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

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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 (gn1) 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 [gn1] and metagranitoid sheets [gn2], 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 6579-NÖ 13487, copyright: Kort & Matrikelstyrelsen (National Survey and Cadastre), Copenhagen, Denmark.

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Abstract


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 Bjærg 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.
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) is 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 structural terminology used in this map description. In addition to the published geological descriptions of Peacock (1956, 1958) and Wyllie (1952–1954), and their scientific results include the regional account of these early investigations and the exploration history of the East Greenland Caledonides includes a comprehensive description of all the major structures in the region. In addition to the published geological maps at a scale of 1:500 000 (Koch & Haller 1971), maps at 1:1 million scale geological map of the northern half of the East Greenland shield is exposed as the 5 to 15 km wide northern part of the map sheet area, and in its southern parts make up poorly exposed ground in Hochsten Fjord and on the island of Shannon. Palaeogene lavas and sills post-date the 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 Hochsten Fjord and on the island of Shannon.

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 Imbriatic 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 Hochsten Fjord 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; Jespen 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 Elnornoye Bay Supergroup around Ardencaple Fjord (Sommer 1957), and the regional geological of the structurally underlining 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 a scale of 1:250 000 (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 Greenland Caledonides was compiled by Haller (1970). The 1:1 million scale geological map of the northern half of the East Greenland Caledonides was compiled by Haller (1970).
Greenland Caledonides (75°–82°N) accompanying Haller (1983) was originally compiled in 1964, and has been superceded 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
2. The Western thrust belt, which is a region of poorly 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 ‘Tekkant ‘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 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; Nunn & 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 Scoreby 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 Bredfjord – Ardenecaple 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).

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 orogenies reworked during Caledonian orogenesis. (3) Post-Caledonian sediments and Palaeoproterozoic orthogneisses reworked from the allochthonous rocks of 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; Nunn & Kalsbeek 1994; Kalsbeek et al. 2008a).

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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 orogenies reworked during Caledonian orogenesis. (3) Post-Caledonian sediments and Palaeoproterozoic orthogneisses reworked from the allochthonous rocks of 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; Nunn & Kalsbeek 1994; Kalsbeek et al. 2008a).

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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 Ardencape Fjord region, have been dated to 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 (gn3), unconformably overlain by two sedimentary sequences, the ‘Trekant’ series (T) and Zebra ‘series’ (Z) (Fig. 6), 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).
Crystalline complexes

The amphibolite facies gneiss complexes 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, meta-saprolites, 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 40Ar/39Ar mineral ages of c. 390 Ma (Dallmeyer & Strachan 1994).

Trekant ‘series’

The Trekant ‘series’ 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.

Fig. 5. Folded, thin-bedded, light-coloured sandstones of the lowermost Zebra ‘series’ unconformably overlying sandstones and siltstones of the Trekant ‘series’ at Prince Axel Nunatak, northern Dronning Louise Land. View towards the south. Cliff height about 120 m. Photo: J.D. Friderichsen.

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.
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 Metoprotrozoic 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 orogen

The Zebra ‘series’ [Z] is a thin sequence of shallow marine quartzites, mudstones, magnetite-hematite-bearing sandstones and limestones, which unconformably overlie the Treakant ‘series’. At the base there is an angular discordance of ~5°–20° with the Treakant ‘series’ (Strachan et al. 1992). Thicker representatives of the Zebra ‘series’ are present in the Imbricate thrust zone where it contains Shlottbomia 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 Shott Formation of the Eleonore Sø and Målebjerg windows (73°45′–74°N) and the Klafterfjord 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 Shlottbomia (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).

Dolerite sills and dykes

Dolerite intrusions [δ] form dense swarms cutting the Treakant ‘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 Midontomerse Dolerites that cut the Independence Fjord Group of eastern North Greenland (Jepsen & Kalsbeek 1979; Kalsbeek & Jepsen 1983; Pedersen et al. 2002).
Germania Land shear zone (GLSZ) that crosses the mouth of Skarvfjorden. 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 slices 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 Nanaraku (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 ‘gn3’ on the map sheet should therefore be ‘gn1’.

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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).
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 Terekant ‘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] 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.

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] 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.
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 Herragen of Orleans 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 Smalfjord 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 Smalfjord 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 microprobe U-Pb zircon ages of between 3000 Ma and 2725 Ma (Stecher & Henriksen 1994). However, the ion microprobe data for the gneisses in the Danmarkshavn area also show the presence of c. 1676 Ma zircons with high, ‘igneous’, Th/U ratios indicative of igneous melting at that time (Nutman & Kalsbeek 1994).

The most widespread gneiss units are grey orthogneisses of variable composition and structure (gn1), 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 (gn2) 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 Friderichen 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 (gn3), 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 homogenous granitic rocks (gn4), 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 (gn5). The supracrustal rock units include marbles and calc-silicate rocks (gn6), cordierite- and sillimanite-bearing paragneisses and mica schists (gn7), and semipelitic and siliceous metasedimentary rocks (gn8). 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, megacyctlic anorthositic and ultramafic igneous rocks occur within the grey gneisses. The metamorphosed mafic gabbroic units are recorded as amphibolites (gn9), and ultramafic rock types (gn10) that include pyroxenites, dunites and hornblendites. East of L. Bistrup Bræ leucogabbro and gabbro-anorthositic (gn11) layers and lenses are locally common. Coarse-grained varieties locally preserve their original phyllosic 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 (gn12), 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 recrystallisa-
tion 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 relation-
ships can be seen they post-date their gneiss host, but are con-
sidered to form part of the same Palaeoproterozoic complex.

Eclogites

Eclogite 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 sug-
gest 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 pres-
sure (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. Coe-
site-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 rela-
tion to the Caledonian orogeny is ascribed to an intracratonic
subduction zone undergoing ultra-high-pressure metamor-
phism 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 discus-
sion 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.
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 [gn1] with occasional foliated metagranitoid units [gn2]. 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 x 110 km in size, which surrounds the outcrop of the Eleonore Bay
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, discordant layers and lenses of quartz-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 (g) 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 (Kalbeek 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. 1999b). 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.
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 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 Bjer (BZ), Kap Alfred (KA), Vibeke So (VS) and Skjoldungebrae (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.

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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 Bjer (BZ), Kap Alfred (KA), Vibeke So (VS) and Skjoldungebrae (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.
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 characterized 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).

Norreland 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 Bruuns Land and the islands around northern Dove Bugt lacks eclogite lenses, and may have been derived from intermediate crustal levels. However, eclogites are abundant.

Fig. 12. WSW–ENE-trending cross-section through the Eleonore Bay Supergroup (EBSG) outcrop where Ardencaple Fjord divides into Bredefjord and Strallefjord. 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).
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.
were indistinguishable, and that eclogitic pods occur in the two sides of the shear zone in Hertugen af Orléans Land. However, Hull & Gilotti (1994) observed that the gneisses on the northern part of the Storstrømmen shear zone are strongly 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. 1.750 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 Palaeoproterozoic 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 Kiledalen 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 heterogeneous deformed gneisses and mylonites at least 8 km wide (Strachan & Tibbet 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 Kiledalen 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 Kiledalen 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 (Fredriksen 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.
strommen 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 Stromstrennen 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 (Friedrichsen 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 & Rava 2002; Gilotti et al. 2004, 2008; McClelland et al. 2006).

Cooling following the Caledonian orogeny is documented by 40Ar/39Ar age data that range from c. 438 to 370 Ma (earliest Silurian to middle–late Devonian; Dallmeyer et al. 1994; Dallmeyer & Strachan 1994). 40Ar/39Ar 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 Arednaple Fjord has yielded a metamorphic cooling age of 415 ± 0.5 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 40Ar/39Ar 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 [g] 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, sheared 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).
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.

**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; Piascek 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 southeast 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 (Piascek 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 (Suarlyk 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 Bte in the western part of Nordmarken (Stemmerik & Piasceki 1990; Piasceki et al. 1994). The widespread occurrence throughout the region of glacial erratics of Jurassic coal, notably west of Skærjorden 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 (Eischer & Pulvertaft 1995) and on figures in Hamann et al. (2005).

The Mesozoic sedimentary rocks of eastern Store Koldewey (Stemmerik & Piasceki 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 (Suarlyk 2003) have upgraded the ‘Vardekløft Formation’ to the Vardekløft Group, and that the Bernbjerg Formation now becomes part of the Hall Breeding 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 Bte, 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. Terraced tree trunks up to 5 m long and 40 cm in diameter are locally common. Identified spores and pollen are listed by Piasceki 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 Kullaj, at the north-west end of Anteksoara, 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 Piasceki 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; Upot 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] 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] 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 Storemonnen. The widely distributed but thin ground moraine cover on plateaux and hillland 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 & Windick 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
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, Th, 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 Germany Land (c. 77°15´N). The oil was probably generated from a Late Palaeozoic source rock dominated by terrrestrially derived organic matter deposited in a lacustrine...
References

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