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Lithostratigraphy, sedimentary evolution and sequence stratigraphy of the Upper Proterozoic Lyell Land Group (Eleonore Bay Supergroup) of East and North-East Greenland

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Eleonore Bay Supergroup, Lyell Land Group, Late Proterozoic, East Greenland, Caledonides, lithostratigraphy, sequence stratigraphy, siliciclastic marine sediments, sedimentary environments, facies associations, outer shelf, inner shelf, shoreface, coastal plain, palaeocoastline orientation, basin physiography, palaeogeographic reconstruction

Cover
View of the Lyell Land Group on the southern shores of Lyell Land and the snow-capped Berzelius Bjerg seen from Scoresby Land. The basal formation of the Lyell Land Group (Kempe Fjord Formation) is not exposed, and most of the overlying Sandertop Formation is covered by scree to the left (west). The rest of the group is well exposed and shows the pale weathering Berzelius Bjerg Formation, followed by the grey to brownish red weathering Kap Alfred Formation. The Vibeke Sø Formation forms a conspicuous pale unit in the centre of the picture and is overlain by the reddish Skjoldungebræ Formation. The top of the group is formed by the yellowish weathering Teufelsschloss Formation. The Lyell Land Group is overlain by grey, red and pale weathering mainly carbonate rocks of the Ymer Ø and Andrée Land Groups. Mountain summit is approximately 1900 m. For geological annotation see Fig. 7.

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Abstract

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The Late Proterozoic Lyell Land Group is an approximately 3 km thick succession of siliciclastic shelf deposits, within the upper part of the Eleonore Bay Supergroup. It is widely exposed in the region between Ardencaple Fjord in the north and Canning Land in the south. In this paper the seven formations named by Sønderholm & Tirsgaard (1993) are formally described. These are from base to top: the Kempe Fjord Formation (400–600 m thick), the Sandertop Formation (200–405 m thick), the Berzelius Bjerg Formation (250–450 m thick), the Kap Alfred Formation (500–640 m thick), the Vibeke Sø Formation (290–325 m thick), the Skjoldungebræ Formation (205–240 m thick) and the Teufelsschloss Formation (35–110 m thick).

Five facies associations have been recognised. Outer shelf deposits dominated by dark green, brown to dark red mudstones with thin sandstone lenses are mainly found in the Sandertop, Kap Alfred and Skjoldungebræ Formations. Storm- and wave-dominated inner shelf deposits comprising fine-grained sandstones and dark heterolithic mudstones are common in the Sandertop, Kap Alfred, Vibeke Sø and Skjoldungebræ Formations and are also found in southern outcrops of the Teufelsschloss Formation. Tidally influenced shoreface deposits form stacks of laterally extensive sandstone bodies separated by heterolithic mudstones and are only found in the middle part of the Kap Alfred Formation. Storm- and wave-dominated shoreface deposits comprise highly mature, thick and laterally very extensive sandstone bodies of which a few may be traced for distances exceeding 150 km. This association is present in several intervals within all formations of the Lyell Land Group. Tidally dominated coastal plain deposits consist of stacked sandstone sheets forming laterally extensive, multistorey units separated by heterolithic mudstones and sandstones. These sediments form part of the Kempe Fjord and Berzelius Bjerg Formations and are also found in northern outcrops of the Teufelsschloss Formation. Evidence from palaeocurrent data combined with regional lithological variations suggest a consistent general N–S coastline with the basin deepening in an eastward direction. Deflection of geostrophic currents suggest a palaeolatitude on the southern hemisphere.

The deposits of the Lyell Land Group are subdivided into four, large-scale sequences which overall show the same general sedimentary evolution through time reflecting large-scale, cyclic changes in relative sea-level. The sequences vary in thickness from 400–1000 m and are all readily traceable 300 km parallel and 100 km perpendicular to inferred palaeocoastline. The development of all sequences indicates that major regional translation of facies are related to large-scale forced regressions. Sequence stratigraphic considerations suggest that correlation of formations of the Lyell Land Group with units of the Petermann Bjerg Group some 75 km to the west may be very difficult to carry out.

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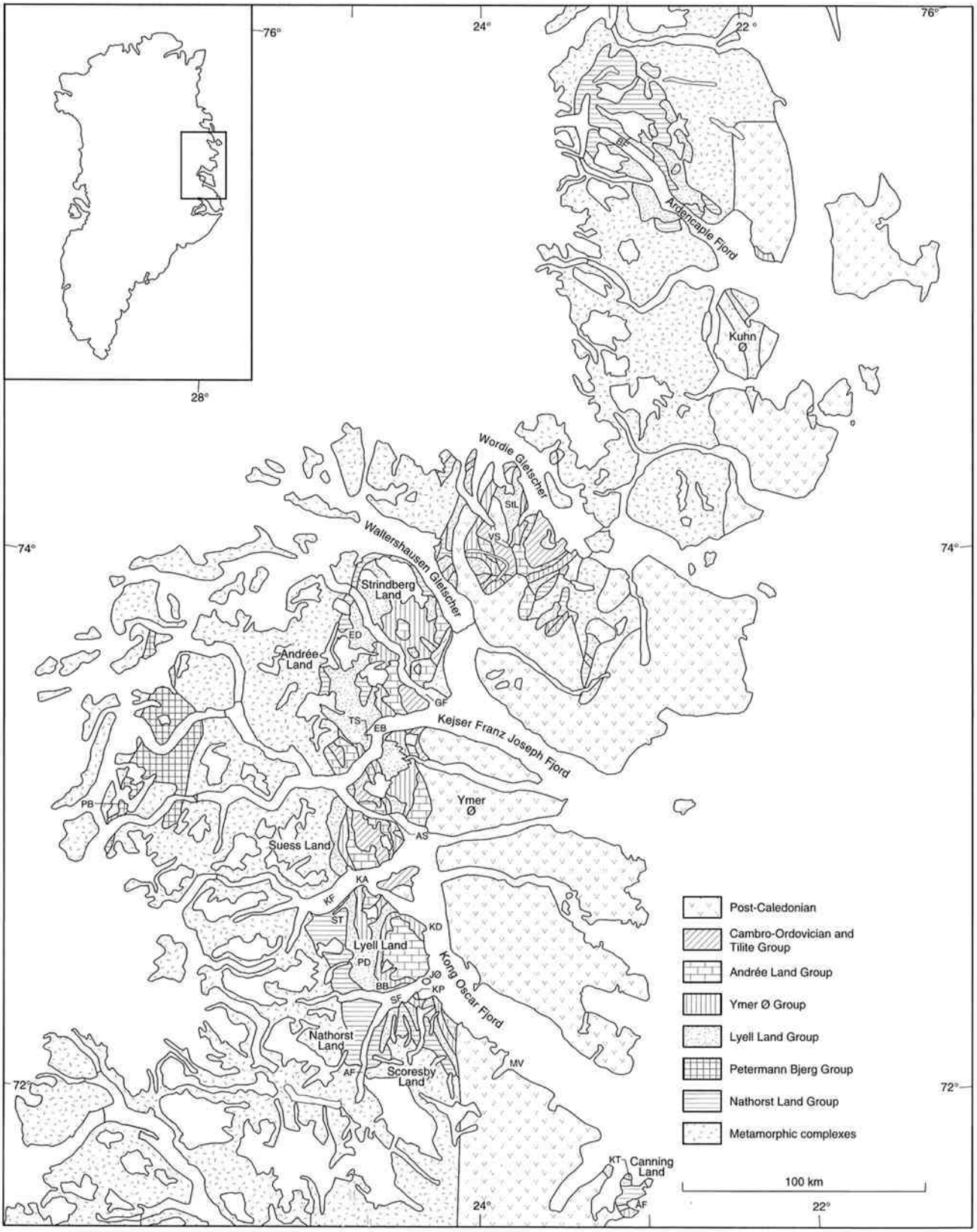

Fig. 1. Simplified geological map showing the distribution of the Eleonore Bay Supergroup outcrops in East and North-East Greenland with geographical place names used in the text from north to south: BF: Bredefjord, StL: Steno Land, VS: Vibeke Sø, ED: Eremitdal, GF: Geologfjord, EB: Eleonore Bugt, TS: Teufelsschloss, PB: Petermann Bjerg, AS: Antarctic Sund, KA: Kap Alfred, KF: Kempe Fjord, ST: Sandertoppene, KD: Kap Dufva, PD: Polhelm Dal, BB: Berzelius Bjerg, SF: Segelsällskapet Fjord, JØ: Jägmästarens Ø, KP: Kap Peterséns, AF: Alpefjord, MV: Mesters Vig, KT: Kap Tyrrell, ÅF: Ålborg Fjord. The 'central fjord zone' coincides with the Eleonore Bay Supergroup outcrop area between Waltershausen Gletscher and Alpefjord. Modified from Sønderholm & Tirsgaard (1993).

Introduction

The Late Proterozoic Lyell Land Group is an approximately 3 km thick succession of siliciclastic shelf deposits, widely exposed in the region between Ardencaple Fjord and Scoresby Land (Fig. 1). It forms part of the more than 16 km thick Eleonore Bay Supergroup (Fig. 2; Sønderholm & Tirsgaard, 1993), in which it overlies an approximately 11 km thick succession of mainly siliciclastic deposits, constituting the Nathorst Land Group. It is overlain by the 1 km thick Ymer Ø Group and 1.5 km thick Andrée Land Group, both consisting predominantly of carbonate platform sediments (Fig. 2). Although dating is poor, the deposits of the Eleonore Bay Supergroup are generally considered to have been laid down during a time period of approximately 200–300 Ma, covering the Late Proterozoic Riphean and Sturtian Epochs (Sønderholm & Tirsgaard, 1993). Together with the overlying Tillite Group and the Cambro-Ordovician succession, the Eleonore Bay Supergroup constitutes a relatively continuous depositional record, which reflects the disintegration and subsequent accretion of a supercontinent in connection with the opening and closing of the Iapetus Ocean (Sønderholm & Tirsgaard, 1993). It has previously been suggested that the Eleonore Bay Supergroup, including the Lyell Land Group, was laid down along a passive continental margin of the Iapetus Ocean (e.g. Harland & Gayer, 1972; Caby & Bertrand-Sarfati, 1988).

Aspects of the sedimentology of the Eleonore Bay Supergroup, including the Lyell Land Group have recently been described by Sønderholm *et al.* (1989), Sønderholm & Tirsgaard (1990), Sønderholm & Tirsgaard (1993) and Tirsgaard (1993), but more comprehensive basinwide studies of the siliciclastic deposits of the Eleonore Bay Supergroup have not previously been published. This paper presents a sedimentological analysis of the Lyell Land Group and includes descriptions and interpretations of a range of depositional environments within the group. From the distribution of the sedimentary environments in time and space, a model of the depositional evolution of the group is suggested. Although biostratigraphic data are missing, the model uses basic sequence stratigraphic principles in order to define the major events in the basin evolution, which reflect basinwide reorganisation of the palaeogeography.

The Lyell Land Group was formally defined by Sønderholm & Tirsgaard (1993) and corresponds to the 'Quartzit Serie' and the lower part of the 'Bunte Serie' of Teichert (1933) and to the 'Quartzit Serie' of Katz (1952), Eha (1953), Fränkl (1953a, b) and Sommer (1957a, b). Sønderholm & Tirsgaard (1993) provided a comprehensive review of the Eleonore Bay Supergroup including the Lyell Land Group along with a historical review and a more detailed lithostratigraphic description. They subdivided the Lyell Land Group into seven formations mappable throughout the area of exposure; formations were defined in a generalised sedimentological log and in the terrain (Sønderholm & Tirsgaard,

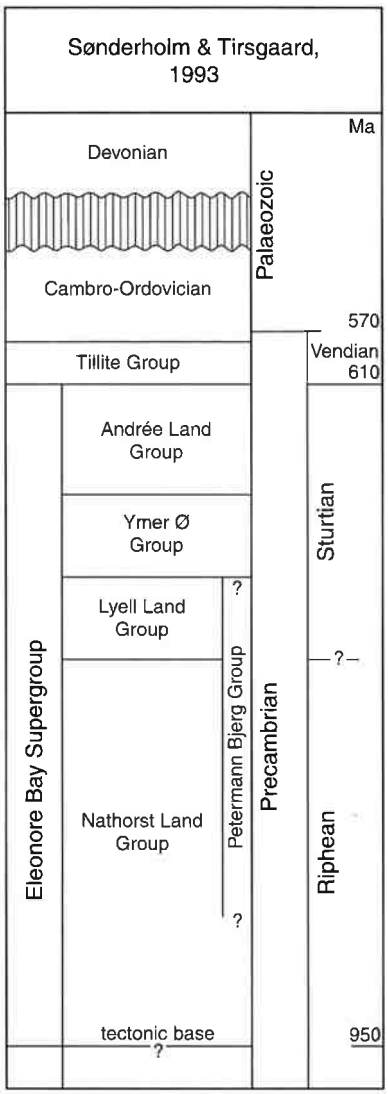

Fig. 2. Lithostratigraphic subdivision of the Eleonore Bay Supergroup after Sønderholm & Tirsgaard (1993).

1993, figs 9, 17–21, 23) but no formal descriptions of the formations were given. In the first section of this paper, these seven formations are formally defined and described in detail. The subdivision and the formation names are identical to those published by Sønderholm & Tirsgaard (1993).

Terminology

In the lithological descriptions of the Lyell Land Group, only basic grain size terms are used, e.g. 'sandstone' is used in preference to 'quartzite' and 'mudstone' instead of 'shale'. Nomenclature of the various stratigraphic units follows that of Sønderholm & Tirsgaard (1993).

There exists no universally accepted subdivision of shelves and shelf environments, or any general consensus on terminology, with consequent ambiguity. Tillman (1985) for instance, subdivides the shelf into shoreface, inner shelf, middle shelf and outer shelf zones, while Reading & Collinson (1996) use the terms shoreface, offshore-transition and offshore zones. Walker & Plint (1992) simply use a twofold subdivision applying the terms shoreface and offshore zone.

In this paper, the shelf is subdivided into three zones: outer shelf, inner shelf and shoreface. Landward of the shoreface lies the coastal plain. The outer shelf lies below storm wave base, and deposition is here dominated by suspension fall-out. The inner shelf lies between the fair-weather wave base and the storm wave base and is characterised by an interaction of oscillatory movements and uni- or bi-directional currents. The shoreface is here defined as that part of the shelf above the fair-weather wave base and therefore is almost constantly influenced by oscillatory wave movements and also includes foreshore deposits. The coastal plain is defined as the extensive, very gently sloping area between the shoreface and the nearest elevated land. It is influenced by marine processes, but it is not dominated by wave activity and may periodically be subaerially exposed and subjected to alluvial processes.

Lithostratigraphy

Lyell Land Group

Sønderholm & Tirsgaard (1993)

History. The Lyell Land Group was defined by Sønderholm & Tirsgaard (1993) as part of the general lithostratigraphic revision of the Eleonore Bay Supergroup. It corresponds to the 'Quartzit Serie' ('bed groups 1–6') as defined by Teichert (1933), and later described in more detail by Katz (1952), Eha (1953), Fränkl (1953a, b), Sommer (1957a, b), Haller (1971), Caby (1972), Caby & Bertrand-Sarfati (1988), Sønderholm *et al.* (1989) and Sønderholm & Tirsgaard (1990). It likewise corresponds to the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. After Lyell Land, where the group is extensively exposed and well preserved (Fig. 1).

Type area. Lyell Land, from Kap Alfred in the north to Berzelius Bjerg in south (Figs 1, 4).

Thickness. The group reaches a maximum thickness of 2800 m in northern Lyell Land around Kap Alfred (Figs 4, 5). In the rest of the central fjord zone, the total thickness is between 2000 and 2500 m (Katz, 1952; Fränkl, 1953a, b). A similar thickness has been reported from the area between Waltershausen Gletscher and Wordie Gletscher (Fig. 1; Haller, 1971; Sønderholm *et al.*, 1989). At least 1500 m are exposed in the

Bredefjord–Ardencaple Fjord area (Sommer, 1957b), and a minimum of 750 m is found in Canning Land (Fig. 1; Sønderholm & Tirsgaard, 1993, figs 12, 19).

Distribution. The group is widely distributed in the area between Wordie Gletscher and the central part of Scoresby Land (cf. Bengaard, 1992). The lower and central parts of the group are widely exposed in the Bredefjord–Ardencaple Fjord region (Fig. 1). On Kuhn Ø (Fig. 1), a 650 m thick succession of sandstones and mudstones of Precambrian age is present. This succession is probably best referred to the lower part of the Lyell Land Group, but may, alternatively, belong to the underlying Nathorst Land Group (Sønderholm & Tirsgaard, 1993). The group is also represented on Canning Land (Caby, 1972; Caby & Bertrand-Sarfati, 1988; Sønderholm & Tirsgaard, 1993) but outcrops are generally poor and tectonised which often results in exposures with a restricted and non-diagnostic stratigraphy. However, the upper part of the group is well exposed in an approximately 750 m thick succession in northern Canning Land around Kap Tyrrell. Caby (1972) reported that the lower part of the group ('bed-groups 1–2/?3') is present around Ålborg Fjord (Fig. 1), but an unequivocal distinction between sandstone and mudstone units within the Lyell Land Group and the underlying Nathorst Land Group is difficult in this area.

Dominant lithology. The group consists of alternating units of white to purple weathering, fine- to medium-grained sandstones, and dark green, brownish or dark red silty mudstones and heterolithic mudstones. The

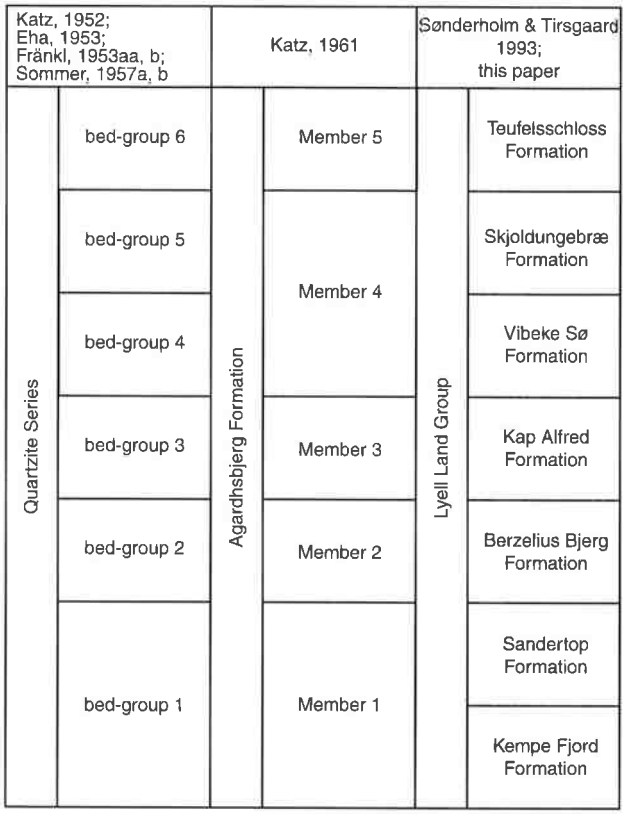

Fig. 3. The subdivision of the Lyell Land Group into seven formations compared with the older, informal subdivisions.

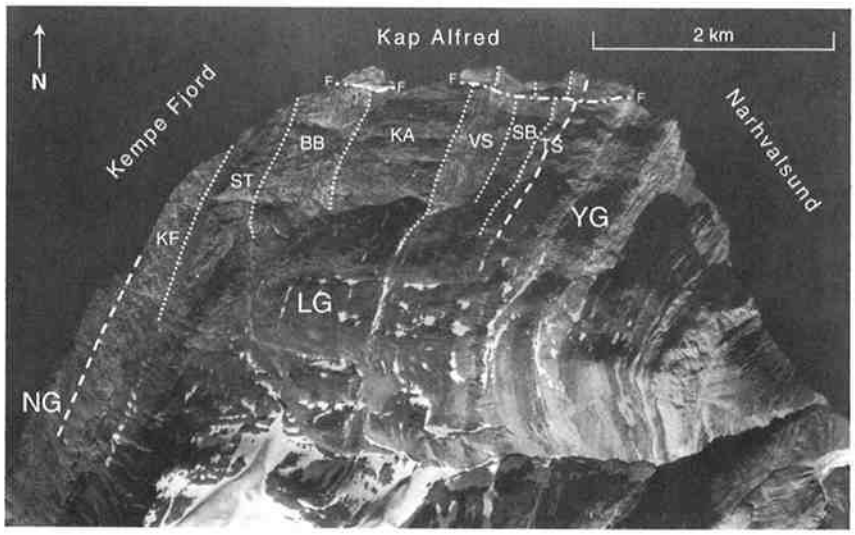

Fig. 4. Aerial photograph of the northern part of Lyell Land. The coastal section along Kempe Fjord around Kap Alfred provides the best continuous exposures of the Lyell Land Group (LG) and includes the type locality of the Kempe Fjord Formation (KF), the Sandertop Formation (ST) and the Kap Alfred Formation (KA) together with well exposed reference sections of the Berzelius Bjerg Formation (BB), the Vibeke Sø Formation (VS), the Skjoldungebræ Formation (SB) and the Teufelsschloss Formation (TS).
NG: Nathorst Land Group, YG: Ymer Ø Group, F: fault.
Photo: Kort- og Matrikelstyrelsen, Denmark, route 888 K-3713 (1985).

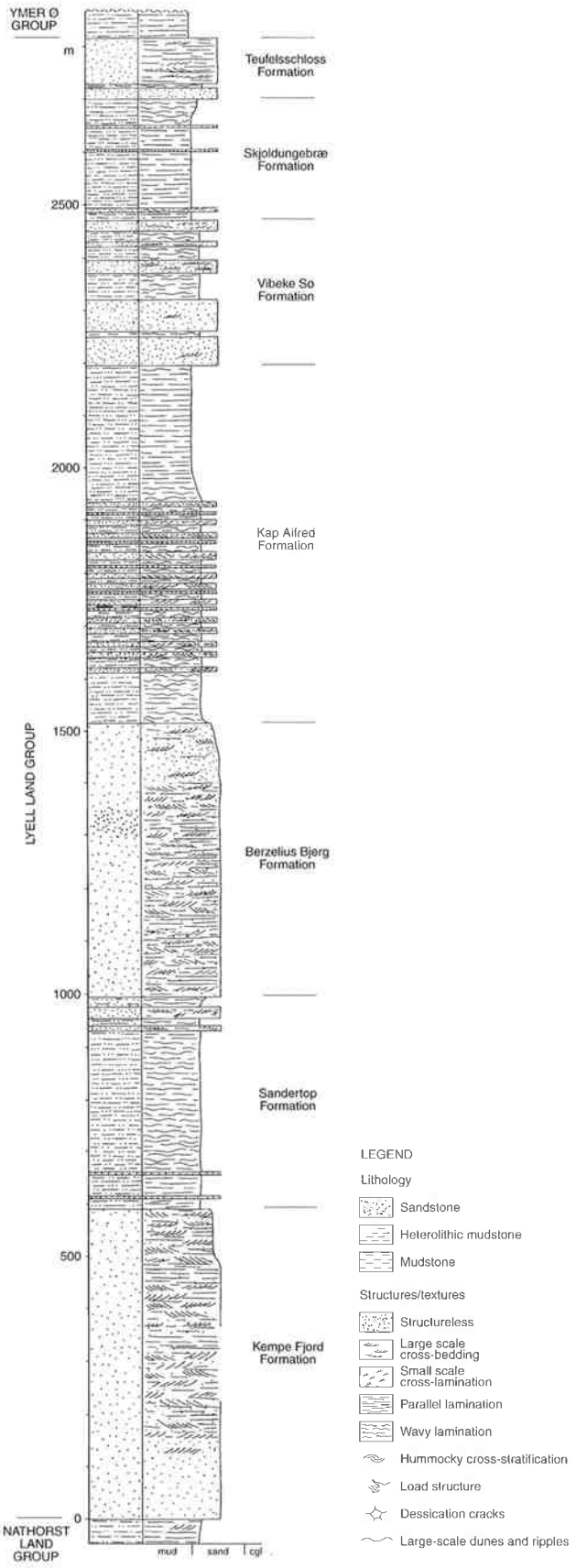

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Fig. 5. Generalised sedimentological log of the Lyell Land Group, measured at Kap Alfred (northern Lyell Land) showing the vertical development of the group and the seven formations. After Sønderholm & Tirsgaard (1993).

thickness of the units varies between 40 and 600 m (Fig. 5). They have a distinct tabular geometry, and can be traced across most of the outcrop area, forming a characteristic lithological pattern which is recognisable from Ardencaple Fjord in the north to Scoresby Land and Canning Land in the south. The group has been subject to a high degree of recrystallisation and is locally strongly deformed, particularly in the lower part.

Fauna and geological age. Thirty-three samples from the group have been processed for acritarchs, but apart from one sample, acritarchs are scarce and poorly preserved. Based on available data, Vidal (1976, 1979) suggested a Sturtian age for the group.

Boundaries. The lower contact is placed where dark green weathering heterolithic mudstones of formation NL3 of the Nathorst Land Group are overlain by a thick succession of white weathering sandstones of the Lyell Land Group (Fig. 6). The upper contact of the group is placed where white sandstones or dark brown heterolithic mudstone deposits of the Lyell Land Group are sharply overlain by dark red or purple mudstones of the Ymer Ø Group (Fig. 7).

Subdivisions. The group was subdivided by Sønderholm & Tirsgaard (1993) into seven formations, corresponding to main sandstone and mudstone units. These comprise the Kempe Fjord Formation, the Sandertop Formation, the Berzelius Bjerg Formation, the Kap Alfred Formation, the Vibeke Sø Formation, the Skjoldungebræ Formation and the Teufelsschloss Formation (Figs 3, 5).

Correlation. The deposits of the Lyell Land Group have been suggested to be coeval with the upper part of the Petermann Bjerg Group which occurs in the nunatak region some 75 km west of the central fjord zone (Figs 1, 2; Haller, 1971). This correlation was maintained by Sønderholm & Tirsgaard (1993), but lithological patterns found in the two regions are not directly comparable and precise correlation of units is still uncertain.

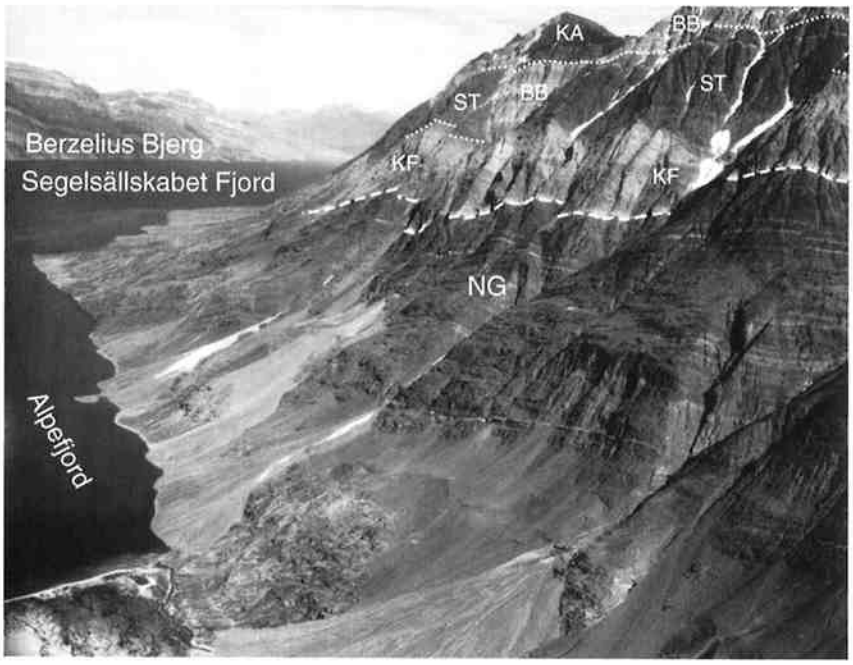


Fig. 6. Boundary between the dark mudstones and heterolithic mudstones of the Nathorst Land Group (NG) and the white sandstones at the base of the Lyell Land Group (LG) as exposed on the eastern coast of Alpefjord, KF: Kempe Fjord Formation, ST: Sandertop Formation, BB: Berzelius Bjerg Formation, KA: Kap Alfred Formation. After Sønderholm & Tirsgaard (1993).

Kempe Fjord Formation

History. The Kempe Fjord Formation was named by Sønderholm & Tirsgaard (1993) without formal description. The formation corresponds to the white or light purple weathering sandstone unit which constitutes the lower part of 'bed-group 1' of Teichert (1933), Katz (1952), Eha (1953), Fränkl (1953a, b) and Sommer (1957a, b) and the lower sandstone unit of Member 1 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. From Kempe Fjord, the large fjord between Lyell Land and Suess Land (Fig. 1).

Type locality. The type locality is found at a well exposed coastal section immediately west of Kap Alfred in northern Lyell Land (Figs 4, 8, 9). Reference sections have not been measured in detail, but according to Katz (1961) good sections may be found in Andrée Land, around Eremitdal in the innermost part of Geologfjord (Fig. 1).

Thickness. At the type locality, the formation reaches a thickness of 585 m (Fig. 9). Similar thicknesses were reported by Katz (1952), Fränkl (1953a), Sommer (1957a) and Haller (1971) from other parts of the central fjord zone (Fig. 1), with the exception of Scoresby Land, where Fränkl (1953b) reported a thickness of only 400 m. In the Bredefjord–Ardencaple Fjord region Sommer (1957b) reported a thickness of approximately 600 m.

Distribution. The Kempe Fjord Formation is a cliff-forming, white to light brown or light purple weathering unit. It overlies dark green recessive mudstones of formation NL3 of the Nathorst Land Group (Sønderholm & Tirsgaard, 1993) and is succeeded by more brownish weathering, recessive, heterolithic mudstones of the Sandertop Formation (Figs 6, 8). The formation is widely distributed in the Bredefjord–Ardencaple Fjord area, in the region between Waltershausen Gletscher and Wordie Gletscher and in the central fjord zone, with the exception of Ymer Ø, where it is not exposed (Eha, 1953). On Kuhn Ø, at least 140 m of white sandstones are preserved; these may correspond stratigraphically to the Kempe Fjord Formation (Sønderholm & Tirsgaard, 1993), but the base of the unit is not exposed. From Canning Land, around Ålborg Fjord, Caby (1972) reported a 100 m thick sandstone unit with an unexposed base, which he tentatively correlated with the basal part of 'bed-group 1' (Kempe Fjord Formation). Correlations in this area are, however, problematic and the unit may be part of overlying formations in the Lyell Land Group or the underlying Nathorst Land Group.

Lithology. The Kempe Fjord Formation consists of white

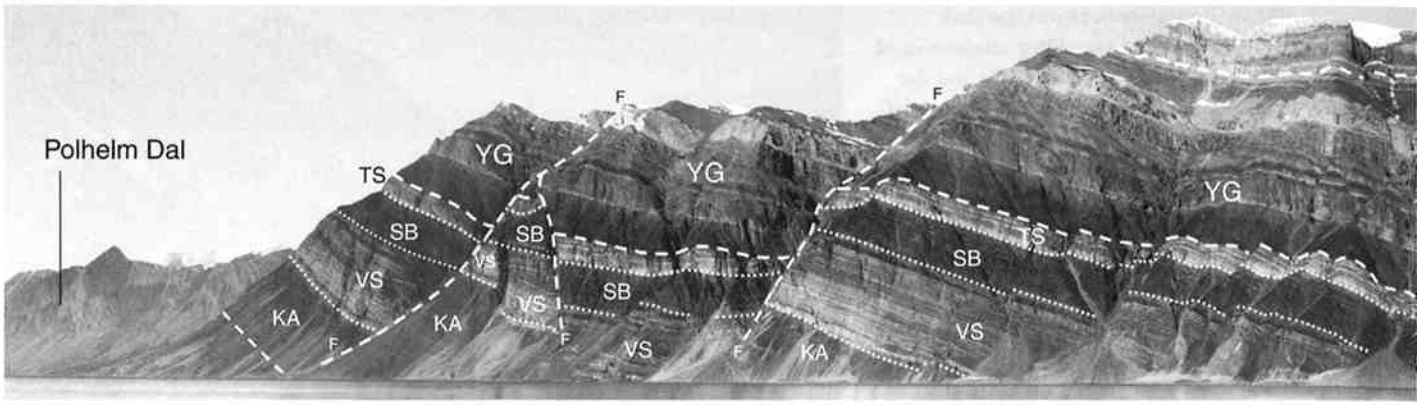


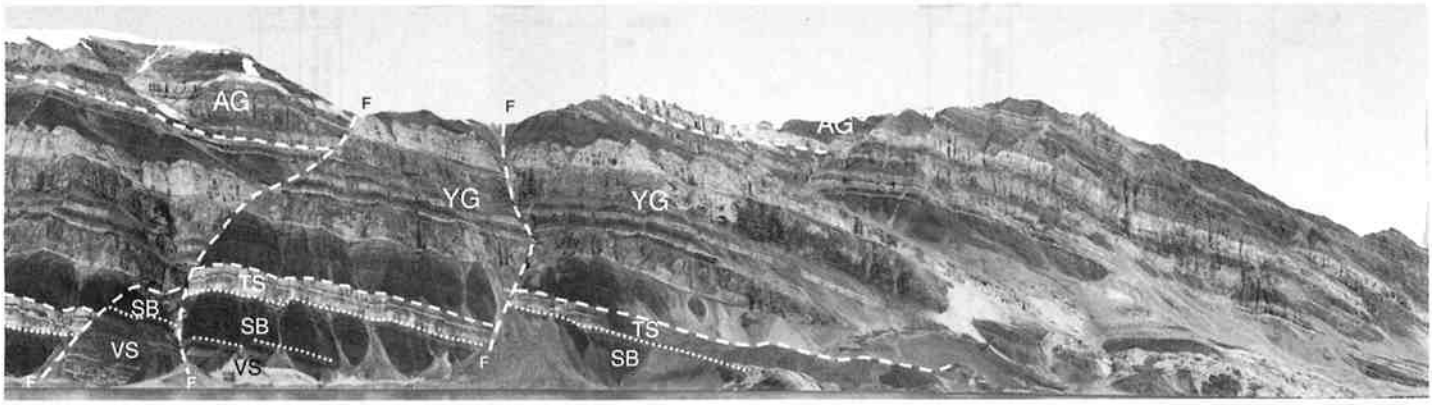
Fig. 7. Photomosaic of Berzelius Bjerg in southern Lyell Land, showing the typical development of the contact between the Lyell Land Group and the overlying Ymer Ø Group (YG), in the central fjord zone. The characteristic development of sandstone and mudstone units constituting the upper four formations of the Lyell Land Group is well exposed. KA: Kap Alfred Formation, VS: Vibeke Sø Formation, SB: Skjoldungebræ Formation, TS: Teufelsschloss Formation, AG: Andrée Land Group, F: fault. Height of Berzelius Bjerg is approximately 1900 m.

to light brown or light purple weathering, fine- to medium-grained sandstones. In the type section (Fig. 9), it can be separated into four units (a–d) based on colour and sedimentary structures. All units have gradational transitions.

The lower unit (a), approximately 85 m thick, consists entirely of structureless white sandstone beds. Bedding is poorly developed but, when visible, is generally a few metres thick. Above follows an approximately 100 m thick white sandstone unit (b) with a low mudstone content and some preserved internal structures, comprising horizontal lamination and large-scale cross-bedding, 10–30 cm high. Locally, herringbone cross-stratification can be observed. Bedding thickness varies from 0.5 m to 2.0 m.

The third unit (c) is approximately 300 m thick and consists of light brown weathering sandstone; individual beds are 0.3–3.0 m thick and display a characteristic sheet-like geometry. The lower contact of each sand sheet is erosive, while the upper surface is covered by a millimetre to centimetre thick mudstone drape often showing desiccation cracks. Beds of wavy and flaser laminated heterolithic sandstone, 0.2–1.0 m thick with numerous desiccation cracks locally separate the sand

Fig. 8. Boundary (dashed) between the light grey sandstones of the Kempe Fjord Formation (KF) and the overlying dark grey mudstones of the Sandertop Formation (ST) at the type locality at Kap Alfred in Lyell Land. Some of the thicker sandstone beds within the Sandertop Formation are exposed. The contact is generally covered in scree, but is exposed at this locality. Above the Sandertop Formation the lower section of the Berzelius Bjerg Formation (BB) is exposed. Width of exposure shown on photograph is approximately 150 m.



sheets. Internally the sand sheets are dominated by horizontal lamination interbedded with sets of large-scale, wedge-shaped cross-bedding and cross-lamination. Individual cross-bedded sets are 10–40 cm thick with tangential or sigmoidal, locally overturned foresets. Reactivation surfaces and herringbone cross-stratification are common. Foreset dip directions show a distinct bi-polar development, with north-north-westerly and south-easterly dip directions at the type locality (Kap Alfred), while dip directions in the southern part of Lyell Land are towards the north-north-east and south.

In the uppermost 100 m of the formation (d), sandstones become more fine-grained and the content of mudstone increases, while the weathering colour becomes more purple. Horizontal lamination is rare, and sets of cross-bedding decrease in size, reaching only 5–20 cm in height, but still showing herringbone cross-stratification. Small-scale cross-lamination becomes more dominant, while desiccation cracks are less common.

Boundaries. The lower boundary is placed where the greenish weathering heterolithic mudstones of the upper part of formation NL3 of the Nathorst Land Group give way to structureless white sandstones of the Kempe Fjord Formation (Fig. 6). The contact is sharp although sandstone beds 10–30 cm in thickness, intercalated with the heterolithic deposits, can be seen to increase in abundance in the uppermost 4–5 m of formation NL3. The upper boundary is placed where the light purple sandstones are succeeded by brownish weathering heterolithic mudstones of the Sandertop Formation (Fig. 8).

Sandertop Formation

History. The formation was named by Sønderholm & Tirsgaard (1993) without formal description. The formation corresponds to the upper dark argillaceous interval of 'bed-group 1' of Teichert (1933), Katz (1952), Eha (1953), Fränkl (1953a, b) and Sommer (1957a, b), and to the upper dark argillaceous interval of Member 1 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. Derived from Sandertoppene, a series of mountain peaks in the northern part of Lyell Land, just southwest of Kap Alfred (Fig. 1).

Type locality. The type locality forms a well exposed coastal section on the southern side of Kempe Fjord just west of Kap Alfred in Lyell Land (Figs 4, 10). A reference section is located in southern Lyell Land, on the eastern side of Polhelm Dal on the gently dipping mountainside of Berzelius Bjerg. Other well exposed sections may be found in Andrée Land, around Eremitdal in the innermost part of Geologfjord (Fig. 1; Katz, 1961).

Thickness. At the type locality, the formation measures 405 m in thickness (Fig. 10). A similar thickness is present in Scoresby Land (Fränkl, 1953b), while a thickness of only 200 m was reported from Andrée Land

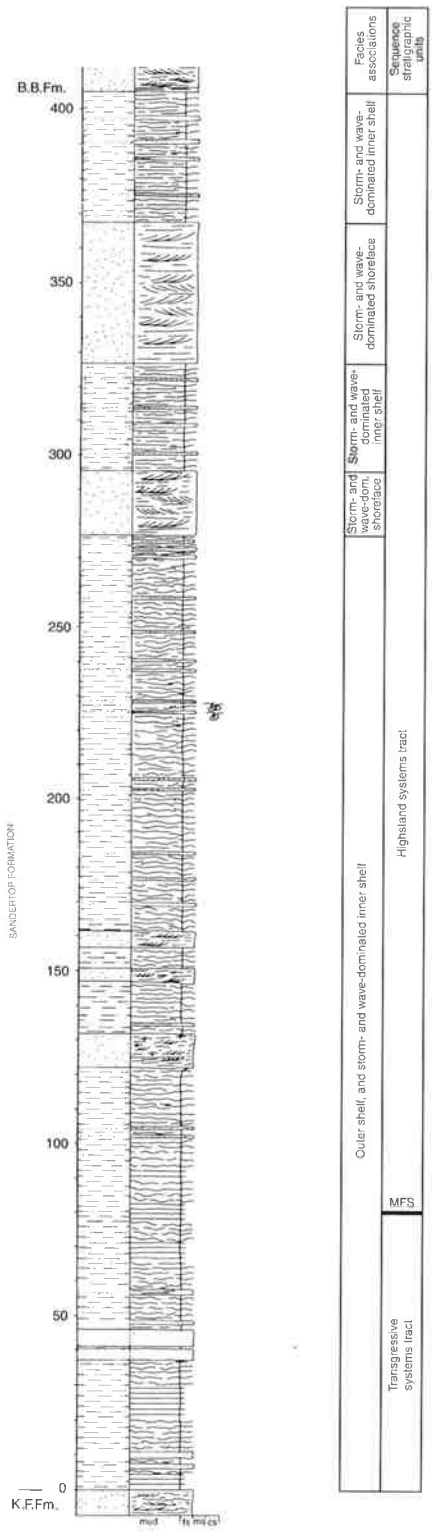


Fig. 9. Type section of the Kempe Fjord Formation (Kap Alfred, northern Lyell Land) showing facies associations and sequence stratigraphic units. The log illustrates the very small variations in grain size throughout the formation. The section has been divided into four units (a–d, see text). N.L.G.: Nathorst Land Group, ST. FM.: Sandertop Formation, SB: sequence boundary. For legend see Fig. 5.

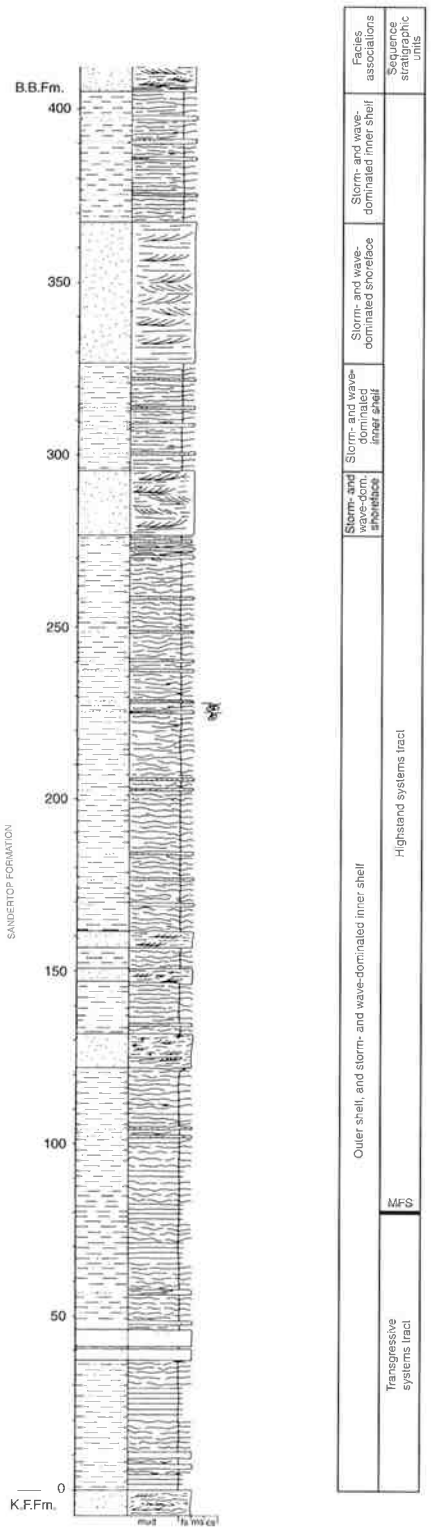


Fig. 10. Type section of the Sandertop Formation (Kap Alfred, northern Lyell Land) showing facies associations and sequence stratigraphic units. The section displays the occasional presence of thin sandstone units within mudstones and heterolithic deposits and the two main sandstone units in the upper part of the formation. K.F. FM.: Kempe Fjord Formation, B.B. FM.: Berzelius Bjerg Formation, MFS: maximum flooding surface. For legend see Fig. 5.

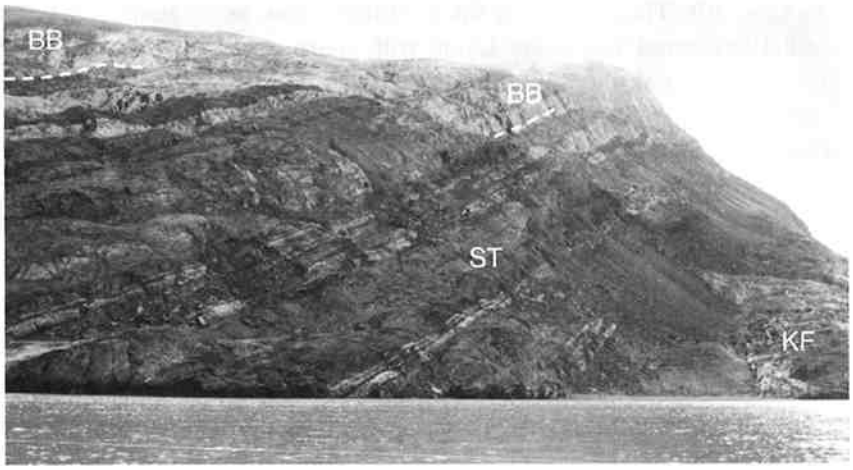


Fig. 11. Characteristic development of the Sandertop Formation (ST) at the type locality (Kap Alfred, northern Lyell Land) showing the strong dominance of dark mudstones and heterolithic deposits, with rare 0.5–2 m thick sandstone units (seen as pale units). The two thick sandstone units in the upper part of the formation are seen immediately below the contact to the overlying Berzelius Bjerg Formation (BB). KF: Kempe Fjord Formation. Width of exposure shown on photograph is approximately 150 m.

and Strindberg Land by Katz (1952) and Fränkl (1953a). In the Bredefjord–Ardencaple Fjord region a thickness of 300 m is reached (Sommer, 1957b).

Distribution. The Sandertop Formation forms a recessive, dark brown unit sandwiched between the white or slightly reddish weathering cliff-forming Kempe Fjord and Berzelius Bjerg Formations (Figs 6, 8, 11). It is present within the Bredefjord–Ardencaple area (Sommer, 1957b) and is widely distributed in the central fjord zone. It may also be present on Kuhn Ø, where a 200 m thick unit dominated by mudstones probably can be correlated with the Sandertop Formation (Sønderholm & Tirsgaard, 1993). In Canning Land, an isolated outcrop at Ålborg Fjord comprising a 400 m thick succession of silty mudstones was tentatively correlated with the upper part of 'bed-group 1' (Sandertop Formation) by Caby (1972). As correlation of the various sandstone and mudstone units of the lower Lyell Land Group is difficult in this area, the unit may be part of the overlying formations in the Lyell Land Group or the underlying Nathorst Land Group.

Lithology. At the type locality the formation is dominated by brownish weathering mudstones and heterolithic mudstones interbedded with 2–10 m thick, white or brownish weathering sandstone units. Two distinct sandstone units, 20 m and 40 m thick, are found in the upper part of the formation (Figs 10, 11).

Mudstones are mainly present in the lower 120 m of the formation where they are dominated by horizontal lamination; individual laminae may locally show micrograding. Lenticular and wavy bedded heterolithic mudstones dominate the upper 280 m of the forma-

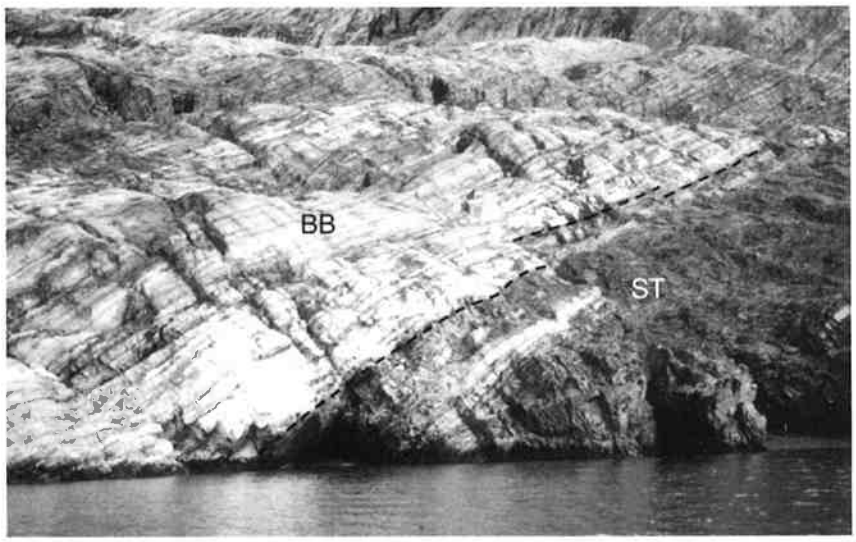


Fig. 12. Well exposed boundary between the Sandertop Formation (ST) and the overlying Berzelius Bjerg Formation (BB) as seen at Kap Alfred, northern Lyell Land. The contact is relatively sharp and marks a transition from inner shelf mudstones to shoreface sandstones. The latter form the basal part of the Berzelius Bjerg Formation and are seen as pale beds which are overlain by tidal channel sand sheets (light grey). Thickness of section shown on photograph is approximately 100 m.

tion (Fig. 10). Thin, 1–15 cm thick, structureless or parallel laminated sandstone layers with sharp contacts are present throughout the formation.

The sandstone units consist of 0.5–1.0 m thick sandstone beds. These are often structureless or show poorly preserved sets with large-scale planar and trough cross-bedding, horizontal lamination and cross-lamination. Contacts with surrounding mudstones may be either sharp or gradational with thin sandstone layers increasing in abundance towards the base of the sandstone units (Fig. 10). The two uppermost thick sandstone units contain better preserved sedimentary structures. They consist of 0.2–1.0 m thick beds separated by thin mudstone interbeds. Internally they reveal large-scale planar cross-beds, often showing herringbone cross-stratification, horizontal lamination and cross-lamination. Numerous clay flakes are scattered throughout the units.

The formation is similarly developed in most other areas within the central fjord zone, except in Strindberg Land and in Andrée Land where sandstone units are more abundant (Katz, 1952; Fränkl, 1953a).

Boundaries. The lower boundary is sharp and is placed at the base of the heterolithic mudstone succession following abruptly upon the white or purple weathering sandstones of the Kempe Fjord Formation (Figs 8, 11). The upper boundary is placed where heterolithic mudstones give way to the overlying sandstone succession of the Berzelius Bjerg Formation (Figs 8, 11, 12).

Berzelius Bjerg Formation

History. The Berzelius Bjerg Formation was named by Sønderholm & Tirsgaard (1993) without formal description. The formation corresponds to 'bed-group 2' of Teichert (1933), Katz (1952), Eha (1953), Fränkl (1953a, b) and Sommer (1957a, b) and to Member 2 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. From the mountain Berzelius Bjerg, located on the southern coast of Lyell Land, along the northern side of the Segelsällskapet Fjord (Figs 1, 7).

Type locality. The type locality is a very well exposed section on the south-western side of the mountain Berzelius Bjerg (Figs 13, 14A). A well exposed reference section has been measured in northern Lyell Land, at Kap Alfred (Figs 4, 14B). Other well exposed sections may be found in Andrée Land, around Eremitdal in the innermost parts of Geologfjord (Fig. 1; Katz, 1961).

Thickness. At the type locality, the formation reaches a thickness of 470 m (Fig. 14A) and in northern Lyell Land it attains a thickness of 530 m (Fig. 14B). From other parts of the central fjord zone thicknesses of 250–300 m have been reported (Katz, 1952; Eha, 1953; Fränkl, 1953a, b). Bengaard (1989), in a detailed photogrammetrical analysis, calculated a similar range of thicknesses in the central fjord zone and confirmed that the Berzelius Bjerg Formation, of all the formations in the Lyell Land Group, shows the most significant thickness variations in the central fjord zone. This variation was not recognised by earlier workers as Sommer (1957a) reported a thickness of only 280 m in Lyell Land. In the Bredefjord–Ardencaple Fjord region the formation reaches a thickness of 350 m (Sommer, 1957b).

Distribution. The Berzelius Bjerg Formation is a cliff-forming, white to reddish or light pink weathering sandstone unit, sandwiched between the dark green or dark brown to black, recessive mudstones of the Sandertop Formation beneath and the Kap Alfred Formation above (Fig. 13). It was reported from the Bredefjord–Ardencaple Fjord region by Sommer (1957b) and Sønderholm *et al.* (1989). It is present in the region between Waltershausen Gletscher and Wordie Gletscher (Haller, 1971; Sønderholm *et al.*, 1989) and widely distributed in the central fjord zone (Katz, 1952; Eha, 1953; Fränkl, 1953a, b; Sommer, 1957a; Bengaard, 1989, 1992). A 210 m thick white sandstone unit with a distinct tripartite subdivision due to a middle brownish section, has been observed on Kuhn Ø and may correspond stratigraphically to the Berzelius Bjerg Formation (Sønderholm & Tirsgaard, 1993). In northern Canning Land around Kap Tyrrell, an at least 100 m thick white sandstone unit, bounded below by a fault, has been suggested to correspond to 'bed-group 2' (Berzelius Bjerg Formation) by Caby (1972). This sandstone unit is considered here to form the basal part of the Vibeke Sø Formation. North of Ålborg Fjord in Canning Land, the upper 100 m of an isolated outlier, possibly belonging to the Lyell Land Group, was tentatively proposed by Caby (1972) to correspond to the Berzelius Bjerg Formation. Correlations in this area are, however, problematic and the unit may be part of overlying formations in the Lyell Land Group or the underlying Nathorst Land Group.

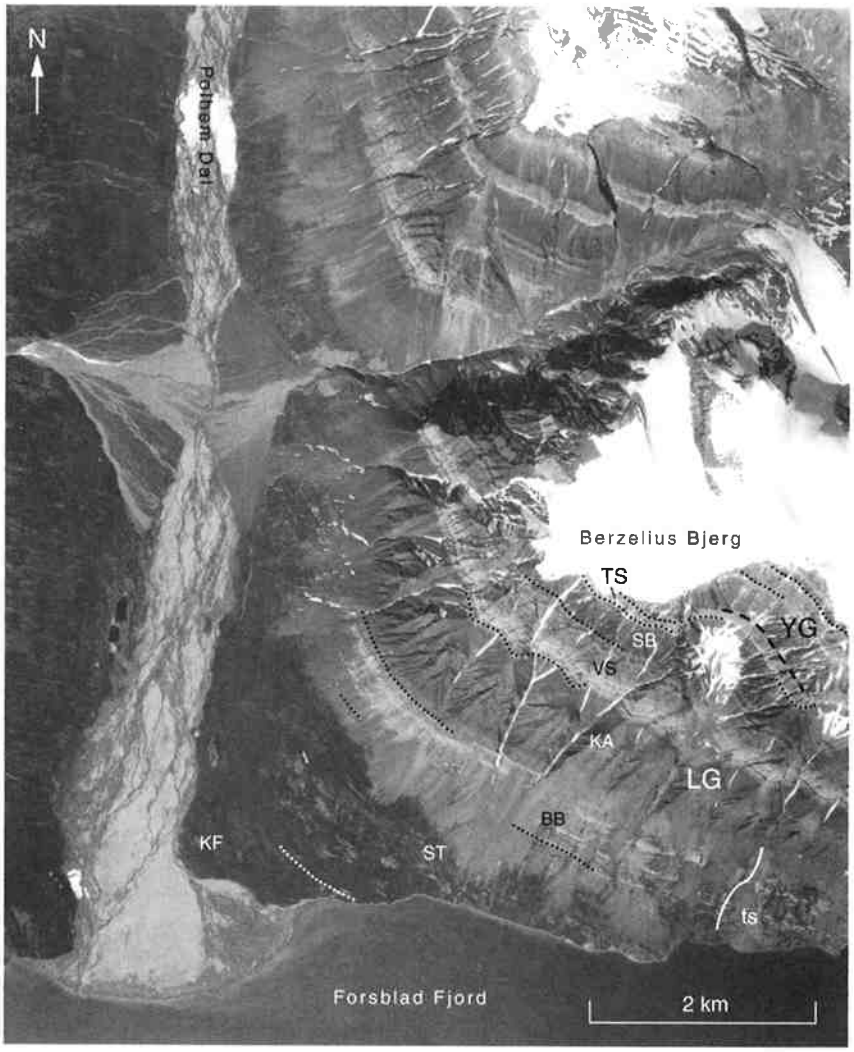


Fig. 13 Aerial photograph of the southern part of Lyell Land showing the type locality of the Berzelius Bjerg Formation (BB; ts: type section). KF: Kempe Fjord Formation, ST: Sandertop Formation, KA: Kap Alfred Formation, VS: Vibeke Sø Formation, SB: Skjoldungebræ Formation, TS: Teufelsschloss Formation, LG: Lyell Land Group, YG: Ymer Ø Group. After Sønderholm & Tirsgaard (1993). Photo: Kort- og Matrikelstyrelsen, Denmark, route 853 H-5568 (1972).

Lithology. At the type locality, the Berzelius Bjerg Formation forms a homogeneous unit of white, light purple to pink or light red weathering sandstone with very subordinate amounts of heterolithic sandstone and mudstone (Fig. 14A).

The formation consists of sand sheets, 0.3–3.0 m in thickness, which are amalgamated to form 30–70 m thick units separated by either 0.3–1.0 m thick heterolithic sandstone or mudstone beds, or 2–15 m thick, structureless white sandstone beds. In the uppermost 40–80 m of the formation the sand sheets die out and are followed by structureless, more fine-grained sandstone deposits, which have a very poorly developed bedding (Fig. 14A, B).

The sand sheets have sharp erosive lower contacts and mud-draped upper contacts with desiccation cracks and ripple-marks. Sedimentary structures are dominated by large-scale planar cross-bedding (10–40 cm sets), interbedded with horizontal lamination, scour and fill structures, and small-scale cross-bedding. Cross-bedded sets may show well-developed herringbone cross-stratification. Measurements on foreset dip directions show a dominantly bi-polar trend with dip directions mainly towards the north-north-west and south-south-east. North-easterly foreset dip directions, roughly perpendicular to the main orientation, occur in southern Lyell Land. The sand sheets lack any vertical evolution of sedimentary structures, but may show a weak upward fining.

The thin heterolithic mudstone and sandstone beds are primarily wavy bedded with varying proportions of mudstone and fine-grained sandstone. On bedding planes desiccation cracks and wave ripple marks are commonly found. The interbedded white sandstone beds reveal very few sedimentary structures, but occasionally large-scale sets of cross-bedding, 20–60 cm thick, are visible.

A similar lithological development is seen in other

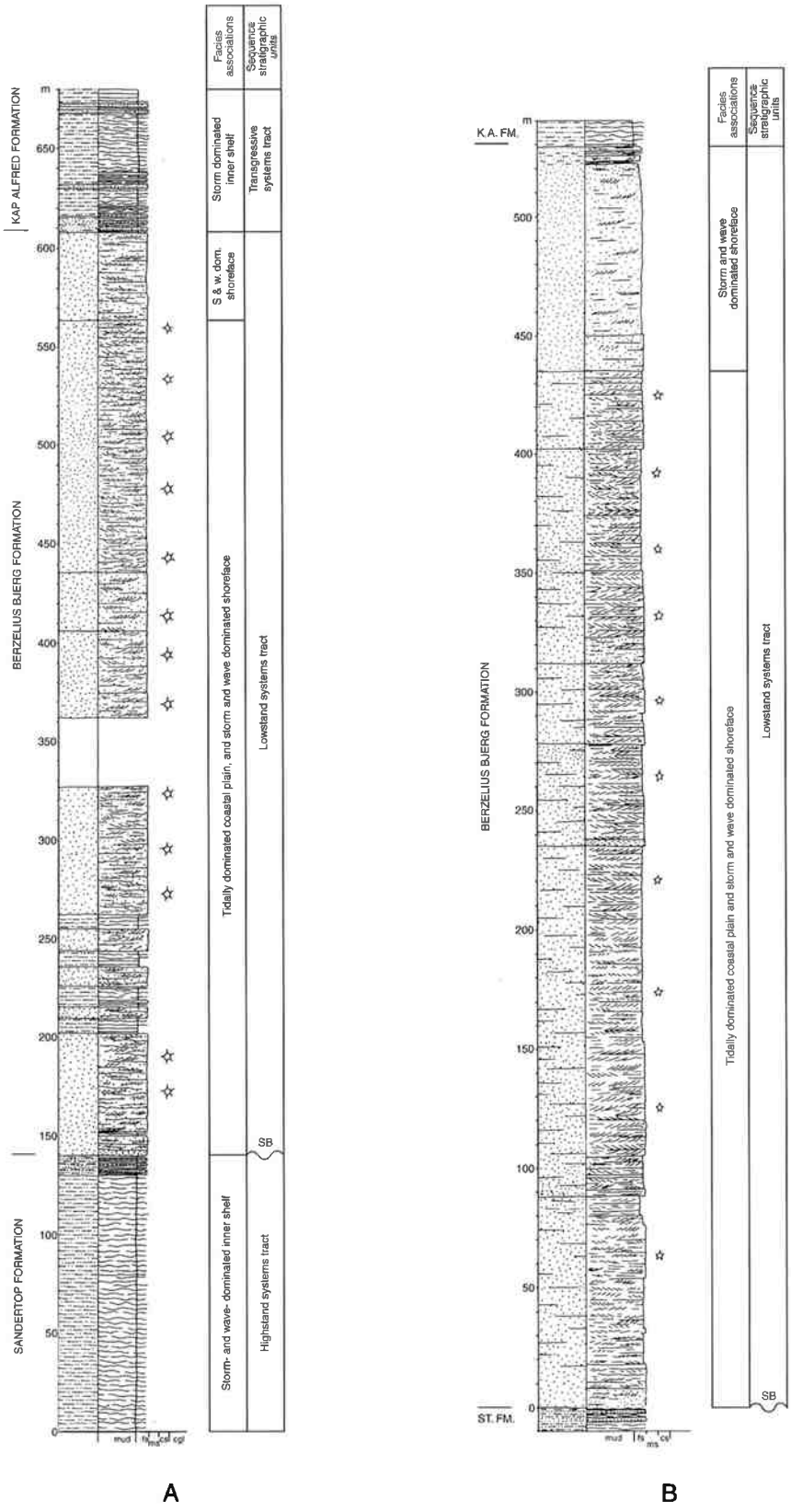


Fig. 14. **A**: Type section of the Berzelius Bjerg Formation (Berzelius Bjerg, southern Lyell Land) showing facies associations and sequence stratigraphic units. At this locality sedimentary structures are extremely well preserved. **B:** Reference section of the Berzelius Bjerg Formation (Kap Alfred, northern Lyell Land) showing facies associations and sequence stratigraphic units. This section is more complete than at Berzelius Bjerg, but sedimentary structures are less well preserved. The log reflects the same depositional environments as in southern Lyell Land, but shoreface deposits in the uppermost part of the formation are better developed in northern Lyell Land. ST. FM.: Sandertop Formation, K.A. FM.: Kap Alfred Formation, SB: sequence boundary. For legend see Fig. 5.

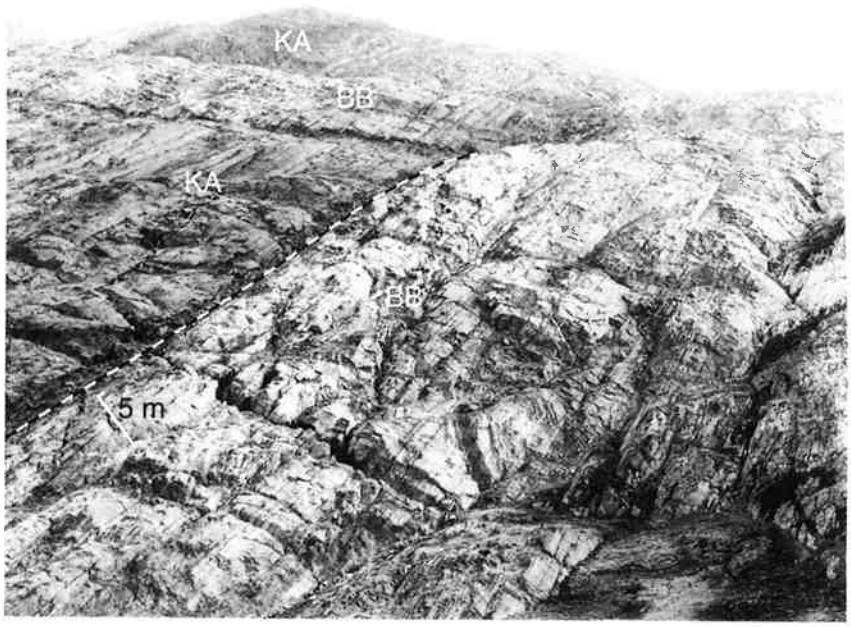


Fig. 15. Boundary (dashed) between shoreface sandstones of the Berzelius Bjerg Formation (BB) and the dark heterolithic inner shelf mudstones of the Kap Alfred Formation (KA) as exposed at Kap Alfred (northern Lyell Land).

parts of Lyell Land. No detailed descriptions currently exist from other parts of the central fjord zone but, based on the descriptions of Katz (1952), Eha (1953), Fränkl (1953a, b) and Sønderholm *et al.* (1989), the Berzelius Bjerg Formation appears to show only minor lateral variations in lithology.

Boundaries. The lower boundary is placed where heterolithic mudstones of the underlying Sandertop Formation are followed by sandstones of the Berzelius Bjerg Formation (Fig. 12). The boundary is sharp, although a weak upward coarsening is seen in the upper 3–5 m of the Sandertop Formation. The upper boundary is placed where white or reddish weathering sandstones are followed by dark green mudstones and heterolithic mudstones of the Kap Alfred Formation (Fig. 15).

Kap Alfred Formation

History. The Kap Alfred Formation was named by Sønderholm & Tirsgaard (1993) without formal description. It corresponds to 'bed-group 3' of Teichert (1933), Katz (1952), Eha (1953), Fränkl (1953a, b), Sommer (1957a, b) and to Member 3 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961). It includes the 'Basiszone', the 'Untere Schieferzone', the 'Bänderzone' and the 'Obere Schieferzone' of Katz (1952), Fränkl (1953a) and Sommer (1957a).

Name. From Kap Alfred, the northernmost point of Lyell Land (Figs 1, 4).

Type locality. The type locality is at Kap Alfred, where the formation is well exposed in an easily accessible coastal section along Kempe Fjord (Fig. 4). Reference sections are located in southern Lyell Land at Berzelius Bjerg (Fig. 7) and in Andrée Land, around Eremitdal in the innermost part of Geologfjord (Fig. 1; Katz, 1961).

Thickness. At the type locality, the formation reaches a thickness of 640 m (Fig. 16). A similar thickness was calculated photogrammetrically by Bengaard (1989), while Sommer (1957a) reported a thickness of only 500 m at Kap Alfred. In the central fjord zone, outside Lyell Land, the Kap Alfred Formation attains a thickness of approximately 500 m (Katz, 1952; Eha, 1953; Fränkl, 1953a, b; Bengaard, 1989; Sønderholm *et al.*, 1989). In the Bredefjord–Ardencaple Fjord region, Sommer (1957b) calculated a thickness of 500–600 m.

Distribution. The Kap Alfred Formation forms a dark, recessive unit between white cliff-forming sandstones of the Berzelius Bjerg Formation below and the lower part of the Vibeke Sø Formation above (Fig. 7). It is widely distributed in the region between Waltershausen Gletscher and Wordie Gletscher (Haller, 1971; Sønderholm *et al.*, 1989) and in the central fjord zone (Katz, 1952; Eha, 1953; Fränkl, 1953a, b; Sommer, 1957a; Bengaard, 1989, 1992). On Kuhn Ø, an at least 250 m

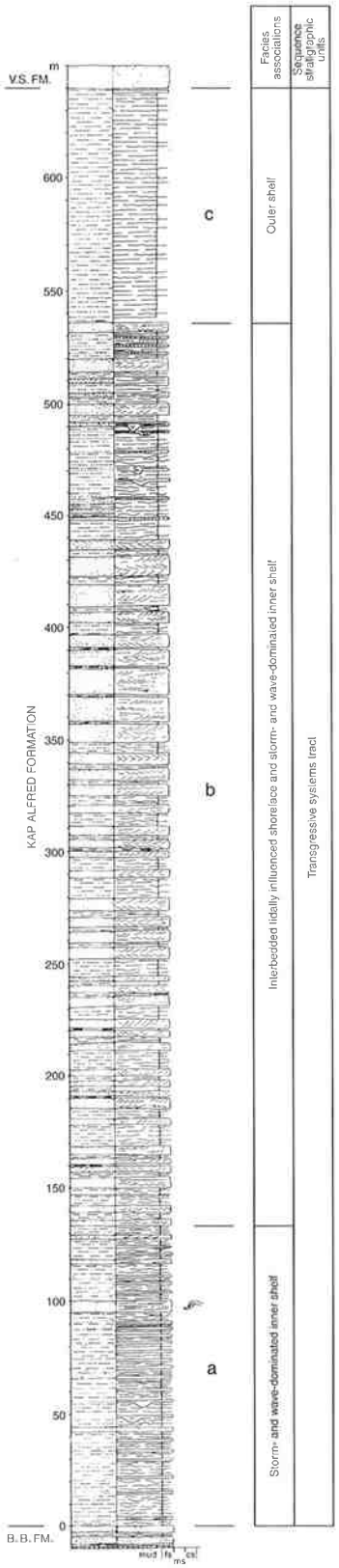


Fig. 16. Type section of the Kap Alfred Formation (Kap Alfred, northern Lyell Land) showing facies associations and sequence stratigraphic units. The log shows the well-developed tripartite division of the formation (a–c, see text). B.B. FM.: Berzelius Bjerg Formation, V.S. FM.: Vibeke Sø Formation. For legend see Fig. 5.

thick succession consisting of sandstones and mudstones may possibly correspond to the Kap Alfred Formation (Sønderholm & Tirsgaard, 1993). The formation is probably not preserved in Canning Land, although Caby (1972) suggested that the entire Lyell Land Group, with the exception of the Kempe Fjord and Sandertop Formations ('bed-group 1'), was included in an approximately 750 m thick succession occurring around Kap Tyrrell in northern Canning Land. Here this mapping unit is considered to comprise only the formations overlying the Kap Alfred Formation.

Lithology. The Kap Alfred Formation consists of dark green to dark grey weathering mudstones and heterolithic mudstones alternating with white, fine- to medium-grained sandstone beds. Variations in the amount of sandstone and mudstone at the type locality has led to a conspicuous tripartite subdivision of the formation (Fig. 16).

The lower part (a) is approximately 130 m thick and is dominated by horizontally laminated mudstones and heterolithic, lenticular and wavy bedded mudstones (Fig. 16). Thin sandstone layers, 5–30 cm thick, with sharp bases are interbedded with the mudstones. These are structureless or show horizontal lamination or cross-lamination. Thicker beds may display hummocky cross-stratification. In southern Lyell Land, and in parts of the central fjord zone, the lower part can be split into a lower 60 m thick section characterised by a high concentration of sandstone layers – 'Basiszone' of Katz (1952), Fränkl (1953a) and Sommer (1957a) – and an upper 60 m thick section consisting predominantly of mudstone – the 'Untere Schieferzone' of Katz (1952), Fränkl (1953a) and Sommer (1957a). In the lower part of the formation, load structures are common in some intervals and diastasis cracks are often observed on bedding planes.

The middle part of the formation (b) is approximately 410 m thick and consists of alternating 1–10 m thick sandstone and heterolithic mudstone units with gradational contacts (Fig. 16). Sandstone units have a sheet-like geometry and generally increase in thickness upwards, thereby creating an upward coarsening succession. The sandstone units are dominated by large-scale planar cross-beds, 5–40 cm thick, interbedded with horizontally and cross-laminated sandstones. Herringbone cross-stratification is common. Foreset dip directions show a strong bimodal trend, indicating dominantly north–south flowing currents. The heterolithic mudstone units are lenticular and wavy bedded. In the Bredefjord–Ardencaple Fjord region this middle

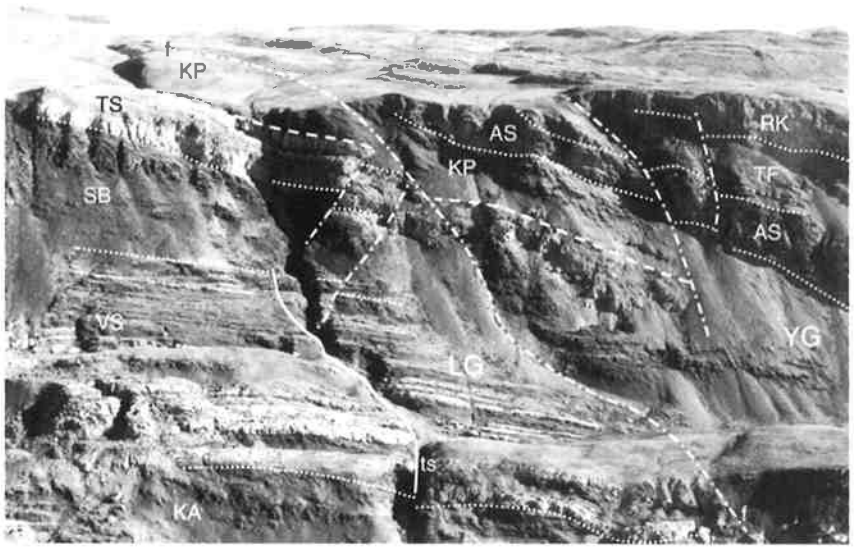


Fig. 17. Type locality of the Vibeke Sø Formation (VS), at the eastern end of Vibeke Sø in Steno Land, showing well exposed contacts to the underlying Kap Alfred Formation (KA) and the overlying Skjoldungebræ Formation (SB). The type section at the eastern end of the Vibeke Sø Formation is shown by the white line (ts). A major fault (f) runs through the central part of the photograph juxtaposing formations of the Lyell Land Group (LG) with the lower formations of the Ymer Ø Group (YG), TS: Teufelsschloss Formation, KP: Kap Peterséns Formation, AS: Antarctic Sund Formation, TF: Tågefjeld Formation, RK: Rytterknægten Formation.

part of the formation contains very little sandstone and the tripartite division, therefore, is much less distinct (Sønderholm *et al.*, 1989).

The upper part (c) is approximately 100 m thick and characterised by dark brown to greenish weathering mudstones with very few sandstone layers, 5–20 cm thick. The mudstones are dominated by horizontal to lenticular lamination (Fig. 16).

Boundaries. At the type locality, the lower boundary of the formation is sharp and is placed at the change from the homogeneous white sandstones of the Berzelius Bjerg Formation to dark, greenish weathering heterolithic mudstones (Figs 7, 15). Where sandstone layers are more common, as in some areas of the central fjord zone (Katz, 1952; Eha, 1953; Fränkl, 1953a; Sommer, 1957a), the contact is more gradational. The upper contact is placed where the dark brown to greenish weathering mudstones are sharply overlain by white sandstone beds forming the base of the Vibeke Sø Formation (Fig. 17).

Vibeke Sø Formation

History. This formation was named by Sønderholm & Tirsgaard (1993) without formal description. The formation corresponds to 'bed-group 4', described from the central fjord zone by Katz (1952), Eha (1953), Fränkl (1953a, b), Sommer (1957a) and Sønderholm *et al.* (1989) and to the lower part of Member 4 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961). In Canning Land around Kap Tyrrell, 'bed-group 4' has not been recognised as a separate unit by Bütler (1948) or Caby (1972) who grouped 'bed-groups 3–6' into a single mapping unit overlying 'bed-group 2'. However, Caby & Bertrand-Sarfati (1988) reinterpreted the stratigraphy of the Kap Tyrrell region and suggested that 'bed-group 2' corresponds to 'bed-group 4' and that 'bed-groups 3–6' correspond to 'bed-group 5' and 'bed-group 6'; this interpretation is followed here.

Name. From the lake Vibeke Sø in Steno Land (Fig. 1).

Type section. The type section is located on the south-facing cliffs at the eastern end of Vibeke Sø in Steno Land (Figs 17, 18A). Reference sections were measured at Kap Alfred in northern Lyell Land, at Kap Peterséns in northern Scoresby Land and at Kap Tyrrell in northern Canning Land (Figs 18, 19).

Thickness. The formation is 325 m thick in the type section (Fig. 18A). Similar thicknesses are found at other localities in the central fjord zone: 300 m at Kap Alfred (Fig. 18B), 315 m at Kap Peterséns (Fig. 18C) and at least 290 m in Canning Land (Fig. 19).

Distribution. The Vibeke Sø Formation forms a characteristic banded unit with a cliff-forming weathering appearance in the basal part. It is readily recognised between the dark, more recessive weathering mudstones of the underlying Kap Alfred Formation and the overlying brick-red mudstones of the Skjoldungebræ Formation (Figs 4, 7, 17). The most northerly outcrops are seen in a restricted area around Ardencaple Fjord, where only the basal, approximately 200 m of the for-

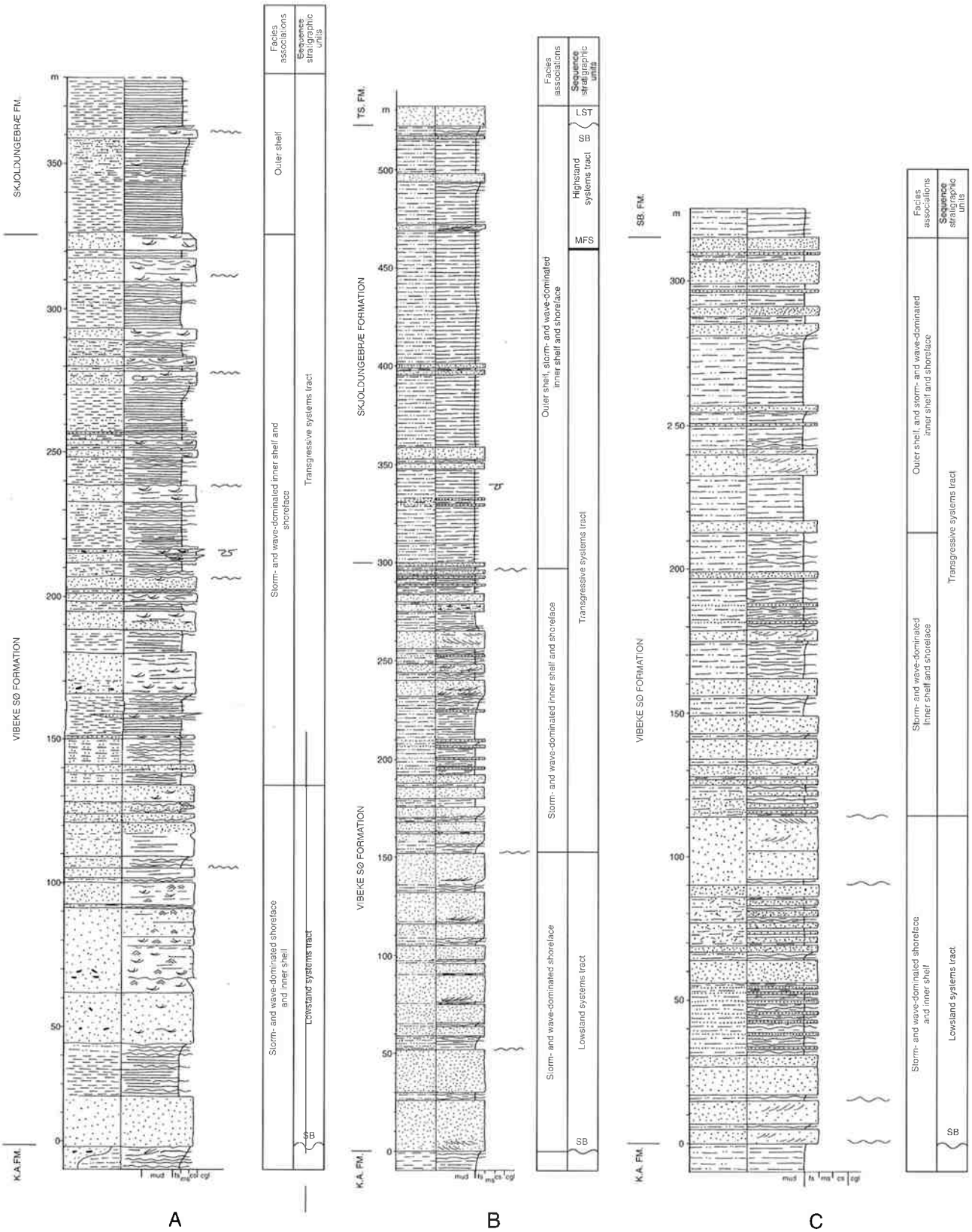


Fig. 18. **A:** Type section of the Vibeke Sø Formation (Vibeke Sø, Steno Land), **B:** reference sections of the Vibeke Sø Formation and Skjoldungebræ Formation (Kap Alfred, northern Lyell Land) and, **C:** reference section of the Vibeke Sø Formation (Kap Peterséns, northern Scoresby Land) showing facies associations and sequence stratigraphic units. The logs all show the characteristic development of overall upward fining in the Vibeke Sø Formation where the thickness of sandstone units decreases upwards, while heterolithic mudstone units increase in thickness. Smaller cycles of upward fining sandstone units are visible within the overall trend. Note that the logs are drawn at different scales. K.A. FM.: Kap Alfred Formation, SB. FM.: Skjoldungebræ Formation, TS. FM.: Teufelsschloss Formation, SB: sequence boundary, LST: lowstand systems tract, MFS: maximum flooding surface. For legend see Fig. 5.

mation are preserved (Sommer, 1957b; Sønderholm *et al.*, 1989). Further south, it occurs throughout the region between Steno Land and Scoresby Land (Fig. 1; cf. Bengaard, 1992). In Canning Land it forms the basal part of the succession found in the Kap Tyrrell area (Fig. 19).

Lithology. The Vibeke Sø Formation consists of generally thinning-upwards successions of sheet-like, quartzitic sandstone units (5–20 m thick), interbedded with 2–20 m thick dark mudstone units (Figs 17–21).

In the type section, the basal part of the formation is characterised by two approximately 20 m thick almost structureless sandstone units which have highly erosive bases showing a relief of up to 20 cm. These two basal sandstones are separated by a mudstone unit (Figs 17, 18A) and are followed by a series of 5–10 m thick sandstone units dominated by small-scale structures interbedded with 2–20 m thick mudstone units (Fig. 21). The sandstone units gradually thin upwards and towards the top of the formation attain thicknesses around 5 m, while the mudstone units gradually thicken upwards (Figs 17–19). Internally the sandstone units consist of 1–2 m thick beds which amalgamate laterally. The sandstone units are dominated by large-scale planar cross-bedding, sometimes with discontinuous mud-drapes on foresets, and by wave ripple lamination. Foreset dip directions show a well-developed unimodal orientation, indicating dominantly northerly flowing currents. In Canning Land, hummocky cross-stratification can be seen within several sandstone units. In Scoresby Land, large-scale three-dimensional sand waves with a relief of up to 50 cm and a wavelength of 5–8 m cover the upper surfaces of many sandstone units. The sand waves have been strongly modified by large- and small-scale wave ripples.

The mudstone units consist largely of dark, greenish to bluish heterolithic mudstone. Variegated red and

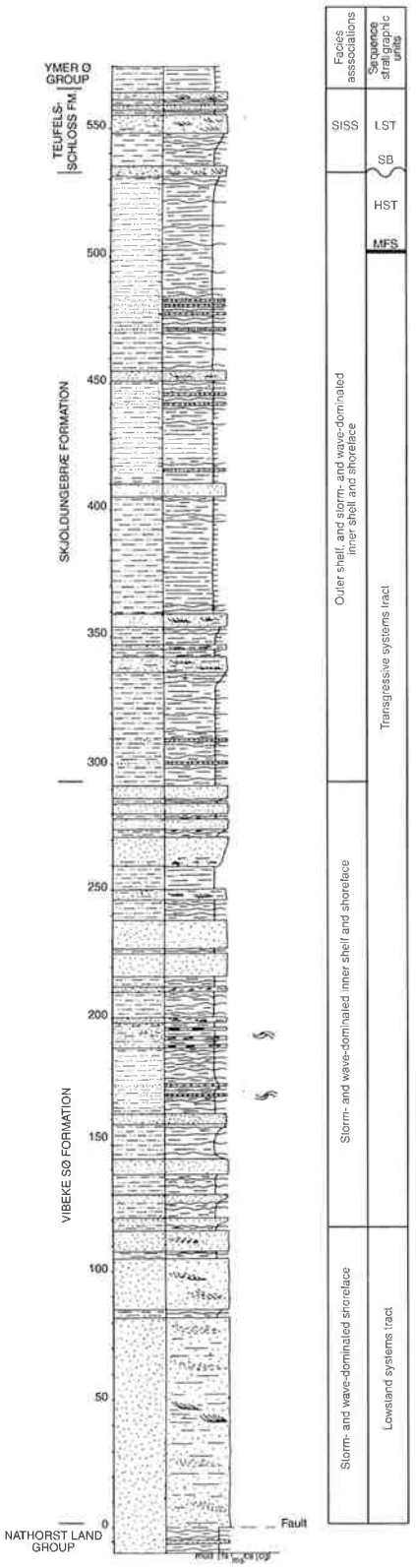


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Fig. 19. Sedimentological log of upper part of the Lyell Land Group as exposed around Kap Tyrrell in Canning Land showing facies associations and sequence stratigraphic units. The log includes reference sections of the Vibeke Sø, Skjoldungebræ and Teufelsschloss Formations. The basal part of the Vibeke Sø Formation may have been faulted out, but the thickness of the formation is very similar to that of the central fjord zone and it is possible that the fault is located right at the base of the formation. Smaller cycles of upward fining sandstone units are weakly discernible within the major upward fining trend. SISS: storm-dominated inner shelf and shoreface. SB: sequence boundary, LST: lowstand systems tract, HST: highstand systems tract, MFS: maximum flooding surface. For legend see Fig. 5.

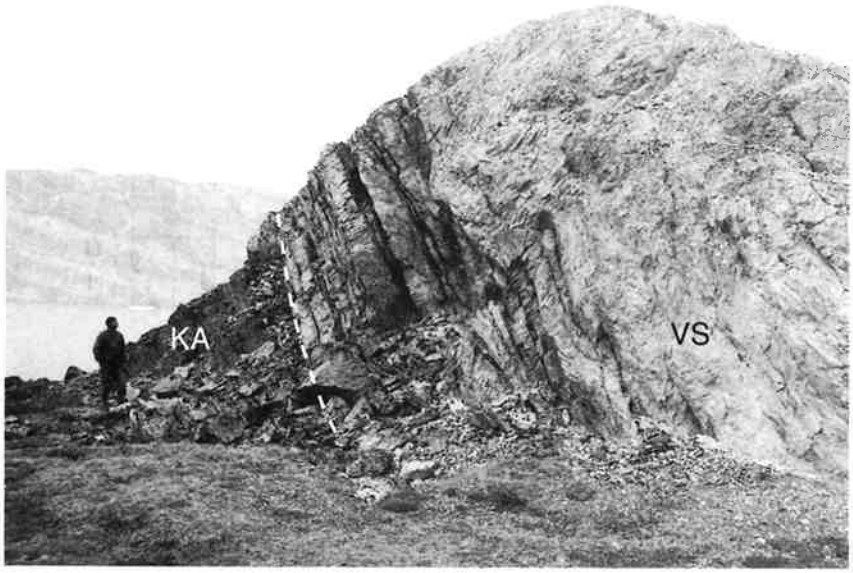

Fig. 20. Well exposed boundary (dashed) between the Kap Alfred Formation (KA) and the Vibeke Sø Formation (VS) at Kap Alfred on Lyell Land. The contact marks a shift from outer shelf mudstones of the Kap Alfred Formation to structureless sandstone, interpreted as shoreface deposits, of the Vibeke Sø Formation. The sandstones show an upward increase in bed thickness over the basal 2 m before they pass into a more than 20 m thick sandstone unit. Person for scale.

green mudstone and dark brownish-red mudstone form minor components. The mudstones are dominated by parallel lamination, sometimes showing a distinct micrograding. Thin, lenticular and wavy bedded sandstones, typically 2–10 cm thick, may locally occur. These sandstone layers are sometimes graded, showing internal parallel lamination or cross-lamination. The heterolithic mudstone units often show a coarsening upward trend caused by a gradual increase in sandstone content (Figs 18, 19).

A similar development is observed at the other localities, although variations do occur. In Lyell Land, the thickness of the two basal sandstone units reaches 26 and 22 m (Fig. 18B), whereas in northern Scoresby Land, three basal sandstone units, 6 m, 10 m and 14 m in thickness, are developed (Fig. 18C); in Canning Land, the two units appear to have amalgamated into a single unit some 80 m thick (Fig. 19).

Boundaries. The lower boundary of the formation is sharp and locally demonstrably erosive, showing scours up to 20 cm deep. The boundary is placed at the base of the first thick, white, structureless sandstone unit above the dark mudstones of the Kap Alfred Forma-

Fig. 21. Characteristic development of the lower part of the Vibeke Sø Formation at Kap Alfred (northern Lyell Land). Structureless sandstone bodies, several metres thick, alternate with 1–2 m thick mudstone units, which in most places are covered by vegetation. The characteristic development of overall upward fining (towards the left) of the formation, where the thickness of sandstone bodies decreases upwards, is well displayed. Structural dip is 55° towards the east (left).

Fig. 22. Boundary (arrow) between the Vibeke Sø Formation (VS) and the Skjoldungebræ Formation (SB) just west of Kap Peterséns, northern Scoresby Land (type locality of the Skjoldungebræ Formation). The boundary is taken at the last more than 3 m thick sandstone bed of the Vibeke Sø Formation and marks the transitional shift from dominantly greenish and grey, inner shelf mudstones and shoreface sandstones to brick-red outer shelf mudstones of the Skjoldungebræ Formation.

tion (Figs 17, 20). In Canning Land, the lower boundary is a fault which is coincident with, or close to the base of the formation.

The upper boundary to the Skjoldungebræ Formation is transitional as mudstones become increasingly dominant towards the top of the Vibeke Sø Formation. It is placed at the top of the last thick (>2 m) laterally persistent sandstone package (Figs 17, 22, 23), which is also associated with a change in colour of the associated mudstones from dominantly greenish and dark grey to dominantly brick-red.

Skjoldungebræ Formation

History. This formation was named by Sønderholm & Tirsgaard (1993) without formal description. It corresponds to 'bed-group 5' of Teichert (1933), Katz (1952), Eha (1953), Fränkl (1953a, b) and Sommer (1957a), and to the upper, dark, flaggy siltstones of Member 4 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. From the glacier Skjoldungebræ located in northern Scoresby Land (Figs 1, 24).

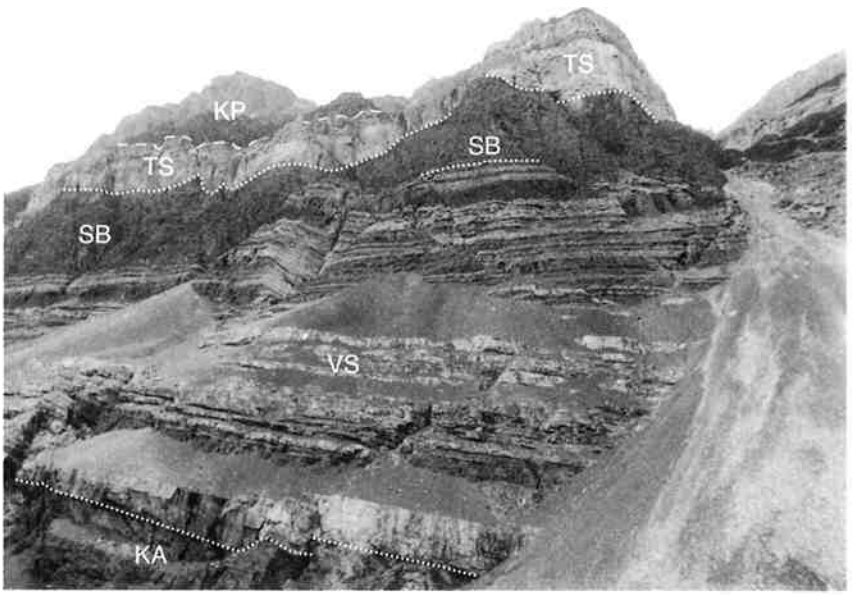

Fig. 23. Berzelius Bjerg in southern Lyell Land (west-facing cliffs along Polhelm Dal), showing a complete section of the Vibeke Sø Formation (VS) and Skjoldungebræ Formation (SB). The characteristic overall upward fining exposed by the two formations is readily observed. The abrupt transition from outer shelf mudstones to shoreface sandstones, which marks the contact between the Kap Alfred Formation (KA) and the Vibeke Sø Formation and between the Skjoldungebræ Formation and the Teufelsschloss Formation (TS) is also visible. KP: Kap Peterséns Formation. Thickness of the Skjoldungebræ Formation is 200 m.

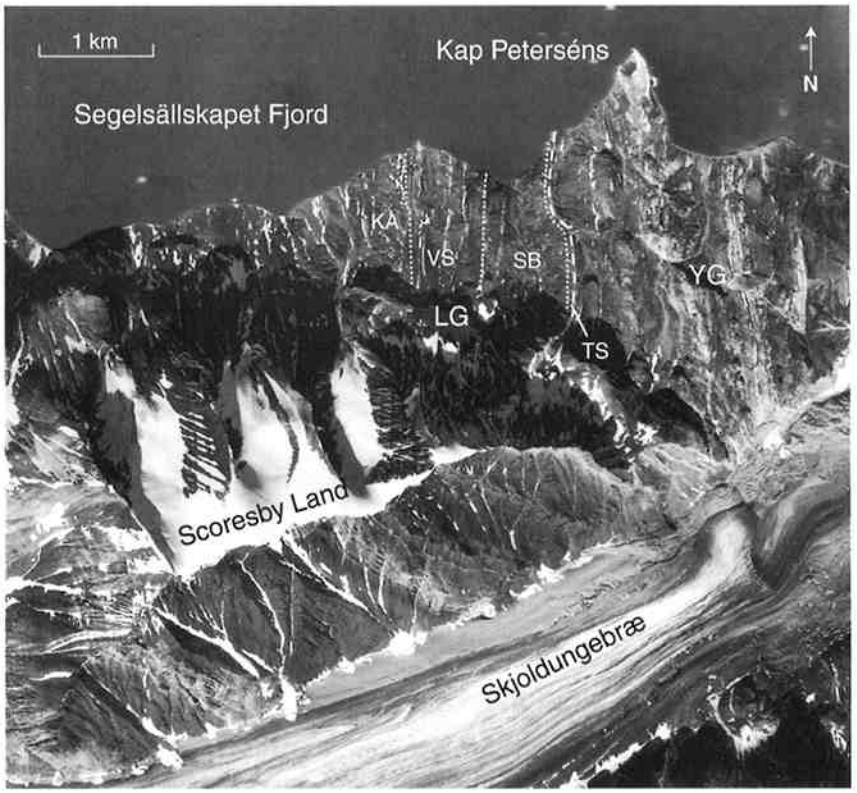

Fig. 24. Aerial photograph of northern Scoresby Land around Kap Peterséns, showing the type locality of the Skjoldungebræ Formation (SB) along the shore of Segelsällskapet Fjord. Good exposures are also present of the Vibeke Sø Formation (VS) and the Teufelsschloss Formation (TS); the latter is very thin in this part of the central fjord zone. Only the top of the Kap Alfred Formation (KA) is well exposed, as the main part of the formation is covered by vegetation and scree. LG: Lyell Land Group, YG: Ymer Ø Group.
Photo: Kort- og Matrikelstyrelsen, Denmark, route 888 L-3785 (1985).

Type locality. The type locality is immediately west of Kap Peterséns in northern Scoresby Land (Figs 24, 25), where it crops out in easily accessible coastal cliff sections. Reference sections are located around Vibeke Sø in Steno Land (Fig. 17), at Kap Alfred in northern Lyell Land (Fig. 18B) on Jägmästarens Ø in Segelsällskapet Fjord (Fig. 26) and in Canning Land (Fig. 19).

Thickness. The thickness of the Skjoldungebræ Formation shows very little variation throughout the region of outcrop. At the type locality, the formation is 206 m thick (Fig. 25), 205 m have been measured at Vibeke Sø in Steno Land (Fig. 17), 220 m at Kap Alfred in northern Lyell Land (Fig. 18B), 205 m on Jägmästarens Ø in Segelsällskapet Fjord (Fig. 26) and 240 m in Canning Land (Fig. 19).

Distribution. The Skjoldungebræ Formation forms a characteristic dark purple, brick-red and dark green, recessive weathering unit, overlying the banded Vibeke Sø Formation and overlain by white, cliff-forming sandstones of the Teufelsschloss Formation (Figs 23, 27, 28). It is widely distributed in the region between Waltershausen Gletscher and Wordie Gletscher and in the central fjord zone (cf. Bengaard, 1992). It is also preserved in the northern part of Canning Land, just south of Kap Tyrrell, where it was grouped into a single mapping unit ('bed-groups 3–6') by Caby (1972) but later recognised as a separate unit (Caby & Bertrand-Sarfati, 1988). The formation is not exposed north of Wordie Gletscher.

Lithology. The Skjoldungebræ Formation consists of a relatively monotonous succession of brick-red, dark purple or dark green mudstones and heterolithic mudstones (Figs 18, 19, 25, 26). Marly mudstones have been described from the Geologfjord area (Katz, 1961). The mudstones and heterolithic mudstones form 20–70 m thick packets, which are separated by 1–3 m thick, locally up to 5 m thick, sandstone beds; this alternation is laterally persistent and exceeds the lateral extent of the exposures.

Mudstones constitute more than 75% of the formation. These are dominated by horizontal lamination, often represented by graded rhythmites, 5–20 mm thick, grading from very fine-grained sandstone or siltstone to mudstone or claystone at the top. The lamination can be compared to the D and E divisions of the Bouma sequence (cf. Bouma, 1962). Heterolithic mudstones locally form 5–10 m thick units. These show lenticular and wavy bedding and are often associated with 5–100 cm thick, fine- to medium-grained sandstone lay-

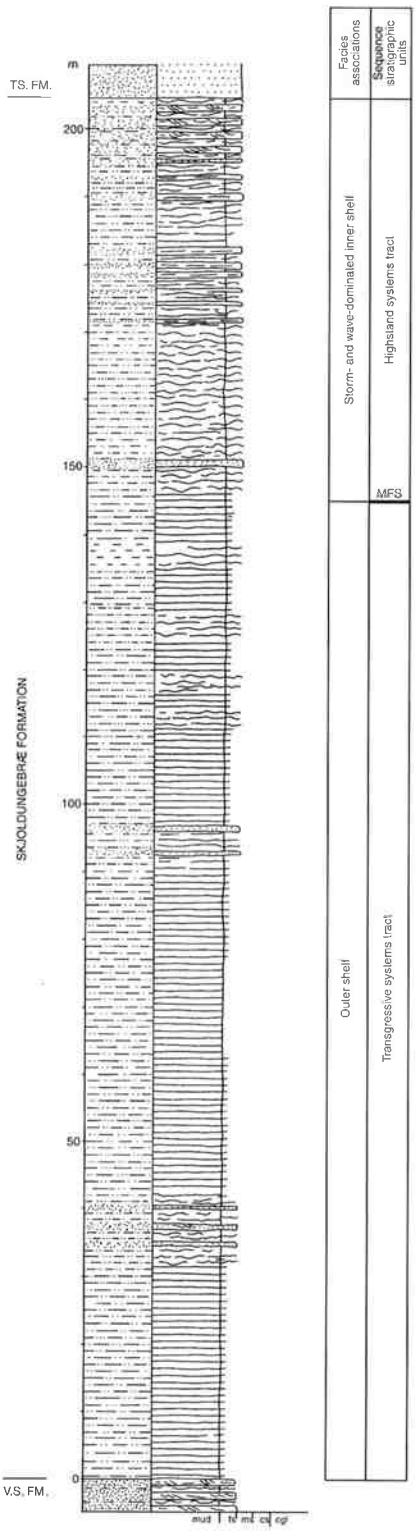

Fig. 25. Type section of the Skjoldungebræ Formation (Kap Peterséns, northern Scoresby Land) showing facies associations and sequence stratigraphic units. The formation is relatively homogeneous, dominated by outer shelf mudstones; thin storm sands are only occasionally present. V.S. FM.: Vibeke Sø Formation, TS. FM.: Teufelsschloss Formation, MFS: maximum flooding surface. For legend see Fig. 5.

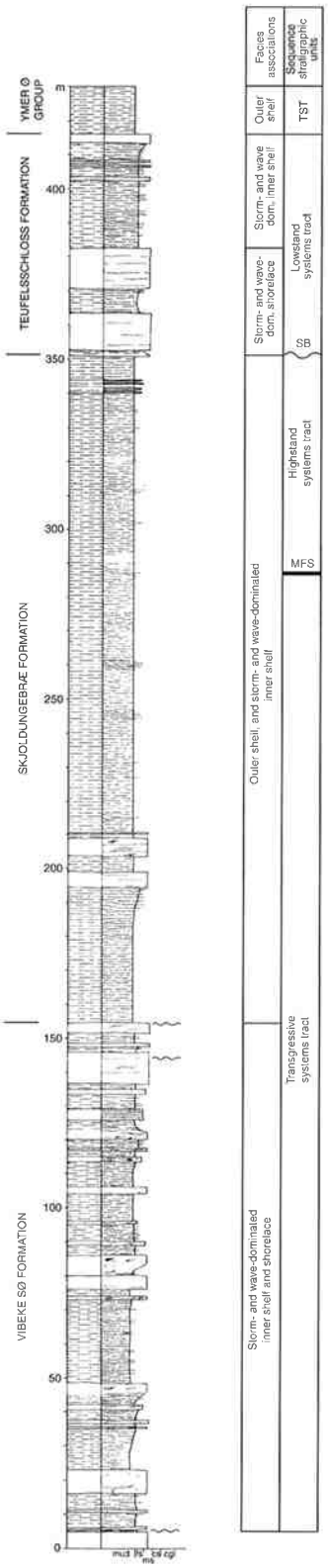

Fig. 26 Sedimentological log of the Lyell Land Group as exposed on Jägmästarens Ø in Segelsällskapet Fjord showing facies associations and sequence stratigraphic units. Only the upper part of the Vibeke Sø Formation is exposed, while complete reference sections of the Skjoldungebræ Formation and Teufelsschloss Formation are well exposed. The Teufelsschloss Formation is relatively thin and consists of interbedded shoreface deposits and heterolithic mudstone deposits of storm dominated inner shelf origin. Coastal plain deposits are absent. SB: sequence boundary, TST: transgressive systems tract, MFS: maximum flooding surface. For legend see Fig. 5.

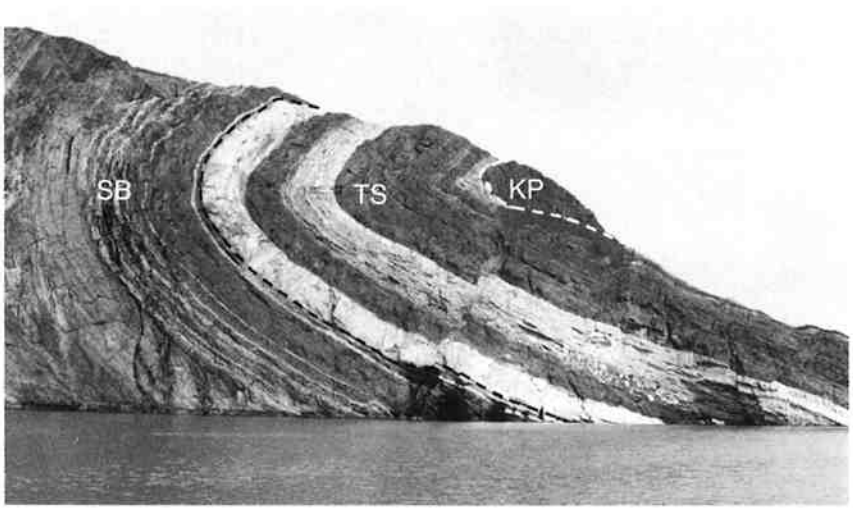

Fig. 27. Boundary between the Skjoldungebræ Formation (SB) and Teufelsschloss Formation (TS) and between the Teufelsschloss Formation and Kap Peterséns Formation (KP) as exposed on Jägmästarens Ø in Segelsällskapet Fjord. The photograph shows the characteristic development of the Teufelsschloss Formation in the southern part of the central fjord zone, where it only comprises storm-dominated inner shelf and shoreface deposits. Tidal channel deposits are absent. The two basal sandstone units, which occur at the base of the formation at the type locality, are also present on Jägmästarens Ø. The lower sandstone unit is approximately 10 m thick.

ers. These have sharp contacts and are dominated by horizontal lamination and cross-lamination. Tool marks and current lineation are locally well developed on bedding planes in some areas, particularly in Canning Land.

The sandstone beds are generally structureless and have very sharp upper and lower contacts (Figs 19, 25–27). Locally, large-scale cross-bedding and horizontal lamination can be observed, commonly in association with mudstone clasts. Large-scale, coarse-grained wave ripples may be observed locally.

Overall vertical trends are absent within the formation, but in the central fjord zone a weak upwards coarsening is seen in the uppermost 40 m of the formation where heterolithic mudstones increase in abundance at the expense of laminated mudstones (Figs 18, 25–27). Significant lateral lithological variations have not been observed within the formation, which appears to be homogeneously developed across the entire area of exposure.

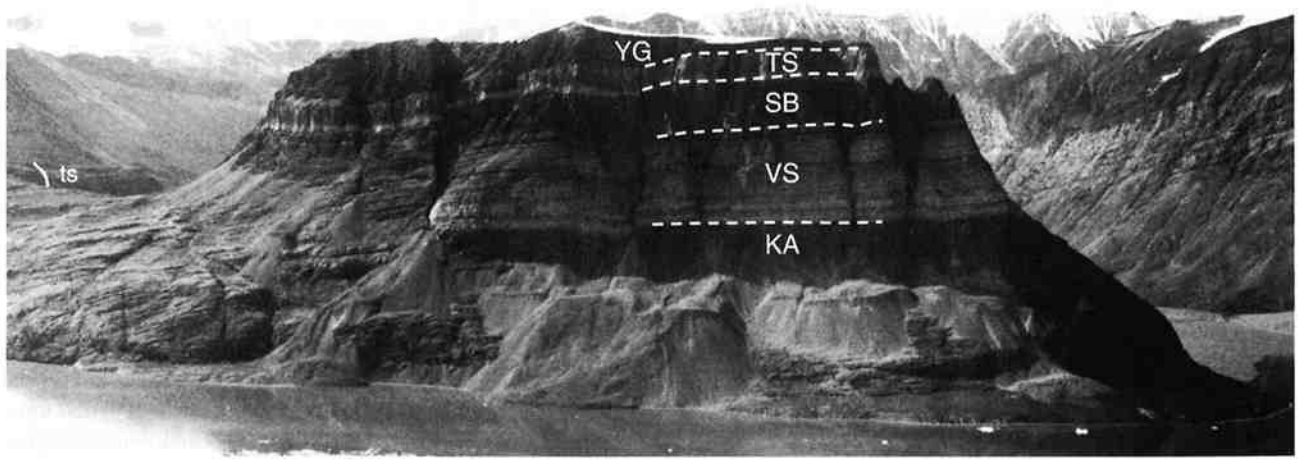

Fig. 28. Type locality of the Teufelsschloss Formation (TS) at the mountain Teufelsschloss, Andrée Land, showing the well exposed contacts to the underlying Skjoldungebræ Formation (SB) and the overlying Ymer Ø Group (YG). The type section (ts) of the Teufelsschloss Formation is located in the valley south of the mountain. Note the conspicuous pale weathering shoreface sandstones forming the base and top of the formation. KA: Kap Alfred Formation. Thickness of Teufelsschloss Formation is 135 m.

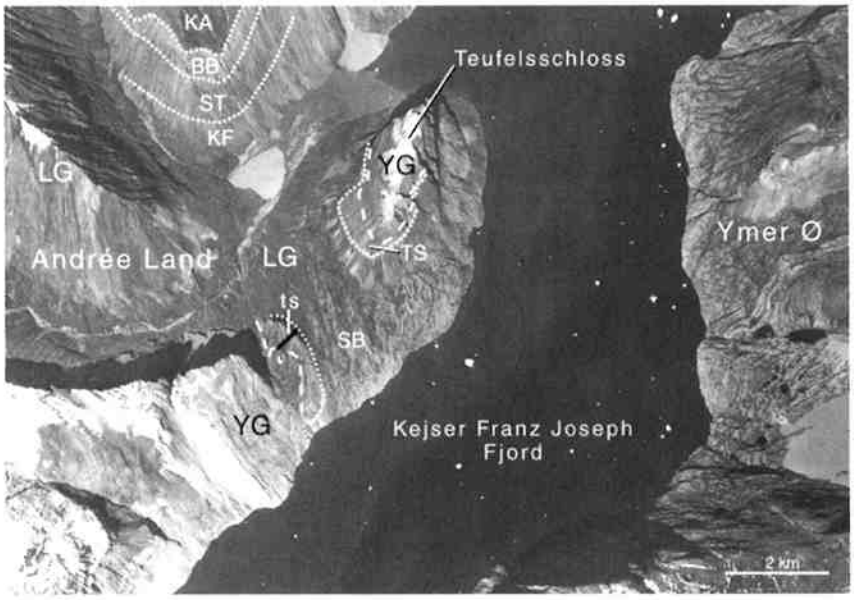

Fig. 29. Aerial photograph of eastern Andrée Land, around Teufelsschloss mountain, showing the location of the type section (ts) of the Teufelsschloss Formation (TS). LG: Lyell Land Group, YG: Ymer Ø Group, KF: Kempe Fjord Formation, ST: Sandertop Formation, BB: Berzelius Bjerg Formation, KA: Kap Alfred Formation, SB: Skjoldungebræ Formation.
Photo: Kort- og Matrikelstyrelsen, Denmark, route 888 K-3723 (1985).

Boundaries. The lower boundary to the Vibeke Sø Formation is transitional as mudstones increase in abundance upwards through the Vibeke Sø Formation. However, the boundary is placed at the top of the last sandstone package which is over 2 m thick (Figs 22, 23). This also corresponds with a shift in colour of the mudstones from dominantly dark greenish-grey or brownish to mainly brick-red, dark purple or dark green. The upper boundary is placed at the change from brick-red or dark green mudstones to a more than 5 m thick, structureless white sandstone bed, marking the base of the Teufelsschloss Formation (Figs 23, 27, 28).

Teufelsschloss Formation

History. The formation was named by Sønderholm & Tirsgaard (1993) without formal description. The formation corresponds to 'bed-group 6', described from the central fjord zone by Teichert (1933), Katz (1952), Fränkl (1953a, b), Eha (1953) and Sommer (1957a) and to Member 5 of the Agardhsbjerg Formation (Fig. 3; Katz, 1961).

Name. After the mountain Teufelsschloss on the south-eastern coast of Andrée Land, south of Eleonore Bugt (Figs 1, 28, 29).

Type locality. The type locality is a prominent, north-facing cliff section in the east–west valley south of the mountain Teufelsschloss (Figs 28–30A). Reference sections are found around Vibeke Sø in Steno Land (Fig. 30B), on Jägmästarens Ø (Figs 26, 27) and in Canning Land (Fig. 19).

Thickness. At the type locality, the formation reaches a thickness of 135 m (Fig. 30A). Similar thicknesses of 107 m are attained in Steno Land (Fig. 30B) and as far south in the central fjord zone as northern Lyell Land (130 m). South of this area it thins rapidly towards the south-east, reaching only 65 m at Kap Dufva (Fig. 1) and on Jägmästarens Ø (Fig. 26) and 60 m at Kap Peterséns in northern Scoresby Land. Fränkl (1953b) reported a thickness of only 15 m some 15 km south of Kap Peterséns. In Canning Land, the thickness is 35 m (Fig. 19).

Distribution. The formation is widely distributed in the region between Waltershausen Gletscher and Wordie Gletscher and in the central fjord zone (cf. Bengaard, 1992). It is also present in northern Canning Land where it was grouped into a single mapping unit ('bed-groups 3–6') by Caby (1972) but later recognised as a separate unit by Caby & Bertrand-Sarfati (1988). It is not exposed in the Bredefjord–Ardencaple Fjord region (Sommer, 1957b; Sønderholm *et al.*, 1989).

Lithology. At the type locality, the formation consists of two basal, white, very well sorted, structureless, fine- to medium-grained sandstone units, 20–25 m thick, separated by approximately 5 m of heterolithic mudstone. The upper sandstone unit is erosively overlain by a 75 m thick succession of wine-red, fine- to

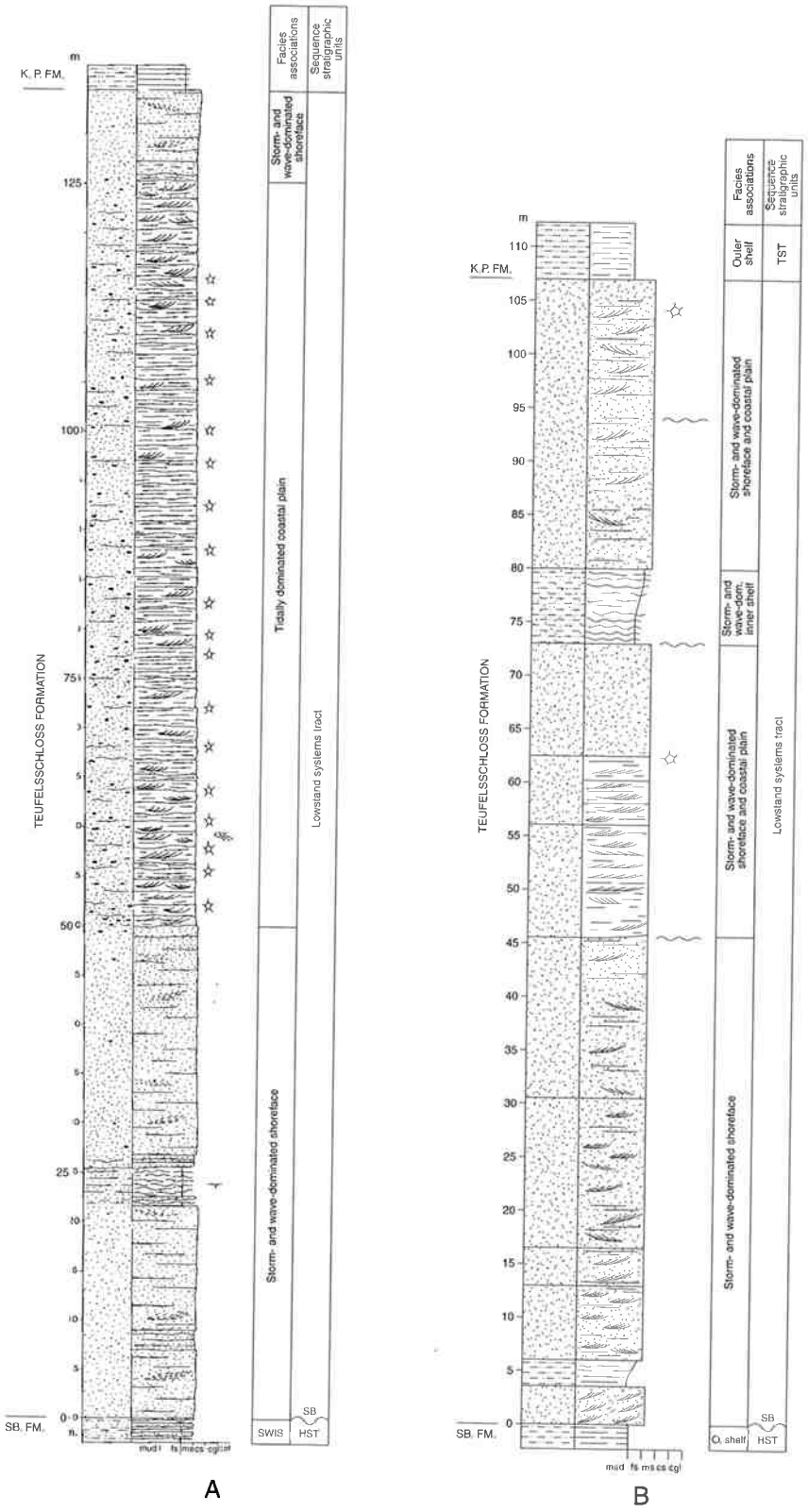

Fig. 30. **A:** Type section of the Teufelsschloss Formation (Teufelsschloss, south-eastern Andrée Land) showing facies associations and sequence stratigraphic units. The section shows the characteristic subdivsion of the formation in the northern Lyell Land – Andrée Land region, where the lower 40–50 m consist of nearly structureless shoreface sandstone deposits, the middle 70–80 m comprise well-developed sand sheets with numerous desiccation cracks, representing sub- to intertidal channels and the upper 5–10 m consist of nearly structureless, white sandstone reflecting renewed shoreface deposition.
B: Reference section of the Teufelsschloss Formation (Vibeke Sø, Steno Land). Here the characteristic tripartite division is absent and instead the formation consists of interbedded storm-dominated shoreface deposits and subtidal deposits; desiccation cracks only occur rarely. SB. FM.: Skjoldungebræ Formation, K.P. FM.: Kap Peterséns Formation, SWIS: storm- and wave-dominated inner shelf, SB: sequence boundary, TST: transgressive systems tract, HST: highstand systems tract. For legend see Fig. 5.

medium-grained sandstone. The uppermost 10 m of the formation consists of a white sandstone unit similar to the units at the base (Figs 28, 30A).

The basal and uppermost sandstone units are poorly bedded and contain very few sedimentary structures but 0.1–1.0 m thick sets of large-scale planar cross-bedding, and ripplemarks are sporadically preserved. In Steno Land, large-scale wave ripples and straight to sinuous crested megaripples are locally preserved on bedding planes.

The middle 75 m of the formation comprise wine-red sandstones showing a well defined bedding developed as 0.3–3.0 m thick sand sheets that can be traced the full length of the exposure. Each sand sheet has a highly erosive base with a relief up to 20 cm and, where the top is preserved, it is draped by a thin mudstone veneer with desiccation cracks. The sand sheets contain well preserved sedimentary structures dominated by parallel lamination and large-scale planar cross-bedding, sometimes forming herringbone cross-stratification. Foreset dip directions show a strongly bimodal orientation indicating flow towards the NW and SE. Scour and fill, cross-lamination, and locally climbing ripple lamination form subordinate structures. Vertical trends in sand sheet thickness, or in the internal structures have not been observed. The heterolithic mudstone deposits separating the two basal sandstone units are wavy and lenticular bedded.

In Steno Land and in Strindberg Land, the wine-red sand sheets in the middle part of the formation are absent and this part consists instead of a 30–70 m thick unit of light brown sandstone (Fig. 30B) which lacks indications of a distinct sand sheet geometry. Sedimentary structures include large-scale cross-bedding (sets 10–40 cm thick), with numerous reactivation surfaces, clay drapes and herringbone cross-stratification. Palaeocurrent directions are towards NW and SE. Desiccation cracks are only rarely seen on bedding planes. In southern Lyell Land, in Scoresby Land and in Canning Land the formation consists of two to three white, structureless sandstone units, 8–20 m thick, separated by dark brownish heterolithic sandstone and mudstone units, 0.5–20 m thick (Figs 26, 27). These are dominated by wavy lamination interbedded with 3–10 cm thick, graded, very fine- to fine-grained sandstone beds.

Boundaries. The lower boundary is placed where a thick, laterally continuous white sandstone unit sharply overlies the more recessive dark brown to dark purple or green mudstones and heterolithic mudstones of the Skjoldungebræ Formation (Figs 17, 23, 27, 28). In the southern part of the central fjord zone and in Canning Land, where the Teufelsschloss Formation consists of several sandstone units separated by heterolithic mudstones, the contact is placed at the base of the first sandstone unit which is more than 5 m thick (Fig. 27). The upper boundary of the Teufelsschloss Formation is placed where white sandstones, or dark brown heterolithic mudstones, are sharply overlain by dark red or purple mudstones of the Kap Peterséns Formation of the Ymer Ø Group (Figs 23, 27, 28, 31; Sønderholm & Tirsgaard, 1993). This contact is widely and well exposed from Canning Land in the east and Scoresby Land in the south, throughout the central fjord zone and as far as Wordie Gletscher in the north (Fig. 1; cf. Bengaard, 1992).

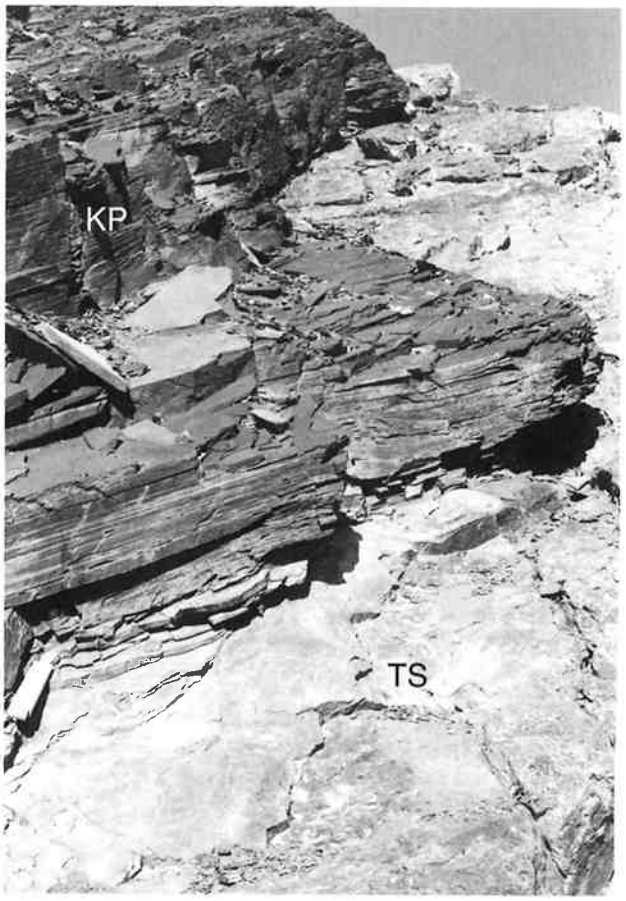

Fig. 31. Close-up of the boundary between the Lyell Land Group (Teufelsschloss Formation, TS) and the Ymer Ø Group (Kap Peterséns Formation, KP) as seen on the southern coast of Ymer Ø. The boundary reflects an abrupt shift from shoreface sandstones to outer shelf mudstones. This marked change in lithology is characteristic of the boundary throughout the central fjord zone. Ruler (20 cm) for scale in lower left corner.