Geology of North-East Greenland (75°–78°N) – the 1988–90 mapping project

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The geological background for the 1988–90 mapping project in North-East Greenland is outlined. The principal geological units represented in the region between Grandjean Fjord and Jökelbugten include rocks of pre-Caledonian, Caledonian and post-Caledonian age. Particular reference is made to the articles resulting from the project which make up this Survey report.

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Geological investigations have been in progress in the East Greenland Caledonides for more than a century (Haller, 1971). However, most work in both the Caledonian fold belt and the post-Caledonian sequences has been carried out between the Scoresby Sund region in the south and Wollaston Forland in the north (between latitudes 70° and 76°N); the region farther north was until recently only known from a variety of reconnaissance investigations, which gave an incomplete picture of the geology. Since 1978 the Geological Survey of Greenland (GGU) has undertaken systematic mapping programmes in this little explored region including a variety of general and specialised geological investigations, from 1978–80 in eastern North Greenland (Peel & Sønderholm, 1991) and from 1988–90 in a sector of North-East Greenland extending from Grandjean Fjord (75°N) to Jökelbugten (78°N) (Henriksen, 1991).

In this paper brief reviews are given of geological work in East, North-East and eastern North Greenland prior to the 1988–90 GGU project, and the main geological divisions within the East Greenland Caledonides are outlined. The regional geology of the region between Grandjean Fjord (75°N) and Jökelbugten (78°N) is summarised on the basis of work during the 1988–90 project. Particular reference is made to the articles appearing in this volume which report on most aspects of work carried out during the project. Papers describing significant research results arising from the 1988–90 project have already appeared in a variety of international journals.

Previous geological work in East, North-East and eastern North Greenland

The earliest geological work in North-East Greenland was a byproduct of the activities of the German North Pole expedition of 1869–70 led by Karl Koldewey, and took the form of a report and geological sketch map of the region from 73° to 76°N (Hochstetter *et al.*, 1874); the northernmost point reached was Germania Land. The next major expedition to visit the region was the 1906–08 Danmark expedition, which explored and mapped the hitherto unknown region north of Germania Land from a base at Danmarkshavn. However, the geological results of this activity were very limited, the most significant being the discovery of Jurassic sediments on the east side of Store Koldewey, described by Ravn (1911). Lauge Koch's first East Greenland expedition of 1926–27, the forerunner of his celebrated series of East Greenland geological expeditions which continued until 1958, included a sledge journey from his base at Scoresbysund to Danmarkshavn, on the basis of which he prepared a regional geological map and concluded that the gneissic terrain of much of North-East Greenland had undergone Caledonian deformation and metamorphism (Koch, 1929). The geological work of Koch's later expeditions was concentrated in the region south of latitude 75°N, but occasional work, mainly of a reconnaissance nature, reached farther north. The most important of these was the visit by Max Sommer to the Eleonore Bay Supergroup outcrops in Ardencaple Fjord in 1955 (Sommer, 1957), and the description of the crystalline complexes of North-East Greenland by Haller (1956) based largely on aerial reconnaissance and a study of aerial photographs.

Geological work in North-East Greenland, apart from the activities of Lauge Koch's geologists, was very sporadic prior to the regional studies by GGU, although the southern part of the region as far north as Hvalrosodden and Danmarkshavn was often visited by expeditions supporting Danish and Norwegian hunting activities, as well as by other Danish and foreign privately sponsored expeditions. Louise Boyd's sixth arctic expedition in 1938, a good ice year, made a 'farthest north' landing by a ship

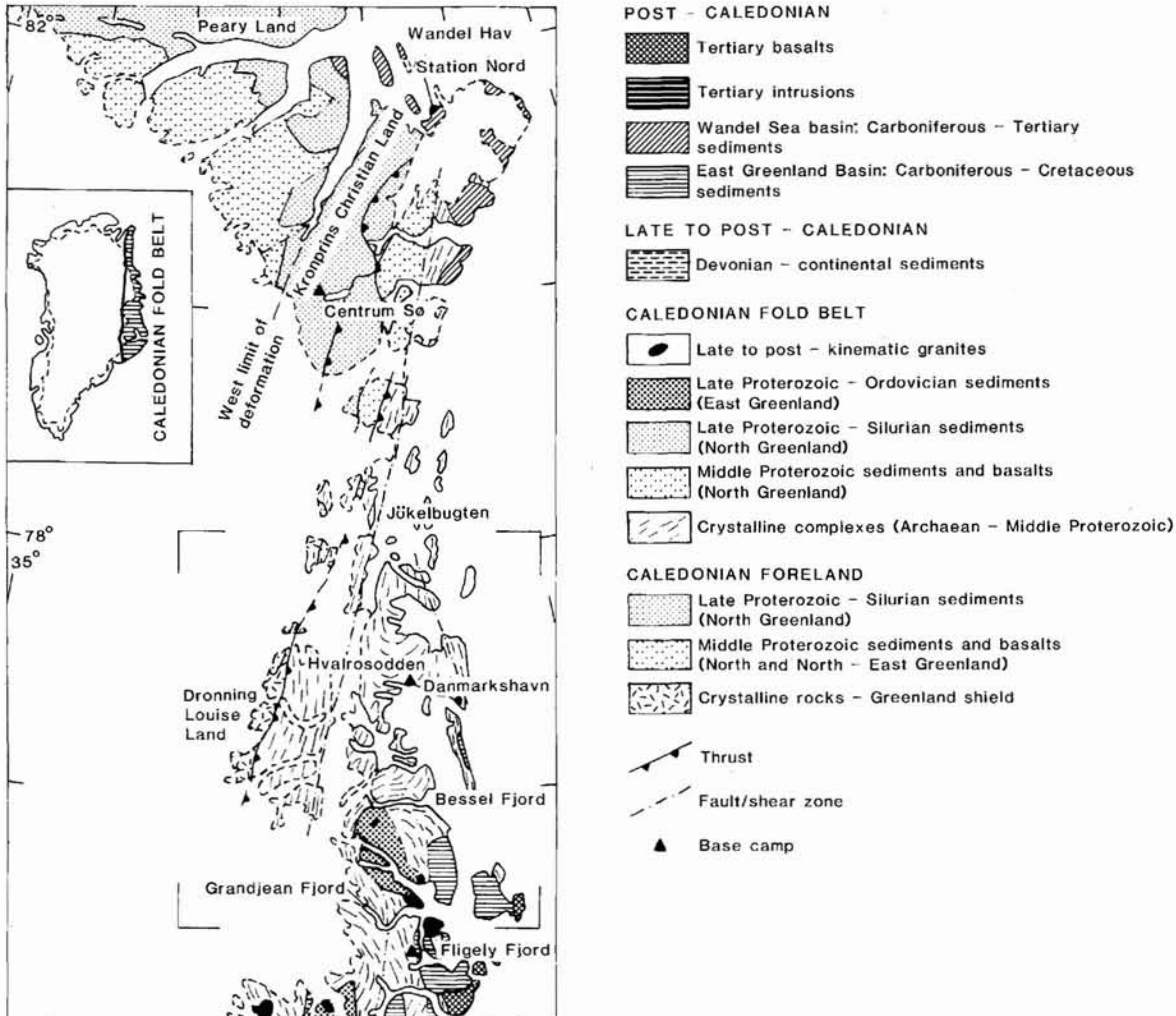

Fig. 1. Simplified geological map of East Greenland showing the Caledonian fold belt, the adjacent foreland and post- Caledonian units. The area outlined by the frame corners is the mapped region between 75°N and 78°N, shown in more detail in Fig. 2.

on the coast of Île de France (77°48'N) and explored many of the fjords of North-East Greenland; the short report by the geologist (Bronner, 1948) included scattered petrological observations, and a note of a find of 'bright green eclogite' near Danmarkshavn subsequently confirmed during GGU's 1988–90 expeditions (see e.g. Gilotti,1993). Much scientific work was carried out by Eigil Knuth's 'Dansk Nordøstgrønlands Ekspedition' of 1938–39 from a base north of the mouth of Mørkefjord, although the work of the only geologist was mainly in eastern North Greenland (Nielsen, 1941). The 1952–54 British North Greenland expedition was based at Britannia Sø in northern Dronning Louise Land, and activities here included important geological work; regional descriptions of the geology of Dronning Louise Land are given by Peacock (1956, 1958), while geological notes of a traverse along Sælsøen are found in Wyllie (1957).

A comprehensive account of the geology of the East Greenland Caledonides is presented by Haller (1971), and includes a historical section giving the development of ideas concerning the evolution of the Caledonides. The fieldwork on which this and Haller's other major regional studies (Haller, 1970; Koch & Haller, 1971) are based, pre-dates GGU's involvement in East and North-East Greenland.

GGU's 1988–90 expeditions to North-East Greenland (75°–78°N) reported here form a part of the Survey's systematic, regional geological work, a principal object being compilation of one of the geological map sheets in the Survey's 1:500 000 series (sheet 10). Studies in East Greenland began in 1968 in the Scoresby Sund region (70°–72°N), and were subsequently expanded into regions farther north. Isotopic age determinations carried out in association with these studies have supported reinterpretations of the fundamental structure of the Caledonian fold belt, summarised by Henriksen (1985, 1986), Henriksen & Higgins (1976) and Higgins & Phillips (1979). Some aspects of regional studies in the northernmost sector of the Caledonian fold belt, in Kronprins Christian Land, are included in the accounts of North Greenland geology by Henriksen (1992) and Peel & Sønderholm (1991).

Interest in the post-Caledonian geology of East Greenland has come into focus especially during the past few decades in connection with oil geological investigations, and extensive studies have been carried out by GGU, by the oil industry, and by projects organised by Copenhagen University and funded by the Danish Ministry for Energy. Recent offshore East Greenland geophysical work has been carried out by the 'Kanumas' project (funded by a consortium of oil companies) (Larsen & Pulvertaft, 1990), and by the Alfred Wegener Institute for Polar and Marine Studies, Bremerhaven. Onshore equivalents to the shelf sediments are mainly exposed to the north and south of the 75°–78°N study area (Christiansen & Pulvertaft, 1992; Stemmerik *et al.*, 1991).

GGU regional studies in North-East and eastern North Greenland will continue in 1993–95, one of the prime objectives being compilation of map sheet 9 in the Survey's 1:500 000 series covering the region 78°–81°N.

GGU's investigations in North-East Greenland 1988–90

The region between Grandjean Fjord and Jökelbugten, between latitudes 75° and 78°N (Fig. 1), was mapped between 1988 and 1990 for compilation of a 1:500 000 geological map sheet (sheet 10 in the Survey's 1:500 000 series), and associated regional geological investigations were carried out to provide an understanding of the general geology of the region. Special investigations aimed at evaluating the economic potential of the region were included in the work, and a study of the Quaternary geology was made in a transect through the northern part of the area. Glaciological studies were carried out in cooperation with a group from the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, Germany.

The field work organised by GGU took place over three seasons, starting in the south and progressing northwards to cover approximately one degree of latitude in each of the summer seasons (July–August). Field work was organised each season with support from a small fixed wing aircraft and two small helicopters (Henriksen, 1989, 1990, 1991). A tent base camp was established at Fligely Fjord (75°49'N, 20°46'W) in 1988, and at Hvalrosodden (76°57'N, 20°07'W) in 1989 and 1990. Geological field work was mainly carried out by two-man parties from small tent camps regularly moved using the helicopters, which also provided limited helicopter reconnaissance. Geological field investigations included 7 or 8 field teams in each of the three seasons. In addition, other groups took advantage of the logistic support organised by GGU, in 1988 a surveying party from the Geodetic Institute, Copenhagen, and in 1989 and 1990 biological and archaeological groups from Grønlands Landsmuseum, Godthåb/Nuuk. In all the expedition personnel numbered 31 participants in 1988, 47 in 1989 and 38 in 1990.

Prior to field work photogeological interpretation of the entire region between 75° and 78°N was undertaken in GGU's photogeological laboratory (Hougaard *et al.*, 1991). At the same time a new set of 1:100 000 topographic maps with 100 m contour intervals was prepared, based on aerial photographs and ground control points supplied by Kort- og Matrikelstyrelsen (KMS), formerly the Geodetic Institute.

Caledonian geology of East, North-East and eastern North Greenland

The East Greenland Caledonian fold belt extends from the Scoresby Sund region (70°N) to Kronprins Christian Land (81°N) as a continuous, 1200 km long coast-parallel belt (Fig. 1). The exposed onshore part of the fold belt is up to 300 km wide, but much of the western border zone against the Precambrian Greenland shield is covered by the Inland Ice.

The Caledonian fold belt at the present level of exposure is dominated by crystalline basement complexes, in some areas with a cover of Upper Proterozoic to Silurian sediments; both basement and cover were deformed during the Caledonian orogeny. In the eastern coastal areas the fold belt is partly concealed by post-Caledonian sediments of Upper Permian to Cretaceous age, while south of latitude 70°N the continuation of the Caledonian fold belt is hidden beneath Tertiary basalts.

Within the region shown in Figure 1, it is convenient to distinguish five major lithostructural divisions. All of these are represented to a greater or lesser extent in the Grandjean Fjord – Jökelbugten area.

(1) *The western marginal zone and foreland of the Caledonian fold belt.* The west margin of the Caledonian fold belt is characterised by major thrusts with substantial westward displacement. In the extreme north these are high level structures, affecting mainly Proterozoic and Lower Palaeozoic sedimentary sequences. Farther south, basement crystalline complexes and supracrustal units of various ages are involved, while in the extreme south the exposed thrust complexes mainly comprise units of crystalline basement. The marginal thrust zone is only well documented in a few sectors of the fold belt, but can be inferred to continue beneath the intervening segments of the Inland Ice. In the Scoresby Sund region, tectonic windows expose crystalline and supracrustal rocks beneath the thrust pile inferred to represent the Caledonian foreland (Phillips *et al.*, 1973). In Dronning Louise Land the foreland is well exposed west of a complex boundary thrust zone (Friderichsen *et al.*, 1990; Strachan *et al.*, 1992, 1994), while in Kronprins Christian Land a zone of major nappes is bordered by a zone of thin-skinned deformation with minor thrust displacement which propagates some distance into the foreland, here formed by a thick and extensive sedimentary platform sequence ranging in age from Upper Proterozoic to Silurian (Hurst *et al.*, 1985).

(2) *Caledonian and pre-Caledonian metamorphic complexes.* These are the dominant rock units in the fold belt, and include infracrustal rocks (gneisses, migmatites and granites) as well as supracrustal sequences (schists, quartzites, marbles). The infracrustal rocks include units yielding Archaean (3.0–3.3 Ga) and Lower Proterozoic (*c.* 1.7–2.0 Ga) protolith ages (Kalsbeek *et al.*, 1993), whereas the supracrustal units comprise sequences which have given Lower Proterozoic (1.9–2.1 Ga) and Middle Proterozoic (1.0–1.2 Ga) metamorphic ages (Hansen *et al.*, 1978; Rex & Gledhill, 1981; Strachan *et al.*, in press). The different sequences are deformed together in intricate fold and thrust patterns.

A long-standing problem of East Greenland geology has been an evaluation of the intensity of Caledonian reworking of the crystalline elements of the fold belt. Haller (1971) presented most clearly the then generally accepted viewpoint that all the gneissic terrain within the East Greenland Caledonides was developed during the rise of a Caledonian front of migmatisation to different levels within the late Proterozoic Eleonore Bay Group (now a 'Supergroup'). As noted above, isotopic studies have demonstrated the survival of Archaean and Proterozoic elements within the crystalline basement terrain, and it is now recognised that the basement complexes have a composite make up, and that the supracrustal enclaves preserved within them and the deformation phases affecting both infracrustal and supracrustal rocks may have a variety of ages (e.g. Henriksen & Higgins, 1976; Higgins *et al.*, 1981). As is reflected in some of the reports in this volume, there remains some uncertainty as to the extent and intensity of Caledonian orogenic activity even in areas mapped in great detail.

(3) *Middle Proterozoic – Ordovician/Silurian sedimentary sequences.* On the platform area in the foreland west of Kronprins Christian Land in eastern North Greenland an undeformed Middle Proterozoic sandstone sequence (the Independence Fjord Group) is overlain by Middle Proterozoic basalts – the Zig-Zag Dal Basalt Formation (Sønderholm & Jepsen, 1991). Equivalents to both these Middle Proterozoic units are also found in the foreland areas of western Dronning Louise Land and in the Caledonian nappes of Kronprins Christian Land together with older crystalline basement complexes.

Upper Proterozoic – Ordovician/Silurian sediments were laid down at the eastern border of the stable Greenland craton, at the west margin of the Iapetus Ocean. The sequences are mainly of miogeosynclinal character, deposited in a shallow water shelf regime, although locally deeper water sediments are found.

Between latitudes 72° and 76°N the sedimentary sequences comprise the Upper Proterozoic Eleonore Bay

Supergroup (Sønderholm & Tirsgaard, 1993), the Tillite Group (Hambrey & Spencer, 1987; Moncrieff & Hambrey, 1990) and Cambrian – Middle Ordovician sediments (Cowie & Adams, 1957; Hambrey *et al.*, 1989). In total the sequence has a cumulative thickness of more than 17 000 m.

In the Kronprins Christian Land region (*c.* 79°–81°N) the age-equivalent strata exhibit a different sedimentary development, as the region forms the easternmost extension of the Proterozoic – Lower Palaeozoic sedimentary basins which characterise North Greenland (Peel & Sønderholm, 1991). Here the shallow water Upper Proterozoic Hagen Fjord Group and its deep water correlatives (Sønderholm & Jepsen, 1991; Clemmensen & Jepsen, 1992) are overlain by Lower Ordovician to late Silurian platform carbonates and trough sediments (Higgins *et al.*, 1991).

(4) *Caledonian intrusives*. Late to post-kinematic acid to intermediate plutonic intrusions are widespread in the southern half of the fold belt (70°–76°N) but are lacking further north. Large intrusions are particularly abundant within a broad zone of migmatites in the central part of the Scoresby Sund region. Intrusions of leucocratic biotite-muscovite granite are also common along the contacts with the late Proterozoic Eleonore Bay Supergroup. The emplacement of these intrusions took place mainly after *c.* 480 Ma, although some older ages of up to 560 Ma could indicate the emplacement of older Caledonian plutonic rocks (Hansen & Steiger, 1971; Hansen *et al.*, 1972, 1973, 1994; Rex & Gledhill, 1981; Steiger *et al.*, 1979). Cooling and uplift following Caledonian regional metamorphism is recorded by K-Ar and $^{40}Ar/^{39}Ar$ mineral ages with the majority in the range 400–370 Ma, and a few somewhat older dates of up to *c.* 440 Ma (Rex & Higgins, 1985; Tucker *et al.*, 1993; Dallmeyer *et al.*, 1994; Dallmeyer & Strachan, 1994).

(5) *Late to post-Caledonian deposits*. A more than 11 000 m thick succession of Middle Devonian to Lower Permian continental sandstones of molasse type was deposited in intermontane basins in the southern part of the fold belt (70°–74°30'N). These deposits were formed during crustal stretching and extensional collapse which took place following the Caledonian orogenic shortening (Larsen & Bengaard, 1991; Olsen & Larsen, 1993; Surlyk, 1990). The main faulting took place between the mid-Devonian and early Carboniferous (Larsen & Marcussen, 1992). In the northern part of the Devonian basin four phases of deformation disturbed sedimentation (Bütler, 1959, 1961); the deformation was dominantly extensional, alternating with compressive and lateral faulting events. In the Jameson Land area middle Devonian to Carboniferous sediments are largely concealed by the younger deposits of the Jameson Land basin, but their presence is well documented from seismic data which reveal that the deepest part of the basin lies at depths of 16–18 km (Larsen & Marcussen, 1992).

A new tectonic and depositional regime was initiated in the Upper Permian with a long series of extensional events which continued into the Mesozoic; marine Upper Permian sediments rest with slight unconformity on the earlier continental clastic sediments in northern Jameson Land. The Jameson Land basin (70°–72°N) developed within continental crust deformed during the Caledonian orogeny, and preserves a considerable thickness of mainly marine Mesozoic sediments (Larsen & Marcussen, 1992; Surlyk, 1990) which have been the principal focus of oil exploration interests. Between Wollaston Forland (74°30'N) and Store Koldewey (76°30'N) the equivalent sequences mainly comprise Jurassic and Cretaceous sediments which rest directly on peneplaned Caledonian crystalline basement. The shelf areas off East Greenland preserve a series of fault-bounded sedimentary basins, with thick sequences of presumed Upper Palaeozoic and Mesozoic sediments (Larsen, 1990). In eastern North Greenland (north of 79°N) the Upper Palaeozoic to Cenozoic sedimentary developments are linked to rifting between Norway, Greenland and Svalbard (Håkansson *et al.*, 1991; Stemmerik & Håkansson, 1991).

The up to 3 km thick Tertiary basalt sequence which hides the southern continuation of the Caledonian fold belt south of Scoresby Sund, and the abundant sills and dykes which are especially conspicuous where they intrude post-Caledonian sediments, are related to events accompanying the Tertiary opening of the North Atlantic Ocean (Larsen & Marcussen, 1992; L.M. Larsen *et al.*, 1989).

Regional geology of the Grandjean Fjord – Jökelbugten area (75°–78°N)

The area covered by the 1:500 000 mapping project covers a north–south strike section of the Caledonian fold belt more than 300 km long and up to 250 km wide. For descriptive purposes this can conveniently be divided into a *c.* 100 km wide *western marginal zone*, and an up to 150 km wide *interior central zone* (Fig. 2, Table 1); the two zones are separated from each other by the *Storstrømmen shear zone* (Strachan & Tribe, 1994).

The *western marginal zone* is itself divided into two parts by a prominent NNE-trending and eastward dipping imbricate thrust zone, which marks the western limit of the Caledonian fold belt. The foreland to the west includes Early Proterozoic gneisses of the Precambrian Greenland shield (Laurentian basement), which are un-

Table 1. Main tectonic/stratigraphic divisions of the Grandjean Fjord – Jökelbugten region (75°–78°N), North-East Greenland

Quaternary	Glaciation / superficial deposits				
Tertiary (Eocene)					Plateau basalts, sills
M.Jur.-E.Cret.					Cont./marine sandst. and shales
U. Carboniferous					Continental sediments
	CALEDONIAN OROGEN				
	Western Marginal Zone				Interior Central Zone
	Foreland		E. Hinterland		
E. Carboniferous E. Devonian	Uplift / cooling and brittle deformation				
Silurian Latest Ordovician	Weak deformation & low grade metamorphism	Shear zones	Deformation and polyphase metamorphism *c.* 445-385 Ma Upright folds Thrusts Sheath folds Amph.-Greenschist facies	Shear zones	Granites *s. l.* Upright folds Isoclinal recumbent folds & thrusts 1-2 phases (partly pre-Caledonian?) Eclogite facies Amphibolite facies
Early Cambrian Late Proterozoic	Zebra Series	Imbricate thrust zone	Zebra Series	Storstrømmen shear zone South of 76°N	Eleonore Bay Supergroup (Upper Proterozoic) Metadolerites
Middle Proterozoic	? ↑ Dolerites Trekant Series		? ↑ Metadolerites Trekant Series		**GRENVILLIAN OROGENESIS** Metamorphism *c.* 1.0 Ga Granites & migmatisation? Metadolerites Smallefjord sequence Metadolerites?
	EARLY PROTEROZOIC OROGENY				
Early Proterozoic	Protoliths to gneiss *c.* 2 Ga		Granite sheets Protoliths to gneiss *c.* 2 Ga Gabbros		Granite sheets *c.* 1.75 Ga Deformation & metamorphism Protoliths to gneiss *c.* 2 Ga Gabbros, ultramafites & anorthosites Supracrustal rocks
Archaean	Early Proterozoic rocks contain components derived from Archaean sources				Danmarkshavn gneiss complex *c.* 3 Ga

conformably overlain by thin sedimentary sequences of the Middle Proterozoic Trekant Series and the Late Proterozoic – Early Cambrian Zebra Series. *Skolithos* trace fossils found in the Zebra Series point to an Early Cambrian age (Friderichsen *et al.*, 1990; Strachan *et al.*, 1992; Tucker *et al.*, 1993). The basement and the Trekant Series are intruded by dense swarms of dolerites, which may form up to 50% of the outcrop. These dolerites have been correlated with the *c.* 1250 Ma old Midsommersø Dolerites in eastern North Greenland (Jepsen & Kalsbeek, 1979; Kalsbeek & Jepsen, 1983). The region east of the imbricate thrust zone in Dronning Louise Land has been conveniently described as the 'eastern hinterland', and is made up of allochthonous Caledonian rock units. The reworked granitoid basement gneisses have yielded protolith ages of *c.* 1.9–2.3 Ma (Kalsbeek *et al.*, 1993; Tucker *et al.*, 1993) as well as Caledonian $^{40}Ar/^{39}Ar$ mineral ages (Dallmeyer *et al.*, 1994; Dallmeyer & Strachan, 1994). These gneisses are cut by metadolerites and amphibolite sheets inferred to be metamorphic equivalents of the dolerite swarms in the foreland. Synclinal inliers of metasediments in the basement gneisses are correlatives of the Proterozoic Trekant and Zebra Series (Strachan *et al.*, 1992). The finds of *Skolithos* in the Zebra Series of the foreland are clear evidence for the Caledonian age of the folding which deforms both metasediments and basement gneisses, and also for the age of the regional amphibolite facies metamorphism, which like the deformation increases in intensity from west to east.

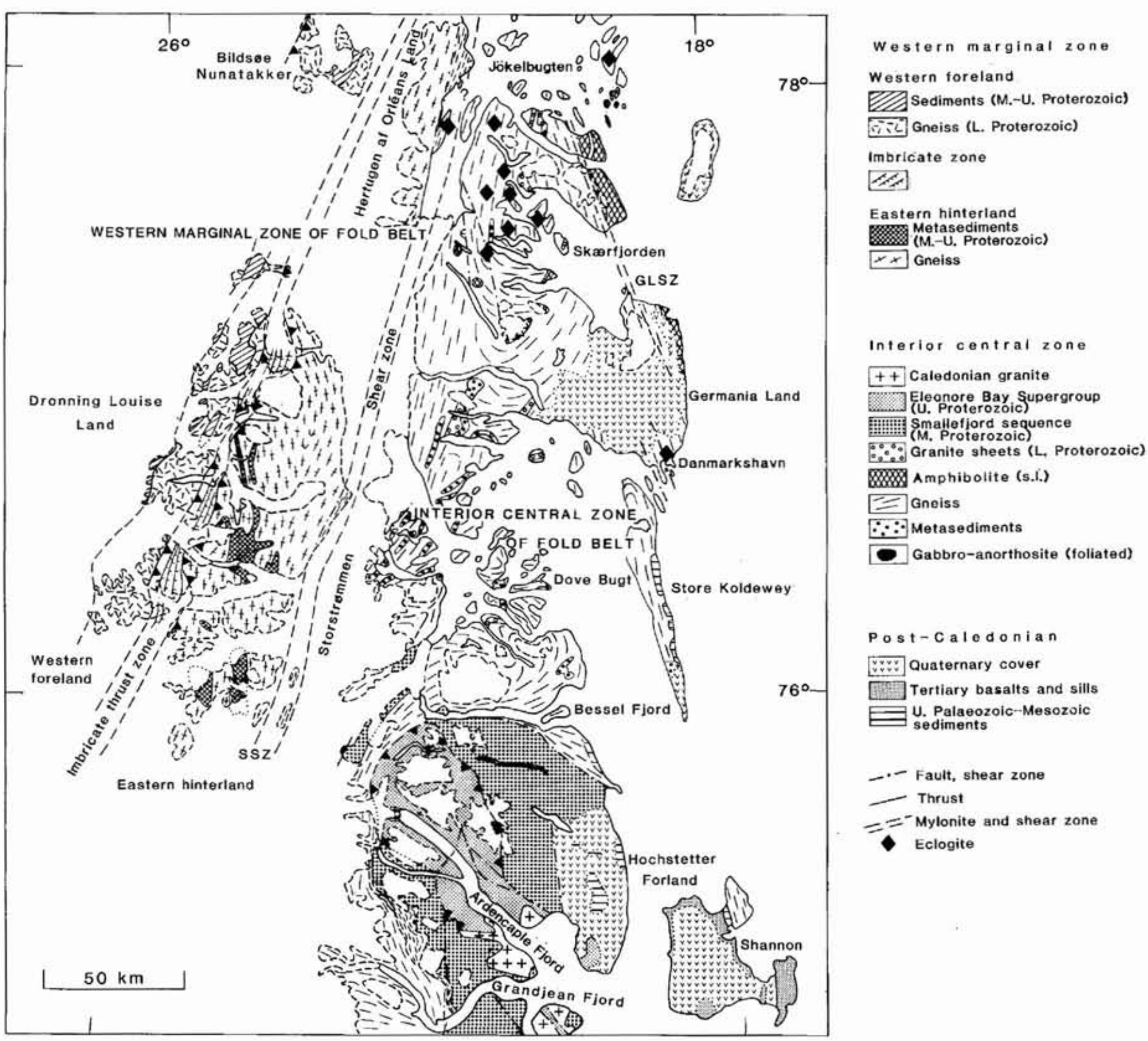

Fig. 2. Geological sketch map of the Grandjean Fjord – Jökelbugten region (75°–78°N) in North-East Greenland. This region is covered by the 1:500 000 map sheet (sheet no. 10; Dove Bugt).

A prominent NNE-trending sinistral shear zone, the *Storstrømmen shear zone*, separates the western marginal zone from the *interior central zone* (Fig. 2; Friderichsen *et al.*, 1990). The amount of displacement across the shear zone, which is up to 7 km wide, is unknown, but the similarities of lithologies on both sides suggest that it is more likely to be tens than hundreds of kilometres (Strachan *et al.*, 1991; Strachan & Tribe, 1994; Hull & Gilotti, 1994).

The *interior central zone* can be traced throughout the region between Grandjean Fjord in the south and Jökelbugten in the north (Fig. 2). It is dominated by infracrustal crystalline gneiss complexes, which have yielded early Proterozoic protolith ages (*c.* 2.0 Ga; Kalsbeek *et al.*, 1993). In the south the gneiss complexes are overlain by a Middle Proterozoic cover sequence, the Smallefjord sequence (Friderichsen *et al.*, 1994), which was deformed and metamorphosed around 1.0 Ga ago (Strachan *et al.*, unpublished data). The basement–cover boundary may have been the location of strong deformation during this Middle Proterozoic orogeny, but shearing along the contact was renewed and accentuated during the Caledonian.

The Upper Proterozoic *Eleonore Bay Supergroup* is preserved in a graben-like enclave centred on Ardencaple Fjord and bounded to the north-east and south-west by the Smallefjord sequence. This enclave trends NW–SE, oblique to the general trend of the fold belt. The Eleonore Bay Supergroup in this region comprises more than 6000 m of sediments, correlateable with the middle part of the over 14 km thick sequence known from its main area of outcrop further south (Sønderholm *et al.*, 1989). Soper & Higgins (1993) interpret the preservation of the Eleonore Bay Supergroup within the gneiss complexes, at Ardencaple Fjord and elsewhere in East Greenland, as a consequence of crustal extension in the Vendian; the marginal faults were reactivated as thrusts during the Caledonian orogeny (see also Higgins & Soper, 1994).

North of Bessel Fjord (76°N) the *interior central zone* is dominated by infracrustal rocks; there are supracrustal rocks locally, but no equivalents to either the Smallefjord sequence or the Eleonore Bay Supergroup. Grey orthogneisses dominate the infracrustal complexes, and are considered to have originated with a main period of crust formation which took place around 2000 Ma ago (Kalsbeek *et al.*, 1993). These orthogneisses are in many places cut by a variety of younger granitic rocks, of which two have yielded U-Pb zircon ages of 1764 and 1739 Ma (Kalsbeek *et al.*, 1993). Geochemical investigations of these granitic rocks suggest they are collision-type and post-orogenic granites. However, they are severely contaminated with older crustal material and are interpreted as representing remnants of an Early Proterozoic orogen formed near the margin of an Archaean continent (Kalsbeek, in press). In the Danmarkshavn area an occurrence of Archaean rocks has previously been documented by Steiger *et al.* (1976), but this area seems to be a relatively small enclave of Archaean age within the early Proterozoic terrain.

Within the gneiss complexes of the Dove Bugt – Jökelbugten region scattered bands and lenses of (?)early Proterozoic supracrustal rocks occur, associated with basic pods and amphibolitic bands (Chadwick *et al.*, 1990; Chadwick & Friend, 1991, 1994; Hull *et al.*, 1994). The supracrustal units include marbles, calc-silicates, semipelitic schists and siliceous rocks, some of which can be used as markers and traced over tens of kilometres. In parts of the Dove Bugt area leucogabbroic and gabbro-anorthosite bands and lenses are present, apparently older than the surrounding grey orthogneisses; they often preserve relict magmatic textures. Similar anorthositic rocks have been found on an isolated nunatak south-west of inner Bessel Fjord (Henriksen *et al.*, 1989). A Sm-Nd model age on this gave 2146 Ma, which is in agreement with the general age of crust formation in the region (Stecher & Henriksen, 1994).

Mafic dykes and sills occur as amphibolitic bands and lenses in many places in the Dove Bugt – Skærfjorden region (Hull, 1994). In detail they often have discordant relationships to the host gneisses, although in general they are conformable to the regional foliation trend. A dense swarm of mafic dykes occurs in the Danmarkshavn area, and swarms are also found in western Dove Bugt (Chadwick *et al.*, 1990). In north-east Germania Land and north of Skærfjorden large areas are dominated by a mafic plutonic complex (Fig. 2). There may be more than one generation of mafic intrusions, but most of those observed were emplaced after the formation of the gneiss complex and were subsequently subjected to amphibolite facies metamorphism. This metamorphism is probably of Caledonian age.

An unexpected new discovery was an extensive medium-temperature *eclogite province* centred on Germania Land and Skærfjorden (Gilotti, 1993, 1994), a confirmation of Bronner's (1948) report of an eclogite at Danmarkshavn. The eclogites occur as pods within the quartzo-feldspathic gneisses over an area extending more than 120 km from north to south. The presence of an extensive eclogite province in North-East Greenland indicates that the continental crust must have been overthickened during their formation; preliminary isotopic work suggests this was probably a Caledonian event (Gilotti & Brueckner, 1993).

The gneissic terrain between Dove Bugt and Jökelbugten is characterised by several phases of superimposed *folding and deformation* (e.g. Fig. 3). A study of the western Dove Bugt area (Chadwick *et al.*, 1990; Chadwick & Friend, 1991, 1994) has demonstrated the presence of at least four phases of folding, together with belts of mylonites. Two phases of early isoclinal folding produced major nappe scale structures, upon which were superimposed two phases of upright folds with north-westerly vergence. The early isoclinal folds deform sheets of 'younger' granites, and all four phases of structures have been interpreted as Caledonian by Chadwick & Friend (1994). North of Dove Bugt the earliest phase of deformation is represented by a penetrative deformation which gave rise to the gneiss foliation (Hull *et al.*, 1994). Minor isoclinal folds and intrafolial folds suggest the possible existence of major isoclinal structures here, but in this northern region the early Proterozoic younger granites seem unaffected by nappe-scale structures. The early deformational events north of Dove Bugt also predate the emplacement of the metabasic dykes, and both the younger granites and the metabasic dykes provide a means of separating the older structures from a younger deformational main event which is probably Caledonian. The Caledonian structures include penetrative deformation and formation of late, major upright folds and major shear zones displaying both ductile and brittle deformation (Hull & Gilotti, 1994). The Storstrømmen shear zone is the most conspicuous and most continuous of these shear zones (Strachan & Tribe, 1994).

Late to post-kinematic *Caledonian granitic* (s.l.) *intrusions* occur mainly in the Grandjean Fjord – Bessel Fjord region between 75° and 76°N. They are mainly emplaced in the boundary zone between the Eleonore Bay Supergroup and the adjacent metamorphic complexes, but some smaller intrusions are also found within the crystalline basement complexes. The Caledonian granites are generally undeformed, although some sheets and veins may show foliation, and where emplaced into the Smallefjord sequence or other basement complexes may be impossible to distinguish from older granitoid rocks. Geochemical and isotopic investigations on some of the Caledonian granites indicate a mixed origin; they were probably derived from melting of crustal material and emplaced *c.* 430–400 Ma ago (Hansen *et al.*, 1994).

Post-Caledonian rocks have a very restricted distribution between Grandjean Fjord and Jökelbugten (Piasecki *et al.*, 1994), although major fault-bounded basins are known to exist offshore, as well as beneath the waters of Dove Bugt west of Store Koldewey (Larsen, 1990). The present-day onshore exposures are associated with faults, and include Upper Palaeozoic sediments north and south

Fig. 3. Photomosaic of small scale refolded isoclinal folds in grey banded gneisses. Note early folded granitoid sheets (behind the hammer) and later cross-cutting, but deformed, granitic veins. North-west corner of Dove Bugt. Hammer handle is 40 cm long.

of Skærfjorden, and Middle Jurassic to Early Cretaceous sandstones on the east side of Store Koldewey and west of innermost Skærfjorden. All the outcrops rest unconformably on peneplaned crystalline basement. Tertiary basalts and intrusive rocks are represented only in the southernmost part of the area, on the island of Shannon (Fig. 2). The outcrops here, and in the Wollaston Forland and Pendulum Øer area immediately south of latitude 75°N, are described by Watt (1994).

On the basis of present knowledge the *economic mineral potential* of the region is considered to be low. Aspects of the mineral showings studied during the 1988–90 expedition are discussed by Jensen (1994) and Jensen & Stendal (1994). One of the most interesting mineralised localities is in north Germania Land where a pyrite-mineralised breccia was found to contain degraded crude oil; the oil is presumed to have migrated along a fault zone from a source rock of probable Upper Palaeozoic age (Christiansen *et al.*, 1991).

References

Bronner, F. E. 1948: Contributions to the geology. *In* Boyd, L. A. The coast of Northeast Greenland. *Am. Geogr. Soc. Spec. Publ.* **30,** 211–224.

Bütler, H. 1959: Das Old Red-Gebiet am Moskusoksefjord. Attempt at a correlation of the series of various Devonian areas in central East Greenland. *Meddr Grønland* **160**(5), 188 pp.

Bütler, H. 1961: Devonian deposits of central East Greenland. *In* Raasch, G. O. (ed.) *Geology of the Arctic* **1**, 188–196. Toronto, U.P.

Chadwick, B. & Friend, C. R. L. 1991: The high-grade gneisses in the south-west of Dove Bugt: an old gneiss complex in a deep part of the Caledonides of North-East Greenland. *Rapp. Grønlands geol. Unders.* **152**, 103–111.

Chadwick, B. & Friend, C. R. L. 1994: Reaction of Precambrian high-grade gneisses to mid-crustal ductile deformation in western Dove Bugt, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Chadwick, B., Friend, C. R. L. & Higgins, A. K. 1990: The crystalline rocks of western and southern Dove Bugt, North-East Greenland. *Rapp. Grønlands geol. Unders.* **148**, 127–132.

Christiansen, F. G. & Pulvertaft, T. C. R. 1992: Petroleum-geological activities in 1991: reassessment of areas of earlier exploration and improvement of information service to industry. *Rapp. Grønlands geol. Unders.* **155**, 28–30.

Christiansen, F. G., Bøjesen-Koefoed, J., Jensen, S. M. & Stemmerik, L. 1991: Oil seep in basement, Germania Land, North-East Greenland. *Open File Ser. Grønlands geol. Unders.* **91/7**, 29 pp.

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.

Cowie, J. W. & Adams, P. J. 1957: The geology of the Cambro-Ordovician rocks of central East Greenland. 1. Stratigraphy and structure. *Meddr Grønland* **153**(1), 193 pp.

Dallmeyer, R. D. & Strachan R. A. 1994: $^{40}Ar/^{39}Ar$ mineral constraints on the timing of deformation and metamorphism, North-East Greenland Caledonides. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Dallmeyer, R. D., Strachan, R. A. & Henriksen, N. 1994: $^{40}Ar/^{39}Ar$ mineral age record in NE Greenland – implications for tectonic evolution of the North Atlantic Caledonides. *J. geol. Soc. Lond.* **151**, 615–628.

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

Gilotti, J. A. 1993: Discovery of a medium-temperature eclogite province in the Caledonides of North-East Greenland. *Geology* **21,** 523–526.

Gilotti, J. A. 1994: Eclogites and related high-pressure rocks from North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Gilotti, J. A. & Brueckner, H. K. 1993: A new eclogite province in the Caledonides of North-East Greenland: preliminary thermobarometry and geochronology. *Terra Nova* **5,** *Abstr. Supp.* **4,** 11 only.

Håkansson, E., Heinberg, C. & Stemmerik, L. 1991: Mesozoic and Cenozoic history of the Wandel Sea Basin area, North Greenland. *Bull. Grønlands geol. Unders.* **160**, 153–164.

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). *Meddr Grønland* **171**(5), 286 pp.

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

Hambrey, M. J. & Spencer, A. M. 1987: Late Precambrian glaciation of central East Greenland. *Meddr Grønland Geosci.* **19**, 50 pp.

Hambrey, M. J., Peel, J. S. & Smith, M. P. 1989: Upper Proterozoic and Lower Palaeozoic strata in northern East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 103–108.

Hansen, B. T. & Steiger, R. H. 1971: The geochronology of the Scoresby Sund area, I: Rb/Sr mineral ages. *Rapp. Grønlands geol. Unders.* **37**, 55–57.

Hansen, B. T., Steiger, R. H. & Henriksen, N. 1972: The geochronology of the Scoresby Sund area, 2: Rb/Sr mineral ages. *Rapp. Grønlands geol. Unders.* **48**, 105–107.

Hansen, B. T., Frick, U. & Steiger, R. H. 1973: The geochronology of the Scoresby Sund area, 5: K/Ar mineral ages. *Rapp. Grønlands geol. Unders.* **58**, 59–61.

Hansen, B. T., Higgins, A. K. & Bär, M.-T. 1978: Rb-Sr and U-Pb age patterns in polymetamorphic sediments from the southern part of the East Greenland Caledonides. *Bull. geol. Soc. Denmark* **27**, 55–62.

Hansen, B. T., Henriksen, N. & Kalsbeek, F. 1994: Age and origin of Caledonian granites in the Grandjean Fjord – Bessel

Fjord region (75°–75°N), North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Henriksen, 1985: The Caledonides of central East Greenland 70°–76°N. *In* Gee, D. G. & Sturt, B. A. (ed.) *The Caledonide orogen: Scandinavia and related areas*, 1095–1113. London: Wiley & Sons Ltd.

Henriksen, N. 1986: Scoresby Sund, 1:500 000 sheet 12. Descriptive text. 27 pp. Copenhagen: Grønlands Geologiske Undersøgelse.

Henriksen, N. 1989: Regional geological investigations and 1:500 000 mapping in North-East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 88–90.

Henriksen, N. 1990: Regional geology and 1:500 000 mapping in North-East Greenland. *Rapp. Grønlands geol. Unders.* **148**, 16–20.

Henriksen, N. 1991: The North-East Greenland project 1988–1990. *Rapp. Grønlands geol. Unders.* **152**, 24–29.

Henriksen, N. 1992: Geological map of Greenland 1:500 000. Descriptive text. Nyeboe Land sheet 7, Peary Land sheet 8, 40 pp. Copenhagen: Grønlands Geologiske Undersøgelse.

Henriksen, N. & Higgins, A. K. 1976: East Greenland Caledonian fold belt. *In* Escher, A. & Watt, W. S. (ed.) *Geology of Greenland*, 182–246. Copenhagen: Geological Survey of Greenland.

Henriksen, N., Friderichsen, J. D., Strachan, R. A., Soper, N. J. & Higgins, A. K. 1989: Caledonian and pre-Caledonian geology of the region between Grandjean Fjord and Bessel Fjord (75°–76°N), North-East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 90–97.

Higgins, A. K. & Phillips, W. E. A. 1979: East Greenland Caledonides – an extension of the British Caledonides. *In* Harris, A. L., Holland, C. H. & Leake, B. E. (ed.) The Caledonides of the British Isles – reviewed. *Spec. Publ. geol. Soc. Lond.* **8**, 19–31.

Higgins, A. K. & Soper, N. J. 1994: Structure of the Eleonore Bay Supergroup at Ardencaple Fjord, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Higgins, A. K., Friderichsen, J. D. & Thyrsted, T. 1981: Precambrian metamorphic complexes in the East Greenland Caledonides (72°–74°N) – their relationships to the Eleonore Bay Group, and Caledonian orogenesis. *Rapp. Grønlands geol. Unders.* **104**, 5–46.

Higgins, A. K., Ineson, J. R., Peel, J. S., Surlyk, F. & Sønderholm, M. 1991: Lower Palaeozoic Franklinian Basin of North Greenland. *Bull. Grønlands geol. Unders.* **160**, 71–139.

Hochstetter, F. von, Lenz, O., Toula, F., Bauer, A. & Heer, O. 1874: Geologie. *In* Koldewey, K. (ed.) *Die Zweite Deutsche Nordpolarfahrt in den Jahren 1869 und 1870 unter Führung von Kapitän Karl Koldewey, Bd. II, Wissenschaftliche Ergebnisse, 471–517.* Leipzig: F. A. Brockhaus.

Hougaard, G., Jepsen, H. F. & Neve, J. 1991: GGU's photogeological laboratory: aerial photogrammetry – a valuable geological mapping tool in Greenland. *Rapp. Grønlands geol. Unders.* **152**, 32–35.

Hull, J. M. 1994: Metamorphosed basic dykes from the Skærfjorden region, 76–78°N, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Hull, J. M. & Gilotti, J. A. 1994: The Germania Land deformation zone and related structures, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Hull, J. M., Friderichsen, J. D., Gilotti, J. A., Henriksen, N., Higgins, A. K. & Kalsbeek, F. 1994: Gneiss complex of the Skærfjorden region 76°–78°N, North Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

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 Ltd.

Jensen, S. M. 1994: Lead isotope signatures of mineralised rocks in the Caledonian fold belt of North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Jensen, S. M. & Stendal, H. 1994: Reconnaissance for mineral occurrences in North-East Greenland (76°–78°N). *Rapp. Grønlands geol. Unders.* **162** (this volume).

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

Kalsbeek, F. 1994: Geochemistry, tectonic setting, and polyorogenic history of Palaeoproterozoic basement rocks from the Caledonian fold belt of North-East Greenland. *Precambrian Res.*

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 intrusive basic magma and sialic crust. *J. Petrol.* **24**, 605–634.

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.

Koch, L. 1929: The geology of East Greenland. *Meddr Grønland* **73** II (1), 1–204.

Koch, L. & Haller, J. 1971: Geological map of East Greenland 72°–76° N.Lat. (1:250,000). *Meddr Grønland* **183,** 26 pp.

Larsen, H. C. 1990: The East Greenland shelf. *In* Grantz, A., Johnson, (G.) L. & Sweeney, J. F. (ed.) The Arctic Ocean region. *The geology of North America* **L,** 185–210. Boulder, Colorado: Geol. Soc. America.

Larsen, H. C. & Marcussen, C. 1992: Sill-intrusion, flood basalt emplacement and deep crustal structure of the Scoresby Sund region, East Greenland. *In* Storey, B. C., Alabaster, T. & Pankhurst, R. J. (ed.) Magmatism and the causes of continental break-up. *Spec. Publ. geol. Soc. Lond.* **68**, 365–386.

Larsen, H. C. & Pulvertaft, T. C. R. 1990: Regional marine seismic reconnaissance. *Rapp. Grønlands geol. Unders.* **148**, 32–34.

Larsen, L. M., Watt, W. S. & Watt, M. 1989: Geology and petrology of the Lower Tertiary plateau basalts of the Scoresby Sund region, East Greenland. *Bull. Grønlands geol. Unders.* **157**, 162 pp.

Larsen, P.-H. & Bengaard, H.-J. 1991: Devonian basin initiation in East Greenland: a result of sinistral wrench faulting and Caledonian extensional collapse. *J. geol. Soc. Lond.* **148,** 355–368.

Moncrieff, A. C. M. & Hambrey, M. J. 1990: Marginal-marine glacial sedimentation in the late Precambrian succession of East Greenland. *In* Dowdeswell, J. A. & Scourse, J. D. (ed.)

Glacimarine environments: processes and sediments. *Spec. Publ. geol. Soc. Lond.* **53**, 387–410.

Nielsen, E. 1941: Remarks on the map and the geology of Kronprins Christians Land. *Meddr Grønland* **126**(2), 35 pp.

Olsen, H. & Larsen, P.-H. 1993: Lithostratigraphy of the continental Devonian sediments in North-East Greenland. *Bull. Grønlands geol. Unders.* **165**, 108 pp.

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.

Peel, J. S. & Sønderholm, M. (ed.) 1991: Sedimentary basins of North Greenland. *Bull. Grønlands geol. Unders.* **160,** 164 pp.

Phillips, W. E. A., Stillman, C. J., Friderichsen, J. D. & Jemelin, L. 1973: Preliminary results of mapping in the western gneiss and schist zone around Vestfjord and inner Gåsefjord, southwest Scoresby Sund. *Rapp. Grønlands geol. Unders.* **58**, 17–32.

Piasecki, S., Stemmerik, L. & Friderichsen, J. D. 1994: Stratigraphy of the post-Caledonian sediments in the Germania Land area, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Ravn, J. P. J. 1911: On Jurassic and Cretaceous fossils from North-East Greenland. *Meddr Grønland* **45**(10), 437–500.

Rex, D. C. & Gledhill, A. R. 1981: Isotopic studies in the East Greenland Caledonides (72°–74°N) – Precambrian and Caledonian ages. *Rapp. Grønlands geol. Unders.* **104**, 47–72.

Rex, D. C. & Higgins, A. K. 1985: Potassium-argon mineral ages from the Greenland Caledonides between 72° and 74°N. *In* Gee, D. G. & Sturt, B. A. (ed.) *The Caledonide Orogen – Scandinavia and related areas,* 1115–1124. London: Wiley & Sons Ltd.

Sommer, M. 1957: Geologische Untersuchungen in den praekambrischen Sedimenten zwischen Grandjeans Fjord und Bessels Fjord (75°–76°n.Br.) in NE-Grönland. *Meddr Grønland* **160**(2), 56 pp.

Sønderholm, M. & Jepsen, H. F. 1991: Proterozoic basins of North Greenland. *Rapp. Grønlands geol. Unders.* **160,** 49–69.

Sønderholm, M. & Tirsgaard, H. 1993: Lithostratigraphic framework of the Upper Proterozoic Eleonore Bay Supergroup of East and North-East Greenland. *Bull. Grønlands geol. Unders.* **167**, 38 pp.

Sønderholm, M., Collinson, J. D. & Tirsgaard, H. 1989: Stratigraphic and sedimentological studies of the Eleonore Bay Group (Precambrian) between 73°30' and 76°N in East Greenland. *Rapp. Grønlands geol. Unders.* **145**, 97–102.

Soper, N. J. & Higgins, A. K. 1993: Basement–cover relationships in the East Greenland Caledonides: evidence from the Eleonore Bay Supergroup at Ardencaple Fjord. *Trans. Roy. Soc. Edinb.: Earth Sci.* **84,** 103–115.

Stecher, O. & Henriksen, N. 1994: Sm–Nd model age of an early Proterozoic gabbro-anorthosite from the Caledonian fold belt in North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Steiger, R. H., Harnik-Šoptrajanova, G., Zimmerman, E. & Henriksen, N. 1976: Isotopic age and metamorphic history of the banded gneiss at Danmarkshavn, East Greenland. *Contrib. mineral. Petrol.* **57**, 1–24.

Steiger, R. H., Hansen, B. T., Schuler, C. H., Bär, M. T. & Henriksen, N. 1979: Polyorogenic nature of the southern Caledonian fold belt in East Greenland: an isotopic age study. *J. Geol.* **87,** 475–495.

Stemmerik, L. & Håkansson, E. 1991: Carboniferous and Permian history of the Wandel Sea Basin, North Greenland. *Bull. Grønlands geol. Unders.* **160**, 141–151.

Stemmerik, L., Christiansen, F. G. & Piasecki, S. 1991: Evaluation of the hydrocarbon potential onshore North-East Greenland (72°–75°N). *Rapp. Grønlands geol. Unders.* **152,** 13–16.

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., Jepsen, H. F. & Kalsbeek, F. 1991: Regional Caledonian structure of Hertugen af Orléans Land, North-East Greenland. *Rapp. Grønlands geol. Unders.* **152**, 95–102.

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.

Strachan, R. A., Friderichsen, J. D., Holdsworth, R. E. & Jepsen, H. F. 1994: Regional geology and Caledonian structure, Dronning Louise Land, North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Strachan, R. A., Nutman, A. P. & Friderichsen, J. D. in press: SHRIMP U-Pb zircon geochronology of the Smallefjord (metasedimentary) sequence: implications for crustal history and structure of the NE Greenland Caledonides. *J. geol. Soc. Lond.*

Surlyk, F. 1990: Timing, style and sedimentary evolution of Late Palaeozoic – Mesozoic extensional basins of East Greenland. *In* Hardman, R. F. P. & Brooks, J. (ed.) Tectonic events responsible for Britain's oil and gas reserves. *Spec. Publ. geol. Soc. Lond.* **55**, 107–125.

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.

Watt, W. S. 1994: Stratigraphy and correlation of the Tertiary plateau basalts in North-East Greenland. *Rapp. Grønlands geol. Unders.* **162** (this volume).

Wyllie, P. J. 1957: A geological reconnaissance through South Germania Land, Northeast Greenland, lat. 77°N, long. 18.5°W to 22°W. *Meddr Grønland* **157**(1), 66 pp.