Reconnaissance of Tertiary structures along Nares Strait, Ellesmere Island, Canadian Arctic Archipelago

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In the coastal area of Ellesmere Island between Copes Bay in the south and Cape Baird in the north, at least three phases of Tertiary structural deformation can be distinguished. These are: 1) Paleocene uplifting, 2) Eocene thrusting and 3) strike-slip faulting, probably not younger than Miocene.

Uplifting is documented by remnants of a coarse, oligomictic, alluvial conglomerate of Tertiary age. In the southern and central part of the area the conglomerate is over-thrusted by Lower Palaeozoic rocks. Conjugate strike-slip faults are present on Darling Peninsula and northern Judge Daly Promontory. Sinistral displacement along the Judge Daly fault zone is estimated tentatively at 19 km.

Thrusting and strike-slip faulting in the Nares Strait area probably correspond to the main phase of the Eurekan orogeny.

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Nares Strait has long been considered a major fracture of the northern hemisphere and various amounts of sinistral displacement, ranging from a few tens to several hundreds of kilometres, have been proposed for this lineament (see Kerr 1980 and this volume for discussion of historical background). If Nares Strait is indeed a zone of strike-slip faulting, then structures which are the result of such strike-slip movement should be exposed along its shores. Published maps from Greenland (Koch 1929, Escher 1970, Dawes & Haller 1979) show that the platform rocks are, along the southeast coast of Nares Strait, without major deformation or features which can be attributed to strike-slip faulting. However along the northwest shore of Nares Strait, on Ellesmere Island between Copes Bay and Cape Baird at the northern tip of Judge Daly Promontory, thrusts, faults and folds originating from both the Ellesmerian (late Palaeozoic) and Eurekan (Tertiary) orogenies, are exposed. These structures form the southeastern margin of the Ellesmere fold belt.

It is the intent of the present investigation firstly to examine the Tertiary structures to see whether some are related to any strike-slip movement along Nares Strait, and secondly to see whether a sequence of separate structural events can be established and if such events can be correlated with the phases of the Eurekan orogeny as defined by Balkwill (1978) farther west in the Sverdrup Basin.

Regional geological setting

Fig. 1 shows the coastal region of eastern Ellesmere Island described in this paper. The area northwest of the plotted features contains various tectonic subdivisions, among them the Ellesmere fold belt. The plotted structures form the southeastern margin of the Ellesmere fold belt and for a discussion of the regional tectonic units and their relation to northern Greenland the reader is referred to the paper in this volume by Higgins et al.

Geological data

Several maps covering the area between Copes Bay and Cape Baird (Fig. 1) have been published by the Geological Survey of Canada. One of the earliest contained in a report by Christie (1964) covers Judge Daly Promontory as far south as Carl Ritter Bay. He suggested transcurrent movement along the Judge Daly fault zone between Cape Defosse and Cape Baird. On a later map and in the accompanying text Christie (1974) pointed out the extension of the Judge Daly fault zone as far south as Carl Ritter Bay.

The area between Carl Ritter Bay and Copes Bay is covered by three maps (Kerr 1973a, b, c) on which the major structural features were named. The same author

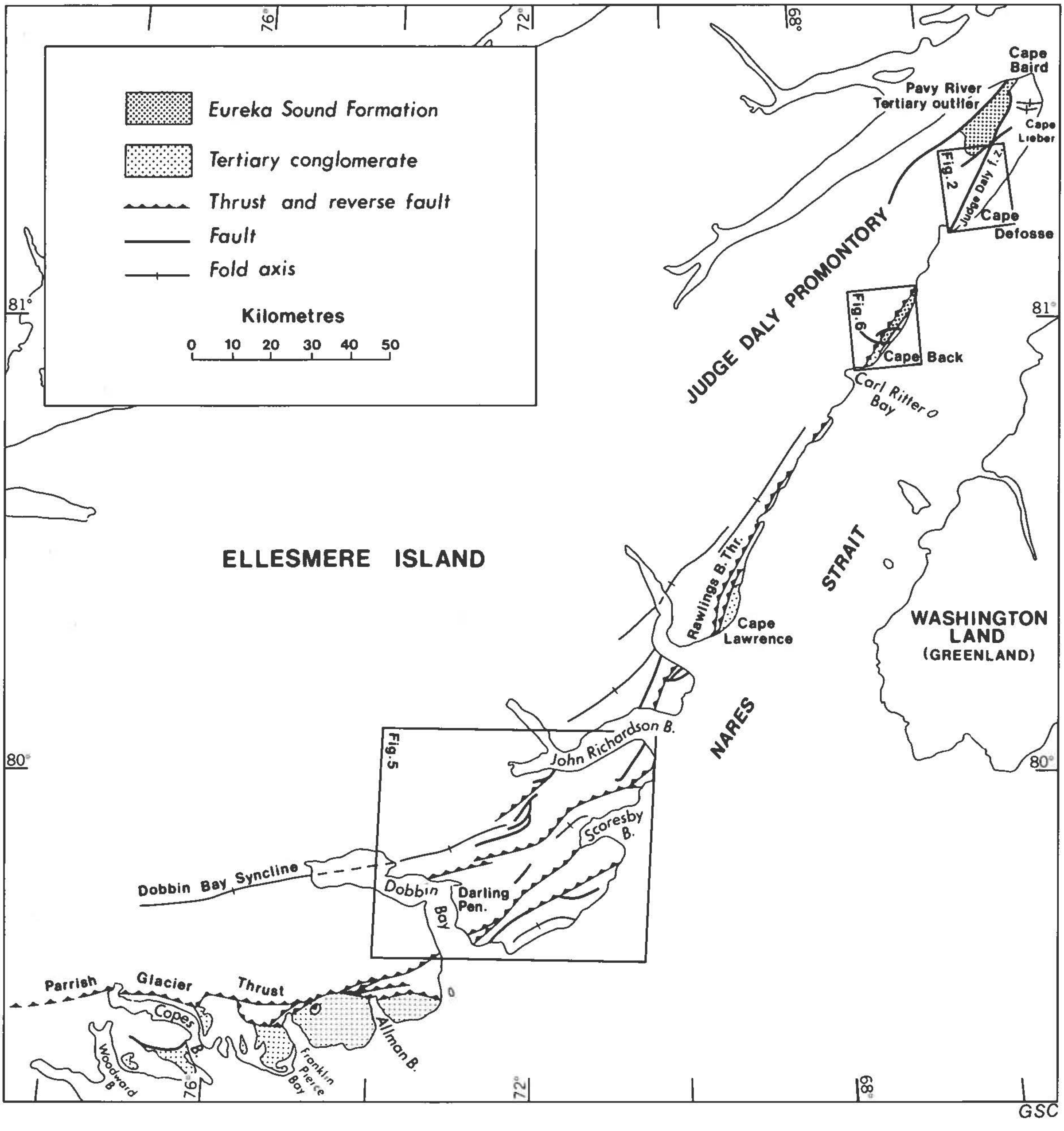


Fig. 1. Index map of central eastern Ellesmere Island, showing the main structural features along the Nares Strait coast and the locations of Figs 2, 5 and 6. Main Tertiary outcrop areas are shown; blank areas in Ellesmere Island are Proterozoic to Devonian of the Franklinian geosyncline.

(Kerr 1967) also named the Judge Daly fault zone. The published maps are generalized and not at sufficiently large scale for detailed structural interpretation of Nares Strait. The present interpretation is based on the re-examination of unpublished photogeological interpretations and field data obtained by the authors during 1972 and 1973 for Sproule Associates Limited, Calgary, Alberta, Canada.

Tertiary stratigraphy

Outliers of Tertiary sediments (Fig. 1) make it possible to distinguish Ellesmerian and Eurekan components in the margin area of the Ellesmere fold belt along Nares Strait. The lithology and distribution of these Tertiary rocks also furnishes important clues for describing a possible sequence of local structural events during the

Eurekan orogeny. Two Tertiary lithofacies are present: sandstone, siltstone, coal and mudstone of the Eureka Sound Formation and a boulder conglomerate. This conglomerate is described in this paper separately from the Eureka Sound Formation although Miall (1981) includes it as the uppermost unit of that formation.

Eureka Sound Formation

The Eureka Sound Formation is present as two significant outliers, one just north of Cape Back and the other one at Pavy River. In both locations the beds are moderately to gently folded and are preserved in graben structures. In the Pavy River outlier the Eureka Sound Formation unconformably overlies Lower Palaeozoic formations. The lithology has been described and interpreted in detail by Miall (1981). Estimated maximum thickness of the Eureka Sound Formation is in the order of 1000 m. The age of the exposed beds is Paleocene on the basis of palynology (R. L. Christie & W. S. Hopkins, pers. comm. 1980) and leaf impressions (Miall 1981).

Conglomerate

The conglomerate is exposed in three areas, at Cape Back, at Cape Lawrence and in isolated patches in the region between Dobbin Bay and Woodward Bay (Fig. 1). It unconformably overlies Lower Palaeozoic rocks. In the southern areas it is flat lying and the Rawlings Bay and Parrish Glacier Thrusts have carried Proterozoic and younger rocks over the conglomerate. At Cape Back a reverse fault has brought the conglomerate against Lower Palaeozoic rocks in the northwest (Fig. 6). The conglomerate and the apparently unconformably (Christie 1974) underlying Lower Palaeozoic formations are steeply dipping. The conglomerate at Cape Back has been described and interpreted as an alluvial fan deposit (Miall 1978, 1981). Generally, the conglomerate is oligomictic and consists of carbonate clasts up to 22 cm in diameter. Conspicuously rare or absent are quartzite, sandstone and noncalcareous siltstone, all lithologies of Lower Cambrian formations of the region. Rare, thin sandstone beds are present and at Cape Lawrence a sandstone bed in the upper part of the formation contains a large number of leaf impressions. Identified as *Crednaria spectabilis* (Heer) Koch, these leaves are of Paleocene age (G. E. Rouse, pers. comm. 1973). The conglomerate is up to 1000 m thick at Cape Lawrence, less elsewhere.

Two features are of importance when relating the conglomerate to the Eurekan structures:

1. The conglomerate is oligomictic. It does not contain any quartzite or sandstone of the Lower Cambrian Ellesmere Group, which structurally overlies the conglomerate along the Parrish Glacier and Rawlings Bay Thrusts. Thus the conglomerate is not derived from the lower parts of the thrust sheets that overlie it.
2. The conglomerate is not continuous beneath the Parrish Glacier Thrust. At Copes Bay the thrust sheet lies alternately on conglomerate or on Siluro-Devonian formations. Because the elevation of the conglomerate surface is higher than that of the Silurian and Devonian strata and no significant change in clast size was observed, the gap between the conglomerate patches is interpreted to have been caused by erosion prior to thrusting. Thus an interval of time must have passed after deposition of the conglomerate and prior to thrusting.

The following sequence of events is therefore suggested. The conglomerate was deposited in alluvial fans adjacent to an uplift, on which the oldest rocks exposed were Middle Cambrian to Silurian. Uplift slowed or ceased and the conglomerate was eroded. Next, thrust sheets were emplaced over the partially eroded conglomerate at Cape Lawrence and in the southern part of the area. Reverse faulting took place at Cape Back.

Eurekan structures

Two types of Tertiary structural regimes can be distinguished. In the north a strike-slip regime is present in the vicinity of the Judge Daly fault zone, in the south a compressive, thrust fault regime is revealed by the Parrish Glacier and Rawlings Bay Thrusts. The intervening areas are influenced by both regimes and strike-slip movement may be superimposed on thrust faults.

Thrusts

Major thrusts without strike-slip overprint are present between Copes Bay and Dobbin Bay (Parrish Glacier Thrust) and at Cape Lawrence (Rawlings Bay Thrust) (Fig. 1).

Parrish Glacier Thrust. – The Parrish Glacier Thrust is well exposed at the heads of Allman and Franklin Pierce Bays, at both sides of Dobbin Bay and it has also been mentioned by Thorsteinsson (1963) at Copes Bay. The thrust plane dips between 30° and 50° to the north and stratigraphic displacement is in the order of 4500 m. The hanging wall consists of Proterozoic to Silurian beds that dip northward, very slightly undulating, at 20° to 40°. In front of the main thrust are several imbricate thrust sheets with partial stratigraphical sequence and a klippe with an almost horizontal thrust plane. The foot wall consists of Tertiary conglomerate, or towards Copes Bay, of Silurian carbonates. The Tertiary and Silurian beds are flat lying and are very little disturbed except for minor drag folds near the thrust.

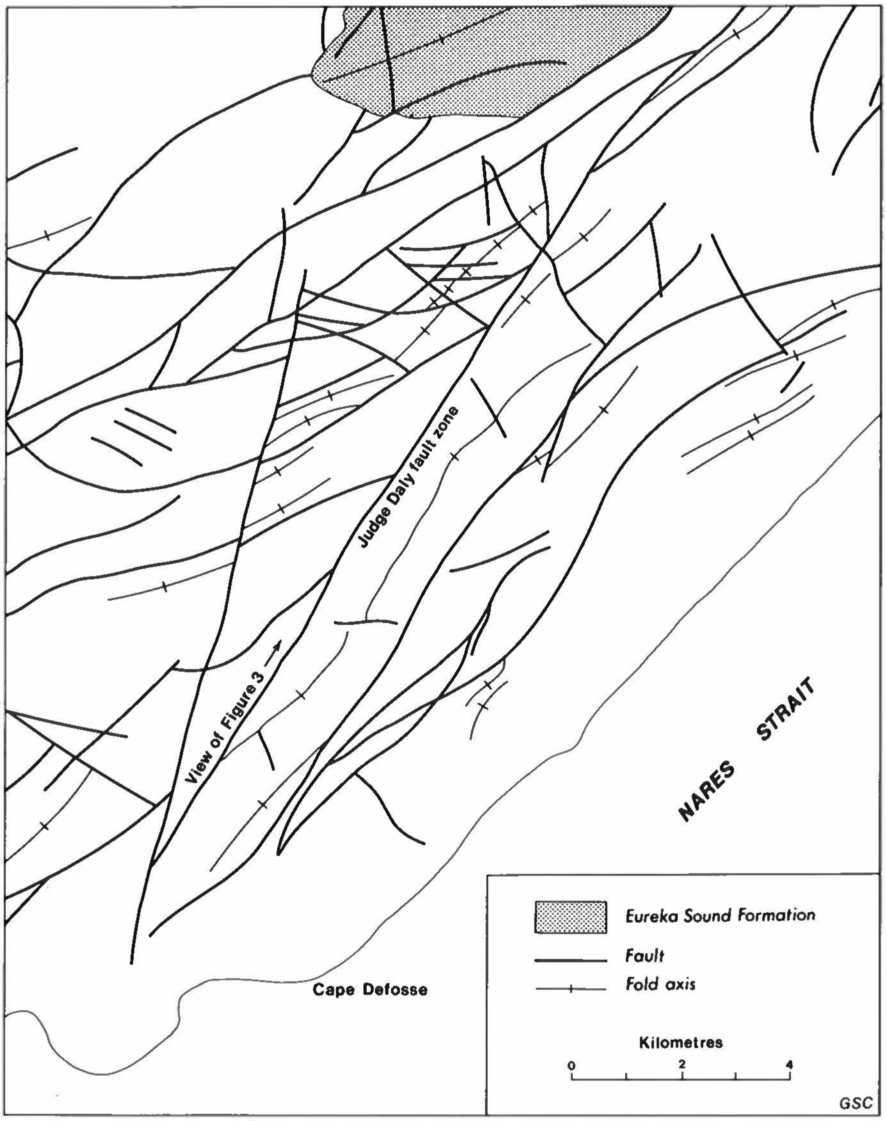


Fig. 2. Main structural features in the Cape Defosse area. For location, see Fig. 1.

Rawlings Bay Thrust. – The structural configuration of the Rawlings Bay Thrust in the Cape Lawrence area is very similar to that of the Parrish Glacier Thrust. The hanging wall dips slightly more steeply to the northwest and in front of the main thrust are an imbricate thrust with a partial stratigraphic sequence and a klippe with a horizontal base.

Strike-slip faults

Two types of strike-slip faulting can be distinguished, divergent strike-slip on northern Judge Daly Promontory and convergent wrenching in the vicinity of Darling Peninsula.

Judge Daly fault zone. – The Judge Daly fault zone is a prominent linear feature on northern Judge Daly Promontory with strong topographic expression (Fig. 2). It is almost 40 km long and is now marked by a linear trench (Fig. 3). Folded Cambrian and Ordovician strata, with fold axes at an acute angle to the fault zone, occupy both sides of the fault in the southern part of the area. In the north, the northwest side of the fault zone consists of Eureka Sound Formation folded into a gentle asymmetric syncline approximately parallel to the fault zone. Drag folds in the Eureka Sound Formation, parallel to the fault scarp, suggest that late vertical movement took place along the fault, downdropping the northwestern side. The main movement, however, is interpreted to be sinistral strike-slip, and this is supported by several lines of evidence.

First there is the presence of larger structures, which are compatible with wrench tectonics. Wilcox et al. (1973) described the attributes of wrench zones, and

Fig. 3. View from helicopter northeastwards along the trench which marks the Judge Daly fault zone (see Fig. 2 for approximate location of photograph). Bedrocks in foreground are folded Ordovician carbonates. The first set of mountains in the background consists of folded Silurian and Devonian carbonates and clastics, while the far mountains, forming the left part of the skyline, consist of folded Cambrian rocks.

singled out en échelon folds and conjugate strike-slip faults as the most important features. No en échelon folds can be identified with certainty. The Ellesmerian fold axes cut the Judge Daly fault zone with an angle of about 25° (Fig. 4) which is close to the most probable angle for left-handed en échelon folds, thus, in this case, the en échelon folds would be parallel to the older folds. At Cape Lieber E–W-striking folds are oblique to Ellesmerian folds. These folds cut the Judge Daly fault zone at an angle of about 60°, too large an angle for true en échelon folds. Such folds, however, could be of Tertiary origin and indirectly related to the strike-slip faulting because of their non-Ellesmerian alignment.

Conjugate strike-slip faults can be identified without difficulty on the northwest side of the southern part of Judge Daly fault zone. These fractures cut Ellesmerian folds and are thus younger, presumably Eurekan. Two sets are present: one is sinistral, striking N10°E and forming an angle of 25° with the Judge Daly fault zone; the second set shows dextral displacement and strikes about N60°W, forming an angle of 100° with the Judge Daly fault zone. The offset is revealed by colour banding of red bed units in the Parrish Glacier and Copes Bay Formations and can be easily observed on airphotos. Ground checking confirmed that the offsets are caused by horizontal, rather than vertical movement. Also fold axes are offset in this area (Fig. 2). The sinistral set of faults represents synthetic strike-slip faults, whereas the dextral set are antithetic strike-slip faults.

The second line of evidence for movement lies in the interpretation of small features. Hematite staining, large pods of brecciation and associated dolomitization of carbonates seem to be confined to the Judge Daly fault zone. Slickensides are very common in the brecciated rocks. Few in situ measurements of slickenside directions could be taken, but some near-horizontal attitudes were recorded. The axes of the Cape Lieber folds trend approximately east–west. In the vicinity of the Judge Daly fault zone the axes bend to the southwest. This deviation from the regional trend is interpreted as drag during left-lateral movement along the fault zone.

The graben containing Eureka Sound Formation to the northwest of the Judge Daly fault zone, caused by downdrop along the zone, is interpreted as a late extensional feature, indicative of divergent strike-slip movement. This interpretation is corroborated by the appar-

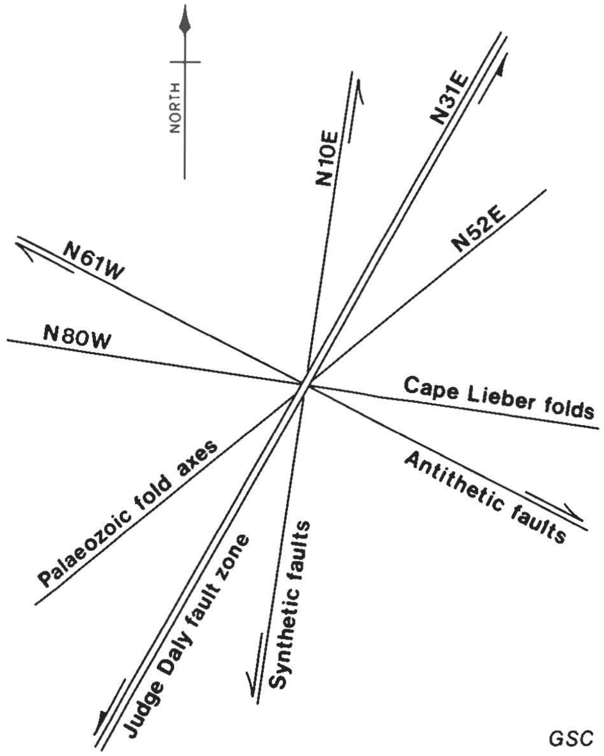


Fig. 4. Plot of directions of the main structural features on northern Judge Daly Promontory.

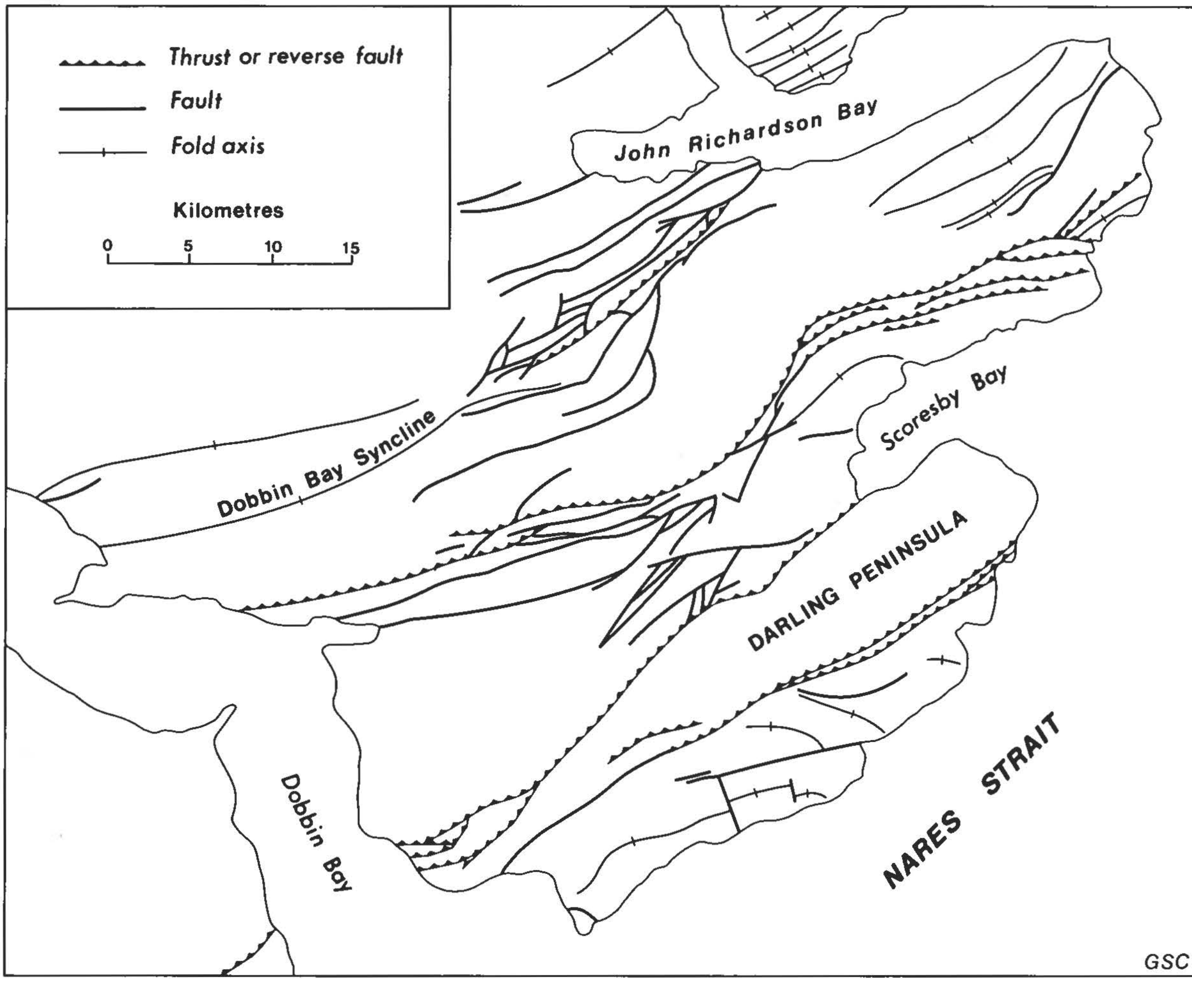


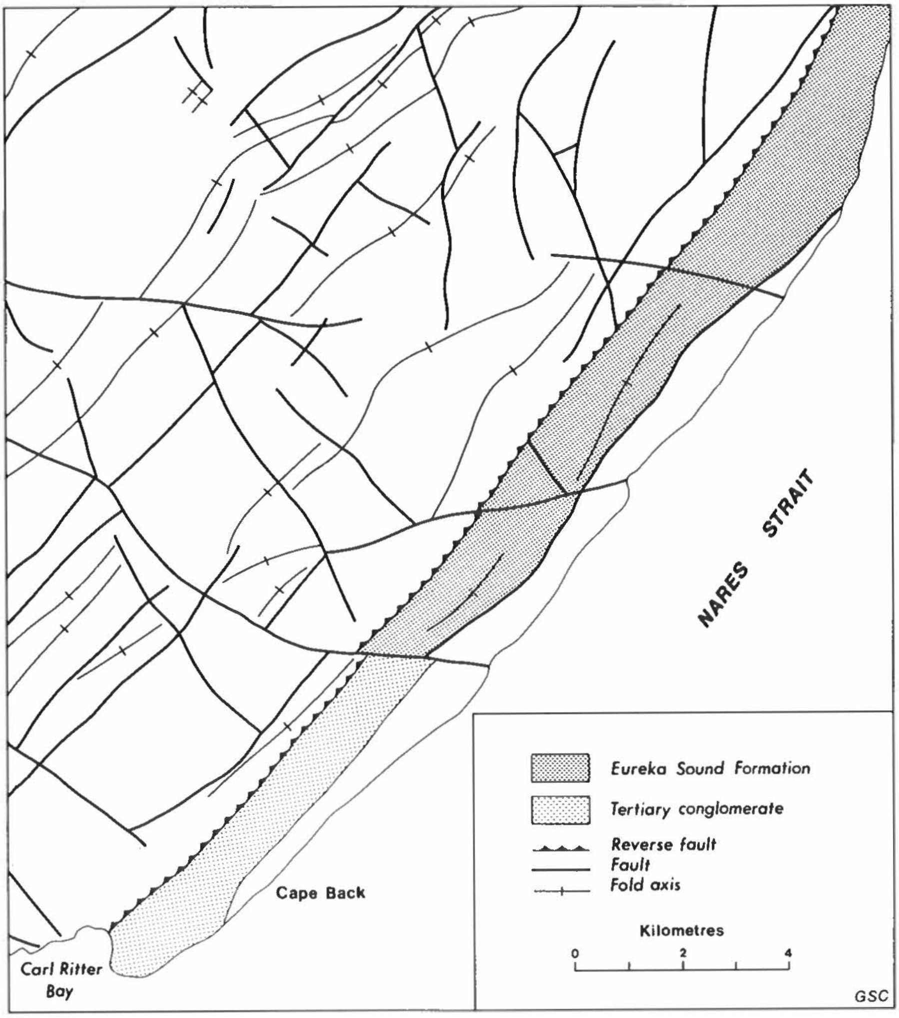
Fig. 5. Main structural features in the Darling Peninsula area. For location, see Fig. 1.

ent absence of thrusts or reverse faults in the vicinity of the Judge Daly fault zone.

Quantitative estimates of displacement along the fault zone are uncertain because of the absence of distinct geological markers and because of the structural fragmentation of the area. The only features found that could be matched tentatively across the fault zone are overturned panels of Lower Cambrian formations. At latitude 81°27'N, longitude 65°00'W, at the eastern side of the Judge Daly fault zone, a northeast plunging anticline (Christie 1974: fig. 1) exposes along its northern flank Rawlings Bay, Kane Basin, Scoresby Bay and Parrish Glacier Formations with an overturned dip of about 70°S. At latitude 81°17'N, longitude 65°45'W, on the western side of the fault zone, a triangular, about 3 km wide fault block consists of a southward (also about 70° and overturned) dipping panel of Rawlings Bay, Kane Basin, Scoresby Bay and Parrish Glacier Formations. If this southern, overturned panel was part of the northern, anticlinal flank, lateral displacement of about 19 km would be needed to realign the two panels. The match however, is uncertain because the anticlinal axis is not contained in the southern fault block. Furthermore no other corroborating alignments across the fault zone are apparent.

Darling Peninsula and adjacent area. – No remnants of Tertiary sediments are preserved in the region between Dobbin Bay and John Richardson Bay (Fig. 5); it is not possible to definitely separate Ellesmerian structures but some inferences can be made. The Ellesmerian structures consist of long, parallel, concentric anticlines and synclines. The Dobbin Bay Syncline appears to be the southeasternmost structure of this type, so that the area to the southeast should be dominated by Eurekan structures. The bedrock there consists of a large number of elongated, northeast-trending fault slices. The slices dip, in part steeply, to the northwest and contain several poorly defined folds. The slices are bounded by thrusts, reverse faults and by faults for which no information on

Fig. 6. Main structural features in the Cape Back area. The southeast boundary of the conglomerate is exposed in a steep cliff and has been mapped variously as a stratigraphic contact (Christie 1974) or as a fault (Miall 1981). The present authors tentatively interpret the contact as a folded unconformity. For location, see Fig. 1.



the dip direction of the fault planes is available. Many of the faults have an arcuate trace and terminate with an acute angle against other faults. They are arranged in a braided pattern of synthetic strike-slip faults typical of strike-slip zones world-wide and known from shears of any magnitude (Tchalenko 1970). No conclusions as to actual lateral movement along these faults can be drawn from the presently available information.

Combined thrusts and strike-slip faults

North of Carl Ritter Bay. – In this area folded Lower Palaeozoic rocks are in fault contact with folded Tertiary sediments (Fig. 6). The reverse fault, that forms the contact between the two rock suites, is an extension of the Rawlings Bay Thrust and also projects into the Judge Daly fault zone.

Evidence for thrusting is the reverse fault noted above and its southwestward extension into the Rawlings Bay Thrust. Indirect evidence for strike-slip faulting is found in the post-Ellesmerian deformation of the Palaeozoic rocks to the northwest of the reverse faults. There the Palaeozoic fold belt is segmented by a large number of normal faults. Two fault trends dominate: one is approximately perpendicular and the other about parallel to the main reverse fault. These faults can be interpreted as conjugate strike-slip faults caused by strike-slip movement along the main reverse fault. A few Ellesmerian fold axes appear to be offset along the faults but insufficient observations are available to distinguish between sinistral and dextral displacement along the synthetic and antithetic fault sets.

Discussion

A sequence of Tertiary events can be proposed for part of Ellesmere Island adjacent to Nares Strait, the area between Copes Bay and Cape Baird.

1. Uplift

Paleocene uplifting is indicated by the presence of the conglomerate. Nothing is known of the extent of the uplift which was the source for the conglomerate, but it must have extended at least from Carl Ritter Bay to Copes Bay. Beyond Copes Bay coarse sediments of this nature are not known from the area of the Central Ellesmere fold belt, but they may have existed and have since been eroded. Uplifting was followed by a structural interlude during which the conglomerate was partially eroded. The length of that erosional interlude is not known, but it had ended by late Eocene when the thrusting began.

2. Thrusting

The thrusting can be dated in the Irene Bay area, about 120 km southwest of Copes Bay. There the Parrish Glacier Thrust or extensions of it overlie the Eureka Sound Formation, the youngest strata of which are of middle Eocene age (West & Dawson 1977, 1980). In the Nares Strait area the thrust sheets containing Palaeozoic formations advanced over the conglomerate, but left it undisturbed. In the area north of Carl Ritter Bay, however, where some strike-slip movement also occurred, the conglomerates are folded. This implies a phase of strike-slip movement distinct from earlier thrusting.

3. Strike-slip faulting

The major effects of strike-slip faulting are seen in two areas: on Darling Peninsula and adjacent areas, and on Judge Daly Promontory north of Carl Ritter Bay. These areas are separated at Cape Lawrence by a structural block which was not affected by strike-slip movement. The presence of an intervening block corroborates the concept of separate thrust and strike-slip phases. If the thrusting and strike-slip movement had been caused simultaneously by the same stress-vector, the Cape Lawrence area would be expected to show strike-slip structures. The concept of separate phases is in agreement with some conclusions from geophysical observations. Kristoffersen & Talwani (1977) and Srivastava (1978) postulated earlier compressional and later strike-slip movement in studies of the relationship between Greenland and the Canadian Arctic Islands. These authors dated the phases earlier than in the present interpretation.

The time of the strike-slip movement cannot be fixed, but it is presumed later than the middle-late Eocene thrusting. The main phase of the Eurekan orogeny lasted from Eocene to early Miocene (Balkwill 1978), presumably the events of central eastern Ellesmere Island are related to this orogeny and thus a tentative maximum time range for the strike-slip movement would be late Eocene to early Miocene. The graben on northern Judge Daly Promontory is the last stage of divergent strike-slip movement in that area and should thus have formed during late Oligocene or early Miocene.

Acknowledgements

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C. D. S. de Vries was responsible for most of the structural field mapping and participated in the initial phases of this re-examination. Owing to de Vries' death in a helicopter accident in July 1979, Mayr is solely responsible for the interpretation and synthesis of the geological data.

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