Regional geology and Caledonian structure, Dronning Louise Land, North-East Greenland

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A major N–S trending thrust zone exposed in Dronning Louise Land marks the western limit of intense Caledonian deformation in East Greenland. Foreland basement to the west of the thrust zone is dominated by orthogneisses which are overlain unconformably by two sedimentary sequences (Trekant Series and Zebra Series). The Zebra Series contains *Skolithos* trace fossils which indicate that it is no older than latest Proterozoic. Metamorphosed correlatives of the Trekant Series and the Zebra Series can be recognised as tectonic slices within the thrust zone, and also as infolds within the allochthonous gneisses which overlie the thrust zone. The dominant Caledonian structures are thought to have resulted from sinistral transpression, which involved partitioning of regional deformation between sinistral strike-slip movements in the east of the region, and generally NW-directed oblique thrusting and folding further to the west.

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Dronning Louise Land is a region of mountainous nunataks extending from latitude 75°50' to 77°25'N in North-East Greenland (Fig. 1). Previous understanding of the geology of the region largely derives from the pioneering work of Peacock (1956, 1958) who established the existence of an east-dipping thrust zone which was interpreted to subdivide Dronning Louise Land into a western group of orthogneisses and an eastern group of paraschists and paragneisses. Haller (1956, 1970, 1971) identified, on the basis of aerial photographic study and limited ground control, a series of N–S trending thrusts and two major sets of folds. The earliest of these fold sets was assigned to a mid- to upper Proterozoic 'Carolinidian' orogeny, the later to the Caledonian orogeny.

The main results of GGU mapping and associated isotopic investigations in Dronning Louise Land have been published elsewhere (Friderichsen *et al.*, 1990; Holdsworth & Strachan, 1991; Strachan *et al.*, 1992; Tucker *et al.*, 1993). This contribution therefore summarises briefly the regional geology of Dronning Louise Land, and highlights the most important conclusions arising from the recent work. The geology is described with reference to three main tectonic units which are referred to informally as the Western Foreland, the Imbricate Zone and the Eastern Hinterland (Fig. 1).

Western Foreland

The Western Foreland comprises a largely orthogneissic basement which is overlain unconformably by the sedimentary rocks of the Trekant Series and Zebra Series. Both the basement and the Trekant Series are intruded by dolerites (Peacock, 1956, 1958).

The basement rocks of the foreland are a series of variably deformed, granitic to granodioritic orthogneisses, which contain amphibolite facies mineral assemblages. Three samples of orthogneiss have yielded Sm-Nd model ages of 2.51, 2.35 and 2.29 Ga (Kalsbeek *et al.*, 1993). Attempts to date directly protolith crystallisation and later metamorphism were unsuccessful (Tucker *et al.*, 1993). Indirect indications of the age of the foreland basement are provided by mineral ages obtained from detrital minerals in the Zebra Series. U-Pb dates for detrital zircon grains separated from a Zebra Series quartz arenite sampled at Helgoland (Fig. 1) define an age range of detritus between 3001 Ma and 1700 Ma (Tucker *et al.*, 1993). Detrital muscovites record $^{40}Ar/^{39}Ar$ mineral cooling ages of *c.* 1700–1600 Ma (Tucker *et al.*, 1993). The data suggest that the foreland basement forms part of a lower Proterozoic mobile belt comprising, in part, reworked Archaean rocks.

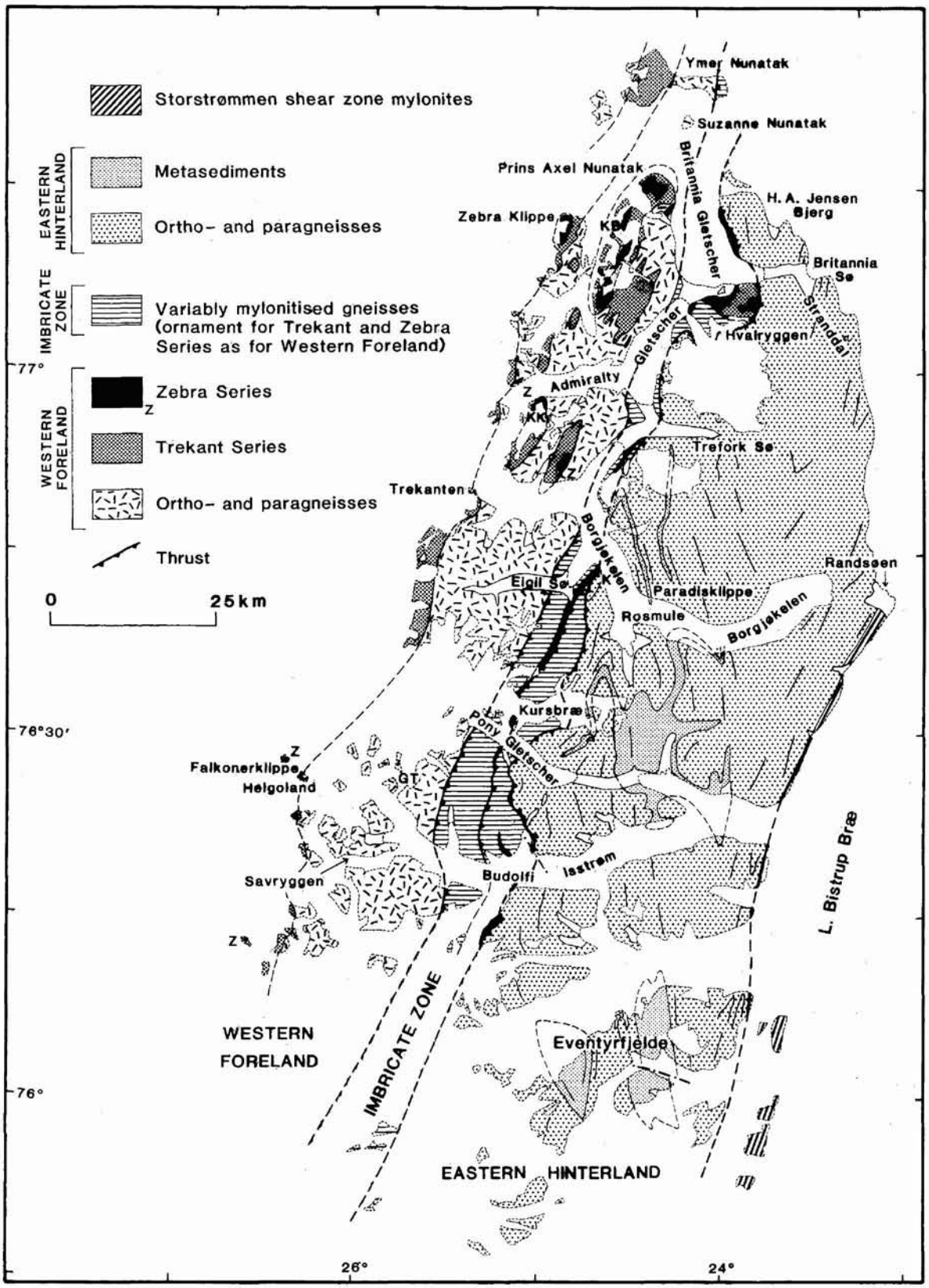

Fig. 1. Geological map of Dronning Louise Land, showing the main tectonostratigraphic units identified, and localities mentioned in the text (modified from Strachan *et al.*, 1992). KB, Krebs Berg; K, Kilen; KK, Kelvin Klippe.

The basement gneisses are overlain unconformably by the sedimentary rocks of the Trekant Series (Fig. 2) (Peacock, 1956). This is a sequence of sandstones, siltstones and conglomerates up to 510 m thick. It has been correlated with the Independence Fjord Group of North Greenland (Peacock, 1956; Clemmensen & Jepsen, 1992). The Trekant Series is progressively affected by Caledonian metamorphism as it is traced eastwards. Adjacent to the Imbricate Zone it is represented by grey-green psammites with local beds of phyllite.

The basement and the Trekant Series are intruded by dolerites (Fig. 2; Peacock, 1956, 1958). They vary in thickness from a few metres to over 100 m. The dolerites have been correlated with the Midsommersø Dolerites in the Independence Fjord Group in North Greenland (Haller, 1971; Kalsbeek & Jepsen, 1983) which have yielded Rb-Sr whole rock isochron ages of *c.* 1250 Ma (Jepsen & Kalsbeek, 1979).

The basement and the Trekant Series are overlain unconformably by the sedimentary rocks of the Zebra Series (Fig. 2; Peacock, 1956, 1958). At Zebra Klippe, Kelvin Klippe and south-west of Krebs Berg (Fig. 1) the Zebra Series also apparently overlies dolerites unconformably. The Zebra Series is a thin sequence of quartzites, mudstones, magnetite- hematite sandstones and limestones. Quartzites of the Zebra Series south-west of Krebs Berg (Fig. 1) contain *Skolithos* trace fossils which show that the Zebra Series is no older than latest Proterozoic. Correlation with the lithologically similar Upper Proterozoic – Early Cambrian Hagen Fjord Group in Kronprins Christian Land (Hurst *et al.*, 1985; Clemmensen & Jepsen, 1992) seems likely.

Imbricate Zone

The Imbricate Zone is characterised by numerous east-dipping thrust sheets which vary from a few metres to several hundred metres in thickness (Fig. 1). Lithologies present include variably deformed basement gneisses, metasedimentary cover rocks and metadolerites. The cover rocks are mostly right-way-up sequences of low to medium metamorphic grade which always stratigraphically overlie basement units within individual thrust sheets. Two distinct cover sequences are recognised and correlated, respectively, with the Trekant and the Zebra Series (Fig. 2).

The Trekant Series is correlated with sequences of pale grey-green psammites which are intruded by metadolerites. These cover rocks closely resemble the more deformed and metamorphosed parts of the Trekant Series in the Western Foreland. The Zebra Series is correlated with sequences of psammites, quartzites, siltstones, magnetite-hematite sandstones and grey dolomitic limestones (Fig. 2); metadolerites are not found in these sequences. Lithological correlation with the Zebra Series is supported by the discovery of trace fossils within quartzites at Kilen (Fig. 1) provisionally identified as *Cruziana* sp. (H. A. Armstrong personal communication to R. E. H.) of latest Proterozoic – Lower Cambrian age.

Peacock (1956, 1958) identified a sequence of quartzites and limestones ('Brittania Sø Group') which were considered to overlie the thrust zone. Recent mapping has shown that the 'Brittania Sø Group' includes rocks correlatable with both the Trekant Series and Zebra Series.

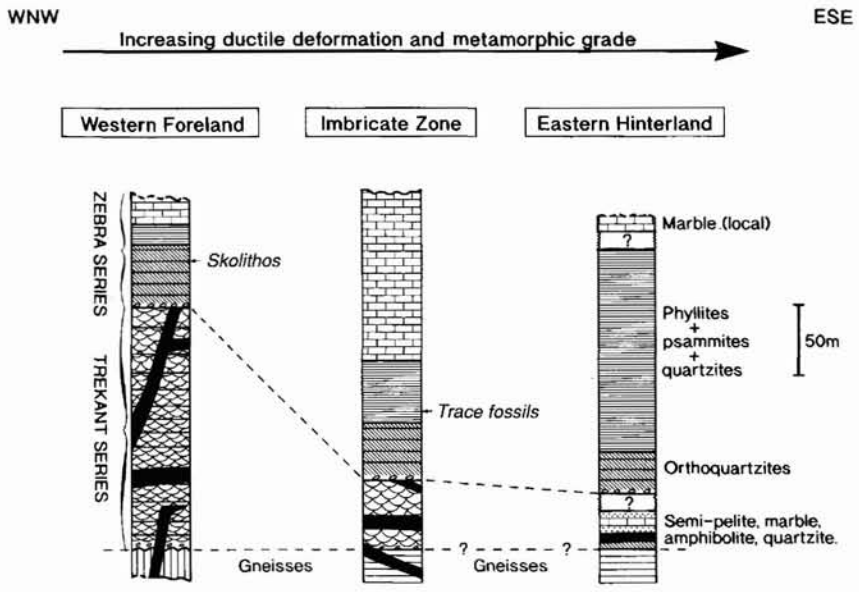

Fig. 2. Simplified schematic stratigraphic sequences and correlation of the cover sediments identified in Dronning Louise Land (from Strachan *et al.*, 1992).

Consequently, the term 'Brittania Sø Group' should be abandoned.

Eastern Hinterland

The rocks which form the Eastern Hinterland (Fig. 1) lie structurally above the Imbricate Zone. They have been subdivided into high-grade, migmatitic basement gneisses and medium-grade, non-migmatitic cover sequences.

Most of the Eastern Hinterland is comprised of regularly banded, acid to intermediate grey orthogneisses, with a few mafic horizons. A granitic orthogneiss sampled north of Eventyrfjelde (Fig. 1) yielded a U-Pb zircon age of 1909^{+6}_{-5} Ma (Tucker *et al.*, 1993) and a Sm-Nd model age of 2.49 Ga (Kalsbeek *et al.*, 1993). Enclaves of older paragneisses (including amphibolites, pelites, calc-silicates and marbles) are common locally. Granitic veins, pegmatites and segregations are widespread and appear to be a product of the regional phase of migmatisation and high-grade metamorphism associated with formation of the gneissic fabrics. The gneisses are intruded by non-migmatised, variably deformed amphibolite sheets which vary from a few centimetres to several tens of metres in thickness. In areas of low tectonic strain, the basement gneisses closely resemble those of the Western Foreland with which they are tentatively correlated (Fig. 2). This implies that the amphibolites are the metamorphosed and deformed equivalents of the dolerites of the Western Foreland.

Parautochthonous cover sequences are preserved in the cores of isoclinal synclines (Fig. 1). They are regarded as cover because they are not intruded by orthogneisses, and they are unmigmatised. Two types of cover sequence have been recognised. The presumed older sequence includes psammitic to semi-pelitic schists, quartzites and minor marbles and calc-silicates (Fig. 2), and is intruded by amphibolites. Correlation with the Trekant Series is likely (Fig. 2). The presumed younger sequence comprises a well-defined succession of (in stratigraphic order): orthoquartzites, interbedded phyllites, psammites, quartzites and minor carbonates, and either magnetite-hematite sandstones or grey limestones (Fig. 2). There are no intrusive amphibolites. The sequence is correlated with the Zebra Series of the Western Foreland and the Imbricate Zone (Fig. 2).

Caledonian structure and metamorphism

The dominant structures and associated metamorphism affect the Zebra Series and its correlatives in all three tectono-stratigraphic units, and are therefore considered to be Caledonian in age. The only pre-Caledonian events which have been identified include the formation of the original basement gneiss complex, and, in the Western Foreland, localised extensional shearing associated apparently with intrusion of dolerites.

'Early' Caledonian deformation

The earliest Caledonian structures are present only in the Eastern Hinterland. They are a series of isoclinal sheath folds which are curvilinear about a N–S mineral extension lineation. Kilometre-scale interfolding of basement and cover occurred during this deformation phase. Shear-sense criteria give top-to-the-north senses of displacement parallel to the mineral lineation. These structures appear to have formed due to northward-directed shearing at low angles to the original basement-cover interface.

'Main-phase' Caledonian deformation

The structures described above are post-dated by formation of upright to moderately inclined folds, north-west-directed thrusting along the Imbricate Zone, and sinistral strike-slip displacements along the Storstrømmen shear zone (Fig. 1). These structures differ considerably in style and intensity of deformation.

Western Foreland. In the west of Dronning Louise Land, Caledonian folds are absent; a weak cleavage is only locally developed within fine-grained Zebra Series sediments. The Trekant Series and Zebra Series have only been affected by anchizone metamorphism. Towards the base of the overlying Imbricate Zone, a single set of open to tight, north-west-verging folds and thrusts is developed on a wavelength of hundreds of metres. Moderate to steep south-east dipping cleavages are parallel to axial surfaces, and contain a slightly oblique, SSE-plunging mineral lineation. Syn-deformational metamorphic grade is low- to mid-greenschist facies, and associated with widespread retrogression of basement lithologies.

Imbricate Zone. Ductile thrusts are associated with belts of mylonite, commonly tens of metres thick, which carry a pervasive south-east-plunging mineral extension lineation. Shear-sense criteria give top-to-the-NW senses of displacement. Syn-mylonitisation sheath folds plunge parallel to the lineation. Ductile thrust-related fabrics are refolded on all scales by open-to-tight folds with moderately ESE-dipping axial surfaces. Variable fold plunges reflect curved hinge lines. The majority of hinges plunge S-SSE, clockwise of the earlier mineral extension lineations. These folds have consistent Z-geometry vergence patterns. The skewed plunge and vergence distribution

implies the presence of a left-lateral differential shear couple during thrusting. Large-scale folds of this group fold higher thrusts north of Budolfi Isstrøm, and root downwards into unfolded lower detachments. This is consistent with a foreland propagating sequence of thrusting. Syn-thrusting metamorphism along the structurally highest (= earliest) thrusts is at low amphibolite facies. Deformation along structurally lower (= later) thrusts is at mid- to low-greenschist facies.

Eastern Hinterland. Main phase structures are generally N–S trending, upright, open-to-isoclinal folds and associated steeply dipping crenulation fabrics. Fold axes lie either subparallel or at low angles to the earlier mineral lineation, and locally display marked curvature. Deformation was accompanied by low amphibolite facies metamorphism. The lower contact of the Eastern Hinterland with the underlying Imbricate Zone is marked by a zone of mylonitic gneisses, several hundred metres thick. Several large-scale main phase folds appear to root into this zone of high strain, which also records the rapid swing of the dominant lineation from N–S into NW–SE orientations. This is thought to indicate that the main phase folding in at least the western part of the Eastern Hinterland occurred synchronously with thrusting in the Imbricate Zone.

Storstrømmen shear zone. The Storstrømmen shear zone (SSZ) is a belt, at least 8 km wide, of sub-vertical mylonites and heterogeneously deformed gneisses which is exposed along the eastern margin of Dronning Louise Land and on nunataks in L. Bistrup Bræ (Fig. 1; cf. also Strachan & Tribe, 1994). Shear-sense criteria indicate a consistent sinistral sense of displacement parallel to a sub-horizontal to gently SSW-plunging mineral lineation. There is every transition from low strain augen of protomylonitic gneisses to belts of ultramylonite up to 50 m wide. The earliest mylonites formed within the low amphibolite facies, and were variably overprinted by greenschist facies mylonites. The mylonites were strongly disrupted locally by formation of cataclasites, breccias and linked brittle fault systems.

Small-scale main phase folds may be traced eastwards into the SSZ, where they fold the mylonite fabric. Their axes steepen and pass through the vertical to form sheath-like structures which are curvilinear about the mineral lineation within the mylonites. Most of the vertically plunging folds display sinistral vergence. These observations imply that main-phase folding was coeval with sinistral shear along the SSZ.

Relative timing of 'main phase' structures. 'Main phase' Caledonian structures are thought to have formed more or less contemporaneously as a result of sinistral transpression which involved partitioned sinistral strike-slip (along the SSZ) and oblique ductile thrusting (Imbricate Zone). This interpretation is supported by the following observations:

1. A comparable range of low amphibolite to greenschist facies mylonites occurs in both the SSZ and the Imbricate Zone; this implies that both deformation zones formed at similar crustal levels.
2. The geometry of 'main phase' folds within the SSZ, where these folds appear to have formed during sinistral shear.
3. The skewed distribution of 'main phase' folds in the Imbricate Zone, and the obliquity of the lineation associated with folding and thrusting in the Imbricate Zone and the Western Foreland.

Conclusions

1. A common basement-cover tectonostratigraphy can be correlated across Dronning Louise Land as far east as the Storstrømmen shear zone. This implies that the Caledonian thrust belt in North-East Greenland does not separate fundamentally different geologic units.
2. The discovery of *in situ* trace fossils within quartzites of the Zebra Series means that these rocks can be no older than the upper Proterozoic. By implication, the structures which deform these rocks and their probable correlatives in the Imbricate Zone and the Eastern Hinterland are Caledonian in age.
3. The earliest recognised Caledonian structures are recumbent folds which resulted from northward-directed shearing, broadly parallel to the trend of the orogen in North-East Greenland.
4. Subsequent 'main phase' Caledonian structures are thought to have resulted from sinistral transpression, which involved partitioning of regional deformation between sinistral strike-slip movements in the east of the region, and generally NW-directed oblique thrusting and folding further to the west.
5. There is no field evidence for any significant orogenic activity between the deposition of the middle Proterozoic Trekant Series and the upper Proterozoic – lower Cambrian(?) Zebra Series. This is consistent with the conclusions of Jepsen & Kalsbeek (1985) who found no existence for the supposed middle to upper Proterozoic 'Carolinidian' orogeny in more northerly parts of the Caledonian belt in North-East Greenland. In contrast, in the region south of Bessel Fjord (75°–76°N), there is isotopic evidence for metamorphism of the Smallefjord Sequence at 954 ± 10 Ma (A. P. Nutman, personal communication; Friderichsen *et al.*, 1994).

Widespread 'Grenville' (*c.* 1000 Ma) activity has been inferred in central East Greenland.

References

Clemmensen, L. B. & Jepsen, H. F. 1992: Lithostratigraphy and geological setting of Upper Proterozoic shoreline-shelf deposits, Hagen Fjord Group, eastern North Greenland. *Rapp. Grønlands geol. Unders.* **157,** 27 pp.

Friderichsen, J. D., Holdsworth, R. E., Jepsen, H. F. & Strachan, R. A. 1990: Caledonian and pre-Caledonian geology of Dronning Louise Land, North-East Greenland. *Rapp. Grønlands geol. Unders.* **148,** 133–141.

Friderichsen, J. D., Strachan, R. A. & Henriksen, N. 1994: Basement-cover relationships and regional structure in the Grandjean Fjord-Bessel Fjord region (75°–76°N), North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Haller, J. 1956: Die Strukturelemente Ostgrönlands zwischen 74° und 78°N. *Meddr Grønland* **154**(2), 27 pp.

Haller, J. 1970: Tectonic map of East Greenland (1:500,000). An account of tectonism, plutonism and volcanism in East Greenland. *Meddr Grønland* **171**(5), 286 pp.

Haller, J. 1971: *Geology of the East Greenland Caledonides,* 413 pp. London: Interscience.

Holdsworth, R. E. & Strachan, R. A. 1991: Interlinked system of ductile strike-slip and thrusting formed by Caledonian sinistral transpression in northeastern Greenland. *Geology* **19,** 510–513.

Hurst, J. M., Jepsen, H. F., Kalsbeek, F., McKerrow, W. S. & Peel, J. S. 1985: The geology of the northern extremity of the East Greenland Caledonides. *In* Gee, D. G. & Sturt, B. A. (ed.) *The Caledonide orogen: Scandinavia and related areas,* 1047–1063. London: Wiley & Sons.

Jepsen, H. F. & Kalsbeek, F. 1979: Igneous rocks in the Proterozoic platform of eastern North Greenland. *Rapp. Grønlands geol. Unders.* **88,** 11–14.

Jepsen, H. F. & Kalsbeek, F. 1985: Evidence for non-existence of a Carolinidian fold belt in eastern North Greenland. *In* Gee, D. G. & Sturt, B. A. (ed.) *The Caledonide orogen: Scandinavia and related areas,* 1071–1076. London: Wiley & Sons.

Kalsbeek, F., Nutman, A. P. & Taylor, P. N. 1993: Palaeoproterozoic basement province in the Caledonian fold belt of North-East Greenland. *Precambrian Res.* **63,** 163–178.

Kalsbeek, F. & Jepsen, H. F. 1983: The Midsommersø Dolerites and associated intrusions in the Proterozoic Platform of eastern North Greenland – a study of the interaction between basic magma and sialic crust. *J. Petrol.* **24,** 605–634.

Peacock, J. D. 1956: The geology of Dronning Louise Land, N.E. Greenland. *Meddr Grønland* **137**(7), 38 pp.

Peacock, J. D. 1958: Some investigations into the geology and petrography of Dronning Louise Land, N.E. Greenland. *Meddr Grønland* **157**(4), 139 pp.

Strachan, R. A. & Tribe, I. R. 1994: Structure of the Storstrømmen shear zone, eastern Hertugen af Orléans Land, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Strachan, R. A., Holdsworth, R. E., Friderichsen, J. D. & Jepsen, H. F. 1992: Regional Caledonian structure within an oblique convergence zone, Dronning Louise Land, NE Greenland. *J. geol. Soc. Lond.* **149,** 359–371.

Tucker, R. D., Dallmeyer, R. D. & Strachan, R. A. 1993: Age and tectonothermal record of Laurentian basement, Caledonides of NE Greenland. *J. geol. Soc. Lond.* **150,** 371–379.