The case against major displacement along Nares Strait

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Dawes, P. R. & Kerr, J. W. 1982. The case against major displacement along Nares Strait. – In: Dawes, P. R. & Kerr, J. W. (eds), Nares Strait and the drift of Greenland: a conflict in plate tectonics. – Meddr Grønland, Geosci. 8: 369–386.

Nares Strait is a conspicuous lineament that suggests it is the site of a fault. The conflict about magnitude of displacement has developed because the interpretation of geological data from the immediate Nares Strait region is at variance with the common interpretations of the geophysical data from the surrounding oceans, which predict Nares Strait as the site of great displacement.

We summarise here the geological and geophysical data presented in this volume that indicate little or no strike-slip, vertical or oblique displacement along Nares Strait, and the conclusion is based on five categories of evidence:

1) there is present-day continuity of geological features from Ellesmere Island to Greenland,
2) the Strait is aseismic, suggesting that it is not a major crustal or lithospheric fracture,
3) a pre-drift reconstruction showing large dextral strike-slip displacement (e.g. 250 km) introduces unacceptable juxtaposing of the Precambrian and Palaeozoic rock provinces,
4) a pre-drift reconstruction showing Greenland and Ellesmere Island separated obliquely by a wide gap is refuted by the geology of the Strait,
5) there are no unequivocal geological or geophysical data from the immediate Strait area, which suggest that Greenland and Ellesmere Island had an initial relative position radically different from present-day geography.

On the basis of 9 regional stratigraphic and structural features and by the definition of 20 geological–geophysical markers that can be traced without apparent offset from Ellesmere Island to Greenland, we conclude that any net left-lateral, strike-slip motion along Nares Strait has been minor — in the range of 0 to 25 km. This argues strongly against the hitherto widely accepted *'pure'* sea-floor spreading origin of Baffin Bay and the Labrador Sea and suggests that other mechanisms must have played an important part in the formation of these oceanic basins.

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The Nares Strait seaway separating Greenland and Ellesmere Island, Canada, shows remarkable linearity over several hundred kilometres (Fig. 1), suggesting it to be the site of a fault (Taylor 1910). Broadly speaking, two very different interpretations have been made of the tectonic history of Nares Strait; one mainly from the geological evidence from lands bordering the Strait and the other from the geophysical evidence collected elsewhere from the surrounding seas and even globally. The geological evidence (supported by geophysical data from Ellesmere Island and Greenland) indicates that the net result of any strike-slip movement along the Strait is minor. Alternatively, the geophysical data from the surrounding oceans (Arctic Ocean, Labrador Sea and Baffin Bay), which rely heavily on the theory of sea-floor spreading, demand much greater displacement, consistently in a left-lateral (sinistral) sense, but varying from about 200 to 400 km. This conflict, which has been debated for many years and summarised by Kerr (1980), is continued by the papers in this volume. In general, the positions of workers have not changed with geological evidence in the Strait being used to support minor displacement and offshore geophysics being used to support great displacement. There are of course exceptions to the general nature of the conflict as outlined above; hence this volume also contains geologically based papers that conclude a case for major displacement (e.g. Newman a) in addition to a mainly geophysically oriented paper from outside the immediate region that concludes little or no movement (e.g. Grant).

This summary is concerned with assessing the geological and geophysical data from the immediate Nares Strait region in terms of the spatial relationship of

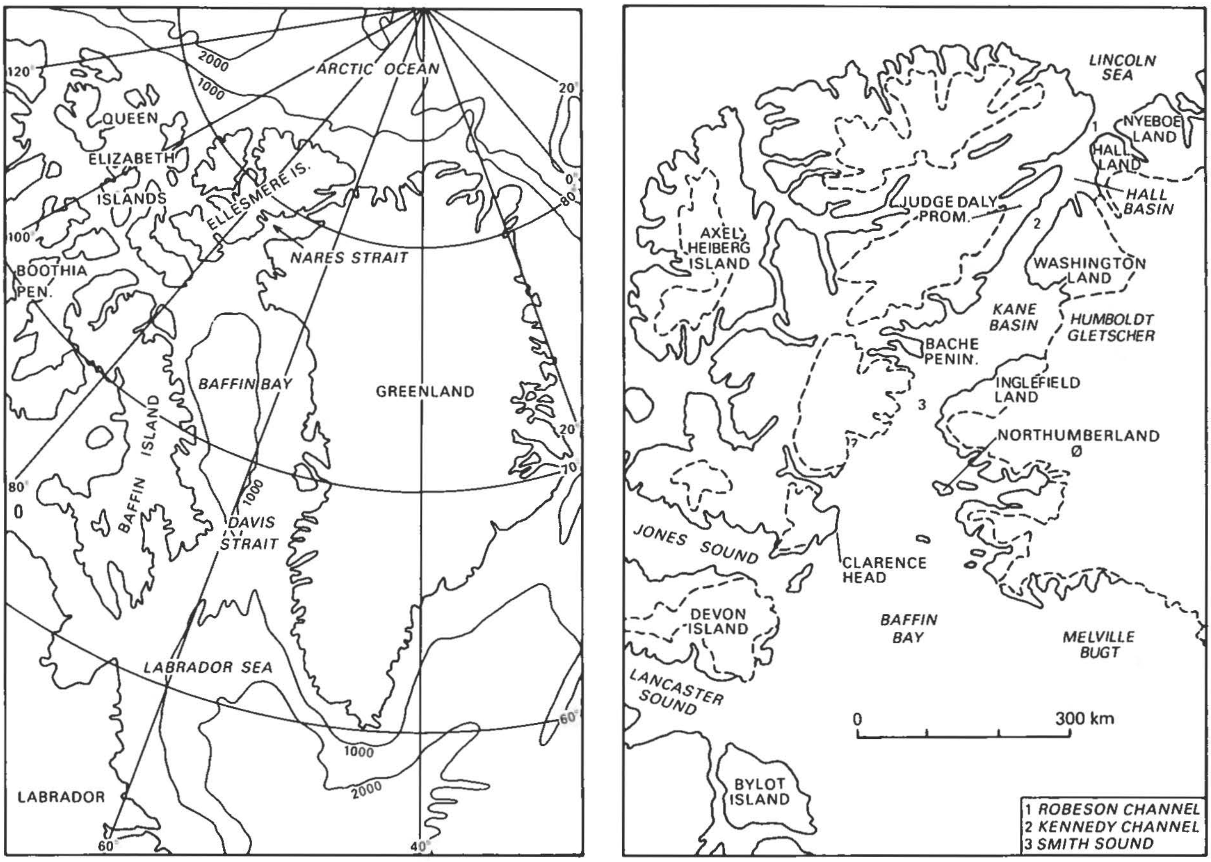


Fig. 1. Index maps of the Nares Strait region. Bathymetry is in metres.

Greenland and Ellesmere Island. We interpret these data as entirely consistent with there having been little or no strike-slip or other displacements along the Strait. We also show that reconstructions with Baffin Bay closed create problems with the Precambrian and Palaeozoic geology which are incompatible with regional stratigraphy and stratigraphic and structural principles.

The main stratigraphic–structural units of the Nares Strait region are illustrated in Fig. 2.

Geological–geophysical markers

The logical way of investigating possible displacement along Nares Strait is to define on Ellesmere Island and Greenland geological boundaries or structures (by both geological and geophysical methods) that are correlatable. Twenty of these geological–geophysical markers can be recognised and these are summarised in Table 1 and illustrated in Fig. 3.

This symposium has made it clear that there is a demand on geologists to use the available geological data to define the amount of sinistral displacement that could have occurred along the Strait. Hence, we have attempted in Table 1 to estimate the maximum net displacement that each marker permits. The markers represent stratigraphical and structural features which have varying reliability as tools for assessing strike-slip motion. Some are precise, well-defined markers, others more poorly defined and imprecise. The accuracy of the estimate of maximum motion that can be determined from any marker depends on a number of factors, the most obvious of which are summarised below.

Definition: the value of a marker depends on how precisely it has been defined by geological and/or geophysical mapping.

Exposure: an exposed marker is of more value than the same marker when in the sub-surface.

Type: steeply-inclined vertical, narrowly-defined, linear bodies or geological contacts give more reliable estimates than shallowly-inclined, broadly or gradationally defined structures or contacts.

Form: continuous and straight markers are more valuable than non-continuous and irregular markers.

Age: accurately dated markers are of more value than markers of uncertain age.

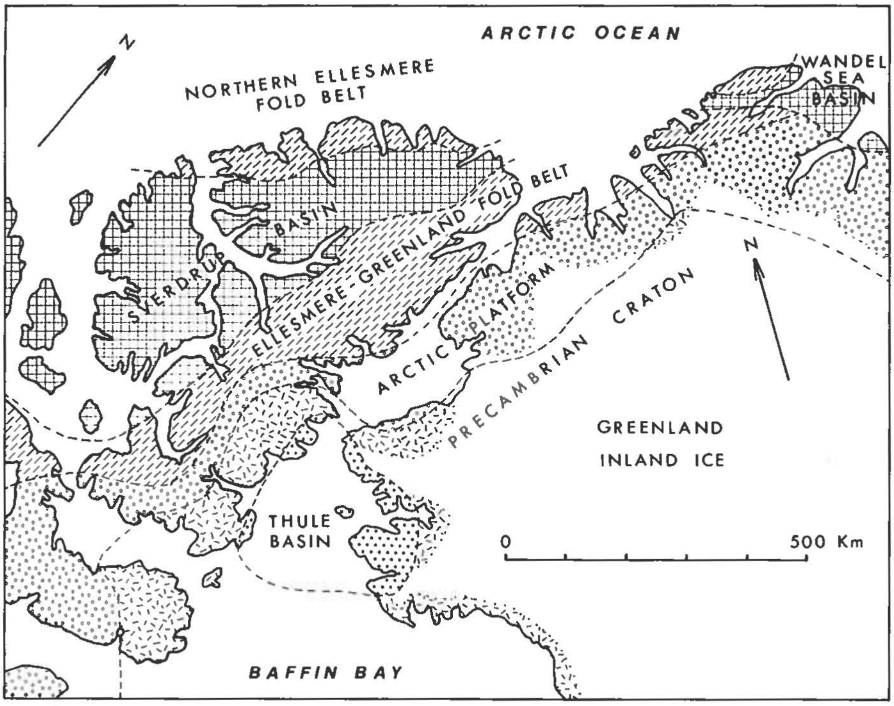


Fig. 2. Main stratigraphic–structural units of the Nares Strait region. The Ellesmere–Greenland and the northern Ellesmere fold belts broadly correspond with the Proterozoic–Devonian Franklinian geosyncline (basin) (cf. Fig. 5B). The northern Ellesmere fold belt includes magmatic rocks — the Pearya geanticline.

Time of formation: markers that existed prior to the supposed displacement are of more value than those which formed during or after displacement.

Angle of intersection: markers transecting the Strait at a high angle of intersection are more valuable than those intersecting at a low angle.

Width of Nares Strait: markers intersecting the Strait at its narrowest parts are of more value than those cutting elsewhere.

The markers recognised in the Nares Strait region vary in reliability. On one extreme are accurately dated, well-exposed, vertical geological facies boundaries which cross the Strait at one of its narrowest parts (e.g. marker 10, Table 1). At the other extreme are broad, magnetic or seismic zones reflecting sub-surface structures of uncertain age and origin that cross the Strait in its widest part (e.g. markers 17 and 20). The restraint on motion imposed by each marker is proportional to the reliability of that marker.

1. Geological continuity between Ellesmere Island and Greenland

The data indicating that geological features are continuous without offset from Ellesmere Island to Greenland are presented in terms of 9 regional geological features (Table 2) and the 20 geological–geophysical markers (Table 1). On the basis of these 29 lines of evidence, there is no reason to envisage that the present-day relative position of Ellesmere Island and Greenland is significantly different from what it was in the past.

In Table 1, restraints in kilometres are given for the most precise markers and these are estimates of the maximum amount of net dextral motion (i.e. restored to an original position) possible from present-day geography. The figures quoted do not suggest that such displacements have occurred. Rather, each figure indicates the maximum displacement that the marker can allow at the present state of definition of that marker. All these markers are dealt with by papers in this volume and the reader is referred in Table 1 to the relevant papers.

Several of the markers, particularly the geophysically defined ones (17 to 20), have not been discussed in the volume in terms of a quantitative estimate of displacement, and no estimate is included for these in Table 1. However, with the possible exception of the linear zone of earthquake epicentres (marker 20 — which reflects a fracture line, the history of which could entirely postdate the supposed displacement), we conclude that all the markers refute major strike-slip movement along Nares Strait of the amount used in many conventional reconstructions (e.g. 200 km or more). All markers, and the regional features given in Table 2, provide a reliable approximate correlation of the position of Greenland and Ellesmere Island. A more exact measure of relative position is provided by the more precise and narrowly defined markers.

Table 1. The geological–geophysical markers that cross Nares Strait without offset

Reference number	Geological–geophysical marker	Estimate of maximum strike-slip displacement possible	Area of intersection with Nares Strait	Reference this volume or otherwise
1	Precambrian (Archaean) marble and marble-rich metasedimentary belt intruded by diagnostic meta-igneous rocks.	100 km	Smith Sound	Frisch & Dawes
2	Northern margin of the Thule Basin indicated by rapid thickness variation in the Proterozoic Thule Group.	75 km	Smith Sound	Dawes et al.
3	Bache Peninsula arch; a structural basement high separating the Thule Basin on the south from the Arctic platform on the north.	100 km	Smith Sound	Peel et al.
4	Northern zero-edge (0 isopach) of the Proterozoic Rensselaer Bay Formation (Thule Group).	100 km	Kane Basin	Peel et al.
5	Cambro-Ordovician platform margin; a linear facies boundary separating southern carbonate and northern trough clastics, that is the site of faults.	100 km	Robeson Channel	Dawes
6	Lower Ordovician evaporite belt represented by two distinct stratigraphic levels; Baumann Fiord Formation (Canada) and Poulsen Cliff and Nygaard Bay Formations (Greenland).	50 km	Kane Basin	Peel & Christie
7	Middle Ordovician evaporite belt; Bay Fiord Formation (Canada) and Cape Webster Formation (Greenland).	50 km	Kennedy Channel	Peel & Christie
8	Cambro-Ordovician hinge line, over which there is a marked thickening of deposits northwards.	150 km	Kennedy Channel	Peel & Christie
9	Upper Ordovician – Silurian platform margin associated with a linear horst; a steep facies front between southern carbonates and northern clastics.	100 km	Robeson Channel	Hurst & Kerr a
10	Lower Silurian (middle Llandovery) near vertical abrupt facies contact separating platform carbonates with platform-edge reefs from mudstone.	25 km	Kennedy Channel	Hurst & Kerr a

11	Silurian carbonate buildup ('reef') belt; part of a regional belt traceable through the Queen Elizabeth Islands and across North Greenland.	100 km	Hall Basin and Kennedy Channel	Hurst & Kerr a, Kerr (1967a, this volume)
12	Southern boundary of significant folding (Ellesmerian) of the mid-Palaeozoic Ellesmere–Greenland fold belt.	50 km	Kennedy Channel to Robeson Channel	Higgins et al.
13	Southern limit of amphibolite-facies rocks in the Ellesmere–Greenland fold belt.	100 km	Robeson Channel and Lincoln Sea	Higgins et al.
14	Lake Hazen – Harder Fjord fracture line; a high-angle fault system of probable early Palaeozoic age reactivated in the Tertiary.	150 km	Lincoln Sea	Dawes, Higgins et al.
15	Judge Daly – Nyeboe Land fracture line; a high-angle fault system of probable early Palaeozoic age, reactivated in the Tertiary.	100 km	Robeson Channel and Lincoln Sea	Dawes
16	Judge Daly Promontory – Wulff Land anticlinal zone exposing Proterozoic strata in the margin of the Ellesmere–Greenland fold belt.	100 km	Robeson Channel	Dawes
17	Region of distinctive magnetic character based on vertical field residuals; the southern boundary of Region IV strikes from Judge Daly Promontory to Nyeboe Land.	?	Robeson Channel	Grant, Coles et al. (1976)
18	Kane Basin magnetic anomaly; a distinctive magnetic high at about 79°30′N between Bache Peninsula and Humboldt Gletscher.	?	Kane Basin	Grant, Riddihough et al. (1973) Coles et al. (1976)
19	Prominent steep gravity gradient indicating fundamental crustal change from Lincoln Sea to Greenland; trend lines strike from Judge Daly Promontory to Nyeboe Land.	?	Robeson Channel and Lincoln Sea	Sobczak, Dawes,
20	An anomalous, linear zone of earthquake epicentres along the northern coast region of Ellesmere Island and Greenland.	?	Lincoln Sea	Wetmiller & Forsyth

The markers are arranged generally from the oldest to the youngest and they are located on Fig. 3. The estimates of strike-slip displacement quoted are rounded off values that indicate the maximum amount of net dextral motion from present-day geography which can be reconciled with present knowledge and definition of the markers. All markers are consistent with zero net strike-slip displacement along Nares Strait, although marker 20 depicts a younger fracture line, the history of which could entirely post-date the supposed displacement discussed at the symposium.

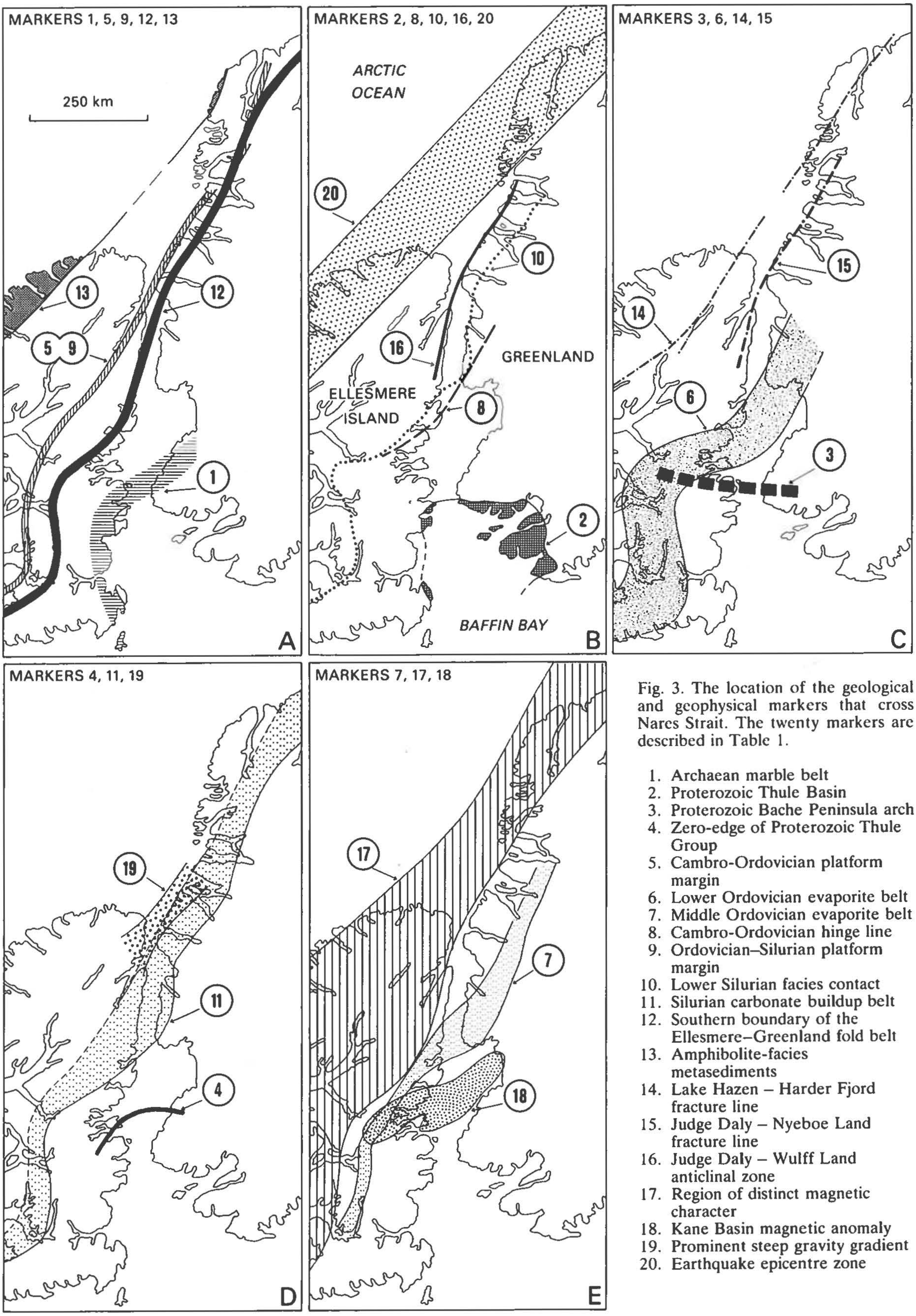


Fig. 3. The location of the geological and geophysical markers that cross Nares Strait. The twenty markers are described in Table 1.

1. Archaean marble belt
2. Proterozoic Thule Basin
3. Proterozoic Bache Peninsula arch
4. Zero-edge of Proterozoic Thule Group
5. Cambro-Ordovician platform margin
6. Lower Ordovician evaporite belt
7. Middle Ordovician evaporite belt
8. Cambro-Ordovician hinge line
9. Ordovician–Silurian platform margin
10. Lower Silurian facies contact
11. Silurian carbonate buildup belt
12. Southern boundary of the Ellesmere–Greenland fold belt
13. Amphibolite-facies metasediments
14. Lake Hazen – Harder Fjord fracture line
15. Judge Daly – Nyeboe Land fracture line
16. Judge Daly – Wulff Land anticlinal zone
17. Region of distinct magnetic character
18. Kane Basin magnetic anomaly
19. Prominent steep gravity gradient
20. Earthquake epicentre zone

Table 2. Main regional features that cross Nares Strait, and their tectonic inference

Reference letter	Type of feature	Tectonic inference	Area of Nares Strait	Reference this volume
A	General distribution and disposition of the Precambrian and Palaeozoic stratigraphic–structural provinces in Ellesmere Island and Greenland.	Ellesmere Island and Greenland developed as adjacent parts of the same plate	Baffin Bay to the Arctic Ocean	This paper Fig. 2
B	Nature and altitude of the Proterozoic erosion surface of the Shield at 79°N.	No major differential vertical movement between Ellesmere Island and Greenland	Kane Basin	This paper Fig. 6, Dawes et al., Peel et al.
C	Proterozoic Thule Group sediments and volcanics; stratigraphy and isopach pattern.	Consistent with little or no Phanerozoic lateral displacement	Northern Baffin Bay and Smith Sound	Dawes et al., Peel et al.
D	Basal Cambrian platform stratigraphy; facies and isopach pattern.	Consistent with little or no post-Cambrian lateral displacement	Smith Sound – Kane Basin	Peel et al.
E	Cambro-Ordovician platform and trough stratigraphy; facies and isopach pattern.	Consistent with little or no post-Ordovician lateral displacement	Kane Basin and Kennedy Channel	Peel & Christie
F	Upper Ordovician and Silurian platform–trough stratigraphy; facies and isopach pattern.	Consistent with little or no post-Silurian lateral displacement	Kennedy Channel to Lincoln Sea	Dawes, Hurst & Kerr a
G	Silurian deep-water basin; turbidite axial flow across North Greenland continued westward along the axis of the Hazen (Ellesmere) trough.	Consistent with little or no post-Silurian lateral displacement	Kennedy Channel to Lincoln Sea	Surlyk
H	Structural and metamorphic pattern of the Ellesmere–Greenland fold belt; zones of fold style, deformation intensity and metamorphic grade.	Consistent with little or no post-Devonian lateral displacement	Kane Basin to Lincoln Sea	Higgins et al.
I	Postglacial emergence zones (isobases) for 8000, 7000 and 6000 B.P.	Glacio-isostatic deformation of the lithosphere has taken place without influence of faulting	Hall Basin and Robeson Channel	England

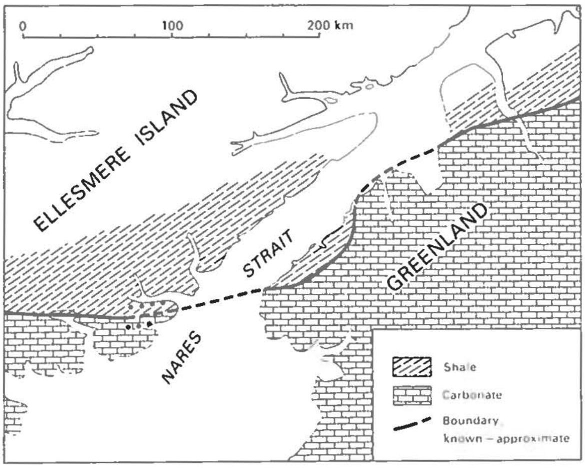


Fig. 4. Sketch showing by solid line the position of the Lower Silurian (middle Llandovery) carbonate-shale facies boundary in the Kennedy Channel area (marker 10 in Table 1). On eastern Ellesmere Island there is a gap in exposure of the actual boundary; here the most likely position is shown by a dashed line and the outer limits of its position are shown by dotted lines.

The most precise of these is the Lower Silurian (middle Llandovery, about 430 m.y.) facies front (marker 10) which is a near vertical contact between two very distinctive rock facies, precisely dated on faunal evidence and crossing Nares Strait at a relatively high angle in one of the narrowest parts of the seaway — Kennedy Channel (see Hurst & Kerr a, this volume). The marker on the Greenland side is precisely located in the high sea-cliffs of Washington Land; on the Ellesmere Island coast it is less well exposed but can be located within a narrow zone on strike across the Strait (Fig. 4). A median line drawn between the two possible extreme positions of the boundary in Ellesmere Island indicates that a net sinistral movement in the range of 0–25 km is compatible with the trend of this marker. This feature can be considered a fine adjustment to the approximate relative positioning of Ellesmere Island and Greenland obtained from other data from the Strait.

The markers and regional geological features summarised in Tables 1 and 2 do not demand any strike-slip motion along Nares Strait. We stress that all are entirely compatible with there having been little or no strike-slip movement along the Strait. Using a combination of all markers, we conclude that any *net* strike-slip displacement has been minor, possibly near zero and not greater than 25 km.

2. Nares Strait as a major lithospheric fracture: the problems

The present-day geological continuity between Ellesmere Island and Greenland discussed above is conclusive evidence that Nares Strait has not had a large net displacement. However, it is not conclusive evidence against movement back and forth, both dextral and sinistral cancelling each other out to give a net displacement of only a short distance or zero. It has been mentioned elsewhere in this volume (e.g. Keen & Peirce) and by Christie et al. (1981) that perhaps a tantalising solution to the Nares Strait debate might be sought in a complex tectonic history in which there has been major dextral displacement along Nares Strait sometime after the mid-Palaeozoic Ellesmerian orogeny, followed by a sinistral movement of Greenland in response to the opening of the surrounding oceans. Such a tectonic history would meet the evidence for present-day geological continuity as well as the fundamental requirements of theories in which Baffin Bay opened by substantial sea-floor spreading and in which Nares Strait acted as a plate boundary.

However, such a speculative scenario is controversial and involves an extreme coincidence; we can find no direct geological evidence in the Nares Strait – Baffin Bay region that suggests major dextral movement of Greenland in the Late Palaeozoic or Mesozoic. On the contrary, three lines of evidence strongly suggest that Nares Strait does not represent a plate boundary that has been involved in a long history of crustal block motion of continental proportions.

Seismic evidence

The boundaries of present-day plates are defined by their seismicity; Nares Strait is aseismic even down to small magnitude levels (Wetmiller & Forsyth, this volume). These authors point out that this lack of seismicity is even more remarkable when compared to areas of seismicity in adjacent Canada and their relationships to known geological structures. Thus, structures like the Boothia Uplift, and structures and arches of the Sverdrup Basin, which have been tectonically active in at least Palaeozoic and/or Mesozoic eras, also show residual seismic expression today. In addition, 'ancient' lineaments of great strike-slip motion in the North Atlantic region, such as for example the Great Glen Fault of Scotland, in which much wrench faulting took place in the late Palaeozoic, also remain seismically active today, indicating a response to the stresses in the evolving North Atlantic. Thus, if Nares Strait had been substantially active for a long period at the same time — and particularly if more recently than such structures, as has been suggested in many plate tectonic sea-floor spreading models — then it would be expected to show at least some sort of seismic activity. That it does not indicates that Nares Strait is not the site of any significant dynamic tectonism and it most likely does not represent a crustal or lithospheric fracture zone that has had a long and complex history.

Magnetic and gravity evidence

Available magnetic and gravity data from Arctic Canada and northern Greenland do not show any indication that Nares Strait represents a fundamental fracture of the crust or lithosphere (see Riddihough et al. 1973, Coles et al. 1976, Sobczak 1978, this volume, Grant, this volume). The major trends of the magnetic field and gravity anomalies can be traced directly across Nares Strait. Furthermore, there are no pronounced magnetic and gravity trends or expressions along the Strait. Indeed, the major magnetic and gravity trends defined by Riddihough et al. (1973) and Sobczak & Stephens (1974) in the northern Nares Strait region are parallel to and coincide with known geological structures which can be traced across Robeson Channel without offset (see Dawes, this volume).

Structural evidence

There is no evidence along the entire shores of Nares Strait from Baffin Bay to Lincoln Sea that indicates a long and complex history of fault movements along the Strait. Major strike-slip faults normally are complex features composed of a zone of dislocation planes, often with splay-out faults and often many kilometres wide. Many, for instance three of the most renowned wrench faults — the San Andreas Fault, the Great Glen Fault and the Alpine Fault of New Zealand — are part of fault systems that far exceed the width of Nares Strait. Despite the remarkably good exposures on the coasts of Nares Strait, no faults, crush zones, shear zones or lineaments parallel to the Strait have been mapped on the Greenland side, and none appear to be present on the islands in the Strait (J. M. Hurst, pers. comm. 1981). Minor shear zones at high angles to the Strait on Greenland (Hurst & Kerr b, this volume) have been considered to be compatible with minor rotation of Greenland. The only dislocations reported in Ellesmere Island are the structures described by Mayr & de Vries (this volume) between Hall Basin and Kane Basin. These authors tentatively suggest that a sinistral strike-slip movement of 19 km has occurred along the Judge Daly fault zone. Christie (1967, 1974) suggested that fault movements in this fault zone were not large-scale movements of the type to be expected when continental blocks have moved in relation to each other. In addition, the Judge Daly fault zone may well be the western part of a regional fracture line which is oblique to Nares Strait; thus any movement along it may not necessarily have resulted in the separation of Ellesmere Island and Greenland as separate plates (Dawes, this volume).

Faults linking Baffin Bay and Lincoln Sea presumably are present offshore in Nares Strait; faults are suggested by geophysical data in southern Nares Strait (Newman b, this volume) and others might be expected to be demarcated as geophysical surveys are carried out farther north. Even so, the presently mapped onshore faults do not support the concept of a complex fracture zone parallel to the Strait, along which there has been major dextral and sinistral movements.

3. The 250 km dextral reconstruction: the problems

This section adopts one of the common palaeogeographic reconstructions in which Greenland has undergone substantial dextral motion along Nares Strait. Evidence for major strike-slip movement along Nares Strait in late Phanerozoic time that fits generally with conventional plate tectonic reconstructions is summarised by Johnson & Srivastava (this volume). The estimates of sinistral wrench displacement vary from 200 to 320 km. Fig. 5 shows a typical pre-drift reconstruction based on a displacement of 250 km in which Baffin Bay has been closed by approximately juxtaposing the shelf edges at about the 1000 m isobaths. Similar (although not identical) reconstructions have been presented in this volume (e.g. Keen & Peirce, Menzies, Peirce, Srivastava & Falconer) and are common in the literature (e.g. Keen et al. 1972, Feden et al. 1979).

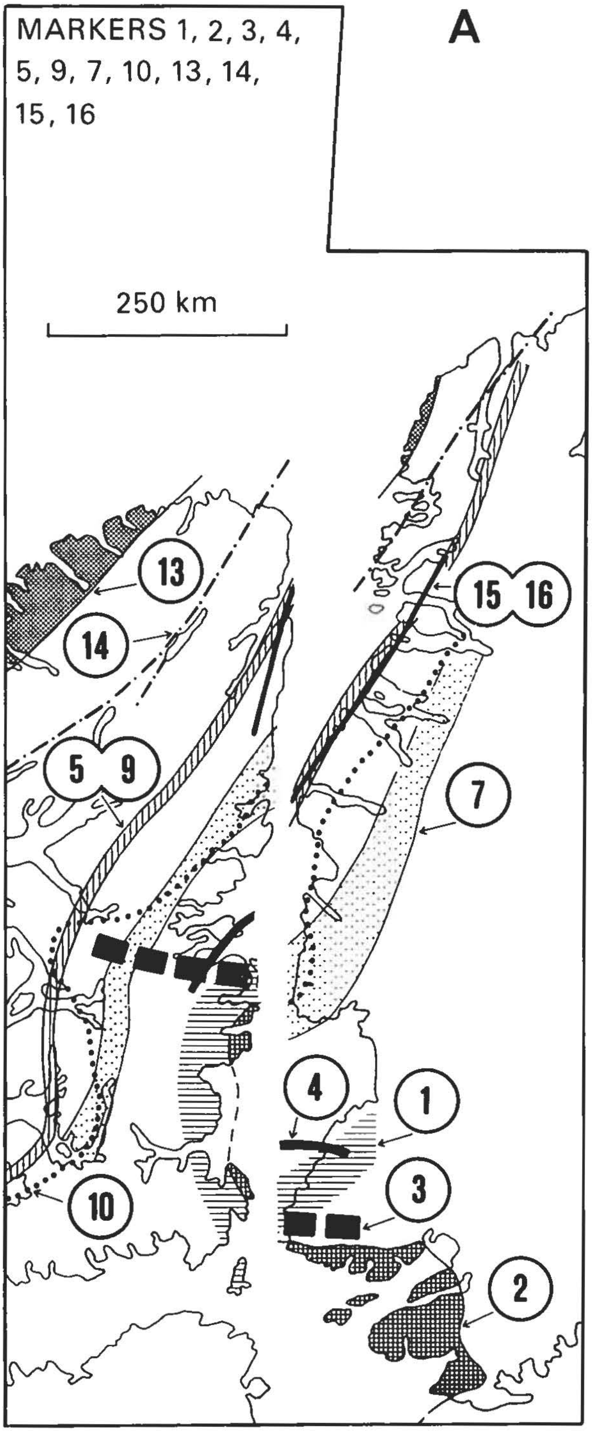
The following considerations show that such a reconstruction cannot represent the relative positions of Ellesmere Island and Greenland in Precambrian to mid-Palaeozoic time.

Disruption of the regional facies belts and geological–geophysical markers

The 250 km dextral reconstruction violates 26 out of the 29 lines of evidence quoted in Tables 1 and 2, and it is strongly argued against by the seismic, gravity and structural data discussed in section 2 above. The evidence that is not in obvious disagreement is the magnetic data (marker 18, Table 1), the postglacial isobase data (I, Table 2) and the earthquake epicentre zone (marker 20, Table 1). The latter two are not diagnostic because of age criteria, since they reflect geological events post-dating the suggested major late Phanerozoic sinistral displacement. Several magnetic anomalies occur in the Nares Strait region including magnetic highs which bridge the Strait without apparent offset (Riddihough et al. 1973). However, as noted by Peirce (this volume), the prominent magnetic high that crosses Kane Basin (marker 18, Table 1) could *theoretically* be matched otherwise in a reconstruction involving 250 km of displacement.

Juxtaposition of Precambrian and Palaeozoic rock units

The reconstruction restoring 250 km of sinistral displacement results in the juxtaposition of Precambrian



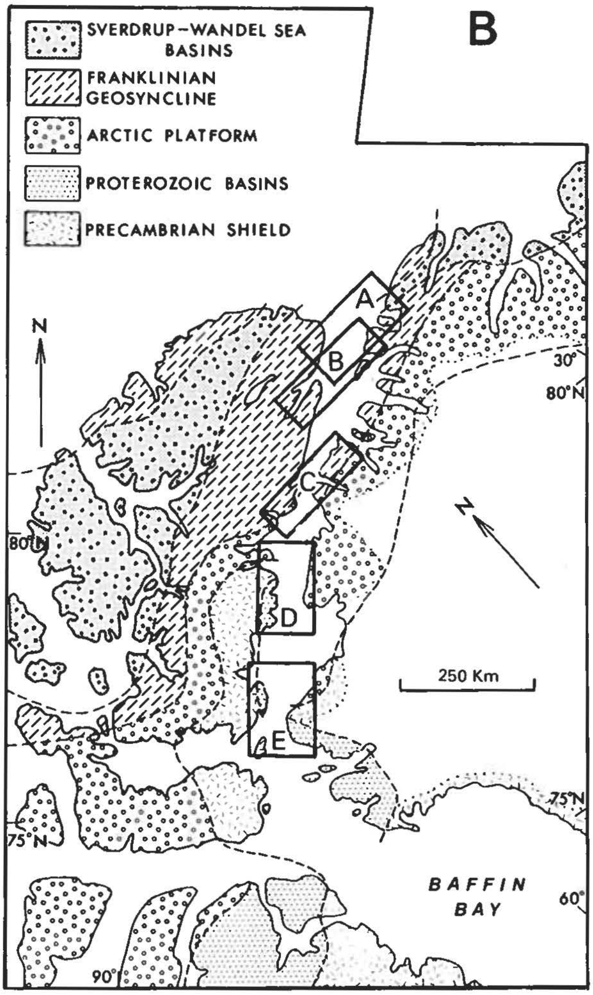


Fig. 5. Maps showing the effects of 250 km dextral displacement on a selection of geological markers (A) and on the main stratigraphic–structural units (B) of the Nares Strait region. The position of the markers and stratigraphic–structural units in present-day geography is given in Figs 3 and 2, respectively; the markers are described in Table 1. Marker 12, the southern boundary of the Ellesmere–Greenland fold belt, which has been the most discussed marker with regard to strike-slip displacement along Nares Strait, is not featured here but in Figs 8 and 9. The five frames lettered A to E locate areas of juxtaposed rock associations that are discussed in the text.

and Palaeozoic rock units which, because of their contrasting sites of formation, are in positions that are either incompatible or extremely unlikely. The most critical geological complications introduced by the reconstruction are discussed below — listed from north to south and grouped in five areas marked on Fig. 5B.

A. Unmetamorphosed Silurian–Devonian turbidites of the Imina Formation forming both sides of present-day Robeson Channel (Trettin 1979, Dawes, this volume, Hurst & Kerr a, this volume, Surlyk, this volume) are now separated and the amphibolite-facies Proterozoic and Cambrian metasediments of northern Peary Land are positioned on regional strike with unmetamorphosed clastic rocks of the Hazen Plateau (see Higgins et al., this volume).

B. Both the Cambrian–Ordovician and Ordovician–Silurian platform margins in the Judge Daly Promontory area in Ellesmere Island (markers 5 and 8, Table 1) are separated from their counterparts in Greenland and placed so that they strike towards the axis of the North Greenland trough.

C. The configuration of the Ellesmere Island – Greenland Silurian turbidite basin (Surlyk, this volume) is completely disrupted and the North Greenland turbidites in Hall Land and Nyeboe Land strike towards the Proterozoic to Ordovician platform strata and the Precambrian Bache Peninsula arch.

The platform succession in Ellesmere Island contains Lower and Middle Ordovician evaporites of lagoonal and sabkha environments (markers 6 and 7, Table 1). These are separated from the equivalent evaporite-bearing formations in Washington Land, Greenland, and placed on strike with clastic strata of a slope to trough environment.

D. The unmetamorphosed Lower Palaeozoic strata of Washington Land (Hurst & Kerr a, this volume, Peel & Christie, this volume) are positioned against the Precambrian Shield with its Proterozoic cover sequence. Thus, the Greenland Silurian reef complex and interdigitating shale facies, which developed at the hinge between platform and basin slope, become separated from its natural counterpart in Canada and juxtaposed with Precambrian crystalline rocks on its basin slope side.

The thick Proterozoic Thule Group sediments and igneous rocks on south-eastern Ellesmere Island and their thinner platform correlatives in Bache Peninsula (Dawes et al., this volume, Peel et al., this volume) are left isolated as a small intracratonic basin with no remnant counterparts in Greenland, and placed in juxtaposition with platform rocks as young as Silurian.

E. The Proterozoic Thule Basin strata and the thin platform sequence over the Bache Peninsula arch in Inglefield Land are displaced from their obvious counterparts in Ellesmere Island, to become a separate intracratonic basin–arch–platform system, also without correlatives across Nares Strait. The thick Proterozoic volcanic–sedimentary succession at Clarence Head, Ellesmere Island — the detailed correlative of the Northumberland Ø succession in Greenland (Dawes et al., this volume) — is placed opposite the conspicuously thin Proterozoic–Cambrian platform rocks of Inglefield Land, a relationship that suggests a northerly-trending basin margin feature in the actual Strait area.

The reconstructed rock associations described above violate the well-established tectonic and stratigraphic framework, and serious problems arise in the interpretation of the geology in terms of universally accepted stratigraphic principles. In general terms, this is based on an ancient continental margin model — a Precambrian craton flanked to the north by a major sedimentary linear basin (geosyncline). There is a deep-water basin in Ellesmere Island (Trettin 1971, 1979) and there is a similar basin with very similar successions in northern Greenland (Dawes 1976, Surlyk et al. 1980). They are fringed to the south by a shallow-water carbonate platform. This couplet is a continuous feature across northern Ellesmere Island and northern Greenland and represents the Franklinian geosyncline of Schuchert (1923). This model also involves a Precambrian Shield which is part of the North Atlantic craton with its intracratonic Proterozoic basins that outcrop to the south of the Proterozoic–Devonian platform–basin couplet. The linear basin was deformed by the mid-Palaeozoic Ellesmerian (Silurian–Devonian) orogeny. Present-day rock distribution on either side of Nares Strait is entirely consistent with such a well-established model. The disruption of straightforward relationships in Precambrian and Palaeozoic rocks, which results from a reconstruction removing 250 km of sinistral displacement, challenges the clear understanding of the regional stratigraphy as well as principles that are accepted world-wide.

Attempts to explain the reconstructed rock associations by differential vertical movements of Ellesmere Island and Greenland are inadequate. For example, the juxtaposition of the Silurian carbonate and shale sections in Greenland close to the Precambrian Shield of Ellesmere Island (Fig. 5) cannot be explained as a product of uplift and erosion of Ellesmere Island, as suggested by Newman & Falconer (1978) and Newman (a, this volume). About midway along Nares Strait at latitude 79°N, the Precambrian Shield erosion surface is delimited precisely by the overlying Proterozoic and younger strata. This erosion surface is at a comparable height above sea level on the facing coasts of Bache Peninsula and Inglefield Land (Fig. 6). Thus, no appreciable difference in net vertical displacement has occurred, at least not in this part of Nares Strait. This is supported by the glacial rebound data from northern Nares Strait (England, this volume), which show no indication that fault movements along Nares Strait have affected the normal isostatic uplift of Greenland and Ellesmere Island.

4. A substantially wider Nares Strait: the problems

Inherent in many conventional reconstructions — those featured in this volume (e.g. Peirce, Srivastava & Falconer) and those published elsewhere (e.g. Bullard et al. 1965, Keen et al. 1972, Sclater et al. 1977, Sweeney et al. 1978, Srivastava 1978) — is the prediction that, *as well as* major sinistral strike-slip displacement along

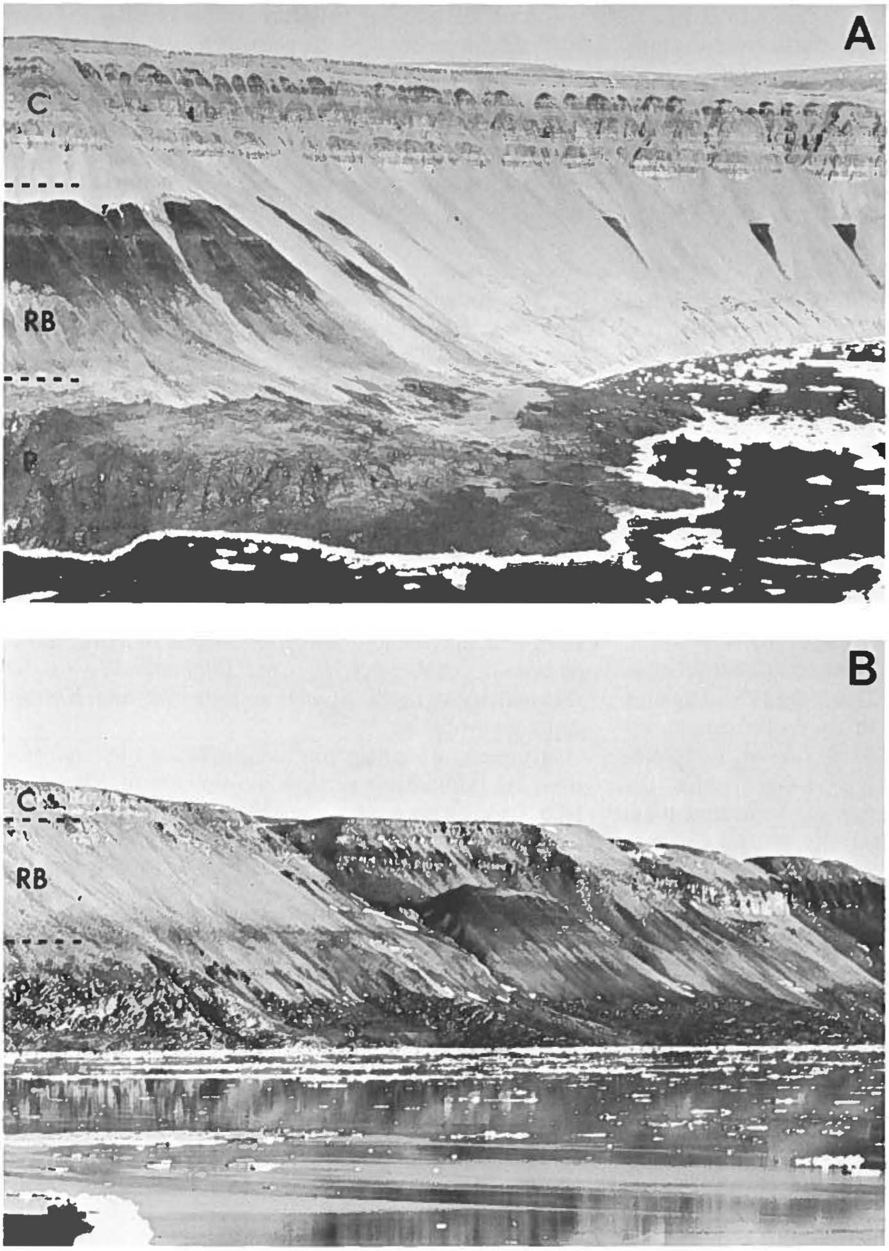


Fig. 6. Views of the Ellesmere Island (A) and the Greenland (B) shores of Nares Strait at about latitude 79°N showing the unconformity between the Precambrian Shield and the overlying flat-lying Proterozoic–Cambrian strata. A = Cape Camperdown, Bache Peninsula, B = east of Force Bugt, Inglefield Land — for locations, see in Figs 1 and 7. P = Precambrian Shield, RB = Proterozoic Rensselaer Bay Formation with two basic sills (dark), C = Cambrian strata with light-coloured clastics of the Dallas Bugt Formation overlain by dolomites of the Cape Leiper and Cape Ingersoll Formations. The Cape Camperdown coastal succession reaches into the Middle Cambrian — the comparable sequence is preserved along the Inglefield Land coast, north-east of Force Bugt (see Peel & Christie, this volume). Note the comparable height above sea level of the erosion surface of the Shield (~ 100 m) and the undeformed nature of the overlying cover. Photographs, A: P. Schledermann, B: J. S. Peel.

Nares Strait, initial separation of Greenland and Ellesmere Island was along a substantially wider Nares Strait. For example, Srivastava (1978) indicates a gap of 220 km between the two landmasses in a reconstruction for late Cretaceous time (Fig. 7), and other models show even greater oblique displacement (e.g. Bullard et al. 1965, Sclater et al. 1977, Sweeney et al. 1978).

The geological evidence against major strike-slip displacement already summarised in the preceding sections, argues against the parts of these reconstructions involving strike-slip. Additional evidence argues against the other feature of these reconstructions, wide separation. The most significant implication of reconstructions suggesting original wide separation is that a substantial volume of crustal material must have disappeared by transformation or subduction or was tectonically shortened by folding and faulting across Nares Strait as Greenland approached Ellesmere Island. There is no evidence on the shores of Nares Strait to suggest that such processes took place on the scale necessitated by the reconstructions. On the contrary, the coastal geology indicates that such dynamic tectonism did not occur. In addition, we have already quoted the data which strongly suggest that Nares Strait does not rep-

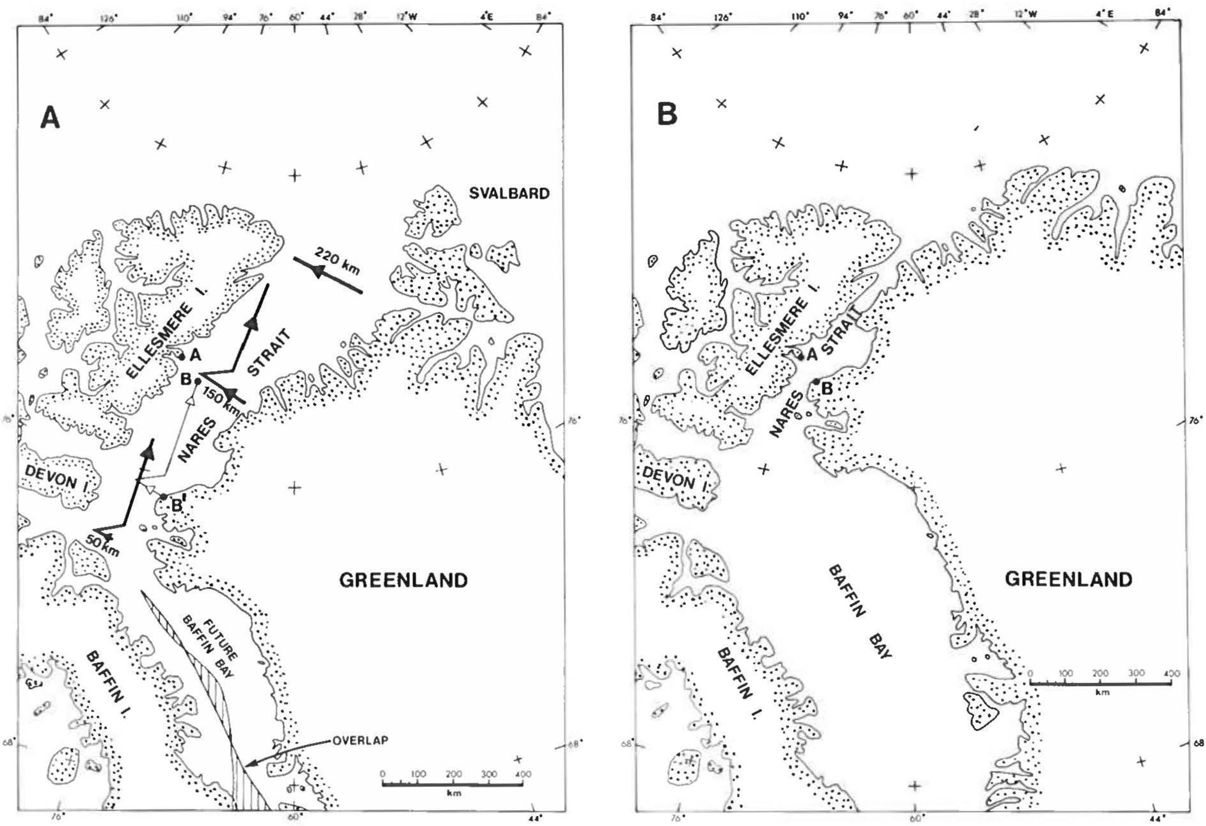


Fig. 7. Transverse drift of Greenland that is implicit in many reconstructions of the Baffin Bay region. A: Pre-drift position of Greenland in the late Cretaceous (Campanian, anomaly 32), with heavy arrows indicating movement directions. If such movements occurred, then a location east of Force Bugt, Inglefield Land (see Fig. 6B) would have originated at point B′, and would have travelled the path shown by the light arrow, to reach its present location at B. B: Present-day geography showing that the location east of Force Bugt, and point A (Cape Camperdown, Bache Peninsula, see Fig. 6A) are now only about 85 km apart. If they originated about 400 km apart as shown on the left, their transverse approach *alone* requires the disappearance (presumably by subduction) of at least 150 km of continental crust. The flat-lying undisturbed nature of the Proterozoic–Cambrian columns at A and B (together with similarly homoclinal Ordovician and Silurian strata) precludes any substantial transverse movement of those points toward each other.

resent a fundamental fracture of the lithosphere — an ancient plate boundary.

The main problem is schematically represented in Fig. 7 that illustrates the reconstruction by Srivastava (1978) and Srivastava & Falconer (this volume) in which a two-phase episode of movement is suggested. Other authors have suggested similar drift paths of Greenland (e.g. Sclater et al. 1977). Bache Peninsula and south-western Inglefield Land are geographic locations that today are about 75 km apart and midway along the Strait (Figs 1 and 7). The close geological correlation between the Precambrian Shield rocks on the shores of Smith Sound has been described in this volume (Frisch & Dawes), and there seems little doubt that in Precambrian and Palaeozoic time the entire region was underlain by continental crust. Thus, since Bache Peninsula and south-western Inglefield Land are several hundred kilometres apart in the reconstruction (Fig. 7), an appreciable segment of continental crust has in some way been dispensed with between the two points during the proposed travel path of Greenland. One would expect such a dynamic geological process — subduction or tectonic shortening or a combination — to leave some visible evidence on the shores of the Strait. Even if one speculated that Nares Strait was formerly the site of oceanic or attenuated crust, similar tectonic problems remain.

The Shield of Bache Peninsula and south-western Inglefield Land shows a well-developed erosion surface, on which flat-lying to shallow-dipping Proterozoic and basal Cambrian strata rest (Fig. 6). These platform successions form spectacular cliff sections on the shores of Nares Strait; they are undeformed, contain unstrained fossils and show no evidence of having been subjected to dynamic forces of the nature necessary to explain the disappearance between them of an extensive segment of continental crust. Furthermore, a guide to the thermal history of this part of the Nares Strait coast has been obtained from the colour index (CAI) of Ordovician and Silurian conodonts which indicates a post-Silurian temperature in southern coastal Washington Land, Greenland, of less than 90°C (Aldridge 1980, R. J. Aldridge and J. S. Peel, pers. comm. 1981); a thermal condition difficult to explain if indeed Nares Strait were the site of a subduction zone.

It is also noteworthy that no late Phanerozoic igneous outcrops are known along Nares Strait that might be related to such a closing of an initial wide gap between Ellesmere Island and Greenland. Volcanic fragments and pebbles, mostly of basalt and of southerly provenance, occur in some clastic beds of the Paleocene Eureka Sound Formation in eastern Ellesmere Island (Miall 1981, 1982). This material is generally considered indicative of an episode of late Phanerozoic magmatism connected to the Nares Strait rift — a point also mentioned in this volume by Peirce. However, the age of the igneous clast material is unknown (A. D. Miall, pers. comm. 1981). Incidentally, the Kane Basin – Smith Sound region is part of an important Proterozoic igneous province which might also be considered a possible source for such basaltic material.

5. Marker evidence for the 250 km reconstruction: the problems

Three lines of evidence based on 'geological–geophysical markers' have been presented in this volume for major sinistral strike-slip displacement of Greenland. These, summarised by Johnson & Srivastava (this volume), are given below.

a) Correlation of the southern boundary of folded and faulted strata of the mid-Palaeozoic Ellesmere–Greenland fold belt (Keen & Peirce, Newman a, Srivastava & Falconer).
b) Correlation of the Proterozoic Thule Group of Greenland with the Proterozoic deposits of the Borden Basin of northern Baffin Island and Bylot Island (Newman a).
c) Correlation of two magnetic high anomalies in the Lincoln Sea (Kovacs).

a) The southern boundary of the Ellesmere–Greenland fold belt with its apparent mis-alignment (Fig. 2) has been the most discussed geological marker in the Nares Strait debate since Wegener (1915, 1924) first drew attention to it in a displacement context (e.g. Kerr 1967a, Trettin et al. 1972, Dawes 1973, Newman 1977, Srivastava 1978). There is no doubt that the southern boundary of the fold belt intersects Nares Strait at different latitudes on Ellesmere Island and Greenland today, and the points of intersection are separated by about 200 km (Figs 2 and 8). A cursory look at this situation might suggest that this is a marker which is compatible with a restoration of 200 km. However, as noted by Higgins et al. (this volume), such restoration introduces a fundamental structural discordance, because the fold trends in the Hall Land – Nyeboe Land region of Greenland trend at a steep angle to the coast, whereas the folds inland on Ellesmere Island have a

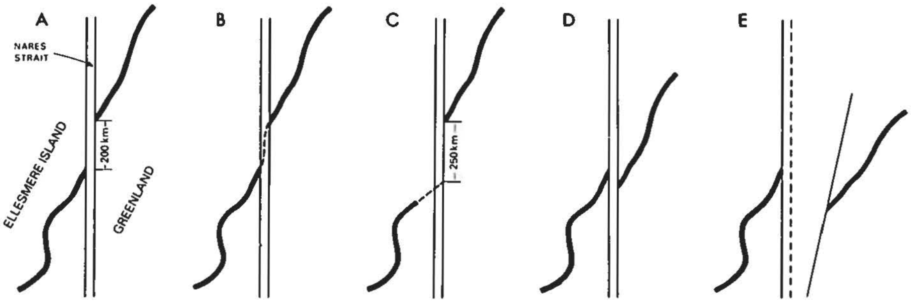


Fig. 8. Diagrammatic representation of Nares Strait and the interpretations placed on the southern boundary of the Ellesmere–Greenland fold belt (marker 12, Table 1).

A: Present-day configuration showing marker 12 intersecting the coasts of Ellesmere Island and Greenland at different latitudes.

B: Interpretation by geologists who have studied the fold belt in the Nares Strait region; the apparent mis-alignment of marker 12 across Nares Strait is due to an original feature of the fold belt margin, entirely consistent with the form of the margin elsewhere in Canada and Greenland. Any sinistral strike-slip faulting along Nares Strait has only accentuated the apparent mis-alignment.

C: Interpretation placed on marker 12 by proponents of conventional plate tectonic reconstructions of the Arctic. The fold belt boundary is interpreted as intersecting the Ellesmere Island coast at a high angle of intersection and the widely separated points of intersection of marker 12 on opposite sides of the Strait are due to about 250 km of sinistral strike-slip displacement of Greenland.

D and E: Diagrammatic reconstructions according to conventional plate tectonic models to illustrate the resultant structural discordancies in the fold belt margin. D: 250 km dextral movement of Greenland. E: 250 km dextral movement, as well as oblique separation, of Greenland and Ellesmere Island to a pre-drift position at the time of initial opening of the Labrador Sea. This corresponds to the reconstruction at anomaly 32 time (late Cretaceous) of Srivastava (1978).

similar trend, but curve near the coast where they strike parallel to the Strait (Fig. 9). As in many fold belts of the world, major fold trends are not straight, and arcuate or sinuous segments are common. The apparent mis-alignment of the Ellesmere–Greenland fold belt margin is the result of a bend or salient in the edge of the fold belt — presumably controlled by some irregularities in the geosyncline margin — that existed before the Strait was formed. A clear remnant of the bend is preserved on Ellesmere Island on the shore of Kane Basin (Kerr 1973a, b) and the site and trend of Nares Strait may well be controlled in some way by the tectonic fabric of this older salient.

There is another salient in the southern edge of the fold belt in south-western Ellesmere Island and Devon Island (Fig. 9) which is accurately mapped on land. To illustrate the suggestion that Nares Strait crosses a similar salient, we show in Fig. 9 a hypothetical seaway identical to Nares Strait in shape, size and orientation. It differs only in location. This hypothetical seaway truncates the fold belt margin at much the same angle as Nares Strait truncates the fold belt margin that now exists in the Nares Strait region. On the hypothetical seaway there is an apparent mis-alignment of the southern boundary of the fold belt by about 300 km and, incidentally, many of the markers shown in Table 1 and Fig. 3 would also show an apparent offset.

We concur to the view expressed in this volume by Higgins et al. that the southern limit of the Ellesmere–Greenland fold belt, on close examination of its structure including main trend of individual folds, supports the case against major strike-slip displacement along the Strait.

In a 250 km reconstruction, the prominent faults in northern Nyeboe Land, Greenland, have been brought into close proximity to the system of faults on the Ellesmere shore of Kane Basin (Newman & Falconer 1978, Newman a, this volume). However, the Nyeboe Land fault zone is a high-angle reverse fault system that coincides with the early Palaeozoic platform margin of the Franklinian geosyncline (Dawes, this volume); the Parrish Glacier thrust in Ellesmere Island is a low-angle thrust system of post-Paleocene age (Mayr & de Vries, this volume). There may well be a tectonic connection between these fault systems since both are situated near and parallel to the southern boundary of the Ellesmere–Greenland fold belt. However, we cannot support such a direct correlation of a low-angle thrust with a high-angle reverse fault as evidence indicating 250 km of strike-slip displacement, particularly since the more obvious continuation of the Nyeboe Land fault zone is the system of high-angle faults on Judge Daly Promontory which also coincide with the early Palaeozoic platform margin.

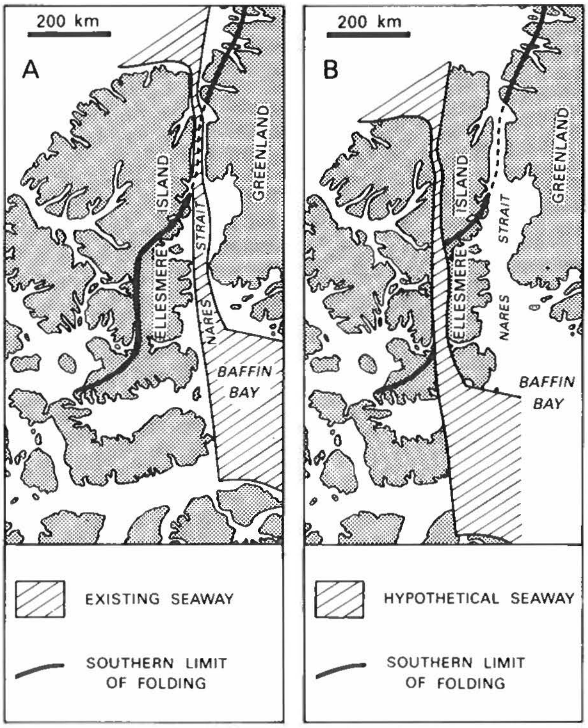


Fig. 9. Maps showing the southern boundary of the Ellesmere–Greenland fold belt (marker 12, Table 1) to illustrate the interpretation that the apparent mis-alignment in this marker along Nares Strait is due to a salient in the fold belt margin, of the same form as present on land in Ellesmere Island.

A: Present-day geography with the Baffin Bay – Nares Strait seaway outlined.

B: Hypothetical case where a seaway of the same shape and size as Nares Strait is located about 150 km to the west resulting in an apparent sinistral offset of marker 12 that simulates the present-day situation at Nares Strait.

b) The similarity of the Thule Group strata in Greenland with the Proterozoic rocks of northern Baffin Island and Bylot Island has been suggested as evidence of original close proximity (Newman a, this volume). The detailed correlation of the Proterozoic successions between Greenland and Ellesmere Island in the Smith Sound region has been outlined in this volume (Dawes et al., Peel et al.). We regard it as geologically unsound to reposition together relatively flat-lying successions of general stratigraphic similarity and age which are now about 400 km apart, and abandon a detailed correlation of successions only tens of kilometres apart, including a major basin margin feature — Bache Peninsula arch.

c) The only 'direct' calculation of strike-slip displacement along Nares Strait based on a geophysical marker is discussed by Kovacs (this volume), who suggests 240 km displacement from aeromagnetic data from the Arctic Ocean. This displacement is based on a pair of magnetic high anomalies described as being separated and offset by the northern continuation of the Wegener fault in Nares Strait. However, the magnetic anomalies used in the displacement analysis in fact occur on the same (north-west) side of the proposed site of the Wegener fault, albeit on either side of a suggested second fault line — the Ellesmere fault zone — that strikes toward Ellesmere Island. Thus, the proposed offset of the two magnetic anomalies bears little relationship to strike-slip displacement between Ellesmere Island and Greenland.

Discussion

The available data from the immediate Nares Strait region have been summarised, and we can find no evidence, neither geological nor geophysical, suggesting that strike-slip displacement of the magnitude necessary to produce major changes in the relative positions of Ellesmere Island and Greenland occurred along Nares Strait. We conclude that any case for major displacement must rest on evidence accumulated elsewhere, particularly in the Labrador Sea, Baffin Bay, the Arctic Ocean and the North Atlantic Ocean systems — as well as globally. Johnson & Srivastava (this volume) have shown that such evidence is mainly geophysical and comes from oceanic areas at some distance from the Strait. This evidence predicts great left-lateral displacement of Greenland during plate tectonic movements in late Phanerozoic time.

The foremost argument in support of great displacement along Nares Strait has been that without such displacement the structure and oceanic crust of Baffin Bay and Labrador Sea cannot be explained by the generally accepted plate tectonic model involving substantial sea-floor spreading. Keen & Peirce (this volume) and Srivastava & Falconer (this volume) have elucidated the various geophysical implications and problems which arise if only minor motion along Nares Strait is accepted. However, there has been a steady accumulation of data, in addition to the Nares Strait evidence, that are difficult to reconcile with a model based on rigid plates and substantial opening of Baffin Bay and Labrador Sea by sea-floor spreading and modifications and alternative interpretations have been suggested (e.g. Kerr 1967b, 1981a, b, Grant 1975, 1980, this volume, van der Linden 1975, 1977, Umpleby 1979). In view of the restraint placed on displacement on the Nares Strait lineament, alternatives based on the data and ideas in such papers must be particularly relevant. Linear magnetic anomalies of the type delimited in the *outer* margins of the Labrador Sea and in Baffin Bay (Srivastava 1978, Jackson et al. 1979) may have a number of possible origins and are not necessarily indicative of the generally accepted model of sea-floor spreading, while a gravity low in the centre of Baffin Bay represents a structure which is not necessarily a spreading ridge. We regard the geophysical interpretations of these specific features as suspect and indicative of a tendency to regard oceans as the products of an oversimplified model of sea-floor spreading, regardless of the restraints placed on such models by onshore geological data.

Monahan & Johnson (this volume) present an illuminating comparison between the physiography of Nares Strait and other major structural lineaments that also have been the centre of long controversies about fault displacement. They conclude that such onland lineaments as the San Andreas Fault and the Great Glen Fault are considerably more amenable to analysis of the amount of strike-slip displacement than is Nares Strait. Despite the fact that the land surrounding Nares Strait is partly ice covered, and the coasts are separated by more than 20 kilometres, we doubt this conclusion for the following reasons:

1) The regional geology of Nares Strait is relatively simple, being composed of rocks and structures of various ages, forming what is essentially a parallel system of stratigraphic–structural units.
2) The regional trend of the stratigraphic–structural units is persistent and is part of a system extending for 3000 km from the Beaufort Sea to the Greenland Sea. In the region of the Strait, the trend is not complicated by tectonic, metamorphic, magmatic or metasomatic processes.
3) Nares Strait cuts obliquely across all the regional stratigraphic–structural units in which a number of uncontroversial geological markers of known age occur.
4) Because of its high arctic location, Nares Strait geology is beautifully exposed: rocks are not covered by vegetation and since it is the site of a seaway, the sea-cliffs form excellent exposures, often continuous for tens of kilometres.
5) Regions of great strike-slip normally have associated structural complications over many, sometimes tens of kilometres from the main fault plane, which often make correlation across the main fault problematical. The coasts of Nares Strait do not show such complexities.

The science of geology has now reached a stage at which acceptance of basic stratigraphic and structural principles allows regional correlations to be made across all the major oceans of the world. In the last decade many papers put forward pre-drift reconstructions based on such rock correlations. This trend is well illustrated by, for example, Schenk's (1981) account of the Meguma Zone of Nova Scotia and the search for a suitable source continent, for which north-western Africa (Morocco) — some 4500 km away in present-day geography — is a prime candidate. Our present understanding of the origin of the Atlantic Ocean system is partly based on such long-range rock correlations and, indeed, Wilson's (1966) initial evidence concerning the closure and the reopening of the Atlantic was based on rock correlations. Recognition of exotic rock segments on the edges of the Atlantic is not at variance with the general thesis of the opening cycle of the Atlantic and as such they are understandably given serious appraisal.

Nares Strait is less than 25 km across in its narrowest part. Several islands in Kennedy Channel composed of various Silurian carbonate facies, which correlate with rocks on the adjacent Greenland coast (J. M. Hurst, pers. comm. 1981), reduce the actual distance across which correlation is made, to about 15 km. It is interesting that many earth scientists have found it difficult to accept correlation of near identical rock successions across such a narrow stretch of water as indicating that the rocks were formed in their present relative positions, when the majority are willing to accept, and to use, the general similarity of rock columns thousands of kilometres apart as evidence that those rocks were formed in close proximity. This is all the more surprising as rock correlations across Nares Strait are not problematical and in no way in conflict with any geological or geophysical data from the Strait area.

Conclusion

A summary of the present geological and geophysical knowledge of the Nares Strait region fails to reveal any feature indicating strike-slip displacement between Ellesmere Island and Greenland. We conclude that the evidence presented at the symposium "Did Greenland drift along Nares Strait?" and in this volume demonstrates that any net strike-slip displacement along Nares Strait has been minor, i.e. in the range of 0 to 25 km. Furthermore, there is no direct evidence to support a tectonic model involving a complicated history of motion along the Strait, with major strike-slip, vertical or oblique movements, that might be accommodated in some suitable scenario and connected to the suggested conventional opening of the surrounding oceans that predicts great sinistral motion of Greenland in late Phanerozoic time. If the evidence indicating geological continuity between Ellesmere Island and Greenland is accepted, modifications should be considered to the widely accepted ideas for the opening of the Labrador Sea and Baffin Bay, which are based on a conventional, substantial sea-floor spreading, rigid-plate model. If the restraints on motion along Nares Strait are ignored, Greenland will continue to be allowed to drift around in response to refinements of such plate tectonic models that are suspect, since they do not incorporate the available data from the immediate onshore regions.

Acknowledgements

We thank numerous colleagues at the Geological Survey of Greenland and the Geological Survey of Canada for co-operation and discussion over a number of years of the geology of the Nares Strait region, in particular R. L. Christie, W. E. Davies, J. M. Hurst, U. Mayr, W. W. Nassichuk, J. S. Peel, R. Thorsteinsson, H. P. Trettin and A. Weidick. A. K. Higgins and J. M. Hurst are thanked for critical reading of the text and we are grateful to Esben Glendal for valuable comments and technical assistance in the preparation of the manuscript. P. Schledermann, Arctic Institute of North America and J. S. Peel, Geological Survey of Greenland, are thanked for the photographs used in Fig. 6. The paper is published with the permission of the Director of the Geological Survey of Greenland.

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