Nares Strait: a conflict between plate tectonic predictions and geological interpretation

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The majority of published plate tectonic models concerning relative movement of North America and Greenland predict sinistral movement of 100 to 250 km along Nares Strait since the mid-Upper Cretaceous. Some models also predict an initial gap of up to 150 km across it in late Cretaceous time. If geological and structural data across Nares Strait convincingly preclude such movements, the plate tectonic models for the area must be revised. Different plate configurations and the problems they pose are presented when a) the Queen Elizabeth Islands are considered part of the Greenland plate and Parry Channel is considered the fossil boundary between the North American and Greenland plates, b) the North American and Greenland plates are considered non-rigid to accommodate the relative motions between them, thereby involving virtually no movement along Nares Strait and c) there is a combination of the previous two situations. The pre-drift reconstructions of Greenland relative to North America show that, if no strike-slip motion is allowed along Nares Strait, serious overlaps occur between the continental crust of the two plates. It is concluded from these reconstructions that either strike-slip motion did take place along Nares Strait as the plate tectonic models have predicted or far more deformation of the plates, not supported from their presently known geology, must have taken place. More detailed geological and geophysical information is needed in the regions surrounding Nares Strait before a definite answer to this problem can be obtained.

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Nares Strait is the most prominent physiographic feature between Greenland and Ellesmere Island (Fig. 1). It has attracted the attention of a large number of geologists, geomorphologists and geophysicists since the suggestion made by Taylor (1910) that it was the locus of a strike-slip fault along which North America had moved southwest away from Greenland. Taylor's idea of a strike-slip fault since then has been adopted by a majority of the geophysicists concerned with the evolution of the North Atlantic, the Labrador Sea, Baffin Bay and the Norwegian–Greenland Sea. It has now been well documented from the results of the Deep Sea Drilling Project and from systematic geophysical surveys of the oceanic regions in the world (for details e.g. see Cox 1973) that large parts of the present oceanic regions were formed due to the separation of lithospheric plates (which include the present landmasses) from each other. Thus, by identifying boundaries of the different lithospheric plates involved and by delineating their direction of motion one can reconstruct their palaeopositions. One of the basic concepts is that the plates involved remained rigid throughout the development of the oceanic regions in question, unless sufficient geological evidence exists to suggest otherwise. Based on this assumption several palaeogeographic reconstructions of Greenland relative to North America and Eurasia have been proposed (e.g. Bullard et al. 1965, Pitman & Talwani 1972, Kristoffersen & Talwani 1977, Le Pichon et al. 1977, Sclater et al. 1977, Kristoffersen 1978, Srivastava 1978).

In many of these reconstructions, Nares Strait has been considered the boundary between the North American and Greenland plates. Few geophysical measurements exist in this region to support such an assumption. Nonetheless, the physiography of this region favours it be a structural boundary, like a transform fault as was pointed out by Wilson (1965). Geologists, on the contrary, have interpreted that structural and lithological units continue across the Strait with little or no offset.

It is beyond the scope of the present paper to describe in detail the land geology bordering Nares Strait; however, a brief description relevant to this paper has been included from the work of Dawes (1973, 1976) and Kerr (1967). The rocks surrounding Nares Strait which form part of Ellesmere Island and northern Greenland fall into four groups; the crystalline basement rocks forming part of the Greenland–Canadian Shield, the un-

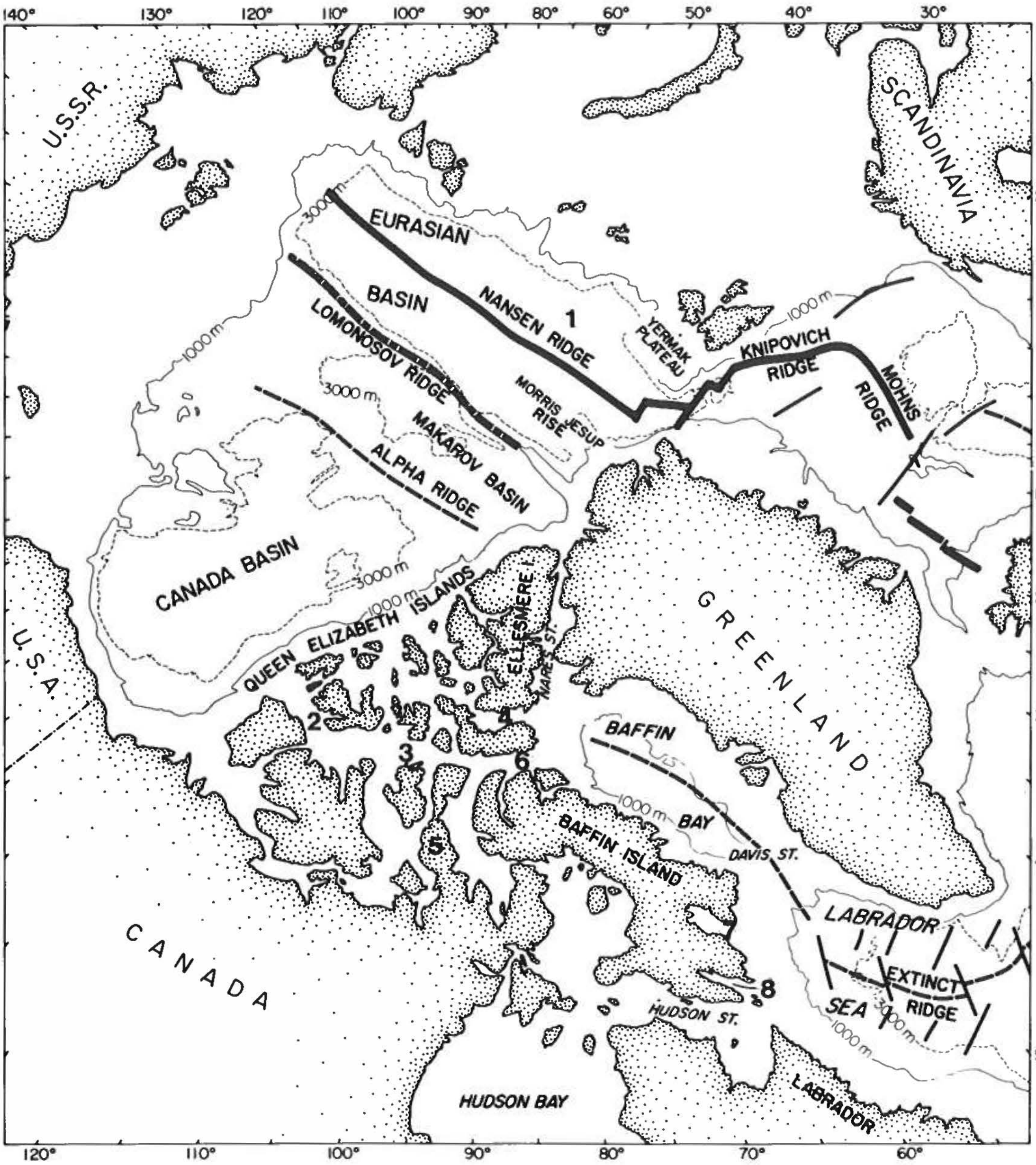

Fig. 1. Map of the regions surrounding Nares Strait. 1 = Nansen Basin, 2 = Viscount Melville Sound, 3 = Parry Channel, 4 = Jones Sound, 5 = Boothia Peninsula, 6 = Lancaster Sound, 7 = Cumberland Sound, 8 = Frobisher Bay.

metamorphosed rocks of Proterozoic and Lower Palaeozoic age forming the stable platform overlying the Shield, and the folded mainly Lower Palaeozoic and Devonian sediments of the Franklinian geosyncline that have been deformed into the Ellesmere–Greenland fold belt. The fourth group is represented by less severely deformed Upper Palaeozoic, Mesozoic and Tertiary strata (Sverdrup Basin) that mainly occupy the central region of Ellesmere Island, but which are not present in Greenland on the shores of Nares Strait. However, a similar Carboniferous to Tertiary sedimentary succession (Wandel Sea Basin) occurs in eastern North Greenland while a volcanic province consisting of mainly rhyolitic lavas and tuffs occurs along the northernmost coast on the shore of the Eurasian Basin. The age of the volcanic rocks has been isotopically dated at about the Cretaceous–Tertiary boundary (Larsen et al. 1978).

Even though different rock units of the Franklinian geosyncline on Ellesmere Island can be correlated with similar rock units on Greenland, the folded rocks show major structural differences. The main difference between them is that in Greenland axial planes of folds dip toward the craton (Dawes 1973, 1976) whereas in Ellesmere Island they more commonly dip towards the Arctic Ocean (Kerr 1967), but there are some exceptions. Such a marked difference in structural style must in some way be controlled by the structure of the Strait. Nares Strait must have been a significant structural site when the difference in fold pattern emerged, probably in the Palaeozoic (Dawes 1973).

According to Dawes et al. (1980), rock units of the Proterozoic Thule Group are present on opposite sides of northern Baffin Bay and Smith Sound on NW Greenland and SE Ellesmere Island. They maintain that certain rock units are so similar in lithology and thickness that unit to unit correlation of both sedimentary and volcanic rocks has been established. This correlation, they suggest, strongly supports the concept of a single intracratonic basin that shows little or no lateral displacement of its units. On the contrary, the projection of the boundary between the folded and unfolded rocks of the Franklinian geosyncline onto a median line in the Strait suggests sinistral displacement of at least 200 km. Whether one should use this boundary to show strike-slip movement along Nares Strait is debatable because of the structural differences which exist between the fold belt on the Canadian and Greenland sides. In general, geologists maintain the opinion that less than 50 km or so of transcurrent motion has taken place along Nares Strait. This has created a dilemma in the minds of many. A detailed account of this controversy has recently been given by Kerr (1980b).

The question therefore arises whether one can explain the evolution of the oceanic regions adjacent to Nares Strait using sea-floor spreading theory and at the same time keep the northern part of Greenland more or less in its present position relative to Ellesmere Island. We have tried to answer this question first by examining the position of Greenland relative to North America and in particular of Ellesmere Island during the successive stages of evolution of the Labrador Sea, Baffin Bay and the Norwegian–Greenland Sea; secondly by examining the consequences if the Queen Elizabeth Islands in the Canadian Arctic are regarded as attached to Greenland throughout their geological history; and thirdly by examining the possibility of non-rigid behaviour of the plates involved.

The regions surrounding Nares Strait

Nares Strait lies near three oceanic regions whose tectonic development has a direct bearing on the dilemma of Nares Strait. These are the Arctic Ocean Basin to the north (this includes Canada Basin, Makarov Basin, Eurasian Basin and the Alpha, Nansen and Lomonosov Ridges), the Norwegian–Greenland Sea to the east and Baffin Bay – Labrador Sea to the south (Fig. 1). Of the three regions the Arctic Ocean Basin is the least explored except for its eastern part, the Eurasian Basin. Recent geophysical measurements carried out in the Eurasian Basin and Norwegian–Greenland Sea (Vogt et al. 1978, 1979, 1981, Feden et al. 1979) have shown that it started to form at the same time as the Greenland Sea when the Lomonosov Ridge (presumably a continental fragment) separated from Scandinavia and northeastern USSR. Geophysical measurements in the Norwegian–Greenland Sea (Talwani & Eldholm 1977) and the Labrador Sea (Srivastava 1978) show that these regions were formed by a sea-floor spreading process due to the separation of Greenland from Eurasia and North America, respectively. These plates have therefore played an important role in the development of oceanic basins not only to the east and west of Greenland but also to the north of it. Nares Strait seems to be the obvious physiographic feature which connects the three basins. It is for this reason that it has been regarded as a boundary between the North American and Greenland plates along which the two plates have moved.

We will first review the geophysical evidence which has been used to substantiate sea-floor spreading in these regions. Fig. 2 is a composite diagram of the magnetic lineations and fracture zones which have been identified in the Labrador Sea, the northeast Atlantic, the Norwegian–Greenland Sea and in the Eurasian Basin. These results have been compiled mainly from published work by Vogt & Avery (1974), Talwani & Eldholm (1977), Srivastava (1978), Grønlie & Talwani (1978), Voppel et al. (1979), Voppel & Rudloff (1980) and Vogt et al. (1981). We have used the more recent time scale of Berggren et al. (1978) rather than the older one of Heirtzler et al. (1968) in assigning ages to each of the magnetic anomalies. Features worth noticing from this diagram are: a) anomalies older than 24 (53 m.y.) lie mainly in the Labrador Sea and in the North Atlantic south of Greenland, b) anomaly 13 (36 m.y.) does not lie in the Labrador Sea but continues north of Charlie–Gibbs Fracture Zone in the northeast Atlantic towards Iceland and c) anomaly 21 (48 m.y.) and possibly 24 are the oldest identifiable anomalies which lie in the Eurasian Basin.

The occurrence of anomaly 24 in the Eurasian Basin, Norwegian–Greenland Sea, Labrador Sea and in the North Atlantic both north and south of the Charlie–Gibbs Fracture Zone clearly shows that spreading in these regions was simultaneous. This implies formation of a triple junction not only south of Greenland but also north of it. The evolution of the Arctic Basin as a whole is not yet well understood. However, from the pattern of the magnetic lineations in the Eurasian Basin (Vogt et al. 1979, Feden et al. 1979) it is most likely that a FFR (Fault, Fault, Ridge) triple junction (e.g. see Pierce, this volume) existed north of Greenland. The triple junction south of Greenland was RRR (Ridge, Ridge, Ridge) type (Laughton 1971, Kristoffersen &

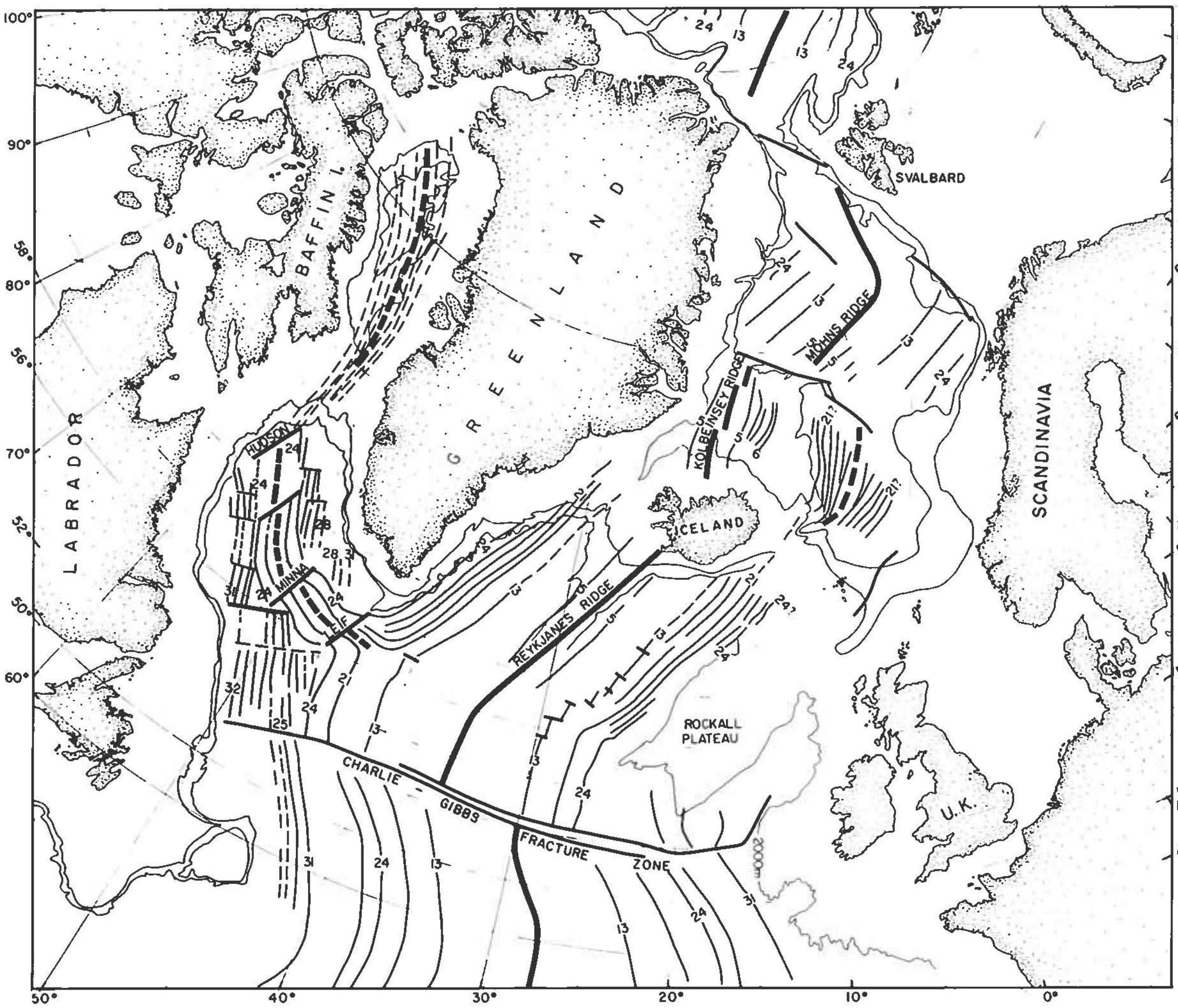

Fig. 2. Magnetic lineations and fracture zones in the North Atlantic Ocean, Labrador Sea and Norwegian–Greenland Sea compiled from sources listed in the text.

Talwani 1977). The absence of anomaly 13 in the Labrador Sea and its continuation towards Iceland has been interpreted as establishing an indication of the time when sea-floor spreading stopped in the Labrador Sea, thus ending the active presence of two triple junctions.

The existence of a triple junction (FFR) north of Greenland is based on the assumption that the Lomonosov Ridge was coupled to the North American plate rather than the Greenland plate (Srivastava & Falconer 1979). Le Pichon et al. (1977), on the other hand, considered that the Lomonosov Ridge was rigidly attached to Greenland through the Canadian Arctic Islands. Though their fit did not involve any lateral motion along Nares Strait, it did across the Boothia Arch with some suggestion of overlap between the Arctic Islands that form part of the Canadian Shield.

We will briefly examine some of the problems arising from different reconstructions.

Nares Strait: a plate boundary

Palaeogeographic positions of Greenland and Eurasia relative to North America at different geological times are shown in Fig. 3. These were obtained by using the pole positions for different regions as given by Srivastava (1978). Reconstructions given by others (Bullard et al. 1965, Pitman & Talwani 1972, Le Pichon et al. 1977, Sclater et al. 1977) based on criteria other than magnetic lineations and fracture zones exist, and differ only in details from the ones shown in Fig. 3.

The sequence of events considered in deriving the palaeogeographic reconstructions is summarized in Table 1. The palaeogeographic reconstructions in Fig. 3 show that Nares Strait has not only been a site of transcurrent motion between northern Greenland and Ellesmere Island, but also a region of compression or sub-

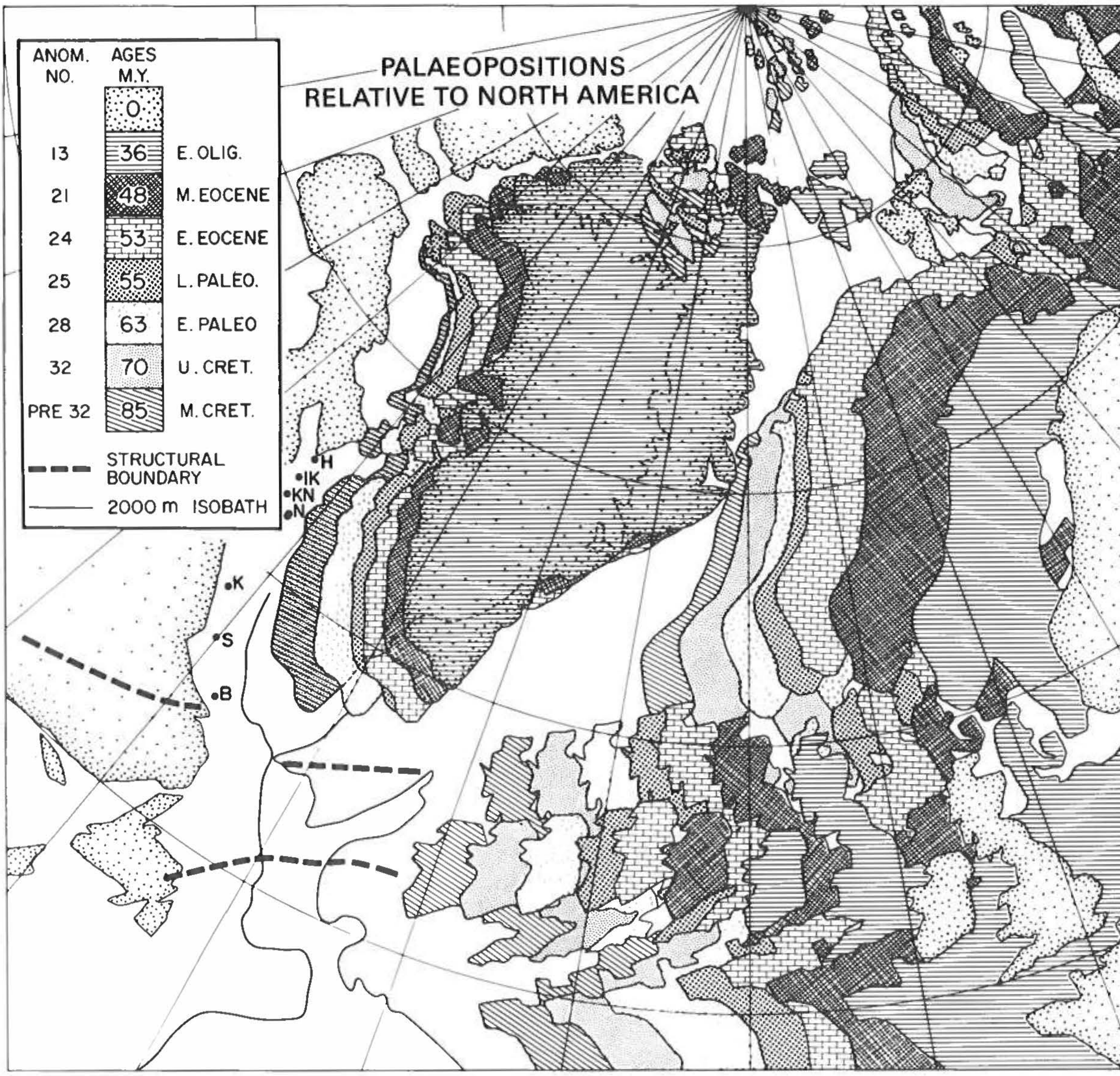

Fig. 3. The palaeogeographic positions of Greenland and Eurasia relative to North America during the successive stages of evolution of the North Atlantic, the Labrador Sea and the Norwegian–Greenland Sea based on the poles of rotation as given by Srivastava (1978). Also shown are the positions of five wells (H–Hellefisk, IK–Ikermiut, KN–Kangâmiut, and N–Nukik 1 and Nukik 2) on the Greenland Shelf and of three wells (K–Karlsefni, S–Snorri, and B–Bjarni) on the Labrador Shelf. Wells on the West Greenland Shelf are rotated to conform with pre-drift plate positions illustrated. The Queen Elizabeth Islands in the Canadian Arctic have been regarded as part of the North American craton in this reconstruction.

duction. We will examine briefly each of these situations.

Fig. 4 shows positions of Greenland relative to North America prior to active sea-floor spreading in the Labrador Sea (Fig. 4a) and at the time of anomaly 25 (55 m.y., Fig. 4b) during which major volcanism took place in the North Atlantic (formation of Iceland–Faeroe Ridge), the northern Labrador Sea, (formation of Davis Strait Sill) and southern Eurasian Basin (formation of Morris Jesup Rise and Yermak Plateau). For the sake of simplicity we have not tried to show the plate boundaries in these reconstructions. Similar reconstructions with plate boundaries have been published by Srivastava (1978). The regions surrounding Nares Strait are our main concern here. At the time of initial opening of the Labrador Sea (Fig. 4a) the position of Greenland shows a gap of 220 km between it and the northern tip of Ellesmere Island, a net displacement from its present position of 330 km to the southwest near the mouth of Smith Sound and of 600 km to the southwest of its southernmost tip. This, however, does not necessarily imply formation of new crust of these magnitudes in

Table 1. Summary of the tectonic events in the North Atlantic, Labrador Sea, Eurasian Basin and Norwegian–Greenland Sea.

Age m.y.	Mag. Ano. No.	North Atlantic	Labrador Sea & Baffin Bay	Eurasian Basin, Norwegian–Greenland Sea
110?		Iberia started to separate from North America thus creating the Newfoundland Basin between Grand Banks and Iberia (1), (2), (3)	Volcanism on the southern Labrador Shelf and on the coast associated with the initial stages of sea-floor spreading in the Labrador Sea (11)	–
95		Bay of Biscay started to open due to rotation of Iberia from Europe (1), (2), (3)	–	–
85	34	Rockall Trough opened due to separation of Rockall and Greenland away from Europe (1) to (4)	–	Commencement of spreading in Makarov Basin (8), (9)
70	32	Opening in Rockall Trough stopped and shifted to the west between southern Labrador coast and Rockall Bank as well to the south between Grand Banks and British Isles (4)	Active sea-floor spreading commenced in the southern Labrador Sea. This gave rise to compressive motion between Queen Elizabeth Islands and northern Greenland (4)	Shear motions between eastern Greenland and Europe and some compression between northern Greenland and Svalbard (4)
63	28	Opening continuing (4)	Active sea-floor spreading commenced in the northern Labrador Sea. More compression between Queen Elizabeth Islands and northern Greenland or along the northern margin of Makarov and Canada Basins (4)	– do –
55	25	– do – Volcanism forming Thulean Rise	Opening in Baffin Bay starting. Volcanism in Davis Strait, on Baffin Island as well as on West Greenland coast. Compression and translational motion between Greenland and Queen Elizabeth Islands (4)	Volcanism in eastern Greenland near Scoresby Sund and on Voring Plateau, Faeroe Islands, on Morris Jesup Rise and Yermak Plateau (4), (10)
53	24	Sea-floor spreading continuing	Active sea-floor spreading commences in Baffin Bay. Translation motion between Greenland and Queen Elizabeth Islands. Drastic change in direction of motion between Greenland and North American plates (4), (5)	Spreading in Makarov Basin stopped and Lomonosov Ridge got firmly coupled to its eastern flank. Active sea-floor spreading started in Nansen Basin, Norwegian–Greenland Sea. Strike-slip motion between Svalbard and northern Greenland (4), (6), (8), (9)
48	21	– do –	Change in direction of motion between Greenland and North America. Strike-slip motion continued between Greenland and Queen Elizabeth Islands (4), (6)	Jump in the ridge axis to the west and formation of Iceland–Faeroe Ridge (7)
36	13	– do –	Extinction of sea-floor spreading in Baffin Bay and Labrador Sea (4), (6)	Extinction of sea-floor spreading in the Norwegian Sea. Break of the land bridge between northern Greenland and Svalbard. Commencement of sea-floor spreading west of the Norwegian Basin (6)

(1) Kristoffersen (1978), (2) Sclater et al. (1977), (3) Le Pichon et al. (1977), (4) Srivastava (1978), (5) Kristoffersen & Talwani (1977), (6) Talwani & Eldholm (1977), (7) Voppel et al. (1979), (8) Srivastava & Falconer (1979), (9) Taylor et al. (1980), (10) Feden et al. (1979), (11) McWhae & Michel (1975).

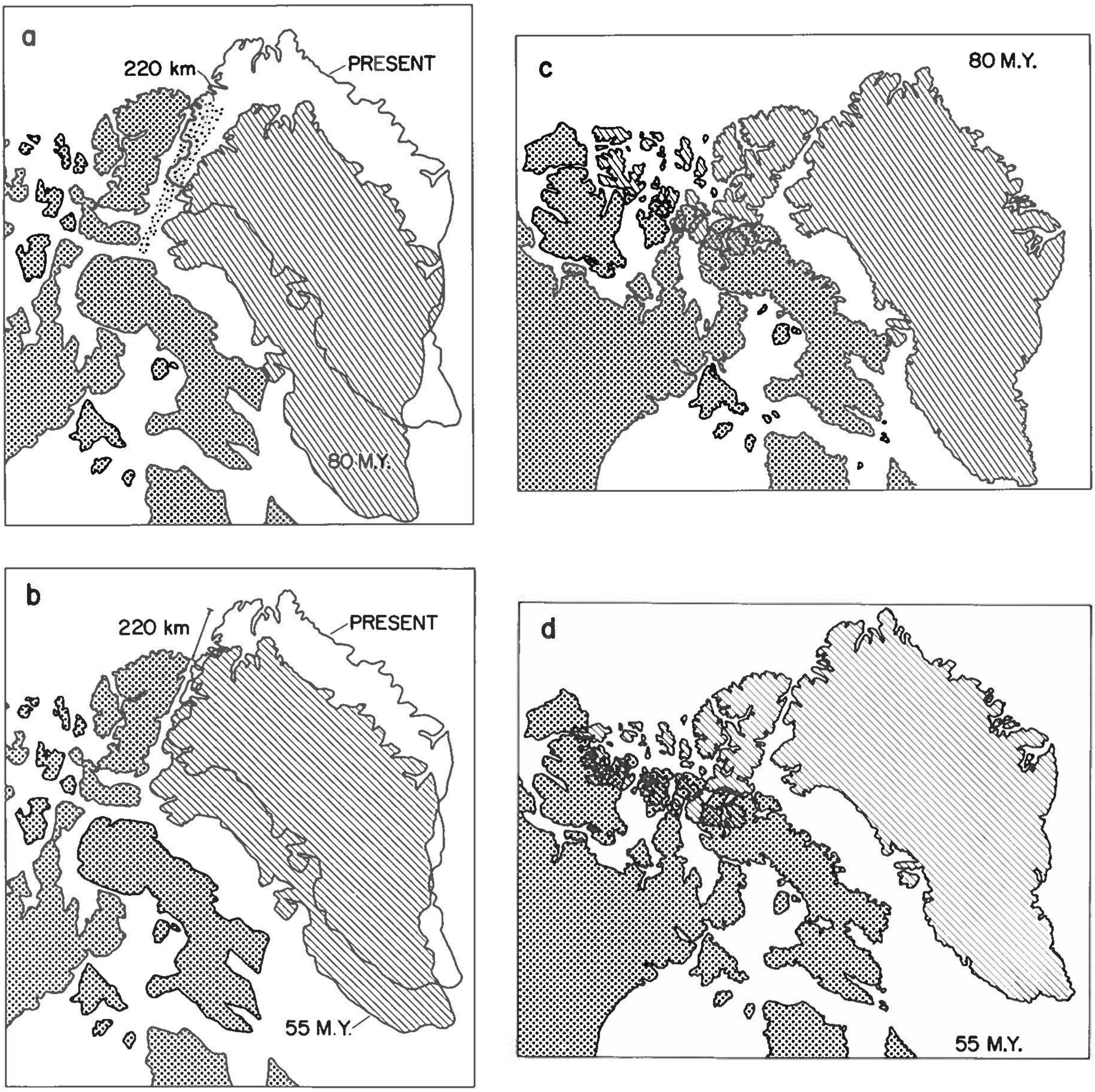

Fig. 4. Palaeogeographic position of Greenland relative to North America prior to active sea-floor spreading in the Labrador Sea (80 m.y.) and at anomaly 25 time (55 m.y.) for the cases when the plate boundary between North America and Greenland lies along Nares Strait (a, b) and when it lies along Parry Channel (c, d).

these regions since the inception of sea-floor spreading in the Labrador Sea. The motion of Greenland in the north was due to translation as well as compression while in the south it was mainly due to extension. Reconstruction at anomaly 25 time (Fig. 4b) shows a left-lateral displacement of 220 km between Greenland and Ellesmere Island along Nares Strait. From the time of initial spreading (Fig. 4a) to anomaly 25 time (Fig. 4b) Greenland moved north with a pivot at the mouth of Lancaster Sound. This perhaps gave rise to compression between Ellesmere Island and northern Greenland. The question arises as to what happened to the material which lay between Ellesmere Island and Greenland. There are three possibilities: a) either it was subducted below Greenland or b) the gap never existed and the required amount of motion was taken up within the Canadian Arctic Islands — probably in the Sverdrup Basin or c) the plate kinematics are poorly controlled and the compressional movement is an artifact. According to Balkwill (1978), the main compression in the Sverdrup Basin took place between mid-Eocene and early Miocene with a maximum lateral shortening of 40 km. This is contrary to what the reconstruction in Fig. 4b suggests. The likelihood of each of these possibilities is further examined later.

Lancaster Sound, Viscount Melville Sound: a plate boundary

If it is assumed that no lateral displacement took place along Nares Strait and that the Queen Elizabeth Islands were always firmly coupled in their present configuration to Greenland rather than to North America, then somewhat different situations are found in the reconstructions (Fig. 4c and 4d). The large overlap between the islands located on either side of Lancaster Sound and Viscount Melville Sound, which results from such reconstructions, is — from a geological point of view — as undesirable, if not more, as the strike-slip motion along Nares Strait.

Viscount Melville and Lancaster Sounds, which form a long arcuate feature, have been regarded as the boundary between the North American and Greenland–Queen Elizabeth Islands plates in these reconstructions mainly because next to Nares Strait they comprise the most prominent physiographic feature. It is equally likely that such a boundary could lie somewhere else among the Arctic Islands, or that the boundary has migrated with time during various episodes of the evolution of the Labrador Sea and Arctic Basin.

The North American plate: a non-rigid plate

Kerr (1981) proposed a configuration of the North American plate including the Canadian Arctic Archipelago relative to Greenland where he has closed part of the Labrador Sea and Baffin Bay without invoking any lateral displacement between Greenland and Ellesmere Island. This is shown in Fig. 5a. The dark solid lines show the regions where compression and crustal extension took place in the North American plate.

The physiography of a number of channels in the Canadian Arctic suggests that they may have been the sites of crustal extension during the early stages of sea-floor spreading (Beh 1975, van der Linden 1977), thus forming grabens and half grabens. Crustal structure under most of these straits still remains unknown, though Kerr (1980a) has interpreted the structure under Lancaster Sound from some neighbouring seismic reflection data.

In his reconstruction, Kerr (1981) has assumed Baffin Bay to be underlain largely by continental crust thereby implying that little or no sea-floor spreading took place in this region. The small movement of Greenland relative to Baffin Island needed in his reconstruction is accommodated by crustal stretching in the formation of Hudson Strait, Frobisher Bay and Cumberland Sound. No refraction data exist to support that the crust under these regions is attenuated. Similarly, the relative movements needed between Ellesmere Island and northern Greenland to close a portion of the Labrador Sea are accommodated by opening a portion of the Sverdrup Basin.

To see the amount of compression that must have occurred within the Sverdrup Basin, we have modified Kerr's reconstruction by considering North America as a rigid plate, with the results shown in Fig. 5b. It shows that about 130 km and 50 km of compression is required at the north and south end of Nares Strait respectively. On the other hand, Balkwill (1978) suggested a maximum compression of 40 km only.

A large portion of the Labrador Sea which to us appears to be underlain by oceanic crust remains open in Kerr's reconstruction. If one regards it as underlain by continental crust then a serious situation develops between Greenland and Eurasia. It has been well accepted by a majority of the workers that the oceanic regions between eastern Greenland and Eurasia and between Eurasia and North America south of Greenland were developed by sea-floor spreading (e.g. see Talwani & Eldholm 1977). Thus, if we close the Norwegian–Greenland Sea with respect to North America to the time of initial opening (Srivastava 1978) and use the position of Greenland as given by Kerr (1981) we find that most of Svalbard overlies northern Greenland (Fig. 5c). Alternatively if we close the Norwegian–Greenland Sea using the poles of rotation given by Talwani & Eldholm (1977) in Fig. 5c a large portion of the North Atlantic south of Greenland, which is definitely oceanic in origin, will remain open.

Fig. 5d shows a reconstruction where Fig. 4a and 5a have been combined. It shows that accommodation of some movement through a deformation of the North American plate (between 50 and 130 km, Fig. 5b) results in a smaller gap (100 km against 220 km) at the northern end of Nares Strait, and less overlap across Davis Strait but still requires 220 km of translational motion along Nares Strait.

The Greenland plate: a non-rigid plate

The reconstructions in Fig. 5c and 5d show that even if some of the relative motion between the Canadian Arctic Islands and northern Greenland is accommodated by deforming the North American plate, considerable lateral motion between northern Greenland and Ellesmere Island is still required. One way to overcome this problem would be to treat Greenland also as a non-rigid plate.

Beh (1975) considered such a situation and post-

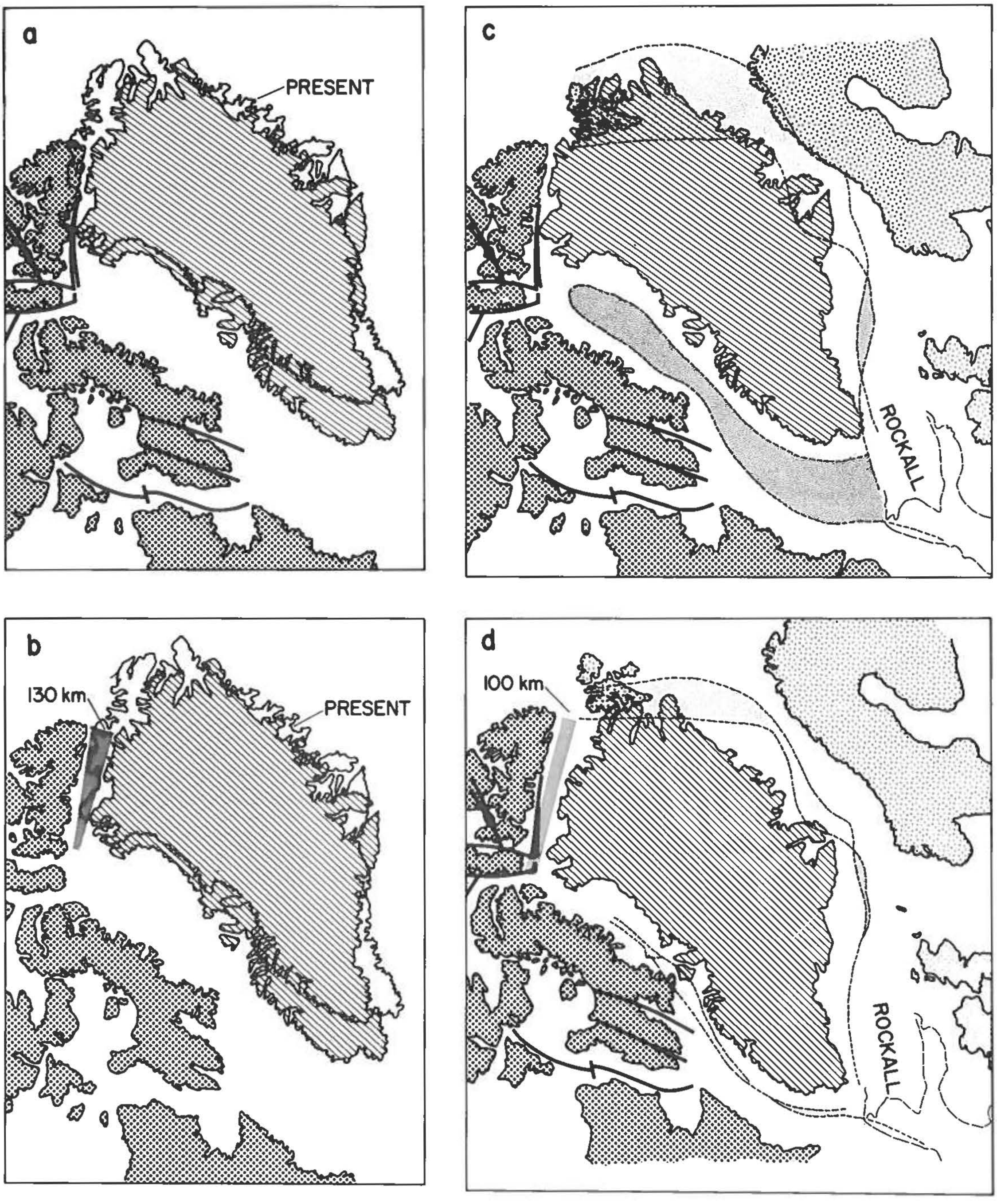

Fig. 5. Palaeogeographic positions of Greenland (striped pattern) relative to North America (dotted pattern): a) as given by Kerr (1981) where part of the relative movement has been accommodated by deforming the continental part of the present North American plate along thick lines, b) Kerr's (1981) reconstruction where the North American plate is considered a rigid plate, c) as given by Kerr (1981) together with the position of the Eurasian plate (open circle pattern) relative to North America as given by Srivastava (1978), and d) at the time of initial opening (Fig. 4a) where North America is considered a non-rigid plate as proposed by Kerr (1981).

ulated a number of shear zones running across the central part of Greenland. He based his interpretation on the published geological information of the Canadian Arctic Islands, on the physiography of the channels running among the islands as well as to the south of them, and the fact that a major part of the Labrador Sea

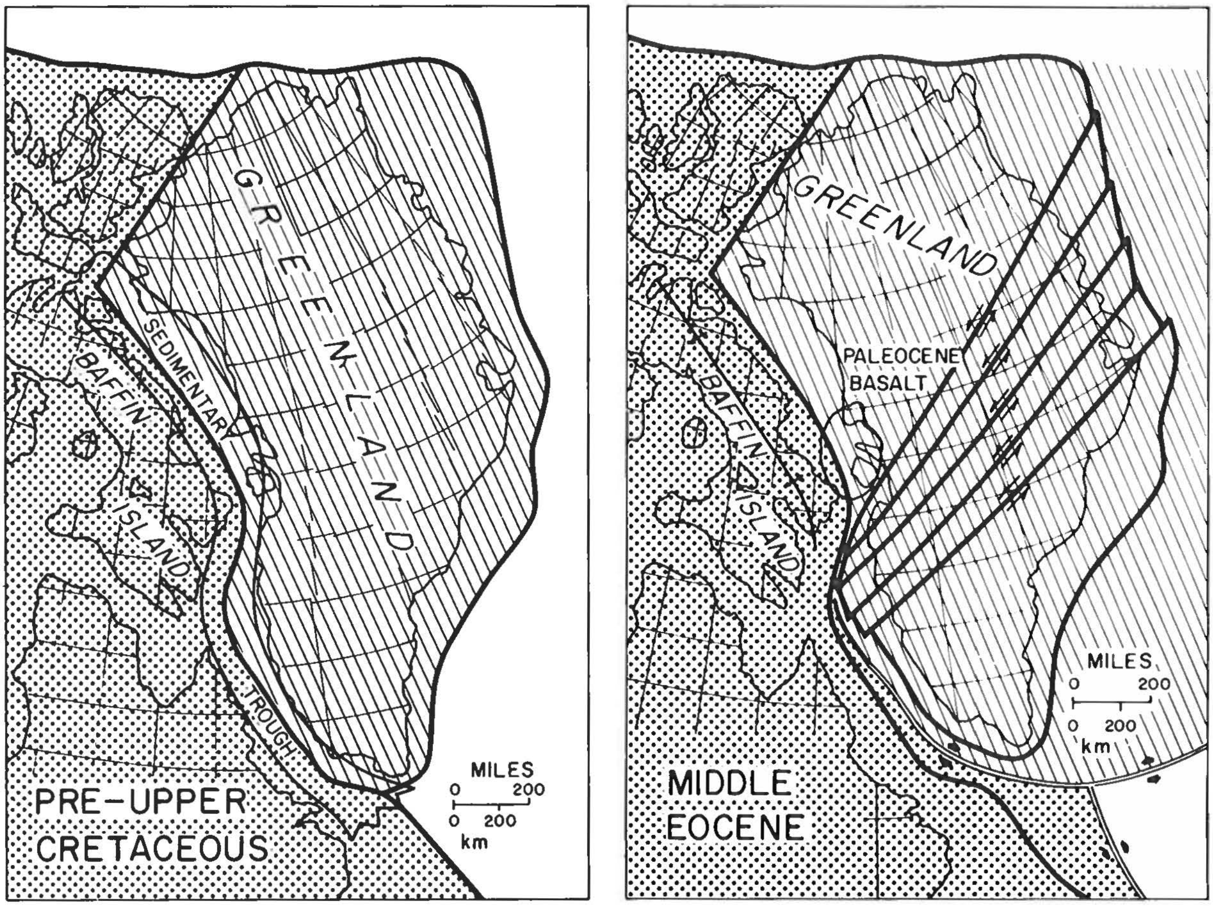

Fig. 6. Palaeogeographic position of Greenland relative to North America in pre-Upper Cretaceous (left) and Middle Eocene times, as proposed by Beh (1975).

and some part of Baffin Bay were formed by sea-floor spreading. Figures 6a and 6b show relative positions of the North American and Greenland plates at pre-Upper Cretaceous and Middle Eocene times. These two reconstructions seem to have overcome the two major objections which geologists have against other reconstructions, namely a) there is hardly any overlap between the landmasses across Davis Strait, and b) the northeastern part of Ellesmere Island remains in its present position relative to northern Greenland. These are achieved by treating the North American and Greenland plates as non-rigid.

According to Beh (1975) sea-floor spreading in the Labrador Sea and Baffin Bay has been accommodated by strike-slip motion along Nares Strait since Middle Eocene (anomaly 21 time) and along some shear zones running across central Greenland for earlier times. Bak et al. (1975) show the presence of some shear zones on the west coast of Greenland but their continuation right across Greenland is not certain. Also, these shear zones are Precambrian features associated with the Proterozoic orogenesis and whether they were rejuvenated during Tertiary is not certain. Beh implies lateral displacement of Greenland relative to Ellesmere Island but in fact his net displacement of the northern part of Ellesmere Island relative to Greenland between mid-Cretaceous (pre sea-floor spreading) and Recent times (post sea-floor spreading in the Labrador Sea) remains small. This is achieved by keeping a large portion of the Sverdrup Basin and the region underlain by Jones, Lancaster, and Cumberland Sounds, Frobisher Bay and Hudson Strait closed by mid-Eocene and then opening them during a later stage of opening in the Labrador Sea. This is contrary to what Kerr (1981) has considered in his reconstructions. Kerr regards the Sverdrup Basin as having been far bigger, prior to sea-floor spreading in the Labrador Sea, than it is today. However he does not give a time frame for the different stages of evolution of the Labrador Sea and Baffin Bay for comparison with Beh's (1975) suggestion.

The pre-drift position of Greenland relative to Ellesmere Island in our reconstruction (Fig. 4a) shows a gap between them of 220 km in the north and of 50 km in the south (near Jones Sound). By late Paleocene (Fig.

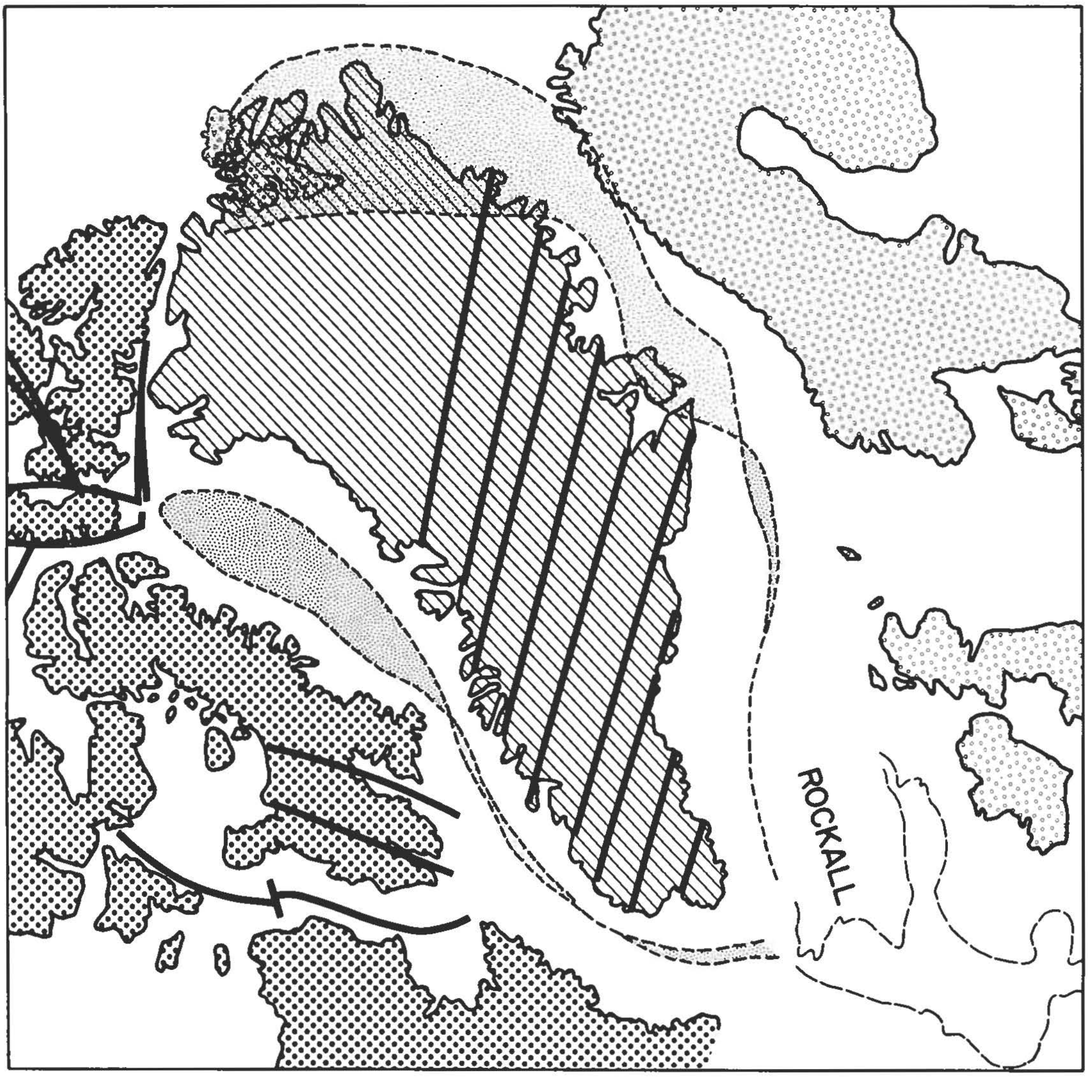

Fig. 7. Palaeogeographic position of Greenland relative to North America where both plates are considered non-rigid and have been deformed along thick lines. The reconstruction combines those given in Figs 4a, 5a and 5d.

4b) the gap is virtually closed and Greenland lies close to Ellesmere Island. Except for the Cretaceous–Tertiary volcanics in northern Greenland (Larsen et al. 1978) there is no other geological evidence either on Ellesmere Island or northern Greenland to support the subduction of material under them. It is thus very likely that the region of the gap was occupied by the southward extension of the far bigger Sverdrup Basin and the subsequent northward movement of Greenland was taken up by folding and faulting within this basin. During the subsequent stages of development of the Labrador Sea, Greenland moved along Nares Strait until early Oligocene when sea-floor spreading ceased in the Labrador Sea and it attained its present position.

If little or no lateral motion took place along Nares Strait as Kerr (1981) maintains, then the only choice would be to move the southern part of Greenland along the shear zones as suggested by Beh (1975). This is shown in Fig. 7 where we have closed the Labrador Sea by introducing shear motion across Greenland along 'hypothetical' shear zones and keeping Baffin Bay and Davis Strait virtually open. We have considered Kerr's (1981) configuration for the North American plate in this construction. A large, undesirable overlap exists between northern Greenland and Svalbard by doing so. This clearly shows that even if we treat the two plates as non-rigid plates strike-slip motion along Nares Strait is essential to avoid such overlaps.

Discussion

We have presented different models of plate configurations in the vicinity of Nares Strait. None of them explains satisfactorily the evolution of the Labrador Sea, Baffin Bay and the North Atlantic Ocean while showing little or no lateral displacement of Greenland relative to Ellesmere Island along Nares Strait. This is because the boundaries of the plates are not well defined throughout. According to plate tectonic theory, provided the plates remain rigid their movements on the surface of the Earth can be described by the poles of rotation over a given interval of time. Plates do break and change their direction of motion which results in a shift of their pole of rotation. In either case, if these changes can be mapped precisely, the movements of the plates and their palaeopositions can be calculated. On the other hand, if the plates acted non-rigidly, their movements cannot be described by use of the same technique and the problem becomes much more complicated in plate tectonic theory. The question of Nares Strait seems to fall somewhere between the two extremes as we have tried to show from the reconstructions. Geophysical measurements in the Labrador Sea show that its evolution can be described satisfactorily using plate tectonic theory by treating Greenland and North America as rigid plates (Srivastava 1978). However, problems arise when we extrapolate the movements of these plates to regions north of the Labrador Sea where the boundaries of these plates are ill defined and the geology of the Canadian Arctic Islands shows that some distortion of the plate and/or shift in the plate boundary was taking place during the same period. Thus models of plate configurations with different boundaries have been considered, which can be grouped into two classes: a) those which explain the evolution of the oceanic regions satisfactorily and show large-scale movements along Nares Strait and b) those which show no displacement along Nares Strait and do not explain the development of the oceanic regions consistent with the geophysical observations.

As we have shown in the preceding sections advocates of models of class a) have largely considered plates rigid while those of models of class b) have considered plates non-rigid and have based their reconstruction largely on matching the present land geology across Nares Strait. The only exception to this is the reconstruction by Beh (1975) who has tried to compromise the situation by introducing large lateral displacement within the Greenland plate along some 'hypothetical' shear zones. Some evidence does indeed exist on the west coast of Greenland for the presence of some shear zones which are related to Proterozoic orogenesis (Bak et al. 1975) but not to Tertiary movement as implied in Beh's (1975) reconstructions.

So what is the solution? The answer to this question rests mainly on the geological and geophysical evidence which has been used in constructing the models. If the geological mapping of land areas surrounding Nares Strait and their interpretation is accurate (for detailed discussion on this see Newman and other papers in this volume), then it is very unlikely that large strike-slip motion along Nares Strait took place as the plate tectonic models have implied. On the other hand, it is equally possible that some refinement in the plate tectonic models may result with the acquisition of additional geophysical data in regions where such is now lacking, but not to the extent to eliminate the strike-slip motion along Nares Strait altogether. In that case there are two possibilities: a) the interpretation of geophysical data in the Labrador Sea, Baffin Bay and Norwegian–Greenland Sea is incorrect, or b) the required motions between the plates were accommodated within the plate in the form of folding, faulting and graben formation. Each possibility will be discussed in turn.

a) Published geophysical information indicates strongly that the marine regions in question were largely formed by sea-floor spreading although in some areas, like northern Baffin Bay, the possibility exists that they may have been formed by stretching of continental crust. Northern Baffin Bay lies close to the pole of rotation for the Labrador Sea from pre-opening time to late Paleocene (Srivastava 1978). During this period, when active sea-floor spreading was taking place in the Labrador Sea, the region of northern Baffin Bay was merely stretched due to large tensional forces. Thus, true oceanic crust was formed in one region while in another region it was the continental crust that was stretched. In either case the amount of movement to be accounted for in plate reconstructions still remains the same. The problem then reduces to one of simple plate kinematics, yielding solutions which show not only large-scale strike-slip motion along Nares Strait but also some compression between Greenland and Ellesmere Island. These solutions regard Nares Strait as a boundary between North America and Greenland plates. We have shown in the preceding sections that the problem even gets worse if we consider the boundary to be somewhere else.

b) Geological information in the Canadian Arctic Archipelago shows that the Sverdrup Basin was a site of crustal subsidence from early Carboniferous to late Cretaceous time and then was subjected to severe folding and faulting during the Eurekan orogeny which ceased prior to the Miocene (Balkwill 1978, Trettin & Balkwill 1979). Crustal subsidence, folding and faulting are often all manifestations of interaction between plates, and their occurrence in the development of the Sverdrup Basin as it exists today must be related to the interaction of the North American plate with the Greenland and Eurasian plates. In general, the tectonic events based on the land geology of the Canadian Arctic Archipelago agree well with the type of interaction between the North American and Greenland plates as predicted from plate tectonic models but they differ in detail. For example, the pre-drift position of Greenland relative to North America supports a larger extent of the Sverdrup Basin during this time. The Basin underwent folding and faulting subsequently, but the total amount of deformation, which includes compression as well as translation, predicted by the plate tectonic model does not agree with what can be interpreted from the presently known land geology. The situation is complicated by the fact that while the sizes of the plates were increasing in the south due to active sea-floor spreading in the Labrador Sea, they were decreasing in the north. Thus, in the south the plates were acting as rigid plates, while at the same time they were acting as non-rigid plates in the north.

Another source of difficulty in relating the predicted motions based on plate tectonic models with the land geology lies in the fact that a great portion of Greenland is ice-covered and all of its geology cannot be extrapolated from the west to the east coasts. To examine if the translational motion predicted from plate tectonic models along Nares Strait could be accommodated by shear motion within Greenland, several hypothetical shear zones were used in one of our reconstructions (Fig. 7). In spite of the introduction of these shear zones, we find that a serious overlap between Svalbard and northern Greenland still remains if no motion is allowed along Nares Strait.

It is thus concluded from the reconstructions presented here that if no motion is allowed along Nares Strait then either the kinematics of the plate tectonic evolution of the North Atlantic, based on magnetic isochrons and other geophysical data, is in error or much more deformation of the North American plate must have taken place than can be inferred from the presently known geology of the Arctic Archipelago. Sobczak (1980, this volume) using the trends of the folds and faults shows possibilities of large fragmentation of the Canadian Arctic Archipelago. Apparently, detailed geophysical information on Baffin Bay, Davis Strait and the oceanic regions surrounding and including Nares Strait, as well as detailed geology of the Arctic Archipelago and ice-covered regions of Greenland, is needed before an acceptable answer to the Nares Strait dilemma can be found.

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