Proterozoic – basal Cambrian stratigraphy across Nares Strait: correlation between Inglefield Land and Bache Peninsula

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In the Kane Basin region of Nares Strait (78° to 79°N) unmetamorphosed Proterozoic and basal Cambrian platform strata overlie the Precambrian Shield both in Inglefield Land in Greenland, and on Bache Peninsula in Ellesmere Island. The platform succession is composed of two shallow-water clastic sequences separated by an erosional disconformity. The lower formation, of multicoloured sandstone and siltstone with minor shale and stromatolitic dolomite, is assigned to the redefined Rensselaer Bay Formation; the upper, composed of red and overlying white sandstone with dolomitic sandstone and siltstone at the top, is assigned to the Dallas Bugt Formation. Basic sills from the Rensselaer Bay Formation have yielded isotopic ages as old as 1200 m.y., while the trace fossils *Rusophycus* and *Skolithos* suggest a basal Cambrian age for the Dallas Bugt Formation.

The platform sequences of Inglefield Land and Bache Peninsula show striking similarity in lithology and thickness and the detail correlation is supported by the evidence from isotopic ages of basic sills and from trace fossils. In both areas the bipartite succession is overlain with apparent conformity by dolomites that pass upwards into limestones containing Early Cambrian macrofauna.

The Rensselaer Bay Formation thickens southwards and passes into the much thicker sedimentary sequence of the Thule Basin, while the Dallas Bugt Formation and the overlying dolomites thicken northwards, indicating that the two formations were laid down in separate sedimentary basins. The close correlation of the platform successions and the corresponding configuration of the depositional slopes on both sides of the Kane Basin clearly indicate that the Proterozoic – Early Cambrian sedimentary pattern has not been radically disturbed by tectonism or by any appreciable transcurrent movement along Nares Strait.

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A striking feature of the unmetamorphosed Proterozoic and Cambrian sequences around Kane Basin (Fig. 1) is the close similarity between clastic and carbonate strata overlying the crystalline basement in Inglefield Land, Greenland, and on Bache Peninsula, Ellesmere Island. The similarity was noted by Schei (Holtedahl 1917), Bentham (1936a, b, 1941) and Wordie (1938), but is best known through observations in both areas made by J. C. Troelsen as a member of The Danish Thule–Ellesmere Land Expedition, 1939–41. Troelsen's preliminary results (Poulsen 1940) were expanded by Poulsen (1946: 304) whose correlations indicated "that the lands round the Kane Basin belong to one and the same morphological unit." Later stratigraphic descriptions by Troelsen (1950) emphasised the similarities, with several formations being recognised as common to both areas. Subsequent field work by Christie (1967) on Bache Peninsula and by J. D. C., P. R. D. and J. S. P. in Inglefield Land (Dawes 1972, 1979, Peel 1978, Collinson et al. in press) has maintained and strengthened the comparison.

This paper summarises the stratigraphy of the predominantly clastic strata which occur on Bache Peninsula and in Inglefield Land between the Precambrian crystalline basement and carbonates of Early Cambrian age. The early Cambrian carbonates and the overlying Cambro-Ordovician part of the sequence are described by Peel & Christie (this volume). Formal description of the units in question is beyond the scope of the present paper and has been undertaken elsewhere (Collinson et

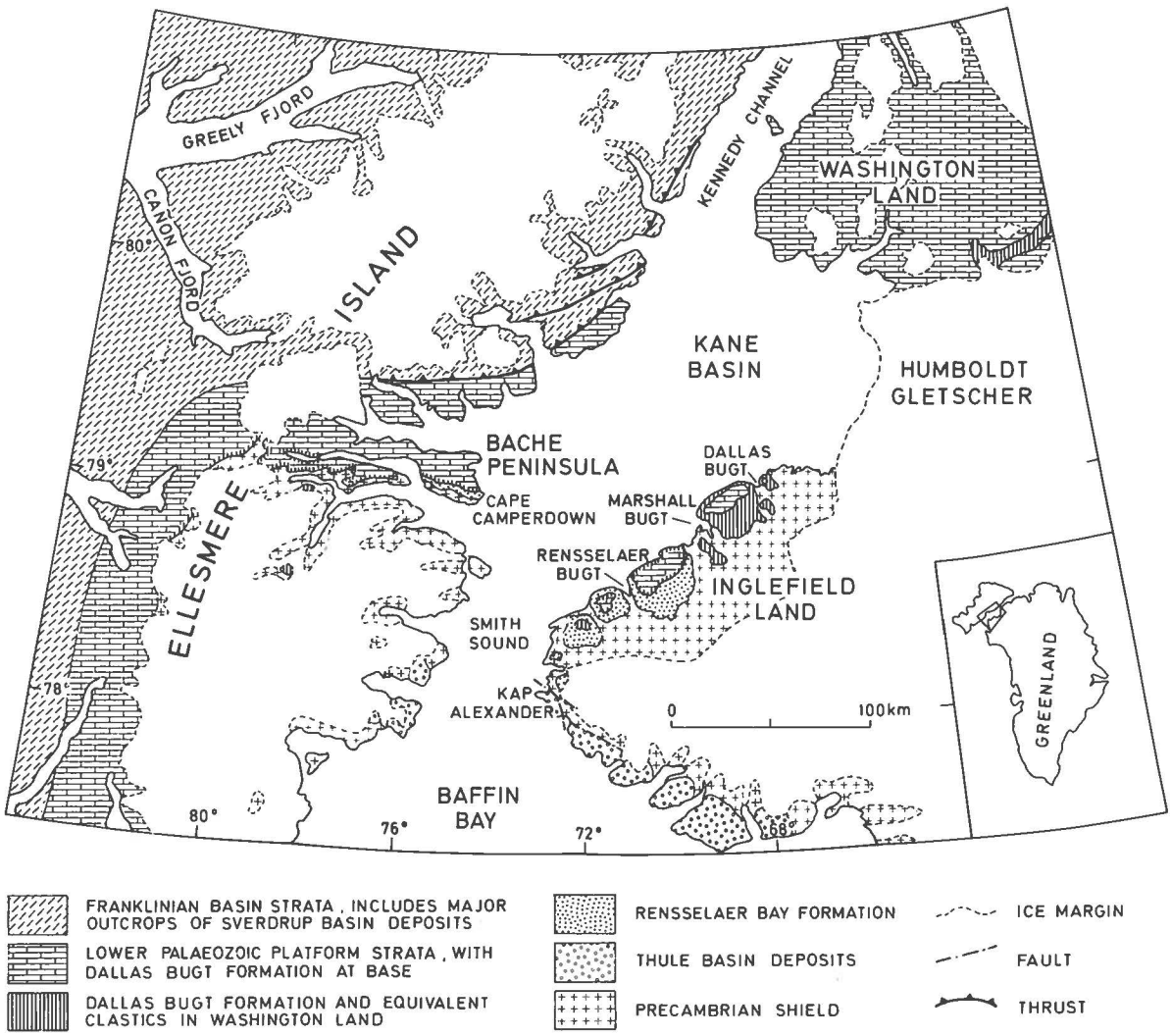


Fig. 1. Geological sketch map of land areas around Kane Basin. The thrusts shown mark the southern margin of the Ellesmere–Greenland fold belt.

al. in press). These clastic strata have previously been considered to form a uniform sequence of either late Precambrian or Early Cambrian age. However, our data indicate that the clastic sequence is composed of two separate formations of widely different ages, which were deposited in two independent basins. The two basins are separated by a regional basement high, the so-called Bache Peninsula arch of Kerr (1967b), although deposits in both basins overlap across the crest of the arch.

This significant revision serves to strengthen the stratigraphic comparison between Bache Peninsula and Inglefield Land. In addition, the line of junction between the two sedimentary basins in the two areas provides a datum which can be used in the present context for evaluation of net displacement along Nares Strait.

On the basis of stratigraphic similarity and the juxtaposition of basin margins across Nares Strait, it is concluded that large-scale net displacement along Nares Strait, i.e. 250 km, suggested on geological and geophysical evidence by authors such as Newman (1977, this volume), Sclater et al. (1977), Newman & Falconer (1978) and Srivastava (1978) has not taken place. These relationships are best explained by the present-day configuration of landmasses.

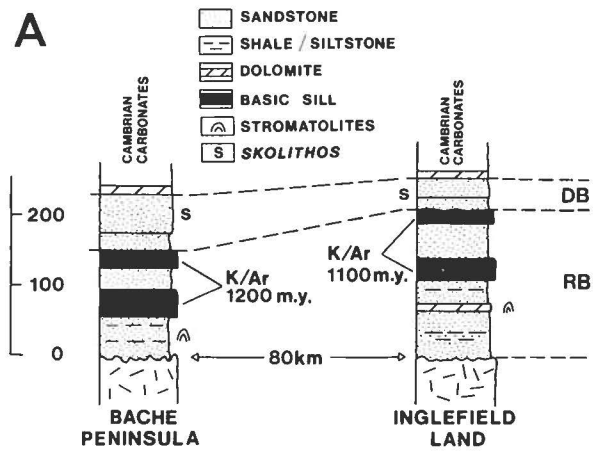
History

The strata described in this paper have previously been assigned to the Rensselaer Bay sandstone or Formation

of Troelsen (1950) and Christie (1967). They overlie the Precambrian Shield with profound unconformity and have been regarded as Proterozoic (Koch 1929, 1933, Bentham 1941, Cowie 1961), Eocambrian (Troelsen 1950, 1956a, b) or Cambrian (Wordie 1938, Kerr 1967a, b, Christie 1967, Cowie 1971) in age. Apparent conformity below proven Lower Cambrian strata, and suggested lateral correlation in Canada with the Lower Cambrian clastics and carbonates of the Franklinian shelf (Kerr 1967a) led to the conclusion that the Rensselaer Bay Formation was solely of Cambrian age, although Christie (1967, 1972) did not exclude the possibility that the lower part of the formation was of Proterozoic age.

Dolerite sills, present in the lower part of the formation in both Canada and Greenland, were isotopically dated on Greenland material as Proterozoic (Dawes et al. 1973). This put in doubt the Palaeozoic age assignment for at least that part of the formation in Greenland and, by inference, also in Bache Peninsula, although Christie's (1967) record of "scolithid-like" structures in the upper part of the Bache Peninsula sequence suggested a basal Cambrian age for part of the formation. Field work in Inglefield Land in 1977, 1978 and 1980 (Peel 1978, Dawes 1979, Collinson et al. in press) demonstrated that a major erosional unconformity exists between a lower sandstone sequence containing the basic sills and an overlying sandstone containing the trace fossils *Rusophycus* and *Skolithos*. Thus, it became clear that a bipartite division of the Rensselaer Bay sandstone/Formation of Troelsen (1950) and Christie (1967) could be achieved in both Greenland and Canada (Fig. 2).

Accordingly, the Rensselaer Bay Formation was restricted by Collinson et al. (in press) to the lower, Proterozoic part of the sequence which contains the isotopically dated intrusions. The upper part was assigned, in the same publication, to a new formation, the Dallas Bugt Formation (Figs 2 and 3). The geographical distribution of the two formations is shown in Fig. 1, from which it can be seen that the Dallas Bugt Formation oversteps the Rensselaer Bay Formation in both Greenland and Canada to lie in stratigraphic contact with the Precambrian Shield.



B

	Bache Peninsula	Inglefield Land	
DALLAS BUGT FORMATION	Sverdrup Member	Marshall Bugt Member	Early Cambrian
		Qáqaitsut Member	
	Bache Peninsula Member	Kap Scott Member	
RENSSELAER BAY FORMATION	Camperdown Member	(not formally subdivided)	Late Proterozoic

Fig. 2. Late Proterozoic and basal Cambrian stratigraphic correlation schemes between Bache Peninsula, Ellesmere Island and Inglefield Land, Greenland. A – generalised composite stratigraphy, RB = Rensselaer Bay Formation, DB = Dallas Bugt Formation; B – current stratigraphic nomenclature.

Stratigraphy

Rensselaer Bay Formation of Inglefield Land

In the type area, around Rensselaer Bugt, the Rensselaer Bay Formation, as redefined by Collinson et al. (in press), is an approximately 220 m thick complex of banded, multicoloured, often dark red and green sandstones and siltstones with subordinate shales which contain beds and lenses of stromatolitic dolomite (Fig. 4). Three principal sedimentary associations are recognised. An association of interbedded mudstone, siltstone and sandstone is characterised by dark red mudstone, and by units of interbedded siltstone and sandstone in beds a few centimetres thick. Dessication cracks and ripple marks are common. A medium-scale cross-bedded sandstone association contains poorly sorted, medium- to coarse-grained sandstones in beds up to 6 m thick, showing cross-bedding in troughs up to 50 cm. Quite well sorted, medium-grained sandstones showing large-scale cross-bedding in sets up to 3 m thick form the third association.

In south-westernmost Inglefield Land, the Rensselaer Bay Formation can be divided into three members, with light coloured, medium- to coarse-grained, cross-bedded sandstones forming the upper and lower members (Fig. 3). In the type area, these latter members are not developed.

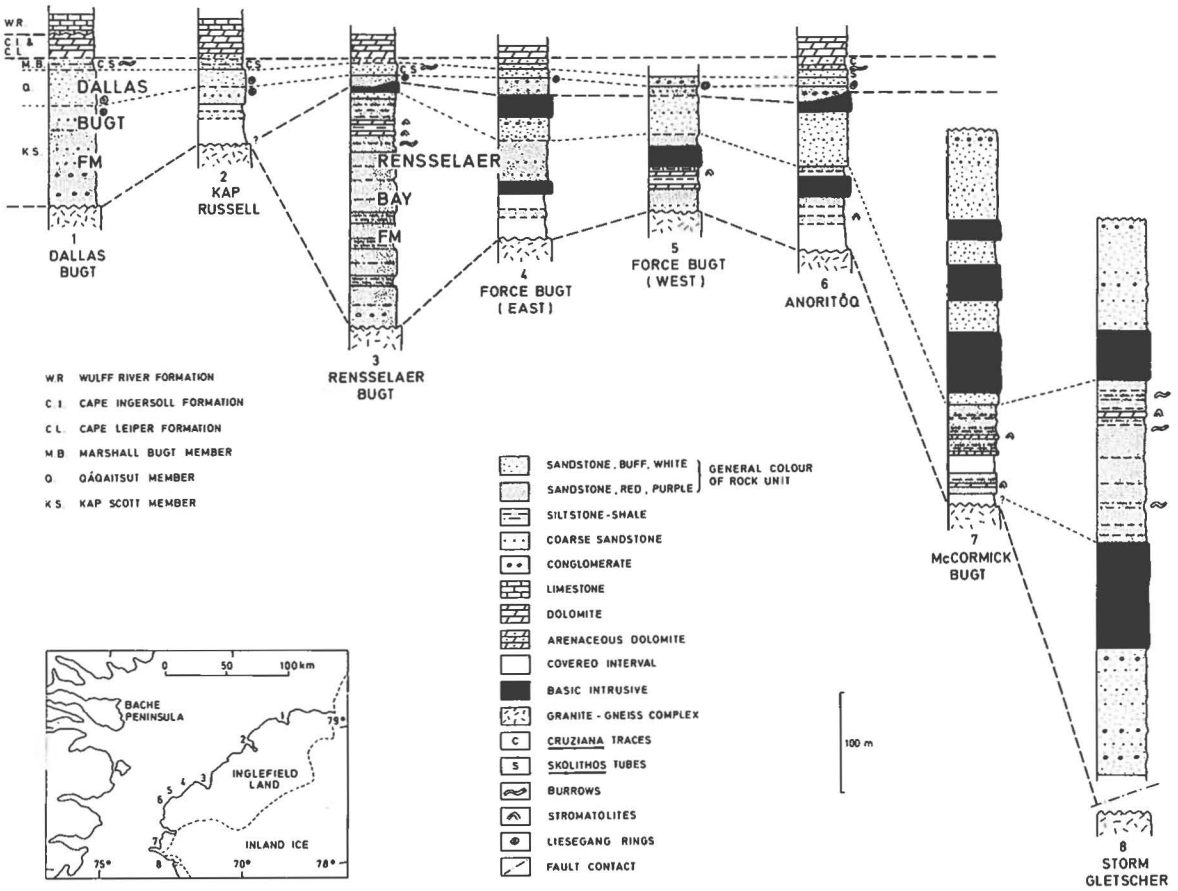


Fig. 3. Stratigraphical relationship between the Rensselaer Bay Formation and the Dallas Bugt Formation in North-West Greenland.

The Rensselaer Bay Formation rests with profound unconformity on crystalline basement (Fig. 5). Around Rensselaer Bugt, in Inglefield Land, the basement shows a local palaeorelief in excess of 150 m within about a kilometre, but elsewhere in Inglefield Land, to the south-west, the unconformity is planar. The upper boundary of the formation with the overlying Dallas Bugt Formation is apparently planar (Fig. 6).

The Rensselaer Bay Formation is intruded by dolerite sills (Figs 5 and 7B), which have yielded K/Ar whole-rock ages in the range 1070 ± 40 m.y. to 1190 ± 40 m.y. (Dawes et al. 1973). Crystalline basement overlain by the formation has yielded dates as young as 1520 m.y. (Larsen & Dawes 1974), suggesting that the Rensselaer Bay Formation is óf late Proterozoic (Helikian) age.

Rensselaer Bay Formation of Bache Peninsula

Collinson et al. (in press) retained only the basal Camperdown Member of Christie's (1967) Rensselaer Bay Formation (*sensu lato*) within the redefined Rensselaer Bay Formation (Fig. 2B). The overlying Bache Peninsula and Sverdrup Members were assigned to the Dallas Bugt Formation, as discussed below. The Camperdown Member consists mainly of thin-bedded, red and green shales and white, greenish and brownish sandstones. Thin calcareous beds, often stromatolitic, sporadically occur. The Camperdown Member has a maximum thickness at Cape Camperdown of about 85 m, but it gradually thins out and eventually disappears to the west (Fig. 1). The member is intruded by two dolerite sills (Fig. 7A). The freshest sample available, from the lower sill, has given a K/Ar whole-rock age of 1197 ± 33 m.y. (Dawes et al., this volume). Where the two dolerite sills are present the member is increased to a maximum of about 140 m in thickness (Fig. 2A).

A correlation in terms of members is not attempted at this time between the section recorded by Christie (1967) in the Camperdown Member at Bache Peninsula and the undivided Rensselaer Bay Formation of Inglefield Land. However, the similarity in lithology, particularly the distinctive red and green colouration, stratigraphic position between crystalline basement and

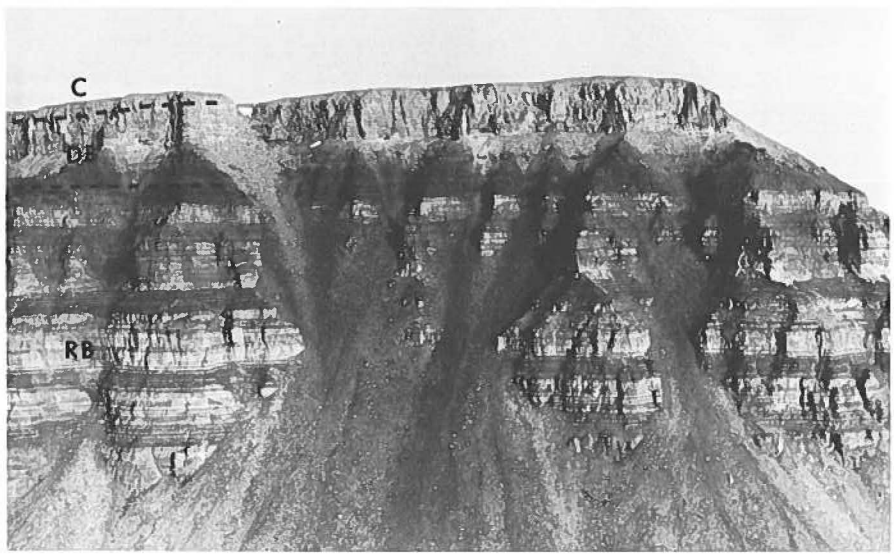


Fig. 4. Cliff section, west of Rensselaer Bugt showing the Proterozoic Rensselaer Bay Formation (RB) overlain by the basal Cambrian Dallas Bugt Formation (DB) and Cambrian carbonates (C). A basic sill forms the uppermost stratum of the Proterozoic sequence (see Fig. 7). Height of section about 200 m.

the Dallas Bugt Formation, and the presence of the dolerite intrusions clearly demonstrate that the Camperdown Member is an integral part of the redefined Rensselaer Bay Formation.

Dallas Bugt Formation of Inglefield Land

This formation has been defined and fully described by Collinson et al. (in press). At the type area around Dallas Bugt (Fig. 1) it attains a maximum thickness of about 150 m. This thickness is gradually reduced to only 25 m at Rensselaer Bugt, but increases slightly again to the south-west (Fig. 3). The formation is subdivided into three members (Figs 2B and 3). A basal Kap Scott Member is mainly composed of cross-bedded, coarse feldspathic sandstones and fine conglomerates which are very heavily stained red-purple by hematite. The member is about 100 m thick at Dallas Bugt, but is reduced to less than 10 m at Force Bugt. The boundary with the overlying Qáqaitsut Member (35 m, thinning to c. 10 m to the south-west) is gradational. This latter member consists predominantly of white, medium to coarse, cross-bedded, quartz-rich sandstones which contain little feldspar. The Marshall Bugt Member (5–10 m) consists of medium- to coarse-grained sandstones and interbedded green siltstones. It is gradational with the dolomites of the overlying Cape Leiper and Cape Ingersoll Formations.

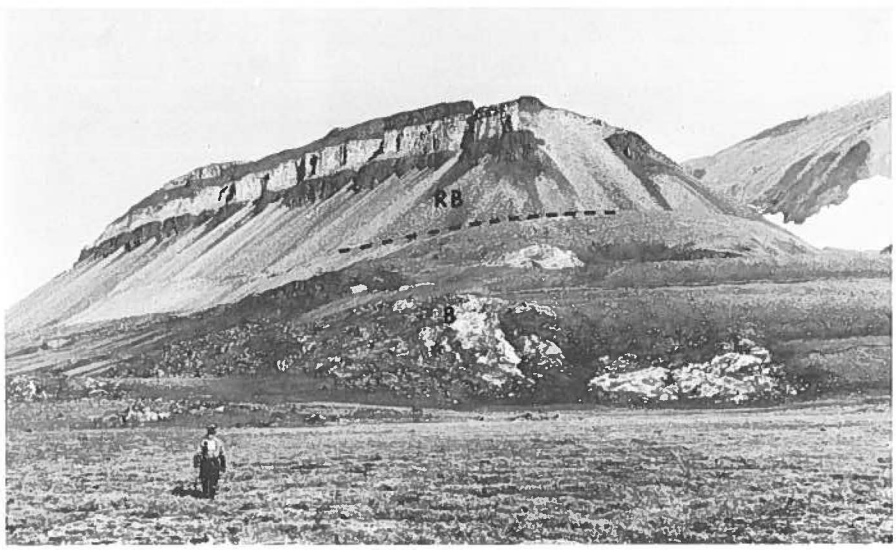


Fig. 5. The Rensselaer Bay Formation (RB), cut by two dolerite sills, overlying the Precambrian crystalline basement (B) at Hatherton Bugt, Greenland. The upper cliff-forming, pale sandstone unit has been referred by Cowie (1971) to the basal Cambrian Sverdrup Member of Bache Peninsula. However, the two basic sills are of Proterozoic age and the use of the name Sverdrup in Greenland is discontinued.

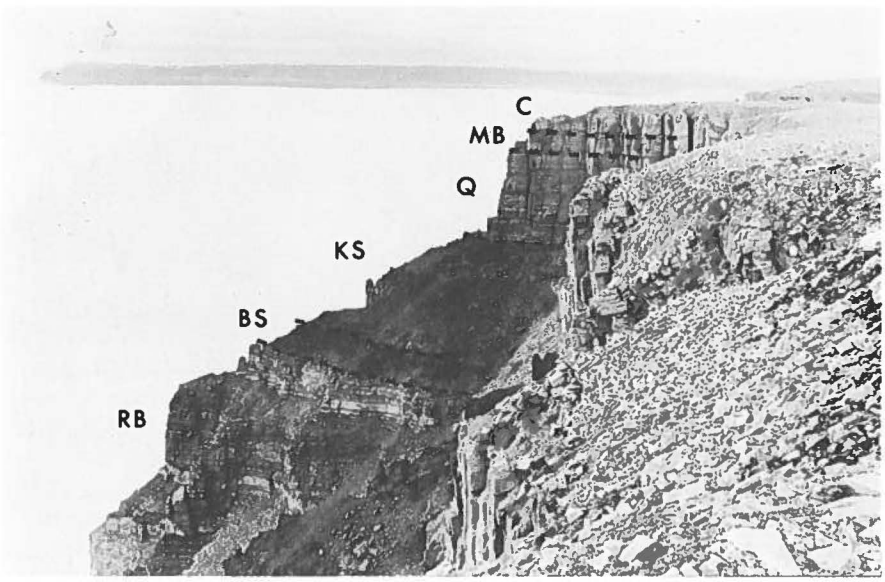


Fig. 6. The disconformity between the Rensselaer Bay Formation (RB) and the Kap Scott Member (KS) of the Dallas Bugt Formation. A basic sill (BS) with an eroded top is present below the unconformity. The boundaries between the Qâqaitsut Member (Q) and the Marshall Bugt Member (MB) of the Dallas Bugt Formation and the overlying Cambrian carbonates (C) are gradational. View is east across Rensselaer Bugt.

The Dallas Bugt Formation lies unconformably on the underlying Rensselaer Bay Formation throughout south-western Inglefield Land (Fig. 6), although the precise contact is often obscured in the field. The unconformity is seen to truncate the dolerite sills within the Rensselaer Bay Formation at Force Bugt. In north-eastern Inglefield Land, the Dallas Bugt Formation lies directly on crystalline basement (Fig. 8).

The Dallas Bugt Formation is considered to be of Early Cambrian age on the basis of its stratigraphic position below carbonates of the Wulff River Formation, which contain Early Cambrian trilobites (C.

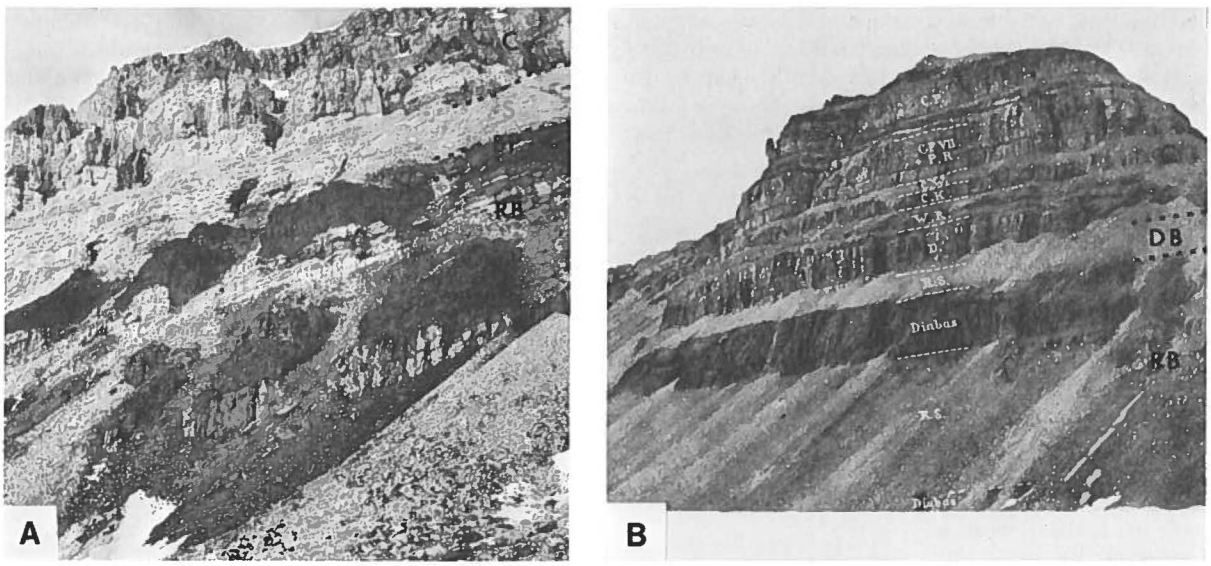


Fig. 7. Comparison of the Proterozoic–Cambrian sequences at Bache Peninsula, Ellesmere Island (A) and in Inglefield Land, Greenland (B). A: Cliff section west of Cape Camperdown, showing the Rensselaer Bay Formation (RB) with two basic sills (dark) overlain by the Dallas Bugt Formation — the Bache Peninsula (BP) and Sverdrup (S) Members — and the Cambrian carbonates (C). From Christie (1967: pl. II). B: The cliffs west of Rensselaer Bugt, showing the Rensselaer Bay Formation (RB) with two basic (Diabas) sills, overlain by the Cambrian succession. From Koch (1933: fig. 13) with original annotations. The Dallas Bugt Formation (DB) includes the upper part of Koch's red sandstones (RS) and the basal part of his dolomite unit (D). The bulk of this unit, and the other strata labelled by Koch, are carbonates of Cambrian age (C). Current designations lie to the right.

Fig. 8. Cambrian clastics of the Dallas Bugt Formation (DB) and succeeding Cambrian carbonates (C), overlying the Precambrian crystalline basement (B) at Marshall Bugt, Inglefield Land. View northwards across Nares Strait to Ellesmere Island. Aerial photograph 544 C–N, No. 11829; copyright Geodætisk Institut, Denmark.

Poulsen 1927, 1958, V. Poulsen 1964) and on the occurrence of *Skolithos* and *Rusophycus* in the Qáqaitsut and Marshall Bugt Members.

Dallas Bugt Formation of Bache Peninsula

Collinson et al. (in press) formally transferred the Bache Peninsula Member and the Sverdrup Member of the Rensselaer Bay Formation (*sensu lato*) of Christie (1967) to the Dallas Bugt Formation, assigning the basal Camperdown Member to the redefined Rensselaer Bay Formation (Fig. 2B). The Dallas Bugt Formation is about 60 m thick at Bache Peninsula. The lower member, the Bache Peninsula Member, consists of 9 m of coarse, purple-brown conglomeratic arkose and thins rapidly to the west. The overlying Sverdrup Member, white or pale yellow weathering, medium- to coarse-grained, cross-bedded sandstone, increases to 95 m in thickness to the west and rests directly on crystalline basement (Fig. 9). In places, the sandstone is characterised by regular, sub-columnar tubes or pipes, probably referable to *Skolithos*.

The Bache Peninsula Member is equivalent to the Kap Scott Member of Inglefield Land (Fig. 2B). The overlying Sverdrup Member is correlated principally with the Qáqaitsut Member, but fine-grained greenish sandstones at the top of the Sverdrup Member (Christie 1967) are probably correlatives of the Marshall Bugt Member.

Fig. 9. Precambrian crystalline basement (B) overlain by recessive, pale sandstones of the Sverdrup Member (S) of the Dallas Bugt Formation and succeeding Cambrian carbonates (C), west of Bache Peninsula, Ellesmere Island. From Christie (1967: pl. V).

Basic intrusions

A well-known feature of the Proterozoic sequences of North-West Greenland is the presence of basic intrusions in the form of dykes and sills (Figs 5 and 7B). Koch (1933) noted that the diabase intrusions, present throughout the Thule district to the south, continued into Inglefield Land and that the igneous province ended around Rensselaer Bugt (Fig. 1).

The age of the intrusions in Inglefield Land and their relationship to the sediments, particularly the dolomites above the clastics now referred to the Rensselaer Bay and Dallas Bugt Formations, have been long debated (Koch 1933: 21, Troelsen 1950: 19, Cowie 1961: 20, Dawes et al. 1973: 63, Christie 1967: 55, Christie 1972: 58, Dawes 1976: 262). Our data indicate that the basic intrusives are restricted to the redefined Rensselaer Bay Formation and that the stratigraphically highest sill has an eroded upper surface when in contact with the overlying Dallas Bugt Formation (Fig. 6). On a large scale, for example in Force Bugt, one sill is cut out at the unconformity. In detail, the upper surface of the sill is irregular, has a rubbly weathering appearance and lacks the chilled margin that characterises the lower contact.

The recognition of the two sandstone sequences reported on in this paper — a lower, redefined Rensselaer Bay Formation of Proterozoic age with intrusions and an upper intrusion-free Dallas Bugt Formation of Early Cambrian age — also explains the restriction of the sills to south-western Inglefield Land, i.e. the outcrop area of the Rensselaer Bay Formation. Basic sills are also restricted to the redefined Rensselaer Bay Formation on Bache Peninsula (Fig. 7A) and again serve to stress the similarity with the Inglefield Land sequence.

Bache Peninsula arch

The name Bache Peninsula arch was given by Kerr (1967b) to a structurally high area of Precambrian crystalline rocks which trends approximately west-north-west between south-western Inglefield Land and the Bache Peninsula area. The arch was defined as a "positive basement feature that influenced the depositional patterns of overlying sediments of Early Cambrian to Late Devonian age" (Kerr 1967b: 485), although it must also have been structurally high in the late Proterozoic, since it forms the northern margin of the Thule Basin (Fig. 10).

The Bache Peninsula arch separates two sedimentary basins: the Thule Basin to the south and the Franklinian Basin to the north and north-west. In essence, the Bache Peninsula arch is a shoulder of the Precambrian Shield projecting out into the Franklinian Basin. While structurally high, it is not a tectonically active feature, although intracratonic faulting accompanied the form-

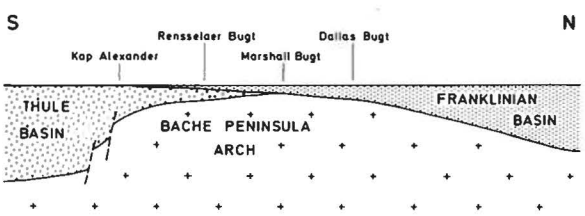


Fig. 10. Schematic section through the Bache Peninsula arch in North-West Greenland, showing the relationship between the intracratonic Thule Basin to the south, and the Franklinian Basin to the north. These relationships are also present in adjacent Ellesmere Island.

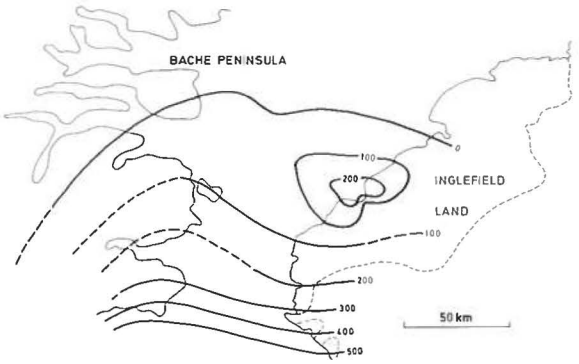


Fig. 11. Isopach map showing the preserved thickness of sediments of the Rensselaer Bay Formation and equivalent Proterozoic deposits at the northern margin of the Thule Basin. Intrusive dolerites are excluded from the thickness estimates.

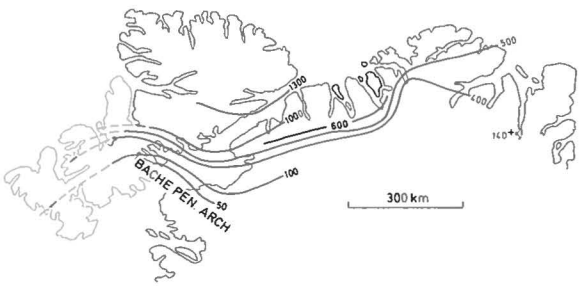


Fig. 12. Isopach map of the Dallas Bugt Formation and equivalent Cambrian clastics in Ellesmere Island and northern Greenland.

ation of the Thule Basin to the south. Thus, in Greenland, the 4.5 km thick Proterozoic sequence of the intracratonic Thule Basin thins northward against the Bache Peninsula arch, although a thin sheet of the Rensselaer Bay Formation persists over the arch (Figs 10 and 11). In Ellesmere Island, there is a paucity of outcrop over the arch and no Proterozoic strata are known between Bache Peninsula (79°N) and the northernmost outcrops of the Thule Basin at about 78°30′N (Dawes et al., this volume). However, a contrast in thickness similar to that in Greenland is evident in Ellesmere Island, with only 85 m of sediment at Bache Peninsula and a sequence at least 1 km thick to the south.

The Dallas Bugt Formation and younger Lower Palaeozoic formations thicken away from the Bache Peninsula arch and the rest of the Precambrian Shield into the Franklinian Basin (Fig. 12). In north-western Greenland, thickening is generally to the north or north-west but, in Ellesmere Island, thickening also takes place to the west as the sedimentary basin swings around the Bache Peninsula arch. The effect of the Bache Peninsula arch decreases westward as it plunges under the Lower Palaeozoic cover sequence that forms central Ellesmere Island (Figs 1 and 12).

Inferences concerning displacement along Nares Strait

All authors who have studied the geology of the land areas around Kane Basin and Smith Sound, from Per Schei (Holtedahl 1917) until the present day, have correlated sections on Bache Peninsula and in Inglefield Land without identifying any geological features which would require a configuration of Greenland relative to Ellesmere Island other than that found at the present day. The geological similarity between the two areas has been stated forcibly by Bentham (1936a, b, 1941) Poulsen (1946), Troelsen (1950, 1956a), Christie (1967), Dawes (1976), Collinson et al. (in press) and Dawes et al. (this volume). These papers contain no reference to geological features which require major strike-slip movement between Ellesmere Island and Greenland.

General correlations of lithology, thickness and age of the late Proterozoic Rensselaer Bay Formation and its contained dolerite intrusions, and the Early Cambrian Dallas Bugt Formation of Inglefield Land and Bache Peninsula indicate conclusively that Greenland and Ellesmere Island developed as part of the same plate at that time. No geological phenomenon exists which demands substantial strike-slip movement along Nares Strait to explain it; neither is there geological evidence to suggest that net displacement of this magnitude has taken place.

In addition to the close similarity in lithology, thickness and age between sequences on either side of Kane Basin, discussed above, four geological features are of particular relevance to any discussion of major displacement along the Strait:

1) Sedimentary sequences on both sides of the Strait show the same disposition in terms of height above sea level and topography to the peneplained surface of the crystalline rocks of the Precambrian Shield. Even though regional structural dips of the sediments above the basement are low (a couple of degrees to the north in the case of the Dallas Bugt Formation in Inglefield Land), any major displacement oblique to regional strike trends along Nares Strait, of the type proposed by Newman (1977), Newman & Falconer (1978), Srivastava (1978) and several papers in this volume, would inevitably produce substantial anomalies in these sediment-basement topographic relationships across the displacement. Discrepancies of this type are not present.
2) A demonstration of the regional continuity of Early Cambrian clastic sedimentation across northern Greenland and Ellesmere Island is provided by an isopach map of the Dallas Bugt Formation and its stratigraphic equivalents (Fig. 12). Of particular note is the effect of the protruding shoulder of Precambrian Shield, the Bache Peninsula arch, on the

configuration of the southern margin of the Franklinian Basin.

3) The boundary between the thick Proterozoic sequence of the Thule Basin and the thin Rensselaer Bay Formation in south-western Inglefield Land delineates a relatively well-defined datum suitable for correlation across Nares Strait (Dawes et al., this volume). While paucity of exposure prevents *precise* location of this datum in Ellesmere Island, it is clear from regional isopach patterns that displacement of Ellesmere Island relative to Greenland in terms of, say, a hundred kilometres is extremely doubtful (Fig. 11).
4) Overlap between the Thule Basin sequence, in the form of the Rensselaer Bay Formation, and the Dallas Bugt Formation of the Franklinian Basin provides a possible marker across Nares Strait at the point at which the Rensselaer Bay Formation disappears. Sections in Inglefield Land are oriented south-west to north-east, while on Bache Peninsula an east-west orientation is present. However, an isopach map drawn on the residual thickness of the Rensselaer Bay Formation, exclusive of dolerite intrusions, emphasises the continuity of this marker (Fig. 11). The anomalous thicknesses around Rensselaer Bugt in Inglefield Land reflect sediment fill in local depressions or valleys in the crystalline basement. In general, the upper, eroded surface of the basement lacks substantial palaeorelief.

Conclusions

Lithological and stratigraphical similarities between the Rensselaer Bay Formation and the Dallas Bugt Formation in Inglefield Land and on Bache Peninsula, together with evaluation of the four geological features discussed in the previous section, are entirely consistent with there having been little or no net displacement along Nares Strait since early Palaeozoic time. It is not possible to refute movements in the range of 0–50 km, in either dextral or sinistral sense. However, movements greater than this produce increasingly unlikely geological relationships. Offsets in the range 50–100 km are considered improbable, while the postulated sinistral movements of 100 km, 200 km, 300 km or even more can be ruled out.

Acknowledgements

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