The crystalline rocks of Germania Land, Nordmarken and adjacent areas, North-East Greenland

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The crystalline rocks of Germania Land, Nordmarken and adjacent areas are dominated by grey, migmatitic quartzo-feldspathic orthogneisses with a complex history of emplacement and deformation. Ultramafites, eclogites and metasedimentary rocks are preserved as inclusions or trails of enclaves within the migmatitic orthogneisses. Later intrusive suites include metadolerite dykes, alkali feldspar metaporphyries and metagabbros.

All these crystalline rocks have suffered thorough metamorphism and deformation, and three fabric events are recognised. Three systems of late mylonite zones are found: west of the study area in Hertugen af Orléans Land, along the east side of Stormlandet and Germania Land, and in northern Store Koldewey and Lille Koldewey.

The region lies within the East Greenland Caledonian fold belt. Available isotopic data suggest the crystalline rocks include Archaean and Early Proterozoic suites. These have undergone variable degrees of later reworking on several occasions. It is unclear how much of the deformation history is Caledonian and how much pre-Caledonian. The latest fault displacements are post-Caledonian, as shown by local preservation of fault bounded outcrops of Carboniferous and Jurassic sedimentary rocks.

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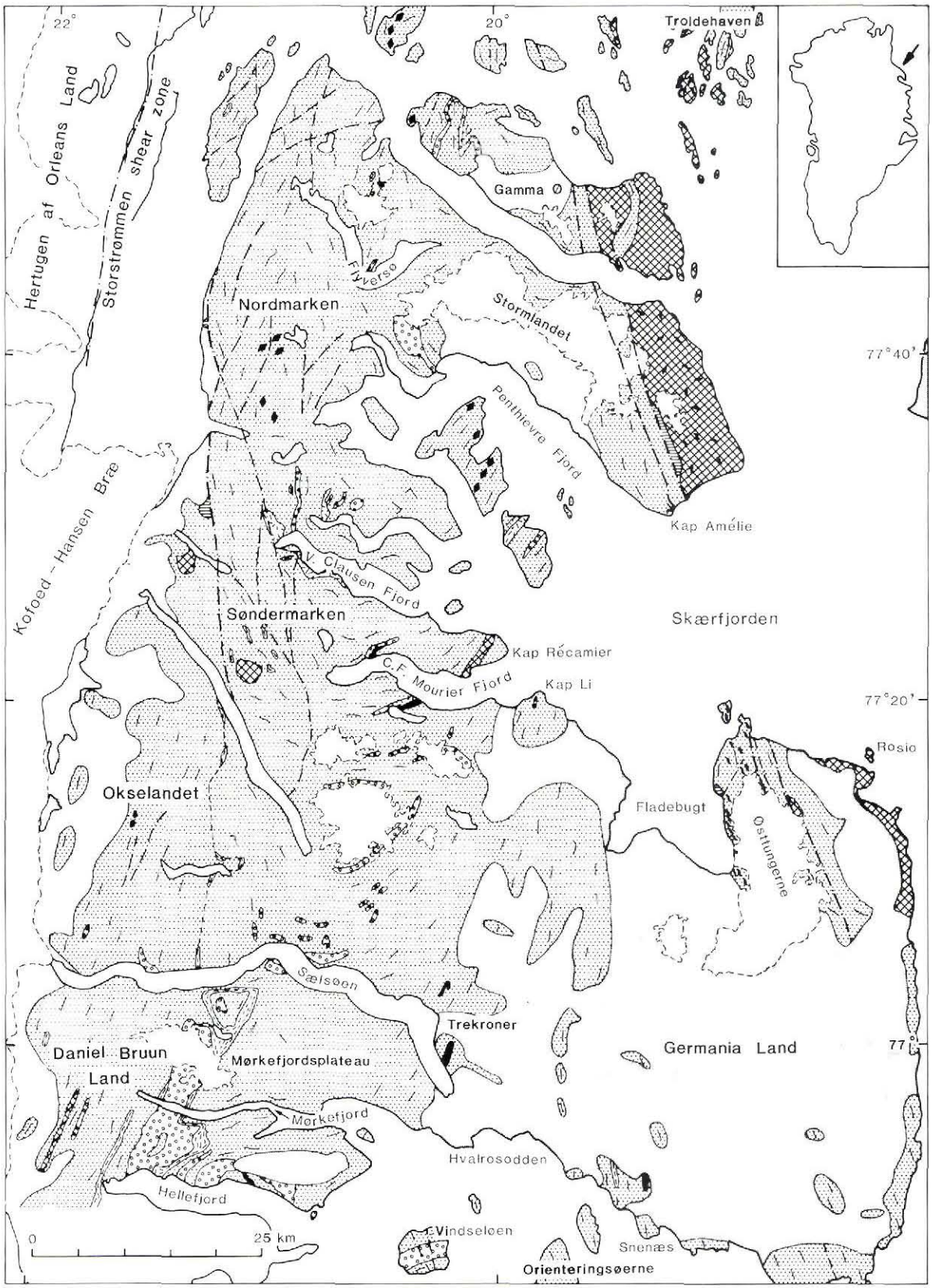
Germania Land, Nordmarken and adjacent areas (including Stormlandet, Søndermarken, Okselandet, islands in southern Jökelbugten, and Store Koldewey, Lille Koldewey and other islands in Dove Bugt; Figs 1 & 2), were mapped during the final summer of the North-East Greenland project 1988–90 (Henriksen, 1991). This region is dominated by a heterogeneous complex of high grade, migmatitic, grey orthogneisses, which contain lenses of older mafic, ultramafic, and metasedimentary rocks. Later intrusive rocks include metadolerite dykes, metaporphyries and metagabbro sheets. While these crystalline rocks clearly form part of the hinterland of the East Greenland Caledonides, published isotopic data on gneisses at Danmarkshavn (Steiger *et al.*, 1976) and unpublished isotopic studies by one of the authors (F. K.) on samples collected in 1988 and 1989 suggest that most of the suite is of Archaean and early Proterozoic genesis. The degree of Caledonian reworking is uncertain. Locally, fault-bounded outcrops of post-Caledonian sedimentary rocks unconformably overlie the crystalline complexes (Stemmerik & Piasecki, 1990). Quaternary deposits are widespread in Germania Land, Okselandet and Stormlandet, but only the most extensive areas are shown in Fig. 1.

Mapping was mainly carried out on aerial photographs at scales of 1:50 000 or 1:150 000. The writers were divided into four mapping teams, each with an area of responsibility. The better exposed parts of the region were mapped on foot from field camps, but large areas (e.g. islands in southern Jökelbugten, Stormlandet, much of Germania Land, plateau areas in Okselandet and the southern two-thirds of Store Koldewey) were seen only on helicopter reconnaissance with a limited number of ground stops. The geology of Hertu-


22°
20°
Troldehaven
Hertugen af Orleans Land
Storstrømmen shear zone
Gamma Ø
Flyverso
Nordmarken
Stormlandet
77°40'
Penthievre Fjord
Kap Amélie
Kofoed-Hansen Bræ
V. Clausen Fjord
Søndermarken
Skærfjorden
Kap Récamier
C.F. Mourier Fjord
Kap Li
77°20'
Rosio
Okselandet
Fladebugt
Ostlungerne
Sælsøen
Trekroner
Germania Land
77°
Daniel Bruun Land
Mørkefjordsplateau
Mørkefjord
Hvalrosodden
Hellefjord
0
25 km
Vindseløen
Snenæs
Orienteringsøerne

gen af Orléans Land and outlying nunataks, west of the shear zone that strikes NNE through Kofoed-Hansen Bræ, is described by Strachan *et al.* (1991). A detailed structural study of the gneiss region in western Dove Bugt, south of the study area in Fig. 1, is to be found in Chadwick & Friend (1991).

The main lithological units are described below in an approximate chronological sequence based principally on discordant intrusive relationships. This section is followed by a description of the structural history based on field relationships.

Older mafic and ultramafic bodies

The oldest (?) rocks are granulite to eclogite facies, mafic to ultramafic bodies, found as deformed inclusions or xenoliths within the grey gneiss complex. These high grade lenses are found throughout Søndermarken, Nordmarken and around Troldehaven, but are less commonly seen in other areas. They vary in size from less than a metre to hundreds of metres in length. These rocks are believed to be some of the oldest in the region, because of their high metamorphic grade, their subsequent partial retrogression to amphibolite facies assemblages, their discordant internal foliations, and because they are intruded by the granitoid protoliths of the grey gneiss complex. Mafic pods and layers which have not experienced such high grade metamorphism, and are thought to be younger, are described in a later section.

The high grade metabasic pods contain eclogitic assemblages of garnet-clinopyroxene and are usually partially retrogressed to hornblende-, biotite- and/or plagioclase-bearing assemblages. Individual pods are rather uniform in mineral proportions, though centimetre-scale banding is a common feature, and garnet-rich layers are often seen. Ultramafites are typically pyroxenites (orthopyroxene-clinopyroxene) but at least one peridotite (olivine-orthopyroxene-clinopyroxene-spinel) was found. All these bodies have rims of amphibolite (hornblende + plagioclase ± garnet), hornblendite or biotite-rich gneisses, and are often cut by hornblendite veins and fractures.

This suite may represent an early, layered mafic-ultramafic complex. The pyroxenites and eclogites are found in close proximity as inclusions in the grey gneisses, and enjoyed the same high grade of metamorphism.

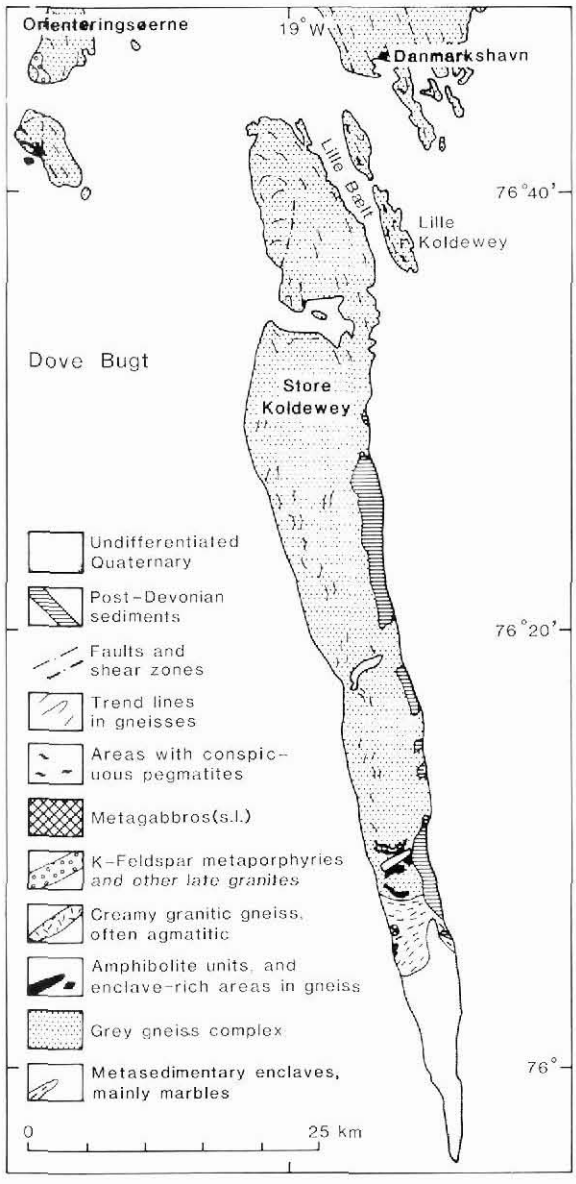


Fig. 2. Geological map of Store Koldewey (primarily reconnaissance) and the islands in north-east Dove Bugt.

Metasedimentary enclaves

Metasedimentary rocks are occasionally found within the grey gneiss complex, usually as small pods and lenses, but in several places as more mappable sheets or semicontinuous trains of boudins. They have been rec-

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Fig. 1. Geological map of Germania Land, Nordmarken, Okselandet, and adjacent areas mapped during the 1990 field season. See Fig. 2 for legend.

ognised around Troldehaven, Flyversø, Weinschenk Ø, the head of V. Clausen Fjord, Søndermarken, Okselandet, Mørkefjordsplateau, Kap Li and on the southern tip of Store Koldewey. Marbles (and associated calc-silicates), quartz-rich metasandstones, and metapelites are of unambiguous sedimentary origin. Some garnet- and biotite-rich schists and gneisses are also probably metasediments.

The relative ages of the various metasedimentary rocks are unknown. Some may have been deformed xenoliths, or perhaps roof pendants, in the original grey gneiss batholith.

Marbles and calc-silicate rocks. Discontinuous, mappable units of marble and calc-silicate rocks are exposed on Mørkefjordsplateau and in eastern Okselandet. These units represent the northward continuation of marble units traced throughout Daniel Bruun Land in 1989 (Chadwick *et al.*, 1990), where they outline isoclinal fold structures (see also Chadwick & Friend, 1991). In Søndermarken the largest marble pod is about 50 m thick, the smallest about 30 cm; the main occurrences are found in two subparallel trains of pods extending over 5 km. South-west of Kap Li, two marble lenses up to 30 m long and 6 m thick occur. A few marble and skarn lenses also crop out on the largest of the Orienteringsøerne, where they are associated with amphibolites.

The marbles comprise calcite, plagioclase and white mica, and a variety of calc-silicate minerals: diopside, forsterite, garnet, sphene, amphiboles, wollastonite (?) and vesuvianite (?).

Quartzose metasedimentary rocks and mica schists. These rocks have been found at a few localities in Okselandet, at Troldehaven, adjacent to Flyversø and on Store Koldewey.

Near Troldehaven, at least 200 m of metamorphosed quartzite, feldspathic sandstone and semipelitic schist are exposed; coarser-grained rocks are also present. Small, highly altered mafic bands and at least one pod of eclogite are present in this sequence.

Quartzites and calcareous metasedimentary rocks are found together along Flyversø. Garnet-bearing psammite, quartzite, and calcareous psammite are interbanded on a centimetre to decimetre scale, along with 5 cm thick mafic amphibolites. Four metasedimentary packages 5–10 m thick, separated by sheets of massive granodioritic orthogneiss, form an imbricate fan.

A thin band (*c.* 10 m) of biotite-sillimanite schist, two-mica schist, and garnet-biotite schist crops out south-west of the head of V. Clausen Fjord. Fibrolitic sillimanite forms sheaves to sprays along foliations in biotite schist and gneiss. This outcrop is one of the few aluminosilicate localities known from the region.

At southern Store Koldewey, a sequence of at least 500 m of paragneisses includes quartzite, garnet-biotite schist, and garnet-bearing psammitic schist with concordant garnet-amphibolite sheets. The sequence is cut by late trondhjemitic pegmatites. On northern Store Koldewey and Lille Koldewey scattered horizons of rusty weathering biotite-garnet rich gneiss and mica schist are found within the gneisses, and are likely to be of sedimentary origin.

Grey gneiss complex

The predominant rock suite is the grey, polyphase gneiss complex which makes up over 90 per cent of Nordmarken and Søndermarken, and is widespread in Okselandet, Germania Land, Lille Koldewey and Store Koldewey. This heterogeneous series of migmatitic quartzo-feldspathic gneisses can be very difficult to subdivide on the outcrop scale, let alone the map scale, because of the variability in mineral proportions and textures over very short distances. Quartz, plagioclase, potassium feldspar and hornblende are ubiquitous constituents; garnet and biotite are abundant, and retrograde phases like muscovite and epidote are common.

The polyphase grey gneiss complex is considered to represent a deformed, metamorphosed and migmatised intrusive suite of batholithic dimensions. In low strain pods and layers it is possible to recognise many cross-

Fig. 3. Agmatitic grey orthogneiss with xenoliths of mafic and ultramafic composition. A shear zone is localised along the sharp margin of a mafic pod, Nordmarken. Photo: J. A. G.

cutting relationships such as dykes, xenoliths and agmatite (Fig. 3), and original igneous textures, supporting our belief that most of the gneiss protoliths are plutonic igneous rocks. This batholith had a long and complex intrusive history which is reflected in the diversity of orthogneisses observed today.

In much of Germania Land distinction can be made between a group of early migmatitic gneisses and a cross-cutting suite of granitic sheets and veins. The early gneisses are banded and veined with enclaves of metasediments and amphibolites, the latter locally abundant. The granitic sheets include more than one phase of granite injection, forming conformable and cross-cutting veins and sheets at all scales from centimetres to several tens of metres; their abundance is strongly variable from a few per cent to over 50 per cent. Comparable local histories can be established in the grey gneiss complex in other areas. Later intrusive suites – metagabbros, metaporphyries, metadolerite dykes and late pegmatites – are discussed in a separate section below.

Mafic-ultramafic pods, boudins, lenses and layers. These units are very common within the grey gneiss complex, although some sections are nearly devoid of mafic rocks. Granulite to eclogite facies lenses thought to be remnants of an early, layered mafic-ultramafic complex are described above.

In Nordmarken and Søndermarken mafic units contain an amphibolite facies assemblage of hornblende-plagioclase ± garnet ± epidote. Some of the smaller bodies are thoroughly retrogressed eclogites, but many of the larger lenses have not experienced such high grade metamorphism. Trains of mafic boudins can be seen on large cliff exposures and on the ground, but no large mappable units are present.

Thin amphibolitic bands are common within the gneisses of Germania Land in some areas. A major amphibolite unit occurs at Trekroner, north-west of Hvalrosodden, and near Snenæs amphibolite bands up to 400 m wide have been mapped.

Some large mafic pods in Okselandet may be remnants of an early generation of basic dykes. Thin basic dykes, apparently younger, but clearly discordant and often folded, occur in many areas, and are described in a later section.

Conspicuous mafic sheets of garnet hornblendite and garnet amphibolite up to 200 m thick are exposed in cliff sections in southern Store Koldewey. These sheets are slightly discordant to the structure in the orthogneisses.

Hornblende migmatite gneiss. One of the most common gneiss types is a dark grey, medium to coarse grained, hornblende-rich, quartzo-feldspathic gneiss. This gneiss contains veins of white to cream weathering granitic material, usually hornblende bearing and often rimmed with a string of hornblende crystals. The gneiss sometimes exhibits a 'speckly' texture of larger hornblende porphyroblasts up to $\frac{1}{2}$ cm in size; this lithology is quite abundant, and may have been generated in different ways.

Banded gneisses. Another common unit is strongly banded gneiss, composed of layers centimetres to decimetres, more rarely metres thick. The bands are often distinct lithologies that vary in composition and mineralogy, and to a lesser extent, in grain size. For example, some gneisses are composed of distinct bands of interleaved metagranodiorite, metadiorite and mafic amphibolite. Other banded gneisses were probably formed by intense deformation of agmatite or earlier migmatite. Agmatite of angular blocks of dioritic to mafic gneiss in a felsic matrix is preserved in low strain pods or macro-augen.

Eastern Germania Land is dominated in many areas by dark, rather homogeneous, banded biotite-garnet gneiss. These gneisses apparently lack the metadolerite dykes seen in other areas (e.g. around Danmarkshavn), but are cut by leucocratic orthogneiss sheets, and locally by swarms of pegmatites.

Creamy metagranite. Yellow to creamy weathering granitic gneiss forms one mappable body, and many smaller layers, lenses, veins and dykes in northern Søndermarken and Nordmarken. This granitic gneiss is very felsic, garnet-bearing, and often exhibits a 'ghost'-like migmatitic texture. Larger blocks and fragments of mafic gneiss are present, producing an agmatitic structure. Contacts with the adjacent grey gneiss complex vary, but are often quite sharp. The creamy gneiss may have been generated by partial melting of the adjacent hornblende gneisses, or may be a distinct, later intrusive body.

Later intrusive suites

Within the grey gneiss complex are numerous unmigmatised sheets and bodies of more homogeneous, massive character. These rocks have a simpler deformation history. A single foliation and lineation are common in these units, and in some cases an igneous fabric is partially or totally preserved. These rock units are therefore probably younger than the main regional migmatisation, but older than the last fabric forming event.

K-feldspar metaporphyries. A suite of clearly intrusive, but now foliated rocks, characterised by abundant potassium feldspar phenocrysts, forms thin sheets (*c.* 10 m) to large mappable bodies. Good examples have been mapped at localities in Søndermarken, Nordmarken, and in a 2 km wide belt that crosses Vindseløen from east to west. Contacts with the grey gneisses are often gradational through a fine-grained, aphyric border phase. Most of the metaporphyry sheets are concordant, but at least one locality in Søndermarken exhibits a clear cross-cutting relationship and contains xenoliths of grey banded gneiss. Mineral proportions vary both within and between the meta-porphyries, from red weathering granitic to reddish-brown to grey granodioritic protoliths. Potassium feldspar, quartz, plagioclase, hornblende, and occasionally garnet and biotite, are the main constituents. The metaporphyries are cut by (deformed) aplites, pegmatites, and locally by basic dykes.

Metagabbros (sensu lato). Bodies of metagabbroic rock (*sensu lato*) have been found at several localities in Søndermarken and near Snenæs in southern Germania Land, and cover extensive areas in eastern Stormlandet and north-east Germania Land.

In southern Søndermarken, there are a few metagabbroic bodies whose igneous textures are very well preserved in the cores, though the margins are highly sheared. Several small 'plugs' of reddish-brown weathering hornblende-plagioclase microgabbro are found along Annekssøen. Similar rocks, though more deformed, are present as sheets within a large augen structure on the Søndermarken plateau. Just west of Kap Récamier, brownish-red weathering quartz-bearing microgabbro (hornblende-plagioclase) forms a large mappable body. The quartz metagabbro is associated with reddish weathering, garnetiferous granitic gneiss.

On both Store Koldewey and Lille Koldewey, gabbro anorthositic rocks have been found locally as bands and lenses 50 cm to 2 m wide, associated with amphibolite bands. These rocks lack the plagioclase megacrysts so conspicuous in the more extensive gabbro anorthosite units in the western part of Dove Bugt (Chadwick *et al.*, 1990). A similar suite of fine grained garnet amphibolites, leucogabbros, and gabbroic anorthosites, cut by metabasaltic dykes, is exposed over a relatively large area near Kofoed-Hansen Bræ.

The eastern part of Stormlandet, east of the prominent lineament, seems to be part of a very large mafic intrusive complex recrystallised to metagabbro, coarse amphibolite and mafic gneiss. Large coarse-grained and irregular cross-cutting pegmatites are characteristic for eastern Stormlandet, and appear sporadically in the metagabbros on the islands in Jökelbugten. The complex also crops out in the north-eastern part of Germania Land and thus has a north–south extent of about 110 km. Marginal facies are often highly sheared adjacent to the tectonised contacts with the grey gneiss complex.

Fig. 4. Mafic dyke cutting obliquely across the foliation in the grey gneiss complex. Nordmarken. Photo: J. A. G.

North of Snenæs, an irregular metagabbroic body up to 400 m wide crops out; composition varies, from intermediate to basic, and relict igneous textures are well preserved except in the foliated margins. Sheets and dykes of leucogranite and pegmatite, a few centimetres to 20 m across, dissect the metagabbroic body.

Metadolerite dykes. Mafic dykes of basaltic composition, cutting across the older gneissic banding at a low angle, are common in Søndermarken and Nordmarken (Fig. 4). A few thin dykes and several large bodies also crop out in Okselandet, and several dykes cut metagabbroic rocks in north-east Germania Land on Rosio. The dykes vary from a few centimetres to several metres in thickness, and are sometimes found in small swarms

of 5–10 dykes; a major swarm is found in the Danmarkshavn area. The dykes are metamorphosed to hornblende + plagioclase ± garnet, though several dykes look unmetamorphosed on fresh surfaces. The metadolerite dykes are deformed: they show pinch and swell, boudinage, a penetrative fabric, and have very schistose margins. Large metadolerite lenses may, however, have relatively undeformed central parts. It is likely that some of the concordant metabasic sheets in the grey gneisses were also originally dykes or sills. There may be more than one generation of metadolerite dykes; three possible generations may be present in Okselandet, but it is not clear which generation, if any, correlates with the Midsommersø dolerites of Dronning Louise Land to the south-west (Friderichsen *et al.*, 1990).

Late granites and pegmatites. Pegmatites and granites are common throughout the region, many of them oriented at high angles to all earlier penetrative structures. Conspicuous swarms cut the metagabbroic bodies in Stormlandet and near Snenæs as noted above. On the east side of Fladebugt a prominent swarm of NNW striking pegmatites locally makes up 60 per cent of the outcrop. Late pegmatites with the same general strike are common in northern Store Koldewey and Lille Koldewey. An extensive granite vein complex occurs in Søndermarken south-west of V. Clausen Fjord. Pegmatites usually consist of coarse-grained K-feldspar, plagioclase, quartz and biotite, with hornblende, muscovite or magnetite as minor constituents.

Structural geology

Foliation and gneissosity are often uniformly oriented over large areas; approximately N–S strikes dominate in Nordmarken, Søndermarken and Okselandet, and roughly NE–SW strikes in Stormlandet, Skærfjorden and western Germania Land (Figs 5 & 6). However, on an outcrop scale, cross-cutting relationships and superimposition of structures permit distinction of at least three fabric forming events. As noted previously, the age of formation of the different crystalline rocks is uncertain, and is probably part Caledonian and part pre-Caledonian. The same can be said of the age of the three fabric forming events. The later upright folding is thought to be Caledonian, whereas some of the brittle faulting is post-Caledonian.

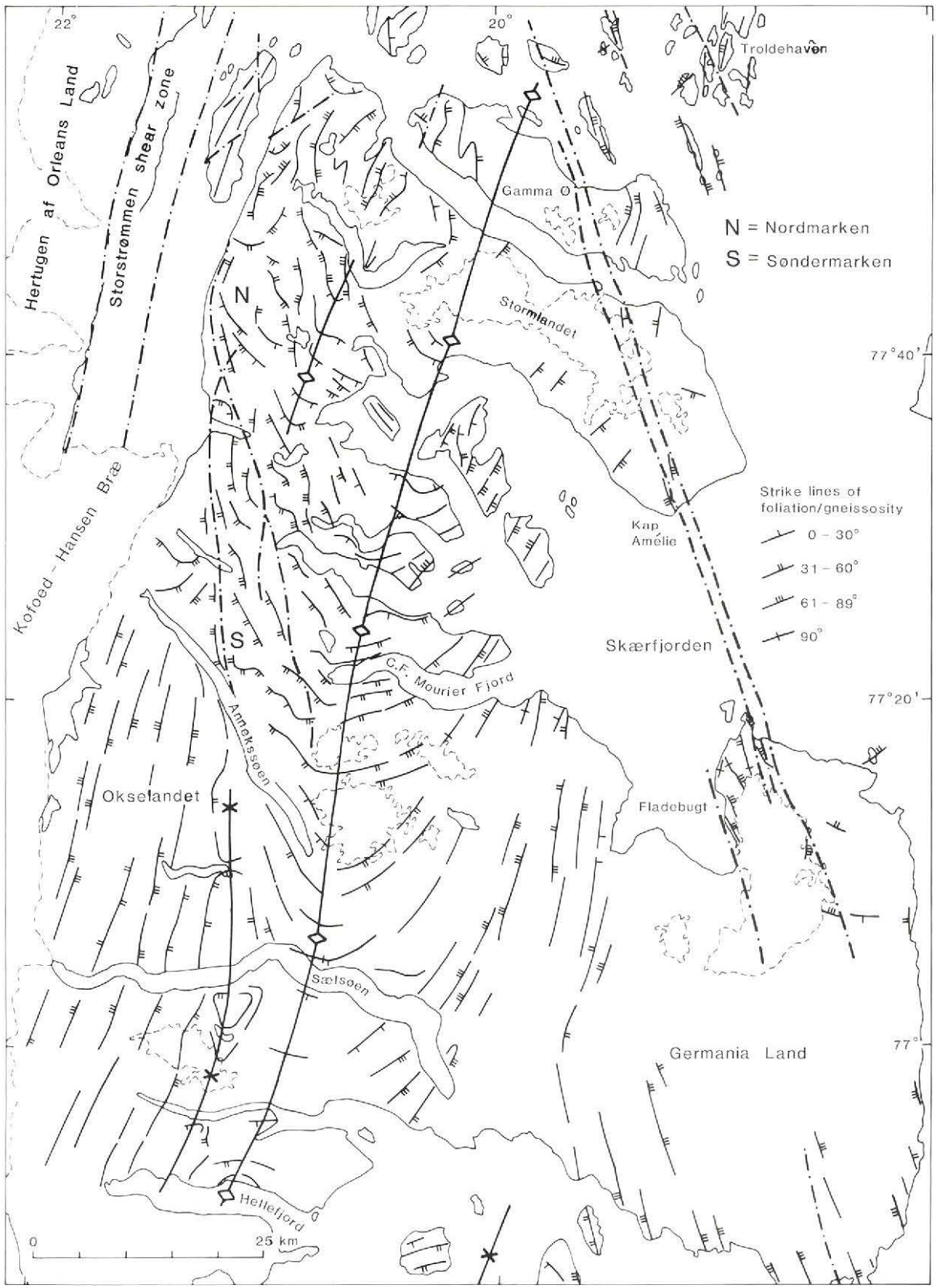
1st fabric event. Some of the high to very high grade mafic and ultramafic pods and boudins contain gneissosity and minor folds that are oblique to the fabric in the surrounding gneisses. Some of this obliquity is certainly due to rigid body rotation of the pods accompanied by shearing and displacement along their margins. However, it is also likely that some of the discordance reflects two fabric forming events; an earlier gneissosity formed during high grade metamorphism (1st fabric event) and a later gneissosity in the enveloping gneisses.

2nd fabric event. The main deformation event in the study area produced a penetrative schistosity and gneissosity accompanied by migmatisation under amphibolite facies conditions. Outcrop scale, inclined to reclined isoclinal folds were also produced. Map scale isoclines were only occasionally observed; for example, the discontinuous double band of marble in Søndermarken is probably a single layer repeated by isoclinal folding. Minor intrafolial isoclines plunge rather uniformly towards the south and north with shallow inclinations (Fig. 6). In general, hinge lines are subparallel to the dominant mineral and stretching lineations (Fig. 6). Boudin and augen structures are ubiquitous features of the study area, and dominate the structural style on the outcrop scale.

3rd fabric event. Several rock types (granitic rocks, basic dykes) cut the gneissosity and migmatitic fabric, and in turn were penetratively deformed at amphibolite facies conditions, indicating a 3rd fabric event. Rocks such as the metaporphyries have a schistosity and/or mineral/shape lineation, but no extensive development of gneissic banding. The larger structures associated with this late fabric are unknown. The earlier structures and fabrics were certainly modified to some extent by this deformation.

Late upright folds. Both the early gneissosity and later schistosity are folded on a map scale to large outcrop scale (Figs 5 & 6). These late folds are generally upright to somewhat inclined, and shallow plunging; axes plunge west to south in Søndermarken and north-east to south-west in Nordmarken. Hinges vary from broad and rounded to rather angular, and the minor folds are often markedly disharmonic. Most prominent is a N–S trending antiform traceable from Hellefjord in the south, across central Sælsøen, the head of C. F. Mourier Fjord, to Stormlandet and Gamma Ø (Fig. 5).

Mylonite zones. There are many small zones of relatively intense deformation in the study area, characterised by straight gneisses, pin-stripe gneisses, protomylonites and augen mylonites. Most of these deformation zones are rather local phenomena; shearing along the margin of a competent mafic pod, for example. Sets of steeply dipping large scale shear zones are found in


22°
20°
Troldehaven
Hertugen af Orleans Land
Storstrømmen shear zone
Gamma Ø
N = Nordmarken
S = Søndermarken
N
Stormlandet
77°40'
Kofoed-Hansen Bræ
Strike lines of foliation/gneissosity
0 - 30°
31 - 60°
61 - 89°
90°
Kap Amélie
S
Skærfjorden
C.F. Mourier Fjord
77°20'
Anneksøen
Fladebugt
Okselandet
Sælsøen
Germania Land
77°
Hellefjord
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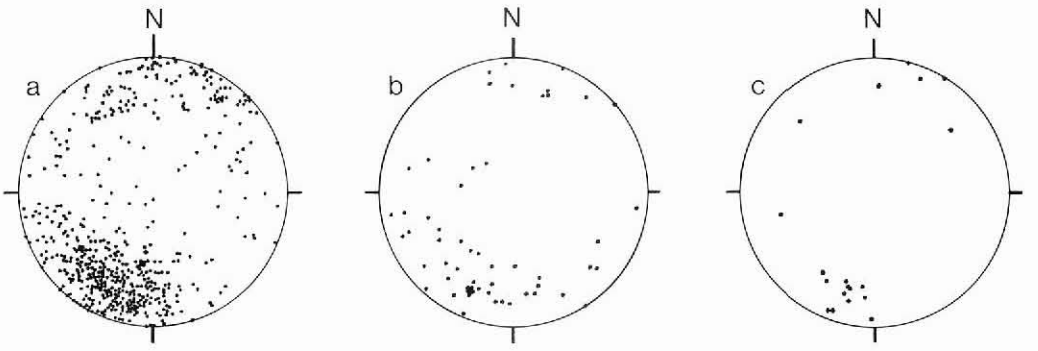

Fig. 6. Lower hemisphere, equal area stereograms of orientation data. (a) Mineral and stretching lineations (all lithologies); (b) Isoclinal hinge lines; (c) Fold axes of late, open to tight upright folds.

three areas: one along the west side of the study area (the Storstrømmen shear zone), another along the eastern side of Stormlandet and Germania Land, and a third on both sides of Lille Bælt.

The Storstrømmen shear zone, which follows the east side of Hertugen af Orléans Land, and continues southwards through Kofoed-Hansen Bræ to Storstrømmen, is described in detail by Strachan *et al.* (1991).

The eastern belt of mylonite zones extends from the northern islands around Troldehaven, south through east-central Gamma Ø, to eastern Stormlandet and into north-east Germania Land. In the north, these mylonite zones form the boundary between the grey gneiss complex to the west and the mafic amphibolites and metagabbros to the east, though both sets of rocks are cut by mylonites and the map pattern is more complex (Fig. 1). The mylonite zones probably formed late in the deformation history at amphibolite facies conditions.

Individual shear zones vary from metres to perhaps hundreds of metres in thickness, and may be many kilometres in length. The mylonitic rocks themselves are black, fine grained, augen (K-feldspar, plagioclase, quartz, hornblende) mylonites, orthomylonites and ultramylonites. Hornblende forms porphyroblasts. Mineral and/or stretching lineations plunge quite shallowly, though there is some variability and moderate plunges have been observed. Kinematic indicators, though sparse, consistently show sinistral movement on these zones. Overall the eastern system of mylonite zones is very similar to the Storstrømmen shear zone.

A zone of high ductile shear strain characterised by numerous thin mylonites forms a 5–6 km wide belt on both sides of Lille Bælt (between northern Store Koldewey and Lille Koldewey). All structures here have a NNW strike.

Brittle faults. Steeply dipping brittle fault zones form many of the prominent N–S trending topographic lineaments seen in the Skærfjorden and Dove Bugt region. Prominent zones can be traced along the west side of Nordmarken and Søndermarken as far as Annekssøen, from eastern Gamma Ø through eastern Stormlandet to north-east Germania Land, and along Store Koldewey. Zones of intense brittle deformation overprint higher grade mylonites at Storstrømmen, Kap Amélie and in eastern Germania Land. Small fault-bounded areas of unmetamorphosed sedimentary rocks are preserved along all these zones, and demonstrate that the latest movements on the faults are post-Caledonian. Brittle features are pervasive near the large faults but scattered brittle overprints are seen throughout the map area. Chlorite and epidote slickensides, and zones of breccia, gouge, foliated cataclasite, ultracataclasite, and pseudotachylite were all observed. Hydrocarbons (oil and tar) were found in a mineralised breccia zone on the east side of Fladebugt (Jensen & Stendal, 1990), and have presumably migrated from one of the post-Caledonian sedimentary sequences.

Fossils and spores recovered from the down-faulted post-Caledonian sedimentary rocks indicate Carboniferous, Jurassic and Cretaceous ages (Stemmerik & Piasecki, 1990; L. Stemmerik & S. Piasecki, personal communication, 1990).

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Fig. 5. Map of major structural features in Nordmarken, Germania Land, Okselandet and adjacent areas. Strike lines of dominant foliation with tick in dip direction and map trace of major folds are shown. Lille Koldewey and Store Koldewey lie south of the map boundary; see geological map of Fig. 2.

Conclusions

A tentative history of intrusion, deformation, and metamorphism has been established for the crystalline basement rocks of Nordmarken, Germania Land, and adjacent areas, based on field relationships. This chronology will certainly be modified and refined as a result of petrographic, geochemical, and geochronological studies that are currently underway, and should be considered provisional at best.

An early mafic to ultramafic complex deformed and metamorphosed at high to very high grades was intruded by a variable suite of granitic to mafic rocks of batholithic dimensions. Small lenses and layers of metasedimentary rocks including metapelites, quartzites, and marbles are also found. Isotopic data from the region indicate both Archaean and Early Proterozoic intrusive ages for the granitoid rocks. The polyphase plutonic suites were deformed, metamorphosed, and migmatised at amphibolite facies. Reclined to recumbent isoclinal folds probably dominate the structural style of this tectonic event.

A third intrusive suite of K-feldspar porphyries, leucogabbros, and at least two generations of mafic dykes cuts the main gneissosity, and is in turn deformed and metamorphosed at amphibolite facies conditions. Both the later schistosity and the earlier gneissosity are subsequently folded about upright hinge planes. Two major systems of amphibolite facies, steeply dipping, sinistral shear zones frame the study area; the Storstrømmen shear zone in the west, and a belt of mylonites in eastern Stormlandet and eastern Germania Land in the east. A third shear zone affects Lille Koldewey and northern Store Koldewey. These mylonite zones were active late in the Caledonian orogeny, and may be coeval with the late upright folds.

All rocks and structures are cut by late, high level faults. Fault bounded outcrops of Carboniferous and Mesozoic strata have been discovered in the study area, suggesting at least two periods of regional brittle deformation.

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