedded with buff, giving the strata a banded appearance.

The sandstones are mainly medium grained, but there is a wide range in grain size, from fine to coarse with, in some sections, a fairly common gradation to granule and conglomerate beds. Cross-bedding and ripple marks have been seen at most levels but generally these structures appear to be more commonplace in the lower strata. Cross-beds, both of planar and trough types, are commonly in 15–50 cm sets but may be over 1 m.

Conglomeratic rocks are typified by rounded quartz pebbles that generally range between 0.5 and 3 cm; exceptionally attaining 8 cm. Blue quartz grains up to 5 mm across characterise some beds. The lithology varies from pebbly sandstone to matrix-supported or, less commonly, orthoquartzitic conglomerates (Fig. 101). The conglomerates are almost invariably quartz oligomictic, with occasional pebbles of other compositions. For example, Munck (1941) records frequent 'rolled fragments' of crystalline rocks, particularly a reddish gneiss, in a 10–15 m thick bed at Siorapaluk.

Conglomeratic layers commonly have gradational contacts to sandstone but sharply defined beds characterise some intervals. In these, upward-fining sequences may occur with a sharp conglomeratic erosive base passing into pebbly sandstone and sandstone. Conglomerate beds occur throughout except in the uppermost part (Herbert Member), but they show varying persistence laterally.

Sandstones range from homogeneous to weakly laminated. Some well-laminated rocks have brown to green-grey argillaceous partings that may be closely spaced or irregular. Shale, commonly brownish green in colour, may form discrete beds, particularly in the lower part and in the transition to the Herbert Member, but many of these are discontinuous. For example at Goding Bay, Jackson (1986) noted a 7 m thick interval of thinly laminated shale-siltstone-sandstone about 40 m from section base. This unit was not registered in the nearby well-exposed sections examined by T. Frisch and R. L. Christie (personal communications, 1990).

The sandstones are quartz arenites showing very limited variation towards subarkose. Feldspar content occasionally reaches 5 per cent, and rare beds, particularly in the upper part, have carbonate as a matrix mineral; some have well-rounded quartzite grains. In the main the sandstones are durable rocks showing authigenic overgrowth of well-rounded quartz grains. There is variation to less durable types that are often coarser grained or conglomeratic, and to hard durable quartzites that are characterised by appreciable secondary silica, grain intergrowth and thorough cementation. The sandstones are mainly well sorted and many are bimodal with rounded overgrown quartz grains, within a matrix or with interstitial, subrounded to subangular grains. Where fine hematite is disseminated in the matrix the rock takes on a variable pinkish hue; at one locality in Olrik Fjord fresh sandstone is speckled green by disseminated copper oxide.

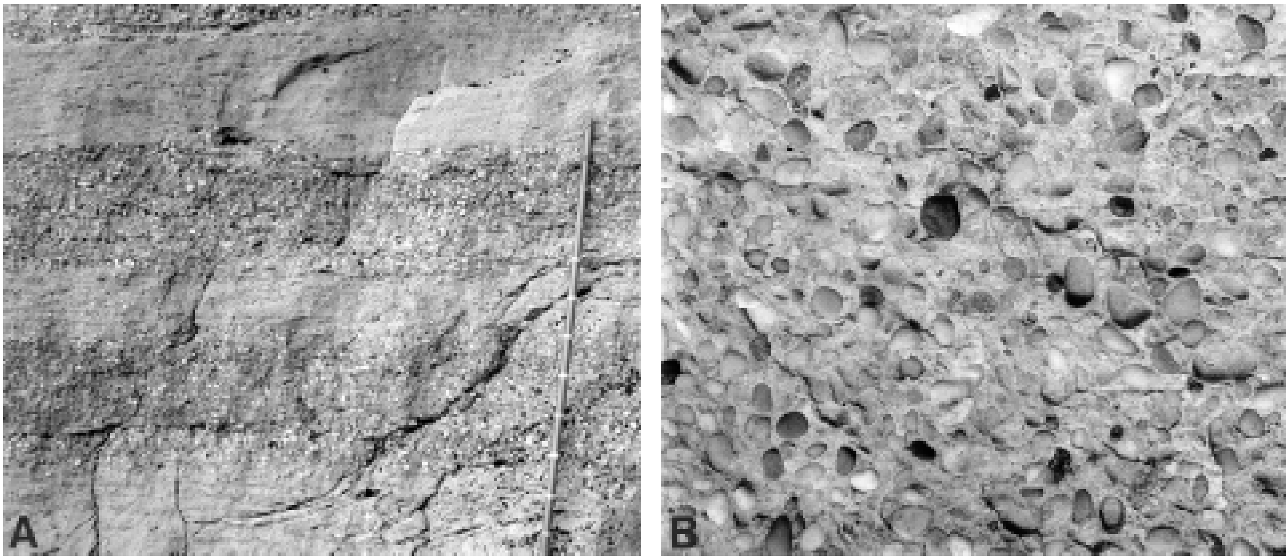

Fig. 101. Conglomerates and sandstones of the Qaanaaq Formation. **A:** fluvial sandstone and conglomerate, Morris Jesup Gletscher, section 41; **B:** bedding plane of quartz-pebble conglomerate with dark pebble in centre about 3 cm across, north side of Olrik Fjord.

Depositional environment. The Qaanaaq Formation is taken to represent varying depositional environments from alluvial plain to marine shoreline (Frisch & Christie, 1982; Jackson, 1986). Much of the succession in Greenland is interpreted as a braidplain deposit while some sections, with bimodal and herringbone cross-beds (Jackson, 1986), show tidal influence. The gross fining-upwards nature with incoming of argillites at the top is seen as a regional regression of the shoreline with a passage to coastal flood plain deposition and, subsequently, as exemplified by the succeeding formations of the Dundas Group, to perhaps an overall deltaic environment.

The presence of conglomerates, abundant in some sections, with trough-bedded sands, and the general absence of fine-grained overbank deposits, suggest overall deposition in a braided river system. The local fining-upward units are taken to be channel bar sands. The thick sections composed almost entirely of sands could represent sheet sand deposits due to the long-lasting migration of channels. Western outcrops may represent marine coastal deposition. For example, the conglomeratic, ripple-marked sands at Goding Bay are regarded by Frisch & Christie (1982) as possible offshore bars, while Jackson (1986), noting the paucity of cross-beds in the succession (compared to the tide-dominated sandstones below – herein referred to the Robertson Fjord Formation), suggests that in periods storm-dominated deposition may have prevailed.

Fossils. Organic-walled microfossils (acritarchs) – see under Herbert Member.

Boundaries and correlation. In Greenland, in eastern and southern outcrops, the Qaanaaq Formation conformably overlies the Wolstenholme Formation along a fairly well-demarcated boundary (Figs 93, 95); elsewhere the underlying strata are those of the Robertson Fjord Formation. This boundary is also distinct, generally marked by the abrupt change from the siltstone-shale dominated, red bed lithology of the Siorapaluk Member to pale sandstones (Figs 85, 88, 91). Where the lowest strata contain red beds, as for example at Bastion Pynt, the eastern point of Herbert Ø (Fig. 109), a somewhat gradational boundary exists and here the contact is placed at the top of the uniformly coloured red bed succession. At Morris Jesup Gletscher, Prudhoe Land, the boundary is drawn below a conglomerate having an erosional base (Fig. 99); at Paine Bluff in Goding Bay it is drawn above a 3 m thick dolomitic subarkose bed (Fig. 79).

The upper boundary of the Qaanaaq Formation represents the upper limit of the Baffin Bay Group in conformable contact with the Dundas Group (Fig. 102). The contact is transitional produced by the gradual increase upwards of darker fine-grained sandstone, siltstone and shale, within the paler sandstone lithology. The width of this transition zone varies. It may involve just several metres of strata in which case the boundary is fairly distinct and can be drawn at the top

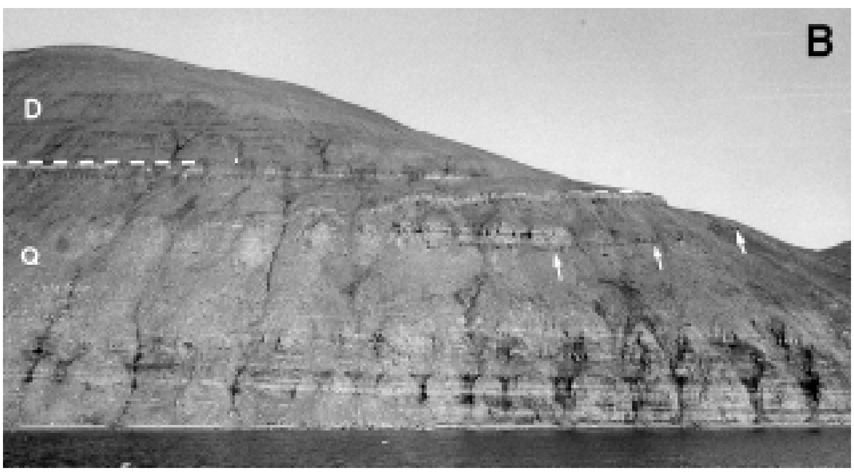

Fig. 102. The boundary of the Baffin Bay Group (Q, Qaanaaq Formation) and Dundas Group (D).
A: Conformable, fairly abrupt contact between pale sandstone-dominated lithology and darker siltstones and shales at Narssaq, Inglefield Bredning, with cliffs about 450 m high.
B: Transitional boundary with disruption of pale sandstone beds, suggesting penecontemporaneous faulting. Thin basic sills occur in the Qaanaaq Formation (Herbert Member) and one sheet (arrowed) strikes parallel to the displaced slab. Western end of Herbert Ø with the summit of the hill at about 350 m.

of the last buff-weathering sandstone (Fig. 102A); elsewhere the gradation is through tens of metres of strata, and the boundary definition is more arbitrary (Fig. 102B), often being determined by regional considerations. In several sections the upper boundary is drawn at the top of a ferruginous sandstone bed (see below under Herbert Member).

There is some evidence of penecontemporaneous faulting at the upper boundary of the Qaanaaq Formation (Fig. 102B) and in Prudhoe Land, for example west of Siorapaluk, the Dundas Group appears to overlap the structurally higher Qaanaaq Formation.

Lack of exposure prevents precise knowledge of the relationship of the Qaanaaq Formation to the Smith Sound Group, but the formation is deemed to thin northwards and to be, at least in part, a lateral equivalent of the Sonntag Bugt Formation (Figs 11, 120).

Subdivisions. The bulk of the Qaanaaq Formation is not formally subdivided but an uppermost, more argillaceous unit, recognised regionally, and in both Canada and Greenland, is defined as the Herbert Member.

Herbert Member

new member

Composition. This member corresponds to the 'upper beds' of Christie (1975) from Aivik Point, and the upper darker part of unit 6 of Dawes (1976b) from Northumberland Ø and Herbert Ø. It can be recognised as a 35–40 m thick interval in the section examined by Munck (1941) at Uvdle, Wolstenholme Fjord.

Name. After Herbert Ø, the eastern of three islands separating Murchison Sund and Hvalsund (Figs 2, 109).

Distribution. In Greenland: Prudhoe Land, Olrik Fjord, western Steensby Land, Northumberland Ø, Herbert Ø, Wolstenholme Fjord and Wolstenholme Ø; in Ellesmere Island, at Aivik Point and probably elsewhere in the Lyman Glacier area.

Geomorphic expression and colour. A light brown- to tan-weathering unit, rather monotonous in appearance, forming generally poorly exposed moderate slopes.

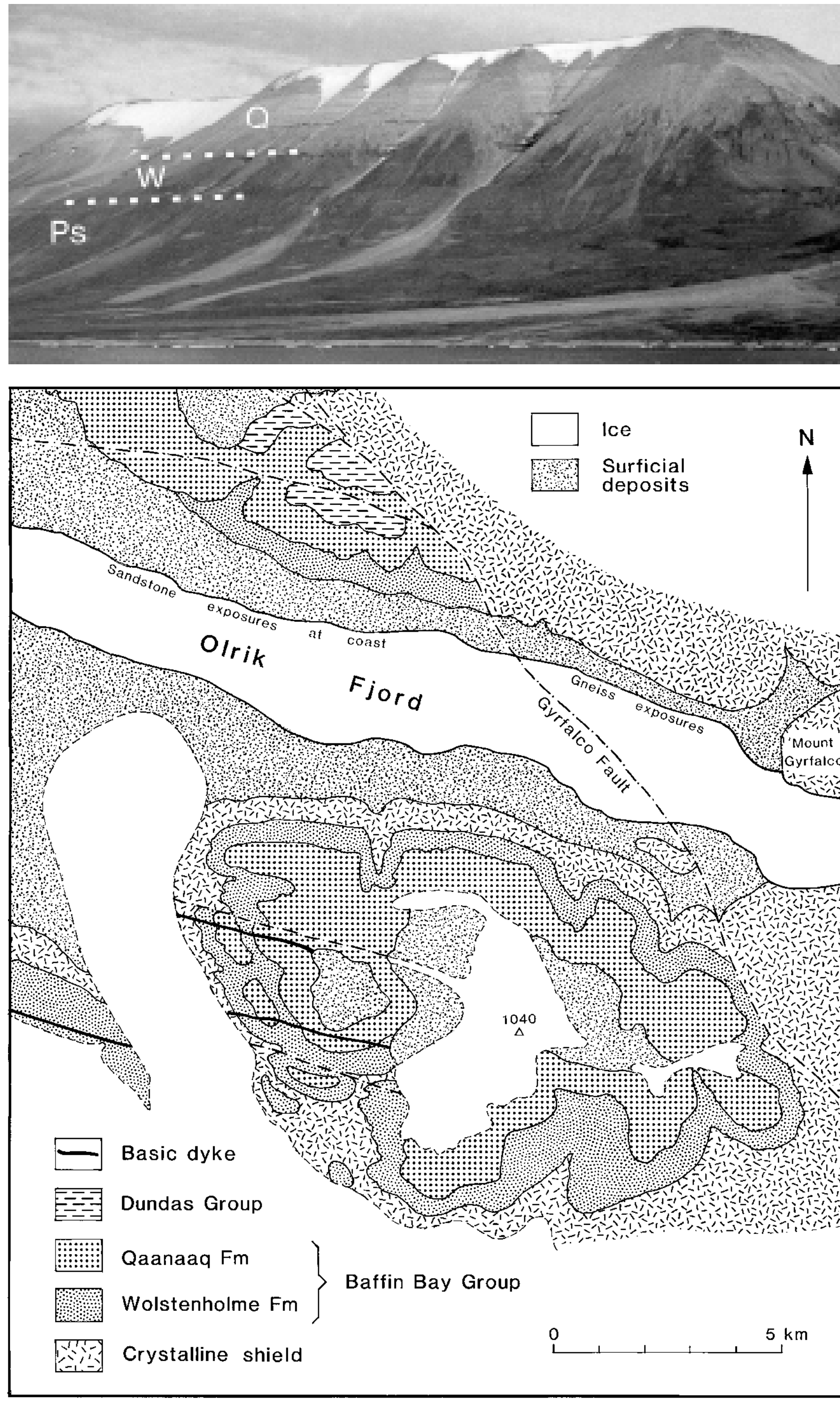

Fig. 103. Geological map and view of inner Olrik Fjord, Greenland, showing the eastern outcrops of the Thule Supergroup. The photographic view is of the south side of the fjord with the Baffin Bay Group overlying the Precambrian shield (Ps).
W = Wolstenholme Formation,
Q = Qaanaaq Formation, with the conspicuous darker Herbert Member forming the upper strata. Height of 1040 is in metres; sea-cliffs are about 700 m high. For location, see Fig. 2.

Type area and reference sections. The type area is the sea-cliffs of western Herbert Ø (Fig. 102); main reference sections are at Aivik Point (section 44, Fig. 99) and Uvdle, Wolstenholme Fjord (see Fig. 105). Other accessible sections, examined but not measured, are on eastern Northumberland Ø (Fig. 48), the interior of Olrik Fjord (Fig. 103) and in western Steensby Land at Kap Powlett and north-east of Kap Leiningen (Fig. 70).

Thickness. Ranges from about 30 m to at least 120 m.

Lithology. The main rock types are sandstone and shale grading to siltstone (Fig. 104). Overall, sandstone predominates. Upwards there is a marked increase in siltstone and shale, and sandstones become finer grained.

Sandstones are mainly buff, grey and brownish, very fine- to medium-grained, variously laminated quartz

Fig. 104. Interbedded sandstone and darker shales of the Herbert Member of the Qaanaaq Formation. Western end of Herbert Ø, south of Kap Lee. Height of the section is about 15 m.

arenites. Some are mildly calcareous and carbonate can form the predominant component of the cement matrix. Many sandstones are ferruginous, characterised by rusty flecks that reach several millimetres in size. Iron compounds are common on bedding surfaces, and rocks can take on a tan colour. The sandstones are mainly thin to medium bedded and planar to lenticular; beds more than 30 cm thick are rare. Thick beds are laterally continuous but in shale-dominated units thin sandstones show lensing.

The shales and siltstones are grey and greenish grey, and commonly weather buff to light brown. They are variously laminated and micaceous, and are ripple marked and mudcracked.

In several areas, the uppermost strata are richer in iron compounds. Dark beds of medium- to very coarse-grained ferruginous sandstone occur at Uvdle, Wolstenholme Fjord (see Fig. 105) and at Narssaq, Inglefield Bredning (Fig. 95). These beds, 75 cm and 1 m thick respectively, are characterised by well-rounded quartz and occasional quartzite grains, with dusty borders, set in a matrix of carbonate and hematite, with or without fine-grained quartz. At Narssaq, the bed is conglomeratic, containing rip-up clasts of ferruginous calcareous sandstone.

Depositional environment. A speculative interpretation of the Herbert Member is that it was deposited by meandering rivers in a coastal plain environment. Lowermost strata may represent point bar sands broken by intermittent overbank silts and clays, while the uppermost finer-grained beds could be a floodplain deposit. This interpretation is supported by abundant mudcracks indicating subaerial exposure, some carbonate precipitation and richly ferruginous beds.

Fossils. Curvilinear to curlicue bedding plane features regarded as trace fossils by Dawes & Bromley (1975) are reinterpreted as diastasis cracks (Cowan & James, 1992). An acritarch assemblage composed of thirteen species is derived from shales from Prudhoe Land (Dawes & Vidal, 1985). The stratigraphically most important taxa are *Kildinosphaera verrucata, K. lophostriata, K. chaginata, Leiosphaerida asperate, Tasmanites rifejicus* and *Satka colonialica*, an assemblage that indicates a Late Riphean age.

Boundaries. The member is bounded by conformable and gradational contacts with unnamed buff sandstones below and with the Dundas Group above (Figs 102, 103). The lower boundary is arbitrarily drawn within a zone of gradation marked by the incoming of thin shale-siltstone beds that increase upwards and pass into the interbedded sandstone and shale lithology of the Herbert Member. This boundary cannot be located regionally with precision but is drawn where shale-siltstone constitutes more than a single isolated bed. The boundary may mark a very gradual incoming of argillaceous material, such as at Aivik Point (Fig. 99), or a more abrupt change as in Olrik Fjord (Fig. 103). The boundary is commonly recognised as a marked colour change from pale brown-buff to the darker hues of the overlying Herbert Member.

In the type area the upper contact of the Herbert Member is drawn on a dark 10–15 cm thick ferruginous sandstone, although elsewhere in the vicinity and on eastern Northumberland Ø a basic sill occupies the contact. At two other sections, viz. at Narssaq, Inglefield Bredning (Fig. 95) and at Uvdle, Wolstenholme Fjord (Fig. 105), similar hematite-rich clastic beds have been conveniently chosen as the boundary.

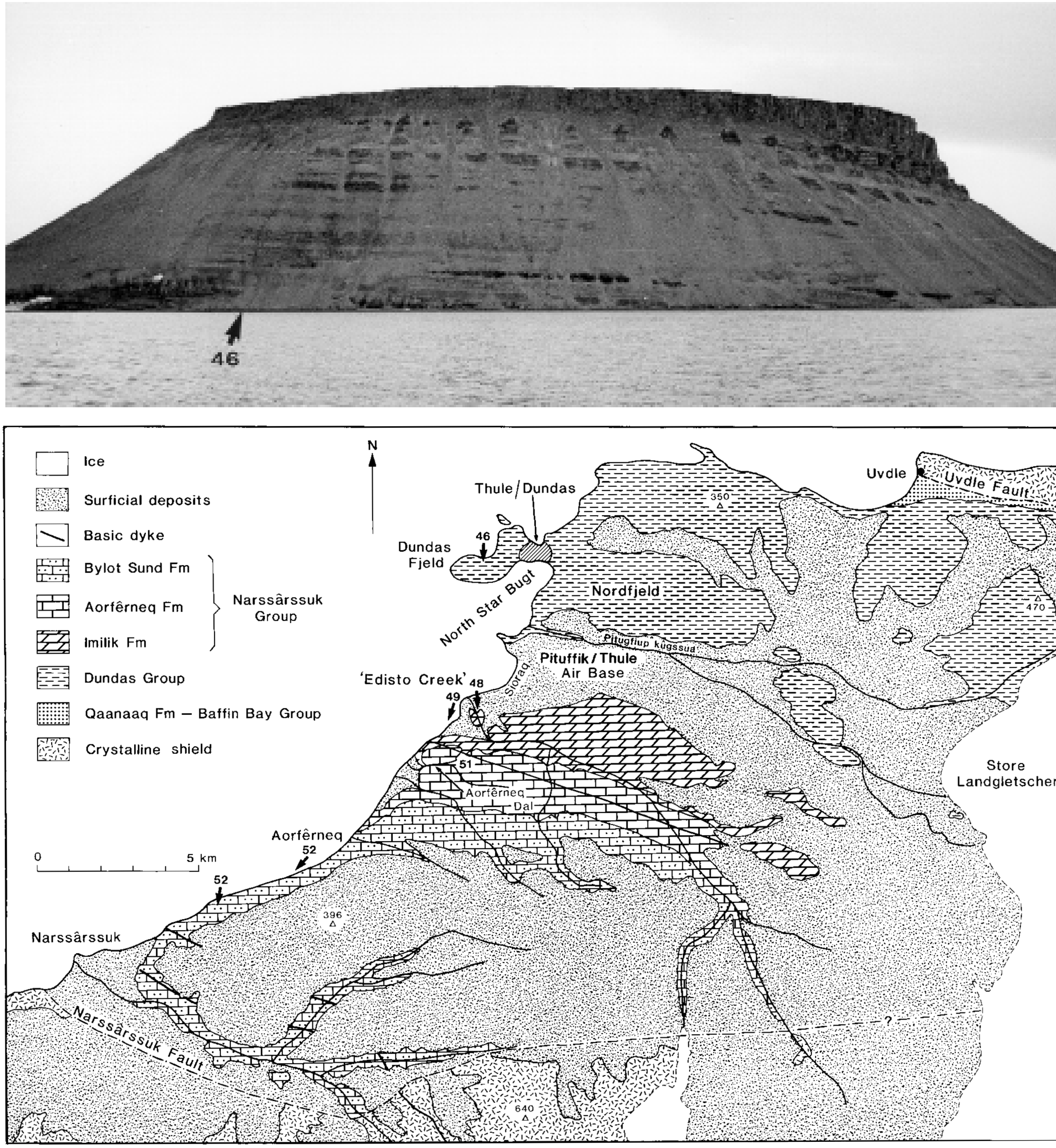

Fig. 105. The mesa-like landmark of the Thule district, Dundas Fjeld (Ummannaq), viewed from the north, and a geological map of the North Star Bugt – Narssârssuk area showing locations of sections 46, 48, 49, 51 and 52. This mountain and adjoining peninsula including Nordfjeld, and the coast between Sioraq and Narssârssuk, are respectively the type areas of the Dundas and Narssârssuk Groups. Section 46, given in Fig. 108, is composed of dark sandstones and shales of the Dundas Group (Steensby Land Formation) capped by a Hadrynian basic sill; summit is at about 225 m. Frequent basic sills in the Dundas Group are not shown on the map (cf. outcrop pattern in Fig. 107) but dykes of the late Hadrynian ESE-trending swarm are shown cutting the Narssârssuk Group. The boundary between the Dundas and Narssârssuk Groups is hidden by the surficial deposits of the wide valley supporting Pituffik. It is assumed to be a tectonic contact with the Narssârssuk Group preserved in a graben structure. The Narssârssuk Fault, limiting the Narsârsssuk Group to the south and juxtaposing it against the Precambrian shield, represents a substantial throw, in the order of kilometres. Heights are in metres. The cross-hatched area marked Thule/Dundas represents the abandoned sites of the Eskimo village and trading station Thule, and that of the Danish settlement, Dundas. For location, see Fig. 2.