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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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Abstract

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

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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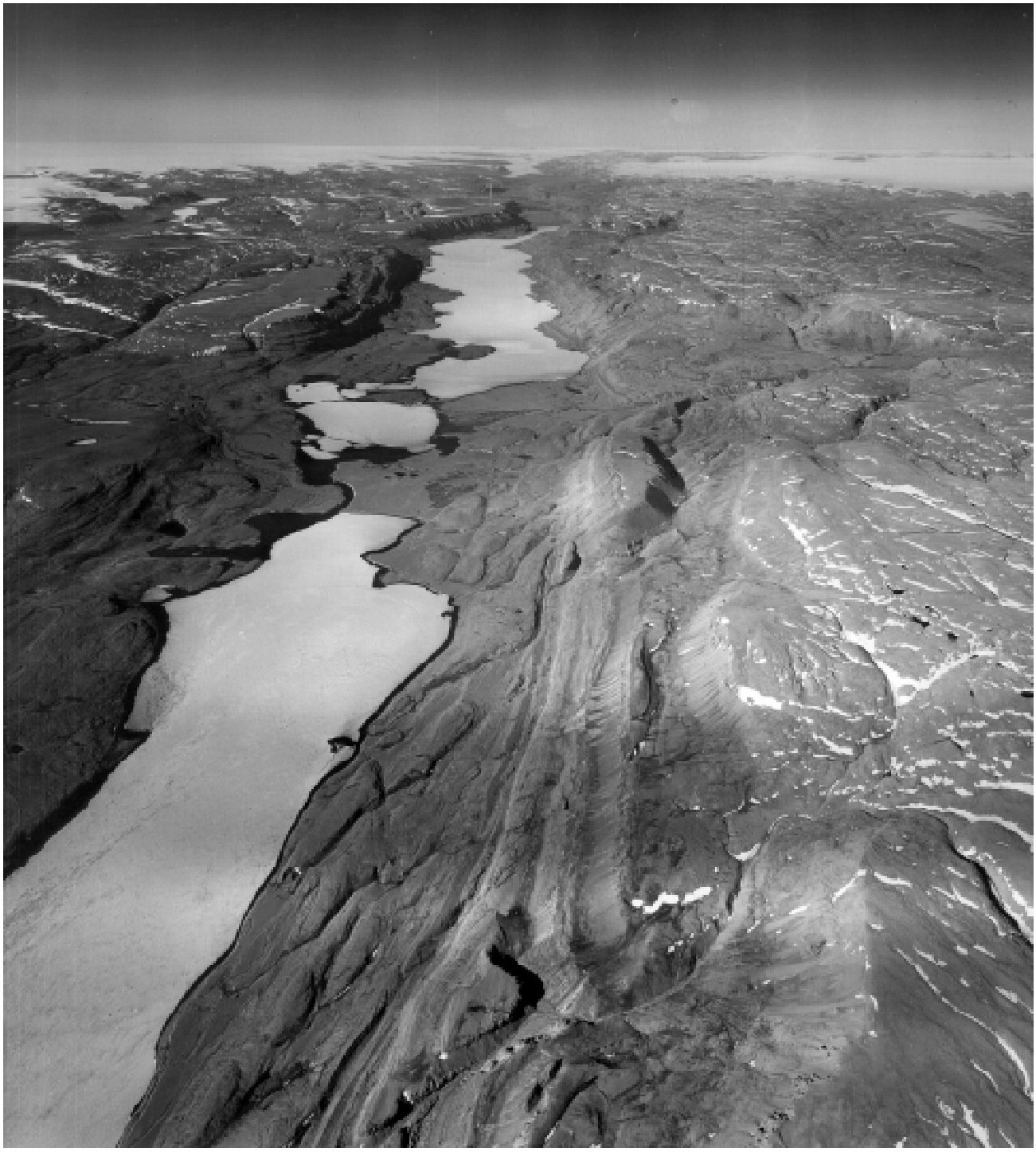


Frontispiece. Early geological observations in eastern North Greenland were particularly centred around Wandel Dal, a major east–west glacial valley system in southern Peary Land that facilitated travel between Independence Fjord and central North Greenland. This view, westwards along the valley with 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

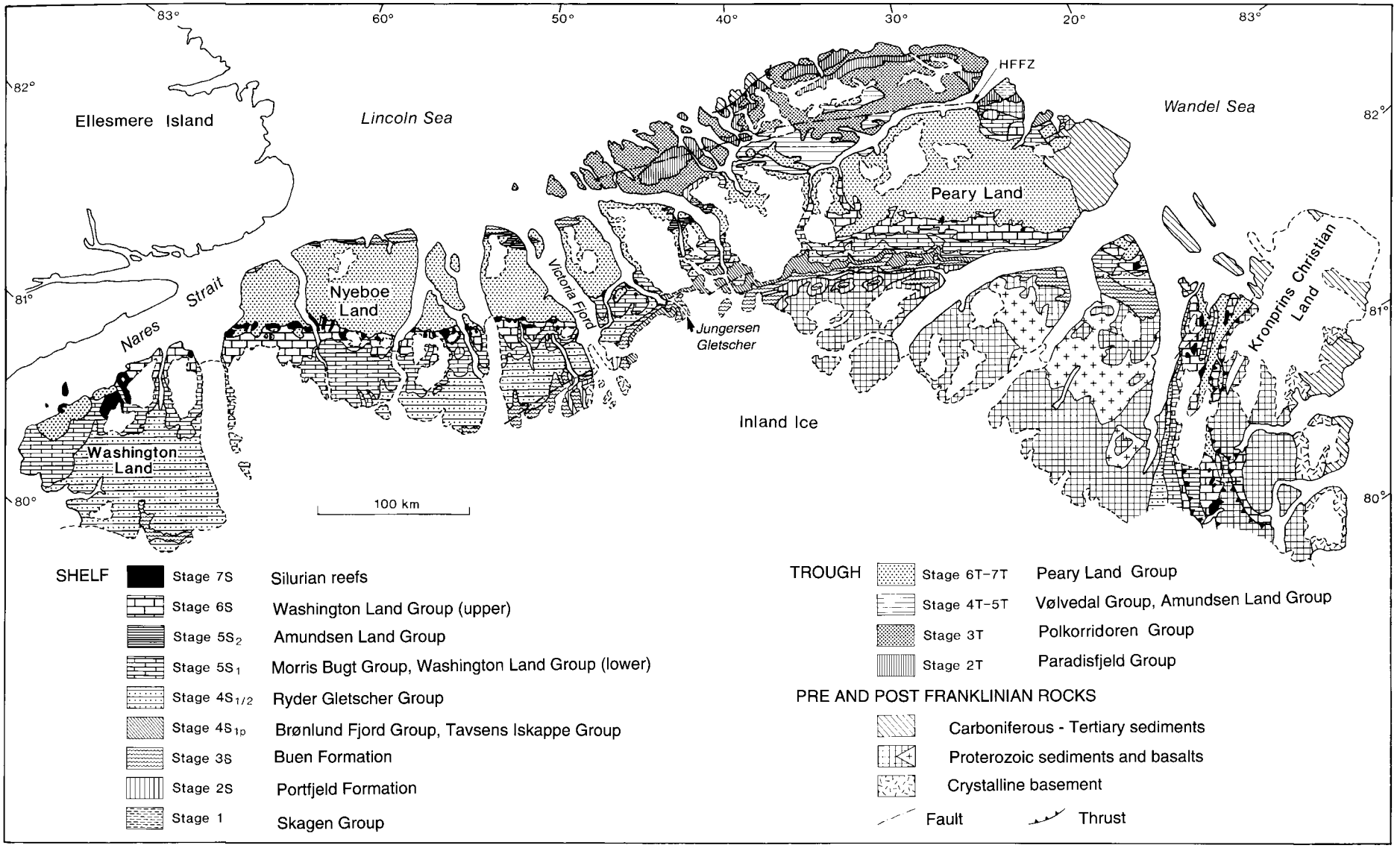
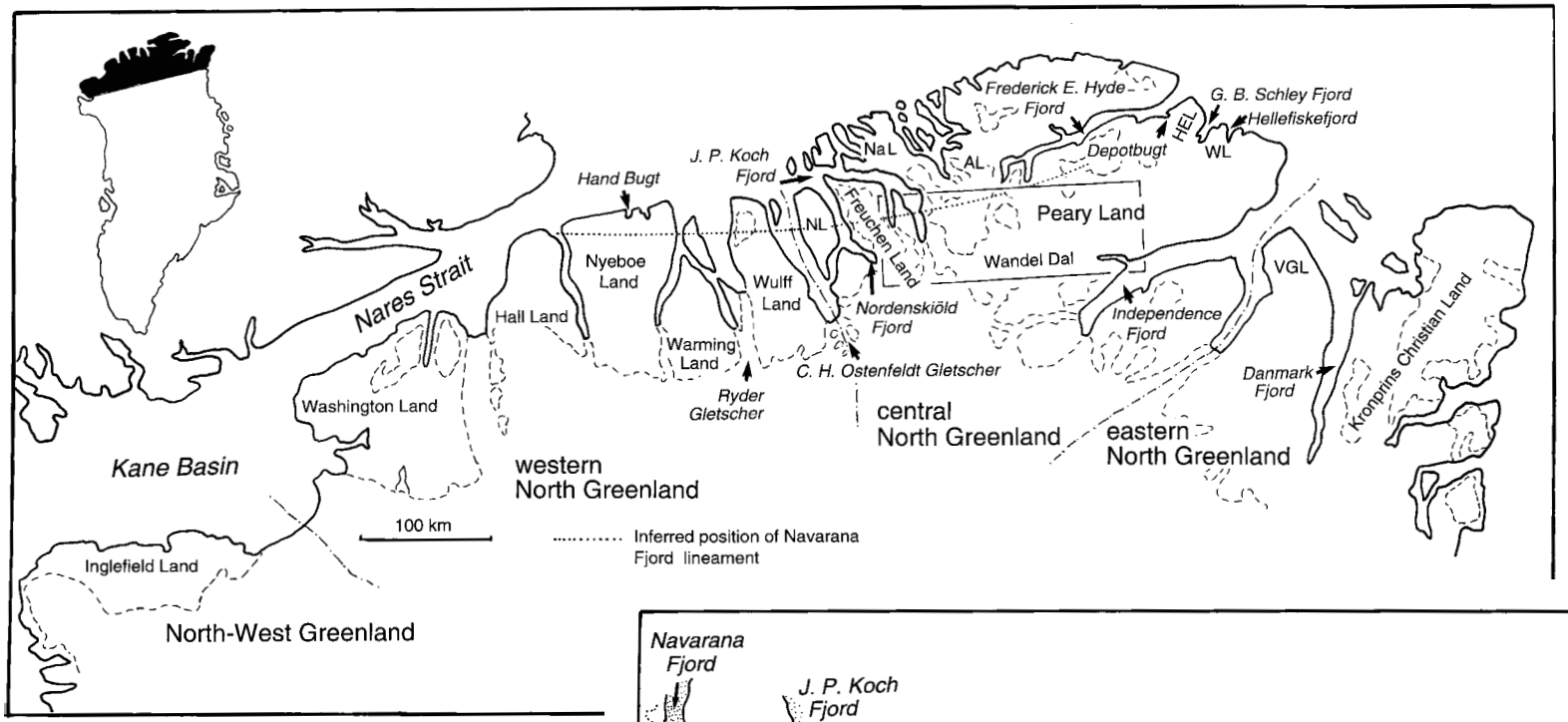
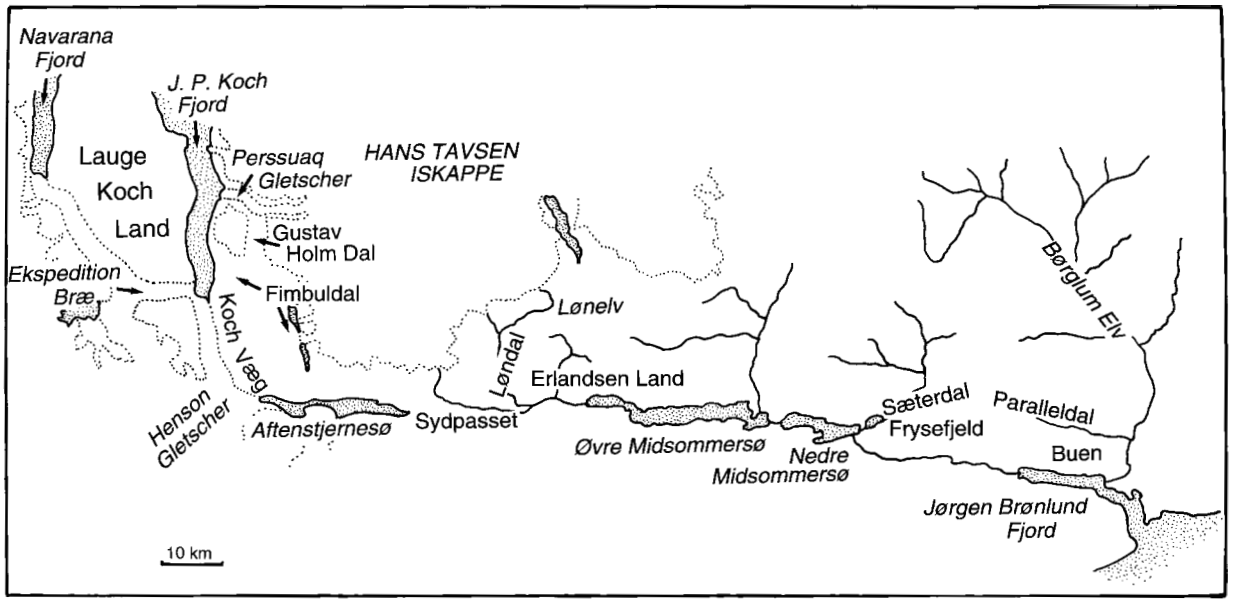


Fig. 2. Geological and location maps of North Greenland. The regional geological map shows the major stratigraphic units of the Franklinian Basin in North Greenland corresponding to the basin evolutionary stages of Higgins *et al.* (1991a); HFFZ, Harder Fjord fault zone. Inset location map (outlined 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).

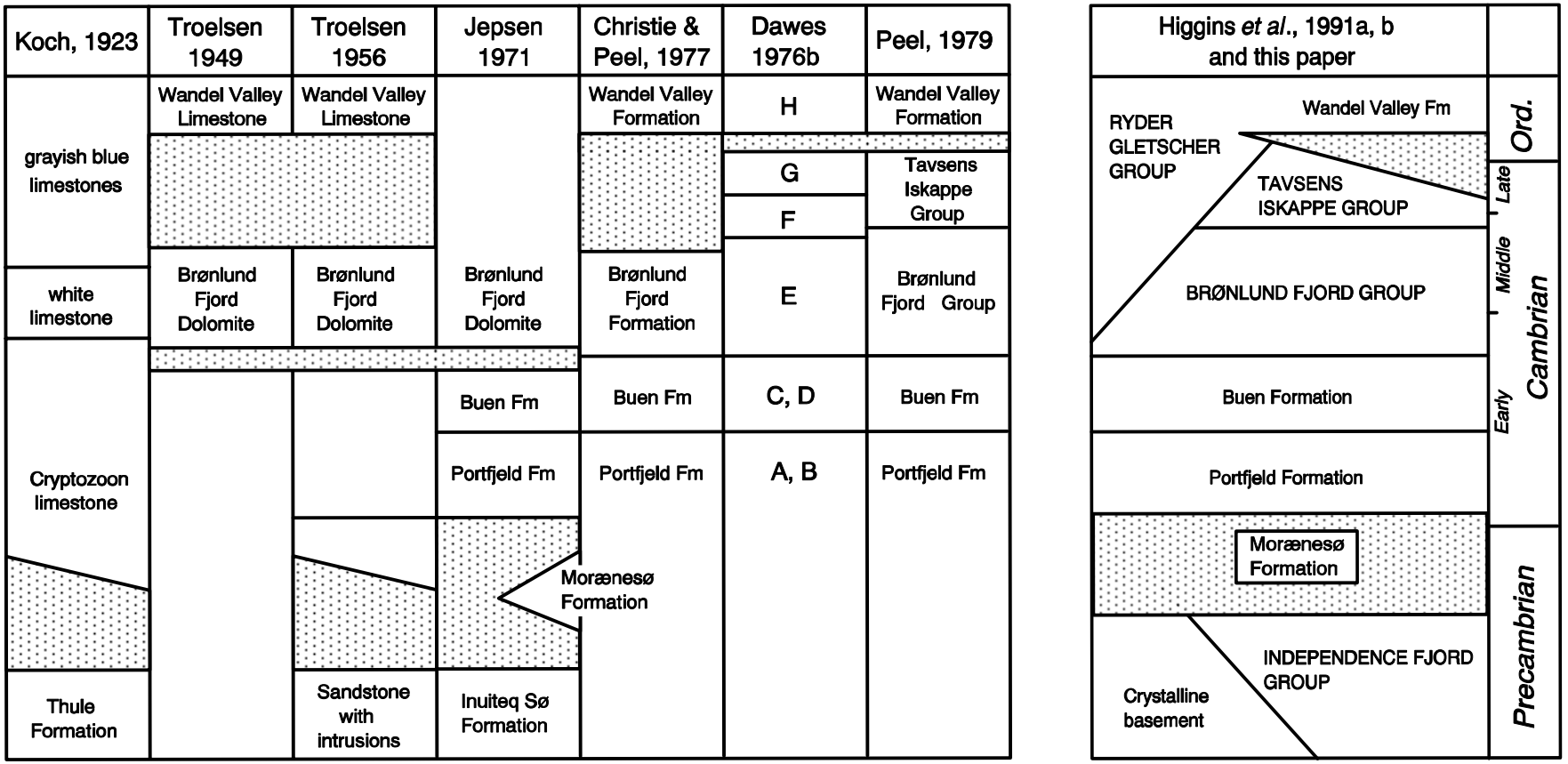


Fig. 4. Previous stratigraphic schemes applied to Precambrian to Lower Ordovician strata in the southern Peary Land region, correlated with the lithostratigraphic framework adopted in this paper. Building on reconnaissance by Koch (1923), Troelsen (1949, 1956) erected the first formal lithostratigraphic 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)

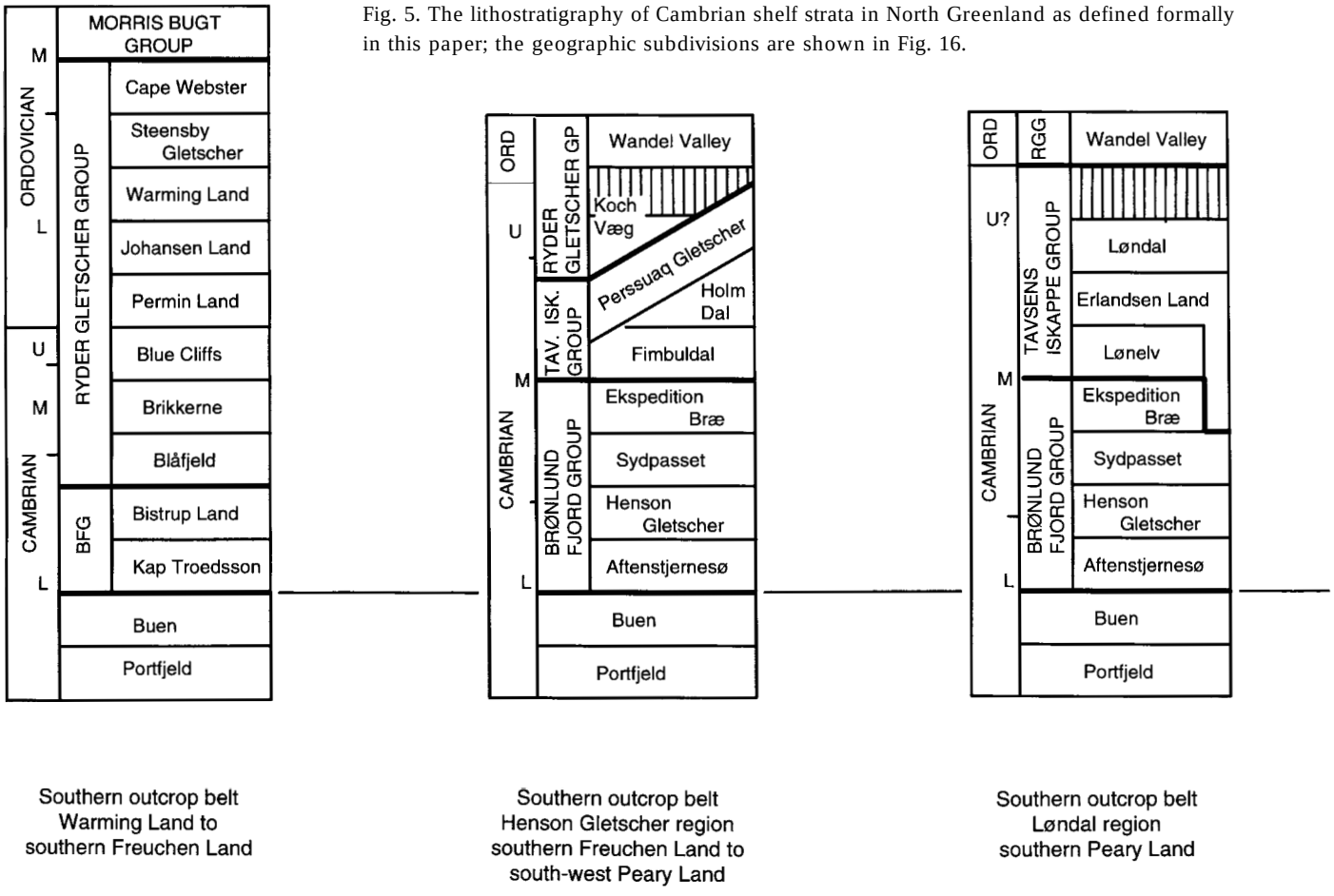


Fig. 5. The lithostratigraphy of Cambrian shelf strata in North Greenland as defined formally in this paper; the geographic subdivisions are shown in Fig. 16.

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.

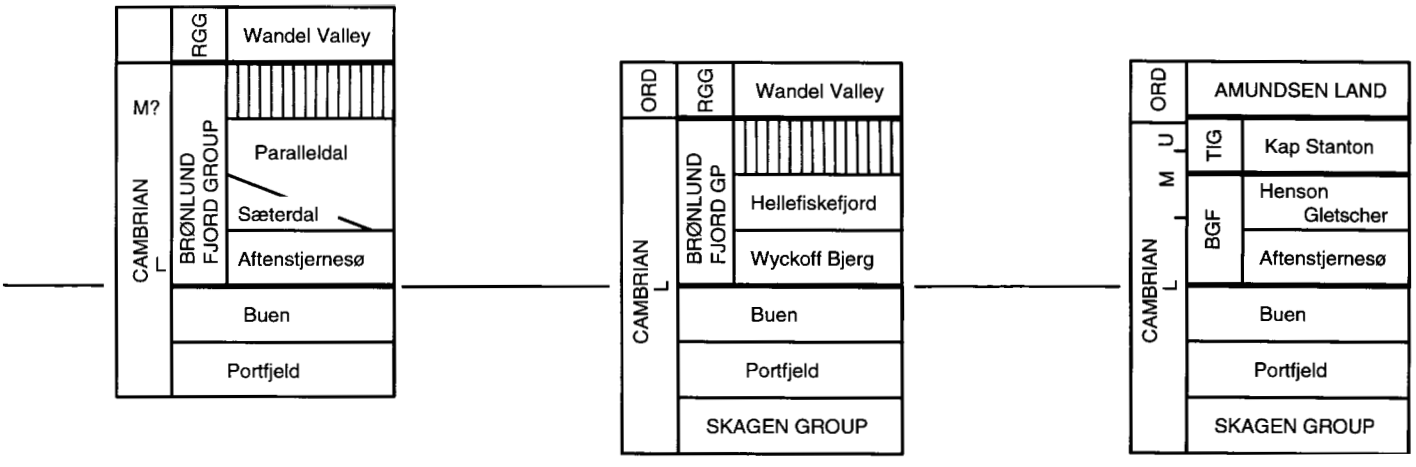
Lithology

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.



Southern outcrop belt
Paralleldal region
south-east Peary Land

Eastern outcrop belt
north-east Peary Land

Northern outcrop belt
from
Nyeboe Land to north-west
Peary Land

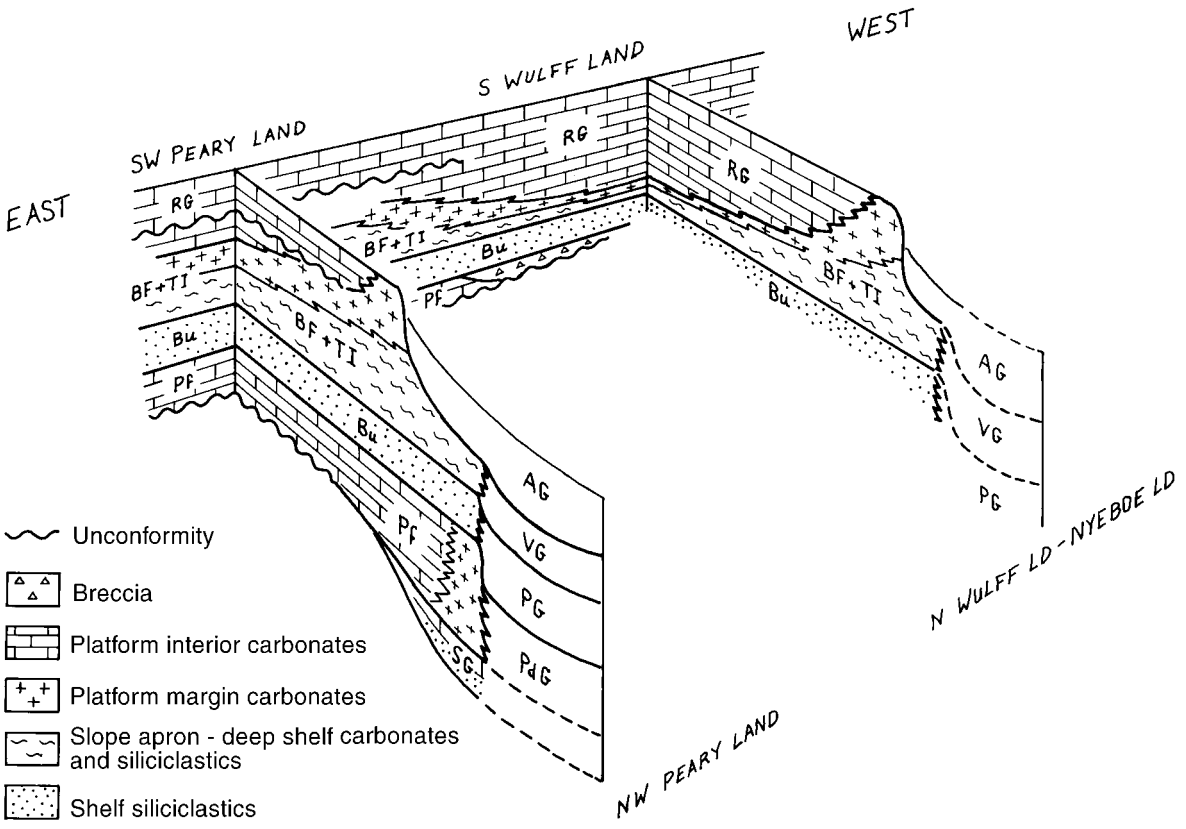


Fig. 6. Fence diagram (view from the north) showing the regional stratigraphy of the Cambrian shelf and deep-water trough. The basin evolutionary stages of Higgins *et al.* (1991a) are represented: Stage 1: Skagen Group (SG); Stage 2: Portfjeld Formation (Pf), Paradisfjeld Group (PdG); Stage 3: Buen 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,

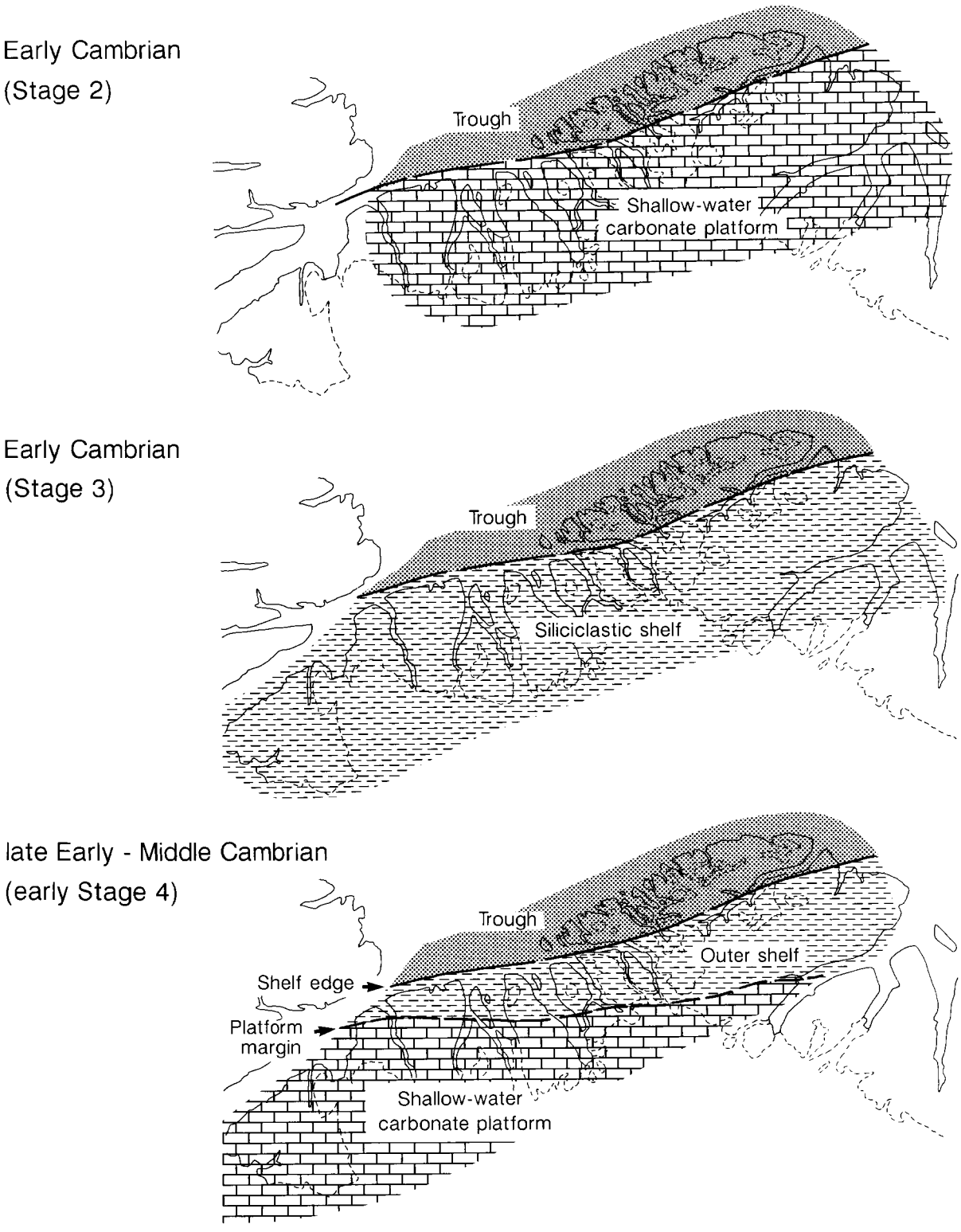


Fig. 7. Stages in the palaeogeographic evolution of North Greenland during the Cambrian; this reconstruction of the position of the Cambrian shelf edge does not take account of inferred slope deposits occurring in allochthonous thrust slices along the northern coastline of western North Greenland (see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

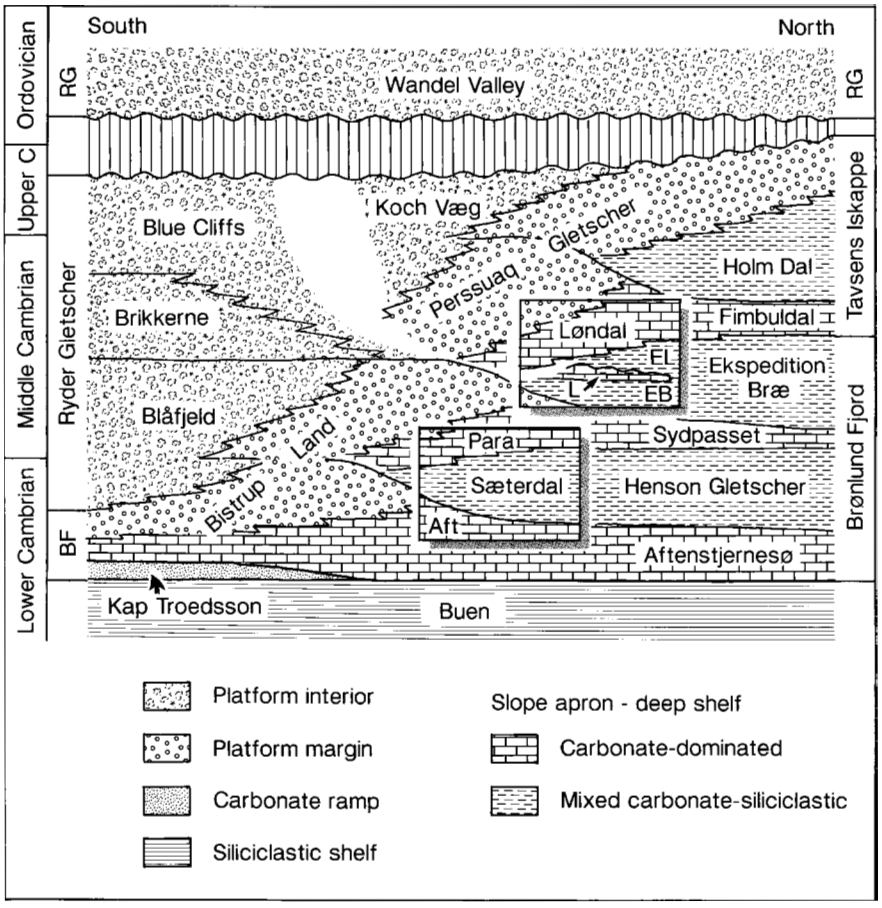


Fig. 8. Schematic diagram showing depositional settings of formations of the Brønlund Fjord (BF), Tavsens Iskappe and Ryder Gletscher (RG) Groups in the southern outcrop belt between Wulff Land and eastern Peary Land. The stratigraphic positions and environmental settings of the Paralleldal and Løndal 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-

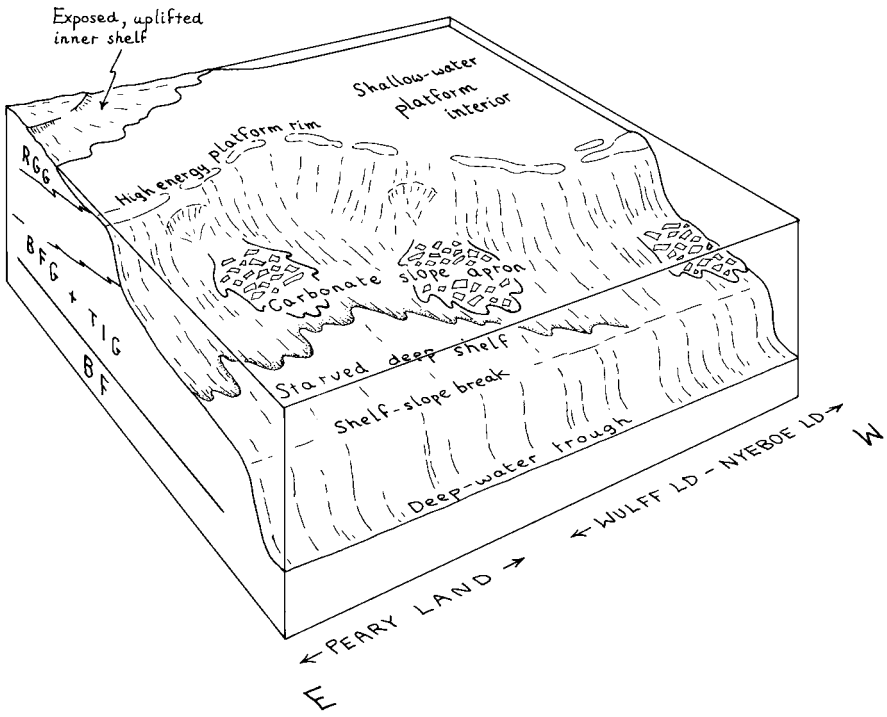


Fig. 9. Block diagram showing the inferred late Middle Cambrian palaeogeography in western and central North Greenland (view from north). BF, Buen Formation; BFG, Brønlund Fjord Formation; TIG, Tavsens Iskappe Group; RGG, Ryder Gletscher Group. From Ineson *et al.* (1994).

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

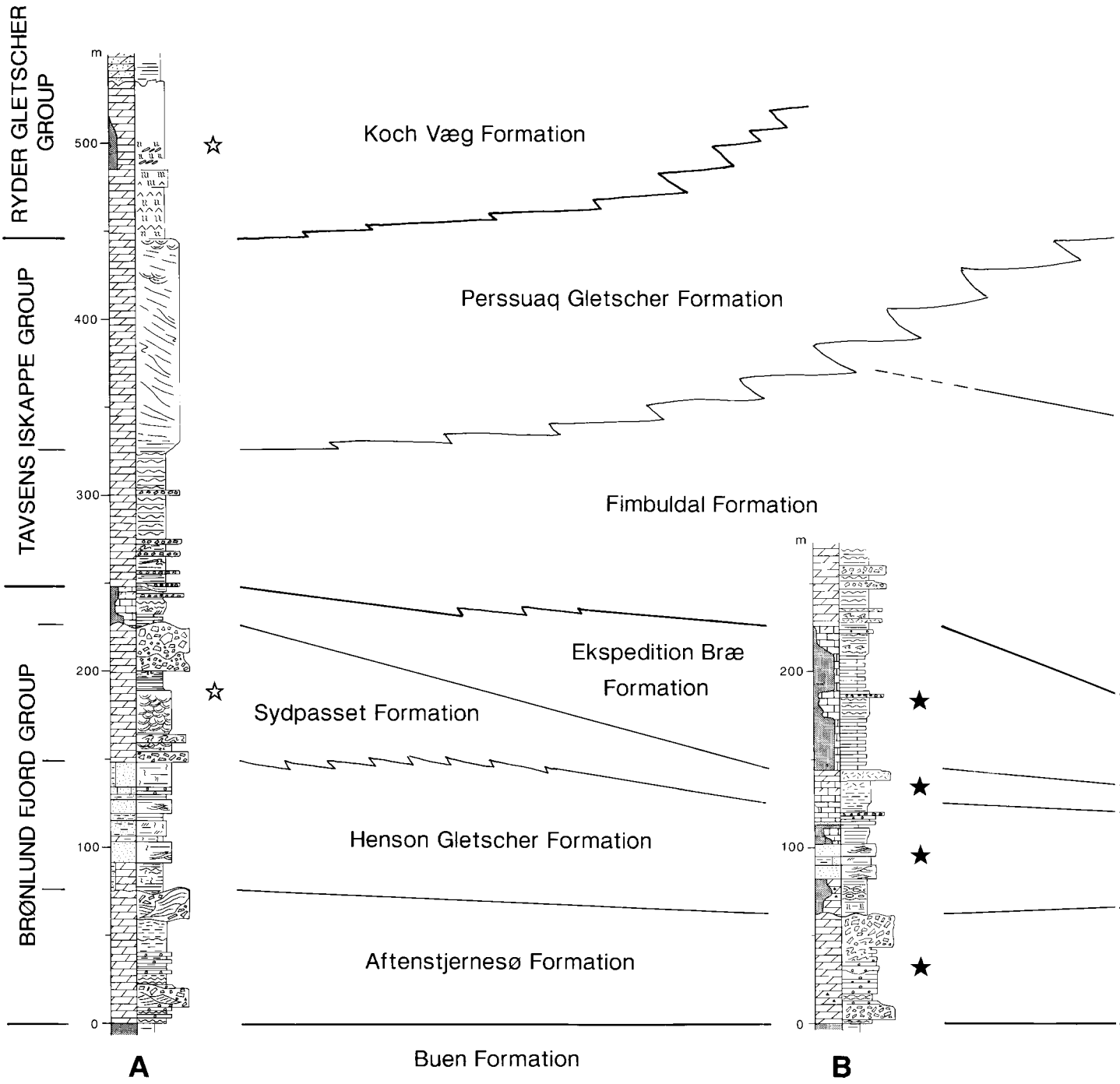
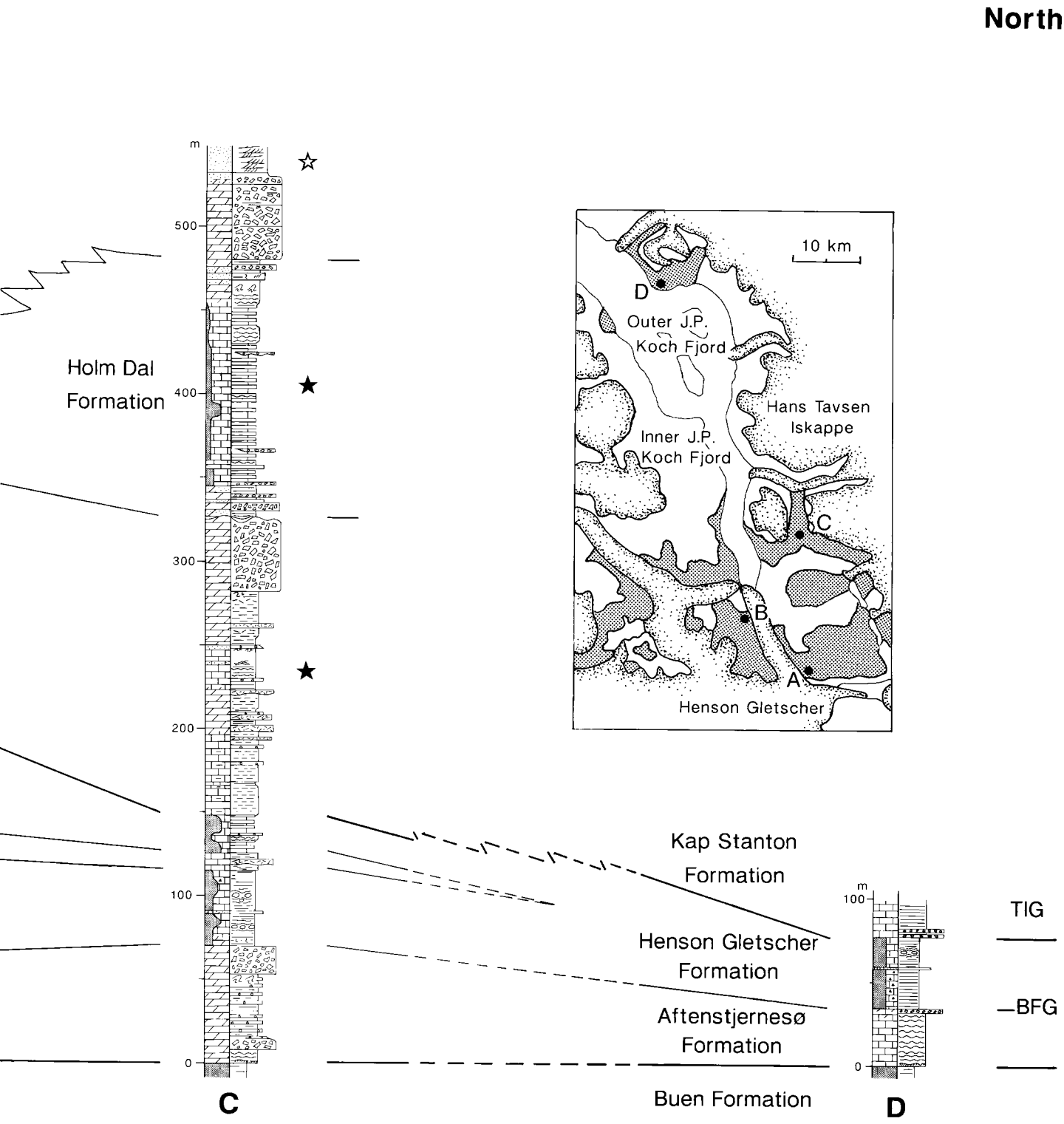


Fig. 10. South-to-north transect linking key sections from the southern (A, B, C) and northern (D) outcrop belts in westernmost Peary Land and Lauge Koch Land; inset map shows the outcrop of the Brønlund Fjord, Tavsens Iskappe and Ryder Gletscher Groups and the section localities. Type sections indicated 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-

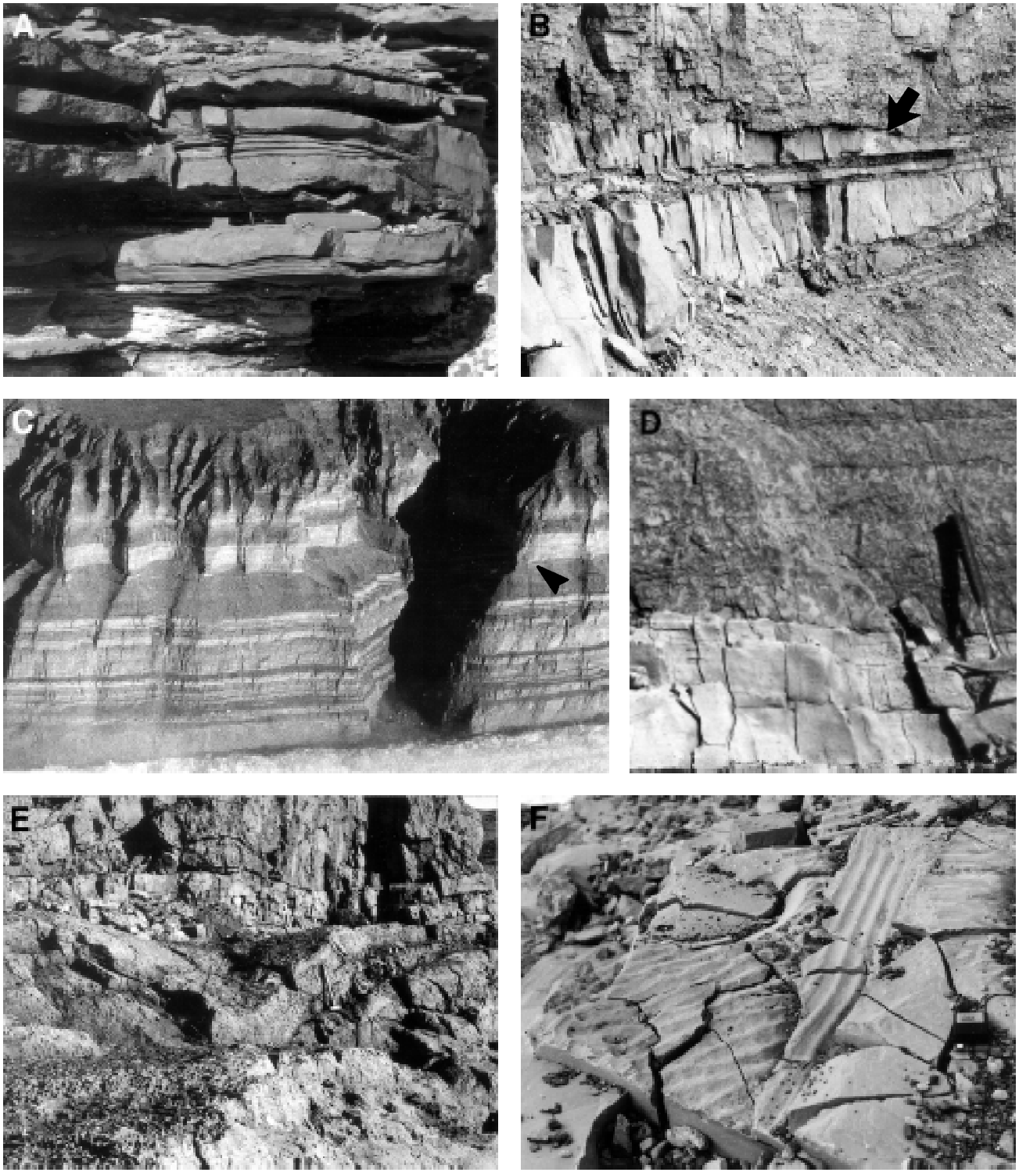


Fig. 11. Ramp and platform interior facies. **A**. Thin-bedded, sharp-based skeletal grainstones and packstones interbedded with calcareous mudstones. Kap Troedsson Formation, southern Wulff Land; penknife (centre) for scale. **B**. Undulating erosional contact (arrowed) between thick storm sand sheets 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-

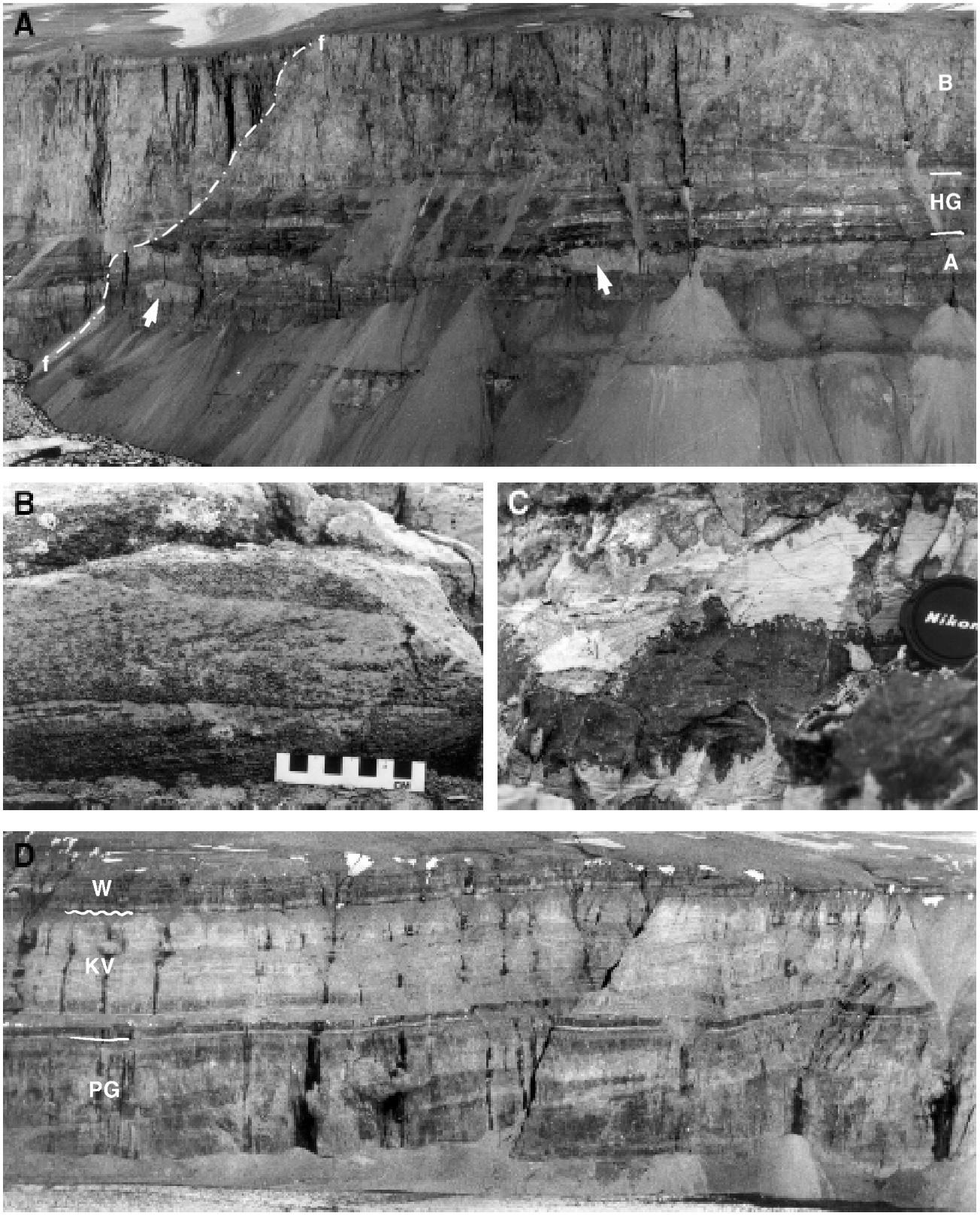


Fig. 12. Platform margin facies. **A**. Massive light-coloured platform margin dolomites (B, Bistrup Land Formation, *c.* 150 m thick) overlying off-platform darker, well-stratified sediments (A, Aftenstjernesø Formation; HG, Henson Gletscher Formation). Note the megabreccia sheet containing massive 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

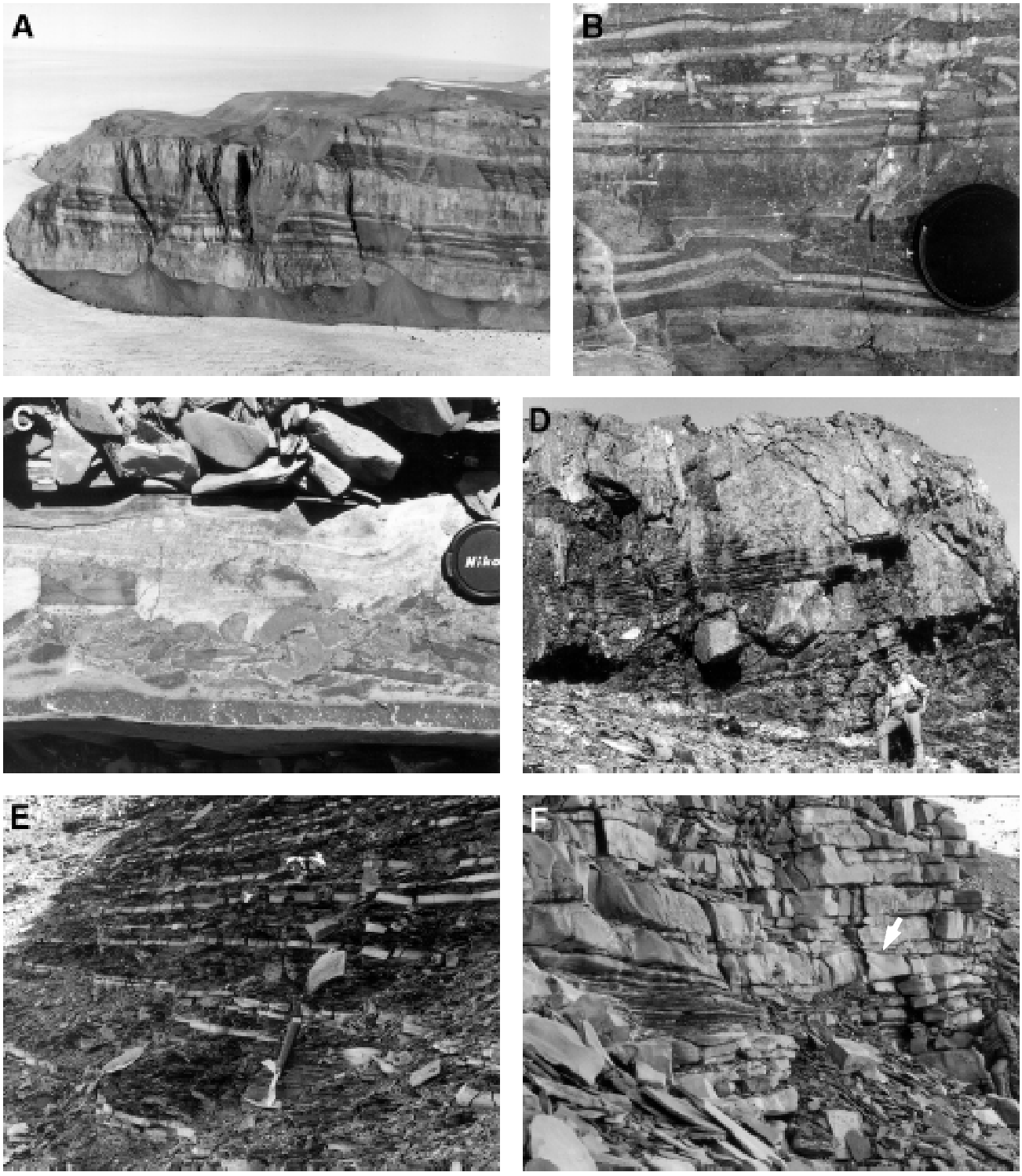


Fig. 13. Slope apron and deep shelf facies. **A**. Brønlund Fjord Group and lower Tavsens Iskappe Group west of Henson Gletscher showing the characteristic alternation of carbonate formations, forming lighter-coloured resistant cliffs, and mixed carbonate - siliciclastic formations, forming darker shaly 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,

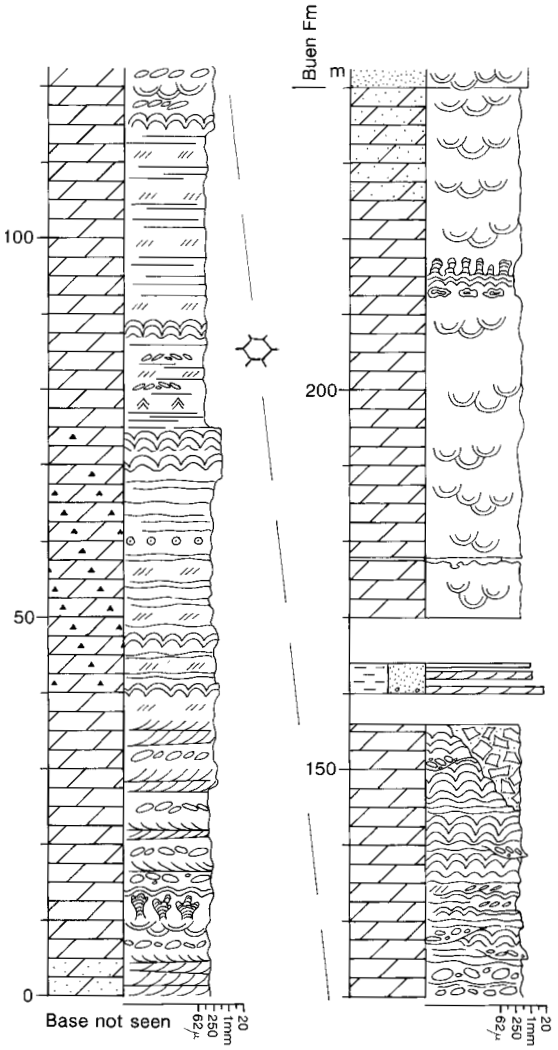
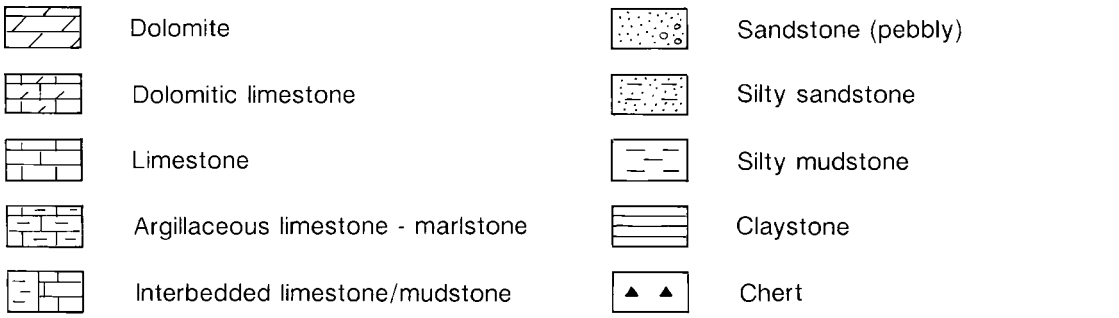


Fig. 14. Typical section through the Portfjeld Formation in southern Peary Land. Note the siliciclastic interval at 150-170 m, associated with a karstic breccia, and the potholed karstic suface at 178 m. The cherty dolomites in the lower half of the formation (40–70 m) form a distinctive dark marker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

Lithology



Structures

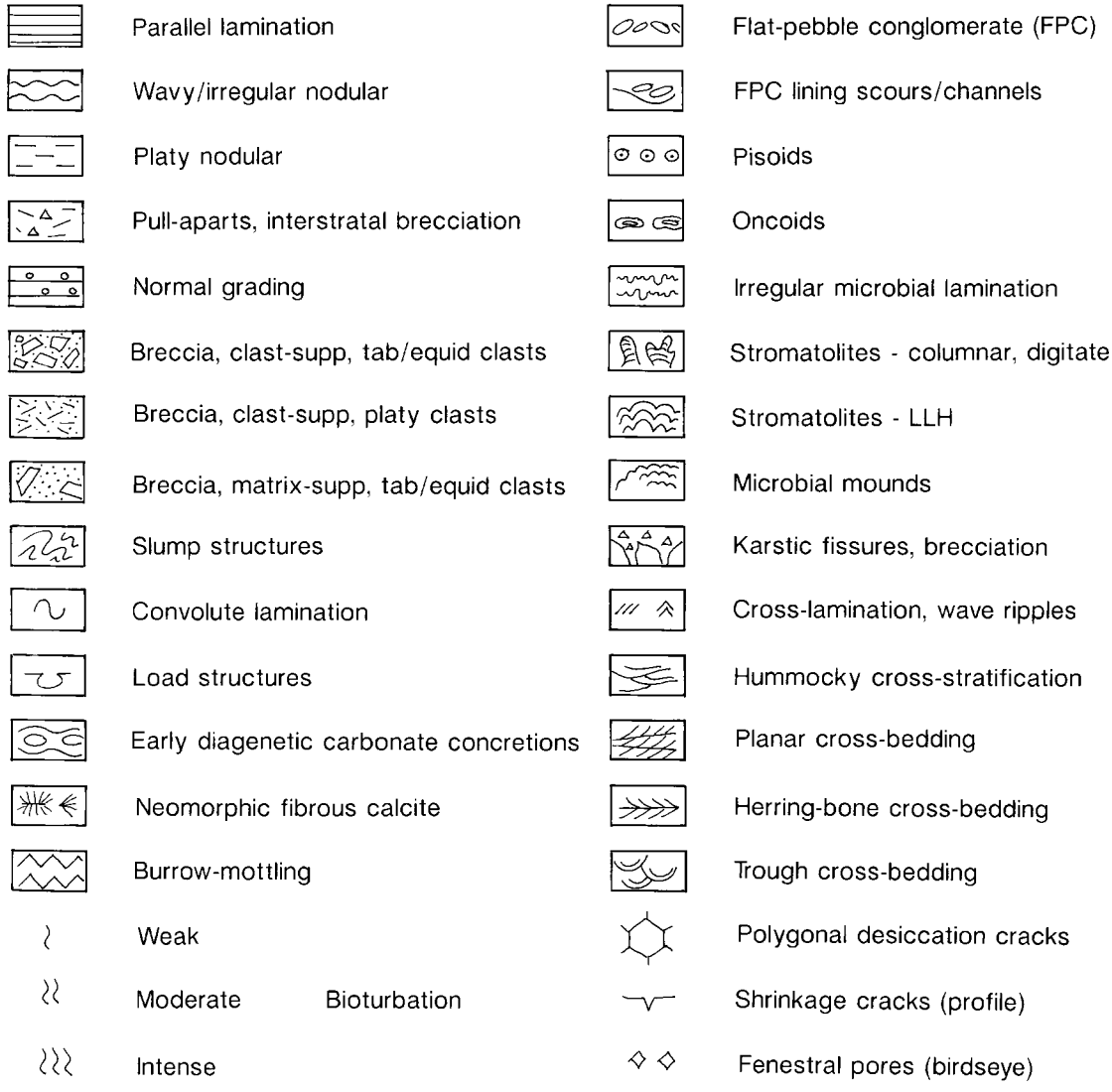


Fig. 14 cont. The accompanying legend is applicable to all stratigraphic logs in this paper. The log profile indicates the grain size of siliciclastic rocks and resedimented carbonate facies coarser than sand grade. For the remaining carbonates, the profile is purely a representation of weathering characteristics.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

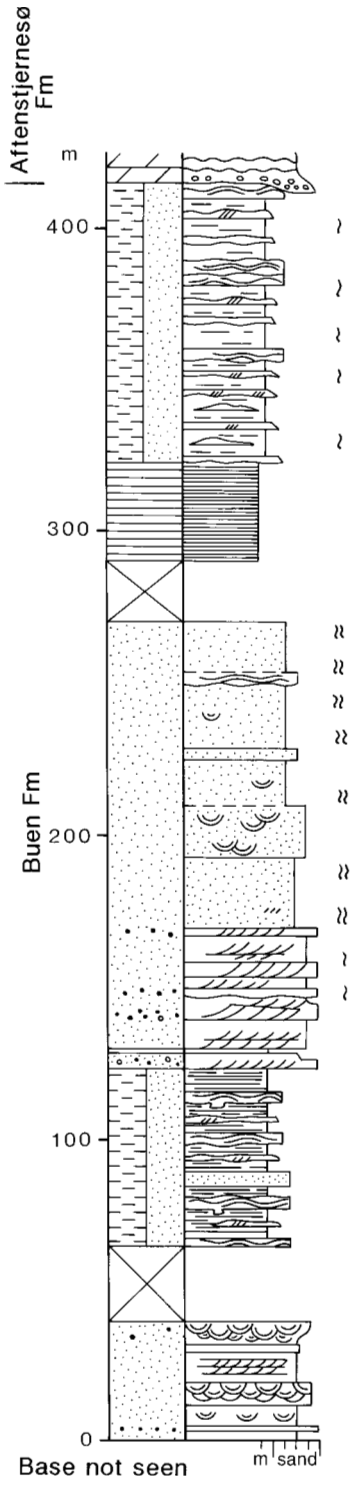


Fig. 15. The Buen Formation at its type locality on the south side of Buen, southern Peary Land, showing the characteristic development into a lower sand-dominated member (0–270 m) and an upper mud-dominated member (270–420 m). Note the erosional contact between the upper Buen Formation and the lowermost 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).

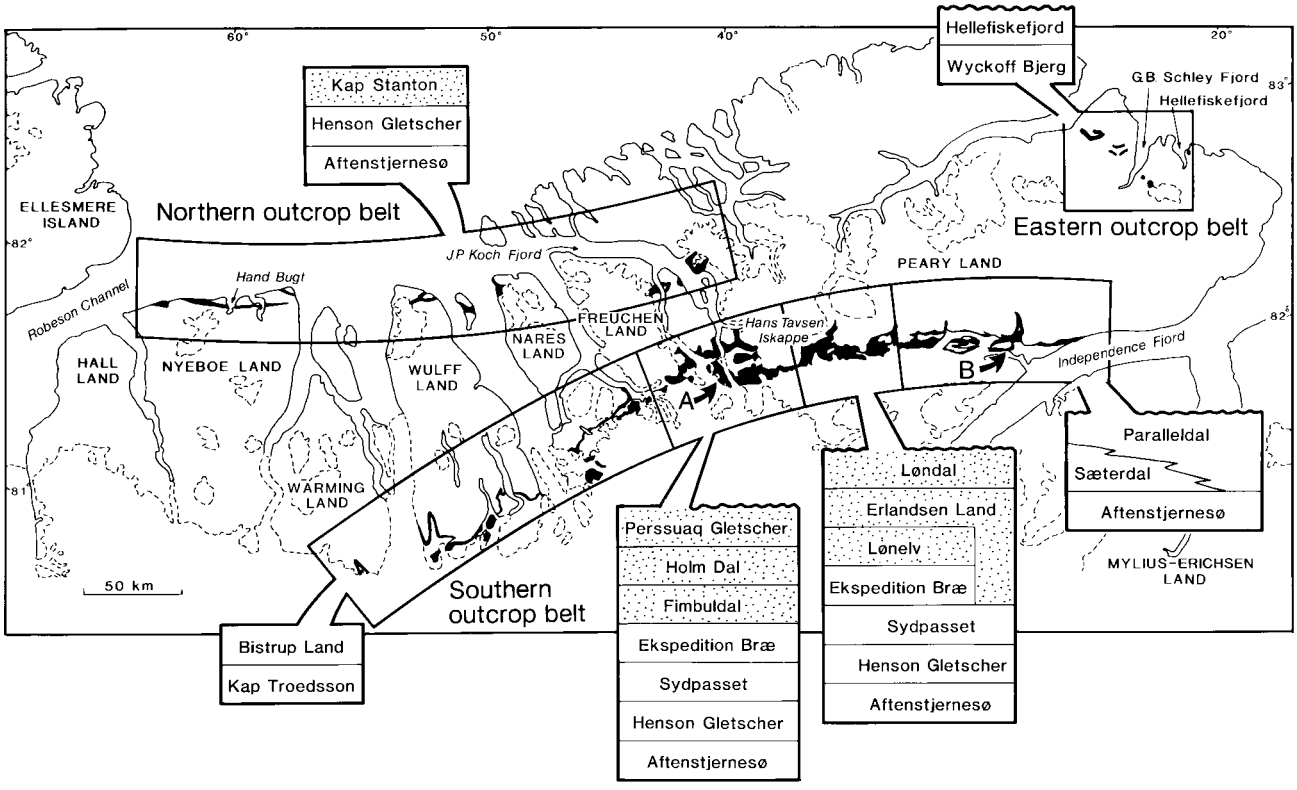


Fig. 16. Map showing the distribution (black) of the Brønlund Fjord and Tavsens Iskappe Groups in North Greenland, and their component formations (Tavsens Iskappe Group stippled). These rocks form three discrete outcrop belts: the southern, northern and eastern outcrop belts. The extensive southern outcrop 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).

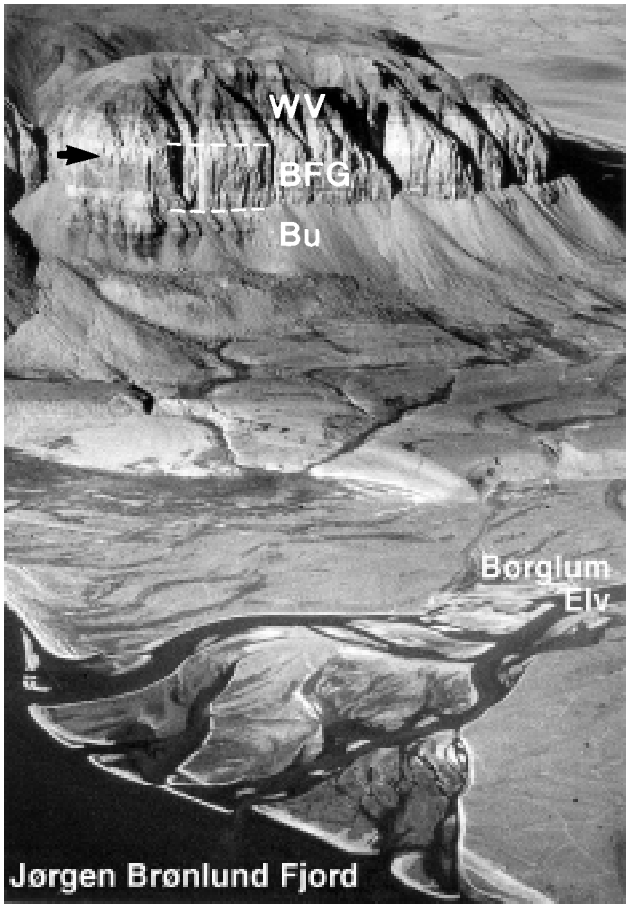


Fig. 17. Type area of the Brønlund Fjord Group (BFG) overlooking the mouth of Børglum Elv and Jørgen Brønlund Fjord in south-east Peary Land. The group (175 m thick) conformably overlies the largely scree-covered Buen Formation (Bu) and is unconformably overlain by the Wandel Valley Formation (WV). Note 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

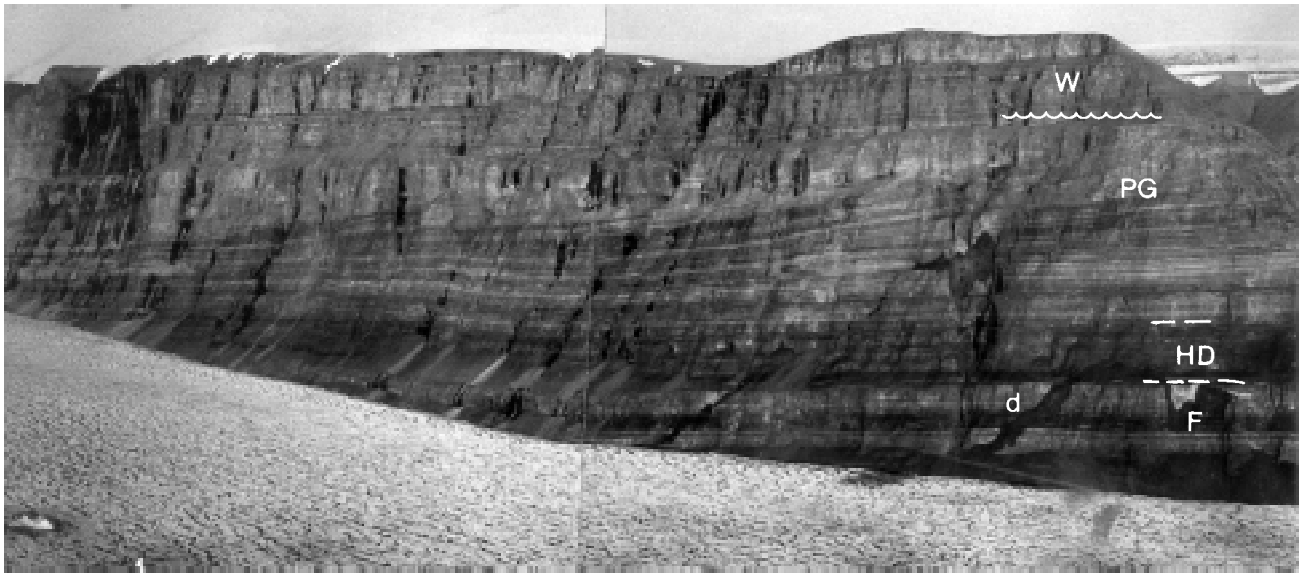


Fig. 19. The Tavsens Iskappe Group in the type area, on the east side of J. P. Koch Fjord, west Peary Land (see Fig. 1A). Carbonates of the Fimbuldal (F) and Holm Dal (HD) Formations are succeeded by a thick succession of prograding siliciclastics and carbonates assigned to the Perssuaq Gletscher Formation (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).

Brønlund Fjord and Tavsens Iskappe Groups: southern outcrop belt

The Brønlund Fjord and Tavsens Iskappe Groups are best developed and most extensively exposed in the southern outcrop belt which stretches some 350 km from the northern shore of Independence Fjord, Peary Land, in the east, to Warming Land, in the west (Fig. 20). This approximately east–west section represents a strike-parallel to oblique transect through a complex, generally northward prograding platform to outer shelf succession (Fig. 8; see previous discussion). The resultant complex lateral variation in lithofacies from eastern Peary Land to Warming Land is reflected in the complexity of the lithostratigraphic scheme (Fig. 5).

As an aid to understanding, the lithostratigraphy of the southern outcrop belt is described here in terms of four regions, each of which displays a characteristic lithostratigraphic succession (Fig. 20). The Henson Gletscher region in west Peary Land and southern Lauge Koch Land is described first, since this includes the reference area of the Brønlund Fjord Group and the type area of the Tavsens Iskappe Group. Passing eastward, the Løndal and Paralleldal regions are described successively. The western development of the Brønlund Fjord Group, between Nordenskiöld Fjord and southern Warming Land, is described in the final section. Formations that extend across the boundaries of these arbitrary regions are formally described when first encountered and only briefly discussed in successively described regions. This approach allows an appreciation both of the full stratigraphic succession in any one region and of the lateral variation within persistent formations (e.g. the Aftenstjernesø Formation, Fig. 5).

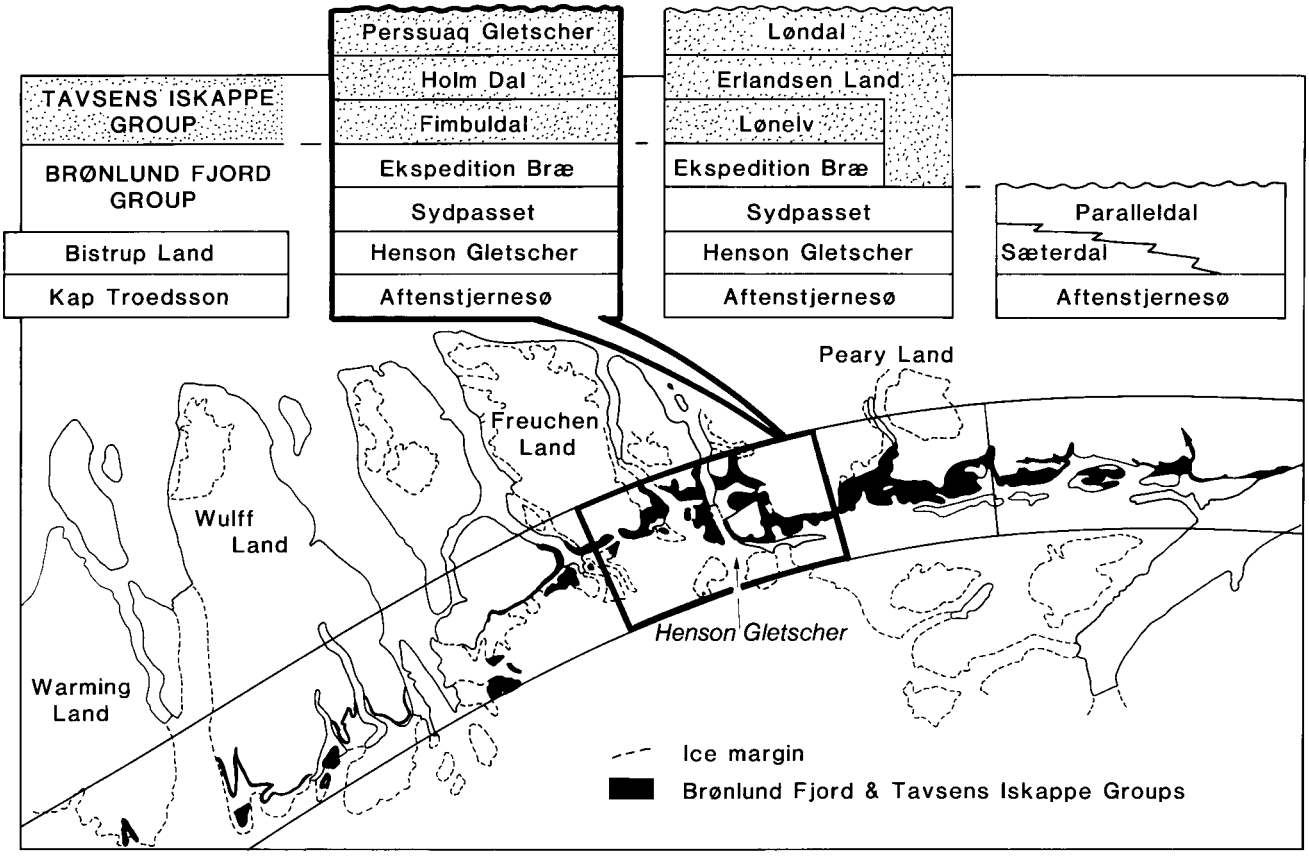


Fig. 20. Map showing the distribution and subdivision of the Brønlund Fjord Group and Tavsens Iskappe Group (stippled) in the Henson Gletscher region in relation to the regional stratigraphy of the southern outcrop belt.

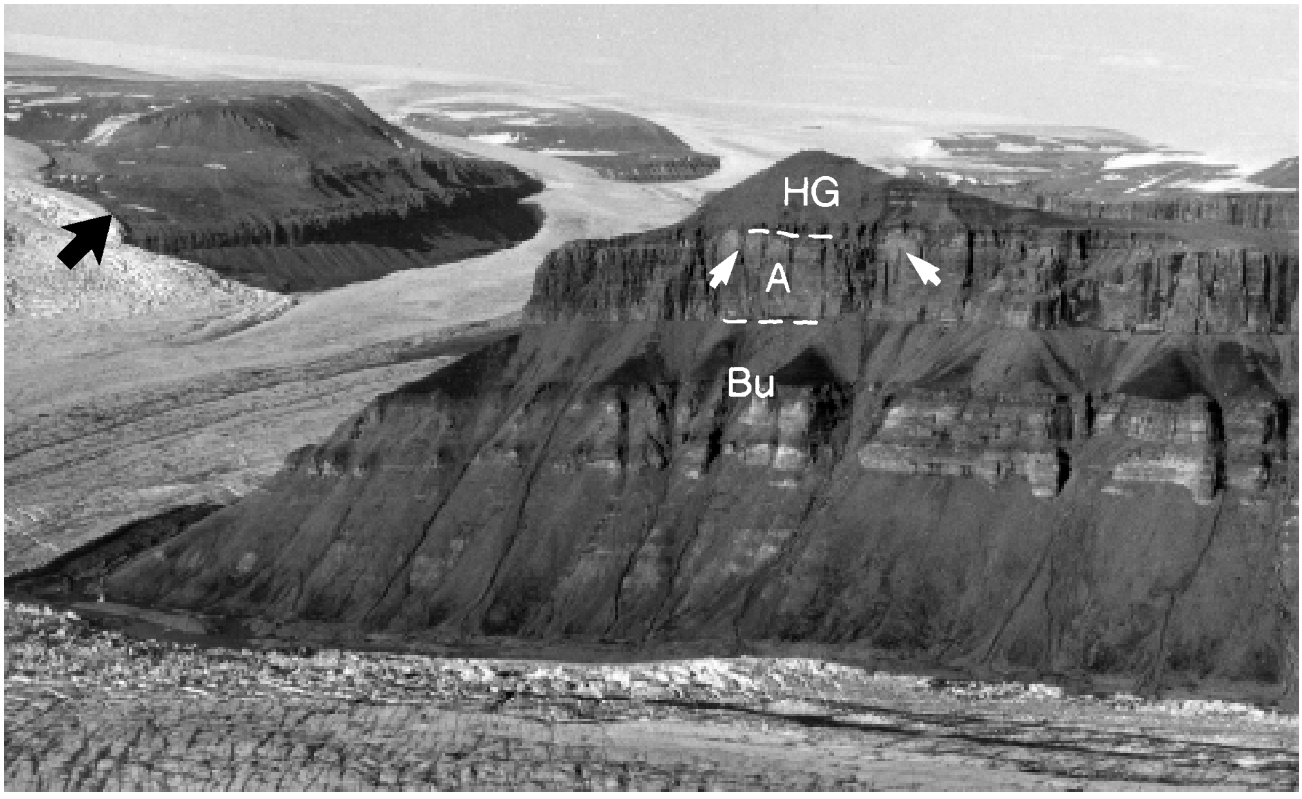


Fig. 21. View eastwards across Jungersen Gletscher (see Fig. 78 for location) of the Buen Formation (Bu) and Aftenstjernesø (A; *c.* 75 m thick) and Henson Gletscher Formations (HG) of the Brønlund Fjord Group near the western limit of the Henson Gletscher region. Note the large pale blocks of platform margin carbonate (small arrows) in the megabreccia bed that caps the Aftenstjernesø Formation. The reference section of the Henson Gletscher is indicated by the large arrow (see Figs 32, 33).

Henson Gletscher region

The region bordered by Hans Tavsen Iskappe to the east and Nordenskiöld Fjord to the west (Fig. 20) consists of a complex network of deeply incised fjords and glaciers (Figs 1, 2, 21) providing spectacular cliff sections through the Cambrian succession. As such, this exceptional area has formed the focus of much of the field endeavour and the reference and type areas for the Brønlund Fjord and Tavsens Iskappe Groups, respectively, occur within the area.

The Brønlund Fjord Group conformably overlies dark, recessive siliciclastic sediments of the Buen Formation and comprises the Aftenstjernesø, Henson Gletscher, Sydpasset and Ekspedition Bræ Formations, all of which have their type sections in the Henson Gletscher region (Figs 10, 22A, 23). The Tavsens Iskappe Group conformably succeeds the Brønlund Fjord Group and consists of the Fimbuldal, Holm Dal and Perssuaq Gletscher Formations (Fig. 22A). In southern localities, around Henson Gletscher, the Tavsens Iskappe Group is overlain conformably by the Koch Væg Formation of the Ryder Gletscher Group, that is described in a later section; elsewhere, the Tavsens Iskappe Group is unconformably overlain by the Wandel Valley Formation (Early – Middle Ordovician).

Brønlund Fjord Group

The Henson Gletscher region includes the reference area of the Brønlund Fjord Group, where the group is most fully developed (up to 240 m thick) and well-exposed.

Aftenstjernesø Formation

new formation

History. The strata assigned here to the Aftenstjernesø Formation have been described informally as formation 1 of the Brønlund Fjord Group (Peel, 1979; Ineson

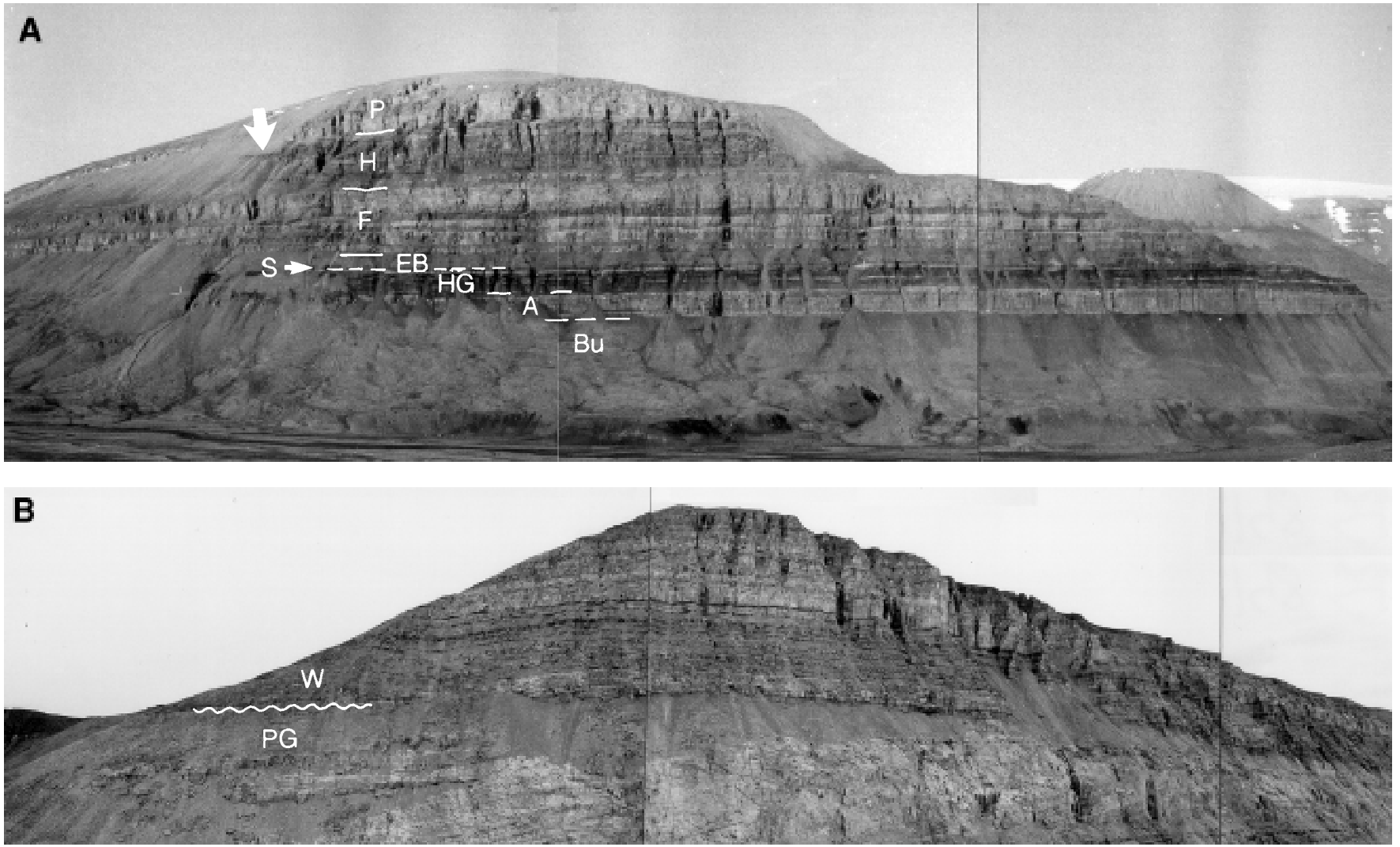


Fig. 22. **A**. Cambrian succession in west Peary Land on the north side of Fimbuldal, just east of the mouth of Gustav Holm Dal (left); the cliff is oriented roughly E–W, along depositional strike. The largely scree-covered Buen Formation (Bu) is succeeded by the Brønlund Fjord Group (A, Aftenstjernesø Formation; HG, Henson Gletscher Formation; S, Sydpasset Formation; EB, Ekspedition Bræ Formation) and the Tavsens Iskappe Group (F, Fimbuldal Formation; H, Holm Dal Formation; P, Perssuaq Gletscher Formation). In its type section (arrowed), the Holm Dal Formation is 155 m thick. **B**. Tavsens Iskappe Group on the east side of the glacier flowing into Navarana Fjord, Lauge Koch Land (Fig. 1). The pale-coloured sandstones and dolomites of the Perssuaq Gletscher Formation (PG) are overlain unconformably by banded dolomites of the Wandel Valley Formation (W). Note the complex clinoform geometry exhibited by the Perssuaq Gletscher Formation (see Fig. 19). The cliff is about 400 m high at the highest point and is oriented roughly N–S, parallel to depositional dip.

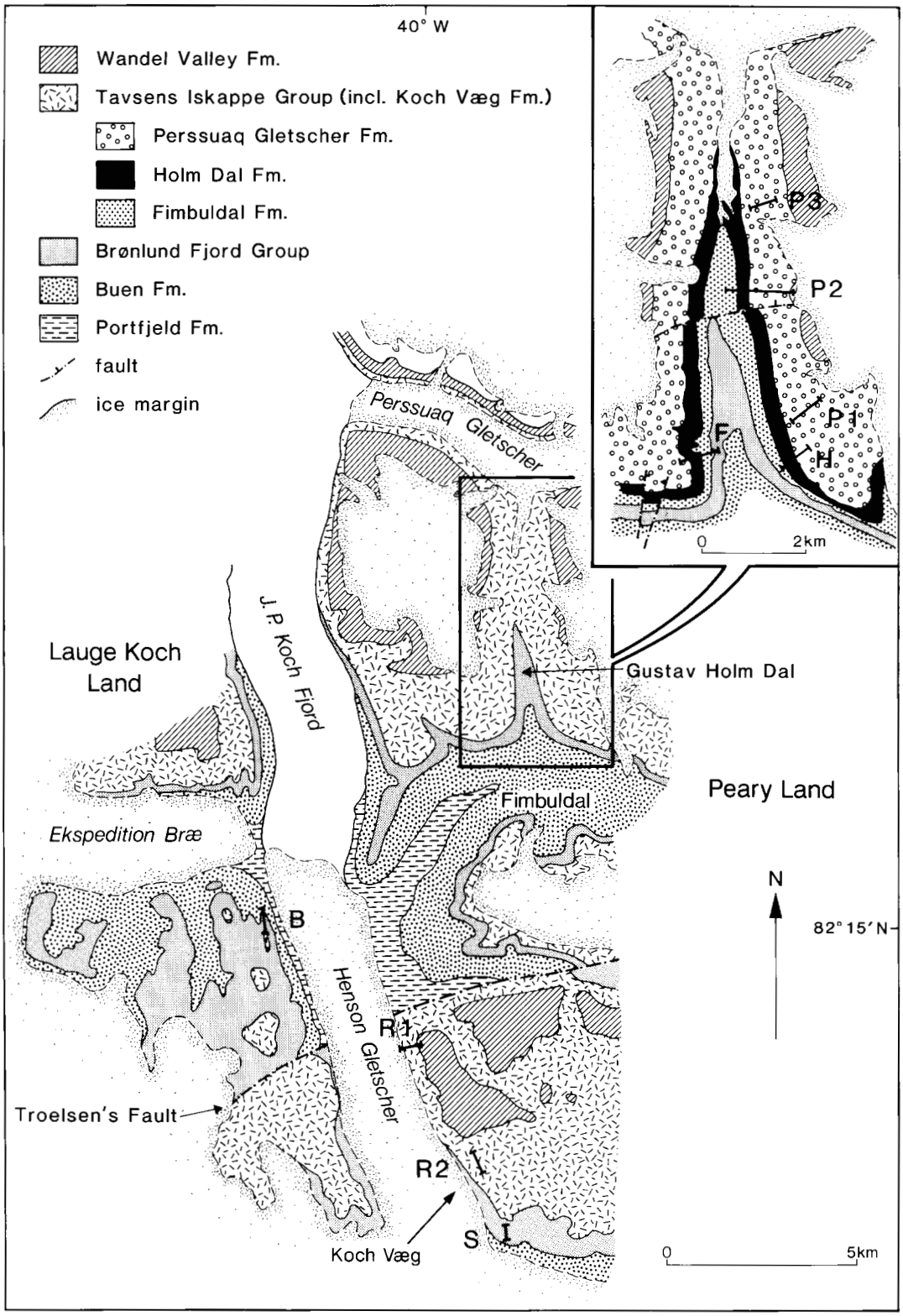


Fig. 23. Geological sketch map of the Henson Gletscher – J. P. Koch Fjord region, west Peary Land, showing the distribution of the Brønlund Fjord and Tavsens Iskappe Groups. B marks the location of the type sections of the Aftenstjernesø, Henson Gletscher, Sydpasset and Ekspedition Bræ Formations (Brønlund Fjord Group); section S is the reference section of the Sydpasset Formation. The locations of the type (and reference) sections of the Fimbuldal (F), Holm Dal (H) and Perssuaq Gletscher (P1-P3) Formations (Tavsens Iskappe Group) are shown in the inset map of Gustav Holm Dal. R1 and R2 indicate the type and reference sections, respectively, of the Koch Væg Formation (Ryder Gletscher Group). Modified from Ineson (1988).

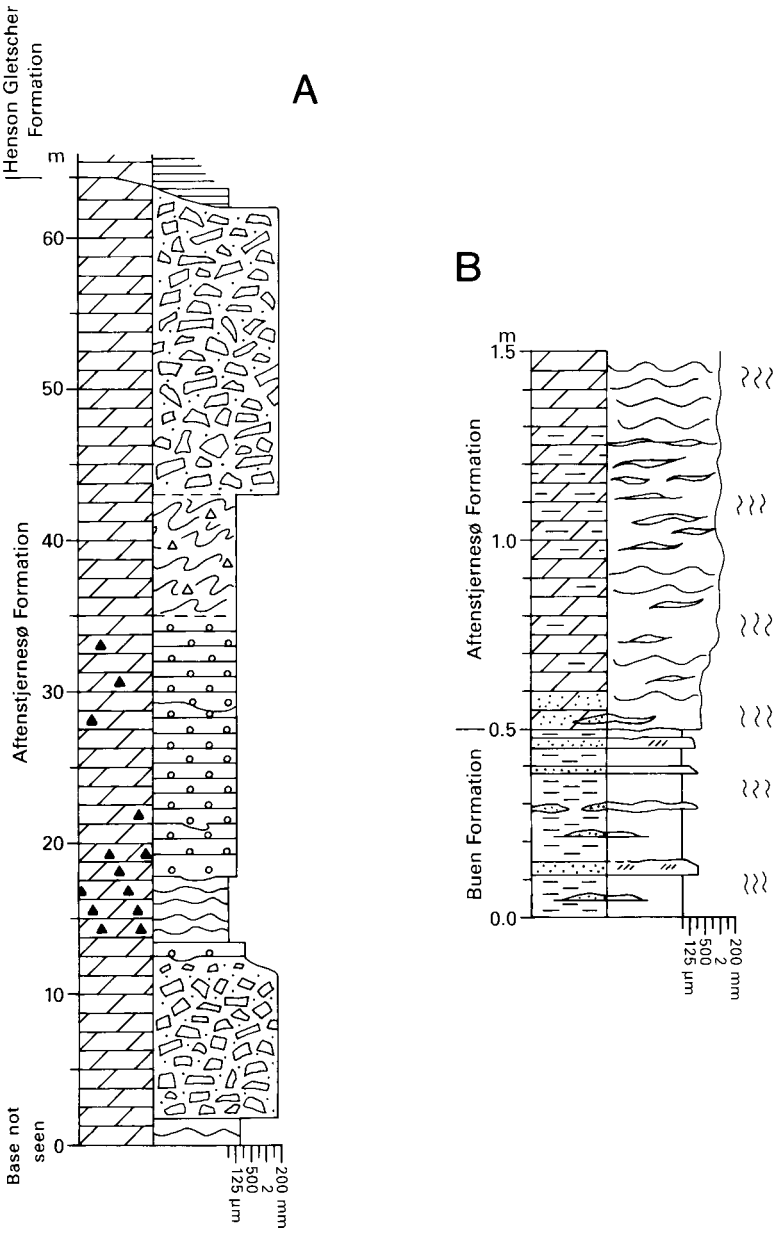


Fig. 24. **A**. Type section of the Aftenstjernesø Formation, Lauge Koch Land (Fig. 23). **B**. Detailed section of the base of the Aftenstjernesø Formation at the western end of Buen, eastern Peary Land (see Fig. 68). See Fig. 14 for legend; sigmoidal signature indicates silty mudstone flasers.

& Peel, 1980). In south-east Peary Land the formation is equivalent to Members A, B and C of the Brønlund Fjord Formation of Christie & Peel (1977). In south-western Peary Land the formation is equivalent to the 'Basal sub-unit' of Unit E of Dawes (1976b).

Name. After Aftenstjernesø, the elongate lake at the western end of Wandel Dal, south-west Peary Land (Fig. 2).

Type section. Fig. 24; 3 km to the south of the snout of Ekspedition Bræ, along the east side of the gully (Figs 23, 25).

Thickness. About 62 m at the type locality. The base is not exposed at the type section, but is estimated to be within 1 m of the base of the measured section (Fig. 24). The formation thickens to the south from the type locality to *c.* 75 m at Henson Gletscher and over 70 m at Jungersen Gletscher, Freuchen Land. It thins eastward from Henson Gletscher to a minimum of 30 m in the Sæterdal area (Fig. 26). Farther east again, the formation thickens to about 130 m in the Børglum Elv valley. In its northern outcrop, between northern Nyeboe Land and north-west Peary Land (Fig. 16), the Aftenstjernesø Formation is typically 25–50 m thick.

Lithology. The Aftenstjernesø Formation characteristi-

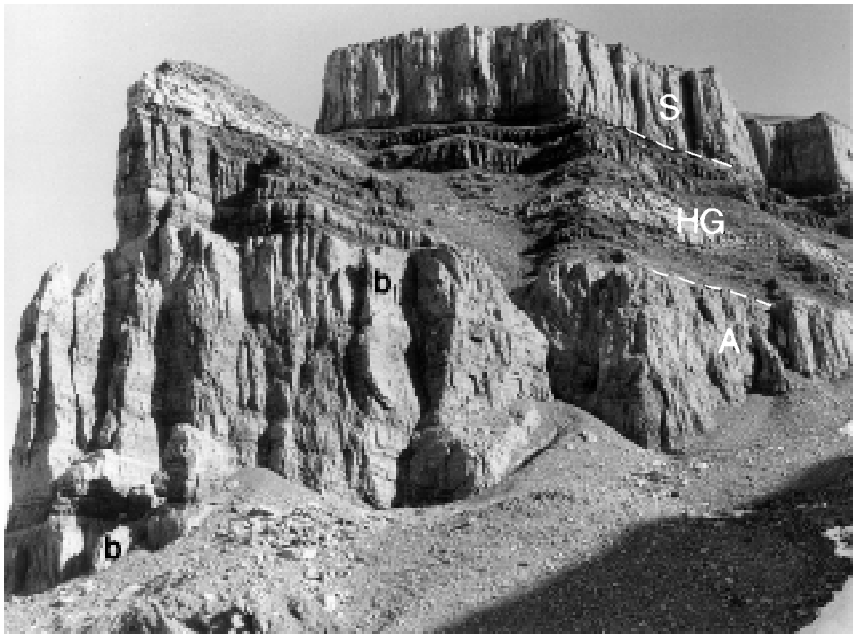


Fig. 25. Type locality of the Aftenstjernesø (A), Henson Gletscher (HG) and Sydpasset (S) Formations, Lauge Koch Land. The type section of the Aftenstjernesø Formation was measured along the base of the cliff from left to right; note the poorly stratified carbonate breccia beds (b) at the base and top of the formation, sandwiching a well-bedded carbonate turbidite interval (see Fig. 24A). The type section of the overlying Henson Gletscher Formation traverses the slopes shown centrally in this photograph; the sandstones in the middle of this formation (see Fig. 31) are clearly visible as a pale-coloured stripe. The type section of the cliff-forming Sydpasset is located in a narrow gully to the right of this photograph (see Fig. 42).

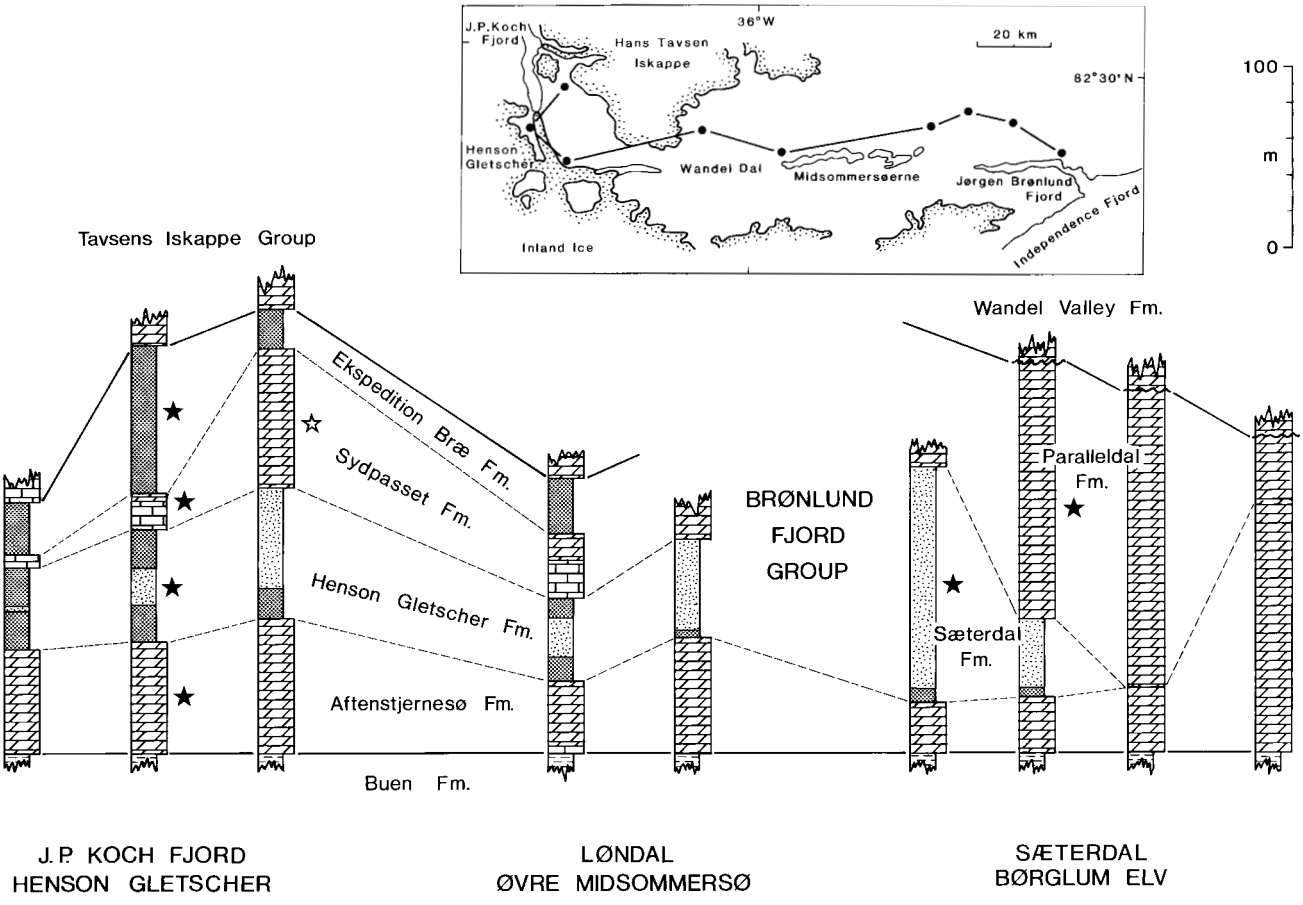


Fig. 26. Generalised stratigraphic logs of the Brønlund Fjord Group in the southern outcrop belt illustrating the stratigraphic relationships and lateral thickness variations from the Henson Gletscher region in the west to Jørgen Brønlund Fjord in the east (see inset map). Type sections are marked by solid stars, reference sections by open stars. Dense stipple denotes argillaceous lime mudstone/dolomite, commonly interbedded with siliciclastic mudstone; see Fig. 14 for remaining symbols.

Fig. 27. Nodular dolomites at the base of the Aftenstjernesø Formation in the type section, overlain abruptly by a dolomitised mass-flow breccia bed. Note the abundant black phosphorite in these basal beds occurring as intraclasts, nodules and discrete hardground surfaces. From Higgins *et al.* (1991a).

cally forms pale, yellow-brown weathering cliffs above the recessive slopes of the underlying Buen Formation (Fig. 22A). It is composed almost entirely of dolomite in the southern outcrop belt although limestones and dolomitic limestones are preserved in the lower 10 m of the formation in Løndal on the east side of Hans Tavsen Iskappe (Fig. 2).

In the type section (Figs 24, 25), the Aftenstjernesø Formation is composed of glauconitic, phosphoritic dolomites, prominent thick breccia beds, dark cherty, wavy-bedded and parallel-laminated dolomites, and thin to medium-bedded, graded dolomites. The basal beds (*c.* 2 m) are iron-grey weathering dolomites, in thin to medium beds, with thin, mudstone interbeds and flasers in the lower metre. Brown-black phosphorite seams up to 2 cm thick are common (Fig. 27) and are associated with dolomite rich in glauconite, phosphatic bioclasts and phosphorite shell moulds. This distinctive basal unit is a characteristic feature of the Aftenstjernesø Formation and is recognised in all outcrop areas, from northern Nyeboe Land to south Peary Land; it is equivalent to Member A of Christie & Peel (1977; see also Frykman, 1980) and is laterally equivalent to the Kap Troedsson Formation in the Nordenskiöld Fjord – Warming Land area. In Løndal, this interval is undolomitised or only partially dolomitised, and comprises bioturbated, glauconitic, skeletal wackestones, packstones and grainstones.

Dolomitised matrix-supported and clast-supported carbonate breccia beds are characteristic of the formation, and in the type section form striking, massive, pale weathering bands near the base and at the top of

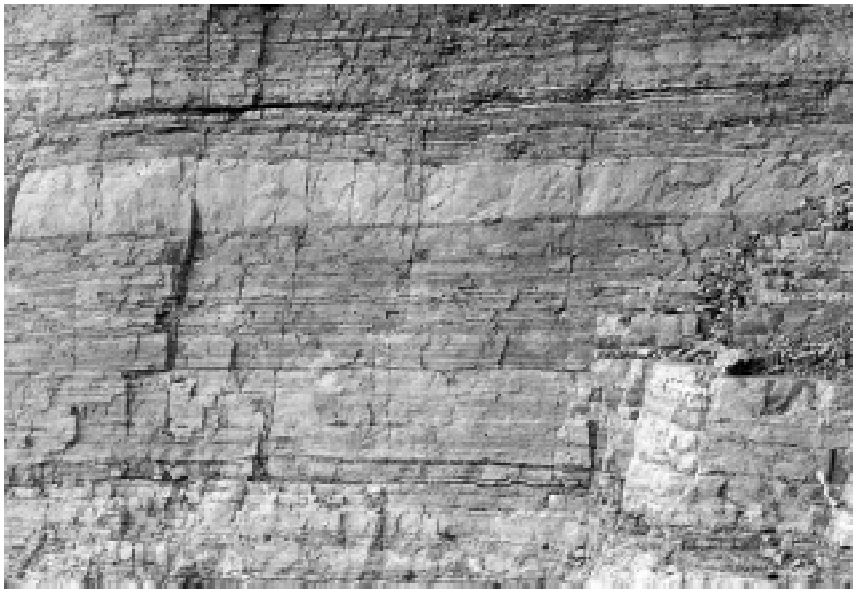


Fig. 28. Thin-bedded dolomites (carbonate turbidites) forming the middle well-bedded portion of the Aftenstjernesø Formation in the type section (see Figs 24, 25). Note that the solitary thick bed (*c.* 0.5 m thick) has a flat base and an irregular top.

the formation (Figs 24, 25). These mass-flow breccia beds range between 0.5 and 20 m in thickness and are composed of pale grey dolomite clasts, typically elongate with average dimensions of 15 × 5 cm in a matrix of smaller pale fragments and dark bitumunous dolomite (see Ineson, 1980; Christie & Peel, 1977, Fig. 8). Thin to medium, parallel-bedded dolomites, exhibiting a crude colour grading, form the middle unit of the formation at the type section (Fig. 28); in some beds relict grain-size grading and the Bouma sequence of sedimentary structures are preserved.

The Aftenstjernesø Formation is composed of comparable lithofacies to the south and east of the type locality, although the graded carbonate beds are less common in southerly exposures, and nodular, platy or wavy-bedded, bioturbated, mid-dark grey dolomites predominate. Pull-aparts, slump folds and thin, discontinuous, brecciated horizons are common features of the formation throughout its outcrop, as are dolomite spar-filled vugs and sheet cracks. At the head of Nordenskiöld Fjord, west of the type section, large pale olistoliths up to 50 m across (Figs 12A, 21) are prominent in the upper levels of the formation. In its northern outcrop, in northern Nyeboe Land, Freuchen Land and north-west Peary Land, the Aftenstjernesø Formation consists largely of dark wavy, nodular thin-bedded lime mudstones and dolomites; phosphoritic, pyritic carbonates mark the base and a single 5–10 m thick breccia bed caps the formation.

Boundaries. The lower boundary of the Aftenstjernesø Formation is taken at the first carbonate bed, conformably overlying the sandstones, siltstones and mudstones of the Buen Formation. Troelsen (1949) proposed the existence of a 'simple erosional disconformity' at the base of his Brønlund Fjord Dolomite, but commonly the boundary is gradational, and only at Troelsen's original type section could an erosive contact be demonstrated (Figs 3, 11B; Frykman, 1980).

West of Øvre Midsommersø (Fig. 26), the Aftenstjernesø Formation is conformably overlain by dark, recessive weathering limestones, dolomites and pale sandstones of the Henson Gletscher Formation (Figs 25, 29). The contact is sharp; black, platy carbonates overlie or drape the planar or hummocky upper surface of the breccia bed capping the Aftenstjernesø Formation.

In central Peary Land, from the eastern end of Øvre Midsommersø to Sæterdal (Fig. 26), the upper boundary is similarly sharp, but the Aftenstjernesø Formation is conformably overlain by the dominantly siliciclastic Sæterdal Formation (Fig. 30). The Sæterdal Formation

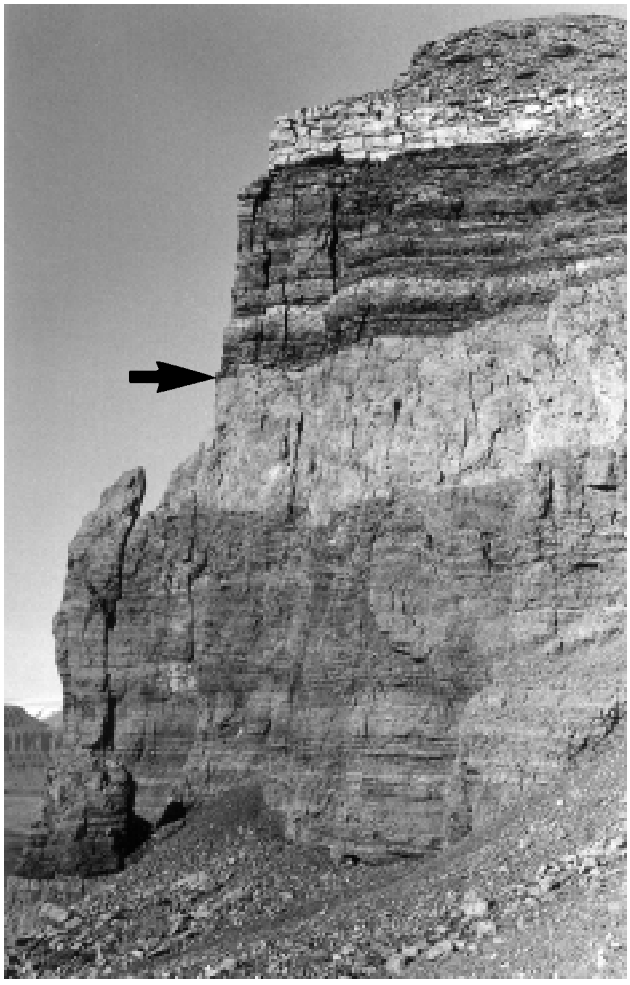


Fig. 29. The massive pale breccia bed capping the Aftenstjernesø Formation is draped (arrow) by the dark dolomites of the Henson Gletscher Formation. Light-coloured sandstones in the middle of the Henson Gletscher Formation cap the exposure; the thin pale bands in the lower Henson Gletscher Formation are bioturbated intervals (see Fig. 31).

pinches out to the south and east from Sæterdal, so that in Paralleldal and on the north side of Frysefjeld, the Aftenstjernesø Formation is conformably overlain by pale weathering carbonates of the Paralleldal Formation (Figs 5, 20). In the cliffs along Børglum Elv, the upper boundary of the Aftenstjernesø Formation is less obvious than elsewhere, but is taken at the change from massive, slumped dolomites into pale cross-stratified dolomites of the Paralleldal Formation (Fig. 17).

Distribution. The formation crops out from the east side of Nordenskiöld Fjord, Freuchen Land, across Lauge Koch Land and southern Peary Land to Independence Fjord (Figs 2, 20), forming conspicuous cliffs to the north of Aftenstjernsø and along the northern

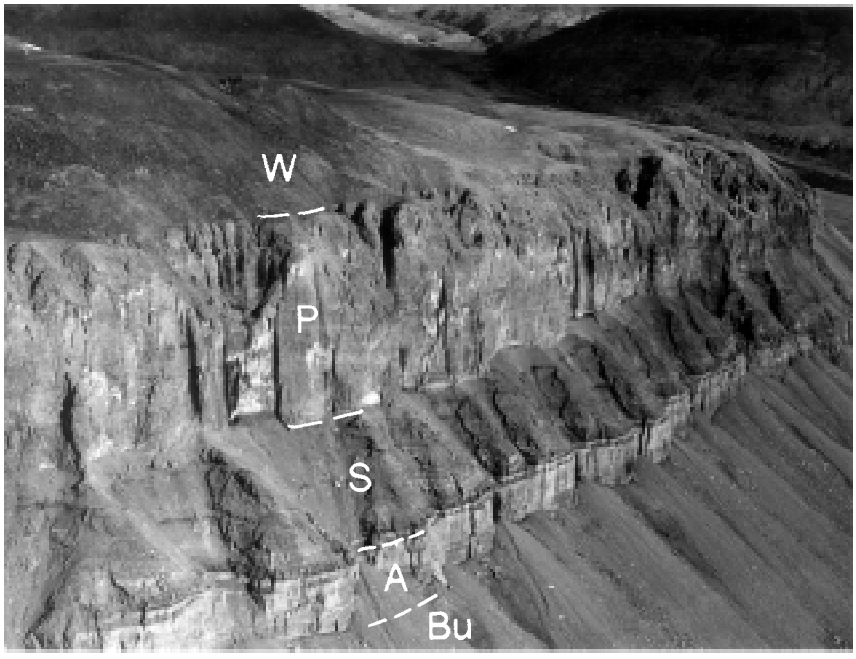


Fig. 30. Brønlund Fjord Group on the north side of Sæterdal, Peary Land (see Fig. 68), conformably overlying the largely scree-covered Buen Formation (Bu) and unconformably overlain by the Wandel Valley Formation (W; Lower – Middle Ordovician, Ryder Gletscher Group). A, Aftenstjernesø Formation; S, Sæterdal Formation; P, Paralleldal Formation.

side of Wandel Dal. It is exposed in folded inliers near the north coast of central North Greenland from Nyeboe Land to north-west Peary Land (Fig. 16). The Aftenstjernesø Formation is correlated with the Kap Troedsson and Bistrup Land Formations of the Nordenskiöld Fjord – Warming Land area (Fig. 8).

Fauna and age. In most outcrops, fossils are only found in the basal phosphoritic carbonates of the formation (Member A of the Brønlund Fjord Formation of Christie & Peel (1977)). A diverse fauna has been recorded (Troelsen, 1949; Christie & Peel, 1977; Palmer & Peel, 1979; Bendix-Almgreen & Peel, 1988), including molluscs, *Chancelloria*, inarticulate brachiopods, trilobites *Bonnia*, *Calodiscus* and *Wanneria*, and the small shelly fossil *Hadimopanella apicata* Wrona, 1982, indicative of the *Bonnia–Olenellus* Zone (late Early Cambrian).

The Henson Gletscher, Sæterdal and Paralleldal Formations, which overlie the Aftenstjernesø Formation, also yield Early Cambrian faunas and the unfossiliferous dolomites of the upper Aftenstjernesø Formation are thus assigned a late Early Cambrian age.

In north-eastern Nyeboe Land an unusually thick development of the Aftenstjernesø Formation is more uniformly fossiliferous. Blaker (1991) has described *Olenellus* associated with *Serrodiscus daedalus*, *S. speciosus* and *S. latus*?. Other fossils include *Hadimopanella apicata* and *Latouchella* (Peel, 1974; Dawes & Peel, 1984; Peel & Larsen, 1984; Bendix-Almgreen & Peel, 1988).

Henson Gletscher Formation

new formation

History. This formation has been described informally as formation 2 of the Brønlund Fjord Group (Peel, 1979; Ineson &Peel, 1980) and is equivalent to the middle sub-unit of Unit E of Dawes (1976b). A detailed study of the distribution of this formation and its lateral variation was given by Christiansen *et al.* (1985, 1987).

Name. After Henson Gletscher, the glacier at the head of J. P. Koch Fjord (Fig. 23).

Type section. Fig. 31; 3 km to the south of the snout of Ekspedition Bræ, Lauge Koch Land, along the east side of the gully (Figs 23, 25).

Reference section. Fig. 32; adjacent to Jungersen Gletscher, southern Freuchen Land (Figs 2, 21, 33, 78).

Thickness. 62 m at the type locality, thickening to the south and west to 73 m at Henson Gletscher (Fig. 26) and 112 m at Jungersen Gletscher. In its northern outcrop, near the north coast of North Greenland, the Henson Gletscher Formation is typically 20–60 m thick but it attains a thickness of 90 m in northern Nyeboe Land.

Lithology. The Henson Gletscher Formation forms dark grey or black weathering, recessive slopes between

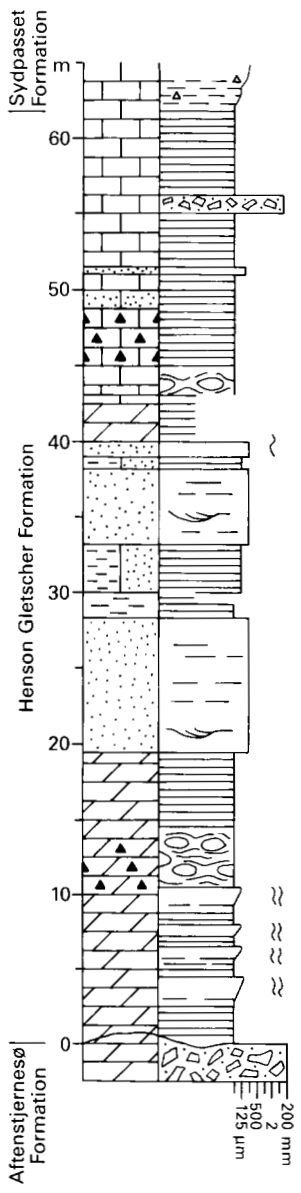


Fig. 31. Type section of the Henson Gletscher Formation, Lauge Koch Land (Figs 23, 25). See Fig. 14 for legend.

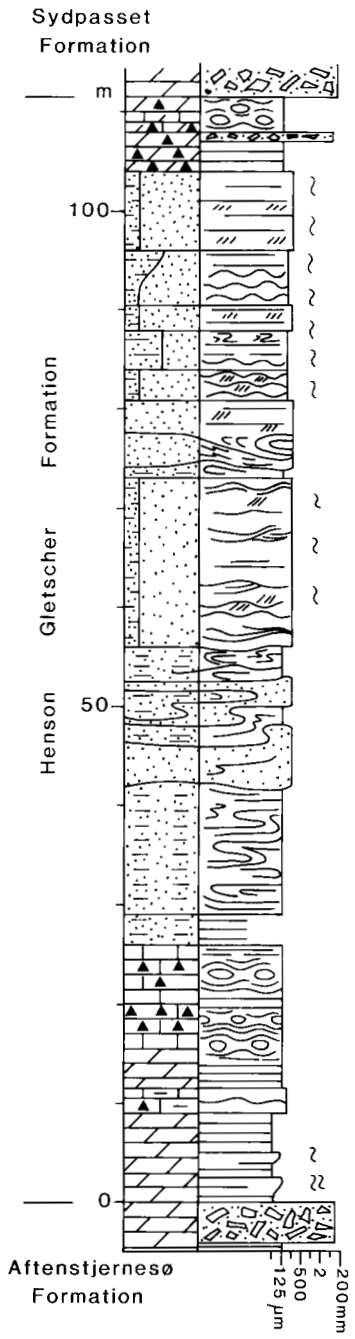


Fig. 32. Reference section of the Henson Gletscher Formation, south Freuchen Land (Figs 21, 33, 78). See Fig. 14 for legend.

the cliff-forming Aftenstjernesø Formation below and the Sydpasset Formation above (Figs 18, 25). It is composed of sooty, shaly weathering, bituminous, thin-bedded and finely laminated dolomites, limestones, calcareous and dolomitic mudstones and pale cream weathering, fine-grained sandstones and siltstones. In more northerly localities, sandstones are subordinate to argillaceous carbonates which characteristically show parallel lamination, well-developed concretions (Figs 34, 35) and contain lenses, stringers and continuous beds of black chert (Fig. 36).

In the type section (Fig. 31), bituminous fissile cherty dolomites and shaly dolomitic mudstones dominate the lower third of the formation, interbedded with pale weathering horizons of bioturbated dolomite (Fig. 29). The carbonates of the upper third of the formation at the type section are largely undolomitised and comprise parallel-laminated, spicular lime mudstones, shelly wackestones, graded beds of peloidal and bioclastic packstone and grainstone, and a prominant limestone breccia bed, approximately 1 m thick.

Dolomitic sandstones and siltstones form a pale

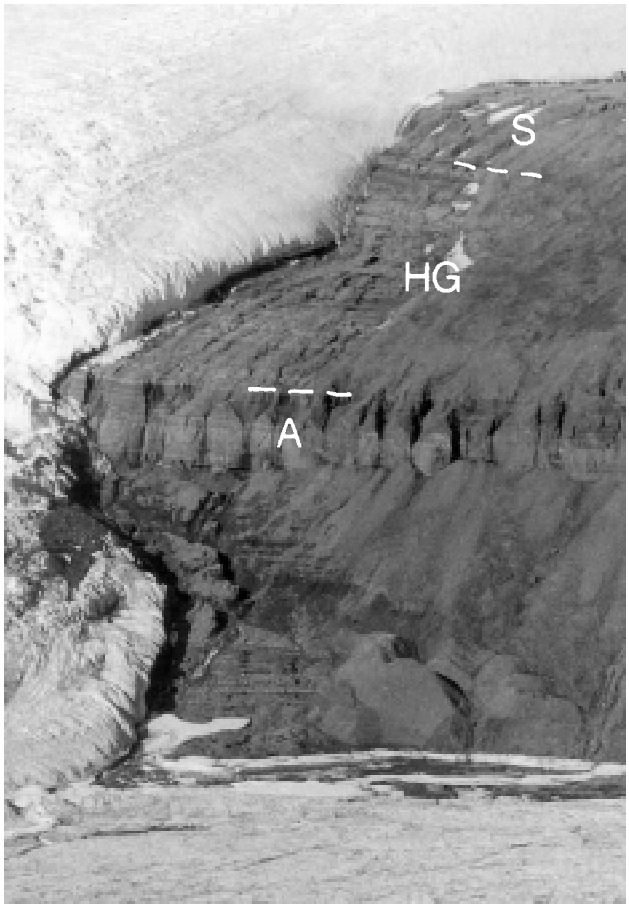


Fig. 33. Reference section of the Henson Gletscher Formation (HG), south Freuchen Land. A, Aftenstjernesø Formation, S, Sydpasset Formation. See Figs 21, 78 for location.

cream weathering unit in the middle of the formation (Figs 25, 29); this unit thickens markedly south of the type section and dominates the formation at Koch Væg (Fig. 10) and at Jungersen Gletscher (Fig. 32). The well-sorted, fine-grained sandstones form 0.1–4 m thick sheets with sharp boundaries (Fig. 13F). They are generally structureless or faintly laminated but locally show hummocky cross-stratification and dish structures. Interbedded with the sand sheets are parallel-laminated and bioturbated silty sandstones and siltstones, which exhibit ripple cross-lamination in southern exposures. Slump sheets of siltstone and silty sandstone are prominent in the formation at Jungersen Gletscher (Fig. 32).

In Løndal, east of Hans Tavsen Iskappe, medium-bedded, coarse skeletal glauconitic packstones and grainstones form pale weathering ledges near the base of the formation. Similar beds can be identified at this stratigraphic level farther to the east, but are represented by pale weathering, glauconitic, medium-coarse crystalline dolomites showing ghosted skeletal grains. At the same locality and in other southern exposures, small-scale trough cross-bedding occurs in mid-grey weathering skeletal dolomites in the upper levels of the formation.

Boundaries. The Henson Gletscher Formation overlies the Aftenstjernesø Formation with apparent conformity. The boundary is sharp and often irregular where dark recessive-weathering carbonates of the Henson Gletscher Formation drape the uppermost

Fig. 34. Laminated bituminous cherty dolomites of the lower Henson Gletscher Formation in the type section (*c.* 12 m above base, Fig. 31). From Higgins *et al.* (1991a).

Fig. 35. Carbonate concretion within laminated argillaceous dolomites; note the evidence of early diagenetic pre- and syn-compactional growth of the concretion. Henson Gletscher Formation, type section.

hummocky breccia bed of the Aftenstjernesø Formation (Fig. 29).

The upper boundary is gradational in detail, although the overlying Sydpasset Formation commonly forms a pale weathering vertical cliff and the boundary is readily defined at the break of slope for mapping purposes (Fig. 18). At the type locality, the boundary is placed where dark weathering, shaly carbonates are overlain by more resistant platy, nodular carbonates of the Sydpasset Formation (Fig. 25). In southernmost exposures (e.g. at Jungersen Gletscher, Figs 32, 33), the upper boundary is placed where recessive sandstones or lime mudstones are sharply overlain by cliff-forming dolomites of varied lithology which are assigned to the Sydpasset Formation. In the northern outcrop belt, the upper boundary is placed where varied nodular platy lime mudstones and breccia beds overlie black, cherty, spicular lime mudstones; the former are assigned to the Kap Stanton Formation of the Tavsens Iskappe Group (see Fig. 5; Ineson *et al*., 1994).

Distribution. In its southern outcrop belt, the Henson Gletscher Formation crops out from Nordenskiöld Fjord in southern Freuchen Land eastward across Lauge Koch

Fig. 36. Laminated bituminous dolomite with black chert lenses and bands. Henson Gletscher Formation, type section.

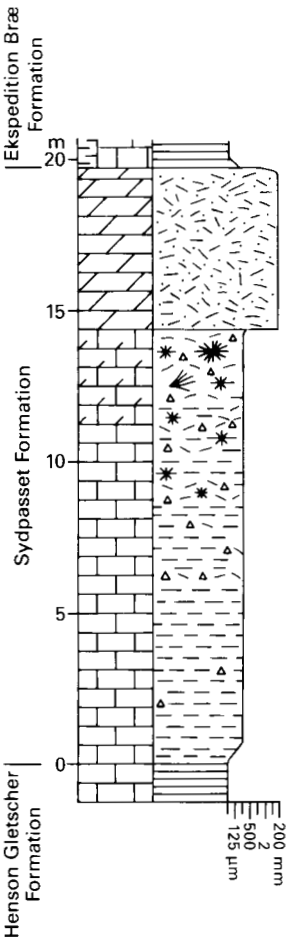


Fig. 37 Type section of the Sydpasset Formation, Lauge Koch Land (Figs 23, 25, 42). See Fig. 14 for legend.

Land and southern Peary Land to Øvre Midsommersø (Figs 2, 20, 26). The formation is not recognised east of an arbitrary north–south line at the eastern end of Øvre Midsommersø. In Sæterdal, east of this line, the Aftenstjernsø Formation is conformably overlain by a thick siliciclastic-dominated formation (Sæterdal Formation; see Fig. 20) which is the lateral equivalent, in part at least, of the Henson Gletscher Formation. In the northern outcrop belt, the Henson Gletscher Formation crops out in anticlinal inliers from northern Nyeboe Land east to north-west Peary Land (Fig. 16).

Fauna and age. The strata of the Henson Gletscher Formation are often richly fossiliferous and have yielded faunas of late Early to late Middle Cambrian age (Palmer & Peel, 1979; Blaker, 1986, 1991; Peel, 1994a). The type section in southern Lauge Koch Land is generally poorly fossiliferous, but Blaker (1991) described Early Cambrian trilobites about 45 m above the base and above the conspicuous pale weathering sandstone unit. Middle Cambrian trilobites of the *Ptychagnostus gibbus* Zone occur only in the uppermost beds in this section and in outcrops in Løndal (Palmer & Peel, 1979; Robison, 1984; Blaker, 1991). The reference section in southern Freuchen Land has yielded abundant fossils indicative of an Early Cambrian (*Bonnia–Olenellus* Zone) age (Blaker, 1991; Peel & Blaker, 1988; Peel, 1989) but Middle Cambrian faunas are absent. Olenellids, *Kootenia* spp., *Bonnia brennus*, *Ogygopsis typicalis*, *O. batis*, *O. virgata*, *Pagetides elegans*, *Arthricocephalus* sp. and *Peronopsis roddyi* are conspicuous (Blaker, 1991).

Early Cambrian faunas have not been located in the northern outcrop belt of the Henson Gletscher Formation although the lower levels of the formation are inferred to be of this age (Ineson *et al.*, 1994; Figs 16, 86). In more eastern outcrops within this northern belt, in outer J. P. Koch Fjord (see Fig. 10), the presence of latest Middle Cambrian faunas (*Lejopyge laevigata* Zone) in the lowest beds of the overlying Kap Stanton Formation suggests that the poorly fossiliferous Henson Gletscher Formation in this region may also extend into the latest Middle Cambrian (Ineson *et al.*, 1994; Babcock, 1994a; Robison, 1994). In northern Nyeboe Land, the Henson Gletscher Formation has yielded rich faunas of early Middle to medial Middle Cambrian age (*Glossopleura* Zone to *Ptychagnostus atavus* Zone) described by Babcock, 1994a; Robison, 1994; Peel, 1994b; see also Poulsen, 1969), suggesting that the top of the formation is diachronous in the northern outcrop belt, younging towards the east. This pronounced diachroneity is also evident when comparing the age of the top of the formation in the northern and southern outcrops. At the reference section, in southern Freuchen Land, the formation is entirely of Early Cambrian age. This diachroneity is attributed by Ineson *et al.* (1994) to the northward pinchout of carbonate slope apron wedges and the resultant amalgamation in northern sections of condensed mud-dominated outer shelf successions which are collectively assigned to the Henson Gletscher Formation (Fig. 10).

Sydpasset Formation

new formation

History. Previously described informally as formation 3 of the Brønlund Fjord Group (Peel, 1979; Ineson & Peel, 1980), the Sydpasset Formation is equivalent to the upper sub-unit of Unit E of Dawes (1976b).

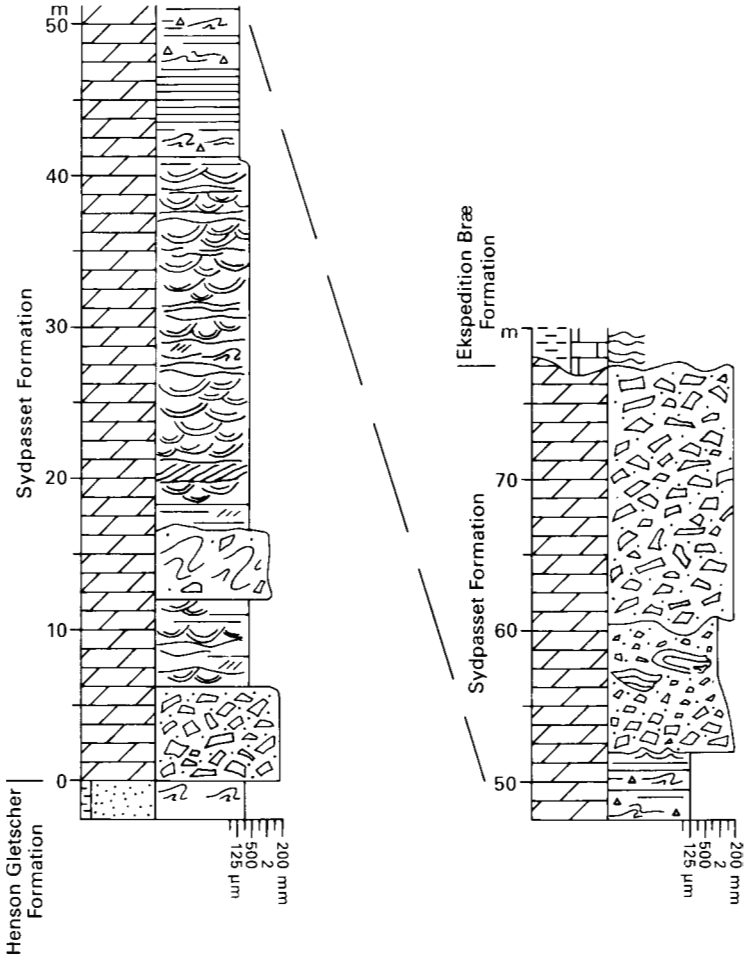


Fig. 38. Reference section of the Sydpasset Formation at the southern end of Koch Væg, south-west Peary Land (Fig. 23). See Fig. 14 for legend.

Name. After Sydpasset at the western end of Øvre Midsommersø, southern Peary Land (Fig. 2).

Type section. Fig. 37; 3 km to the south of the snout of Ekspedition Bræ (Fig. 23), along the eastern side of the gully (Fig. 25).

Reference section. Fig. 38; south Koch Væg, western Peary Land (Fig. 23).

Thickness. 20 m at the type locality, thinning northwards (Fig. 26). The formation is generally thicker in southern exposures, and in western Peary Land the formation thickens markedly south of Troelsen's Fault (Figs 10, 23), reaching a maximum measured thickness of 77 m at the south end of Koch Væg (Fig. 38).

Lithology. Pale weathering, cliff-forming carbonates of the Sydpasset Formation form a distinctive mapping unit separating the recessive formations above and below (Figs 18, 39). In exposures around the head of J. P. Koch Fjord (Fig. 23), distinctive platy, nodular limestones (microsparites) and dolomites dominate the formation. The nodular component weathers pale grey and forms platy sheets (5–10 mm thick), lenses and spheres interbanded with, and enclosed by, dark grey laminated carbonate (Fig. 40A). These platy nodular carbonates commonly exhibit pull-aparts, interstratal breccia lenses and buckle folds attributed to slope creep of differentally cemented lime mudstones (see Fig. 13B; Ineson & Surlyk, 1995, Fig. 9.5a). Coarse, fibrous, replacive calcite is often intimately associated with the nodules, radiating from or enclosing the pale nodular forms and locally forming spectacular radial-fibrous, oval or spherical concretions up to 20 cm across (Fig. 40B).

The Sydpasset Formation is characteristically capped by one or more carbonate breccia beds. In the type section (Fig. 37) and other sections around the head of J. P. Koch Fjord, the breccia bed is thin (*c.* 5 m), commonly dolomitised, and is composed of flat, platy clasts, lithologically similar to the underlying *in situ* nodular carbonates.

The formation changes character in southern locali-

Fig. 39. Cliff-forming carbonates of the Sydpasset Formation (S) at the type locality; note the gradational base with the Henson Gletscher Formation (HG) beneath and the sharp top, overlain by the largely scree-covered argillaceous carbonates of the Ekspedition Bræ Formation (EB). Viewed westwards across J. P Koch Fjord to Fimbuldal.

ties, thickening considerably (Figs 10, 38) and variably composed of mid-grey, trough cross-bedded skeletal dolomites, dark grey, laminated dolomites and wavy bedded, nodular bioturbated dolomites. The capping breccia beds are thick, sometimes composite and locally contain pale, cross-bedded dolomite clasts up to tens of metres across. Indeed, at Jungersen Gletscher, huge olistoliths of pale dolomite, up to 100 m across, protrude from the top of the Sydpasset Formation.

Boundaries. The lower boundary of the formation is marked by a distinct break in slope where the cliff-forming carbonates of the Sydpasset Formation conformably overlie the recessive carbonates and clastics of the Henson Gletscher Formation (Fig. 18). At the type locality (Figs 25, 39) the boundary is placed where bituminous shaly limestones of the Henson Gletscher Formation are overlain by more prominent-weathering, platy, nodular or thin wavy-bedded dark carbonates. At Koch Væg and along the northern side of Wandel Dal, the lower boundary is marked by an abrupt lithological change from fine-grained, pale cream sandstones into resistant dolomites (Fig. 38). At Jungersen Gletscher, the base of the formation is placed where dark cherty, laminated lime mudstones and dolomites are overlain by a resistant dolomite breccia bed (Fig. 32).

West of the western end of Øvre Midsommersø (Figs 2, 20), the Sydpasset Formation is conformably overlain by the uppermost formation of the Brønlund Fjord Group, the Ekspedition Bræ Formation. East of this point, which is defined by the western limit of the Lønelv Formation (Figs 5, 20), the Sydpasset Formation forms the uppermost unit of the Brønlund Fjord Group and is overlain conformably by the Erlandsen Land Formation, the basal formation of the Tavsens Iskappe Group in this area (see Fig. 63). In both cases, the upper boundary is sharp, although often irregular, the uppermost breccia of the Sydpasset Formation being overlain by recessive, thin-bedded dark dolomites and argillaceous lime mudstones (Fig. 39).

Distribution. The Sydpasset Formation crops out from Jungersen Gletscher in southern Freuchen Land eastward to the eastern end of Øvre Midsommersø (Figs 2, 20), where an arbitrary north–south line forms the limit of the formation. It is well exposed around the head of J. P. Koch Fjord, in Fimbuldal, along Koch Væg and along the banks of Lønelv on the east side of Hans Tavsen Iskappe (Figs 2, 20, 23). The formation can be traced as a well-defined feature on the north side of Sydpasset and Øvre Midsommersø.

Fauna and geological age. The formation is characteristically unfossiliferous, but fragments of inarticulate brachiopods (cf. *Linnarssonia*) and the phosphatic tube *Hyolithellus* have been recorded from bioclastic dolomites in the reference section at the south end of Koch Væg (Figs 23, 38; Palmer & Peel, 1979; Peel, 1979). This fauna was also collected by Dawes (1976a) and thought to indicate an Early Cambrian age, by comparison with Early Cambrian faunas from basal beds of

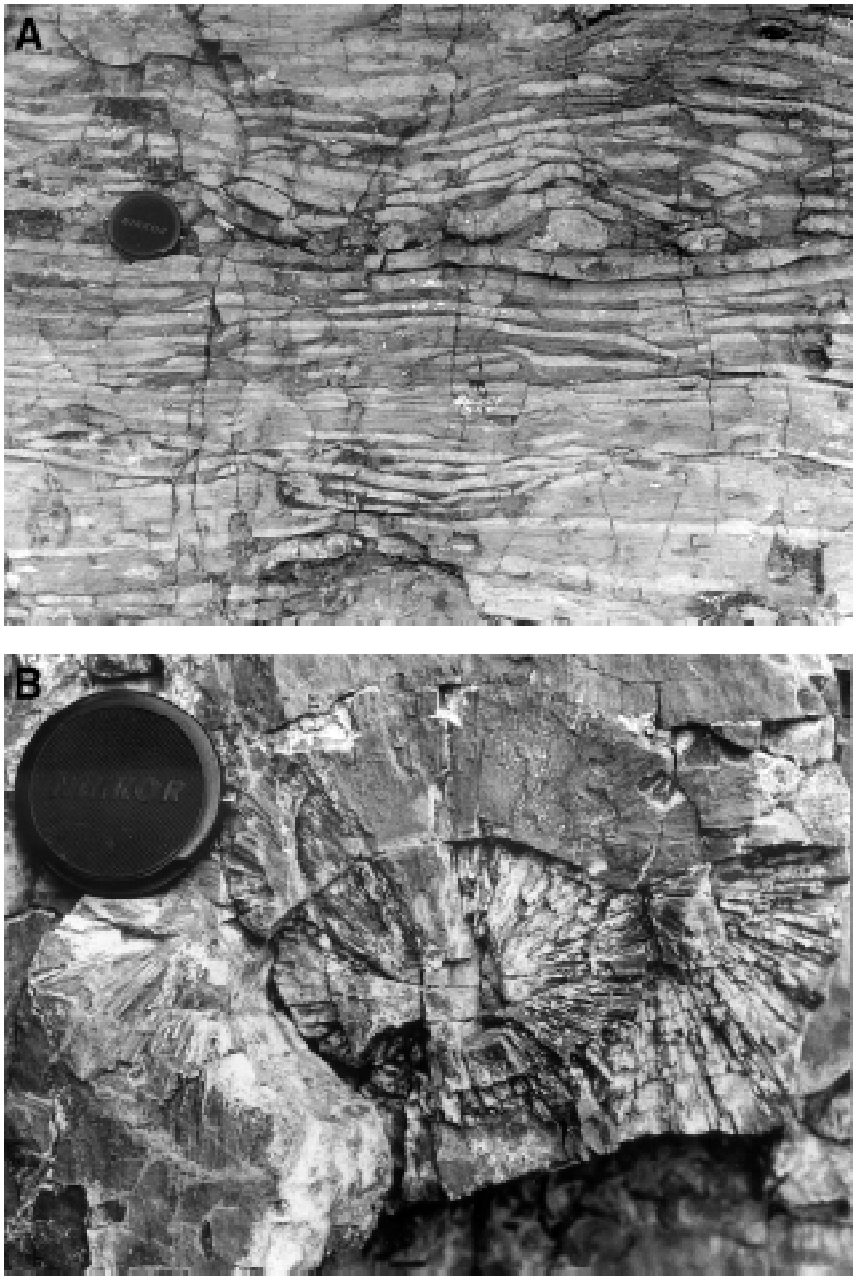


Fig. 40. **A**. Nodular dolomitic lime mudstones of the Sydpasset Formation at the type section showing the characteristic platy, lenticular and ovoid nodular forms. **B**. Fibrous neomorphic calcite showing two distinct phases of development. Sydpasset Formation, type section.

the Aftenstjernesø Formation. However, fieldwork in 1978 demonstated the presence of Middle Cambrian faunas in the subjacent Henson Gletscher Formation in its type section and adjacent localities and the Sydpasset Formation was assigned a Middle Cambrian age on account of its stratigraphic position. In these localities the formation is of undoubted medial Middle Cambrian age on account of faunas obtained from the underlying and overlying formations. However, at the reference section (Fig. 38), where the meagre fauna was obtained, the Sydpasset Formation is much thickened with respect to northerly outcrops and the underlying Henson Gletscher Formation yields only Early Cambrian faunas; the first unambiguous Middle Cambrian faunas occur in the overlying Ekspedition Bræ Formation at this locality (Palmer & Peel, 1979). It is likely, therefore, that the lowest carbonates assigned to the Sydpasset Formation at this and other southern localities are of Early Cambrian age.

At Jungersen Gletscher, southern Freuchen Land, dark weathering, resistant dolomites assigned to the lower Sydpasset Formation yielded fragments of polymeroid trilobites, inarticulate brachiopods and *Latouchella*, probably of Middle Cambrian age. Immediately

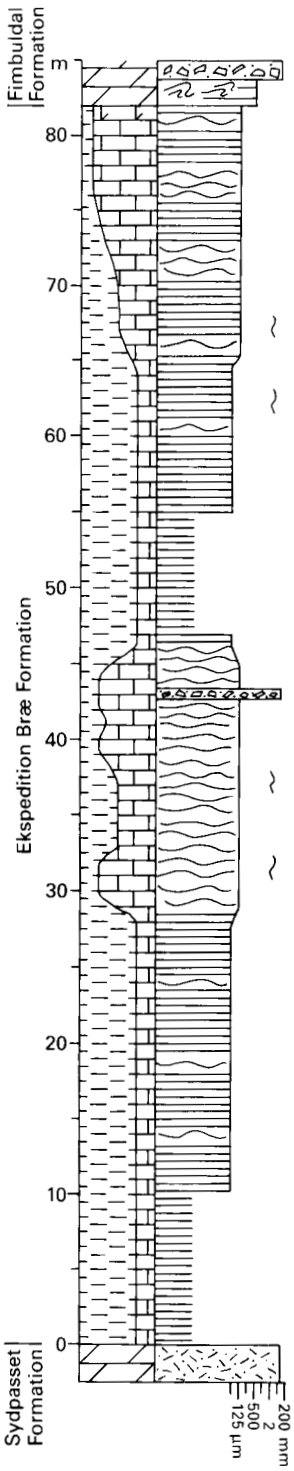


Fig. 41. Type section of the Ekspedition Bræ Formation, Lauge Koch Land (Figs 23, 42). See Fig. 14 for legend.

underlying beds of the Henson Gletscher Formation have yielded olenellid and other trilobites of late Early Cambrian age (Blaker, 1986, 1991).

Ekspedition Bræ Formation

new formation

History. The formation has been previously referred to as formation 4 of the Brønlund Fjord Group (Peel, 1979; Ineson & Peel, 1980) and is equivalent in part to Unit F of Dawes (1976b).

Name. After Ekspedition Bræ, the small glacier flowing east into the head of J. P. Koch Fjord, east Freuchen Land (Fig. 23).

Type section. Fig. 41; 3 km to the south of the snout of Ekspedition Bræ (Figs 23, 42) up the east side of the gully and south along the crest of the ridge.

Thickness. At the type locality the formation is 82 m thick, thinning to about 30 m at Koch Væg, to the south, and at the mouth of Gustav Holm Dal, to the north-east (Figs 10, 23, 26). The Ekspedition Bræ Formation thins westward across southern Freuchen Land, finally wedging out at the junction of Jungersen Gletscher and Nordenskiöld Fjord.

Lithology. The Ekspedition Bræ Formation forms recessive, grey weathering slopes between cliff-forming formations above and below (Figs 18, 39, 42). At the type section, dominant strata are pale weathering, thin-bedded, dark grey lime mudstones and skeletal wackestones, interbedded with grey-green shaly, calcareous mudstones (Fig. 43, see also Fig. 13E). Bedding is parallel or slightly wavy and the lime mudstones commonly show diffuse parallel lamination and are locally bioturbated. Skeletal, peloidal packstones and grainstones form about 5% of the type section and are sometimes normally graded with erosive, scoured bases. A prominent limestone breccia bed occurs in a carbonate-dominated interval roughly halfway up the section (Fig. 41). It is composed of tabular lime mudstone clasts (average dimensions 0.03 × 0.1 m) in a dark, dolomitic lime mudstone matrix. A distinctive multiple phosphorite hardground occurs at 68.5 m above the base of the type section.

Although the formation thins north-eastward across J. P. Koch Fjord, it is lithologically identical to the type

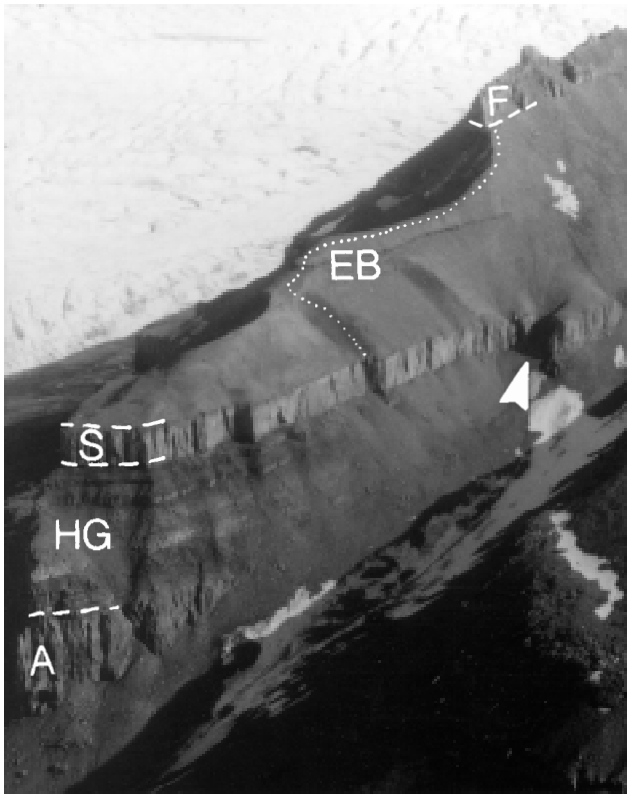


Fig. 42. The type locality of the Aftenstjernesø (A), Henson Gletscher (HG), Sydpasset (S) and Ekspedition Bræ (EB) Formations, Lauge Koch Land. The type section of the Sydpasset Formation is located in the narrow gully (arrow); the Ekspedition Bræ type section (dotted line) is constructed by traversing the lower slopes and ascending the ridge to the base of the Fimbuldal Formation (F, Tavsens Iskappe Group).

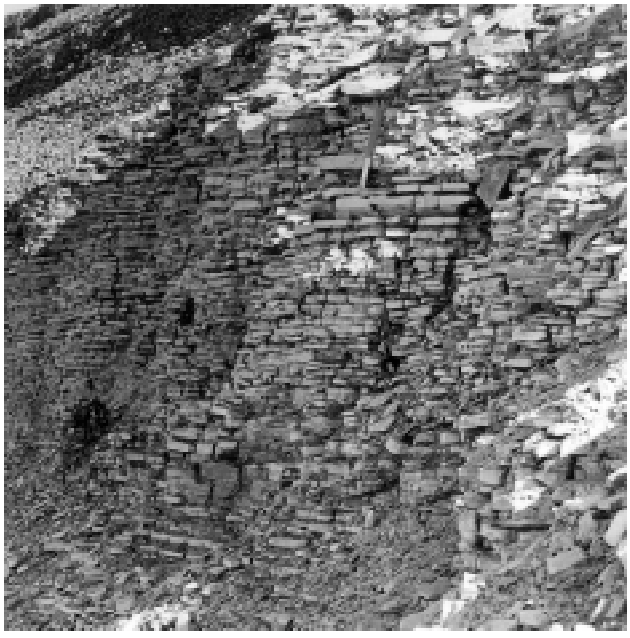


Fig. 43. Thinly interbedded lime mudstones and calcareous siliciclastic mudstones of the Ekspedition Bræ Formation in the type section.

section. To the south at Koch Væg (Fig. 23), the argillite content decreases, occurring only as thin interbeds and partings between irregular, wavy beds of bioturbated lime mudstone, wackestone, cross-laminated skeletal grainstone and packstone. Slumped intervals and limestone breccia beds occur more frequently in such southern sections. Grey-green siliciclastic mudstones are dominant near Jungersen Gletscher in the west, however, with limestones being most conspicuous in the basal few metres.

Boundaries. The Ekspedition Bræ Formation conformably overlies the massive carbonate breccia beds of the upper Sydpasset Formation with a sharp contact, which may be planar or hummocky (Figs 18, 38, 39).

The formation is conformably overlain by the basal beds of the Tavsens Iskappe Group: the Fimbuldal Formation to the west of Hans Tavsen Iskappe and the Lønelv Formation to the east of the ice cap (Fig. 5). At the type section, the boundary is sharp (Figs 41, 42) where the recessive argillaceous carbonates are overlain abruptly by cliff-forming dolomites of the Fimbuldal Formation. Elsewhere the boundary is less distinct. On the east side of J. P. Koch Fjord, the Ekspedition Bræ Formation is overlain by cliff-forming, argillaceous, platy, nodular limestones assigned to the Fimbuldal Formation with the boundary taken at the incoming of the nodular limestones, which approximately coincides with the break of slope. At Koch Væg, the upper boundary is placed where argillaceous limestones and dolomitic limestones are overlain by pale cream weathering, laminated and slumped dolomites, assigned here to the Fimbuldal Formation.

East of Hans Tavsen Iskappe, in Løndal, argillaceous limestones of the Ekspedition Bræ Formation are overlain abruptly by cliff-forming, pale yellow-weathering dolomites of the Lønelv Formation.

Distribution. The Ekspedition Bræ Formation crops out in southern Freuchen Land, Lauge Koch Land and western Peary Land; Jungersen Gletscher forms the western limit of the formation. The formation is not recognised east of a point to the north of Sydpasset (Figs 2, 20). Here, the overlying Lønelv Formation pinches out (Figs 5, 20), and the recessive carbonates of the Ekspedition Bræ Formation coalesce with

the lithologically similar Erlandsen Land Formation. Farther east, it is no longer possible to map these similar carbonates as two separate formations, so the combined unit is assigned to the Erlandsen Land Formation.

The Ekspedition Bræ Formation generally weathers recessively and is only consistently exposed in steep cliffs, for example along J. P. Koch Fjord, in Fimbuldal and at Koch Væg (Figs 22A, 23).

Fauna and age. The Ekspedition Bræ Formation is richly fossiliferous; it has yielded well-preserved faunas of agnostoid and ptychoparioid trilobites, helcionelloids and inarticulate brachiopods, indicative of the medial Middle Cambrian (Palmer & Peel, 1979). The trilobite genera include *Peronopsis*, *Ptychagnostus*, *Syspacephalus* and *Elrathia*, an assemblage that is thought to indicate a maximum age range from high *Ptychagnostus gibbus* Zone to high *Ptychagnostus atavus* Zone (R. A. Robison, written communication, 1981).

Tavsens Iskappe Group

The Henson Gletscher region is the type area of the Tavsens Iskappe Group and includes the type localities of the Fimbuldal, Holm Dal and Perssuaq Gletscher Formations; the group ranges from 400 m to 700 m in thickness in this region.

Fimbuldal Formation

new formation

History. This formation is equivalent to the informal formation T1 of Ineson & Peel (1980) and approximately equivalent to formation 1 of Peel (1979). At Koch Væg, south-western Peary Land, the formation is equivalent to the upper part of Unit F of Dawes (1976b), beds which were initially included in formation 4 of the Brønlund Fjord Group (Peel, 1979).

Name. After Fimbuldal, the valley linking the head of J. P. Koch Fjord to Wandel Dal, west Peary Land (Figs 2, 23).

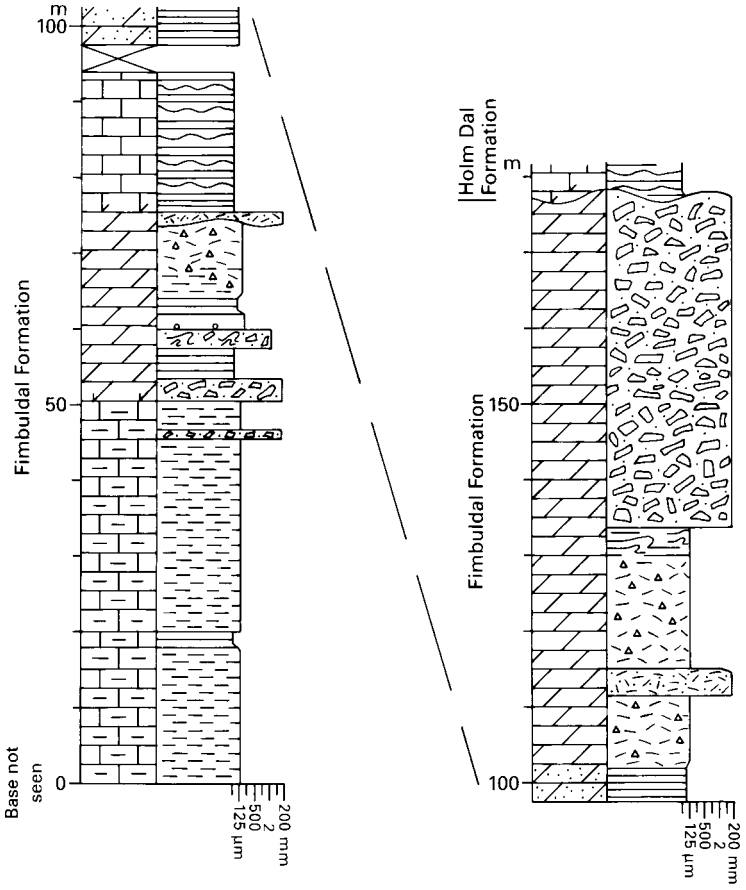


Fig. 44. Type section of the Fimbuldal Formation, west Peary Land (Figs 23, 45). See Fig. 14 for legend.

Type section. Fig. 44; gully on the west side of Gustav Holm Dal, south-west Peary Land (Figs 23, 45).

Thickness. Approximately 180 m at the type locality, thinning south to about 80 m at Koch Væg (Figs 10, 46).

Lithology. The Fimbuldal Formation is composed of alternating units of dark weathering, recessive and pale weathering, cliff-forming carbonates, producing characteristic terraced exposures (Fig. 45) above the recessive, argillaceous carbonates of the Ekspedition Bræ Formation.

In northern exposures around the head of J. P. Koch Fjord, the formation comprises a varied sequence of platy, nodular limestones (microsparites) and dolomites, skeletal wackestones, bituminous parallel-laminated lime mudstones, and thin, graded beds of intraclastic peloidal lime grainstone, interbedded with pale weathering carbonate breccia beds. Platy, nodular carbonates dominate the lower half of the type section and exhibit undulatory bedding, pull-aparts and discontinuous brecciated horizons (Fig. 47). The clast-supported breccia beds range from less than a metre to 40 m in thickness and are commonly dolomitised together with adjacent, thin-bedded carbonates. Clasts are mostly tabular (average dimensions of 2 cm × 10 cm) and, where undolomitised, are composed of lime mudstone, wackestone and peloidal packstone in a lime mudstone matrix. Pale weathering blocks of ooidal grainstone occur sporadically in the breccia beds (Fig. 48) and locally are of house-sized proportions.

South of Ekspedition Bræ and in the Henson Gletscher area, the formation is made up of thin-bedded dolomites, interbedded with dolomite breccia beds. At Koch Væg, the formation is 80 m thick and comprises a lower pale weathering interval (*c.* 30 m) of laminated, locally slumped dolomite, interbedded with dolomite breccia beds (0.5–2 m thick), overlain by about 50 m of thin wavy-bedded, dark grey dolomites (Fig. 10).

Boundaries. The Fimbuldal Formation conformably overlies the Ekspedition Bræ Formation. The boundary is not exposed at the type locality, but on the east side of Gustav Holm Dal (Fig. 23) it is placed at the first appearance of prominent weathering, platy, nodular limestones above the recessive lime mudstones and calcareous mudstones of the Ekspedition Bræ Formation (Fig. 22A). At the southern end of the Koch Væg cliffline, the boundary is placed where pale yellow weathering dolomites overlie recessive argillaceous carbonates assigned to the Ekspedition Bræ Formation.

Fig. 45. Type locality of the Fimbuldal Formation (F) on the west side of Gustav Holm Dal, west Peary Land (Fig. 23). The boundary with the underlying Ekspedition Bræ Formation (EB, Brønlund Fjord Group) is not exposed; the top of the Fimbuldal Formation is highly irregular and draped by argillaceous carbonates of the Holm Dal Formation (H). The terraced nature of this locality is typical of the formation in all but the steepest of exposures.

In the Henson Gletscher area, the formation is conformably overlain by cliff-forming ooidal dolomites assigned to the Perssuaq Gletscher Formation (Fig. 46). The boundary is placed at the base of the first cream weathering, ooidal dolomite bed. The Perssuaq Gletscher Formation is strongly diachronous from south to north (Figs 10, 46) and consequently, to the north of the head of J. P. Koch Fjord, the Fimbuldal Formation is conformably overlain by the Holm Dal Formation which, in turn, is overlain by the Perssuaq Gletscher Formation (Figs 22A, 46). In this area the boundary is

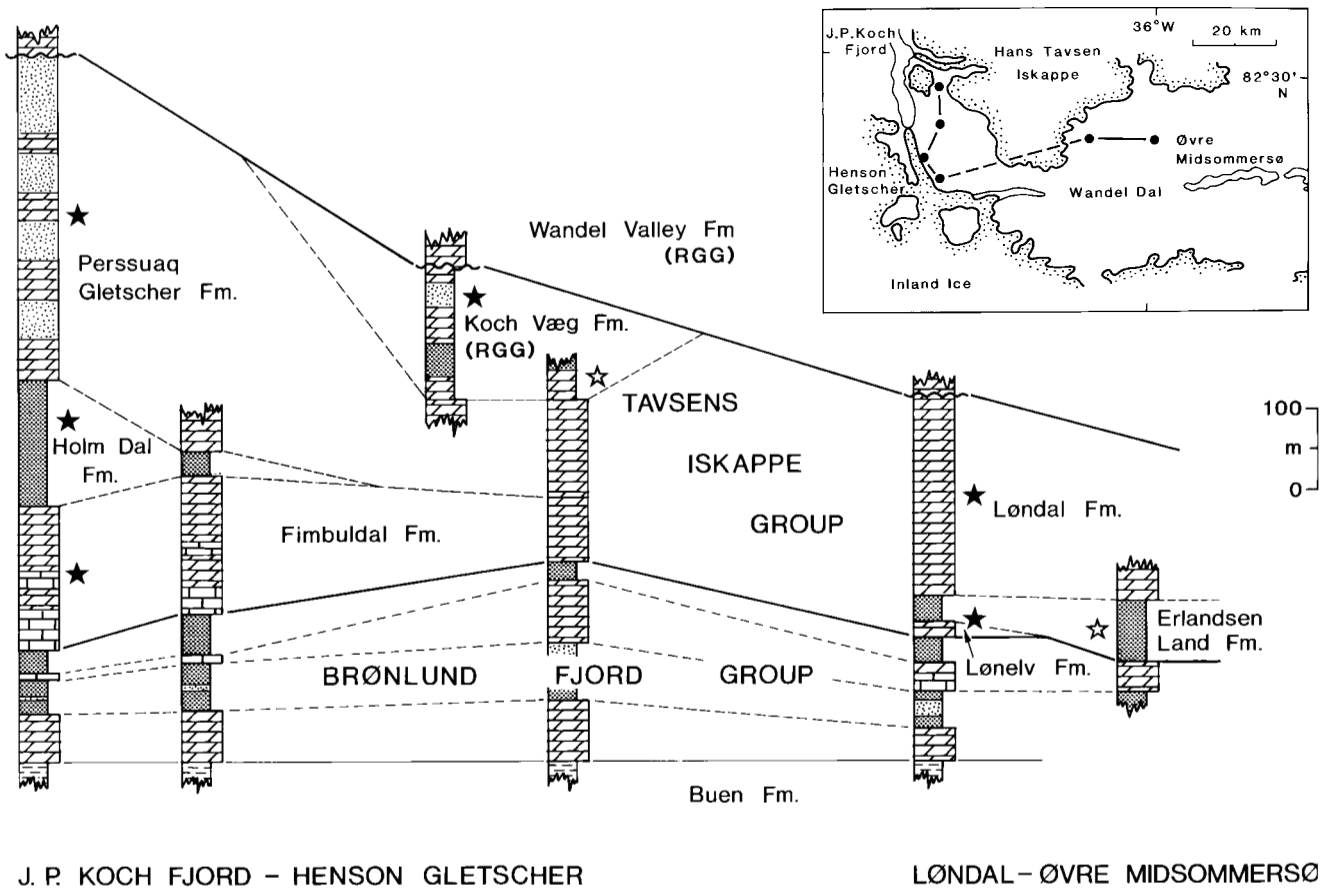


Fig. 46. Generalised stratigraphic logs of the Tavsens Iskappe Group showing the stratigraphic relationships and lateral thickness variations in the Henson Gletscher and Løndal regions of west Peary Land (see inset map). The formations of the Brønlund Fjord Group are shown on Fig. 26. Type sections are indicated by solid stars, reference sections by open stars. Note that the upper levels of the Tavsens Iskappe Group are typically poorly exposed, where accessible, and the generalised logs are constructed in part from float and inference from adjacent cliff sections. See Figs 14, 26 for explanation of symbols.

sharp and is placed where dark recessive, thin-bedded carbonates rest on the uppermost cliff-forming carbonate breccia bed of the Fimbuldal Formation (Figs 22A, 44, 45). The boundary may be planar or hummocky and locally has a relief of up to 5 m.

Distribution. The formation is recognised from the western margin of Hans Tavsen Iskappe, south-west Peary Land, westwards to Jungersen Gletscher, southern Freuchen Land (Fig. 2). In south-western Peary Land it is well exposed in Gustav Holm Dal and along northern Fimbuldal (Fig. 22A) and in the vertical cliffs flanking J. P. Koch Fjord and Henson Gletscher (Fig. 19). Additional accessible sections are located at the south end of Koch Væg and on the south side of Fimbuldal, but the type section is the most complete.

Fauna and age. At the type section as well as on the south side of Fimbuldal, dark bituminous limestones (80–90 m above the base) yield a diverse fauna of agnostoid and ptychoparioid trilobites, brachiopods and sponge spicules. The agnostoid trilobites include species that are indicative of the North American *Ptychagnostus punctuosus* Zone of the medial Middle Cambrian (Peel, 1982a; Robison, 1984). The remainder of the formation is unfossiliferous, but the lower beds of the overlying Holm Dal Formation yield faunas indicative of the latest Middle Cambrian (Palmer & Peel, 1979; Peel, 1982a, 1988b, c; Robison, 1984, 1988) and consequently the upper beds of the Fimbuldal Formation are of probable late Middle Cambrian age.

In southern exposures, around Henson Gletscher, the Fimbuldal Formation is unfossiliferous, but a medial Middle Cambrian age is suggested by its stratigraphic position.

Holm Dal Formation

History. The formation has been described informally as formations 2 and T2 of the Tavsens Iskappe Group (Peel, 1979; Ineson & Peel, 1980). It was formally described by Ineson (1988).

Name. After Gustav Holm Dal, the north–south valley linking Fimbuldal with Perssuaq Gletscher, south-west Peary Land (Figs 2, 23).

Type Section. Fig. 49; north of the prominent gully on the east side of Gustav Holm Dal, at the junction with Fimbuldal (Figs 22A, 23).

Thickness. 155 m at the type locality, thinning south to about 30 m on the south side of Fimbuldal and pinching out altogether a few kilometres south of this locality (Fig. 46). The formation appears to thicken northwards from the type section.

Lithology. The Holm Dal Formation forms recessive, dark weathering slopes between the terraced Fimbuldal Formation below and the pale weathering cliff-forming Perssuaq Gletscher Formation above (Fig. 22A). At the type section, it is dominated by thin, parallel-bedded and wavy-bedded, dark grey dolomites and lime mudstones with grey-green weathering, silty, calcareous mudstone partings and interbeds (Fig. 50). Parallel lamination is the dominant sedimentary structure and is defined locally by thin lenses and laminae (maximum thickness of 10 mm) of skeletal lime

Fig. 47. Platy nodular dolomites of the Fimbuldal Formation at the type section. Note the undulating bedding and local disruption of the nodular fabric.

Fig. 48. A limestone mass-flow breccia bed in the Fimbuldal Formation composed of dark lime mudstone clasts and large blocks of white ooid grainstone in a lime mudstone matrix. Hammer, centre left, for scale; south side of Fimbuldal, west Peary Land.

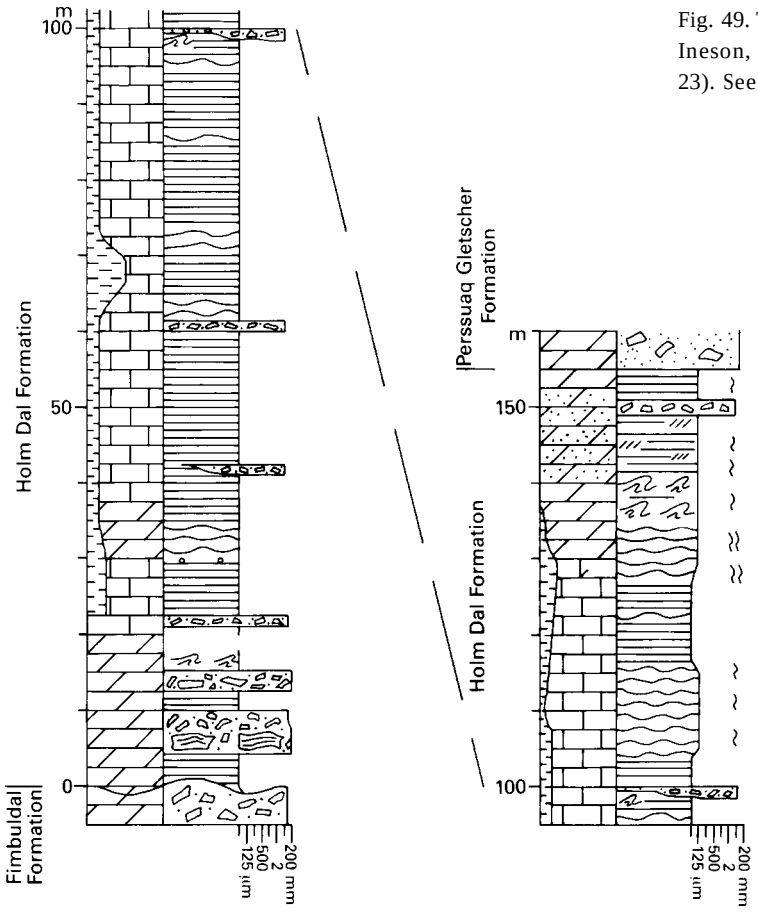


Fig. 49. Type section of the Holm Dal Formation (redrawn from Ineson, 1988), Gustav Holm Dal, west Peary Land (Figs 22A, 23). See Fig 14 for legend.

packstone and grainstone. About 1 km north of the type section, richly fossiliferous skeletal lime grainstones are associated with black phosphoritic layers near the base of the formation. Wavy-bedded peloidal and skeletal lime grainstones, packstones and wackestones become important in the upper third of the formation; they form a prominent bench approximately 110 m above the base of the formation (Fig. 49). The upper beds are dolomitised in the type section and include an interval of parallel-laminated and bioturbated, fine-grained, dolomitic sandstones which locally show small-scale cross-stratification and current-rippled bedding planes. Slumped, brecciated horizons and carbonate breccia beds up to 5 m thick occur frequently near the base and top of the formation. A detailed description of the sedimentology of the Holm Dal Formation was given by Ineson (1988).

Boundaries. The Holm Dal Formation overlies the Fimbuldal Formation with a sharp, but apparently conformable boundary (Figs 22A, 49). Along Gustav Holm Dal, this boundary undulates markedly with a relief of up to 5 m, but elsewhere it is planar.

The Holm Dal Formation is conformably overlain by the Perssuaq Gletscher Formation (Fig. 22A). At the type locality the boundary is placed where recessive laminated, dark sandy carbonates are abruptly overlain by a massive cliff-forming dolomite breccia bed (see Fig. 55). The boundary between these formations is, however, clearly diachronous on the scale of a fjord wall (see Fig. 19). Pale wedge-shaped units of dolomites and sandstones, assigned to the Perssuaq Gletscher Formation, thin northwards, interdigitating with dark thin-bedded carbonates (Fig. 19) and eventually pinch out into the underlying Holm Dal Formation. For mapping purposes, the zone of interdigitation is included in the Perssuaq Gletscher Formation.

Distribution. The formation crops out around the head of J. P. Koch Fjord in south-west Peary Land and westward across Freuchen Land to the glacier at the head of Navarana Fjord. It pinches out approximately 5 km south of the type section, and is not recognised south of the head of J. P. Koch Fjord (Figs 23, 46). The Holm Dal Formation is well exposed in the cliffs along J. P. Koch Fjord, Navarana Fjord and around the junction

Fig. 50. Thin-bedded argillaceous lime mudstones of the Holm Dal Formation in the type section; from Ineson (1988). Additional facies of this formation were illustrated by Ineson (1988).

of Fimbuldal and Gustav Holm Dal (Figs 19, 22A), but accessible exposures are rare, the type section being the most complete.

Fauna and age. Apart from the uppermost 30 m, this formation is richly fossiliferous, yielding a diverse fauna of agnostoid and other trilobites, molluscs and brachiopods (Robison, 1988; Hood & Robison, 1988; Peel, 1988c; Zell & Rowell, 1988; see also Bergström & Ineson, 1988). The trilobite fauna is dominated by polymeroids that are most characteristic of the lower and middle *Cedaria* Zone (early Dresbachian) as widely applied in North America. Agnostoid species are characteristic of the upper part of the *Lejopyge laevigata* Zone (Robison, 1988).

Perssuaq Gletscher Formation

new formation

History. This formation is equivalent to formations 3 and 4 of Peel (1979) and formation T3 of Ineson & Peel (1980). It is equivalent to Unit G of Dawes (1976b), at the southern end of Koch Væg.

Name. After Perssuaq Gletscher, a distributary of Hans Tavsen Iskappe, which flows west into J. P. Koch Fjord in south-west Peary Land (Figs 1, 23).

Type area and type section. East side of Gustav Holm Dal, south-west Peary Land (Figs 23, 51). The formation is poorly exposed in accessible terrain and lateral facies variation is great. Therefore, the formation is defined herein from a composite section made up of three sections along the east side of Gustav Holm Dal. Together, these sections illustrate the main features of the formation in the type area, but following Hedberg (1976), the most complete section (Fig. 51, section B) is designated the type section (holostratotype); the adjacent sections (Fig. 51, sections A and C) are thus reference sections (parastratotypes).

Thickness. Approximately 400 m at the type section (Fig. 51). The formation apparently thins northwards in Gustav Holm Dal, as the underlying Holm Dal Formation thickens, but exposures north and west of the type area are inaccessible, so an accurate measure is impossible.

At the south end of Koch Væg, the formation is 120–150 m thick (Fig. 46); comparable thicknesses are observed south of Navarana Fjord.

Lithology. The cliff-forming, yellow-brown weathering formation is composed of cross-bedded dolomites, dolomitic sandstones and silica-cemented sandstones (quartz arenites), interbedded with slumped intervals and breccia beds. At the type section, the lower half of the formation comprises fine- to medium-grained sandstones interbedded with breccia beds which range from 0.5 to 40 m in thickness. In the lower 100 m of the formation, the breccias are composed predominantly of dolomite, but quartz sand forms an increasing proportion of both matrix and clasts up-section (Fig. 52).

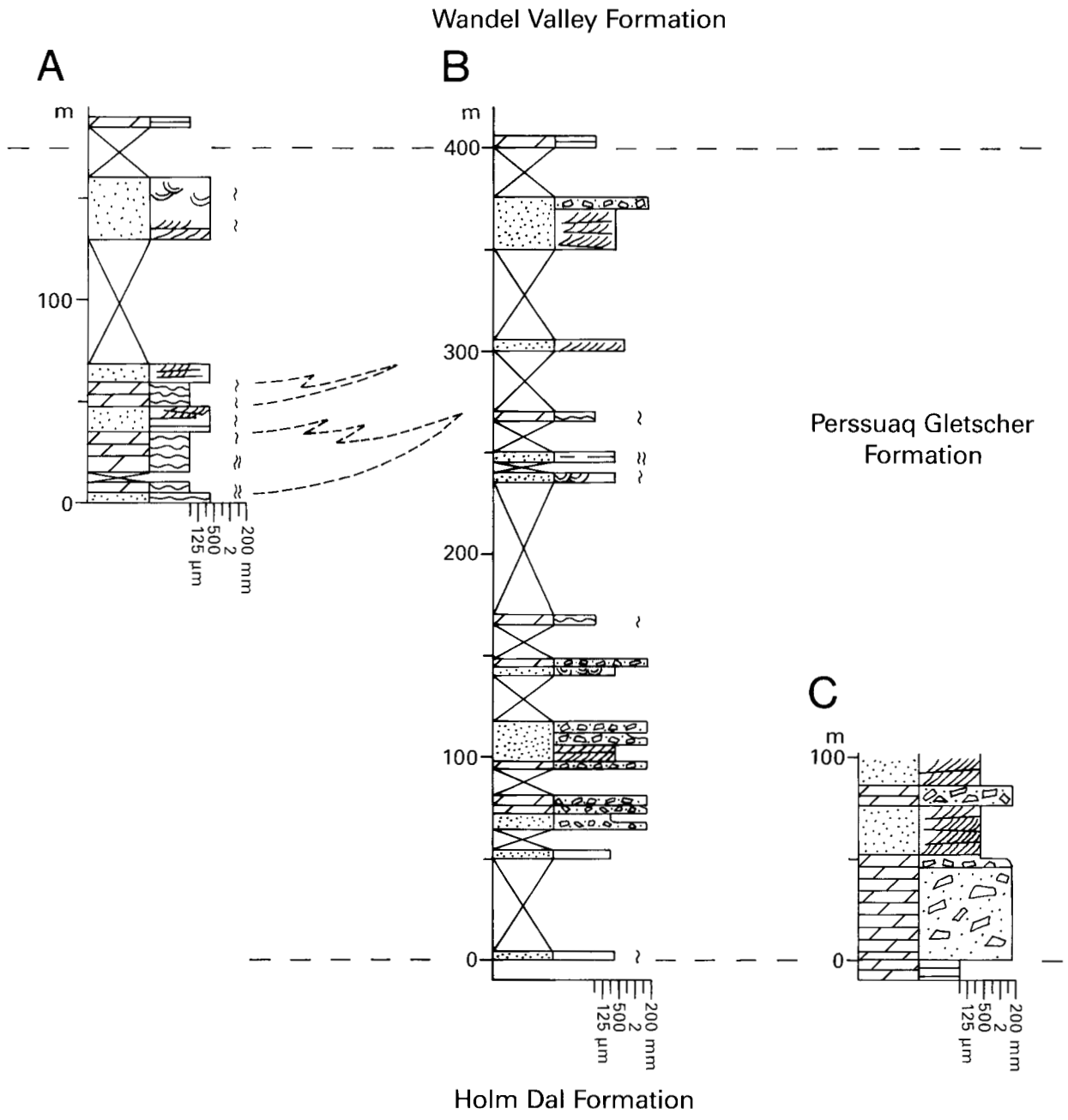


Fig. 51. Type (B) and reference (A, C) sections of the Perssuaq Gletscher Formation, Gustav Holm Dal, west Peary Land (Fig. 23). See Fig. 14 for legend.

The sandstones commonly show tabular and trough cross-bedding (0.1–1 m sets), convolute bedding and parallel lamination. Parallel-laminated and small-scale cross-bedded sandstones (Fig. 53), bioturbated dolomitic sandstones and burrow-mottled pale dolomites make up the upper half of the formation at the type locality. At the northern end of Gustav Holm Dal (Fig. 51), dark grey-brown weathering, wedge-shaped units of dark grey, thin, wavy-bedded silty dolomites are intercalated with the pale siliciclastic sediments that characterise the formation in the type area. The dark recessive units pinch out southwards so that they are not represented in the type section, but thicken markedly to the north with concomitant attenuation and eventual pinching out of the intercalated pale units, which locally show northward dipping clinoforms. This interdigitation and northward progradational pattern is well illustrated in the cliffs along J. P. Koch Fjord (Fig. 19).

South of the type area, the formation is composed

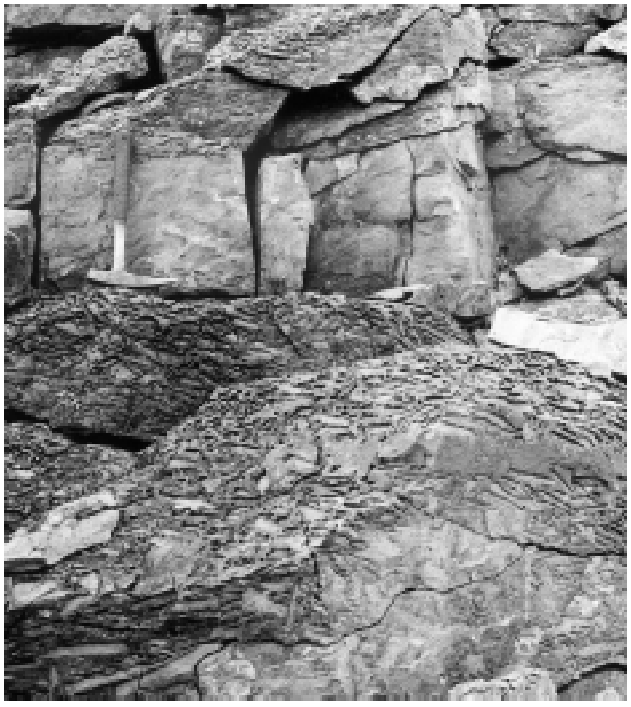


Fig. 52. Sandy dolomite mass-flow breccia beds in the type section of the Perssuaq Gletscher Formation. Note the abrupt grading into a structureless sandstone cap, succeeded above the hammer by the next coarse breccia bed.

of pale yellow, structureless or cross-bedded, medium to thick-bedded, medium-coarse crystalline dolomite, in which ooids and bioclasts are locally recognisable. Along Koch Væg, lenticular bodies of ooidal dolomite, intercalated with darker weathering dolomites, describe sigmoidal clinoforms dipping northwards at up to 30 degrees (Figs 10, 54, 100A).

Along the glacier flowing into the head of Navarana Fjord, the formation comprises an alternation of siliciclastic and carbonate units showing northward-dipping clinoform bedding (Fig. 22B); these accessible sections are analagous to the vertical cliff sections along J. P. Koch Fjord (Fig. 19). The carbonate units (2–10 m thick) comprise light-coloured, bioturbated dolomites and thrombolitic mounds. Siliciclastic units, dominated by well-sorted, fine-grained sandstones (quartz arenites), are up to 40 m thick and consist of matrix-rich conglomerates, trough cross-bedded, laminated and bioturbated sandstones (Surlyk & Ineson, 1987).

Boundaries. North of the head of J. P. Koch Fjord, the formation conformably overlies the Holm Dal Formation (Figs 22A, 46). The boundary is poorly exposed at the type section and is defined in the reference section at the south-east corner of Gustav Holm Dal (Fig. 51C), where cliff-forming dolomite breccias rest with a sharp planar contact on dark recessive laminated dolomites of the underlying Holm Dal Formation (Fig. 55). The Perssuaq Gletscher Formation interfingers with the Holm Dal Formation as described previously and, for mapping purposes, the zone of interdigitation is included in the Perssuaq Gletscher Formation (Fig. 19).

South of the head of J. P. Koch Fjord, the Holm Dal Formation is not recognised and the Perssuaq Gletscher Formation conformably overlies the Fimbuldal Formation (Fig. 46). At the southern end of Koch Væg, dark thin-bedded dolomites assigned to the Fimbuldal Formation are overlain by pale ooidal dolomite of the Perssuaq Gletscher Formation. The change is gradational, the two rock types being interbedded over a 10 m interval. The boundary is placed at the base of the first discrete pale bed of ooidal dolomite.

To the north of Troelsen's Fault (Fig. 23), the formation is unconformably overlain by Lower – Middle Ordovician dolomites of the Wandel Valley Formation. The contact is rarely exposed in accessible sections, and even in cliff sections, the unconformity is commonly delineated by a recessive, scree-covered ledge (Fig. 19). The boundary is apparently sharp and planar and, although bedding is commonly sub-parallel, an angular discordance of up to 15 degrees can be observed locally where the underlying Perssuaq Gletscher sediments exhibit depositional dips (Fig. 19).

Fig. 53. Medium-grained sandstones of the Perssuaq Gletscher Formation showing tabular cross-bedding in sets 5–10 cm thick. Gustav Holm Dal, west Peary Land.

Fig. 54. Northward prograding platform margin carbonates of the Perssuaq Gletscher Formation (PG) along Koch Væg on the east side of Henson Gletscher. The Perssuaq Gletscher Formation is abruptly overlain by platform interior carbonates of the Koch Væg Formation (KV) which in turn is overlain unconformably by the Wandel Valley Formation (W; both Ryder Gletscher Group). Cliff height *c.* 600 m. From Higgins *et al.* (1991a).

To the south of Troelsen's Fault, the cliff-forming thick-bedded dolomites of the Perssuaq Gletscher Formation are overlain conformably by recessive pale weathering dolomites, argillaceous dolomites and sandstones of the Koch Væg Formation (Figs 46, 54). The boundary is readily defined in cliff section (see Fig. 54), but where accessible at the south end of Koch Væg, the boundary is poorly exposed, being placed broadly where cross-stratified ooidal and sandy dolomites give way to faintly laminated and burrow-mottled dolomites. At the type section of the Koch Væg Formation (Fig. 23; see Ryder Gletscher Group), the boundary is placed at the change from pale to dark weathering dolomites which approximately corresponds to the break in slope.

Distribution. The Perssuaq Gletscher Formation is restricted to south-west Peary Land and Freuchen Land, west of Hans Tavsen Iskappe. It crops out along Navarana Fjord, south J. P. Koch Fjord and Henson Gletscher (Figs 2, 23) and extends east to the western margin of Hans Tavsen Iskappe. The Perssuaq Gletscher Formation is exposed in excellent cliff sections along the fjords and along Henson Gletscher, but accessible sections with adequate exposure are scarce. It is best examined in Gustav Holm Dal, along the southern edge of Koch Væg and on the western side of the glacier flowing north into Navarana Fjord.

Fauna and age. The formation is characteristically unfossiliferous, but mottled dolomites near the top of the formation in southern Gustav Holm Dal yielded a poorly silicified fauna of tergomyan (cf. *Proplina*) and hyperstrophic onychochilacean molluscs (Ineson & Peel, 1980), a fauna that supports the general Late Cambrian age suggested on stratigraphic grounds in the type area. Simple conodonts including *Hirsutodontus hirsutus* have been obtained from dark dolomites at

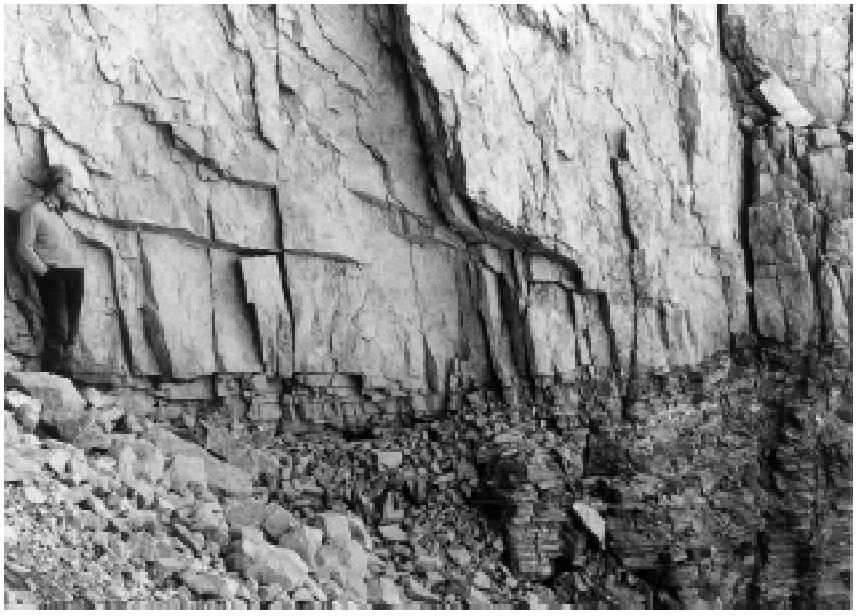


Fig. 55. Abrupt boundary between thin-bedded dark dolomites of the uppermost Holm Dal Formation in its type section and massive pale dolomites of the overlying Perssuaq Gletscher Formation (reference section A, Fig. 51). From Ineson (1988).

the north end of Gustav Holm Dal, indicating a latest Cambrian or earliest Ordovician age (Miller *in* Peel, 1982a; Smith & Bjerreskov, 1994). The strongly progradational pattern of sedimentation exhibited by this formation in this area (see Fig. 19) indicates that the uppermost strata of the formation north of Gustav Holm Dal are most likely of Early Ordovician age.

The age of the formation south of Troelsen's Fault is less certain. At the south end of Koch Væg, the youngest Cambrian faunas obtained are of medial Middle Cambrian age from the Ekspedition Bræ Formation of the Brønlund Fjord Group (Palmer & Peel, 1979). It can be demonstrated in northern exposures that the base of the Perssuaq Gletscher Formation is strongly diachronous from south to north (Figs 8, 10) and thus, although the formation is largely of Late Cambrian age in the type area, it may be wholly of Middle Cambrian age in southern exposures.

Løndal region

The Løndal region, as employed here, extends east from Hans Tavsen Iskappe across Løndal and western Erlandsen Land to the major valley north of the eastern end of Øvre Midsommersø (Figs 2, 16, 56–58). Within this region, the Brønlund Fjord Group conformably overlies the Buen Formation and is represented by the Aftenstjernesø, Henson Gletscher, Sydpasset and Ekspedition Bræ Formations, as defined above from the Henson Gletscher region. The succeeding Tavsens Iskappe Group comprises three new formations: the Lønelv, Erlandsen Land and Løndal Formations. The Tavsens Iskappe Group is unconform-ably overlain by the Wandel Valley Formation (late Early – Middle Ordovician). Two formations, the Ekspedition Bræ Formation of the Brønlund Fjord Group and the Lønelv Formation of the Tavsens Iskappe Group, are only recognised in the western part of the area, in Løndal itself (Figs 26, 46, 57).

Brønlund Fjord Group

This group in the Løndal region is closely comparable to that of the reference area (Henson Gletscher region) and the constituent formations are readily recognised (Figs 26, 58). The total thickness of the group is 152 m, measured on the west side of Løndal.

Aftenstjernesø Formation

The formation is about 40 m thick in this area. It comprises a fawn to grey-brown weathering succession of dolomitised carbonate turbidites and nodular dolomites, capped by a distinctive 5 m thick mass-flow breccia bed that is locally composite (see Ineson, 1985). Of particular note in this area is the local preservation of about 2 m of only partially dolomitised or undolomitised glauconitic skeletal lime grainstones, packstones and bioturbated wackestones at the base of the formation (Frykman, 1980).

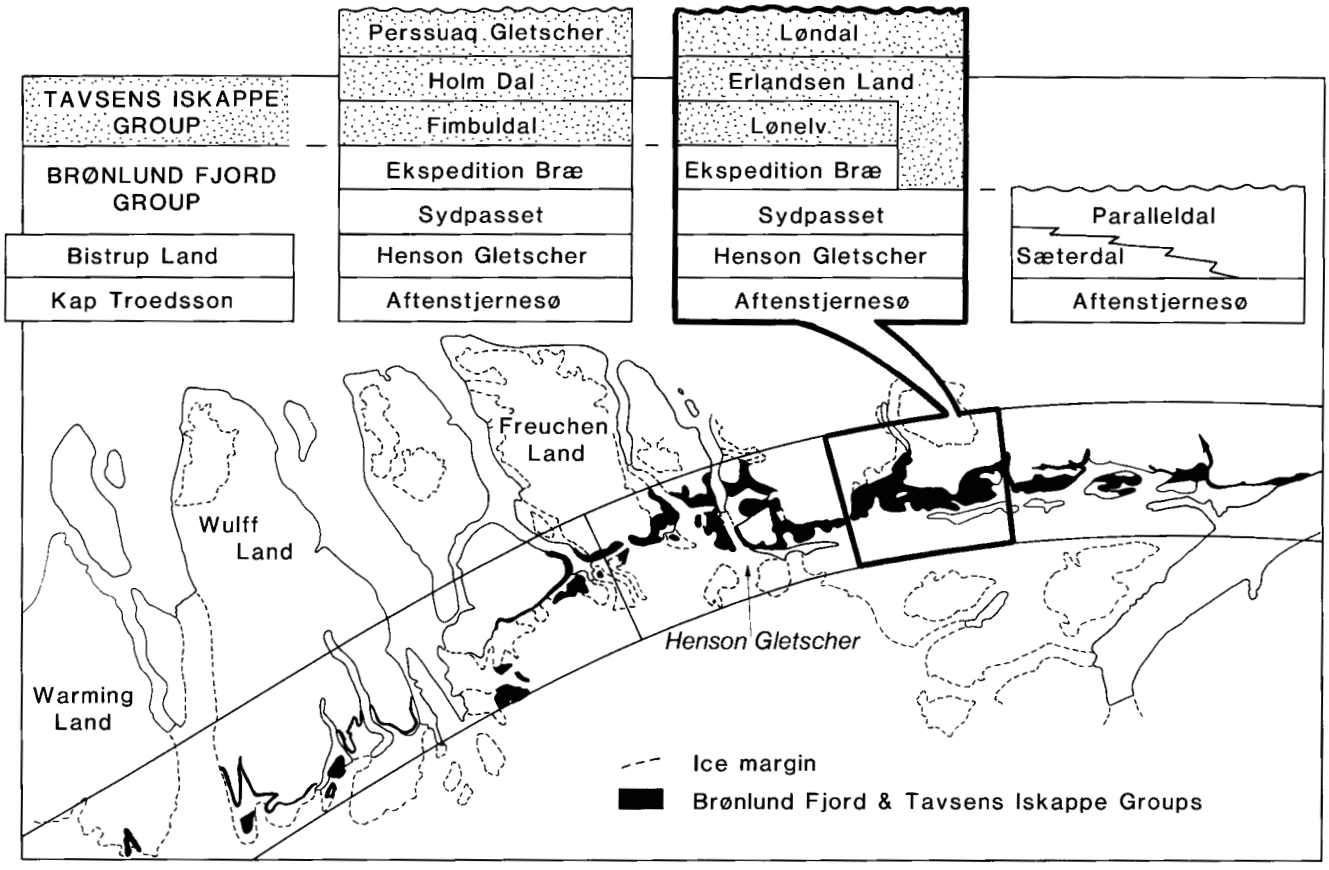


Fig. 56. Map showing the location and stratigraphy of the Løndal region in relation to the remainder of the southern outcrop belt of the Tavsens Iskappe and Brønlund Fjord Groups.

Henson Gletscher Formation

The Henson Gletscher Formation is 45.5 m thick on the western bank of Lønelv and it shows a comparable tripartite division to that seen in the type section. Argillaceous carbonates at the top and base of the formation are separated by a pale weathering siliciclastic sand-rich interval, 22 m thick. The lower carbonate interval includes two highly fossiliferous coarsening-upwards cycles, 2–2.5 m thick, that grade up from laminated, black lime mudstones through bioturbated wavy-bedded lime mudstones and wackestones to coarse, glauconitic, skeletal grainstones and packstones containing abundant trilobites of Early Cambrian age. Blaker (1991) has described 11 species of trilobites from these beds, including *Bonnia brennus, Kootenia marcoui, Lancastria plana, Ogygopsis batis, O. typicalis, Olenellus* cf. *O. truemani, Pagetides elegans* and *Peronopsis roddyi*.

Phosphatised wackestones at the top of the formation, immediately below the Sydpasset Formation, yield agnostoid and molluscan faunas of Middle Cambrian age, with abundant stenothecoids and helcionelloids such as *Latouchella* and *Protowenella*.

Sydpasset Formation

The Sydpasset Formation is about 35 m thick in Løndal. The lower half is composed of dolomitic limestones showing spectacular platy and fibrous nodular forms; these are particularly well displayed along the western banks of Lønelv. Two thick dolomitised breccia beds make up the upper 17 m of the formation.

Ekspedition Bræ Formation

The Ekspedition Bræ Formation is 30 m thick in Løndal and comprises wavy and parallel-bedded argillaceous, fossiliferous lime mudstones that are locally slumped and partially disaggregated; clast-rich limestone breccia

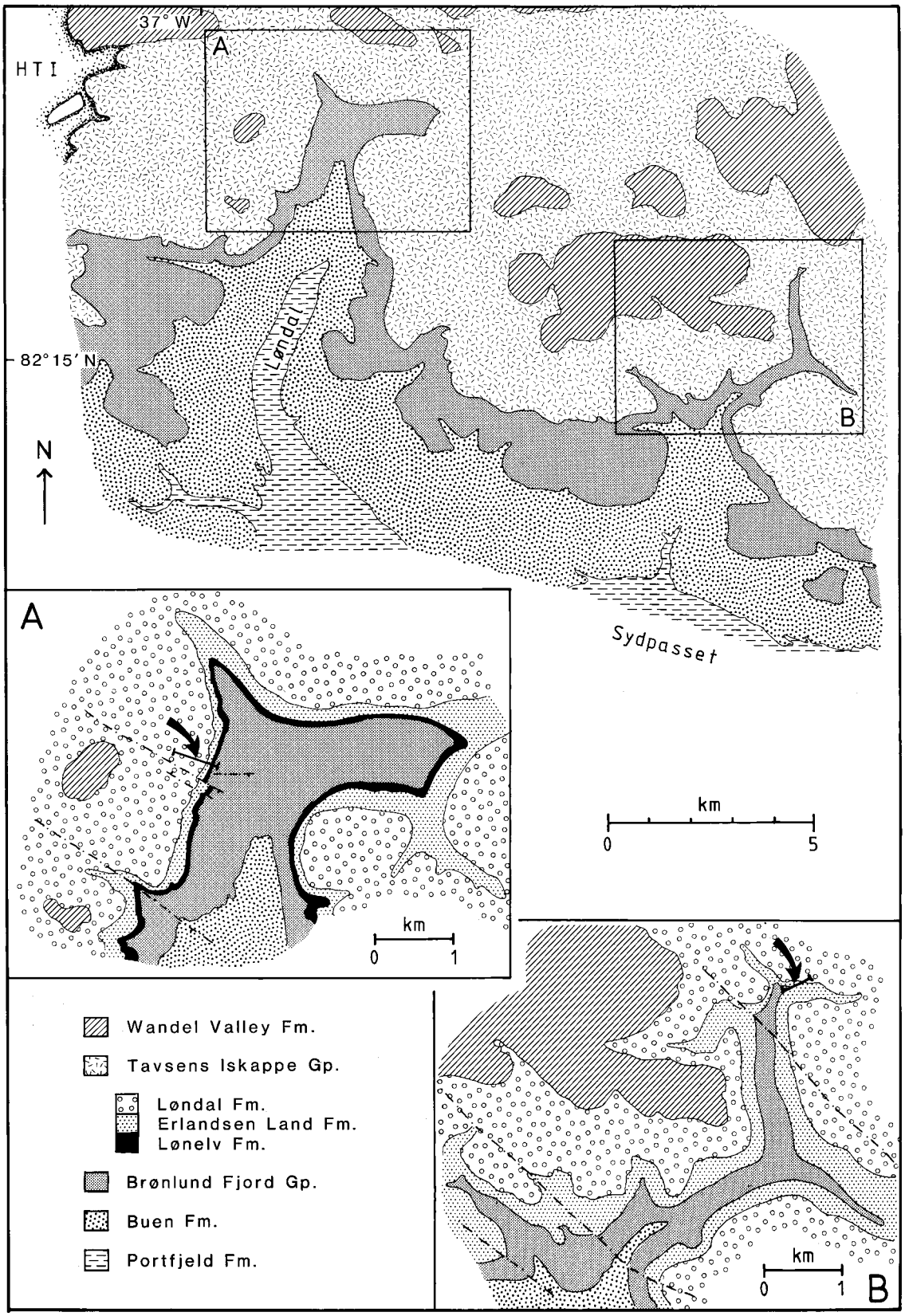


Fig. 57. Geological sketch map of the Løndal region, southern Peary Land showing the distribution of the Brønlund Fjord and Tavsens Iskappe Groups. Inset A shows the location of the type sections of the Lønelv, Erlandsen Land and Løndal Formations on the west side of Løndal; the reference section of the Erlandsen Land Formation is shown on inset B. HTI, Hans Tavsen Iskappe.

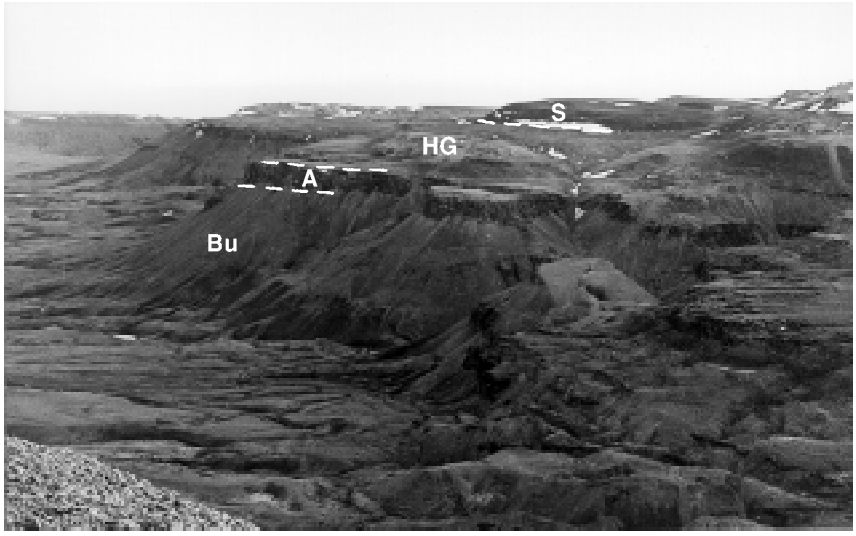


Fig. 58. Cambrian strata on the west side of Løndal, south-west Peary Land, viewed towards the south-west. The largely scree-covered Buen Formation (Bu) is succeeded by the distinctive terraces of the Brønlund Fjord Group (A, Aftenstjernesø Formation; HG, Henson Gletscher Formation; S, Sydpasset Formation).

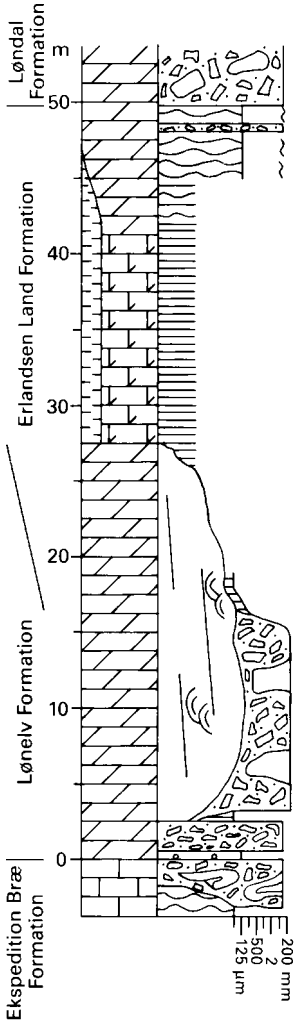


Fig. 59. Type sections of the Lønelv and Erlandsen Land Formations, north-west Løndal, southern Peary Land (Figs 56, 57, 60). Note that the top of the Lønelv Formation is highly irregular; large protruding blocks often display bedding at high angles to the regional dip. See Fig. 14 for legend.

beds occur at several levels in the formation. The Ekspedition Bræ Formation is not recognised east of the point in western Erlandsen Land where the Lønelv Formation of the Tavsens Iskappe Group pinches out (see Figs 46, 56 and definition of Ekspedition Bræ Formation).

Tavsens Iskappe Group

The Tavsens Iskappe Group in the Løndal region has a total thickness of about 300 m. Although biostratigraphic data are few, the Lønelv and Erlandsen Land Formations are thought to be roughly equivalent to the upper Ekspedition Bræ Formation (Brønlund Fjord Group) in the Henson Gletscher region (Figs 5, 8) whereas the Løndal Formation probably equates to the Fimbuldal and Holm Dal Formations.

Lønelv Formation

new formation

History. Previously described informally as formation T5 of the Tavsens Iskappe Group (Ineson & Peel, 1980).

Name. After Lønelv, the south-flowing river near the south-eastern margin of Hans Tavsen Iskappe, south-west Peary Land (Figs 2, 57).

Type section. Fig. 59; west side of Løndal, south-west Peary Land (Figs 2, 57, 60).

Thickness. 15–30 m at the type locality. The top of the

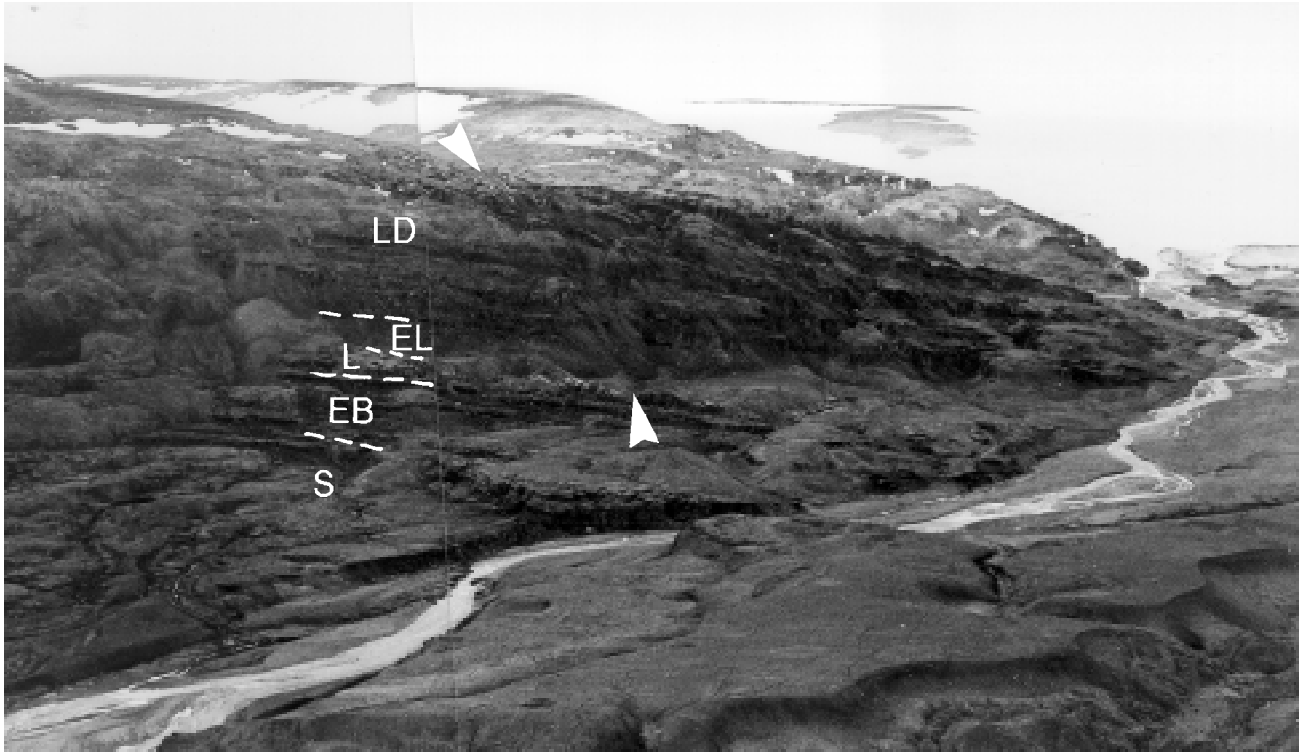


Fig. 60. Cambrian strata on the west side of the western tributary of Lønelv, looking northwards to the south-eastern margin of Hans Tavsen Iskappe. The Sydpasset (S) and Ekspedition Bræ (EB) Formations of the Brønlund Fjord Group are overlain by the Lønelv (L), Erlandsen Land (EL) and Løndal Formations (LD) of the Tavsens Iskappe Group. The type sections of the latter three formations were measured up the central gully (arrows).

formation is locally highly irregular, but the formation is estimated to have an average thickness of 15–20 m. It thins and pinches out completely about 9 km south-east of the type locality (Figs 46, 57).

Lithology. The pale yellow or cream weathering dolomites of the Lønelv Formation form prominent crags between the recessive Ekspedition Bræ and Erlandsen Land Formations (Fig. 60). At the type section, the formation is apparently composed of two separate breccia beds, sandwiching a thin interval (0.1–2 m) of thin-bedded, parallel-laminated, dark grey, medium crystalline dolomite, which is commonly distorted and locally absent (Figs 59, 61). Lateral exposure is limited, however, and the bedded interval may equally represent a rafted slab within a single thick debris bed. A thin interval (*c.* 0.5 m) of medium- to thick-bedded, pale, faintly laminated and graded dolomite is present at the base of the formation at the type section. The breccia beds are composed mainly of elongate or equidimensional, angular to sub-rounded clasts of pale, medium-coarse crystalline dolomite which locally shows cross-stratification, 'ghost' ooids and a crude bedding which is often at high angles to true bedding (Fig. 59). Elongate, folded, dark grey dolomite slabs form a minor proportion of the clasts. The pale clasts range from a few centimetres in diameter to huge blocks, 30 m across, which locally protrude up to 12 m from the top of the upper breccia bed, producing the irregular top of the Lønelv Formation (Figs 59, 60).

Boundaries. The Lønelv Formation conformably overlies the Ekspedition Bræ Formation with a sharp planar contact. At the type section, the lower boundary is placed where cliff-forming pale weathering dolomites overlie the uppermost limestone breccia bed of the Ekspedition Bræ Formation (Fig. 59).

The Lønelv Formation is overlain, apparently conformably, by the Erlandsen Land Formation. The boundary is sharp and locally irregular, with a relief of 12 m at the type section. Dark grey, recessive weathering, thin-bedded dolomites drape the upper pale breccia of the Lønelv Formation.

Distribution. The formation is only recognised on the east side of Hans Tavsen Iskappe in the vicinity of Løndal (Figs 46, 57). It crops out from the margin of the icecap, east into Løndal and pinches out approxi-

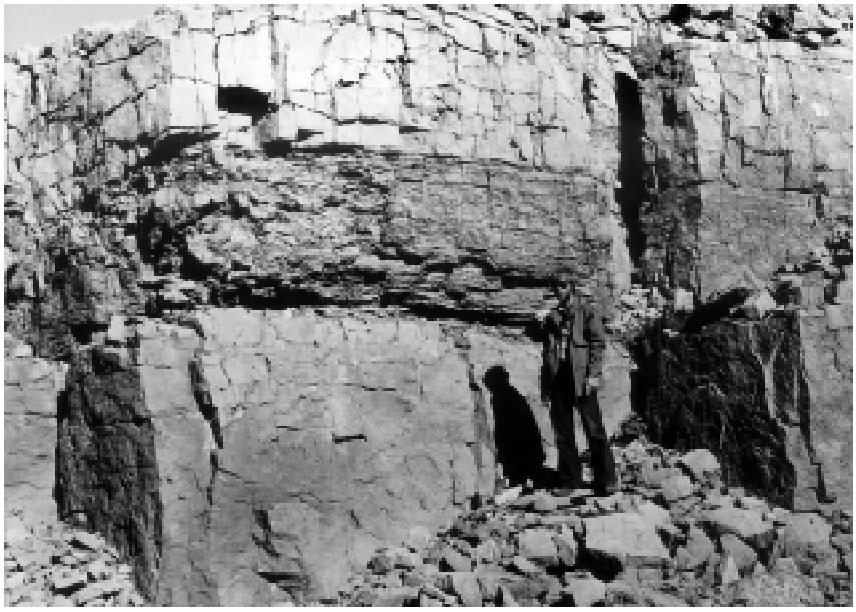


Fig. 61. Lønelv Formation in the type section showing disrupted thin-bedded dolomites (a clast?) sandwiched between pale structureless mass-flow carbonate breccia.

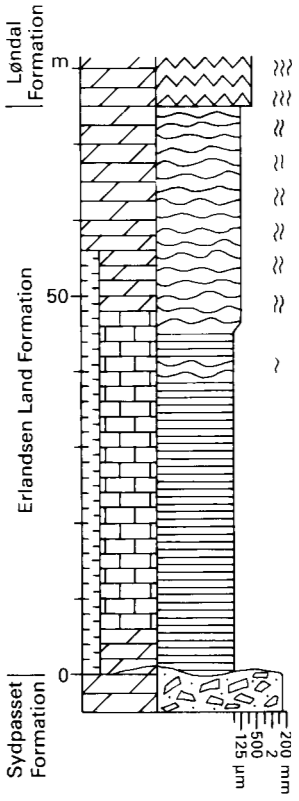


Fig. 62. Reference section of the Erlandsen Land Formation, east of Løndal, southern Peary land (Figs 56, 57, 63). See Fig. 14 for legend.

mately 9 km south-east of the type section. It is best exposed along the west side of Løndal.

Fauna and geological age. Fossils have not been found in the Lønelv Formation, but the formation is considered to be of medial Middle Cambrian age on account of its stratigraphic position between the Ekspedition Bræ and Erlandsen Land Formations, both of which yield medial Middle Cambrian faunas.

Erlandsen Land Formation

new formation

History. This formation has been informally described as formation T6 of the Tavsens Iskappe Group (Ineson & Peel, 1980).

Name. After Erlandsen Land, south central Peary Land (Fig. 2).

Type section. Fig. 59; west side of Løndal, south-west Peary Land (Figs 57, 60).

Reference section. Fig. 62; east side of narrow valley, 13 km east of type section (Figs 57, 63).

Thickness. The formation varies from 22–33 m at the type locality. The base is highly irregular at the type locality and consequently the thickness of the formation is variable, but it is estimated to have an average thickness of 25 m in Løndal. At the reference section,

the Lønelv Formation is not recognised and beds assigned to the Erlandsen Land Formation conformably overlie the Sydpasset Formation and attain a thickness of 75 m (Figs 46, 62, 63).

Lithology. The Erlandsen Land Formation is characterised by dark grey to yellow-brown weathering, thin-bedded carbonates forming recessive slopes between the cliff-forming formations above and below (Figs 60, 63). At the type locality, the basal beds are parallel-laminated and bioturbated, dark grey, fine to medium crystalline, calcareous dolomites with argillaceous partings. These pass up into thin, parallel-bedded, argillaceous lime mudstones that show faint parallel lamination, locally defined by skeletal packstone and grainstone laminae. The middle part of the formation is poorly exposed at the type section, and the lithological data were obtained from frost-heaved blocks and float. Fine to medium crystalline dolomites at the top of the formation exhibit thin, irregular wavy bedding (Fig. 59) and a discontinuous wispy lamination and faint mottling attributable to bioturbation. A thin (0.5 m), clast-supported breccia bed near the top of the formation in the type section is composed of tabular, dark grey dolomite clasts (average dimensions 3 × 10 cm) in an argillaceous dolomite matrix.

The Erlandsen Land Formation is lithologically uniform east of the type locality. In the ravine north of Øvre Midsommersø it comprises a thick succession of thin, parallel-bedded, argillaceous lime mudstones (Fig. 64) and platy or wavy bedded, bioturbated dark grey dolomites.

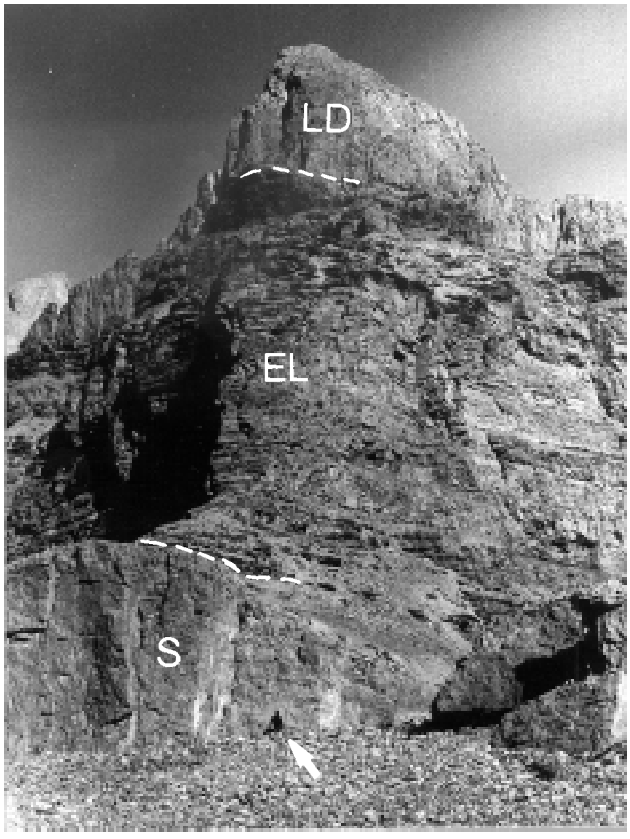


Fig. 63. The Erlandsen Land Formation (EL) in the reference section (Fig. 62), comprising thin-bedded argillaceous carbonates sandwiched between pale cliff-forming dolomites of the Sydpasset (S; Brønlund Fjord Group) and Løndal (LD) Formations. Figure (arrowed) for scale.

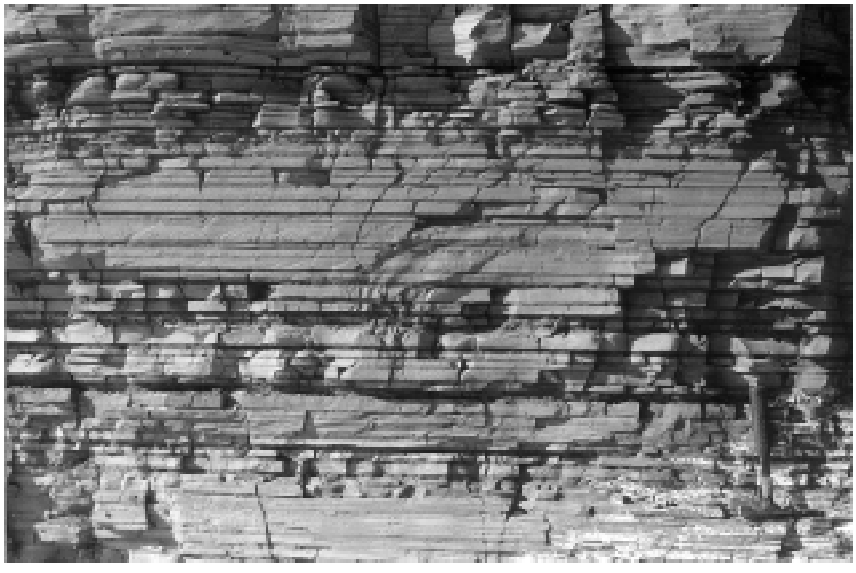


Fig. 64. Thin, parallel-bedded lime mudstones with calcareous mudstone partings; Erlandsen Land Formation, reference section.

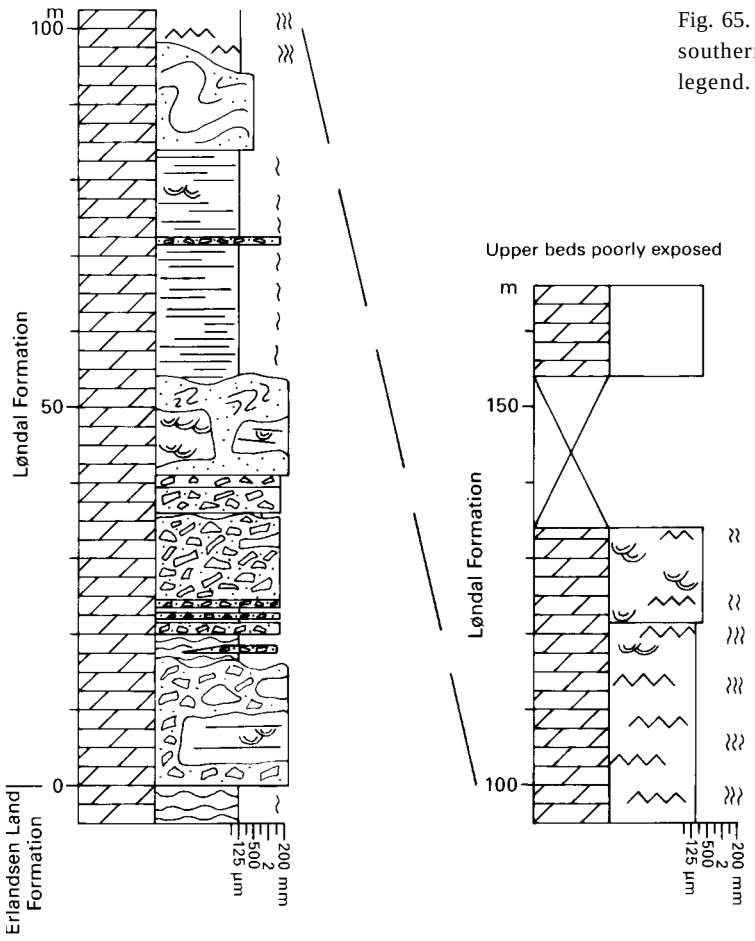


Fig. 65. Type section of the Løndal Formation, Løndal, southern Peary Land (Figs 56, 57, 60). See Fig. 14 for legend.

Boundaries. At the type section, the base of the formation is sharp but highly irregular; it overlies the Lønelv Formation with apparent conformity. The boundary is placed where the pale weathering, massive dolomites of the Lønelv Formation are overlain by thin-bedded, dark grey dolomites. The Lønelv Formation pinches out approximately 9 km south-east of the type section (Fig. 46), and the carbonates of the Ekspedition Bræ and Erlandsen Land Formations coalesce into one indivisible succession of dark weathering, recessive, thin-bedded carbonates which conformably overlies the Sydpasset Formation. These strata are assigned to the Erlandsen Land Formation, and consequently the Ekspedition Bræ Formation is not recognised to the east of this point, and the Erlandsen Land Formation of the Tavsens Iskappe Group conformably overlies the Sydpasset Formation of the Brønlund Fjord Group (Figs 5, 46, 56). The boundary is sharp and often hummocky and is placed where platy, dark grey, recessive weathering dolomites overlie pale cream weathering, cliff-forming dolomites of the upper Sydpasset Formation (Fig. 63).

The Erlandsen Land Formation is conformably overlain by the Løndal Formation. In the type section, the boundary is sharp and planar where the upper wavy bedded dolomites are abruptly overlain by a massive, grey-brown weathering dolomite breccia bed (Fig. 59). At the reference section, the boundary is placed at the break of slope, where thin, wavy bedded dark grey dolomites are overlain by yellow-brown weathering, cliff-forming dolomites showing faint sub-horizontal burrow-mottling (Figs 62, 63).

Distribution. The formation is recognised east of Hans Tavsen Iskappe and it crops out from the eastern margin of the ice cap, east across Erlandsen Land to the limit of outcrop of the Tavsens Iskappe Group, about 8 km north of the eastern end of Øvre Midsommersø (Fig. 56).

Exposure is poor in central Erlandsen Land with the best exposed areas being around Løndal; accessible sections with reasonable exposure are obtainable at the type and reference localities (Fig. 57).

Fig. 66. Large-scale lenticular packaging of strata within the Løndal Formation, north of the type section. Viewed towards the south, this represents a strike section through northward-prograding platform foreslope deposits and illustrates the lenticular nature of individual prograding lobes. Section illustrated is about 200 m thick.

Fauna and age. Fossils are locally abundant and these include brachiopods, molluscs and trilobites, indicative of a medial Middle Cambrian age (Palmer & Peel, 1979; R. A. Robison, written communication, 1981).

Løndal Formation

new formation

History. The Løndal Formation has been informally described as formation T7 of the Tavsens Iskappe Group (Ineson & Peel, 1980).

Name. After Løndal, the north–south valley near the eastern margin of Hans Tavsen Iskappe, south-west Peary Land (Figs 2, 57).

Type section. Fig. 65; on the west side of Løndal, south-west Peary Land (Figs 57, 60).

Thickness. Approximately 250 m at the type section. The upper third of the formation is poorly exposed at the type section and the thickness given is an estimate.

Lithology. The Løndal Formation is composed of cliff-forming dolomites showing pale yellow, golden brown and dark grey-brown weathering colours. At the type section (Fig. 65), the lower 50 m of the formation is dominated by dolomite breccia beds interbedded with dark grey, bituminous, thin-bedded and parallel-laminated dolomites. The breccia beds range from 0.5 m to 30 m in thickness and are composed of a mixture of tabular, dark, laminated clasts and boulders and slabs of pale yellow weathering ooidal and coarse crystalline dolomite in a darker dolomite matrix. The basal breccia bed is variable in thickness laterally and locally contains huge pale dolomite slabs up to 100 m across.

The breccia-dominated basal unit is overlain by a succession of thin-bedded, yellow-brown weathering, medium to fine crystalline dolomites; pale laminae and thin graded beds (5–20 cm thick) alternate with darker grey-brown weathering dolomite. Bioturbation increases up the formation and the thin-bedded and laminated dolomites give way to grey-brown weathering, mottled, medium-bedded to thick-bedded dolomites in which lamination is commonly absent or discontinuous.

Pale cream weathering, medium to coarse crystalline dolomites are common near the middle, and they dominate the upper half of the Løndal Formation in the type section. They are commonly medium-bedded and structureless, but slumped beds, intraclastic, oncolitic and ooidal horizons and cross-bedding are recognisable locally.

Lateral facies variation in the Løndal Formation is clearly evident in Løndal. To the north of the type section, the pale dolomites (above 70 m in the type section) interdigitate with dark, grey-brown weathering, bioturbated dolomites which form a progressively larger proportion of the formation in northern Løndal. Figure 66 illustrates the 3-dimensional complexity of this transition. This south-to-north facies variation is recognisable throughout the outcrop area, the more southerly exposures showing a dominance of pale weathering ooidal dolomites whereas, in northern exposures, the Løndal Formation is dominated by darker weathering dolomites which include bioturbated do-

lomites, parallel-laminated, graded dolomites and dolomite breccia beds.

Boundaries. The cliff-forming Løndal Formation conformably overlies the recessive and dark weathering carbonates of the Erlandsen Land Formation. At the type locality, the base is sharp and planar and is placed where wavy-bedded, dark grey dolomites are overlain by a prominent dolomite breccia bed (Fig. 65). To the east, at the reference locality of the Erlandsen Land Formation, the base of the Løndal Formation is defined at the change in weathering colour and break of slope, where yellow-brown weathering, medium-bedded, burrow-mottled dolomites overlie thin, wavy-bedded dark grey dolomites (Figs 62, 63).

The Løndal Formation is overlain unconformably by the Wandel Valley Formation. The upper beds of the formation are poorly exposed throughout Erlandsen Land, however, and the unconformity has not been observed in detail. The upper beds of the Løndal Formation are pale weathering dolomites, which are grossly similar to the overlying Wandel Valley Formation, so the boundary is often difficult to locate in poor exposure. The unconformable nature of the boundary is thus not demonstrable but is assumed by correlation with adjacent areas (Figs 5, 46).

Distribution. The formation crops out from the eastern margin of Hans Tavsen Iskappe, east across Erlandsen Land to the eastern limit of the Tavsens Iskappe Group, north of the eastern end of Øvre Midsommersø (Figs 2, 56). It is best exposed and accessible along the west side of Løndal and in the ravine at the reference section of the Erlandsen Land Formation (Fig. 57).

Fauna and age. The Løndal Formation is generally unfossiliferous, but dark dolomites near its base yield phosphatic brachiopods which resemble the Middle Cambrian acrotretid *Prototreta* (A. R. Palmer, written communication 1979). On the basis of this meagre fauna and the stratigraphic position, a late Middle Cambrian age is indicated, although the upper beds may be of early Late Cambrian age.

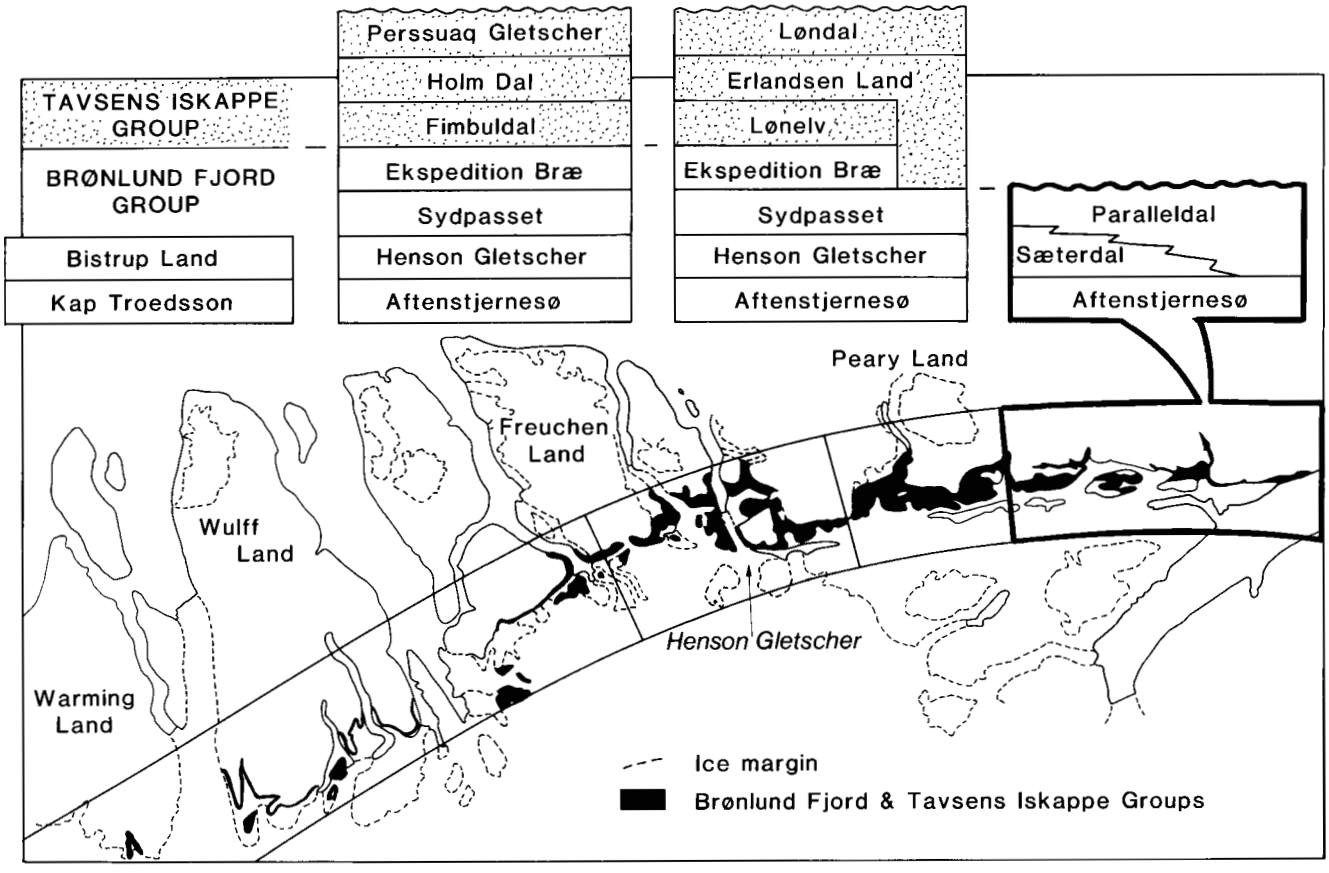


Fig. 67. Map showing the location and stratigraphy of the Paralleldal region in relation to the remainder of the southern outcrop of the Brønlund Fjord Group.

Paralleldal region

This region extends from the eastern end of Øvre Midsommersø to the shores of Independence Fjord (Figs 2, 67). In this area, the Brønlund Fjord Group conformably overlies the Buen Formation (Early Cambrian) and is overlain unconformably by the Wandel Valley Formation (late Early – Middle Ordovician) of the Ryder Gletscher Group; the Tavsens Iskappe Group is not represented. The Brønlund Fjord Group in this region consists of the Aftenstjernesø, Sæterdal and Paralleldal Formations; the Sæterdal Formation is recognised only in the western part of the Paralleldal region (Figs 5, 26, 67, 68).

Brønlund Fjord Group

On the north side of Paralleldal, at the type section of the Paralleldal Formation, the Brønlund Fjord Formation is 215 m thick; the group thins both southwards and eastwards to the mouth of Børglum Elv, the type area, where the group is about 175 m thick.

Aftenstjernesø Formation

The formation thickens eastward from 27–40 m in Sæterdal and western Paralleldal to *c.* 130 m at Børglum Elv (Figs 26, 68). In western Paralleldal, north of Frysefjeld, the formation has a distinctive banded appearance, made up of a thin, basal, yellow-brown stripe, a middle, dark grey-brown weathering dolomite interval and an upper pale cream weathering unit. The basal pale weathering unit (*c.* 2 m thick) consists of nodular, argillaceous skeletal dolomites, typically containing detrital glauconite and phosphorite, and black phosphorite seams (Member A of Christie & Peel, 1977; fossils from this interval were noted by Peel *et al.*, 1974; Palmer & Peel, 1979; Bendix-Almgren & Peel, 1988). The succeeding beds are thin, parallel-bedded, mid to dark grey dolomites, locally displaying grading, interbedded with nodular dolomites showing irregular, amoeboid and burrow-shaped nodule forms. A clast-supported breccia bed (1–12 m thick) occurs at the top of the formation in many sections.

Similar facies form the thickened Aftenstjernesø Formation in the Børglum Elv valley, where the formation is dominated by a highly distinctive, thick breccia bed that immediately overlies the phosphoritic nodular dolomites ('Member A') at the base of the formation. This breccia bed is thickest at the mouth of Børglum Elv (30–40 m) and it thins north and west, wedging out between the western end of Buen and Frysefjeld (Fig. 68). The breccia is typically clast-supported, composed of tabular and irregular, nodular clasts of coarse pebble to cobble grade (see Christie & Peel, 1977, Fig. 8). It also includes large, pale dolomite blocks several tens of metres across which commonly protrude from the top of the breccia bed; they are draped by darker, thin-bedded dolomite, producing the hummocky, billowing surface that is so conspicuous in the cliffs around the mouth of Børglum Elv and north of Jørgen Brønlund Fjord (Figs 3, 17).

Sæterdal Formation

new formation

History. The formation has been referred to informally as formation 5 of the Brønlund Fjord Group (Palmer & Peel, 1979; Ineson & Peel, 1980).

Name. After Sæterdal, central southern Peary Land, the north-east to south-west trending valley that meets Wandel Dal at the eastern end of Nedre Midsommersø (Figs 2, 68).

Type section. Fig. 69; the type section is on the east side of a steep stream valley (Fig. 70) entering the north-western side of Sæterdal (Fig. 68).

Thickness. Approximately 130 m at the type section (Fig. 69), thinning west along the north side of Wandel Dal to the western limit of the formation, north of the eastern end of Øvre Midsommersø (Fig. 67). The Sæterdal Formation thins rapidly east and south of the type section, eventually pinching out about 18 km east of the type locality (Figs 26, 68).

Lithology. The siliciclastic-dominated Sæterdal Formation forms banded recessive slopes between the cliff-forming carbonate formations above and below (Fig. 30). At the type section (Fig. 69), units dominated by cream weathering, thin-bedded to thick-bedded, fine-grained sandstones alternate with dark, recessive units dominated by parallel-laminated, ripple cross-laminated and bioturbated siltstones and silty sandstones. The pale sandstones are well-sorted, although locally containing shell fragments and outsize siltstone clasts. They form laterally persistent beds, 0.1–1 m thick (Fig. 71); erosive contacts and bed amalgamation are

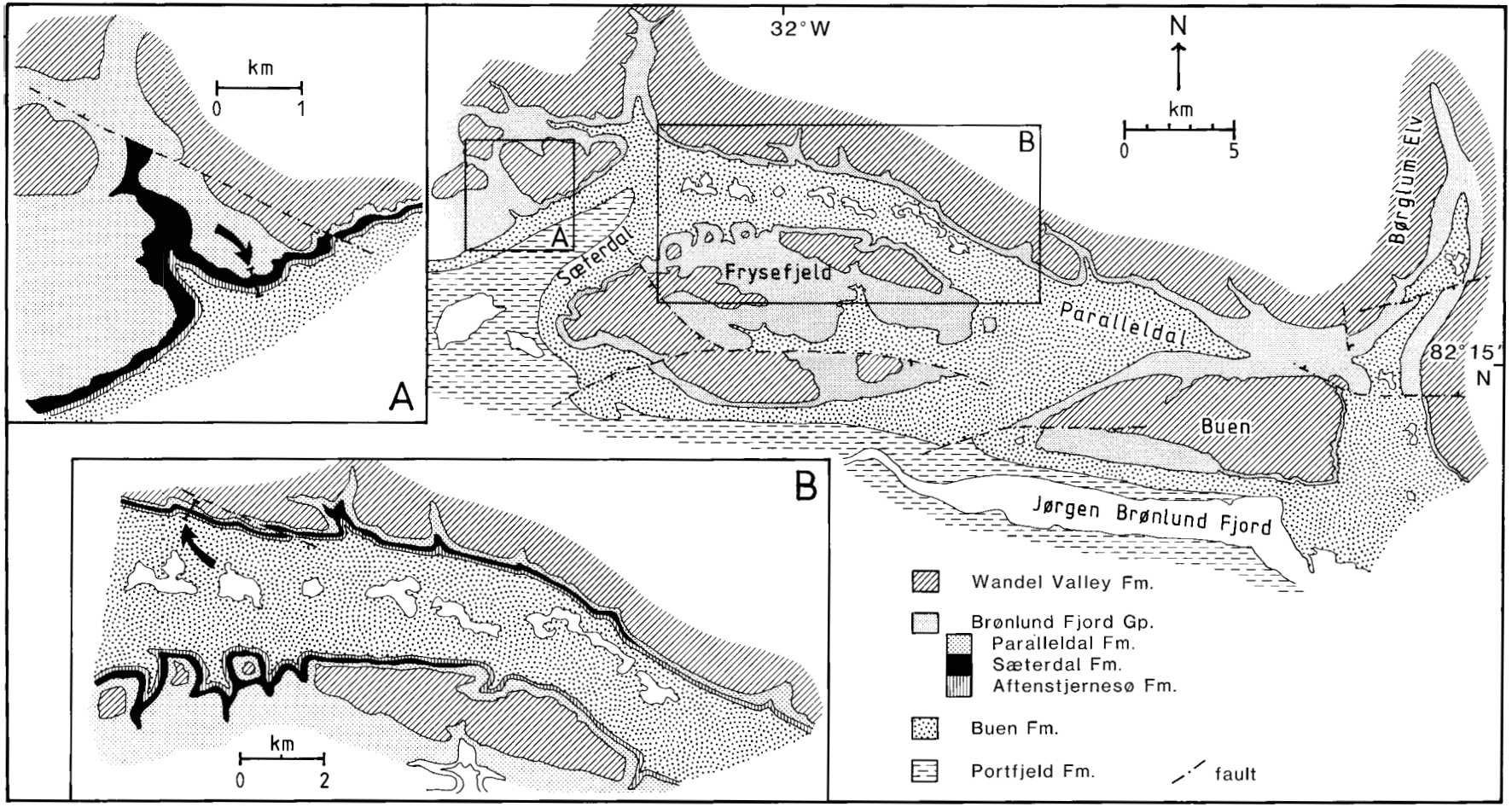


Fig. 68. Geological sketch map of the Paralleldal region showing the distribution of the Brønlund Fjord Group from the eastern end of Nedre Midsommersø to the type area of the group at Jørgen Brønlund Fjord (see Fig. 17). Inset maps A and B show the locations of the type sections of the Sæterdal and Paralleldal Formations respectively; note that the Sæterdal Formation pinches out eastwards (inset B).

observed locally. Internally, the beds are commonly structureless or show diffuse parallel lamination, but locally they exhibit normal grading, hummocky cross-stratification, internal erosion surfaces and convolute lamination. Slump folds are common at the type section. Dark, laminated, bioturbated and glauconitic skeletal dolomites occur at the base of the formation.

The sand-dominated intervals thin east and west of the type section, concomitant with the thinning of the formation, but the overall lithological character varies little throughout its outcrop.

Boundaries. The formation conformably overlies the Aftenstjernesø Formation and is conformably overlain by the Paralleldal Formation. The lower boundary is sharp, planar or irregular and at the type section is placed where cliff-forming dolomites of the Aftenstjernesø Formation are overlain by recessive black, platy dolomites (Figs 30, 69, 70).

The upper boundary is defined at the abrupt change from recessive weathering siliciclastic sediments to the overlying cliff-forming carbonates (Fig. 69). At the type section, it is somewhat obscured by mottling, fracturing, brecciation and geopetal cavity fills, features which are interpreted as the result of karstic processes at the sub-Wandel Valley Formation unconformity (Ineson, 1985). Elsewhere, the boundary is planar and sharp where cliff-forming carbonate mass-flow breccia overlies recessive dolomitic sandstones and dolomites (see Figs 72, 73).

Distribution. The Sæterdal Formation crops out from the western arbitrarily defined limit, north of the eastern end of Øvre Midsommersø, eastwards along the northern side of Wandel Dal, on both sides of Sæterdal and the western end of Paralleldal (Figs 2, 67, 68). The formation pinches out to the south and east of Sæterdal, and thus does not occur on the south side of Frysefjeld, nor east of central Paralleldal (Figs 26, 68).

The formation is poorly exposed along the north side of Wandel Dal and over much of Frysefjeld. It is well exposed on the north side of Sæterdal, but commonly inaccessible.

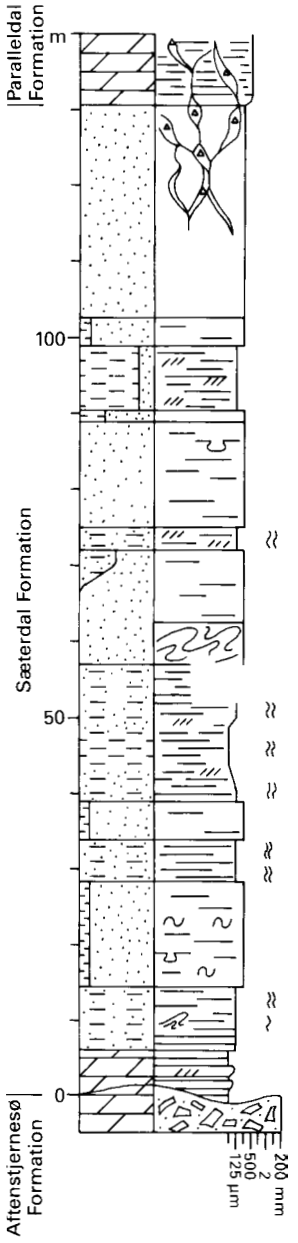


Fig. 69. Type section of the Sæterdal Formation, north-west side of Sæterdal, southern Peary Land (Figs 68, 70). See Fig. 14 for legend.

Fauna and age. The formation is poorly fossiliferous in general, but sandstone beds locally yield a diverse fauna including moulds of articulate and inarticulate brachiopods (*Kutorgina* and *Nisusia*) and trilobites indicative of a late Early Cambrian age (Palmer & Peel, 1979). Blaker (1991) described *Bonnia brennus, Kootenia marcoui* (both of which also occur in the Henson Gletscher Formation, to the west), *Olenellus* cf. *O. gilberti* and undetermined ptychoparioids. The fossils occur at various stratigraphic levels with the highest being about 20 m from the top of the formation. Thus it seems likely that the whole formation is of late Early Cambrian age.

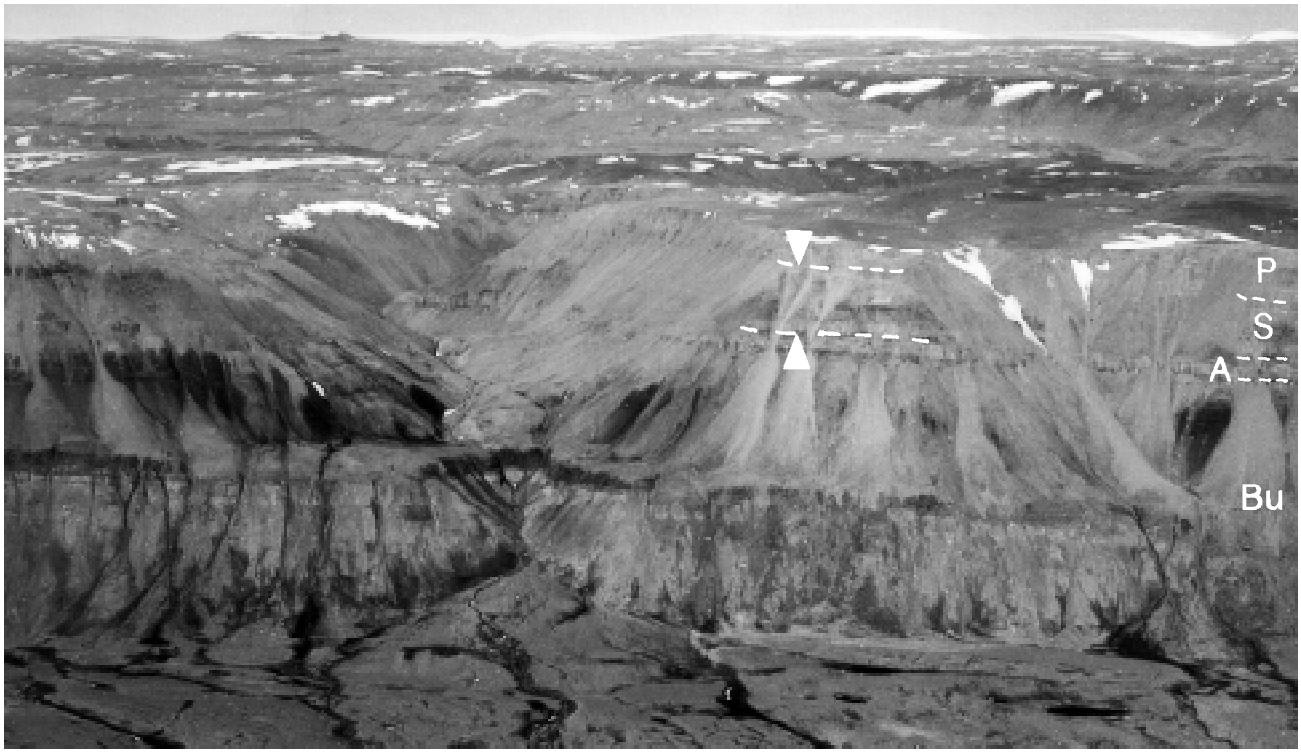


Fig. 70. Cambrian succession on the north-west side of Sæterdal: the largely scree-covered upper Buen Formation (Bu) is succeeded by cliff-forming dolomites of the Aftenstjernesø Formation (A), banded siliciclastics and subordinate carbonates of the Sæterdal Formation (S; type section arrowed) and poorly exposed carbonates of the Paralleldal Formation (P).

Paralleldal Formation

new formation

History. The formation has been described informally as formation 6 of the Brønlund Fjord Group (Ineson & Peel, 1980). It forms the uppermost formation of the Brønlund Fjord Group in the Sæterdal–Børglum Elv region of central southern Peary Land (Figs 5, 17, 67). At Børglum Elv, it is equivalent to Member D of the Brønlund Fjord Formation of Christie & Peel (1977).

Name. After Paralleldal, central southern Peary Land, the east–west trending valley between the north-east end of Sæterdal and Børglum Elv (Figs 2, 68).

Type section. Fig. 72; the type section was measured up a steep gully on the north side of Paralleldal (Figs 68, 73), approximately 2 km east of Sæterdal.

Thickness. The formation attains a thickness of 141 m at the type locality, thinning westward along Sæterdal. The formation thickens eastwards from the type section, as the underlying Sæterdal Formation thins, reaching a maximum measured thickness of 165 m on the north side of Paralleldal (Fig. 68). In the valley of Børglum Elv, the formation is approximately 40 m thick (Fig. 26).

Lithology. The dolomites of the Paralleldal Formation commonly form steep cliffs above the recessive Sæterdal Formation and below the pale thin-bedded dolomites of the Pyramideplateau Member of the Wandel Valley Formation (Fig. 73). At the type section (Figs 72, 73), the lower third of the formation shows grey-brown weathering and is composed of dark grey, laminated, nodular and graded dolomites (Fig. 74), interbedded with thick breccia beds which locally contain rafts of thin-bedded dolomite up to 5 m thick. The remainder of the strata at the type section weathers orange-brown or pale yellow and is composed largely of oolitic, bioclastic, intraclastic and peloidal dolomites showing medium-scale to small-scale trough and tabular cross-bedding. Parallel-laminated dolomites and dolomite breccia beds occur in places. The upper 30 m of the formation at the type section comprise pale medium-coarse crystalline dolomite which is predominantly structureless but large tilted angular blocks of pale, medium- to thick-bedded, cross-bedded dolomite can be identified locally (Fig. 72).

Fig. 71. Fine-grained structureless sheet sandstones with thin siltstone interbeds and partings; *c.* 1.5 m of section illustrated. Sæterdal Formation, north Paralleldal.

East and south of the type section, the lower darker weathering interval comprises dark grey-black, silty, laminated, bioturbated and burrow-mottled dolomites; thin silicified bioclastic horizons near the base of the formation yield a diverse fauna of trilobites, molluscs, brachiopods and archaeocyathans. The dark dolomites are overlain by, and to the south interdigitate with, massive cream weathering, fine to coarsely crystalline dolomites (Fig. 75). Locally, granular cross-bedded varieties can be differentiated from the fine crystalline mottled, shelly dolomites (wackestone texture) containing archaeocyathans (Fig. 76), but more commonly these dolomites are structureless, vuggy and highly recrystallised. In the Børglum Elv region, the formation is characterised by pale yellow weathering, sugary dolomites locally showing trough cross-bedding in sets up to 0.3 m thick (see Fig. 12B).

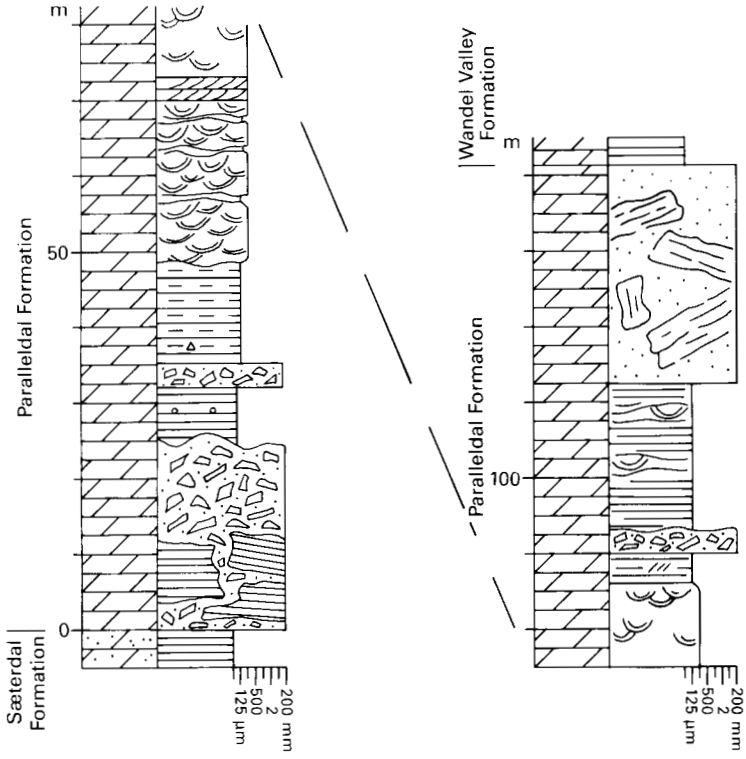


Fig. 72. Type section of the Paralleldal Formation at the western end of Paralleldal, southern Peary Land (Figs 68, 73). See Fig. 14 for legend.

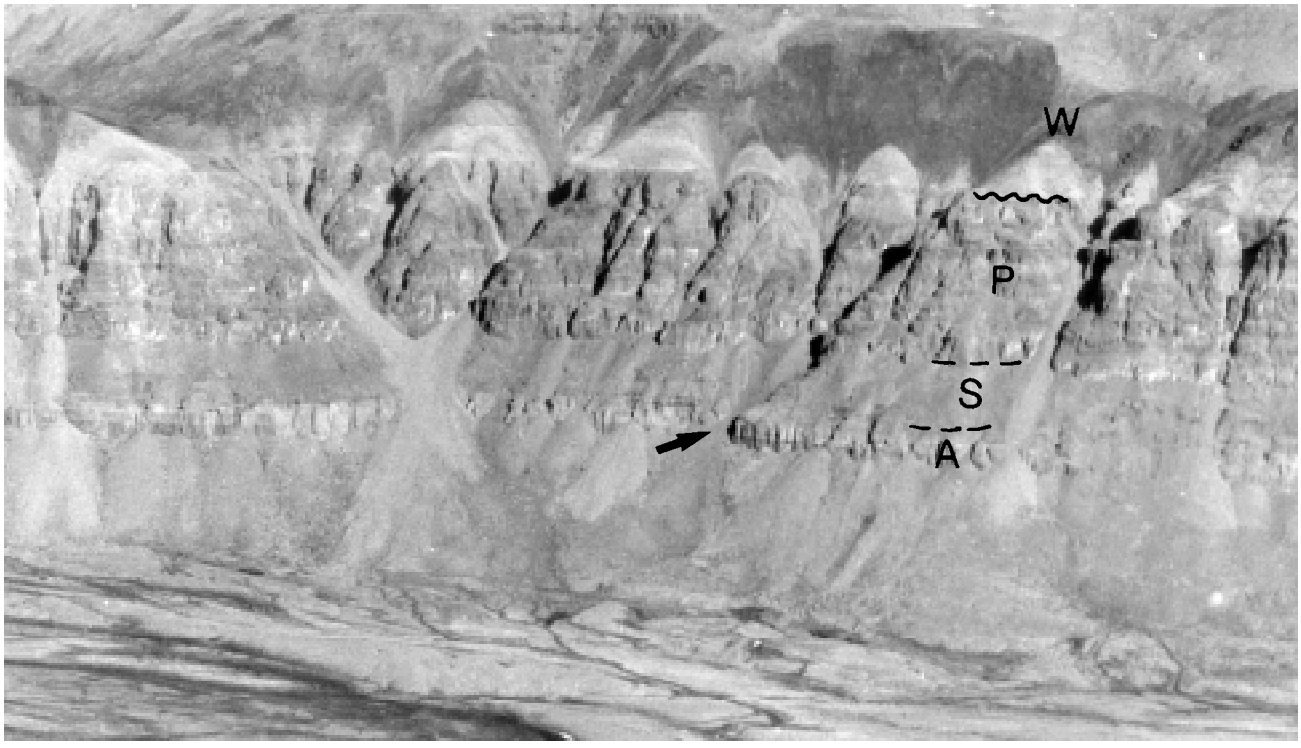


Fig. 73. Type section (arrowed gully) of the Paralleldal Formation (P) on the north side of Paralleldal. A, Aftenstjernesø Formation; S, Sæterdal Formation; W, Wandel Valley Formation.

Fig. 74. Parallel-laminated dark dolomites in the type section of the Paralleldal Formation (*c.* 25-30 m above the base, see Fig. 72), with occasional lenticular skeletal grainstone beds (at upper centre).

Boundaries. In its western outcrop, the formation conformably overlies the Sæterdal Formation. The boundary is sharp and planar and is placed where fine-grained sandstones and silty sandstones are overlain by dolomites (Figs 30, 72, 73). In eastern Paralleldal, on the southern side of Frysefjeld and around Børglum Elv (Fig. 68), the Paralleldal Formation conformably overlies the Aftenstjernesø Formation. In Paralleldal, the boundary is sharp and is defined by the incoming of dark shaly, recessive dolomites which overlie cliff-forming, grey-brown weathering, thin-bedded dolomites and breccia beds of the Aftenstjernesø Formation (Fig. 75). In the Børglum Elv valley the lower boundary is less distinct and, for mapping purposes, is taken at the change in weathering colour, from brownish-grey to pale yellow (Fig. 17). At outcrop, the boundary is defined at the first recognisable cross-bedded dolomite bed overlying structureless or slumped dolomites, assigned here to the Aftenstjernesø Formation.

The Paralleldal Formation is unconformably overlain by the Wandel Valley Formation (late Early – Middle Ordovician) with a sharp and planar contact, marked by a change from pale yellow weathering, coarsely crystalline, cliff-forming dolomites into recessive, pale grey, fine crystalline dolomites (Figs 17, 73, 75).

Fig. 75. Paralleldal Formation (P) on the north side of Paralleldal showing the interdigitation of dark laminated fossiliferous dolomites and pale archaeocyathan-bearing dolomites reflecting northward (left) progradation of shallow-water facies. A, Aftenstjernesø Formation; W, Wandel Valley Formation.

Distribution. The western limit of the Paralleldal Formation is arbitrarily defined at a line running north from the eastern end of Øvre Midsommersø (Fig. 67). East of this line the Paralleldal Formation crops out along the north side of Wandel Dal, along Sæterdal, Paralleldal and the Børglum Elv valley to the shores of Independence Fjord (Figs 67, 68). The formation is poorly exposed west of Sæterdal but well exposed in Paralleldal and the valley of Børglum Elv.

Fauna and age. At most localities, fossils are scarce; the type section has yielded only indeterminate, poorly-preserved trilobites and inarticulate brachiopods. A diverse fauna has been collected from the lower half of the formation in central Paralleldal (see Figs 75, 76), including regular archaeocyathans, trilobites (including *Kootenia* and olenellids), *Salterella*, brachiopods (*Kutorgina* and orthides) and various molluscs (including *Yochelcionella*, *Latouchella* and *Cambridium*). The archaeocyathan assemblage is typical of the middle – late Toyonian Stage of the late Early Cambrian (Debrenne & Peel, 1986). The upper beds of the formation may therefore extend into the Middle Cambrian.

Fig. 76. Silicified archaeocyathans in the Paralleldal Formation on the north side of Paralleldal (locality shown in Fig. 75).

Nordenskiöld Fjord – Warming Land region

The Brønlund Fjord and Tavsens Iskappe Groups as recognised in the Henson Gletscher – J. P. Koch Fjord region extend westwards, essentially unchanged, to

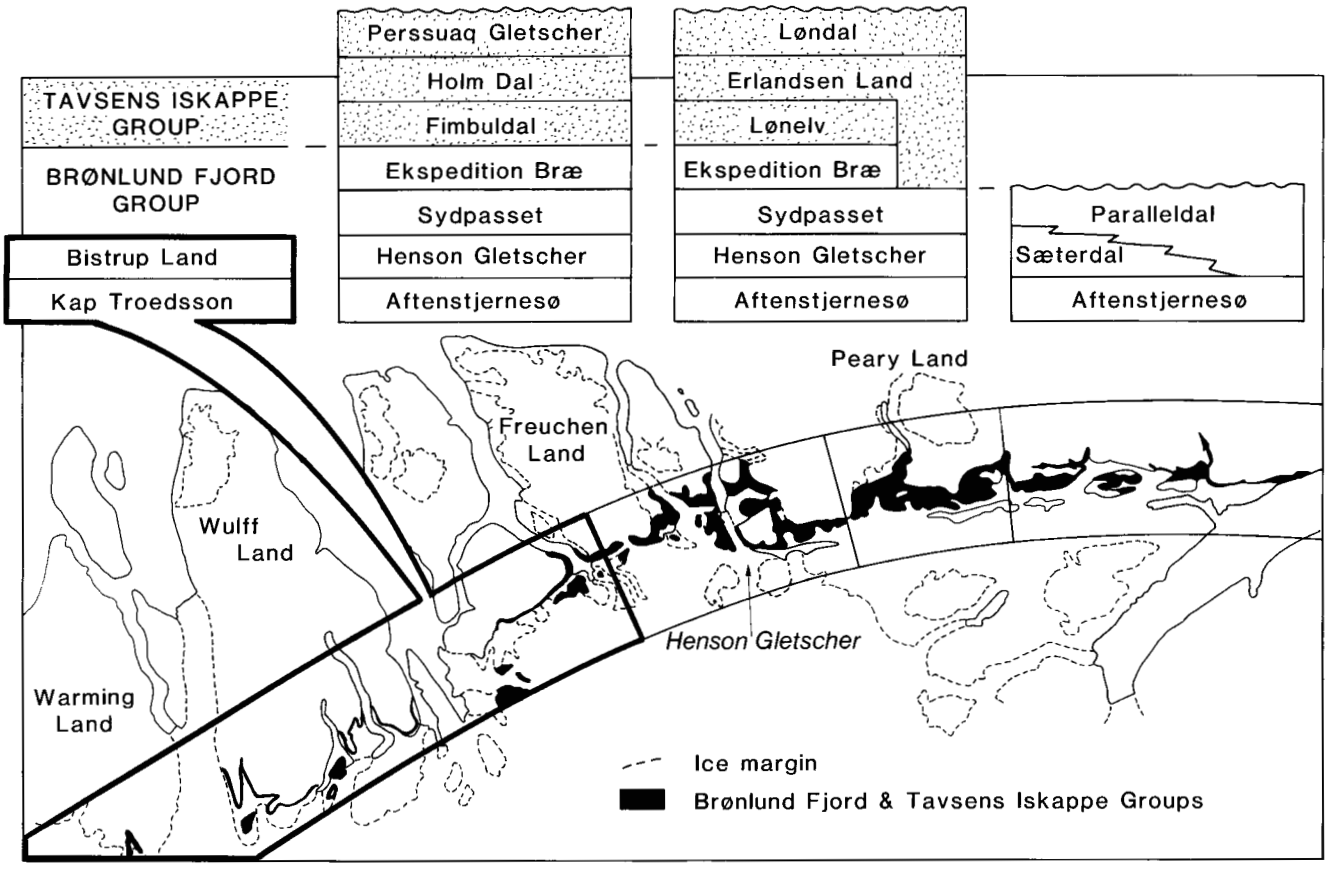


Fig. 77. Map showing the location and stratigraphy of the Nordenskiöld Fjord – Warming Land region in relation to the remainder of the southern outcrop belt.

the head of Nordenskiöld Fjord in south-west Freuchen Land. A complex facies transition occurs in this key area between the off-platform dominated strata of the Brønlund Fjord and Tavsens Iskappe Groups to the east and north-east and the western succession from Nordenskiöld Fjord to Warming Land which is dominated by platform interior strata of the Ryder Gletscher Group (see Fig. 105; Peel & Wright, 1985; Ineson & Peel, 1987). In this western area, ramp, slope apron and platform margin strata assigned to the Brønlund Fjord Group form only the lower 100 m of a thick succession (*c.* 500 m) of Cambrian carbonates.

Brønlund Fjord Group

The Brønlund Fjord Formation in the Nordenskiöld Fjord – Warming Land area is represented by the Kap Troedsson Formation and the Bistrup Land Formation (Fig. 77). These overlie the Buen Formation and are themselves overlain by strata assigned to the Ryder Gletscher Group (Ineson & Peel, 1987). Through much of the area, the Brønlund Fjord Group is about 100 m thick but thickens dramatically to about 350 m in the immediate vicinity of Nordenskiöld Fjord (see Fig. 105).

Kap Troedsson Formation

new formation

History. This formation was described informally as formation RG 1 of the Ryder Gletscher Group (Peel & Wright, 1985), but was subsequently reassigned to the Brønlund Fjord Group (Ineson & Peel, 1987). It is equivalent to the basal part of the 'undifferentiated Cambrian carbonate unit' of Peel (1980).

Name. After Kap Troedsson, a promontory into the Inland Ice in south-west Wulff Land (Fig. 78)

Type section. Fig. 79; on the eastern side of the major north–south, un-named, valley in south-west Wulff Land (Fig. 78).

Thickness. 25 m at the type section, thickening to a

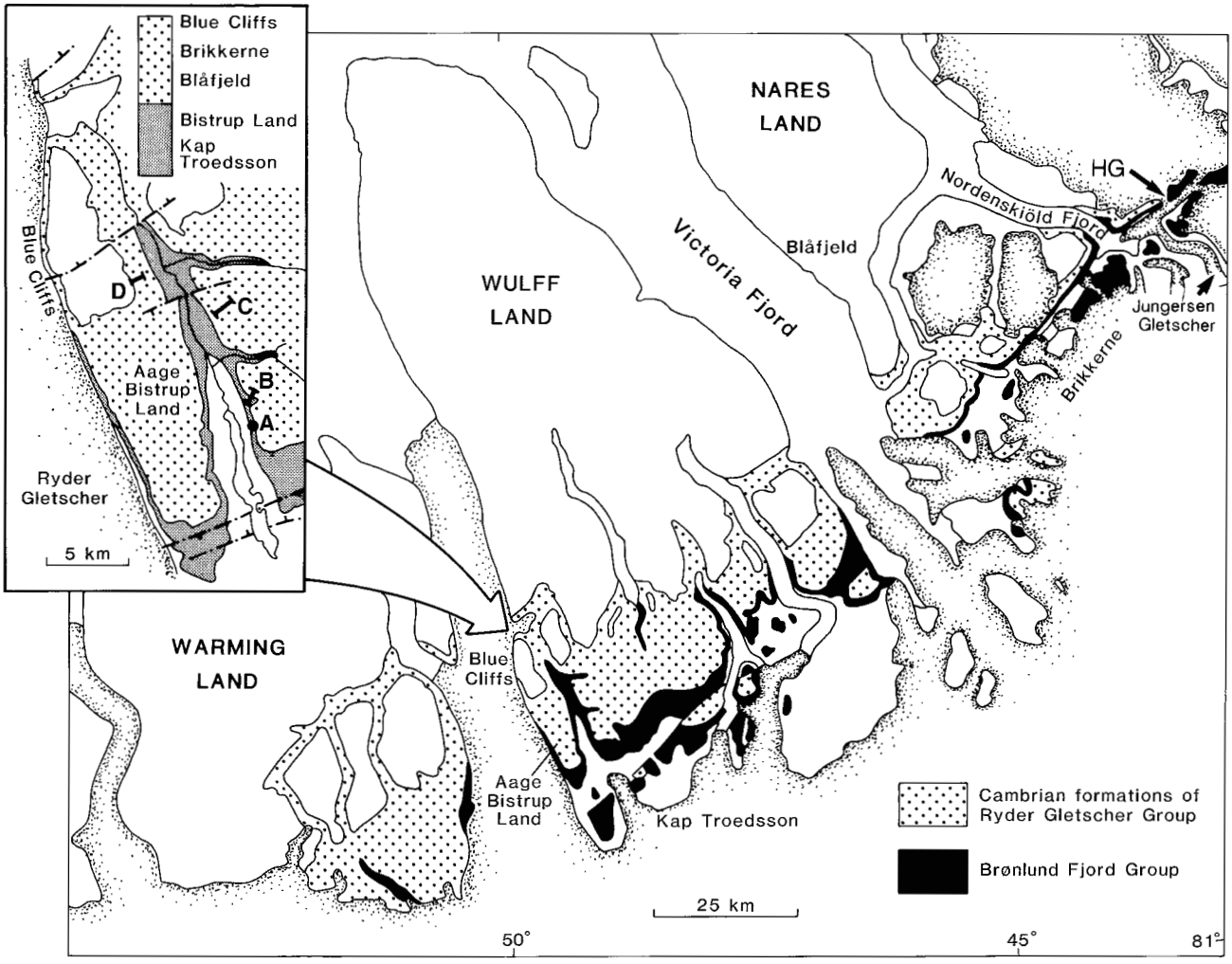


Fig. 78. Map showing the distribution of the Brønlund Fjord Group and the Cambrian formations of the Ryder Gletscher Group between Nordenskiöld Fjord in the east and south-east Warming Land in the west; HG, reference section of the Henson Gletscher Formation (see Figs 21, 32, 33). Section A (inset map) is the type section of the Kap Troedsson Formation (Brønlund Fjord Group), B is the type section of the Bistrup Land Formation (Brønlund Fjord Group), C includes the type sections of the Blåfjeld, Brikkerne and Blue Cliffs Formations (Ryder Gletscher Group) and D is the reference section of the Blue Cliffs Formation.

maximum of 65 m immediately east of C. H. Ostenfeldt Gletscher at the head of Victoria Fjord (Fig. 78). The formation thins eastwards from this locality and is much reduced in thickness (*c.* 10 m) at Nordenskiöld Fjord which forms the eastern limit of the formation (Fig. 78).

Lithology. The Kap Troedsson Formation forms a distinctive iron grey or dark grey limestone unit between recessive black shales of the Buen Formation beneath and golden-brown crags of the overlying Bistrup Land Formation (Fig. 80). Thin-bedded pale grey dolomites occur at the top of the formation but it mainly comprises a thin-bedded succession of silty, skeletal intraclastic grainstones and packstones with minor lime mudstones, intercalated with bioturbated green-grey silty mudstones (Fig. 81). The medium-grained to very coarse-grained skeletal limestone beds are 5–20 cm thick and typically have sharp, gently erosional bases and burrowed tops; U-shaped burrows (*Arenicolites*) are common. Some beds contain intraformational clasts up to cobble size; current ripple cross-lamination and hummocky cross-stratification are commonly observed. Siliciclastic siltstone interbeds are glauconitic in places while phosphoritic hardgrounds were recorded from limestones in the middle of the formation (Peel & Wright, 1985). On the east side of C. H. Ostenfeldt Gletscher, coarse skeletal limestones are rare and the formation is composed largely of parallel-bedded lime mudstones with silty mudstone interbeds and partings.

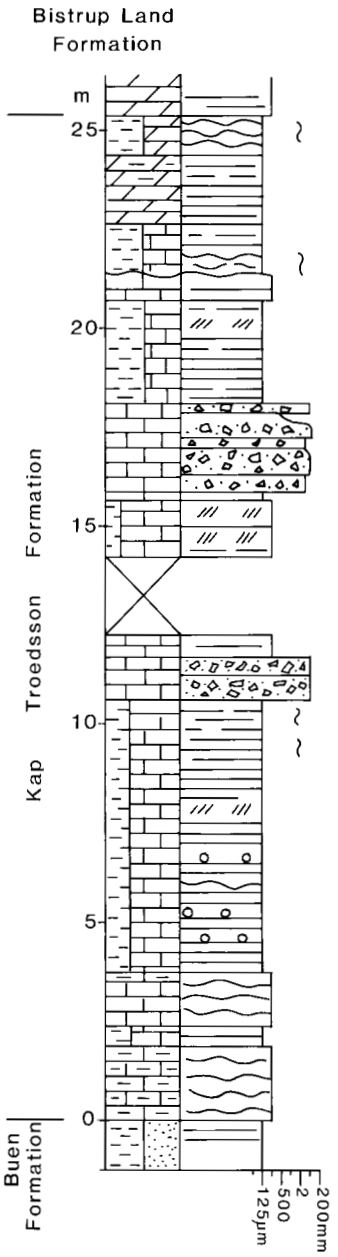


Fig. 79. Type section of the Kap Troedsson Formation, south-west Wulff Land (Figs 78, 80). See Fig. 14 for legend.

Boundaries. The carbonate-dominated Kap Troedsson Formation conformably overlies the siliciclastic Buen Formation. Rare thin skeletal limestones have been recorded from the upper levels of the Buen Formation in the Wulff Land area; the boundary is thus defined at the point where argillaceous limestones become the dominant lithology. At outcrop this boundary is abrupt and rarely ambiguous, although often poorly exposed. The formation is conformably overlain by the Bistrup Land Formation with the boundary being placed at the transition from grey, thin-bedded argillaceous limestones and dolomites into cliff-forming yellow-brown dolomites (Figs 79, 80).

Distribution. The Kap Troedsson Formation crops out from southern Warming Land westwards across southern Wulff Land to Nordenskiöld Fjord (Fig. 78); this forms the eastern limit of the formation. Farther east, across the fjord, the Kap Troedsson Formation correlates with a thin, but distinctive interval of glauconitic, phosphoritic carbonates that form the basal unit of the Aftenstjernesø Formation (Member A of the Brønlund Fjord Formation of Christie & Peel, 1977; see also Frykman, 1980).

Fauna and age. The skeletal intraclastic limestones of the Kap Troedsson Formation contain a rich, but often fragmented, fauna of trilobites and inarticulate brachiopods of late Early Cambrian age. Reports of *Olenellus*, *Callavia*, *Wimanella* and *Botsfordia* by geologists of Greenarctic Consortium, reported by Dawes from Wulff Land (1976, p. 268), are probably based on material collected from this formation, as are also the fossiliferous limestones noted by Peel (1980) from the upper Buen Formation. Blaker (1991) described the trilobites *Calodiscus lobatus*, *Ekwipagetia marginata*, *Kootenia*, *Labradoria misera*? and *Olenellus* cf. *O. truemani*, of which the latter also occurs in the Henson Gletscher Formation in Løndal and in southern Freuchen Land.

Bistrup Land Formation

new formation

History. The formation has been referred to informally as RG2 (Peel & Wright, 1985). Initially assigned to the Ryder Gletscher Group but subsequently reassigned to the Brønlund Fjord Group (Ineson & Peel, 1987), it forms part of the 'undifferentiated Cambrian carbonate unit' of Peel (1980).

Name. After Aage Bistrup Land (Fig. 78).

Type section. Fig. 82; on the eastern side of the major north–south, un-named, valley in south-west Wulff Land (Fig. 78).

Thickness. 73 m at the type section. The formation has a constant thickness across Warming Land and Wulff Land (Fig. 78) but thickens rapidly immediately southwest of Nordenskiöld Fjord where the formation is in excess of 350 m thick.

Lithology. The Bistrup Land Formation consists wholly of dolomite and typically forms yellow-brown or rusty

Fig. 80. Thin-bedded argillaceous limestones of the Kap Troedsson Formation (KT) in the type section overlain by cliff-forming dolomites of the Bistrup Land Formation (BL).

red weathering crags (Fig. 80). At the type section it is composed of two distinct portions. The lower portion (*c.* 55 m thick) consists of medium-bedded to thick-bedded graded or structureless dolomites interbedded with breccia beds up to 15 m thick (Figs 82, 83). The breccias are of coarse pebble grade, matrix-supported and show flat or rarely erosional contacts; some beds show a weak coarse-tail grading in their uppermost levels. The upper portion (18 m thick) shows pale cream or yellow weathering colours and consists of coarse intraclastic dolomites in beds 10–40 cm thick, typically showing hummocky cross-stratification (Fig. 84); trough cross-bedding and flat or low-angle parallel lamination are present in places.

At the head of Nordenskiöld Fjord, where the formation is vastly thicker than at the type locality, a similar subdivision is possible. The lower, darker weathering portion (*c.* 150 m) consists largely of platy, nodular dolomites showing varying degrees of disruption from minor pull-aparts and buckles to chaotically brecciated dolomite. Large exotic blocks of pale dolomite occur in places and large-scale wavy undulating bedding (wavelengths of tens of metres) is characteristic of this interval on the south-east side of Nordenskiöld Fjord. The upper, pale weathering portion is at least 200 m thick in this area and it forms vertical cliffs on either side of the fjord (Fig. 85). This upper part consists largely of structureless, coarsely recrystallised pale

Fig. 81. Thin-bedded skeletal lime grainstones and packstones interbedded with burrowed siltstones; a minor normal fault cuts the succession. Kap Troedsson Formation, south-west Wulff Land (locality B, Fig. 78).

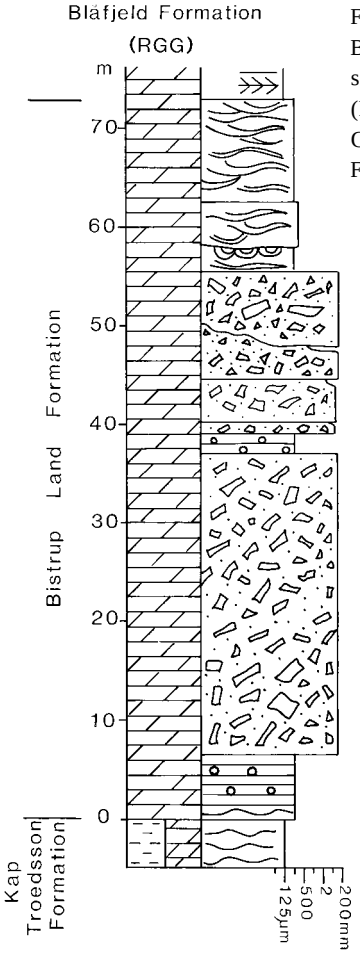


Fig. 82. Type section of the Bistrup Land Formation, south-west Wulff Land (Fig. 78). RGG, Ryder Gletscher Group. See Fig. 14 for legend.

dolomite, locally showing clinoforms dipping to the north. Recognisable primary facies include cross-bedded ooid, intraclast and pisoid grainstones with thin intervals of columnar stromatolites and microbial laminites. West of Nordenskiöld Fjord, this interval includes a vaguely banded dolomite succession of microbial boundstones with subordinate grainstones. These stromatolitic dolomites show flat, crinkly and domal lamination, and in detail exhibit clotted textures and arborescent, plumose and columnar growth forms (Ineson & Peel, 1987); archaeocyathids occur locally. Syndepositional internal cavities contain stalactitic, pendant microbial structures and are lined with early fibrous cement fringes, locally interspersed with internal sediment (see Fig. 12C).

Boundaries. The Bistrup Land Formation conformably overlies the Kap Troedsson Formation over most of its outcrop; the boundary is placed where cliff-forming yellow-brown dolomites overlie dark grey, argillaceous dolomites and limestones (Fig. 80). On the north-east side of Nordenskiöld Fiord, in Freuchen Land, cliff-forming pale dolomites assigned to the Bistrup Land Formation overlie recessive dark carbonates and siliciclastics of the Henson Gletscher Formation (Fig.85); the boundary is inaccessible but appears sharp and planar.

Fig. 83. Bistrup Land Formation at the type section showing the basal unit of parallel-bedded dolomites (carbonate turbidites) capped by a structureless mass-flow breccia bed. About 5 m of section illustrated.

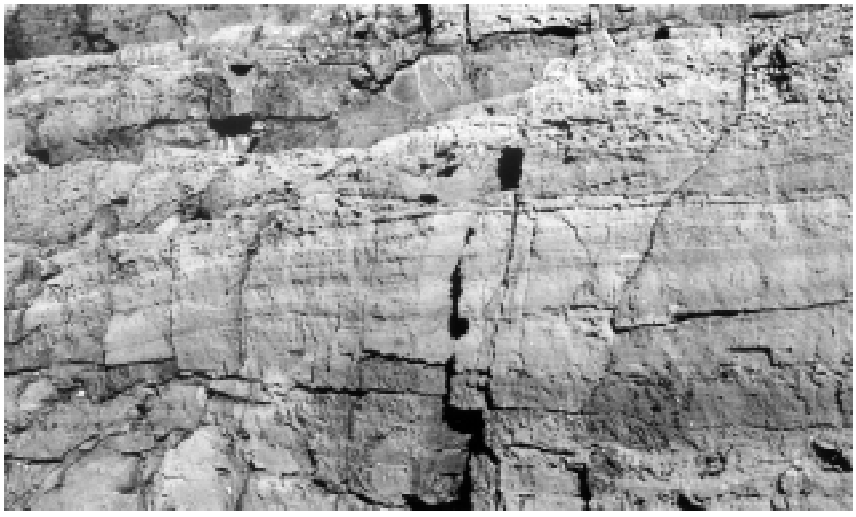


Fig. 84. Dolomites (intraclastic grainstones) near the top of the Bistrup Land Formation (locality C, Fig. 78) showing hummocky cross-stratification; section illustrated *c.* 0.6 m thick.

In the type area, the Bistrup Land Formation is overlain by dark grey-brown oncolitic and stromatolitic dolomites of the Blåfjeld Formation of the Ryder Gletscher Group (RG3 of Peel & Wright, 1985). The junction is sharp and is marked by an abrupt facies change from pale cross-bedded dolomitised grainstones to dark, burrow-mottled, oncoidal dolomites (Fig. 82). Around Nordenskiöld Fjord, the top of the formation is either poorly exposed or in inaccessible cliffs; it is overlain, apparently conformably, by thin-bedded to medium-bedded pale dolomites and sandstones assigned to the Blue Cliffs Formation of the Ryder Gletscher Group (Fig. 85; see Fig 105)).

Distribution. The Bistrup Land Formation is recognised from south Warming Land in the west to south-west Freuchen Land in the east (Fig. 78). North-east of Nordenskiöld Fjord, along the north side of Jungersen Gletscher, the massive, pale, platform margin carbonates of the Bistrup Land Formation grade laterally towards the north-east into the slope facies of the Sydpasset Formation of the Brønlund Fjord Group. Consequently this forms the eastern limit of the Bistrup Land Formation.

Fauna and age. The only fossils known from this formation are poorly preserved archaeocyathans which occur in the greatly thickened development of the formation on the western side of Nordenskiöld Fjord, where the formation is overlain by beds assigned to the Blue Cliffs Formation of the Ryder Gletscher Group (Ineson & Peel, 1987). Elsewhere in North Greenland, archaeocyathans are only recorded from the Paralleldal Formation in Peary Land (Debrenne & Peel, 1986) where they occur in rocks interpreted to represent a comparable environmental setting. The Paralleldal Formation fauna indicates a middle – late Toyonian (latest Early Cambrian) age. In the absence of more precise determination, the fauna from the Bistrup Land Formation can only be ascribed a general late Early Cambrian age.

The Blåfjeld and Brikkerne Formations, which overlie the Bistrup Land Formation in Warming Land, Wulff Land and most of the land area south of Nares Land, have not yielded fossils. The succeeding Blue Cliffs Formation has yielded Middle Cambrian trilobites from near the base of formation in south-western Wulff Land. The Bistrup Land Formation is overlain directly by this formation at Nordenskiöld Fjord.

The Bistrup Land Formation is laterally equivalent, to the east and north-east, to the Sydpasset Formation; this relationship can be observed along the cliffs on the north side of Jungersen Gletscher and Nordenskiöld Fjord (Figs 8, 105). As discussed earlier, the Sydpasset Formation is of late Early – Middle Cambrian age in its more southern exposures. The Ekspedition Bræ Formation, of medial Middle Cambrian age, overlies the Sydpasset Formation at Jungersen Gletscher and it apparently wedges out above the easternmost portion of the Bistrup Land Formation. It is possible, therefore, that the Bistrup Land Formation extends up into the Middle Cambrian in this area.

In summary, the Bistrup Land Formation is probably of late Early Cambrian age throughout its western outcrop (Wulff Land, Warming Land) but may extend up into the Middle Cambrian in its easternmost outcrop adjacent to Nordenskiöld Fjord.

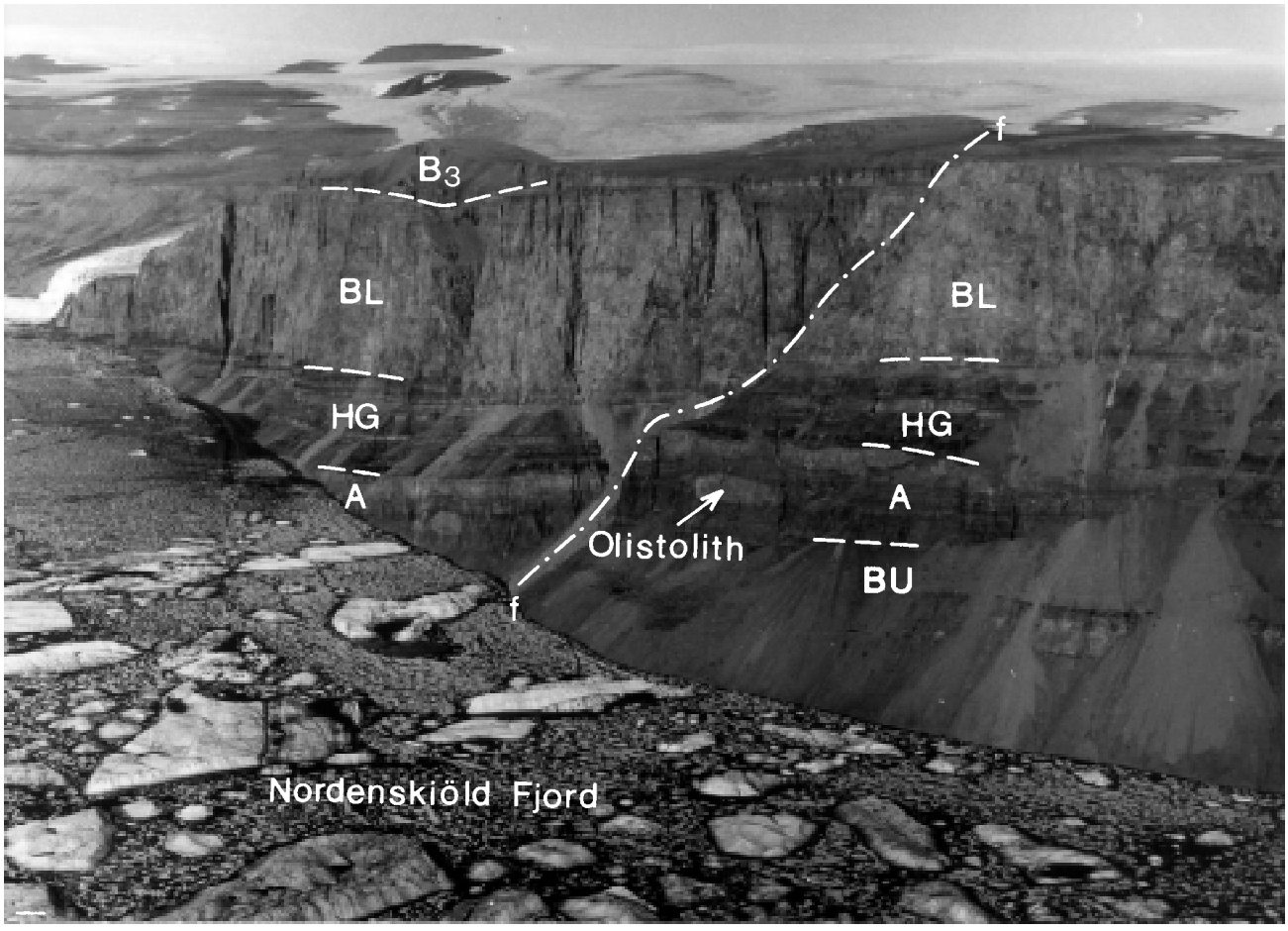


Fig. 85. Cambrian succession at the head of Nordenskiöld Fjord showing the markedly thickened Bistrup Land Formation (BL; 150–180 m thick in this section) overlying the banded slopes of the Henson Gletscher Formation (HG). Note the pale olistolith blocks in the megabreccia bed that caps the Aftenstjernesø Formation (A). BU, Buen Formation; B3, Blue Cliffs Formation; f–f, fault. From Higgins *et al.* (1991a).

Brønlund Fjord and Tavsens Iskappe Groups: northern outcrop belt

The Brønlund Fjord and Tavsens Iskappe Groups crop out in a series of anticlinal inliers and thrust slices within the southern part of the North Greenland fold belt from Nyeboe Land eastward to western Peary Land (Fig. 86). Three formations are recognised, corresponding to the lower three units of the four-part Cambrian – Lower Silurian 'starved basin' sequence described by Higgins & Soper (1985). The lower two of these formations are assigned to the Aftenstjernesø and Henson Gletscher Formations of the Brønlund Fjord Group, as defined from the southern outcrop belt around Henson Gletscher. The Kap Stanton Formation, representing the third unit of Higgins & Soper (1985), was defined by Ineson *et al.* (1994; Peel, 1994a) and assigned to the Tavsens Iskappe Group. The fourth unit, composed of cherty black graptolitic mudstones, has been referred to the Amundsen Land Group as defined from the trough succession (Friderichsen *et al.*, 1982; Higgins *et al.*, 1991a, b).

Correlation between the northern and southern outcrop belts (Figs 10, 87) was discussed by Ineson *et al.* (1994). The boundaries of the Aftenstjernesø Forma-

tion are considered essentially isochronous throughout North Greenland. In contrast, the overlying Henson Gletscher Formation in the northern outcrop belt is equivalent to the Henson Gletscher, Sydpasset, Ekspedition Bræ and lower Fimbuldal Formations of the southern outcrop belt (Figs 10, 87). The Kap Stanton Formation equates roughly to the uppermost Fimbuldal, Holm Dal and Perssuaq Gletscher Formations of the southern outcrop.

Brønlund Fjord Group

The Brønlund Fjord Group typically ranges in thickness from 50 m to 100 m, but thickens westward and is up to 150 m thick in northern Nyeboe Land (Fig. 88).

Aftenstjernesø Formation

This formation is readily recognised throughout the northern outcrop belt where it is 25–80 m thick, thinning northwards and eastwards. It conformably overlies dark shaly mudstones of the Buen Formation (Figs 88, 89). The base of the Aftenstjernesø Formation is typically marked by a pyritic and phosphoritic horizon (cf. the 'Member A' interval of the southern outcrop belt). The formation is composed of nodular, thin-bedded argillaceous, dark grey to black lime mudstones or dolomites, capped by a laterally continuous, clast-supported carbonate breccia bed up to 20 m thick (Fig. 89). Graded limestone beds occur rarely. The formation has yielded a late Early Cambrian fauna from several localities (see Higgins & Soper, 1985; Davis & Higgins, 1987). Blaker (1991) described trilobites *Serrodiscus daedalus, S. speciosus, S. latus?* and *Olenellus* in association with *Latouchella* and inarticulate brachiopods. *Hadimopanella arctica* Wrona, 1982 is abundant in some samples (Peel & Larsen, 1985; Bendix-Almgreen & Peel, 1988).

Henson Gletscher Formation

This formation forms a dark grey or black recessive interval between the more resistant carbonates of the Aftenstjernesø and the Kap Stanton Formations (Figs 88, 89). It is commonly between 20 m and 60 m thick but attains 90 m in northern Nyeboe Land. The Henson Gletscher Formation is characterised by black, calcareous, shaly mudstones and black cherts, with subordinate spicule-rich argillaceous carbonates. Massive or medium- to thin-bedded, white, very fine-grained sandstones form units up to several metres thick in the

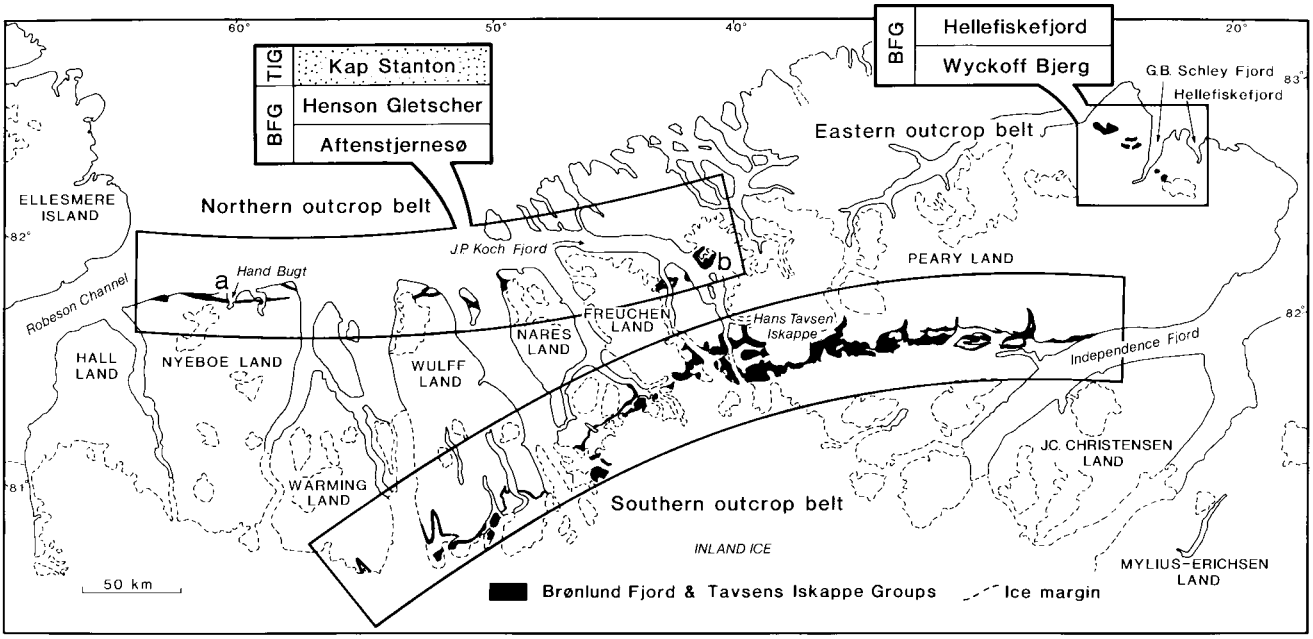
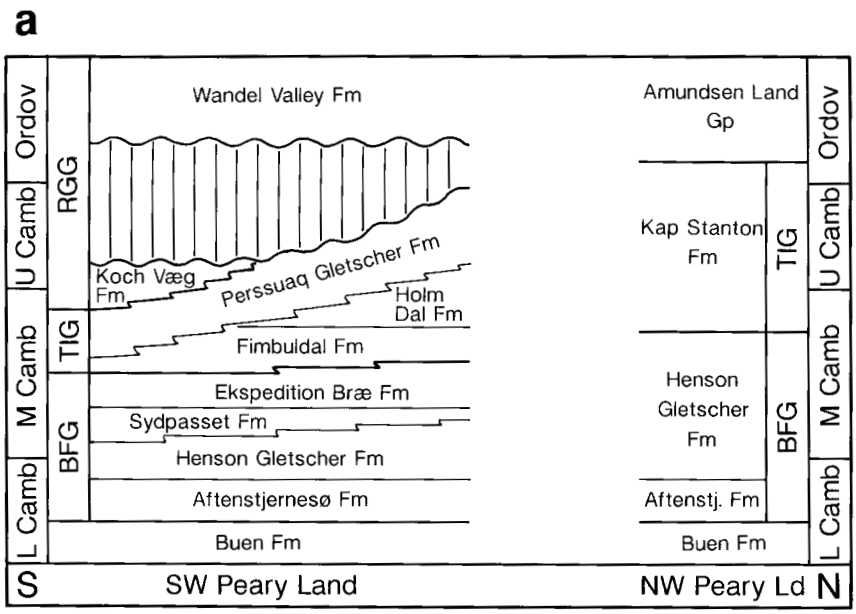


Fig. 86. Map showing the distibution of the Brønlund Fjord and Tavsens Iskappe Groups and the stratigraphic subdivision of the northern and eastern outcrop belts. Localities a and b in the northern outcrop belt indicate the position of stratigraphic sections a and b in Fig. 88. Modified from Ineson *et al.* (1994).



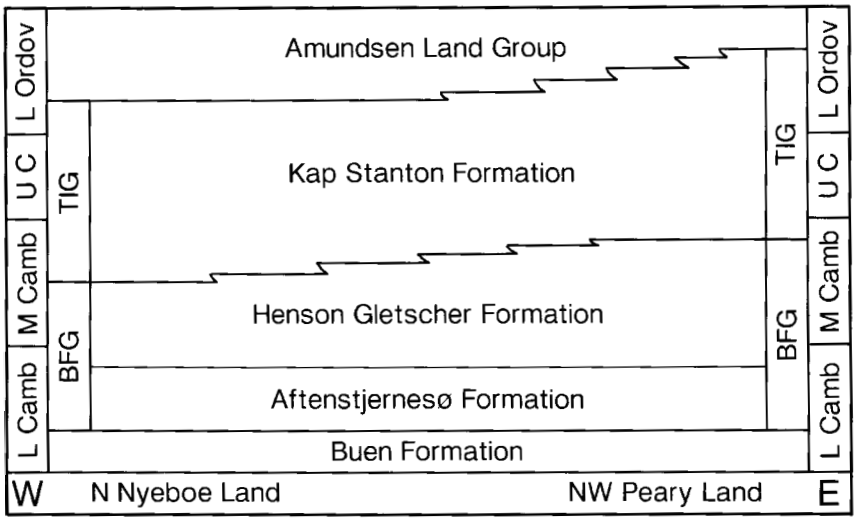


Fig. 87. Lithostratigraphy of the Brønlund Fjord (BFG) and Tavsens Iskappe Groups (TIG) in (**a**) a south-to-north transect in west Peary Land, showing the relationship between the stratigraphies of the southern and northern outcrop belts, and (**b**) a west-to-east transect in the northern outcrop belt (i.e. from locality a to locality b in Fig. 86). RGG, Ryder Gletscher Group. From Ineson *et al.* (1994).

lower half of the formation in northern Wulff Land and northern Nyeboe Land; they are typically structureless but locally display hummocky cross-stratification or dish structures.

The thick succession assigned to the Henson Gletscher Formation in northern Nyeboe Land (Fig. 88a) has yielded rich agnostoid and polymeroid trilobite faunas indicative of the *Glossopleura, Ptychagnostus gibbus* and *Ptychagnostus atavus* Zones of the Middle Cambrian. Detailed taxonomy and discussion of these and other faunas are given by Babcock (1994a, b), Robison (1994) and Peel (1994b). At this locality, the Henson Gletscher Formation ranges in age from the late Early Cambrian to the medial Middle Cambrian but the top of the formation probably extends up into the late Middle Cambrian in eastern sections of the northern outcrop belt (Fig. 87; Ineson *et al.*, 1994).

Tavsens Iskappe Group

The Tavsens Iskappe Group is 100–350 m thick in the northern outcrop belt and is represented by a single formation, the Kap Stanton Formation (Ineson *et al.*, 1994; Peel, 1994a).

Kap Stanton Formation

History. Strata of this formation have been previously referred to informally as the 'dolomite unit', the third of four units making up the 'Cambrian–Lower Silurian

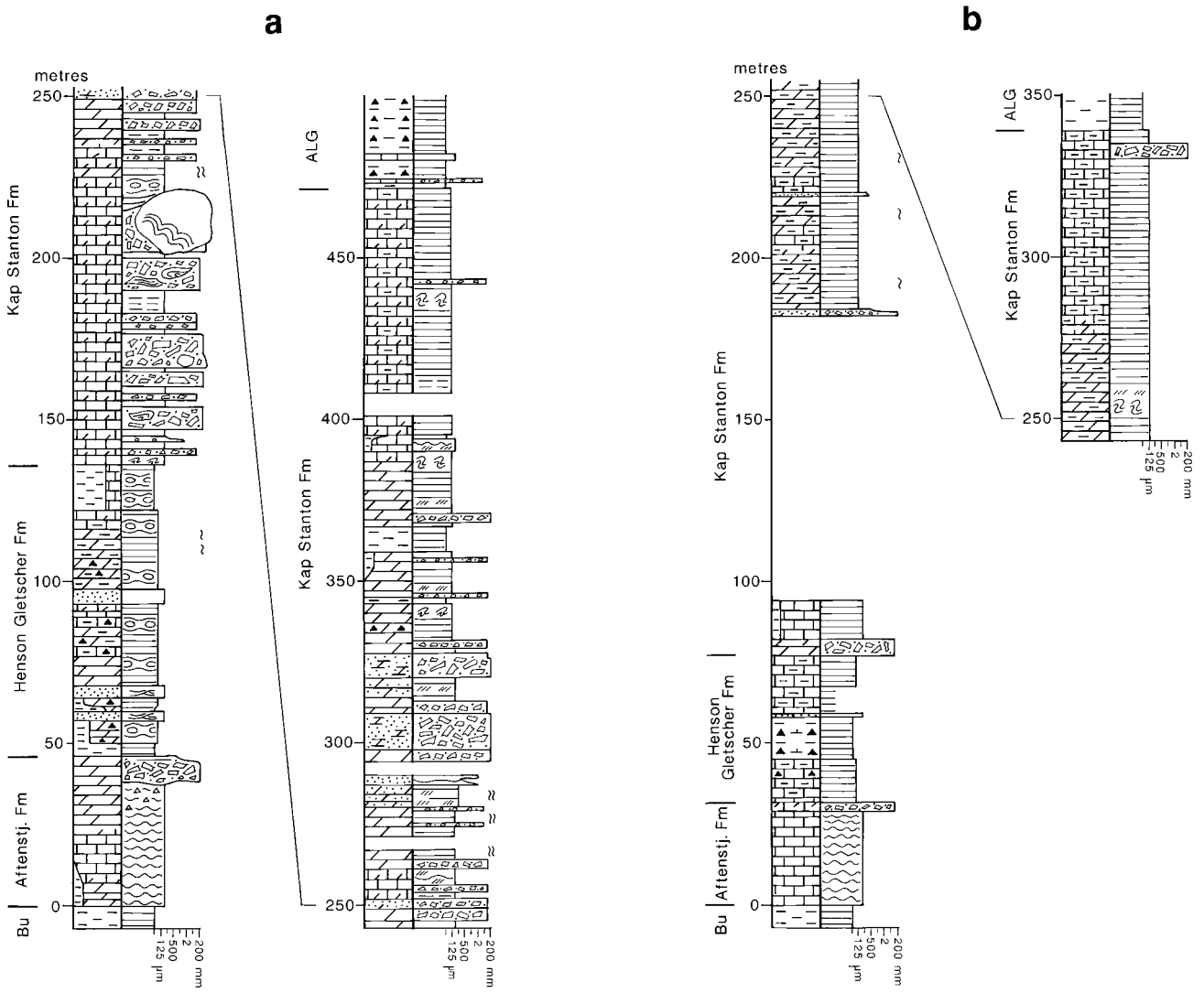


Fig. 88. Stratigraphic sections through the Brønlund Fjord and Tavsens Iskappe Groups in the northern outcrop belt. **a**, northern Nyeboe Land; **b**, outer J. P. Koch Fjord (see Fig. 86). Bu, Buen Formation, Aftenstj., Aftenstjernesø; ALG, Amundsen Land Group. Modified from Ineson *et al.* (1994).

starved basin sequence' described by Higgins & Soper (1985). The Kap Stanton Formation was formally defined by Ineson *et al.* (1994; see also Peel, 1994a).

Name. After Kap Stanton, a prominent cape in northern Nyeboe Land (Fig. 90).

Type section. Fig. 91; the type section is about 1 km west of Hand Bugt on the north coast of Nyeboe Land. The section of steeply dipping, overturned strata crops out along the east side of a small north–south stream gully, on the ridge overlooking the west shore of Hand Bugt (Fig. 90).

Thickness. About 350 m at the type section. The Kap Stanton Formation varies in thickness from *c.* 100 m in northern Wulff Land and Lauge Koch Land to nearly 200 m in south-east Nansen Land and over 300 m in Nyeboe Land (Fig. 88).

Lithology. The carbonate-rich, yellow weathering strata of this formation contrasts strongly with the black or dark grey mudstones, cherts and shaly carbonates above and below (Fig. 89). The Kap Stanton Formation is dominated by dark grey or black argillaceous dolomites and limestones. The proportion of siliciclastic mud to carbonate mud is variable both vertically and laterally within the formation. The dark carbonate-rich mudstones typically show parallel-lamination but in some sections laminated carbonates alternate with paler,

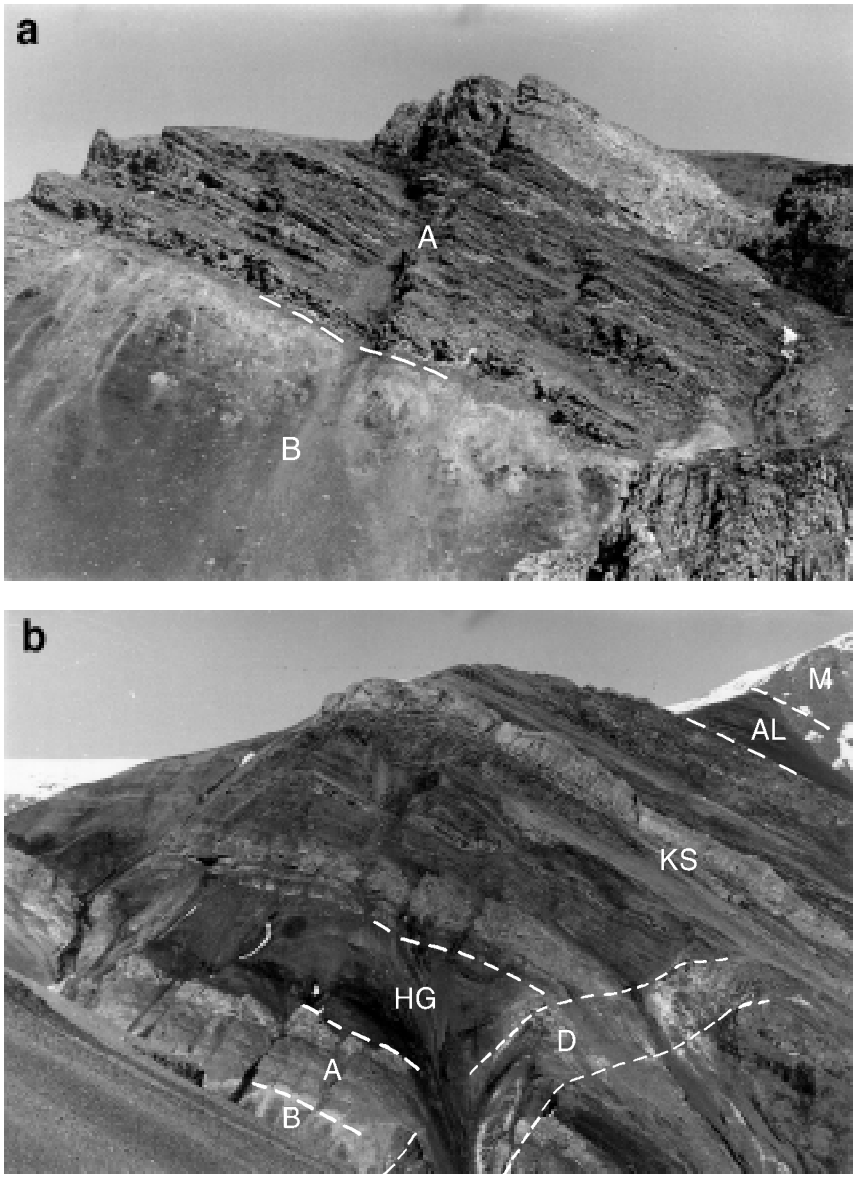


Fig. 89. **a**. Aftenstjernesø Formation (A) overlying the scree-covered Buen Formation (B). The pale scree at the base of the Aftenstjernesø Formation reflects the presence of a distinctive pyritic marker bed at this boundary. Note also the massive carbonate breccia bed (*c.* 7 m thick) capping the formation. East side of Navarana Fjord, Lauge Koch Land. **b**. Cambrian to Silurian succession on the east side of Navarana Fjord, Lauge Koch Land. B, Buen Formation (Lower Cambrian); A, Aftenstjernesø Formation (Lower Cambrian); HG, Henson Gletscher Formation (Lower – Middle Cambrian); KS, Kap Stanton Formation (Middle Cambrian – Ordovician); AL, Amundsen Land Group (Ordovician); M, Merqujoq Formation (Lower Silurian); D, Tertiary dyke. The Aftenstjernesø Formation is about 30 m thick. From Ineson *et al.* (1994).

burrowed carbonate mudstones producing a distinctive banded structure on a scale of tens to hundreds of centimetres.

At the type section, the formation is carbonate-rich relative to eastern outcrops and consists of nodular or thin-bedded argillaceous lime mudstones and dolomites interbedded frequently with carbonate turbidites (e.g. Fig. 13C) and clast-supported carbonate breccia beds (Fig. 91). The nodular carbonates commonly display slope-creep deformation structures: pull-aparts, brittle slumps and interstratal breccia lenses and bands (Fig. 92); partially dolomitised nodular carbonates often weather to a striking orange-dark grey banding – the tiger limestones of Dawes (1976). The clast composition of the mass-flow breccias suggests that they were mostly derived locally (Higgins & Soper, 1985), but the type section also includes a large (20 m) olistolith of light grey stromatolitic limestone (Fig. 91).

Farther east, the succession is less varied (Fig. 88b), composed largely of laminated dark shaly carbonate mudstones, interspersed locally with paler burrowed intervals, rare units of ripple cross-laminated peloidal grainstone and prominent carbonate breccia beds. The mass-flow breccias are more varied in composition than those at the type section, containing quartz sand and equidimensional blocks of pale carbonate in addition to the dominant platy lime mudstone clasts (see Fig. 13D).

Boundaries. The Kap Stanton Formation lies conform-

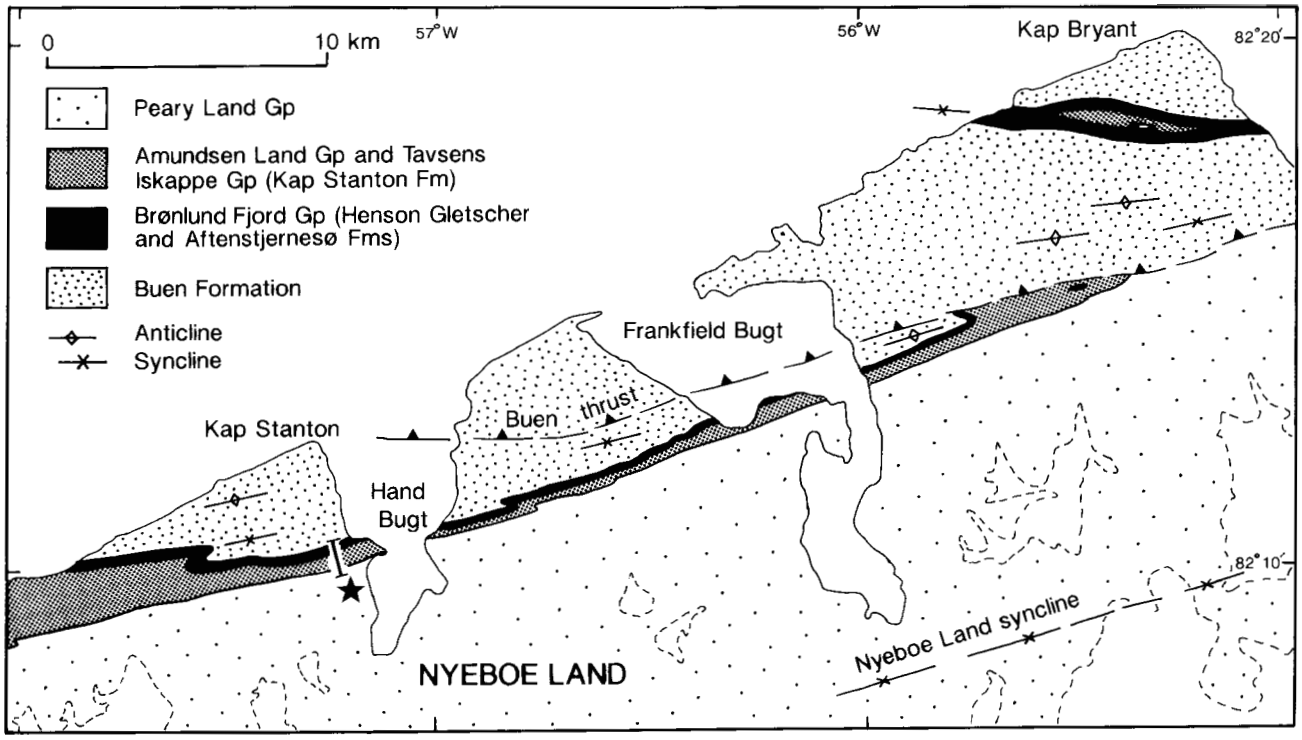


Fig. 90. Sketch geological map of north-eastern Nyeboe Land, showing the location (star) of the type section of the Kap Stanton Formation, west of Hand Bugt. From Ineson *et al.* (1994).

ably between the dark mudstones, cherts and carbonates of the Henson Gletscher Formation beneath and the Amundsen Land Group above (Fig. 89b). The base is placed at the transition from black mudstones, cherts and subordinate platy lime mudstones to thin-bedded or nodular argillaceous carbonate mudstones. In places (e.g. Fig. 88b), the base of the formation is marked by a thick carbonate breccia bed.

The top is placed where argillaceous platy carbonates (or carbonate-rich siliciclastic mudstones) are succeeded by black cherts and mudstones assigned to the Amundsen Land Group. At many localities, a carbonate breccia bed occurs immediately beneath the top of the Kap Stanton Formation.

Distribution. The formation crops out in thrust slices and anticlinal inliers near the north coast of central North Greenland, from north-west Peary Land in the east to northern Nyeboe Land in the west (Fig. 86).

Fauna and age. As discussed by Ineson *et al.* (1994; see also Peel, 1994a), the boundaries of the Kap Stanton Formation are demonstrably diachronous (Fig. 87b); the formation has a maximum proven age range of medial Middle Cambrian to Early Ordovician. In northern Nyeboe Land, the base of the formation lies within the *Ptychagnostus atavus* Zone of the medial Middle Cambrian whereas in eastern sections this boundary is of late Middle Cambrian (*Lejopyge laevigata* Zone) age. Graptolites in the upper levels of the formation and in the overlying Amundsen Land Group indicate that the upper boundary is also diachronous across the northern outcrop belt (Fig. 87b; Higgins *et al.*, 1992; Ineson *et al.*, 1994).

Babcock (1994b; see also Fletcher *et al.*, 1988) noted that polymeroid trilobite faunas from the Kap Stanton Formation described by Babcock (1994a) are of Baltic aspect, representing cool, deeper water, outermost shelf to upper slope biofacies. The presence in underlying strata of the Henson Gletscher Formation (and throughout North Greenland) of trilobite faunas of Laurentian aspect, living in warmer shallow waters, allowed Babcock (1994b) to recognise clear segregation of trilobite biofacies, which he interpreted as evidence of a Middle Cambrian thermocline in marine waters around Laurentia.

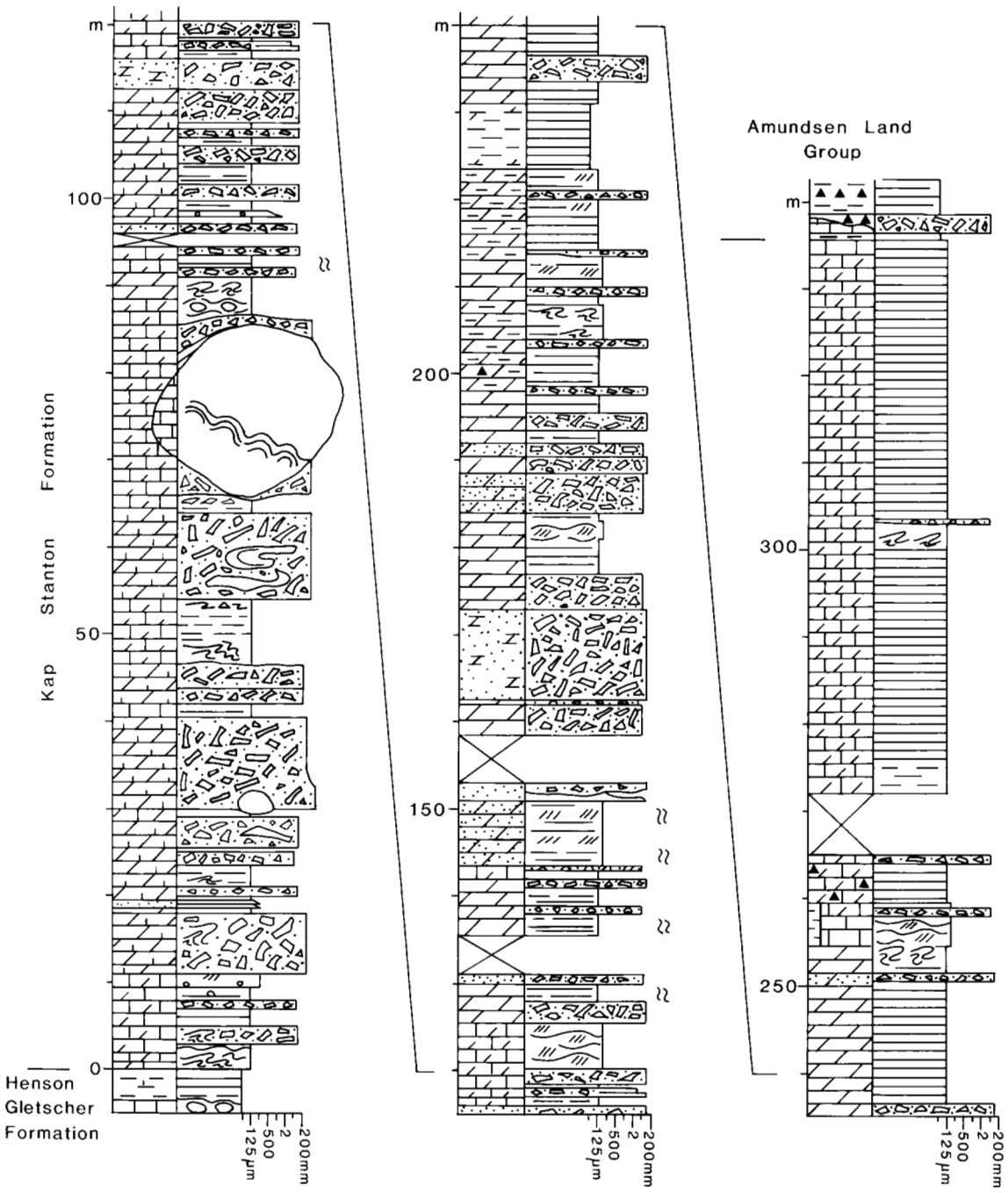


Fig. 91. Type section of the Kap Stanton Formation, northern Nyeboe Land (Fig. 90). See Fig. 14 for legend. From Ineson *et al.* (1994).

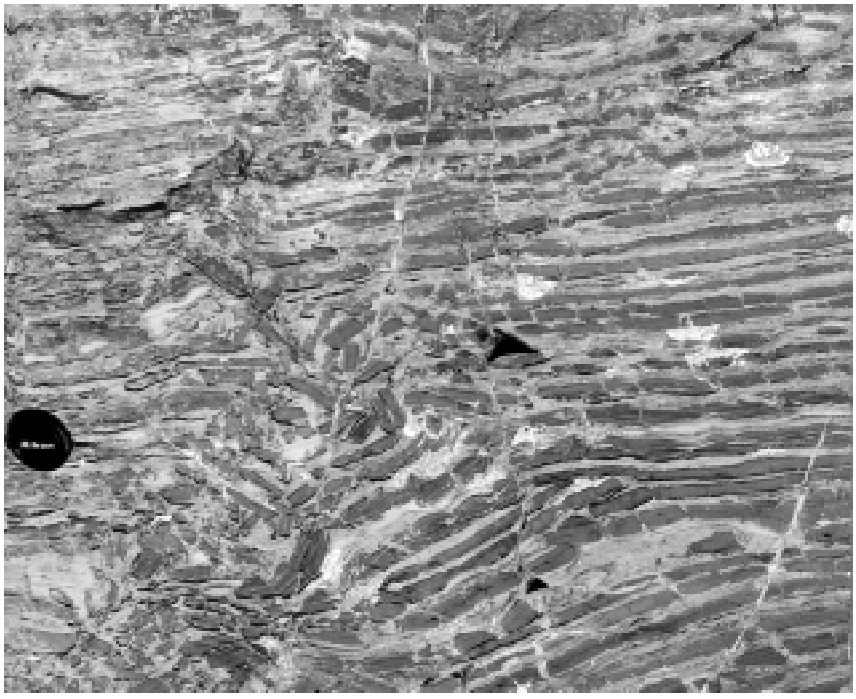


Fig. 92. Platy nodular argillaceous lime mudstones of the Kap Stanton Formation in the type section showing pull-aparts and brittle slump folds of inferred slope creep origin. Additional facies of the Kap Stanton Formation were illustrated by Ineson *et al.* (1994). From Ineson *et al.* (1994).

Brønlund Fjord Group: eastern outcrop belt

Cambrian shelf strata crop out intermittantly in block-faulted terrain in the G. B. Schley Fjord area of north-eastern Peary Land (Christie & Ineson, 1979), between Frederick E. Hyde Fjord in the north-west and the eastern coast of Wyckoff Land (Figs 86, 93). The Brønlund Fjord Group conformably succeeds dark grey-green, shaly mudstones of the upper Buen Formation (the Schley Fjord shale of Troelsen, 1956) and is itself overlain with probable unconformity by light grey dolomites of the Wandel Valley Formation of late Early – Middle Ordovician age (Fig. 86, 94). The correlation between these isolated, poorly fossiliferous outcrops and the more extensive southern and northern outcrop belts is not attempted at formation level.

Brønlund Fjord Group

The Brønlund Fjord Group ranges in thickness from 115 m to 265 m in this area and is subdivided into the Wyckoff Bjerg and the Hellefiskefjord Formations.

Wyckoff Bjerg Formation

new formation

History. Described informally as the 'lower unit' of the Brønlund Fjord Group by Christie & Ineson (1979).

Name. After Clarence Wyckoff Bjerg, a prominent peak in eastern Wyckoff Land (Fig. 93).

Type section. Fig. 95A; east side of narrow valley, approximately 500 m south of the shoreline, eastern Wyckoff Land (Fig. 93).

Reference section. Fig. 95B; south side of north-westerly trending river valley, approximately 13 km east of the head of G. B. Schley Fjord, Wyckoff Land (Figs 93, 94).

Thickness. The formation is 105 m at the type section (Fig. 95A) and at least 125 m thick at the reference section (Fig. 95B). It thins rapidly towards the north-west across G. B. Schley Fjord and is only 35 m thick in central Hans Egede Land.

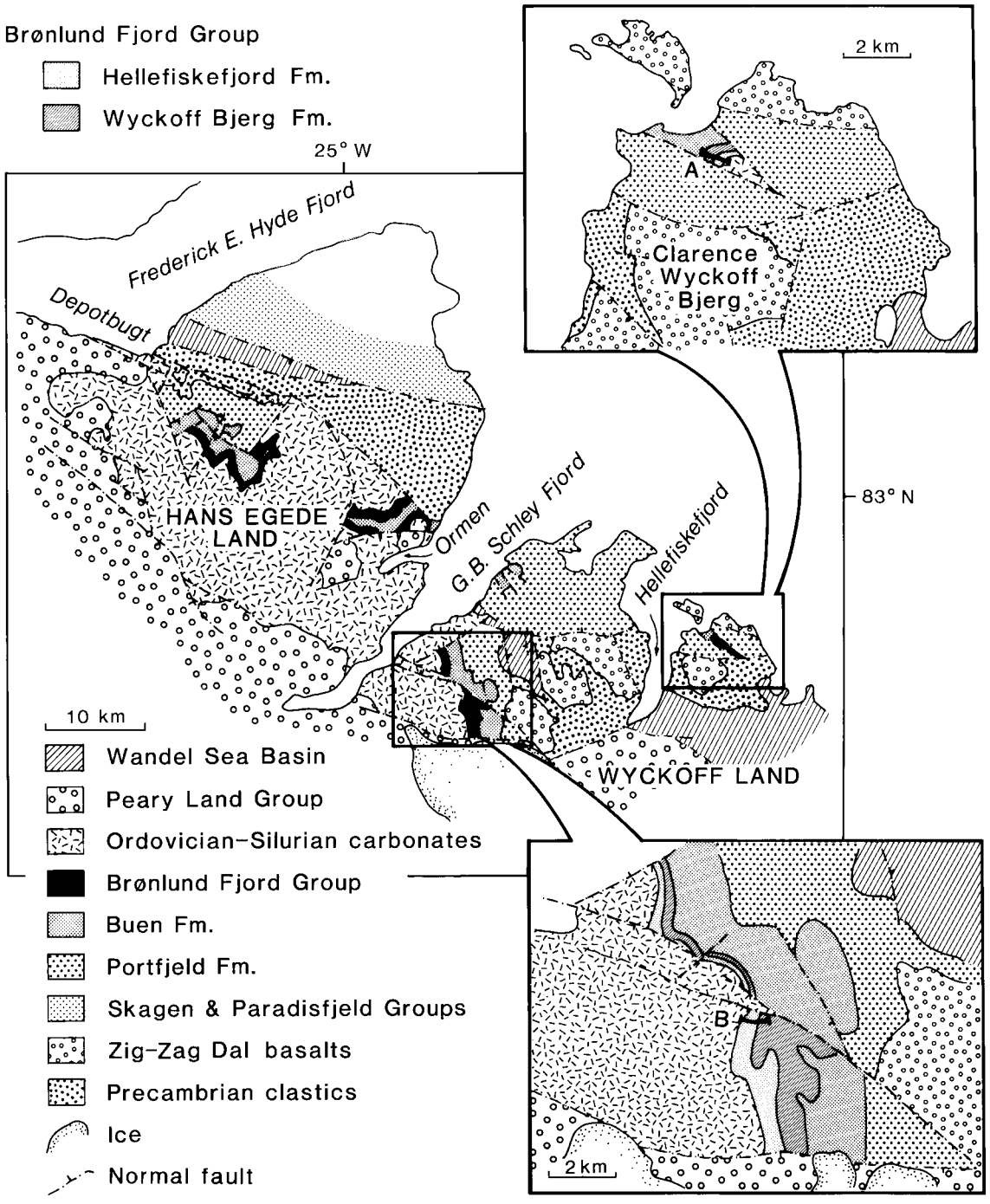


Fig. 93. Geological sketch map of the eastern outcrop belt of the Brønlund Fjord Group in north-east Peary Land. The inset maps show the locations of the type (A) and reference (B) sections of the Wyckoff Bjerg and Hellefiskefjord Formations of the Brønlund Fjord Group. Based on field mapping by R. L. Christie and J. R. Ineson.

Fig. 94. View north-west from Wyckoff Land in the foreground across G. B. Schley Fjord to Hans Egede Land and, in the far distance, Frederick E. Hyde Fjord and the mountains of eastern Johannes V. Jensen Land (Fig. 93). Cambrian and Ordovician strata in the foreground young to the south-west (left); the Portfjeld (Pf) and Buen (Bu) Formations form the low-lying land whilst the succeeding Brønlund Fjord Group (BF) and Ordovician–Silurian carbonates (O–S) produce more resistant features. Note the distinctive banded outcrop of the Wandel Valley Formation, immediately overlying the Brønlund Fjord Group. The reference section of the Wyckoff Bjerg and Hellefiskefjord Formations is located at the mouth of the deeply shaded valley (arrow indicates top of section). Photo: Kort- og Matrikelstyrelsen, Copenhagen – route 548C–N 4298.

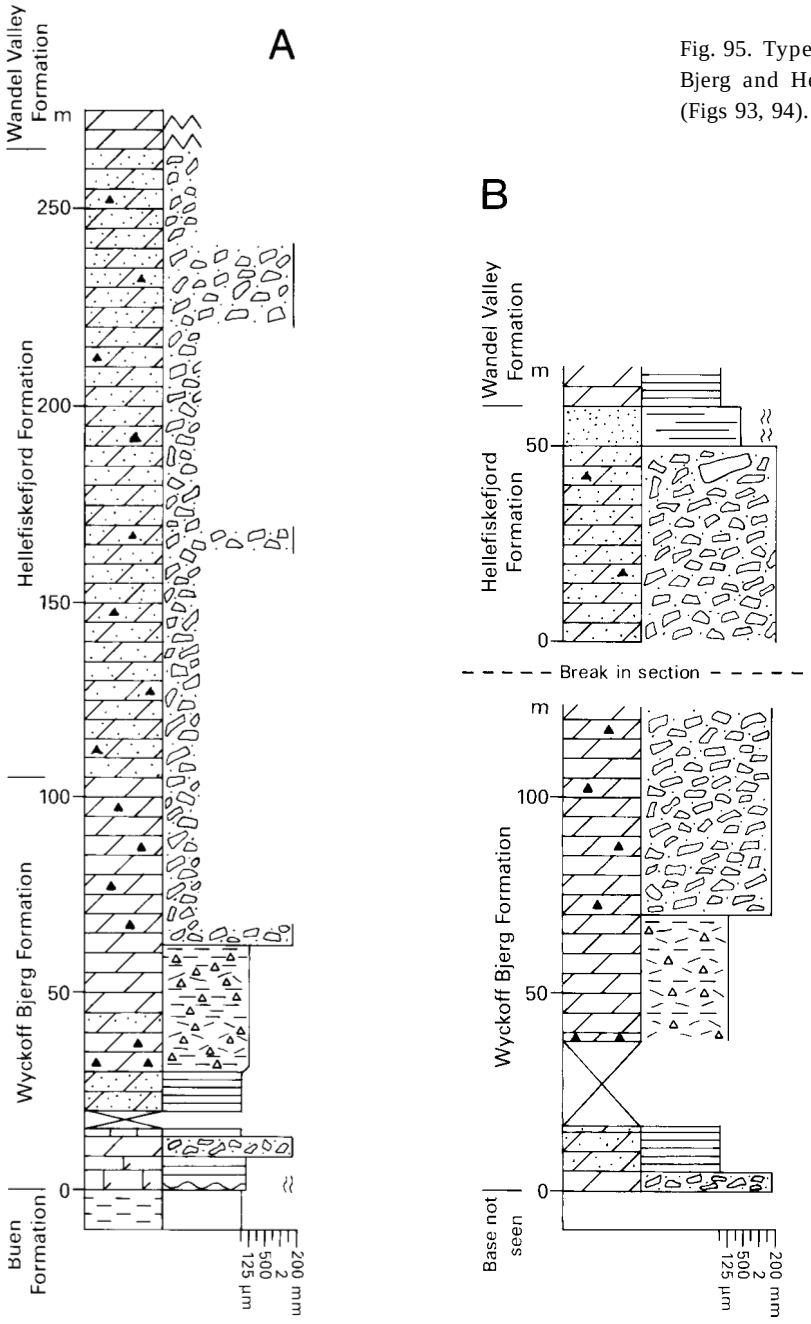


Fig. 95. Type (A) and reference (B) sections of the Wyckoff Bjerg and Hellefiskefjord Formations, north-east Peary Land (Figs 93, 94). See Fig. 14 for legend.

Lithology. The Wyckoff Bjerg Formation typically comprises pale grey weathering, cliff-forming, dolomite breccias and platy, nodular dolomites alternating with intervals of sooty black, laminated dolomites and rare limestones. At the type section, grey-green fossiliferous mudstones of the Buen Formation are succeeded by a thin interval (4.4 m) of bioturbated, dolomitic, skeletal wackestones and packstones rich in trilobite fragments. Pyrite and argillaceous partings are common. These beds pass upwards into parallel-laminated, dark grey-black, silty, sandy limestones (lime mudstones, peloidal wackestones) and dolomites, which locally display small-scale synsedimentary deformation structures such as microfaults, pull-aparts and minor slump folds. A massive, clast-supported dolomite breccia bed forms a prominent ledge in these recessive sediments at both the type and reference sections (Figs 95, 96).

The upper 75 m of the formation are composed of prominent, pale grey weathering, medium to coarse crystalline dolomites. Platy nodular dolomites (Fig. 97), showing abundant evidence of *in situ* brecciation, are overlain by chaotic dolomite breccia with randomly oriented clasts (commonly 5–20 cm) in a pale, vuggy, dolomite matrix. Chert is common, forming up to 10% of the rock. A discrete black chert bed up to 1 m thick occurs at the base of the platy nodular dolomites but,

Fig. 96. Clast-supported mass-flow dolomite breccia of the Wyckoff Bjerg Formation in the reference section; note the irregular, nodular form of clasts.

in general, chert is more widely disseminated, replacing platy nodules and breccia clasts.

To the west of G. B. Schley Fjord, the Wyckoff Bjerg Formation is poorly exposed but is apparently composed mainly of chaotic dolomite breccia comprising platy, tabular clasts (5–15 cm) in a pale grey, locally sandy, dolomite matrix.

Boundaries. The Wyckoff Bjerg Formation conformably overlies the Buen Formation and, in turn, is overlain by the Hellefiskefjord Formation (Fig. 95). The lower boundary is abrupt and is defined where grey-green, shaly mudstones (Buen Formation) are overlain by pale, locally rusty-brown weathering, dolomitic limestones.

Pale grey, cherty dolomite breccias of the Wyckoff Bjerg Formation pass gradationally upwards into golden-brown weathering, dolomite-sandstone breccias assigned to the Hellefiskefjord Formation (Fig. 95). The boundary is taken at the change in weathering colour from pale grey to golden-brown; this is a distinctive, readily-mapped junction and, in outcrop, coincides with an abrupt increase in the silica content of the rock (replacive chert and primary sand grains) from less than 10% to over 50%. Being partly a diagenetic feature, this boundary is probably diachronous.

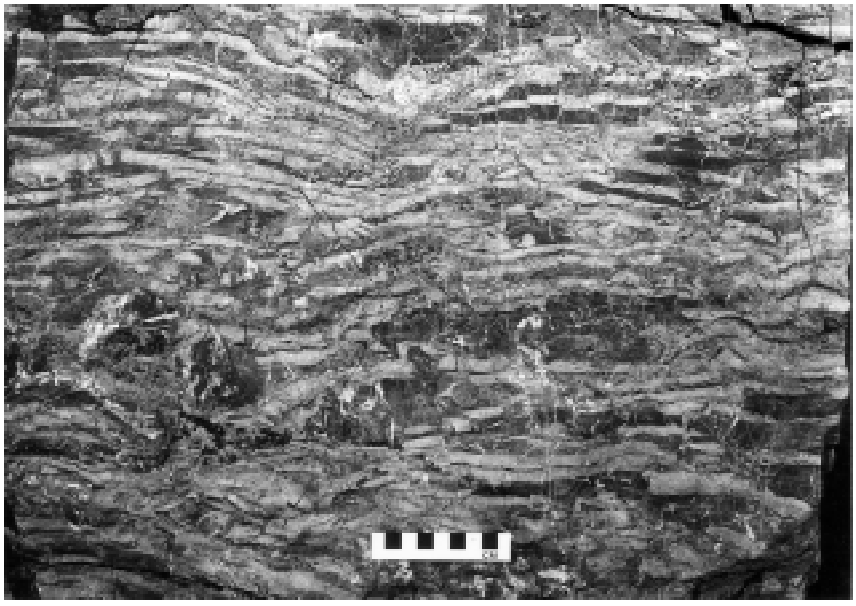


Fig. 97. Cherty platy nodular dolomites of the Wyckoff Bjerg Formation in the type section.

Fig. 98. Clast-supported mass-flow breccia composed of sandstone clasts in a partially silicified dolomite matrix. Hellefiskefjord Formation, Hans Egede Land.

Distribution. Between G. B. Schley Fjord and Hellefiskefjord, the main outcrop of the formation trends approximately north–south, bounded by major faults which juxtapose the Cambrian rocks against Silurian carbonate and siliciclastic sediments (Figs 93, 94). The type section, east of Hellefiskefjord, occurs in a fault-bounded outlier, flanked by older Cambrian and Precambrian rocks (Fig. 93).

West of G. B. Schley Fjord, the formation crops out in two areas: north of Ormen and in a discontinuous NW–SE trending belt, south-east of Depotbugt (Fig. 93). Dips are variable and normal faults are numerous but, in general, the succession youngs towards the south or south-west.

Fauna and age. Diagnostic fossils have not been recovered from the Wyckoff Bjerg Formation. The formation conformably overlies argillaceous rocks of the Buen Formation which contain olenellid trilobite faunas of Early Cambrian age (V. Poulsen, 1974; Palmer & Peel, 1979; Blaker, 1991) and hence is assigned a similar Early Cambrian age.

Hellefiskefjord Formation

new formation

History. Informally described as the 'upper unit' of the Brønlund Fjord Group by Christie & Ineson (1979).

Name. After Hellefiskefjord, the north–south trending fjord east of G. B. Schley Fjord in north-eastern Peary Land (Fig. 93).

Type section. Fig. 95A; east side of the narrow valley traversing fault-bounded outlier of Cambro–Ordovician rocks north of Clarence Wyckoff Bjerg, eastern Wyckoff Land (Fig. 93). The intermittent exposures and frost-heaved float of the type section provide a measure of

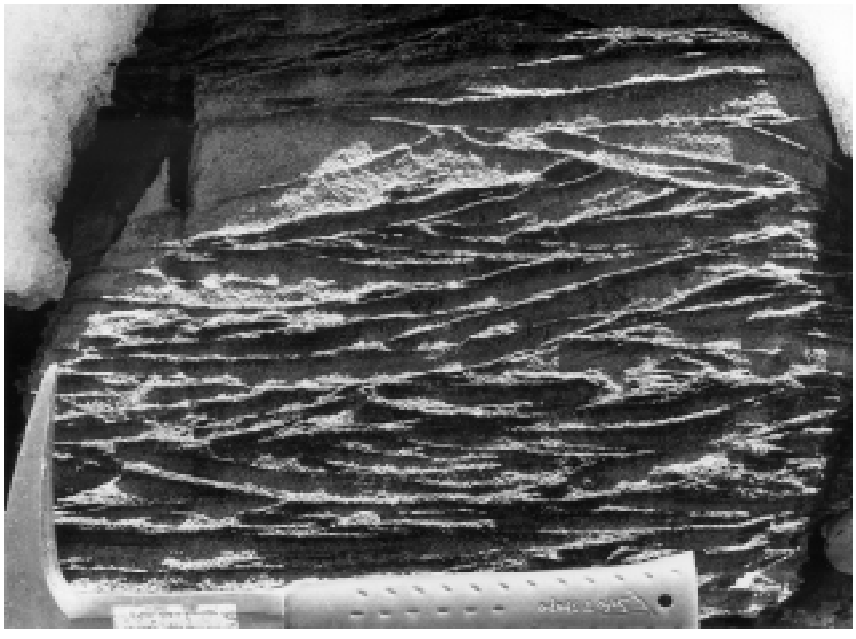


Fig. 99. Sandy ooidal dolomites showing trough cross-bedding. Hellefiskefjord Formation, east of G. B. Schley Fjord, north-east Peary Land.

formation thickness and a crude indication of lithological variation. Elsewhere, superior exposure is marred by limited stratigraphic extent and probable fault complications.

Reference section. Fig. 95B; steep western slopes of north–south trending river valley, approximately 12 km east of the head of G. B. Schley Fjord, Wyckoff Land (Figs 93, 94).

Thickness. 150 m at the type section. The formation thins towards the north-west into Hans Egede Land where it has a measured thickness of 80 m.

Lithology. The Hellefiskefjord Formation weathers a characteristic golden-brown colour, in sharp contrast to the grey carbonates of the underlying Wyckoff Bjerg Formation and the overlying Wandel Valley Formation. It compries a thick amalgamated succession of clast-supported chaotic breccia beds, which are generally indivisible in the poor exposures available and individual bed thicknesses are generally unknown. The breccias are composed of rectangular slabs (commonly 5–30 cm) of brown weathering, dolomitic sandstone and silicified laminated dolomite, set in a pale grey, cherty dolomite or sandy dolomite matrix (Fig. 98). The sandstone clasts are medium to fine grained, display cross-bedding, parallel lamination and bioturbation, and in places are up to 4 m thick and 15 m long.

Trough cross-bedded, sandy, ooidal dolomites (Fig. 99) outcrop within a succession of sandstone-dolomite breccias a few kilometres east of G. B. Schley Fjord (Fig. 93); exposure is poor so that it is not clear if these cross-bedded dolomites are *in situ* or if they form part of large, derived slabs, as seen elsewhere in the formation.

Boundaries. The Hellefiskefjord Formation overlies conformably the Wyckoff Bjerg Formation; the boundary is placed at the weathering colour change (grey to golden-brown) which coincides with an abrupt increase in the proportions of chert and quartz sand.

The formation is overlain by pale grey, laminated dolomites of the Wandel Valley Formation (late Early – Middle Ordovician). Although poorly exposed in the type section, the boundary is sharp and planar in the reference section and is placed at the junction between laminated, bioturbated sandstones (possibly a large breccia clast) and pale grey, silty dolomites (Fig. 95B).

In the absence of reliable biostratigraphic data, the stratigraphic significance of this planar, apparently conformable boundary is not clear; by analogy with the southern outcrop belt of the Brønlund Fjord Group (see Fig. 5), it probably represents a major hiatus (see also Peel & Smith, 1988; Higgins *et al*., 1991a).

Distribution. The distribution of the Hellefiskefjord Formation closely follows that of the underlying Wyckoff Bjerg Formation (see above).

Fauna and age. Fossils have not been found in the Hellefiskefjord Formation and its age is thus poorly constrained. It conformably overlies the Wyckoff Bjerg Formation of probable Early Cambrian age and is overlain,with inferred unconformity, by the late Early – Middle Ordovician Wandel Valley Formation. A late Early–Middle Cambrian age is considered most likely.

Ryder Gletscher Group: amended definition

The Ryder Gletscher Group is a thick succession of platform carbonates and subordinate siliciclastics of late Early Cambrian to Middle Ordovician age. It occurs from Kronprins Christian Land in the east to Inglefield Land in the west (see below). Four Cambrian formations, equivalent in age to the Brønlund Fjord (in part) and Tavsens Iskappe Groups, are defined here from central North Greenland (see Fig. 8).

Ryder Gletscher Group

History. The Ryder Gletscher Group was defined by Peel & Wright (1985) to encompass a succession of platform carbonates and subordinate siliciclastic sediments of largely Cambrian age outcropping in the southern Wulff Land – southern Warming Land area; earlier references to these strata are noted by Peel & Wright (1985). Following subsequent fieldwork, Ineson & Peel

(1987) expanded the scope of the group both stratigraphically, to include platform carbonates of Early to Middle Ordovician age, and geographically to include Cambrian–Ordovician strata that crop out across northern Greenland from Kronprins Christian Land in the east to Inglefield Land in the west. Ineson & Peel (1987) also transferred the lowermost two formations of the original Ryder Gletscher Group (informally referred to as formations RG1 and RG2 by Peel & Wright, 1985) to the Brønlund Fjord Group (the Kap Troedsson and Bistrup Land Formations as defined here).

Name. After Ryder Gletscher, the larger glacier between Wulff Land and Warming Land (Figs 2, 78).

Type area. The area around Ryder Gletscher in southern Wulff Land and south-east Warming Land.

Dominant lithology. The Ryder Gletscher Group comprises a heterogeneous succession of platform carbonates with subordinate siliciclastic sediments and evaporites. In the type area, the Cambrian portion of the group comprises dark, burrow-mottled dolomites and subordinate lime mudstones interbedded with pale weathering, mud-cracked, microbial laminites, dolomitised ooid grainstones and stromatolitic biohermal dolomites. Siliciclastic facies occur towards the top of the Cambrian succession and become increasingly important towards the east. Ordovician strata of the Ryder Gletscher Group in the type area comprise a basal, highly distinctive white sandstone formation (the Permin Land Formation of Bryant & Smith, 1985, 1990), succeeded by a varied association of interstratified dark, brown-grey, burrowed and light-coloured, stromatolitic, mud-cracked dolomites; fine-grained sandstones and evaporites occur at certain levels. The lithostratigraphy of the Ordovician portion of the Ryder Gletscher Group in the type area was described by Sønderholm & Due (1985; see also Higgins *et al*., 1991a). Comparable facies, with local variations, occur in the Ryder Gletscher Group of Inglefield Land and Washington Land to the west (Peel & Christie, 1982; Peel, 1982b) and Peary Land and Kronprins Christian Land to the east (Christie & Peel, 1977; Peel, 1982b; Ineson *et al*., 1986; Peel & Smith, 1988).

Boundaries. In the type area of southern Wulff Land, the Ryder Gletscher Group conformably overlies the Bistrup Land Formation of the Brønlund Fjord Group; the boundary is placed where burrow-mottled, dark grey-brown oncolitic dolomites abruptly succeed hummocky cross-stratified, yellow weathering dolomite grainstones. The Ryder Gletscher Group is conformably succeeded in its type area (and throughout North Greenland) by the Morris Bugt Group; the boundary in the type area is placed where grey microbially laminated dolomites of the Cape Webster Formation are succeeded by dark grey to black, bituminous, micritic limestones (see Sønderholm & Due, 1985).

In Inglefield Land and Washington Land, to the west, the Ryder Gletscher Group conformably overlies Cambrian siliciclastic sediments of the Dallas Bugt and Humboldt Formations (Peel & Christie, 1982; Higgins *et al*., 1991a). In eastern areas of North Greenland, the Ryder Gletscher Group gradually oversteps the Tavsens Iskappe and Brønlund Fjord Groups (Early – Late Cambrian) in Peary Land to lie directly on the Lower Cambrian Buen Formation in Valdemar Glückstadt Land. In Kronprins Christian Land, Early Ordovician strata of the Wandel Valley Formation assigned to the Ryder Gletscher Group rest unconformably on Proterozoic siliciclastic sediments.

Distribution. From Inglefield Land in the west to Kronprins Christian Land in the east (Fig. 2). Cambrian formations assigned to the group are only recognised west of Hans Tavsen Iskappe.

Geological age. Late Early Cambrian to Middle Ordovician.

Subdivision. The Ryder Gletscher Group comprises a total of 25 formations as described by Ineson & Peel (1987; see also Fig. 2 in Higgins *et al*., 1991a). Four previously undefined Cambrian formations of the Ryder Gletscher Group are geographically and geologically associated with Cambrian units described herein from the southern outcrop belt and these formations are formally proposed below. They are the Koch Væg Formation in the Henson Gletscher region of westernmost Peary Land, and the Blåfjeld, Brikkerne and Blue Cliffs Formations in the type area of the Ryder Gletscher Group in southern Wulff Land and adjacent Warming Land.

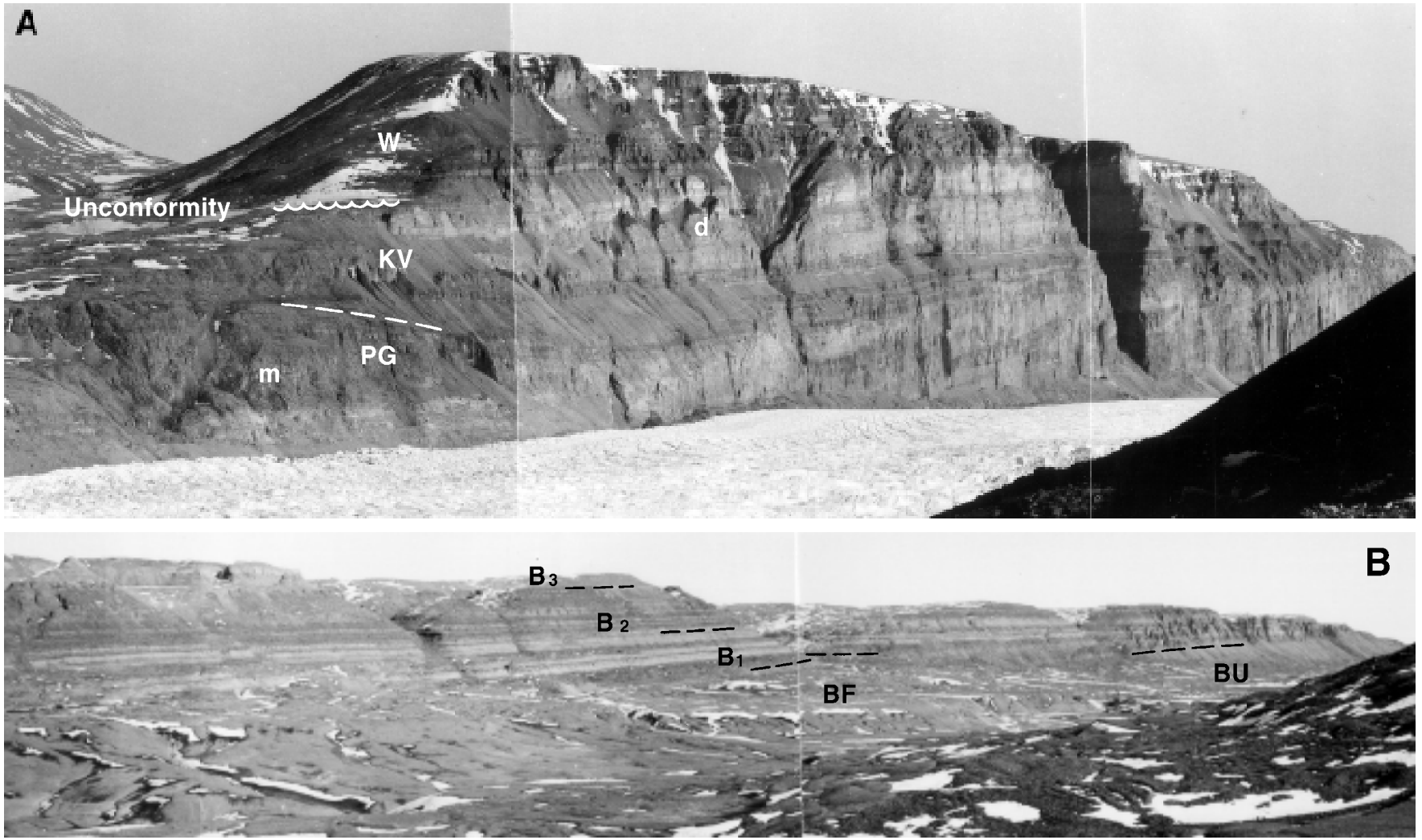


Fig. 100. **A**. Cambrian and Ordovician strata exposed in Koch Væg on the east side of Henson Gletscher, west Peary land (Fig. 23). The Perssuaq Gletscher Formation (PG, Tavsens Iskappe Group) shows spectacular clinoform bedding reflecting northward (left) progradation of the platform margin; a mound-like structure (m) is developed in this formation at the northern end of Koch Væg. The conformably overlying succession of shallow-water platform carbonates and subordinate siliciclastics are assigned to the Koch Væg Formation (KV) of the Ryder Gletscher Group. The Cambrian succession is capped by an unconformity beneath the well-bedded dolomites of the Wandel Valley Formation (W, Lower – Middle Ordovician, Ryder Gletscher Group). The cliff is about 600 m high and is cut by a Tertiary dyke (d). **B**. Cambrian strata in south-west Wulff Land on the eastern side of the broad north–south valley (Fig. 78, section C indicated by annotation BF–B3). Shelf siliciclastics of the Buen Formation (BU, extreme right) are succeeded by ramp and incipient platform margin strata of the Brønlund Fjord Group (BF, Kap Troedsson and Bistrup Land Formations). The overlying platform interior carbonates of the Ryder Gletscher Group are assigned to the Blåfjeld (B1), Brikkerne (B2) and Blue Cliffs (B3) Formations; note the well-developed cyclicity and lateral persistence of stratal units, in contrast to the platform margin sediments of the Perssuaq Gletscher Formation (see above). The Blåfjeld Formation (B1) is *c.* 100 m thick. From Higgins *et al.* (1991a).

Ryder Gletscher Group: southern outcrop belt

The Cambrian platform carbonates defined herein and assigned to the Ryder Gletscher Group (Early Cambrian – Middle Ordovician) occur within the southern outcrop belt (Figs 2, 78) with main outcrops in southern Warming Land, southern Wulff Land and the land area south of Nares Land. To conform to the geographical regions adopted earlier, the four new formations are grouped under the Henson Gletscher region (Koch Væg Formation) and the Nordenskiöld Fjord – southern Warming Land region (Blåfjeld, Brikkerne and Blue Cliffs Formations; see Figs 5, 8).

Henson Gletscher region

Cambrian strata in this area are mainly assigned to the Brønlund Fjord and Tavsens Iskappe Groups, as described earlier. Cambrian platform carbonates assigned to the Ryder Gletscher Group crop out on the east side of the northern extension of Henson Gletscher near its junction with J. P. Koch Fjord (Fig. 23) and are well exposed in the steep cliffs of Koch Væg, above the glacier (Fig. 100A).

Koch Væg Formation

new formation

History. Previously described informally as formation T4 of the Tavsens Iskappe Group (Ineson & Peel, 1980), the Koch Væg Formation is equivalent to the 'medium-grained dolomite and limestone' forming the upper beds of Unit G of Dawes (1976b).

Name. After Koch Væg, the precipitous east side of

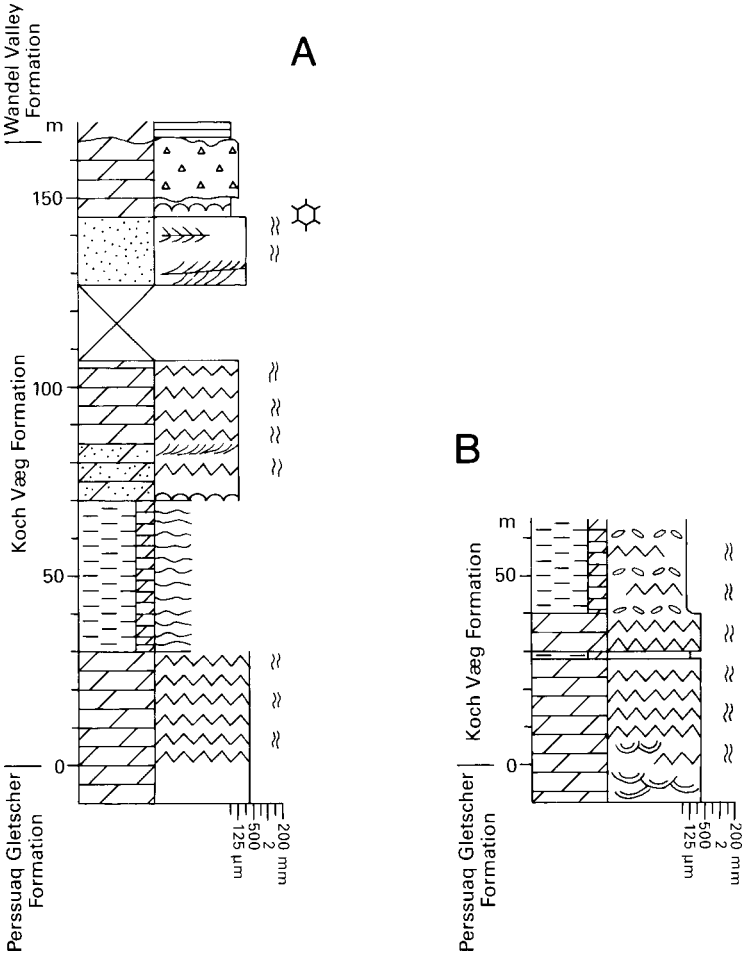


Fig. 101. Type (A) and reference (B) sections of the Koch Væg Formation at the north and south ends, respectively, of Koch Væg, west Peary Land (Figs 23, 100A). The distinctive dark band observed in this formation at Koch Væg (see Figs 100A, 102) occurs at 30–40 m in the reference section. See Fig. 14 for legend.

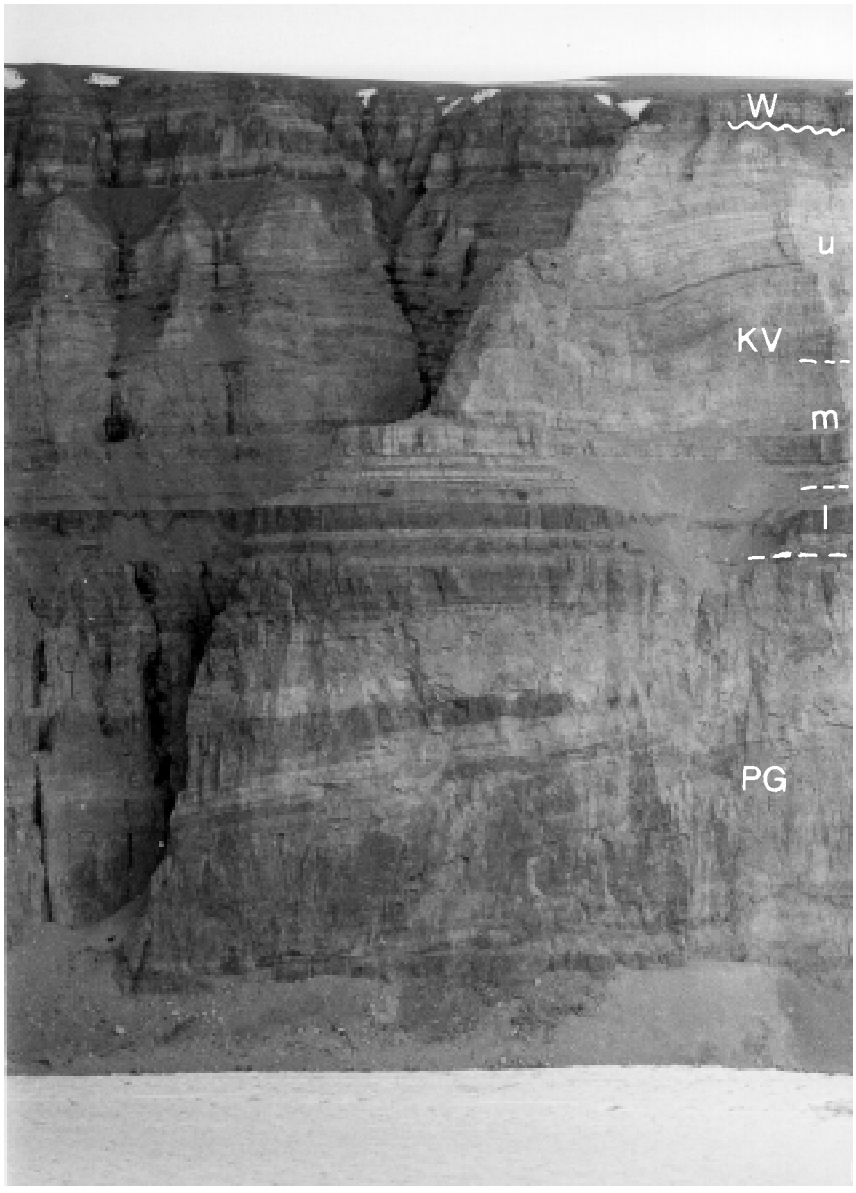


Fig. 102. Close-up view of central Koch Væg (Fig. 100A, right, at the prominent deep cleft). The Perssuaq Gletscher Formation (PG) shows well-developed clinoforms, dipping northwards (left), and is succeeded by more regularly bedded strata assigned to the Koch Væg Formation (KV); the lower (l), middle (m) and upper (u) units of the Koch Væg Formation are described in the text. Note the distinctive resistant dark band within the lower unit, the dark-light rhythmic banding and the sharp, locally irregular top of the middle unit and the gentle open folds in the bedding of the upper unit. W, Wandel Valley Formation.

Henson Gletscher, south-west Peary Land (Figs 23, 100A).

Type and reference sections. The type section (Fig. 101A) is defined just south of the major east–west trending fault (Troelsen's Fault; Figs 23, 100A), by Henson Gletscher, Peary Land. Owing to heavily weathered and locally inaccessible exposures, the type section alone does not fully characterise the formation. Thus, following Hedberg (1976), the formation is defined here from a composite section comprising the type section and a reference section located at the south end of Koch Væg (Fig. 101B).

Thickness. The thickness of this formation is poorly known. Accessible sections are rare and generally poorly exposed, but the formation is about 165 m thick at the type section. Estimates from cliff sections further south (see Fig. 102) yield values of 150–200 m.

Lithology. The formation is composed of generally pale weathering dolomites, argillaceous dolomites and sandstones. As noted above, the Koch Væg Formation is poorly exposed where accessible and correlation from the measured sections to the vertical cliff sections is tentative. The formation is broadly divisible into three units. The lower unit is roughly 70 m thick in the type section but appears to be only half this thickness in the cliff section farther south (Fig. 102). It is dominated by bioturbated, burrow-mottled, unfossiliferous

Fig. 103. Burrow-mottled dolomites in the Koch Væg Formation at the reference section.

dolomites that become more argillaceous up-section. The lowermost 30–40 m comprises medium to thick-bedded, light cream and yellow-brown weathering, medium to coarse-crystalline dolomites. Mottling is common, often delineating burrows (Fig. 103), and is defined by variation in colour, porosity and grain size, and locally by chert blebs and stringers. Although not recognised in the type section, a prominent dark grey weathering interval (*c.* 10 m thick) of intensely bioturbated dolomite caps these beds farther south along Koch Væg where it forms a distinctive marker (Figs 100A, 102). The succeeding beds of this lower unit of the Koch Væg Formation are thinner bedded and more argillaceous, forming a recessive ledge in cliff sections (Figs 101, 102). Flaggy, pale-weathering burrowed dolomites are interbedded with grey-green weathering silty mudstones and thin (3–20 cm) beds of flat pebble conglomerate. This interval is poorly exposed at the type section but is better represented at the reference section (Fig. 101B).

The middle, cliff-forming unit between 40 and 50 m thick weathers yellow-brown or dark grey and comprises burrow-mottled, medium to thick-bedded, pale grey dolomites and sandy dolomites. Cross-bedding was observed locally. Accessible outcrop of this unit is scarce; in cliff section it appears to have a gradational base to the argillaceous dolomites beneath and often has a dark-light banded appearance, particularly in its lower part (Fig. 102). The upper beds in contrast appear poorly stratified in cliff section and the top of this unit is sharp, locally with irregular relief (Fig. 102); this surface is of inferred karstic origin.

The uppermost unit (*c.* 70 m thick) has a distinctive, well-stratified, pale fawn- or green-grey appearance (Fig. 102). In cliff section the unit locally shows undulating bedding or open folding (Fig. 102). This may reflect drape of, or collapse into, irregular depressions on the basal (karstic?) surface of the upper unit. In the type section, this unit comprises cross-bedded and bioturbated sandstones, interbedded locally with silty, microbially-laminated dolomites. Grey-

Fig. 104. Cross-bedded, fine-grained sandstones with occasional vertical burrows *(Monocraterion)*. Koch Væg Formation, type section.

green silty mudstones form thin recessive interbeds and partings throughout. The fine- to medium-grained dolomitic sandstones show parallel lamination and tabular or trough cross-bedding in 2–10 cm sets (Fig. 104). They are commonly burrowed and are interbedded with mottled or structureless bioturbated dolomitic sandstones and sandy dolomites. Units of microbially-laminated dolomite, 0.2–1.5 m thick, occur more frequently towards the top of the formation. Planar or crinkly lamination is dominant, but small domal stromatolites are represented; desiccation cracks occur locally. The formation is capped by a pale weathering, massive, karstic breccia about 20 m thick, with an irregular base and hummocky top (Fig. 101A). It is composed of angular dolomite and sandstone clasts up to 30 cm across in a vuggy matrix of chert and coarse crystalline dolomite.

Boundaries. The Koch Væg Formation overlies the Perssuaq Gletscher Formation with apparent conformity (Fig. 100A, 102). The boundary is sharp in cliff sections, but in outcrop the lithological change appears gradational, from pale ooidal dolomites of the Perssuaq Gletscher Formation into bioturbated, darker weathering dolomites of the Koch Væg Formation (Fig. 101B). It should be noted, however, that exposure is poor at this level in the reference section and the marked boundary observed in cliff sections was not located at outcrop. At the type section, the boundary is placed at the first appearance of grey, burrow-mottled, fine to medium crystalline dolomites (Fig. 101A).

The Koch Væg Formation is unconformably overlain by upper Lower – Middle Ordovician dolomites of the Wandel Valley Formation (Peel, 1979; Peel & Smith, 1988). The unconformity is planar on a regional scale (Figs 100A, 102) and bedding is typically sub-parallel. At the type section, the upper beds of the Koch Væg

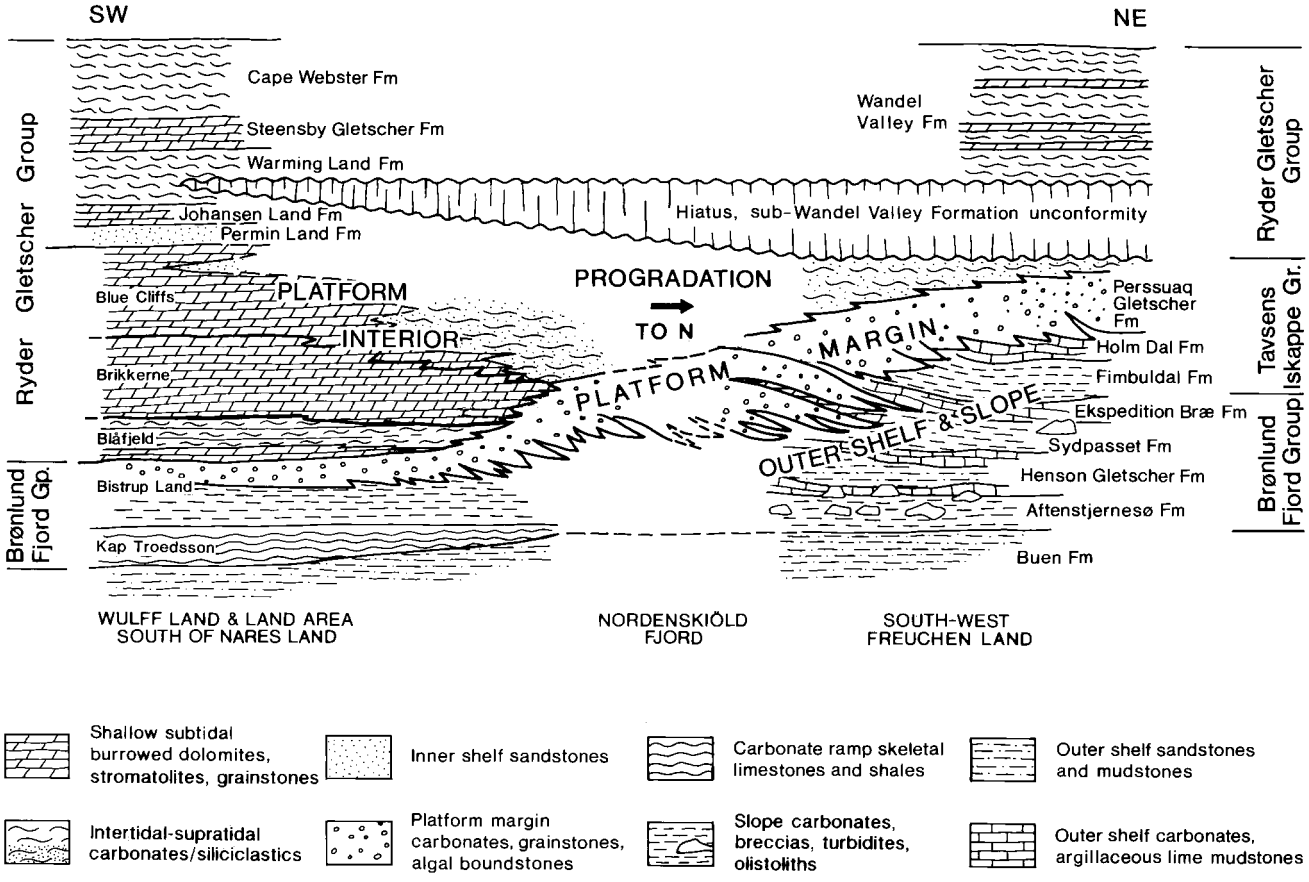


Fig. 105. Schematic diagram showing the stratigraphic relationships between the platform interior strata of the Ryder Gletscher Group and the platform margin, slope and deep shelf sediments of the Brønlund Fjord and Tavsens Iskappe Groups in the vicinity of Nordenskiöld Fjord, central North Greenland. Note that adjacent to the fjord, the Blue Cliffs Formation rests directly on massive platform margin dolomites assigned to the Bistrup Land Formation (see Fig. 85). Exposure of the upper Perssuaq Gletscher Formation is poor in this immediate area so its contact with the Bistrup Land Formation is not observed and the presence of platform interior facies above the Perssuaq Gletscher Formation is speculative. Modified from Higgins *et al.* (1991a).

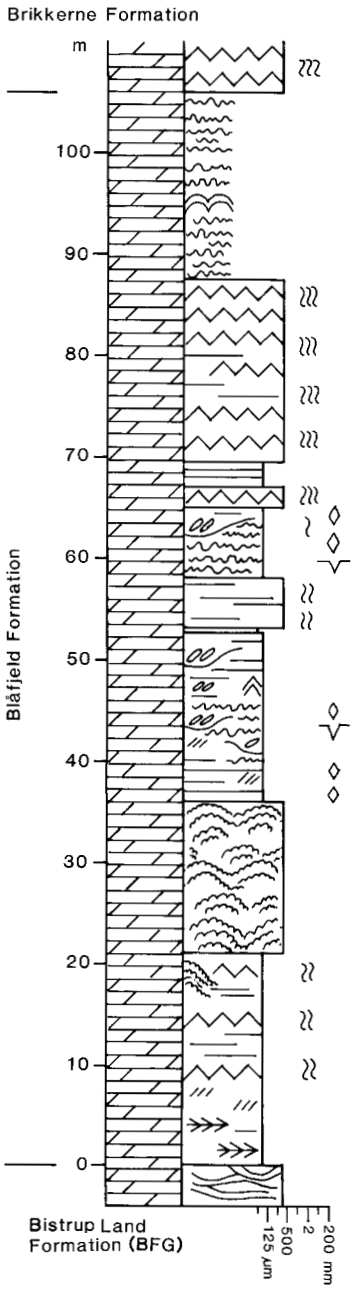


Fig. 106. Type section of the Blåfjeld Formation, south-west Wulff Land (Figs 78, 100B). The succession is readily subdivided into a lower uniform dark-weathering unit (0-36 m) and an upper banded succession of interbedded dark subtidal and light peritidal dolomites (36–106 m). See Fig. 14 for legend.

Formation are intensely brecciated to a depth of 20 m below the unconformity and the plane of the unconformity is irregular and hummocky, with a relief of up to a few metres, draped by the pale grey, thin-bedded and laminated, cherty dolomites of the Wandel Valley Formation.

Distribution. The formation has a restricted distribution and is only recognised south of Troelsen's Fault, west of Hans Tavsen Iskappe in south-west Peary Land (Fig. 23). It crops out from the east side of Henson Gletscher eastwards to Fimbuldal, near the western margin of Hans Tavsen Iskappe. The formation is well exposed along the east wall of the glacier (Figs 100A, 102), but is only accessible at the northern and southern extremities of Koch Væg.

Fauna and age. Fossils have not been recovered. The formation conformably overlies the Perssuaq Gletscher Formation which is considered to be of Middle to Late Cambrian age in this area, and is unconformably overlain by the Wandel Valley Formation of late Early Ordovician – Middle Ordovician age. A late Middle – Late Cambrian age is thought most likely.

Nordenskiöld Fjord – Warming Land region

The Cambrian portion of the Ryder Gletscher Group in the region from Nordenskiöld Fjord in the east, to southern Warming Land in the west, is represented by the Blåfjeld, Brikkerne and Blue Cliffs Formations (Figs 5, 100B, 105).

Blåfjeld Formation

new formation

History. This formation was described informally as RG2 (in part) and RG3 of the Ryder Gletscher Group by Peel & Wright (1985) and equates to the redescribed informal formation RG3 of Ineson & Peel (1987, see discussion therein).

Name. After Blåfjeld, a hill on the western coast of Nares Land (Fig. 78). Composed of Ordovician–Silurian strata, Blåfjeld lies north of the broad outcrop of the Ryder Gletscher Group which extends east–west from Nordenskiöld Fjord to Victoria Fjord, in terrain with few named geographical features.

Type section. Fig. 106; east side of the prominent north–south valley, east of Ryder Gletscher, Wulff Land (Figs 78, 100B, 107).

Thickness. 106 m at the type section. A comparable thickness is maintained over much of its outcrop but the formation thins rapidly eastwards just west of Nordenskiöld Fjord (Fig. 105).

Lithology. The Blåfjeld Formation is composed wholly

Fig. 107. Typical development of the Blåfjeld (B1), Brikkerne (B2) and lowermost Blue Cliffs (B3) Formations in south-west Wulff Land. Note the cyclic alternation of dark subtidal dolomites and light intertidal-supratidal dolomites in the Blåfjeld Formation.

of dolomite and characteristically shows a distinctive banded outcrop pattern (Fig. 107). This results from an alternation of intervals of grey-brown weathering, medium-bedded to thick-bedded, dark grey dolomites and very pale, silvery-grey, thin-bedded dolomites.

In the type section (Fig. 106), the formation is readily subdivided into a lower homogeneous dark-weathering unit and a thicker, upper banded unit. The lower unit (36 m thick) comprises dark grey-brown weathering dolomite; medium to thick bedding is evident in the lower half of the unit but the upper levels are massive and show only subtle bedding structure. The lower bedded interval comprises burrow-mottled dolomites with subordinate thin (*c.* 10 cm thick) intraclastic grainstone beds that display trough or planar herring-bone cross-bedding. Oncoids become increasingly common up-section and form discrete oncoid packstone/grainstone beds towards the top of this interval. The uppermost 15 m of this basal dark unit of the Blåfjeld Formation comprises dark grey-brown, faintly mottled dolomite. Although overtly massive, crude bedding defines large symmetrical to elongate mounds, 5–10 m across with relief of up to several metres (see Fig. 11E); these mounds are especially well-developed near the base of this massive interval. Stromatolitic lamination is rarely observed and these are best described as thrombolite mounds.

The upper unit (70 m thick) is a succession of pale silvery-grey, recessive-weathering dolomites alternating with prominent units of burrow-mottled, locally laminated grey-brown dolomites (Figs 106, 107). The former display planar or crinkly microbial lamination, domal stromatolites, bird's-eye fenestrae, desiccation cracks and wave-ripples (Fig. 108A). Lenticular flat-pebble conglomerate beds (10–20 cm thick) occur at regular intervals and thin dark burrow-mottled dolomite beds are locally present. The prominent thick grey-brown units are typically more massive and characterised by burrow-mottling (Fig. 108B). Faint lamination is discernable locally and thin (max. 1 m) light grey stromatolitic dolomite beds occur rarely.

Contacts between the pale stromatolitic dolomite

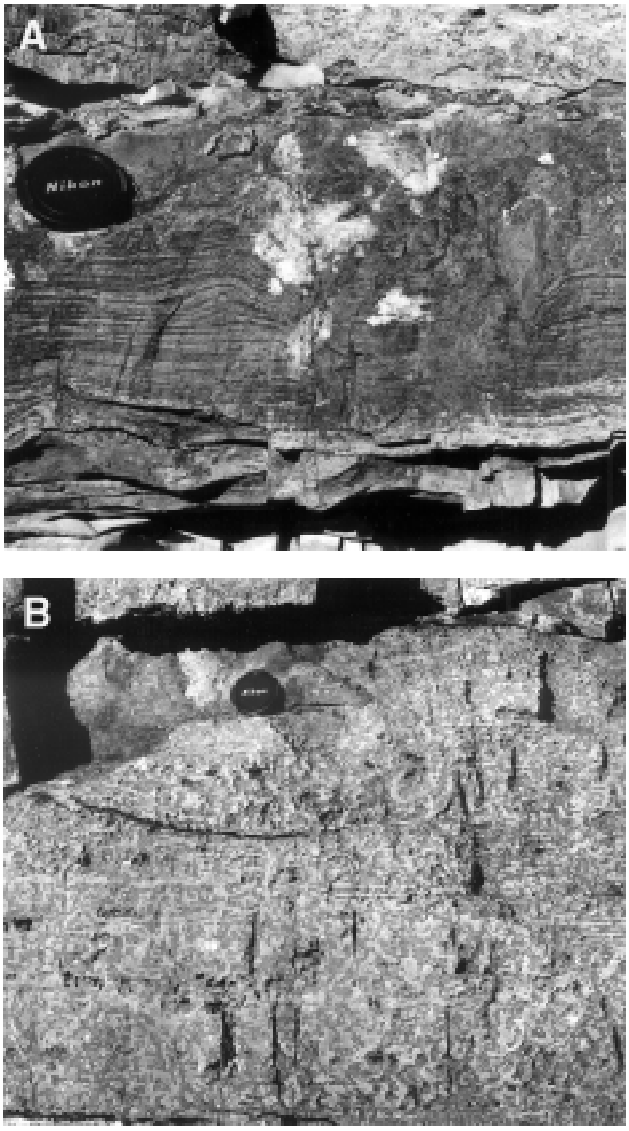


Fig. 108. **A**. Stromatolitic dolomites. **B**. Burrow-mottled dolomites; note local preservation of weak parallel stratification. Blåfjeld Formation, type section.

units and the succeeding burrow-mottled facies are typically sharp (see Fig. 11D); such dark-light couplets are laterally persistent and retain a constant thickness at outcrop scale (i.e. up to 10 km).

Boundaries. The Blåfjeld Formation conformably overlies the Bistrup Land Formation; the boundary is placed where dark, grey-brown weathering, mottled dolomites overlie mid-grey to light grey or cream bedded dolomites that commonly show relict grainstone textures and cross-bedding. This boundary is readily recognised in cliff sections (Fig. 100B). The top of the formation is defined at the base of the massive, cliff-forming, grey-brown dolomites of the Brikkerne Formation overlying the upper pale microbial dolomites of the Blåfjeld Formation (Fig. 107).

Distribution. The Blåfjeld Formation crops out in southern Wulff Land, Warming Land, and in the land area south of Nares Land (Fig. 78). The easternmost limit of the formation, a few kilometres west of the head of Nordenskiöld Fjord, is defined by the point where the well-bedded platform interior carbonates of the Blåfjeld Formation interdigitate with massive platform margin carbonates of the Bistrup Land Formation (Fig. 105).

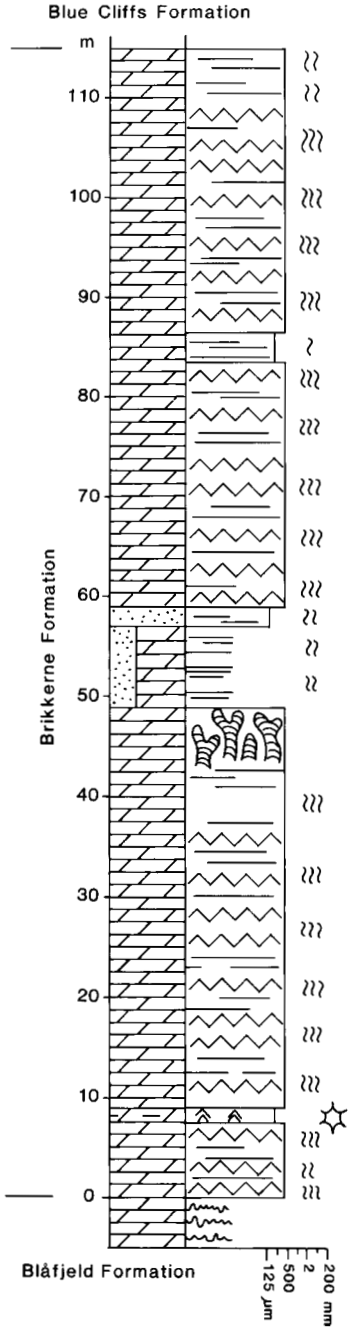


Fig. 109. Type section of the Brikkerne Formation, south-west Wulff Land (Figs 78, 100B). See Fig. 14 for legend.

Fig. 110. Microbial dolomites forming a low-relief mound within the Brikkerne Formation at the type section. The vertical and horizontal sections illustrate the complex linked columnar form of the stromatolitic framework (light component). From Higgins *et al.* (1991a).

Fauna and age. No fossils have been recovered from the dolomites of the Blåfjeld Formation. An Early to Middle Cambrian age is assumed on grounds of its stratigraphic position and correlation to deeper-water outer shelf strata assigned to the Brønlund Fjord Group.

Brikkerne Formation

new formation

History. Previously referred to informally as formation RG4 of the Ryder Gletscher Group (Peel & Wright, 1985; Ineson & Peel, 1987).

Name. After Brikkerne, a series of nunataks south of Nares Land, to the east of the head of Victoria Fjord (Fig. 78). Some uncertainty surrounds the geographical placement of the feature. The Army Map Series (AMS) 1:250 000 topographic map series and the 1:500 000 Geological Map Sheet 7 (Nyeboe Land) published by the Geological Survey of Greenland (1989) identify Brikkerne as a single dumbbell-shaped nunatak, but approved usage followed here indicates a string of hills and nunataks forming the southern margin of the land area south of Nares Land.

Type section. Fig. 109; east side of the major north–south valley, south-west Wulff Land.

Thickness. The Brikkerne Formation is 115 m thick at the type section. Although of relatively uniform thickness across Warming Land and south Wulff Land, the formation thins eastwards in the vicinity of Nordenskiöld Fjord (see Fig. 105 and discussion below).

Lithology. The Brikkerne Formation characteristically forms prominent dark grey-brown weathering cliffs between the banded Blåfjeld Formation beneath and the light grey-green argillaceous carbonates of the Blue Cliffs Formation. The Brikkerne Formation is a uniform succession of thick-bedded unfossiliferous burrow-mottled dolomites. In the type section this monotonous succession of bioturbated, locally faintly laminated dolomites is interrupted at three levels by more varied facies. A 1 m thick unit of silty, sandy dolomites, 8 m above the base (Fig. 109), shows lamination of inferred microbial origin, wave ripples and desiccation cracks. A distinctive pale grey sucrosic dolomite unit at 43–49 m in the type section (Fig. 109) shows spectacular columnar stromatolites (Fig. 110). Laterally, such stromatolite units are seen to wedge out over several tens of metres within the more typical dark bioturbated facies and represent low-relief stromatolitic bioherms. In the type section a sandy glauconitic dolomite unit (*c*. 10 m thick) overlies the stromatolitic interval.

Boundaries. The base of the Brikkerne Formation is sharp and planar; it is placed where dark grey-brown, prominent weathering dolomites overlie pale silvery-grey stromatolitic dolomites of the upper Blåfjeld Formation (Fig. 107). The top of the formation is placed at the boundary between these cliff-forming dark dolomites and recessive-weathering, poorly-exposed, argillaceous lime mudstones assigned to the Blue Cliffs Formation.

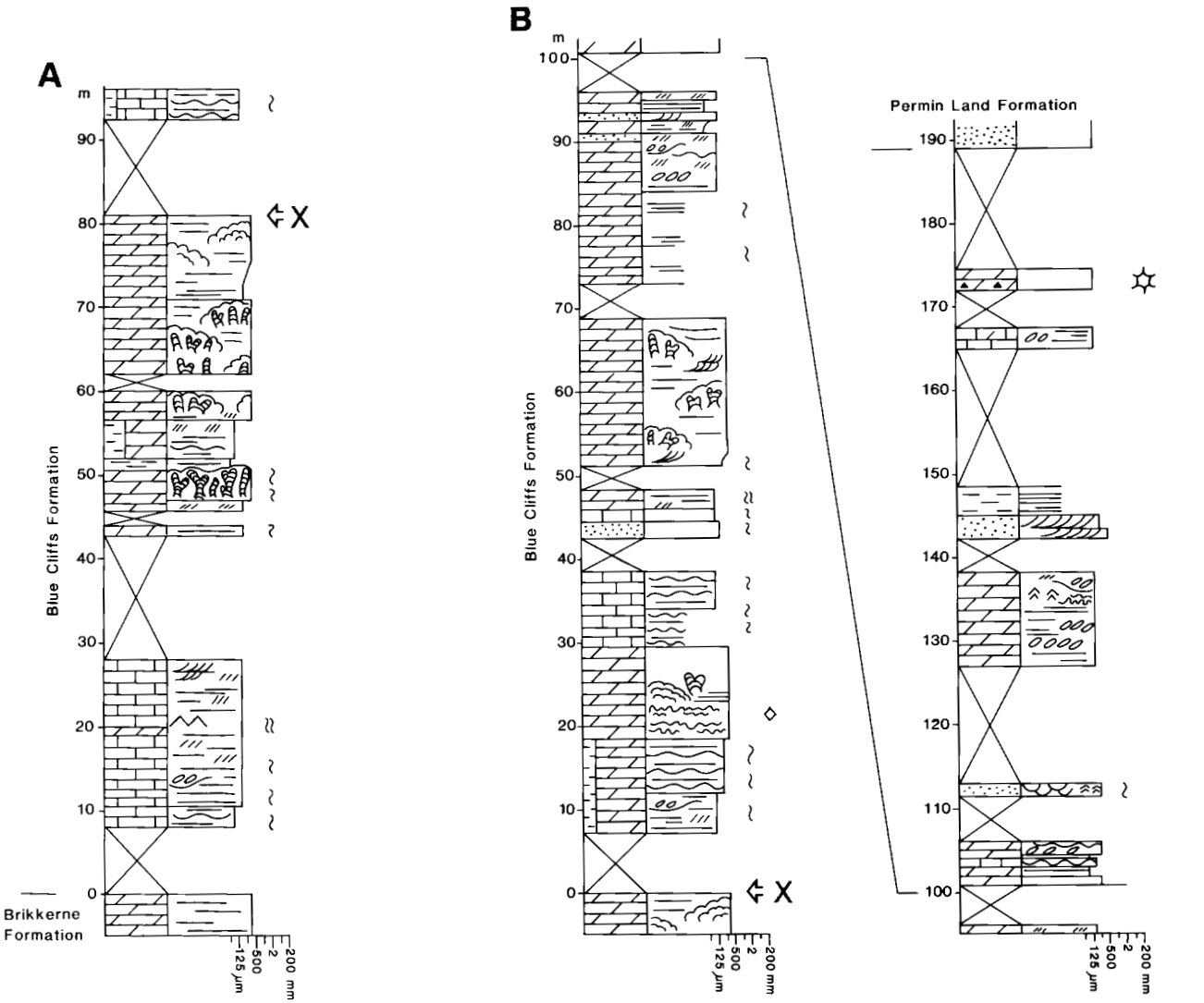


Fig. 111. **A**. Type section of the Blue Cliffs Formation, south-west Wulff Land (Fig. 78, locality C). **B**. Reference section of the Blue Cliffs Formation, south-west Wulff Land (Fig. 78, locality D). X marks the top of a marker bed that is recognised in both the type and reference sections. See Fig. 14 for legend.

Distribution. The Brikkerne Formation forms a distinctive dark weathering unit throughout Warming Land and southern Wulff Land and extends eastwards across the land area south of Nares Land to a point a few kilometres south-west of the head of Nordenskiöld Fjord where it interdigitates with pale carbonates of the Bistrup Land Formation (Brønlund Fjord Group, see Fig. 105).

Fauna and age. No fossils were recovered from the dolomites of the Brikkerne Formation; a Middle Cambian age is assumed on the basis of its stratigraphic position above the ?Lower to Middle Cambrian Blåfjeld Formation and beneath the Blue Cliffs Formation which yields late Middle Cambrian faunas in its lower part (see below).

Blue Cliffs Formation

new formation

History. Previously referred to informally as formations RG5 and RG6 of the Ryder Gletscher Group (Peel & Wright 1985).

Name. After Blue Cliffs, the precipitous south-western margin of Wulff Land, along Ryder Gletscher (Fig. 78, see also Fig. 11C).

Type and reference sections. The Blue Cliffs Formation is defined on the basis of two incomplete sections in the prominent north–south valley in south-west Wulff Land (Fig. 78). The southernmost of these, on the eastern side of the valley (Fig. 78, locality C), illustrates

Fig. 112. Microbial dolomites forming part of a mound within the Blue Cliffs Formation in the type section, showing a distinctive narrow columnar stromatolite form.

the lower part of the formation and is here defined as the type section (Fig. 111A). The reference section (Fig. 111B), on the western side of the valley about 5 km to the north-west (Fig. 78, locality D), illustrates the upper two-thirds of the formation and the upper boundary.

Thickness. The total thickness of the Blue Cliffs Formation is approximately 270 m; the type section illustrates the lower 80 m and the reference section the upper 190 m of strata.

Lithology. The Blue Cliffs Formation is a varied succession of limestones, dolomites, sandstones and mudstones. The proportion of siliciclastic strata increases both stratigraphically upwards and eastwards in the formation (see Figs 105, 111). The formation typically forms recessive weathering light coloured slopes and is generally poorly exposed, particularly in its uppermost levels.

The lower 30 m of the formation in the type section are dominated by wavy to parallel thin-bedded lime mudstones with interbeds and partings of silty mud-

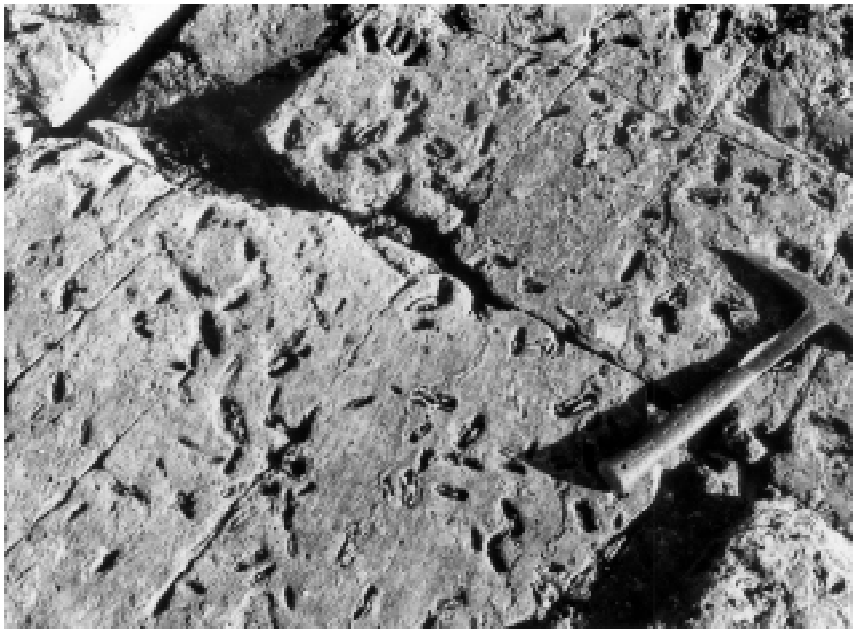


Fig. 113. Sandstone bedding plane showing characteristic cross-sections through *Diplocraterion* burrows. Blue Cliffs Formation, reference section.

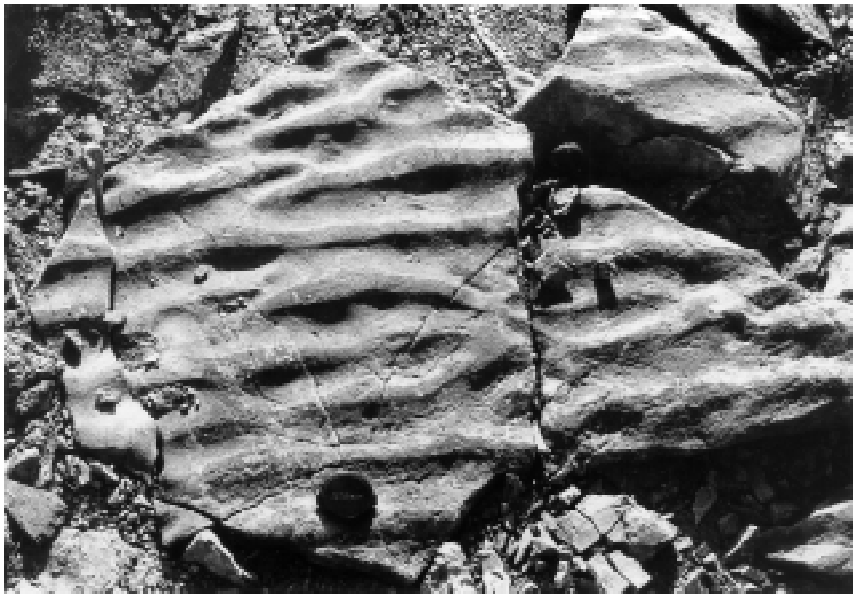


Fig. 114. Sandstone bedding plane showing flat-topped wave-ripples. Blue Cliffs Formation, south-west of Nordenskiöld Fjord.

stone that lend a green-grey colour to weathered slopes; the boundary between this green shaly facies and the dark brown weathering, cliff-forming dolomites of the Brikkerne Formation beneath is a distinctive mapping horizon. Rare fossiliferous lime packstone and grainstone beds show cross-lamination and small-scale cross-bedding; lenticular flat-pebble conglomerate beds are present in places. Bioturbation is common.

The upper half of the type section as well as the lower *c.* 70 m of the reference section comprise a cyclic succession of laminated and cross-laminated dolomites, stromatolitic biohermal dolomites and dolomitised grainstones. Typical cycles are 10–25 m thick and coarsen up from argillaceous lime mudstones or dolomites at the base to massive dolomite units comprising stromatolitic mounds (Fig. 112) interfingering laterally with carbonate grainstones. The units of mounds and grainstones are laterally continuous at the scale of outcrop, with individual mounds varying in diameter from about 1–10 m; the intervening grainstone facies commonly displays cross-bedding. Such bioherm-grainstone units typically form more resistant ledges and one such distinctive pale brown weathering massive unit (about 20 m thick) caps the type section and defined the top of the informal RG5 of the preliminary stratigraphic subdivision (Peel & Wright, 1985).

The upper 120 m of the Blue Cliffs Formation is typically poorly exposed (see Fig. 111B). It comprises a varied succession of light-coloured, recessive weathering dolomites, limestones, sandstones and silty mudstones. The proportion of siliciclastics increases up the succession and laterally from west to east. In the reference section, these upper beds of the Blue Cliffs Formation are parallel to wavy, thin-bedded dolomites and lime mudstones interbedded with cross-laminated carbonates and flat-pebble conglomerates. Wave-rippled surfaces are common and microbial lamination and desiccation cracks occur in places. Sandstones occur as thin interbeds and units up to several metres thick. They show small- to medium-scale trough and planar cross-bedding and wave-rippled bedding planes and are locally bioturbated (Fig. 113). Green and purple silty mudstones interbedded with pale dolomites form a conspicuous unit (about 10 m thick) at about 90 m below the top of the formation in the reference section.

The proportion of siliciclastic sediments increases eastwards and they dominate the upper half of the formation just west of Nordenskiöld Fjord. In this area, trough and planar cross-bedded, well-sorted fine to medium-grained sandstones form units up to 10 m thick; flat, low-angle lamination, herring-bone cross-bedding and wave-rippled, desiccation-cracked bedding surfaces occur locally (Fig. 114, see also Fig 11F). These sandstone packets alternate with stromatolitic dolomites, wave-rippled dolomites and flat-pebble conglomerates.

Boundaries. The base of the Blue Cliffs Formation is defined where greenish-grey, recessive weathering argillaceous lime mudstones overlie prominent dark grey-brown burrow-mottled dolomites assigned to the Brikkerne Formation. Approaching Nordenskiöld Fjord, in the land area south of Nares Land, the underlying

Fig. 115. Platform interior strata of the Ryder Gletscher Group east of the southern tip of Nares Land. The unconformity (u) separating the lower, gently folded strata from the upper, homoclinal strata becomes increasingly significant eastwards, correlating with the sub-Wandel Valley Formation unconformity that separates Cambrian from Ordovician strata over much of central North Greenland (see Figs 5, 6, 19, 54). The unconformity is not recognised farther west than this locality. These exposures exemplify, on a small-scale, the regional stratigraphic relationships at the top of the Blue Cliffs Formation. In its western outcrop, as on the flanks of this local fold structure, the Blue Cliffs Formation (B3) is conformably overlain by the siliciclastic Permin Land Formation (PL). In eastern areas, however, the Blue Cliffs Formation is unconformably overlain by Ordovician strata, as over the crest of this anticlinal structure. J, Johansen Land Formation; WA, Warming Land Formation; SG, Steensby Gletscher Formation; CW, Cape Webster Formation. The Permin Land Formation is 23 m thick. From Higgins *et al.* (1991a).

Blåfjeld and Brikkerne Formations pinch out into the massive carbonates of the Bistrup Land Formation such that the Blue Cliffs Formation is seen to ultimately rest conformably on the Bistrup Land Formation on either side of the fjord (Fig. 105). The boundary is placed where massive, structureless pale-coloured dolomites are succeeded by well-bedded dolomites and siliciclastic sediments.

The character and definition of the top of the Blue Cliffs Formation also varies from the west to the east. In Warming Land, southern Wulff Land and the land area south of Nares Land, the Blue Cliffs Formation is conformably overlain by Upper Cambrian – Lower Ordovician strata of the Permin Land Formation, forming a conspicuous regional marker horizon (Figs 11C, 105, 115). The boundary is placed where recessive weathering microbially-laminated dolomites, flat-pebble conglomerates and subordinate thin-bedded sandstones are succeeded by massive cliff-forming white sandstones assigned to the Permin Land Formation. Bryant & Smith (1985) noted the possibility of confusion between the thin sandstones of the Blue Cliffs Formation and the sandstone-dominated Permin Land Formation and thus defined the boundary at the base of the first 10 m sandstone unit.

As shown in Fig. 105, the regional unconformity developed beneath the Wandel Valley Formation (late Early – Middle Ordovician) in central North Greenland

decreases in stratigraphic significance westwards such that the hiatus cannot be recognised west of Nares Land where it is seen within the Warming Land Formation (Fig. 115). The Permin Land Formation has been traced to about 20 km west of the head of Nordenskiöld Fjord and to the east of this point the top of the Blue Cliffs Formation is an unconformity; banded peritidal carbonates of the Wandel Valley Formation abruptly overlie the mixed siliciclastic sediments and carbonates of the upper Blue Cliffs Formation. Bedding in these two formations is typically parallel but along Nordenskiöld Fjord, gentle open folds locally deform the Blue Cliffs Formation and truncation may be observed at the unconformity.

Distribution. The Blue Cliffs Formation crops out from Warming Land in the west to just north-east of Nordenskiöld Fjord in southern Freuchen Land (Fig. 78).
Fauna and age. The Blue Cliffs Formation is only sparsely fossiliferous. Limestones near the base of the formation have yielded trilobites of late Middle Cambrian age, whereas forms near the middle of the formation include *Terranovella* sp., indicating a middle Dresbachian (Late Cambrian) age (Palmer *in* Peel, 1980). The upper levels of the formation are unfossiliferous but, on the basis of correlation to the Washington Land area of western North Greenland, Bryant & Smith (1985, 1990; Smith & Bjerreskov, 1994) suggested that the uppermost beds of the Blue Cliffs Formation approached the Cambrian–Ordovician boundary. The Blue Cliffs Formation thus ranges in age from late Middle Cambrian to uppermost Late Cambrian or earliest Ordovician, at least in its western outcrop. Farther east, the upper beds of the formation are probably stratigraphically older due to truncation at the sub-Wandel Valley Formation unconformity.

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