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The Eurekan Deformation of North and Eastern North Greenland

By Nikos Lyberis[1] and Geoff Manby[2]

THEME 6: Eurekan Tectonics in Canada, North Greenland, Spitsbergen; Fold Belts adjacent to Extensional Ocean Basins

Summary: The Late Proterozoic to Mesozoic sedimentary cover of North and eastern North Greenland, including the Late Cretaceous Kap Washington volcanics, were folded and thrust faulted in Late Cretaceous-Early Tertiary time. In North Greenland, this deformation produced NNW-SSE to N-S shortening of several tens of kilometers and ^{40}Ar-^{39}Ar data suggest that motion on two major thrust zones had ceased by 62 Ma. Rb/Sr isotopic ages of 103 Ma, 93 Ma, 92 Ma and 69 Ma have been obtained from dykes chemically related to the Kap Washington volcanics. In eastern North Greenland, the shortening was limited to 20 % over the 40 km section and NE-SW directed. The lack of evidence for strike-slip movement along the Trolle Land fault system of eastern North Greenland argues against a transpressional origin for the deformation of the intervening blocks. Palynological evidence from undeformed Tertiary rocks indicates that the deformation in this region had been accomplished by mid-Palaeocene time. In North and eastern North Greenland, the resultant deformation patterns and the stress tensors calculated for fault populations are consistently orthogonal to the continental margins. The Late Cretaceous-Early Tertiary deformation in North and eastern North Greenland coincided with the early Eurekan events of the Canadian Arctic islands and the West Spitsbergen Fold Belt of Svalbard. This deformation preceded sea floor spreading in the Arctic Ocean Basin; before the dextral relative motion between the Greenland-Svalbard blocks.

INTRODUCTION

An outline of the Eurekan (Cretaceous to Early Tertiary) structural evolution of North and eastern North Greenland is presented here to illustrate how the boundary conditions have controlled the pattern of deformation. The Early Palaeozoic to Mesozoic rocks of North and eastern North Greenland record the effects of the Devonian-Carboniferous Ellesmerian orogeny and the Late Cretaceous-Early Tertiary Eurekan event (DAWES & SOPER 1973, DEPAOR et. al. 1989). The effects of these tectonic events are also widely exposed in the Canadian Arctic islands and in Svalbard (MANBY & LYBERIS 1992, 1994, 1996, LYBERIS & MANBY 1993a, 1993b, MANBY et. al. 1994). Svalbard was located close to eastern North Green land before the North-Atlantic-Arctic Ocean (TALWANI & ELDHOLM, 1977, SRIVASTAVA & TAPSCOTT, 1986, LYBERIS & Manby 1993a, 1993b). The early stages of the Late Cretaceous-Oligocene Eurekan orogeny in Ellesmere Island, the Eurekan deformation of North Greenland and the West Spitsbergen Fold Belt of Svalbard are attributed to Late Cretaceous-Palaeocene convergence between Greenland and Eurasia (e.g. DEPAOR et al. 1989, LYBERIS & MANBY 1993a).

[1] University of Paris VI, Department of Geotectonics, 4 Place Jussieu, B. 129, 75252 Paris cedex 5. France.
[2] University of Greenwich, School of Earth Sciences, Chatham Maritime, Kent ME4 4AW, England.

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A synthesis of meso-micro fold axial, axial planar cleavage orientations, fault plane and fault plane microstructures gathered from the vicinity of the major faults is given to illustrate the orientations of the principal stress axes linked to the Eurekan deformation of North and eastern North Greenland. The stress tensor has been calculated from the fault populations and slickenside lineations using the method proposed by ETCHECOPAR (1981) which gives the orientations of the maximum, intermediate and minimum principal stress axes. New isotopic age determinations on muscovite micas extracted (laser ablation$^{40}Ar/^{39}Ar$) from mylonites within the Kap Cannon thrust zone and from primary biotites within the post Ellesmerian dykes (Rb/Sr) are reported. The new isotopic age determinations throw new light on the timing of the Eurekan deformation and its relationship to the intrusion of the dense dyke swarm associated with the peralkaline Kap Washington volcanic suite of North Greenland.

GEOLOGICAL SETTING

In Northern Greenland the region of Peary Land is dominated by a thick Proterozoic-Phanerozoic succession of rocks, that represents an extension of the Proterozoic to Mid-Palaeozoic Franklinian Basin of Canada (Fig. 1). In eastern North Greenland and in the extreme north of Peary Land (Lockwood Ø and Kap Kane), the overlying Permo-Carboniferous to Tertiary rocks of the Wandel Sea Basin are un-metamorphosed. These two successor Basins developed on the margins of an older Pre-Cambrian Shield. The Franklinian Basin consists of a Cambro-Ordovician carbonate platform succession to the south and a Flysch trough sequence to the north, which extended southwards over the platform in Silurian time. In Devonian-Carboniferous time, the Proterozoic to Mid-Palaeozoic rocks, of the Franklinian Basin, were affected by the Ellesmere orogeny. This orogeny produced low-grade metamorphism and E-W trending structures in a 600 km long and ca 100 km wide zone (Fig. 1), known as the North Greenland fold belt (SOPER & HIGGINS 1987, 1990). The intensity of the deformation and metamorphism increases northwards and two main phases of coaxial folding have been identified (HIGGINS et. al. 1985). To the north of the Harder Fjord Fault Zone (Fig. 1), the folds are north vergent while to the south structures verge towards the platform (SOPER & HIGGINS 1990). The Early Palaeozoic rocks of the Peary Land region have not been affected by the N-S oriented Caledonian orogeny of East Greenland.

The northwestern edge of Peary Land is characterised by an interbedded sequence of siliciclastics and per-alkaline volcanics known as the Kap Washington Volcanic Suite (SOPER et al. 1982, BROWN et al. 1987). The Kap Washington volcanics consist of a strongly bimodal suite of basaltic lavas, comendites, comenditic ash-flow tuffs and the distinctive rhyolitic lavas (BROWN et al. 1987). The volcanics lie unconformably on a succession of Late Palaeozoic (Carboniferous-Permian) rocks and on strongly cleaved Cambro-Ordovician shales. These rocks are overthrust, from the south, by the Ellesmerian, North Greenland fold belt rocks, along the Kap Cannon thrust zone (BATTEN et al. 1981, SOPER et al. 1982, BROWN et al. 1987). The Kap Washington volcanics are considered, from palynological evidence, to be of Late Cretaceous age (BATTEN et al. 1981). A dense swarm of NNW-SSE trending dolerite dykes cuts the North Greenland fold belt rocks and the Permo-Carboniferous sediments (BROWN & PARSONS 1981). The Kap Washington Volcanics and the dykes have been interpreted to be the result of Late Cretaceous rifting and in the densest part of the dyke swarm a 20 % extension has been estimated (SOPER et al. 1982).

The Lower Palaeozoic Cambro-Ordovician to Silurian rocks of Peary Land are transected to the south by the 5 km wide, E-W trending Harder Fjord Fault Zone (Fig. 1). To the northeast of Frigg Fjord, a sequence of marine siltstones and sandstones of Santonian age lie within the Harder Fjord fault zone (HÅKANSSON et. al. 1981). A number of basaltic dykes and sills, compositionally the same as those cutting the Kap Washington volcanics, are also found within the fault zone and, they are deformed together with the Santonian rocks. The lack of post-Santonian marine sedimentation, during the intrusion of the dykes and the volcanics, is indicative of Late Cretaceous regional uplift.

The NW-SE trending Wandel Sea Basin (Fig. 1) in eastern North Greenland is developed on a basement of variable origins. To the north, the Late Palaeozoic sequences of the Wandel Sea Basin unconformably overlie the E-W Franklinian trough and carbonate platform sequences of the North Greenland fold belt. To the south, however, the basin fill rests on the highly deformed and metamorphosed, N-S trending, Proterozoic-Early Palaeozoic Caledonian orogen of East Greenland. The junction, therefore, of the two differently oriented orogens is masked by the Wandel Sea Basin fill and the East Greenland Caledonian orogen appears to extend onto the offshore continental margin of northeastern Greenland (DAWES 1976).

The basin fill consists of a succession of Carboniferous to Early Tertiary platform rocks. The northwestern part of the basin exhibits a series of 5 NW-SE striking steep faults that constitute the Trolle Land Fault system which has controlled the sedimentation (HÅKANSSON & STEMMERIK 1989). The Wandel Sea Basin has been considered to record a Late Silurian-Tertiary, polyphasal history of 7-9 compressional, extensional, dextral and sinistral strike-slip events (HÅKANSSON & PEDERSEN 1982, HÅKANSSON & STEMMERIK 1989). Flat-lying, continental siliciclastics with coal and plant layers are found in the southern part of the Wandel Sea Basin. These rocks, which have been assigned a Mid-Palaeocene age (BOYD 1990), suggest the deformation of the Wandel Sea Basin fill was accomplished within the Late Cretaceous-Palaeocene interval.

DEFORMATION OF NORTH PEARY LAND

In North Greenland, the Eurekan deformation gave rise to a sequence of north-vergent thrust sheets. The structurally lowest and northernmost thrust sheet (Lockwood Ø; Fig. 2a

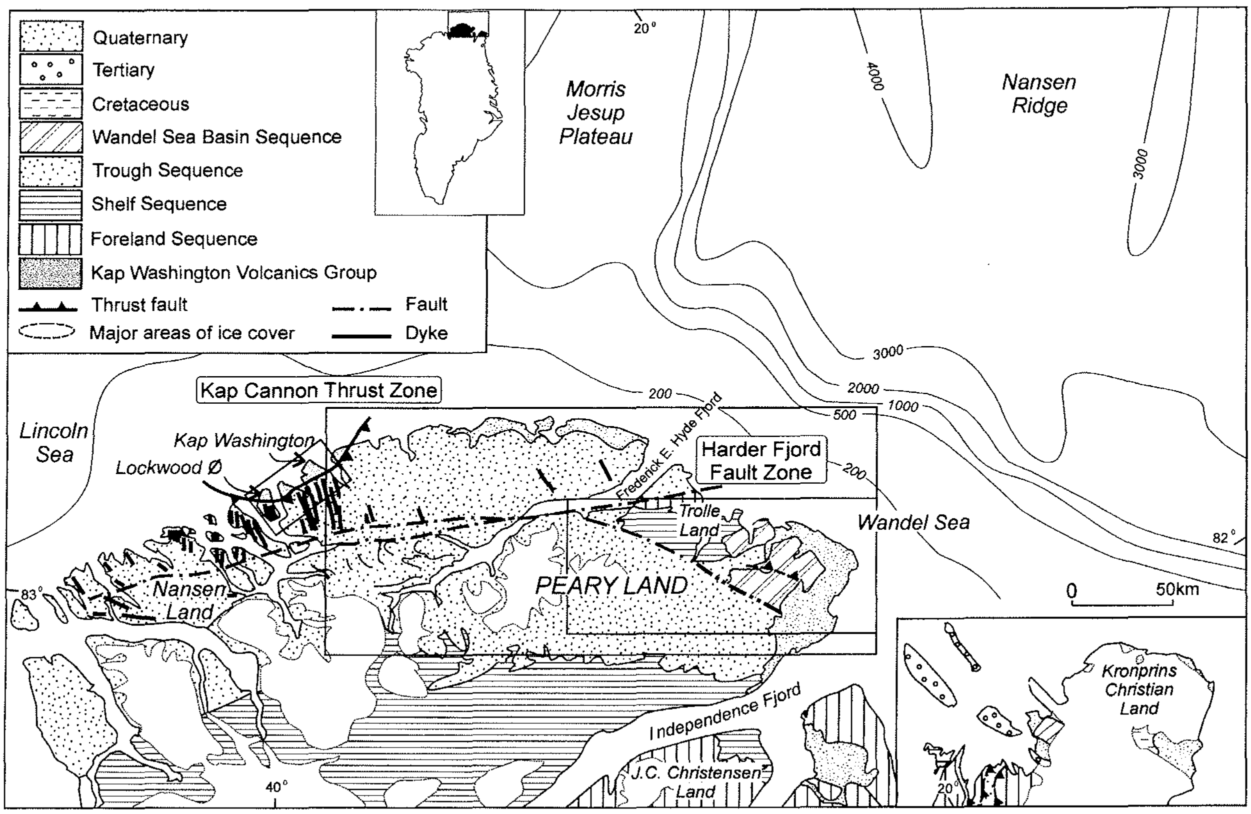

Fig. 1: General map of North and eastern North Greenland showing location of study areas.

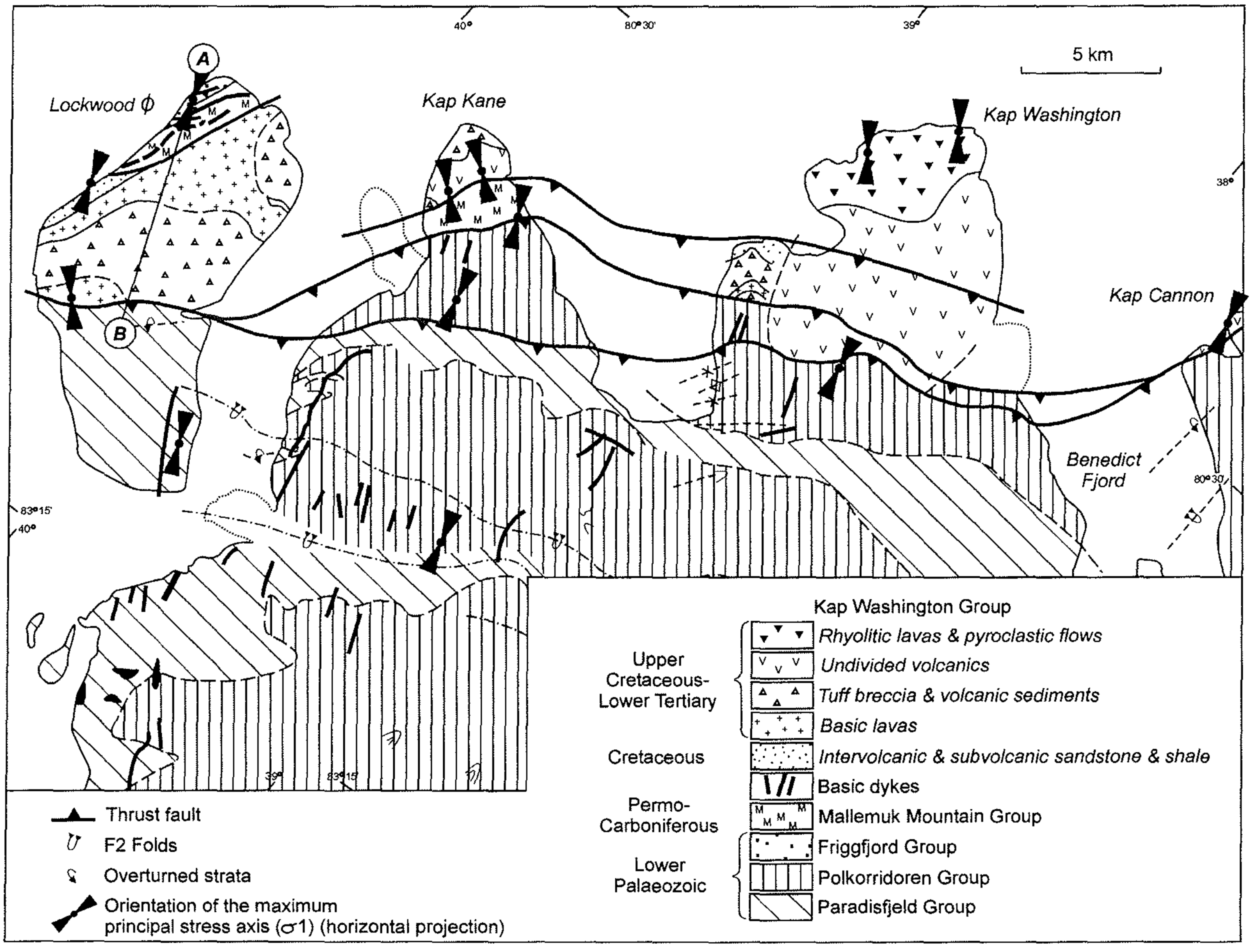

Fig. 2a: Simplified geological map of the Kap Cannon Thrust Zone, North Greenland. Large black arrows indicate horizontal projetion of the principal compressive stress axes.

and 2b) contains a folded and weakly metamorphosed and imbricated basement of Early Palaeozoic rocks unconformably overlain by cleaved Permo-Carboniferous carbonates and siliciclastics. A thick, coarse-grained, alkaline gabbro-

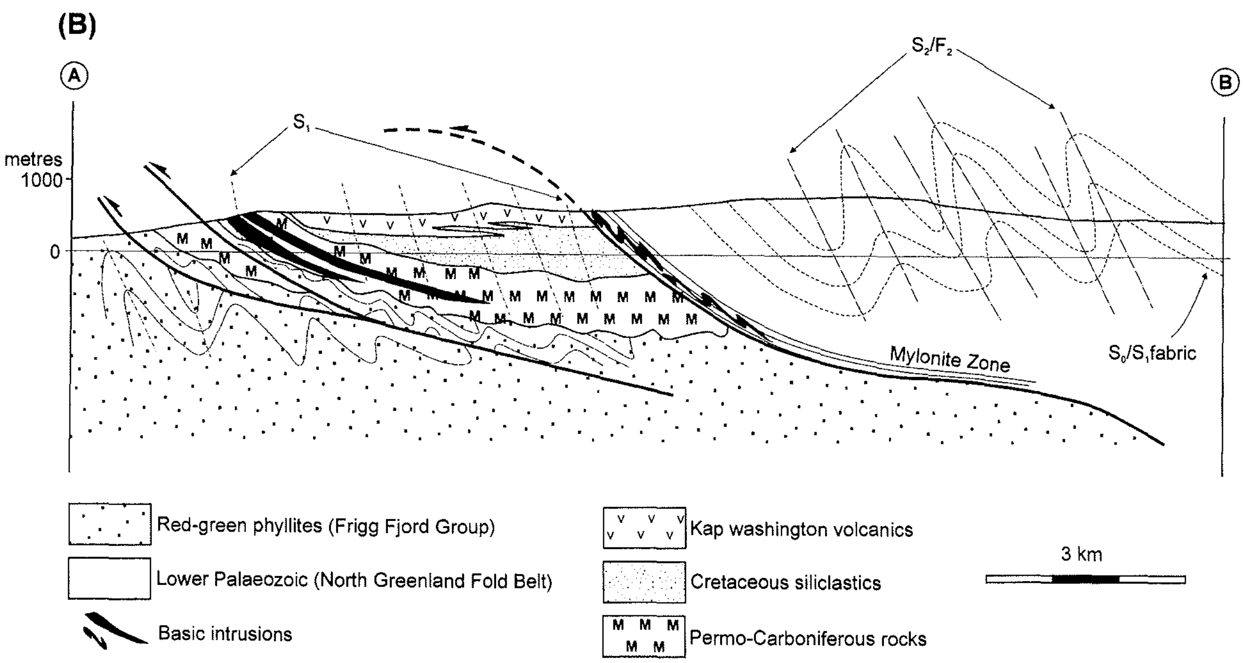

Fig. 2b: Cross-section of the thrust zone on Lockwood Ø.

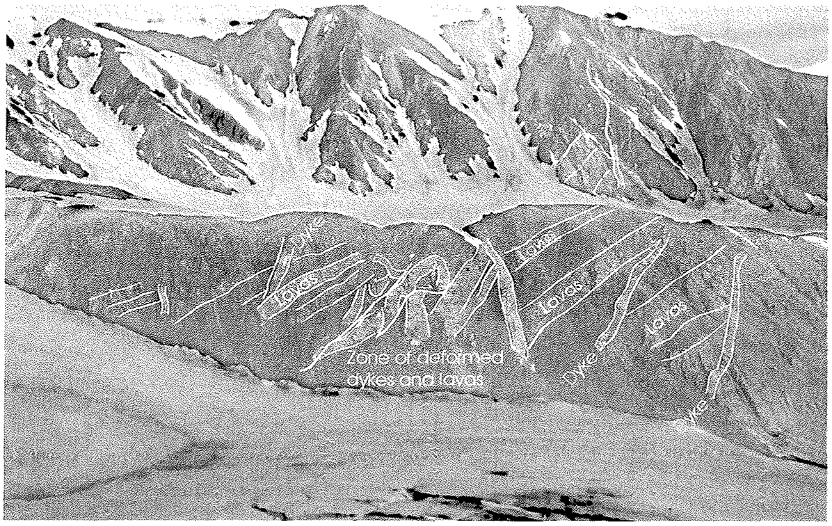

Fig. 3: View looking northwards on eastern Lockwood Ø at the Kap Washington volcanics and crosscutting dykes. Note the apparent deformation of the lavas/dykes.

dolerite sheet that is cut by thin, felsic dykes intrudes these carbonates. The interbedded Cretaceous plant-bearing sediments and Kap Washington volcanics overstep this sequence. The lower part of the volcanic succession, on the western side of Lockwood Ø, is dominated by rhyolites and welded tuffs interlayered with rubbly topped basaltic flows. On the east, welded tuffs and lapilli-tuffs are interbedded with sandstones and ignimbrites. In this sequence is a unit of volcanic ashes and shales that contain plant and treestem remains. These rocks are overlain by a mixed sequence of volcaniclastics,

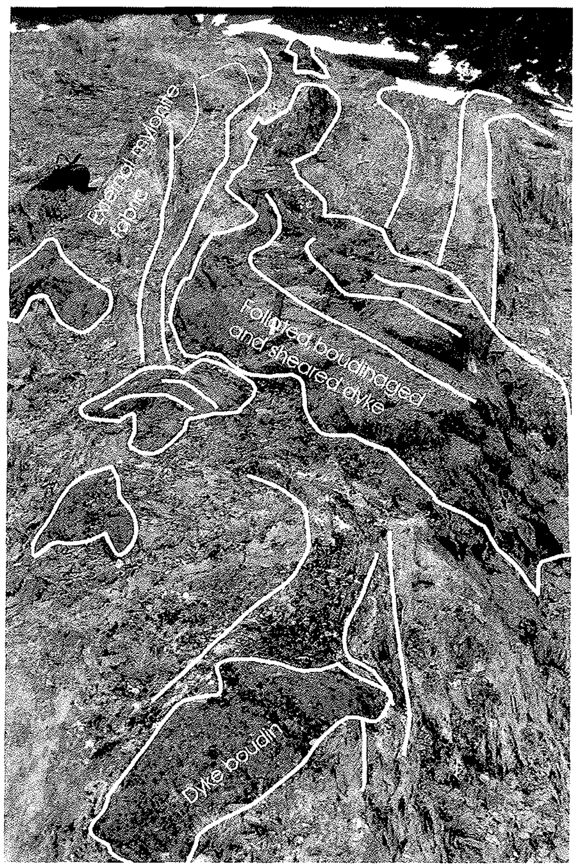

Fig. 4: Boudinaged sheared and retrograded basaltic sheet in the thrust zone mylonites, Lockwood Ø.

breccias with occasional basaltic flows and plant bearing sediments (Brown & Parsons 1981). The entire sequence of volcanics is cut by, N-S trending, rhyolitic to basaltic dykes that are sometimes composite. The deformation of the volcanics is characterised by brittle shearing fabrics and well-developed cleavages parallel to the main (Kap Cannon) thrust-fault zone. The crosscutting relations of the dykes and lavas (etc.) and the character of their deformation are illustrated in Figure 3. In the central part of Lockwood Ø, the volcanics are over thrust by the North Greenland fold belt rocks along an E-W trending mylonite zone that dips steeply to the south (Soper et. al. 1982). In this mylonite zone, tightly folded, strongly boudinaged and cleaved alkaline basaltic dykes are found (Fig. 4). The dykes are commonly retrograded and typically contain greenschist facies assemblages. In some of the thicker basaltic sheets, the original igneous mineral assemblages are preserved in the internal, unfoliated part. To the south of the thrust, the Ellesmerian rocks are affected by a bedding-parallel (S_1) cleavage. The associated F_1 folding can only be recognised at outcrop scale and north vergent F_2 folds of decametric to centimetric scale refold these. The F_2 folds are accompanied by a well-developed south dipping pressure solution cleavage. The E-W trending F_1-F_2 folds are cut by the N-S dykes. The dykes commonly exhibit steep south-dipping shears, occasional duplication by thrusting (Fig. 5) and sheared margins. One of the dykes cutting the main foliation in the Ellesmerian rocks on one of the islands west of Lockwood Ø gave a 92 Ma Rb/Sr biotite age.

In Kap Kane (Fig. 2a), the lowest thrust sheet consists entirely of the Kap Washington volcanics with a clear stratigraphy. The lowest exposed unit consists of massive welded and fragmented tuffs that are overlain by trachytes, well-bedded tuffs and conglomeratic layers. These are succeeded by alternations of comendites and well-bedded volcaniclastics. The uppermost components consist of flinty to spherulitic rhyolites, volcaniclastics and breccias. The highest exposed unit is a rubbly basalt (e.g. Brown & Parsons 1981, Brown pers. com. 1994.). The deformation of the volcanics on Kap Kane is inhomogeneously distributed; the less competent fine-grained volcaniclastics show a steep, south dipping spaced cleavage. The more competent trachytes are often strongly foliated along their margins and small-scale duplex structures may be

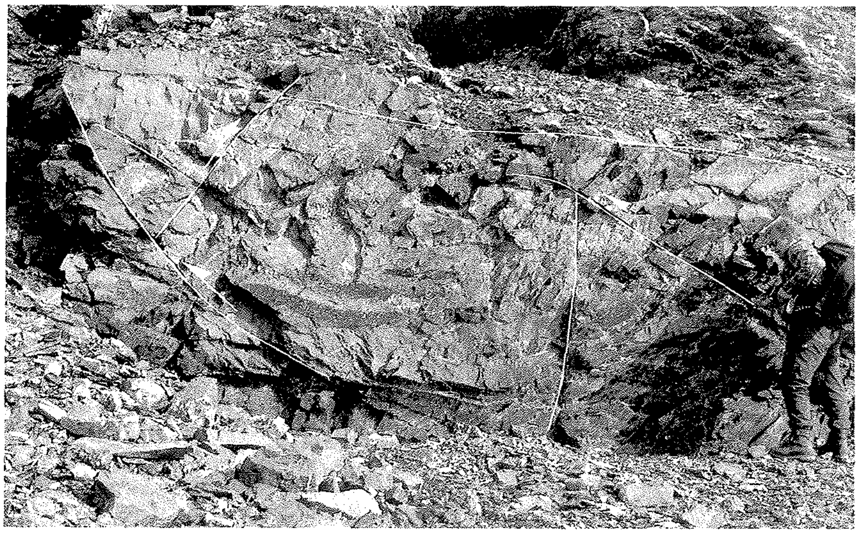

Fig. 5: Brittle faulting in dyke cutting the Ellesmerian rocks, Lockwood Ø. North is to the left.

developed. These volcanics are over thrust by an imbricated Permo-Carboniferous sequence that is in turn over thrust by the mylonitised, north Greenland fold belt rocks (Fig. 2a). The thrust fault at the base of the Permo-Carboniferous rocks corresponds to a high-level brittle structure. The thrust fault at the base of the base Early Palaeozoic, North Greenland fold belt rocks, however, is characterised by a wide zone of mylonitisation that suggests this structure originated at crustal depths below the brittle-ductile transition for quartz-rich rocks. Five km south of the main thrust, a zone of mylonitisation that incorporates a highly deformed basaltic sheet of Kap Washington affinity affects the North Greenland fold belt rocks. This sheet intrudes a marble unit and is accompanied by a several centimeters wide metamorphic aureole in which biotite, amongst other minerals, has grown. The authors have obtained well-defined laser ablation ^{40}Ar-^{39}Ar 69 Ma age (Upper Cretaceous) determinations from the micas in the contact aureole. The biotites from the thermal aureole are randomly oriented and show no evidence of shearing and the 69 Ma age is taken to correspond to the thermal resetting of the ^{40}Ar-^{39}Ar system at the time of the intrusion.

The thickest development of the volcanics is preserved on the Kap Washington peninsula (Brown & Parsons 1981, Soper et. al. 1982). The volcanics are dominated by alternations of rhyolites; trachytes (comendites) welded breccias and tuffs with a variety of lapilli tuffs and volcaniclastics with occasional basaltic lavas. On the western corner of Kap Washington, the volcanics are found interbedded with Late Cretaceous plant-bearing sediments. Toward the northern tip of the peninsula, the volcanics are cut by two south-dipping thrusts and in one locality, a broad angular fold can be observed. In contrast to Kap Kane, imbricated Permo-Carboniferous rocks are not found on the Kap Washington peninsula suggesting that the bounding thrusts are connected at a shallow depth as branch lines (Fig. 2a). A 30-40 m thick sequence of mylonites again incorporating a basaltic sheet (Fig. 6) is exposed on the eastern side of Kap Washington in the overthrust North Greenland fold belt rocks. The mylonites affect greenschist facies, chloritoid-quartz-muscovite phyllites with well-developed S-C fabrics that indicate a top-to-the-north shear sense consistent with the motion on the main thrust. Large-scale, north vergent, F2 folds are widely developed in the over thrust North Greenland fold belt rocks to the south (cf. Soper & Higgins 1987).

Fig. 6: Dolerite sheet in mylonites from eastern Kap Washington. Note near isoclinal folding and boudinage.

In Kap Cannon, only a limited exposure of the volcanics is found but the over-thrust zone can be directly observed. The volcanics are cut by dense arrays of brittle-shear zones and are affected by extensive hydrothermal alteration. The Ellesmerian rocks that are thrust over the volcanics are extensively mylonitised and display a range of brittle to ductile structures. The thickness of the mylonites varies from a few to several tens of meters. In the mylonite zone, basic igneous bodies are again found and ductile shear zones in which, the original igneous mineral assemblage is replaced by an epidote-amphibolite association traverse one of these sheets. The involvement of the basaltic dykes/sills in this and other shear zones suggests that the motion of the thrust sheets post-dates the dyke intrusion (see SOPER et al. 1982). The 62 Ma (Early Palaeocene) laser ablation ^{40}Ar-^{39}Ar ages obtained for micas from the mylonite zones on Kap Cannon and Kap Washington suggest that motion on the thrust faults must have ceased in Mid-Palaeocene time.

Stress tensor calculations using the method described by ETCHECOPAR et al. (1981) for fault populations in all of the major fault zones, in the Lockwood Ø - Kap Cannon area, show a consistent N-S to NNW-SSE pure compressional stress pattern, orthogonal to the main thrust faults (Fig. 2a) and near-parallel to the dyke orientation.

In the E-W trending, Harder Fjord Fault Zone, Palaeozoic and Cretaceous rocks are cut by north-vergent thrust faults produced by a N-S oriented shortening (Fig. 7). The basic sills that intrude the Cretaceous sediments are hydrothermally altered and in some cases, the margins are strongly sheared. These sills are cut by steep N-S dykes which may be composite having porphyritic basalt margins intruded by aphyric varieties and they have sheared margins. The Early Palaeozoic rocks immediately to the north of the fault zone are cut by compositionally similar basaltic sheets that appear to be folded (Frigg Fjord area, see Fig. 7). The dykes truncate the F2 folds but the folds in the basalts are coaxial with the F2 structures suggesting that while they post-date the latter, post intrusion shortening, has folded the dykes and tightened the F2 folds. At the western end of the Harder Fjord fault zone in Peary Land two large N-S dykes cut the Early Palaeozoic rocks in the footwall to the fault. These dykes are extensively altered with strongly foliated margins and small-scale, south

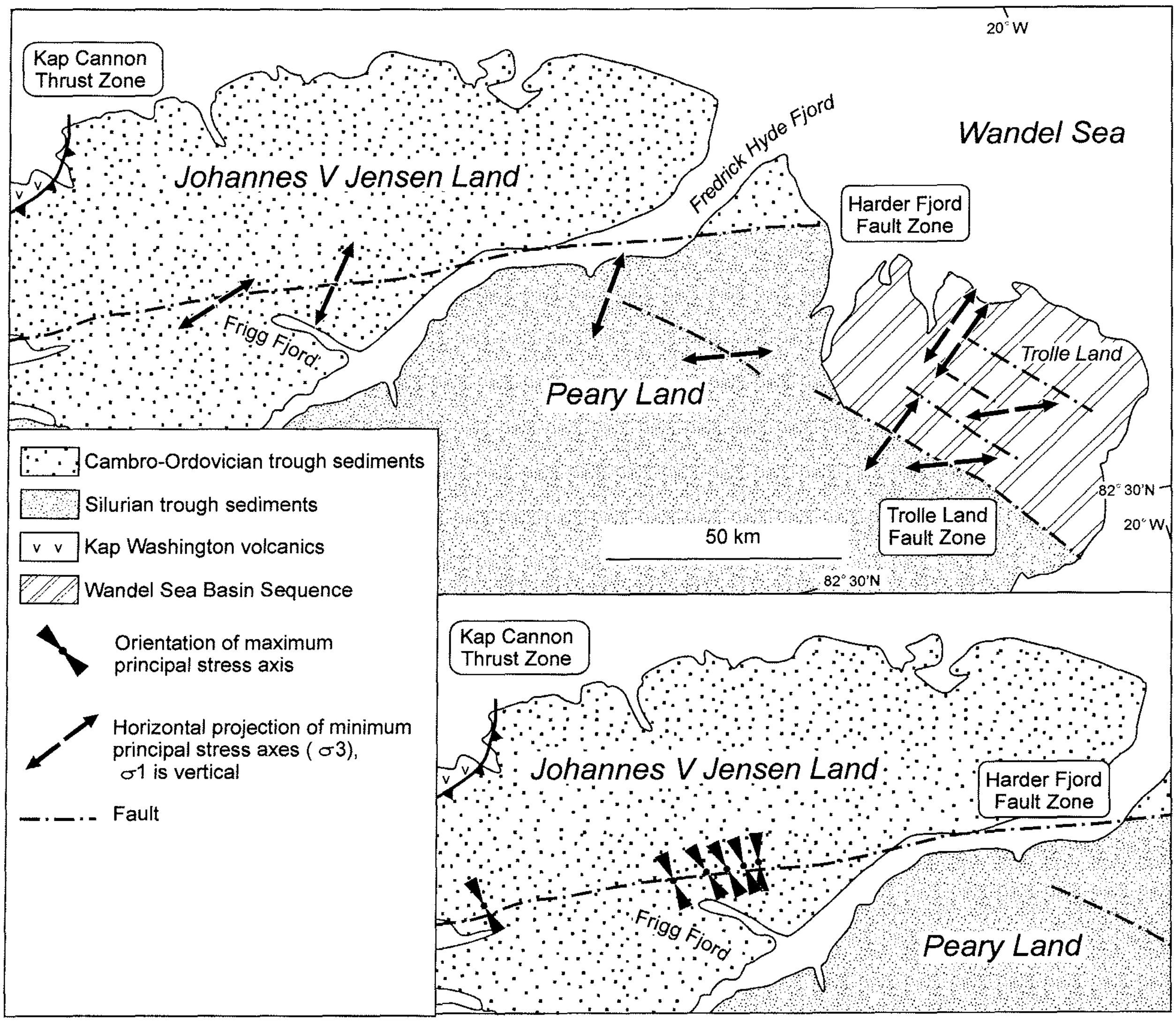

Fig. 7: Map of northern Peary Land showing orientation of the horizontal projection of the principal compressive stress axes along the Harder Fjord Fault Zone.

Fig. 8: Strongly foliated margin to large gabbroic sheet north of the Harder Fjord Fault Zone (west). Note the imbrication of the foliation and duplex-like structure produced. North is to the left.

dipping duplex structures (Fig. 8). The dykes are also dislocated by steep, south dipping thrust faults. The calculated stress tensors for the Harder Fjord Fault Zone give a dominantly, NNW-SSE oriented compression that post-dates the dykes. Fault plane microstructures also indicate that this compression was succeeded by a later extension that was oblique to the main fault zone NE-SW to ENE-WSW (Fig. 7). Chemically the dykes are identical to those linked to the Kap Washington Volcanic Suite and thin felsic centimeter-scale dykes, similar to those found on Lockwood Ø, cut the larger basaltic bodies. Biotite separated from the large dykes, rocks for Rb/Sr dating, have yielded 103 Ma and 93 Ma ages that are taken to record the timing of intrusion.

On a regional scale, Cambrian to Silurian rocks of the Franklinian Basin are affected by early south vergent F_1 folds that are overprinted by north-vergent F_2 folds with steep south-dipping axial planar fabrics. The intensity of the F_2 folds increases northward, towards the Kap Cannon thrust zone (SOPER & HIGGINS 1987). To the west, however, in Nansen Land and the adjacent islands, the F1 folds are upright and the F2 folds are weakly developed (FRIDERICHSEN & BENGAARD 1985, SOPER & HIGGINS 1987). Fifteen to twenty kilometers south of the Harder Fjord Fault Zone, the F_2 folds die out. The F_1 and F_2 folds are interpreted to belong to the Ellesmerian orogen (e.g. SOPER & HIGGINS 1987). The F_2 folds axial planar fabrics, however, are consistently perpendicular to the transport direction of the Kap Cannon thrust zone. The overall structure indicates that the Cambro-Ordovician rocks have been pushed over the volcanics, ascending along a thrust from the brittle-ductile transition crustal levels to the surface. The presence of thick mylonites indicates a significant amount of shortening and crustal ascent and the horizontal strain would be expected to be accompanied by folding in the hanging wall. The F_2 folds have the vergence and the direction of those expected to be associated with the thrusting and mylonite fabrics. In addition, many of the larger, N-S dykes are cut by steep, south-dipping shears and they are occasionally duplicated by thrusting. These relationships together with the absence of Carboniferous syn- or post-orogenic sediments suggest that the north vergent F_2 folds are, at least partially, contemporaneous to the Kap Cannon thrust.

DEFORMATION OF THE WANDEL SEA BASIN

The Trolle Land area

The Wandel Sea basin (Fig. 9a) overlies the junction between the N-S trending Caledonian orogen to the south and the E-W trending Ellesmere orogen to the north. The basin fill consists of a Late Palaeozoic to Mesozoic shallow marine sedimentary sequence (PEEL 1985). In Trolle Land, the basin is transected by a series of five NW-SE trending faults, which parallel the northeast Greenland margin and that are spaced at regular ca 10 km intervals (Fig. 9a). These faults are considered to have controlled the sedimentation patterns of the basin (HÅKANSSON & STEMMERIK 1989). The westernmost of the faults, the 100-km long Trolle Land fault, is the most extensive but the other faults within this system do not exceed 10-20 km in length. The Trolle Land fault (Fig. 9a) does not extend beyond Fredrick Hyde Fjord and appears to be truncated by the Harder Fjord Fault zone. Transverse, NE-SW faults intersect the main faults and define a succession of fault-bounded blocks.

In southwestern Trolle Land Carboniferous clastics and carbonates lie unconformably on the Early Palaeozoic. The Trolle Land fault runs close to the boundary between the two rock groups (Fig. 9a) resulting in some, limited down-to-the-east normal faulting of the Carboniferous and Upper Jurassic-Cretaceous rocks. This fault appears as a notable photo-lineament but it does not correspond to a basin margin fault and only limited post-Silurian movement on the fault can be demonstrated. The Trolle Land faults may have originated as normal faults accompanying the sedimentation that were reworked as contractional faults, in Late Cretaceous time. The overall Eurekan deformation pattern of the Wandel Sea basin fill consists of inhomogeneously distributed NW-SE trending folds and thrust faults that parallel the Trolle Land fault system (Fig. 9a).

The folding is most intense close to the NW-SE faults where they are often disrupted by the faulting. The concentration of folds along the fault traces and presence of thrust faults in the hinge regions may indicate that the folds were "forced" by the faulting. This is particularly evident along the fault that separates the two eastern Permo-Carboniferous blocks (Figs. 9a, 9b). Folds trending parallel to the NE-SW fault in the valley northwest of the Cretaceous block and folds with N-S to NNE-SSW oriented axial traces, indicating an E-W to ESE-WSW oriented compression, are exposed in stream sections on the eastern strandflats (Fig. 9a). To the northeast edge of this block, WNW-ESE oriented folds have been found, resulting from NNE-SSW oriented compression (Fig. 9a). This pattern of folding, rotated in the vicinity of the block boundaries, appears to have been controlled by the local fault distribution rather than by the regional compressional stress pattern which is orthogonal to the Wandel Sea Basin. In the intervening blocks the folds are broader, more open and, in some cases, periclinal. The cumulative shortening, perpendicular to the margin, recorded by these folds and thrust faults is estimated, from simple line balancing, to be 20 % for the 40-km wide Wandel Sea Basin.

The stress tensors calculated for post-Cretaceous fault populations related to the main NW-SE trending compressional

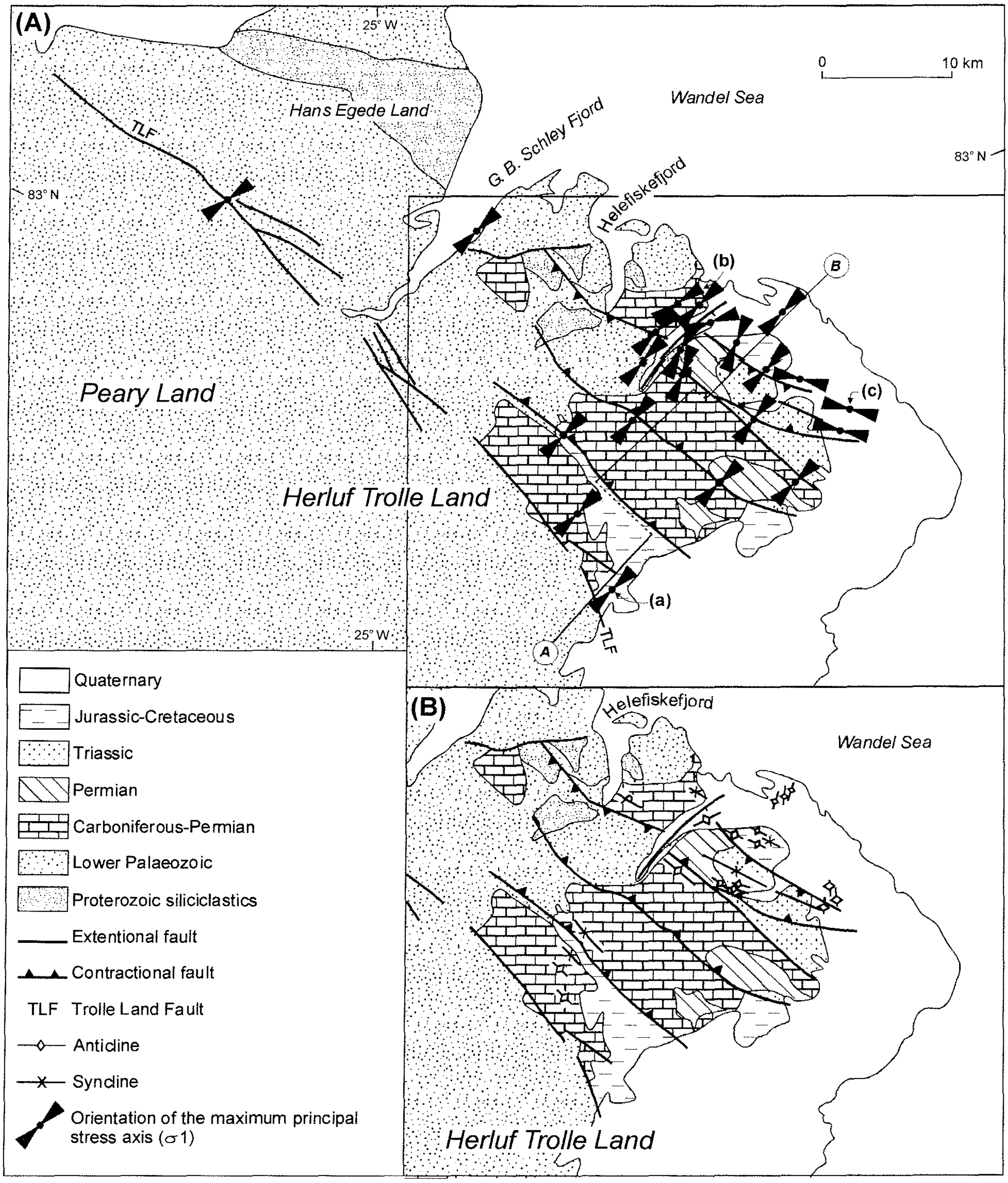

Fig. 9a: Geological map of the Trolle Land segment of the Wandel Sea Basin, eastern North Greenland, includes orientations of the horizontal projection of the principal compressive stress axes.

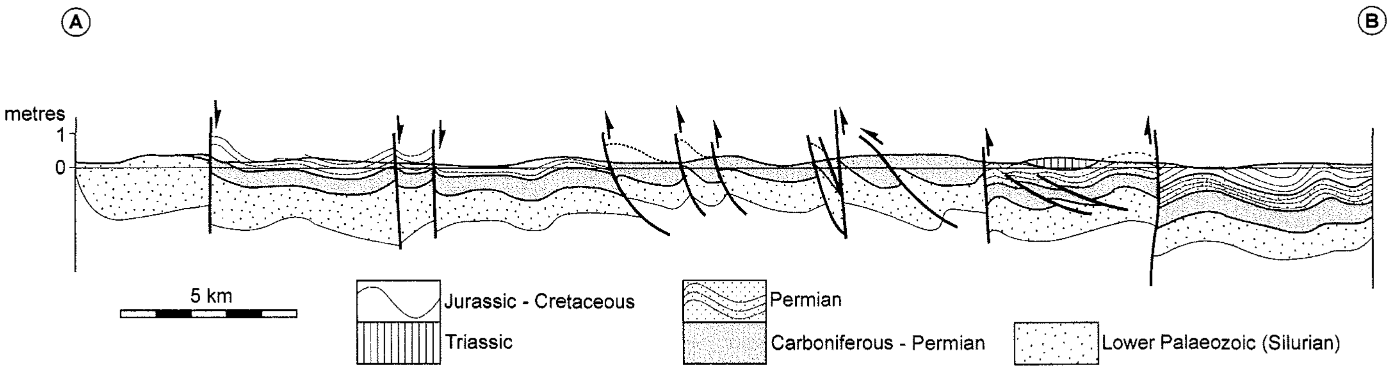

Fig. 9b: Simplified cross-section of Trolle Land showing main faults and fold relations.

structures of Trolle Land consist of an average 035-060° oriented pure compression (Fig. 9a). Towards the corners of the blocks, the direction of compression is rotated, N-S or E-W, consistently orthogonal to the block boundaries (Fig 9a). The stress tensors calculated from the normal faults give extensional events with NW-SE oriented extension and/or NE-SW extension orthogonal to the Wandel Sea margin (Fig. 9a). This extensional event post-dates the folding and can be attributed to the Eocene dextral motion of the Greenland/Svalbard blocks and to the post-Eocene extension of the Wandel Sea margin during the opening of the North Atlantic Ocean.

The lack of evidence for strike-slip movements along any of the Wandel Sea basin faults shows that a pull-apart and transtensional origin for the Late Palaeozoic-Mesozoic basins and a transpressional mechanism for the folding of the sediments are unlikely. The mobilistic model, involving several strike-slip tectonic motions on any of the map scale faults (e.g. Fig. 9a) for the post-Late Palaeozoic evolution of the basin is not supported by our structural field observations despite an extensive search. The non-linear geometry and lack of relay patterns of these faults is inconsistent with a strike-slip model. In addition, there is no evidence to suggest that this fault system extends southwards to Kronprins Christian Land, as has been proposed (HÅKANSSON & STEMMERIK 1989).

Kronprins Christian Land

The Station Nord and Kilen areas of Kronprins Christian Land (Fig. 10a) contain Carboniferous to Cretaceous sequences overlying the metamorphic rocks of the East Greenland Caledonian orogen. The predominantly shallow-marine Carboniferous to Cretaceous sedimentary succession is punctuated by several breaks which have been interpreted as signifying changes in a general pattern of strike-slip tectonic events (HÅKANSSON & STEMMERIK 1989).

The 25 km long, 5-10 km wide Kilen area is dominated by a 3 km thick succession of mainly Jurassic to Cretaceous marine clastics, although in one small locality, thrust faulted and strongly sheared Carboniferous gypsiferous rocks with limestones are found (HÅKANSSON et al. 1993). The sheared gypsum layers exhibit isoclinal, intrafolial, small-scale folds that are refolded about upright WNW-ESE axes. The apparent polyphase deformation of the gypsum layers clearly reflects the shearing and highly incompetent nature of these rocks rather than a sequence of tectonic events. The gypsum represents a decollément zone, which has permitted the folding of the overlying rocks (Fig. 10b). Upright folds affect the Late Jurassic to Late Cretaceous rocks with WNW-ESE to E-W axes that largely plunge shallowly to the west in the southeastern part of the Kilen inlier (Fig. 10a). In the northwest, however, folds plunge predominantly to the ESE although some westerly plunges are found. The folds are associated with arrays of oblique reverse-dextral NW-SE and NE-SW oblique reverse-sinistral faults that have accommodated the continued shortening of these rocks. Small-scale accommodation thrust faults accompany many of the folds. In stream sections in the southeast and northwest parts of the inlier of these structures are cut by NW-SE striking steep, down-to-the-northeast, normal faults. The stress tensor calculations from the fault planes associated to the folds show a NE-SW oriented pure compression, orthogonal to the Northeastern Greenland margin, that is oblique to the fold axes (Fig. 10a). In two localities has a NNE-SSW oriented compression, orthogonal to the fold axes, been found.

The significance of the fold orientations in the Kilen area, that are not found elsewhere in northeastern Greenland, and their relationship with the flat-lying Cretaceous rocks on the eastern shore of Kronprins Christian Land is unclear (Fig. 10a). The localised occurrence of these folds could suggest that they might have been produced by a mechanism other than that responsible for the regional deformation of the Wandel Sea Basin fill. The Carboniferous gypsum layers could permit, for example, the rotation of fold axes in the Jurassic-Cretaceous cover noted above possibly by a gravity sliding mechanism following the Late Cretaceous uplift. It is notable that the fold axial traces in the Kilen area coincide with the northeast extension of the main East Greenland Caledonian orogen trends (e.g. BENGAARD & HENRIKSEN 1986). The Caledonian crustal discontinuities may thus have imposed the boundary conditions on the Late Cretaceous deformation of the Wandel Sea basin fill in this region.

SUMMARY AND DISCUSSION

At least 15-20 km of shortening has been produced by the Kap Cannon thrust zone in North Greenland (SOPER & HIGGINS 1987). If, however, the shortening on the south dipping shear zones within the North Greenland Fold Belt rocks is taken into account, then more than 30 km is suggested. The shearing and retrogression of the sill/dykes, their partial involvement in the F_2 folding and the northward vergence of the F_2 folds suggests that all of this deformation is related to the Eurekan thrust motion. The north vergent F_2 folds are confined, to the south and to the west, within the area of the Eurekan deformation and increases in intensity northwards further suggesting that these structures be, in part, of a similar age. It is suggested therefore that the Eurekan event in North Greenland has produced a shortening of several tens of kilometers, which also affected the Harder Fjord Fault Zone. This shortening was most likely responsible for the post-Santonian uplift of North Greenland. The isotopic ages obtained from the mylonites suggest that the movement along the Kap Cannon thrust must have ceased by mid-Palaeocene time.

Most of the dykes found throughout North Greenland parallel the Eurekan shortening direction (Fig 1). The deformation of the intrusive and the host rocks indicates that the dykes were intruded into a NNW-SSE to N-S trending array of fractures. This orientation coincides with the direction of shortening and the fractures are in the position of tension gash-like structures (ENE-WSW extension), which could have permitted the intrusion of the dykes. A prolonged period of dyke intrusion prior to and possibly coinciding with the Eurekan deformation is suggested from the Rb/Sr 103 Ma, 93 Ma and 69 Ma ^{40}Ar-^{39}Ar ages reported above. We cannot, therefore, exclude the possibility that some of the dykes were intruded contemporaneously with the North Greenland phase of Eurekan compression.

The main structures on the margin of the Wandel Sea basin affecting the Late Palaeozoic-Mesozoic rocks consist of an array of NW-SE trending faults that have recorded some extensional movement in Late Palaeozoic time. The overall distribution of the folding and thrusting shows a direction of shortening, perpendicular to the offshore boundaries, probably inherited, of the northeastern Greenland margin with variations along the corners of the faulted blocks. NW-SE trending strike-slip faults and associated structures have not been found nor is there any evidence for strike-slip motion on the Trolle Land faults. The NW-SE trending folds and thrust faults within the Late Palaeozoic-Mesozoic sedimentary cover and

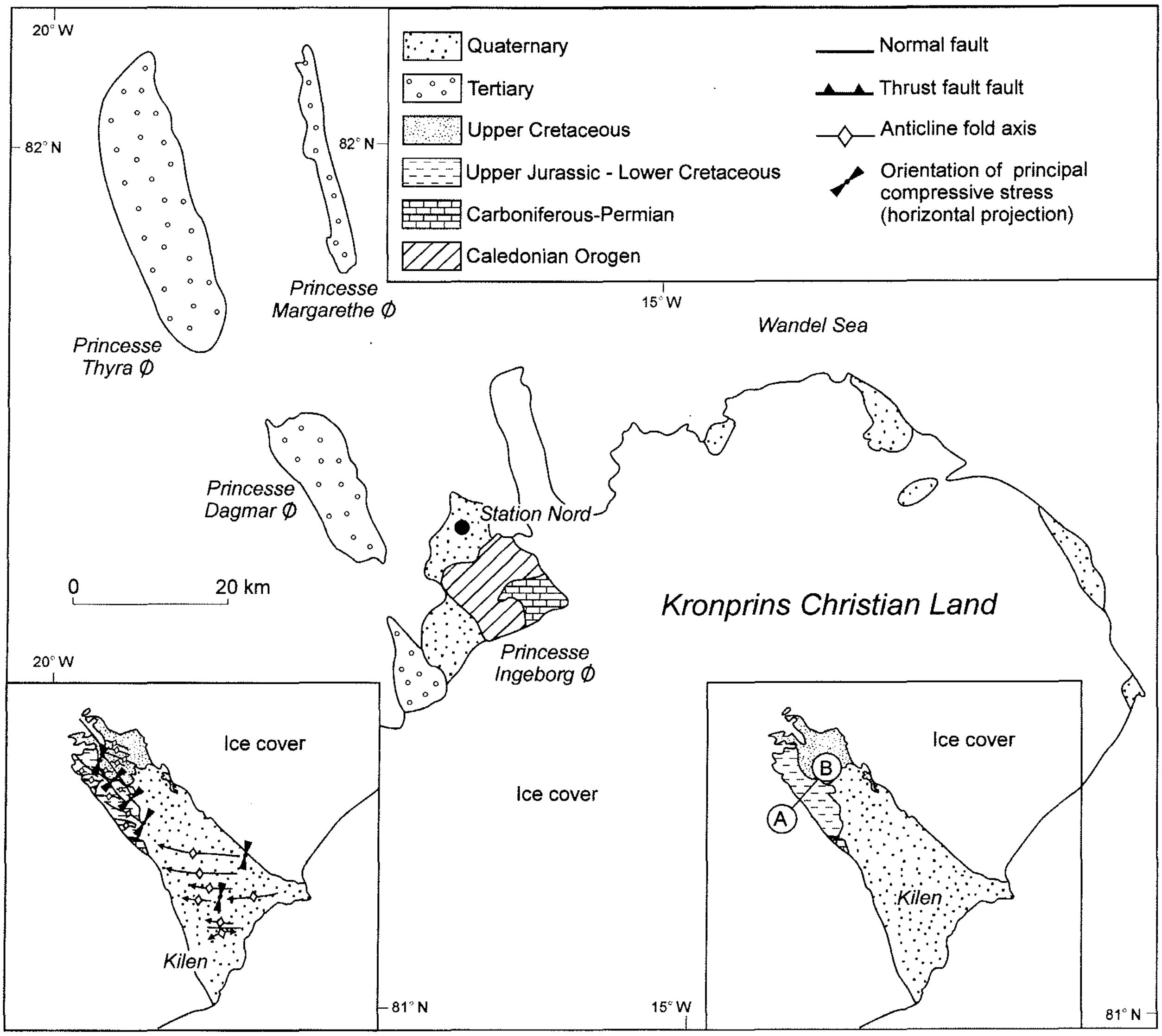

Fig. 10a: Simplified geological map of Kronprins Christian Land showing orientations of the horizontal projection of the principal compressive stress axes and fold axes (for Kilen only).

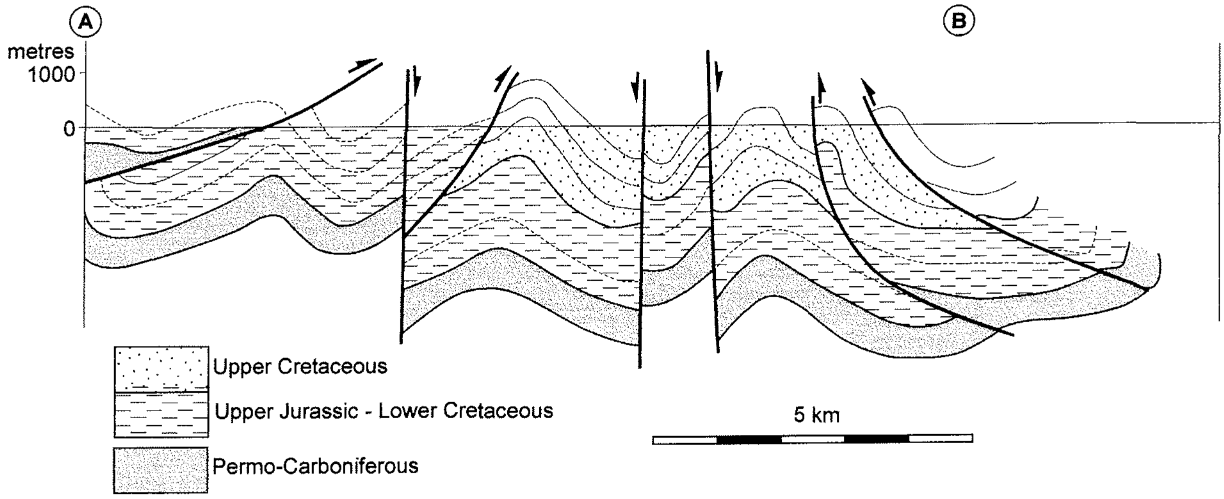

Fig. 10b: Cross-section of the Kilen Inlier showing styles of folding and thrust faulting.

the undeformed Late Palaeocene rocks of the Wandel Sea basin margin suggest that these faults have been reworked by compression in the Late Cretaceous to Palaeocene interval because the Palaeocene strata of the Wandel Sea basin (BOYD 1990) are undeformed (e.g. HÅKANSSON & PEDERSEN 1982). The lack of strike-slip movements along any of the Wandel Sea basin margin faults shows that a transpressional origin for the folding of the intervening blocks is unlikely.

In North and eastern North Greenland, the contraction is consistently orthogonal to the continental margin suggesting that the geometry of the inherited continental margin boundaries have conditioned the orientation of the structures. Numerical modelling (ENGLAND & JACKSON 1989) suggests that the width of a deformed zone in a strike slip system should be narrow with respect to its length. In contrast, a compressional movement orthogonal to the block boundary would be expected to produce a wide zone of deformation, as is the case in North and eastern North Greenland. The broad zone of folding and thrusting in North and eastern North Greenland is, therefore, more likely to be the result of convergent than strike-slip motion.

A strike-slip origin for the Wandel Sea Basin margin deformation pattern might be taken to imply a partitioning between the observed compressional structures and a hypothetical (offshore?) major strike-slip fault. The proposed dextral strike-slip movement should, however, have been of Late Palaeocene-Eocene age but the compressional deformation of the Wandel Sea Basin margin was concluded by this time.

The kinematic reconstruction's suggest that Svalbard was adjacent to northeastern Greenland, before the Late Palaeocene sea-floor spreading began in the North Atlantic - Arctic Ocean basins (TALWANI & ELDHOLM 1977, SRIVASTAVA & TAPSCOTT 1986, LYBERIS & MANBY 1993a, 1993b, MANBY & LYBERIS 2000, 2001). The weak deformation of the Wandel Sea Basin fill makes difficult the link between this section of eastern North Greenland and the strongly deformed West Spitsbergen Fold Belt. In the West Spitsbergen Fold Belt and the Wandel Sea Basin, the Eurekan deformation appears to be the result of orthogonal convergence. It should be noted, however, that the transitional structures between North Greenland and Svalbard that may have existed would be located on the subsequently thinned and submerged continental margins of the two blocks. By combining ^{40}Ar-^{39}Ar age spectra with apatite fission track-length models from the Palaeogene basins of western and Central Svalbard, KLEINSPEHN (1998) suggests that Late Cretaceous (80-85 Ma) uplift took sediment source terrains through the isotherms for Ar closure. The uplift continued reaching apatite partial annealing temperatures in latest Cretaceous time (~70 Ma). This uplift of sediment sources in northern Svalbard and Greenland continued to ~55 Ma when opening of the Eurasian Basin began. These data lend added support to that presented here suggesting that the Eurekan deformation of western Svalbard and Northern Greenland took place in Late Cretaceous-Palaeocene time, before the dextral relative motion between the blocks.

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