Regional Caledonian structure of Hertugen af Orléans Land, North-East Greenland

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Three structural elements of the East Greenland Caledonides are present in Hertugen af Orléans Land: (1) a marginal NNE–SSW trending zone of crystalline basement rocks overlain by middle Proterozoic sediments (Trekant Series) in the westernmost nunatak area, characterised by folds and thrusts; (2) a central NNE–SSW trending belt of allochthonous orthogneisses dominated by upright and west-vergent folds; and (3) and eastern N–S trending sinistral shear zone of intensely sheared, mylonitic gneisses (Storstrømmen shear zone).

This structural pattern is a continuation of the structural elements in Dronning Louise Land, 40 km to the south-south-east. The late Caledonian Storstrømmen shear zone and its northward continuation define a 10 km wide linear feature of regional significance which can be followed along strike for more than 300 km.

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Hertugen af Orléans Land is a region of dispersed nunataks which extends from 77° 30′ to 78° 40′ in North-East Greenland (Fig. 1). The region of study covers Bildsøe Nunatakker, Laub Nunatakker and Hertugen af Orléans Land (Fig. 1). The westernmost part of the area, including Bildsøe Nunatakker, Laub Nunatakker, Tuborgfondet Land, Garde Nunatakker and Nørreland, was seen only on helicopter reconnaissance. Most of Sønderland, Søndre Mellemland and Nørre Mellemland were mapped on aerial photographs at a scale of 1:50 000, mainly working from camps. The region lies within the East Greenland Caledonian fold belt. The only published map is that of Haller (1983) who indicated that Hertugen af Orléans Land is largely underlain by basement gneisses which to the west are involved in the marginal thrust and fold belt which defines the western limit of the East Greenland Caledonides.

The mapping in 1990 reported on here has provided new information concerning the extent and nature of the various metasedimentary and orthogneissic rock units within this part of the Caledonides, and a structural framework for their evolution. The geology of Hertugen af Orléans Land is similar in many respects to that of Dronning Louise Land to the south, previously mapped in 1989 (Friderichsen *et al.*, 1990). The geology is best described with reference to (1) the marginal thrust and fold belt (Bildsøe Nunatakker, Laub Nunatakker, Garde Nunatakker, Tuborgfondet Land and Nørre Biland); (2) allochthonous orthogneisses which structurally overlie the thrust belt (Sønderland, Søndre Mellemland, Nørre Mellemland and Nørreland); and (3) a steep, NNE-trending zone of sinistral ductile shear, believed to be the continuation of the Storstrømmen shear zone identified in Dronning Louise Land (Friderichsen *et al.*, 1990; Holdsworth & Strachan, 1991). The geology of the Nordmarken region east of the Storstrømmen shear zone (Fig. 1) is described by Friderichsen *et al.* (1991).

Marginal thrust and fold belt

It is only possible to provide a generalised description of the geology because of the reconnaissance nature of the mapping. The marginal thrust and fold belt is thought to be structurally equivalent to parts of the Western Foreland and Imbricate Zone of Dronning Louise Land (Friderichsen *et al.*, 1990). It comprises schists and gneisses which are inferred to represent basement to a metasedimentary sequence correlated with the Trekant Series of Dronning Louise Land (Peacock, 1956a,b, 1958; Haller, 1983; Friderichsen *et al.*, 1990). Both units are intruded by a suite of meta-dolerites.

Basement complex. The rocks of this complex are well exposed on parts of Bildsøe Nunatakker and Laub Nu-

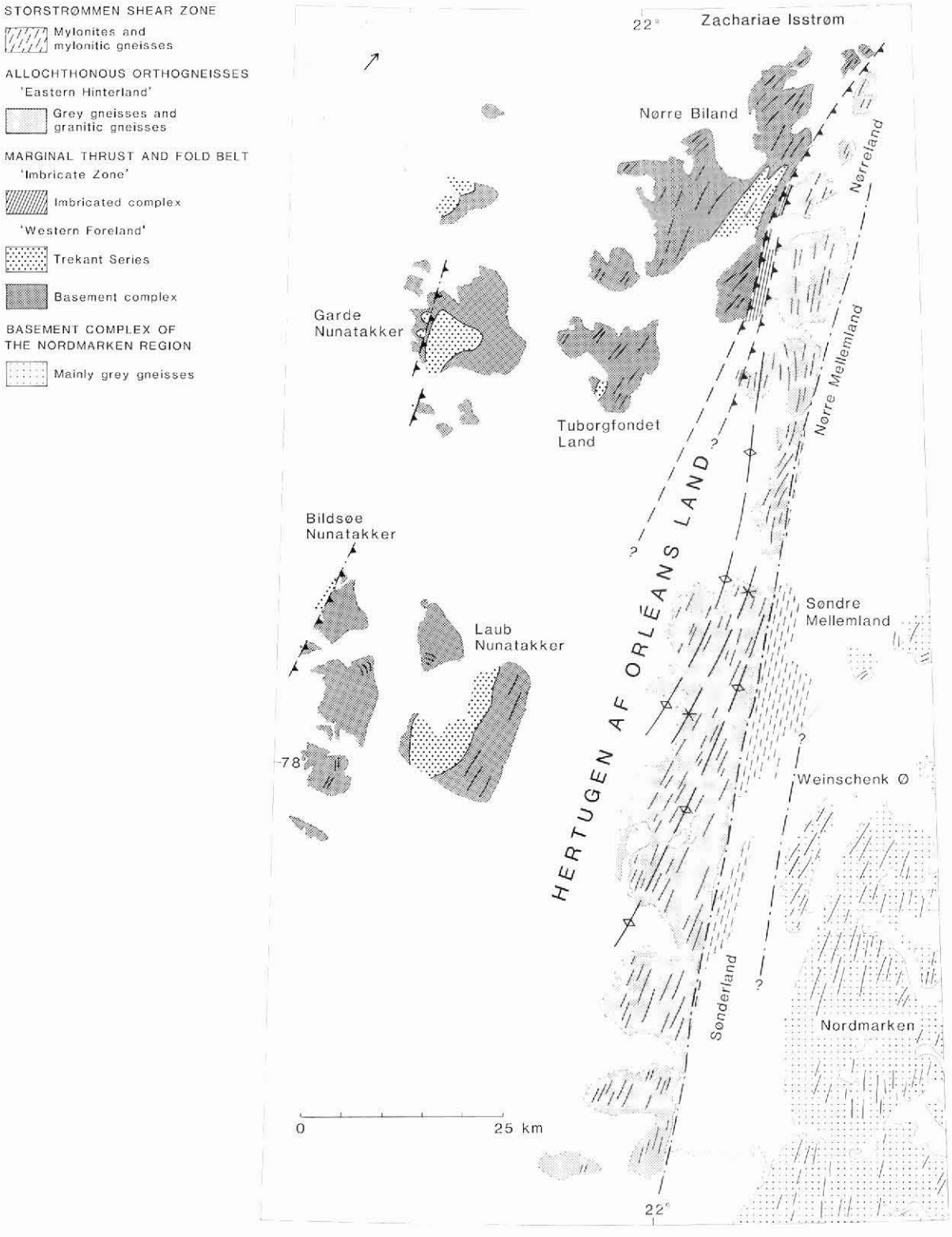


Fig. 1. Geological sketch map of Hertugen af Orléans Land. Nomenclature between inverted commas indicates correlation with the Dronning Louise Land region (Friderichsen *et al.*, 1990) 40 km SSW of the southern limit of the figure.

natakker (Fig. 1). The dominant types are banded biotite-muscovite schists and gneisses which contain concordant sheets of retrogressed amphibolite and foliated granitoid rocks. A metasedimentary protolith is inferred for most of these rocks. Similar lithologies are exposed in Nørre Biland, in Tuborgfondet Land and on Garde Nunatakker (Fig. 1). Although these rocks are thought to represent basement to the Trekant Series, they differ markedly from the orthogneisses which underlie the Trekant Series in the western part of Dronning Louise Land (Friderichsen *et al.*, 1990). Both the relative and absolute ages of the two complexes are unknown.

Trekant Series. The Trekant Series is well exposed in the eastern part of Nørre Biland and on Garde Nunatakker, and scattered exposures also occur on parts of Bildsøe Nunatakker and Laub Nunatakker. It is represented by variably cleaved, greenschist facies metasandstones and meta-quartzites with occasional phyllite bands. The sandstones and quartzites are locally pebbly and conglomeratic. Unmodified stratigraphic contacts with the basement complex were not observed. These rocks are identical to deformed and metamorphosed Trekant Series rocks adjacent to and within the Imbricate Zone of Dronning Louise Land (Friderichsen *et al.*, 1990).

Meta-dolerites. The basement complex and Trekant Series are intruded by medium-grained meta-dolerites which vary in thickness from a few metres to tens of metres. Meta-dolerites within the basement complex are typically steeply-dipping dykes, whereas those within the Trekant Series are sub-concordant sills emplaced at a low angle to bedding. The meta-dolerites are correlated with the regional suite of mid-Proterozoic age (*c.* 1250 Ma) which has been recorded extensively in northern Greenland (Haller, 1971; Jepsen & Kalsbeek, 1979; Kalsbeek & Jepsen, 1983) and western parts of Dronning Louise Land (Peacock, 1956a,b, 1958; Friderichsen *et al.*, 1990).

Pre-Caledonian structure. Schistose and linear fabrics and related minor isoclinal folds within the basement complex are thought to be almost entirely pre-Caledonian in age. The dominant planar fabrics are subhorizontal or gently dipping and contain a penetrative NNE-trending stretching and mineral lineation. No major folds related to these structures were identified. Critical evidence relating to the age of these structures was observed at one locality on Laub Nunatakker, where mylonitised basement rocks are cut at high angles by an undeformed meta-dolerite dyke. This demonstrates the existence of a pre-Caledonian mylonitisation event not recorded in Dronning Louise Land.

Caledonian structures. By analogy with Dronning Louise Land, Caledonian structures are likely to be represented by major thrusts and upright folds. On Garde Nunatakker (Fig. 1) major thrusts which dip moderately (35°–50°) to the east imbricate rocks of the basement complex and the Trekant Series. Mesoscopic shear criteria indicate a west-directed sense of thrust movement. In the extreme west of Bildsøe Nunatakker (Fig. 1) a tectonic contact between mylonitic basement complex and *underlying* Trekant Series dips gently to the west. Shear criteria also indicate a west-directed sense of movement, and this structure may represent a folded thrust.

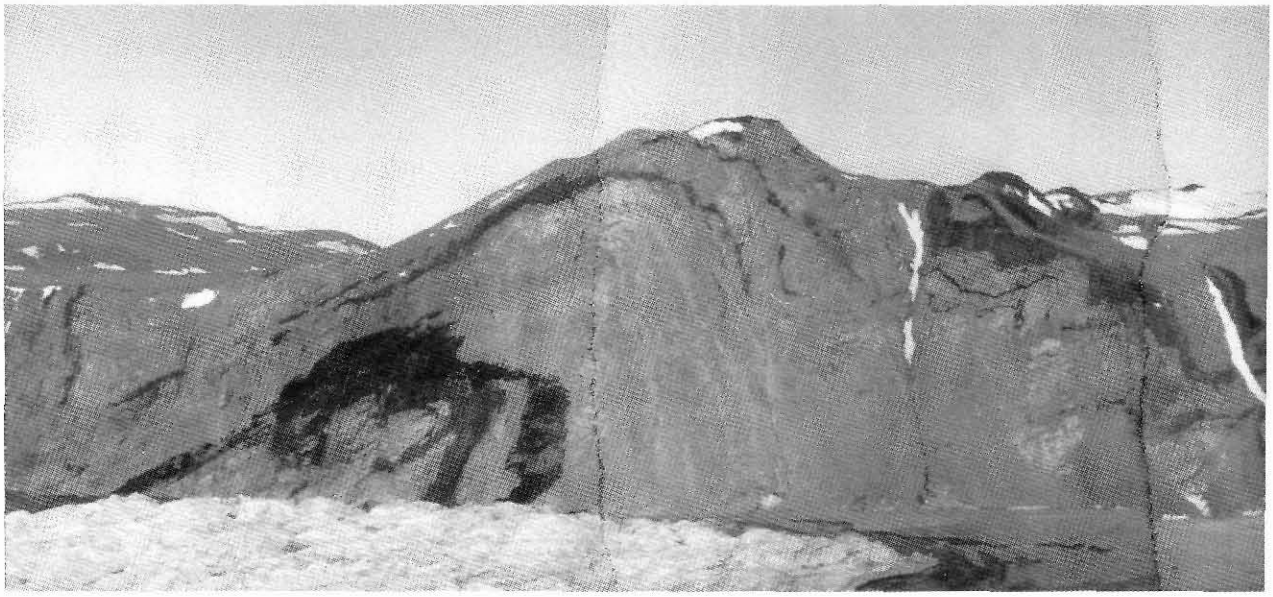
The Trekant Series rocks which lie structurally above the westernmost zone of imbrication are deformed by a series of prominent upright, NNE-trending folds. The Trekant Series carries a pervasive cleavage which is axial-planar to these structures. In south-eastern Nørre Biland (Fig. 1) major upright folds are east-vergent (Fig. 2) and associated with minor east-directed thrusts; the overall geometry of these structures is analogous to the 'backfolds' and 'pop-up' structures described from thrust belts elsewhere (Boyer & Elliott, 1982; Butler, 1982).

The roof thrust to the marginal thrust and fold belt is exposed in the northern part of Nørre Mellemland and in the southern part of Nørreland (Fig. 1) where it dips steeply (60°–70°) to the east and is underlain by a narrow NNE-trending zone of imbricated basement and Trekant Series, which is thought to correlate with the Imbricate Zone of Dronning Louise Land. Both the roof thrust and the onlying orthogneisses appear to have been deformed (and steepened) by the east-vergent folds observed within the Trekant Series.

Allochthonous orthogneisses

Most of Sønderland, Søndre Mellemland, Nørre Mellemland and Nørreland (Fig. 1) are underlain by an orthogneiss complex which lies structurally above the marginal thrust and fold belt, and is therefore assumed to have been overthrust to the west. It is thought to correlate with the lithologically similar Eastern Hinterland orthogneisses of Dronning Louise Land which occupy an equivalent structural position further south. The main lithological units are described in approximate chronological sequence, their relative ages having been established as far as possible on the basis of discordant intrusive relationships. Quantitatively, the most important are units of grey orthogneiss which make up *c.* 90% of the complex.

Older mafic and ultramafic bodies. The oldest rocks are volumetrically minor mafic to ultramafic bodies found as variably retrogressed inclusions in the grey gneisses (Fig. 3). They are generally lensoid and vary in



size from 1–10 m in length. Most contain amphibolite facies assemblages of hornblende + plagioclase ± garnet ± biotite. Some also contain pyroxene, possibly indicative of a higher grade of metamorphism. Occasionally a centimetre-scale compositional layering is present and where observed is generally discordant to the dominant fabrics within the younger gneisses.

Grey gneisses. These are the dominant rock type, and are variably banded, migmatitic mafic and felsic gneisses, composed of an amphibolite facies assemblage of quartz + feldspar + biotite ± hornblende ± muscovite ± garnet. Different gneiss types are interbanded on all scales from centimetres to tens of metres, but it was not possible to identify any persistent marker units. The commonly strongly banded aspect of these gneisses reflects the heterogeneous nature of their protoliths, inferred to be a series of dioritic-tonalitic-granodioritic plutonic rocks. Veins or leucosomes of white, granitoid material are common and thought to represent the result of segregation during high-grade metamorphism and deformation.

Granitic gneisses. Bands of granitic gneiss form a subordinate group of rocks (< 10% of the complex). They occur as concordant sheets up to 400 m thick within the grey gneisses. The granitic gneisses are foliated, relatively homogeneous, pink-grey gneisses which contain an amphibolite facies assemblage of biotite + garnet + plagioclase + quartz ± hornblende. The granitic gneisses are not migmatised, and are thought to have been emplaced after high-grade metamorphism (and deformation) of the grey gneisses.

Augen gneisses. Coarse-grained augen gneisses are locally present as 3–5 m thick sheets within the grey gneisses. They are composed of quartz + feldspar + biotite + muscovite, and carry a prominent augen texture defined by mica and shape fabrics of quartz and feldspar which wrap around feldspar megacrysts. Contacts with the grey gneisses are sharp and locally discordant.

Meta-dolerites. Mafic sheets (up to 3 m thick) composed of an amphibolite facies assemblage of hornblende + plagioclase ± quartz locally intrude the grey gneisses and the granitoid gneisses. They are not migmatised and in areas of low strain are clearly discordant with the host gneisses. Relationships with the augen gneisses are unknown.

Granites and pegmatites. Undeformed granitic veinlets and pegmatites are found throughout the gneiss complex, and cut all earlier fabrics.

Regional structure. All components of the orthogneiss complex, apart from the late granites and pegmatites, are affected by two major phases of deformation. The earliest of these is represented by minor isoclinal sheath folds (Fig. 4) which are curvilinear about a NNE-trending mineral and stretching lineation. Shear criteria, including rotated porphyroclasts and shear pods, indicate a general northward direction of transport parallel to this lineation. Substantial metamorphic recrystallisation has occurred parallel to the axial surfaces of these folds. These structures are post-dated by a series of major, close to open, upright folds which trend NE to NNE, broadly parallel with earlier lineations and fold axes. Only locally are these folds accompanied by the development of new axial surface fabrics. This structural

Fig. 2. Major upright east-vergent folding of the Trekant Series rocks and associated dolerites immediately west of the roof thrust to the marginal thrust and fold belt. South-facing cliff, south-eastern Nørre Biland.

history is directly comparable with that of the Eastern Hinterland gneisses of Dronning Louise Land (Friderichsen *et al.*, 1990). Stratigraphic evidence in Dronning Louise Land suggests that these structures are Caledonian in age.

Storstrømmen shear zone

The Storstrømmen shear zone is represented by a 8–10 km wide belt of steep, heterogeneously deformed gneisses and mylonites which has been traced along the eastern margin of Hertugen af Orléans Land as far north as Nørre Mellemland (Fig. 1). The contact between the orthogneisses to the west and the shear zone is on a regional scale marked by late brittle faults which dip steeply to the east. The basement gneisses do, however, show increasing signs of ductile shear over a distance of *c.* 300 m as the shear zone is approached, and minor shear zones are locally developed up to 2–3 km west of the shear zone. It is not therefore thought that the brittle faults which border the shear zone have large displacements. The eastern margin of the shear zone lies in the fjord between Weinschenck Ø and Hertugen af Orléans Land (Fig. 1).

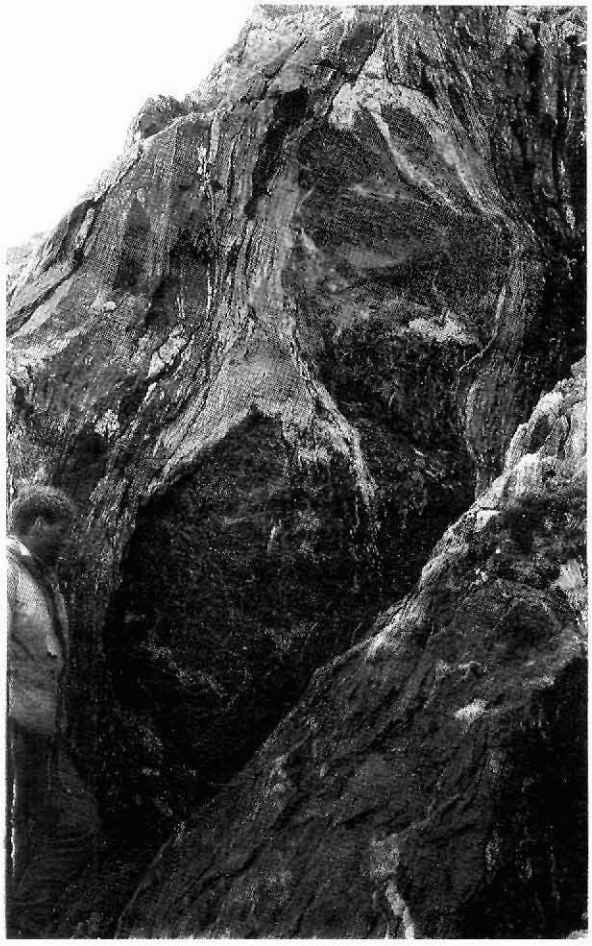


Fig. 3. Older mafic to ultramafic pods enclosed within banded grey gneisses. Søndre Mellemland, 3 km west of Storstrømmen shear zone.

Fig. 4. Closed outcrop patterns characteristic of early sheath folds deforming grey gneisses. South-facing cliff, Søndre Mellemland, 4 km west of Storstrømmen shear zone.

The shear zone comprises a series of mylonite zones which anastomose around belts and augen of lower tectonic strain, within which the gneissic protoliths are variably reworked. All units carry a NNE-trending foliation which is either steeply or moderately inclined to the SSE, and 10°–15° oblique to the tectonic trend within the orthogneisses to the west. A prominent stretching lineation plunges either subhorizontally or gently to the SSW.

Individual mylonite belts may be up to 500 m wide and traceable for at least 5 km. The mylonites are typically dark, fine-grained, porphyroclastic rocks which are locally ultramylonitic (Fig. 5). There is every transition from these into highly strained mylonitic gneisses which preserve relict gneissic fabrics, and belts up to 500 m wide of gneisses which have apparently undergone less reworking. At least three sets of folds are present within the shear zone: (1) isoclinal folds to which the mylonite fabric is axial planar (Fig. 6); (2) steeply-plunging tight folds which fold the mylonite fabric and may be curvilinear about the stretching lineation; (3) upright to moderately inclined, open to isoclinal folds which are coaxial with the linear fabric. Amphibole and garnet appear to be stable within some mylonites, implying that early stages of ductile shear occurred within at least upper greenschist facies.

A sinistral sense of displacement parallel to the stretching lineation may be deduced from a variety of shear criteria. These include rotated porphyroclasts (sigma and delta types) (Fig. 7), shear pods, C-S fabrics, and mesoscopic shear zones. Macroscopic sinistral shear zones up to 900 m wide are present on the NNE-trending peninsula west of Weinschenck Ø (Fig. 1). On Nørre Mellemland (Fig. 1) sinistral displacements within the shear zone are post-dated by west-vergent folding and overthrusting of the mylonites onto the orthogneisses to the west.

Fig. 5. Inclusion of early mafic to ultramafic lithology within mylonites of the Storstrømmen shear zone. NNE-trending peninsula, Søndre Mellemland.

Fig. 6. Isoclinal folds deforming and transposing mylonite fabric within the Storstrømmen shear zone. NNE-trending peninsula, Søndre Mellemland.

There is a concentration within and proximal to the shear zone of a variety of minor intrusions which are inferred to have been at least partly emplaced during ductile shear. In south Sønderland and Søndre Mellemland the earliest intrusions are swarms of distinctive pink, granitoid sheets up to 2 m thick, which are isoclinally folded and mylonitised. They apparently pre-date emplacement of white-grey leucocratic intrusions, which are also heterogeneously mylonitised. Syn- to late-tectonic, variably foliated granitoid pegmatites are discordant to the mylonite fabric and earlier intrusions. At two localities the mylonites are intruded by weakly foliated metabasic sheets.

A concentration of subvertical brittle fault zones occurs within and proximal to the shear zone. Extensive brecciation and cataclasis is evident along these zones, and is associated with widespread retrogression to epidote and chlorite-bearing assemblages. These features are thought to be related to late- to post-Caledonian displacements along the major lineament defined by the Storstrømmen shear zone.

Conclusions

The continuation of the Caledonian thrust and fold belt previously recognised in Dronning Louise Land northwards to the Hertugen af Orléans Land region is confirmed. The westernmost zone of thrusting when extrapolated southwards would lie just to the west of Dronning Louise Land. This may indicate that much of the Western Foreland basement and cover of Dronning Louise Land (Friderichsen *et al.*, 1990) may also lie above analogous thrusts, although the displacements along these structures are likely to be limited.

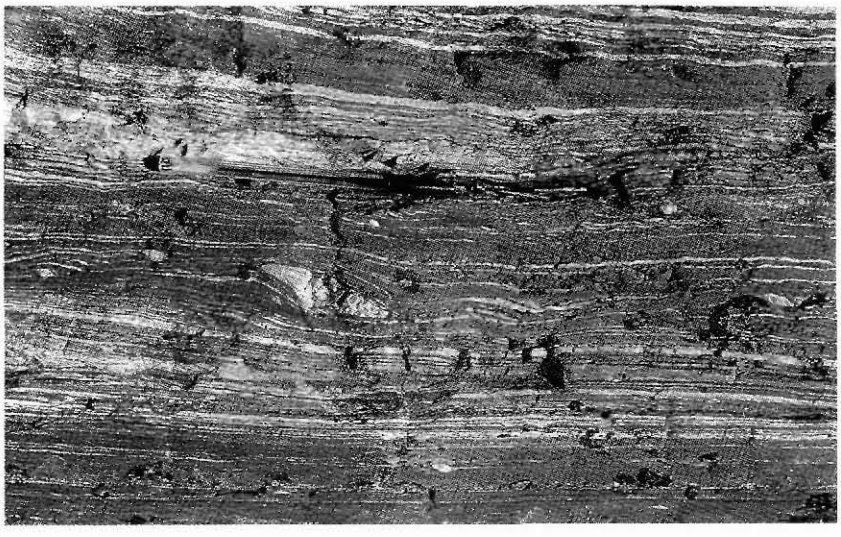


Fig. 7. Sinistral shear indicator (sigma-type porphyroclast) within vertical mylonitic grey gneisses of the Storstrømmen shear zone. NNE-trending peninsula, Søndre Mellemland.

The Storstrømmen shear zone, first identified in south-east Dronning Louise Land (Friderichsen *et al.*, 1990), has been traced as a 10 km wide zone of heterogeneous sinistral shear as far north as Nørre Mellemland. This is a total along strike distance of *c.* 300 km. Previous suggestions that this shear zone is an important regional structure, across which there are likely to have been major lateral displacements (tens to hundreds of kilometres), are confirmed.

The thrust and fold belt and the Storstrømmen shear zone converge northwards, and it seems likely that the orthogneisses west of the shear zone are truncated by these structures in the region of Zachariae Isstrøm north-east of Nørreland.

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