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Cambrian shelf stratigraphy of North Greenland

Jon R. Ineson and John S. Peel

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Franklinian Basin, North Greenland, shelf setting, Cambrian, lithostratigraphy, platform carbonates, outer shelf carbonates and siliciclastics

Cover
Lower – Middle Cambrian strata near the head of Nordenskiöld Fjord, north of Jungersen Gletscher, Freuchen Land. Reddish sandstones and succeeding, scree-covered mudstones of the Buen Formation (at glacier level) are conformably overlain by proximal slope-outer shelf carbonates and siliciclastics of the Brønlund Fjord Group. This area has proved critical in the correlation from Cambrian platform interior and platform margin strata to the equivalent slope and outer shelf carbonates and siliciclastics. Exposed Brønlund Fjord Group section is *c.* 300 m thick.
Photo: Jakob Lautrup

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Contents

Abstract

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The Lower Palaeozoic Franklinian Basin is extensively exposed in northern Greenland and the Canadian Arctic Islands. For much of the early Palaeozoic, the basin consisted of a southern shelf, bordering the craton, and a northern deep-water trough; the boundary between the shelf and the trough shifted southwards with time. In North Greenland, the evolution of the shelf during the Cambrian is recorded by the Skagen Group, the Portfjeld and Buen Formations and the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups; the lithostratigraphy of these last three groups forms the main focus of this paper.

The Skagen Group, a mixed carbonate-siliciclastic shelf succession of earliest Cambrian age was deposited prior to the development of a deep-water trough. The succeeding Portfjeld Formation represents an extensive shallow-water carbonate platform that covered much of the shelf; marked differentiation of the shelf and trough occurred at this time. Following exposure and karstification of this platform, the shelf was progressively transgressed and the siliciclastics of the Buen Formation were deposited. From the late Early Cambrian to the Early Ordovician, the shelf showed a terraced profile, with a flat-topped shallow-water carbonate platform in the south passing northwards via a carbonate slope apron into a deeper-water outer shelf region. The evolution of this platform and outer shelf system is recorded by the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups.

The dolomites, limestones and subordinate siliciclastics of the Brønlund Fjord and Tavsens Iskappe Groups represent platform margin to deep outer shelf environments. These groups are recognised in three discrete outcrop belts – the southern, northern and eastern outcrop belts. In the southern outcrop belt, from Warming Land to south-east Peary Land, the Brønlund Fjord Group (Lower–Middle Cambrian) is subdivided into eight formations while the Tavsens Iskappe Group (Middle Cambrian – lowermost Ordovician) comprises six formations. In the northern outcrop belt, from northern Nyeboe Land to north-west Peary Land, the Brønlund Fjord Group consists of two formations both defined in the southern outcrop belt, whereas a single formation makes up the Tavsens Iskappe Group. In the eastern outcrop area, a highly faulted terrane in north-east Peary Land, a dolomite-sandstone succession is referred to two formations of the Brønlund Fjord Group.

The Ryder Gletscher Group is a thick succession of shallow-water, platform interior carbonates and siliciclastics that extends throughout North Greenland and ranges in age from latest Early Cambrian to Middle Ordovician. The Cambrian portion of this group between Warming Land and south-west Peary Land is formally subdivided into four formations.

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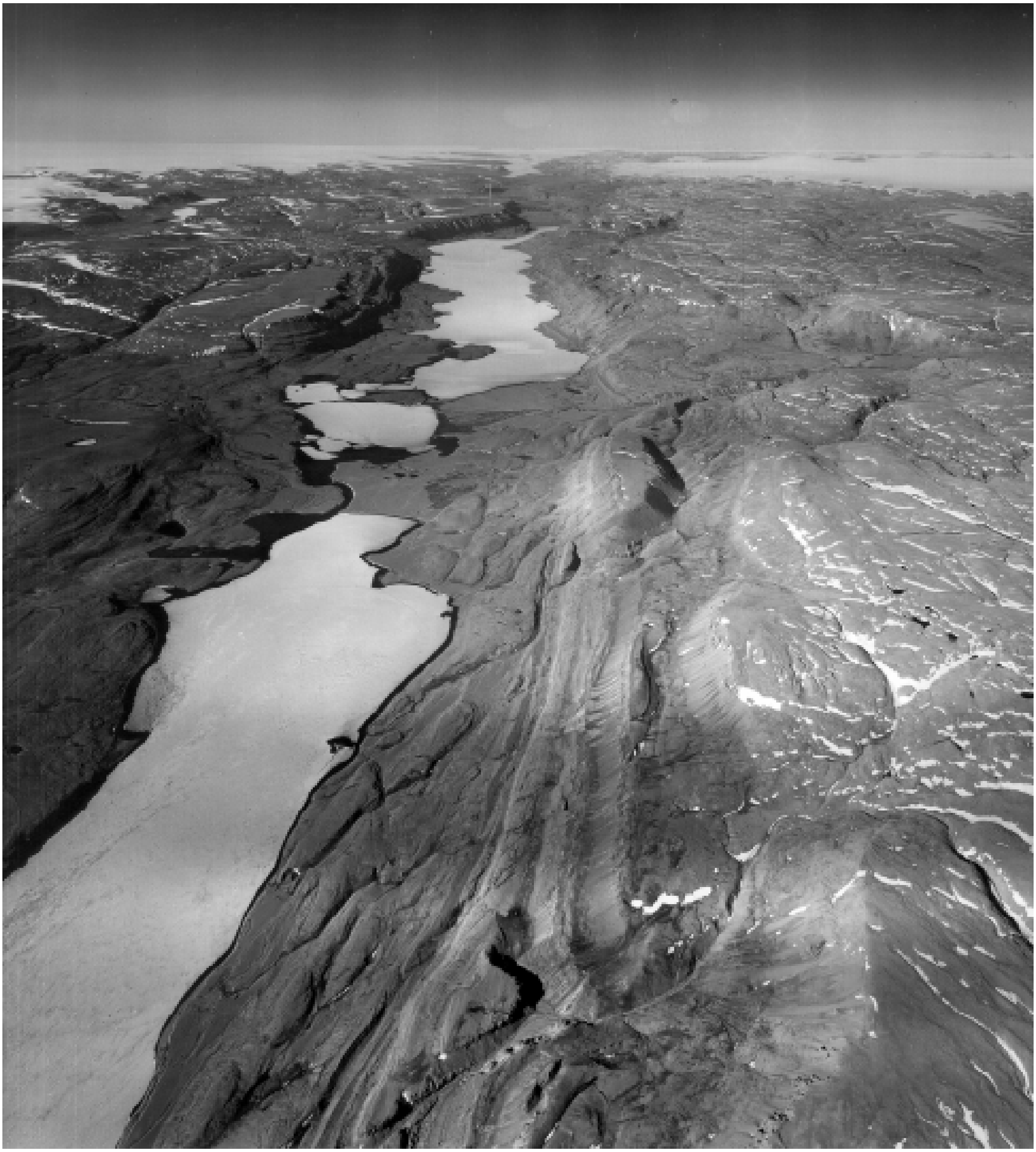


Frontispiece. Early geological observations in eastern North Greenland were particularly centred around Wandel Dal, a major east–west glacial valley system in southern Peary Land that facilitated travel between Independence Fjord and central North Greenland. This view, westwards along the valley with its major elongate lakes (Midsommersøerne), illustrates the typical plateau landscape created by the gentle northerly-dipping Lower Palaeozoic shelf succession. Cambrian strata described in this bulletin flank the valley while Proterozoic sandstones and basic intrusions form the valley floor. The light-coloured carbonates forming the plateau top (right) are referred to the Brønlund Fjord Group, described in detail herein. Photo: Kort- og Matrikelstyrelsen, Copenhagen – route 548 G-V 10209.

Introduction

The Cambrian is represented in northern Greenland by successions of sedimentary rocks which were deposited mainly in shallow-water carbonate platform, shelf and deep-water trough environments. Extensive outcrops occur from Inglefield Land (North-West Greenland) to Danmark Fjord (eastern North Greenland) as part of the eastern continuation of the Franklinian Basin succession of the Canadian Arctic Islands (Trettin, 1989; Trettin *et al.*, 1991; Higgins *et al.*, 1991a, b; Figs 1, 2). The Greenland segment of this succession includes about 8 km of Cambrian–Silurian sedimentary rocks which crop out in a belt measuring almost 1000 km east–west, with a maximum north–south dimension of about 200 km. As in adjacent Arctic Canada, the Franklinian Basin of northern Greenland embraces a southern shelf succession with a general northerly dip, and a northern deep-water trough succession; no northern limit to the deep-water trough has been recognised in Greenland (Higgins *et al.*, 1991a, b; Surlyk, 1991). Deposition within the Franklinian Basin was terminated by the mid-Palaeozoic Ellesmerian Orogeny. Deformation in Greenland was largely confined to the deep-water trough succession with the formation of the E–W trending North Greenland fold belt. Deformation decreases to the south and dies out in a zone of thrusts and monoclinal folds near the shelf-trough boundary. The Franklinian Basin succession as an entity is overlain unconformably by Carboniferous – Cenozoic strata comprising the Wandel Sea Basin in eastern and northern areas of North Greenland (Fig. 2; Håkansson *et al.*, 1991; Stemmerik & Håkansson, 1991).

Cambrian deposits of the southern shelf succession overlie Precambrian crystalline basement in Inglefield Land in the west (Peel *et al.*, 1982), and possibly around the head of Victoria Fjord (Henriksen & Jepsen, 1985). Proterozoic sedimentary basins are overlain by Cambrian shelf deposits of the Franklinian Basin in south-western Inglefield Land and the area east of Victoria Fjord (Dawes, 1976a; Dawes *et al.*, 1982; Peel *et al.*, 1982; Sønderholm & Jepsen, 1991; Surlyk, 1991; Clemmensen & Jepsen, 1992). The base of the Franklinian Basin succession is not exposed in outcrops of the northern deep-water succession and it is possible that late Proterozoic strata may be present beneath known Cambrian sections. Within the trough succession and in western outcrops of the shelf succession, Cambrian – Ordovician sedimentation was essentially continuous. In areas to the east of Nordenskiöld Fjord, the Cambrian succession is unconformably overlain by carbonate strata of the Wandel Valley Formation (late Early–Middle Ordovician; see Figs 3, 4). These gradually overstep the Cambrian outcrop towards the east and south-east such that the Wandel Valley Formation lies directly on the Kap Holbæk Formation (Hagen Fjord Group) of presumed late Proterozoic age in Kronprins Christian Land (Sønderholm & Jepsen, 1991; Higgins *et al.*, 1991a, b).

Historically, the Cambrian of northern Greenland is best known from Inglefield Land and Washington Land, in the west (beyond the present study area), where carbonate-dominated platform interior deposits (now referred to the Ryder Gletscher Group) yielded rich faunas during the early geographical and geological exploration (Koch, 1925; Poulsen, 1927, 1958, 1964; Troelsen, 1950; Cowie, 1961, 1971; Dawes, 1976a). Recent work in this region is reported by Henriksen & Peel (1976), Palmer & Peel (1981), Peel & Christie (1982), Bergström & Peel (1988) and Higgins *et al.* (1991a, b). Although preceded by important reconnaissance work in the late 1940's (Troelsen, 1949; Fig. 3), much of the knowledge of the Cambrian in areas to the east of Washington Land is of more recent origin. It stems, as discussed below, largely from regional geological investigations conducted by the Geological Survey of Greenland between 1978–85 during the two phases of its North Greenland Project (Henriksen & Higgins, 1991).

This bulletin describes the lithostratigraphy of the Cambrian platform margin to deep shelf succession (Brønlund Fjord and Tavsens Iskappe Groups), which crops out from Warming Land west to southern Peary Land in a near continuous belt just north of the margin of the Inland Ice, and in scattered outcrops farther north, along the north coast from Nyeboe Land to north-east Peary Land. In addition, four new Cambrian formations of the Ryder Gletscher Group are proposed for platform interior deposits associated with the southern outcrop belt of the Brønlund Fjord and Tavsens Iskappe Groups.

Fig. 1. The Cambrian of the J. P. Koch Fjord – Henson Gletscher region of western Peary Land proved to be the key for understanding both the stratigraphic relationships and Cambrian shelf evolution. The view of the two photographs (*c.* 20% overlap) is broadly eastwards. **A.** The cliffs flanking J. P. Koch Fjord towards Hans Tavsen Iskappe. The cliffs along the fjord are in excess of 1000 m high and expose Lower Cambrian to Middle Ordovician carbonate-dominated strata, dipping gently northwards; spectacular clinoforms are evident in the Cambrian succession along this cliff section (see Fig. 19). The valley just visible in the middle distance is Gustav Holm Dal, the valley linking Perssuaq Gletscher on the left and Fimbuldal, the wide valley curving inland from the head of J. P. Koch Fjord (far right) eastwards to the icecap. These three features lend their names to formations of the Tavsens Iskappe Group, defined from Gustav Holm Dal. Photo: Kort- og Matrikelstyrelsen, Copenhagen – route 547K–Ø 11299.

History of research

Strata described in the present publication were first recorded by Koch (1923) who reported an unfossiliferous series of white limestones (100 m) occurring on the northern side of Jørgen Brønlund Fjord in southern Peary Land (Figs 2, 4). Troelsen (1949) summarised and interpreted Koch's observations and gave the name Brønlund Fjord Dolomite to these pale-weathering dolomites (Fig. 3). Subsequently, he recorded early Cambrian fossils from the basal beds of the unit (Troelsen, 1956; Peel *et al.*, 1974). Troelsen's (1949) account was based on a two week visit to the Jørgen Brønlund Fjord area during 1947 as a member of the *Danish Peary Land Expeditions 1947–50*. The scant published record of field observations made during 1948 and 1949 (see Peel *et al.*, 1974; Christie & Peel, 1977) fails to reflect the insight into the geology of southern Peary Land which J. C. Troelsen acquired through his dog-sledge expeditions to G. B. Schley Fjord in the east, and to J. P. Koch Fjord in the west. Troelsen's published observations were reviewed by Cowie (1961; 1971) and Dawes (1971; see also Dawes 1976a, b).

Jepsen (1971) described the succession occurring below the Brønlund Fjord Formation in southern Peary Land, proposing two formations now known to be of Early Cambrian age, i.e. the Portfjeld Formation and the overlying Buen Formation (Fig. 4). Christie & Peel (1977) re-described the Brønlund Fjord Formation (Early Cambrian) in the area adjacent to the type locality in southern Peary Land.

In the late 1940s, J. C. Troelsen (unpublished field data) had noted that the Cambrian carbonate succession above the siliciclastic Buen Formation in the J. P. Koch Fjord area differed from that near Jørgen Brøn-

Fig. 1 cont.
B. Henson Gletscher (far right) enters the southern end of J. P. Koch Fjord, meeting at the mouth of Fimbuldal (see also **A**). The ice tongue in the foreground (left) is Ekspedition Bræ; four formations of the Brønlund Fjord Group are defined from the terraced exposures just south (right) of this tongue overlooking Henson Gletscher. On the far side of the glacier, Cambrian and Lower Ordovician strata are exposed along Koch Væg, a cliff up to 600 m high. The elongate lake (top, centre right), Aftenstjernesø, occurs at the western end of a major valley system, including Sydpasset and Wandel Dal, that extends eastwards to Independence Fjord (Fig. 2). Photo: Kort- og Matrikelstyrelsen, Copenhagen – route 547K–Ø 11292.

lund Fjord. This was confirmed by Dawes (1976b) on the basis of a brief reconnaissance visit. Middle Cambrian fossils were collected by Dawes from limestones interpreted as lying above the Brønlund Fjord Formation but below the Wandel Valley Formation (Early – Middle Ordovician) which also overlies the Brønlund Fjord Formation in its type area.

In 1978, the Geological Survey of Greenland initiated regional geological investigations of Peary Land as part of its North Greenland Project 1978–80. On the basis of studies in south-western Peary Land, Peel (1979) elevated the Brønlund Fjord Formation to the status of a group, recognising four constituent un-named formations in the area around the head of J. P. Koch Fjord. Overlying strata were referred to another new group, the Tavsens Iskappe Group with originally four constituent un-named formations, which was in turn unconformably overlain by the Wandel Valley Formation (Fig. 4). Christie & Ineson (1979) recognised probable Cambrian carbonates occurring above the Buen Formation in the G. B. Schley Fjord area of easternmost Peary Land.

Ineson & Peel (1980) revised the Brønlund Fjord and Tavsens Iskappe Groups following field work in 1979; these observations formed the basis for the more detailed study by Ineson (1985).

Hurst & Peel (1979) and Peel (1980) confirmed earlier records summarised by Dawes (1976a) of a Cambrian carbonate succession overlying the Buen Formation in southern Wulff Land which showed similarities to the Cambrian succession from Washington Land to the west (Henriksen & Peel, 1976; Peel & Christie, 1982). No lithological correlation was immediately apparent, however, with Peary Land, to the east. Continuity of outcrop with the latter area was quickly established during the early stages of the second phase of the

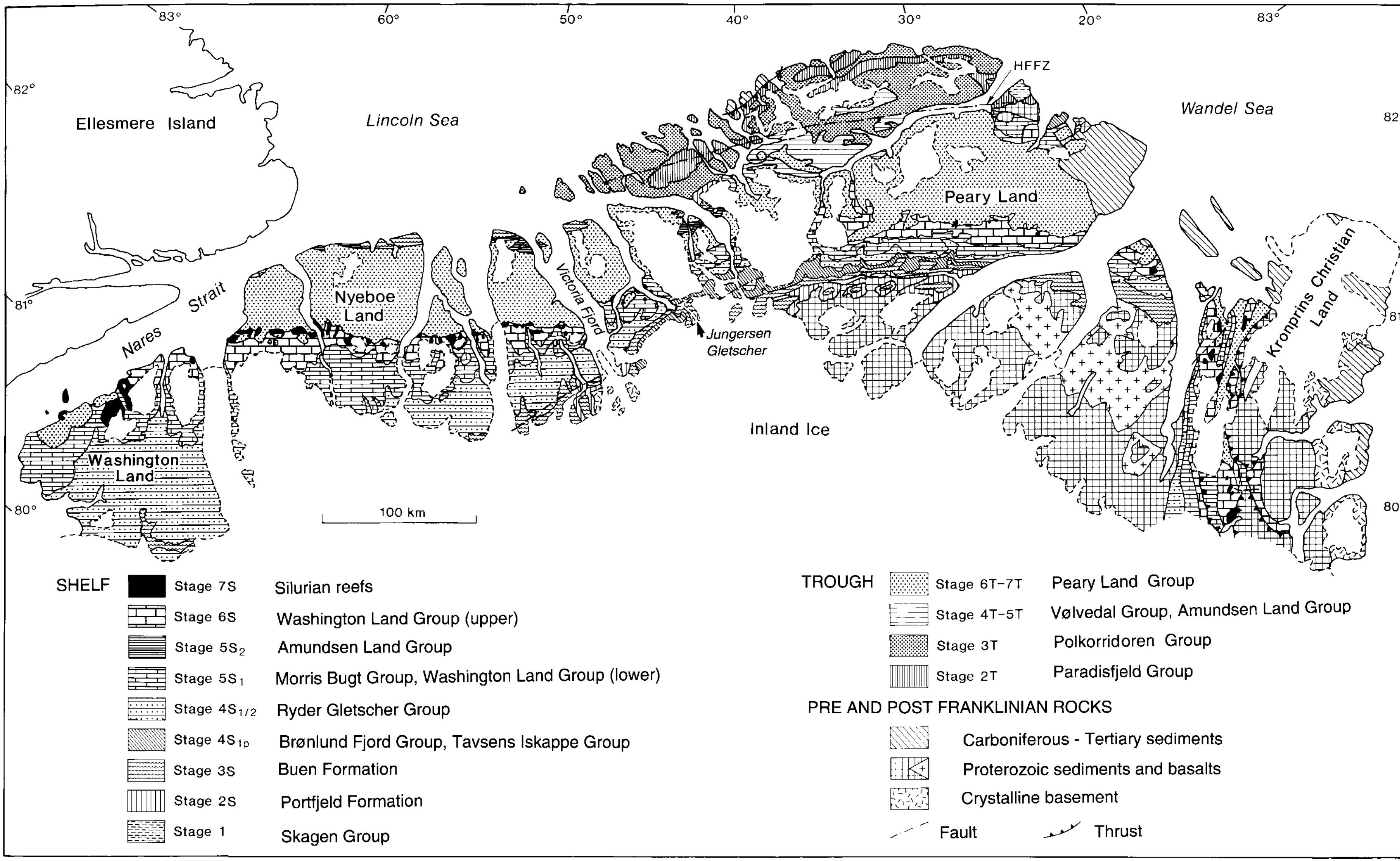
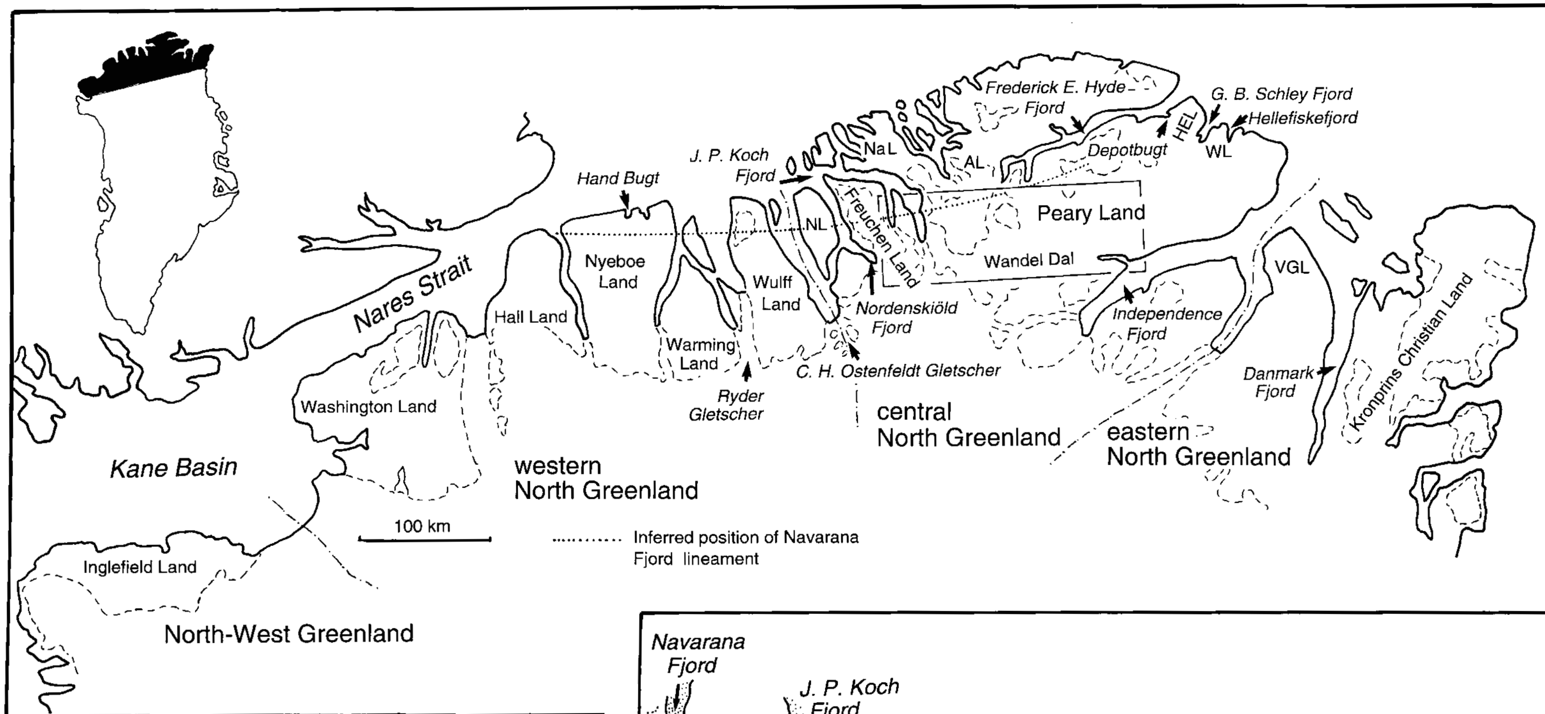
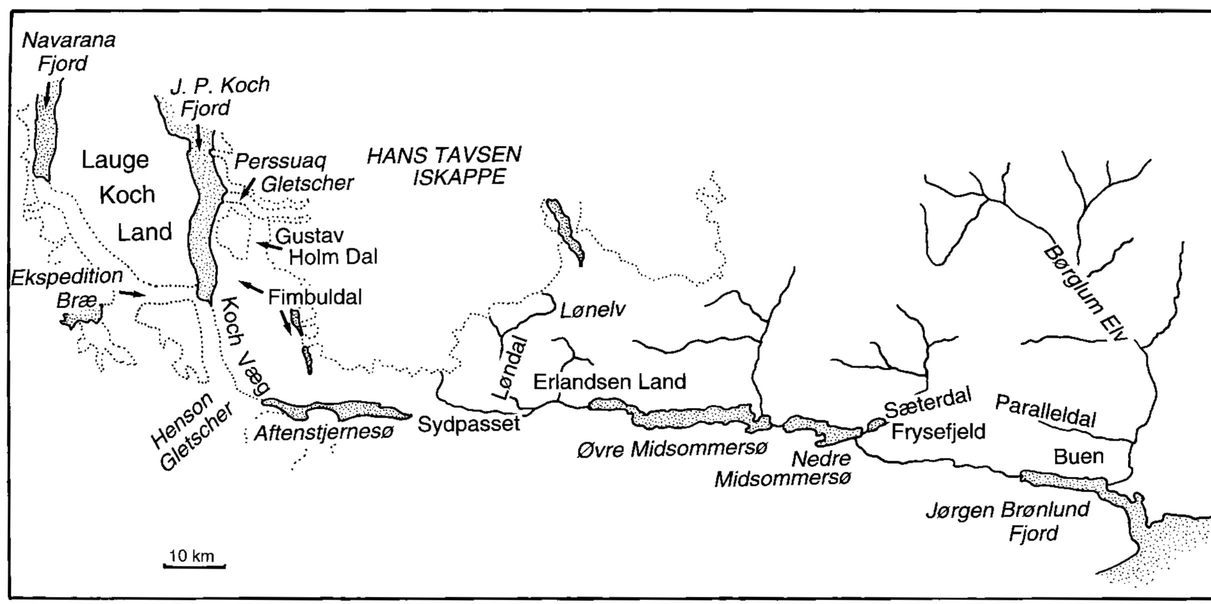


Fig. 2. Geological and location maps of North Greenland. The regional geological map shows the major stratigraphic units of the Franklinian Basin in North Greenland corresponding to the basin evolutionary stages of Higgins *et al.* (1991a); HFFZ, Harder Fjord fault zone. Inset location map (outlined area) shows the localities in southern Peary Land from the Henson Gletscher region in the west through Wandel Dal to Jørgen Brønlund Fjord and the western shores of Independence Fjord. Modified from Higgins *et al.* (1991a).





AL	Amundsen Land
HEL	Hans Egede Land
NL	Nares Land
NaL	Nansen Land
VGL	Valdemar Glückstadt Land
WL	Wyckoff Land

Fig. 2 cont.

Fig. 3. The early stratigraphic subdivision by J. C. Troelsen in the Jørgen Brønlund Fjord area, formed the basis for subsequent regional stratigraphic work (Jepsen, 1971; Christie & Peel, 1977) and the starting point for this detailed study of the Cambrian. This photograph from Troelsen (1949, fig. 7) illustrates the type section of the Brønlund Fjord Dolomite (B) at Buen, west of the mouth of Børglum Elv, southern Peary Land (see Figs 2, 17). This formation, subsequently elevated to the Brønlund Fjord Group (Peel, 1979), is underlain by siliciclastics referred by Troelsen to the Thule Group (T) and re-assigned to the Buen Formation by Jepsen (1971). The section is capped by the Wandel Valley Limestone (W), the Wandel Valley Formation of current usage. Cliff height is *c.* 500 m.

North Greenland Project 1984–85 and Peel & Wright (1985) proposed stratigraphic nomenclature, involving the description of the Ryder Gletscher Group.

Subsequently, Ineson & Peel (1987) revised the concept of the Ryder Gletscher Group recognising that the Brønlund Fjord Group extended as far west as Warming Land. In these western outcrops, Cambrian carbonates and associated siliciclastic sediments of the Ryder Gletscher Group succeed carbonates of the Brønlund Fjord Group. In southern Peary Land, Lower Ordovician carbonates of the Wandel Valley Formation, now assigned to the Ryder Gletscher Group, unconformably overlie the Cambrian Brønlund Fjord and Tavsens Iskappe Groups (Fig. 4).

In addition, the second phase of the North Greenland Project stimulated recognition of the Brønlund Fjord and Tavsens Iskappe Groups in outer shelf successions affected by late Palaeozoic (Ellesmerian) deformation along the southern margin of the North Greenland fold belt (Higgins & Soper, 1985; Higgins *et al.*, 1992; Ineson *et al.*, 1994; Peel, 1994a). Earlier Cambrian stratigraphic units, i.e. the Skagen Group and the Portfjeld and Buen Formations, are also recognised in this setting (Higgins *et al.*, 1991a, b).

Embracive summaries of Cambrian shelf stratigraphy and the evolution of the Franklinian Basin in Greenland have been given by Higgins *et al.* (1991a, b). The present paper formally describes Cambrian stratigraphic nomenclature for North Greenland (Fig. 5) employed in these and other recent publications (e.g. Christiansen, 1989).

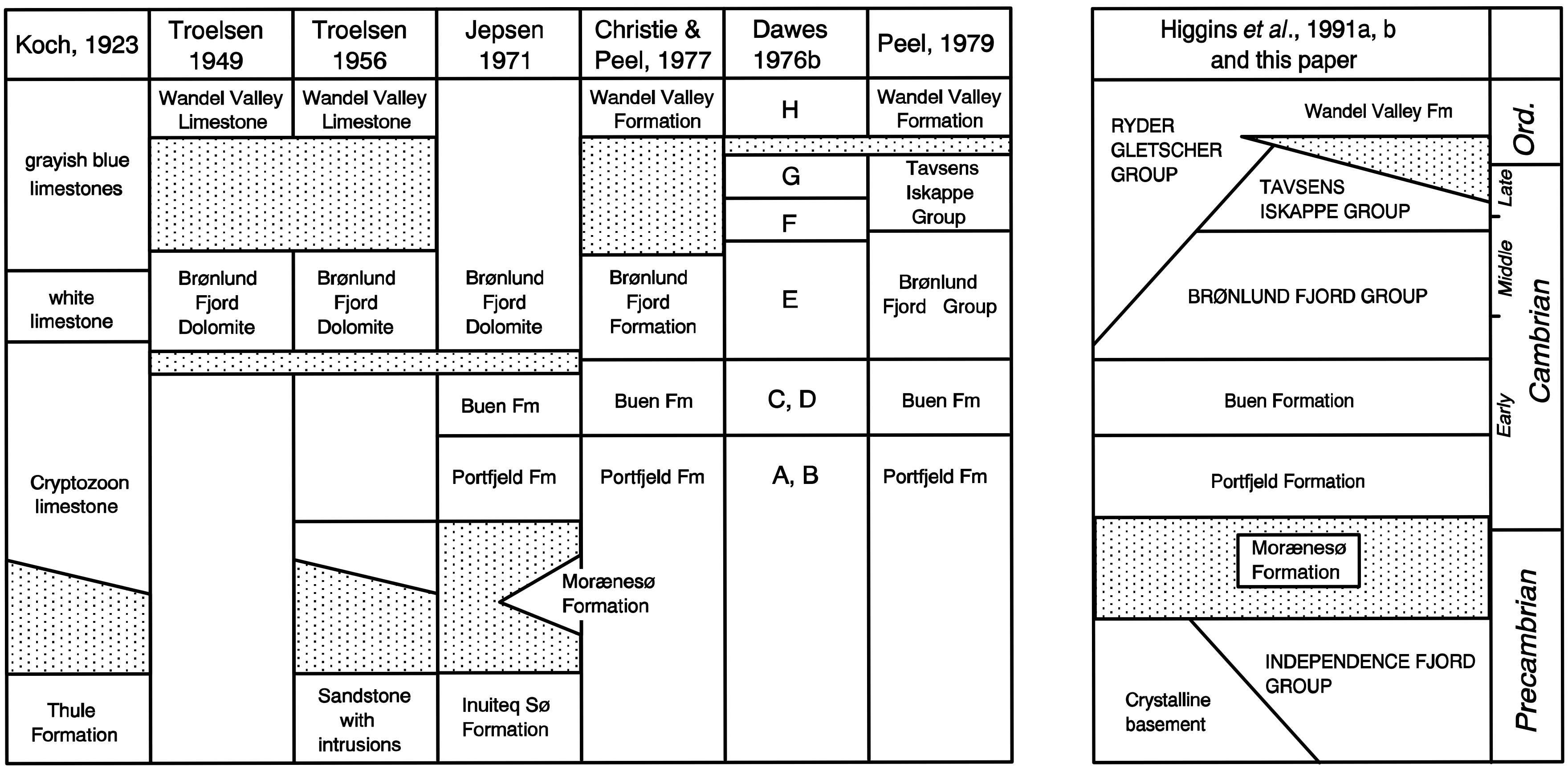


Fig. 4. Previous stratigraphic schemes applied to Precambrian to Lower Ordovician strata in the southern Peary Land region, correlated with the lithostratigraphic framework adopted in this paper. Building on reconnaissance by Koch (1923), Troelsen (1949, 1956) erected the first formal lithostratigraphic subdivision. This was expanded stratigraphically downwards by Jepsen (1971) and upwards by Christie & Peel (1977) to include the Ordovician and Silurian succession. The North Greenland Project (1978–80, 1984–85) permitted integration of data from central North Greenland and the erection of the detailed lithostratigraphic subdivision presented here.

Geological framework

Terminology

Depositional settings

Although general agreement has been reached on the definition of carbonate depositional settings (see discussion in Tucker & Wright, 1990), complications arise in mixed carbonate-siliciclastic regimes. Tucker & Wright (1990) followed Read (1982) in adopting platform as a broad term to describe a range of carbonate settings, including flat-topped, steep-margined settings (their rimmed shelves) and gently sloping carbonate ramps. This classification, incorporating a restricted definition of 'shelf', results in ambiguity in mixed carbonate-siliciclastic settings since a siliciclastic shelf is generally understood with respect to modern continental shelves on passive margins, i.e. a gently inclined surface bordered landward by the shoreline and deepening to a break in slope (typically in several hundreds of metres of water) at the transition into deep marine environments (e.g. Vanney & Stanley, 1983).

To resolve this problem, the term platform is used here in the restricted sense of Schlager (1981; see also Wilson, 1975) to represent a shallow-water, flat-topped carbonate setting bordered landward by the shoreline and basinward by an abrupt break in slope; this slope break is typically marked by a semi-continuous rim or barrier composed of reefs or carbonate sand banks. This, then, is analogous to the 'rimmed shelf' of many workers (e.g. Ginsburg & James, 1974; Read, 1982; Tucker & Wright, 1990). The carbonate ramp is used in the sense of Ahr (1973) and Read (1982) to describe a gently sloping surface (generally less than 1 degree) that grades from nearshore high-energy (inner or shallow ramp) to offshore low-energy (outer or deep ramp)

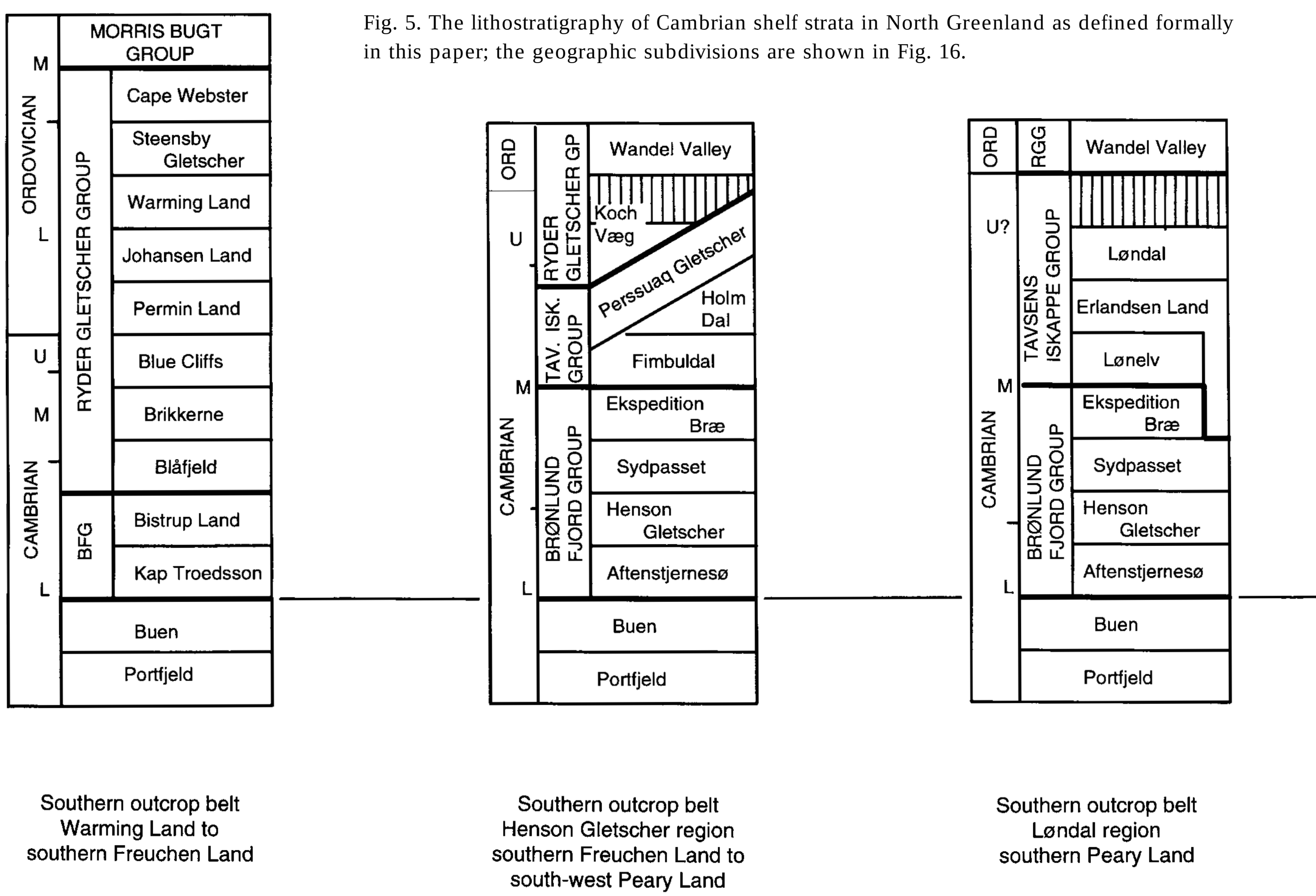


Fig. 5. The lithostratigraphy of Cambrian shelf strata in North Greenland as defined formally in this paper; the geographic subdivisions are shown in Fig. 16.

environments (see Tucker & Wright, 1990). This profile resembles that of a siliciclastic shelf.

The term shelf, therefore, refers here to the broad setting bordered by the shoreline towards the craton and by the shelf-slope break in a basinward direction at the transition into deep-water environments. The shallow-water carbonate platform thus occupies the 'inner shelf' whereas the 'outer shelf' stretches from the platform margin through the carbonate slope to the lip of the deep-water trough (see Figs 7, 9). This definition permits consistent usage when discussing wholly siliciclastic episodes in basin evolution (e.g. the Lower Cambrian Buen Formation), wholly carbonate episodes (e.g. the Lower Cambrian Portfjeld Formation) and mixed carbonate-siliciclastic episodes when the shelf consisted of a shallow-water platform in the south flanked to the north by a carbonate slope that graded distally into the outermost shelf (e.g. see Figs 6–9). The Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups, as defined in this paper, represent a platform-to-outer shelf setting of this type.

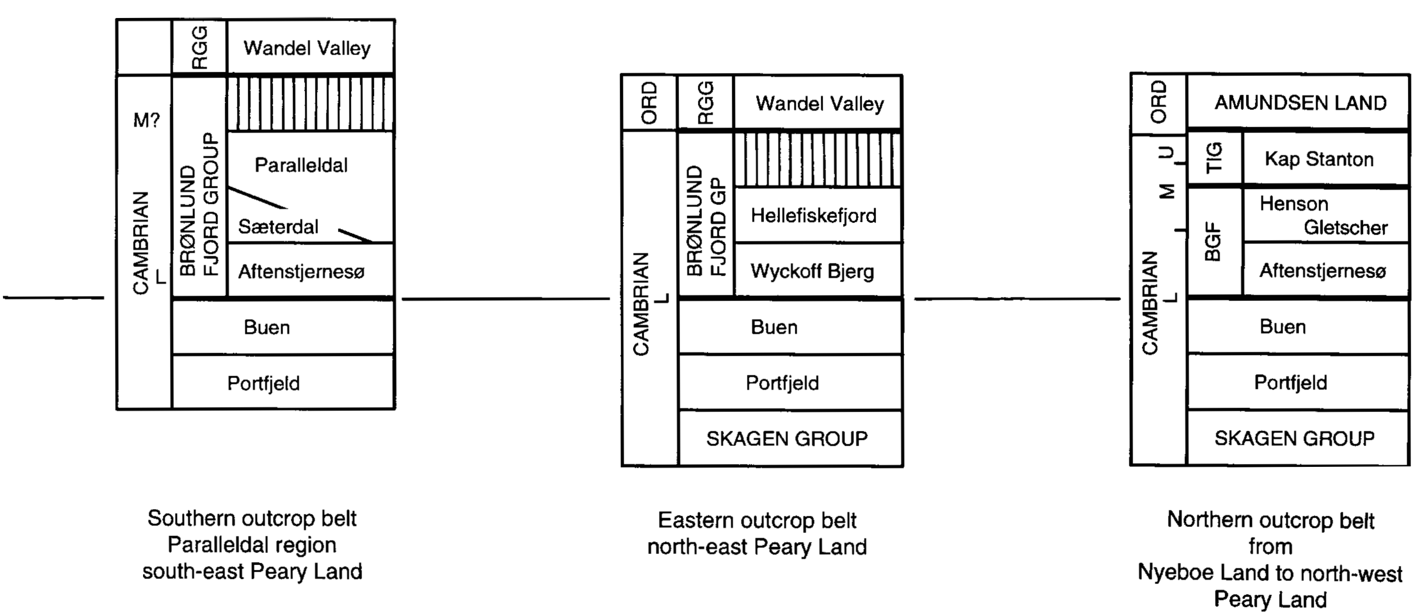
Lithology

In recent literature, particularly from North America, rocks composed of the mineral dolomite are termed 'dolostones'. This term is not adopted here; following normal practise at the Geological Survey of Denmark and Greenland, both the rock and the mineral are referred to as 'dolomite'.

Regional setting

During the early Palaeozoic, North Greenland formed part of the Franklinian Basin, which extended westwards into Arctic Canada (Fig. 2). In Greenland, the preserved basin fill stretches almost 1000 km from east to west and 200 km from north to south. The succession is about 8 km thick and is essentially of early Palaeozoic age, although possibly extending down into the latest Proterozoic and up into the earliest Devonian.

The outcrop pattern of the Lower Palaeozoic broadly parallels the east–west coastline of North Greenland (Fig. 2). Archaean crystalline basement and overlying Proterozoic sedimentary strata crop out along the fringes of the Inland Ice in the south and east. Lower Palaeozoic strata occupy most of the remaining ice-free terrain. Outliers of late Palaeozoic and Mesozoic age unconformably overlie the Franklinian Basin strata in eastern areas of North Greenland (see Stemmerik & Håkansson, 1991; Håkansson *et al.*, 1991). Rocks of the Franklinian Basin are largely undeformed in the south; the degree of deformation increases northwards and the metamorphic grade is amphibolite facies in northernmost North Greenland; details of the structure and metamorphic history are given in Higgins *et al.* (1985) and Soper & Higgins (1990). The full evolutionary history of the Franklinian Basin in North Greenland is given in recent review articles (Higgins *et al.*, 1991a, b); a brief description is given here with emphasis on the Cambrian shelf.



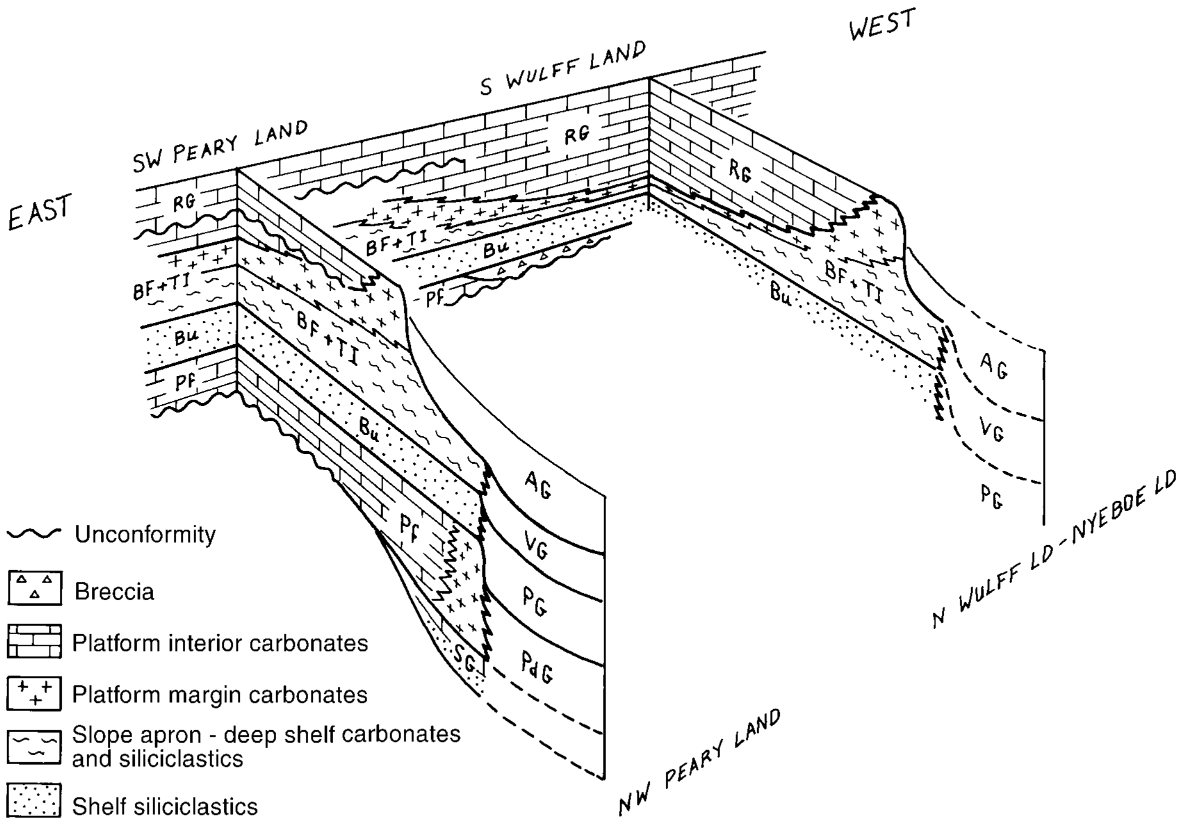


Fig. 6. Fence diagram (view from the north) showing the regional stratigraphy of the Cambrian shelf and deep-water trough. The basin evolutionary stages of Higgins *et al.* (1991a) are represented: Stage 1: Skagen Group (SG); Stage 2: Portfjeld Formation (Pf), Paradisfjeld Group (PdG); Stage 3: Buen Formation (Bu), Polkorridoren Group (PG); Stage 4: Brønlund Fjord Group (BF), Tavsens Iskappe Group (TI), Ryder Gletscher Group (RG), Vølvedal Group (VG); Stage 5: Amundsen Land Group (AG). From Ineson *et al.* (1994).

For much of the early Palaeozoic, the basin consisted of two discrete depositional elements: a *shelf* to the south, bordering the craton, passing northwards into a deep-water *trough*. The position and nature of the transition from shelf to trough varied during the early Palaeozoic (Hurst & Surlyk, 1983; Surlyk & Hurst, 1983, 1984). In certain periods (e.g. Early Cambrian and Late Ordovician – Early Silurian), the entire shelf region was the site of shallow-water carbonate sedimentation and the shelf-to-trough transition was an abrupt, often precipitous scarp (see Surlyk & Ineson, 1987, 1992; Peel *et al.*, 1992). At other times (e.g. late Early Cambrian), the shelf was dominated by siliciclastics and showed a typical continental shelf profile with a shelf-slope break at an inferred depth of several hundred metres of water. Intermediate profiles were also represented, for example from the late Early Cambrian to the earliest Ordovician, during which time a shallow-water carbonate platform occupied the southern inner region of the shelf, grading northwards onto the mixed carbonate-siliciclastic outer shelf. This, in turn, passed abruptly into the deep-water trough.

The position of the shelf-to-trough transition follows a number of roughly east–west lineaments. These features represent deep-seated faults or monoclines that were important controls of relative subsidence rates and thus sediment production and distribution patterns. These linear structural features became successively active during the early Palaeozoic resulting in backstepping of the shelf margin (Surlyk *et al.*, 1980, Surlyk & Hurst, 1983, 1984). Thus, from the earliest Cambrian to the Early Ordovician, the shelf margin followed a line from Frederick E. Hyde Fjord through outer J. P. Koch Fjord and north of the present Wulff Land – Nyeboe Land coastline (Fig. 2). In the Early Ordovician, the margin shifted southwards to the Navarana Fjord lineament, which proceeded to control the position of the carbonate platform margin until the late Llandovery. At this time, the platform foundered and basinal sediments progressively onlapped the shelf,

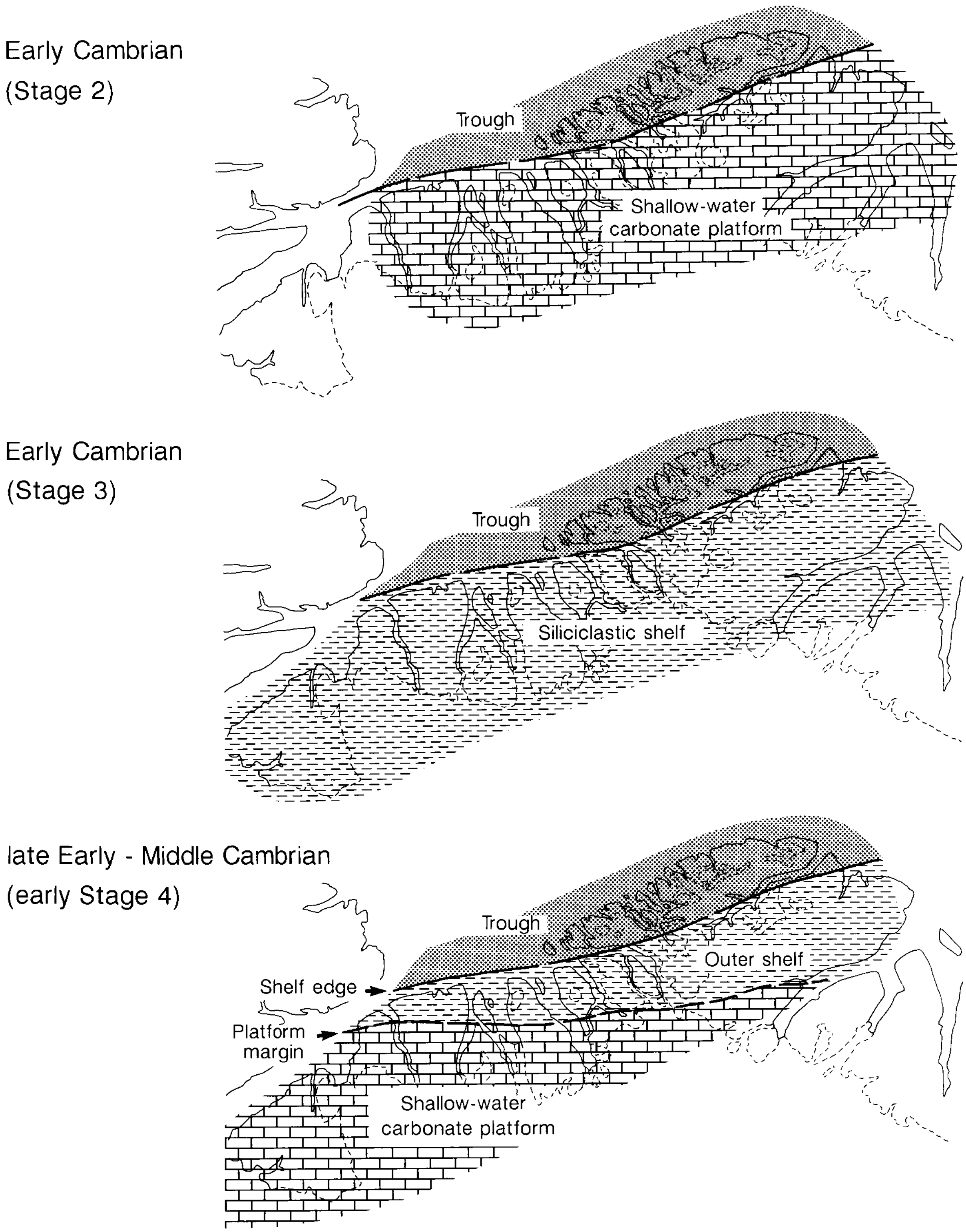


Fig. 7. Stages in the palaeogeographic evolution of North Greenland during the Cambrian; this reconstruction of the position of the Cambrian shelf edge does not take account of inferred slope deposits occurring in allochthonous thrust slices along the northern coastline of western North Greenland (see Higgins *et al.*, 1992). Stage 1 (Skagen Group) is referred to in Fig. 6. From Ineson *et al.* (1994).

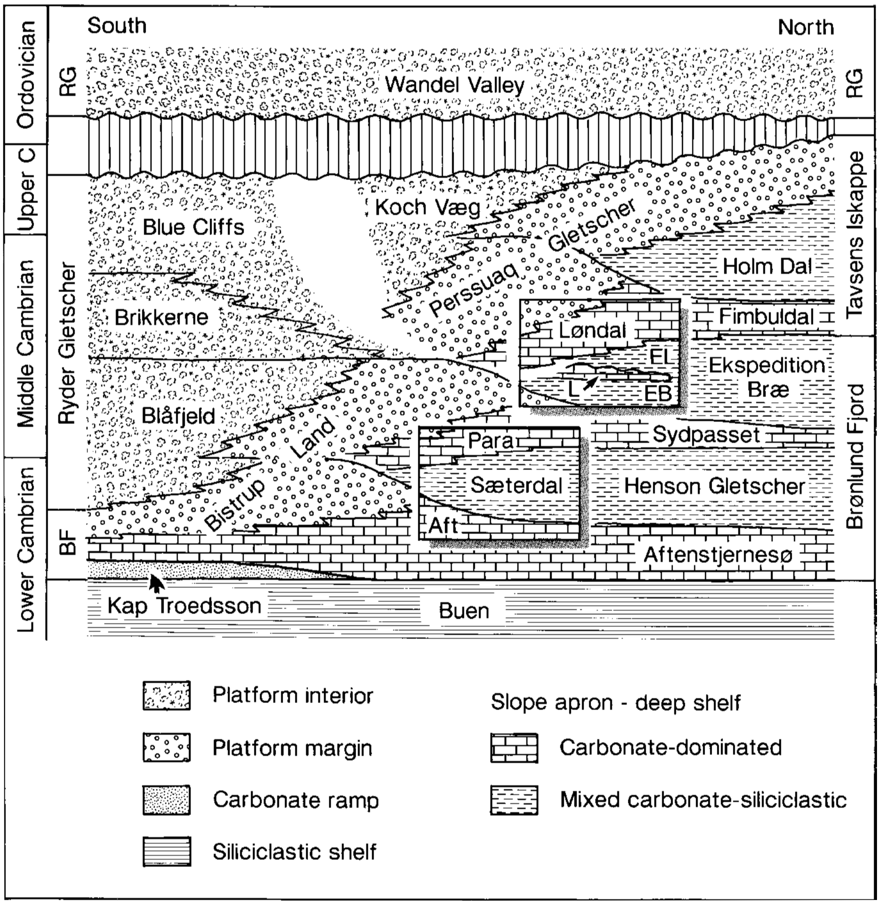


Fig. 8. Schematic diagram showing depositional settings of formations of the Brønlund Fjord (BF), Tavsens Iskappe and Ryder Gletscher (RG) Groups in the southern outcrop belt between Wulff Land and eastern Peary Land. The stratigraphic positions and environmental settings of the Paralleldal and Løndal sections are indicated by the lower and upper insets respectively. Inferred minor breaks within the platform interior succession (Ryder Gletscher Group) are not indicated; no vertical or lateral scale implied. Note that the relationships between geographically separate formations are simplified; e.g. the relationship between the Bistrup Land and Perssuaq Gletscher Formations is unknown due to lack of exposure. Aft, Aftenstjernesø; Para, Paralleldal; EB, Ekspedition Bræ; L, Lønelv; EL, Erlandsen Land.

with ultimate drowning of the preserved shelf at the Llandovery–Wenlock boundary. Deep-water sedimentation continued over North Greenland until at least the latest Silurian; the Franklinian Basin was uplifted and deformed during the mid-Palaeozoic Ellesmerian orogeny.

Stratigraphic framework and shelf evolution

The Cambrian sedimentation history of the North Greenland shelf from Peary Land in the east to Nyeboe Land in the west (Fig. 2) is recorded by the Skagen Group (?lowermost Cambrian), the Portfjeld and Buen Formations (Lower Cambrian) and the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups (Lower – Upper Cambrian; Fig. 6). In recent reviews (Higgins *et al.*, 1991a, b), shelf evolution during the Cambrian has been considered in terms of four stages.

The mixed carbonate-siliciclastic Skagen Group, representing Stage 1 of Higgins *et al.* (1991a, b), is recognised in isolated exposures from north-east Peary Land in the east, to northern Wulff Land in the west (Figs 2, 6). The Skagen Group records deposition on a storm-dominated shelf following the initial transgression of Proterozoic basement and prior to significant differentiation of discrete shelf and trough settings.

The Portfjeld Formation (Stage 2; Figs 6, 7) conformably overlies the Skagen Group in these northern outcrops but also extends widely over central areas of North Greenland where it unconformably overlies Upper Proterozoic strata. It records the development of a shallow-water carbonate platform over much of the Franklinian shelf in North Greenland. At the northern limit of the shelf, the platform was fringed by a belt of carbonate sands and stromatolitic mounds, deposited under shallow-water, high-energy conditions. Recent fieldwork has demonstrated that the margin had developed a steep profile by the end of Portfjeld times (Higgins *et al.*, 1991a; Peel *et al.*, 1992). Equivalent deeper-water carbonates and siliciclastics of the incipient trough are assigned to the Paradisfjeld Group (Figs 6, 7).

Following exposure and karstification of the plat-

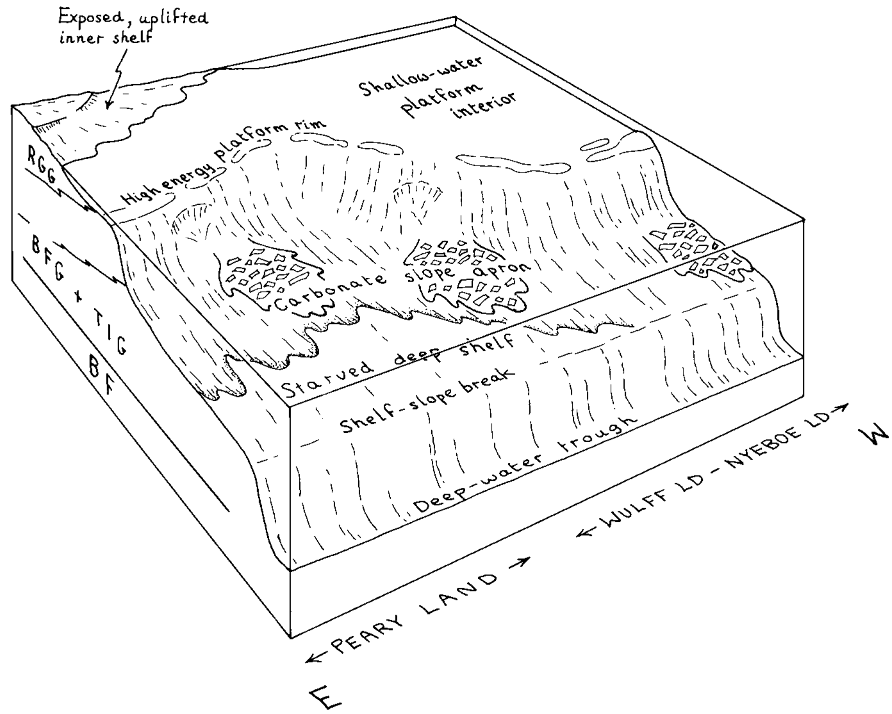


Fig. 9. Block diagram showing the inferred late Middle Cambrian palaeogeography in western and central North Greenland (view from north). BF, Buen Formation; BFG, Brønlund Fjord Formation; TIG, Tavsens Iskappe Group; RGG, Ryder Gletscher Group. From Ineson *et al.* (1994).

form, the shelf was transgressed; the siliciclastic shelf strata deposited during this episode (Stage 3; Figs 6, 7) are assigned to the Buen Formation, which is recognised throughout central and east North Greenland and can be correlated with similar siliciclastic formations in westernmost North Greenland. The basinal Polkorridoren Group, a thick succession of sandstone turbidites and mudstones, is at least partially equivalent to the Buen Formation on the shelf, although much of the coarser detritus may have bypassed the exposed shelf prior to the transgression recorded by the Buen Formation.

The mud-dominated strata of the upper part of the Buen Formation are succeeded abruptly by carbonates of late Early Cambrian age; this boundary heralds the development of a major early Palaeozoic carbonate platform that ultimately extended over the entire Franklinian shelf. During the early phases of its development (Stage 4), however, the shallow-water platform was restricted to the southern, inner portion of the shelf and passed northwards into a deeper-water outer shelf setting. The outer shelf graded northwards into the deep-water trough (Figs 8, 9). The precise nature of the shelf-to-trough transition at this time is unknown. Although demonstrably a steep escarpment during the latter part of Stage 2 and early Stage 3 (upper Portfjeld Formation and lower Buen Formation, see above), relief on this structure may have been more subdued by late Early Cambrian times. The thickness contrast between the outermost shelf deposits (Brønlund Fjord and Tavsens Iskappe Groups in the northern outcrop belt) and the age-equivalent basinal Volvedal Group, however, indicates that this structural feature continued to control relative sediment accumulation rates throughout the Cambrian and into the Ordovician (see Friderichsen *et al.*, 1982; Higgins *et al.*, 1991a, b, 1992).

The fundamental subdivision of the shelf environment from the late Early Cambrian to the Early Ordovician is reflected in the stratigraphic scheme (Figs 6, 8, 10): platform interior strata are assigned to the Ryder Gletscher Group whereas platform margin, carbonate slope apron and deep shelf strata are assigned to the Brønlund Fjord and Tavsens Iskappe Groups. The deeper-water outer shelf sediments grade southwards and up-section into platform margin and platform interior facies reflecting a general northward progradation of the platform during the Cambrian (Figs 8–10).

This simple south to north progradational pattern, however, does not explain the east–west variation in the Cambrian stratigraphy (see Figs 4–6). In western and much of central North Greenland, the shelf subsided uniformly from the Early Cambrian to the Early Silurian, accumulating a thick conformable succession of platform carbonates. In contrast, the eastern margin of the North Greenland craton experienced uplift during the Middle and Late Cambrian, probably in response

South

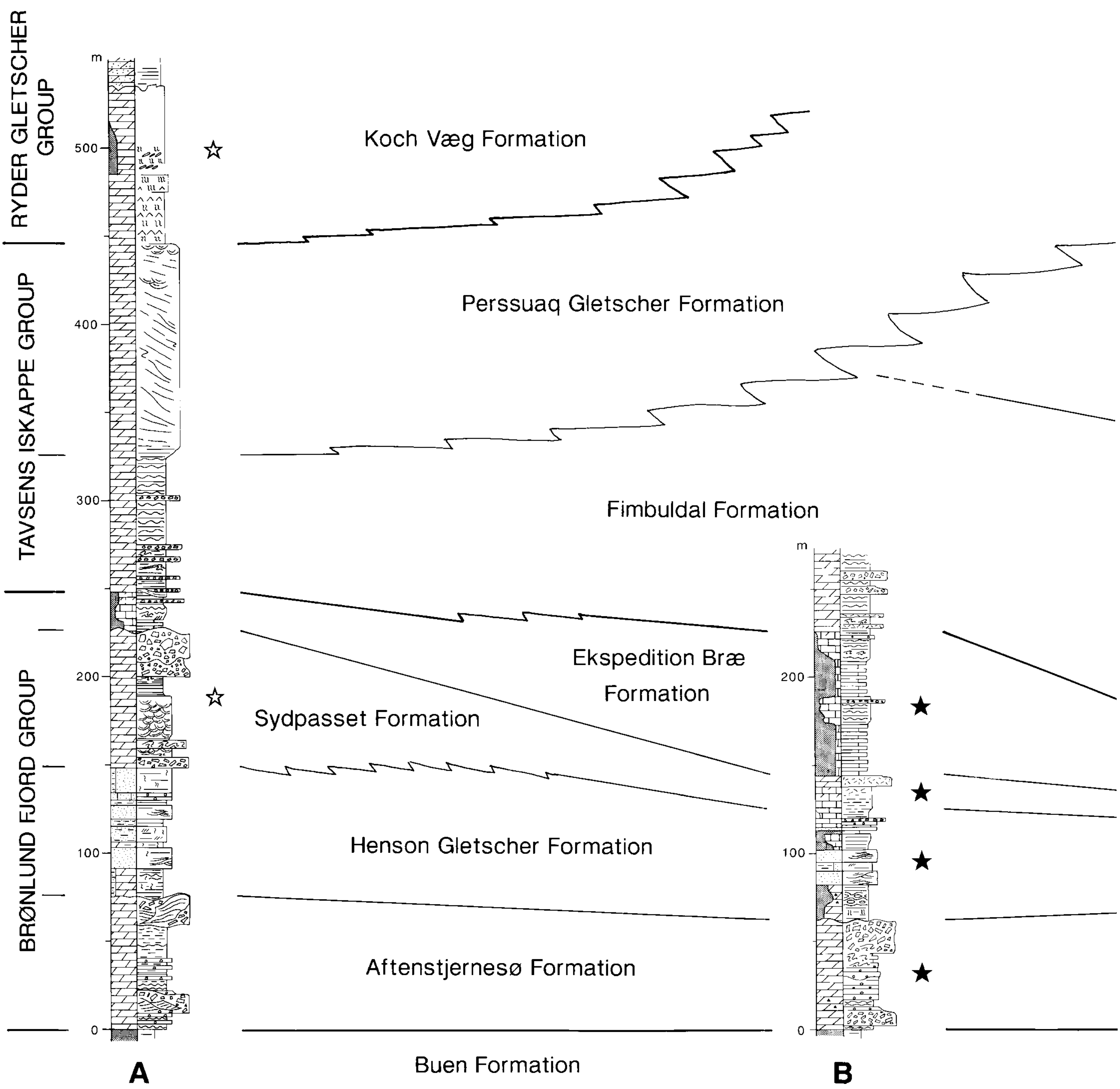
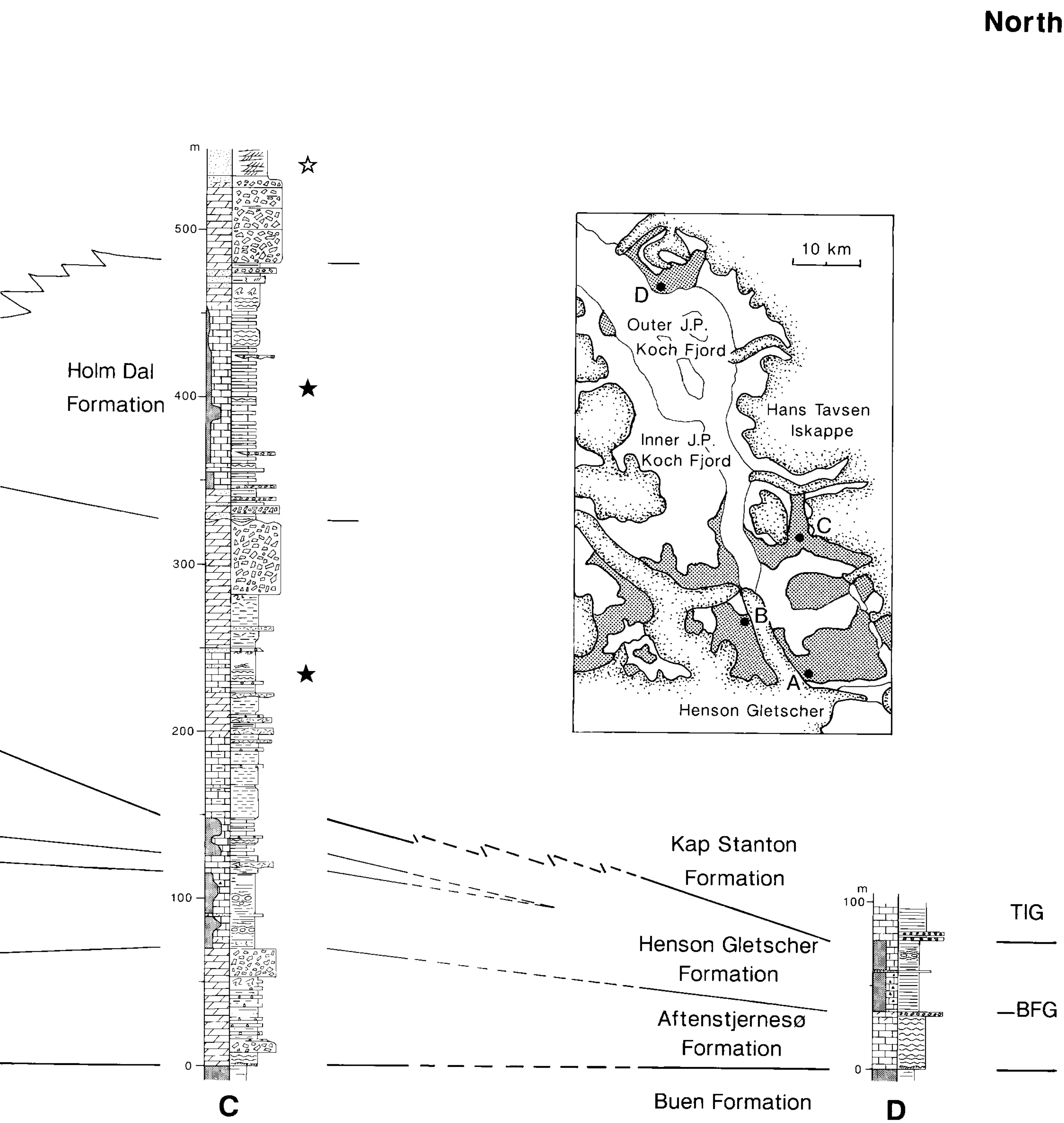


Fig. 10. South-to-north transect linking key sections from the southern (A, B, C) and northern (D) outcrop belts in westernmost Peary Land and Lauge Koch Land; inset map shows the outcrop of the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups and the section localities. Type sections indicated by solid stars, reference sections by open stars; see Fig. 14 for legend. This transect illustrates the marked south-to-north diachronism of the Perssuaq Gletscher Formation recording the northward



progradation of the shallow-water carbonate platform. Note that the carbonate-dominated Sydpasset Formation thins rapidly northwards in the southern outcrop belt and is not recognised in the northern outcrop belt. The cyclicity within the off-platform deposits, forming the basis for the lithostratigraphic subdivision, is clearly illustrated in this transect; note that the carbonate-dominated formations (Aftenstjernesø, Sydpasset and Fimbuldal Formations) are capped by prominent and persistent carbonate debris sheets.

to an early collisional event along the western margin of the Iapetus Ocean (Surlyk & Hurst, 1984; Surlyk, 1991). This resulted in progressive exposure of eastern shelf areas during the Cambrian and the development of a regional unconformity at the base of the Wandel Valley Formation (uppermost Lower – Middle Ordovician; Figs 4, 5). The uplift had the greatest magnitude and duration in the east so that the hiatus decreases in stratigraphic importance westwards and is not recognised farther west than the land area south of Nares Land (Figs 2, 5, 6).

Thus, in the southern outcrop belt (Fig. 2), the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups record northward progradation of shallow-water carbonate sediments over outer shelf deposits. In eastern areas, the platform became progressively emergent during the Cambrian and platform interior facies (i.e. Ryder Gletscher Group) are only locally preserved beneath the Wandel Valley Formation basal unconformity (Figs 5, 6). In western North Greenland and adjacent areas of central North Greenland, however, platform margin deposits in the upper levels of the Brønlund Fjord Group are conformably succeeded by Cambro-Ordovician platform carbonates assigned to the Ryder Gletscher Group (Fig. 6). It may be inferred that the Ryder Gletscher Group also conformably overlies the Tavsens Iskappe Group in the subsurface in this western area, as indicated on Figure 6.

In the northern outcrop belt from outer J. P. Koch Fjord to northern Nyeboe Land (Fig. 2), the carbonate slope apron and deep, outer shelf sediments of the Brønlund Fjord and Tavsens Iskappe Groups were deposited basinward of the maximum northernmost extent of the platform (Fig. 6). They are overlain by black, cherty, graptolitic mudstones of Early Ordovician age (Amundsen Land Group), reflecting a shift in the position of the trough margin in the Early Ordovician from north of the northern coastline of central areas of North Greenland to the Navarana Fjord lineament (Figs 2, 6). The easternmost sections of the northern outcrop belt, in Navarana Fjord and outer J. P. Koch Fjord, can be readily correlated with the southern outcrop belt since the transition from platform to carbonate slope apron is superbly exposed in these southern exposures (Fig. 10; Ineson & Peel, 1980, 1987; Higgins *et al.*, 1991a, b). West of Nordenskiöld Fjord (Fig. 2), however, this transition is not exposed; platform carbonates dominate the southern outcrop and outer shelf facies make up the northern outcrop belt, the intervening margin being buried beneath younger strata. The stratigraphy of the northern outcrop belt and implications of this region for an understanding of shelf evolution were given by Ineson *et al.* (1994).

Facies and depositional environments

The primary aim of this paper is the presentation of the lithostratigraphy of the Cambrian strata of North Greenland. It is not the intention here to provide a fully documented sedimentological analysis; certain facies descriptions are published (Ineson, 1980, 1988; Surlyk & Ineson, 1987; Ineson *et al.*, 1994; Ineson & Surlyk, 1995) and a detailed facies analysis was presented by Ineson (1985). However, a summary of the main facies types that typify the major depositional environments is considered essential, facilitating an appreciation of the broad setting of the individual formations defined below.

As discussed earlier, the Brønlund Fjord, Tavsens Iskappe and lower Ryder Gletscher Groups record the initiation and evolution of a carbonate platform on the North Greenland shelf from the late Early Cambrian to the earliest Ordovician. The transition from siliciclastic to carbonate-dominated shelf is recorded by the lowermost Brønlund Fjord Group (Kap Troedsson Formation in western areas and lowermost Aftenstjernesø Formation in central North Greenland; Fig. 8). During this initial stage of platform development a *carbonate ramp* formed. The remainder of the Brønlund Fjord Group and the Tavsens Iskappe and Ryder Gletscher Groups record the progressive northward progradation of a flat-topped shallow-water platform and flanking carbonate slope apron on the deeper-water outer shelf. Three broad environmental settings are recognised (see Ineson, 1985; Higgins *et al.*, 1991a, b): *platform interior, platform margin* and *carbonate slope apron to deep shelf*; the positions of the individual formations within this broad environmental transect are shown schematically in Figures 8 and 10.

Carbonate ramp

Ramp facies are best developed in the Kap Troedsson Formation in western areas of North Greenland. They comprise thin-bedded skeletal and intraclastic grainstones, packstones and lime mudstones with calcareous silty mudstone interbeds and partings (Fig. 11A). Coarse grainstone beds have scoured bases, burrowed tops and in some cases show cross-lamination and hum-

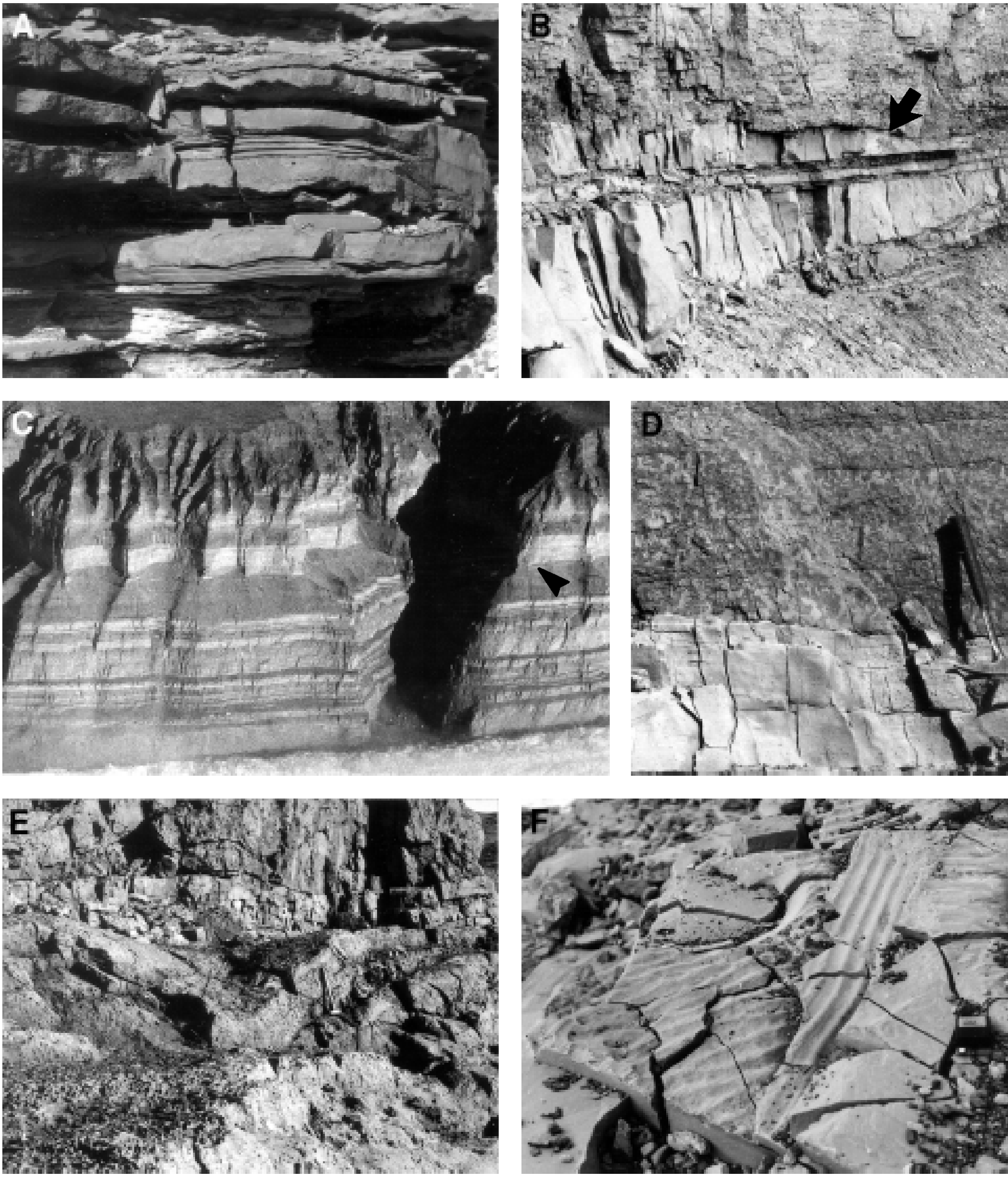


Fig. 11. Ramp and platform interior facies. **A**. Thin-bedded, sharp-based skeletal grainstones and packstones interbedded with calcareous mudstones. Kap Troedsson Formation, southern Wulff Land; penknife (centre) for scale. **B**. Undulating erosional contact (arrowed) between thick storm sand sheets of the Buen Formation and the lowermost phosphoritic dolomites of the Aftenstjernesø Formation. Brønlund Fjord, Peary Land; thick sand sheet is 1 m thick. **C**. Platform interior facies of the Ryder Gletscher Group exposed along Blue Cliffs, Wulff Land (cliff height *c.* 600 m). Note the lateral continuity of the cyclic carbonates in the lower half of the cliff (Blue Cliffs Formation); the succeeding broad pale band (base arrowed) is the shallow marine siliciclastics of the Permin Land Formation. **D**. Sharp contact between light-coloured intertidal-supratidal dolomites and the succeeding darker burrow-mottled subtidal facies. Blåfjeld Formation, south Wulff Land. **E**. Thrombolite mounds. Blåfjeld Formation, south Wulff Land; hammer (centre right) for scale. **F**. Wave-rippled, thin-bedded sandstones. Blue Cliffs Formation, south-west Nordenskiöld Fjord.

mocky cross-stratification. Glauconite and phosphoritic hardgrounds are observed rarely.

East of Nordenskiöld Fjord, the Kap Troedsson Formation of western parts is correlated with a thin interval (2–7 m thick) of nodular burrowed wackestones, skeletal packstones and grainstones (largely dolomitised) at the base of the Aftenstjernesø Formation (see Frykman, 1980). Glauconite and phosphorite are abundant, the latter occurring as detrital grains in winnowed shell lags, as irregular nodules and as coatings on hardground surfaces (e.g. see Fig. 27).

These facies record deposition on a storm-dominated carbonate ramp; the Kap Troedsson Formation in the south-west represents a more proximal, mid-ramp setting, lying between storm and fairweather wave base. The condensed unit at the base of the Aftenstjernesø Formation in the east, however, is indicative of a more distal, sediment-starved outer ramp setting. The shift from the siliciclastic shelf represented by the Buen Formation to the subsequent carbonate-dominated shelf recorded by the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups has been attributed to transgression and drowning of siliciclastic sediment sources (Hurst & Surlyk, 1983). Indeed, a well-developed ravinement surface is observed at the base of the carbonate succession in eastern Peary Land (Fig. 11B).

Platform interior

These well-bedded, cyclic, carbonate-dominated strata (Fig. 11C) are characterised by three assemblages of facies. The first of these, comprising pale-coloured stromatolitic dolomites and dark burrow-mottled dolomites (Fig. 11D), typifies the Blåfjeld, Brikkerne and lower Koch Væg Formations. The pale, often silvery-grey, dolomites show parallel, crinkly, tufted or domal (LLH) stromatolitic lamination, desiccation cracks and bird's-eye fenestrae; flat-pebble conglomerates occur in places. This facies is indicative of deposition on low-energy tidal flats in the high intertidal to supratidal zone. The darker burrow-mottled dolomites (Fig. 11D) show relict mudstone and wackestone fabrics and lack both open marine faunas and evidence of emergence; this facies represents deposition in a low-energy, restricted subtidal environment. Thin oncoid grainstone and packstone beds and thrombolitic or stromatolitic bioherms occur locally in this facies (Fig. 11E) testifying to the importance of microbial activity in this subtidal setting.

The relative proportions of these two broad facies types is variable, ranging from sections dominated by subtidal burrow-mottled dolomites (e.g. Brikkerne Formation, lower Koch Væg Formation) to sections showing a well-developed cyclic alternation of dark subtidal and light intertidal – supratidal dolomites, typically on a metre to decimetre scale (e.g. Blåfjeld Formation, middle Koch Væg Formation; Fig. 11D). Such well-developed mud-rich shallowing-upward cycles characterise restricted, low-energy platforms (James, 1979) and are suggestive of a platform that either possessed an effective marginal barrier system that was able to protect and isolate a low energy, restricted lagoon or a wide platform that was able to dissipate wave energy.

The second facies assemblage, as represented by much of the Blue Cliffs Formation, consists of argillaceous lime mudstones (or dolomites), dolomitised carbonate grainstones and stromatolitic bioherms, often arranged in well-developed shoaling cycles. The lime mudstones are thin-bedded, commonly bioturbated and interbedded locally with skeletal grainstones and packstones and flat-pebble conglomerates. This facies is fossiliferous, containing trilobites of inner shelf aspect. These largely fine-grained sediments form the lower part of 10–25 m thick cycles capped by carbonate grainstones and stromatolitic bioherms, occurring in intimate association and forming thick-bedded to massive, generally pale-coloured dolomite units. The bioherms may be isolated, up to several metres in height and 1–10 m in diameter, or linked in bioherm complexes; internally, they show varied domal and columnar stromatolite forms. They are interbedded, and interdigitate laterally, with cross-bedded grainstones showing relict ooid, pisoid and intraclast grain fabrics. The typical shoaling cycles, from subtidal mud-rich fossiliferous carbonates to shallow subtidal (or intertidal), moderate to high energy grainstones and microbial bioherms, are closely comparable to the idealised 'grainy' stromatolite shoaling cycle described by James (1979), although the cycles of the Blue Cliffs Formation appear to lack intertidal-supratidal caps.

The third facies assemblage, that comprises interbedded dolomites, siltstones and sandstones, occurs in the upper Blue Cliffs Formation and the upper Koch Væg Formation. The carbonates include pale-coloured laminites of inferred microbial origin, often showing desiccation cracks, flat-pebble conglomerates and wavy-bedded burrowed lime mudstones. These are interbedded with fine- to medium-grained, well-rounded quartz arenites showing trough, planar and herring-bone cross-bedding, wave-ripple cross-lamina-

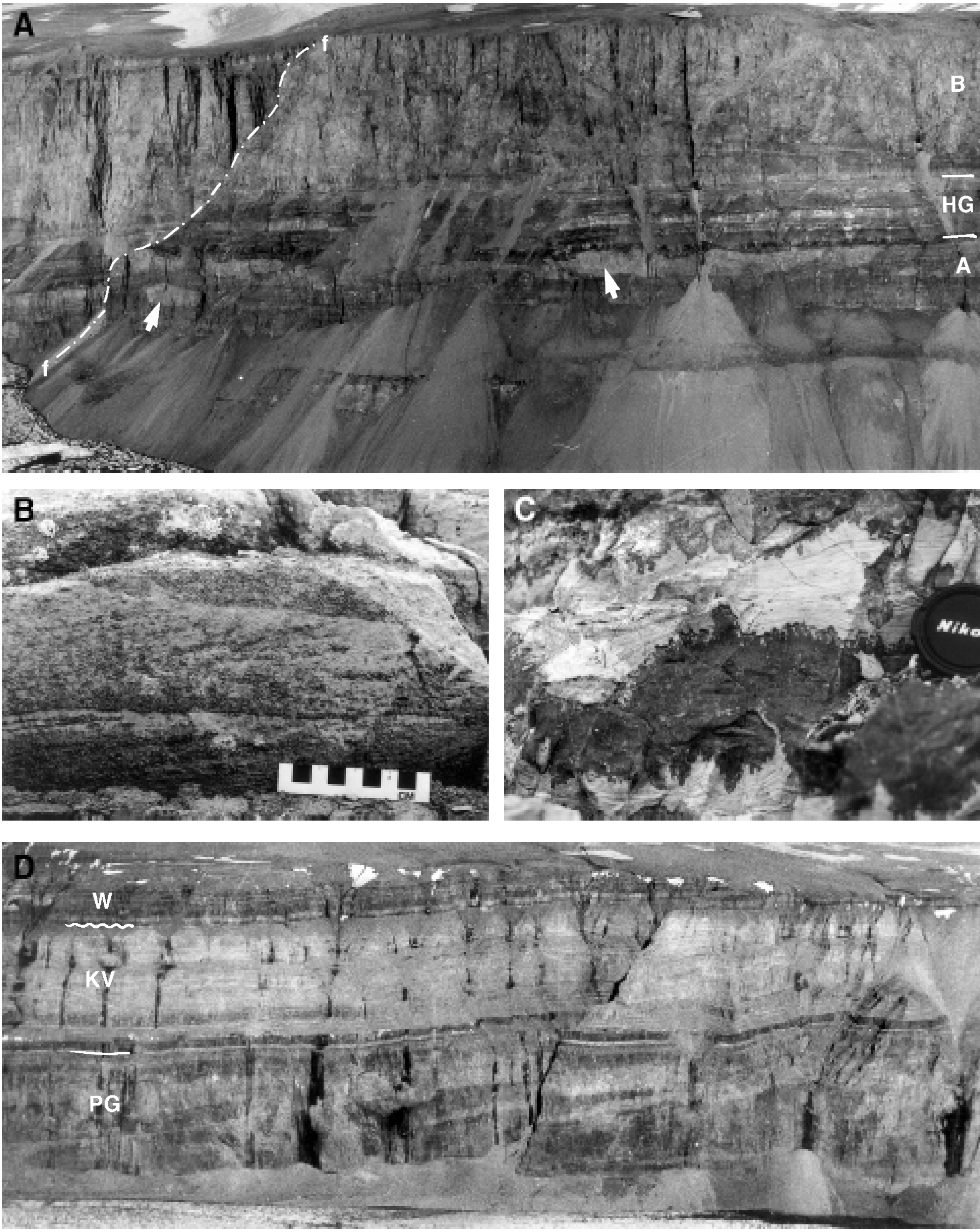


Fig. 12. Platform margin facies. **A**. Massive light-coloured platform margin dolomites (B, Bistrup Land Formation, *c*. 150 m thick) overlying off-platform darker, well-stratified sediments (A, Aftenstjernesø Formation; HG, Henson Gletscher Formation). Note the megabreccia sheet containing massive pale blocks of platform carbonate (arrows) that caps the Aftenstjernesø Formation. North-east Nordenskiöld Fjord. **B**. Cross-bedded dolomitised grainstones of the Paralleldal Formation, Peary Land. **C**. Thrombolitic dolomites with internal cavities lined by pendant and micro-arborescent microbial structures and infilled by fibrous early marine(?) cement. Bistrup Land Formation, south-west Nordenskiöld Fjord. **D**. Northward (left) prograding platform margin carbonates of the Perssuaq Gletscher Formation (PG; *c*. 200 m exposed) succeeded by platform interior facies of the Koch Væg Formation (KV). W, Wandel Valley Formation. Koch Væg, west Peary Land.

tion (Fig. 11F), desiccation cracks and local bioturbation (including *Skolithus* and *Monocraterion*). Although typically poorly exposed, the gross features of this assemblage suggest deposition in a very shallow subtidal to intertidal setting.

Platform margin

Both the shallow-water platform interior carbonates and the deeper-water, off-platform strata are well-bedded and despite widespread dolomitisation typically preserve primary depositional features. In contrast, the platform margin carbonates are poorly stratified dolomites, often forming massive near-structureless cliffs up to 150 m high (Fig. 12A), and only locally retaining primary grain fabrics or sedimentary structures.

Three broad facies are recognised, representing the platform edge and foreslope:

1. Dolomitised, cross-bedded carbonate grainstones are a characteristic component of the platform margin strata (Fig. 12B); ooid grainstones dominate with subordinate bioclastic, peloidal and intraclastic grainstones. Medium-scale trough cross-bedding is typical but planar and hummocky cross-stratification are also present.

2. Associated with the cross-bedded grainstones in Lower Cambrian sections are biostromal dolomites. These are often poorly bedded and contain archaeocyathans, and in places display a well-developed microbial boundstone fabric (Fig. 12C; Ineson & Peel, 1987).

3. The transition from the platform edge to the deeper-water outer shelf deposits is represented by spectacular foreslope deposits showing clinoform bedding dipping northward at angles up to 30 degrees (Fig. 12D); these are the third and most distinctive facies of the platform margin strata. They are pale-coloured, thick-bedded dolomites, including crudely parallel-stratified or cross-bedded grainstones and mass-flow breccia beds.

Platform margin carbonates are represented in the Bistrup Land and Paralleldal Formations of the Brønlund Fjord Group and the Perssuaq Gletscher and Løndal Formations of the Tavsens Iskappe Group. The Perssuaq Gletscher Formation includes both carbonate and siliciclastic facies. The latter are largely of Late Cambrian age; they display well-developed clinoform bedding and appear overtly similar to the carbonate foreslope facies. The main lithologies are trough cross-bedded, medium-grained quartz arenites interbedded with sandy mass flow deposits, bioturbated sandstones and thrombolitic dolomites (Surlyk & Ineson, 1987). This regressive siliciclastic pulse was associated with progressive exposure of the eastern shelf and the formation of the sub-Wandel Valley Formation unconformity (see e.g. Surlyk, 1991). The distinctive clinoform bedding (see Figs 19, 22B) displayed by this siliciclastic succession is thought to have resulted in part from the depositional relief inherited from the previous carbonate-dominated regime.

Carbonate slope apron to deep shelf

The Brønlund Fjord and Tavsens Iskappe Groups are dominated by off-platform, deeper-water carbonates and siliciclastics; they are well-bedded and characteristically form terraced slopes (Fig. 13A). Although highly variable in detail (see Ineson, 1985, 1988), the succession is typified by thinly bedded, dark, fine-grained carbonates and siliciclastics interbedded with carbonate turbidites and mass-flow breccia beds. In proximal settings, adjacent to the platform margin, these deeper water sediments are largely dolomitised (over 80% dolomites) but the proportion of dolomite decreases northwards (basinward) to less than 10% in outermost deep shelf sediments.

The succession shows marked large-scale cyclicity, prominent carbonate-dominated units alternating with more recessive weathering mixed siliciclastic-carbonate units (Fig. 13A). This cyclicity, which is particularly well-developed in the southern more proximal sections, forms the basis for the lithostratigraphic subdivision (see Figs 8, 10, 13A). The proportion of carbonate, in both carbonate-dominated and mixed formations, decreases northwards away from the coeval platform. The carbonate formations ultimately shale out, some 50–70 km north of the platform and the outermost shelf to upper basin slope strata are a condensed succession of black, cherty, calcareous or dolomitic mudstones (see Higgins *et al*., 1992).

In the Henson Gletscher region, where the cyclicity is particularly well-developed, the carbonate-dominated off-platform formations are the Aftenstjernesø and Sydpasset Formations (Brønlund Fjord Group) and the Fimbuldal Formation (Tavsens Iskappe Group) (Fig. 13A). They comprise an alternation of nodular lime

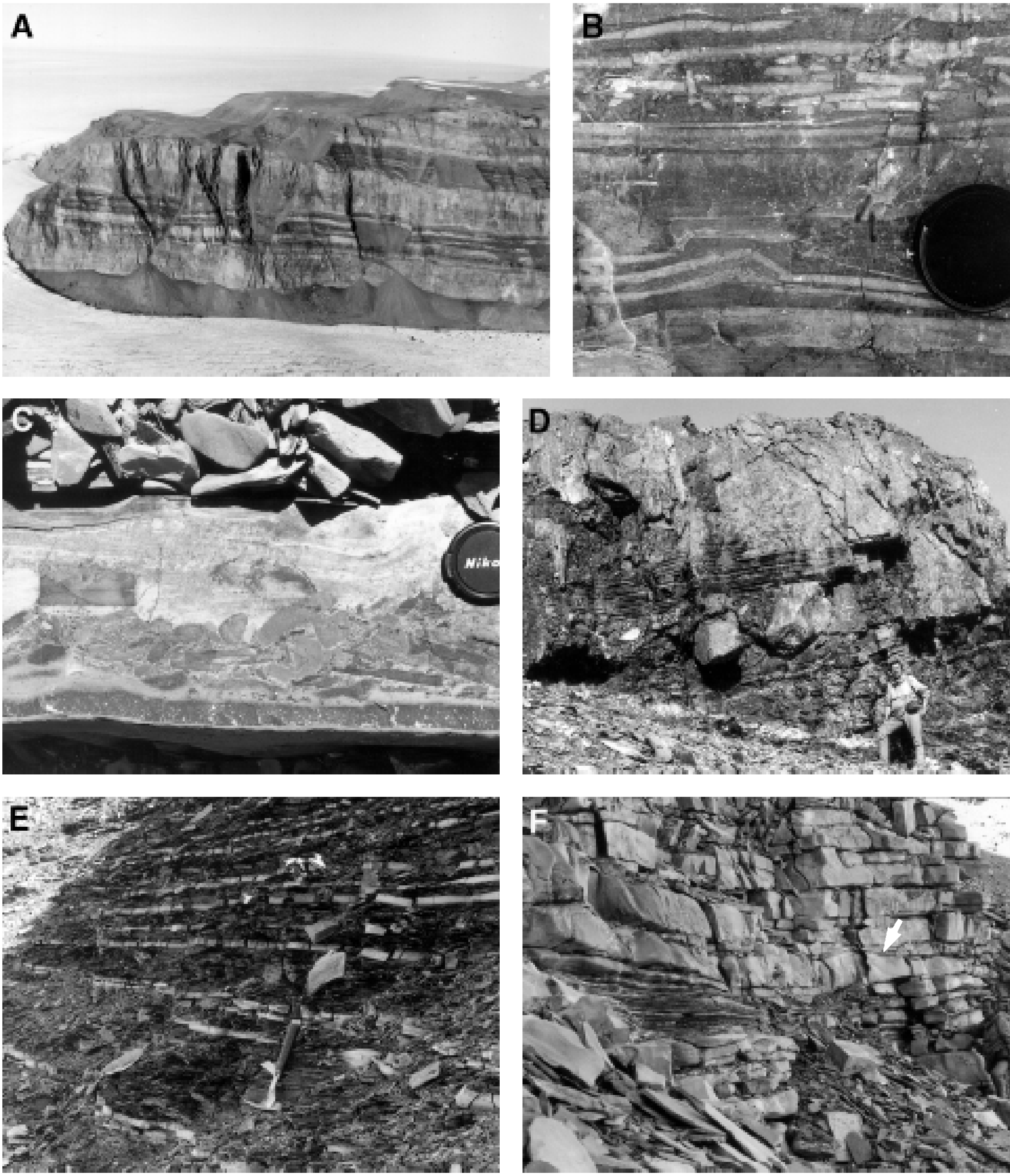


Fig. 13. Slope apron and deep shelf facies. **A**. Brønlund Fjord Group and lower Tavsens Iskappe Group west of Henson Gletscher showing the characteristic alternation of carbonate formations, forming lighter-coloured resistant cliffs, and mixed carbonate - siliciclastic formations, forming darker shaly slopes. Cliff height *c.* 350 m. **B**. Platy nodular lime mudstones showing evidence of downslope creep – pull-aparts, minor buckles and interstratal breccias. Sydpasset Formation, Lauge Koch Land. **C**. Limestone turbidite. Kap Stanton Formation, north Nyeboe Land. **D**. Limestone breccia bed (debris flow deposit) containing both equidimensional pale-coloured blocks derived from the platform margin and rafts of thin-bedded slope apron carbonate. Kap Stanton Formation, outer J. P. Koch Fjord. **E**. Thin lime mudstone beds alternating with dark calcareous silty mudstone. Ekspedition Bræ Formation, Lauge Koch Land. **F**. Medium- to thick-bedded, fine-grained sandstones interbedded with bioturbated heterolithic sandstones and silty mudstones; note pinch-and-swell of individual beds (e.g. arrowed bed). Henson Gletscher Formation, Freuchen Land.

mudstone (or dolomite), graded carbonates and chaotic carbonate breccia beds. The very thinly bedded, platy nodular carbonates are a striking and distinctive facies (Fig. 13B). Although presently composed of dolomite or neomorphic calcite, the well-developed nodular banding probably reflects an original alternation of turbiditic and hemipelagic lime mud, enhanced by early diagenetic, differential cementation. This facies shows abundant evidence of downslope creep and sliding of partially lithified sediment, including pull-aparts, boudinage, creep folds, interstratal breccia lenses and irregular hummocky bedding (Fig. 13B; Ineson & Surlyk, 1995). In more proximal sections, within some 10 km of the platform margin, bioturbation is evident and the nodular bedding is more typically wavy or irregular in form.

The graded carbonate beds are 2–60 cm thick and, where undolomitised, range from silty lime mudstones to peloidal, intraclastic or ooidal grainstones, locally showing Bouma divisions (T_{ab}, T_{abc}; Fig. 13C). They are the deposits of turbidity currents derived from the upper slope and platform margin. Carbonate breccia beds are a distinctive and characteristic facies of this and other off-platform successions (e.g. Cook *et al*., 1972; Cook & Taylor, 1977; Hiscott & James, 1985). In the North Greenland Cambrian, they range from 0.2–50 m in thickness (typically 1–10 m), and are mainly non-channelled, sheet-like bodies, correlatable in many cases for several tens of kilometres (see Fig. 10). The breccias are typically clast-supported, with an interstitial carbonate mud matrix, and they are unstratified and chaotic (Fig. 13D), although grading and organised clast fabrics are recognised. Although dominated by platy or nodular clasts of off-platform origin, large blocks of platform margin grainstone (up to house-size) are prominent in certain beds, particularly within the extensive 'megabreccia' sheets that cap the carbonate-dominated formations (Fig. 12A; Ineson, 1985; Ineson & Surlyk, 1995). This spectacular redeposited carbonate facies records deposition from slides and viscous debris flows (Ineson, 1980, 1988).

The mixed siliciclastic-carbonate formations in the Henson Gletscher region are the Henson Gletscher and Ekspedition Bræ Formations (Brønlund Fjord Group; see Figs 8, 10, 13A) and the Holm Dal Formation (Tavsens Iskappe Group). They are characterised by calcareous mudstones, organic-rich marlstones and lime mudstones (Fig. 13E), interbedded in places with thin limestone turbidites and mass-flow breccia beds. Glauconitic skeletal packstones and cross-bedded grainstones, interbedded with burrowed wackestones, occur in more proximal sections, within 10 km of the coeval platform.

Quartz sand and silt are often present but are of minor significance in these mixed siliciclastic-carbonate formations. However, a siliciclastic sand wedge, up to 125 m thick, occurs within the off-platform succession at around the Early to Middle Cambrian boundary. Assigned to the Henson Gletscher Formation and the laterally equivalent Sæterdal Formation, this sand wedge is persistent along depositional strike (roughly east–west) for more than 300 km and pinches out some 40 km north of the coeval platform (see Fig. 10). It is composed of light-coloured, thin to very thick bedded sheet sandstones that are often structureless but may show dewatering structures, parallel-lamination and weak normal grading. In southern, more proximal sections, these beds are commonly lenticular; they pinch-and-swell and show hummocky cross-stratification (Fig. 13F). Interbedded silty sandstones and siltstones are commonly bioturbated but may show current ripple cross-lamination or parallel lamination.

The marked cyclicity shown by these off-platform strata, carbonate-dominated formations alternating with mixed siliciclastic-carbonate formations, has been attributed to relative sea-level change (Surlyk & Ineson, 1987; Ineson & Surlyk, 1992; 1995). The carbonate-dominated off-platform deposits represent extensive carbonate slope aprons shed from the actively aggrading and prograding carbonate platform during relative highstands of sea level. Such apron sediments extend some 50–70 km north of the contemporaneous platform carbonates before pinching out within condensed deep shelf sediments (Fig. 10; Ineson & Surlyk, 1995). The mixed siliciclastic-carbonate formations record periods of relative lowstand of sea level when the carbonate export potential of the platform was limited due to extensive exposure whereas siliciclastic sediment bypassed the platform and contributed significantly to off-platform sedimentation. This well-developed reciprocal sedimentation pattern in the Cambrian off-platform strata of North Greenland provides the basis for both the lithostratigraphy presented in this paper and for the sequence stratigraphic subdivision (Ineson & Surlyk, 1992, 1995).

Early Cambrian lithostratigraphy

The primary aim of this study is the sub-division and formal definition of the Brønlund Fjord Group and the Tavsens Iskappe Group, and part of the Ryder Gletscher Group, in their outcrop across North Greenland from Nyeboe Land to Peary Land. Cambrian strata in Washington Land and Inglefield Land, to the west, are not included here and references to published descriptions are given above. The following descriptions of the Skagen Group, the Portfjeld Formation and the Buen Formation are included to provide a full account of Cambrian shelf stratigraphy in North Greenland.

Skagen Group

The Skagen Group, as defined by Friderichsen *et al.* (1982), forms the oldest stratigraphic unit of the Franklinian Basin succession in North Greenland. In its type area in north-east Peary Land, it consists of a thick, deformed succession of sandstones and shales; the base is not exposed and it is stratigraphically overlain by the Paradisfjeld Group (Figs 2, 6).

In northern Wulff Land, northern Freuchen Land and the area around Depotbugt, on the southern shore of Frederick E. Hyde Fjord in eastern Peary Land (Fig. 2), a thick succession of mixed carbonate and siliciclastic sediments tentatively referred to the Skagen Group (Surlyk & Ineson, 1987; Higgins *et al*., 1991a) occupies an analagous position within the shelf succession; it is overlain conformably by the Portfjeld Formation (Fig. 6), the shelf equivalent of the Paradisfjeld Group. Farther south, these deposits are absent and the Portfjeld Formation rests unconformably on Upper Proterozoic strata (Fig. 6). The assignment of this lowermost succession of the Lower Palaeozoic shelf succession to the Skagen Group is followed here, but formal description of the succession is not attempted.

The sub-Portfjeld succession is best exposed in northern Wulff Land where it is at least 500–600 m thick; the base is not exposed. The mixed succession of siliciclastic and carbonate sediments becomes more carbonate-rich upwards and ultimately grades into the pale-coloured platform carbonates of the overlying Portfjeld Formation. Surlyk & Ineson (1987) divided the succession into five informal formations (1–5), reflecting the alternation between mudstone-rich, sandstone-rich and carbonate-rich intervals. Formations 1 and 3 (*c*. 200 m and 120 m in thickness, respectively) consist of thinly interbedded silty mudstone and fine-grained sandstones showing wavy and flaser bedding: occasional thicker sandstone beds show hummocky cross-stratification, and dark dolomite beds occur in places. Formations 2, 4 and 5 are each 50–100 m thick and form resistent crags. They are a varied sedimentary assemblage including coarse pebbly sandstones showing hummocky cross-stratification, parallel-stratification and very large scale trough cross-bedding, dark grey intensely veined dolomite and hummocky cross-stratified intraclastic and oolitic dolomite.

In northern Freuchen Land, the exposed succession (*c*. 45 m thick) consists of cross-bedded sandstones comparable to formation 2 in Wulff Land (Surlyk & Ineson, 1987), overlain by dark argillaceous dolomites that grade up into the pale-weathering dolomitised grainstones of the Portfjeld Formation. Higgins & Soper (1985) reported about 65 m of dark shale, siltstone, sandy dolomite and cross-bedded, coarse-grained sandstone beneath the Portfjeld Formation, east of central J. P. Koch Fjord (Fig. 2). At Depotbugt, near the mouth of Frederick E. Hyde Fjord, the Portfjeld Formation overlies a poorly exposed succession of dark, laminated mudstones, thin-bedded sandstones and stromatolitic dolomites with desiccation cracks. The possibility of slight angular discordance at the boundary between the Skagen Group and the Portfjeld Formation in this area was discussed by Christie & Ineson (1979).

The age of the Skagen Group is uncertain since no fossils have been recovered in Greenland. Its base is not seen, although stratigraphic relationships suggest that in north-east Peary Land it succeeds Proterozoic quartzites and volcanics (Christie & Ineson, 1979). The overlying Portfjeld Formation has yielded spirally coiled cyanobacteria of general latest Proterozoic – Early Cambrian aspect, but these are of uncertain biostratigraphic value (Peel, 1988a). The Skagen Group has been correlated with the Kennedy Channel Formation of Ellesmere Island (Dawes & Peel, 1984) which has yielded faunas of Early Cambrian age (Long, 1989a; Trettin *et al*., 1991).

Portfjeld Formation

The Portfjeld Formation crops out extensively in central and eastern North Greenland, but is not recognised to the west of Wulff Land nor east of Danmark Fjord (Fig. 2). In its northern outcrop the Portfjeld Formation overlies the Skagen Group (Fig. 6) whereas in more southerly outcrops it rests unconformably on Proterozoic strata. The Portfjeld Formation is overlain by siliciclastic sediments of the Buen Formation. The boundary is sharp and planar over much of southern Peary Land and O'Connor (1979) suggested a conformable relationship. However, the boundary is locally highly irregular; steep-sided depressions some tens of metres in diameter occur at this boundary south of Øvre Midsommersø, infilled by the lowermost Buen Formation sandstones. Furthermore, in central North Greenland, the uppermost beds of the Portfjeld Formation are locally reddened, fractured and in places highly brecciated (Davis & Higgins, 1987). It is considered likely therefore that the upper boundary of the Portfjeld Formation represents a significant karstified hiatal surface (Higgins *et al*., 1991a).

The Portfjeld Formation is 206 m thick at the type section in southern Peary Land (Jepsen, 1971). The formation thickens westward, attaining 290 m west of Øvre Midsommersø, but thins and ultimately wedges out to the south-east of the type area (O'Connor, 1979). The Portfjeld Formation thickens markedly towards the north. In north-east Peary Land the formation is 400–700 m thick (Christie & Ineson, 1979) and 500–700 m thick in the north-west Peary Land and northern Freuchen Land area (Higgins *et al*., 1991a).

In southern Peary Land, the Portfjeld Formation is characterised by pale grey to yellow weathering, thin to medium-bedded dolomites which commonly include flat-pebble conglomerates, cross-bedded ooidal, intraclastic dolomites and stromatolitic dolomites (Fig. 14). Medium to coarse-grained sandstone intervals occur in places, particularly in the upper third of the formation (Fig. 14), often associated with brecciated or irregular pot-holed surfaces of probable karstic origin. A persistent unit of dark cherty dolomite forms a distinctive marker in southern Peary Land (O'Connor, 1979; Peel, 1988a). In northern exposures, the formation is dominated by dolomitised ooid-intraclast grainstones showing trough cross-bedding and hummocky cross-stratification, with subordinate pisolitic and oncolitic grainstones and complex stromatolitic bioherms.

In southern Wulff Land and the land area south of Nares Land, the Portfjeld Formation *sensu stricto* is absent and is replaced by a distinctive megabreccia unit (85–270 m thick) which overlies gneissic basement and is succeeded by siliciclastic sediments of the Buen Formation. It includes large slabs, up to tens of metres across, of Portfjeld Formation dolomite, some of which were incorporated in a semi-lithified, plastic condition (Hurst & Peel, 1979; Surlyk & Ineson, 1987; Higgins *et al*., 1991; Surlyk, 1991).

Stromatolites are locally conspicuous in the Portfjeld Formation but no macrofossils have been found. Jepsen (1971) suggested an Eocambrian or Early Cambrian age on the basis of its stratigraphic position below the Lower Cambrian Buen Formation. Pedersen (1970,

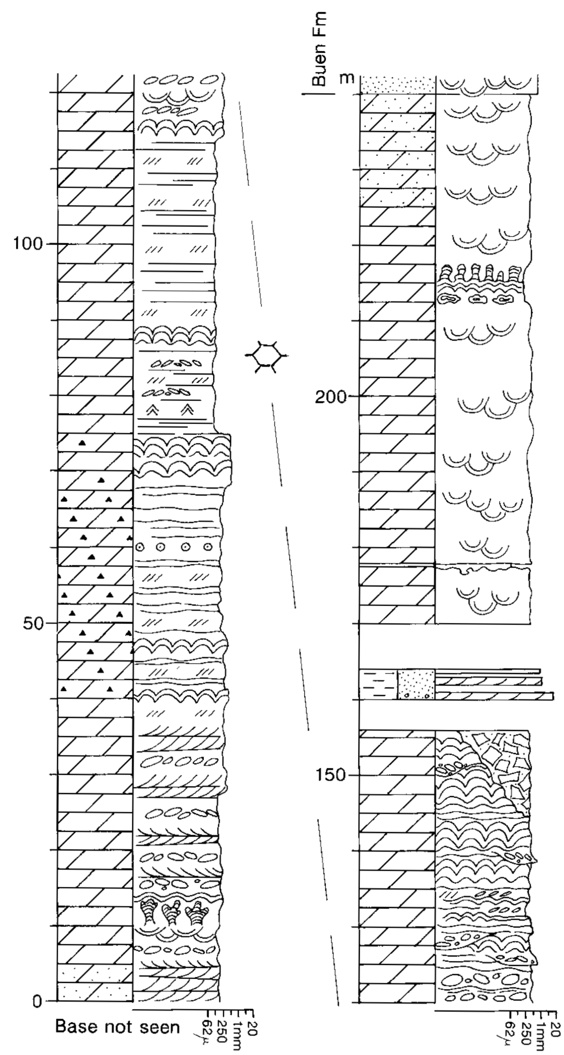


Fig. 14. Typical section through the Portfjeld Formation in southern Peary Land. Note the siliciclastic interval at 150-170 m, associated with a karstic breccia, and the potholed karstic suface at 178 m. The cherty dolomites in the lower half of the formation (40–70 m) form a distinctive dark marker in southern Peary Land. Section measured by R. L. Christie and J. R Ineson on the north side of Nedre Midsommersø.

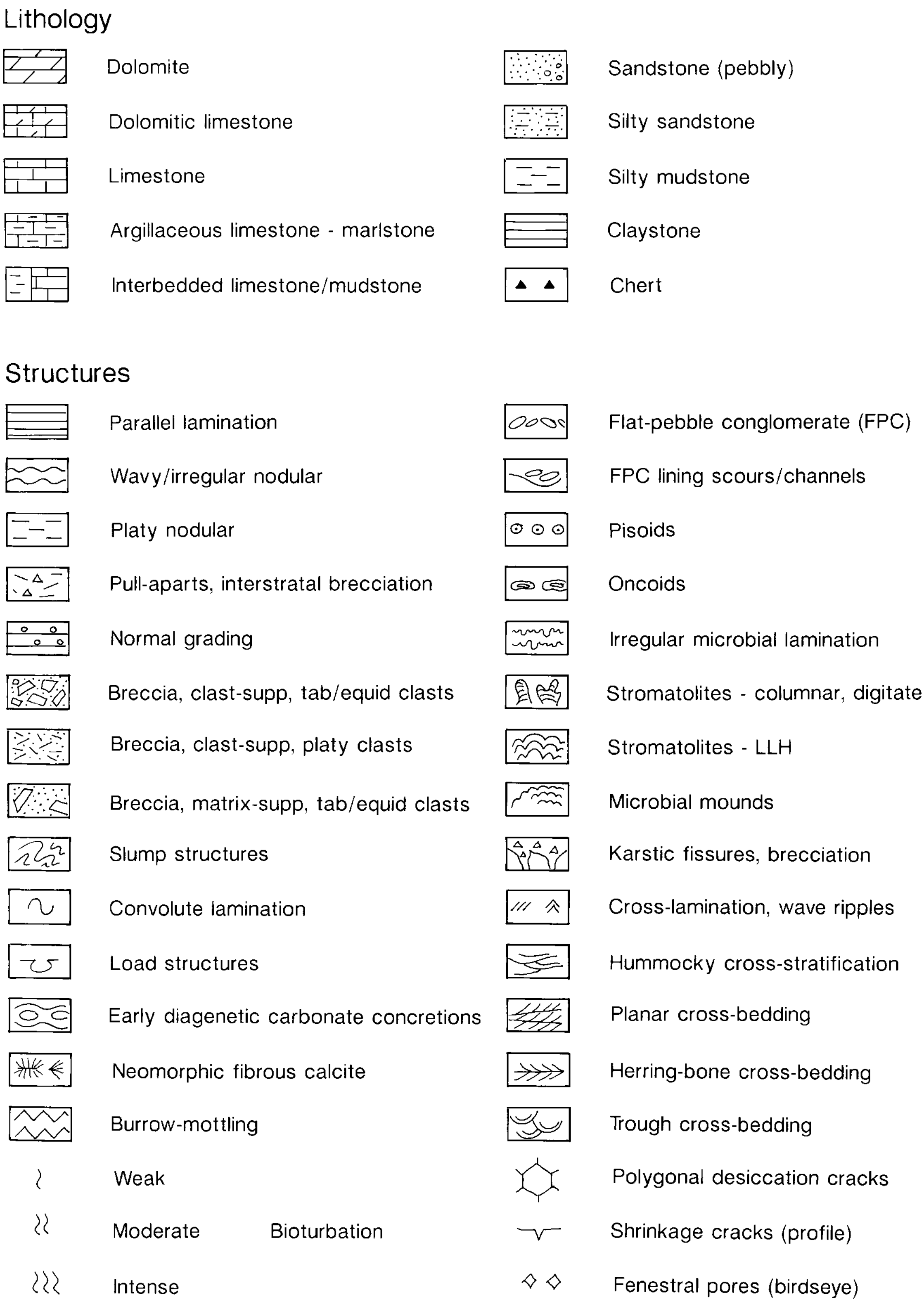


Fig. 14 cont. The accompanying legend is applicable to all stratigraphic logs in this paper. The log profile indicates the grain size of siliciclastic rocks and resedimented carbonate facies coarser than sand grade. For the remaining carbonates, the profile is purely a representation of weathering characteristics. Supp, supported; tab, tabular; equid, equidimensional; LLH, laterally-linked hemispheroids.

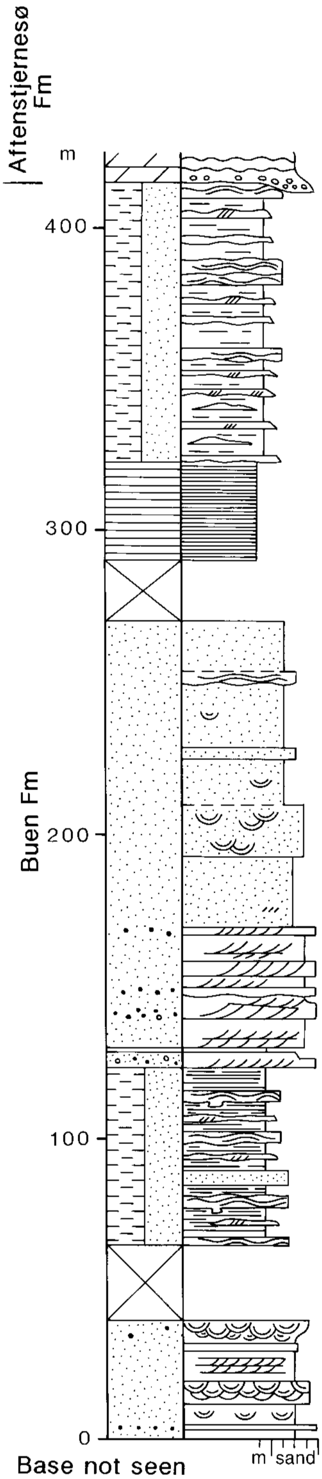


Fig. 15. The Buen Formation at its type locality on the south side of Buen, southern Peary Land, showing the characteristic development into a lower sand-dominated member (0–270 m) and an upper mud-dominated member (270–420 m). Note the erosional contact between the upper Buen Formation and the lowermost carbonates of the Brønlund Fjord Group (see Fig. 11B). See Fig. 14 for legend; m, mud.

1976) and Peel (1980, 1988a) recorded sparse fossils from the prominent dark cherty horizon in the lower half of the formation in southern outcrops. These include spirally coiled cyanobacteria referred to *Spirellus*, *Obruchevella* and *Jiangispirellus* by Peel (1988a) but offer little precision for biostratigraphic age determination other than indicating a general late Proterozoic – Early Cambrian age. The Portfjeld Formation has been correlated with the Ella Bay Formation of Ellesmere Island (Dawes & Peel, 1984; Long, 1989b), which is suggested to be of Early Cambrian age (Long, 1989b).

Buen Formation

The Buen Formation (Jepsen, 1971) is 325–500 m thick in southern Peary Land and in the southern parts of central North Greenland, but it thickens northwards to an estimated 700 m in southern Nansen Land at the transition into the deep-water basin (Higgins & Soper, 1985; Higgins *et al.*, 1991). The formation is informally subdivided into a lower sand-dominated member and an upper mud-dominated member (Fig. 15). Sand content decreases northwards; the sandstone member thus dominates in southern exposures whereas the formation is mud-dominated in north-east Peary Land and northern parts of central North Greenland. In north-east Peary Land, the mud-rich Buen Formation is partly equivalent to the Schley Fjord shale of Troelsen (1956).

The lower sandstones show large-scale compound cross-bedding, herring-bone cross-bedding and hummocky cross-stratification. Bioturbation is common and *Skolithos* burrows are locally abundant (Bryant & Pickerill, 1990). Rare horizons of stromatolitic sandy dolomite were recorded in this sandstone member in north Wulff Land.

The upper, mud-dominated member typically consists of dark grey-green claystones and siltstones in which parallel lamination is often preserved, but bioturbation is common. At some localities, particularly in south-east Peary Land (Fig. 15), these mudstones are interbedded with thin to medium-bedded, medium to fine-grained sandstones showing current ripple cross-lamination and hummocky cross-stratification.

The Buen Formation overlies the Portfjeld Formation in southern Peary Land and Freuchen Land, and the megabreccia unit in southern Wulff Land and the land area south of Nares Land (Figs 2, 6). It is overlain by the Brønlund Fjord Group (Peel, 1979; Ineson & Peel, 1980); the upper boundary appears sharp at many localities and has been described as an erosional disconformity or unconformity (Troelsen, 1956; Jepsen, 1971). In detail, however, the boundary is gradational where not scoured and is regarded as a conformable sedimentary contact (Frykman, 1980).

The lower, sand-dominated member of the Buen Formation in southern outcrops has not yielded body fossils, although a variety of trace fossils of typical Early Cambrian aspect were described by Bryant & Pickerill (1990). Trace fossils are also recorded from the upper part of the formation (Bergström & Peel, 1988; Bryant & Pickerill, 1990) but the mud-dominated strata have also yielded abundant macrofossils. Olenelloid trilobites, including *Olenellus (Mesolenellus) hypoboreus* and other fossils occur in mudstones at the base of this upper unit in southern Peary Land; *Olenellus svalbardensis* is also described from the uppermost part of the formation in north-east Peary Land (Poulsen, 1974; Blaker, 1991; Palmer & Repina, 1993). Lane & Rushton (1992) have described a problematic Early Cambrian trilobite from the upper part of the formation in northern Freuchen Land, in association with sponges (Rigby, 1986). Examination of acritarch assemblages by Vidal & Peel (1993) has confirmed the general late Early Cambrian age of the Buen Formation in its southern outcrop belt.

In north-western Peary Land an unusual fauna of Burgess Shale type, comprising poorly skeletised arthropods, worms, sponges, articulated halkieriids and other problematic fossils (the Sirius Passet fauna) occurs in mudstones in the lowest part of the formation (Rigby, 1986; Conway Morris *et al.*, 1987; Conway Morris & Peel, 1990, 1995; Peel, 1990; Peel *et al*., 1992; Budd, 1993, 1994). The presence of the olenelloid trilobite *Buenellus higginsi* indicates an Early Cambrian (*Nevadella* Zone) age (Blaker, 1988, 1991; Palmer & Repina, 1993; Conway Morris & Peel, 1995).

Brønlund Fjord and Tavsens Iskappe Groups: amended definition

The Brønlund Fjord and Tavsens Iskappe Groups are recognised in three geographically distinct outcrop belts, here termed the southern, northern and eastern outcrop belts (Fig. 16). Description of the formal lithostratigraphy follows this geographical demarcation. Formal definition of the Brønlund Fjord and Tavsens Iskappe Groups given by Peel (1979) is expanded herein to include information acquired from adjacent areas since the 1978 field season (Ineson & Peel, 1980, 1987; Higgins & Soper, 1985; Peel & Wright, 1985; Davis & Higgins, 1987).

Brønlund Fjord Group

History. Peel (1979) raised the Brønlund Fjord Formation (originally the Brønlund Fjord Dolomite; see Fig. 4) of previous usage (Troelsen, 1949, 1956; Christie & Peel, 1977) to the rank of group and informally recognised four formations in the J. P. Koch Fjord area of south-west Peary Land. The former Brønlund Fjord Formation of the Jørgen Brønlund Fjord area was tentatively correlated with the lower two formations described from south-west Peary Land (Peel, 1979). A correlation was established between these two areas during the 1979 field season (Ineson & Peel, 1980) which necessitated the description of a further two formations within the Brønlund Fjord Group in central south Peary Land. In addition, two formations reported from the G. B. Schley Fjord area (eastern outcrop belt of this paper) by Christie & Ineson (1979) were included within the group. Following fieldwork in 1984 and 1985, a further two informally described formations recognised by Peel & Wright (1985) in the Nordenskiöld Fjord – Warming Land area were assigned to the Brønlund Fjord Group by Ineson & Peel (1987) and the lowest two formations in the J. P. Koch Fjord area were recognised in the northern outcrop belt (cf. Higgins *et al*., 1991a, b).

Name. From Jørgen Brønlund Fjord, south Peary Land (Figs 16, 17).

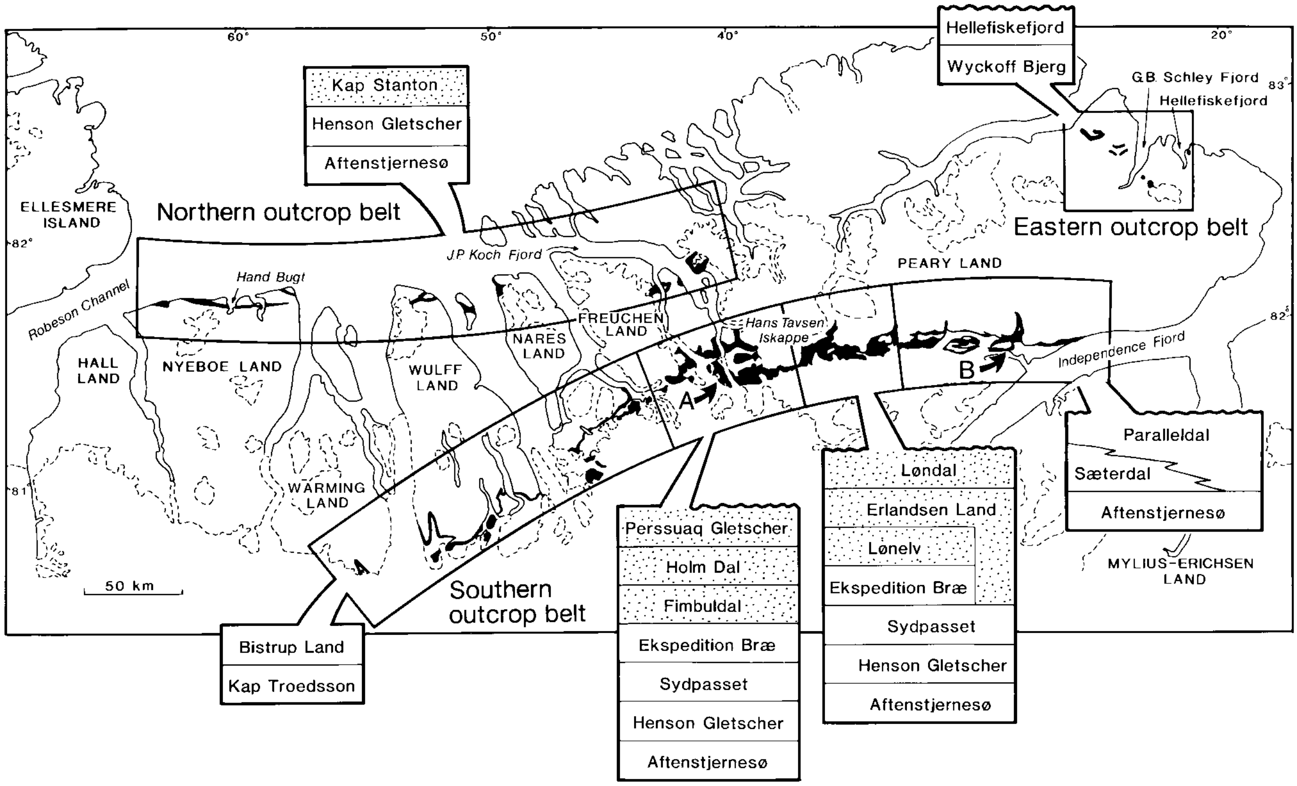


Fig. 16. Map showing the distribution (black) of the Brønlund Fjord and Tavsens Iskappe Groups in North Greenland, and their component formations (Tavsens Iskappe Group stippled). These rocks form three discrete outcrop belts: the southern, northern and eastern outcrop belts. The extensive southern outcrop belt, extending from southern Warming Land to south-eastern Peary Land, is subdivided into four regions for the purposes of lithostratigraphic description. A, reference area and type area of the Brønlund Fjord and Tavsens Iskappe Groups, respectively; B, type area of the Brønlund Fjord Group. Modified from Higgins *et al.* (1991a).

Type area. Peel (1979) designated the north side of Jørgen Brønlund Fjord (Fig. 17) as the type area of the group in accordance with the type area of the former Brønlund Fjord Formation (Fig. 3; Troelsen, 1949, 1956). A reference area was defined on the west side of Henson Gletscher in easternmost Lauge Koch Land (Figs 1, 16) where the group is well exposed and fully developed (Peel, 1979).

Thickness. About 175 m in the type area. The group thickens westward due to the eastward overstep of the unconformably overlying strata of the Wandel Valley Formation (Early – Middle Ordovician). Where fully developed, in south-west Peary Land, it reaches a maximum measured thickness of about 240 m (Figs 10, 18). In the northern outcrop belt (Fig. 16) the Brønlund Fjord Group is 50–150 m thick whereas it attains a thickness of 115–265 m in the eastern outcrop belt.

Dominant lithology. In the type area, the group is composed of yellow-brown weathering, cliff-forming dolomite, which includes dark, thinly bedded, laminated and graded dolomites and thick dolomite breccia beds. Pale cream weathering, structureless or cross-bedded dolomite forms the upper unit of the group in the type area (Fig. 17).

Farther west, in the reference area around the head of J. P. Koch Fjord, the group is more varied consisting of cliff-forming units of thick-bedded dolomite breccias, nodular dolomites and limestones, and dolomitised carbonate turbidites, alternating with recessive intervals of thin-bedded, bituminous, argillaceous and cherty dolomites and lime mudstones (Figs 10, 18). Cream-coloured, fine-grained sandstones and dark siltstones form a minor part of the group in northern exposures within the reference area, but thicken southward to form a distinctive pale stripe in cliff sections along Henson Gletscher.

In the northern outcrop belt (Fig. 16), dark, cherty, laminated or nodular lime mudstones and calcareous shales are typical of the group. In the eastern outcrop belt (Fig. 16), the group consists largely of an amalgamated stack of dolomite breccia beds and sandstone-dolomite breccia beds; dark, laminated dolomite intervals occur in places.

Boundaries. The Brønlund Fjord Group conformably overlies the Buen Formation and is conformably overlain by the Tavsens Iskappe Group in west Peary Land, Lauge Koch Land, Freuchen Land and the northern outcrop belt (Figs 5, 16). Eastward from Henson Gletscher, the Wandel Valley Formation (Ryder Gletscher Group of Early – Middle Ordovician age) progressively oversteps the Tavsens Iskappe Group such that the Wandel Valley Formation rests unconformably on the Brønlund Fjord Group to the east of Øvre Midsommersø (Figs 5, 16); the Brønlund Fjord Group is itself also gradually overstepped such that the Wandel Valley Formation lies directly on the Buen Formation south of Independence Fjord.

In the Nordenskiöld Fjord – Warming Land area, the Brønlund Fjord Group is conformably overlain by the Ryder Gletscher Group (Fig. 5). In the eastern outcrop belt, the Brønlund Fjord Group is overlain with probable unconformity by the Wandel Valley Formation (Christie & Ineson, 1979).

Distribution. The group crops out continuously for some 350 km from Independence Fjord westward to southern Warming Land (Fig. 16). The Brønlund Fjord Group also crops out in folded inliers in its northern outcrop belt from western Peary Land to Nyeboe Land; it is present in fault blocks in its eastern outcrop belt.

Geological age. Late Early – late Middle Cambrian.

Subdivision. The Brønlund Fjord Group consists of eight formations in the southern outcrop belt (Figs 5, 16). Of these, the Aftenstjernesø Formation is recognised throughout southern Peary Land, Lauge Koch Land and Freuchen Land. East of Øvre Midsommersø, the Henson Gletscher, Sydpasset and Ekspedition Bræ Formations are not recognised and the Aftenstjernesø Formation is followed conformably by the Sæterdal and Paralleldal Formations. The Brønlund Fjord Group in the Nordenskiöld Fjord – Warming Land region comprises the Kap Troedsson and Bistrup Land Formations; together these formations correlate eastwards with the Aften-stjernesø Formation.

In the northern outcrop belt, the group consists of only the Aftenstjernesø and Henson Gletscher Formations while in the eastern outcrop belt it is divided into the Wyckoff Bjerg and Hellefiskefjord Formations (Figs 5, 16).

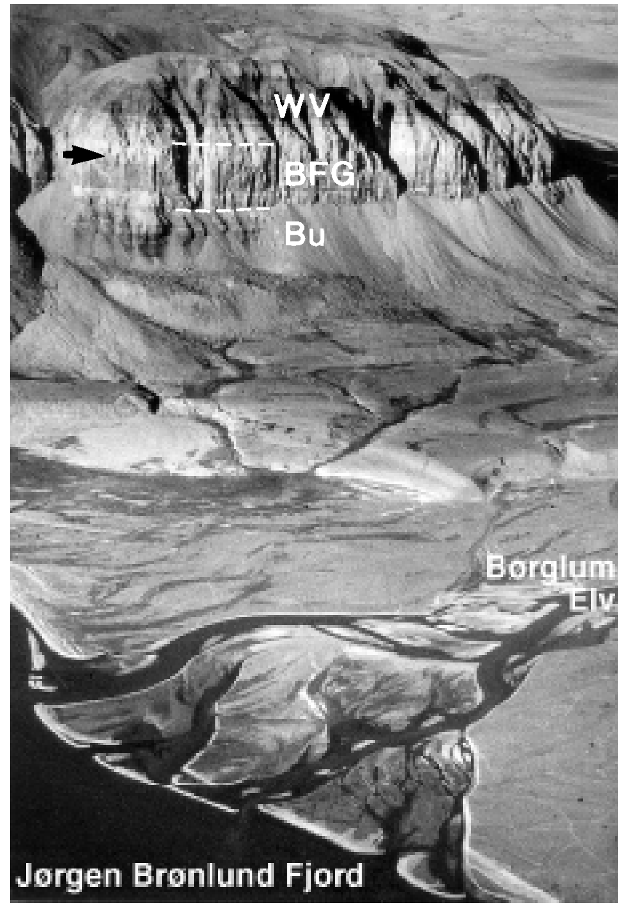


Fig. 17. Type area of the Brønlund Fjord Group (BFG) overlooking the mouth of Børglum Elv and Jørgen Brønlund Fjord in south-east Peary Land. The group (175 m thick) conformably overlies the largely scree-covered Buen Formation (Bu) and is unconformably overlain by the Wandel Valley Formation (WV). Note the tripartite subdivision of the group: the lower light and middle dark stripe make up the Aftenstjernesø Formation and the upper pale stripe is the Paralleldal Formation (arrow indicates the boundary). The lower pale unit of the Aftenstjernesø Formation is a 30–40 m thick dolomite breccia bed with an irregular, hummocky top. Modified from Peel & Smith (1988).

Tavsens Iskappe Group

History. Peel (1979) erected the Tavsens Iskappe Group to describe the strata in west Peary Land that conformably overlie the Brønlund Fjord Group and are unconformably overlain by the Wandel Valley Formation (Early – Middle Ordovician). Four formations were informally described from Gustav Holm Dal, west of Hans Tavsen Iskappe (Figs 1, 16) and a thickness of 900 m was suggested for the group. A correlation between this locality and exposures of the group farther to the south and to the east of the outcrop was not attempted.

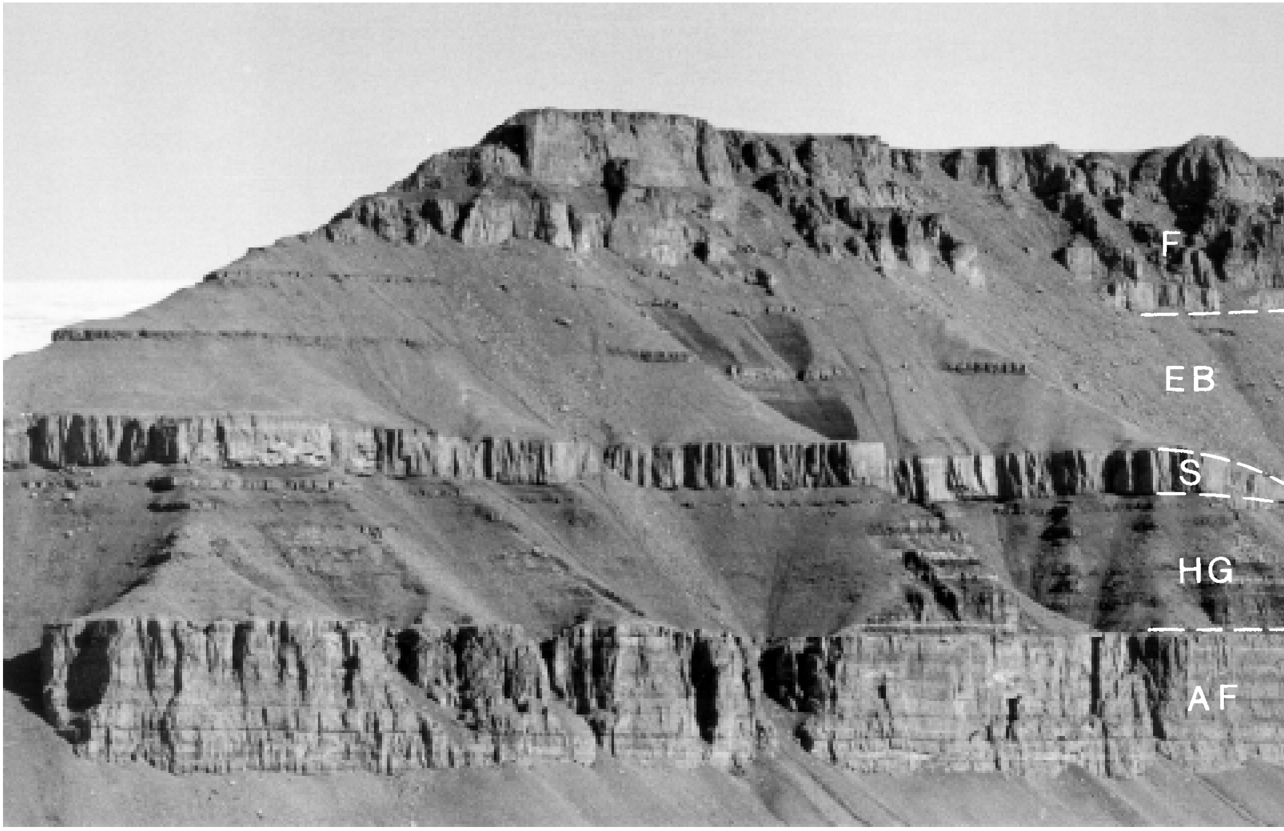


Fig. 18. Typical terraced exposures of the Brønlund Fjord Group in the reference area, the prominent cliffs of the Aftenstjernesø (AF) and Sydpasset (S) Formations alternating with the reccessive-weathering Henson Gletscher (HG) and Ekspedition Bræ (EB) Formations. The Fimbuldal Formation (F; Tavsens Iskappe Group) caps the succession. East of the head of J. P. Koch Fjord, west Peary Land; total exposed thickness *c.* 300 m. From Higgins *et al.* (1991a).

Fieldwork in 1979 led to slight redefinition of the formations and the total thickness assessed to be as about 700 m (Ineson & Peel, 1980). Seven formations were recognised within the Tavsens Iskappe Group; four in the Henson Gletscher area and three in Løndal, to the east of Hans Tavsen Iskappe (Fig. 16). Bordering Henson Gletscher in the south (Fig. 1), the Tavsens Iskappe Group is equivalent to the upper beds of Unit F and Unit G of Dawes (1976b).

Following the field seasons of 1984 and 1985, the uppermost informally described formation (T4) of the Tavsens Iskappe Group at Henson Gletscher was reassigned to the Ryder Gletscher Group (Ineson & Peel, 1987); it is formally described here as the Koch Væg Formation. Work in the northern outcrop belt during this period led to recognition of the Tavsens Iskappe Group in this area (Higgins *et al.*, 1991a, b) where it is represented by the Kap Stanton Formation, defined recently by Ineson *et al.* (1994). Formation T2 of Ineson & Peel (1980) was formally defined as the Holm Dal Formation of the Tavsens Iskappe Group (Ineson, 1988; Peel, 1988b).

Name. After Hans Tavsen Iskappe, south-west Peary Land (Fig. 16). The name Tavsens Iskappe Group was defined by Peel (1979) from Hans Tavsen Iskappe. This genitive form is no longer maintained in current geographical nomenclature. Thus, the icecap itself is now referred to as Hans Tavsen Iskappe, although the group name retains the original spelling.

Type area. The area bordering Henson Gletscher and the head of J. P. Koch Fjord, south-west Peary Land (Figs 1A, 16, 19).

Thickness. Approximately 700 m in Gustav Holm Dal, thinning to an estimated 400 m at Koch Væg, in the south, and to about 300 m in Løndal, in the east (see Fig. 46). The preserved thickness of the group decreases eastward from Løndal due to progressive overstep by

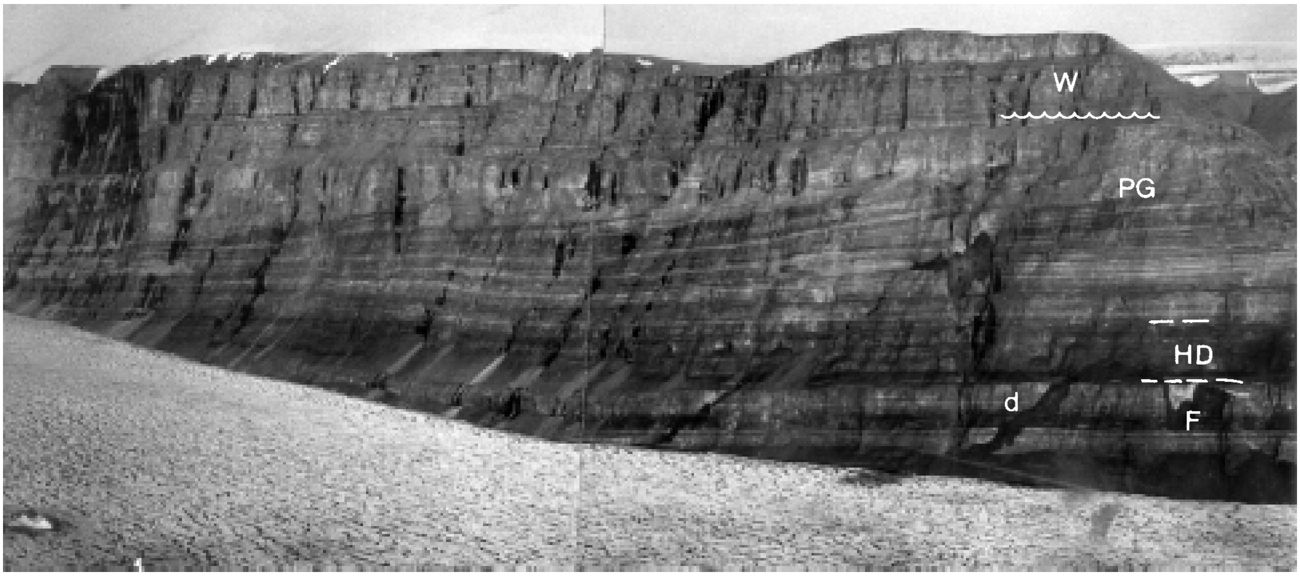


Fig. 19. The Tavsens Iskappe Group in the type area, on the east side of J. P. Koch Fjord, west Peary Land (see Fig. 1A). Carbonates of the Fimbuldal (F) and Holm Dal (HD) Formations are succeeded by a thick succession of prograding siliciclastics and carbonates assigned to the Perssuaq Gletscher Formation (PG). This Middle Cambrian – lowermost Ordovician succession is overlain unconformably by the Wandel Valley Formation (W). Height of cliff about 1000 m; d, dyke. From Higgins *et al.* (1991a).

the Wandel Valley Formation. Thickness ranges from 110 m to 300 m in the northern outcrop belt.

Dominant lithology. The group consists of a varied sequence of dark, recessive limestones and dolomites, pale weathering dolomites and sandstones. Near the head of J. P. Koch Fjord, the group commences with platy, nodular and thin-bedded argillaceous lime mudstones interbedded with prominent dolomitised breccia beds. These are overlain by mixed sandstone-dolomite breccia beds, cross-bedded and bioturbated dolomitic or quartz-cemented sandstones; these beds typically display northward-dipping clinoforms (Fig. 19). At Henson Gletscher and in the area to the east of Hans Tavsen Iskappe, the group commences with dark, thin-bedded dolomites and argillaceous limestones, interbedded with dolomitised breccia beds. These are followed by prominent pale weathering, cross-bedded dolomites that are commonly oolitic and locally show clinoform bedding (Fig 10).

In the northern outcrop belt, yellow weathering, dark grey argillaceous dolomites, limestones and calcareous or dolomitic claystones are interbedded at regular intervals with carbonate breccia beds.

Boundaries. The Tavsens Iskappe Group conformably overlies the Brønlund Fjord Group (Figs 5, 16). In the Henson Gletscher region, the Tavsens Iskappe Group is succeeded conformably by the Koch Væg Formation. Elsewhere in the southern outcrop belt, the Tavsens Iskappe Group is unconformably overlain by the Wandel Valley Formation. In the northern outcrop belt, the group is overlain conformably by black, cherty mudstones of the Amundsen Land Group (Fig. 5).

Distribution. In the southern outcrop belt, the group is recognised from southern Freuchen Land eastward across Lauge Koch Land and west Peary Land to the valley north of the eastern end of Øvre Midsommersø (Figs 2, 16) where the group is overstepped by the Wandel Valley Formation.

In the northern outcrop belt, the Tavsens Iskappe Group is recognised in folded inliers from western Peary Land to northern Nyeboe Land (Fig. 16).

Geological age. Middle Cambrian – earliest Ordovician.

Subdivision. Six formations are recognised in the southern outcrop belt, three on each side of Hans Tavsen Iskappe (Figs 5, 16). A single formation of the Tavsens Iskappe Group, the Kap Stanton Formation, is represented in the northern outcrop belt (Fig. 16).