GEOLOGICAL SURVEY OF DENMARK AND GREENLAND MAP SERIES 4 • 2009

Descriptive text to the Geological map of Greenland, 1:500 000, Dove Bugt, Sheet 10

Niels Henriksen and A.K. Higgins

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

Geological Survey of Denmark and Greenland Map Series 4

Keywords
East Greenland, Caledonian orogeny, geological mapping, Palaeoproterozoic, Mesoproterozoic, Neoproterozoic, thrust units.

Cover
Extract from the southern part of the Dove Bugt map sheet. An infracrustal complex with Palaeoproterozoic gneisses (**gn**$_1$) is overlain by Mesoproterozoic semipelitic schists and gneisses of the Smallefjord sequence (**S**). Younger Neoproterozoic metasedimentary rocks of the Eleonore Bay Supergroup are depicted by deeper bluish, green, brown and yellow colours all labelled by capital letters. The bright red colours are Caledonian intrusive granites (**gi**) that cut through the metasedimentary successions. All units have been reworked to varying degrees during the Caledonian orogeny.

Frontispiece: facing page
View north-eastwards from Ad. S. Jensen Land across the ice-covered waters of Dove Bugt, with Germania Land and the cliffs forming the west side of Store Koldewey on the horizon. The terrain in the foreground and on the islands in Dove Bugt comprises Palaeoproterozoic orthogneisses [**gn**$_1$] and metagranitoid sheets [**gn**$_2$], which form part of the Nørreland thrust sheet. The rocks have been extensively reworked during the Caledonian orogeny. Maximum altitudes are about 1000 m, and the narrowest part of Manniche Sø, nearest the camera, is about 500 m across. Oblique aerial photograph route 657F-NØ 13487, copyright: Kort & Matrikelstyrelsen (National Survey and Cadastre), Copenhagen, Denmark.

Chief editor of this series: Adam A. Garde
Scientific editor of this volume: Adam A. Garde
Editorial secretaries: Jane Holst and Esben W. Glendal
Referee: Ellen M.O. Sigmond, Geological Survey of Norway, Leiv Eirikssons Vei 39, N-7491 Trondheim, Norway
Illustrations: Eva Melskens
Digital photographic work: Benny M. Schark
Layout and graphic production: Annabeth Andersen
Printers: Schultz Grafisk, Albertslund, Denmark
Manuscript received: 6 October 2008
Final version approved: 26 June 2009
Printed: 1st October 2009

ISSN 1604-9780
ISBN 978-87-7871-255-4

Citation of the name of this series
It is recommended that the name of this series is cited in full, viz. Geological Survey of Denmark and Greenland Map Series.
If abbreviation of this volume is necessary, the following form is suggested: Geol. Surv. Den. Green. Map Series 4, 32 pp. + map.

Available from
Geological Survey of Denmark and Greenland (GEUS)
Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
Phone: +45 38 14 20 00, fax: +45 38 14 20 50, e-mail: geus@geus.dk

or at *www.geus.dk/publications/maps*


Germania Land
Store Koldewey
Dove Bugt
Manniche Sø

Contents

Abstract 5
Introduction 7
Geological setting 9
Caledonian foreland 11
Crystalline complexes 12
Trekant 'series' 12
Dolerite sills and dykes 13
Zebra 'series' 13
Caledonian orogen 13
Imbricate thrust zone 14
Western thrust belt 15
Nørreland thrust sheet 16
Crystalline gneiss complexes and associated rocks 16
Eclogites 17
Hagar Bjerg thrust sheet 18
Crystalline gneiss complexes 18
Mesoproterozoic metasedimentary rocks – Smallefjord sequence 18
Neoproterozoic sedimentary rocks – Eleonore Bay Supergroup 20
Caledonian orogenesis 21
Structures and tectonic units 21
Metamorphism and orogenic cooling 25
Granites 25
Post-Caledonian sedimentary rocks and Palaeogene basalts 26
Carboniferous sedimentary rocks 26
Jurassic–Cretaceous sedimentary rocks 26
Palaeogene basalts and sills 27
Quaternary 27
Mineralisation and oil geological indications 28
Acknowledgements 29
References 29

Abstract

Henriksen, N. & Higgins, A.K. 2009: Descriptive text to the Geological map of Greenland, 1:500 000, Dove Bugt, Sheet 10.
Geological Survey of Denmark and Greenland Map Series 4, 32 pp. + map.

The Dove Bugt 1:500 000 scale geological map sheet covers a segment of the East Greenland Caledonian orogen extending between latitudes 75°–78°N and longitudes 16°–29°W. The region was mapped in the summers of 1988–1990 as part of a regional Survey mapping programme, and the map sheet was printed in 1997.

The region covered by the Dove Bugt map sheet is dominated by Palaeoproterozoic gneiss complexes, with smaller amounts of Mesoproterozoic and Neoproterozoic metasedimentary rocks, and isolated strips of Palaeoproterozoic and Lower Palaeozoic sedimentary rocks. All these rock units have been reworked to a varying degree during the Caledonian orogeny. Post-Caledonian sedimentary rocks occur in the south-east corner of the map sheet area and as narrow, fault-bounded enclaves elsewhere, while Palaeogene basaltic lavas and sills crop out on the island of Shannon.

The rocks of the Caledonian orogen form a number of major thrust domains. The most extensive and structurally lowest is the Nørreland thrust sheet which is characterised by lenses and layers of medium-temperature, high-pressure eclogites. The Western thrust belt occupies a broad zone of eastern Dronning Louise Land that comprises Palaeoproterozoic gneiss complexes interleaved with Palaeoproterozoic and Palaeozoic metasedimentary rocks. This thrust domain is separated from the foreland rocks of western Dronning Louise Land by the Imbricate thrust zone. In the south-west part of the map sheet the highest structural domain, the Hagar Bjerg thrust sheet comprises three rock sequences: crystalline gneisses, the Mesoproterozoic Smallefjord sequence and the Neoproterozoic Eleonore Bay Supergroup.

The crystalline gneiss complexes that dominate the map sheet area and make up a significant proportion of the different Caledonian thrust domains have all yielded protolith ages of *c.* 2 Ga. They are attributed to a major period of crust formation in the Palaeoproterozoic. The gneisses have been variably affected by Caledonian deformation and metamorphism.

Authors' address

Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.

E-mail: *nielshen@mail.dk* and *akh@geus.dk*

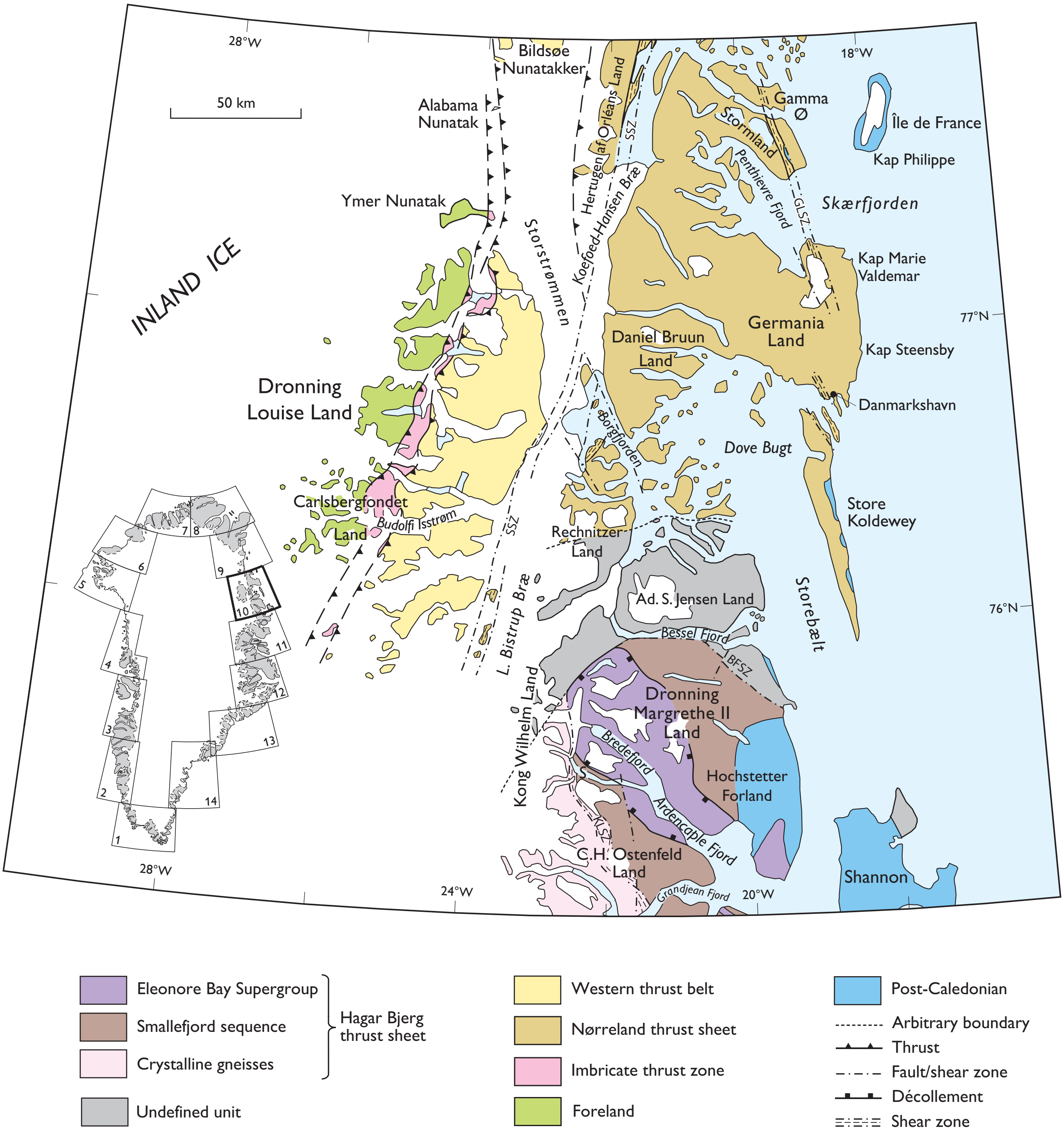


Fig. 1. Structural domains within the 1:500 000 Dove Bugt map sheet (Sheet 10). The N–S-trending Imbricate thrust zone crossing Dronning Louise Land separates the foreland from the Western thrust belt to the east. The contacts with the extensive Nørreland thrust sheet farther east (that in its northern part contains eclogites) are largely hidden beneath major glaciers; a hypothetical N–S-trending thrust contact is depicted along Storstrømmen running west of Hertugen af Orléans Land and merging to the south with the Storstrømmen shear zone (**SSZ**). An undefined unit north of the Bessel Fjord shear zone (**BFSZ**) may represent a higher structural level of the Nørreland thrust sheet. The south-dipping Bessel Fjord shear zone delineates the northern boundary of the Hagar Bjerg thrust sheet. **GLSZ**: Germania Land shear zone. **KLSZ**: Kildedalen shear zone.

Introduction

The Dove Bugt map sheet (sheet no. 10) is a bedrock geological map in the 1:500 000 scale regional map series of the Geological Survey of Denmark and Greenland (GEUS). It depicts the general geology of a segment of North-East Greenland between latitudes 75°–78°N and longitudes 16°–29°W (Fig. 1). The ice-free land area is up to 200 km wide, bordered to the east by the North Atlantic Ocean and to the west by the Inland Ice. Due to the high arctic setting, vegetation is sparse and exposures are generally excellent (see Frontispiece). On the legend of the map sheet, which was printed in 1997 (Henriksen 1997), the terms 'Lower', 'Middle' and 'Upper' are used for divisions of the Proterozoic corresponding to the Palaeoproterozoic, Mesoproterozoic and Neoproterozoic of current usage. Similarly, whereas the former traditional term 'Tertiary' is employed on the map sheet legend, the term Palaeogene (= lower Tertiary) is used in this description.

The Dove Bugt region (75°–78°N) forms part of the 1300 km long East Greenland Caledonian orogen (70°–81°30′N), and the structural terminology used in this map description is adapted from that defined in a recent volume describing the East Greenland Caledonian orogen (Higgins *et al.* 2008). Palaeoproterozoic crystalline gneiss complexes dominate the region, but these have been reworked to a varying degree during the Caledonian orogeny. Most of the rock units on the map sheet form parts of major Caledonian thrust sheets (Fig. 1), displaced westwards across the foreland that is preserved in the western zone of the large nunatak area of Dronning Louise Land. High-level thrust sheets occur south of Bessel Fjord (76°N), whereas the crystalline complexes extending through Dove Bugt and Skærfjorden are correlated with the deep-level Nørreland thrust sheet that is characterised by the presence of eclogitic enclaves. An intermediate-level Western thrust belt crops out in eastern Dronning Louise Land. Most of the structures and fabrics in the gneisses are of Caledonian age, but pre-Caledonian structures have survived in low-strain areas in the thrust sheets and in the foreland rocks of western Dronning Louise Land. The border of the Caledonian orogen against the foreland of the Precambrian Greenland shield is exposed as the 5 to 15 km wide north-south-trending Imbricate thrust zone in Dronning Louise Land (Fig. 1). Mesoproterozoic and Neoproterozoic sedimentary rocks occur south of Bessel Fjord, and are correlated with the upper part of the Hagar Bjerg thrust sheet in the Kong Oscar Fjord region (Sheet 11; Escher 2001). Post-Caledonian rocks are locally preserved, of which Upper Palaeozoic and Mesozoic deposits occupy small fault-bounded enclaves in northern parts of the map sheet area, and in its southern parts make up poorly exposed ground in Hochstetter Forland and on the island of Shannon. Palaeogene lavas and sills post-date the Mesozoic sediments on Shannon.

The broad structural domains recognised throughout the orogen (Fig. 2) have been outlined by Higgins & Leslie (2008), and the westward foreland-directed thrust systems described by Leslie & Higgins (2008). In the region to the south of Dove Bugt, there has been increased recognition during the past decade of the evidence for Caledonian extensional displacements associated with orogenic collapse (Strachan 1994; Hartz & Andresen 1995; Elvevold *et al.* 2000; Strachan *et al.* 2001; Gilotti & McClelland 2008), and the links with the formation of the late orogenic Devonian basins (Larsen *et al.* 2008).

North of the Dove Bugt map sheet boundary, within the Lambert Land map sheet (Sheet 9; Jepsen 2000), Proterozoic to Lower Palaeozoic volcanic and sedimentary rocks are widespread in Kronprins Christian Land (79°–81°30′N). Here, a complete E–W transition across the orogen is well preserved: from the undisturbed Caledonian foreland in the west (Higgins *et al.* 2001a, b), through a thin-skinned fold and thrust belt, to a region characterised by major westwards-directed Caledonian thrust sheets in the east (Leslie & Higgins 2008). South of the Dove Bugt map sheet boundary in the Kong Oscar Fjord region (Sheet 11; Escher 2001) major foreland windows and a series of major thrust sheets with displacements of hundreds of kilometres have been recognised (e.g. Elvevold *et al.* 2000; Higgins & Leslie 2000, 2008; Higgins *et al.* 2004).

The earliest geological work in the Dove Bugt region was carried out by scientists attached to pioneer exploration expeditions during the latter part of the 19th and the beginning of the 20th centuries. The first systematic reconnaissance work was undertaken during the series of East Greenland geological expeditions led by Lauge Koch between 1926 and 1958. These activities included the mapping of the region 75°–76°N published at a scale of 1:250 000 by Koch & Haller (1971), studies of the Neoproterozoic Eleonore Bay Supergroup around Ardencaple Fjord (Sommer 1957), and the regional geology of the structurally underlying crystalline complexes (Haller 1956). A British Joint Services expedition visited the nunatak area of Dronning Louise Land in 1952–1954, and their scientific results include the regional geological descriptions of Peacock (1956, 1958) and Wyllie (1957). John Haller's (1971) regional account of the geology of the East Greenland Caledonides includes a comprehensive account of these early investigations and the exploration history of the region. In addition to the published geological maps at 1:250 000 scale (Koch & Haller 1971) covering the southern part of the Dove Bugt region (75°–76°N), tectonic maps at a scale of 1:500 000 covering all the East Greenland Caledonides were compiled by Haller (1970). The 1:1 million scale geological map of the northern half of the East

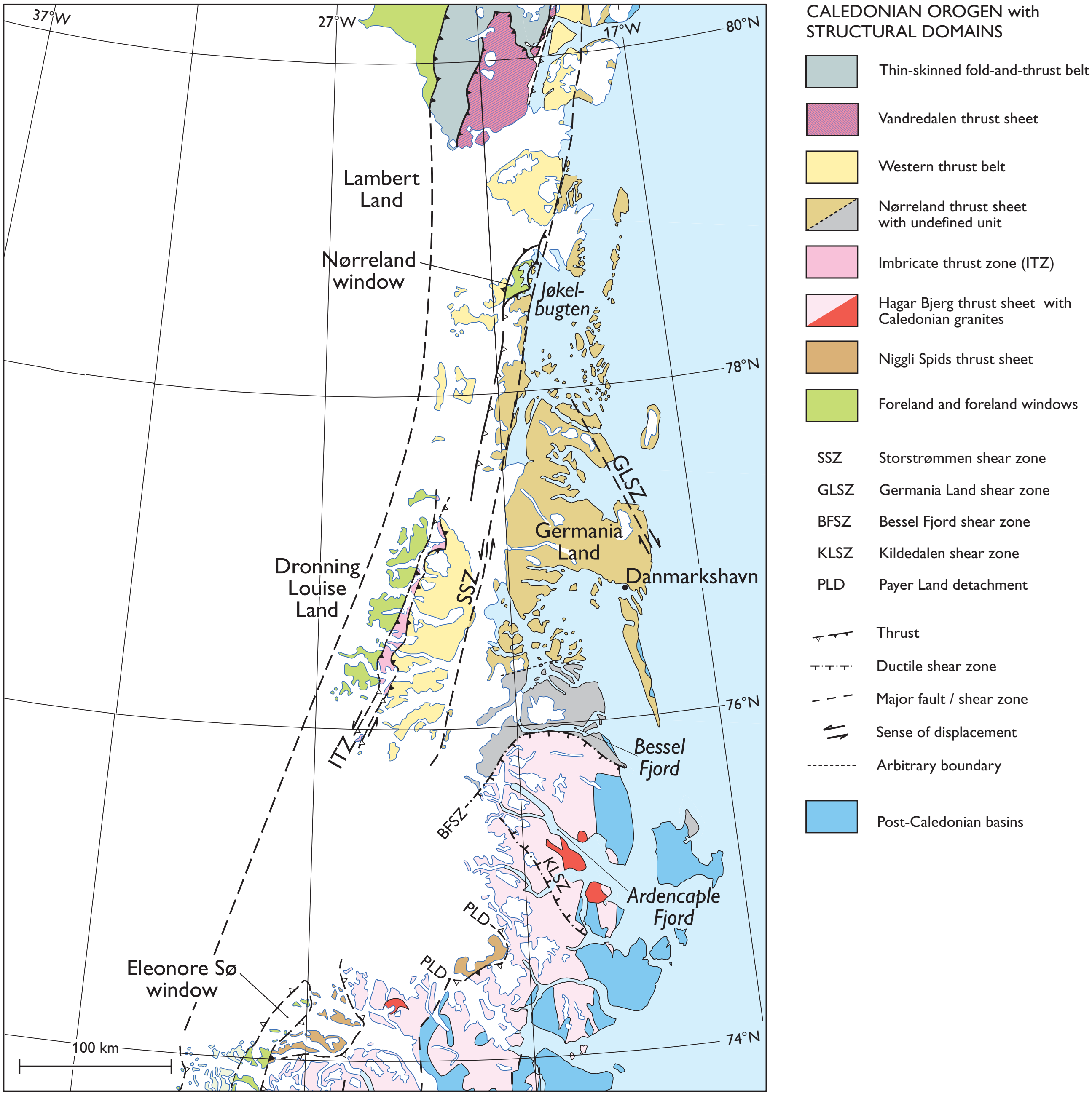


Fig. 2. Principal geological domains of central parts of the East Greenland Caledonides (from Higgins & Leslie 2008).

Greenland Caledonides (75°–82°N) accompanying Haller (1983) was originally compiled in 1964, and has been superseded by new geological mapping and interpretations. A new 1:1 million scale geological map of the entire East Greenland Caledonian orogen (70°–82°N) incorporating the new interpretations has been published by the Survey (Henriksen 2003; see also Henriksen & Higgins 2008).

New topographic maps of the Dove Bugt region at scale 1:100 000 with 100 m contours were drawn out in the Survey's photogrammetric laboratory as a basis for the Survey's regional geological mapping project in 1988–1990. At the same time Survey geologists undertook photogeological interpretations of the entire region between 75°N and 78°N (Hougaard *et al.* 1991). This photogrammetric work was based on super wide-angle aerial photography at a scale of *c.* 1:150 000, with ground control points supplied by Kort & Matrikelstyrelsen (National Survey and Cadastre).

The Survey's geological mapping of the Dove Bugt region was undertaken during the summer field seasons of 1988–1990 by a team of more than 20 geologists (see index map on the map sheet). A collection of 19 papers on the regional geology of this part of North-East Greenland (Higgins 1994), based on the results of the Survey's mapping campaign, supplements this map description and provides a summary of most aspects of the geology from Precambrian basement to Quaternary glacial deposits and glaciological studies. The printed Dove Bugt 1:500 000 scale geological map sheet was compiled on the basis of geological field maps mainly at scale 1:100 000 and photogeological interpretations, via a transitional draft at 1:250 000 scale.

Geological setting

The region covered by the Dove Bugt map sheet extends from Grandjean Fjord in the south (75°N) to Hertugen af Orléans Land in the north (78°N). With respect to the Caledonian orogen it can be divided into three principal geological regions (Fig. 1): (1) A western foreland area bordering the Inland Ice, which crops out in western Dronning Louise Land and Ymer Nunatak. This comprises part of the crystalline Precambrian craton and overlying Mesoproterozoic to Lower Palaeozoic sedimentary successions. The foreland outcrops of western Dronning Louise Land are separated from the allochthonous rocks of the Caledonian orogen by the 5–15 km wide Imbricate thrust zone. (2) The Caledonian orogen that is divisible into a series of major thrust domains: the Western thrust belt, the Nørreland thrust sheet, and south of Bessel Fjord, the northernmost representatives of the Hagar Bjerg thrust sheet (see below, and Fig. 2). The gneissic elements of the thrust domains are dominated by Palaeoproterozoic orthogneisses reworked during Caledonian orogenesis. (3) Post-Caledonian sediments and Palaeogene basalts and sills. The volcanic rocks are chiefly found in the south-eastern parts of the map area. Quaternary glacial deposits are widespread, but are only indicated on the map where they obscure the bedrock over extensive areas, mainly coastal lowlands such as Shannon and Île de France and the margins of major glaciers.

The major thrust domains of the Caledonian orogen are described here following the usage of Higgins & Leslie (2008), and include (Figs 1, 2):

1. The Imbricate thrust zone.
2. The Western thrust belt, which is a region of poorly defined thrust sheets made up of Palaeoproterozoic orthogneisses overlain by sandstones of the Trekant 'series', correlated with the Palaeoproterozoic Independence Fjord Group (Collinson *et al.* 2008) and in addition locally thin representatives of the Lower Cambrian and Lower Ordovician Zebra 'series' (Smith & Rasmussen 2008). The proportion of sandstones exposed in the individual thrust sheets decreases southwards throughout the Western thrust belt; sandstones dominate the northern part of the map sheet, in Lambert Land (79°15′N) and farther north, whereas gneisses dominate in eastern Dronning Louise Land.
3. The Nørreland thrust sheet, widely exposed in the Dove Bugt to Skærfjorden region and dominated by Palaeoproterozoic orthogneisses, but containing high-pressure eclogite xenoliths generated at depths of >50 km.
4. A thrust sheet assemblage regarded as the northernmost correlatives of the Hagar Bjerg thrust sheet. It is only preserved south of Bessel Fjord and comprises Palaeoproterozoic gneisses overlain by Mesoproterozoic metasedimentary successions (Smallefjord sequence) and the Neoproterozoic Eleonore Bay Supergroup.

The main orogenic events and the lithostratigraphic divisions recognised in the Dove Bugt region are summarised in Fig. 3. The crystalline gneiss terrain, both within the Caledonian orogen and in the western foreland areas, forms part of an extensive region of Palaeoproterozoic juvenile crust generated *c.* 2000 Ma ago, and with isotopic evidence of orogenic events until 1750 Ma ago (Kalsbeek *et al.* 1993, 2008a; Kalsbeek 1995). A small area of crystalline gneisses around Danmarkshavn (76°40′N) appears to be the only remnant of Archaean (*c.* 3 Ga) rocks within this segment of the Caledonian orogen (Steiger *et al.* 1976; Nutman & Kalsbeek 1994; Kalsbeek *et al.* 2008a).

Evidence for early Neoproterozoic thermal events (*c.* 950–930 Ma; Sveco-Norwegian, Fig. 3), is widely recognised in the Kong Oscar Fjord and Scoresby Sund regions (map sheets 11 and 12, Fig. 1) farther south in the East Greenland Caledonides (Kalsbeek *et al.* 2000, 2008b; Watt & Thrane 2001). In the Dove Bugt map area such events are limited to the high-grade metasedimentary rocks of the Smallefjord sequence that crop out south of Bessel Fjord (76°N); here, metamorphic growth rims dated at 955 ± 13 Ma occur on detrital zircon grains (Strachan *et al.* 1995b).

Representatives of the Neoproterozoic Eleonore Bay Supergroup are preserved in a fault-bounded enclave in the Bredefjord – Ardencaple Fjord area in the southern part of the map sheet area. This succession can be directly correlated at group and formation level with the main area of outcrop of the Eleonore Bay Supergroup between latitudes 72°–74°30′N, and exhibits Caledonian deformation and low to medium grade metamorphism (Sønderholm & Tirsgaard 1993; Soper & Higgins 1993; Higgins & Soper 1994; Gilotti *et al.* 2008).

Age in Ma not to scale	POST-CALEDONIAN SEDIMENTARY ROCKS AND BASALTS	
Quaternary	Glaciation and superficial deposits	
		Outer coastal regions
Palaeogene	Eocene	Basaltic sills [β_2]
	Eocene	Plateau basalts [β_1]
55	Barremian	Shales and sandstones [CB]
Early Cretaceous	Valanginian (*c.* 134 Ma)	Congl., sandstones, siltstones [CV]
Late Jurassic	Kimmeridgian (*c.* 152 Ma)	Sandstones and shales [JK]
	Callovian–Oxfordian (*c.* 160 Ma)	Sandstones [JC]
Early Jurassic	Hettangian (*c.* 203 Ma)	Continental sandstones with coal [J]
Late Carboniferous	Westphalian (*c.* 308 Ma)	Continental sandstones [C]

	Foreland	CALEDONIAN FOLD BELT	
		Western thrust belt	**Nørreland and Hagar Bjerg thrust sheets**
	Precambrian Greenland Shield	Imbricate thrust zone	Storstrømmen shear zone
Middle Carboniferous			Late pegmatites 315–320 Ma
Middle Devonian		Uplift, extension, cooling and brittle deformation 420 – *c.* 350 Ma	Uplift, extension, cooling and brittle deformation 420 – *c.* 350 Ma
400 Early Silurian			*Granite* [gi] (431– 428 ± 1–3 Ma)
	Caledonian overprint	Deformation and polyphase metamorphism	Deformation and polyphase metamorphism *Migmatisation*
Late Ordovician	Low-grade *metamorphism*	*Metamorphism* (amphibolite–greenschist facies)	*Metamorphism* (445 ± 10 – *c.* 390 Ma) (eclogite facies; amphibolite – low greenschist facies)
	Weak deformation	Upright folds	Upright folds (two phases)
		Thrusts	Thrusts
	Zebra 'series 2' [Z] *c.* 480 Ma	Sheath folds	Early isoclinal folding; nappe-scale structures
Cambrian		Zebra 'series' [Z]	
542	Zebra 'series 1' [Z] *c.* 520 Ma		Eleonore Bay Supergroup [YG, SB, KA, BZ, ST, KF, NG] (deposition *c.* 900 – 660 Ma?)
			Metadolerites
Neoproterozoic			**SVECO-NORWEGIAN OROGENY** (south of 76°N) *Metamorphism* (955 ± 13 Ma) *Granites / migmatisation / deformation* Metadolerites
Mesoproterozoic			Smallefjord sequence [S] (deposition 1035–955 Ma)
	Dolerites [δ]	Dolerites [δ]	Metadolerites
	Trekant 'series' [T] ~ 1740 Ma?	Trekant 'series' [T]	
		PALAEOPROTEROZOIC OROGENY	**PALAEOPROTEROZOIC OROGENY**
		Granite sheets	*Granite sheets* [g] (1764 ± 20; 1739 ± 11 Ma)
			Deformation (early isoclinal folds) *Metamorphism* (1967 ± 8 Ma) *Migmatisation*
Palaeoproterozoic		Gneiss complex [gn_1 & gn_2]	Gneiss complex [gn_1 & gn_2] (1963 ± 6 Ma; 1974 ± 17 Ma) Gabbros, mafic dykes, ultramafites, anorthosites
	Gneiss complex [gn_3] 2.3–2.5 Ga		Supracrustal rocks
2500			**ARCHAEAN OROGENY**
Archaean	(Archaean sources)		Danmarkshavn gneiss complex [gn_1] (2725–3000 Ma)

Fig. 3. Summary of orogenic events and lithostratigraphic divisions in the Dove Bugt region. Letter combinations in square brackets are those used on the printed map sheet.

Caledonian granites, generated by melting of the metasedimentary Smallefjord sequence, and emplaced into the lower levels the Eleonore Bugt Supergroup in the Ardencaple Fjord region, have been dated to *c.* 431–428 Ma (late Early Silurian; Strachan *et al.* 2001; Kalsbeek *et al.* 2008b).

Rock sequences post-dating the Caledonian orogeny occur mainly in the outer coastal region, where small areas of Carboniferous and Jurassic–Cretaceous sedimentary rocks are preserved mainly in fault-bounded outcrops. Palaeogene (lower Tertiary) basalts unconformably overlie Mesozoic sediments on the island of Shannon in the south-east corner of the map sheet, where sills are particularly prominent. These post-Caledonian rocks are described in a separate section below.

The descriptions below follow that of the legend on the map, with modifications to accord with present-day knowledge, and are presented in three sections: (1) Caledonian foreland. (2) Caledonian orogen. (3) Post-Caledonian sedimentary rocks and basalts.

Caledonian foreland

Western Dronning Louise Land, and Ymer Nunatak located immediately to the north, are interpreted as Caledonian foreland (Figs 1, 4). These areas form parts of the Precambrian Greenland craton, which made up part of the eastern margin of the North American continent of Laurentia. However, western Dronning Louise Land exhibits Caledonian deformation, decreasing in intensity westwards from the Imbricate thrust zone, and is thus parautochthonous rather than strictly autochthonous foreland. The Palaeoproterozoic to Lower Palaeozoic successions (see below) overlying the crystalline gneisses in western Dronning Louise Land can be correlated with those of equivalent age in the foreland windows along the length of the orogen (Higgins *et al.* 2001a; Smith *et al.* 2004; Collinson *et al.* 2008; Smith & Rasmussen 2008).

The western foreland of Dronning Louise Land is dominated by Palaeoproterozoic crystalline gneiss complexes [**gn**$_3$], unconformably overlain by two sedimentary sequences, the Trekant 'series' [**T**] and Zebra 'series' [**Z**] (Fig. 4), which are separated by a major hiatus of over 1 Ga. The latter two names correspond to the original descriptions of Peacock (1956, 1958). The stratigraphic terminology has been revised since the map sheet was printed (see below). The Palaeoproterozoic Trekant 'series' and underlying gneisses have been intruded by dense swarms of doleritic sheets and dykes [δ], which are of presumed Mesoproterozoic age. The overlying younger Zebra 'series' is Lower Cambrian and Lower Ordovician in age, and is not cut by dyke swarms; it rests unconformably on either crystalline gneisses or the sediments of the Trekant 'series' (Fig. 5; Strachan *et al.* 1994).

Fig. 4. The foreland terrain of southern Dronning Louise Land, looking north-north-west. The nunataks are mainly comprised of varied gneisses [**gn**$_3$] cut by thick dykes and sheets of metadolerite [**δ**]. The gneisses are unconformably overlain to the west (left side of photograph) by light-coloured sandstones of the Trekant 'series' [**T**] dipping westwards at low angles. The highest peaks reach 2300 m, about 700 m above the adjacent glacier surface. The field of view in the near foreground is 7 km wide. Photograph from Lauge Koch's aerial photograph collection, Geological Museum, Copenhagen.

Crystalline complexes

The amphibolite facies gneiss complexes [$\mathbf{gn_3}$] of western Dronning Louise Land are for the most part homogeneous granitoid orthogneisses. Concordant sheets of amphibolite are commonly found associated with the orthogneisses, and local metasedimentary units up to 100 m thick (schists, metapsammites, marbles) can be traced along strike for distances of several kilometres (Friderichsen *et al.* 1990; Strachan *et al.* 1992, 1994). The gneisses have yielded Sm-Nd model ages of *c.* 2.51, 2.35 and 2.29 Ga interpreted as protolith ages (Kalsbeek *et al.* 1993). The Caledonian thermal overprint is reflected in ^{40}Ar/^{39}Ar mineral ages of *c.* 390 Ma (Dallmeyer & Strachan 1994).

Trekant 'series'

The Trekant 'series' [**T**] comprises a sequence of sandstones, siltstones and conglomerates (Fig. 4), up to 510 m thick, which is cut by swarms of basic dykes. Representatives of the Trekant 'series' also occur in the Imbricate thrust zone, and correlatives (see below) are found in eastern Dronning Louise Land and other parts of the Western thrust belt.

The Trekant 'series' has been correlated with the Palaeoproterozoic Independence Fjord Group of the Caledonian foreland of eastern North Greenland (Clemmensen & Jepsen 1992; Kalsbeek *et al.* 1999; Pedersen *et al.* 2002; Collinson *et al.* 2008). Swarms of basic dykes and sills (the Midsommersø Dolerites) intruding the Independence Fjord Group have given Rb-Sr whole-rock ages of *c.* 1230 Ma (Kalsbeek & Jepsen 1983). Recent U-Pb geochronological studies of baddeleyite from a dolerite sample have yielded a somewhat older age of 1382 ± 2 Ma (Upton *et al.* 2005; Collinson *et al.* 2008). Widespread sandstone successions with basic intrusions are also found in Caledonian thrust sheets in Kronprins Christian Land, eastern North Greenland, and a correlation with the Independence Fjord Group of the foreland has usually been assumed. Ion microprobe U-Pb zircon ages on rhyolitic volcanic rocks interbedded with the sandstones in the Caledonian thrust sheets, indicate that deposition of these sandstones extended back to at least 1740 Ma. (Kalsbeek *et al.* 1999; Pedersen *et al.* 2002). Thus, the most probable interpretation is that the age of the sandstones attributed to the Independence Fjord Group ranges from *c.* 1740–1380 Ma. Alternatively, there could be two sandstone successions of identical appearance but significantly different ages.

Fig. 5. Folded, thin-bedded, light-coloured sandstones of the lowermost Zebra 'series' [**Z**] unconformably overlying sandstones and siltstones of the Trekant 'series' [**T**] at Prins Axel Nunatak, northern Dronning Louise Land. View towards the south. Cliff height about 120 m. Photo: J.D. Friderichsen.

In eastern North Greenland siltstone units interbedded with sandstones of the Independence Fjord Group on the foreland have yielded Rb-Sr whole-rock age data suggesting that diagenesis took place at about 1380 Ma (Larsen & Graff-Pedersen 1980). No isotopic age data are available for the Trekant 'series' in Dronning Louise Land. However, if the succession corresponds to the older part of the age range suggested for the Independence Fjord Group, there might be only a comparatively short time gap (~250 Ma?) between the protolith age of the crystalline gneiss complexes and deposition of the overlying Trekant 'series'.

Dolerite sills and dykes

Dolerite intrusions [δ] form dense swarms cutting the Trekant 'series' and underlying basement gneisses (Fig. 4), and locally form up to 50% of the outcrop (Peacock 1958; Strachan *et al.* 1992). The intrusions vary in thickness from a few metres to over 100 m, and have been compared to the Midsommersø Dolerites that cut the Independence Fjord Group of eastern North Greenland (Jepsen & Kalsbeek 1979; Kalsbeek & Jepsen 1983; Pedersen *et al.* 2002).

Zebra 'series'

The Zebra 'series' [**Z**] is a thin sequence of shallow marine quartzites, mudstones, magnetite-hematite-bearing sandstones and limestones, which unconformably overlie the Trekant 'series' (Fig. 5). The sequence is less than 100 m in thickness, and is not intruded by dolerites. At the base there is an angular discordance of 5–20° with the Trekant 'series' (Strachan *et al.* 1992). Thicker representatives of the Zebra 'series' are present in the Imbricate thrust zone where it contains *Skolithos* and *Cruziana sp.* trace fossils (Strachan *et al.* 1994) that date the series to the earliest Cambrian (Crimes 1992; Smith *et al.* 2004).

The quartzites of the Zebra 'series' (Zebra 'series 1' of Smith & Rasmussen 2008) have been correlated with the Kap Holbæk Formation of eastern North Greenland (81°N), the Slottet Formation of the Eleonore Sø and Målebjerg windows (73°45′–74°N) and the Kløftelv and Bastion Formations of the central fjord zone (71°45′–74°N; Smith *et al.* 2004; Smith & Rasmussen 2008). The formations in the foreland and parautochthonous foreland windows contain well-developed *Skolithos* (Higgins *et al.* 2001a). The upper limestones of the Zebra 'series' (Zebra 'series 2' of Smith & Rasmussen 2008) have been correlated with the Målebjerg Formation of the Eleonore Sø and Målebjerg windows (73°45′–74°N) and the Danmarks Fjord Member of the Ordovician Wandel Valley Formation in North Greenland (Smith & Rasmussen 2008).

Caledonian orogen

The Dove Bugt map area is dominated by rock units that form part of the Caledonian orogen; the conventional synonymous term 'fold belt' is used on the map sheet legend. As noted above, the western margin of the Caledonian orogen is well exposed in the nunatak area of Dronning Louise Land as a NNE–SSW-trending Imbricate thrust zone (Figs 1, 6, 7). In the crystalline complexes that dominate the Dove Bugt map sheet, various orthogneisses are distinguished, together with minor occurrences of amphibolite, anorthosite and ultrabasic rocks. Subsequent work north and south of the map sheet boundary has facilitated regional divisions of the Caledonian orogen into structural domains (Fig. 2; Higgins & Leslie 2008). Thus eastern Dronning Louise Land forms the southernmost part of the so-called Western thrust belt. The widespread Palaeoproterozoic felsic orthogneisses and associated metadioritic to metagabbroic rocks that occupy the broad coastal region around Dove Bugt and Skærfjorden are part of the high-grade Nørreland thrust sheet that extends southwards via a lower-grade undefined unit (Figs 1, 2) to the E–W-trending Bessel Fjord shear zone. The Mesoproterozoic metasedimentary rocks of the Smallefjord sequence and the Neoproterozoic Eleonore Bay Supergroup crop out in a restricted area around Ardencaple Fjord and Bredefjord in the southern part of the map, and the Smallefjord sequence has tectonic contacts against adjacent Palaeoproterozoic gneisses. These latter units are included in the Hagar Bjerg thrust sheet (Fig. 2). Caledonian granite intrusions, produced by partial melting of metasedimentary rocks belonging to the Smallefjord sequence, form widespread lenses and large bodies in the Smallefjord sequence itself and have also migrated upwards into the Eleonore Bay Supergroup (Higgins & Soper 1994; Strachan *et al.* 2001).

Several major shear zones cross the region of the map sheet (Fig. 1). The most important ones are the NNE–SSW-trending Storstrømmen shear zone (SSZ), the E–W-trending Bessel Fjord shear zone (BFSZ) and the NNW–SSE-trending

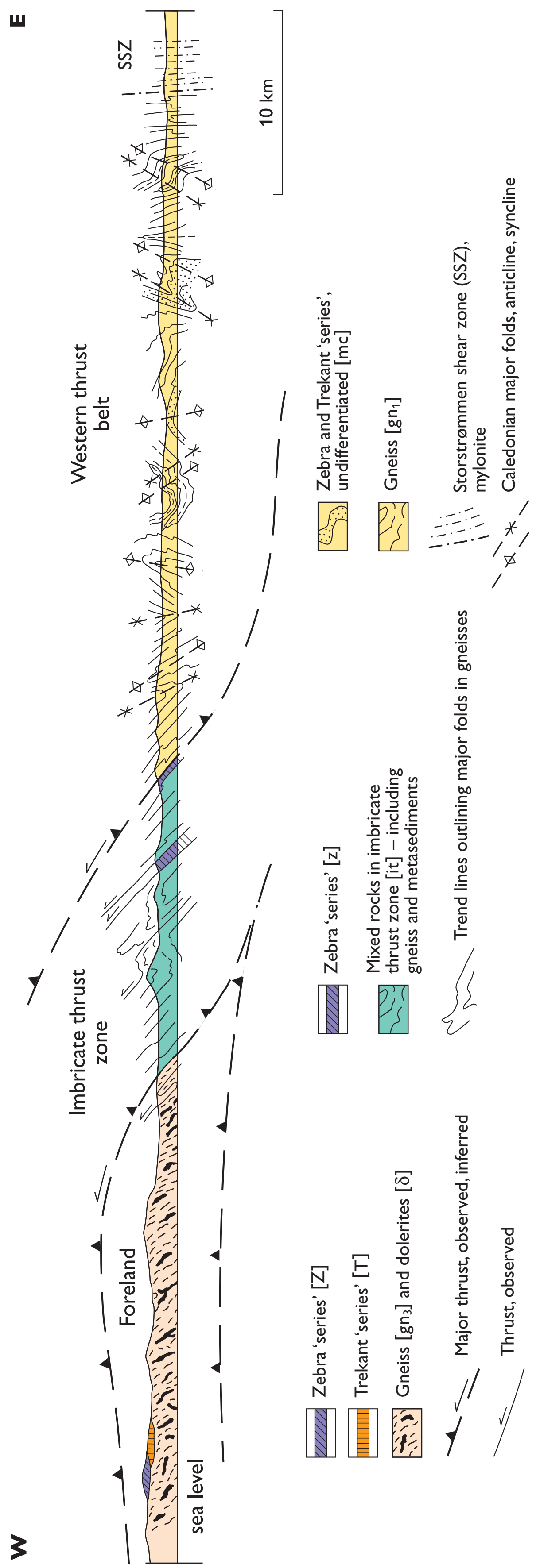


Fig. 6. West–east cross-section of Dronning Louise Land, showing the E-dipping Imbricate thrust belt separating the foreland from the gneiss-dominated Western thrust belt of eastern Dronning Louise Land. Letter combinations in brackets in the legend are those used on the printed map sheet. Colours of structural domains after Fig. 1. The foreland rocks exhibit Caledonian deformation, and a splay off the Imbricate thrust zone that ends as a blind thrust is depicted running west beneath the foreland. Modified from Strachan *et al.* (1992).

Germania Land shear zone (GLSZ) that crosses the mouth of Skærfjorden. In addition, shear zones are conspicuous near Danmarkshavn and on islands in Borgfjorden between Daniel Bruun Land and Rechnitzer Land. Shear zones bound the Smallefjord sequence centred on Ardencaple Fjord and Bredefjord. The E–W-trending Bessel Fjord shear zone (BFSZ) follows the south side of Bessel Fjord dipping southwards at moderate angles, while the NW–SE-trending Kildedalen shear zone (KDSZ) dips north-eastwards at low angles (Figs 1, 10). Extensional faults re-activating earlier thrusts, distinguished on Fig. 1 as décollement zones, bound the outcrop of the Eleonore Bay Supergroup.

Imbricate thrust zone

The Imbricate thrust zone is a major NNE–SSW-trending thrust zone 5–15 km wide that traverses Dronning Louise Land and separates the foreland to the west from allochthonous thrust sheets to the east. Sedimentary sequences and associated basic rocks within the Imbricate thrust zone have all been correlated with rock units in the foreland to the west (Strachan *et al.* 1992, 1994). In most of the Imbricate thrust zone deformation is intense, and the sheared metasedimentary rocks and metadolerites, together with wedges and slivers of basement gneisses, have been mainly mapped as a unit of mixed rocks [**it**] (Fig. 7). Where outcrops of the two cover sequences in the foreland (Zebra 'series', Trekant 'series') are sufficiently large to be shown at the scale of the map these are indicated [**Z, T**], as are metamorphosed representatives of basic intrusive sheets and dykes [δ].

The continuation of the Imbricate thrust zone north of Dronning Louise Land runs close to the eastern edge of both Ymer Nunatak and Alabama Nunatak (Fig. 1), and has been projected northwards to pass along the west side of the Bildsøe Nunatakker by Higgins & Leslie (2008). If correct, this would mean that the parts of the Bildsøe Nunatakker at the northern boundary of the Dove Bugt map sheet east of longitude 24°W belong to the Western thrust belt as shown on Fig. 1 and not the foreland; the gneisses here marked as '$\mathbf{gn_3}$' on the map sheet should therefore be '$\mathbf{gn_1}$'.

Fig. 7. The E-dipping thrust contact at the upper boundary of the Imbricate thrust belt at Durham Klippe on the north side of Budolfi Isstrøm. Layered gneisses [**gn_1**] and thick metadoleritic dykes [**δ**] of the Western thrust belt occur in the hanging wall of the thrust. Light-coloured quartzites of the Zebra 'series' [**Z**] (too thin to depict on the printed map sheet) are visible just below the thrust together with undifferentiated mixed rocks [**it**]. The cliffs of Durham Klippe reach about 400 m above the glacier surface.

Western thrust belt

The crystalline rocks of eastern Dronning Louise Land were distinguished by the earliest investigators as the 'eastern hinterland' (Peacock 1956, 1958). Metasedimentary sequences are widespread, and appear to structurally overlie the gneisses; in places they seem to be preserved in the cores of isoclinal synclines that have subsequently been refolded by open structures. On the map these metasedimentary rocks are depicted as a mixed undifferentiated unit [**mc**]. Strachan *et al.* (1994) interpreted an older series of psammitic to semipelitic schists, quartzites and minor marbles intruded by basic sheets (now amphibolites) as correlateable with the Trekant 'series' [**T**] of the foreland. A presumed younger sequence of interlayered quartzites, phyllites and minor carbonates, but not cut by amphibolitic dykes, was correlated with the Zebra 'series' [**Z**].

Higgins & Leslie (2008) placed eastern Dronning Louise Land within the Western thrust belt, a region of poorly defined thrust sheets traceable through the nunatak region as far north as Lambert Land (79°15´N). Here mapping detail is greater and J.C. Escher and K.A. Jones (personal communications 1995) distinguished a set of northward-verging thrust sheets reworked by later west-verging thrust sheets. The eastern boundary of the Western thrust belt is depicted on Fig. 1 as an unexposed E-dipping thrust running west of Hertugen af Orléans Land, and southwards as far as the Storstrømmen shear zone; it is presumed to continue beneath L. Bistrup Bræ west of Rechnitzer Land.

The dominant gneisses [**gn_1**] are acid to intermediate grey orthogneisses with local mafic enclaves, in which intense Caledonian deformation has commonly obliterated early structures and fabrics (Strachan *et al.* 1992). The broad similarities between the gneisses with their overlying metasedimentary rocks [**mc**] found in eastern Dronning Louise Land and those of the foreland region immediately to the west suggested to Strachan *et al.* (1992) that the Caledonian Imbricate thrust zone did not separate markedly different geological terrains. As a consequence, it was thought that the displacement along the Imbricate thrust zone was probably only limited with respect to the structurally underlying foreland.

Nørreland thrust sheet

The gneiss complexes that dominate the region north of Bessel Fjord, extending through the Dove Bugt region, Germania Land and the Skærfjorden region to the northern boundary of the map sheet (78°N) and westwards including Hertugen af Orléans Land, are considered to form part of a mainly high-grade complex of Caledonian thrust sheets distinguished as the Nørreland thrust sheet. North of Danmarkshavn the gneisses contain Caledonian eclogites (see below), and this part of the Nørreland thrust sheet is also known as the 'North-East Greenland eclogite province' (Gilotti 1993; Gilotti *et al.* 2008). The gneisses around Dove Bugt and extending southwards to the Bessel Fjord shear zone are still regarded as part of the Nørreland thrust sheet, although here they are generally in amphibolite facies (Gilotti *et al.* 2008); the southern part of this region is shown on Fig. 1 as an undefined unit, see the description of the Smallefjord sequence in the following. Gilotti & McClelland (2008) record that it is unlikely that the gneisses of the Nørreland thrust sheet, as distinguished here, represent a single crustal slab but so far no internal thrust contacts have been recognised. The existence of non-migmatitic equivalents to the Smallefjord sequence west of the head of Bessel Fjord could indicate that this region may be part of a separate thrust unit, or perhaps a higher level of the Nørreland thrust sheet (Figs 1, 2).

Crystalline gneiss complexes and associated rocks

The allochthonous crystalline gneiss complexes of the Nørreland thrust sheet have yielded protolith ages of *c.* 2 Ga, and are considered to have developed during a major period of crust formation in the Palaeoproterozoic (Kalsbeek *et al.* 1993); they have been variably reworked during Caledonian orogenesis. The only known enclave of rocks yielding Archaean protolith ages is located near Danmarkshavn (76°40´N), where layered gneisses have given zircon U-Pb, whole rock Rb-Sr and ion micoprobe U-Pb zircon ages of between 3000 Ma and 2725 Ma (Steiger *et al.* 1976; Nutman & Kalsbeek 1994). However, the ion microprobe data for the gneisses in the Danmarkshavn area also show the presence of *c.* 1967 Ma zircons with high, 'igneous', Th/U ratios indicative of incipient melting at that time (Nutman & Kalsbeek 1994).

The most widespread gneiss units are grey orthogneisses of variable composition and structure [$\mathbf{gn_1}$]; as employed on the map the designation also embraces layered, veined and migmatitic varieties. Ion microprobe ages of 1963 ± 6 Ma and 1974 ± 17 Ma of zircons from two orthogneiss units [$\mathbf{gn_1}$] indicate emplacement at about the same time as the high-grade Palaeoproterozoic metamorphism (1967 ± 8 Ma) of the above mentioned enclave at Danmarkshavn (Kalsbeek *et al.* 1993; Nutman & Kalsbeek 1994).

The internal structures of the Palaeoproterozoic gneisses often reflect their composite origin, with large-scale fold structures and evidence of emplacement of several generations of granitic rocks. The felsic gneisses are generally biotite and hornblende bearing with a tonalitic to quartz dioritic composition. Descriptions of the gneiss terrain in various parts of the region are given by Friderichsen *et al.* (1991, 1994), Chadwick & Friend (1994) and Hull *et al.* (1994).

In many places the gneisses are cut by a variety of younger, foliated metagranitoid sheets [$\mathbf{gn_2}$], which often preserve conspicuous feldspar augen. Many such bodies are found on the western side of Dove Bugt, where they occur as subconcordant, pink-coloured sheets emplaced into the older grey orthogneisses (Chadwick & Friend 1994). Younger homogeneous granitic rocks [**g**], with or without feldspar augen, can be distinguished locally, and are viewed as post-migmatitic and late orogenic with respect to the Palaeoproterozoic event. Ion microprobe zircon U-Pb ages of 1764 ± 20 Ma and 1739 ± 11 Ma (Kalsbeek *et al.* 1993) for two of the younger granites suggest that they were emplaced more than 200 Ma after the formation of the protoliths of the grey gneisses.

Within the gneiss complexes scattered layers and lenses of metasedimentary lithologies of possible Palaeoproterozoic age occur, often associated with basic pods and amphibolites [**a**]. The supracrustal rock units include marbles and calc-silicate rocks [**c**], cordierite- and sillimanite-bearing paragneisses and mica schists [**ms**], and semipelitic and siliceous metasedimentary rocks [**qg**]. Some of the supracrustal rock units can be traced along strike for tens of kilometres, and can be used as marker layers outlining major fold structures. These supracrustal lithologies are envisaged to be the remnants of a once much more widespread succession which was disrupted by the emplacement of the voluminous grey orthogneisses (Chadwick & Friend 1994).

In addition to the supracrustal remnants, layers and lenses of gabbroic, gabbro-anorthositic, megacrystic anorthositic and ultramafic igneous rocks occur within the grey gneisses. The metamorphosed mafic gabbroic units are recorded as amphibolites [**a**], and ultramafic rock types [**ub**] that include pyroxenites, dunites and hornblendites. East of L. Bistrup Bræ leucogabbroic and gabbro-anorthositic [**ga**] layers and lenses are locally common. Coarse-grained varieties locally preserve their original porphyritic textures, although completely recrystallised and essentially composed of basic plagioclase and hornblende. Anorthositic rocks on an isolated nunatak south-west of inner Bessel Fjord have yielded a Sm-Nd model age of 2146 Ma (Henriksen *et al.* 1989; Stecher & Henriksen 1994).

Deformed and metamorphosed mafic dykes and sills are indicated on the map as amphibolitic layers and lenses [**a**], and discordant relationships to the foliation in the host gneisses are often preserved. Dense swarms of amphibolitic dykes occur in the Danmarkshavn area, in the western Dove Bugt area (Chadwick *et al.* 1990) and in the area around Skærfjorden (Hull *et al.* 1994). Several generations of mafic intrusions can often be distinguished, and a Mesoproterozoic to Neoproterozoic age of emplacement has been proposed (Fig. 3), with subsequent metamorphism and recrystallisation during the Caledonian orogeny (Hull *et al.* 1994).

The coastal areas of north-east Germania Land and large areas north-east of Skærfjorden consist of metamorphosed mafic rocks [**mb**], now comprising hornblende + plagioclase ± garnet, which are envisaged to have originally formed dioritic–gabbroic complexes within the Palaeoproterozoic crust. A tonalitic body in eastern Gamma Ø has yielded an ion-microprobe zircon age of 1963 ± 6 Ma (Nutman & Kalsbeek 1994).

A variety of gabbroic, dioritic or quartz-dioritic bodies [**mg**] occur within the grey orthogneisses. Where age relationships can be seen they post-date their gneiss host, but are considered to form part of the same Palaeoproterozoic complex.

Eclogites

Eclogitic pods were recognised in the orthogneiss complexes of Germania Land and the area around Skærfjorden in 1989 (Fig. 8), and proved subsequently to be part of an extensive medium-temperature, high-pressure eclogite province. This North-East Greenland eclogite province is now known to extend over a south to north distance of about 400 km between Danmarkshavn (*c.* 76°40´N) and eastern Kronprins Christian Land (*c.* 81°N; Gilotti 1993). Detailed studies suggest the eclogite pods are remnants of basic intrusions, emplaced into the protoliths of the grey orthogneisses and subjected to medium-temperature (600–750°C), high pressure (1.5–2.2 GPa) metamorphism (Brueckner *et al.* 1998; Elvevold & Gilotti 2000).

The high pressures and temperatures are attributed to thickening of the East Greenland continental margin during crustal imbrication associated with west-directed Caledonian thrusting (Gilotti *et al.* 2008). Typical mineral assemblages in the eclogites are omphacite + garnet ± quartz ± rutile. Coesite-bearing ultra-high-pressure eclogites are exposed in the easternmost part of the region and have been dated at *c.* 365–350 Ma (McClelland *et al.* 2006). Their late age in relation to the Caledonian orogeny is ascribed to an intracratonic subduction zone undergoing ultra-high-pressure metamorphism at crustal depths in excess of 100 km (Gilotti & McClelland 2007). The large pressure difference within the thrust sheet implies tectonic contacts with other parts of the Nørreland thrust sheet.

The absence of eclogitic enclaves in the Dove Bugt region may have structural implications (see the following discussion of structures and tectonic units).

Geochronological studies by Brueckner *et al.* (1998) yielded a spread of Caledonian ages of 440–370 Ma for the eclogite facies metamorphism, but more recent work has given ages between 414 and 393 Ma (Gilotti *et al.* 2004); as noted above the localised ultra-high-pressure metamorphism has given younger ages of 365–350 Ma. Localities with occurrences of eclogites *sensu stricto* are marked with a special symbol [*] on the map sheet.

Fig. 8. Eclogite pod in layered gneisses [$\mathbf{gn_1}$] in the southern part of Hertugen af Orléans Land. Eclogite pods are widely distributed in the Nørreland thrust-sheet terrain north of Danmarkshavn, and are indicated on the printed Dove Bugt map sheet by green asterisks [*].

Hagar Bjerg thrust sheet

The region south of Bessel Fjord contains extensive outcrops of Palaeoproterozoic basement gneisses and the Mesoproterozoic Smallefjord metasedimentary sequence, as well as the Neoproterozoic Eleonore Bay Supergroup succession; the Smallefjord sequence in C.H. Ostenfeld Land has a tectonic contact along the Kildedalen shear zone with Palaeoproterozoic crystalline gneiss complexes (Fig. 10). These units are considered northern equivalents of the Hagar Bjerg thrust sheet of the Kong Oscar Fjord region to the south (72°–75°N; see Fig. 2).

The limits of the Hagar Bjerg thrust sheet are not well defined on the Dove Bugt map. This major structural element was first established after mapping of the Kong Oscar Fjord region (72°–75°N) in 1997–1998. The regional structural divisions presented here are the result of subsequent interpretation (Higgins & Leslie 2008; Leslie & Higgins 2008).

The equivalent of the Smallefjord sequence in the Kong Oscar Fjord region is the commonly migmatitic Krummedal sequence that forms the intermediate level of the Hagar Bjerg thrust sheet (Elvevold *et al.* 2000; Higgins *et al.* 2004; Higgins & Leslie 2008). The widespread Neoproterozoic to Lower Palaeozoic succession in the Kong Oscar Fjord region makes up the structurally overlying and highest structural level, known as the Franz Joseph allochthon (Higgins *et al.* 2004). As is the case with the equivalent units in the Kong Oscar Fjord region, the Smallefjord sequence and the Eleonore Bay Supergroup on the Dove Bugt map sheet are cut by Caledonian granites, and a similar high structural level is envisaged. Major shear zones, thrusts and extensional faults bound the sedimentary outcrops to the north, south and west (Fig. 1; Friderichsen *et al.* 1994; Higgins & Soper 1994; Higgins & Leslie 2008).

Crystalline gneiss complexes

The gneisses attributed to the Hagar Bjerg thrust sheet on Fig. 1 do not differ significantly from those around Dove Bugt that are part of the Nørreland thrust sheet. The main outcrops of gneisses in the Hagar Bjerg thrust sheet are in south-west C.H. Ostenfeld Land and south of Grandjean Fjord. They are mainly amphibolite facies grey gneisses [**gn$_1$**] with occasional foliated metagranitoid units [**gn$_2$**]. Amphibolite layers can be conspicuous, and there are occasional thin units of mica schist [**ms**] and carbonate [**c**]. Major fold structures are conspicuous on the steep walls of Heinkel Gletscher (Fig. 9).

Mesoproterozoic metasedimentary rocks – Smallefjord sequence

High-grade migmatitic schists and paragneisses are widespread between Grandjean Fjord (75°N) and Bessel Fjord (76°N), and are distinguished on the map sheet as the Smallefjord sequence [**S**] (Friderichsen *et al.* 1994). The Smallefjord sequence crops out over a region about 70 × 110 km in size, which surrounds the outcrop of the Eleonore Bay

Fig. 9. Basement orthogneisses [**gn$_1$**] within the Hagar Bjerg thrust sheet, displaying a major W-facing isoclinal fold in the centre of the photograph that is refolded by later open folding about a steeply dipping axial surface. At the left side of the photograph is a thick zone of black, podded amphibolite [**a**]. Looking north at the north wall of innermost Grandjean Fjord at the front of Heinkel Gletscher. Cliff height about 1200 m.

Fig. 10. Low-angle discordance between basement orthogneisses [**gn_1**] and strongly sheared gneisses of the Kildedalen shear zone [**KLSZ**]. Psammitic and semipelitic rocks of the Smallefjord sequence [**S**] with scattered granitic veins and thin sheets at the top. The north-western part of C.H. Ostenfeld Land looking north-east. Cliff height about 400 m. From Friderichsen *et al.* (1994).

Supergroup centred on Ardencaple Fjord and Bredefjord. The Bessel Fjord and Kildedalen shear zones define the northern and south-western limits of the Smallefjord sequence against the basement orthogneisses (Fig. 10). North-west of Smallefjord the Smallefjord sequence is present as strips in the gneisses.

The Smallefjord sequence mainly comprises medium- to coarse-grained semipelitic schists and gneisses, interlayered with psammitic schists. Calc-silicate pods and lenses occur in places. Characteristic mineral assemblages in semipelitic lithologies are quartz + plagioclase + biotite + muscovite ± garnet ± sillimanite ± kyanite, indicative of amphibolite facies metamorphism. The metasedimentary rocks of the Smallefjord sequence are often strongly migmatised, with abundant, discontinuous, concordant layers and lenses of quartzo-feldspathic material. This neosome material may locally form up to 30–50% of the total rock volume, and comprises approximately equal proportions of quartz, plagioclase and K-feldspar with minor amounts of biotite and muscovite.

Subconcordant sheets and pods of foliated amphibolite [**a**] occur locally, and are interpreted as metamorphosed basic intrusions (dykes and sills); they have suffered the same degree of deformation and metamorphism as the metasedimentary rocks. Irregular sheets and lenses of strongly deformed granites and augen granites [**gi**] cut the foliation in the schists in many places. The studies of Strachan *et al.* (2001) demonstrate that the granite sheets and lenses are Caledonian in age, and contemporaneous with the granite plutons emplaced into the structurally overlying Eleonore Bay Supergroup.

As noted above, the Smallefjord sequence has been broadly correlated with the Krummedal supracrustal sequence that is widely distributed farther south (70°–74°30′N) in the East Greenland Caledonides (Strachan *et al.* 1995b), and is considered to be of similar age. Like the Krummedal sequence, the Smallefjord sequence preserves evidence of a late Mesoproterozoic – early Neoproterozoic metamorphic event (Kalsbeek *et al.* 2000). U-Pb ion probe analyses of detrital zircons from the Smallefjord sequence have given ages between *c.* 1800 and 1035 Ma, but in addition new rims of a few zircons have revealed an age of 955 ± 13 Ma indicative of a high grade tectonothermal event (Strachan *et al.* 1995b). The Smallefjord sequence is thus considered to have been deposited later than *c.* 1035 Ma and prior to a regional metamorphic event at *c.* 955 Ma. The succession was subjected to renewed deformation and metamorphism during the Caledonian orogeny, documented by further growth of metamorphic zircon at 445 ± 10 Ma (Strachan *et al.* 1995b).

The northernmost representatives of the Smallefjord sequence may be the narrow strips of metasedimentary rocks that occur around Soranerbræen north-west of the main areas of outcrop. In contrast to the migmatitic sedimentary rocks of the main area of outcrop, the latter outcrops are non-migmatitic; structurally they probably belong to a higher level of the thrust complex, perhaps a separate thrust sheet. The succession has not been observed in eastern Dronning Louise Land, and in the northern parts of the Dove Bugt map sheet, the small areas and narrow layers of metasedimentary rocks recorded [**ms, c**] cannot be equated with the Smallefjord sequence with any confidence. The uncertain structural position of the region around Ad. S. Jensen Land has been indicated as an undefined unit on Figs 1 and 2.

Fig. 11. The upper Eleonore Bay Supergroup on the north-east side of Ardencaple Fjord. The view is an oblique section through tight folds with steeply dipping fold axes associated with the Brædal fold pair (see Fig. 12), which are disrupted by several steeply dipping faults. **NG**, Nathorst Land Group; **KF**, Kempe Fjord Formation; **ST**, Sandertop Formation. Profile height about 1200 m.

Neoproterozoic sedimentary rocks – Eleonore Bay Supergroup

The distinctive Neoproterozoic sedimentary succession of the Eleonore Bay Supergroup (Fig. 11) is preserved in a décollement-bounded enclave centred on Ardencaple Fjord and Bredefjord, and can be correlated at group and formation levels with the main developments farther south in East Greenland (71°40´–74°30´N; Sønderholm *et al.* 1989, 2008; Sønderholm & Tirsgaard 1993; Tirsgaard & Sønderholm 1997). A succession about 6000 m thick is preserved around Ardencaple Fjord, corresponding to the lower and middle parts of the up to 13.5 km thick Eleonore Bay Supergroup. The succession is disturbed by a simple pattern of major Caledonian folds (Fig. 12; see also below). The following groups are recognised (Sønderholm *et al.* 1989; Higgins & Soper 1994).

Nathorst Land Group [**NG**]: Up to 8 km thick in its type area (72°15´N), the upper approximately 2 km of this succession are present north and south of Bredefjord, with isolated outcrops in southern Hochstetter Forland. The succession consists of alternating units of quartz arenite, interbedded sandstone and mudstone, and black silty mudstone. Metamorphic grade varies from low greenschist facies at the summits of the highest peaks to amphibolite facies at the lowest stratigraphic levels. Sedimentary structures (e.g. ripple marks, cross-bedding) are often well preserved, even at moderate metamorphic grades, but may also be obscured or obliterated by deformation.

Lyell Land Group: Six units, each from 240 to 700 m thick, are recognised, and correspond to the lower six formations of the group in its type area (Sønderholm & Tirsgaard 1993; Tirsgaard & Sønderholm 1997). From oldest to youngest these are the Kempe Fjord [**KF**], Sandertop [**ST**], Berzelius Bjerg [**BZ**], Kap Alfred [**KA**], Vibeke Sø [**VS**] and Skjoldungebræ [**SB**] Formations. They comprise white, brown and purple weathering quartz arenites and dark green, brown and deep red silty mudstones. The principal exposures lie north and south of innermost Ardencaple Fjord, and between Bredefjord and Smallefjord.

Ymer Ø Group [**YG**]: Isolated outcrops of limestone and dolomite that occur in southern Hochstetter Forland are referred to the Ymer Ø Group (Sønderholm *et al.* 1989; Sønderholm & Tirsgaard 1993), but the succession is incomplete.

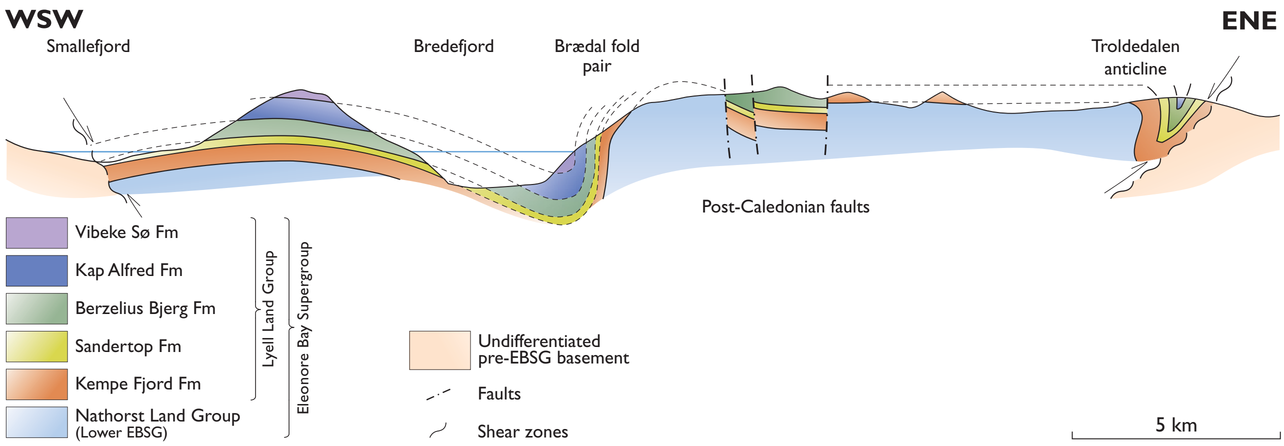


Fig. 12. WSW–ENE-trending cross-section through the Eleonore Bay Supergroup (**EBSG**) outcrop where Ardencaple Fjord divides into Bredefjord and Smallefjord. The tight folds at the eastern margin of the Eleonore Bay Supergroup outcrop (Troldedalen anticline) are controlled by displacements on the marginal shear zone. Redrawn from Higgins & Soper (1994).

Caledonian orogenesis

The Dove Bugt map sheet is dominated by rock units forming parts of major Caledonian thrust sheets. The structures and fabrics preserved within the gneiss complexes and metasedimentary rocks are predominately Caledonian in age, as are the major shear and deformation zones that dissect the region (Fig. 13). Regional metamorphic assemblages are also Caledonian in age, and the melting of metasedimentary rocks has led to emplacement of conspicuous Caledonian leucogranites at high structural levels (Fig. 14).

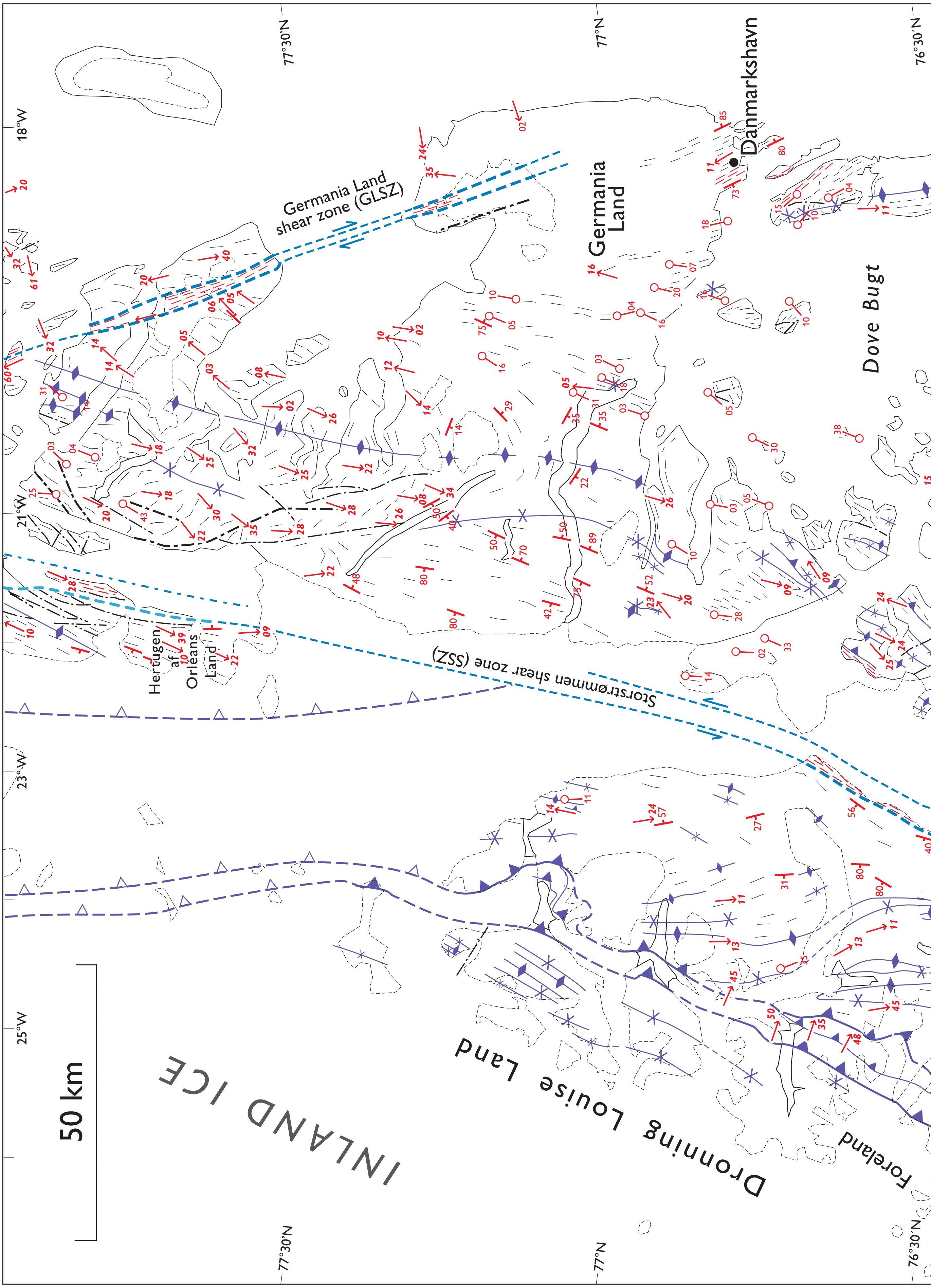
Structures and tectonic units

The major folds, faults and deformation zones within the Dove Bugt map sheet are ascribed to the Caledonian orogeny and related succeeding movements. Although the Caledonian orogen of this region comprises thrust sheets corresponding to distinctly different structural levels (Fig. 1), the major fold structures throughout the region are broadly N–S-trending (Fig. 13).

Imbricate thrust zone: The Imbricate thrust zone that traverses Dronning Louise Land marks the western border of the Caledonian orogen (Figs 1, 6, 7, 13). It is characterised by numerous E-dipping thrust sheets that vary from a few metres to several hundred metres in thickness (Strachan *et al.* 1992, 1994). Lithologies present within the Imbricate thrust zone include deformed basement gneisses, metasedimentary successions and metadolerites. Ductile thrusts are associated with belts of mylonite tens of metres thick, and shear-sense criteria indicate top-to-the-NW sense of displacement. Thrust-related fabrics are refolded at all scales by open to tight folds. Plunge and vergence of structures imply left-lateral differential shear during thrusting. Large-scale folds which deform higher thrusts may root downwards into unfolded lower detachments. Syn-thrusting metamorphism ranges from low amphibolite facies along the structurally highest thrusts to mid- to low-greenschist facies along the structurally lower thrusts (Strachan *et al.* 1994). The Caledonian deformation of the foreland rocks in the footwall of the Imbricate thrust zone implies the existence of a hidden thrust below the foreland rocks of western Dronning Louise Land; the intensity of deformation decreases rapidly westwards. Higgins & Leslie (2008) interpreted this hidden thrust as a splay off the Imbricate thrust zone that ends as a blind thrust just west of present day Dronning Louise Land (Fig. 6).

Western thrust belt: The gneiss terrain in eastern Dronning Louise Land, designated the 'eastern hinterland' in many regional descriptions (Strachan *et al.* 1992, 1994) following the usage of Peacock (1956, 1958), is here interpreted as forming part of the Western thrust belt of Higgins & Leslie (2008). The main structures are N–S-trending, upright open to isoclinal folds (Figs 5, 13) with associated steeply dipping crenulation fabrics. Deformation was accompanied by low amphibolite facies metamorphism and the main phase of folding has been interpreted as synchronous with the thrusting in the Imbricate thrust zone, and thus Caledonian in age (Strachan *et al.* 1992, 1994).

Nørreland thrust sheet: The gneiss terrain north of Bessel Fjord, extending through the Dove Bugt area and into Germania Land, corresponds to the 'interior central zone of the fold belt' in some descriptions (e.g. Henriksen 1994). The gneiss region of Rechnitzer Land, southern Daniel Bruun Land and the islands around northern Dove Bugt lacks eclogite lenses, and may have been derived from intermediate crustal levels. However, eclogites are abundant


Danmarkshavn
Germania Land
Dove Bugt
Germania Land shear zone (GLSZ)
Storstrømmen shear zone (SSZ)
Hertugen af Orléans Land
INLAND ICE
Dronning Louise Land
Foreland
50 km
77°30′N
77°N
76°30′N
18°W
21°W
23°W
25°W

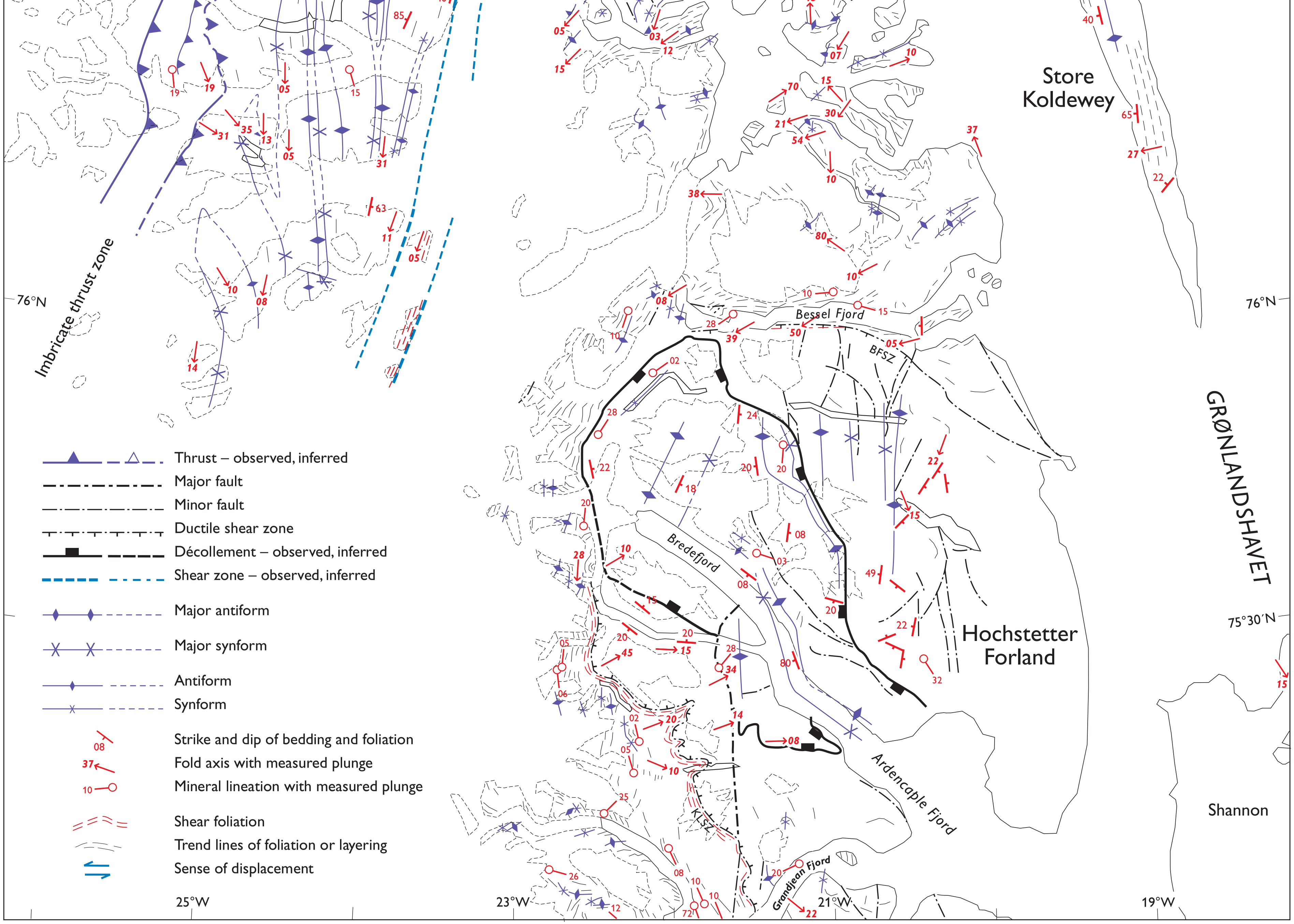


Fig. 13. Structural map of the Dove Bugt region, showing trends of major folds, thrusts and shear zones. **BFSZ**: Bessel Fjord shear zone. **KLSZ**: Kildedalen shear zone.

around Danmarkshavn (76°40′N), and widespread in Nordmarken, Stormland and Hertugen af Orléans Land, up to and beyond the map sheet limit. North of the map sheet boundary, in Nørreland (78°40′N), the thrust sheet structurally overlying the Nørreland foreland window comprises eclogite-bearing gneisses. The presence of Caledonian eclogites demonstrates that the gneisses that host them originated at depths >45–60 km, while structural relationships indicate that an episode of rapid exhumation (synorogenic extension) was followed by involvement in westward thrusting.

Field work has distinguished at least four phases of superimposed folding and deformation in the gneisses (Chadwick *et al.* 1990; Chadwick & Friend 1991, 1994). Two phases of early isoclinal folding produced nappe-scale structures, and these were deformed by two sets of later upright folds with north-westerly vergence. The later upright folds have approximately N–S trends (Fig. 13) and can be compared with the similarly trending major Caledonian folds of eastern Dronning Louise Land. Some Palaeoproterozoic granites (*c.* 1750 Ma) north of Dove Bugt cut fold structures that must be of Palaeoproterozoic age or older. Similarly, in the Skærfjorden region (77°–78°N) deformed and metamorphosed mafic dykes cut early isoclinal folds, indicating that their intrusion post-dates Palaeproterozoic deformation (Hull *et al.* 1994). There is thus clear evidence that the cross-cutting metagranites and metadolerite dykes separate two main deformation events – an older pre-Caledonian (Palaeoproterozoic) and a younger Caledonian event.

Shear zones: The region covered by the Dove Bugt map sheet is traversed by several major shear zones. These include the Storstrømmen shear zone, the Germania Land shear zone, the Bessel Fjord shear zone and the Kildedalen shear zone (Figs 1, 13).

The NNE–SSW-trending Storstrømmen shear zone is a belt of subvertical mylonites and intensely deformed gneisses, which crops out along the fringe of eastern Dronning Louise Land and is well exposed farther north along the eastern coastal part of Hertugen af Orléans Land (Figs 1, 13). Shear-sense criteria indicate a consistent sinistral sense of displacement, parallel to a subhorizontal to gently plunging lineation (Strachan *et al.* 1994). The earliest mylonites were formed under low amphibolite facies conditions, and are often overprinted by greenschist facies mylonites. In Hertugen af Orléans Land the Storstrømmen shear zone is described as a steep belt of heterogeneously deformed gneisses and mylonites at least 8 km wide (Strachan & Tribe 1994). In the earliest descriptions of the Storstrømmen shear zone it was speculated that displacements might be of the order of hundreds of kilometres (Holdsworth & Strachan 1991). However, Hull & Gilotti (1994) observed that the gneisses on the two sides of the shear zone in Hertugen af Orléans Land were indistinguishable, and that eclogitic pods occur in the gneisses both to the east and the west. They argue that the shear zone is thus unlikely to be a regional terrane boundary, and may have only modest (9–17 km) sinistral displacement.

With respect to the Germania Land shear zone (Figs 1, 13), the sense of displacement is problematic, but essentially right-lateral with elements of left-lateral slip on subsidiary zones (Hull & Gilotti 1994). Shear zones parallel to the Germania Land shear zone occur around Danmarkshavn and along the north-eastern coast of Store Koldewey (Hull & Gilotti 1994).

The Bessel Fjord and Kildedalen shear zones are broad zones of strongly sheared gneisses that follow the boundary between the Smallefjord sequence and the basement gneiss terrain (Figs 1, 10, 13).

Hagar Bjerg thrust sheet: The E–W-trending Bessel Fjord shear zone marks the northern limit of the presumed equivalent of the more than 20 km thick Hagar Bjerg thrust sheet of the Kong Oscar Fjord region. It incorporates a lower unit of Palaeoproterozoic gneisses, a middle unit of metasedimentary rocks (the Krummedal/Smallefjord sequence), with the highest stratigraphical level formed by the Eleonore Bay Supergroup. The broad NW–SE-trending Kildedalen shear zone crossing C.H. Ostenfeld Land marks the south-western boundary of the outcrop of the main Smallefjord sequence; strongly sheared gneisses of the shear zone are discordant with the layering in the basement orthogneisses (Fig. 10). The west and north-west boundaries of the thrust sheet are not well established. A separate subunit of the thrust sheet may be present west and north-west of the head of Bessel Fjord.

The Neoproterozoic Eleonore Bay Supergroup succession is preserved in the décollement-bounded enclave centred on Ardencaple Fjord and Bredefjord. The sedimentary rocks of the Eleonore Bay Supergroup are subhorizontal or gently warped into open folds, but there are several belts of more intense folding (Figs 10–12). The marginal shear zones preserve evidence of both extension and compression. Since the trend of major NW–SE-trending structures is controlled by the marginal shear zones, Soper & Higgins (1993) and Higgins & Soper (1994) considered that extension to form the graben-like structure preceded compression and formation of the folds. Later, more open folds trend NNE–SSW. The extensional phase was linked by Soper & Higgins (1993) to a major rift episode of Vendian age considered related to the opening of Iapetus, for which some supporting evidence is found in the unstable sedimentary developments recorded in the uppermost Eleonore Bay Supergroup (Frederiksen 2000). However, Strachan (1994), Hartz & Andresen (1995) and Strachan *et al.* (2001) prefer to equate the extension with the late Caledonian extensional events associated with collapse and exhumation of the Caledonian orogen.

Tectonic models: Early tectonic models for the Dove Bugt region suggested that the sinistral strike slip on the Storstrømmen shear zone and westward thrusting were essentially synchronous, and took place within a sinistral transpression scenario (Holdsworth & Strachan 1991; Strachan *et al.* 1992, 1995a). It was suggested that the Storstrømmen shear zone might root into a low-angle detachment, and form part of a flower structure model. The recognition of the Nørreland foreland window north of the map sheet boundary (78°40′N; Hull & Friderichsen 1995), and of the Eleonore Sø and Målebjerg windows south of the map sheet boundary in the Kong Oscar Fjord region (73°15′–74°15′N; Higgins & Leslie 2000, 2008), demonstrates major westward displacements totalling several hundred kilometres for the overlying thrust sheets. Regional models for the East Greenland Caledonides now indicate that parts of the western marginal zone of the orogen exhibit more-or-less thin-skinned deformation, while the eastern part comprises an assemblage of both deep-rooted and medium-level thrust sheets (Higgins & Leslie 2000, 2008; Higgins *et al.* 2001a; Leslie & Higgins 2008). This concept has been adopted with modifications in the present descriptive text to the Dove Bugt map sheet.

Metamorphism and orogenic cooling

Caledonian regional metamorphism affected the entire Dove Bugt map region. The metamorphic grade in the crystalline gneiss complexes is mainly amphibolite facies, but over a wide region in the north, mineral assemblages in basic inclusions bear witness to a Caledonian eclogite facies event dated at *c.* 410–390 Ma (Brueckner *et al.* 1998; Gilotti *et al.* 2008). The Neoproterozoic sedimentary rocks of the Eleonore Bay Supergroup exhibit amphibolite facies assemblages at the lowest exposed levels, and low grade to almost unmetamorphosed assemblages at the highest stratigraphical levels. Zircon dates from the Smallefjord sequence indicate a latest Ordovician age for the Caledonian metamorphism of 445 ± 10 Ma (Friderichsen *et al.* 1994; Strachan *et al.* 1995b), but this age is queried by Gilotti *et al.* (2008) as it is older than all the *c.* 435–425 Ma Caledonian granite ages (Kalsbeek *et al.* 2008b). Localised ultra-high pressure metamorphism in the Nørreland thrust sheet at *c.* 363–350 Ma is considered to mark the end of Caledonian continental convergence (Gilotti & Ravna 2002; Gilotti *et al.* 2004, 2008; McClelland *et al.* 2006).

Cooling following the Caledonian orogeny is documented by ^{40}Ar/ ^{39}Ar age data that range from *c.* 438 to 370 Ma (earliest Silurian to middle–late Devonian; Dallmeyer *et al.* 1994; Dallmeyer & Strachan 1994). ^{40}Ar/ ^{39}Ar age data on muscovite from late to postkinematic Caledonian granites have yielded cooling ages ranging from 423 ± 1 to 412 ± 0.6 Ma, while metamorphic muscovite from the Eleonore Bay Supergroup around Ardencaple Fjord has yielded a metamorphic cooling age of 415 ± 0.7 Ma and hornblende from an amphibolite in the Smallefjord sequence has yielded a cooling age of *c.* 426 ± 2 Ma. Most mineral cooling ages from the basement orthogneisses and the various Proterozoic metasedimentary rocks range between *c.* 400 and 370 Ma. The youngest cooling ages recorded in the region come from muscovite from late cross-cutting pegmatites in the Danmarkshavn region, where an ^{40}Ar/ ^{39}Ar age of 314 ± 1.3 Ma was recorded (Dallmeyer *et al.* 1994). Comparable whole rock Rb-Sr and K-Ar ages of *c.* 320 Ma were obtained by Steiger *et al.* (1976) from the gneisses at Danmarkshavn which have yielded Archaean protolith ages. Isotopic studies of the North-East Greenland eclogites indicate that the Caledonian eclogite facies event was succeeded by slow cooling and exhumation, as recorded by Rb-Sr biotite ages of *c.* 357–326 Ma (Brueckner *et al.* 1998).

Granites

Caledonian granitic intrusions occur in the Grandjean Fjord – Bessel Fjord region (75°–76°N), within the Eleonore Bay Supergroup and Smallefjord sequence, and in the boundary zone between these metasedimentary rocks and the crystalline gneiss complexes (Hansen *et al.* 1994; Strachan *et al.* 2001). However, Caledonian granites are unknown north of Bessel Fjord and are not found in the Nørreland thrust sheet. Only one type of Caledonian granite [**gi**] is shown on the map sheet. Most examples studied are leucocratic, fine- to medium-grained granites, comprising quartz, microcline, plagioclase, biotite and muscovite; some bodies are granodioritic in composition, and syenitic varieties have also been noted.

Many granite bodies are undeformed, and where emplaced into the Eleonore Bay Supergroup they form stocks or plutons up to 5–10 km in diameter with clearly cross-cutting boundaries (Fig. 14). Other granite bodies, notably those emplaced into the Smallefjord sequence, comprise heterogeneous, sheeted and veined complexes, in places exhibiting migmatitic textures.

Despite their variable appearance in the field, zircon U-Pb isotopic studies on the granites indicate that they were broadly contemporaneous and emplaced *c.* 431–428 Ma ago (Strachan *et al.* 2001). Sm-Nd, Rb-Sr and major and trace element analyses from areas farther south in East Greenland indicate that the high-level Caledonian granites are predominantly of S-type, derived from the partial melting of metasedimentary rocks of the Mesoproterozoic Krummedal sequence (Kalsbeek *et al.* 2001, 2008b). The granites in the Grandjean Fjord – Bessel Fjord region were evidently formed in a similar manner, by melting of the Smallefjord sequence metasedimentary rocks (Strachan *et al.* 2001).

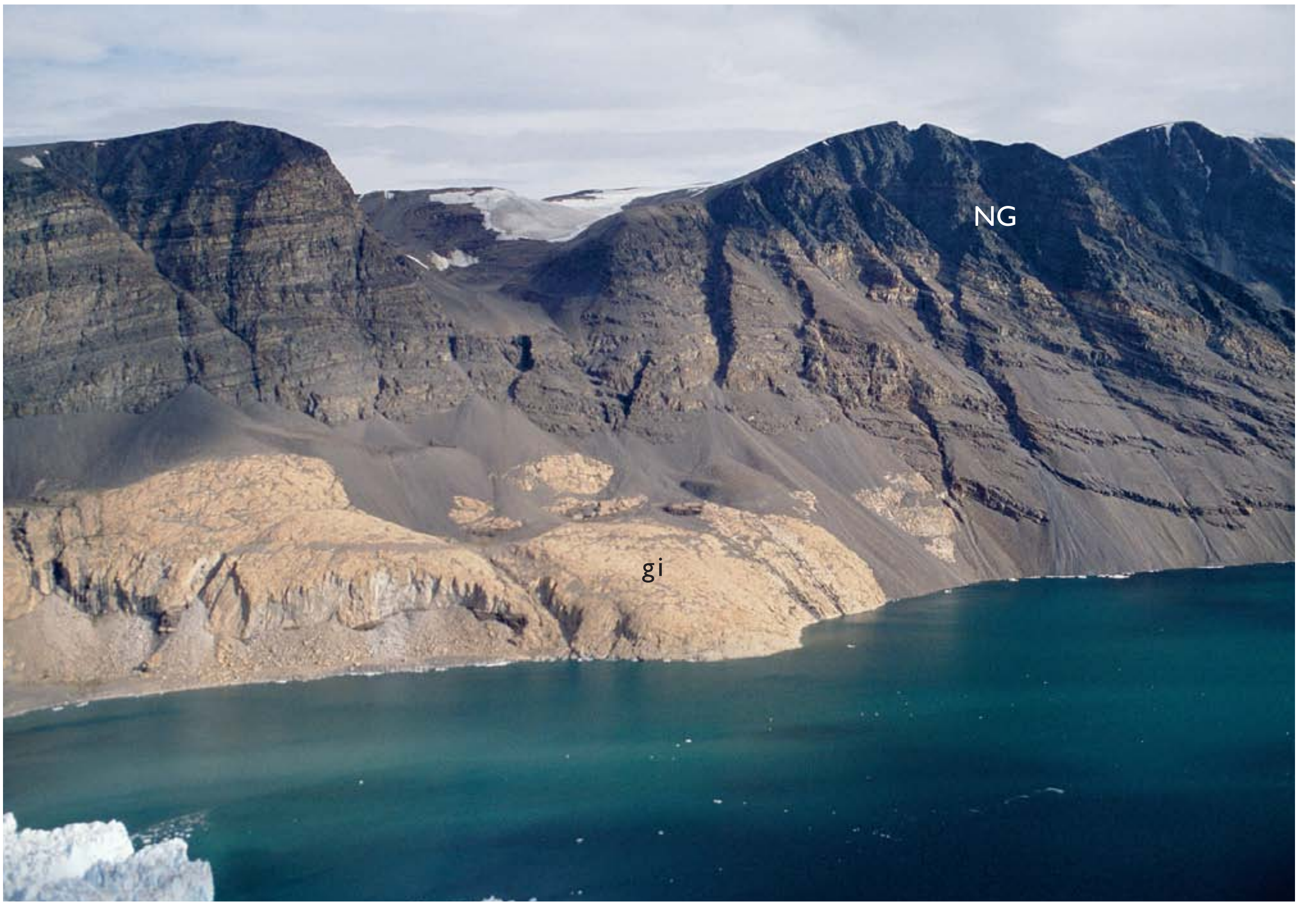


Fig. 14. Caledonian granite [**gi**] cutting dark sedimentary rocks of the Nathorst Land Group [**NG**] at the head of Bredefjord, looking north. Highest summits are 1200 m above the fjord.

Post-Caledonian sedimentary rocks and Palaeogene basalts

Carboniferous sandstones are preserved in a few small downfaulted outcrops within the dominantly gneissic terrain. Jurassic–Cretaceous sediments crop out in the outer coastal regions of the south-eastern part of the map sheet, and Palaeogene (lower Tertiary) basaltic flows and sills are found on the island of Shannon.

Carboniferous sedimentary rocks

Sedimentary rocks of Carboniferous age [**C**] occur along Chatham Elv in Stormlandet (*c.* 77°35′N), and east of Fladebugt (77°15′N), in both cases associated with faults. The outcrops along Chatham Elv occur in a narrow, *c.* 10 km long, NNW–SSE-trending fault block within crystalline gneisses. The succession comprises a 60 m thick basal conglomerate unit, overlain by 15 m of conglomerates, sandstones and siltstones (Friderichsen *et al.* 1991; Hull & Gilotti 1994; Piasecki *et al.* 1994). East of Fladebugt a succession up to 25 m thick is dominated by massive quartzites unconformably overlying crystalline gneisses; this small outcrop lies just east of the projected trace of a major fault, which in the south-east corner of Fladebugt is conspicuous due to the rusty weathering of pyrite mineralisation. Both successions contain plant fossils, spores and pollen which indicate an Upper Westphalian (Middle Upper Carboniferous) age (Piasecki *et al.* 1994). The occurrence of Upper Carboniferous fluviatile sedimentary rocks indicates that this region was part of the East Greenland continental basin during the Late Palaeozoic.

Jurassic–Cretaceous sedimentary rocks

The most important rift phase in the Mesozoic in East Greenland began in the Middle Jurassic (late Bajocian), intensified in the Late Jurassic, and waned in the Early

Cretaceous (Hauterivian). This rifting was associated with northward transgression across crystalline basement terrain that brought parts of the present-day Kuhn Ø, Hochstetter Forland, Shannon and Store Koldewey in the Dove Bugt map area within the depositional basin (Surlyk 2003). Sedimentary rocks of Jurassic–Cretaceous age are preserved in a 40 km long N–S-trending zone on the east side of the island Store Koldewey, and in three small fault-bounded occurrences on the east side of Koefoed-Hansen Bræ in the western part of Nordmarken (Stemmerik & Piasecki 1990; Piasecki *et al.* 1994). The widespread occurrence throughout the region of glacial erratics of Jurassic coal, notably west of Skærfjorden and in Germania Land, indicates that deposits of Jurassic age were once much more extensive, and may perhaps be present beneath the Inland Ice to the west. Major Mesozoic sedimentary basins have been identified from geophysical studies beneath the waters of Dove Bugt and on the shelf offshore (Larsen 1990; Christiansen & Pulvertaft 1992; Hamann *et al.* 2005). These are not depicted on the Dove Bugt map sheet, but the outlines of basins with >4 km of sediments are shown on the 1:2 500 000 Geological map of Greenland (Escher & Pulvertaft 1995) and on figures in Hamann *et al.* (2005).

The Mesozoic sedimentary rocks of eastern Store Koldewey (Stemmerik & Piasecki 1990) are referred to four lithologically distinct units ranging in age from Middle Jurassic to Lower Cretaceous, most of which are richly fossiliferous. In the south about 60 m of Middle Jurassic (Callovian–Oxfordian) sandstones with a middle siltstone unit are referred to the 'Vardekløft Formation' [**JC**] on the map sheet. Upper Jurassic (Kimmeridgian) sandstones succeeded by shales form a *c.* 75 m thick succession in the north, indicated as the Bernbjerg Formation [**JK**] on the map sheet. Lower Cretaceous sediments are represented by a 50–60 m succession of Valanginian conglomerates, sandstones and siltstones referred to the Palnatokes Bjerg Formation [**CV**], and about 90 m of silty shales and sandstones of Barremian or younger age [**CB**]. Note that recent lithostratigraphic revisions (Surlyk 2003) have upgraded the 'Vardekløft Formation' to the Vardekløft Group, and that the Bernbjerg Formation now becomes part of the Hall Bredning Group. These changes reflect the interpretation of the Jurassic – Early Cretaceous succession as part of a syn-rift megasequence.

Three small outliers of Jurassic sedimentary rocks [**J**] occur on the east side of Koefoed-Hansen Bræ, all preserved in down-faulted blocks on the west side of N–S-trending faults. The two northern localities comprise very coarse-grained conglomerates with quartzitic sandstones in which coal fragments and silicified wood are conspicuous. Petrified tree trunks up to 5 m long and 40 cm in diameter are locally common. Identified spores and pollen are listed by Piasecki *et al.* (1994). The flora is comparable to the Lower Jurassic of the Scoresby Sund region of East Greenland (70°–72°N; Harris 1935). The third locality is a small Jurassic outcrop immediately east of Kulhøj, at the north-west end of Annekssøen, which is too small to be shown on the printed map sheet. The *c.* 5 m thick succession of alternating shale, coal and limestone was first recorded by Koch (1917), and new investigations have been reported in Piasecki *et al.* (1994).

Scattered outcrops of Jurassic and Cretaceous sedimentary rocks occur in Hochstetter Forland and on the island of Shannon in the south-eastern part of the map sheet; they essentially correspond to the units found on the eastern side of Store Koldewey.

Palaeogene basalts and sills

The island of Shannon (*c.* 75°15′N) preserves the northernmost representatives of the Palaeogene (lower Tertiary) plateau basalt province of East Greenland. The basalts on Shannon are 55–50 Ma old (Eocene), and are a northward extension of the succession of subaerial lava flows described from Hold with Hope (*c.* 73°30′N) and Wollaston Forland (*c.* 74°30′N; Upton *et al.* 1984; Watt 1994). The latter localities preserve a 600–700 m thick succession comprising uniform tholeiitic lavas with flow thicknesses of 20–25 m, which unconformably overlie Mesozoic sedimentary rocks of various ages implying a period of significant erosion preceding the onset of volcanism.

On Shannon basaltic sills [β_2] crop out in low coastal cliffs forming a crescent-shaped outcrop, while the inland low-lying areas of the island are largely covered by Quaternary deposits. Flat-lying tholeiitic lavas [β_1] have been identified on the east coast of Shannon, where three flows are recorded (Watt 1994). A *c.* 10 m thick unit of intrabasaltic sediment of unconsolidated quartzitic sand with iron concretions separates two of the lava flow units near Kap Pansch.

Quaternary

Quaternary deposits, mainly Upper Pleistocene in age, are depicted on the map sheet as undifferentiated cover. These deposits are found mainly in coastal lowland areas (Shannon, Hochstetter Forland, Germania Land and Île de France), in broad valleys, and along the eastern margin of Storstrømmen. The widely distributed but thin ground moraine cover on plateaux and highland areas is generally not shown. Quaternary geological investigations were only included in the mapping project in 1990 (Landvik 1990), but additional field work was undertaken on Hochstetter Forland in 1992 (Björck *et al.* 1994), in Jøkelbugten and on Île de France in 1998 (Bennike & Weidick 1999, 2001) and on Store Koldewey in 2003 (Bennike *et al.* 2004).

Reconnaissance Quaternary investigations along a profile from Dronning Louise Land to Île de France demonstrated that, apart from a few nunataks, the area was completely inundated by the Inland Ice in Late Weichselian time (Funder *et al.* 1998). Even the higher mountains on Store Koldewey were covered by ice during the last glacial maximum (Håkansson *et al.* 2007), indicating that the ice extended far beyond the present coastal areas. Studies of the glaciology and Quaternary deposits around Storstrømmen have shown that this part of the region was deglaciated in a period from *c.* 35 000 to *c.* 25 000 years before Present (Weidick *et al.* 1996). Four major successive ice-front positions have been identified between the outer coast and the present Inland Ice margin. In three regions Quaternary sediments were found underlying till deposits, and these probably contain material older than the latest Late Weichselian glaciation (Landvik 1990). The region was to a large extent deglaciated in the early Holocene, between *c.* 11 000 and *c.* 8000 years ago (Bennike & Björck 2002). During the period from *c.* 6000 to 1500 years before present the glaciers Storstrømmen and Koefoed Hansen Bræ did not exist, and an open strait existed west of the Germania Land region that was thus an island (Weidick *et al.* 1996). Holocene uplift is indicated by the presence of marine terraces at *c.* 30 m a.s.l. in the inner fjords and at *c.* 60 m a.s.l. on the outer coast.

Investigations of the Quaternary deposits on Hochstetter Forland indicate a correlation with the detailed glaciation record established in the Scoresby Sund region (*c.* 71°N; Björck *et al.* 1994; Adrielson & Alexanderson 2005). In the Scoresby Sund region the maximum glaciation occurred during the Saalian between 240 and 130 ka ago, at which time the whole region was overridden by the Inland Ice. After the Eemian interglacial between 125–115 ka, glaciers filled the valleys and fjord basins and extended onto the inner shelf in the Early Weichselian on three occasions separated by interstadials. A last stadial in the Mid- to Late Weichselian lasted for almost 50 ka until the beginning of the Holocene, *c.* 11 700 years before Present.

A more than 20 m thick pre-Pleistocene succession of shallow water marine sediments was discovered in 1990 on the northernmost part of Île de France (Landvik 1994), and was investigated in detail in 1998 (Bennike *et al.* 2002). Studies of the shells and the palaeomagnetic signature date the sequence to between 3.58 and 2.60 Ma (Middle Pliocene). The flora and fauna of dinoflagellates, foraminifera and molluscs indicate a seawater temperature somewhat higher than the present. Another succession of marine deposits occurring on Store Koldewey has been dated to between 2.6 and 1.8 Ma (Bennike *et al.* 2004).

Mineralisation and oil geological indications

Reconnaissance for indications of mineralisation was carried out in connection with the regional geological mapping programme, mainly in the Caledonian orogen between 76° and 78°N (Jensen & Stendal 1994). These investigations included visits to known mineral showings characterised by rust zones and skarns, and follow-up visits to localities where geochemical anomalies had been detected by earlier investigations.

Jensen & Stendal (1994) grouped the showings and geochemical anomalies into three genetic and apparent age types: (1) Palaeoproterozoic to Mesoproterozoic skarns; (2) mineralised showings and skarns related to Caledonian thrust and shear zones; and (3) pyrite-mineralised post-Jurassic fault breccias. They concluded that the potential for base metal sulphides and rare earth element-bearing minerals in skarns is low. Iron oxides (magnetite and hematite) and pyrite are present in moderate amounts associated with Caledonian thrust zones and late faults.

Geochemical investigations based on stream sediment sampling have revealed elevated levels of Se, Th, U, W, La, Ce, Nd, Tb, Yb and Lu near the contacts between granitic intrusions and supracrustal rocks, e.g. south of Bessel Fjord (76°N) where Caledonian granites and pegmatites intrude the Smallefjord sequence. Such regional geochemical distributions essentially reflect the surface geology. For example, the contrast in element distribution across the Bessel Fjord shear zone reflects the dominance of gneiss lithologies north of the fjord and metasedimentary lithologies (Smallefjord sequence, Eleonore Bay Supergroup) south of the fjord.

Mineralisation associated with post-Jurassic fault breccias is characterised by prominent rust zones which extend over distances of 1–2 km (Jensen & Stendal 1994); e.g. at Fladebugt (*c.* 77°15′N) and in Nordmarken (*c.* 77°45′N). These pyrite-mineralised fault breccias separate down-faulted blocks of Palaeozoic and Mesozoic sedimentary rocks from the adjacent crystalline gneisses. Geochemical analyses of stream sediments from the Fladebugt fault zone reveal slightly elevated values for Au, Ba, Hf and U.

The most interesting hydrocarbon finds are relics of crude oil in the mineralised breccias associated with the steep NNW–SSE-trending fault zone at Fladebugt, north-western Germania Land (*c.* 77°15′N). The oil was probably generated from a Late Palaeozoic source rock dominated by terrestrially derived organic matter deposited in a lacustrine environment (Christiansen *et al.* 1991). A siltstone sample from the Carboniferous sedimentary rocks at Chatham Elv, eastern Stormlandet, was found to have *c.* 1% total organic content (TOC). This was reported by Piasecki *et al.* (1994) as a Type III kerogen, with a thermal alteration index (TAI) of 2, showing the sediments were buried to a maximum depth of 1.5–2 km. These data are of interest in connection with the evaluation of the petroleum potential of the offshore basins of North-East Greenland, several of which preserve sediment thicknesses of 10–12 km (Hamann *et al.* 2005).

Acknowledgements

Discussions with colleagues during and subsequent to the field mapping programme have significantly helped our interpretations. We acknowledge in particular the perceptive review and helpful comments of Ellen M.O. Sigmond.

References

Adrielson, L. & Alexanderson, H. 2005: Interaction between the Greenland ice sheet and the Liverpool Land coastal ice cap during the last two glacial cycles. Journal of Quaternary Science **20**, 269–283.

Bennike, O. & Björck, S. 2002: Chronology of the last recession of the Greenland ice sheet. Journal of Quaternary Science **17**, 211–217.

Bennike, O. & Weidick, A. 1999: Observations on the Quaternary geology around Nioghalvfjerdsfjorden, eastern North Greenland. Geology of Greenland Survey Bulletin **183**, 57–60.

Bennike, O. & Weidick, A. 2001: Late Quaternary history around Nioghalvfjerdsfjorden and Jøkelbugten, North-East Greenland. Boreas **30**, 205–227.

Bennike, O., Abrahamsen, N., Bak, M., Israelson, C., Konradi, P., Matthiessen, J. & Witkowski, A. 2002: A multi-proxy study of Pliocene sediments from Île de France, North-East Greenland. Palaeo [Palaeogeography, Palaeoclimatology, Palaeoecology] **186**, 1–23.

Bennike, O., Cremer, H., Håkansson, L. Hultzch, N., Klug, M., Kobabe, S. & Wagner, B. 2004: Quaternary geological and biological studies on Store Koldewey and on Geographical Society Ø. Reports on Polar and Marine Research **475**, 51–74.

Björck, S., Wohlfarht, B., Bennike, O., Hjort, C. & Persson, T. 1994: Revision of the Early Holocene lake sediment based chronology and event stratigraphy on Hochstetter Forland, NE Greenland. Boreas **23**, 513–525.

Brueckner, H.K., Gilotti, J.A. & Nutman, A.P. 1998: Caledonian eclogite-facies metamorphism of Early Proterozoic protoliths from the North-East Greenland eclogite province. Contributions to Mineralogy and Petrology **130**, 103–120.

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. Rapport Grønlands Geologiske Undersøgelse **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. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 53–70.

Chadwick, B., Friend, C.R.L. & Higgins, A.K. 1990: The crystalline rocks of western and southern Dove Bugt, North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **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. Rapport Grønlands Geologiske Undersøgelse **155**, 28–30.

Christiansen, F.G., Bojesen-Koefoed, J.[A.], Jensen, S.M. & Stemmerik, L. 1991: Oil seep in basement, Germania Land, North-East Greenland. Open File Series Grønlands Geologiske Undersøgelse **91/7**, 18 pp.

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

Collinson, J.D., Kalsbeek, F., Jepsen, H.F., Pedersen, S.A.S. & Upton, B.G.J. 2008: Paleoproterozoic and Mesoproterozoic sedimentary and volcanic successions in the northern parts of the East Greenland Caledonian orogen and its foreland. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 73–98.

Crimes, T.P. 1992: The record of trace fossils across the Proterozoic–Cambrian boundary. In: Lipps, J.H. & Signor, P.W. (eds): Origin and early evolution of the Metazoa, 177–202. New York: Plenum Press.

Dallmeyer, R.D. & Strachan, R.A. 1994: $^{40}Ar/^{39}Ar$ mineral age constraints on the timing of deformation and metamorphism, North-East Greenland Caledonides. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 153–162.

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. Journal of the Geological Society (London) **151**, 615–628.

Elvevold, S. & Gilotti, J.A. 2000: Pressure–temperature evolution of retrogressed kyanite eclogites, Weinschenk Island, North-East Greenland Caledonides. Lithos **53**, 127–147.

Elvevold, S. *et al.* 2000: Tectonic architecture of the East Greenland Caledonides 72°–74°30´N. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/88**, 34 pp.

Escher, J.C. 2001: Geological map of Greenland, 1:500 000, Kong Oscar Fjord, Sheet 11. Copenhagen: Geological Survey of Denmark and Greenland.

Escher, J.C. & Pulvertaft, T.C.R. 1995: Geological map of Greenland, 1:2 500 000. Copenhagen: Geological Survey of Greenland.

Frederiksen, K.S. 2000: A Neoproterozoic carbonate ramp and base-of-slope succession, the Andrée Land Group, Eleonore Bay Supergroup, North-East Greenland: sedimentary facies, stratigraphy and basin evolution, 242 pp. Unpublished Ph.D. thesis, University of Copenhagen, Denmark.

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. Rapport Grønlands Geologiske Undersøgelse **148**, 133–141.

Friderichsen, J.D., Gilotti, J.A., Henriksen, N., Higgins, A.K., Hull, J.M., Jepsen, H.F. & Kalsbeek, F. 1991: The crystalline rocks of Germania Land, Nordmarken and adjacent areas, North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **152**, 85–94.

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). In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 17–33.

Funder, S., Hjort, C., Landvik, J.Y., Nam, S.-I., Reeh, N. & Stein, R. 1998: History of a stable ice margin – East Greenland during the Middle and Upper Pleistocene. Quaternary Science Reviews **17**, 77–123.

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. & McClelland, W.C. 2007: Characteristics of, and a tectonic model for, ultrahigh-pressure metamorphism in the overriding plate of the Caledonian orogen. International Geology Review **49**, 777–797.

Gilotti, J.A. & McClelland, W.C. 2008: Geometry, kinematics, and timing of extensional faulting in the Greenland Caledonides – a synthesis. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 251–271.

Gilotti, J.A. & Ravna, E.J.K. 2002: First evidence for ultrahigh-pressure metamorphism in the North-East Greenland Caledonides. Geology **30**, 551–554.

Gilotti, J.A., Nutman, A.P. & Brueckner, H.K. 2004: Devonian to Carboniferous collision in the Greenland Caledonides: U-Pb zircon and Sm-Nd ages of polyphase high-pressure and ultrahigh-pressure metamorphisms. Contributions to Mineralogy and Petrology **148**, 216–235.

Gilotti, J.A., Jones, K.A. & Elvevold, S. 2008: Caledonian metamorphic patterns in Greenland. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 201–225.

Håkansson, L., Graf, A., Strasky, S., Ivy-Ochs, S., Kubik, P.W., Hjort, C. & Schlüchter, C. 2007: Cosmogenic 10Be-ages from the Store Koldewey island, NE Greenland. Geografiska Annaler **89A**, 195–202.

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

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

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

Haller, J. 1983: Geological map of Northeast Greenland 75°–82°N. Lat. 1:1,000,000. Meddelelser om Grønland **200**(5), 22 pp. + 1 map.

Hamann, N.E., Whittaker, R.C. & Stemmerik, L. 2005: Structural and geological development of the North-East Greenland shelf. In: Doré, A.G. & Vining, B.A. (eds): Petroleum geology: North-West Europe and global perspectives. Proceedings of the 6th Petroleum Geology Conference, 887–902. London: Geological Society.

Hansen, B.T., Henriksen, N. & Kalsbeek, F. 1994: Age and origin of Caledonian granites in the Grandjean Fjord – Bessel Fjord region (75°–76°N), North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 139–151.

Harris, T.M. 1935: The fossil flora of Scoresby Sound, East Greenland. 4: Ginkgoales, Coniferales, Lycopodiales and isolated fructifications. Meddelelser om Grønland **112**(1), 176 pp.

Hartz, E. & Andresen, A. 1995: Caledonian sole thrust of central East Greenland: a crustal-scale Devonian extensional detachment? Geology **23**, 637–640.

Henriksen, N. 1994: Geology of North-East Greenland (75°–78°N) – the 1988–90 mapping project. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 5–16.

Henriksen, N. 1997: Geological map of Greenland, 1:500 000, Dove Bugt, Sheet 10. Copenhagen: Geological Survey of Denmark and Greenland.

Henriksen, N. 2003: Caledonian Orogen, East Greenland 70°–82°N. Geological map 1:1 000 000. Copenhagen: Geological Survey of Denmark and Greenland.

Henriksen, N. & Higgins, A.K. 2008: Caledonian orogen of East Greenland 70°N–82°N: Geological map at 1:1,000,000 – concepts and principles of compilation. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 345–368.

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. Rapport Grønlands Geologiske Undersøgelse **145**, 90–97.

Higgins, A.K. (ed.) 1994: Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 209 pp.

Higgins, A.K. & Leslie, A.G. 2000: Restoring thrusting in the East Greenland Caledonides. Geology **28**, 1019–1022.

Higgins, A.K. & Leslie, A.G. 2008: Architecture and evolution of the East Greenland Caledonides – an introduction. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 29–53.

Higgins, A.K. & Soper, N.J. 1994: Structure of the Eleonore Bay Supergroup at Ardencaple Fjord, North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 91–101.

Higgins, A.K., Leslie, A.G. & Smith, M.P. 2001a: Neoproterozoic – Lower Palaeozoic stratigraphical relationships in the marginal thin-skinned thrust belt of the East Greenland Caledonides: comparisons with the foreland of Scotland. Geological Magazine **138**, 143–160.

Higgins, A.K., Smith, M.P., Soper, N.J., Leslie, A.G., Rasmussen, J.A. & Sønderholm, M. 2001b: The Neoproterozoic Hekla Sund Basin, eastern North Greenland: a pre-Iapetan extensional sequence thrust across its rift shoulders during the Caledonian orogeny. Journal of the Geological Society (London) **158**, 487–499.

Higgins, A.K. *et al.* 2004: The foreland-propagating thrust architecture of the East Greenland Caledonides 72°–75°N. Journal of the Geological Society (London) **161**, 1009–1026.

Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds) 2008: The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 368 pp. + 1 map and 1 CD.

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

Hougaard, G., Jepsen, H.F. & Neve, J.K. 1991: GGU's photogeological laboratory: aerial photogrammetry – a valuable geological mapping tool in Greenland. Rapport Grønlands Geologiske Undersøgelse **152**, 29–32.

Hull, J.M. & Friderichsen, J.D. 1995: Geology of basement rocks in northern North-East and eastern North Greenland. In: Higgins, A.K. (ed.): Express report: eastern North Greenland and North-East Greenland 1995, 11–21. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Hull, J.M. & Gilotti, J.A. 1994: The Germania Land deformation zone and related structures, North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 113–127.

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-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 35–51.

Jensen, S.M. & Stendal, H. 1994: Reconnaissance for mineral occurrences in North-East Greenland (76°–78°N). In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 163–168.

Jepsen, H.F. 2000: Geological map of Greenland, 1:500 000, Lambert Land, Sheet 9. Copenhagen: Geological Survey of Denmark and Greenland.

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

Kalsbeek, F. 1995: Geochemistry, tectonic setting and poly-orogenic history of Palaeoproterozoic basement rocks from the Caledonian fold belt of North-East Greenland. Precambrian Research **72**, 301–315.

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. Journal of Petrology **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 Research **63**, 163–178.

Kalsbeek, F., Nutman, A.P., Escher, J.C., Friderichsen, J.D., Hull, J.M., Jones, K.A. & Pedersen, S.A.S. 1999: Geochronology of granitic and supracrustal rocks from the northern part of the East Greenland Caledonides: ion microprobe U-Pb zircon ages. Geology of Greenland Survey Bulletin **184**, 31–48.

Kalsbeek, F., Thrane, K., Nutman, A.P. & Jepsen, H.F. 2000: Late Mesoproterozoic to early Neoproterozoic history of the East Greenland Caledonides: evidence for Grenvillian orogenesis? Journal of the Geological Society (London) **157**, 1215–1225.

Kalsbeek, F., Jepsen, H.F. & Jones, K.A. 2001: Geochemistry and petrogenesis of S-type granites in the East Greenland Caledonides. Lithos **57**, 91–109.

Kalsbeek, F., Thrane, K., Higgins, A.K., Jepsen, H.F., Leslie, A.G., Nutman, A.P. & Frei, R. 2008a: Polyorogenic history of the East Greenland Caledonides. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 55–72.

Kalsbeek, F., Higgins, A.K., Jepsen, H.F., Frei, R. & Nutman, A.P. 2008b: Granites and granites in the East Greenland Caledonides. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 227–249.

Koch, I.P. 1917: Survey of Northeast Greenland. Meddelelser om Grønland **46**(2), 79–468.

Koch, L. & Haller, J. 1971: Geological map of East Greenland 72°–76°N. Lat. (1:250,000). Meddelelser om Grønland **183**, 26 pp. + 13 maps.

Landvik, J.Y. 1990: Quaternary geology along a profile from Dronning Louise Land to Île de France. In: Henriksen, N. *et al.*: Express report: North-East Greenland 1990, 57–60. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Landvik, J.Y. 1994: The last glaciation of Germania Land and adjacent areas, northeast Greenland. Journal of Quaternary Science **9**, 81–92.

Larsen, H.C. 1990: The East Greenland shelf. In: Grantz, A., Johnson, [G.] L. & Sweeney, L.F. (eds): The Arctic Ocean region. The geology of North America **L**, 185–210. Boulder, Colorado: Geological Society of America.

Larsen, O. & Graff-Petersen, P. 1980: Sr-isotopic studies and mineral composition of the Hagen Bræ member in the Proterozoic clastic sediments at Hagen Bræ, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **99**, 111–118.

Larsen, P.-H., Olsen, H. & Clack, J.A. 2008: The Devonian basin in East Greenland – review of basin evolution and vertebrate assemblages. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 273–292.

Leslie, A.G. & Higgins, A.K. 2008: Foreland-propagating Caledonian thrust systems in East Greenland. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 169–199.

McClelland, W.C., Power, S.-E., Gilotti, J.A., Mazdab, F. & Wopenka, B. 2006: U-Pb SHRIMP geochronology and trace-element geochemistry of coesite-bearing zircons, North-East Greenland Caledonides. In: Hacker, B., McClelland, W.C. & Liou, J.G. (eds): Ultrahigh-pressure metamorphism: deep continental subduction. Geological Society of America Special Paper **404**, 23–43.

Nutman, A.P. & Kalsbeek, F. 1994: Search for Archaean basement in the Caledonian fold belt of North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 129–133.

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

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

Pedersen, S.A.S., Craig, L.E., Upton, B.G.J., Rämö, O.T., Jepsen, H.F. & Kalsbeek, F. 2002: Palaeoproterozoic (1740 Ma) rift-related volcanism in the Hekla Sund region, eastern North Greenland: field occurrence, geochemistry and tectonic setting. Precambrian Research **114**, 327–346.

Piasecki, S., Stemmerik, L., Friderichsen, J.D. & Higgins, A.K.1994: Stratigraphy of the post-Caledonian sediments in the Germania Land area, North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 177–184.

Smith, M.P. & Rasmussen, J.A. 2008: Cambrian–Silurian development of the Laurentian margin of the Iapetus Ocean in Greenland and related areas. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 137–167.

Smith, M.P., Rasmussen, J.A., Robertson, S., Higgins, A.K. & Leslie, A.G. 2004: Lower Palaeozoic stratigraphy of the East Greenland Caledonides. In: Higgins, A.K. & Kalsbeek, F. (eds): East Greenland Caledonides: stratigraphy, structure and geochronology. Geological Survey of Denmark and Greenland Bulletin **6**, 5–28.

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

Sønderholm, M. & Tirsgaard, H. 1993: Lithostratigraphic framework of the Upper Proterozoic Eleonore Bay Supergroup of East and North-East Greenland. Bulletin Grønlands Geologiske Undersøgelse **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. Rapport Grønlands Geologiske Undersøgelse **145**, 97–102.

Sønderholm, M., Frederiksen, K.S., Smith, M.P. & Tirsgaard, H. 2008: Neoproterozoic sedimentary basins with glacigenic deposits of the East Greenland Caledonides. In: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides: evolution of the northeast margin of Laurentia. Geological Society of America Memoir **202**, 99–136.

Soper, N.J. & Higgins, A.K. 1993: Basement–cover relationships in the East Greenland Caledonides: evidence from the Eleonore Bay Supergroup at Ardencaple Fjord. Transactions of the Royal Society of Edinburgh, Earth Sciences **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. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 135–137.

Steiger, R.H., Harnik-Šoptrajanova, G., Zimmerman, E. & Henriksen, N. 1976: Isotopic age and metamorphic history of the layered gneiss at Danmarkshavn, East Greenland. Contributions to Mineralogy and Petrology **57**, 1–24.

Stemmerik, L. & Piasecki, S. 1990: Post-Caledonian sediments in North-East Greenland between 76° and 78°30´N. Rapport Grønlands Geologiske Undersøgelse **148**, 123–126.

Strachan, R.A. 1994: Evidence in North-East Greenland for Late Silurian – Early Devonian regional extension during the Caledonian orogeny. Geology **22**, 913–916.

Strachan, R.A. & Tribe, I.R. 1994: Structure of the Storstrømmen shear zone, eastern Hertugen af Orléans Land, North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 103–112.

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. Journal of the Geological Society (London) **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. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 71–76.

Strachan, R.A., Chadwick, B., Friend, C.R.L. & Holdsworth, R.E. 1995a: New perspectives on the Caledonian orogeny in Northeast Greenland. In: Hibbard, J.P., van Staal, C.R. & Cawood, P.A. (eds): Current perspectives in the Appalachian–Caledonian orogen. Geological Association of Canada, Special Paper **41**, 303–322.

Strachan, R.A., Nutman, A.P. & Friderichsen, J.D. 1995b: SHRIMP U-Pb geochronology and metamorphic history of the Smallefjord sequence: NE Greenland Caledonides. Journal of the Geological Society (London) **152**, 779–784.

Strachan, R.A., Martin, M.W. & Friderichsen, J.D. 2001: Evidence for contemporaneous yet contrasting styles of granitic magmatism during extensional collapse of the northeast Greenland Caledonides. Tectonics **20**, 458–473.

Surlyk, F. 2003: The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin **1**, 659–722.

Tirsgaard, H. & Sønderholm, M. 1997: Lithostratigraphy, sedimentary evolution and sequence stratigraphy of the Upper Proterozoic Lyell Land Group (Eleonore Bay Supergroup) of East and North-East Greenland. Geology of Greenland Survey Bulletin **178**, 60 pp.

Upton, B.G.J., Emeleus, C.H. & Beckinsale, R.D. 1984: Petrology of the northern East Greenland Tertiary flood basalts: evidence from Hold with Hope and Wollaston Forland. Journal of Petrology **25**, 151–184.

Upton, B.G.J., Rämö, O.T., Heaman, L.M., Blichert-Toft, J., Kalsbeek, F. & Jepsen, H.F. 2005: The Mesoproterozoic Zig-Zag Dal Basalts and associated intrusions of eastern North Greenland: mantle plume – lithosphere interaction. Contributions to Mineralogy and Petrology **149**, 40–56.

Watt, G.R. & Thrane, K. 2001: Early Neoproterozoic events in East Greenland. Precambrian Research **110**, 165–184.

Watt, W.S. 1994: Stratigraphy and correlation of the Tertiary plateau basalts in North-East Greenland. In: Higgins, A.K. (ed.): Geology of North-East Greenland. Rapport Grønlands Geologiske Undersøgelse **162**, 185–194.

Weidick, A., Andreasen, C., Oerter, H. & Reeh, N. 1996: Neoglacial glacier changes around Storstrømmen, North-East Greenland. Polarforschung **64**, 95–108.

Wyllie, P.J. 1957: A geological reconnaissance through south Germania Land. Meddelelser om Grønland **157**(1), 66 pp.