GEOLOGICAL SURVEY OF DENMARK AND GREENLAND MAP SERIES 1 · 2004

Explanatory notes to the Geological map of Greenland, 1:500 000, Humboldt Gletscher, Sheet 6

Peter R. Dawes

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

Geological Survey of Denmark and Greenland Map Series 1

Keywords
Northern Greenland, Nares Strait, Palaeoproterozoic, Mesoproterozoic, Lower Palaeozoic, Neogene, Quaternary, map units, economic geology.

Cover
Extract of the Humboldt Gletcher map sheet showing homoclinal Cambro-Silurian strata of the Franklinian Basin in Washington Land, and the locations of the Neogene Bjørnehiet Formation (black star symbol) and, east of Bjørnehiet, fault-controlled zinc-lead-barium mineralisation (red square symbol).

Peter R. Dawes
Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
E-mail: prd@geus.dk

Chief editor of this series: Peter R. Dawes
Scientific editor: A.K. Higgins
Editorial secretaries: Birgit Eriksen and Esben W. Glendal
Critical readers: Thomas Frisch, Canada (map), A.K. Higgins, Denmark (explanatory notes), Andrew V. Okulitch, Canada (map and explanatory notes), Franco Pirajno, Australia (map)
Illustrations: Kristian Anker Rasmussen
Digital photographic work: Benny Munk Schark and Jakob Lautrup
Graphic production: Knud Gr@phic Consult, Odense, Denmark
Printers: Schultz Grafisk, Albertslund, Denmark
Explanatory notes submitted: 12 July 2004
Final version approved: 1 October 2004
Printed: 26 November 2004

ISBN 87-7871-144-4

Geological Survey of Denmark and Greenland Map Series
The series *Geological Survey of Denmark and Greenland Map Series* replaces *Geology of Denmark and Greenland Map Series.*

Citation of this series
It is recommended that the name of this series is cited in full, viz. *Geological Survey of Denmark and Greenland Map Series.*
If abbreviation of this volume is necessary, the following form is suggested: *Geol. Surv. Den. Green. Map Series* 1, 48 pp. + map.

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

or

Geografforlaget Aps
Rugårdsvej 55, DK-5000 Odense C, Denmark
Phone: +45 63 44 16 83, fax: +45 63 44 16 97, e-mail:go@geografforlaget.dk

Contents

Abstract 5
Introduction 7
General geology and regional structure 8
Physical environment 9
  Climate and vegetation 9
  Physiography 9
  Exposure 9
  Working season, access and logistics 9
Map data and geological research 11
  Data sources and field work 11
  History of geoscientific research 11
Palaeoproterozoic Inglefield mobile belt 13
  Age and chronology 13
  Portrayal of map units 13
  Structure and metamorphism 13
    Sunrise Pynt Straight Belt 14
    Faults and lineaments 14
  Prudhoe Land complexes 14
    Prudhoe Land supracrustal complex (**ps** and **pq**) 14
    Prudhoe Land granulite complex (**grn**) 15
  Etah Group 15
    Gneiss (**gn**) 16
    Calc-silicate gneiss (**c**) 16
    Marble-dominated sequence (**m**) 17
    Amphibolite, pyribolite, metagabbro (**a**) 18
    Ultramafic rock (**u**) 18
    Quartzite (**q**) 18
  Etah meta-igneous complex and late granitoids 18
    Gneiss (**go**) 19
    Quartz diorite (**qd**) 20
    Monzogranite (**gk**) 20
    Syenite (**sy**) 20
    Metamafic dykes 21
    Gabbro (**g**) 21
    Leucogranite and leucopegmatite (**red 'fish' symbol**) 21
    Granite (**gr**) 21
  Late felsic minor intrusions 22
Mesoproterozoic Thule Basin 23
  Structure and metamorphism 23
  Thule Supergroup 24
    Nares Strait Group 24
    Cape Combermere Formation (**CN**) 24
    Nares Strait Group, undifferentiated (**NG**) 25
    Smith Sound Group, undifferentiated (**SS**) 25
    Dolerite sills (**s**) 25
    Dundas Group: Kap Powell Formation (**PD**) 25
Proterozoic dolerite dykes 26
    Palaeo- and ?Mesoproterozoic dykes ($\mathbf{d_1}$) 26
    Neoproterozoic dykes ($\mathbf{d_2}$) 26

Palaeozoic Franklinian Basin 27
  History and literature 27
  Portrayal and description of map units 28
  Structure and metamorphism 28
  Basal Cambrian clastic deposits 29
    Dallas Bugt Formation (**D**) 29
    Humboldt Formation (**H**) 30
  Ryder Gletscher Group 30
    Cape Leiper and Cape Ingersoll Formations (**I**) 30
    Kastrup Elv Formation (**K**) 30
    Telt Bugt Formation (**T**) 31
    Wulff River, Cape Kent and Cape Wood Formations (**R**) 31
    Cass Ford Formation (**F**) 32
    Cape Clay and Christian Elv Formations (**C**) 33
    Poulsen Cliff and Nygaard Bay Formations (**N**) 33
    Canyon Elv and Nunatami Formations (**E**) 34
    Cape Webster Formation (**W**) 34
  Morris Bugt Group 34
    Kap Jackson and Cape Calhoun Formations (**J**) 34
    Aleqatsiaq Formation (**A**) 35
  Washington Land Group 35
    Petermann Halvø, Kap Godfred Hansen, Bessels Fjord and Offley Island Formations (**G**) 36
    Adams Bjerg Formation (**B**) 37
    Pentamerus Bjerge and Hauge Bjerge Formations (**P**) 37
    Kap Morton Formation (**M**) 37
  Peary Land Group 38
    Cape Schuchert and Lafayette Bugt Formations (**L**) 39
Late Cenozoic 39
  Neogene 39
    Bjørnehiet Formation (**black star symbol**) 39
    Wood locality (**red cross symbol**) 40
  Quaternary 40
    Ice limits 40
    Pre-Holocene deposits 40
    Deltas, terraces and marine limit 41
Economic geology 41
  Inglefield mobile belt 41
    Rust zones (**red dot symbol**) 41
    Magnetite (**mag**) 42
    Copper-gold mineralisation (**green dot symbol**) 42
  Franklinian Basin 42
    Zinc-lead-silver mineralisation (**yellow square symbol**) 43
    Zinc-lead-barium mineralisation (**red square symbol**) 43
    Petroleum geology 43
Acknowledgements 43
References 44

Abstract

Dawes, P.R. 2004: Explanatory notes to the Geological map of Greenland, 1:500 000, Humboldt Gletscher, Sheet 6.
Geological Survey of Denmark and Greenland Map Series 1, 48 pp. + map.

These explanatory notes cover the map region bounded by latitudes 78°N and 81°N and longitudes 56°W and 74°W, with geology shown on the land areas between Nares Strait – the seaway between Greenland and Ellesmere Island, Canada – and the Inland Ice. The bedrock geology is composed of Precambrian and Lower Palaeozoic provinces that continue across Nares Strait into Canada. Map units and mineral occurrences are described in general terms and are proceeded by sections on physical environment, logistics, data sources and geoscientific research. The notes are aimed at the practical user and a guide for further reading.

The bedrock is composed of three provinces separated by unconformities, each representing a hiatus of *c.* 500 Ma during which basic dykes were emplaced. *The Palaeoproterozoic Inglefield mobile belt*, forming the crystalline shield, is an E–W-trending belt of deposition and orogeny characterised by polyphase magmatism, deformation and high-grade metamorphism. Clastic deposition, with magmatism at *c.* 1985 Ma, are the oldest events recorded, followed by the accumulation of the Etah Group (carbonate, pelitic and psammitic sediments with supposedly coeval mafic and ultramafic rocks) between 1980 and 1950 Ma ago. These rocks were intruded 1950 to 1915 Ma ago by the Etah meta-igneous complex, that records polyphase plutonism (intermediate to felsic, with some basic and magnetite-rich rocks), followed by deformation and partial melting producing granites 1785 to 1740 Ma ago. *The Mesoproterozoic Thule Basin,* defined by the unmetamorphosed and little deformed Thule Supergroup, records sedimentation and basaltic volcanism at least as old as 1270 Ma. The faulted, north-eastern basin margin shown on the map preserves the passage from the basinal sequence to a relatively thin platform succession invaded by basic sills. *The Palaeozoic Franklinian Basin* is represented by a homoclinal Cambrian to Silurian shelf carbonate succession and a major Silurian reef complex, with coeval siliciclastic slope deposits. The map region includes the classical area for Franklinian stratigraphy, now composed of 29 formations and four groups – Ryder Gletscher, Morris Bugt, Washington Land and Peary Land Groups.

The only younger units preserved in the map region are widespread *Quaternary* deposits, an isolated outcrop of coarse-grained fluvial deposits (Bjørnehiet Formation) and non-carbonised wood erratics of *Neogene* age.

Five mineral occurrence types are shown on the map: in lithologies of the Inglefield mobile belt, sulphide-graphite rust zones, a magnetite deposit and copper-gold mineralisation and in the Franklinian Basin, commercially drilled, zinc-lead-silver and zinc-lead-barium mineralisations. The basic ingredients of a petroleum model exist in the Franklinian Basin but prospectivity is low.

Author's address
Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.
E-mail: prd@geus.dk

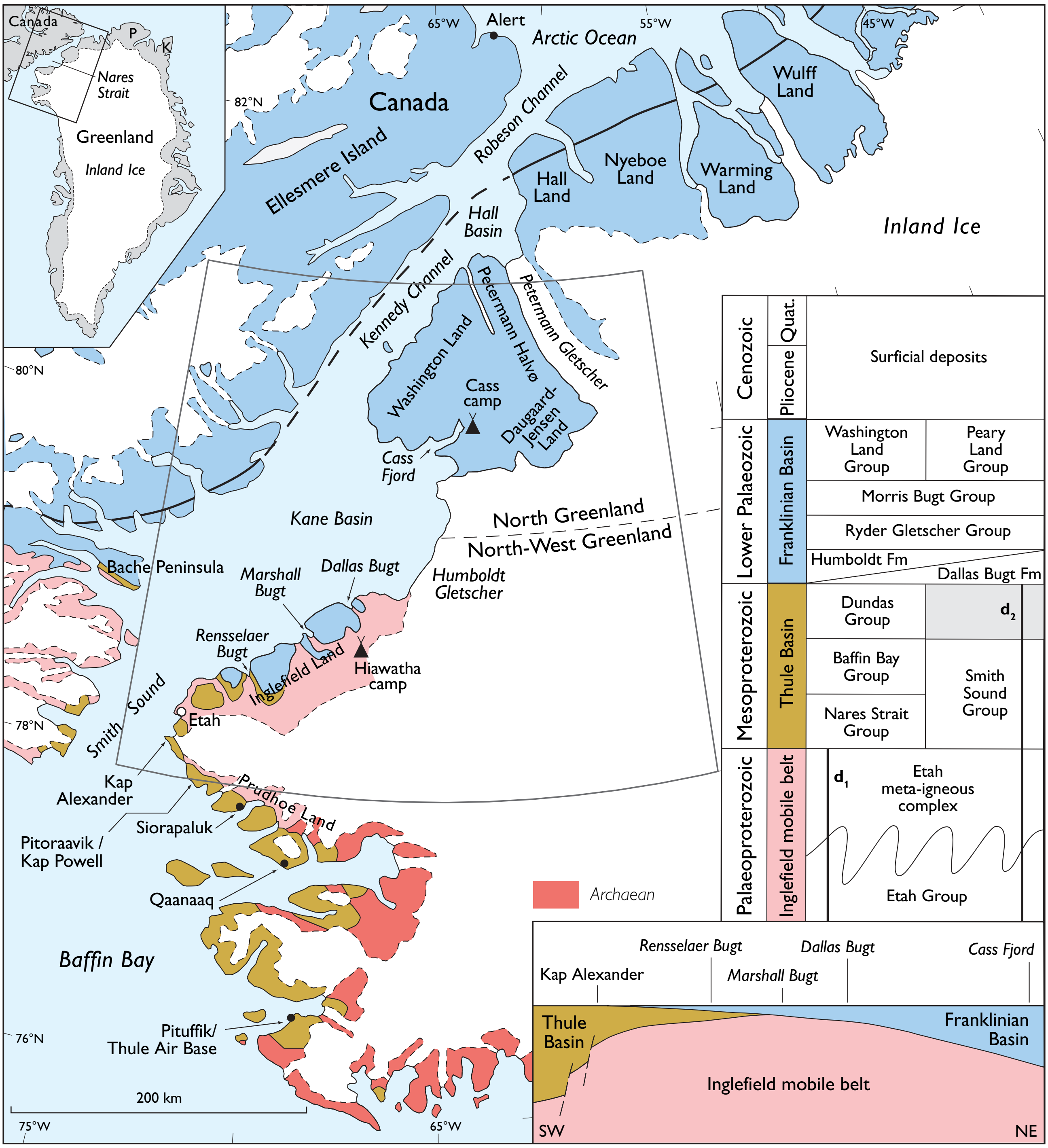

Fig. 1. Simplified geological map of the Nares Strait region with an outline of the Humboldt Gletscher map sheet (**black frame**) and an inset map showing regional location. A schematic cross-section illustrates the relationships between the three main bedrock provinces of the map sheet and a general stratigraphic chart gives the principal lithostratigraphic divisions. Outcrops of Carboniferous to Palaeogene rocks on Ellesmere Island, Canada (Sverdrup Basin) are not shown. It should be noted that the Baffin Bay Group is not exposed in the map sheet region but it crops out immediately to the south, east of Pitoraavik and Kap Powell. The Smith Sound Group, forming the main outcrops of the Thule Basin on the map sheet, is the northern platform and basin margin equivalent of the Nares Strait and Baffin Bay Groups and the **grey shading** in the stratigraphic chart emphasises the major hiatus with the Franklinian Basin. The implied contact between the basinal Dundas Group and the Franklinian Basin is fictitious since the strata occur in essentially different regions (see cross-section). The **sinuous black line** on the map in the Franklinian Basin represents the southern limit of Ellesmerian (Palaeozoic) folding, with its offshore position **dashed**. The **vertical black lines** marked $\mathbf{d}_1$ and $\mathbf{d}_2$ in the stratigraphic chart represent the two main periods of Proterozoic basic dykes. **Black dots** are present-day settlements; **open circle** marked Etah is an abandoned settlement. **Blank areas** are ice. **Nares Strait** is the seaway joining Baffin Bay and the Arctic Ocean. On the inset map: **P**, Peary Land; **K**, Kronprins Christian Land. Modified from Dawes *et al.* (2000a).

Introduction

The Humboldt Gletscher map sheet (Sheet 6) is bounded by latitudes 78°N and 81°N and longitudes 56°W and 74°W, and shows the geology of the south-eastern side of Nares Strait, the seaway between Greenland and Ellesmere Island, Canada. Bordering map sheets are Thule (Sheet 5) and Nyeboe Land (Sheet 7) to the south and north, respectively (Dawes 1991a; Henriksen 1992). As a sheet of the 1:500 000 'Geological map of Greenland' series, geology is not shown on Canadian territory but the geological relationship with Ellesmere Island is depicted on the 'Tectonic provinces' inset map. Hans Ø, the small island in mid-Kennedy Channel, is shown on the map to be closer to Greenland than Canada, and is coloured. However, pending agreement between the respective nations the island is officially neutral territory.

In these explanatory notes the English names for the various parts of Nares Strait are used, viz. from south to north, Smith Sound, Kane Basin, Kennedy Channel, Hall Basin and Robeson Channel whereas Danish equivalents of the first three appear on the map sheet (Fig. 1). Variation in the location of place names on different maps of Nares Strait can occur, for example the capes along the outer coast of Inglefield Land. In some cases this blurs the precise location of historical and geological sites, including stratigraphical type localities. Thus for example, the classical sea-cliff section through Proterozoic and Lower Palaeozoic strata first illustrated by Koch (1933, fig. 13, plate 2) as 'Cape Ingersoll', and so featured by Cowie (1961, figs 1, 8) and Dawes (1997, fig. 8), does not correspond to the Kap Ingersoll of the Humboldt Gletscher map sheet. The cliff section is farther west and marked Kap Grinnell on the map sheet. Similar confusion pertains to several localities along the coast of Nuussuaq between Blomsterbækken and Kap Kent that have also been used in stratigraphical nomenclature.

A major part of the map sheet is covered by the Inland Ice, with the 100 km-wide Humboldt Gletscher dividing the land into two parts: in the south, Inglefield Land and northern Prudhoe Land, and to the north, Washington Land – with its subordinate areas of Daugaard-Jensen Land and Petermann Halvø – and south-westernmost Hall Land (Fig. 1). This bipartite division is reflected in the two-column design of the map legend that accentuates the regional structure: in the south, Precambrian shield overlain by Mesoproterozoic and Palaeozoic strata; in the north, the main part of the Palaeozoic succession.

These explanatory notes are designed as an extended map legend with 42 map units and 5 mineralisations described. They are aimed at the practical user needing an introduction to the geology – for example, a mineral exploration company – rather than the specialist seeking details about one particular aspect. The reference list is intended as the key to more information rather than complete documentation of the known geology. In 1999, prior to the concluding field work for the map sheet, a status report was released containing a detailed history of research and an exhaustive bibliography, with over 350 published and unpublished references split into 12 sections dealing with onland and offshore geoscientific disciplines (Dawes 1999). The history of geoscientific research and reference list given here complement that status and focus on the last decade.

Sections on the physical environment, and on practical aspects such as access and logistics, are aimed at the needs of exploration companies and other potential visitors. Where at all relevant, citations are given to illustrations in the literature while hitherto unpublished photographs have been chosen as illustrations. Thus, the classical coastal section at Sunrise Pynt illustrating the intimate association of metasedimentary and meta-igneous rocks of the shield, featured in several other publications, is not reproduced here (e.g. Dawes 1976, fig. 228; 1988, fig. 3; Frisch & Dawes 1982, fig. 3; Schjøth *et al.* 1996, fig. 3).

General geology and regional structure

The Humboldt Gletscher map sheet is dominated by Precambrian and Lower Palaeozoic rocks, with minor Neogene deposits and a widespread Quaternary cover. There are three major bedrock provinces, all of which continue across Nares Strait into Canada: the crystalline shield – more specifically the Palaeoproterozoic Inglefield mobile belt, the Mesoproterozoic Thule Basin and the Palaeozoic Franklinian Basin. The major unconformities separating these provinces are well preserved in Inglefield Land (Fig. 1), where in the south-west the unmetamorphosed Mesoproterozoic Thule Supergroup (Smith Sound Group) overlies the shield with profound unconformity (Fig. 2; also Dawes 1976, fig. 229; 1997, fig. 9). Poor exposure inland, and coastal scree, hide the precise location of the feather-edge of the Smith Sound Group but it must lie somewhere west of Minturn Elv. To the north-east, the Franklinian Basin (Dallas Bugt Formation) directly overlies the shield (see Fig. 15; also Peel *et al.* 1982, fig. 8), and in the south-west oversteps formations of the Smith Sound Group (see Fig. 11; also Dawes 1997, figs 14, 32).

SHRIMP U-Pb zircon and Rb-Sr isotopic analyses show that the Palaeoproterozoic Inglefield mobile belt – an E–W-trending complex belt of deposition and orogeny characterised by polyphase magmatism, deformation and metamorphism – was formed between 1985 and 1740 Ma ago; K-Ar analyses show cooling until *c.* 1650 Ma (Larsen & Dawes 1974; Dawes *et al.* 1988; summarised in: Dawes 1999 and Nutman *et al.* 2004). Following a period of basic dyking at *c.* 1630 Ma (designated $\mathbf{d_1}$), intensely deformed and high-grade rocks underwent a long period of erosion to mature peneplanation prior to the onset of Mesoproterozoic deposition. Isotopic dating of basic sills in Inglefield Land and adjacent Ellesmere Island (Dawes *et al.* 1973; Frisch & Christie 1982; Dawes & Rex 1986; summarised in: Dawes 1997, 1999) indicate that the basal Thule Basin strata are older than 1270 Ma. Thus, the hiatus between the shield and Thule Basin represents a time gap of at least 400, possibly 500 Ma. The younger hiatus, between the Thule and Franklinian Basins, is of similar magnitude, but is much less conspicuous being located within homoclinal strata of similar lithology (see Peel *et al.* 1982, figs 4, 6). The break is well documented between Force Bugt and Rensselaer Bugt, where a persistent basic sill in the sea cliffs (shown on the map), is in places eroded away below the Cambrian Dallas Bugt Formation (see Fig. 11; also Dawes 1997, figs 32, 44). Basic dykes (designated $\mathbf{d_2}$) with K-Ar ages in the range 675–625 Ma cut Thule Basin strata but not the Cambrian (Dawes *et al.* 1982).

In broad terms, the outcrop pattern of strata preserved in the map region reflects the planar attitude of the palaeo-erosion surface on the shield. However, in some areas, for example east of Rensselaer Bugt, palaeorelief exceeds 150 m. In Inglefield Land, the peneplain with its overlying sedimentary cover is tilted gently to the north-north-west while the cover has been stripped off inland (e.g. Koch 1928, 1929a, 1933, plate III; Troelsen 1950; Cowie 1961, fig. 9). The shallow dip of the homoclinal succession persists north of Humboldt Gletscher, where in southernmost Daugaard-Jensen Land the shield must be close to present exposure level beneath basal Cambrian strata. The regional dip determines that the youngest strata of the Franklinian Basin are exposed along Kennedy Channel.

Fig. 2. Profound unconformity between steeply-dipping, variable rocks of the Palaeoproterozoic Inglefield mobile belt and homoclinal Mesoproterozoic Thule Supergroup (Smith Sound Group) with conspicuous basic sills. The actual unconformity is largely obscured by talus. Orthogneisses dominate the shield with interleaved units of paragneiss, amphibolite and granitoids, only the main units of which are shown on the map. View is north over Dodge Gletscher (right foreground) with plateau height at *c.* 400 m a.s.l.

Physical environment

Climate and vegetation

The map region is a high-arctic desert with continuous permafrost, low ice melting rates and low precipitation, the mean annual 10–15 cm falling mostly as snow. Summers are short and cool, and in the winter the sun is below the horizon for nearly four months from October to February. In spring (May and June) temperatures rise above zero and in summer (July and August) they are normally between zero and 10°C with a July mean of 3–4°C. The sea is frozen for most of the year and navigable only for a short summer in restricted areas such as Smith Sound. Winds, that can develop rapidly and often blow from the Inland Ice, strongly influence sea ice conditions during the summer. Coastal fog is common in summer, especially in the southwest. The map region supports a low, minimal vegetation restricted to low vascular plants, dwarf shrubs, mosses and lichens. Lichens hinder geological observations and where profuse as on steep 'bird cliffs', for example on the northern side of Foulke Fjord, the rocks are significantly camouflaged.

Physiography

Physiographically, most of the region represents a cliff-bounded, highland plateau or concordant upland, the upper surface of which is parallel to the regional bedding of the sedimentary cover, or as in the interior of Inglefield Land, an exhumed Precambrian peneplain (Figs 3, 9A). Thus, at least two planation surfaces are preserved, one across the shield below the Mesoproterozoic Thule Basin and the second, a late Cenozoic (pre- or early Pleistocene) level covered by glacial deposits and forming the present upper land surface (Nichols 1969; Figs 2, 3, 15, see also Dawes & Christie 1991, fig. 3.3).

The coasts are rugged with impressive steep cliffs. Elevations of the plateau surface vary from near sea level to 1000 m, with the highest elevations on flat-topped nunataks in Hall Land (1020 m). Many local ice caps are present north of Humboldt Gletscher, where the plateau is best preserved and dissected by broad, flat-floored glaciated valleys, canyons and steep-sided fjords. The inland relief can reach several hundred metres, and along Bessels Fjord and Petermann Gletscher it reaches 700 to 800 m (see Dawes 1976, fig. 221). Ice-dammed lakes are found in steep-sided valleys in southern Daugaard-Jensen Land. Local geology produces the dome-shaped uplands of coastal Washington Land where Silurian reefs up to 500 m thick form rounded summits separated by lowlands of shale (see Fig. 21B; also Dawes 1971, plate 2; Dawes & Christie 1991, fig. 3.7; Higgins *et al.* 1991a, fig. 51, 1991b, fig. 7.35).

In Inglefield Land, relief is more subdued and the plateau is gently inclined seawards from 600–700 m a.s.l. near parts of the Inland Ice to the 300–400 m sea cliffs of the outer coast. Inland, the extensive level upland that coincides with the regional palaeosurface mentioned above, is a featureless landscape with a widespread moraine cover that hosts hundreds of shallow lakes and ponds (Fig. 9A). The only large lakes occur near the Inland Ice margin; west of Hiawatha Gletscher a chain of lakes known as Septembersøerne occupy a glacier-scoured valley. In the short summer season, meltwater from the Inland Ice and melting snow drains into rivers that have cut deep valleys to the coast.

Exposure

The steep, often precipitous, sea cliffs provide excellent study sections in the Mesoproterozoic and Palaeozoic stratigraphy. These and the valley scarps inland, provide the best exposures, although many are inaccessible and have prominent talus slopes at their bases (see Figs 11, 16). Away from these cliffs, bedrock exposure is poor. The distribution of Quaternary deposits shown on the map is to some extent misleading, as large areas both north and south of Humboldt Gletscher depicted as bedrock have an almost continuous surficial cover (Fig. 3). In effect, all plateau surfaces have a blanket of till and frost-shattered bedrock rubble and even the rounded rocky hills that characterise some shield exposures, for example in north-eastern Inglefield Land, are strewn with glacial boulders and debris. The best shield exposures are along the coast, and in some of the deep northerly trending valleys, such as those along Kuussuaq, Tufts Elv and Minturn Elv.

Working season, access and logistics

The months July and August are best suited for modern helicopter-supported field work, with 24 hours daylight and minimum snow cover. New snow and poor light begin to hamper field observations in early

Fig. 3. Typical landscape of south central Washington Land showing the regional plateau surface representing a Cenozoic peneplain, with wide Quaternary-filled valleys and restricted exposure. View is north towards the ice-capped plateau of Petermann Halvø. Foreground slope with relief of *c.* 300 m is composed of the Cass Fjord Formation (**F**) with the Kap Coppinger Member near the top as a pale marker unit *c.* 2 m thick. Upper slopes are formed of the Cape Clay and Christian Elv Formations (**C**).

September. The map region is located north of Greenland's permanent settlements. Qaanaaq, the capital town of Qaanaap (Thule) municipality, has airport facilities and lies about 100 km to the south, while Thule (Pituffik) air base, with harbour facilities for ocean vessels, is located at 76°30′ N (Fig. 1; hereafter referred to as Pituffik). A number of huts used by Inuit hunting parties exist in Inglefield Land, the best preserved are at Foulke Fjord, Rensselaer Bugt, Marshall Bugt and Pariserfjord.

Early Survey mapping was undertaken by locally-hired boat but restricted by ice to south of Kap Hatherton (Dawes 1972; Frisch 1981); later work was supported to varying degrees by fixed-wing aircraft and helicopter. In August, Smith Sound can be reached by boat, and ship-based exploration with supporting helicopter has been undertaken in Inglefield Land (Sharp 1991). However, heavy and unpredictable ice conditions farther north make such operations hazardous. In some years, Washington Land can be reached during the short sailing season, as in 1998 when a reinforced tug boat carried supplies and equipment for an exploration company from Pituffik to Cass Fjord (Pirie *et al.* 1999). Access to Kennedy Channel requires vessels with ice-breaking capacity.

Established landing strips for light aircraft, such as the Twin Otter, exist at the Survey base-camp sites at Hiawatha Gletscher and Cass Fjord (Fig. 1; see Thomassen & Dawes 1996, fig. 1; Dawes *et al.* 2000b, fig. 3) and at a number of other sites, for example Rensselaer Bugt. In summer, flat snow-free river and coastal terraces, as well as the upper plateau surface, provide promising sites for unprepared landings. Lake ice can support light aircraft until late May. The practicality of using frozen lakes was tested in 1998 and 1999, when exploration companies using Twin Otter gained access to Petermann Halvø direct from Resolute, Canada (Cope & Beswick 1999; Pirie *et al.* 1999).

Map data and geological research

Data sources and field work

The map sources forming the basis of the map sheet are cited on the map. The mapping campaigns on the inset map 'Geological Survey mapping' are covered by the following publications: **1971**, Dawes (1972); **1975–1977**, Henriksen & Peel (1976), Peel (1977, 1978); **1978**, Dawes (1979); **1984–1985**, GGU (1985, 1987); **1995**, Thomassen & Dawes (1996); **1999**, Dawes *et al.* (2000a), Bennike (2000). Mineral occurrences are based on information in Sharp (1991), Appel *et al.* (1995), Cope & Beswick (1999), Iannelli (1999, 2002b) and Thomassen *et al.* (2000b).

In the 1970s, field work was untertaken mainly on foot from boat and fly camps. In 1971, 1978 and 1984–1985, Survey work reached parts of the map region although the main activities were centred on adjoining map sheets in the south and north. Mapping of the Humboldt Gletscher region occurred in three stages: 1975–1977 and 1995, respectively north and south of Humboldt Gletscher, and in 1999 throughout the map region. With limited air support, the 1975–1977 work led to compilation of a pre-Quaternary map helped by extensive photo-interpretation (Jepsen *et al.* 1983). The 1995 mapping, that had the benefit of an airborne electromagnetic and magnetic survey (Geoterrex 1994; Figs 4, 5), modified the photogeological work of Bengaard (1995) and included northern Prudhoe Land (Dawes 1996). The final mapping in 1999 that concentrated on the shield with spot checks on the Franklinian succession, was specifically directed to the 1:500 000 map scale, and to visiting all parts of the shield rather than detailed study of selected parts (Dawes *et al.* 2000a). Unravelling of lithologies and the chronology were priorities but the reconnaissance style of the work did not allow regional differentiation of the various lithologies covered by map units paragneiss (**gn**) and orthogneiss (**go**) (see later *Portrayal of map units*).

History of geoscientific research

Geological reporting from Smith Sound started with Sutherland (1853), with the first map sheets appearing in the late 1920s and early 1930s – Washington Land, Koch (1929b, plate III; 1931 in Dawes & Haller 1979, plate 2), and Inglefield Land, Koch (1933, plate II). The 150 years of exploration, from overwintering ship and dog-sledge expeditions to short summer visits by helicopter, have been described by Dawes (1999). Modern work with on-site helicopter, began in the early 1990s with a survey of gossans in Inglefield Land (Sharp 1991). Since then, there have been two main periods of work: 1994–1995 and 1997–1999, both of which involved airborne geophysical surveys, Survey mapping and commercial exploration. Figure 4 shows the coverage of geophysical surveys and systematic stream-sediment/soil geochemical sampling.

1994–1995. In 1994, an airborne geophysical survey revealed an unusually large number of electromagnetic anomalies and promising mineral targets on Inglefield Land (Fig. 5; Geoterrex 1994; Stemp & Thorning 1995a) and dark circular features, originally reported on aerial photographs by Sharp (1991), were picked up on flight line videos and interpreted as a diatreme swarm (Bengaard 1995; Stemp & Thorning 1995b). This stimulated considerable commercial interest and field work, including a winter visit, but the diatreme story was short-lived with the circles turning out to be surficial features (Coppard 1996; Gowen & Kelly 1996). The Survey's 1995 work in Inglefield Land included traditional mapping (Thomassen & Dawes 1996), a stream-

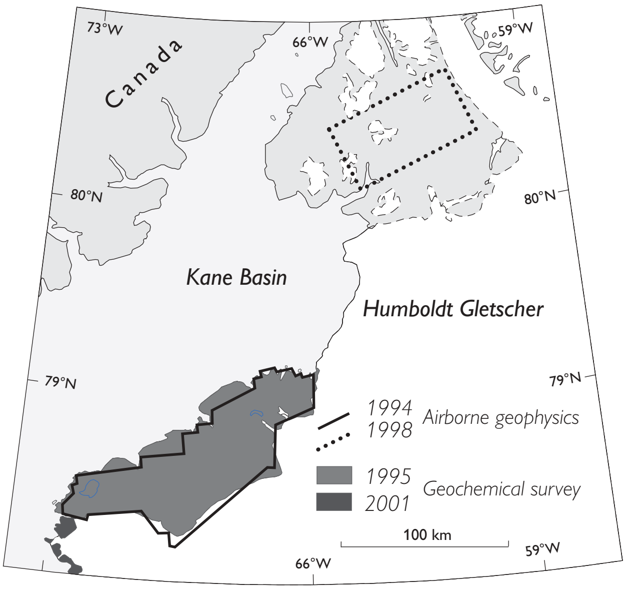

Fig. 4. Map showing the areas of the Humboldt Gletscher map sheet covered by airborne electromagnetic and magnetic surveys and systematic stream-sediment geochemical data. Areas of *local* soil and drainage sampling by commercial companies are not shown, i.e. south of Humboldt Gletscher, Christensen (1985), Sharp (1991), Coppard (1996) and Gowen & Kelly (1996), and north of the glacier, Cope & Beswick (1999) and Pirie *et al.* (1999).

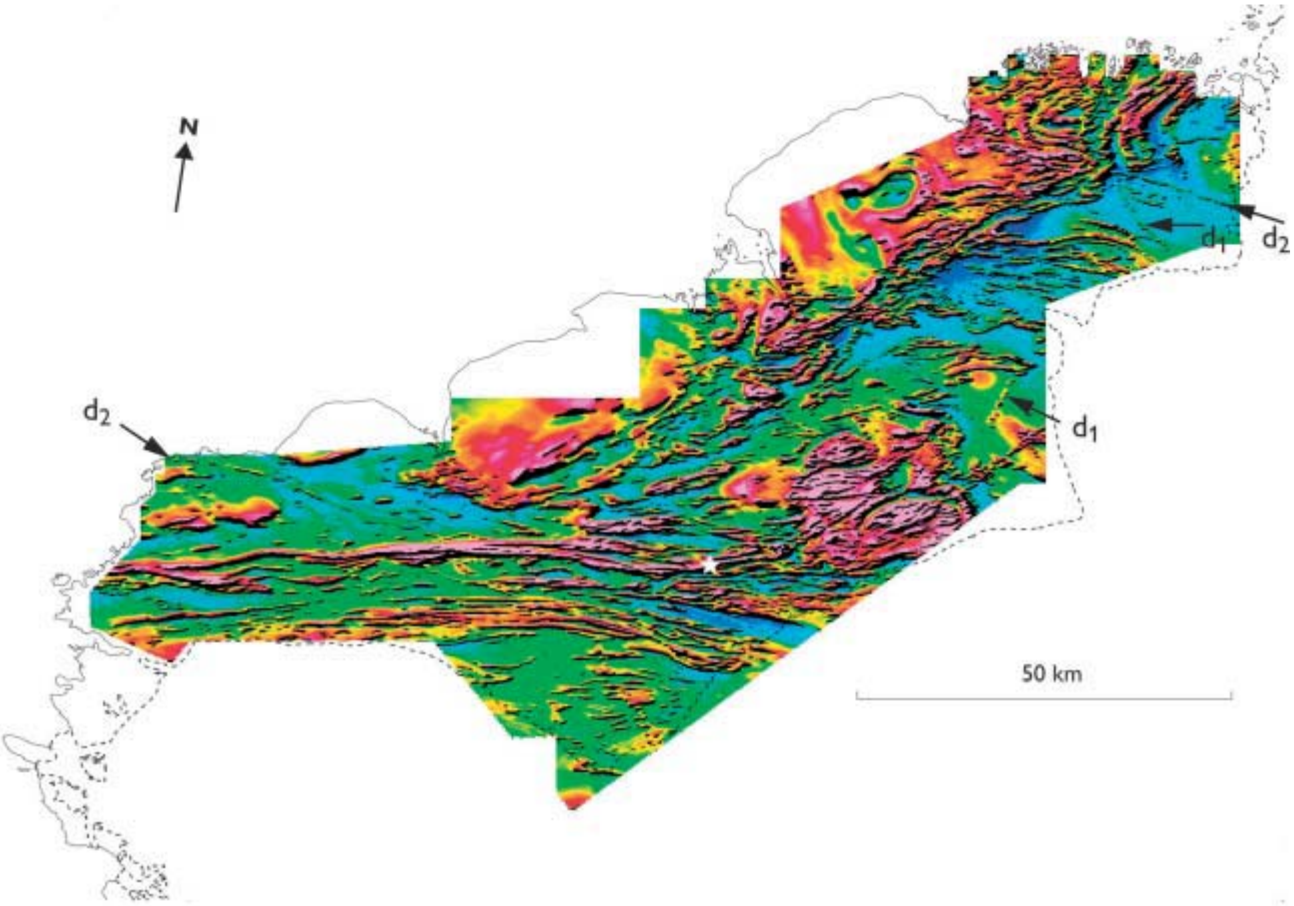

Fig. 5. Total magnetic intensity map of Inglefield Land, modified from Schjøth *et al.* (1996). The **white star**, near the peak value of 15.400nT, locates the massive magnetic float locality shown on the map sheet; **arrows** with $\mathbf{d_1}$ and $\mathbf{d_2}$ mark prominent magnetic lineaments reflecting three directions of basic dykes. The Sunrise Pynt Straight Belt is the persistent zone of E–W-trending parallel anomalies *c.* 15 km wide stretching from the south-western coast to the Inland Ice. For regional location, see Figs 1 and 4.

sediment/soil geochemical survey (Steenfelt & Dam 1996) and mineral exploration with the check of geophysical anomalies and rust zones (Appel *et al.* 1995; Thomassen & Appel 1997). The origin of the 'pseudodiatremes' was also addressed (Appel 1996). A main result of the 1994–1995 work, both governmental and commercial, was a set of thematic maps furnished with geological, geophysical, geochemical and mineral occurrence descriptions (Schjøth *et al.* 1996), now available in digital format (Schjøth & Thorning 1998). Gravity data were collected in 1994 and 1995 (Forsberg *et al.* 1994, 1995).

1997–1999. The discovery in 1997 of base metal mineralisation in Ordovician strata on Petermann Halvø (Jensen & Schønwandt 1998) led to commercial activity and an airborne magnetic and electromagnetic survey, and in 1999, drilling (Geoterrex-Dighem 1998; Cope & Beswick 1999; Pirie *et al.* 1999; Rasmussen 1999). Also in 1999, the Survey's *Kane Basin* project undertook mapping and associated stratigraphical and structural investigations, including surficial geology, sedimentology and petroleum studies, and mineral exploration (Bennike 2000; Dawes *et al.* 2000a, b; Iannelli 2002a). The latter work focussed on known mineral occurrences and fault zones, and checking of geochemical and geophysical anomalies (Iannelli 2000b; Pirajno *et al.* 2000, 2001, 2003; Thomassen *et al.* 2000a, b).

Post-1999. Since 1999, relatively little work has been undertaken. During the *Nares Strait Geoscience Cruise 2001* aeromagnetic data were collected over parts of Smith Sound and southern Kane Basin and samples for various analytical procedures were collected (Jackson *et al.* 2002). The Survey project *Qaanaaq 2001* – regional mineral exploration and geochemical sampling – reached as far north as Foulke Fjord (see Fig. 4; Steenfelt *et al.* 2002; Thomassen *et al.* 2002a). Recent publications deal with the thermal history of Smith Sound based on fission track dating (Hansen *et al.* 2004), and the crustal evolution of the Palaeoproterozoic Inglefield mobile belt based mainly on SHRIMP U-Pb zircon dating (Nutman *et al.* 2004).

Palaeoproterozoic Inglefield mobile belt

The Inglefield mobile belt of mainly granulite grade rocks underlies Inglefield Land and northern Prudhoe Land continuing south onto the Thule map sheet and west into Canada. The continuity of the Precambrian geology with Ellesmere Island has been stressed by Frisch & Dawes (1982) and Dawes *et al.* (1988), with the term 'Ellesmere Island – Inglefield Land belt' used to describe occurrences of the same gneiss, supracrustal and igneous suites on both sides of Smith Sound (Dawes 1988). The name 'Inglefield mobile belt' is used on the 1:2 500 000 Geological map of Greenland (Henriksen *et al.* 2000), a name now in vogue for the Greenland part of the Ellesmere–Greenland mobile belt (Dawes *et al.* 2000a). The belt has been considered to be the eastern extension on the Thelon Tectonic Zone of Arctic Canada (Hoffman 1988).

Age and chronology

SHRIMP ages reported here are U-Pb zircon ages from Nutman *et al.* (2004). Clastic deposition with magmatism at *c.* 1985 Ma in Prudhoe Land, are the earliest events recorded. Regional subsidence and major deposition in Inglefield Land took place between *c.* 1980 and 1950 Ma, with polyphase plutonism between *c.* 1950 and 1915 Ma, and later granitoids emplaced at *c.* 1750 Ma.

The chronological order of the five map units in the legend is based on field relationships and SHRIMP U-Pb zircon work. The relative ages of the youngest three groups are readily established in the field: the Etah Group (deposition *c.* 1980–1950 Ma) is intruded on all scales by the polyphase Etah meta-igneous complex (*c.* 1950–1915 Ma), after which there has been intense deformation and partial melting giving rise to later granites (*c.* 1785–1740 Ma). The relative ages of the two Prudhoe Land complexes is less certain but the varying thickness of the supracrustal packages (**ps**) within orthogneiss (**grn**), including rafts of sediment in gneiss, suggest invasion of **ps** by **grn**. Paragneisses of the Etah Group (**gn**) are characterised by unimodel detrital age populations centred on 2000–1980 Ma: thus they might well be derived from the Prudhoe Land granulite complex (**grn**) that has yielded a SHRIMP age of 1985 Ma (for details, see map unit descriptions).

Portrayal of map units

Due to intimate and complex relationships on all scales between metasediments and meta-igneous rocks, and the presence of anatectic melts, distinction between para- and orthogneisses in the field is not everywhere clear-cut. This fact, plus the reconnaissance nature of some of the mapping, determine that paragneiss (**gn**) and orthogneiss (**go**) units in many places can only be depicted as intermixed packages of both lithologies (Fig. 2; also Dawes *et al.* 2000a, fig. 3B). The same applies to other units, for example, the marble-dominated sequence (**m**) that can contain appreciable meta-igneous rock components (see Dawes 1976, fig. 228; 1988, fig. 3), while areas of late anatectic granite (**gr**), too irregular to be mapped individually, are common in unit **gn.** Some of the latter areas are marked on the map by red 'fish' symbols (see under *Leucogranites and leucopegmatites*). Gradational relationships between igneous rock types and the differentiation of map units are mentioned under *Etah meta-igneous complex – mapping constraints*.

Structure and metamorphism

The tectono-magmatic history of the Inglefield mobile belt is clearly complex with the bulk of the rocks having been repeatedly deformed under high-grade metamorphic conditions with several episodes of anatectic melting. Sillimanite and cordierite in metasediments, as well as very widespread hypersthene, indicate low- to medium pressure granulite facies conditions. Retrogression is seen in the form of local reddening, in places associated with shear zones, with partial replacement of orthopyroxene, development of chlorite and less abundantly hematite.

The majority of the rocks show directional fabrics of some sort, either mineral foliation or migmatitic to gneissic layering. Many paragneisses contain a conspicuous anatectic melt fraction and are true migmatites. Fabrics can be referred to several deformation events, with a late fabric being thoroughly penetrative and transposing older fabrics. This has itself been deformed at least twice and is involved in map-scale interference structures, such as the horseshoe-shaped Wulff structure in north-eastern Inglefield Land that involves rocks of the Etah meta-igneous complex (see Dawes 1976, fig. 230; 1988, fig. 6). Although three fold generations can be documented in outcrop-scale, there were almost certainly more phases. At least two major episodes of isoclinal folding producing map-scale structures with preserved hinges affected the Etah Group, at least one of which post-dates the Etah meta-igneous complex. Contact relationships between Etah Group rocks and those of the meta-igneous complex – that include inclusions of folded paragneiss in plutonic rock (see Dawes *et al.* 2000a, fig. 4A) – demonstrate that at least two, but possibly more, foliation or gneiss-forming episodes pre-date the magmatic suite. Single outcrops of orthogneiss showing interference fold patterns are common (see Dawes 1988, fig. 7).

Sunrise Pynt Straight Belt

A conspicuous feature of the map sheet is the E–W-trending Sunrise Pynt Straight Belt composed of moderately to steeply dipping rocks extending from Sunrise Pynt 100 km to the Inland Ice margin (Fig. 5). Within it, rocks of the Etah Group and Etah meta-igneous complex are intricately interleaved and intensely deformed in tight, upright to slightly overturned folds (see Dawes 1976, fig. 228; 1988, fig. 3). The belt represents a high-strain zone with westerly plunging lineations. It seems that during a N–S compressional event late in the deformational history, all pre-existing structures were transposed into the common steeply dipping linear trend. SHRIMP dating suggests that the site of this linear feature played a role in the early stages of basin development, with rocks of different detrital provenance on either side: Archaean to the south, Palaeoproterozoic to the north (Nutman *et al.* 2004).

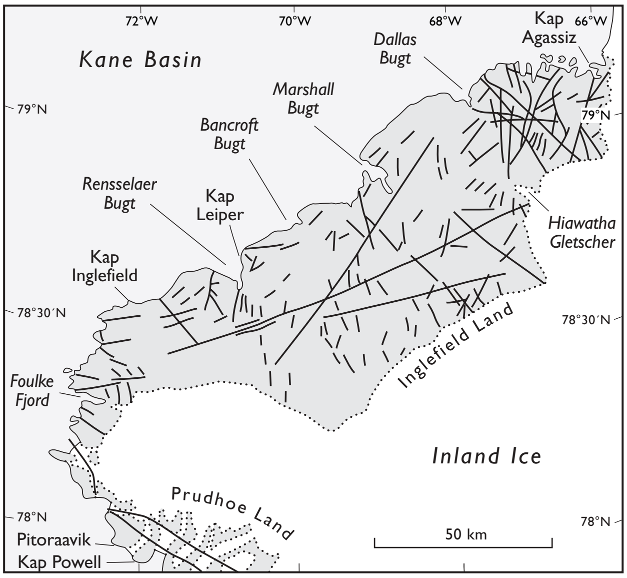

Fig. 6. Main lineaments of Inglefield Land and northern Prudhoe Land plotted from field observations, photogeological maps of Gray (1975) and Bengaard (1995), and interpretation of aeromagnetic data by R.W. Stemp (GEUS). The three most persistent lineaments (NE–SW to ENE–WNW) are interpreted by Stemp as 'possible faults'.

Faults and lineaments

The shield is criss-crossed by lineaments, both joints and faults, with a wide range of directions that are particularly common in the north-east (Fig. 6). Three main directions are recognised by Bengaard (1995): NNW–SSE, N–S and NNE–SSW to NE–SW. Aerial photographs or the photogeological maps in Gray (1975) and Bengaard (1995) show that the vast majority of these lineaments do not penetrate the Mesoproterozoic to Palaeozoic cover (see Nichols 1969, fig. 29). This relationship is illustrated by one of the most conspicuous lineaments – a NNW–SSE-trending fault forming a deep cleft subparallel with Minturn Elv – that disappears under the Palaeozoic cover east of Bancroft Bugt. However, some faults of this direction do penetrate the cover, and probably reflect rejuvenation of older structures. Several NW–SE-striking lineaments probably represent weathered-out basic dykes, for example the dyke with a strong magnetic response north-east of Hiawatha Gletscher trends into a deep linear fracture that crosses the Wulff structure east of Dallas Bugt. For the sake of clarity, only lineaments affecting the outcrop pattern are shown on the map sheet; these are mainly faults cutting Mesoproterozoic and Palaeozoic strata (see later).

Prudhoe Land complexes

Two map units of crystalline rocks, intricately associated, occur in northernmost Prudhoe Land. They represent the oldest rocks recognised in the Inglefield mobile belt and both have their largest exposures farther south on the Thule map sheet.

Prudhoe Land supracrustal complex (**ps** and **pq**)

Name. Dawes (1991a).

Other literature. Steenfelt *et al.* (2002), Thomassen *et al.* (2002a, b).

Age. Field relationships are equivocal but metasedimentary rocks (**ps** and **pq)** were probably intruded by granulites (**grn**, see below). In the Thule map region to the south, quartzite – assumed to be coeval with **pq** – has yielded a SHRIMP detrital age spectrum of 3200–2250 Ma, while associated mica schist gives a good metamorphic age of 1923 ± 8 Ma (Nutman *et al.* 2004). Deposition thus took place between *c.* 2250 and 1920 Ma ago.

Distribution and lithology. This map unit is represented by brown to rusty weathering, recessive well-layered units interleaved with orthogneisses (**grn**). The

Fig. 7. Large recumbent fold (Bamse isocline) in orthogneisses of the Prudhoe Land granulite complex at Sonntag Bugt; supracrustal rocks form less resistant units in the fold core and upper limb. Height of cliffs is *c.* 600 m with Bamse Gletscher below the fold.

main rock types are garnetiferous mica schists and garnet paragneisses, with thin units of pale quartzite. One main outcrop shown on the map occupies the core of a major recumbent fold – the Bamse isocline (Fig. 7). Notably, the supracrustal sequences vary in thickness and are often reduced to discontinuous layers and lenses of quartzite within **grn**. The letter symbol **pq** on the map in Sonntag Bugt refers to such inclusions and layers, too small to be depicted at the map scale.

Prudhoe Land granulite complex (grn)

Name. Dawes (1991a).

Other literature. Callisen (1929), Dawes (1988, fig. 8), Steenfelt *et al.* (2002), Thomassen *et al.* (2002b).

Age. SHRIMP ages are available from two samples of hypersthene gneiss from Sonntag Bugt (Nutman *et al.* 2004). An age of 1984 ± 8 Ma is interpreted as close to the age of the igneous protolith, with a younger age of 1886 ± 25 Ma marking a recrystallisation event.

Distribution and lithology. This map unit is dominated by brown-weathering, cliff-forming, hypersthene orthogneisses, that vary from homogeneous to strongly foliated. Fresh surfaces are typically grey to greenish grey and mauve, and frequently contain blue quartz. The complex also contains grey weathering, less homogeneous gneiss varieties that are often veined and migmatitic, as well as pyribolite layers. The cliffs of Sonntag Bugt and adjoining glaciers expose good sections (Fig. 7).

Etah Group

Name. Etah Formation: Koch (1929a, 1933); Etah Group: Dawes (1972).

Other literature. Dawes (1976, figs 228, 229; 1988, figs 3, 5), Frisch & Dawes (1982, fig. 3), Schjøth *et al.* (1996), Steenfelt & Dam (1996), Thomassen & Dawes (1996), Dawes *et al.* (2000a).

Composition and age. The four sedimentary and two igneous units of this group (**gn**, **m**, **c**, **q**, and **a**, **u**) are regarded here to be integral parts of a single supracrustal succession. Although strictly speaking, the stratigraphic code would exclude intrusions from a group, all strongly altered mafic (**a**) and ultramafic (**u**) rocks are grouped together here for three reasons. (1) Some mafic rocks are known to be metavolcanic in origin, (2) **a** and **u** are often spatially associated and in some outcrops there is compositional gradation between them and, (3) outcrops are not known in sufficient detail to warrant map separation into supracrustal rocks and later intrusions. Some mafic and ultramafic intrusions may be coeval with early phases of the Etah meta-igneous complex.

Two paragneiss (**gn**) samples from Marshall Bugt and Dallas Bugt have yielded almost unimodal detrital zircon age populations centred on 2000–1980 Ma, and one of these samples shows a good metamorphic age of *c.* 1920 (Nutman *et al.* 2004). These ages bracket deposition to between *c.* 1980 and 1920 Ma. In contrast, a sample of mature quartzite (**q**) from Terrasseelv, south of the Sunrise Pynt Straight Belt, has yielded a complex age range of detrital zircon grains from 3250

Fig. 8. A typical paragneiss lithology is garnetiferous biotite-sillimanite-cordierite gneiss, here with porphyroclastic garnet. South-west of Hiawatha Gletscher.

to 2350 Ma (dominated by 2600–2450 Ma grains) indicating derivation from another much older source. The provenance divide separating northern and southern paragneisses may possibly be along the Sunrise Pynt Straight Belt. All units of the Etah Group are cut by intrusions of the Etah meta-igneous complex, the oldest at 1949 ± 13 Ma (map unit **qd**) constrain deposition to between *c.* 1950 and 1980 Ma.

Gneiss (gn)

This unit, corresponding to the 'grey gneiss' of Koch (1933) and the 'garnet granulites' of Sharp (1991), covers more than 50% of the shield outcrop, and with the exception of those lithologies rich in magnetite, generally is reflected on the aeromagnetic map by low magnetic intensities (Fig. 5; Schjøth *et al.* 1996). The high-grade and intensely deformed pelitic to quartzo-feldspathic paragneisses represent a sedimentary pile that must originally have been many kilometres thick. The gneisses invariably contain garnet, with or without sillimanite, biotite, cordierite, graphite, magnetite and iron sulphides. Garnet can form large porpyroblasts (Fig. 8), as well as thin seams and in places the mineral is retrogressed to biotite. Many paragneisses contain a varying anatectic melt fraction, commonly of more than one generation, forming transitions to migmatitic gneiss and *bona fide* migmatite.

Broadly speaking, gneisses are of two main types that with detailed work could be mapped out. Both can be migmatitic. One is a clearly pelitic assemblage containing appreciable garnet, biotite and sillimanite, with or without cordierite, and that can be schistose; the other is a more leucocratic massive suite of gneisses that are layered on a large scale but homogeneous in hand sample. The latter generally have lower garnet contents and lack visible aluminosilicates. Many of the leucocratic rocks have pink to reddish colours and resemble rocks of other map units: leucogranite (**gr**) and granitic orthogneiss (**go**). Some may owe their quartzo-feldspathic nature to psammitic parentage but others represent granitic anatectic melts. *In situ* partial melting has produced leucosomes that range from cm-size veins, layers and pods to km-size masses of garnetiferous leucogranite, alaskite and granitic pegmatite. These are often interleaved with gneissic lithologies but can also be discordant. At a larger map scale these granitoids could be mapped out; on the map sheet some areas are shown by red 'fish' symbols (see under *Leucogranite and leucopegmatite*).

Reddish brown and rusty weathering tracts, intercalated with the paler paragneiss, are particularly conspicuous in central and north-eastern Inglefield Land. These contain iron sulphides and many are gossanous. The most extensive tracts are indicated on the map as 'rust zones' (see under *Economic geology*).

Calc-silicate gneiss (c)

Varicoloured calc-silicate gneissic rocks in north-easternmost Inglefield Land form this map unit, the largest outcrop of which borders Martonne Fjord. The gneisses, regarded as being derived from impure carbonates and marls, occur with thin layers of diopside marble and packages of garnet paragneiss. The rocks can be intensely invaded by felsic material, mainly pink to red and reddish brown, medium- to coarse-grained granite and pegmatite sheets and dykes (see Thomassen & Dawes 1996, fig. 4A; Thomassen *et al.* 2000b, fig. 15). The gneisses are typically fine-grained with weathering colours in green, pink, buff, grey to reddish brown hues and they are often mottled. Common types are

Fig. 9. Typical creamy white exposures of Etah Group marble, Inglefield Land. **A**: Aerial view of marble belt overlying, in the foreground, steeply-dipping paragneisses. View is to the north-east with Tufts Elv cutting N–S across the 2 km wide belt. **B**: Upright, moderately plunging antiform in marble preserved within orthogneisses. South-east of Marshall Bugt with a section height *c.* 150 m. The view **A** shows the low-relief landscape typical of much of the interior of Inglefield Land that represents an exhumed Precambrian peneplain. Photos: Tom Frisch.

finely layered, diopside calc-silicate, darker diopside granitic gneiss and pink siliceous gneiss that can contain leucosome fractions. Minor bands and horizons include pink to greenish calcareous schist, and apple-green forsterite-bearing and darker green hornblende-bearing calc-silicates. At one locality, well-layered skarn rocks occur in what is interpreted as a layered mafic–ultramafic intrusion into a carbonate sequence (Pirajno *et al.* 2000; Thomassen *et al.* 2000b, fig. 14; see under *Economic geology*).

Marble-dominated sequence (m)

This map unit comprises supracrustal packages in which marble and calc-silicate rocks layered on a cm- to dm-scale are dominant, interleaved with pelitic and semi-pelitic gneisses and amphibolite. One main lithology is a white, medium- to coarse-grained calcite marble that can be peppered with green diopside crystals, and that contains forsterite, wollastonite and spinel. This is commonly interleaved with a variety of buff to lemon and greenish coloured dolomitic marbles, containing wollastonite- and diopside-rich layers. With increase in diopside and feldspar content, the marble grades into grey, green and pink to brown calc-silicate marble and calc-silicate rocks that can contain macroscopic quartz. Where intercalated with white marble strikingly banded rocks exist (see Dawes & Higgins 2000, frontispiece).

The marble-dominated units generally coincide with lows on the aeromagnetic map, and also stand out well from the air because of their pale colour (Fig. 9A; also Frisch & Dawes 1982, fig. 4; Dawes *et al.* 2000a, fig. 3A). Due to invasion by igneous rock and intense deformation, the marble units vary considerably in thickness, from 2-km packages to metre-scale pods, with a common end product as ‘pearls on a string’. In a broad sense, this variation also portrays the regional outcrop pattern. Thus, the most coherent and thickest exposures are in the south-west where a main belt can be traced in the Sunrise Pynt Straight Belt from the coast to the Inland Ice at the head of the Minturn Elv. In contrast, typical exposures in central and north-eastern Inglefield Land are thinner, discontinuous tracts and isolated inclusions, mainly within orthogneiss (Fig. 9B).

Carbonate rocks invaded by granite were initially described from Sunrise Pynt by Low (1906), a now classical cliff section that beautifully illustrates the intimate association of deformed metasediments and different phases of dioritic and granitic rocks (see Dawes 1976, fig. 228; 1988, fig. 3; Frisch & Dawes 1982, fig. 3). These spatial relationships are present throughout Inglefield Land (see Thomassen & Dawes 1996, fig. 3A; Dawes *et al.* 2000a, fig. 3B). The relationships between marble, calc-silicate rocks and intrusions, with deformation and mobilisation of marble, are often spectacular and include pinch-and-swell, boudinage and fragmentation trains (see Dawes 1988, figs 9–11). Marble often coincides with high-strain zones where intrusive contacts are obliterated by intense deformation; thus, carbonate rocks often contain tectonic sheets and inclusions of granite and other host rocks while marble occurs as enclaves in granite.

Amphibolite, pyribolite, metagabbro (**a**)

Rocks of basaltic composition form the main component of the map unit. They are intimately associated with ultramafic rocks and quartz-feldspathic gneiss of intermediate composition that can have frequent hornblende-rich seams and layers. These interlayered sequences are up to several hundreds of metres thick, often interfolded and tectonically interleaved with para- and orthogneisses. The mafic to intermediate components contain hornblende and plagioclase ± pyroxene ± quartz and vary from dark green amphibolite to greenish-grey pyribolite to pale green and grey diorite. Most are fine- to medium-grained, laminated to finely layered; some coarse-grained rocks with poorly developed lamination are metagabbros. Although often foliated, many rocks are massive with little compositional variation. However, in several of the thicker and more coherent packages, for example, the unit trending north-east from Marshall Bugt, and those around Terrasseelv, relic highly-deformed pillow structures are present that together with compositional layering, indicate a metavolcanic origin. Other discrete units with fairly well-defined contacts are taken to be intrusive and these in places show compositional layering with varying plagioclase content that may be relic magmatic layering. Layered mafic–ultramafic complexes have also been recognised (see under *Calc-silicate gneiss* above and *Ultramafic rock* below).

Ultramafic rock (**u**)

Ultramafic rocks are often associated with mafic rocks (**a**), but few bodies are large enough to be shown on the map. They are fairly common in southern Inglefield Land around Terrasseelv, where the largest bodies occur. Typically, the units are a few metres thick but some locally exceed 100 m. They tend to be discontinuous layers, often broken up into lenses but one E–W-striking unit north of Terrasseelv is coherent for almost 10 km. This body is composed of basal metapyroxenite and metaharzburgite followed upwards by metagabbro with gradations to amphibolite and pyribolite, relationships that suggest a layered complex.

The ultramafic rocks are massive to poorly foliated and crudely layered, medium- to very coarse-grained, metapyroxenite, metahornblendite and metaharzburgite, with minor serpentinite. They weather black to dark green and brown. Biotite is common in some rock types. Near the headwaters of Minturn Elv, a brecciated ultramafic–mafic mass invaded by alkali granite contains veins of magnetite, phlogopite, spinel and tourmaline; Appel (1997) has reported Al-rich warwickite from a nearby locality. Other ultramafic rocks contain mineralisations (see under *Economic geology*).

Quartzite (**q**)

Quartzite is rare in the Etah Group. Apart from outcrops within the Prudhoe Land supracrustal complex (**pq**), the only discrete units on the map sheet are around Terrasseelv in southern Inglefield Land. Here, several highly deformed quartzite units up to two metres thick are interleaved with isoclinally folded paragneiss. The single body large enough for map depiction is associated with an ultramafic layer. It is an almost pure quartzite that in places has wispy biotite traces representing contorted bedding. SHRIMP zircon analyses show that it received some of its quartz from an Archaean source (see above, under *Etah Group*).

Etah meta-igneous complex and late granitoids

Name. Dawes (1972).

Other literature. Bugge (1910), Koch (1933), Dawes (1976, 1988, 1996), Frisch (1981), Frisch & Dawes (1982), Schjøth *et al.* (1996), Steenfelt & Dam (1996), Thomassen & Dawes (1996), Dawes *et al.* (2000a).

Composition and age. The Etah meta-igneous complex comprises intermediate to felsic intrusions with subordinate basic and magnetite-rich rocks, that show varying degrees of deformation and migmatisation. As mentioned under the Etah Group, it is possible that some mafic and ultramafic rocks included in that group, are coeval with intrusions of this complex.

All gradations are seen from homogeneous rocks with preserved igneous textures to weakly foliated rocks and those with thoroughly penetrative fabrics, to severely deformed recrystallised layered gneiss. In the outer parts and along the margins of the largest intrusions, pervasive foliation and gneissic fabrics can be developed while smaller bodies may be gneissified throughout and tectonically interleaved with other rock types.

Cross-cutting relationships demonstrate that dioritic and tonalitic rocks are the early components, followed by different felsic phases; a chronology confirmed by the five SHRIMP zircon ages (Nutman *et al.* 2004). Interpreted as intrusion ages for the igneous protolith, the dates show a range from *c.* 1950 to 1915 Ma; for individual ages, see map unit descriptions. The compositional range, supported by the available geochemical data (e.g. Steenfelt & Dam 1996; Schjøth & Thorning 1998; the author, unpublished analyses) suggest that the rocks represent members of a former magmatic arc.

Mapping constraints. The common gradational relationships between massive, seemingly undeformed rocks and intensely folded gneisses outlined above, determine that the choice between map units diorite (**qd**), syenite (**sy**) and granite (**gk**), and gneiss (**go**) is often arbitrary. This is particularly the case with respect to quartz diorite that regionally is a very common rock but is often gneissified and interleaved with other lithologies. Map unit **qd** is reserved for non-gneissic quartz diorite but the same rock type is widespread within **go**.

Late granitoids. Field relationships show that many post-tectonic granitic and pegmatitic phases occur, but because of the reconnaissance nature of the mapping, only one map unit (**gr**) is separated on the map from the Etah meta-igneous complex (see Fig. 10). Late granitoids are also indicated schematically by red ‘fish’ symbols (see map unit *Leucogranite* and *leucopegmatite*). However, SHRIMP ages demonstrate that some of these late granitoid phases are considerably younger than the main phases of magmatism. Thus, the ‘fish’ symbol covers rocks of two periods: late phases of the Etah meta-igneous complex (*c.* 1925–1915 Ma) and younger intrusions (*c.* 1750–1740 Ma). This explains the positioning of the unit in the map legend.

Gneiss (**go**)

Age. The most reliable ages for rocks of this map unit are two SHRIMP dates from north-eastern Inglefield Land interpreted as protolith intrusion ages: 1943 ± 11 Ma on a grey tonalitic gneiss and 1920 ± 16 Ma on a coarser grained, less deformed, syenitic rock (Nutman *et al.* 2004). These refine the Sm-Nd model age of 1.99 Ga obtained on a quartz dioritic rock from Kap Agassiz (quoted in Dawes 1999, p. 33).

Character. This map unit is the second largest of the shield, generally appearing as highs on the aeromagnetic map, with the most continuous exposures in the south-west and north-east (Fig. 5). The unit comprises mainly orthogneisses and it represents a very variable collection of rocks with respect to composition, colour, structural fabric, degree of migmatisation, intrusion size and outcrop. The compositional range is from diorite, tonalite, quartz diorite, granodiorite, monzogranite, syenite to granite, reflected by a colour range from very dark grey and greenish to pale grey and buff.

The rocks are mainly medium-grained, varying from homogeneous to foliated varieties containing pale leucosome fractions and to true veined gneiss. Exposures range from highly deformed and isoclinally folded bodies that can be up several kilometres thick to less deformed sheets under a metre thick. Gradational relationships from massive, relatively undeformed rock into gneiss can be traced in single outcrop and, despite intense deformation, intrusive contacts and xenoliths are preserved.

The orthogneisses contain varying amounts of biotite, hornblende and pyroxene: hypersthene is widespread but clinopyroxene can also be present. Locally, garnet and magnetite occur in more than accessory amounts and some granodiorites and granites have appreciable K-feldspar that can be megacrystic. Due to gradational relationships and the scale of the mapping, greenish quartz diorite, mapped separately as map unit **qd**, are also included in this map unit (see *Etah meta-igneous complex – mapping constraints*). Copper-gold mineralisation can be associated with the orthogneisses (see *Economic geology*).

The four rock types listed below serve to illustrate the wide lithological range of the gneiss (**go**) map unit. (1) Melanocratic, isoclinally folded, hypersthene tonalitic veined gneiss that characterises coastal exposures south of Foulke Fjord (see Dawes 1988, fig. 7; Dawes *et al.* 2000a, fig. 4B); (2) Pale, hypersthene, magnetite-rich, generally massive quartz diorite, present at the headwaters of the Minturn Elv, that can have closely-spaced anatectic veins giving a gneissic appearance; (3) Light-weathering biotite granodiorite, poor or lacking orthopyroxene, weakly gneissic, and veined more or less concordantly by white granitic melt veins, and that forms massive whalebacks with exfoliation surfaces east of the head of Marshall Bugt; (4) Light brown, leucocratic, medium- to coarse-grained K-feldspar syenite, slightly foliated, a sample of which from the western limb of the Wulff structure has given a 1920 Ma SHRIMP age (see above).

Quartz diorite (**qd**)

Age. SHRIMP intrusive age of 1949 ± 13 on a rock from the arcuate Hiawatha pluton (Nutman *et al.* 2004).
Character. Hypersthene quartz diorite from Foulke Fjord was among the earliest rocks described from the region (Bugge 1910), being later reported by Koch (1933) from several places in north-east Inglefield Land. Due to rock gradations, invasion by granitoids, and tectonic interleaving, the character of the original plutons is obscured. The two largest coherent bodies – the Foulke Fjord and Hiawatha plutons – represent sheets up to 2 km thick. Bugge's rock type is composed of orthopyroxene, olive-green hornblende and biotite, with oligoclase, K-feldspar and quartz. Garnet and magnetite occur in some varieties. These rocks are dark grey to brownish weathering, and although 'igneous-looking', the rocks are recrystallised, with plagioclase as grey to greenish equigranular grains. Fresh surfaces show the greenish colour and greasy reflectance characteristic of hypersthene granulites, with in places blue quartz. The rock can have a network of more felsic, but still greenish, veins. The rocks are generally massive to foliated but as mentioned above, rocks with true gneissic fabric are referred to the previous map unit. There is a gradation from the classical Foulke Fjord rock type to darker-weathering diorites and pale weathering granodiorites, such as the thin units near the Inland Ice margin south of Hiawatha Gletscher.

Monzogranite (**gk**)

Age. SHRIMP intrusive age of 1924 ± 29 Ma on a rock from the Humboldt pluton (Nutman *et al.* 2004).
Character. Two plutons in north-eastern Inglefield Land that show compositional and textural affinity are grouped in this map unit, but they may not be of the same age. The name 'monzogranite' is used in a broad sense to cover rocks that vary between monzonite, syenite and adamellite. The exposed parts of the plutons coincide with high intensities on the aeromagnetic map (Fig. 5). The largest outcrop, the Humboldt pluton, has the most pronounced magnetic signature, and its eastern margin is hidden under Humboldt Gletscher. The Jarl pluton on the western coast of Jens Jarl Fjord has its northern part under the sea. Both have preserved igneous textures and contain assorted xenoliths while their margins are somewhat tectonised. Where undeformed, rock types of both plutons display K-feldspar megacrysts in a medium- to coarse-grained matrix.

The *Humboldt pluton* is a reddish brown-weathering syenogranite with varying quartz content, with biotite and lesser amounts of orthopyroxene. Garnet is present locally, particularly around paragneiss xenoliths in stages of assimilation. In central parts, feldspar megacrysts show a crude alignment in an undeformed matrix, but towards the margins, the granite often shows an intense foliation, generally parallel to the structural grain of the country rocks. Interleaving of deformed megacrystic rock and paragneiss is common at the pluton margins, while tabular bodies, noticeably less porphyritic, occur within the adjacent country rocks. The *Jarl pluton* is a quartz-poor orthopyroxene granite with varying biotite content, characterised by an impressive assortment of paragneiss, pink granite and orthogneiss xenoliths varying from cm-scale to over 50 m across.

Syenite (**sy**)

Age. Isotopic age data are not available but the main syenite complex could be coeval with the syenitic bodies included within the gneiss (**go**) map unit; one of these has yielded a SHRIMP zircon age of 1920 Ma (Nutman *et al.* 2004).
Character. This map unit comprises the large intrusive massif and small satellite intrusions in south central Inglefield Land – herein called the Minturn intrusive complex – that are conspicuous on the aeromagnetic map due to their high magnetic susceptibility (Fig. 5). Heavy surficial cover, particularly on the north and north-east, hides the limits of the complex but the magnetic anomaly indicates a larger body than depicted on the map. Available chemical analyses define a complex of monzonitic-syenitic affinity (Steenfelt & Dam 1996; unpublished analyses). The rocks are readily identifiable in the field because of their very dark colour caused by black lichens that thrive on them. Many rock surfaces, as well as joint planes, can be completely overgrown by lichens, and even morainic boulders and cobbles are so characterised, thus creating a useful mapping tool (Appel 1996; Schjøth *et al.* 1996; Hansen *et al.* in press). The complex is composed of a number of closely-spaced sheet-like bodies several kilometres thick, often interleaved with much thinner units of paragneiss and marble. Where syenite sheets amalgamate, the country rocks may form large slivers

and xenoliths. Like the quartz diorite (**gz**) and monzogranite (**gk**) plutons, the Minturn intrusive complex is variably deformed, with central parts of the thickest sheets composed of the most homogeneous lithologies that grade into intensely deformed, foliated rocks at the margins. The overall structure of the main complex is thought to be a dome-shaped doubly plunging antiform (Dawes *et al.* 2000a).

Most rocks are fine- to medium-grained, rather massive and some contain K-feldspar megacrysts. The rocks are dark-weathering, mostly dark brown to deep purple, occasionally reddish, with fresh surfaces often purplish. All are feldspar-rich, with a variable ratio of K-feldspar to plagioclase, with or without quartz. Biotite is the main mafic mineral, often in association with magnetite and orthopyroxene. In the eastern part of the complex, a coarse-grained greyish variety with feldspar laths has a texture and mineralogy resembling larvikite (Steenfelt & Dam 1996). Deformed rocks are often altered, and these can have reddened feldspars and show chloritisation of mafic minerals.

Metamafic dykes (not distinguished on the map)

Age. These minor intrusions cut rocks of the gneiss (**go**) and quartz diorite (**qd**) map units, as well as at least two phases of red anatectic melt fractions within the paragneisses; some dykes are invaded by pale granitic veins.
Character. Thin tabular bodies of metamafite up to a metre thick, occasionally thicker, occur sporadically throughout Inglefield Land, and were first described from the Smith Sound coast (Frisch 1981; Frisch & Dawes 1982, fig. 7). The rocks are fine- to medium-grained, homogeneous to slightly foliated, composed of pyroxene, hornblende, with or without biotite, and plagioclase that is occasionally porphyroblastic. The bodies have sharp to diffuse contacts, varying from subcordant to markedly discordant indicating their intrusive origin. The dykes clearly post-date much of the tectonic activity that has affected the country rocks; folded dykes have not been reported. Compositional and textural variation suggests that the dykes may be of more than one age.

Gabbro (g)

Age. This gabbro unit is possibly coeval with the metamafic dykes described above.
Character. The unit is represented by small outcrops of brown to greenish weathering, medium- to coarse-grained gabbro at the headwaters of Minturn Elv. Although poorly exposed, the gabbro appears as a subconcordant part of the E–W-trending succession southwest of the main Minturn intrusive complex (**sy**). Intrusive contacts with marble and paragneiss, and also possibly with syenite, are preserved. The gabbro is not associated with amphibolitic and ultramafic rocks, and appears much fresher than the Etah Group metagabbros (**a**). Thus, the rocks are regarded as later intrusions that have escaped some of the metamorphic and tectonic history.

Leucogranite and leucopegmatite (red 'fish' symbol)

Age. As explained under *Etah meta-igneous complex – Late granitoids*, this map symbol schematically represents granitoids of two distinct ages. Two grey granites, from south-west of Hiawatha Gletscher and the headwaters of Minturn Elv, have given SHRIMP zircon ages of 1915 ± 10 Ma and 1752 ± 25 Ma, respectively. Both are interpreted as protolith ages (Nutman *et al.* 2004).
Character. This map symbol indicates areas within paragneiss (**gn**) that contain conspicuous felsic material intercalated with gneiss or in irregular masses. Where studied, the material is thought to have been derived from partial melting of the gneisses. Relationships vary from concordant and transitional to gneissic structure; larger bodies may have a thoroughly intrusive character and cut across the gneiss foliation. The rocks are commonly medium- to coarse-grained with gradations to pegmatitic varieties, quartzo-feldspathic and deficient in mafic minerals, with some containing garnet, biotite and muscovite. There is a variation from red to pink granites that can be foliated, and that grade into the granite (**gr**) map unit to grey, buff and white, more homogeneous varieties. From the air, the latter leucocratic varieties can easily be mistaken for marble.

Granite (gr)

Age. A red granite cutting paragneiss at Force Bugt has given a SHRIMP zircon age of 1741 ± 15 Ma that is interpreted as the age of the igneous protolith (Nutman *et al.* 2004).
Character. The red granites characterising this map unit were among the first shield rocks on the map sheet to be described (Kane 1856). Varieties of granite occur but main types are leucocratic, pink to red and russet coloured, medium- to coarse-grained, and homogeneous with or without K-feldspar megacrysts. The rocks may contain biotite and garnet, and some are foliated and contain biotite-rich schlieren (Fig. 10). The

Fig. 10. Red leucocratic granite invading biotite paragneiss as large masses, sheets and pods. Older anatectic streaks and veins occur parallel to foliation. East of Kap Inglefield.

main outcrops are along the outer coast, for example, between Cairn Pynt and Rensselaer Bugt; occurrences too small to portray on the map are shown by red 'fish' symbols (see above). Granite veins, dykes and sheets are often conspicuous in the surrounding host rocks that are predominantly paragneisses (**gn**), and cross-cutting relations indicate there are several generations. Minor intrusions into marble (**m**) can be very irregular in form due to carbonate remobilisation, and distorted layers, discontinuous bodies and inclusions are common (Dawes 1988, figs 10, 11; Thomassen & Dawes 1996, fig. 4A; Dawes *et al.* 2000a, fig. 3B).

As mentioned under the gneiss unit (**gn**), appreciable leucosome derived by anatectic melting characterises the paragneiss, especially in the neighbourhood of red granite outcrops. Transitions from pink biotite-garnet gneiss with sporadic leucosome through veined and migmatitic gneiss to homogeneous red leucogranite illustrate progressive stages of partial melting. On a regional scale, migmatisation appears to increase northwards, for example along the coast towards Cairn Pynt, and in sections along Tufts Elv and Minturn Elv. Thus, the red granites (**gr**) that are concentrated along the outer coast, with the associated cross-cutting minor intrusions, are thought to represent remobilised melts derived mainly from paragneiss (**gn**). Field relationships indicate a complex history of granite formation and several phases can be documented in a single outcrop. Earlier phases can be foliated with gneissic schlieren, later phases are more homogeneous and cross-cutting but still affected by folding, while some sheets seem to be post-tectonic.

Late felsic minor intrusions
(not depicted on the map)

Age. Minor intrusions associated with granite (**gr**) have been described above. Other cross-cutting intrusions grouped here as 'late' on account of their relationship to gneissic structure, almost certainly represent a variety of ages. A NW–SE-trending dyke of group (2) below, south of Hiawatha Gletscher, has given a SHRIMP age of 1783 ± 22 Ma that, although analytically poor, indicates a relatively young intrusion. Another sample (probably from the same dyke) yielded a SM-Nd model age of *c.* 3000 Ma, indicating derivation by melting or reworking of Archaean crust (Mike A. Hamilton, personal communication 1999; Dawes 1999; Nutman *et al.* 2004).

Character. Undeformed linear to sinuous felsic dykes and sheets up to 10 m wide post-date all gneiss fabrics and migmatite veins, but are cut by brittle faults. There are two main intrusion types: (1) pale to white, medium-grained alaskite and pegmatite sheets and dykes, noted throughout Inglefield Land with a wide range of directions and attitudes; and (2) generally thinner, salmon to brick-red, mainly fine- to medium-grained syenitic dykes, seen only east of 68°N, and that form local swarms with varying trends (N–S, ENE–WSW, NW–SE) from area to area. It is not known whether dykes of group (2) represent a single intrusion period: they invariably cut alaskite and pegmatites of group (1) but they are themselves cut by leucopegmatite.

Mesoproterozoic Thule Basin

The Thule Basin is defined by a thick sedimentary-volcanic succession – the Thule Supergroup – that straddles northern Baffin Bay and Smith Sound and has its western exposures in Canada. The Humboldt Gletscher map sheet covers the north-eastern extremity of the basin. The Supergroup directly overlies the shield and is disconformably overlain by Cambrian beds of the Franklinian Basin (Figs 2, 11). A minimum age is provided by cross-cutting basic dykes that have yielded K-Ar ages of 676 and 627 Ma, and south of the map sheet, ages around 730 Ma (Dawes *et al.* 1973, 1982; Dawes & Rex 1986). The lower strata – the Nares Strait and Smith Sound Groups – are broadly coeval with the Mackenzie magmatism at *c.* 1270 Ma (see below). The youngest strata exposed in the map region, the Dundas Group, have yielded a microfossil fauna from Kap Powell (Fig. 1) of Ectasian and/or Stenian age (Samuelsson *et al.* 1999), in agreement with the conclusions of Hofmann & Jackson (1996).

Structure and metamorphism

Structurally, two parts of the Thule Basin, with very different outcrop size, are shown on the Humboldt Gletscher map sheet. The central basin margin is in the extreme south-west, bordered on the north by the relatively thin platform succession that peters out west of Minturn Elv. The basin margin is marked by faults. The three NW–SE-trending faults on the map, all with downthrow to the south-west, mark a structurally active zone. The Dodge Gletscher Fault (and probably the other faults) was active during basin development as shown by stratal thickness changes, for example,

Fig. 11. The unconformity between the Thule and Franklinian Basins at Force Bugt. Red beds of the Mesoproterozoic Smith Sound Group (**SS**, Rensselaer Bay Formation) invaded by two basic sills (**s**), the lower of which is mostly scree-covered, the upper is eroded and cut out by the unconformity. Overlying strata **DI**, comprise lower, heavily scree-covered Cambrian clastic rocks of the Dallas Bugt Formation overlain by cliff-forming Cape Leiper and Cape Ingersoll Formations, with the latter formation distinguishable at the top of the buttress due to its reddish (darker) colour. **R**, Wulff River, Cape Kent (**ck**) and Cape Wood Formations; **F**, Cass Fjord Formation forming the upper plateau. Height of the sea cliffs *c.* 250 m.

those between Kap Alexander and Crystal Palace Cliffs (see Dawes 1997, figs 26, 27). The present expression of the margin is as fault blocks with the Thule Basin strata bordered inland by the shield.

The Thule Basin strata are unmetamorphosed and little deformed, with the gentle dips mirroring the north-westerly slope of the underlying palaeosurface. The extensive NW–SE block faulting mentioned above causes some variation in otherwise shallow dips and there is local crushing along faults. Faults of similar direction, as well as ENE–WSW-striking normal faults affect the strata north of Foulke Fjord. Contact metamorphism adjacent to some sills and dykes is seen as colour changes and baking of argillaceous rock.

Thule Supergroup

The Thule Supergroup has been formally divided into five groups, 15 formations and 16 members (Dawes 1997). Three groups are present in the Humboldt Gletscher map region. The Smith Sound Group occurring north of Sonntag Bugt, represents the northern platform and basin margin deposits, and forms the largest exposures by far. The coeval Nares Strait Group and the younger Dundas Group are only exposed in fault blocks in the extreme south-west in northern Prudhoe Land (Fig. 12; also Dawes 1997, fig. 1).

Nares Strait Group

Name. Dawes (1991a).
Other literature. Dawes (1997, figs 1, 64).
Age. Ectasian. In the Humboldt Gletscher map region, basal strata of the group are not exposed. The oldest rocks seen are volcanics (**CN**) probably coeval with the sill of the Mackenzie igneous episode that has a $^{207}Pb/^{206}Pb$ baddeleyite age 1268 Ma (LeCheminant & Heaman 1991). These are overlain by clastic rocks (**NG**).
Distribution and thickness. This group represents the oldest strata of the central basin succession that farther south on the Thule map sheet is at least 1200 m thick. In the Humboldt Gletscher map region, a *c*. 450 m thick section on nunataks east of Sonntag Bugt, has concealed fault contacts against the shield inland and to the Dundas Group seawards (Fig. 12). An occurrence of basalt, discovered in 2001 at Rensselaer Bugt, is also referred to this group (see below).

Cape Combermere Formation (**CN**)

Name. Dawes (1997).
Other literature. Steenfelt *et al.* (2002).
Age. Ectasian. All isotopic ages are from outside the limits of the map sheet, for example, 1268 Ma given above and whole-rock K–Ar ages of 1284 ± 37 Ma, 1205 ± 36 Ma, 1173 ± 43 Ma on basic sills and the 1222 ± 36 Ma age on lava (Frisch & Christie 1982; Dawes & Rex 1986).
Lithology. The Cape Combermere Formation represents rift volcanism with intermittent deposition in shallow water to terrestrial environments. In the map region it is formed of dark-weathering, cliff-forming basaltic rocks. Examined on the largest nunatak, these are dark green to black vesicular lavas, with intrusive material, and overlying thin, dark purple shales, possibly lithic tuffs (Fig. 12; also Dawes 1997, fig. 64).
New occurrence. Pillow lava has recently been reported from south-east of Rensselaer Bugt: a single outcrop at least 20 m thick, partly scree-covered from overlying sediments (Zentilli & Grist 2002). In this area appreciable relief characterises the palaeosurface of

Fig. 12. The Thule Basin margin at Sonntag Bugt, northern Prudhoe Land. View is south-west from the Bamse isocline (Fig. 7) across Bamse Gletscher to fault blocks of the Nares Strait Group (**CN** and **NG**) and Dundas Group (**D**). **CN**, Cape Combermere Formation; **NG**, recessive Josephine Headland Formation with resistant Bamse Gletscher Member (**bg**) in mid-section, overlain by pale cliff-forming Clarence Head Formation. **d**$_2$, Neoproterozoic basic dyke. **Dash-dot** lines are faults. Relief along Bamse Gletscher is *c*. 500 m.

the shield and it seems likely that the basalt flowed in a submarine valley (see below, also under *General geology and regional structure*). From the chemistry supplied by Marcos Zentilli (personal communication 2004), the basalt is correlated with the Cape Combermere Formation, thus extending rift volcanism northwards onto the platform.

Nares Strait Group, undifferentiated (**NG**)

Composition. Josephine Headland and Clarence Head Formations (Dawes 1997).

Lithology. In the Humboldt Gletscher map region the Josephine Headland Formation is recessive, thin-bedded with a pale purple hue, composed of shales and fine-grained sandstones that are often calcareous and can be stromatolitic, and darker purple ?volcaniclastic shales. One cliff-forming, paler weathering unit in mid-section, composed of coarser sandstone is the Bamse Gletscher Member of Dawes (1997; Fig. 12). The formation marks a marine transgression after the volcanism of the Cape Combermere Formation, with a shallow shelf as the overall depositional environment. The overlying cliff-forming Clarence Head Formation comprises white, very clean sandstone, representing deposition in a shallow marine, primarily tidal environment.

Smith Sound Group, undifferentiated (**SS**)

Name. Dawes (1997).

Age. Ectasian. The entire succession is older than the dolerite sills (**s**) that invade it (see below).

Lithology. All Greenland outcrops of the Smith Sound Group occur in the Humboldt Gletscher map region. A full lithostratigraphic description of the five formations recognised is found in Dawes (1997, pp. 30–58, figs 5, 8, 9, 14–47; see also Dawes 1979, fig. 7). The group, 0 to 700 m thick, shows two types of thickness variation: those related to the faulted basin margin around Kap Alexander (see above, under *Structure and metamorphism*) and those related to local infillings of topographic lows in the eroded shield, for example east of Rensselaer Bugt (see above, under *Cape Combermere Formation*). The group is composed of varicoloured sandstones and shales, including red beds, with subordinate stromatolitic carbonates cut by basic sills (**s**; Figs 2, 11). Across the faulted basin margin, pale coarse-grained clastic rocks and quartz-pebble conglomerate come in. The strata were deposited in an overall shelf environment with shallow water and subaerial deposition, during which supratidal to marginally marine, and intermittently lacustrine, sedimentation prevailed.

Dolerite sills (**s**)

Age. Ectasian or Stenian. Whole-rock K-Ar ages on basaltic sills in the map region are in the range 1190–1070 (Dawes *et al.* 1973, 1982) but their intrusive age may be as old as the *c.* 1270 Ma volcanics of the Nares Strait Group.

Character. Dolerite sills, 10 to 70 m thick, occur within the Smith Sound Group. Sill rock is dark grey to greenish grey, homogeneous to microporphyritic, rarely vesicular, with chilled margins; central parts of sills are often gabbroic. Sills are very conspicuous in the landscape, and two in particular are persistent and also occur on the opposite side of Smith Sound on Ellesmere Island (Figs 2, 11; also Koch 1933, plate I; Christie 1967, plate II; Dawes 1997, fig. 12). In south-westernmost sections, three sills create a tiered structure to the sea cliffs, such as the Crystal Palace Cliffs (see Dawes & Christie 1982, fig. 3). Only selected intrusions are shown on the map, in particular those forming the upper land surface and therefore large outcrops. In places, thickness variations down to zero are due to deep erosion prior to deposition of Cambrian strata (see Peel *et al.* 1982, fig. 6; Dawes 1997, fig. 32).

Dundas Group, Kap Powell Formation (**PD**)

Names. Dundas Group (Dawes 1991a); Kap Powell Formation (Dawes 1997).

Age. Ectasian or Stenian (see earlier under *Mesoproterozic Thule Basin*). The Kap Powell Formation comprises the youngest Thule Basin strata in the Humboldt Gletscher map region being restricted to a fault block (Fig. 12). South of the map region, it overlies the Nares Strait and Baffin Bay Groups. The strata are in fault contact with the Nares Strait Group along the Bamse Gletscher Fault that, with downthrow of over 1 km, cuts out the entire Baffin Bay Group (Dawes 1991a).

Lithology. A section at least 500 m thick forms the sea-cliffs on the south side of Sonntag Bugt and these exposures continue to Kap Powell, 15 km to the south (see Dawes 1997, figs 108, 111, 112). The rocks are dark weathering, regularly interbedded, sandstones, siltstones and shales, commonly calcareous with some yellow weathering dolomites. The overall depositional setting is deltaic to offshore, with common coarsening- and thickening-upwards cycles representing progradational delta front sequences.

Proterozoic dolerite dykes

All mafic dykes in the Humboldt Gletscher map region are of Proterozoic age. South of Humboldt Gletscher they show up on the magnetic data as four main trends: NW–SE, NE–SW, ESE–WNW and ENE–WSW (Stemp & Thorning 1995b; Figs 5, 13). The two map categories portrayed – Palaeoproterozoic and ?Mesoproterozoic (**d**$_1$) and Neoproterozoic (**d**$_2$) – equate with the chronology in the Thule region to the south, and are confirmed by available isotopic age and chemical data. Dykes of the two categories have sharply contrasting compositions (see below). Although cross-cutting relationships are known, no systematic field chronology has been established and dykes placed in the older category are probably of more than one age.

Field characteristics of all dykes are similar: vertical to steeply dipping, linear to slightly sinuous, undeformed, with chilled contacts. They are between a metre to 15 m thick, with an occasional dyke up to 30 m thick. Igneous textures are preserved, formed by plagioclase laths, clinopyroxene, orthopyroxene and opaque minerals, with or without biotite, hornblende and olivine. Most dykes are brown to reddish-weathering and seemingly unmetamorphosed, but greenish dykes typically show chloritisation of mafic minerals and intense sericitisation of feldspar.

Dykes typically tend to weather out into gullies, and due to the profuse Quaternary cover, particularly inland over the shield, and the prominent Palaeozoic cover in coastal areas, relatively few dykes can be traced over any distance in the field. For example, the conspicuous magnetic signatures interpreted as NE–SW-trending dykes south-west of Hiawatha Gletscher coincide with areas of widespread ground moraine, and these dykes have not been seen in the field (Figs 5, 13). As a minor rock type, few dykes are shown on the map, the selection being based on where it is practical to show them without obscuring the sometimes dense structural detail.

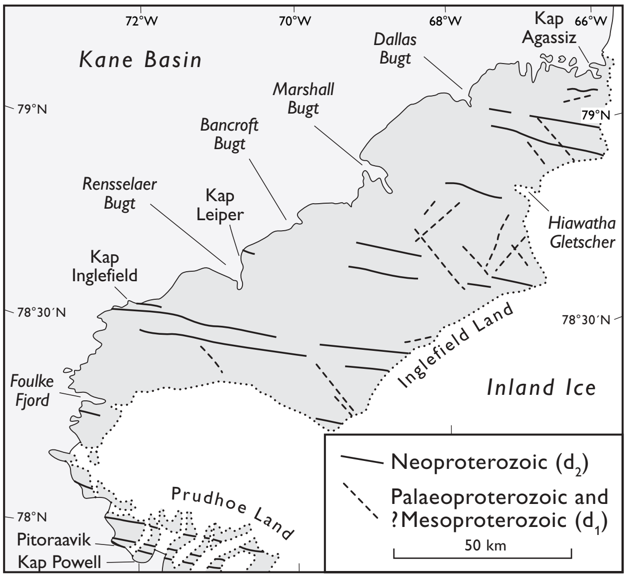

Fig. 13. Distribution of Proterozoic basic dykes on Inglefield Land and Prudhoe Land, based on field observations and aeromagnetic data. The western (coastal) extent of the Neoproterozoic ESE–WNW-trending swarm in central and north-eastern Inglefield Land is obscured by Franklinian Basin strata.

Palaeo- and ?Mesoproterozoic dykes (d$_1$)

Dykes of this category, seen mainly in central and north-eastern Inglefield Land, are of two main directions: NW–SE-trending and NE–SW-trending with some variation to ENE–WNW-trending. They cut all lithologies of the shield but exposures showing the relationship to Thule Basin deposits are not present in the map region. ENE–WNW-trending dykes often appear concordant to the main structural grain, but in detail they are highly discordant. The NW–SE-trending dykes form the northern, strike extension of a regional swarm that have yielded K–Ar ages of 1563 ± 60 Ma, 1538 ± 46 Ma and 1450 ± 44 Ma (Dawes *et al.* 1973; Dawes & Rex 1986). Thus, they were emplaced and eroded prior to deposition of the Thule Supergroup (Fig. 1). They are trachybasalt to trachyandesite in composition and form the northern part of 'Melville Bugt dyke swarm' of Nielsen (1987, 1990) that has a Rb–Sr age of 1645 ± 35 Ma. This age is now refined by the Palaeoproterozoic U–Pb baddeleyite age of 1629 ± 1 Ma (Mike A. Hamilton, personal communication 2004). The age of the NE–SW- to ENE–WNW-trending dykes is unknown but in the Thule region to the south, NE-trending dykes have K-Ar ages of 1667 ± 50 Ma and 1313 ± 39 Ma (Dawes & Rex 1986). It is thus possible that some dykes of this category are of Mesoproterozoic age.

Neoproterozoic dykes (d$_2$)

Dykes of this category have an ESE–WNW strike throughout Inglefield Land and northern Prudhoe Land, cutting the Thule Supergroup but not the Palaeozoic rocks (Figs 1, 12, 13). The most persistent dyke seen in the magnetic data can be traced from Smith Sound west of Kap Inglefield intermittently to the Inland Ice. Other dykes with strong magnetic signatures, for example the two dykes striking towards Dallas Bugt, are obscured in the west by the overlying Franklinian strata (Fig. 5). One coastal exposure – the Kap Leiper dyke – featured on early maps and discussed in the literature (e.g. Koch 1920, 1933, plate II; Callisen 1929; Christie 1967), has yielded a K–Ar age of 627 ± 25 Ma, consistent with its position below basal Cambrian strata (Dawes *et al.* 1982, fig. 4). A master dyke at Pitoraavik, just south of the Humboldt Gletscher map sheet, has yielded an age of 676 ± 25 Ma. The dykes are Ti-rich quartz tholeiites (Nielsen 1990) with a TiO_2 content that can exceed 5 wt%. They constitute the northern flank of the so-called 'Thule dyke swarm' that occurs in Greenland as far south as 75°N, and represents a continental-scale swarm at least 300 km wide that continues into Canada.

Palaeozoic Franklinian Basin

The Franklinian Basin extends for more than 2000 km through the Canadian Arctic Islands and northern Greenland preserving a stratigraphic record of late Proterozoic to late Devonian age. In Greenland, the thickest sedimentary section is in Peary Land (Fig. 1) where the basin forms a platform and orogenic belt 200 km wide. With the exception of the earliest phase of development, the basin was differentiated into two E–W-trending provinces: a southern shelf and slope and a northern deep-water trough. The boundary between shelf and trough shifted position with time and southerly basin expansion in the Silurian resulted in a final foundering of the shelf that led to deposition of clastic sediments over carbonates.

The Humboldt Gletscher map sheet covers the westernmost exposures of the Franklinian Basin in Greenland, mainly shelf carbonates with a major reef complex – a section almost 3500 m thick – and Silurian siliciclastic slope deposits 500 m thick. The succession is of Early Cambrian (Atdabanian) to Late Silurian (Ludlow) age. Just north of the map sheet in Hall Land, trough deposits reach up into the Devonian when deposition was curtailed by the Ellesmerian orogeny.

History and literature

The Humboldt Gletscher map sheet covers the classical area for Franklinian Basin stratigraphy. Historically, it was the first part of the basin to be explored leading to initial subdivision of the succession into 16 formations (Koch 1929a). Fifteen of these were mapped in the map region, with most type localities being in coastal Inglefield Land and Washington Land, with just three formations anchored to the north in Hall Land. The fossils recovered – lauded as "the most complete collections of early Palaeozoic fossils hitherto known from arctic lands" (Poulsen 1927, p. 237) – and well publicised through the monographic studies of C. Poulsen, G. Troedsson and C. Teichert, formed the basis of later work by Troelsen (1950). This stimulated the spread of the stratigraphical names to Canada. For historical reviews, see Dawes & Haller (1979), Christie & Dawes 1991 and Dawes (1991b).

These beginnings, and later work by the Survey and others from the mid-1960s, have provided a wealth of stratigraphical and palaeontological information and 80 papers pertaining to the map sheet alone are cited in the review of Dawes (1999). Modern, systematic lithostratigraphic accounts at formational and member level have been published for the main part of the succession, i.e. the Morris Bugt, Washington Land and Peary Land Groups – respectively, Smith *et al.* (1989), Hurst (1980a) and Hurst & Surlyk (1982) – but not for the older part, the Ryder Gletscher Group of Ineson & Peel (1987, 1997). The Silurian shelf–slope transition on the map sheet is well known from sedimentological and palaeogeographical analyses (Hurst 1981; Hurst & Surlyk 1983). For the setting of the Franklinian Basin strata in the context of regional basin evolution in Greenland, the reviews of Hurst (1980b), Hurst & Surlyk (1984), Sønderholm & Harland (1989a) and Higgins *et al.* (1991a, b) are relevant. Correlation with adjacent Ellesmere Island is dealt with by Dawes & Kerr (1982) and Trettin (1991). The most recent stratigraphical work in the Humboldt Gletscher map region is reported by Iannelli (1999, 2002a, b) and Dawes *et al.* (2000a).

Portrayal and description of map units

The Lower Palaeozoic succession on the map sheet is formally subdivided into four groups and 29 formations. Map scale limits depiction solely at formation level, whereas portrayal of only groups would produce a misleading over-simplified impression. Map unit choice is for the most part based on the 1:250 000 maps of Jepsen *et al.* (1983) and Bengaard (1995), although the Mesoproterozoic–Palaeozoic unconformity was not recognised on the latter map. The homoclinal nature of the succession and the steep cliff-bounded plateau landscape determine that boundaries have been adjusted to allow satisfactory portrayal. Nevertheless, in western outcrops, it has been necessary to compromise and pool the thin basal Cambrian clastic deposits (Dallas Bugt Formation) with dolomite formations of the Morris Bugt Group. On the map sheet, the Washington Land Group, characterised by reef and reef-related sediments, is composed of eight formations that have been grouped into four map units: **G**, Petermann Halvø, Kap Godfred Hansen, Bessels Fjord and Offley Island Formations; **B**, Adams Bjerg Formation; **P**, Pentamerus Bjerge and Hauge Bjerge Formations; **M**, Kap Morton Formation. All four map units contain carbonate buildups. On the Nyeboe Land map sheet to the north within strata equivalent to **G**, major buildups are shown schematically by asterisks. This is not practised on the Humboldt Gletscher map sheet apart from the major buildup in unit **B** at Kap Jefferson. Most buildups in unit **G** are known from the steep cliff sections, such as those along Bessels Fjord and Petermann Gletscher, where closely-spaced unit boundaries are not conducive to symbol overprints. Many of the buildups of unit **P** are large enough to be individually shown and within unit **L** each outcrop of unit **P** represents a single buildup.

The comments on the map concerning the nomenclature and formational composition of the Ryder Gletscher and Washington Land Groups are expanded on below under each group. Many of the map units extend north-east onto the Nyeboe Land map sheet or westwards into Canada, but the descriptions here pertain strictly to the Humboldt Gletscher map region. In some cases they are compiled from many sources, including unpublished Survey data, but for convenience in the descriptive text, references are kept to a minimum. Where possible, the photographs chosen to illustrate the map units are from inland, less publicised sections, rather than the classical coastal outcrops and type localities illustrated in the literature.

Structure and metamorphism

The flat-lying to shallow-dipping strata are unmetamorphosed and undeformal containing unstrained fossils. Conodont Alteration Index values indicate regional temperatures of less than 90°C due to former overburden (Aldridge 1980) and thus comparable to other maturity parameters indicating low thermal maturity in the region (Christiansen 1989). The regional tilt is 1–3° towards the NNW but there are many local variations, both in dip amount and direction. For example, in southern Daugaard-Jensen Land, north-east of Kap Lyngbæk, the general dip is towards the NNE, yet photogrammetric measurements define a number of fault blocks with vertical displacements up to 80 m

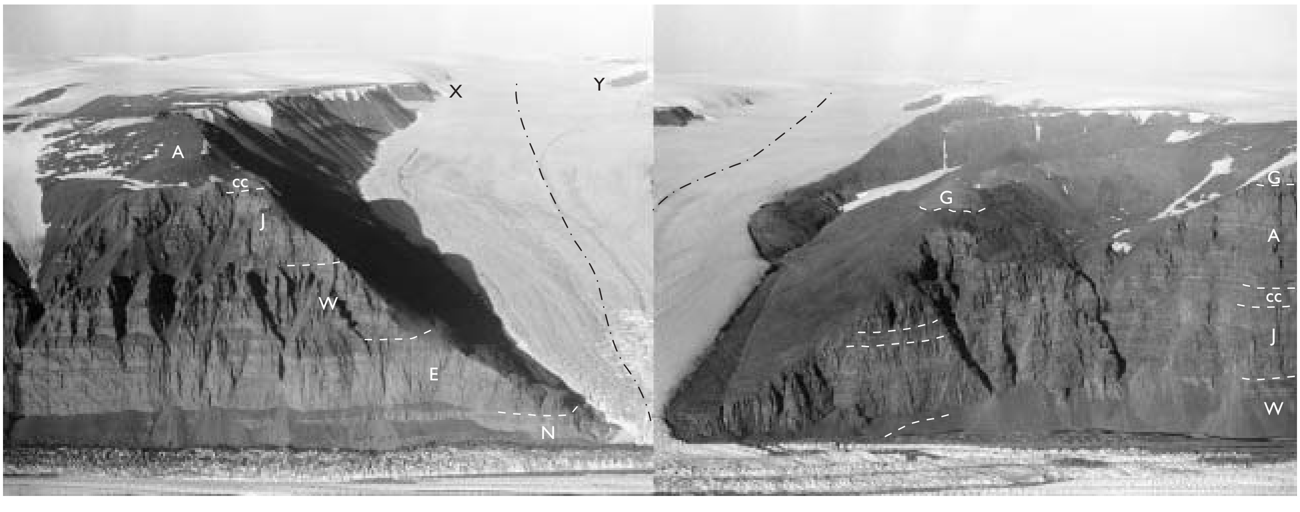

Fig. 14. Faith Gletscher Fault (**dash-dot** line) on the west side of Petermann Gletscher showing downthrow to the north. Map units in stratigraphical order: **N**, Poulsen Cliff Formation with at the top the resistant Nygaard Bay Formation; **E**, Canyon Elv Formation and Nunatami Formation; **W**, Cape Webster Formation; **J**, Kap Jackson Formation and thin recessive Cape Calhoun Formation (**cc**); **A**, Aleqatsiaq Formation and **G**, Petermann Halvø Formation. Two oblique views up Faith Gletscher with points **X** and **Y**, marking the true width of the glacier, recognisable on both images. Height of cliffs about 900 m. Photos: Hans F. Jepsen.

that have their own local dips in directions varying between NNW and ENE (Jepsen & Dueholm 1978). Other variations in dip direction and amount, as seen along Petermann Gletscher and in Inglefield Land, are due to broad flexures with opposing dips of up to 3°. The steepest dips occur in connection with faulting, for example on Petermann Halvø, in the valley west of Kap Bemerton, dips of up to 67° have been measured north of the main fault, in an area that has a general dip of 5–15° to the NNW (Cope & Beswick 1999).

The most persistent faults affecting the outcrop pattern north of Humboldt Gletscher strike between ENE–WSW and ESE–WNW; subsidiary directions are NNW–SSE and NNE–SSW. Many faults are associated with colour anomalies due to ferroan dolomitisation, and base-metal mineralisation is known (Iannelli 1999; see Dawes *et al.* 2000a, fig. 7 and under *Economic geology*). The Faith Gletscher Fault on Petermann Halvø has the largest recorded displacement on the map sheet with a minimum northern downthrow of 365 m (Fig. 14). Since this structure cannot be located to the west in the well-exposed walls of Bessels Fjord, and it seems to pass laterally into a monocline in Hall Land, it is interpreted as a hinged fault zone (Iannelli 1999). In Inglefield Land, ENE–WSW-trending lineaments, not included on the map because they do not affect outcrop pattern but shown on Figure 6, are parallel to the coastline suggesting it is structurally controlled. Subsidiary faults occur both north and south of Humboldt Gletscher, and in Inglefield Land vertical displacements of over a hundred metres are recorded, for example, on the NNE–SSW-trending fault west of Rensselaer Bugt (see Dawes 1997, fig. 5). In Washington Land, a swarm of NNW–SSE-trending lineaments that reach the coast at Kap Jefferson, are brecciated, dolomitised crush zones with a small strike-slip element; it is possible these are related to the formation of the Nares Strait submarine valley (Hurst & Kerr 1982a).

Basal Cambrian clastic deposits

Early Cambrian clastic strata, present both south and north of Humboldt Gletscher, represent a marine transgression across the peneplaned eroded shield, and in the south-west, over the Mesoproterozoic Smith Sound Group (Figs 11, 15). At present, the strata are placed in two formations: the Dallas Bugt Formation with three members in Inglefield Land, and the Humboldt Formation in Daugaard-Jensen Land. Correlation of the Daugaard-Jensen Land succession at member level with strata in Inglefield Land is established and it has been recommended that the Dallas Bugt Formation be extended to cover these strata throughout the map region (Dawes *et al.* 2000a). The Humboldt Formation is thus superfluous and can be abandoned.

Dallas Bugt Formation (**D**)

Name. Peel *et al.* (1982); a reference is made herein to an ‘in press’ report defining the formation and its members that remains unpublished (Collinson *et al.* 1982).
Other literature. Peel (1982), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a).
Age. Early Cambrian (Atdabanian).
Thickness and lithology. The Dallas Bugt Formation is often covered by scree (Figs 11, 15). It is *c.* 145 m thick around Dallas Bugt, thins to *c.* 20 m at Force Bugt, and pinches out east of Kap Inglefield on the palaeoslope above a basic sill (see Dawes 1997, fig. 14). Red to purple-brown arkosic sandstones with con-

Fig. 15. Unconformity between the Precambrian shield and the Franklinian Basin at Marshall Bugt, Inglefield Land. Map unit **Dl**, typical scree-covered Cambrian clastics of the Dallas Bugt Formation topped by resistant dolomites of the Cape Leiper and Cape Ingersoll Formations. Cliff height about 200 m. Holocene raised beaches in the foreground. The view illustrates the two regional erosion surfaces: a Precambrian level across the shield and a late Cenozoic level forming the upper land surface.

glomerates form the basal strata (Kap Scott Member), overlain by white to pale yellow weathering, cross-bedded sandstones (Qáqaitsut Member), and topped by finer grained sandstones interbedded with green bioturbated mudstones (Marshall Bugt Member; see Peel *et al.* 1982, fig. 6). Towards the top, the strata become dolomitic, and there is a transition into the overlying dolomites of the Cape Leiper Formation (see units **H** and **I**). For depositional environment, see Humboldt Formation, below.

Humboldt Formation (**H**)

Name. Jepsen & Dueholm (1978), Peel (1978).
Other literature. Peel & Christie (1982), Higgins *et al.* (1991a, b), Bergström & Peel (1988).
Age. Early Cambrian (Atdabanian).
Thickness and lithology. This siliciclastic formation is at least 160 m thick, exposed in the area around Romer Søer in southern Daugaard-Jensen Land. The base of the formation is not exposed. It is a lateral equivalent of the Dallas Bugt Formation of Inglefield Land, the tripartite division of which is readily recognisable. Thus, basal fluvial sandstones and conglomerates, are succeeded by cross-bedded, bioturbated, shallow marine clastics of tidal origin, with the upper interbedded sandstone and mudstone indicating a middle to lower shoreface environment.

Ryder Gletscher Group

Name. Peel & Wright (1985), Ineson & Peel (1987, 1997).
Other literature. Peel & Christie (1982), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a), Iannelli (2002a, b).
Age. Latest Early Cambrian to Middle Ordovician.
Thickness and lithology. The Ryder Gletscher Group conformably overlies the basal clastic deposits and has a composite thickness in the map region of at least 1700 m. It represents restricted shallow-water platform interior carbonate and siliciclastic deposits, in which several large sedimentary sequences are present; for example, two shallowing-upwards Ordovician cycles topped with evaporitic strata. It is stressed that no systematic spatial study or recent stratigraphical work has been undertaken for several formations of this group. Much information given here, particularly in Inglefield Land, is pieced together from local sections reported on in Poulsen (1927), Koch (1929a), Troelsen (1950), Cowie (1961), Peel & Christie (1982), Peel *et al.* (1982), Dawes *et al.* (2000a) and Iannelli (2000a, b), together with unpublished Survey observations by Hans F. Jepsen, Jon R. Ineson, Svend Stouge and the author.
Map subdivisions and nomenclature. The Ryder Gletscher Group extends for 1000 km across northern Greenland from Inglefield Land to Kronprins Christian Land (Fig. 1). Formational composition varies from area to area in response to regional lithological changes, and the bipartite legend of the map sheet reflects such variations across the Humboldt Gletscher. Thus, the interval between the basal Cambrian clastic deposits and the Cass Fjord Formation is represented north and south of Humboldt Gletscher by two and five formations, respectively. The map units are based on formations that have type localities along the coasts of Kane Basin whereas the type area of the Ryder Gletscher Group is 300 km distant in south-eastern Warming Land on the adjoining map sheet (Fig. 1). The Inland Ice covers much of the region between Petermann Gletscher and Warming Land, but transition to the formational subdivision of the type area can be seen in the Humboldt Gletscher map region in the nunatak terrain of southern Hall Land (Fig. 16).

Cape Leiper and Cape Ingersoll Formations (**I**)

Names. Troelsen (1950).
Other literature. Cowie (1961), Peel & Christie (1982), Dawes *et al.* (2000a).
Age. Early Cambrian (?Atdabanian).
Thickness and lithology. This map unit of Inglefield Land comprises cliff-forming, pale-weathering dolomites that thin from *c.* 50 m on Nuussuaq to about less than 30 m at Force Bugt (Fig. 11). Definition of the lower boundary with the Dallas Bugt Formation is not everywhere precise because of the gradation from sandstone to dolomite but in detail an erosional surface (within the uppermost Dallas Bugt Formation) heralds the final shift to carbonate sedimentation. The lower and thicker part of the map unit (Cape Leiper Formation) is composed of yellow grey-weathering, cross-stratified dolomites, that towards the south-west, for example at Kap Grinnell (= Kap Ingersoll of Cowie 1961), become arenaceous and often stylolitic. In contrast, the upper thin unit (Cape Ingersoll Formation) is distinctly reddish-weathering composed of hard grey dolomite, in places burrowed and with stromatolitic mounds (Fig. 11). The bipartite unit is regarded as representing the northwards progradation of a carbonate ramp, and can be correlated with the lower two units of the Kastrup Elv Formation exposed north of Humboldt Gletscher (see below).

Kastrup Elv Formation (**K**)

Name. Henriksen & Peel (1976).
Other literature. Peel & Christie (1982), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a).

Fig. 16. Ryder Gletscher Group in south-western Hall Land illustrating transition with type area stratigraphy to the north-east, cf. Bryant & Smith (1985, fig. 2), Sønderholm & Due (1985, fig. 5) and Higgins *et al.* (1991a, fig. 29, 1991b, fig. 7.15). Map unit **F**, well-bedded carbonates and siliciclastic rocks (Cass Fjord Formation = Blue Cliffs Formation) with at the top a pale 30 m thick, cliff-forming quartz sandstone (Kap Coppinger Member = Permin Land Formation), overlain by map unit **C**, dolomites and limestones, split into lower dark weathering (Cape Clay Formation = Johansen Land Formation) and thicker more recessive, brown-weathering sequences (Christian Elv Formation = Warming Land Formation).

Age. Early to Middle Cambrian.

Thickness and lithology. This formation of southern Daugaard-Jensen Land comprises *c.* 140 m of well-bedded, mottled, alternating pale and dark yellowish grey dolomites, with some thin silty horizons and burrows at many levels (see Higgins *et al.* 1991a, fig. 28A). More finely crystalline laminated dolomites with stromatolites occur in the upper part. Four informal units have been recognised in this shallow marine sequence, all about the same thickness and numbered from oldest upwards 1 to 4 in Dawes *et al.* (2000a, fig. 6). The lowermost two (correlating with map unit **I**) are dominated by dolomitised grainstones, with mottling and bioturbation particularly in the upper one, are regarded as subtidal deposits on the proximal parts of the juvenile carbonate shelf. The two upper units comprise cyclic peritidal dolomites and burrow-mottled subtidal dolomites that record deposition in a protected platform interior.

Telt Bugt Formation (**T**)

Name. Henriksen & Peel (1976).

Other literature. Peel & Christie (1982), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a), Iannelli (2002a).

Age. Middle Cambrian.

Thickness and lithology. This formation is composed of brown-grey weathering, thin and irregularly bedded, grey banded, mottled lime mudstones with silty laminations and horizons, together with dolomite-filled burrows and small mounds. The overall environment is intertidal and subtidal. The boundary with the underlying Kastrup Elv Formation is essentially a dolomitisation front subparallel to bedding, but regionally this is markedly diachronous. Thus, the formation has a maximum thickness of *c.* 100 m around the eastern lake of Romer Søer, thinning to the north and west, so that at Telt Bugt it is *c.* 40 m thick. East of Cass Fjord less than 5 m thick (see Peel & Christie 1982, fig. 4; Higgins *et al.* 1991a, fig. 28A). On the map, the feather-edge of the formation proved impractical to portray, and its termination is shown along Kastrup Elv, north of Henryk Arctowski Iskappe, and along the main fault east of Bjørnehiet. In reality, it continues farther west to peter out somewhere east of Cass Fjord. Upwards, the strata pass gradually into dolomitised carbonates of the Cass Fjord Formation.

Wulff River, Cape Kent and Cape Wood Formations (**R**)

Names. Poulsen (1927), Koch (1929a).

Other literature. Poulsen (1946), Troelsen (1950), Cowie (1961), Peel & Christie (1982), Higgins *et al.* (1991a, b), Dawes (2000a).

Age. Early to Middle Cambrian.

Thickness and lithology. This tripartite, carbonate-dominated map unit of Inglefield Land correlates broadly with the upper part of the Kastrup Elv Formation (Wulff River Formation = unit 3; Cape Kent Formation = unit 4) and the Telt Bugt Formation (= Cape Wood Formation) of Daugaard-Jensen Land (Dawes 2000a, fig. 6). However, there are marked facies variations with that sequence, reflecting a more proximal platform position. An impression of this can be obtained from comparison of the section from Nuussuaq (Dawes 2000a, fig. 6) with that from Kap Grinnell (i.e. Kap Ingersoll of Cowie 1961, fig. 3). Individual formations thin to the south-west so that the map unit varies from *c.* 160 m on Nuussuaq to less than 60 m at Force Bugt.

In north-eastern exposures, the Wulff River Formation is dominated by locally dolomitised burrowed lime mudstones and minor conglomerates with some interbeds of grey, often glauconitic, calcareous fine-grained sandstones; in the south-west glauconitic sandstones and siltstones dominate, with some more resistant limestone beds. The Cape Kent Formation is a very distinctive cliff-forming unit, up to 20 m thick, that acts as a regional marker, separating relatively recessive strata below and above (Figs 11, 17; also Peel & Christie 1982, fig. 6). Over much of its outcrop, the formation is composed of pale-weathering, uniform and hard, locally dolomitised oolitic limestone, representing deposition on subtidal shoals and sand banks in turbulent water. In the Kap Ingersoll – Kap Grinnell area, oolite development has not been recognised, the interval being more arenaceous and dolomitised, with glauconitic sands and silts (Cowie 1961); however, oolitic limestone occurs farther west, as it does in adjacent Canada. The Cape Wood Formation varies appreciably in facies both laterally and vertically. The lower part is generally recessive and composed of grey to greenish glauconitic sandstones with conglomeratic intervals, interbedded with yellow-weathering, grey limestones that are variably arenaceous; this heterogeneous unit passes upwards into resistant dark and light banded carbonate-dominated strata.

Cass Fjord Formation (**F**)

Names. Poulsen (1927), Koch (1929a).

Other literature. Troelsen (1950), Henriksen & Peel (1976), Palmer & Peel (1981), Bryant & Smith (1985), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a), Iannelli (2002a, b).

Age. Late Middle Cambrian to Early Ordovician.

Thickness and lithology. This is the thickest formation of the Ryder Gletscher Group and it forms the largest outcrops of all map units. Most workers recognise a number of mappable units (Henriksen & Peel 1976; H.F. Jepsen, unpublished data 1976; Palmer & Peel 1981; Dawes *et al.* 2000a). Five members based on viable map units between from Cass Fjord and Petermann Fjord have been described by Iannelli (2000b). The formation varies in thickness from at least 380 m in the vicinity of Kap Coppinger, to a maximum of 420 m farther west and to 283 m logged about 15 km east of Cass Fjord. This variation is also seen in the one formalised member that thins from 25 m to 1 m over the same distance (see below). The thickness estimate of 470 m 'east of the head of Cass Fjord' (Henriksen & Peel 1976) – a composite of several smaller sections – appears too high unless abrupt thickening is envisaged. On Inglefield Land, much of the formation has been eroded away leaving in places a little more than 100 m forming the upper plateau (Fig. 17). The formation conformably overlies the Telt Bugt and Cape Wood Formations, with the boundary usually taken at the incoming of intraformational conglomerates, but in western exposures at Cass Fjord it disconformably overlies the Kastrup Elv Formation.

The Cass Fjord Formation is mostly characterised by cliff-forming carbonate and siliciclastic strata deposited in subtidal, intertidal to locally supratidal conditions. Lithologies are very variable but two are dominant: greenish-grey, thin, often irregularly, bedded platy lime mudstone with silty laminae, and laterally extensive beds of intraformational flat-pebble conglomerate. Also present are massive thin bedded dolomites, stromatolitic mounds, siltstones and bituminous limestones, grainstones and white, brown-weathering sand-

Fig. 17. Sea cliffs at Kap Francis, Inglefield Land, showing Cass Fjord Formation (**F**) overlying map unit **R**, Cape Wood Formation with the thin Cape Kent Formation (**ck**) visible just above the scree that hides the Wulff River Formation and older dolomites. Height of the cliffs *c.* 300 m.

stones. Bioturbation can be intense. Thin anhydrite and gypsum-bearing beds are locally common, and some oolitic limestone occurs. One marker unit of white sandstone, with thin dolomite incursions, has been defined as the Kap Coppinger Member (Bryant & Smith 1985; Figs 3, 16, 18; Dawes *et al.* 2000a, fig. 7).

Cape Clay and Christian Elv Formations (**C**)

Names. Cape Clay Formation: Poulsen (1927), Koch (1929a, b); Christian Elv Formation: Henriksen & Peel (1976).

Other literature. Peel & Christie (1982), Fortey & Peel (1989), Higgins *et al.* (1991a, b), Pirie *et al.* (1999), Dawes *et al.* (2000a), Iannelli (2000a).

Age. Early Ordovician to late Early Ordovician.

Thickness and lithology. This limestone-dominated map unit is at least 160 m thick. Together with the upper part of the Cass Fjord Formation (above the Kap Coppinger Member), it represents the lower dominantly subtidal part of a major shallowing-upwards cycle, the upper part of which is map unit **N** (see below; Figs 3, 18). The Cape Clay Formation, 45 to 50 m thick, comprises cliff-forming, burrow-mottled, grey lime mudstones, with subordinate intermixed stromatolitic to thrombolitic limestones, sponge mounds and flat-pebble conglomerates. Dolomite occurs in eastern outcrops. Here lead-zinc mineralisation is associated with pervasively dolomitised limestones, vuggy to bituminous dolomites and pseudobreccia, and includes massive pyrite beds (see under *Economic geology*). A pale sandstone unit up to 5 m thick (known informally as 'Franks Quartzite'), marks the top of the formation on Petermann Halvø (Pirie *et al.* 1999). The Christian Elv Formation is 112 m thick at Christian Elv but slightly thicker farther east; it is a banded semi-resistant sequence darker than the Cape Clay Formation (see Peel & Christie 1982, fig. 8). The formation is mainly composed of grey lime mudstones, often algal laminated and with small stromatolitic mounds, intraformational conglomerates and subordinate dolomites that appear to increase in abundance eastwards. Greenish shales and thin wavy-bedded limestones form the basal strata above the Cape Clay Formation while the upper part includes a distinctive white, cross-bedded sandstone unit up to 25 m thick – the 'Upper white marker' of H.F. Jepsen (unpublished data 1976; see Iannelli 2000a, plate 2). These latter two units form the lower and upper of the three members described by Fortey & Peel (1989, fig. 5).

Poulsen Cliff and Nygaard Bay Formations (**N**)

Names. Troelsen (1950).

Other literature. Henriksen & Peel (1976), Peel & Christie (1982), Fortey & Peel (1990), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a), Iannelli (2002a).

Age. Early Ordovician.

Thickness and lithology. This map unit is up to 165 m thick and dominated by evaporitic deposits. It forms the upper part of the shallowing-upwards sedimentary cycle mentioned under the previous map unit (**C**), representing mainly intertidal to peritidal deposition. It is generally recessive with many scree-covered intervals. The Poulsen Cliff Formation varies from *c.* 100 to 125 m whereas the overlying Nygaard Bay Formation appears to be fairly constant at 40–45 m (Fig. 18; see also Peel & Christie, fig. 9). The lower formation comprises variable shaly dolomites, laminated lime mudstones and shales with both algal and wave-formed lamination, and dolomitic sandstones. Conspicuous beds of laminated to massive anhydrite and gypsum

Fig. 18. Ordovician strata in Hellerup Land, Petermann Gletscher: formations of the Ryder Gletscher Group overlain by the Kap Jackson Formation (**J**) of the Morris Bugt Group that forms the craggy summit. **F**, Cass Fjord Formation, with pale Kap Coppinger Member just above scree; **C**, Cape Clay Formation and more recessive Christian Elv Formation; **N**, pale, recessive Poulsen Cliff Formation topped by darker Nygaard Bay Formation; **E**, cliff-forming Canyon Elv Formation with much thicker Nunatami Formation forming the cliff summit; **W**, Cape Webster Formation, forming poorly exposed slopes. Foreground cliff is *c.* 500 m high.

occur (see Higgins *et al.* 1991a, fig. 34). Intraformational breccias, stromatolitic mounds and fist-size chert nodules are locally common, as are small-scale intraformational faults and soft sediment deformation features. Evaporite beds decrease in abundance northwards from the type locality at Poulsen Klipper. The Nygaard Bay Formation is distinctly bipartite, formed of a lower cliff-forming member of cyclic thin-bedded dense limestones, intraformational conglomerates and shaly limestones with chert nodules, and an upper recessive member of laminated to massive anhydrite intermixed with shales and dolomites (Fig. 14; also Higgins *et al.* 1991a, fig. 33, 1991b, fig. 7.17).

Canyon Elv and Nunatami Formations (**E**)

Names. Canyon Elv Formation: Peel & Cowie (1979), previously Cape Weber Formation of Troelsen (1950); Nunatami Formation: Poulsen (1927), Koch (1929a, b).
Other literature. Peel & Christie (1982), Sønderholm & Due (1985), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a), Iannelli (2002a).
Age. Early Ordovician.
Thickness and lithology. This limestone map unit is up to 220 m thick and forms the subtidal base of a major shallowing-upwards cycle that has map unit **W** as its upper part (Figs 14, 18). Both formations are cliff-forming as at Canyon Elv, with the Canyon Elv Formation the less resistant of the two (see Peel & Cowie 1979, fig. 5; Peel & Christie 1982, fig. 9). This formation is 40–60 m thick and composed of intermixed hard, buff-grey to brownish, burrow mottled to fossiliferous lime mudstones and thin beds of intraformational limestone breccia. In places, basal strata are rusty brown with Fe-rich intraformational breccia and shales. Iannelli (2002a) recognised two mappable members. Barite occurs along bedding planes and joints, and as stringers, giving the limestones a distinctive patchy, white-spotted appearance; this phenomenon may correspond to some of the irregular white 'chalklike' features mentioned by Troelsen (1950). The overlying Nunatami Formation is paler in colour, distinctively cliff forming, richly fossiliferous, and up to 160 m thick. Planar to wavy bedded, burrow-mottled, grey lime mudstone is the main rock type, together with intraformational breccia and locally shale. Heavily bioturbated intervals are associated with black to brown-grey chert; where chert is extensive, the beds are nodular layered and rubbly. The upper part of the formation contains thin laminated dolomite beds with stromatolites, as well as gastropod-rich beds and oolitic limestone. Numerous colour anomalies associated with iron staining occur (see under *Economic geology*).

Cape Webster Formation (**W**)

Name. Koch (1929a, b).
Other literature. Peel & Christie (1982), Sønderholm & Due (1985), Higgins *et al.* (1991a, b).
Age. Middle Ordovician.
Thickness and lithology. The Cape Webster Formation comprises pale, recessive dolomitic strata, often covered by talus from the overlying cliffs of the Kap Jackson Formation (Figs 18, 19; see Troelsen 1950, fig. 8; Peel & Christie 1982, fig. 10; Higgins *et al.* 1991a, fig. 33). There are both thickness and facies variations from south to north. At the type locality on the cliffs above Nunatami, the formation is *c.* 290 m thick and contains a middle member of thin-bedded evaporite and evaporitic dolomite, whereas in northern exposures this member is absent in a section that varies from 175 m to 240 m thick. There, the bulk of the formation comprises an intermixed succession of cyclic, thin laminated, buff- to green-grey, burrow-mottled fine-grained dolomites with dissolution breccia, dolomitic shales and siltstones, with sporadic limestone beds.

Morris Bugt Group

Name. Peel & Hurst (1980).
Other literature. Hurst (1980a), Smith *et al.* (1989), Higgins *et al.* (1991a, b).
Age. Late Middle Ordovician to Early Silurian.
Thickness and lithology. Throughout the Humboldt Gletscher map region, the Morris Bugt Group rests conformably on the Ryder Gletscher Group (Kap Webster Formation). It represents carbonate deposition in open marine conditions and in relatively deep water, compared to the restricted shallow water of the underlying group. The group is between 540 and 750 m thick comprising dark weathering, cliff-forming dolomitic limestones, with one distinctive recessive argillaceous unit in mid-section (Fig. 19; also Smith et al. 1989, fig. 3A). Three formations are recognised, divided into two map units.

Kap Jackson and Cape Calhoun Formations (**J**)

Names. Kap Jackson Formation: Smith *et al.* (1989); Cape Calhoun Formation: Troedsson (1926), Koch (1929a).
Other literature. Troelsen (1950), Peel & Hurst (1980), Higgins *et al.* (1991a), Iannelli (2002a).
Age. Late Middle to Late Ordovician.
Thickness and lithology. This map unit thins northwards from nearly 370 m along the south coast of

Washington Land to *c.* 290 m in Bessels Fjord. The two formations contrast in lithology, recessivity and thickness: the Kap Jackson Formation is cliff forming and from *c.* 300 to 230 m thick; the overlying Cape Calhoun Formation varies from *c.* 70 to 60 m and is distinctively recessive (Figs 14, 19). The older formation is composed mainly of dark, rubbly weathered, brown-grey dolomitic lime mudstones that for the most part have a nodular bedding (see Smith *et al.* 1989, fig. 5). Stylolites are common, and fossiliferous hardgrounds are iron stained and pyrite impregnated. The lower part (Gonioceras Member) comprises brownish weathering, massive lime mudstones that have varying clay/silt content and can be porcellaneous; some beds contain brown chert. Thin, yellow silty beds occur. The lime mudstones of the upper part (Troedsson Member) tend to be grey and burrow-mottled, with occasional greenish, less resistant, marly beds and dense dark grey to black lime mudstones. The Cape Calhoun Formation – an easily recognisable unit because of its greenish hue and recessivity bounded by much thicker resistant carbonates – is composed of green grey to bluish green nodular lime mudstones characterised by shale/silt partings (see Smith *et al.* 1989, fig. 6).

Aleqatsiaq Formation (**A**)

Name. Peel & Hurst (1980), Hurst (1980a).

Other literature. Hurst (1981), Sønderholm *et al.* (1987), Sønderholm & Harland (1989a, b), Smith *et al.* (1989), Higgins *et al.* (1991a, b), Dawes (2000a), Iannelli (2002a).

Age. Late Ordovician to Early Silurian.

Thickness and lithology. This cliff-forming formation, representing deposition in open marine to slightly restricted carbonate platform conditions, comprises micritic to fossiliferous limestones that have a distinctive rubbly weathered, nodular and burrow-mottled character. It shows extensive pervasive dolomitisation and emits a petroliferous odour. The Aleqatsiaq Formation thickens from *c.* 250 m at the type locality in south-western Pentamerus Bjerge to *c.* 380 m at Faith Gletscher (Fig. 14). The three members described by Iannelli (2002a) serve to illustrate the lithological variation; these generally correlate with the tripartite subdivision based mainly on sections to the north-east of the map sheet (see Sønderholm *et al.* 1987, fig. 3A, B; Smith *et al.* 1989, fig. 3A). The lower member is dark brown to brown-grey weathering, characterised by lime mudstones and fossiliferous grainstones, with minor, brown-grey chert lenses and limestone breccia; the middle member is light-grey to buff weathered, with limestones that vary from structureless to biostromal with mounds up to 15 m high; the upper member is grey to brown weathering, intermixed lime mudstone and dolomites, with sporadic brown-grey chert, and occasional mounds up to 50 m high.

Washington Land Group

Name. Hurst (1980a).

Other literature. Hurst (1980b, 1981), Hurst & Kerr (1982b), Hurst & Surlyk (1983), Sønderholm *et al.* (1987), Sønderholm & Harland (1989a), Higgins *et al.* (1991a, b), de Freitas & Nowlan (1998), Dawes *et al.* (2000a).

Age. Early to Late Silurian.

Thickness and lithology. The Washington Land Group shows complex facies variations reflected by the subdivision in the map area into eight formations that are the result of the southwards expansion and increased subsidence of the trough to the north (see

Fig. 19. Ordovician to Silurian strata along Petermann Gletscher viewed to the north, with Hubert Gletscher (**Hu**) visible in the distance. Ryder Gletscher Group: **E**, Nunatami Formation; **W**, recessive Kap Webster Formation. Morris Bugt Group: **J**, Kap Jackson Formation and thin recessive Cape Calhoun Formation (**cc**); **A**, Aleqatsiaq Fjord Formation. Washington Land Group: **G**, Petermann Halvø and Bessels Fjord Formations. **Arrow** on the foreground cliff marks a structure that may be a palaeovalley cut into **A** and filled by **G**, but this has yet to be confirmed. Height of the cliffs is over 900 m with unit **cc** about 60 m thick.

later, under *Peary Land Group*). The formations are grouped into four map units. The succession comprises a very diverse complex of carbonate lithologies, including major buildups and reef-derived deposits, lime mudstones, dolomitic limestones, dolomites and resedimented limestone conglomerates, together with subsidiary siltstones and shales. These represent a range of platform, shelf and slope environments. The spectacularly developed carbonate buildups, developed at several levels, have been referred to a number of settings, for example, intrashelf/shallow ramp, shelf margin, platform margin/deeper ramp and slope. Buildups occur in all four map units (**G**, **B**, **P**, **M**) but, apart from unit **B** (Adams Bjerg Formation), individual reefs are not depicted by symbols on the map (see earlier, under *Portrayal and description of map units*). Throughout the map region, the Washington Land Group conformably overlies the Morris Bugt Group (Aleqatsiaq Formation; Fig. 20) and interdigitates with siliciclastic strata of the Peary Land Group. Its maximum thickness is unknown, since the succession is truncated by the present-day erosion surface but the composite thickness in the map area is at least 1700 m.

Subdivisions and map nomenclature. It needs to be stressed that the subdivision of the Washington Land Group used on the Humboldt Gletscher map sheet is that formalised by Hurst (1980a). Nomenclatorial revision is pending, but remains unpublished, although new terminology has been prematurely used in several publications without reference to divergences from formal stratigraphy. Thus, on the adjoining Nyeboe Land map sheet (Henriksen 1992) and in one regional synthesis (Higgins *et al.* 1991a), informal stratigraphy is used. Changes relevant for the Humboldt Gletscher map sheet are that in Higgins *et al.* (1991a) three formations – Bessels Fjord, Offley Island, Kap Lucie Marie – are replaced by the new but undefined Djævlekløften Formation while on the Nyeboe Land map sheet, the Kap Morton and Kap Maynard Formations, are *also* included in this informal unit (Fig. 20).

Petermann Halvø, Kap Godfred Hansen, Bessels Fjord and Offley Island Formations (G)

Names. Hurst (1980a).

Other literature. Hurst & Surlyk (1983), Sønderholm *et al.* (1987), Sønderholm & Harland (1989a), Higgins *et al.* 1991b), Iannelli (2002a).

Age. Early Silurian.

Thickness and lithology. A very variable complex of platform and slope carbonates make up this map unit, several lithologies of which emit a strong petroliferous odour. It is composed of a sequential package of three formations (Petermann Halvø, Bessels Fjord and Offley Island Formations), as well as a reef-debris formation (Kap Godfred Hansen Formation). A pale marker unit of mounds and limestone breccia, well seen in Bessels Fjord, forms the lower strata of the Offley Island Formation (see Hurst 1980a, figs 33, 35; Hurst & Surlyk 1984, fig. 7) so that only the basal 100 m of this formation occurs on Humboldt Gletscher map sheet. The Kap Godfred Hansen and Petermann Halvø Formations conformably overlie the Morris Bugt Group (Aleqatsiaq Formation; Figs 14, 19), and interdigitate with the Pentamerus Bjerge Formation, a boundary shown arbitrarily on the map along the SE–NW-trending valley draining into Fossilbugt.

The Kap Godfred Hansen Formation is up to 350 m thick around Kap Godfred Hansen where it is essen-

	JOHN BROWN ISKAPPE – PETERMANN HALVØ			
	Hurst 1980a	Higgins *et al.* 1991a	Henriksen 1992	Dawes this paper
WASHINGTON LAND GROUP	Kap Maynard	Kap Maynard	Djævlekløften*	outside map
	Kap Morton	Kap Morton		Kap Morton
	Carbonate buildup and related formations: Kap Godfred Hansen, Hauge Bjerge, Pentamerus Bjerge			
	Kap Lucie Marie	Djævlekløften*	Djævlekløften*	outside map
	Offley Island			Offley Island
	Bessels Fjord			Bessels Fjord
	Petermann Halvø	Petermann Halvø	Petermann Halvø	Petermann Halvø
M.B.Gp	Aleqatsiaq Fjord MORRIS BUGT GROUP			

Fig. 20. Simplified scheme for the shelf sequence in the *northernmost part* of the map sheet with nomenclature based on Hurst (1980a), shown with that used on the adjoining map sheet (Nyeboe Land; Henriksen 1992) and in one regional account (Higgins *et al.* 1991a). The Djævlekløften Formation, marked with an **asterisk** and used inconsistently in the literature, remains undefined. The Kap Godfred Hansen, Hauge Bjerge and Pentamerus Bjerge Formations are included to complete the succession but their mid-table position is arbitrary and no attempt is made to portray their stratal relations. Each of these formations overlies the Morris Bugt Group and interdigitates with other formations.

tially a wedge of reef debris dominated by thick beds of resedimented carbonate breccia, with intervals of lime mudstone and grainstone (see Hurst 1980a, fig. 24; 1980b, fig. 13). The formation is considered to be derived from the reef complex making up the Pentamerus Bjerge (part of map unit **P**). The Petermann Halvø Formation is a pale marker, 65 to 95 m thick, of cliff-forming shallow shelf carbonates (Fig. 14; see Sønderholm & Harland, 1989a, fig. 5). The strata are mainly massive to mottled, micritic to fossiliferous limestones that are occasionally dolomitised, and that contain chert lenses and scattered vugs. Mound structures are common and these produce an undulating upper contact with up to 15 m relief. The overlying bipartite sequence on the map sheet (Bessels Fjord and Offley Island Formations, see Hurst 1980a, fig. 38), is an intermixed package of carbonate buildups and reef-derived bioclastic strata that intercalate and interdigitate with more flat-lying beds that vary in facies relative to the position on the carbonate platform. The buildups, up to 200 m thick, are mainly composed of pale, massive lime mudstones with some stromatoporoid, coral and crinoid biostromes. Inter-mound facies include bioclastic limestones and lime mudstones that vary from grey to black, and from laminated to nodular bedded, with shaly and cherty variants, as well as minor grainstone.

Adams Bjerg Formation (**B**)

Name. Hurst (1980a).
Other literature. Hurst (1980b, 1981), Sønderholm & Harland (1989a), Higgins *et al.* (1991a, b).
Age. Early Silurian.
Thickness and lithology. This formation is more than 300 m thick and restricted to the Kap Jefferson area. It is composed of two main parts: at the coast a carbonate buildup – the Kap Jefferson mound – and a flatish lying sequence composing the bulk of the exposure of creamy white, crystalline dolomite, structureless to laminated, in places stromatolitic, and with discontinuous beds of breccia and many vuggy levels (see Hurst 1980a, fig. 17). The buildup has a massive fenestral dolomite core, flanked by laminated, argillaceous dolomites that show both planar and domal stromatolites, and breccia beds. Both these lithologies are capped by dolomitised crinoid limestone (see Hurst 1981, figs 3, 4). The formation overlies the Aleqatsiaq Fjord Formation and interdigitates with, and is overlapped by, respectively, the Kap Schuchert and Lafayette Bugt Formations of the Peary Land Group.

Pentamerus Bjerge and Hauge Bjerge Formations (**P**)

Names. Hurst (1980a).
Other literature. Hurst (1980b, 1981), Sønderholm & Harland (1989a), Higgins *et al.* (1991a, b), Dawes *et al.* (2000a).
Age. Early–Middle Silurian.
Thickness and lithology. This map unit comprises major carbonate buildups, both core and flank deposits, as well as inter-buildup facies. The largest reefs exceed 500 m in thickness. Core facies with domal dips include lime mudstones, skeletal and bioclastic wackestones and stromatoporoid-, coral- and crinoid-rich rudstones; flank deposits comprise graded beds of bioclastic limestones, crinoidal grainstones and chaotic coarse megabreccia beds. Common inter-buildup deposits are dark cherty lime mudstones, laminated grainstones and shales. The strata overlie map unit **A** (Aleqatsiaq Formation, Morris Bugt Group) and interdigitate with map unit **L** (Peary Land Group; Fig. 21). While they are grouped together here as one map unit, the two formations contrast in outcrop form. Thus, the Pentamerus Bjerge Formation that takes its name from the uplands south-west of John Brown Iskappe, comprises a complex of extensive buildups that interdigitate and laterally coalesce, while the Hauge Bjerge Formation is composed of temporally and spatially isolated buildups often forming dome-shaped high ground that are embedded in less resistant siliciclastic strata of the Peary Land Group (Fig. 21). Buildup types from the map region are well illustrated in the literature: see Norford (1972, plate 6), Hurst (1980a, figs 21, 22, 52, 57; 1980b, figs 8, 9, 14); Sønderholm & Harland (1989a, fig. 9); Higgins *et al.* (1991a, fig. 51; 1991b, fig. 7.35) and Dawes *et al.* (2000a, fig. 8).

Kap Morton Formation (**M**)

Name. Hurst (1980a).
Other literature. Hurst (1981), Peel (1984), de Freitas *et al.* (1993).
Age. Middle to Late Silurian.
Thickness and lithology. This map unit of shallowly dipping, well-bedded, mainly pale carbonates, about 450 m thick, occurs on the west side of John Brown Iskappe overlying map unit **G**, and forms the *c.* 200 m succession on Hans Ø in mid-Kennedy Channel. It corresponds to the Kap Morton Formation of Hurst (1980a), but also includes strata referred to the Kap Godfred Hansen and Pentamerus Bjerge Formations (see Hurst 1980a, figs 24, 28). In the highest ground fringing the ice cap, it includes a stratal interval that probably equates with the Kap Maynard Formation (Fig.

20). Described in the literature mainly from sections north of the map sheet, the lower part of the map unit comprises massive, light grey, lime mudstones with incursions of bioclastic limestone and resedimented carbonate conglomerate. On Hans Ø, where the section is characterised by alternating pale and darker carbonates that are in part dolomitised, a pinnacle reef occurs together with stromatoporoid- and coral-rich biostromal beds (see de Freitas *et al.* 1993, fig. 7). The lime mudstones, both in Washington Land and on Hans Ø, are characterised by articulate megalodont bivalves (see Hurst 1980a, fig. 50; de Freitas 1990, fig. 2; de Freitas *et al.* 1993, fig. 4). The lithology of the upper part of the map unit is poorly known, but on aerial photographs it has the same well-layered character as the lower strata, and to the succession north of the map sheet referred by Hurst (1980a) and Jepsen *et al.* (1983) to the Kap Maynard Formation. The Hans Ø succession, with its Ludlow fauna, was referred to the Kap Maynard Formation by de Freitas *et al.* (1993, fig. 5), but is placed here in the Kap Morton Formation.

Peary Land Group

Name. Hurst (1980a), Hurst & Surlyk (1982).

Other literature. Larsen & Escher (1987), Higgins *et al.* (1991a).

Age. Early–Late Silurian.

Thickness and lithology. Seen regionally, the Peary Land Group represents a major southwards expansion of the deep-water trough characterised by flysch deposition dominated by siltstone and sandstone turbidites. Exposures in the Humboldt Gletscher map region represent the distal south-western part of the group with turbidites deposited in a carbonate slope environment. Main lithologies are black shaly mudstones interbedded with lime mudstones, cherts, resedimented limestone conglomerates and thin grainstone beds. The group overlies the Morris Bugt Group (Aleqatsiaq Formation) and interdigitates with its lateral platform carbonate equivalent, the Washington Land Group (Fig. 21A, B). The present-day erosion surface defines the top of the Peary Land Group. Thus the maximum thick-

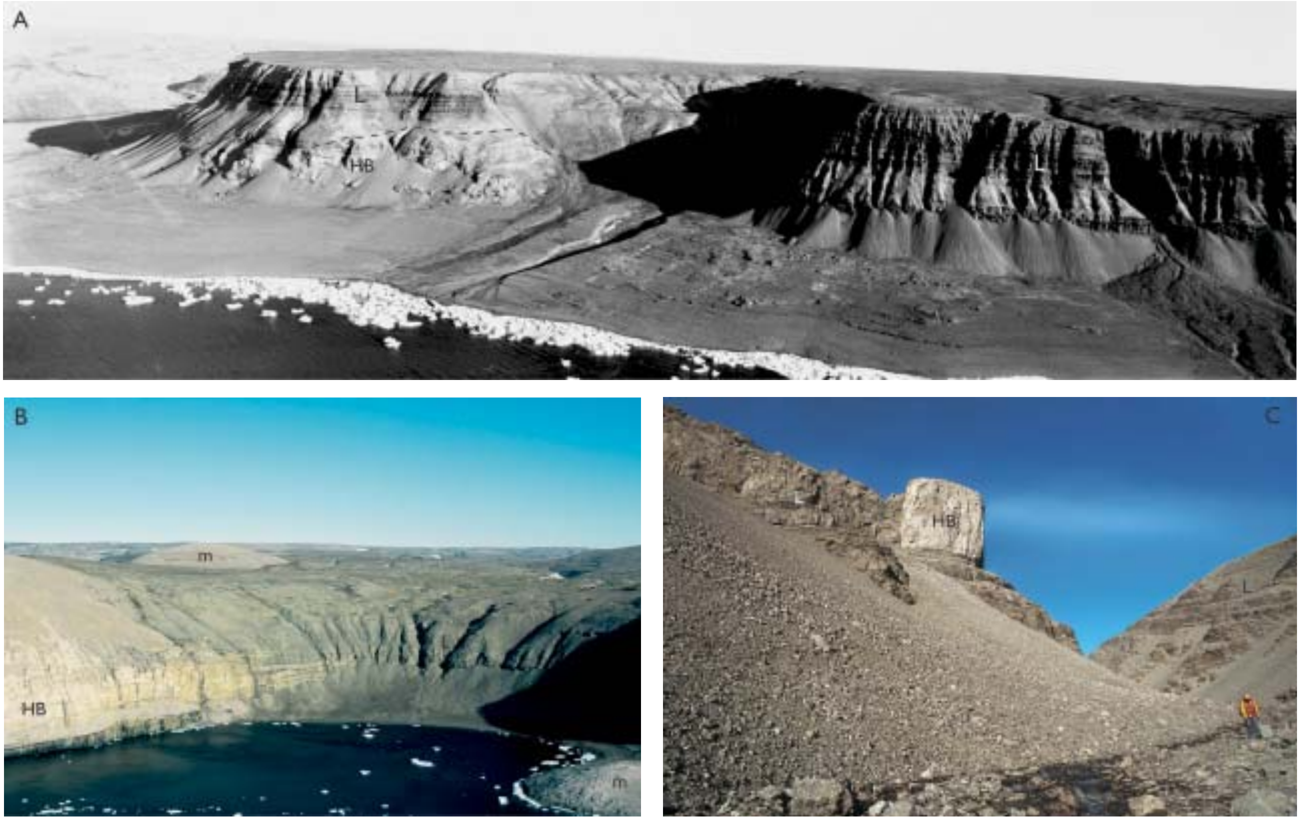

Fig. 21. Silurian facies relationships in coastal Washington Land involving carbonate buildups of the Hauge Bjerge Formation (**HB**) and slope sediments of the Peary Land Group (**L**). **A**: A major buildup (**HB**) overlying the Aleqatsiaq Formation that forms the poorly-exposed slopes above the shore, surrounded and overlain by the Lafayette Bugt Formation (**L**). About 10 km north of Kap Jefferson, with the plateau at *c.* 350 m and Holocene raised beaches at the mouth of the valley. Photo: Jakob Lautrup. **B**: Southern flank of Kap Constitution buildup (**HB**) showing interdigitation with sediments of the Cape Schuchert and Lafayette Bugt Formations (**L**). Dome-shaped hill in the background and the small peninsula bottom right are individual mounds (**m**). Section at the head of the bay is *c.* 300 m thick. Photo: Martin Sønderholm. **C**: Lafayette Bugt Formation (**L**) just east of the Kap Independence buildup composed of graptolitic shales, calcareous siltstones, with variously intermixed carbonate clast breccia beds and isolated reef olistoliths. The large block (**HB**) is *c.* 10 m across. Photo: Sven Monrad Jensen.

ness of the succession is unknown, but in Washington Land at least 500 m are preserved.

Cape Schuchert and Lafayette Bugt Formations (**L**)

Names. Cape Schuchert Formation: Koch (1929a); Lafayette Bugt Formation: Hurst (1980a).

Other literature. Norford (1972), Dawes & Haller (1979), Hurst (1981), Hurst & Surlyk (1983, 1984), Christiansen & Nøhr-Hansen (1989), Higgins *et al.* (1991a, b).

Age. Early–Late Silurian.

Thickness and lithology. In the Humboldt Gletscher map region, two formations, both with type localities in coastal Washington Land, correspond to the entire Peary Land Group preserved. The map unit is dominated by dark argillaceous strata, representing continuing deepening of the sea, and both formations contain resistant beds composed of pale carbonate debris shed from the developing reef complexes of the Washington Land Group (map units **G**, **B** and **P**). The basal strata are starved slope sediments of the Cape Schuchert Formation, 50 to 80 m thick, dominated by black, thin bedded, bituminous cherty lime mudstones, laminated mudstones and thin chert beds, and in places interbedded with thin carbonate turbidites (see Hurst 1980a, fig. 60; 1981, fig. 8). The overlying Lafayette Bugt Formation, more than 400 m thick, is characterised by thick units of black, planar laminated, graptolitic shale, interbedded with lime mudstones (see Hurst 1980a, fig. 62; Hurst & Surlyk 1984, fig. 15). In the neighbourhood of reefs, beds of resedimented carbonate breccia can exceed 10 m thick and isolated blocks of reef-facies limestone are common; these can stand out as knolls (Fig. 20C; also Hurst 1980b, fig. 8B; Dawes *et al.* 2000a, fig. 8).

Late Cenozoic

Neogene deposits are locally present north of Humboldt Gletscher; in contrast, Quaternary deposits are widespread and profuse. Although there is a long history of investigations dealing with surficial geology and glacial history – illustrated by more than 50 references pertaining to the map sheet cited in Dawes (1999) – no *systematic* survey of the Cenozoic geology of the region has been undertaken. Following attempts at mapping and regional synthesis in the 1950s and 1960s with air support from Pituffik (e.g. Davies & Krinsley 1962; Nichols 1969; Davies 1972, 1984a, b), later knowledge has been based on opportunistic observations and visits during which shells, peat and wood were collected for radiocarbon dating (Weidick 1976, 1977, 1978; C. Hurst in Peel 1978; Blake 1987). Historically, the coastland of Smith Sound has received much attention, and work in the 1980s included lake sediment studies with core sampling for palaeoecological analysis (Blake *et al.* 1992). Recent investigations have been concentrated north of Humboldt Gletscher where a late Cenozoic history has been established (Bennike 1998, 2000, 2002; Bennike & Jepsen 2000). For the most recent regional synthesis, see Funder (1989) and references therein.

Neogene

The two map units shown – Bjørnehiet Formation and non-carbonised wood – are of uncertain age. They are considered to be Neogene (?Pliocene) by comparison with wood-bearing sediments of Miocene–Pliocene age in adjacent Ellesmere Island and of Plio-Pleistocene age in eastern North Greenland (see Bennike 1990, 1998, 2000). Like these deposits, but unlike the surrounding Quaternary cover, the Bjørnehiet Formation is affected by fault movements.

Bjørnehiet Formation (**black star symbol**)

Name. Jepsen (1982).

Distribution and lithology. Cemented fluvial clastic sediments are known from a single occurrence *c.* 30 km north of the head of Cass Fjord, preserved on the banks of a N–S river valley. The formation is *c.* 45 m thick and estimated to cover 15 km^2. The main lithology is a carbonate-clast, matrix-supported oligomictic conglomerate with coarse-grained sandstone intervals. Basal beds, containing cobbles of shield rocks, rest with erosional unconformity on faulted Lower Palaeozoic carbonates. No *in situ* fossils have been found, but the formation was considered by Jepsen (1982) to be the source of branches and trunks of wood in the river valley north of the outcrop, although Bennike (2000) found no evidence for this. Dating of the wood has given non-finite ^{14}C ages (see below). The formation is overlain by unconsolidated glacial deposits: it is thought to have been deposited in a preglacial river system and faulted prior to glacial overburden.

Wood locality (**red cross symbol**)

This map symbol represents finds of loose pieces of non-fossilised wood in river valleys of three areas: in Washington Land, inland from Aleqatsiaq Fjord; on Petermann Halvø, west of Kap Bemerton; and in Daugaard-Jensen Land, north of Kap Lyngbæk. The wood fragments, smooth and abraded due to river transport, are up to 12 cm in diameter and 176 cm long. Wood is mentioned by Jepsen (1982), studied and illustrated by Bennike (1998, fig. 4; 2000, fig. 2) and dated to be older than 51 ka years B.P. (Weidick 1978). No *in situ* source is known. The most coherent distribution is along the valley draining into Aleqatsiaq Fjord where wood fragments form a 60-km trail from sea level to *c.* 600 m, ending just short of an ice cap. It is thus tempting to assume a source from deposits that are, or originally were, below the ice, and this gains credibility from adjacent Ellesmere Island, where high-elevation Pliocene sediments with wood are known (Bennike 2000).

Quaternary

Quaternary deposits that totally conceal bedrock form extensive areas in the Humboldt Gletscher map region. However, since it is essentially a bedrock map, overburden is only portrayed in a schematic manner. Some comments on distribution have been already given in the sections *Physiography* and *Exposure*. Broadly speaking, deposits are of two main types: glacial till that blankets the plateaux, and glacio-fluvial and fluvial sediments found mainly in river valleys. If portrayed en bloc, these deposits would cover well over 50% of the ice-free land, as can be seen for example on the glacial geology map of Davies (1984b). As a general rule, where illustrative bedrock elements need to be portrayed, Quaternary deposits are not shown. This applies both to field extrapolations and those obtained by photogrammetric procedures enabling the projection of stratigraphy and faults under areas of overburden, as is the principle of the pre-Quaternary map of Jepsen *et al.* (1983).

Conspicuous Quaternary features *not shown* on the map sheet are the gently sloping till plains forming the upper plateau surface on Franklinian Basin strata that mirrors the late Cenozoic peneplain. This cover is relatively undisturbed and probably up to 5 m thick. The most extensive expanses of drift shown are over the shield in the interior of Inglefield Land, a belt flanking the Inland Ice initially recognised by Koch (1933, plate II). This cover has been modified by solifluction, periglacial and fluvial processes. These deposits, that can be 30 m thick, support many lakes in an otherwise featureless terrain (Nichols 1969). North of Humboldt Gletscher, large flat-bottomed valley systems contain an appreciable thickness of fluvial and alluvial sands and gravels, and these are shown on the map (Fig. 3). In eastern Daugaard-Jensen Land, south-west of Kap Coppinger, where relief is relatively subdued, the distinction between river deposits and ground moraine modified by glacio-fluvial and solifluction action is obscure. In this region, Quaternary deposits are shown along watercourses, although on the intervening ground, bedrock (Cass Fjord Formation) is rarely seen and then only as frost-shattered rubble.

Ice limits

Erratics occur throughout the map region from sea-level to the highest ground, and generally decrease in abundance towards the north-west. As regards provenance, the most significant erratics are shield lithologies occurring on Palaeozoic strata along the Nares Strait coast, and porphyry erratics – a rock type unknown *in situ* – found between the ice margin and Kennedy Channel (Nichols 1969; Blake *et al.* 1992; Bennike 2000; Dawes *et al.* 2000b). The source area of the porphyry erratics must lie beneath the Inland Ice, indicating that the whole region was covered by the Greenland ice sheet during the Pleistocene. Morainic features connected with stages of ice retreat have been mapped (e.g. Nichols 1969; Davies 1984a; Blake *et al.* 1992; Appel 1996).

Pre-Holocene deposits

Interglacial deposits with both plant and animal remains are of very restricted outcrop. The main locality along the north side of the Humboldt Gletscher has given the oldest radiocarbon dates: 37.3 ka B.P. on marine shell fragments and > 45 ka B.P. on plant remains (Bennike 2000, 2002; Bennike & Jepsen 2000). Pre-Holocene shell fragments have also been recorded from Inglefield Land (Blake 1987; Blake *et al.* 1992).

Deltas, terraces and marine limit

The coastal Quaternary deposits shown on the map sheet are a variety of deltaic, marine and littoral deposits, in places forming well-developed terrace systems in marine deltas and along major rivers (see Nichols 1969, figs 11, 12). Holocene raised beaches are common along the outer coast (Figs 15, 21A) and the text-book examples at Rensselaer Bugt are perhaps the most spectacular, the beaches being continuous from the marine limit down to present sea level (see Nichols 1969, figs 6, 8, 9; Tedrow 1970, fig. 16). Recent data north of Humboldt Gletscher on Holocene marine limits following the last deglaciation, add to earlier investigations in the south (Nichols 1969; Blake *et al.* 1992; Bennike 2000, 2002). They fit a regional emergence pattern with contours parallel to Nares Strait. The marine limit is tilted to the south-east with a maximum of 110 m a.s.l. in northern Petermann Halvø (just north of the map sheet), about 85 m in western Washington Land and at Smith Sound, with the lowest values around 65 m on either side at the Humboldt Gletscher. Radiocarbon dates providing minimum ages of the last deglaciation range from 9.3 to 7.6 ka B.P. (Bennike 2002) while the oldest dated Holocene non-marine sediment is 8 ka B.P. from the base of a lacustrine section at Kap Inglefield (Blake *et al.* 1992).

Economic geology

Exploration of mineral and oil/gas potential up to 1999, both Survey and commercial, has been summarised in a report by Dawes (1999) that contains some 30 references relating to onshore prospecting including geological, geophysical and geochemical studies. Those from the last ten years are cited here under *History of geoscientific research*. The economic geology reviewed here, and the occurrences shown on the map, relate to two of the three geological provinces: the Palaeoproterozoic Inglefield mobile belt and the Palaeozoic Franklinian Basin. The main potential of the third province, the Mesoproterozoic Thule Basin, lies within the thick basinal succession to the south on the Thule map sheet (Dawes 1991a), for example, base metal correlatives of the Nanisivik deposit of northern Baffin Island, Canada.

Of the five mineral occurrences shown on the map sheet, the two within the Franklinian Basin have been commercially drilled.

Inglefield mobile belt

Early reconnaissance-type prospecting concentrated on the metal potential of the widespread gossans, and on the carbonate supracrustal rocks that are similar in setting and age to the host rocks of the Black Angel lead-zinc deposit of West Greenland (Gray 1975; Christensen 1985; Sharp 1991). Helped by airborne geophysics, and soil and rock geochemistry, exploration in the last decade has revealed promising enrichments of iron, copper and gold.

Reports on the mineral potential have identified three main mineralisation types classified in terms of host rock: paragneiss-, orthogneiss- and mafic–ultramafic-hosted (Dawes *et al.* 2000a; Pirajno *et al.* 2000, 2001, 2003; Thomassen *et al.* 2000a, b). The latter type includes the skarn-hosted mineralisation of Thomassen *et al.* (2000b). The occurrences shown on the map sheet have been selected for their regional and conspicuous nature (rust zones), their correspondence with the region's highest magnetic values (magnetite) and for the most promising metal values (copper and gold mineralisation).

Rust zones (**red dot symbol**)

Rust zones are present throughout Inglefield Land, being especially common in central and north-eastern parts where many are gossanous (Sharp 1991). They have strike lengths from a few metres to 5 km, and widths from cm-scale to around 200 m. Those chosen for map portrayal are the largest and most conspicuous; all are east of longitude 69°W. The most spectacular show colour variations from dark red and brown to locally orange and bright yellow-brown (see Gray 1975, frontispiece; Thomassen & Appel 1997, fig. 1; Thomassen *et al.* 2000b, frontispiece, figs 1, 8, 13). Rust zones in the west are less common, relatively small and non-gossanous.

The rust zones are sulphide ± graphite-bearing paragneisses and schistose rocks that are intercalated with other lithologies of map unit **gn**. Within the rust zones, disseminated pyrrhotite, with minor pyrite and chalcopyrite, are concentrated in horizons and bands subparallel to the main gneiss foliation; in places massive pyrrhotite occurs in bodies up to 30 m long and 0.5 m wide (see Dawes *et al.* 2000a, fig. 10; Pirajno *et al.* 2003, fig. 3). Mineralised grab samples have returned up to 1.4 ppm gold, 0.27% copper and 0.15% zinc (Thomassen *et al.* 2000b). A genesis model proposed by Pirajno *et al.* (2003) involves brines acting on sheared and mylonitic paragneisses, and in which both graphite and biotite played a role in the enrichment of copper and gold.

Magnetite (**mag**)

Magnetite exceeds accessory status in many rock types, including paragneiss (**gn**), orthogneiss (**go**) and the Minturn intrusive complex (**sy**). The most prominent linear magnetic high, with a peak value of 15.400nT, stretches east from Hatherton Bugt for about 80 km, passing into a cluster of non-linear anomalies that reflect the Minturn complex (Fig. 5; Stemp & Thorning 1995b). Much of the linear anomaly is concealed by overburden but in the area of the peak value, magnetite-rich cobbles (90% magnetite, 10% olivine) are abundant. This locality is marked **mag** on the map and pinpointed on Figure 5. Farther east around Minturn Elv, magnetite-rich orthogneisses are common, and massive magnetite seams, lenses and layers up to 20 cm thick occur within mafic and ultramafic rocks. The massive magnetite float originally located by Rio Tinto (Coppard 1996), together with the *in situ* occurrences to the east, form the Minturn Elv magnetite occurrence of Appel *et al.* (1995). The float is derived from a concealed magmatic deposit with elevated contents of nickel and vanadium that could extend over tens of kilometres along the magnetic high and represent appreciable tonnage.

Copper-gold mineralisation (**green dot symbol**)

Rock samples with values up to 12.5 ppm Au and 1.28% Cu, indicative of a copper-gold association have their highest gold enrichments in a 70 km-long NE–SW-trending belt, informally termed the 'North Inglefield Land gold belt' (Dawes *et al.* 2000a; Thomassen *et al.* 2000a, b; Pirajno *et al.* 2001). This enriched belt coincides with a magnetic lineament interpreted as a deep-seated structure (Stemp & Thorning 1995b). The major mafic–ultramafic unit east of Marshall Bugt runs parallel to the belt, and in addition to gold and copper, is anomalous in zinc, vanadium and manganese.

The three map localities, chosen for their metal enrichment and briefly presented below, serve to illustrate the varying host rocks involved. Details are found in Thomassen *et al.* (2000b). The locality at the western end of Septembersøerne, is a rust zone in paragneisses with intercalations of metapyroxenite with semi-massive pyrrhotite and chalcopyrite, samples of which have given up to 6.9 ppm gold and 0.38% copper. The Skarn mineralisation shown about 10 km south-west of Kap Agassiz, has yielded samples with values up to 0.6 ppm gold and 0.91% copper, and is within sheared calc-silicate rocks and orthogneiss intruded by a layered mafic–ultramafic complex (see Thomassen *et al.* 2000b, fig. 14). The north-eastern locality in the McGary Øer has returned the highest gold and copper values (cited above). The analysed sample is a malachite-stained, sheared quartz-rich rock within orthogneiss that contains ore minerals bornite, chalcopyrite, chalcocite, covellite, magnetite and hematite, and 20 micron-size gold grains.

Franklinian Basin

Early prospecting in the Humboldt Gletscher region was spurred by exploration in neighbouring Canada that led to the discovery of high-grade lead-zinc deposits and hydrocarbon fields. After galena and sphalerite were found in 1966 as vug fillings in Silurian reef carbonates at Kap Schuchert, Washington Land (Norford 1972), exploration crossed Nares Strait to reach the Lower Palaeozoic deposits in the Humboldt Gletscher region, and farther north-east across Greenland to Kronprins Christian Land (Fig. 1). Canadian-based Greenarctic Consortium was the main participant with a five-year concession (Stuart-Smith & Sproule 1970; Cominco 1971; Stuart-Smith & Campbell 1971) and between 1969 and 1973, appraisal of the petroleum potential was also undertaken (Stuart-Smith 1970; Stuart-Smith & Wennekers 1977).

Apart from the two mineralisations described below and shown on the map, others worthy of mention are: barite mineralisation is characteristic of the Canyon Elv Formation (Dawes *et al.* 2000a); red to orange-brown limonite and/or hematite stained zones, up to several hundred metres long, occur in the burrow-mottled limestones of the Nunatami Formation, typically associated with dolomitisation along dislocation zones (Iannelli 2002a); and pyrite impregnation is a characteristic of the hardgrounds in the Kap Jackson Formation (see under the map units described earlier).

Zinc-lead-silver mineralisation (**yellow square symbol**)

Discovered in 1997, this zinc-lead-silver mineralisation occurs along a fault-controlled valley on Petermann Halvø within the upper part of the Cape Clay Formation (Jensen 1998; Jensen & Schønwandt 1998). It comprises the 'Petermann prospect' of the Platinova / Rio Tinto exploration venture (Cope & Beswick 1999; Pirie *et al.* 1999), that acccording to Iannelli (2002b) bears the hallmarks of a Mississippi Valley-type deposit. The mineralisation is associated with intense dolomitic alteration zones and strong gravity signatures, being dominated by pyrite, with marcasite, smithsonite and hydrozincite, and with as later phases, galena and sphalerite. These ore minerals occur as open space infills within massive, burrow-mottled, micritic to stromatolitic dolomitised limestones and lime mudstones, with the main sites along NW–SE- to NNW–SSE-trending fault lineaments that splay off the main E–W- to ENE–WSW-trending steeply inclined fault. Grab samples have yielded values up to 41% Zn, 0.3% Pb and 211 ppm silver (Pirie *et al.* 1999). The entire showing has a strike length of *c.* 19 km (Iannelli 1999; Dawes *et al.* 2000a). On the map sheet, only the eastern and drilled part of this tract is shown. Drill core from ten holes revealed no economic-grade intersections but impressive local mineralisation, for example, a 23 m thick bed of massive pyrite (Cope & Beswick 1999).

Zinc-lead-barium mineralisation (**red square symbol**)

Situated east of Bjørnhiet, Cass Fjord, this zinc-lead-barium mineralisation is the 'Cass prospect' of the Platinova / Rio Tinto exploration venture. It was discovered in 1999 and comprises several mineralised sites along a 4 km strike length zone adjacent to a major ESE–WNW-trending regional fault (Cope & Beswick 1999; Iannelli 1999, 2002b). The mineralisation is hosted in three massive 'reactive' limestone levels in the lower half of the Cass Fjord Formation, with the lowest being the most pervasively dolomitised and most extensively mineralised. The main mineralisation consists of fine-grained, brown amber sphalerite, and medium- to coarse-grained galena and barite set in a buff to brown ferroan dolomite. Barite also forms seams and open space infills; galena can occur in eye-catching crystals up to 3 cm across (see Dawes *et al.* 2000a, fig. 11). The single 107 m deep drill hole returned an intersection of 8.4% zinc, 0.04% lead and 94 ppm silver over an interval of 1.2 m (Cope & Beswick 1999). The mineralisation style shows affinities with an 'Irish-type' model (Iannelli 2002b).

Petroleum geology

The Lower Palaeozoic strata of the Humboldt Gletscher map region were included in regional petroleum assessments undertaken initially by industry in the 1970s (see references above, under *Franklinian Basin*) and later by the Survey, mainly in the 1980s. The latter work included a modern interpretation of the tectono-sedimentary evolution of the basin, evaluation of source rocks and their thermal maturity pattern, and analysis of potential reservoirs. Results can be found in Christiansen *et al.* (1985), Christiansen (1989 and references therein) and Christiansen & Nøhr-Hansen (1989). The basic ingredients of a petroleum model exist: Silurian shelf margin biostromal limestones and major bioherms (Washington Land Group) as potential reservoirs, mantled and juxtaposed by dark argillites (Lafayette Bugt Formation) as the source as well as the seal for fluids in the reefs. Early mature organic-rich shales on Washington Land have a fair to excellent potential as source rocks (Christiansen & Nøhr-Hansen 1989) and several reefs represent small palaeo-oil fields with pore space filled with bitumen (Christiansen 1989; Dawes *et al.* 2000a). However, prospectivity is low since most of the major reefs are exhumed, and the regional geology militates against major subsurface plays.

Acknowledgements

Apart from helpful comments from colleagues at the Geological Survey of Denmark and Greenland (GEUS), the author is grateful for the external reviews to the map compilation by Andrew V. Okulitch and Thomas Frisch of, respectively, the Vancouver and Ottawa offices of the Geological Survey of Canada, and Franco Pirajno of the Geological Survey of Western Australia, Perth. Andrew Okulitch and A.K. (Tony) Higgins (GEUS), provided constructive reviews of these explanatory notes that have also benefited from comments by Ole Bennike, Jon R. Ineson, Martin Sønderholm and Bjørn Thomassen (GEUS). I am grateful to Jon Ineson and Svend Stouge for providing unpublished stratigraphical information and to Thomas R. Iannelli (London, Ontario) for map information. Special thanks are due to Hans F. Jepsen (GEUS), who was always willing to consult his notes and memory for stratigraphic information from field seasons 1976 and 1977, much of which unfortunately remains unpublished. Marcus Zentilli, (Dalhousie University, Halifax, Canada), kindly supplied information on a new pillow lava outcrop at Rensselaer Bugt. Technical help at GEUS with illustrations and photographic work from Jakob Lautrup, Kristian Anker Rasmussen and Benny Munk Schark is acknowledged.

References

Aldridge, R.J. 1980: Conodont colour as a guide to thermal history: variation in the upper Llandovery strata of North Greenland, 4 pp. Unpublished report, Geological Survey of Denmark and Greenland, Copenhagen, Denmark.

Appel, P.W.U. 1996: Minturn circles: a new glacial feature. Canadian Journal of Earth Sciences **33**(10), 1457–1461.

Appel, P.W.U. 1997: Al-rich warwickite from Inglefield Land, North-West Greenland. Mineralogical Magazine **61**, 693–698.

Appel, P.W.U., Dawes, P.R., Schønwandt, H.K., Thomassen, B. & Thorning, L. 1995: The Minturn Elv magnetite occurrence, Inglefield Land, North-West Greenland. Open File Series Grønlands Geologiske Undersøgelse **95/14**, 15 pp.

Bengaard, H.-J. 1995: Photogeological interpretation of Inglefield Land, North-West Greenland. Open File Series Grønlands Geologiske Undersøgelse **95/4**, 21 pp. + map.

Bennike, O. 1990: The Kap København Formation: stratigraphy and palaeobotany of a Plio-Pleistocene sequence in Peary Land, North Greenland. Meddelelser om Grønland Geoscience **23**, 85 pp.

Bennike, O. 1998: Late Cenozoic wood from Washington Land, North Greenland. Geology of Greenland Survey Bulletin **180**, 155–158.

Bennike, O. 2000: Notes on the late Cenozoic history of the Washington Land area, western North Greenland. Geology of Greenland Survey Bulletin **186**, 29–34.

Bennike O. 2002: Late Quaternary history of Washington Land, North Greenland. Boreas **31**, 260–272.

Bennike, O. & Jepsen, H.P. 2000: A new interglacial sequence from Washington Land, northern Greenland. Polar Research **19**(2), 267–270.

Bergström, J. & Peel, J.S. 1988: Lower Cambrian trace fossils from northern Greenland. In: Peel, J.S. (ed.): Cambrian–Jurassic fossils, trace fossils and stratigraphy from Greenland. Rapport Grønlands Geologiske Undersøgelse **137**, 43–53.

Blake, W.Jr. 1987: Geological Survey of Canada radiocarbon dates XXVI. Geological Survey of Canada Paper **86-7**, 60 pp.

Blake, W.Jr., Boucherle, M.M., Fredskild, B., Janssens, J.A. & Smol, J.P. 1992: The geomorphological setting, glacial history and Holocene development of 'Kap Inglefield Sø', Inglefield Land, North-West Greenland. Meddelelser om Grønland Geoscience **27**, 42 pp. + map.

Bryant, I.D. & Smith, M.P. 1985: Lowermost Ordovician sandstones in central North Greenland. Rapport Grønlands Geologiske Undersøgelse **126**, 25–30.

Bugge, C. 1910: Petrographische Resultate der 2ten Fram-Expedition. Report of the 2nd Norwegian Arctic Expedition 'Fram' 1898–1902, **3**(22), 38 pp. Kristiania: Videnskabs-Selskabet.

Callisen, K. 1929: Petrographische Untersuchung einiger Gesteine von Nordgrönland. Meddelelser om Grønland **71**(4), 217–255.

Christensen, K. 1985: Greenex A/S. Greenex' Prospektering 1985, 20 pp. Unpublished report, Greenex A/S, Copenhagen, Denmark (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **20058**).

Christiansen, F.G. (ed.) 1989: Petroleum geology of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **158**, 92 pp.

Christiansen, F.G. & Nøhr-Hansen, H. 1989: The Silurian shales of central and western North Greenland: evaluation of hydrocarbon source rock potential. Rapport Grønlands Geologiske Undersøgelse **143**, 47–71.

Christiansen, F.G., Nøhr-Hansen, H., Rolle, F. & Wrang, P. 1985: Preliminary analysis of the hydrocarbon source rock potential of central and western North Greenland. Rapport Grønlands Geologiske Undersøgelse **126**, 117–128.

Christie, R.L. 1967: Bache Peninsula, Ellesmere Island, Arctic Archipelago. Geological Survey of Canada Memoir **347**, 63 pp.

Christie, R.L. & Dawes, P.R. 1991: Geographic and geological exploration. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 5–25. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Collinson, J.D., Dawes, P.R., Peel, J.S. & Christie, R.L. 1982: Late Proterozoic and basal Cambrian stratigraphy of Inglefield Land, Washington Land and Bache Peninsula, Kane Basin region (78°–80°N), 33 pp. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark.

Cominco 1971: Pb-Zn mineralization in northern Greenland and the Silurian facies front, 5 pp. Unpublished report, Cominco Ltd., Vancouver, Canada (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **20357**).

Cope, I. & Beswick, J. 1999: Washington Land Report, 30 pp. + enclosures. Unpublished report Rio Tinto Mining and Exploration Limited, Bristol, UK (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **21718**).

Coppard, J. 1996: Greenland, Inglefield Land exclusive exploration licence 11/95. 1995 year end report, 13 pp. Unpublished report, RTZ Mining and Exploration Limited, Bristol, UK (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **21555**).

Cowie, J.W. 1961: Contributions of the geology of North Greenland. Meddelelser om Grønland **164**(3), 47 pp.

Davies, W.E. 1972: Landscape of northern Greenland. Cold Regions Research and Engineering Laboratory Special Report **164**, 67 pp. + maps (Hanover, New Hampshire, USA)

Davies, W.E. 1984a: Ice margin positions of North Greenland, 1:1 000 000. Unpublished map sheet, United States Geological Survey (in archives of Geological Survey of Denmark and Greenland, GEUS map **N24**).

Davies, W.E. 1984b: Glacial geology of North Greenland, 1:500 000, sheet 1 (Washington Land). Unpublished map sheet, United States Geological Survey (in archives of Geological Survey of Denmark and Greenland, GEUS map **N25b**).

Davies, W.E. & Krinsley, D.B. 1962: The recent regimen of the ice cap margin in North Greenland. In: Variations of the regime of existing glaciers. International Association of Hydrological Sciences **58**, 119–130.

Dawes, P.R. 1971: The North Greenland fold belt and environs. Bulletin of the Geological Society of Denmark **20**(3), 197–239.

Dawes, P.R. 1972: Precambrian crystalline rocks and younger sediments of the Thule district, North Greenland. Rapport Grønlands Geologiske Undersøgelse **45**, 10–15.

Dawes, P.R. 1976: Precambrian to Tertiary of northern Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 248–303. Copenhagen: Geological Survey of Greenland.

Dawes, P.R. 1979: Field investigations in the Precambrian terrain of the Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **95**, 14–22.

Dawes, P.R. 1988: Etah meta-igneous complex and the Wulff structure: Proterozoic magmatism and deformation in Inglefield Land, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **139**, 24 pp.

Dawes, P.R. 1991a: Geological map of Greenland, 1:500 000, Thule, sheet 5. Copenhagen: Geological Survey of Greenland.

Dawes, P.R. 1991b: Lauge Koch: pioneer geo-explorer of Greenland's far north. Earth Sciences History **10**(2), 130–153.

Dawes, P.R. 1996: Precambrian and Lower Palaeozoic geology. Geological map, 1:500 000. In: Schjøth, F., Steenfelt, A. & Thorning, L. (eds): Regional compilations of geoscience data from Inglefield Land, North-West Greenland. Thematic Map Series Grønlands Geologiske Undersøgelse **96/1**, 9–20 and Map 96/1–011.

Dawes, P.R. 1997: The Proterozoic Thule Supergroup, Greenland and Canada: history, lithostratigraphy and development. Geology of Greenland Survey Bulletin **174**, 150 pp.

Dawes, P.R. 1999: A review of geoscientific exploration and geology in the Kane Basin region of Greenland, central Nares Strait. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/32**, 58 pp. + 5 maps.

Dawes, P.R. & Christie, R.L. 1982: History of exploration and geology in the Nares Strait region. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 19–36.

Dawes, P.R. & Christie, R.L. 1991: Geomorphic regions. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 27–56. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Dawes, P.R. & Haller, J. 1979: Historical aspects in the geological investigation of northern Greenland. Part 1. New maps and photographs from the 2nd Thule Expedition 1916–1918 and the Bicentenary Jubilee Expedition 1920–1923. Meddelelser om Grønland **200**(4), 38 pp.

Dawes, P.R. & Higgins, A.K. (eds) 2000: Review of Greenland activities 1999. Geology of Greenland Survey Bulletin **186**, 105 pp.

Dawes, P.R. & Kerr, J.W. (eds) 1982: Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 392 pp.

Dawes, P.R. & Rex, D.C. 1986: Proterozoic basaltic magmatic periods in North-West Greenland: evidence from K/Ar ages. Rapport Grønlands Geologiske Undersøgelse **130**, 24–31.

Dawes, P.R., Rex, D.C. & Jepsen, H.F. 1973: K/Ar whole rock ages of dolerites from the Thule district, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **55**, 61–66.

Dawes, P.R., Peel, J.S. & Rex, D.C. 1982: The Kap Leiper basic dyke and the age of the dolerites of Inglefield Land, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **110**, 14–19.

Dawes, P.R., Larsen, O. & Kalsbeek, F. 1988: Archean and Proterozoic crust in North-West Greenland: evidence from Rb-Sr whole-rock age determinations. Canadian Journal of Earth Sciences **25**(9), 1365–1373.

Dawes, P.R. *et al.* 2000a: Kane Basin 1999: mapping, stratigraphic studies and economic assessment of Precambrian and Lower Palaeozoic provinces in north-western Greenland. Geology of Greenland Survey Bulletin **186**, 11–28.

Dawes, P.R., Thomassen, B. & Andersson, T.I. 2000b: A new volcanic province: evidence from glacial erratics in western North Greenland. Geology of Greenland Survey Bulletin **186**, 35–41.

de Freitas, T.A. 1990: Implications of glacial sculpture on Hans Island, between Greenland and Ellesmere Island. Journal of Glaciology **36**(124), 129 only.

de Freitas, T.A. & Nowlan, G.S. 1998: A new, major Silurian reef tract and overview of regional Silurian reef development, Canadian Arctic and north Greenland. Bulletin of Canadian Petroleum Geology **46**(3), 327–349.

de Freitas, T.A., Brunton, F. & Bernecker, T. 1993: Silurian megalodont bivalves of the Canadian Arctic and Australia: paleoecology and evolutionary significance. Palaios **8**(5), 450–464.

Fortey, R.A. & Peel, J.S. 1989: Stratigraphy and hystricurid trilobites of the Christian Elv Formation (Lower Ordovician) of western North Greenland. Rapport Grønlands Geologiske Undersøgelse **144**, 5–15.

Fortey, R.A. & Peel, J.S. 1990: Early Ordovician trilobites and molluscs from the Poulsen Cliff Formation, Washington Land, western North Greenland. Bulletin of the Geological Society of Denmark **38**(1–2), 11–32.

Forsberg, R., Ekholm, S. & Olsen, H. 1994: Gravity measurements in the Thule area, Greenland 1994, 29 pp. Unpublished Survey and Processing report, Kort & Matrikelstyrelsen, Copenhagen, Denmark.

Forsberg, R., Ekholm, S., Madsen, B., Jensen, A. & Olsen, H. 1995: Gravity and GPS measurements in Greenland 1995. Nares Strait ('OP Bouguer 95') and East Greenland regions, 55 pp. Unpublished Survey and Processing report, Kort & Matrikelstyrelsen, Copenhagen, Denmark.

Frisch, T. 1981: Comparative note on the Precambrian basement of southern Inglefield Land and eastern Ellesmere Island. Rapport Grønlands Geologiske Undersøgelse **105**, 14–18.

Frisch, T. & Christie, R.L. 1982: Stratigraphy of the Proterozoic Thule Group, southeastern Ellesmere Island, Arctic Archipelago. Geological Survey of Canada Paper **81-19**, 13 pp.

Frisch, T. & Dawes, P.R. 1982: The Precambrian Shield of northernmost Baffin Bay: correlation across Nares Strait. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 79–88.

Funder, S. (coordinator) 1989: Quaternary geology of the ice-free areas and adjacent shelves of Greenland. In: Fulton, R.J. (ed.): Quaternary geology of Canada and Greenland. Geology of Canada **1**, 742–792. Ottawa: Geological Survey of Canada (also The geology of North America **K-1**, Geological Society of America).

Geoterrex 1994: Logistics and processing report of an airborne GEOTEM electromagnetic and magnetic survey over Inglefield Land, Greenland, for the Geological Survey of Greenland, 58 pp. + appendices. Unpublished report, Geoterrex, Ottawa, Canada (in archives of Geological Survey of Denmark and Greenland, Copenhagen).

Geoterrex-Dighem 1998: Logistics and processing report. Project AEM Greenland 1994–98. Airborne GEOTEM/magnetic survey over Washington Land/Daugaard-Jensen Land in western North Greenland, 12 pp. + appendices. Unpublished report, Geoterrex-Dighem Limited, Ottawa, Canada (in archives of Geological Survey of Denmark and Greenland, Copenhagen).

GGU 1985: Report on the 1984 geological expedition to central and western North Greenland. Rapport Grønlands Geologiske Undersøgelse **126**, 128 pp.

GGU 1987: Report on the 1985 geological expedition to central and western North Greenland. Rapport Grønlands Geologiske Undersøgelse **133**, 168 pp. + map.

Gowen, J. & Kelly, J.G. 1996: Inglefield Land exploration programme 1995, 15 pp. Unpublished report, Nunaoil A/S, Copenhagen, Denmark (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **21447**).

Gray, J. 1975: Report on the geology and the mineral potential of the Inglefield Land area, Northwest Greenland, 1973 field season, 21 pp. + appendices, plates, map. Unpublished report, Internationalt Mineselskab A/S, Edmonton, Alberta, Canada (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **20807**).

Hansen, E.S., Dawes, P.R., & Thomassen, B. in press: Epilithic lichen communities in High Arctic Greenland: physical, environmental, geological and sociological aspects of their ecology in Inglefield Land (78°–79°N). Arctic and Alpine Research.

Hansen, K., Dawes, P.R. & Frisch, T. 2004: Fission track study of Precambrian rocks of Canada and Greenland across Nares Strait. 10th International conference on fission track dating and thermochronology, Amsterdam, 8–13 August, 2004. Abstract TEC–14–0, 126 only.

Henriksen, N. 1992: Geological map of Greenland, 1:500 000, Nyeboe Land, sheet 7, Peary Land, sheet 8. Descriptive text, 40 pp. + 2 maps. Copenhagen: Geological Survey of Greenland.

Henriksen, N. & Peel, J.S. 1976: Cambrian – Early Ordovician stratigraphy in south-western Washington Land, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **80**, 17–23.

Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R. 2000: Greenland from Archaean to Quaternary. Descriptive text to the Geological map of Greenland 1:2 500 000. Geology of Greenland Survey Bulletin **185**, 93 pp. + map.

Higgins, A.K., Ineson, J.R., Peel, J.S., Surlyk, F. & Sønderholm, M. 1991a: Lower Palaeozoic Franklinian Basin of North Greenland. In: Peel, J.S. & Sønderholm, M. (eds): Sedimentary basins of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **160**, 71–139.

Higgins, A.K., Ineson, J.R., Peel, J.S., Surlyk, F. & Sønderholm, M. 1991b: Cambrian to Silurian basin development and sedimentation, North Greenland. In: Trettin, H.P. (ed.): Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 109–161. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Hoffman, P.E. 1988: United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia. Annual Review of Earth and Planetary Science **16**, 543–603.

Hofmann, H.J. & Jackson, G.D. 1996: Notes on the geology and micropaleontology of the Proterozoic Thule Group, Ellesmere Island, Canada and North-West Greenland. Geological Survey of Canada Bulletin **495**, 26 pp.

Hurst, J.M. 1980a: Silurian stratigraphy and facies distribution in Washington Land and western Hall Land, North Greenland. Bulletin Grønlands Geologiske Undersøgelse **138**, 95 pp.

Hurst, J.M. 1980b: Palaeogeographic and stratigraphic differentiation of Silurian carbonate buildups and biostromes of North Greenland. American Association of Petroleum Geologists Bulletin **64**(4), 527–548.

Hurst, J.M. 1981: Platform edge and slope relationships: Silurian of Washington Land, North Greenland and comparison to Arctic Canada. Bulletin of Canadian Petroleum Geology **29**(3), 408–419.

Hurst, J.M. & Kerr, J.W. 1982a: Brecciated lineaments in Washington Land, North Greenland, and their relation to Nares Strait. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 193–198.

Hurst, J.M. & Kerr, J.W. 1982b: Upper Ordovician to Silurian facies patterns in eastern Ellesmere Island and western North Greenland and their bearing on the Nares Strait lineament. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 137–145.

Hurst, J.M. & Surlyk, F. 1982: Stratigraphy of the Silurian turbidite sequence of North Greenland. Bulletin Grønlands Geologiske Undersøgelse **145**, 121 pp.

Hurst, J.M. & Surlyk, F. 1983: Depositional environments along a carbonate ramp to slope transition in the Silurian of Washington Land, North Greenland. Canadian Journal of Earth Sciences **20**(3), 473–499.

Hurst, J.M. & Surlyk, F. 1984: Tectonic control of Silurian carbonate-shelf margin morphology and facies, North Greenland. American Association of Petroleum Geologists Bulletin **68**(1), 1–17.

Iannelli, T.R. 1999: Preliminary report on the results of field work: Kane Basin project, northwestern Greenland, 24 pp. Unpublished report TRI-EX Consultants Ltd., London, Ontario, Canada (in archives of Geological Survey of Denmark and Greenland, GEUS File report **21851**).

Iannelli, T.R. 2002a: Kane Basin Project: Cambrian to Silurian stratigraphic sections from Washington Land, northwestern Greenland, 40 pp. Unpublished report TRI-EX Consultants Ltd., London, Ontario, Canada (in archives of Geological Survey of Denmark and Greenland, GEUS File report **21853**).

Iannelli, T.R. 2002b: A review of Cass Fjord Formation stratigraphy and Cambro-Ordovician carbonate-hosted base metal mineralization, Washington Land, northwestern Greenland, 32 pp. Unpublished report TRI-EX Consultants Ltd., London, Ontario, Canada (in archives of Geological Survey of Denmark and Greenland, GEUS File report **21852**).

Ineson, J.R. & Peel, J.S. 1987: Cambrian platform – outer shelf relationships in the Nordenskiöld Fjord region, central North Greenland. Rapport Grønlands Geologiske Undersøgelse **133**, 13–26.

Ineson, J.R. & Peel, J.S. 1997: Cambrian shelf stratigraphy of North Greenland. Geology of Greenland Survey Bulletin **173**, 120 pp.

Jackson, H.R. *et al.* 2002: Cruise 2001 *Louis S. St Laurent* passages. Pathways to the Arctic seismic survey and geoscientific experiment, Resolute (Nunavut) to Thule (Greenland). Geological Survey of Canada Open File **4828**, 157 pp.

Jepsen, H.F. 1982: The Bjørnehiet Formation: a faulted preglacial conglomerate, Washington Land, North Greenland. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 151–155.

Jepsen, H.F. & Dueholm, K.S. 1978: Computer supported geological photo-interpretation. Rapport Grønlands Geologiske Undersøgelse **90**, 146–150.

Jepsen, H.F., Henriksen, N., Hurst, J.M. & Peel, J.S. 1983: Geology, 1:250 000, Washington Land and Daugaard-Jensen Land. Copenhagen: Geological Survey of Greenland.

Jensen, S.M. 1998: Carbonate-hosted Zn-Pb-Ag mineralisation in

Washington Land, western North Greenland. Geology of Greenland Survey Bulletin **180**, 67–72.

Jensen, S.M. & Schønwandt, H.K. 1998: A new carbonate-hosted Zn-Pb-Ag occurrence in Washington Land, western North Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1998/3**, 31 pp.

Kane, E.K. 1856: Arctic explorations: The Second Grinnell Expedition in search of Sir John Franklin, 1853, '54, '55. **1**, 464 pp.; **2**, 467 pp. Philadelphia: Childs & Peterson.

Koch, L. 1920: Stratigraphy of Northwest Greenland. Meddelelser Dansk Geologisk Forening **5**(17), 78 pp.

Koch, L. 1928: The physiography of North Greenland. In: Vahl, M. *et al.* (eds): Greenland **1**, The discovery of Greenland, exploration and nature of the country, 491–518. Copenhagen & London: C.A. Reitzel & Oxford University Press.

Koch, L. 1929a: Stratigraphy of Greenland. Meddelelser om Grønland **73**, 2(2), 205–320.

Koch, L. 1929b: The geology of the south coast of Washington Land. Meddelelser om Grønland **73**, 1(1), 39 pp.

Koch, L. 1933: The geology of Inglefield Land. Meddelelser om Grønland **73**, 1(2), 38 pp.

Larsen, O. & Dawes, P.R. 1974: K/Ar and Rb/Sr age determinations on Precambrian crystalline rocks in the Inglefield Land – Inglefield Bredning region, Thule district, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **66**, 4–8.

Larsen, P.-H. & Escher, J.C. 1987: Additions to the lithostratigraphy of the Peary Land Group (Silurian) in western and central North Greenland. Rapport Grønlands Geologiske Undersøgelse **133**, 65–80.

LeCheminant, A.N. & Heaman, L.M. 1991: U-Pb ages for the 1.27 Ga. MacKenzie igneous events, Canada: support for the plume initiation model. GAC/AGC, MAC/AMS, SEG meeting, Toronto. Program with abstracts **16**, A73 only.

Low, A.P. 1906: Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on board D.G.S. Neptune 1903–1904, 355 pp. Ottawa: Government Printing Bureau.

Nichols, R.L. 1969: Geomorphology of Inglefield Land, North Greenland. Meddelelser om Grønland **188**(1), 109 pp.

Nielsen, T.F.D. 1987: Mafic dykes swarms in Greenland: a review. In: Halls, H.C. & Fahrig, W.F. (eds): Mafic dyke swarms. Geological Association of Canada Special Paper **34**, 349–360.

Nielsen, T.F.D. 1990: Melville Bugt dyke swarm: a major 1645 Ma alkaline magmatic event in west Greenland. In: Parker, A.J., Rickwood, P.C. & Tucker, D.H. (eds): Mafic dykes and emplacement mechanisms, 497–505. Rotterdam, Netherlands: A.A. Balkema.

Norford, B.S. 1972: Silurian stratigraphic sections at Kap Tyson, Offley Ø and Kap Schuchert, northwestern Greenland. Meddelelser om Grønland **195**(2), 40 pp.

Nutman, A.P., Dawes, P.R. & Kalsbeek, F. 2004: Palaeoarchaean, Neoarchaean and Palaeoproterozoic complexes in northern Greenland: a new terrane constellation for the High Arctic. Manuscript to be submitted to Precambrian Research.

Palmer, A.R. & Peel, J.S. 1981: Dresbachian trilobites and stratigraphy of the Cass Fjord Formation, western North Greenland. Bulletin Grønlands Geologiske Undersøgelse **141**, 46 pp.

Peel, J.S. 1977: Cambrian–Silurian studies in Washington Land, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **85**, 30–33.

Peel, J.S. 1978: Geological investigations in Lower Palaeozoic terrain of northern Greenland between 78°30'N and 81°30'N. Rapport Grønlands Geologiske Undersøgelse **90**, 14–16.

Peel, J.S. 1982: The Lower Paleozoic of Greenland. In: Embry, A.F. & Balkwill, H.R. (eds): Arctic geology and geophysics. Canadian Society of Petroleum Geologists Memoir **8**, 309–330.

Peel, J.S. 1984: Geological reconnaissance on Hans Ø, North Greenland, 4 pp. Unpublished preliminary report, Geological Survey of Greenland, Copenhagen, Denmark.

Peel, J.S. & Christie, R.L. 1982: Cambrian–Ordovician platform stratigraphy: correlations around Kane Basin. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 117–135.

Peel, J.S. & Cowie, J.W. 1979: New names for Ordovician formations in Greenland. In: Peel, J.S. (compiler): Lower Palaeozoic stratigraphy and palaeontology: shorter contributions. Rapport Grønlands Geologiske Undersøgelse **91**, 117–124.

Peel, J.S. & Hurst, J.M. 1980: Late Ordovician and early Silurian stratigraphy of Washington Land, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **100**, 18–24.

Peel, J.S. & Wright, S.C. 1985: Cambrian platform stratigraphy in the Warming Land – Freuchen Land region, North Greenland. Rapport Grønlands Geologiske Undersøgelse **126**, 17–24.

Peel, J.S., Dawes, P.R., Collinson, J.D. & Christie, R.L. 1982: Proterozoic – basal Cambrian stratigraphy across Nares Strait: correlation between Inglefield Land and Bache Peninsula. In: Dawes, P.R. & Kerr, J.W. (eds): Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland Geoscience **8**, 105–115.

Pirajno, F., Thomassen, B., Iannelli, T.R. & Dawes, P.R. 2000: Copper-gold mineralisation in Inglefield Land, NW Greenland. Newsletter of the International Liaison Group on Gold Mineralization **30**, 117–135.

Pirajno, F., Thomassen, B. & Dawes, P.R. 2001: Copper-gold mineralisation in the Palaeoproterozoic Inglefield mobile belt, Northwest Greenland. Australian Institute of Geoscientists, AIG News **66**, 1–10.

Pirajno, F., Thomassen, B. & Dawes, P.R. 2003: Copper-gold occurrences in the Palaeoproterozoic Inglefield mobile belt, northwest Greenland: a new mineralisation style? Ore Geology Reviews **22**, 225–249.

Pirie, J., Valle, G.D., van der Stijl, F., Coppard, J. & Andersen, E. 1999: Report on August 1998 exploration activity, Washington Land Project, 21 pp. + enclosures. Unpublished report, Platinova A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **21833**).

Poulsen, C. 1927: The Cambrian, Ozarkian and Canadian faunas of Northwest Greenland. Meddelelser om Grønland **70**(1/2), 233–343.

Poulsen, C. 1946: Notes on Cambro-Ordovician fossils collected by the Oxford University Ellesmere Land Expedition 1934–35. Quarterly Journal of the Geological Society of London **102**(3), 299–337.

Rasmussen, T.M. 1999: Airborne electromagnetic and magnetic survey in Washington Land and Daugaard-Jensen Land, western North Greenland. Results from project AEM Greenland 1998. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/10**, 19 pp. + 12 maps.

Samuelsson, J., Dawes, P.R. & Vidal, G. 1999: Organic-walled microfossils from the Proterozoic Thule Supergroup, Northwest Greenland. Precambrian Research **96**(1), 1–23.

Schjøth, F. & Thorning, L. 1998: GIS compilation of geoscience data: an ArcView GIS version of previously published thematic maps from Inglefield Land, North-West Greenland.

Danmarks og Grønlands Geologiske Undersøgelse Rapport **1988/107**, 59 pp. + CD-ROM.

Schjøth, F., Steenfelt, A. & Thorning, L. (eds) 1996: Regional compilations of geoscience data from Inglefield Land, North-West Greenland. Thematic Map Series Grønlands Geologiske Undersøgelse **96/1**, 35 pp. + 51 maps.

Sharp, G. 1991: Gossan search on Inglefield Land, North West Greenland, 22 pp. + appendices. Unpublished report, RTZ Mining and Exploration Limited, Bristol, UK (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **21084**).

Smith, P.M., Sønderholm, M. & Tull, S.J. 1989: The Morris Bugt Group (Middle Ordovician – Silurian) of North Greenland and its correlatives. In: Peel, J.S. (ed.): North Greenland stratigraphy and petroleum geology. Rapport Grønlands Geologiske Undersøgelse **143**, 5–20.

Sønderholm, M. & Due, P.H. 1985: Lower and Middle Ordovician platform carbonate lithostratigraphy of Warming Land, Wulff Land and Nares Land, North Greenland. Rapport Grønlands Geologiske Undersøgelse **126**, 31–46.

Sønderholm, M. & Harland, T.L. 1989a: Franklinian reef belt, Silurian, North Greenland. In: Geldsetzer, H.H.J., James, N.P. & Tebbutt, G.E. (eds): Reefs, Canada and adjacent areas. Canadian Society of Petroleum Geologists Memoir **13**, 356–366.

Sønderholm, M. & Harland, T.L. 1989b: Latest Ordovician – earliest Silurian carbonate mounds, western North Greenland. In: Geldsetzer, H.H.J., James, N.P. & Tebbutt, G.E. (eds): Reefs, Canada and adjacent areas. Canadian Society of Petroleum Geologists Memoir **13**, 241–243.

Sønderholm, M., Harland, T.L., Due, P.H., Jørgensen, L.N. & Peel, J.S. 1987: Lithostratigraphy and depositional history of Upper Ordovician – Silurian shelf carbonates in central and western North Greenland. Rapport Grønlands Geologiske Undersøgelse **133**, 27–40.

Steenfelt, A. & Dam, E. 1996: Reconnaissance geochemical mapping of Inglefield Land, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1996/12**, 27 pp. + 49 maps.

Steenfelt, A., Dawes, P.R., Krebs, J.D., Moberg, E. & Thomassen, B. 2002: Geochemical mapping of the Qaanaaq region, 77°10′ to 78°10′N, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2002/65**, 29 pp. + 48 maps.

Stemp, R.W. & Thorning, L. 1995a: A new airborne electromagnetic and magnetic survey of Inglefield Land, North-West Greenland: Project AEM Greenland 1994–1998. Rapport Grønlands Geologiske Undersøgelse **165**, 64–68.

Stemp, R.W. & Thorning, L. 1995b: Airborne electromagnetic and magnetic survey of Inglefield Land, North-West Greenland. Results from project AEM Greenland 1994. Open File Series Grønlands Geologiske Undersøgelse **95/1**, 45 pp. + 4 maps.

Stuart-Smith, J.H. 1970: Hydrocarbon potential of northern Greenland. American Association of Petroleum Geologists Bulletin **54**(12), 2507 only.

Stuart-Smith, J.H. & Campbell, D.L. 1971: The geology of Greenland north of latitude 74º30′N. Report No. 2, **2**. Mineral prospects of northern Greenland, 62 pp. + 3 map folios. Unpublished report, J.C. Sproule and Associates Ltd., Calgary, Canada for Greenarctic Consortium (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **20811**).

Stuart-Smith, J.H. & Sproule, J.C. 1970: The geology of Greenland north of latitude 74°30′. Report No. 1, Field season 1969, **1**, 65 pp. Unpublished report, J.C. Sproule and Associates Ltd., Calgary, Canada for Greenarctic Consortium (in archives of Geological Survey of Denmark and Greenland, GEUS Report File **20802**).

Stuart-Smith, J.H. & Wennekers, J.H.N. 1977: Geology and hydrocarbon discoveries of Canadian Arctic Islands. American Association of Petroleum Geologists Bulletin **61**, 1–27.

Sutherland, P.C. 1853: On the geological and glacial phaenomena of the coasts of Davis' Strait and Baffin's Bay. Quarterly Journal of the Geological Society of London **9**, 296–312.

Tedrow, J.C.F. 1970: Soil investigations in Inglefield Land, Greenland. Meddelelser om Grønland **188**(3), 93 pp.

Thomassen, B. & Appel, P.W.U. 1997: Ground check of airborne geophysical anomalies and regional rust zones in Inglefield Land, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/141**, 43 pp.

Thomassen, B. & Dawes, P.R. 1996: Inglefield Land 1995: geological and economic reconnaissance in North-West Greenland. Bulletin Grønlands Geologiske Undersøgelse **172**, 62–68.

Thomassen, B., Dawes, P.R., Iannelli, T.R. & Pirajno, F. 2000a: Gold indications in northern Inglefield Land, North-West Greenland: a preliminary report from project Kane Basin 1999. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/9**, 14 pp.

Thomassen, B., Pirajno, F., Iannelli, T.R., Dawes, P.R. & Jensen, S.M. 2000b: Economic geology investigations in Inglefield Land, North-West Greenland: part of the project Kane Basin 1999. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2000/100**, 98 pp. + 2 maps.

Thomassen, B., Dawes, P.R., Steenfelt, A. & Krebs, J.D. 2002a: *Qaanaaq 2001*: mineral exploration reconnaissance in North-West Greenland. Geology of Greenland Survey Bulletin **191**, 133–143.

Thomassen, B., Krebs, J.D. & Dawes, P.R. 2002b: *Qaanaaq 2001*: mineral exploration in the Olrik Fjord – Kap Alexander region, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **20002/86**, 72 pp. + map.

Trettin, H.P. (ed.) 1991: Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada **3**, 569 pp. + map vol. Ottawa: Geological Survey of Canada (also The geology of North America **E**, Geological Society of America).

Troedsson, G.T. 1926: On the Middle and Upper Ordovician faunas of northern Greenland. I. Cephalopods. Meddelelser om Grønland **71**, 1–157.

Troelsen, J.C. 1950: Contributions to the geology of Northwest Greenland, Ellesmere Island and Axel Heiberg Island. Meddelelser om Grønland **149**(7), 86 pp.

Weidick, A. 1976: Glaciations of Northern Greenland – new evidence. Polarforschung **46**(1), 26–33.

Weidick, A. 1977: C^{14} dating of Survey material carried out in 1976. Rapport Grønlands Geologiske Undersøgelse **85**, 127–129.

Weidick, A. 1978: C^{14} dating of Survey material carried out in 1977. Rapport Grønlands Geologiske Undersøgelse **90**, 119–124.

Zentilli, M. & Grist, A.M. 2002: Fission track thermogeochemistry study. In: Jackson, H.R. *et al.*: Cruise 2001 *Louis S. St Laurent* passages. Pathways to the Arctic seismic survey and geoscientific experiment, Resolute (Nunavut) to Thule (Greenland). Geological Survey of Canada Open File **4828**, 94–107.