The Nyeboe Land fault zone: a major dislocation on the Greenland coast along northern Nares Strait

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The name Nyeboe Land fault zone is proposed for a major dislocation zone in the western part of the North Greenland fold belt, traceable along the outer coast for 300 km. Two other names are introduced: 1) the Hand Bugt fault, a reverse fault that juxtaposes strata at least as old as Cambrian to the north, against Silurian rocks to the south, and 2) the Wulff Land anticline, a major fold structure that parallels the fault zone and the outer coast. The Wulff Land anticline is regarded as having formed during the main diastrophism of the Franklinian geosyncline in Devonian time; the Nyeboe Land fault zone is considered an expression of later Tertiary reactivation.

Stratigraphic data are presented that define more accurately than hitherto the Franklinian Cambro-Ordovician platform margin. This roughly coincides with the Nyeboe Land fault zone that probably had a history dating back at least to the early Palaeozoic. The location of a steep Bouguer gravity gradient in the coastal area of Nyeboe Land suggests that a deep-seated crustal structure controlled the margin of the Franklinian trough and the site of the Nyeboe Land fault zone.

The Nyeboe Land fault zone, the Wulff Land anticline and the platform margin can be correlated across Nares Strait with on-line features on Judge Daly Promontory within the central Ellesmere fold belt. This indicates that any strike-slip movement along Nares Strait has only resulted in minor net displacement between Greenland and Ellesmere Island.

The Nyeboe Land fault zone is correlated with the Judge Daly fault zone of Ellesmere Island to define an extensive fracture line that is oblique to Nares Strait. It is concluded that main crustal displacements in the late Phanerozoic probably took place along fracture systems oblique to Nares Strait rather than affecting the separation of Greenland and Ellesmere Island as separate plates.

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There is a general consensus that the Nares Strait lineament is fault controlled, but little as to the nature of the structure. Is the Strait the site of a transcurrent fault (Taylor 1910, Wegener 1924, du Toit 1937, Wilson 1963), a megashear (Carey 1958, Hilgenberg 1966), a transform fault (Wilson 1965), a rift valley (Kerr 1967a), a subduction zone (see Srivastava 1978), a spreading centre (Miall 1981), or even a combination of these structures?

In view of this discussion, it is unfortunate that little direct evidence of the existence of the Nares Strait fault can be found on land in Greenland. However, structural data are available which have a bearing on the tectonic origin of the Strait. It is with this in mind that a fault zone on the North Greenland coast on the shore of the Lincoln Sea is described in this paper (Figs 1 and 2). This important tectonic feature of the North Greenland fold belt is named here the Nyeboe Land fault zone. It strikes from the Robeson Channel over to Peary Land. Its eastern termination is unknown, but it has an onshore extent of at least 300 km.

Furthermore, the coastal area of Nyeboe Land, where the largest continuous stretch of the fault zone is exposed, has been suggested as the site of important Lower Palaeozoic facies changes that represent geological markers used in correlation across the Strait (Christie et al. 1981, Hurst & Kerr, this volume). Since no specific geological description of northern Nyeboe Land exists in the literature, a brief account of the main rock lithologies involved in the fault zone is also presented as a contribution to this discussion.

The Nyeboe Land fault zone coincides with a major anticlinal structure of the North Greenland fold belt. Correlation between Greenland and Ellesmere Island of the fault zone, the anticlinal structure, as well as rock lithologies is suggested and the implications of the correlation to the structure of Nares Strait and to the question of motion along it are explored.

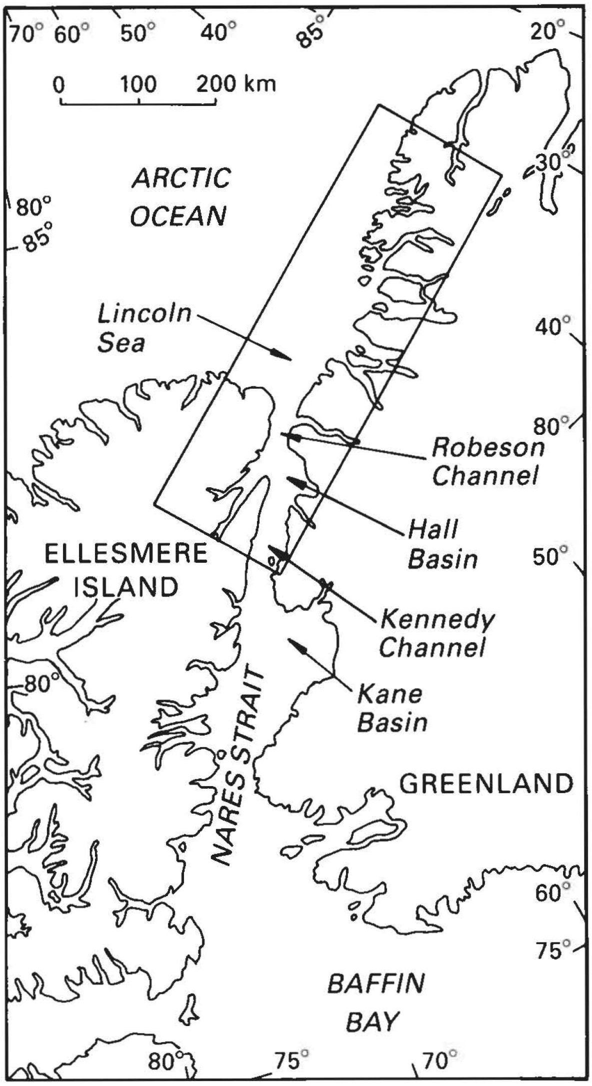

Fig. 1. Index map of the Nares Strait region. The frame marks the area covered by Fig. 7.

Investigations

Geological reconnaissance in the Hall Land – Wulff Land region (Fig. 2) was carried out by the present author in 1965 and 1966 (in 1965 with J. H. Allaart) during Operation Grant Land (Christie 1967). In 1966 several localities showing substantial fault displacements were examined and the fault zone was traced across northern Nyeboe Land. The fault zone was not examined in its entirety and it was mapped to the east by aerial reconnaissance and photogeological interpretation. Some geological data from the region of the fault zone have been included in several regional accounts (e.g. Dawes 1976).

Koch (1920) recognised several faults in north-western Nyeboe Land east of Kap Brevoort and on the basis of aerial photographs Haller (in Haller & Kulp 1962) suggested that important faults occurred in the region between Hall Land and J. P. Koch Fjord (see Figs 4 and 7 for location names). He interpreted the structures to form a Tertiary thrust-fold system, with a distinct southward drive.

Stratigraphy

Proterozoic(?) to Silurian strata occur in the fault zone and the rocks represent varying palaeoenvironments ranging from platform carbonates to trough clastics. Only an outline of the main strata is given here in so far as they help to interpret the structure of the fault zone and its relationship to the Franklinian platform margin. The general stratigraphy of the fault zone is summarised in Table 1.

Hall Land

In northern Hall Land a well-exposed cliff section exposes two successions of markedly contrasting character (Fig. 3); a lower carbonate group, interpreted as a platform facies, and a thick overlying clastic group of typical trough facies. This section has been examined to the east of Kap Ammen (Allaart 1965).

The *carbonate group* is about 550 m thick composed of four unnamed formations. Its base is not exposed. Two dark units, seen on Fig. 3, the lower at sea level, are composed of mainly fine-grained, dark grey, mottled dolomitic limestones and these alternate with units of rather massive light grey limestones. Thin-bedded dark limestones, shales and cherts occur in the uppermost part. In the western part of the cliff section at Kap Porter an isolated carbonate mass with irregular bedding resembles a reef (Dawes & Haller 1979); this is now interpreted as a platform margin slumped mass (Hurst & Kerr, this volume).

Faunal evidence indicates an Upper Ordovician to Lower Silurian (middle Llandovery or later) age for the carbonate group (J. S. Peel in Dawes 1976).

The *clastic group* has a total thickness that probably exceeds 1500 m; its top is not seen. The group is composed of a complex succession of turbidites: sandstones, siltstones and shales. Near the base there are some cherts, dark platy limestones and thin limestone beds. Towards the exposed top thin beds of limestone, often brecciated, come in. The sandstones are calcareous greywackes in the sense of Pettijohn (1954) and they have a characteristically high carbonate content; about 50 per cent carbonate in total rock mineral composition.

From field and photogeological work five map units have been erected and these have been mapped in Nyeboe Land within the main fault zone (Figs 3 and 4).

The age of the clastic group in Hall Land is Lower Silurian to latest Silurian (Pridoli) or ?early Devonian

Table 1. Geological history of the Nyeboe Land fault zone.

		MAIN SEDIMENTARY AND METAMORPHIC ROCK			TECTONISM AND METAMORPHIC REGIME
CENOZOIC	QUAT.	Glacial, fluvio-glacial and marine gravel, sands and silt			Uplift, erosion Isostatic movement
CENOZOIC	TERTIARY	Quartz-calcite veins, breccias, mylonite			Normal faulting Thrust faulting, folding, mylonitisation, hydro-thermal activity
UPPER PALAEOZOIC –MESOZOIC	CARBONIFEROUS –CRETACEOUS	(Sverdrup Basin – Wandel Sea Basin deposition, major marine transgression. No rocks yet known in Nyeboe Land fault zone)			
UPPER PALAEOZOIC –MESOZOIC	DEVONIAN	Quartz-calcite veins Chlorite-muscovite slate, psammite			Uplift, erosion Extensional faulting Polyphase folding, minor thrusting, low-grade metamorphism
		Hall Land	Nyeboe Land	Wulff Land	
LOWER PALAEOZOIC	SILURIAN	Calcareous greywacke, siltstone, shale Dark platy limestone, chert Carbonate buildup	Calcareous greywacke, siltstone, shale, chert-pebble conglomerate Calcareous slate	Calcareous greywacke, siltstone, shale, chert-pebble conglomerate	
LOWER PALAEOZOIC	ORDOVICIAN	Dark and pale dolomitic limestone	Variable limestones and breccias ?	Dolomitised siltstone, shale, carbonate breccio-conglomerate	Fluctuating position of platform margin possibly associated with fault movements
LOWER PALAEOZOIC	CAMBRIAN		Arkose, quartz sandstone, shale Variable limestones Dark bituminous limestone, breccia, chert, shale Dark limestone Pale limestone	Sandstone, arkose, conglomerate, siltstone, shale Pale dolomite	
PREC.	PROT.		?	Black shale Sandstone, conglomerate, siltstone	Subsidence – ? faulting

Bendix-Almgreen & Peel 1974, Berry et al. 1974, Dawes 1976, Surlyk et al. 1980).

Nyeboe Land – Hendrik Ø

The main fault of the Nyeboe Land fault zone (Hand Bugt fault) separates northern and southern areas of contrasting stratigraphy (Figs 4 and 5).

The *southern area* is composed of map units 3, 4 and 5 of the clastic group (Fig. 4). Lithologies are generally comparable with the Hall Land succession although coarser-grained rocks occur, and pebbly sandstone and chert-pebble conglomerates (Hendrik Conglomerate of Dawes 1966) form thick incursions in the uppermost part of the sequence. Some graptolite-bearing shales stratigraphically above the Hendrik Conglomerate are

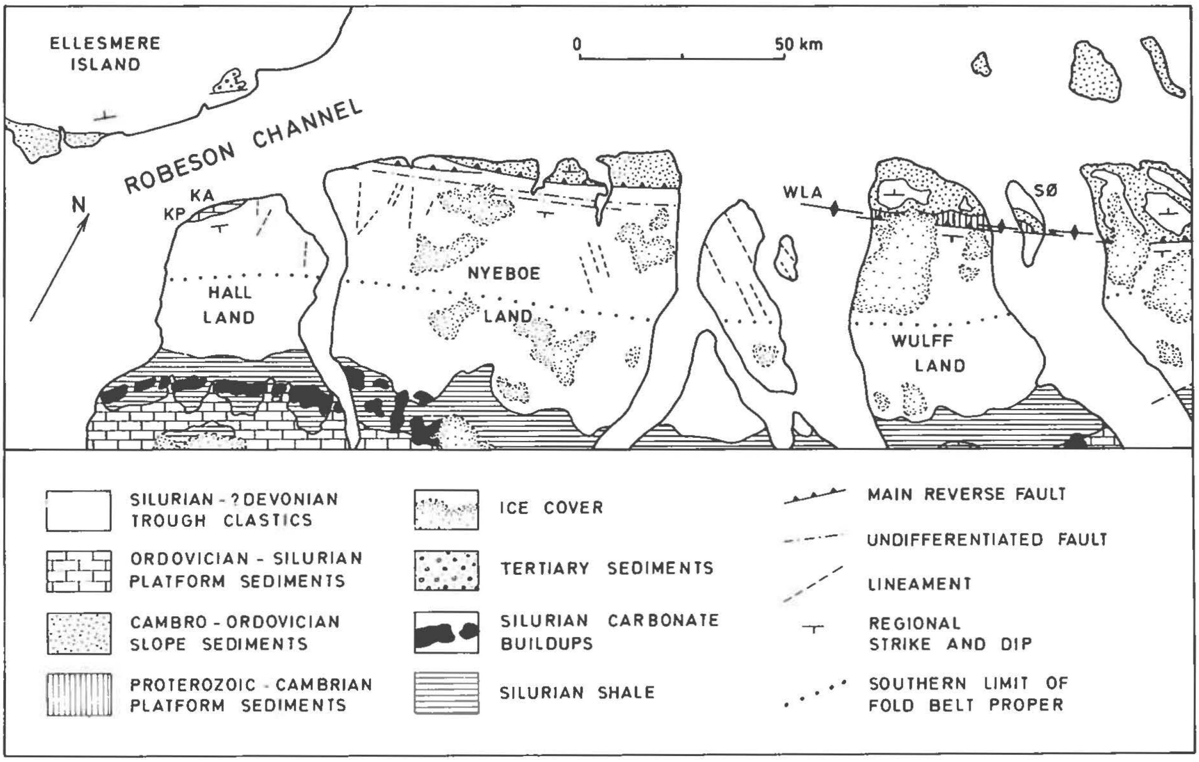

Fig. 2. Geological map of the Hall Land – Wulff Land region showing the Nyeboe Land fault zone. KP = Kap Porter, KA = Kap Ammen, SØ = Stephenson Ø, WLA = Wulff Land anticline.

of Upper Silurian (early Ludlow) age (Berry et al. 1974).

The fault block south of Repulse Havn (Fig. 4) is composed of map units 1 and 2 as well as older carbonate strata. The oldest rocks observed are a variable limestone succession containing dark, often bituminous, limestones, light limestones with some breccio-conglomerates, and calcareous slates. These limestones have yielded an indeterminate crinoid-coral fauna indicating a post-Cambrian, probably Ordovician age.

In the *northern area* a faulted and highly folded succession of unknown but undoubtedly large thickness is composed of two main rock sequences. These are a Cambrian mainly carbonate sequence and a clastic sequence of probably younger age.

The carbonate sequence, at least 600 m thick, is composed of pale limestone and breccio-conglomerates, dark, often bituminous, limestones, some of which are black, dense and dolomitic, banded typically yellow and grey 'tiger' limestones and a variety of mainly dark, thin-bedded limestones, calcareous shales and slates. Some thin chert and siliceous shale beds occur. The carbonate breccio-conglomerates are very common and a frequent type is intraformational breccias locally and directly derived from banded 'tiger' limestones. Dark bituminous limestones have yielded Lower and Middle Cambrian trilobite faunas (Poulsen 1969, Peel 1974, 1979).

The clastic sequence forms some large outcrop areas (Fig. 4) as well as tracts interfolded with the carbonate sequence. The clastic sequence is at least 300 m thick, possibly considerably more, and is composed of dark, in places rusty, weathering and sulphide-bearing rocks, shales, slates, quartz sandstones, arkoses with some quartzite, and sandy conglomerate beds containing shale clasts. Impure limestone and calcareous sandstones also occur. The rocks are of low metamorphic grade and commonly have a waxy sheen due to secondary mica and in places chlorite.

Only simple trace fossils are known from the clastic sequence and its age is uncertain. The strata in this region are intensely folded and faulted, but way-up criteria at several localities suggest that a substantial thickness of the clastic rocks is younger than the carbonates. In the Hand Bugt – Frankfield Bugt area the clastic sequence dips north and overlies the carbonate sequence in what appears to be an undisturbed stratigraphical relationship (Fig. 5). The clastic rocks show some graded bedding and bottom structures suggesting it to be a turbiditic suite, but the rocks contrast with the Silurian turbidites south of the Hand Bugt fault in several characters, notably in mineral composition.

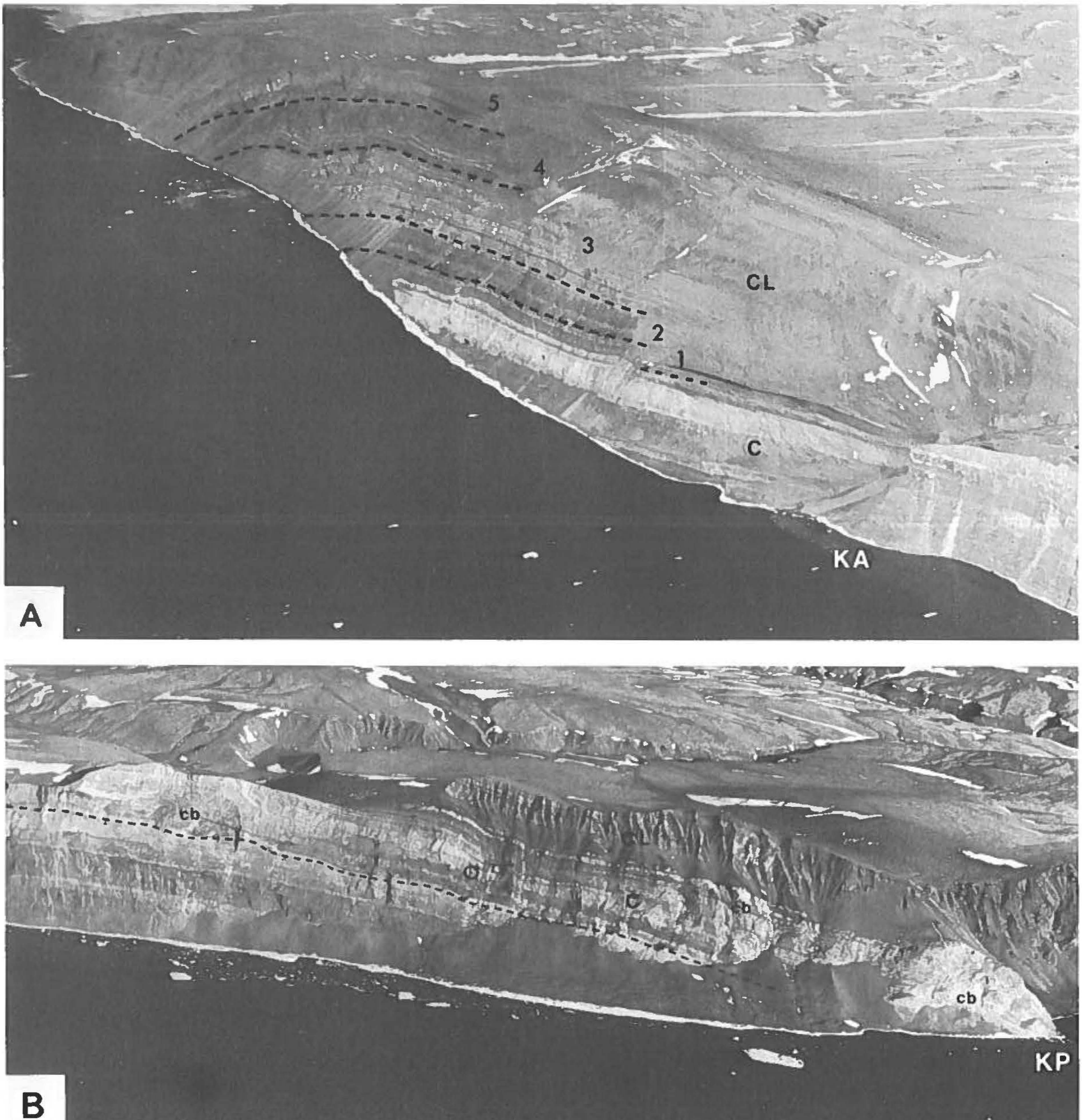

Fig. 3. Cliffed coast of northern Hall Land: east (A) and west (B) of Kap Ammen. Upper Ordovician – Lower Silurian carbonate group (C) overlain by Silurian clastic group (CL). A: the five map units of the clastic group are indicated, B: stratigraphic irregularities in the carbonate group due to tectonic dislocation (dashed line) and carbonate buildups (cb). Highest part of the cliffs in both views is above 700 m. KA = Kap Ammen, KP = Kap Porter. Aerial photographs 546 K–S, A: no. 2198, B: no. 2193; copyright Geodætisk Institut, Denmark.

The clastic rocks are correlated with the turbidites of Formation A or the older Polkorridoren Group of Peary Land (Dawes & Soper 1979). These rocks are now known to be of Cambrian age (Hurst & Surlyk 1980, J. M. Hurst, pers. comm.). Since the clastic rocks in Nyeboe Land overlie carbonates as young as Middle Cambrian, correlation with the younger Formation A is favoured.

Wulff Land

In Wulff Land on the north side of the Hand Bugt fault, a thick and variable succession contains Proterozoic(?)

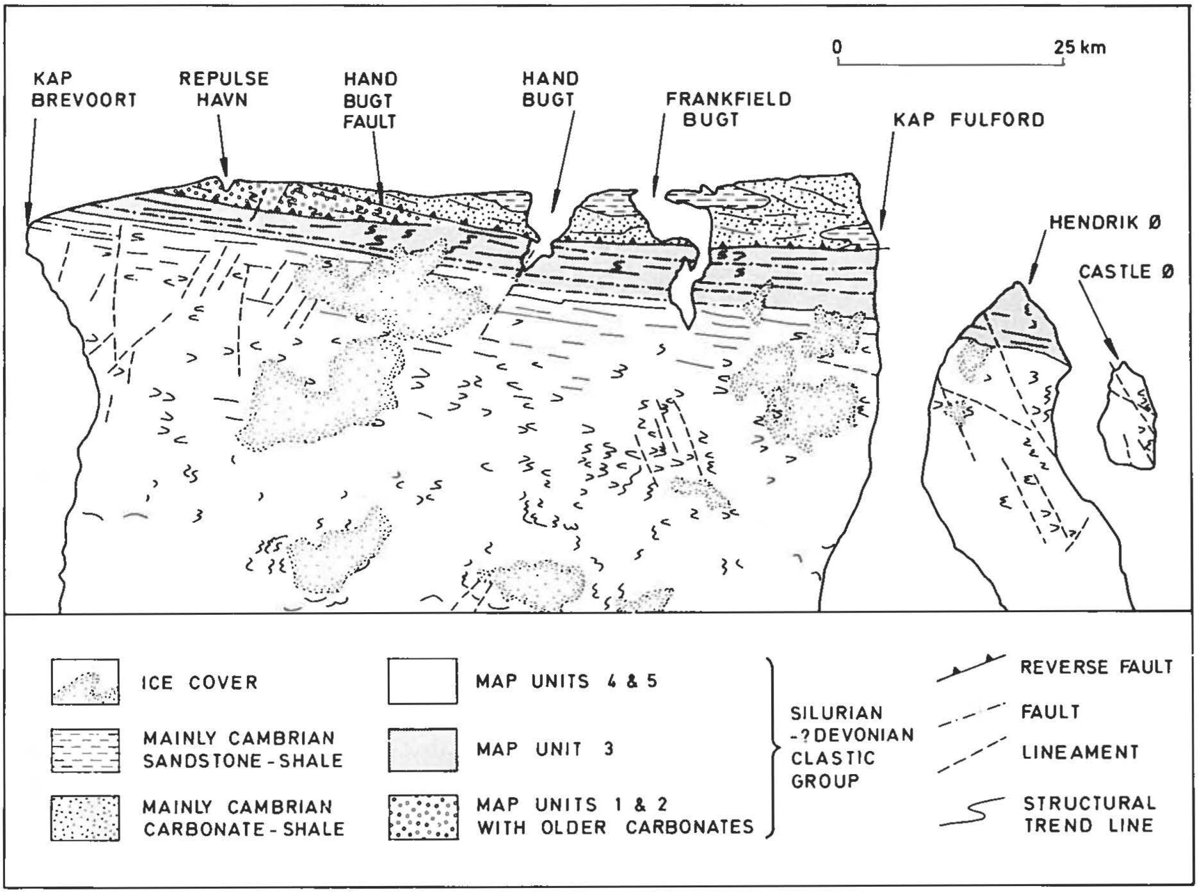

Fig. 4. Geological map of the Nyeboe Land fault zone, Nyeboe Land and Hendrik Ø.

to Silurian rocks. The base of the succession is not seen (cf. Koch 1920) and a sequence of at least 400 m of sandstone, siltstone and partly dolomitic calcareous and quartzitic conglomerate, with dark shale beds at the top, are the oldest rocks exposed. Overlying this is a pale massive dolomite at least 350 m thick that is regarded as a possible equivalent of the earliest Cambrian Portfjeld Formation known from the platform of Peary Land (J. S. Peel, pers. comm.). An overlying 450 m thick sequence of arkosic sandstone, quartz-pebble conglomerate, siltstone, bioturbated mudstone and black shale is reminiscent of the Buen Formation also described from Peary Land. These rocks are overlain by a sequence of dolomitised siltstones and shales and dolomitised breccio-conglomerates regarded by J. M. Hurst (pers. comm.) as equivalent of Formation B of Dawes & Soper (1979). The top of the succession is composed of Silurian turbidites which correlate with the clastic group of Hall Land, Nyeboe Land and Wulff Land, south of the Hand Bugt fault.

Sedimentary facies distribution

The main lithologies of the fault zone are summarised in Table 1 and an interpretation in terms of general depositional environment is given in Fig. 6. A relatively complete and stratigraphically undisturbed succession through the Franklinian geosyncline is preserved in the study region in northern Wulff Land. There a major transgressive cycle can be recognised involving the Proterozoic and Cambrian platform clastics and carbonates, through the Ordovician slope mudstones and carbonate breccio-conglomerates to the Silurian trough turbidites. In the Hall Land – Nyeboe Land region two transgressive cycles are indicated with the Lower and Middle Cambrian platform? and slope carbonates being followed by trough turbidite sedimentation. Platform sedimentation was again prevalent in Upper Ordovician time, or earlier, after which a second episode of trough turbidites reached the region and persisted throughout the Silurian.

The fluctuating position of the platform–trough margin illustrated by the Hall Land, Nyeboe Land and Wulff Land sections coincides in a general way with the

Fig. 5. View of the Nyeboe Land fault zone looking east across Nyeboe Land, showing the Hand Bugt fault (dashed line) and the steeply-dipping linear belt south of it. 1: Late Cambrian(?) clastic sequence, 2: Cambrian carbonate-shale sequence, 3: Silurian turbidites. Aerial photograph 546 E-Ø, no. 11577; copyright Geodætisk Institut, Denmark.

site of the Nyeboe Land fault zone. This suggests that the fault zone may have had a fundamental influence on the depositional history of the region. This conclusion gains some support from the sedimentary facies model suggested further to the east in Peary Land (Surlyk et al. 1980).

The southernmost known extent of the Cambro-Ordovician slope deposits is plotted in Fig. 7. The eastern extension of the fault zone is unknown but it is not apparent as a cross-cutting post-depositional fracture in the region between J. P. Koch Fjord and Frederick E. Hyde Fjord (A. K. Higgins, pers. comm.). However the fault zone does strike towards the platform edge – slope boundary as defined in the Frederick E. Hyde Fjord region of Peary Land (Dawes & Soper 1979, Hurst 1979). Hurst & Surlyk (1980) and Surlyk et al. (1980) have suggested that the Lower Palaeozoic platform–slope boundary in Peary Land is controlled by E–W-trending fault systems and the main syndepositional fault (Navarana Fjord fault) is placed in central Peary Land immediately south of Frederick E. Hyde Fjord (Surlyk et al. 1980: fig. 1). The Nyeboe Land fault zone is more or less on line with the proposed site of this master fault in central Peary Land. To the west, the Navarana Fjord fault strikes across North Greenland south of the Nyeboe Land fault zone. The relationship of the Nyeboe Land fault zone to the syndepositional faults envisaged by Hurst & Surlyk (1980) and Surlyk et al. (1980) is not yet clear but the Nyeboe Land fault zone could well represent a major fracture in the en echelon system of faults proposed by the above authors.

Of further interest is the fact that the Silurian turbidites outcropping across the whole of North Greenland for over 600 km have a persistent palaeocurrent transport direction from the east (see Surlyk, this volume) which has led Hurst & Surlyk (1980) to assume the presence of a northern barrier that influenced the direction of turbidite flow. Such a well-defined barrier may well have been a faulted uplift. The E–W-trending turbidite trough across western North Greenland is

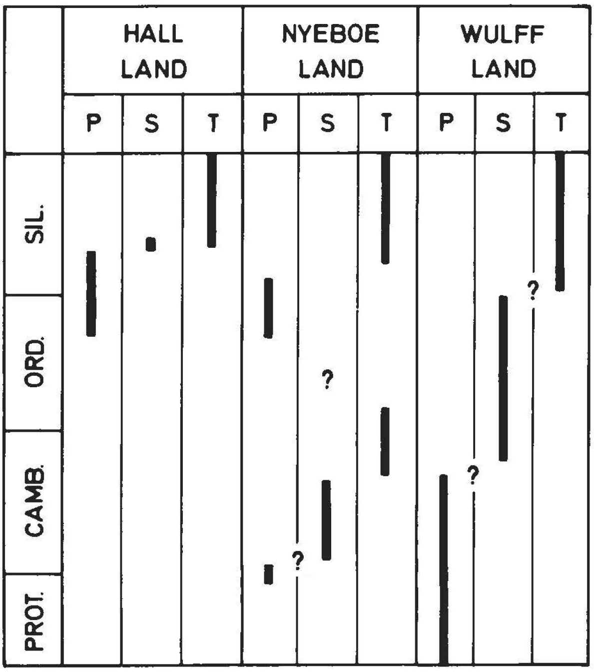

Fig. 6. Schematic representation of platform (P), slope (S) and trough (T) facies of the Nyeboe Land fault zone region.

preserved south of the Nyeboe Land fault zone, and this raises the question of whether the fault zone could also have had influence on the deposition of the Silurian turbidites. Thus the tectonic history of the Nyeboe Land fault zone should be studied in the light of possible influence on sedimentation throughout the whole of the Lower Palaeozoic.

Structure of the fault zone

The extent of the Nyeboe Land fault zone is seen in Fig. 7. It strikes approximately ENE, more or less parallel with the regional structural trend of the North Greenland fold belt and to the outer coast of Nyeboe Land. It consists of several high-angle, sub-parallel strike faults. Some WNW-trending lineaments crossing Hendrik Ø, Castle Ø and the coastal area of eastern Nyeboe Land may represent splay-out faults of the main fault zone. In addition to the main faults shown in Fig. 4, Haller (1971: fig. 157) recognises faults with a more easterly trend, i.e. oblique to the regional stratification. No field data are available at this time to confirm that this trend is a main fracture system.

The most conspicuous dislocation of the fault zone is a reverse fault that has a steeply-dipping (>75°) to vertical fault plane, the dip direction of which is mainly to the north, although steep dips to the south have been observed. This master fault is named the *Hand Bugt fault*, after the bay where it is well exposed (Figs 5 and 8). This fault separates rock successions of profoundly different ages: to the north an uplifted block contains strata at least as old as Cambrian while to the south Silurian clastic rocks occur. In the area to the west of Hand Bugt where Middle Cambrian rocks are in fault contact with Silurian strata, the regional trend of the strata in the uplifted northern block is discordant to the fault and, at the present level of exposure, strata are cut out towards the east.

The strata of the northern uplifted block are highly deformed and a variety of fold styles exist; the majority have steeply inclined limbs. In many places near the Hand Bugt fault the rocks are steeply-dipping and strata are commonly crushed and mylonitised at the actual

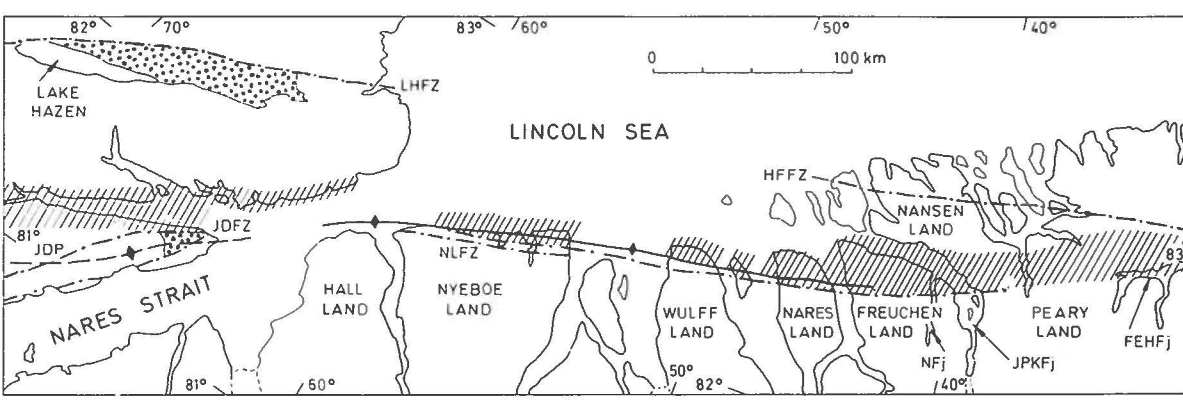

Fig. 7. Map of western North Greenland and north-eastern Ellesmere Island. Full black line marks the trend of the Wulff Land anticline; dashed line marks the position of the Judge Daly anticlinorium; cross-hatching represents the southern outcrops of the Cambro-Ordovician slope deposits, including Formation B of Greenland and Hazen Formation of Ellesmere Island. The dot ornament represents the Permian to Tertiary Sverdrup Basin deposits; only the main Tertiary outlier on Judge Daly Promontory (JDP) is shown. NLFZ = Nyeboe Land fault zone, JDFZ = Judge Daly fault zone, HFFZ = Harder Fjord fault zone, LHFZ = Lake Hazen fault zone, NFj = Navarana Fjord, JPKFj = J. P. Koch Fjord, FEHFj = Frederick E. Hyde Fjord.

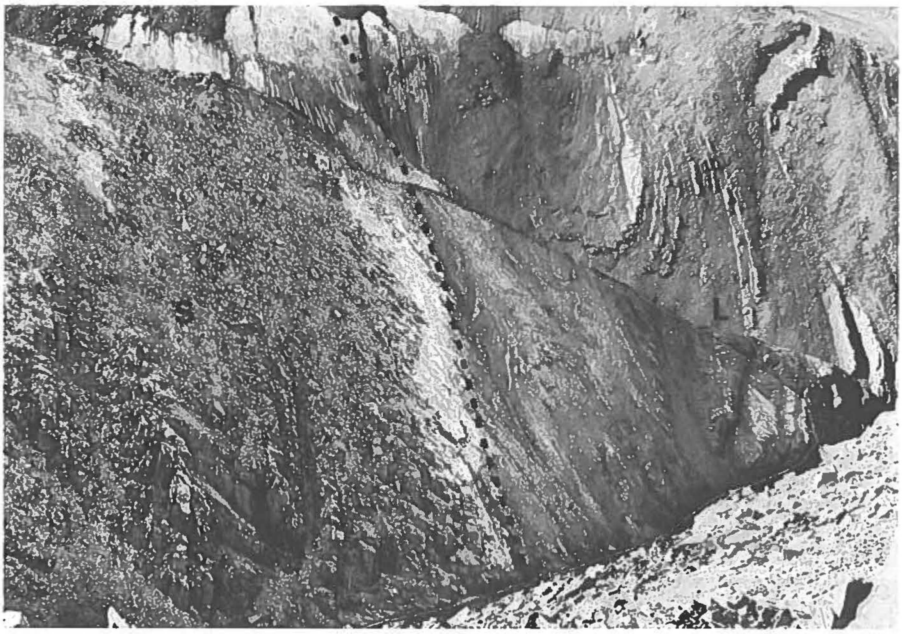

Fig. 8. The Hand Bugt fault, Nyeboe Land viewed from the east. Steep, northerly-dipping fault plane with Silurian sandstone and shale (S) to the south, up-faulted Cambrian limestone, carbonate breccio-conglomerate and shale (L) to the north. Some folding in the up-faulted block is due to the fault movement. Height of the section above the river is about 300 m.

fault plane. The rocks are commonly brecciated and severely invaded by anastomosing calcite-quartz veins. Drag folds occur in the northern rocks at the fault plane (Fig. 8) and east of Frankfield Bugt these folds plunge to the east. Several other faults and crush zones occur cutting up the highly folded rock succession north of the Hand Bugt fault, but none of these have been traced for any distance.

The Hand Bugt fault is bounded to the south by an impressive steeply-dipping linear belt of upturned Silurian strata traceable throughout Nyeboe Land (Fig. 5) where it is up to 4 km wide, and across northern Hendrik Ø and onto Wulff Land. Within this linear belt of vertical to steeply-dipping strata several high-angle strike faults occur and, in some cases, recessive shale units appear to have acted as the dislocation surfaces. Many of the faults have steep southerly-dipping planes and it is difficult to identify such high-angle strike faults due to the concordance of fault planes and bedding. Apparently, these faults have not disturbed the essential stratigraphic order of the Silurian succession. It is uncertain if the faults represent fractures of the same type as the Hand Bugt fault or whether they represent southerly-dipping normal faults developed during or after the regional upturning.

In Hall Land no evidence of the Hand Bugt fault with its uplifted northern block is present, although the high, steep coastline suggests fault control (Fig. 3). However, in the carbonate sequence exposed in the sea cliffs near Kap Ammen and Kap Porter, there is thickening of the sequence which is regarded as repetition of stratigraphy due to fault tectonics. This structure is interpreted as the southerly expression of the Nyeboe Land fault zone.

In Wulff Land, the Hand Bugt fault truncates the southern limb of a major anticlinal structure and juxtaposes a northerly-dipping correct way-up succession of Proterozoic(?) to Silurian strata, in the uplifted northern block, against a southerly-dipping sequence of Silurian and (?) older rocks to the south. The sequence north of the reverse fault contains conspicuous black shale units, the outcrop pattern of which in northernmost Wulff Land suggests that several faults transect the area.

Between Nares Land and Peary Land (Fig. 7) the Hand Bugt fault is visible on aerial photographs as a topographical depression, although, due to widespread ice cover, particularly on Freuchen Land, little is known about the consistency of the faulting throughout the region. The reverse fault is well exposed on the east side of Navarana Fjord (J. M. Hurst, pers. comm.). In this area it juxtaposes, on the north side, a dark sequence of siltstones, mudstones and carbonate breccio-conglomerates (correlatable with Ordovician Formation B of Dawes & Soper 1979) against Silurian clastic rocks. The fault forms a distinct step in the coast on the east side of J. P. Koch Fjord and it probably coincides farther east with the conjectural extension of the syndepositional Navarana Fjord fault of Surlyk et al. (1980).

Wulff Land anticline

The major ENE-trending antiform which transects northern Wulff Land (Koch 1920) was visited in 1966 and platform-type Proterozoic(?) and Cambrian rocks were located in its core (Dawes 1976). The name Wulff Land anticline is proposed for this large structure which can be traced for over 200 km between Nyeboe Land and Nares Land (Figs 2 and 7). In Nyeboe Land the structure is highly dissected by the Nyeboe Land fault zone, but regional dips and orientation of small-scale folds indicate its general trend. In this region it is more of an anticlinorium with highly deformed strata in its central area. In the Wulff Land – Stephenson Ø area the anticline plunges to the east, but its continuation across Freuchen Land and towards Peary Land is unmapped although suggested on aerial photographs.

The anticline has normal way-up sequences on both northern and southern limbs, but the southern limb is truncated by the Hand Bugt fault. The anticline is considered an integral part of the mid-Palaeozoic structural pattern of the fold belt although the attitude of the limbs has undoubtedly been affected by the later fault movements.

Tectonic history of the fault zone

The relationship of the Nyeboe Land fault zone to both folding and regional metamorphic and hydrothermal mineral composition of the rocks is briefly outlined here. The main tectonic and metamorphic events recognised in the fault zone area are summarised in Table 1.

Folding and metamorphism

In the North Greenland fold belt the intensity of the mid-Palaeozoic deformation and metamorphism seen on a regional scale increases progressively northwards (Fränkl 1955, Dawes & Soper 1973).

The location of the fault zone relative to the fold intensity is illustrated by the bedding traces shown in Fig. 4. The southern part of the Nyeboe Land fault zone is marked by the sudden incoming of the linear belt of steeply-inclined to vertical strata in which tight to isoclinal folds occur (Fig. 5). This upturned linear belt is considered to have been formed during the fault movements that resulted in the uplift of the northern coast area along the Hand Bugt fault. The fault movements affected the attitude and style of the folds of this linear belt.

The folds within the northern uplifted block vary from rather tight to steeply-inclined structures to less frequent, more open folds with moderate dips. The cleavage-bedding relationships suggest that at least two main ages of folds occur. Minor thrusts and faults occur on fold limbs and quartz-calcite veins are associated with fractures and tension gashes. Although essentially a strike fault, the Hand Bugt fault is discordant in detail to the fold pattern and regional stratification of the Cambrian rocks on the north side of the fault (Fig. 5).

The fault zone coincides in a regional sense with the boundary of the incoming of metamorphic mica (Dawes 1976). The highest grade rocks in northern Nyeboe Land have both muscovite and chlorite in equilibrium with quartz and carbonate indicating a metamorphic grade corresponding to the low greenschist facies. Penetrative flow (slaty) cleavage dominates the argillaceous lithologies.

The northerly prograding metamorphic pattern seen elsewhere in the fold belt is disrupted by the Hand Bugt fault, where there is an abrupt increase in metamorphic grade. Hence, in the Kap Fulford area, Cambrian(?) turbidites with a distinct waxy sheen uplifted along the fault are in juxtaposition with relatively unmetamorphosed Silurian turbidites of similar lithology to the south. The Hand Bugt fault thus clearly post-dates the development of the regional thermal gradient that resulted in greenschist metamorphism.

In many places in the northern area north of the Hand Bugt fault, quartz-calcite veining is common in areas of crushing and brecciation. Veins have a variety of forms and thicknesses and they can be irregular and anastomosing. In places, some veins are deformed and show slickenside surfaces, and cross-cutting relationships between veins exist, providing evidence of repeated crushing and brecciation.

A summary of the above data, together with those given earlier in the description of the fault zone, indicates the following relationship of the faulting to the tectonic and metamorphic events.

1) The Nyeboe Land fault zone post-dates at least two ages of folds and associated cleavages, the main low-grade regional metamorphism and some fracturing and quartz-calcite veining.
2) The Nyeboe Land fault zone is associated with compressive uplift that influenced the style and regional attitude of the earlier folded rocks, and it was accompanied by brecciation, crushing and intense hydrothermal veining, as well as mylonitisation and folding.

Age and dimension of the fault movements

It has long been established that in both North Greenland and Ellesmere Island two major orogenies affected the Franklinian geosyncline, i.e. the mid-Palaeozoic Devonian–Carboniferous) Ellesmerian orogeny and the Tertiary Eurekan orogeny. In contrast to Ellesmere Island, where a thick late Palaeozoic, Mesozoic and Tertiary succession is preserved in the Sverdrup Basin (Balkwill 1978), no post-Devonian strata have yet been discovered in the Nyeboe Land region by which the Tertiary tectonic events can be readily differentiated.

However, to the east in Peary Land, where post-orogenic strata exist (Wandel Sea Basin), Tertiary tectonic and metamorphic events can be distinguished (Dawes & Soper 1973, Soper et al., this volume).

The Nyeboe Land fault zone post-dates the mid-Palaeozoic deformation and metamorphic pattern of the fold belt and the present author follows Haller (1971, Haller & Kulp 1962) in regarding the faulting as of Tertiary age. In view of the lack of Sverdrup Basin – Wandel Sea Basin deposits in this region, no direct evidence is yet available of late Phanerozoic tectonism. The age adopted here is based on regional chronological correlation with the adjacent areas both to the east (Peary Land) and west (Ellesmere Island). It would be a striking anomaly if the Nyeboe Land region represented the only large segment of the Innuitian Province that had escaped tectonic overprinting. However, the fault zone probably represents the site of a much older fracture associated with the southern margin of the Franklinian geosyncline as implied by the Lower Palaeozoic sedimentary facies distribution described in this paper. Thus, one explanation of the geometry of the Hand Bugt fault might be that an original syndepositional normal fault at the trough margin was later reactivated in the Tertiary and essentially transposed into a high-angle reverse fault. Evidence that the Nyeboe Land fault zone occupies the site of an ancient structure — probably related to a fundamental change in thickness of the crust — is discussed later in the section describing the gravity field of northern Nares Strait.

The main movement along the Nyeboe Land fault zone has been uplift of northern strata along steep fault planes. The net throw along the Hand Bugt fault is considerable since Cambrian and Silurian strata are in juxtaposition. Nevertheless, the strata were highly folded prior to the faulting and the reverse fault coincides with the Wulff Land anticline (Figs 2 and 7). Thus the actual net displacement is uncertain. However, since all, or perhaps the greater part of, the Ordovician succession (known to be present in areas to the west and east) is cut out, a movement of at least 1 km, and possibly considerably more, is indicated.

The linear belt marking the southern limit of the fault zone is regarded as the outer welt of the Tertiary tectonism that affected this part of the North Greenland fold belt. As mentioned earlier the precise nature of the steep strike faults present within this belt is uncertain, although it seems likely that normal fault movements (slides) may have occurred along the southerly-dipping fault planes in response to the regional upturning.

Correlation across Nares Strait

The Nyeboe Land fault zone is only 25 km distant from north-eastern Ellesmere Island across the Robeson Channel — the narrowest part of Nares Strait. The geological features described in this paper are major regional elements of the Franklinian geosyncline and thus they are to be expected in some form on the north-western side of Nares Strait. Corresponding Lower Palaeozoic facies, and structures comparable to the Nyeboe Land fault zone and Wulff Land anticline occur on Judge Daly Promontory of Ellesmere Island (Fig. 7).

Lower Palaeozoic facies distribution

The close geological similarity between Hall Land and north-eastern Ellesmere Island has been long established and the opposite coasts of Robeson Channel are composed of folded and on-strike Silurian trough turbidites characterised by calcareous greywacke. Trettin (1979) has referred these Silurian strata of the Hall Land – Nyeboe Land region (the clastic group of this paper) to the Imina Formation of Canada. In addition, the older rock sequences exposed in the Nyeboe Land fault zone show striking lithological similarity to the platform, slope and trough sequences of the Judge Daly Promontory region described by Kerr (1967b, 1968), Trettin (1971), Christie (1974) and Trettin & Balkwill (1979).

Hurst & Kerr (this volume) have dealt with the correlation of certain Lower Palaeozoic facies across Nares Strait including a suggested on-line correlation of the carbonates at Kap Ammen, Hall Land, with the platform margin (horst block?) that can be traced through Judge Daly Promontory and to the south-west through Ellesmere Island. This platform margin was a stable feature during the Upper Ordovician and Lower Silurian and it separates the platform carbonates to the south-east from a variable sequence of clastic rocks to the north-west (Trettin 1979, Trettin & Balkwill 1979). Downflexing of this platform margin occurred in late Lower Silurian time and trough turbidites in both Ellesmere Island and Greenland covered the carbonates, as illustrated by the Hall Land section (Fig. 3). It is of interest that the present-day southern limit of the Silurian turbidites (Imina Formation), although affected by erosion, is also essentially on-line across Nares Strait from central Hall Land to Judge Daly Promontory.

The recognition of Cambro-Ordovician platform, slope and trough deposits in an uplifted fault block makes it possible to locate the earlier position of this platform margin more accurately in Greenland than hitherto. This margin was located in Cambro-Ordovician time in northern Nyeboe Land at the site of the Nyeboe Land fault zone. Extensive cover of the Silurian turbidites in and south of the fault zone prevent a more precise definition. In Ellesmere Island the Cambro-Ordovician platform margin is represented by a facies boundary between carbonates of the Cornwallis Group on the south-east and slope deposits — mudstones, turbidites, cherts and resedimented conglomerates — of the Hazen Formation to the north-west (Kerr 1968, Trettin 1979, Trettin & Balkwill 1979). On Judge Daly

Promontory this facies boundary is a linear feature, parallel with and slightly north-west of the later Upper Ordovician–Lower Silurian position.This linear feature is associated with faulting (U. Mayr, pers. comm.) and is on-line with the Nyeboe Land fault zone; the position of the same margin in Greenland (Fig. 7).

Wulff Land anticline

The only major fold structures in eastern Ellesmere Island which involve Lower Palaeozoic strata and bring up Proterozoic rocks in their cores are a belt of NE-trending, fault-disturbed anticlines traceable throughout Judge Daly Promontory sub-parallel to the coast of Kennedy Channel. In the south-west large wavelength folds have a constant strike and form a broad anticlinorium (Kerr 1967b, 1973); to the north-east the fold pattern is complicated by faulting, but a major anticline exposing Proterozoic rocks reaches the north-eastern tip of the promontory (Christie 1974). The folds are parallel with the margin of the Franklinian geosyncline and they deform rocks of facies corresponding to those of the Nyeboe Land fault zone; thus correlation with the Wulff Land anticline is strongly suggested. The structural composition of the North Greenland fold belt adjacent to and north of the Wulff Land anticline is unknown as the area is under the Lincoln Sea. Therefore it is uncertain whether structures of the Wulff Land type bringing up Proterozoic strata form a discrete belt in Greenland as they do on Judge Daly Promontory.

Nyeboe Land fault zone

Major Tertiary faults are common on Judge Daly Promontory in north-eastern Ellesmere Island: dislocations that hold an important position in discussions about strike-slip movement along Nares Strait (Wilson 1963, Christie 1964, 1967, 1974, Kerr 1967a, Miall 1981, Mayr & de Vries, this volume). In north-eastern Judge Daly Promontory two major high-angle faults (Fig. 7) delimit a region that is highly dissected by faults that are sub-parallel to the mid-Palaeozoic Ellesmerian fold pattern. The two major faults transect the coast at the northern end of the promontory and they strike into the southern end of the Robeson Channel. Likewise in Greenland, the main dislocation of the Nyeboe Land fault zone is a high-angle fault of assumed Tertiary age, sub-parallel to the Palaeozoic folds and it strikes into the opposite end of Robeson Channel. Thus correlation is suggested between the fault zones of Nyeboe Land and Judge Daly Promontory, and they are proposed here to be parts of a single fracture line — the Judge Daly – Nyeboe Land fracture line. It should be noted that the Judge Daly fault zone was used by Kerr (1967a) specifically to describe the south-eastern fault on Judge Daly Promontory; in this paper it is used for convenience to include both faults (Fig. 7).

Tertiary sedimentary strata of the Eureka Sound Formation are preserved as down-faulted outliers between the two major faults on Judge Daly Promontory and in a faulted coastal outcrop (Christie 1974). Thus it is possible to demonstrate a Tertiary tectonic history involving Paleocene folding, uplift and erosion, Eocene southerly-directed thrusting, followed by Oligocene or Miocene strike-slip movement and extensional down-faulting (Miall 1981, Mayr & de Vries, this volume). In the absence of post-Franklinian deposits no comparable chronological detail can be recognised in the Nyeboe Land fault zone. Thus it is uncertain if the main tectonic event in Greenland causing uplift of the northern coastal block should be correlated with the Paleocene or the Eocene compressive tectonism known from Judge Daly Promontory. Furthermore, no data exist at the present time for strike-slip movements in the Nyeboe Land fault zone although it should be stressed that no detailed structural analysis has been undertaken.

In addition to the Tertiary chronology that can be elucidated, it is most probable that the Judge Daly fault zone also had an older history. Christie (1974) suggests that all major lineaments on north-eastern Judge Daly Promontory may have been active in pre-Tertiary time and that such movements accounted in part for the Tertiary sedimentary basins. Furthermore, although the north-western part of Judge Daly Promontory is not yet mapped in detail, the Cambro-Ordovician platform margin has been mapped as a very sharp facies contact which is also associated with faulting (U. Mayr, H. P. Trettin, pers. comm.); a relationship that suggests some syndepositional fault control.

The Nyeboe Land fault zone has been correlated by some workers (Newman 1977, Newman, this volume) with a major thrust zone in central Ellesmere Island on the west side of Kane Basin. This correlation has been used in support of a pre-drift position of Greenland and Ellesmere Island involving 250 km of strike-slip displacement along Nares Strait. The main dislocation of this thrust zone is the Parrish Glacier thrust that, according to Mayr & de Vries (this volume), is a low-angle, southerly-directed thrust associated with imbricate thrust sheets which has transported Proterozoic and Lower Palaeozoic strata over Paleocene conglomerates. Correlation of this thrust with the Nyeboe Land fault zone violates the continuity of the Cambro-Ordovician platform margin outlined in this paper (as well as the Upper Ordovician – Silurian margin described by Hurst & Kerr in this volume) which, coincidently or not, occurs on both sides of Nares Strait in the same area as high-angled fault zones. Furthermore, a problem of 'timing' arises if widely separated Tertiary (?Eocene) dislocation zones are used to conclude major (late Paleocene – Eocene) displacement of Greenland and Ellesmere Island.

Harder Fjord fault zone

A second major fault zone, the Harder fjord fault zone, occurs in the North Greenland fold belt and although not described in detail in this paper it is within the region shown in Fig. 7. This fault zone has a long and complex tectonic history (Soper et al. 1980) possibly going back to the early Palaeozoic (Hurst & Surlyk 1980, Surlyk et al. 1980). The sense of net displacement is downthrow to the south and the mountainous terrain of northern Peary Land has been likened to a horst (Fränkl 1955, Haller & Kulp 1962). The main fault planes are typically high-angled and the fault zone has been active in Paleocene or later Tertiary time since Paleocene strata are caught up in the zone (Croxton et al. 1980). There is also evidence of pre-Tertiary magmatism along it (Dawes & Soper 1979, Soper et al. 1980, Parsons 1981). Evidence of Recent fault movement occurs in the form of earthquake epicentres and solfatara activity in its eastern part (Dawes & Peel 1981).

The Harder Fjord fault zone is on direct strike with the Lake Hazen fault zone of Ellesmere Island (Higgins et al., this volume) and while the two fault zones are separated by 200 km of open water, both are traceable for much longer distances in Greenland and Ellesmere Island respectively, and their persistence, strike and nature invite correlation. The Lake Hazen and the Harder Fjord fault zones have affected and preserved Late Palaeozoic, Mesozoic and Tertiary strata of the Sverdrup and Wandel Sea Basins, respectively. The Lake Hazen fault zone shows many features in common with its Greenland counterpart, i.e. a long and complex tectonic history, high-angle faults along which the Grant Land Mountains have been uplifted as a thrust block in the north, and a comparable Tertiary, post-Paleocene age for the latest movements (Trettin 1971).

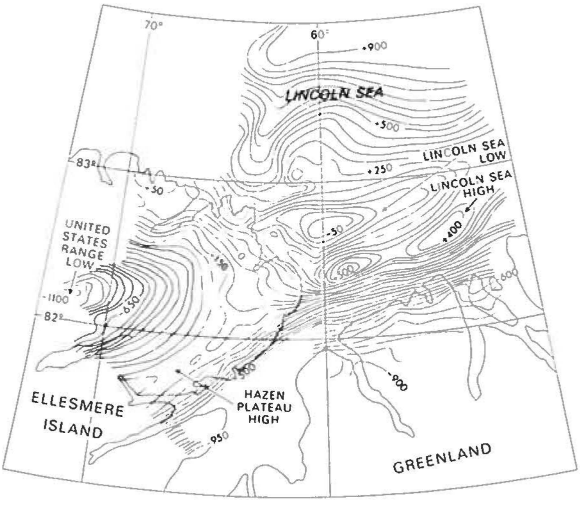

Fig. 9. Bouguer anomaly map of northern Nares Strait region redrawn after Sobczak & Stephens (1974). Gravity contours are of 50 mgal intervals.

Gravity field of northern Nares Strait

Sobczak & Stephens (1974) have described the Bouguer anomaly gravity field of the northern Nares Strait region on the basis of 70 field stations in northern Ellesmere Island, Greenland and the Lincoln Sea (Fig. 9). The most notable features of this in the context of the geological features described in this paper are: 1) that the primary gravity anomalies trend sub-parallel to the regional structural elements of the Ellesmere–Greenland fold belt and 2) that a prominent north-easterly trending gravity gradient is continuous from Judge Daly Promontory across the Robeson Channel to the northern coastal area of Nyeboe Land. The Hazen Plateau and Lincoln Sea highs (maximum anomaly 50 mgal) and a parallel belt of gravity lows over Judge Daly Promontory and northern Nyeboe Land (minimum anomaly –95 mgal) are separated by a steep horizontal gradient (maximum –3.68 mgal/km) that is interpreted by Sobczak & Stephens (1974: 1) as representing "an abrupt step-like thickening of the crust of 10 km or more from the northwest to the southeast". These authors conclude that the change in crustal thickness may represent the crust–mantle boundary of the stable craton as earlier depicted in the region by Riddihough et al. (1973).

The significant point for the present discussion is that this strong gravity gradient of more than 100 mgal coincides regionally with the Franklinian platform margin and with the Judge Daly – Nyeboe Land fracture line as defined in this paper. Also in detail there exists a remarkable correlation with fault lineaments. Thus in Nyeboe Land, the primary gravity anomaly trends are exactly parallel with the Nyeboe Land fault zone and they transect the northern coastline and the regional structural trend of the fold belt at an oblique angle. Thus the "step-like thickening of the crust" mentioned by Sobczak & Stephens (1974) may be coincident with a block fault system at the margin of the Franklinian geosyncline, movements along which caused downflexing and subsidence that controlled the trough sedimentation. Whatever the true origin of the gravity gradient, its spatial correlation with the platform margin and a major fracture system strongly suggests that it represents a structure at least as old as early Palaeozoic. A deep-seated change in crustal character or thickness associated with the passage from normal continental crust to attenuated continental or oceanic crust remains one possibility. Sobczak & Stephens (1974) suggest that it may be related to an ancient plate boundary.

Inferences about Nares Strait

This paper defines four geological features in northern Greenland that can be correlated with corresponding features in Ellesmere Island. This allows inferences to be made on the relative positions of the two landmasses as well as on the proposed structure of the Strait. The four features are:

1) Cambro-Ordovician platform margin
2) Mid-Palaeozoic Wulff Land anticline
3) Tertiary Nyeboe Land fault zone
4) Tertiary Harder Fjord fault zone

Both fault zones, 3) and 4), almost certainly represent the sites of Palaeozoic fractures.

Transcurrent movement

It is not necessary to invoke strike-slip movement between Greenland and Ellesmere Island in order to effect an acceptable correlation of the four geological features outlined above. This suggests a relative position of the two landmasses, in at least Palaeozoic and Tertiary time, that was not far removed from present-day geography. This conclusion refutes conventional reconstructions that involve major movement between Greenland and Ellesmere Island (e.g. Srivastava 1978). This is also supported by other geological features in the northern Nares Strait region discussed elsewhere in this volume by Higgins et al. and Hurst & Kerr, and also by the steep gravity gradient that crosses Robeson Channel without offset (Sobczak & Stephens 1974).

Considered individually, features of Tertiary age are of limited value as indicators of any early Tertiary (Paleocene–Eocene) displacement other than providing a minimum age of any motion. However, in this case the Nyeboe Land fault zone most probably represents the site of a much older (pre-drift) fracture. Particular importance is attached to these four geological features since they record events which represent a span of 500 m.y. from the early Palaeozoic to the Cenozoic and yet each correlates directly across Nares Strait. If Sobczak & Stephen's (1974) interpretation of the steep gravity gradient across the Robeson Channel is correct then the geological record represented by on-line correlatable features is extended well into the Precambrian. However, each of the features transects the Robeson Channel at the same low angle and a *precise* control of the amount of strike-slip net movement which could have occurred is impossible.

The most suitable feature is the Cambro-Ordovician platform margin, since this undoubtedly formed prior to the suggested late Phanerozoic strike-slip motion and prior to the mid-Palaeozoic and Tertiary tectonism of the Franklinian geosyncline. The geological reliability of the feature on both sides of Nares Strait suggests that net sinistral transcurrent movements of up to 50 km do not disrupt the facies pattern unacceptably. Displacements greater than this produce an increasingly problematical mismatch of the platform margin; a net displacement greater than 100 km can be ruled out.

Structure

Kerr (1967a) suggested that Nares Strait is a Tertiary rift valley and he proposed a major fault parallel to the northern coasts of Hall Land and Nyeboe Land. The inference of normal faulting in the Robeson Channel–Lincoln Sea area was, in the absence of onshore data, based solely on the morphology of the coastline. The Hand Bugt fault indicates that a main tectonic event in the coastal region of Hall Land and Nyeboe Land was compressional and not extensional causing coastal down-faulting. Assuming the compression to be Tertiary, the onshore evidence, at least on the Greenland side, does not support an extensional rift valley in the Lincoln Sea area.

The Judge Daly – Nyeboe Land fault line is sub-parallel to the regional fold pattern and southern margin of the Ellesmere–Greenland fold belt. It is thus oblique to Nares Strait. The two major faults in north-eastern Judge Daly Promontory can be traced to the south-west as part of a regional thrust and fault belt which is parallel with and follows the Kennedy Channel coast into the Kane Basin area. Just south of 80°N this belt swings markedly to the west and the dislocations strike inland (Kerr 1967a, Mayr & de Vries, this volume). Therefore, like the mid-Palaeozoic (Ellesmerian) fold structures, this regional thrust-fault belt has also a section that is more or less parallel to Nares Strait.

Christie (1964, 1967) drew attention to the striking linearity of major faults in Judge Daly Promontory and he demonstrated strike-slip displacement of major fold structures. However, he concluded that movements "such as would occur if continental blocks were to shift tens or hundreds of kilometres" have not occurred (Christie 1967: 3, 1974). Mayr & de Vries (this volume) report evidence of sinistral strike-slip motion amounting to about 19 km within the Judge Daly fault zone.

The fault zone correlation suggested in this paper raises the question of how far strike-slip displacements recorded in Judge Daly Promontory or elsewhere along the fault line have influenced the relative positions of Greenland and Ellesmere Island as separate 'plates' and whether such displacements can be used as a direct indication of the amount of strike-slip motion that has occurred along Nares Strait. Since the Judge Daly – Nyeboe Land fault line is oblique to Nares Strait, any strike-slip displacements along it may not necessarily have been translated into overall motion through Nares Strait (Baffin Bay to Lincoln Sea), and such movements may not have contributed to the separation of Greenland and Ellesmere Island. Major tectonic stresses propagated northwards into the Nares Strait region as a result of the crustal evolution of Baffin Bay and the surrounding oceans, may well have been translated into dislocations oriented oblique to Nares Strait. In this context the deep-seated structure that crosses the Robeson Channel (Sobczak & Stephens 1974) could have hindered in some way the passage of tectonic forces through Nares Strait having the effect of transposing them along fractures parallel to it, i.e. along the Judge Daly – Nyeboe Land fracture line.

The recognition of the Judge Daly – Nyeboe Land and the Harder Fjord – Lake Hazen fracture lines indicates that extensive dislocations of comparable length to Nares Strait, but oblique to it, were of considerable importance in this part of the Arctic in Tertiary time. Moreover, the bedrock geology of the two oblique dislocation lines demonstrates a complex Tertiary history involving compressional and extensional tectonism, including various types of fault and thrust displacements, to say nothing of a pre-Tertiary history that included tectonism and in at least Peary Land extrusive and intrusive magmatism. This contrasts markedly with the Nares Strait lineament across which correlations of geological features of Precambrian to Cenozoic age can be satisfactorily made without invoking strike-slip or vertical displacements and along which no evidence exists of regional shearing or compressive structures which might be connected to a Tertiary subduction zone.

Therefore, without invoking a tantalising and complicated tectonic history for Nares Strait, e.g. a post-Devonian dextral displacement followed by a more or less equal amount of sinistral displacement in response to the generally accepted models for opening of the surrounding oceans, the geology of the northern Nares Strait region suggests that main crustal displacements in the late Phanerozoic took place along fractures oblique to Nares Strait rather than along it.

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