

**Descriptive text to the Geological
map of Greenland, 1:500 000,
Lambert Land, Sheet 9**

Anthony K. Higgins

Geological Survey of Denmark and Greenland Map Series 7

Keywords

East Greenland, Caledonian orogeny, Palaeoproterozoic, Mesoproterozoic, Neoproterozoic, Palaeozoic, Mesozoic, thrust units.

Cover

Extract from the central part of the Lambert Land map sheet. The map units north and south of Centrumso are Palaeozoic units of the Thin-skinned fold-and-thrust belt, also exposed in a strip along Sæfæxi Elv to Marmorvigen. The Vandredalen thrust sheet comprises the Rivieradal Group (R) with outcrops of the carbonate formations of the Hagen Fjord Group (FB) along the western frontal area. The mountainous areas west of Hekla Sund and Lynn Ø comprise Palaeoproterozoic–Mesoproterozoic gneisses and dolerites, and tholeiitic volcanic rocks of the Aage Berthelsen Gletscher Formation (BG) and Hekla Sund Formation (HS).

Frontispiece: facing page

Intense folding in Proterozoic sandstones and doleritic rocks on the south side of Ingolf Fjord. The light-coloured rocks are Independence Fjord Group quartzites and the dark units doleritic dykes and sills; the deformation is part of a large-scale fold duplex that raised the Vandredalen thrust sheet above exposure level in this region. The author (in red) with the other members of the mapping team: Stig A.S. Pedersen (left), Graham Leslie (behind) and N.J. Soper. Photo: Niels Henriksen.

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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

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Contents

Abstract	5
Introduction	7
Geological setting	9
Caledonian foreland	11
Proterozoic	
Independence Fjord Group (IF)	11
Zig-Zag Dal Basalt Formation (Z)	11
Midsommersø Dolerites (MD)	11
Rivieradal Group (R)	13
Hagen Fjord Group (HF)	15
Cambrian	
Kap Holbæk Formation (KH)	16
Ordovician–Silurian	
Ryder Gletscher Group (W)	17
Morris Bugt Group (TU, BR)	17
Washington Land Group (SH, OF)	17
Silurian	
Peary Land Group (L)	17
Caledonian orogen	18
Palaeoproterozoic	
Crystalline complexes	18
Meso–Palaeoproterozoic	
Independence Fjord Group (IF)	18
Aage Berthelsen Gletscher & Hekla Sund Formations (BG, HS)	19
Mesoproterozoic	
Metadolerites (? Midsommersø Dolerites) (Md)	20
Late Mesoproterozoic	
Metasedimentary and metavolcanic rocks	20
Caledonian orogenesis	21
Thin-skinned fold-and-thrust belt	22
Vandredalen thrust sheet	23
Western thrust sheet	24
Nørreland thrust sheet	25
Post-Caledonian rocks	26
Wandel Sea Basin	26
Early Carboniferous	26
Carboniferous–Permian	26
Late Jurassic	26
Mineralisation	27
Acknowledgements	27
References	28

Abstract

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The Lambert Land 1:500 000 scale geological map sheet covers a segment of the East Greenland Caledonian orogen extending between latitudes 78°–81°N and longitudes 13°–29°W. The region was geologically mapped in the summers of 1978–1980 and 1993–1995 as part of a regional Survey mapping programme, and the map sheet was printed in 2000.

The region covered by the Lambert Land map sheet comprises a northern segment of the East Greenland Caledonides that is in thrust contact with the Caledonian foreland. The contact is an E-dipping, NNE–SSW-trending thrust that runs through Kronprins Christian Land from west of Blåso in the south to the region east of Sjælland Fjælde in the north. The Caledonian foreland succession is exposed in Mylius-Erichsen Land and Amdrup Højland on the west side of Danmark Fjord, and in western Kronprins Christian Land on the east side of Danmark Fjord. The several kilometre thick foreland succession ranges in age from Palaeoproterozoic to Silurian. In western Kronprins Christian Land the undeformed Ordovician–Silurian carbonates of the foreland pass eastwards into the so-called Thin-skinned fold-and-thrust belt developed in the same strata that farther eastwards are structurally overlain by the allochthonous Vandredalen thrust sheet. This thrust sheet is in its turn overlain by a group of thrust sheets that make up the mountainous high ground of central parts of Kronprins Christian Land, and structurally form the so-called Western thrust belt; these rock units have a deeper crustal origin. In the extreme east the Nørreland thrust sheet is exposed in a coastal strip that comprises Palaeoproterozoic crystalline gneisses that include eclogite-facies enclaves and units of meta-igneous and metasedimentary rocks.

Post-Caledonian rocks crop out in the north-eastern coastal parts of the map sheet area, and include sedimentary rocks of early Carboniferous to late Jurassic age that form part of the Wandel Sea Basin succession. Undifferentiated Quaternary deposits, ground moraine, alluvial fans and talus are distinguished where they obscure significant areas of bedrock.

Author's address

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

E-mail: *akh@geus.dk*

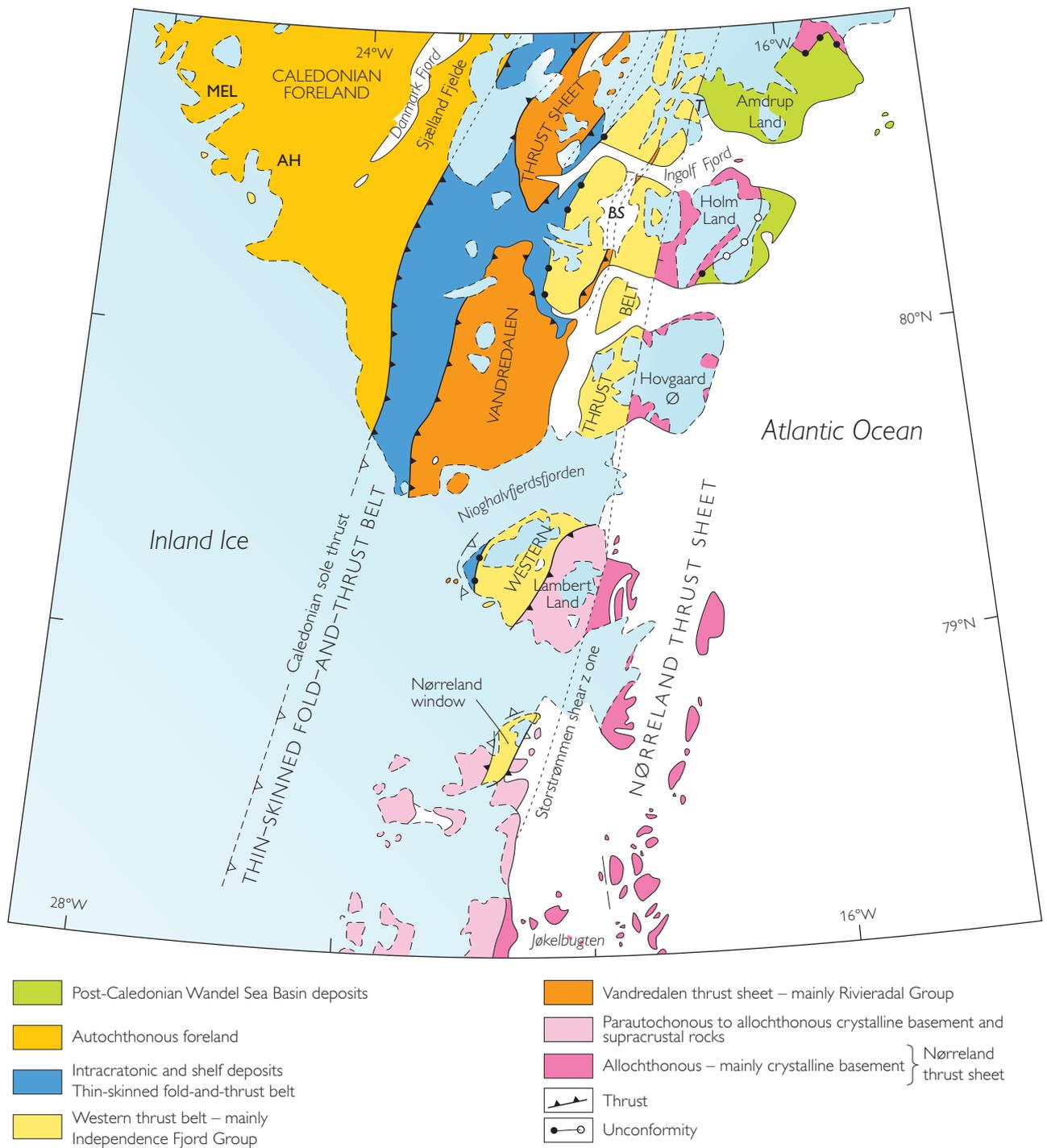


Fig. 1. Synoptic tectonic map showing main structural units, as modified by Higgins & Leslie (2008). AH: Amdrup Højland. MEL: Mylius-Erichsen Land. BS: Brede Spærregletscher. T: Tobias Gletscher.

Introduction

The Lambert Land map sheet (Sheet 9) is a bedrock geological map in the 1:500 000 scale regional map series of the Geological Survey of Denmark and Greenland (GEUS). The map sheet depicts the general geology of a segment of northernmost East Greenland and eastern North Greenland between latitudes 78° and 81°N and longitudes 13° and 29°W (Fig. 1). The map sheet spans the boundary between the Survey's regions of eastern North Greenland and North-East Greenland, that runs approximately along latitude 79°30'N (Ghisler 1990). The extensive ice-free land areas are 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. The Lambert Land map sheet was printed in 2000 (Jepsen 2000).

The Lambert Land region (78°–81°N) forms part of the 1300 km long East Greenland Caledonian orogen (70°–81°30'N), and includes a segment of the Proterozoic–Palaeozoic foreland. 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). The broad structural domains recognised throughout the orogen have been outlined by Higgins & Leslie (2008), and the westward foreland-directed thrust systems are described by Leslie & Higgins (2008). The latter article includes two W–E cross-sections through southern Kronprins Christian Land. Place names outside the map sheet area can be found in the description of northern East Greenland place names (Higgins 2010).

The foreland succession is exposed west of Danmark Fjord in Mylius-Erichsen Land and Amdrup Højland and in western Kronprins Christian Land on the east side of Danmark Fjord. The several kilometres thick foreland succession ranges in age from Palaeoproterozoic to Silurian. In western Kronprins Christian Land, the undeformed Ordovician–Silurian carbonates of the foreland pass eastwards into the so-called Thin-skinned fold-and-thrust belt developed in the same strata, that farther eastwards are structurally overlain by the allochthonous Vandredalen thrust sheet. This in its turn is overlain by a group of thrust sheets that make up the mountainous high ground of central parts of Kronprins Christian Land, and structurally form the so-called Western thrust belt. In the extreme east, the Nørreland thrust sheet (the Thick-skinned thrust belt of the synoptic map in the south-west corner of map sheet; Jepsen 2000) comprises Palaeoproterozoic crystalline gneisses that include eclogite-facies enclaves and units of meta-igneous and metasedimentary rocks.

The earliest exploration of the region covered by the Lambert Land map sheet was that by the 1906–1908 Danmark-Ekspeditionen, whose mission was to explore and survey the then largely unknown region north of Kap Bismarck

(76°42'N) and to link up with the explorations of Robert E. Peary in North Greenland (Friis 1909; Amdrup 1913). Four depot-laying journeys were made northwards from the expedition base at Danmark Havn (76°46'N, 18°41'W) to Jøkelbugten in the winter of 1906–07, in preparation for the main spring sledge journeys. In March 1907 four sledge parties left Danmark Havn, in total 10 men and 86 dogs. Two of the parties turned back at about 80°30'N, surveying on the way and reaching Danmark Havn again in late April. The two other groups travelled along the outer coast of Kronprins Christian Land, and then parted company. J.P. Koch's party went northwards along the east coast of Peary Land as far as Kap Bridgman (83°29'N), and then retraced its outward steps to reach Danmark Havn in June 1907. The three-man party led by Ludvig Mylius-Erichsen sledged westwards to explore Independence Fjord and Danmark Fjord, and were forced by open water to spend the summer on the west side of Danmark Fjord (81°30'N). Men and dogs suffered badly due to poor hunting, and the party was already in weakened condition when they resumed their return journey in mid-October 1907. Ludvig Mylius-Erichsen and Niels Peter Høeg-Hagen died, possibly near Nioghalvfjerdingsfjorden (79°37'N), while Jørgen Brønlund reached the east point of Lambert Land (Brønlunds Grav; 79°09'N) before he also died. The 1906–08 Danmark-Ekspeditionen achieved most of its surveying objectives, and its geological observations included recognition of the Carboniferous sediments of Amdrup Land. The geological results of Mylius-Erichsen's party were lost when they died, and their diaries have never been recovered despite extensive searches.

During the 1909–1912 Alabama-ekspeditionen, Ejnar Mikkelsen and Iver P. Iversen crossed the margin of the Inland Ice between Dronning Louise Land (76°40'N) and the inner part of Danmark Fjord (80°34'N), and then followed the outer coast of Kronprins Christian Land in their search for traces of the lost diaries and bodies of Ludvig Mylius-Erichsen and Niels Peter Høeg-Hagen. Ejnar Mikkelsen (1922) records fossil-bearing sedimentary rocks around Danmark Fjord, but the party was forced to abandon their sample collections on their way home. While they were away their ship, *Alabama*, sank in its winter harbour on the north-east coast of the island Shannon, and they were not picked up until the summer of 1912 (Mikkelsen 1913).

In 1933, during the 1931–1934 Treårsekspeditionen, Lauge Koch made an aerial reconnaissance of southern Kronprins Christian Land, reached by seaplane from the vicinity of Norske Øer (79°04'N), and reported considerable thicknesses of slightly folded sedimentary rocks (Koch 1955).

In the winter of 1938–1939, Elmar Drastrup and Finn Kristoffersen made a journey by dog sledge along the outer



Fig. 2. The basecamp at Centrumso, Kronprins Christian Land. The two small helicopters were used to transport two-person geological field teams to new camp sites at 6–7-day intervals. The Twin Otter aircraft was mainly used for transport of helicopter fuel from Station Nord to Centrumso. The large tent held supplies for the aircraft, while the small tents at left housed base camp staff and geologists. Photo: Jakob Laurrup.

coast of East Greenland to Ingolf Fjord, and via innermost Ingolf Fjord explored a new route to the interior of Kronprins Christian Land (Drastrup 1945); they were unable to reach Peary Land as they had hoped, and returned the same way. Eigil Nielsen was a member of the 1938–1939 expedition led by Eigil Knuth and Ebbe Munck based at Mørkefjord (76°56'N, 20°19'W), and in the spring of 1939 made a long sledge journey northwards that reached Nakkehoved (81°30'N) in easternmost Kronprins Christian Land. On the way Eigil Nielsen investigated the sedimentary rocks in southern Holm Land, and then sledged to innermost Ingolf Fjord where observations were made of the Silurian carbonate rocks of Sødalen (80°34'N; Nielsen 1941).

Lauge Koch's expeditions to East Greenland (1926–1927, 1929–1930, 1931–1934, 1936–1938) resumed in 1947, on a more regular basis than before World War II, and with an almost entirely geological bias (Koch 1961). However, Catalina flying boats soon replaced ships for transport, and after construction of the airport at Mestersvig (72°14'N, 23°55'W) in 1952, DC-4 aircraft were used for transport of personnel and goods to Greenland; Norseman aircraft were extensively used for aerial reconnaissance and photography. In 1952 geological parties worked from a base established by Catalina flying boat on the south shore of Centrumso, and the first regional stratigraphical and structural observations were carried out in southern Kronprins Christian Land and around the southern end of Danmark Fjord (Adams & Cowie 1953; Fränkl 1954, 1955).

John Haller's (1971) regional geological account of the East Greenland Caledonides was based on his extensive work carried out during Lauge Koch's expeditions between 1949 and 1958. His subsequent map compilations produced the 1:250 000 scale geological maps of Koch & Haller (1971) that cover the region 72°–76°N, three tectonic maps on a scale of 1:500 000 of the entire East Greenland Caledonides (Haller

1970), and the 1:1 million scale geological map of the northern half of the East Greenland Caledonides (75°–82°N) that accompanied Haller (1983). However, all these maps have been superseded by new geological mapping and interpretations.

The Geological Survey of Greenland (GGU, from 1995 part of the Geological Survey of Denmark and Greenland) carried out regional geological mapping of eastern North Greenland in the period 1978–1980 that included detailed investigations of the Proterozoic successions west of Danmark Fjord and the Palaeozoic successions of western Kronprins Christian Land (Collinson 1980; Jepsen *et al.* 1980; Sønderholm & Jepsen 1991). The period 1993–1995 saw the completion of the regional mapping of the Lambert Land map sheet, with up to 20 field teams working out from a base camp established at the west end of Centrumso (Fig. 2; Henriksen 1996). Two helicopters and a Twin Otter aircraft supported the Survey's mapping activities, and also provided logistical support for glaciological teams from the Alfred Wegener Institute working on the margin of the Inland Ice and three two-man teams of botanists.

The Survey's geological mapping expeditions were carried out using new topographic maps on a scale of 1:100 000, drawn out in the Survey's photogrammetric laboratory. Prior to the fieldwork in 1993–1995 Survey geologists undertook photo-geological interpretations of the entire region. The printed Lambert Land map sheet was compiled on the basis of geological field maps drawn mainly on a scale of 1:100 000. A new 1:1 million scale geological map of the entire East Greenland Caledonian orogen (70°–82°N) incorporating new structural interpretations has been published by the Survey (Henriksen 2003), and a folded copy of that map sheet accompanies the recently published description by Higgins *et al.* (2008).

Geological setting

The Lambert Land map sheet area (78°–81°N) extends from Jøkelbugten in the south to Amdrup Land and Danmark Fjord in the north (Fig. 1). The eastern half of the map sheet is dominated by rock units of the Caledonian orogen and is in thrust contact with the Caledonian foreland exposed in the north-west corner of the map sheet on both sides of Danmark Fjord (Table 1).

The Mesoproterozoic to Lower Palaeozoic rocks of the foreland are generally flat-lying, and those on the Lambert Land map sheet are part of widespread outcrops that extend to the north and north-west through Mylius-Erichsen Land, J.C. Christensen Land and Heilprin Land (Peel & Sønderholm 1991; Fig. 3). The Mesoproterozoic rocks include an undis-

turbed cratonic sequence of mainly alluvial sandstones (Independence Fjord Group) at least 2 km thick that is presumed to have been deposited on a peneplained crystalline basement; its base is not exposed. These sandstones are overlain by undisturbed Mesoproterozoic basalts (the Zig-Zag Dal Basalt Formation), which were extruded approximately 1230 Ma ago (Fig. 4). Equivalents to the basalts are found in the form of abundant sills and dykes (the Midsommersø Dolerites) emplaced into the Independence Fjord Group sandstones. The Mesoproterozoic sedimentary and volcanic succession is separated from Neoproterozoic sedimentary deposits by a prominent hiatus spanning a period of more than 400 Ma, and marked by a regional erosional unconformity. The Neopro-

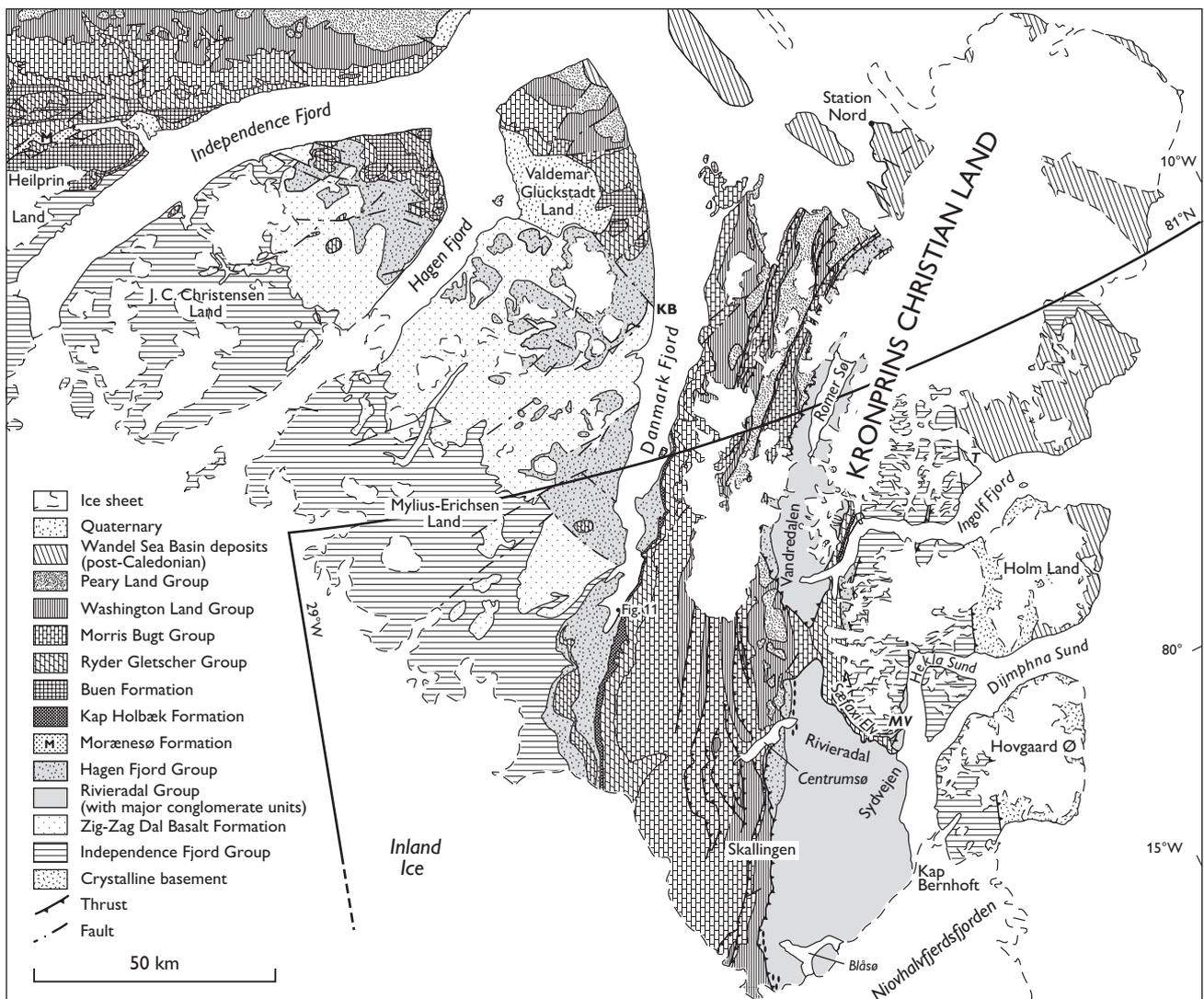


Fig. 3. Geological map of part of central and eastern North Greenland, showing the distribution of the Proterozoic and Palaeozoic rock units. KB: Kap Bernhard. MV: Marmorvigen. T: Tobias Gletscher. North boundary of the Lambert Land map sheet is shown by the solid line following 81°N and 29°W. Modified from Sønderholm *et al.* (2008, their fig. 2).

Table 1. Foreland and paraautochthonous stratigraphy

Chrono-stratigraphy	Lithostratigraphy	Age	Lithology
Middle Silurian (Wenlock)	Lauge Koch Land Formation	c. 426 Ma	Up to 400 m, black shale and limestone at base, shaly turbiditic siltstone and sandstone above
Lower Silurian (Llandovery)	Samuelsen Høj Formation		Conspicuous reef limestone, up to 20 m high
	Odins Fjord Formation		Up to 320 m limestone and dolostone
	Turesø Formation		Up to 350 m limestone and dolostone
	Børglum River Formation		c. 430 m dark burrow-mottled limestone
	Sjælland Fjælde Formation		c. 100 m burrow-mottled limestone and dolostone
Lower Ordovician	Wandel Valley Formation	c. 480 Ma	c. 335 m limestone and dolostone <i>40 Ma hiatus</i>
Lower Cambrian	Kap Holbæk Formation	c. 520 Ma	0–180 m mudstone and sandstone <i>125 Ma hiatus</i>
Cryogenian	Hagen Fjord Group	c. 650–750 Ma	c. 740 m siliciclastic rocks overlain by calcitic and dolomitic limestone
Mesoproterozoic	Zig-Zag Dal Basalt Formation	c. 1350–1380 Ma	c. 1350 m basaltic lavas: extrusive equiv. of Midsommersø Dolerites
Palaeoproterozoic	Independence Fjord Group with Aage Berthelsen Gl. Formation	c. 1740 Ma	c. 2 km quartzitic sandstone with c. 400 m tholeiitic volcanic rocks

Formation colours correspond to those on the printed map.

terozoic succession that overlies the Zig-Zag Dal Basalt Formation comprises up to 1500 m of shallow marine sediments known as the Hagen Fjord Group. The upper unit of the Hagen Fjord Group was formerly considered to be the Kap Holbæk Formation (KH), but recognition of a major unconformity at its base and the presence of *Skolithos* burrows led Smith *et al.* (2004b) to re-interpret it as Lower Cambrian in age. The Kap Holbæk Formation comprises up to 150 m of sandstones, and is overlain by an Early Ordovician to Early Silurian carbonate succession that represents the easternmost part of the Franklinian Basin, a major basin that extends westward across North Greenland into the Canadian Arctic Islands, a distance of about 2000 km.

East of Danmark Fjord, the undeformed Ordovician–Silurian carbonate succession of the foreland passes eastwards into the deformed rocks of the Caledonian orogeny that can be divided into a series of structural belts (Fig. 1; Higgins & Leslie 2008; Leslie & Higgins 2008). The westernmost structural domain is the Thin-skinned fold-and-thrust belt developed in the Ordovician–Silurian carbonate succession. A series of NNE–SSW-striking and E-dipping Caledonian thrusts characterises this belt, and there is generally a displacement of a few kilometres on each thrust. Farther eastward, structurally below the Vandredalen thrust sheet, the thin-skinned thrusts penetrate to deeper levels; and thrust duplexes and W-verging recumbent folds are developed in the Hagen Fjord Group and Independence Fjord Group sandstones. These folds and thrusts raise the Vandredalen thrust sheet above exposure level; well-exposed cliff sections occur in the western parts of central Ingolf Fjord.

The Vandredalen thrust sheet structurally overlies the Thin-skinned fold-and-thrust belt, and comprises distinctive rock types belonging to the Proterozoic Rivieradal and Hagen Fjord Groups. The Vandredalen thrust sheet has a westward displacement of 30–50 km and its well-exposed, NNE–SSW-trending frontal ramp can be followed for 200 km through central parts of Kronprins Christian Land. Hurst & McKerrow (1981a, b, 1985) had estimated 100–150 km displacement westwards, much in line with Haller's (1971) interpretation. The Rivieradal Group is confined to the allochthonous Vandredalen thrust sheet, and was evidently deposited in an east-facing half-graben, the Hekla Sund Basin of Higgins *et al.* (2001b); the remnants of the west margin of this rift basin and the root zone of the Vandredalen thrust sheet can be traced as a narrow strip of metasedimentary rocks from Marmorviggen northward along the west side of Hekla Sund, and along Brede Spærregletscher to the north side of Ingolf Fjord (Fig. 1, see also Fig. 7).

The Western thrust belt is composed of a group of thrust sheets that structurally overlie the Vandredalen thrust sheet. The Western thrust belt is dominated by white quartzites of the Independence Fjord Group, which are cut by numerous black doleritic dykes and sills (Midsommersø Dolerites), interbedded with a number of volcanic units. The Western thrust belt can be traced from east-central Ingolf Fjord southward to Hekla Sund and through western Hovgaard Ø (Fig. 1). Farther south the thrust belt continues into Lambert Land where both north- and west-directed thrust units have been distinguished, and into the large nunataks along the Inland Ice margin west of Jøkelbugten.

The Nørreland thrust sheet is made up of a broad zone of Palaeoproterozoic gneiss complexes that over an extensive region contain abundant Caledonian eclogitic enclaves. The northernmost outcrops are on Hovgaard Ø and Holm Land in easternmost Kronprins Christian Land, where the contact with

lower-grade rocks to the west that make up the Western thrust belt is a prominent lineament known as the East Greenland fault zone. The best known outcrops are in eastern Lambert Land and west of Jøkelbugten in Nørreland, from which the Nørreland thrust sheet takes its name.

Caledonian foreland

Proterozoic

Independence Fjord Group (IF)

The lowest stratigraphic unit of the foreland is the Independence Fjord Group, which is composed of a succession of clastic sediments at least 2 km thick (Collinson *et al.* 2008). It is widely exposed in eastern North Greenland and crops out on the north-east part of the Lambert Land map sheet in Mylius-Erichsen Land and Amdrup Højland (Fig. 3). Its base is not exposed, and it is presumed to rest on Archaean crystalline gneisses. There is little or no tectonic disturbance, and individual units can be traced over long distances. The continuity of stratigraphic units, the very gradual thickness changes and the non-marine nature of the sediments suggest the succession is the fill of a widespread intracratonic sag basin (Collinson 1980; Collinson *et al.* 2008). On the map sheet the succession south of Independence Fjord (81°30'N) is referred to the Norsemandal Formation. It is divided into five members, three sandstone members several hundred metres thick (Nc, Na, Nf) and two thinner fine-grained members dominated by red siltstones (Nh, Nk). The age of the Independence Fjord Group is partially constrained by a U-Pb baddeleyite age of 1382 ± 2 Ma on one of the intruding dolerites (Upton *et al.* 2005), and a Rb-Sr isotope age of 1380 Ma on clay minerals from one of the siltstones (Larsen & Graff-Petersen 1980). The Hekla Sund Formation (HS), an 1100 m succession of lavas interbedded with the Independence Fjord Group within the Caledonian orogeny (see below), has yielded an age of 1740 ± 6 Ma (Kalsbeek *et al.* 1999; Pedersen *et al.* 2002). The depositional age of the Independence Fjord Group can thus be constrained to between *c.* 1750 and *c.* 1400 Ma.

The lowest of the three sandstone members, the Academy Gletscher Member (Nc), comprises a monotonous sequence of medium- and coarse-grained, feldspathic to quartzitic, cross-bedded sandstones more than 900 m thick. The middle of the sandstone members, the Astrup Fjord Member (Na), is a *c.* 300 m thick sequence of medium to coarse-grained, feldspathic, cross-bedded sandstone. The highest sandstone member, the Fiil Fjord Member (Nf), comprises at least 600 m of medium- to coarse-grained, cross-bedded quartzite. The two siltstone members (Nk, Nh) are up to 90 m thick, and comprise dark

red siltstones with thin sandstone interbeds; halite pseudomorphs and desiccation mud cracks are common. Collinson *et al.* (2008) provide descriptions of the sedimentology of the Independence Fjord Group and interpretations of the sandstone-siltstone boundaries.

Zig-Zag Dal Basalt Formation (Z)

The Zig-Zag Dal Basalt Formation consists of a 1350 m succession of tholeiitic flood basalts that directly overlies the Independence Fjord Group (Figs 3, 4). It has been divided into three main units (Basal Unit, Aphyric Unit, Porphyritic Unit; Kalsbeek & Jepsen 1984), but these are not distinguished on the map sheet. Breaks in the volcanicity are indicated by interbasaltic sediments (Zi) and local erosion. The main outcrops are north-east of Danmark Fjord (Fig. 3). The two upper units are together comprised of some thirty flows, individually up to 120 m thick. Some flows can be traced over long distances. Most flows have amygdaloidal or flow-brecciated tops, suggesting subaerial effusion, and pahoehoe surfaces are locally preserved.

The most comprehensive description of the Zig-Zag Dal Basalt Formation is that by Upton *et al.* (2005), who conclude that magma generation took place in an upwelling mantle plume, at increasingly shallower depths, beneath an attenuating continental lithosphere. The lavas of the Porphyritic Unit are considered to represent essentially uncontaminated plume-source melts. The Zig-Zag Dal Basalt Formation is considered to be contemporaneous with and genetically related to the Midsommersø Dolerites (see below), that are found as abundant intrusions in the Independence Fjord Group (Kalsbeek & Jepsen 1983).

Midsommersø Dolerites (MD)

The Midsommersø Dolerites (MD) comprise a multitude of sheets of dolerite and associated more siliceous rocks that cut the sandstones of the Independence Fjord Group. The dolerite sills can be more than 100 m thick, and are often traceable for tens of kilometres along fjord walls. U-Pb analyses on baddeleyite from one dolerite have yielded an age of 1382 ± 2 Ma (Upton *et al.* 2005).



Fig. 4. South-eastern Mylius-Erichsen Land looking south-east, with quartzitic sandstones of the Norsemandal Formation (Fiil Fjord Member, Nf) overlain by tholeiitic basalts of the Zig-Zag Dal Basalt Formation (Z). Photo: Niels Henriksen.

Three general groups of intrusive rocks are recognised: normal dark grey to black dolerite, totally altered red and greenish mottled rocks ranging from dolerite to fine-grained granophyric rocks, and very siliceous rocks (the ‘rheopsammiter’

of Kalsbeek & Jepsen 1983). The different rock types appear to be more or less contemporaneous; intersections are common but show no systematic differences in age.



Fig. 5. Kap Canis Major in central Ingolf Fjord, looking north; mainly light-coloured sandstones of the Independence Fjord Group (LY or HG on the map sheet) with infolded black remnants of the Midsommersø Dolerites or Hekla Sund Formation. Photo: Niels Henriksen.

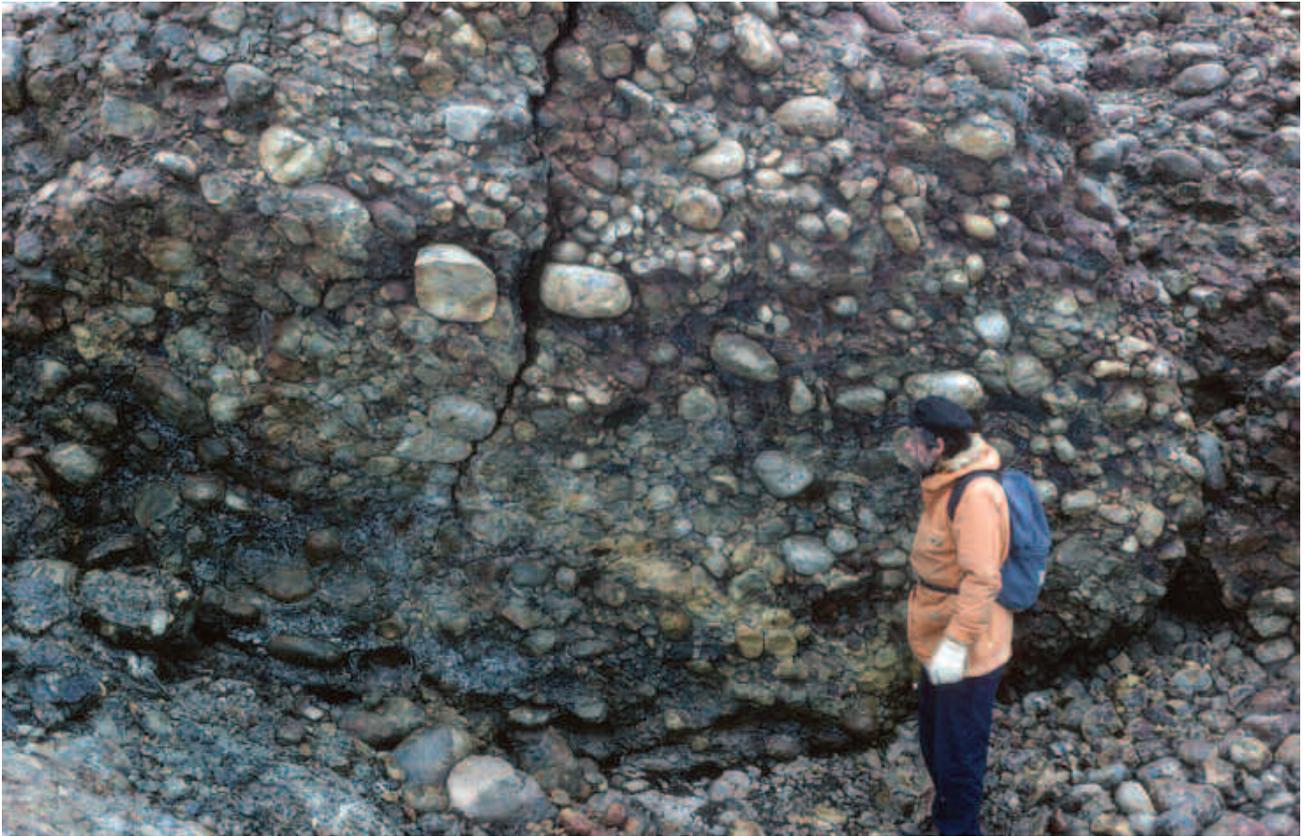


Fig. 6. Rivieradal Group in western Vandredalen. At this locality clasts are very variable in size and almost exclusively derived from Independence Group quartzites.

On the Lambert Land map sheet, the Midsommersø Dolerites crop out west of Danmark Fjord, but metadolerites (**Md**) considered to be equivalents of the Midsommersø Dolerites are found within the Caledonian orogen cutting the strongly folded Independence Fjord Group sandstones of eastern Kronprins Christian Land (Fig. 5), Lambert Land and the nunataks west of Jøkelbugten.

Rivieradal Group (**R**)

In the Lambert Land map sheet area, the Rivieradal Group is widely exposed in central Kronprins Christian Land, entirely within the Vandredalen thrust sheet; it was formally defined by Smith *et al.* (2004a). The main outcrops occur in Skallingen and in Vandredalen on both sides of Nunatami Elv. The group represents a syn-rift deep-water succession deposited in an east-facing half-graben that was originally located at least 40 km east of the present outcrop area (Higgins *et al.* 2001a). The original depositional basin was at least 200 km long (parallel to the bounding rift faults) and 50 km wide (see also Fig. 16).

The maximum cumulative thickness of the Rivieradal Group has been estimated at 7.5–10 km (Higgins *et al.* 2001b), but there is a strong proximal to distal polarity and several of the units may be partly lateral equivalents to each other. In northern Vandredalen a total thickness of 4500 m has been measured (Smith *et al.* 2004a) comprising a basal 200 m thick

unit of strongly sheared conglomerates, a 500 m thick phyllite-dominated unit and then 2200 m of strata dominated by thick-bedded sandstone turbidites. An estimated 500 m gap in exposure is followed by about 1200 m of sandstone and mudstone. Laterally and vertically this succession grades into deep-marine basin plain mudstone and equivalent phyllitic rocks (Sønderholm *et al.* 2008). The most proximal sediments are found along the leading edge of the Vandredalen thrust sheet, where coarse-grained, clast-supported conglomerate units (Fig. 6) occur along strike in three distinct areas (Fig. 7). The conglomerate clasts vary in size from a few tens of centimetres (Fig. 8) to over a metre, with occasional boulders up to 3–4 m in size (Fig. 9). The clasts are derived from the Independence Fjord Group and the Midsommersø Dolerites, which can be presumed to have been exposed to active erosion along the western margin of the Rivieradal Group basin. In the southernmost outcrops around Blåsø, the occurrence of granite and quartz pebbles in the conglomerates indicates an additional metamorphic basement source, suggesting that a deeper erosional level was exposed to erosion here.

Overall, the Rivieradal Group is characterised by point sources of sediment input which generated substantial conglomerate fan deltas, associated with sandy proximal turbidites. Between the fans and in the eastern part of the basin, sedimentation was dominated by mud and calcareous mud. As the basin filled, the depositional style switched from deep to

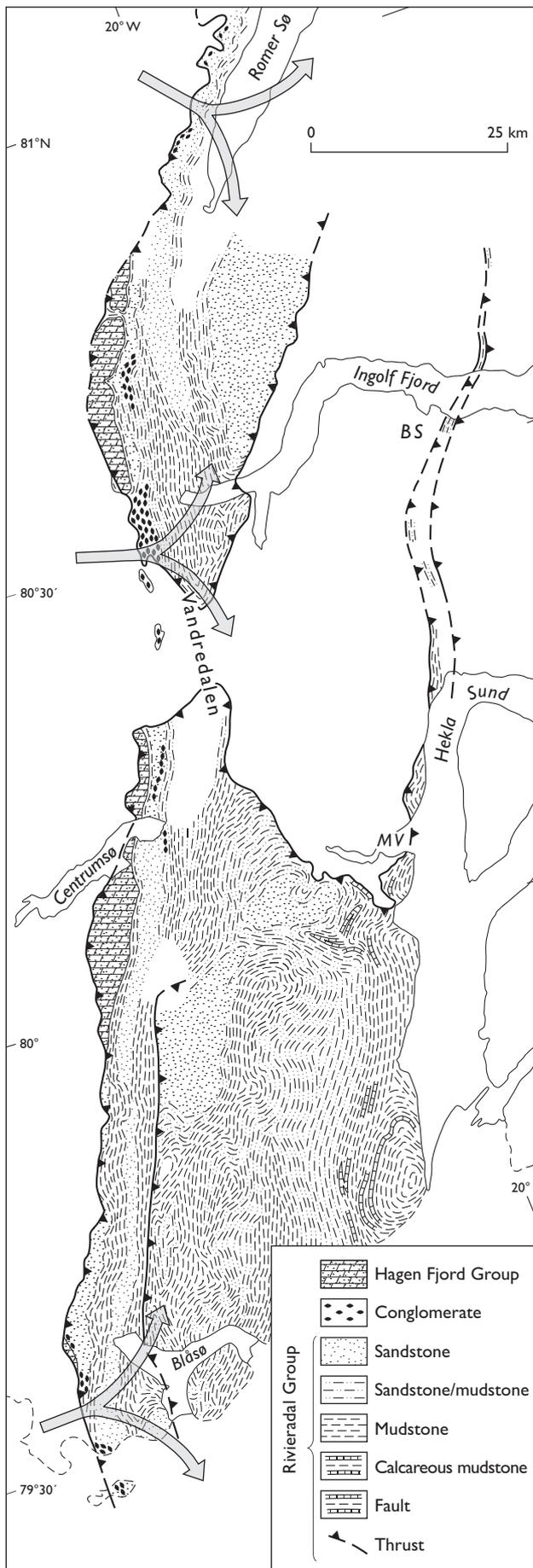


Fig. 8. Rivieradal Group conglomerates on the west side of Vandredalen. The large weathered-out boulders in the foreground are well sorted and show an imbricate development. The bedded units in the background are nearly all coarse conglomerates.

shallow marine, and less localised, more laterally persistent, tidal and storm-dominated deposition began to predominate (Smith *et al.* 2004a).

The Rivieradal Group is overlain by the Hagen Fjord Group, with particularly well-exposed contacts along the western outcrops of the Vandredalen thrust sheet in northern Vandredalen west of the head of Ingolf Fjord (Fig. 10), and in southern Vandredalen around the east end of Centrunso.

Fig. 7. Lithological variations within the Rivieradal Group (from Higgins *et al.* 2001b, their fig. 6). Proximal sedimentary rocks and overlying deposits of the Hagen Fjord Group occur in the west along the leading edge of the Vandredalen thrust sheet. Note the three main sources of sediment input determined by the location of coarse conglomerate units. BS: Brede Spærregletscher. MV: Marmorvigen. Used with permission of the Geological Society of London.

Fig. 9. Giant boulder (3–4 m in diameter) in the Rivieradal Group conglomerates on the west side of Vandredalen. From Higgins *et al.* (2001b, their fig. 7). Reproduced with permission of the Geological Society of London.



Hagen Fjord Group (HF)

The Hagen Fjord Group unconformably overlies Mesoproterozoic strata that have been invaded by intrusions of the Midsommersø Dolerites (1380 Ma). It comprises a lower siliciclastic part of three formations (Jyske Ås, Campanuladal, Catalinafeld), of which only the first two are found in the Lambert Land map sheet area; the upper carbonate-dominated part of the Hagen Fjord Group comprises two formations (Kap Bernhard and Fyns Sø; Fig. 10).

The Jyske Ås Formation (J) is up to 500 m thick, and records a marine transgression that succeeded the long hiatus represented by the sub-Hagen Fjord Group unconformity. The main part of the sequence comprises large-scale cross-bedded sandstone, interpreted as of beach and shallow tidal-shelf origin. The formation only occurs west of the rift shoulder that marks the margin of the Rivieradal Group basin. The Campanuladal Formation (CD) (110–175 m) comprises a variegated

succession of fine- to medium-grained sandstone, including a distinctive stromatolitic dolomite, and is thought to record a transition to more offshore conditions (Sønderholm *et al.* 2008). The Jyske Ås and Campanuladal Formations are best exposed in the foreland region west of Danmark Fjord, but limited exposures of probable equivalents occur along the west flanks of Prinsesse Caroline-Mathilde Alper and Prinsesse Elisabeth Alper between Hjørnegletscher and Sæfaxi Elv. East of Hjørnegletscher, Jepsen & Kalsbeek (1985) described an 84 m thick sequence between the Independence Fjord Group quartzites and the Kap Bernhard Formation that begins with conglomerates, which they informally termed the ‘Hjørnegletscher conglomerate’ and ends with sandstones and siltstones which they compared with the Campanuladal Formation (Jepsen & Sønderholm 1994). Farther south, between Solvig and Marmorvigen on the western flanks of Prinsesse Caroline-Mathilde Alper, Higgins & Jepsen (1993) and

Fig. 10. West side of Vandredalen showing the distinctive yellow colour of the Fyns Sø Formation and reddish-purple colour of the Kap Bernhard Formation constituting the carbonate units of the Hagen Fjord Group. Underlying units include variable thicknesses of conglomerates and quartzites of the Rivieradal Group and dark shales and mudstones that have been compared to the Campanuladal Formation.





Fig. 11. The west side of Hjørnegletscher (for location see Fig. 3) showing the irregular palaeokarst topography eroded in the Fyns Sø Formation (FS) prior to the deposition of the Kap Holbæk Formation (KH). Two prominent channels (C) in the unconformity surface are indicated. Slightly simplified after Smith *et al.* (1999, their fig. 8).

Higgins & Soper (1994) recorded variable thicknesses of conglomerate and sandstone.

The Kap Bernhard Formation consists of reddish-brown limestone (150–215 m), interpreted as marking a change from siliciclastic, shallow-shelf deposition to incipient carbonate-platform deposition. This distinctively coloured unit is well-exposed on the east side of Danmark Fjord, and also crops out along Sæfaxi Elv and on both sides of Vandredalen. It thins dramatically eastwards along Sæfaxi Elv, and pinches out at Marmorvigen where the overlying yellow dolostones of the Fyns Sø Formation directly overlie the Independence Fjord Group. The yellow dolostones of the Fyns Sø Formation (about 325 m) record the establishment of a well-developed carbonate platform; a new reference section 356 m thick was measured 12 km north of Kap Holbæk in 1995 (Craig & Jepsen 1995). Stromatolitic horizons occur throughout the formation, and are particularly common in the uppermost parts. Both the Fyns Sø and Kap Bernhard Formations (FB) crop out on both sides of Danmark Fjord. Allochthonous representatives of both formations (FB) are also well preserved in the frontal parts of the Vandredalen thrust sheet along the west side of Vandredalen (Fig. 10), where they overlie the Rivieradal Group together with representatives of the Campanuladal Formation (CD).

Cambrian

Kap Holbæk Formation (KH)

The oldest Palaeozoic sedimentary rocks in Kronprins Christian Land are the Lower Cambrian sandstones of the Kap Holbæk Formation. In the foreland to the west of Danmark Fjord, this unit overlies stromatolitic dolostones of the Fyns Sø

Formation, and was formerly considered to be the upper formation of the Hagen Fjord Group. However, the Kap Holbæk Formation contains deep *Skolithos* burrows that extend vertically for many tens of centimetres (Clemmensen & Jepsen 1992). The presence of deep *Skolithos* burrows indicates a Tommotian (Early Cambrian) or younger age (Crimes 1992; Smith *et al.* 2004b). In the Sæfaxi Elv and Marmorvigen areas the succeeding, Ordovician, Wandel Valley Formation (W) nearly everywhere directly overlies Neoproterozoic carbonates of the Fyns Sø Formation, and the Kap Holbæk Formation is mainly present only as the fill of palaeokarst systems eroded in the Fyns Sø Formation (Fig. 11). At Hjørnegletscher, Jepsen & Sønderholm (1994) recognised a succession of about 50 m of quartzites that were attributed to the Kap Holbæk Formation, and in 1995 Higgins & Soper (1995) measured a succession of about 180 m in the Kap Holbæk Formation on the west side of inner Ingolf Fjord, comprising mainly thin-bedded and cross-bedded quartzite with some siltstone and shale intervals.

Fränkl (1955) documented quartz arenite-filled caves and channels in the uppermost part of the Fyns Sø Formation in Sæfaxi Elv, and in 1995 a significant palaeocave locality was found on the west side of Hjørnegletscher (Smith *et al.* 1999, 2004b; Fig. 11). In 1993, several localities of sandstone-filled channels in the Fyns Sø Formation were located on the north side of Sæfaxi Elv, possibly including Fränkl's original unconformity locality (Fränkl 1955); the localities observed by Jepsen & Higgins were at an altitude of 85 m. The Kap Holbæk Formation comprises fine- to coarse-grained sandstones with interbedded mudstones. It belongs to a phase of siliciclastic shelf development that farther to the north is associated with turbidites of the deep-water Franklinian trough that extends across the whole of North Greenland (Higgins *et al.* 1991).

Ordovician–Silurian

Ryder Gletscher Group (**W**)

In the central and western parts of North Greenland, deposition on the shelf was continuous from the Early Cambrian to the Early Ordovician (Higgins *et al.* 1991). However, in the eastern parts of North Greenland, including Kronprins Christian Land and the foreland region to the west, uplift produced a high that was not inundated until a major sea-level rise in the late Early Ordovician. This sea-level rise was marked by development of a carbonate-dominated shelf that continued until the late Llandovery (early Silurian). In the map region, the Ryder Gletscher Group comprises the Wandel Valley and Sjølland Fjelde Formations (**W**), and ranges from Early Ordovician to Middle Ordovician in age. The Wandel Valley Formation comprises peritidal and subtidal carbonates about 300–400 m in thickness, and the Sjølland Fjelde Formation about 100 m of grey, burrow-mottled dolostone.

The Ryder Gletscher Group crops out in a broad strip on the east side of Danmark Fjord where it unconformably overlies the Kap Holbæk Formation (see Fig. 3). It also crops out in central Kronprins Christian Land in a zone extending from Hjørnegletscher in the north, along the west side of Ingolf Fjord to Solvig, through eastern Vandredalen, and along the south side of Sæfæxi Elv to Marmorvigen; the ‘Hærefjeld Formation’ of Hurst (1984) that he interpreted as an allochthonous deep-water Silurian succession was reinterpreted by Rasmussen & Smith (1996) as the parautochthonous Wandel Valley Formation, a view confirmed by conodont identifications (see also Smith *et al.* 2004b).

The southernmost outcrops of the Wandel Valley Formation occur in westernmost Lambert Land, where unlike any other locality in the region they unconformably overlie quartzites of the Independence Fjord Group. This demonstrates a continued eastward unroofing below the sub-Wandel Valley unconformity (Smith *et al.* 2004b). The contact is disrupted by an imbricated thrust system that forms part of a large-scale thrust stack, and this part of the Wandel Valley Formation is the only part of the platform succession to be truly allochthonous.

Morris Bugt Group (**BR, TU**)

In the map region, the Morris Bugt Group comprises the carbonate rocks of the Børglum River Formation (**BR**) and Turesø Formation (**TU**) that range in age from Middle Ordovician to Early Llandovery. Both formations are well exposed in Vandredalen below thrust units of the Rivieradal Group (see also Fig. 17). The base of the Børglum River Formation is

marked by a major flooding surface. The subtidal carbonates of the formation are monotonous, burrow-mottled lime mudstones and wackestones; the upper part is highly fossiliferous (Smith & Rasmussen 2008). The Turesø Formation (up to 320 m) is a distinctly banded unit composed of subtidal burrow-mottled limestones and peritidal dolostones. Its boundary with the overlying Odins Fjord Formation represents another flooding surface.

Washington Land Group (**OF, SH**)

In Kronprins Christian Land, the Washington Land Group comprises the Odins Fjord Formation and the Samuelson Høj Formation. The Odins Fjord Formation (**OF**) mainly comprises golden-brown weathering, highly fossiliferous limestones, with a distinctive 35 m thick dolostone 100 m above the base; it is early to middle Llandovery in age. This formation is capped by reefs of the Samuelson Høj Formation (**SH**) that are up to 300 m thick with diameters of up to 5 km, although most are much smaller (Smith *et al.* 2004a). The initiation of reef growth is well-constrained by conodonts to the *celloni* biozone (mid-Telychian, upper Llandovery; Armstrong 1990). The Washington Land Group represents the final development of the passive margin shelf sequence that was progressively drowned throughout North Greenland by the Silurian turbidites of the Peary Land Group.

Silurian

Peary Land Group (**L**)

The major influx of great thicknesses of siliciclastic deep-water deposits in the late Llandovery (*turriculatus-spiralus* graptolite biozones) synchronously across the basin is the final phase in the development of the Franklinian Basin. The thick successions of sandstone turbidite deposits record dominant, westward current directions, and are interpreted to derive from erosion of the rising Caledonian mountains and to mark the onset of Scandian deformation and uplift at 435 Ma.

In Kronprins Christian Land outcrop is restricted to the parautochthonous Thin-skinned fold and thrust belt, where the Samuelson Høj reefs are abruptly overlain by black mudstones and bituminous carbonates assigned to the Profil-fjeldet Member of the Lauge Koch Land Formation (**L**). The black mudstones and carbonates have a thickness of about 50 m and are overlain by about 150 m of sandstone turbidites that are truncated by thrusts.

Caledonian orogen

Palaeoproterozoic

Crystalline complexes

Palaeoproterozoic quartzo-feldspathic orthogneisses (**gn₁**) with sheets of metagranitoid rocks (**gn₂**) are widespread in the outer coastal region and islands south of Hovgaard Ø, with the northernmost outcrops on Wegener Øer just north of Holm Land; they form part of the largest Palaeoproterozoic province in Greenland extending for more than 800 km from *c.* 73°N to *c.* 83°30' N (Kalsbeek *et al.* 1993, 2008). The northern parts of this province (and most of the crystalline complexes covered by the Lambert Land map sheet) are characterised by the occurrence of Caledonian eclogites, formed by high-pressure metamorphism of Palaeoproterozoic protoliths; they make up the lower parts of the structural entity known as the Nørreland thrust sheet (Higgins & Leslie 2008).

Most of the orthogneisses and metagranitoid rocks have a normal calc-alkaline chemical composition, and are strongly deformed. The crystalline complexes of the Lambert Land map sheet area have not been investigated in detail, but it is likely that Caledonian deformation is superimposed on Palaeoproterozoic structural patterns.

Within the crystalline complexes, a variety of layers and enclaves of other rock types have been distinguished. These include metagabbroic, dioritic and quartz-dioritic rocks (**mg**) in a small enclave on southern Holm Land, amphibolite (**a**) common everywhere with layers and large bodies on the Franske Øer, some of which were clearly originally dykes and sills, ultramafic rocks (**ub**) and leucogabbro and anorthosite (**ga**) common in many areas and evidently the protoliths of the eclogites, of which detailed studies have been made by Gilotti *et al.* (2008). In addition marbles and calc-silicates (**c₁**) and siliceous metasedimentary rocks (**qg₁**) have been recorded in a few areas. Hull & Friderichsen (1995) record a 60–80 m large enclave of isoclinally folded metasedimentary and metavolcanic rocks north of Kap Bergendahl with exceptionally well-preserved primary structures and textures.

Meso–Palaeoproterozoic

Independence Fjord Group (**IF**)

Lithological similarities between the widespread quartzitic succession of the Caledonian foreland (Independence Fjord Group) and the strongly deformed quartzites within the Caledonian orogen that are exposed in spectacular fjord sections in eastern Kronprins Christian Land (see Fig. 5), led to

the assumption that they were of the same age. In both regions the quartzite successions are invaded by abundant basaltic dykes and sills, assumed to be equivalent in age to the Mesoproterozoic Zig-Zag Dal Basalt Formation of the foreland (*c.* 1380 Ma). This assumption was thrown into question by a well-defined zircon age of 1740 ± 6 Ma on rhyolitic rocks of the Hekla Sund Formation (Kalsbeek *et al.* 1999) that is interbedded with the quartzite succession within the Caledonian orogen. The geological setting of the quartzites of the foreland and Caledonian orogen quartzitic sequences is also somewhat different (Collinson *et al.* 2008). The quartzites of the foreland were deposited in an intracratonic basin during a period of slow subsidence, whereas those in eastern Kronprins Christian Land were formed during a period of active rifting interrupted by volcanic activity (Pedersen *et al.* 2002). It is now considered that the quartzitic succession of eastern Kronprins Christian Land represents the oldest part of a sedimentary sequence that grades upwards into the quartzitic sandstones of the foreland; if correct this sedimentary sequence (Independence Fjord Group) thus ranges in age from *c.* 1740 Ma to shortly prior to 1380 Ma (see discussion in Collinson *et al.* 2008).

Detailed mapping of the folded Independence Fjord Group successions in the alpine regions north and south of Ingolf Fjord has led to distinction of a number of formations within the Independence Fjord Group. Two three-part divisions are recognised respectively west and east of the remnants of the Rivieradal Group rift basin (the so-called Hekla Sund Basin) that can be traced from Marmorvigen along the west side of Hekla Sund, then along Brede Spærregletscher to Ingolf Fjord and farther north along Vardegletscher (Pedersen *et al.* 1995; Collinson *et al.* 2008; Fig. 12).

In the western succession the lowest unit is the Ingolf Fjord Formation (**IG**), which comprises about 200 m of thick-bedded quartzitic to arkosic sandstones with thin intercalations of conglomerate. Towards the top, thin beds of volcanic ash and volcanic bombs are increasingly common, precursors of the pillow lavas and hyaloclastics of the Aage Berthelsen Gletscher Formation (**BG**) that is separately described below. Above the 400 m thick volcanic division is a further succession of about 800 m of cross-bedded yellow- or red-weathering quartzitic sandstones referred to the Caroline-Mathilde Alper Formation (**CM**). The sandstones are interpreted as fluvial to near-shore, shallow-water deposits.

The eastern three-part division begins with about 2500 m of cross-bedded quartzitic sandstones referred to the Hovgaard Ø Formation (**HG**), with abundant dolerite sheets that account for about 50% of the outcrop. Cross-bedded conglomerates are common towards the top. This unit is overlain

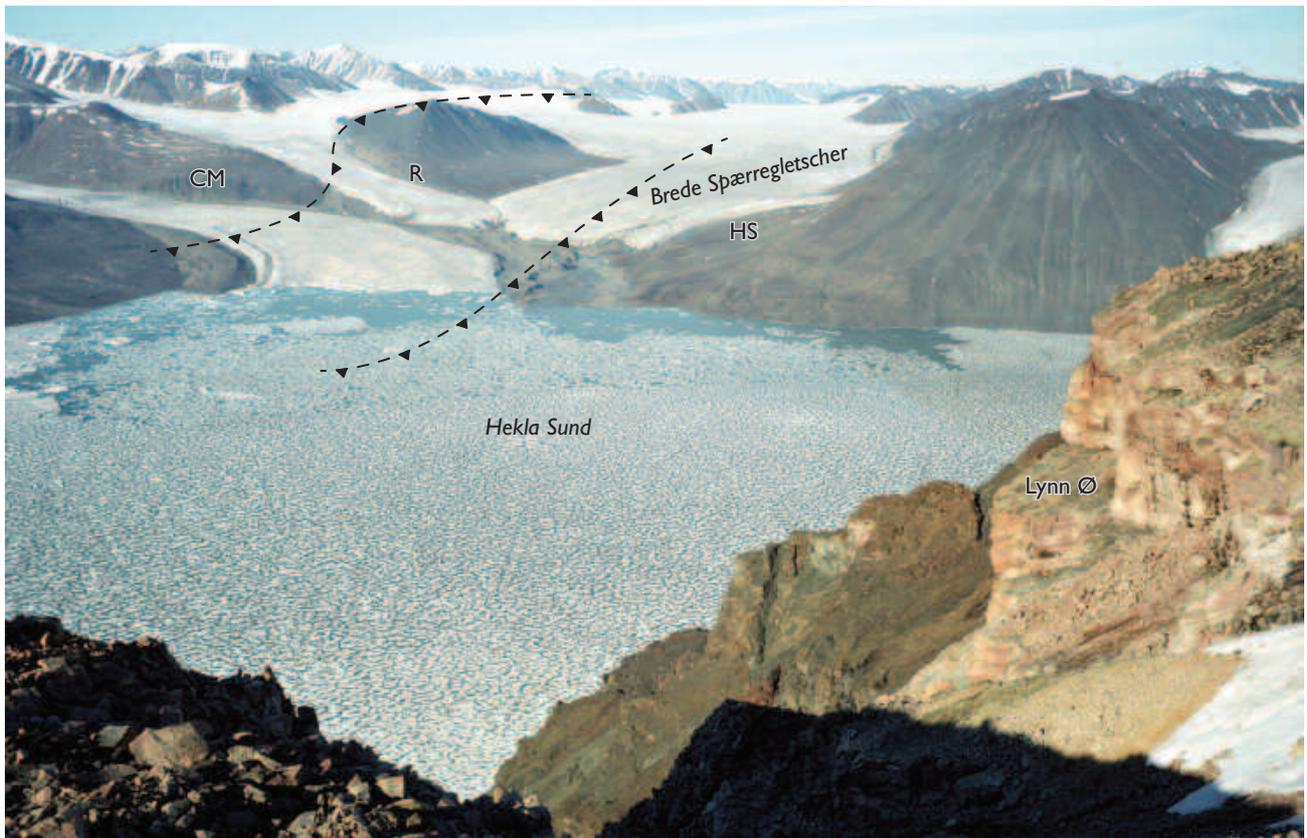


Fig. 12. View to the north across Hekla Sund to the thrust-bounded enclave of Rivieradal Group sediments (R) that crops out along Brede Spærregletscher. Quartzitic sandstones of the Independence Fjord Group (CM) occur west of Brede Spærregletscher, and the Hekla Sund Formation basaltic rocks (HS) are well-exposed in the mountainous area to the east of the Rivieradal Group and on Lynn Ø in the right foreground.

by the volcanic Hekla Sund Formation (HS), described further below. The uppermost sandstone division, referred to the Lynn Ø Formation (LY), consists of about 250 m of arkoses and cross-bedded polymict conglomerates. The clasts, up to 20 cm across, comprise pebbles of gneiss, sandstone, granite, vein-quartz and basalt.

Throughout the folded sandstone succession in eastern Kronprins Christian Land there is evidence of syndepositional deformation. Sandstone beds are truncated by minor listric faults and draped by sandstones unaffected by the faulting. Pedersen *et al.* (1995) concluded that sedimentation took place in part in rift basins subject to active faulting, where fault scarps locally exposed the crystalline basement rocks found as clasts in the conglomerates. The numerous dolerite dykes and sheets throughout the succession are broadly correlated with the Midsommersø Dolerites of the foreland.

South of Nioghalvfjerdssjorden, broad areas of undifferentiated Independence Fjord Group (IF) quartzitic sandstones associated with metadolerites (Md) crop out in Lambert Land, within the Nørreland window, and in the nunataks west of Jøkelbugten. In these areas, the scale of the field mapping has not allowed differentiation into formations.

Aage Berthelsen Gletscher & Hekla Sund Formations (BG, HS)

The Aage Berthelsen Gletscher Formation (BG) defined by Pedersen *et al.* (2002) comprises a *c.* 400 m thick succession dominated by pillow lavas and hyaloclastics. It crops out in the Prinsesse Caroline-Mathilde Alper north-west of Hekla Sund, on both sides of Aage Bertelsen Gletscher (the place name was given for Aage Bertelsen, one of the artists on the 1906–1908 Danmark-Ekspedition, and is correctly spelt on the printed map sheet, but the formation was defined as Aage Berthelsen Gletscher Formation). The succession is different from that of the Hekla Sund Formation, and geochemical data suggest that the two formations were derived from different mantle sources.

The Hekla Sund Formation (HS) is made up of about 1100 m of basalts and andesitic basalts with minor rhyolites. The best exposed outcrops are on northern Lynn Ø on the south side of Hekla Sund (Fig. 12) where detailed sampling has been carried out (Pedersen *et al.* 2002); further extensive outcrops occur on the north side of Hekla Sund east of Brede Spærregletscher. In the central part of the succession two distinctive horizons of conglomerates and arkosic sandstones occur within the lavas. The upper conglomerate contains large bould-

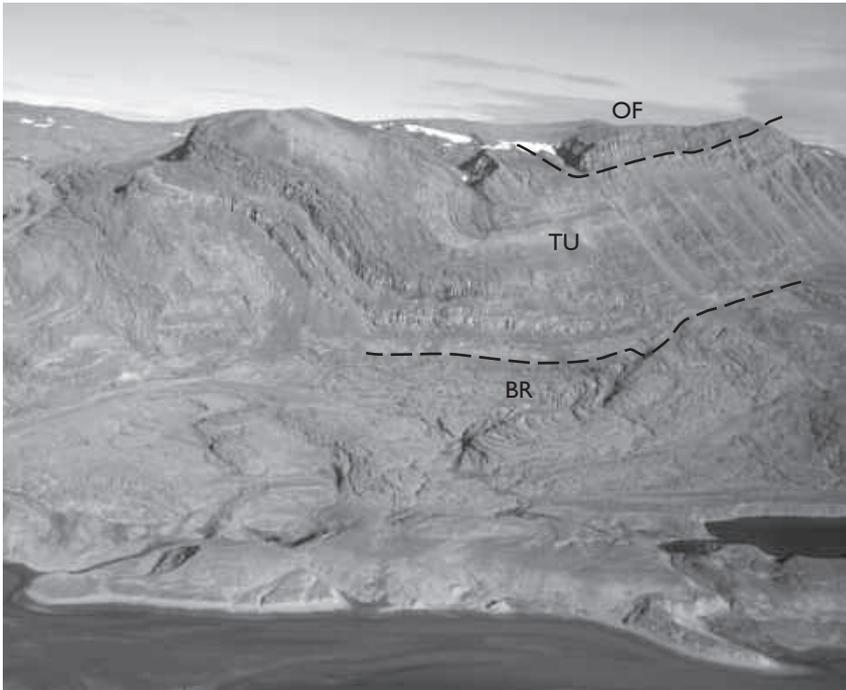


Fig. 13. Folded Middle Ordovician to Silurian carbonate rocks in the Thin-skinned fold-and-thrust belt, 5 km west of Centrumso, looking northwards. BR: Børglum River Formation. TU: Turesø Formation. OF: Odins Fjord Formation. From Smith *et al.* (2004a, their fig. 6).

ders of granitic rocks, sandstone and basalt. One of the rhyolites has yielded a well-defined zircon age of 1740 ± 6 Ma (Kalsbeek *et al.* 1999).

Mesoproterozoic

Metadolerites (? Midsommersø Dolerites) (Md)

All the outcrops of the Independence Fjord Group within the Caledonian orogen are characterised by the common occurrence of cross-cutting metadolerite dykes and sheets (Md). Although they are often strongly folded as a consequence of Caledonian orogenic deformation, correlation with the Midsommersø Dolerites of the foreland is generally assumed.

This correlation is based on lithological similarities and limited Sm-Nd geochemical data (Collinson *et al.* 2008). They are distinct from Sm-Nd data for samples from the Hekla Sund and Aage Berthelsen Gletscher Formations, although there is a possibility that dolerites similar in age to the *c.* 1740 Ma lavas may also be present.

Late Mesoproterozoic

Metasedimentary and metavolcanic rocks

South of Nioghalvfjærdsfjorden there are outcrops of pelitic rocks and volcanic rocks in Lambert Land and on several large nunataks west of Jøkelbugten (Jones & Escher 1995; Hull & Friderichsen 1995). Rock types recorded include pelitic and



Fig. 14. Large-scale thrust duplex looking south across central Ingolf Fjord. From Higgins & Leslie (2008, their fig. 12).

Caledonian orogenesis

semipelitic metasedimentary rocks (*ms*), siliceous metasedimentary horizons (*qg₂*), marbles and calc-silicate rocks (*c*), and metavolcanic rocks (*mv*) in a unit overlying the pelitic and semipelitic metasedimentary rocks. Metadolerite intrusions (*δ*) have been emplaced into these metasedimentary and metavolcanic rocks. Their age is uncertain, but a late Mesoproterozoic age is considered most probable.

In Lambert Land, calcareous hornblende schist makes up a monotonous unit that passes upwards into an amphibolite-dominated sequence (*mv*) interpreted as volcanic in origin. Similar amphibolites with a high garnet content occur as thrust-bounded sheets on Schnauder Ø.

In the nunatak region west of Jøkelbugten, a diverse suite of siliclastic metasedimentary rocks (*ms*) forms a schist belt with the main outcrops on Bildsø Nunatakker, Tuborgfondet Land and Nørre Biland. These are thought to be equivalent to similar rocks associated with the metavolcanic units in Lambert Land. The metasedimentary rocks are dominated by muscovite-biotite ± garnet/hornblende schists with some calcareous and quartzitic bands. Occasional cross-bedding has been recorded in the quartzitic bands. The metasedimentary rocks are intruded by metadolerite and pink-weathering K-feldspar metaporphyritic bodies.

The Caledonian orogen of East Greenland is composed of a sequence of westward-propagating thrust sheets created during the collision of a broad sector of Baltica with the north-east margin of Laurentia (Leslie & Higgins 2008). In Kronprins Christian Land in the northernmost sector of the orogen, corresponding to the region covered by the Lambert Land map sheet, the transition from intact to imbricated foreland is perfectly preserved in a foreland-propagating succession of major thrust sheets. The division into structural domains used here (Fig. 1) follows that of Higgins & Leslie (2008), and differs slightly from that of the synoptic tectonic map on the map sheet (Jepsen 2000). The westernmost domain, known as the Thin-skinned fold-and-thrust belt, involves in its western part only the Ordovician–Silurian carbonate formations recognised in the foreland that range from gently (Fig. 13) to tightly folded. The NNE–SSW-striking and E-dipping Caledonian thrusts that disrupt the succession typically have a few kilometres displacement on each thrust. Farther eastward the thrusts penetrate to deeper levels and the Independence Fjord Group makes up a spectacular fold-and-thrust duplex that is well exposed in central Ingolf Fjord (Fig. 14). The Thin-skinned fold-and-thrust belt is structurally overlain by the Vandredalen thrust sheet, which is made up of a distinctive package of rocks of the Neoproterozoic Rivieradal and Hagen Fjord Groups that has been transported westward some 30–50 km. In its turn the Vandredalen thrust sheet is structurally overlain by a

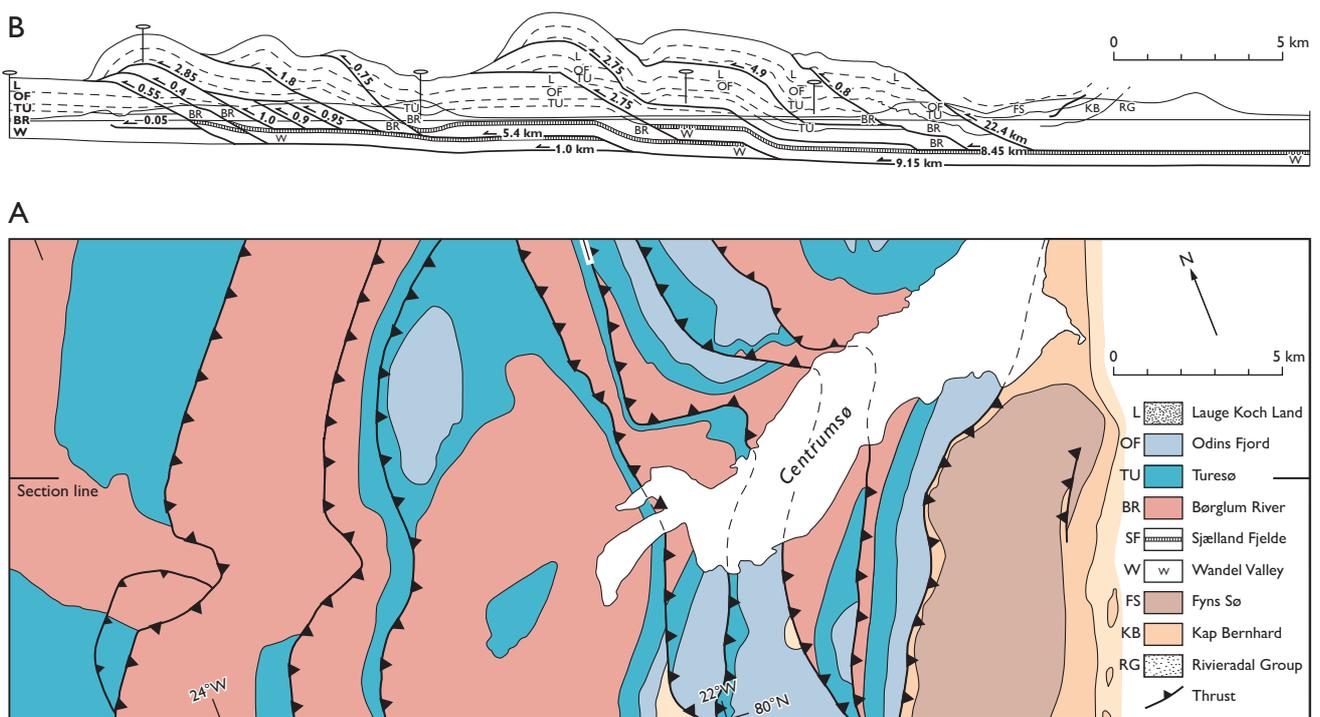


Fig. 15. Geological map and restored cross-section of the Thin-skinned fold-and-thrust belt around Centrumso. A: Geological map and location of section line. B: Cross-section with calculated displacements on individual thrusts in kilometres (e.g. 2.75) based on a line and area balance. Only the Sjælland Fjelde Formation is given a distinctive ornament, with other formations indicated by two-letter abbreviations. Modified from Higgins *et al.* (2004, their fig. 4).

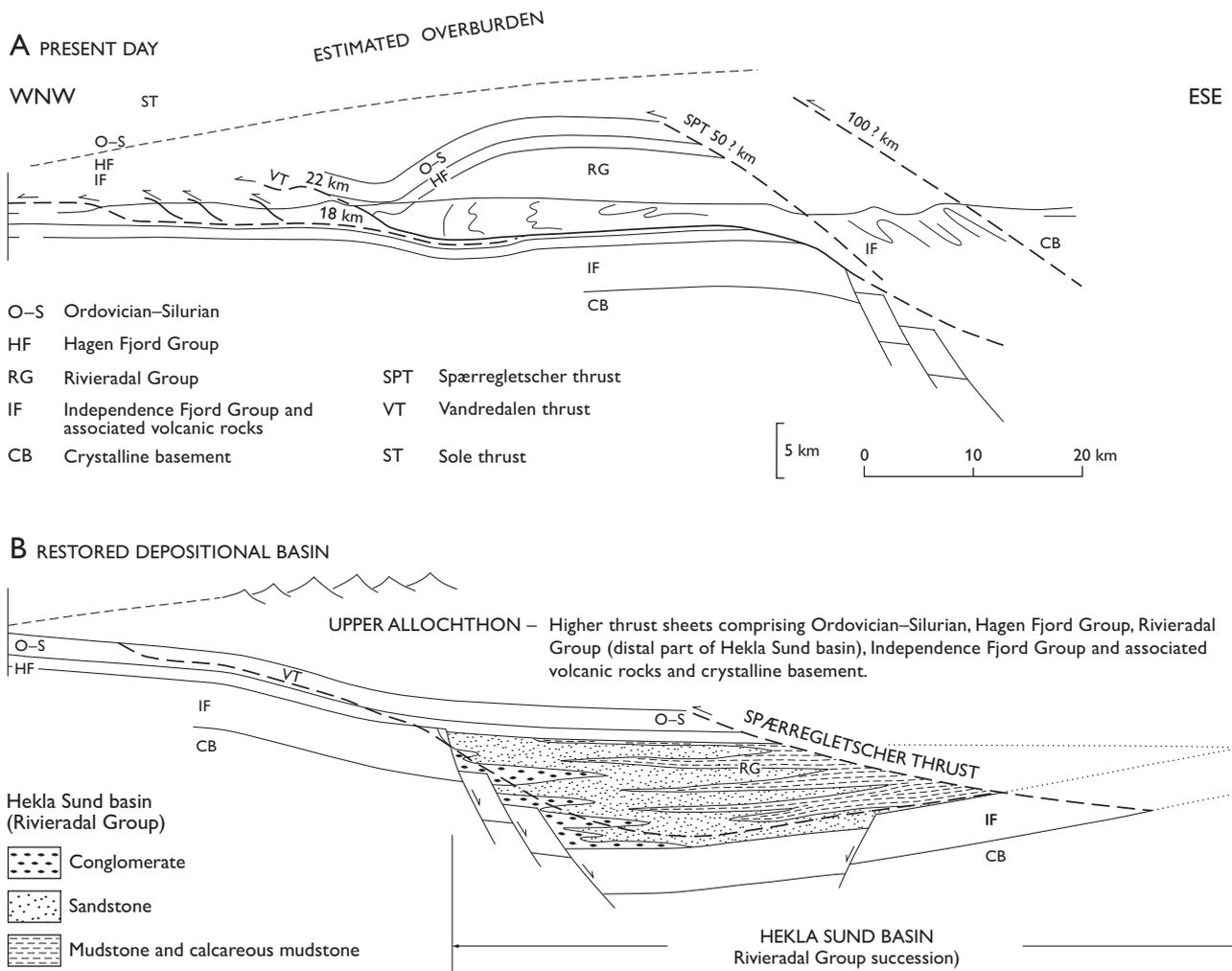


Fig. 16. A: Schematic WNW–ESE cross-section of the Vandredalen rift system with estimated overburden calculated from conodont alteration temperatures (after Rasmussen & Smith 2001). B: The same section with displacements on the thrusts restored, showing the fault-bounded control of the west margin of the Hekla Sund Basin. From Smith *et al.* (2004b, their fig. 2). Note the west side of the half-graben is characterised by wedge-shaped proximal conglomerates.

group of thrust sheets defined by Higgins & Leslie (2008) as the Western thrust belt that is well exposed in east-central Ingolf Fjord where it is dominated by folded white quartzites of the Independence Fjord Group and cross-cutting dykes and sills, together with volcanic units. Southwards the Western thrust belt continues to Hekla Sund and western Hovgaard Ø, through Lambert Land and into the large nunataks along the Inland Ice margin west of Jøkelbugten. The easternmost structural domain is the Nørreland thrust sheet, of which that part east of the Storstrømmen shear zone (see Fig. 1) comprises Palaeoproterozoic gneiss complexes that contain abundant Caledonian eclogitic enclaves; these high-grade rocks dominate the coastal region. This domain corresponds to the Thick-skinned thrust belt on the synoptic tectonic map of the Lambert Land map sheet.

The different structural domains are described individually in more detail below.

Thin-skinned fold-and-thrust belt

In western Kronprins Christian Land undeformed Ordovician–Silurian platform carbonates of the autochthonous foreland pass eastwards into the Thin-skinned fold-and-thrust belt developed in the same rocks. The NNE–SSW-trending, east-dipping Caledonian thrusts each have displacements from a few hundred metres to several kilometres, with the thrusts following long flats developed in the Børglum River Formation. A line and area restoration of a well-exposed WNW–ESE section through the western part of the Thin-skinned fold-and-thrust belt demonstrates about 18 km total displacement (see Fig. 15; Higgins *et al.* 2004), representing a shortening of about 45% in the line of section. Conodonts and macrofossils provide biostratigraphic control in the carbonate succession. And a by-product of the conodont studies is that their alteration colours provide an estimate of maximum burial temperatures, and thus the thickness of the overlying thrust sheets.

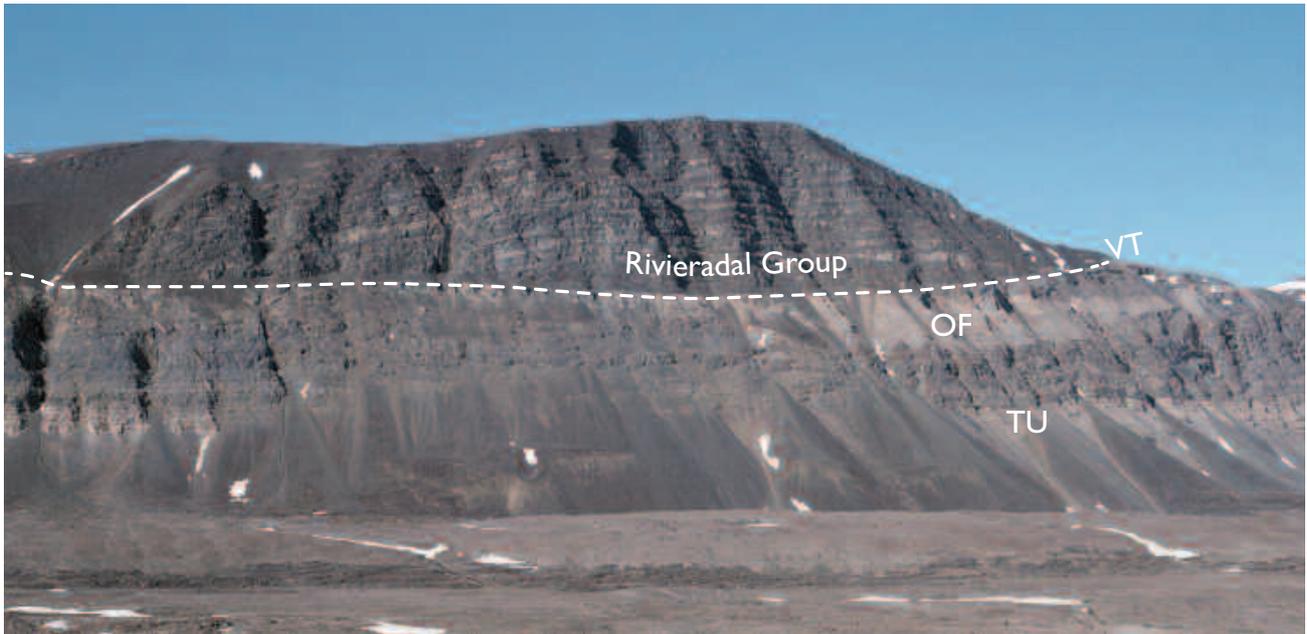


Fig. 17. The klippe of Rivieradal Group on the west side of Vandredalen. Conglomerates of the Neoproterozoic Rivieradal Group are in contact along the Vandredalen thrust (VT) with the underlying Ordovician Odins Fjord Formation (OF) and Turesø Formation (TU).

The thickness of the thrust sheets deduced from the estimated burial temperatures ranges from about 6.4 km to 12.5 km from west to east across the width of the Thin-skinned fold-and-thrust belt (Rasmussen & Smith 2001). As the estimated former thickness of the overlying Vandredalen thrust sheet is insufficient to yield the recorded temperatures, it is most likely that higher thrust sheets, presumably parts of the Western thrust belt, must once have extended across the region.

In eastern Vandredalen, lower levels of the Neo-proterozoic–Ordovician succession are exposed (Hagen Fjord Group, Kap Holbæk Formation, Sjølland Fjelde and Wandel Valley Formations) along the western flanks of Prinsesse Caroline-Mathilde Alper. The alpine region itself comprises light-coloured quartzites of the Independence Fjord Group and dolerite dykes and sills spectacularly exposed in west-central Ingolf Fjord in a large-scale fold and thrust duplex (Fig. 14).

In the alpine regions of the Prinsesse Caroline-Mathilde Alper and the Prinsesse Elisabeth Alper, the Caledonian thrusting within the Independence Fjord Group has raised the Vandredalen thrust (the roof thrust of the Thin-skinned fold-and-thrust belt) above exposure level. Farther south, south of Sæfaxi Elv, the floor thrust of the Thin-skinned fold-and-thrust belt appears to have remained within the Ordovician carbonates as far as Marmorvigen, and as a consequence the overlying Rivieradal Group sediments form extensive outcrops in the region known as Skallingen.

Vandredalen thrust sheet

The Vandredalen thrust sheet is a well-defined thrust sheet, almost entirely confined to southern Kronprins Christian Land, and largely made up of a Neoproterozoic clastic succession (the Rivieradal Group) that was deposited in an east-facing half-graben (Fig. 16). During Caledonian orogenesis the fill of the half-graben was displaced westwards across its rift shoulders (Higgins *et al.* 2001b), such that rocks of the Neoproterozoic Rivieradal Group now structurally overlie Ordovician–Silurian strata of the Thin-skinned fold-and-thrust belt to the west. The Rivieradal Group grades upwards into the Hagen Fjord Group, of which the red and yellow weathering carbonate units (Kap Bernhard and Fyns Sø Formations) are most conspicuous, and are well-exposed over the *c.* 200 km long N–S-trending frontal ramp of the thrust sheet. Outliers of the conglomeratic units of the Rivieradal Group are spectacularly exposed on the west side of Vandredalen (Fig. 17). Correlations of cut-offs of the Fyns Sø Formation in the hanging wall and footwall of the Vandredalen thrust demonstrate that westward displacement of the thrust sheet during the Caledonian orogeny ranged from about 35 to 50 km.

The root zone of the Vandredalen thrust sheet is preserved as the narrow strip of metasedimentary rocks traceable northwards along the west side of Hekla Sund, from Marmorvigen across the alpine region along Brede Spærregletscher (see Figs 7, 12), and on the north side of Ingolf Fjord for a further 50 km to the inner part of Tobias Gletscher. At Marmorvigen a large horse (slice) of Independence Fjord Group rocks is preserved between the Ordovician carbonates in the footwall of the Vandredalen thrust and the overlying Neoproterozoic Rivi-

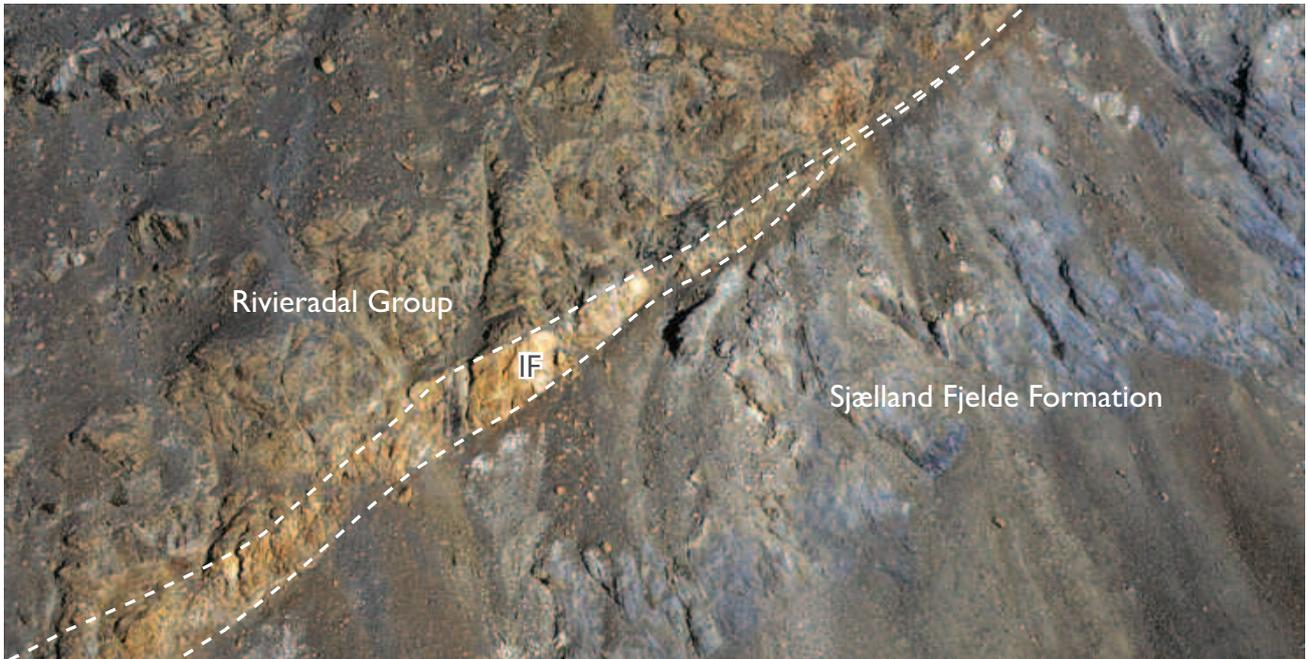


Fig. 18. Slice (horse) of Independence Fjord Group quartzite (IF) trapped along the Vandredalen thrust between Neoproterozoic Rivieradal Group sediments and Ordovician carbonates of the Sjælland Fjelde Formation. West side of upper Hjørnegletscher. Photo: Jakob Laurrup.

eradal Group strata. This is interpreted as a slice of Independence Fjord Group quartzites detached from the west rift margin of the Hekla Sund Basin; the latter name has been used for the sedimentary rift basin in which the Rivieradal Group accumulated (Higgins *et al.* 2001b), a basin that from the preserved remnants of the Rivieradal Group is estimated to have been at least 50 km wide and more than 200 km long from north to south. Horses of Independence Fjord Group rocks occur along the line of the Vandredalen thrust on the south side of Sæfæxi Elv, and on the west side of Hjørnegletscher (Fig. 18); the largest horse observed comprises a 1000 m wide slab of quartzite cut by dolerite dykes.

Western thrust belt

This general term is used for a group of poorly defined thrust sheets that structurally overlie the Vandredalen thrust sheet and crop out in the nunatak region west of Jøkelbugten and in western Lambert Land; they also occupy a broad strip of mountainous terrain extending from western Hovgaard Ø through Lynn Ø and into the high mountains on both sides of central Ingolf Fjord. In its southern area of outcrop this thrust belt comprises amphibolite facies Proterozoic gneisses interleaved with quartzites of the Independence Fjord Group. Northwards the proportion of gneisses decreases, and from

western Hovgaard Ø and farther north the thrust belt narrows and only consists of thrust imbricates of Independence Fjord Group quartzites and associated volcanic rocks.

On Lambert Land, Jones & Escher (1995) distinguished two distinct thrust events within the Western thrust belt, an early phase of N-directed thrusting and a later of westward thrusting. They distinguished seven, thin, N-directed thrust sheets separated by ductile thrusts that form an in-sequence northward-propagating thrust stack. Large segments of the early thrust stack were carried westwards in later series of six W-directed thrust sheets.

The well-exposed cliff sections along central Ingolf Fjord, Hekla Sund and western Hovgaard Ø are dominated by white quartzites of the Independence Fjord Group and black doleritic dykes and sills (see Fig. 5). These units are interleaved in a thrust duplex that is tightly folded in places (see Frontispiece).

The Western thrust belt lies in the hanging wall of the Spærregletscher thrust, which is also the roof thrust of the Vandredalen thrust sheet. The Spærregletscher thrust dips eastwards at steep to moderate angles, and can be traced across Ingolf Fjord and southward along Brede Spærregletscher to Hekla Sund. The waters of Hekla Sund hide its southern continuation, apart from a small outlier that caps the summit of Kap Bernhoft where white quartzites are in thrust contact with metasedimentary rocks of the Rivieradal Group.

Nørreland thrust sheet

The Nørreland thrust sheet makes up the deepest, preserved level of the East Greenland Caledonides. In the Lambert Land map sheet area, the Nørreland thrust sheet is exposed in the outer coastal region of Jøkelbugten, in eastern Lambert Land and on eastern Hovgaard Ø, with the northernmost exposures on northern Holm Land and Wegener Øer. The exposures are dominated by high-grade Palaeoproterozoic gneiss complexes that contain abundant Caledonian eclogitic lenses. Study of the eclogites has demonstrated that the continental crust of this region has been subjected to medium temperature (600–750°C), high pressure (1.5–2.2 GPa) metamorphism, attributed to thickening of the East Greenland continental margin during crustal imbrication associated with W-directed Caledonian thrusting (Brueckner *et al.* 1998; Elvevold & Gilotti 2000; Gilotti *et al.* 2008). Ultra-high pressure, coesite-bearing eclogites are exposed in parts of the region (McClelland *et al.* 2006).

The western limit of the Nørreland thrust sheet is poorly defined in the south due to the scattered exposures in the nunatak region west of Jøkelbugten and the reconnaissance scale of the mapping. Eclogite-bearing orthogneisses structurally overlie lower-grade gneiss complexes in Lambert Land and Nørreland, and the description of the relationships around the Nørreland window led to the use of the Nørreland thrust

sheet for the overlying high-grade rock units (Hull & Friderichsen 1995; Gilotti *et al.* 2008). The Nørreland thrust sheet must have been exhumed from depths greater than 50 km and displaced westward across higher-level rock units. The conodonts extracted from Ordovician limestones in the footwall of the thrust that bounds the Nørreland window have alteration colours indicative of an overburden of less than 15 km (Rasmussen & Smith 2001), which is substantially less than the thicknesses needed for eclogite formation. This demonstrates that significant displacement on the Nørreland thrust must be younger than the Devonian-age (415–390 Ma) eclogites in the hanging wall (Gilotti *et al.* 2004). To the north of Nioghalvfjerdingsfjorden the western boundary of the Nørreland thrust sheet coincides with the East Greenland Fault Zone, a prominent but almost entirely unexposed fault with the latest movements showing downthrow to the east.

No obvious internal thrust contacts have been observed within the high-grade terrain of the Nørreland thrust sheet, but Gilotti *et al.* (2008) consider it unlikely that this extensive region represents a single crustal slab. Indeed the local presence of ultra-high pressure eclogites (mentioned above) requires a tectonic contact to account for the large pressure difference that separates the ultra-high pressure eclogite terrain from other parts of the Nørreland thrust sheet.

Post-Caledonian rocks

Wandel Sea Basin

Post-Caledonian rocks are restricted to exposures in eastern Holm Land and more extensive outcrops in Amdrup Land, north of outer Ingolf Fjord. All these rock units were deposited as a result of rifting between Greenland, Svalbard and Norway in the Wandel Sea Basin (Stemmerik & Håkansson 1989).

Early Carboniferous

The Lower Carboniferous Sortebakker Formation (C_1) is restricted to the southernmost part of Holm Land, and comprises a thick succession of fluvial sandstone and shale divided into two parts by a low-angle disconformity (Stemmerik & Håkansson 1989; Stemmerik *et al.* 1994). The lower unit is composed of shale-dominated fluvial cycles, whereas the upper part comprises sandstone-dominated cycles and channelised sandstone bodies. Sedimentary profiles measured in 1994 indicate a thickness in excess of 1000 m for the formation.

Carboniferous–Permian

The marine sediments of the mid-Carboniferous to Permian Mallebuk Mountain Group include the Kap Jungersen and Foldedal Formations (C_2) (Fig. 19) and the Midnatfjeld and Kim Fjelde Formations (P). In southern Amdrup Land the succession is gently E-dipping, but in northern Amdrup Land there is folding and displacement associated with NNW–SSE-trending faults. In general terms the formations thin westwards, from less than 100 m near the East Greenland Fault Zone to about 600 m at Kap Jungersen. The succession is dominated by cyclically interbedded shelf carbonates, with thick bryozoan build-ups in its lower part (Stemmerik & Håkansson 1989; Stemmerik *et al.* 1994).

Late Jurassic

The youngest bedrocks exposed in the Lambert Land map sheet area are Late Jurassic siliciclastic sedimentary rocks of the Ladegårdsåen Formation (LA). These rocks are preserved in the cores of ENE–WSW-trending synclines in eastern Amdrup Land (Stemmerik *et al.* 1998).

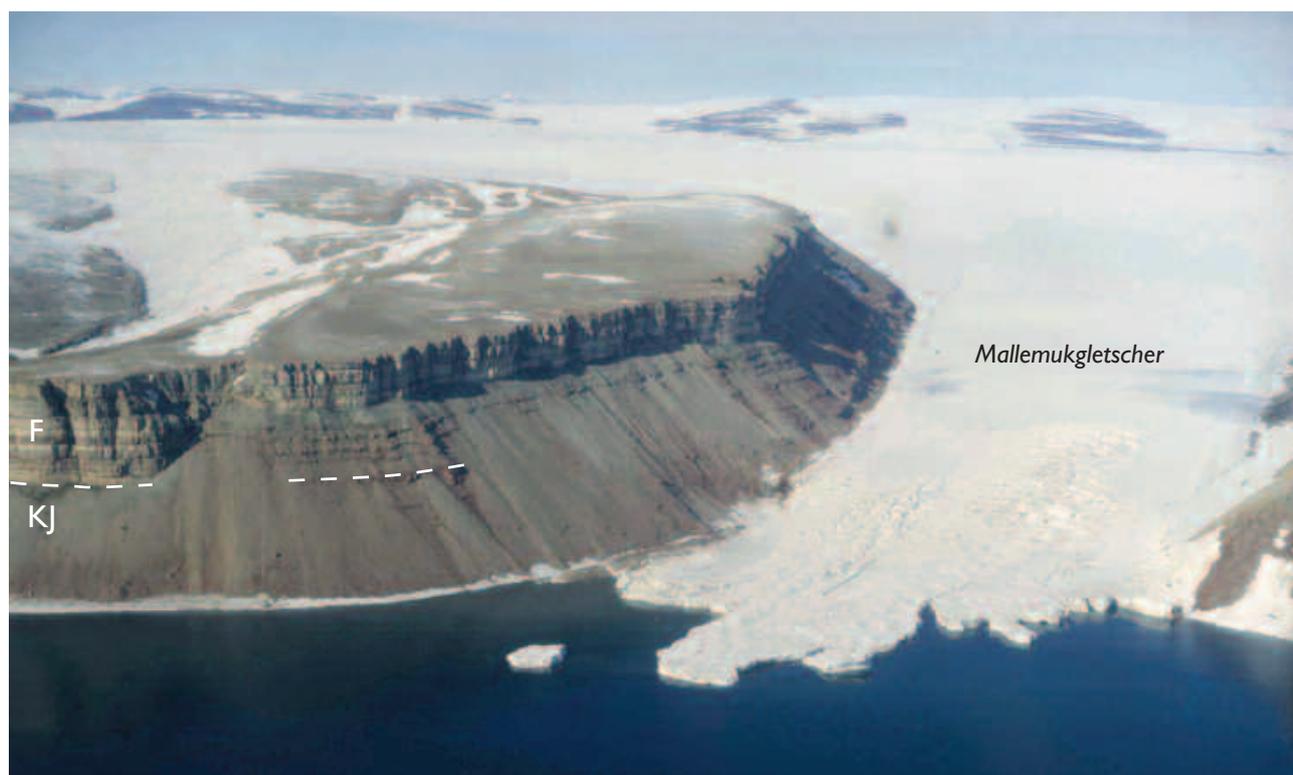


Fig. 19. Mallebukgletscher looking west, showing Late Carboniferous sediments of the Kap Jungersen (KJ) and Foldedal (F) Formations (C_2 on the map sheet). Photo: Niels Henriksen.

Mineralisation

The known indications of mineralisation in the region of map sheet 9 have been summarised by Henriksen (1996). The Middle Proterozoic Zig-Zag Dal Basalt Formation and parts of the Hagen Fjord Group have been shown to have a potential for Cu mineralisation, and studies in the Hagen Fjord Group sandstones in J.C. Christensen Land suggest that the Cu mineralisation associated with regional faults. High Au values in Silurian carbonates may be related to thrust zones and associated karstic features. Petroleum geological investigations have mainly been focused on the post-Caledonian successions of the Wandel Sea Basin, as these onshore exposures provide important information on the general North Atlantic geological evolution and the continental shelf offshore North-East Greenland in particular.

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Geological Survey of Denmark and Greenland

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