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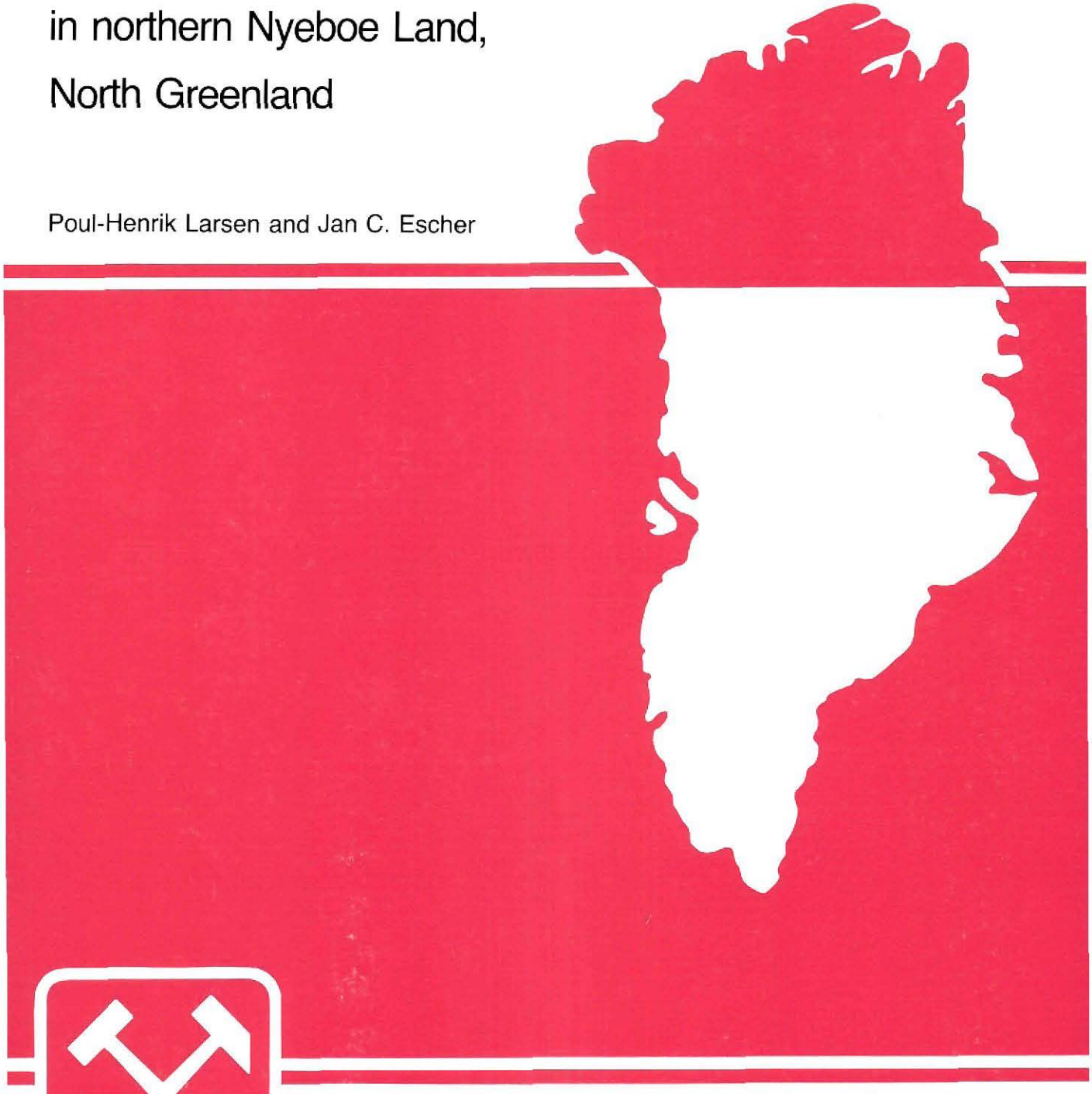
Poul-Henrik Larsen and Jan C. Escher



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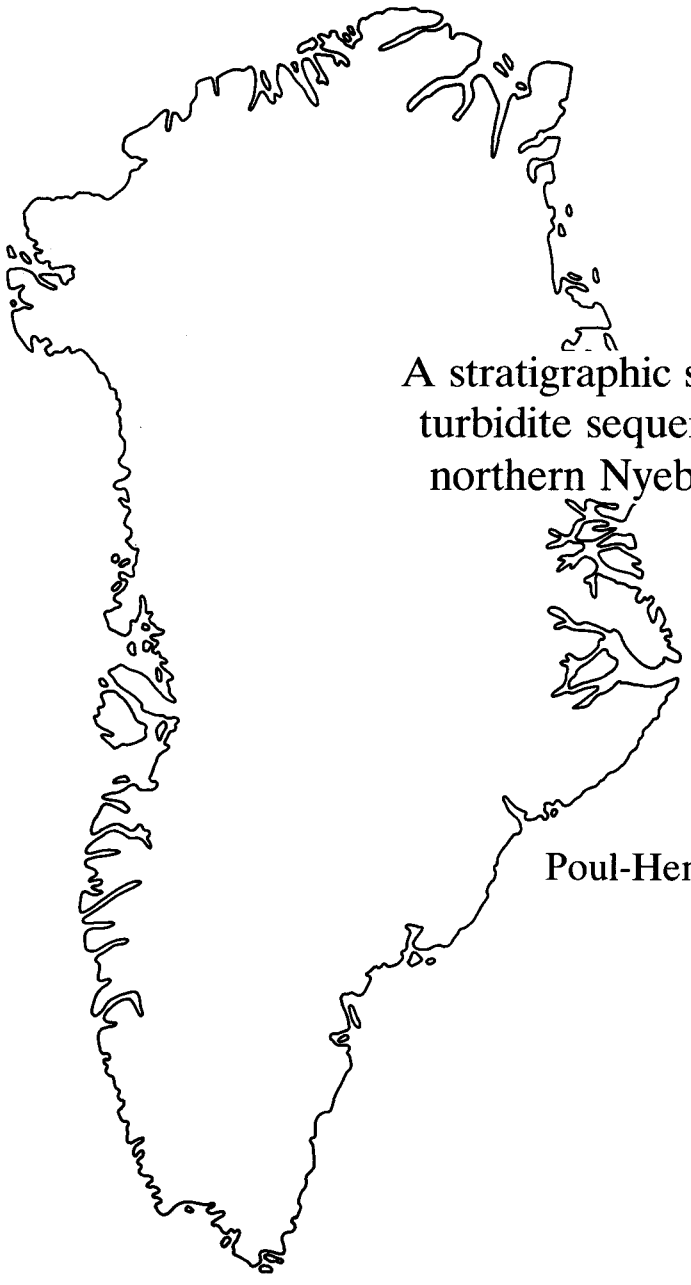

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A stratigraphic section is presented through the 6330 m thick Silurian turbidite sequence of the Peary Land Group at Hand Bugt in northern Nyeboe Land, North Greenland. Thickness, age and sediment characteristics of the Merqujôq, Lauge Koch Land, Wulff Land and Nyeboe Land Formations, the Castle Ø Member of Nordkronen Formation and the Chester Bjerg Formation are described.

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Grønlands Geologiske Undersøgelse
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Geological Survey of Greenland

The Geological Survey of Greenland (GGU) is a research institute affiliated to the Mineral Resources Administration for Greenland (MRA) within the Danish Ministry of Energy. As with all other activities involving the non-living resources in Greenland, GGU's investigations are carried out within the framework of the policies decided jointly by the Greenland Home Rule Authority and the Danish State.

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Contents

Dansk sammendrag

Artiklen præsenterer en stratigrafisk profil gennem de 6330 m tykke, sandede, silure dybhavssedimenter i Peary Land Gruppen i Hand Bugt, det nordlige Nyeboe Land, Nordgrønland. Desuden beskrives tykkelse, alder og sedimentære karakteristika for Merqujôq, Lauge Koch Land, Wulff Land og Nyeboe Land Formationerne, Castle Ø Member i Nordkronen Formationen samt Chester Bjerg Formationen.

Imaqarnersiuineq

Allaaserisami Kalaallit Nunaata avannaani, Nyboe Landip avannaa tungaani, Hand Bugtimi sioqqat imarpissuup naqqata kinnganeri qaleriissitaartut 6330 meterinik issussuseqartut, silurip nalaani kiviorarsimasut ilisaritinneqarput. Kiisalu Merqujôme, Lauge Koch Landimi, Wulff Landimi Nyboe Landimilu Formationit, tassa kinnganerit immikkoortinneqarsinnaasut issussusaat, pisoqaassusaat isikkuilu allaaserineqarput. Taakkulu saniatigut Nordkronen Formationip iluani immikkoortut Castle Ø Member-imik taaguutillit kiisalu Chester Bjerg Formation allaaserineqarput.

Introduction

During the regional mapping programme by the Geological Survey of Greenland in western North Greenland in 1984–85 (Henriksen, 1985, 1987), two weeks were used for geological investigations in Hand Bugt, northern Nyeboe Land. At this locality a section is exposed across the strike of the Nyeboe Land linear belt of Dawes (1982) which is an E–W trending zone of nearly vertically dipping Silurian turbidites. The belt is traceable over a distance of more than 170 km from Kap Brevoort in the west to Stephenson Ø in the east (Fig. 1) (Larsen & Escher, 1985, 1987). In the Hand Bugt area the belt reaches a width of about 5–7 km and the area offers an excellent opportunity to study a long stratigraphic section through the Silurian deep-water sediments exposed in the cliffs around the bay (Fig. 2).

The Silurian turbidite sequence is referred to the Peary Land Group by Hurst & Surlyk (1982), being a part of the thick Lower Palaeozoic deep-water sequence deposited in the Franklinian Basin of North Greenland and northern Ellesmere Island, Canada (Trettin & Balkwill, 1979). The evolution and stratigraphy of the basin in North Greenland is described by Surlyk & Hurst (1983, 1984) and Higgins *et al.* in press.

This paper presents a long and almost complete section through the Silurian turbidite succession in western North Greenland, documenting the thicknesses, ages and sedimentological characteristics of the formations and members of the Peary Land Group.

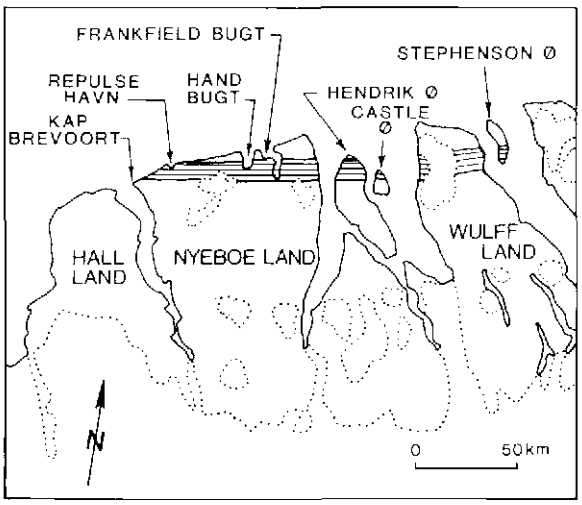


Fig. 1. Western North Greenland showing geographical names mentioned in the text. The Nyeboe Land linear belt is indicated from Kap Brevoort to Stephenson Ø.

Sedimentary logs and beds thickness diagrams

The stratigraphic section measured through the Silurian turbidite sequence in the Hand Bugt area is presented in Plate 1 and a generalised section log is shown in Fig. 2. The measured section has been divided into two parts as shown in Plate 1 and in the oblique aerial photo of the locality (Fig. 3). The lower part (section 14a in Fig. 3) covers the basal 259 m of the Peary Land Group turbidites which outcrop in the northern part of the Hand Bugt region. The upper part (section 14b in Fig. 3) covers approximately 3300 m of the Silurian turbidites located to the south. A stratigraphic sequence of approximately 2000 m separating the two sections has not been investigated.

Selected parts of sections 14a and 14b have been logged in detail and standardised according to the lithology and structure legend shown in Fig. 4. Other parts have been logged in general applying the lithostratigraphic facies scheme shown in Fig. 4, which was erected by Hurst & Surlyk (1982), with some additions by Larsen & Escher (1985, 1987).

Bed thickness diagrams are used to illustrate systematic variations in the thickness of sandstone turbidites and the relations of sandstone turbidite sequences versus mudstone intervals (Figs 9–10, 12, 15).

To construct a bed thickness diagram each Bouma-division (Bouma, 1962) of a single turbidite bed is plotted horizontally showing the sand/silt divisions (Tabcd) to the right and the mudstone division (Te) to the left. Sequences of alternating Tc and Te divisions are also plotted to the left. Non-graded, structureless fine sandstone turbidites, which cannot be described by Bouma-divisions, are plotted to the right in the diagrams with the same ornamentation as the Ta-divisons. This way of plotting the thickness of each turbidite bed gives a visual

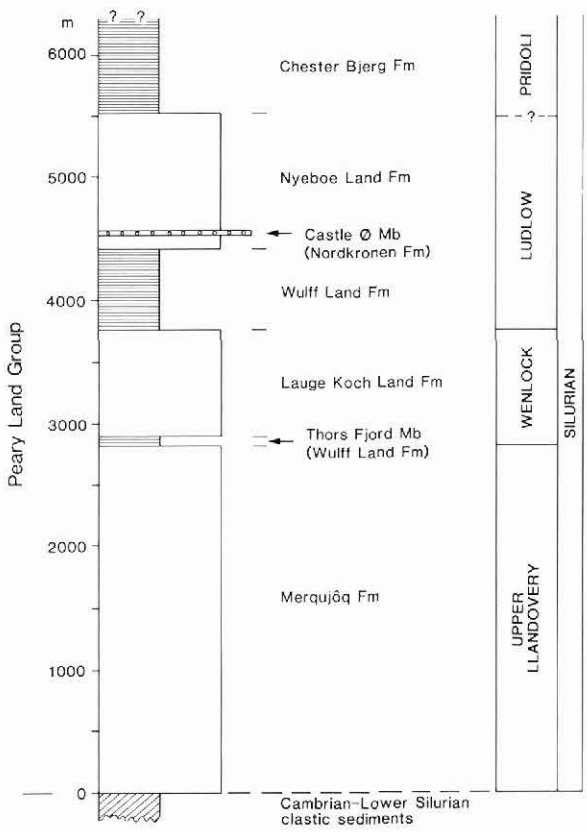


Fig. 2. Generalised section log of the 6330 m thick succession of Silurian turbidites of the Peary Land Group measured in Hand Bugt, northern Nyeboe Land.

impression of the bed thickness variations and the sand (silt)/mud ratio. It also provides an easy way to delineate sandstone versus mudstone intervals and to illustrate the dominating Bouma-division(s) involved.

Merqujôq Formation

The Merqujôq Formation was erected by Hurst & Surlyk (1982) and forms the lowermost lithostratigraphic unit of the Peary Land Group exposed in the Nyeboe Land linear belt at Hand Bugt (Fig. 3). Hurst & Surlyk (1982, fig. 2 & plate 4) described the formation in central North Greenland and predicted its occurrence in northern Nyeboe Land, although it was not distinguished on their reconnaissance map. Larsen & Escher (1985) traced the Merqujôq Formation westward into northern Nyeboe Land. Here it corresponds to 'map unit 3' of Dawes (1982, fig. 49). On Hendrik Ø it includes unit '3A' of Dawes & Peel (1984).

Section 14a (Plate 1) represents the lowermost 259 m of the Merqujôq Formation, while the basal part of

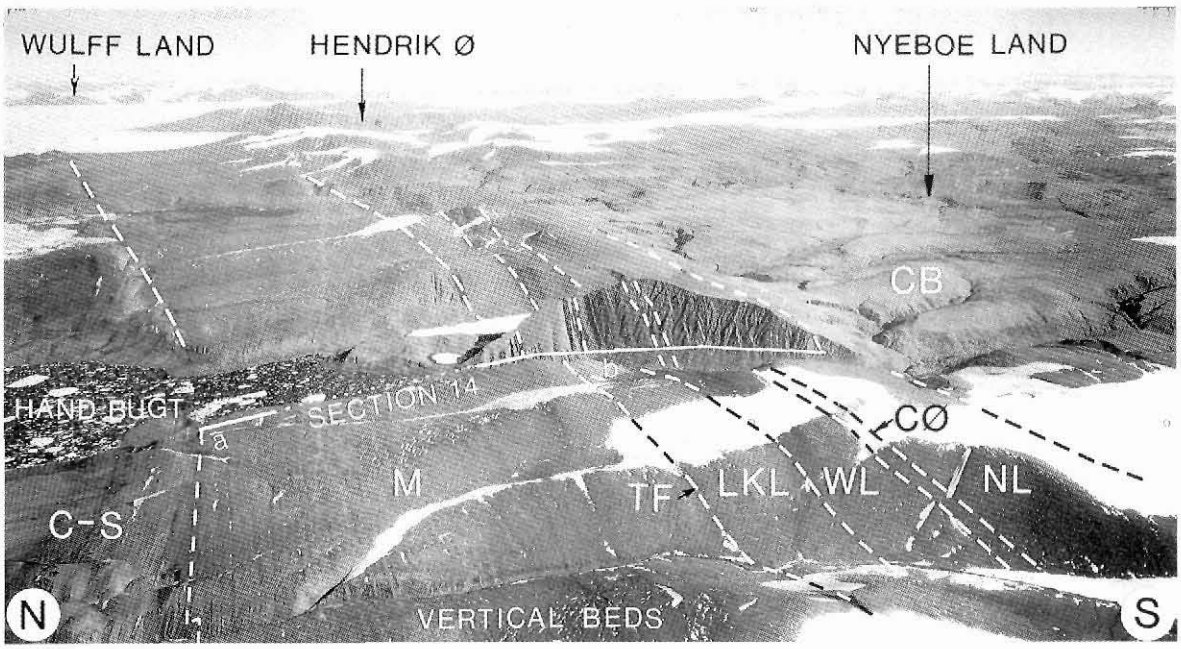


Fig. 3. View to the east across northern Nyeboe Land of the steeply dipping Silurian turbidites of the Nyeboe Land linear belt. C-S: Cambrian – Lower Silurian clastic sediment, M: Merqujôq Formation, TF: Thors Fjord Member (Wulff Land Formation), LKL: Lauge Koch Land Formation, WL: Wulff Land Formation, NL, Nyeboe Land Formation, CØ: Castle Ø Member (Nordkronen Formation), CB: Chester Bjerg Formation. Aerial photograph 546 E-Ø, no. 11575; copyright Kort- og Matrikelstyrelsen, Denmark.

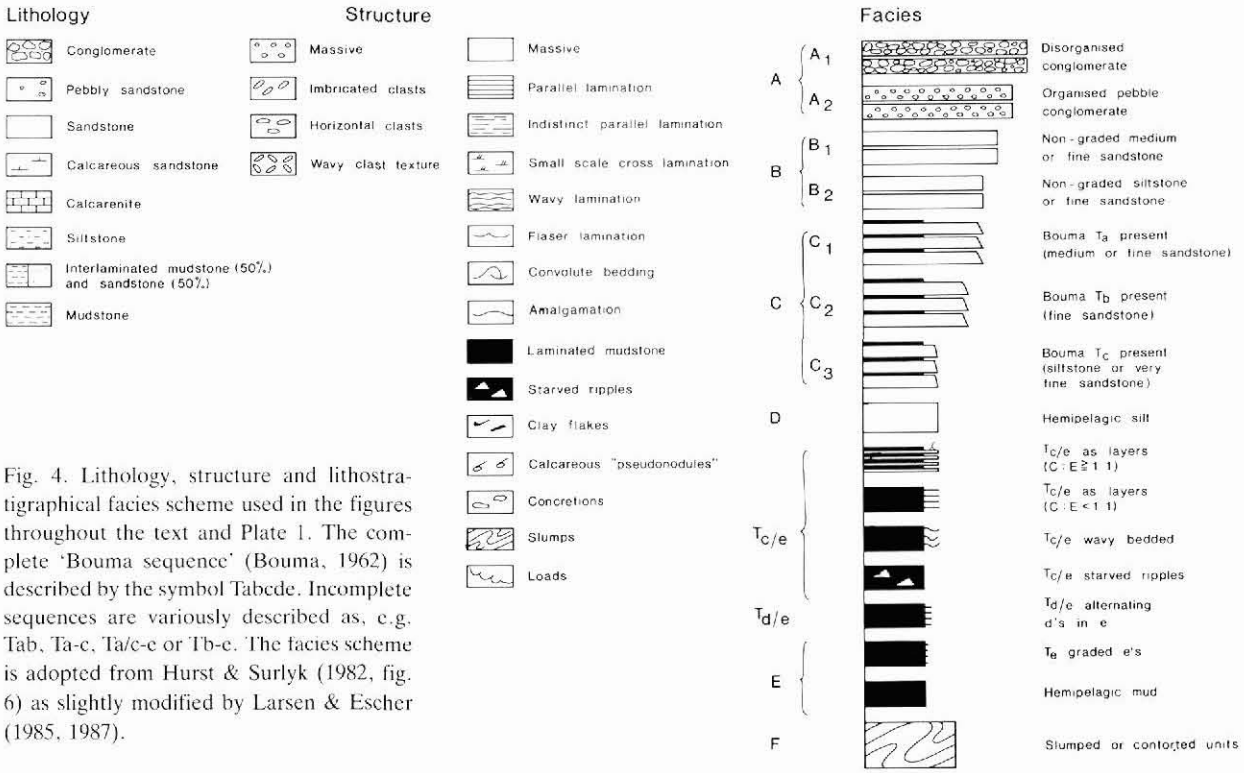


Fig. 4. Lithology, structure and lithostratigraphical facies scheme used in the figures throughout the text and Plate 1. The complete 'Bouma sequence' (Bouma, 1962) is described by the symbol Tabcde. Incomplete sequences are variously described as, e.g. Tab, Ta-c, Ta/c-e or Tb-e. The facies scheme is adopted from Hurst & Surlyk (1982, fig. 6) as slightly modified by Larsen & Escher (1985, 1987).

section 14b (0–597 m) represents the top of the formation. The stratigraphic thickness between the top of section 14a and the base of section 14b is approximately 2 km, giving a total thickness for the Merqujôq Formation at Hand Bugt of about 2800 m.

Section 14a

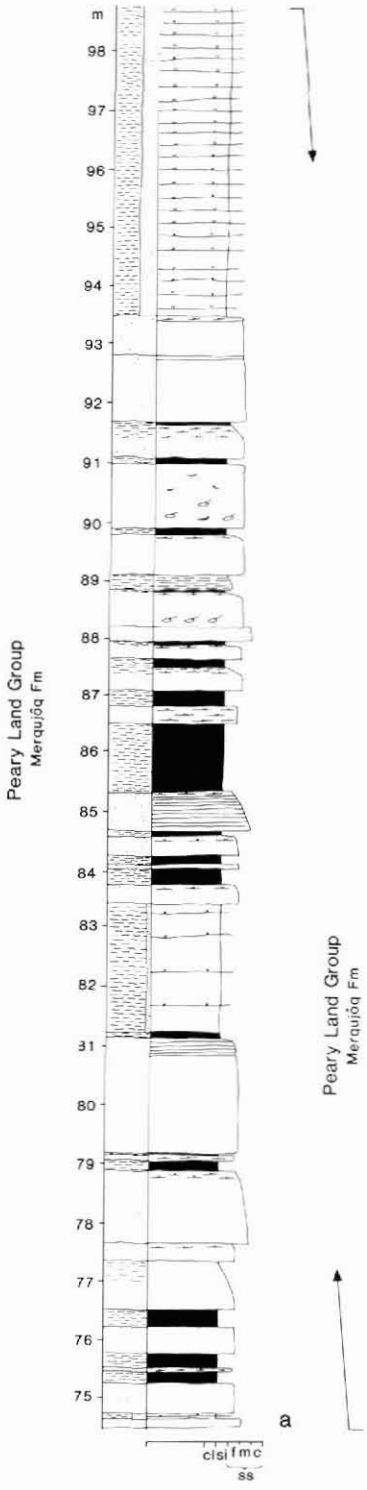
Section 14a (Plate 1) which has been logged in detail, represents the lowermost part of the Merqujôq Formation at Hand Bugt.

The section is characterised by buff-yellow to brown weathering siltstone and parallel bedded well-sorted, quartz dominated fine grained sandstone turbidites. A high carbonate content is often seen as grey weathering spots or 'pseudo-nodules' giving the sandstone units a mottled appearance (Larsen, 1986).

The fine sandstone turbidites display a variety of typical Bouma sequences. Ta/c, Tbc and Tabc sequences are most abundant, but non-graded, structureless fine sandstone divisions also occur (Plate 1 and Figs 5, 6). The soles of the turbidites show flute casts and load casts together with a variety of other structures including chevron marks and grooves. Palaeocurrent data indicate a general westward sediment transport, although some variation is present (Fig. 7a).

A statistical representation of bed thicknesses and the sand/mud ratio in section 14a is shown in Fig. 8A. The sandstone turbidites occur in beds from a few centimetres to 3 m in thickness. However, the medium-bedded and thick-bedded turbidites are the most abundant types comprising more than 80% of the beds (Fig. 8Aa). The thick-bedded turbidites make up more than 50% of the total cumulative thickness of the fine grained sandstone beds (Fig. 8Ab), while the sandstone turbidites taken together account for nearby 60% of the measured section (Fig. 8Ac). Mudstone turbidites (Te divisions), together with the abundant sequences of alternating Tc and Te divisions (Tc/e facies), account for the remaining 40%. The sandstone/mudstone ratio is > 1 (Fig. 8Ad).

Systematic variation in bed thickness of the sandstone turbidites can often be demonstrated in the section. Distinct thickening upward cycles are found in the lower part, represented by the detailed log in Fig. 5 and the bed thickness diagram in Fig. 9, while distinct thinning upward cycles appear in the upper part (Figs 6, 10). The individual cycles are characteristically separated by thick packages of alternating layers of cross-laminated (often convoluted), very fine grained sandstone or coarse siltstone (Tc) and silty mudstone (Te), here called Tc/e-facies. No distinct difference in facies associ-



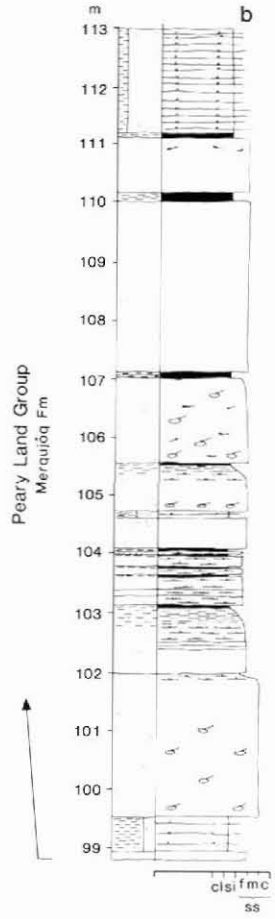


Fig. 5. Detailed log of part of section 14a (Plate 1, a-b) of the Merqujôq Formation. Legend given in Fig. 4.

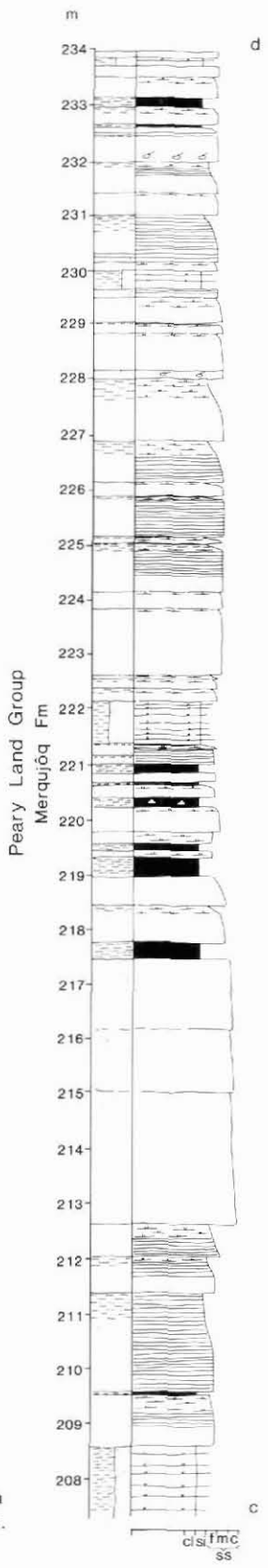


Fig. 6. Detailed log of part of section 14a (Plate 1, c-d) of the Merqujôq Formation. Legend given in Fig. 4.

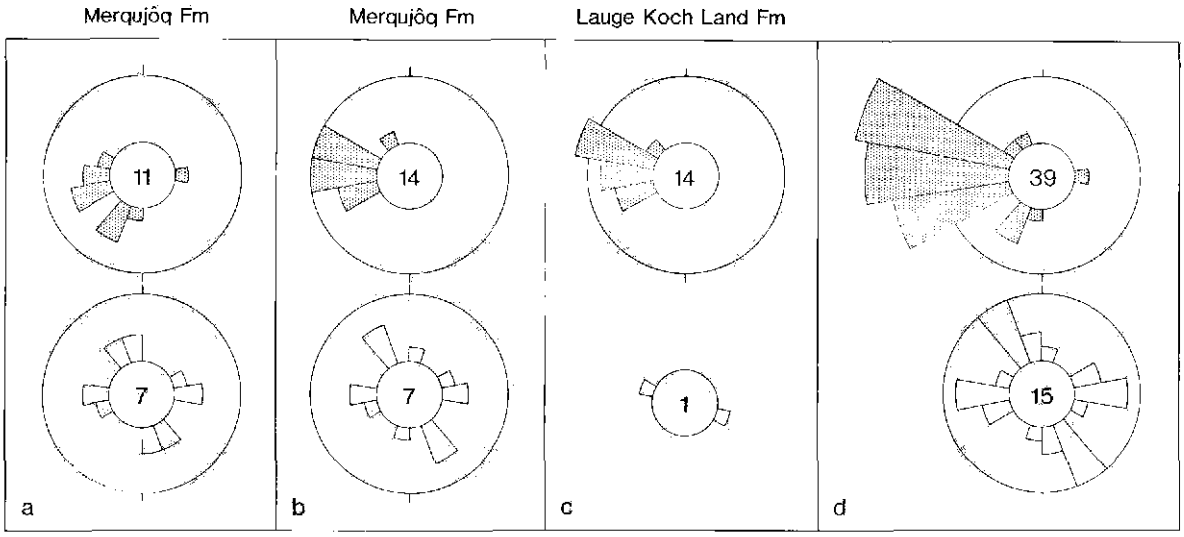


Fig. 7. Grouped palaeocurrent data for the Silurian turbidites at Hand Bugt. Stippled rose diagrams are directional measurements and (e.g. flutes); open rose diagrams are trend measurements (e.g. grooves). a. Section 14a (Plate 1, 0–259 m) b. Section 14b (Plate 1, 0–597 m) *c*. Section 14b (Plate 1, 680–1532 m) d. Sum of a,b and c above.

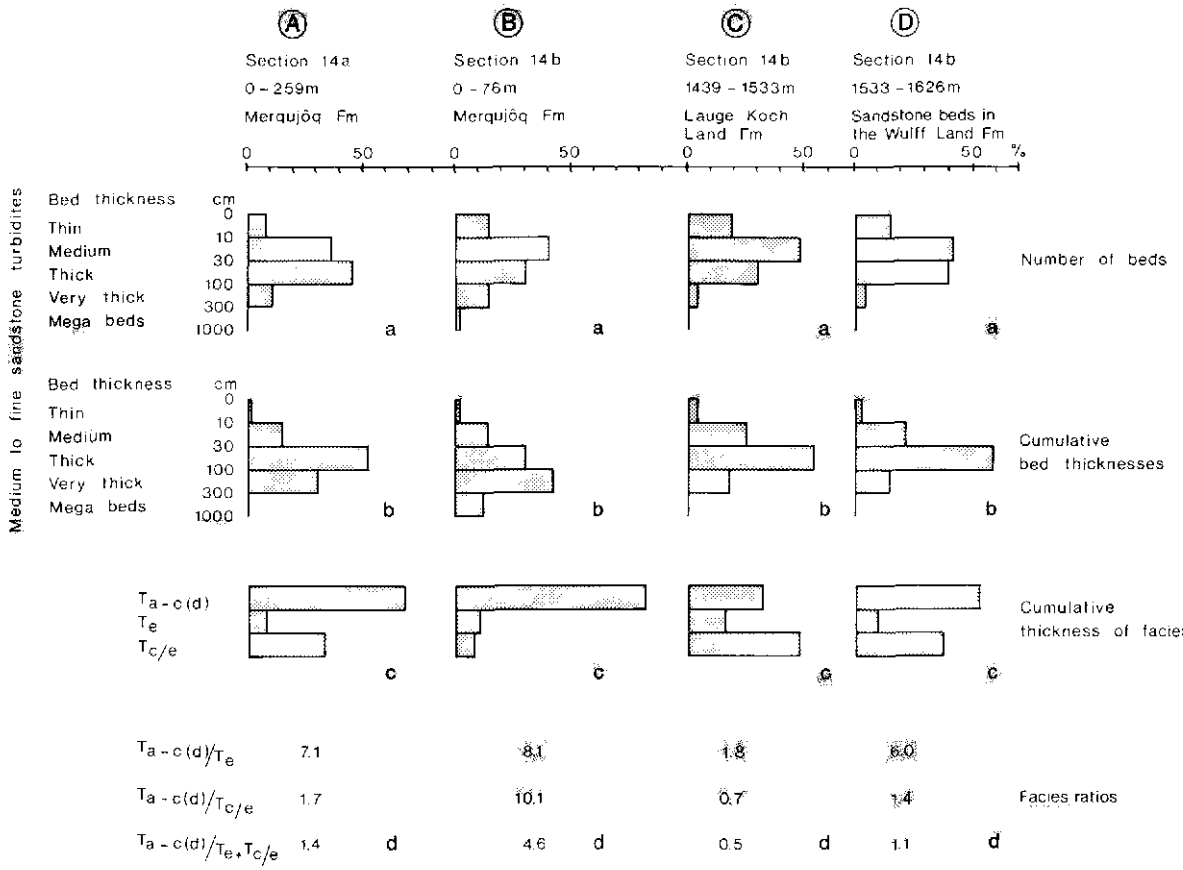


Fig. 8. Statistical representation of bed thicknesses and sand/mud ratios. a. Frequency of sandstone turbidites (Ta-c(d)) in each bed thickness interval. Non-graded structureless, sandstone beds are included. b. Cumulative thickness of beds within each bed thickness interval as percentage of total thickness in the individual sections. *c*. Cumulative thickness of facies as percentage of total thickness in the individual sections. Non-graded structureless sandstone beds are calculated in the Ta-c(d) facies. d. Sand/mud ratios calculated in three different ways based on data from *c*.

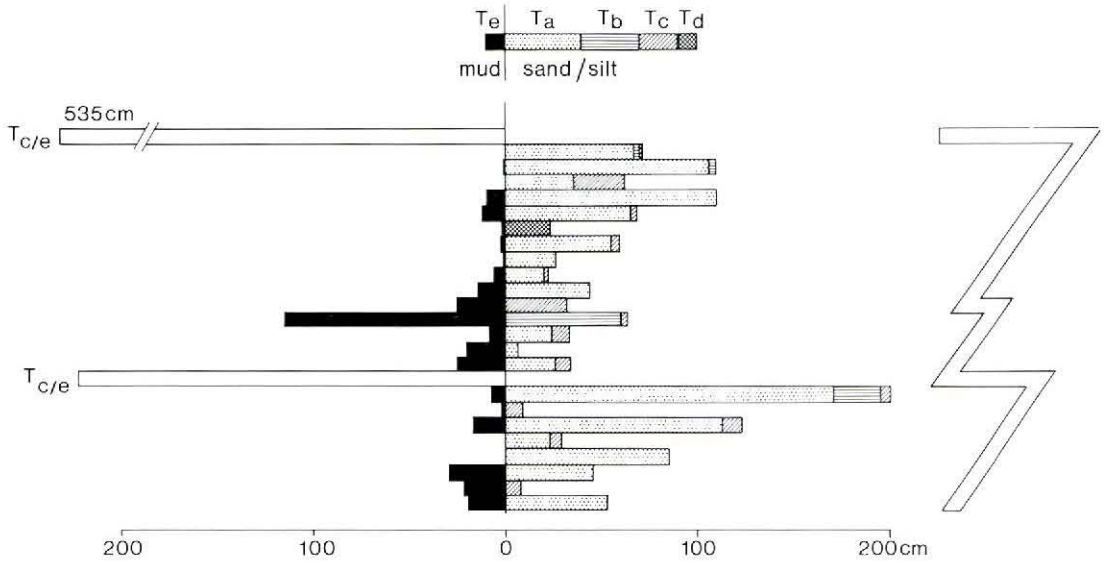


Fig. 9. Bed thickness diagram showing thickening-upward cycles of sandstone turbidites separated by Tc/e facies (Plate 1, section 14a, 75–93 m). The diagram represents the lower part of the section in Fig. 5.

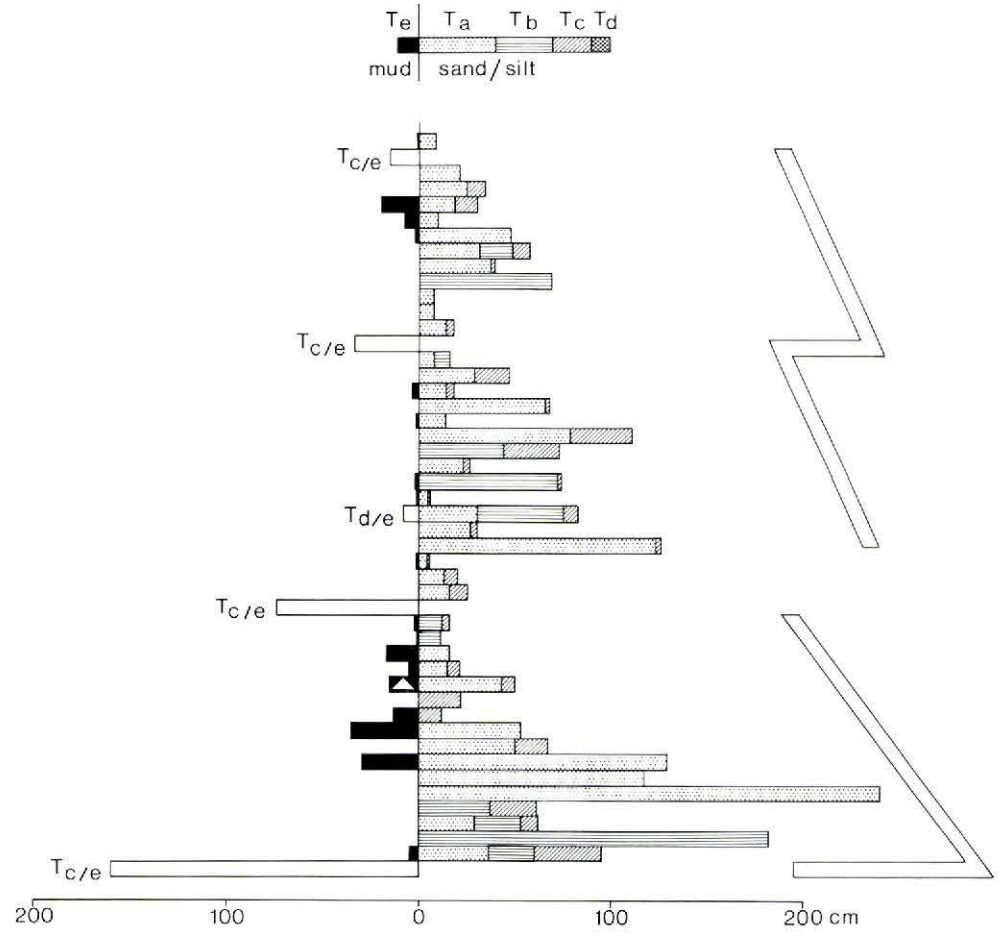


Fig. 10. Bed thickness diagram showing thining-upward cycles of sandstone turbidites separated by Tc/e facies. The minor cycles make up a major composite cycle showing a general thining-upward sequence (Plate 1, section 14a, 209–234 m). The diagram represents the section in Fig. 6.

ations can be demonstrated between the thickening upward cycles and thinning upward cycles; in both cases the sand/mud ratio is > 1 (Figs 9, 10).

Channels have not been observed in the section and all turbidites normally show planar bed shapes.

Only poorly preserved graptolites (*Monograptus* sp.: GGU 315500) have been recovered from the section. However, the age of section 14a is Late Llandovery since a suite of earliest Late Llandovery graptolites *Monograptus becki/curvus*, *M. turriculatus*, *M. regularis/nudus*, *M.* aff. *hali* and *Pristiograptus variabilis* indicating the *turriculatus* Zone was obtained 3.75 m below the base of the Merqujôq Formation 5 km east of Hand Bugt (Higgins & Soper, 1985; personal communication, 1986), and Late Llandovery graptolites are also present in section 14b (see below).

Section 14b

The basal part of section 14b (Plate 1) represents the topmost 597 m of the Merqujôq Formation at Hand Bugt. The lowermost 76 m has been measured in detail while the remainder was logged following the facies scheme in Fig. 4. The lowermost 76 m are characterised by buff-yellow to brown weathering, medium to fine grained sandstone turbidites. The turbidites show abundant Tabc, Ta/c and Tbc Bouma sequences, but non-graded structureless medium or fine grained sandstones also occur (Fig. 11). The sandstone turbidites have characteristically loaded and fluted soles.

A statistical representation of bed thicknesses and sand/mud ratios in section 14 (0–76 m) is shown in Fig. 8B. The sandstone turbidites occur in beds from a few centimetres to 6.5 m in thickness. However, the medium and thick-bedded turbidites are the most abundant types comprising approximately 70% of the beds (Fig. 8Ba). Although very thick-bedded turbidites (1-3 m) are few in number, they account for more than 40% of the total cumulative thickness of the sandstones (Fig. 8Bb). When taken together the sandstone turbidites make up more than 80% of the measured section (Fig. 8Bc), giving a sandstone/mudstone ratio >> 1 (Fig. 8Bd).

Systematic variations in bed thickness in the section (0–76 m) cannot be demonstrated. Instead a distinct medium to fine grained sandstone turbidite sequence with a sand/mud ratio approaching infinity can be demonstrated in the lower part and is here represented by the log in Fig. 11 and the bed thickness diagram in Fig. 12. The sequence is bounded below and above by packages (1.5–2.5 m) of mudstone turbidites or Tc/e facies.

Such sandstone dominated units, 5–10 m thick, are frequently found in the rest of the Merqujôq Formation (76–597 m) which has been logged using the facies scheme in Fig. 4. The sandstone dominated units tend to occur isolated and are separated by 5–20 m thick

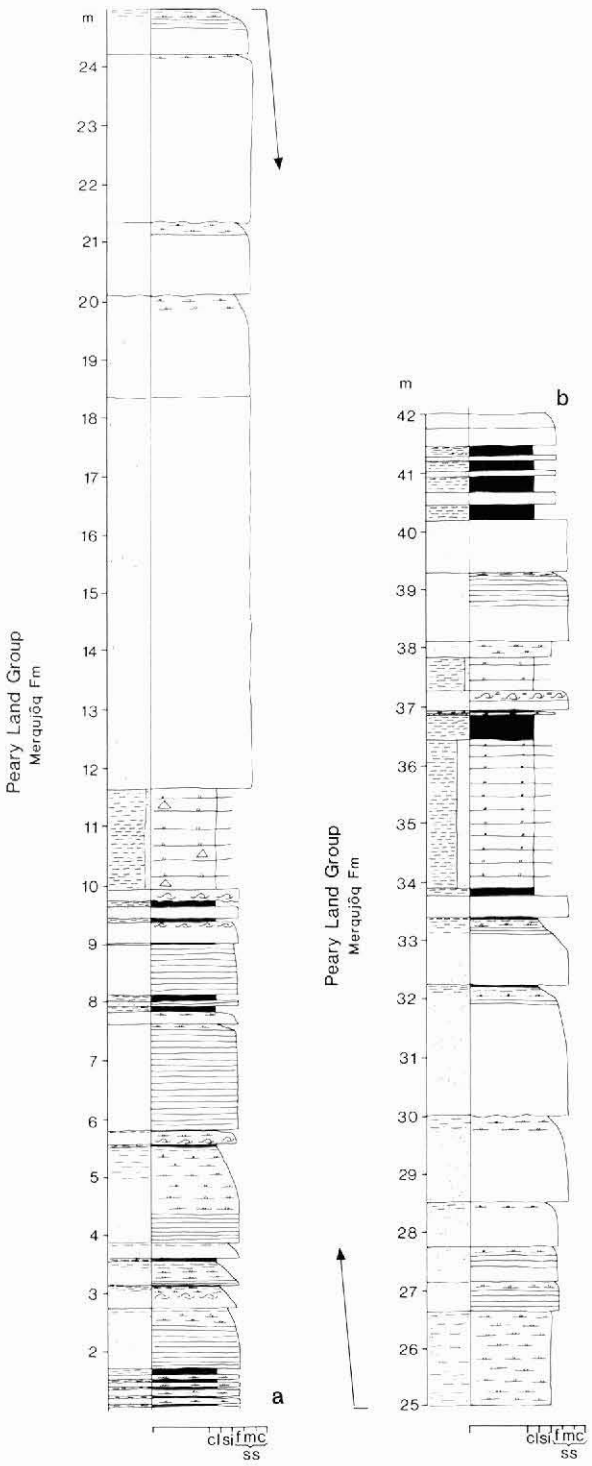


Fig. 11. Detailed log of part of section 14b (Plate 1, a-b) of the Merqujôq Formation. Legend given in Fig. 4.

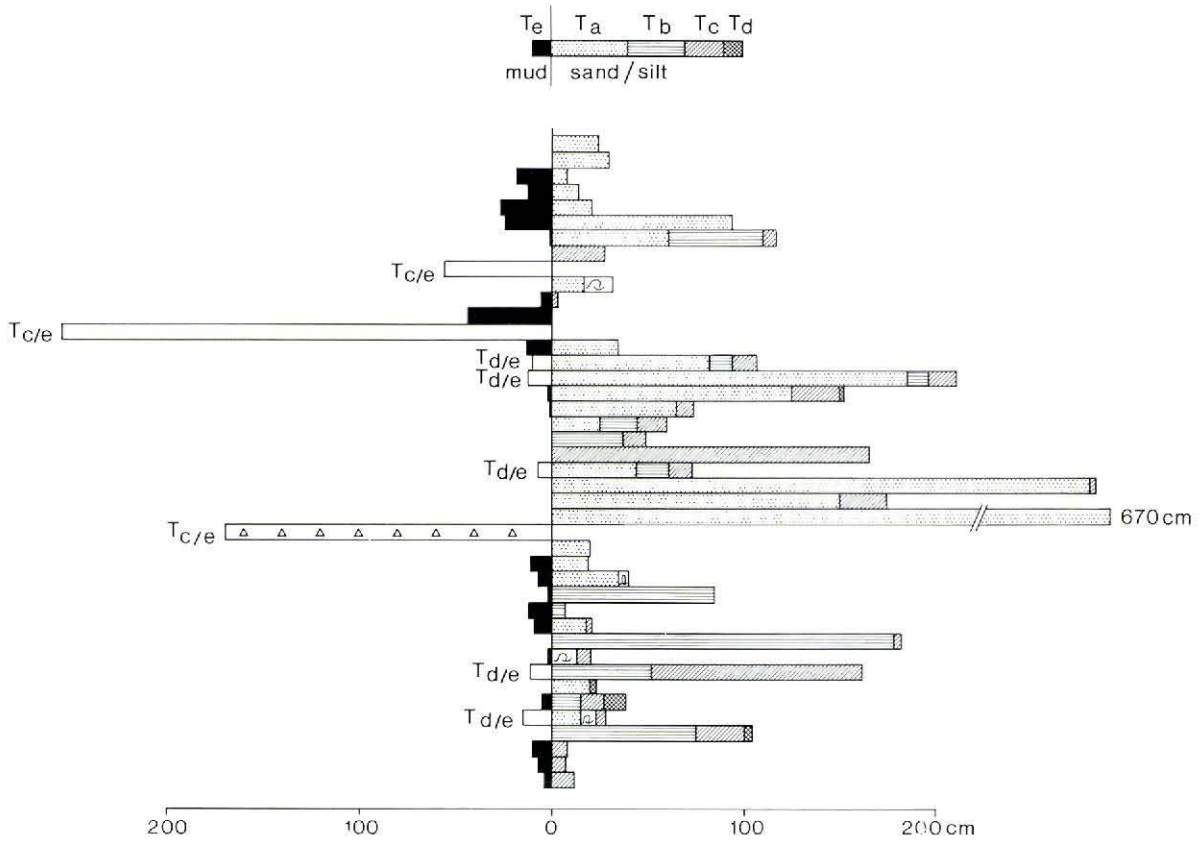


Fig. 12. Bed thickness diagram representing the sediment log of Fig. 11 (Plate 1, section 14b, 1–42 m) showing a sequence of very thick beds (0.50–6.70 m) arranged in a symmetric thinning and thickening-upward cycle bounded below and above by packages (1.5–2.5 m) of mudstone and siltstone turbidites (Tc/e facies).

Fig. 13. Thinning-upward cycle in the Merqujôq Formation of section 14b (Plate 1). Thickness of cycle is approximately 15 m.

units of facies E and Tc/e. Some of the sandstone units show internal systematic bed variations reflecting thickening or thinning upward cycles (Fig. 13). The E and Tc/e facies sequences separating the sandstone units become increasingly thicker up the section and in the top part (*c.* 496–596 m) the D-facies is conspicuous and makes up a considerable part of the sediment volume.

Channels have not been observed and all turbidites normally show planar bed shapes. Palaeocurrent data from the top of the Merqujôq Formation show a general westward sediment transport although minor variations may occur (Fig. 7b).

Graptolites are scarce and poorly preserved. *Cyrtograptus ?sakmaricus* (GGU 315469) *Monoclimacis vomerina* aff. *M. crenulata* (GGU 315469) found at the base of section 14b (0–597 m) indicate the *sakmaricus* Zone of the latest Llandovery. Finds of *Monograptus ?praecedens* (GGU 315470), *M. priodon* (GGU 315473), *Monoclimacis* sp. (GGU 315470) and *?Pristiograptus* sp. (GGU 315473) indicate that this part of section 14b representing the top of the Merqujoq Formation was deposited within the latest Llandovery.

Faunal evidence from the base of the Merqujôq Formation in northern Nyeboe Land and on Stephenson Ø indicates a Late Llandovery age of the sediments (Higgins & Soper, 1985) (see also section 14a). A loose block collected between the top of section 14a and the base of section 14b contained *Monograptus spiralis* and *Retiolites geinitizianus angustidens* (A. K. Higgins & N. J. Soper, personal communication, 1986), thus indicating the presence of the *spiralis* Zone of the Late Llandovery. The approximately 2.8 km thick sequence of deep-water sediments representing the Merqujôq Formation was therefore probably deposited exclusively within the Late Llandovery (Fronian–Telychian).

Thors Fjord Member

The Thors Fjord Member was erected by Hurst & Surlyk (1982) in eastern North Greenland as part of the Wulff Land Formation. The member was mapped in western North Greenland by Larsen & Escher (1985, 1987). At Hand Bugt the Thors Fjord member outcrops between 597 m and 680 m in section 14b (Plate 1).

The member (83 m thick) is characterised by thin-bedded mudstone and siltstone turbidites (Tc/e and Tde) set against a background of silty mudstone (Te). The silty mudstones are grey to black and often have a high lime mud content.

Thin fine grained sandstone or siltstone Tc/e and Tde turbidites (2–15 cm thick) are ubiquitous, while rare thicker bedded silty sandstone and fine grained sandstone turbidites occur as Ta/c, Ta-c and Tb types. These beds are often calcarenitic. Rare thin pebble beds with crinoid debris and carbonate clasts have been observed.

Only poorly preserved graptolites were recovered from the Thors Fjord Member at Hand Bugt. These comprise *Monograptus priodon*, *M. priodon* aff. *M. speciosus* and *Pristiograptus* sp. (all GGU 315474) which indicate an age at the Llandovery–Wenlock transition. In a section through the same mudstone unit on Hendrik Ø 50 km east of Hand Bugt (Fig. 1), graptolites are abundant but often very poorly preserved. No age diagnostic graptolites were recovered, but finds of the species *Monograptus priodon* (GGU 315524), *Monoclimacis vomerina* (GGU 315524), *Cyrtograptus* sp. (GGU 315524) and *Pristiograptus ?dubius* (GGU 315523) suggest a Late Llandovery to Early Wenlock age for the unit. Graptolite assemblages collected within the Thors Fjord Member in Hall Land 75 km west of Hand Bugt (Fig. 1) indicate the *spiralis* Zone of Late Llandovery (Larsen & Escher, 1987).

Lauge Koch Land Formation

The Lauge Koch Land Formation was erected by Hurst & Surlyk (1982). In western North Greenland it corresponds to the 'lower mapping unit' of Larsen & Escher (1985) following the redefinition of the formation as proposed by Larsen & Escher (1987).

At Hand Bugt the unit comprises 853 m of fine grained sandstone, siltstone and mudstone turbidites exposed between 680 m and 1533 m in section 14b (Plate 1). The lowermost part (680–1439 m) has been logged using the facies scheme shown in Fig. 4, while the uppermost part (1439–1533 m) has been logged in detail.

The lowermost *c.* 760 m of the Lauge Koch Land Formation are characterised by buff-yellow weathering fine grained sandstone turbidites showing a variety of Bouma sequences. The C1-facies is the most abundant facies.

The fine grained sandstone turbidites occur in packages, normally 5–10 m thick, separated by mudstone units (E and Tc/e facies) approximately 2–5 m thick. In the central part of the section (*c.* 1000–1100 m) D-facies dominate the sequence, but the overall sand/mud ratio is generally > 1. Bed shapes are normally planar throughout the sequence, though one minor channel has been observed (1375 m).

The uppermost *c.* 95 m of the Lauge Koch Land Formation, which has been measured in detail, are characterised by buff-yellow to brown weathering fine grained sandstone turbidites in packages of 5–10 m separated by 5–15 m thick mudstone units. The fine grained sandstone turbidites display abundant Tab, Tabc(d) and

Ta/c Bouma sequences, but non-graded structureless fine grained sandstones also occur (Fig. 14).

A statistical representation of bed thicknesses and sand/mud ratios of the uppermost *c.* 95 m of the formation is shown in Fig. 8C. The sandstone turbidites appear in beds from a few centimetres to 2 m in thickness. The medium-bedded turbidites are the most abundant type comprising almost 50% of the beds (Fig. 8Ca), while the thick-bedded turbidites make up more than 50% of the cumulative thickness of the sandstone turbidites (Fig. 8Cb). The fine grained sandstone turbidites taken together only account for 30% of the measured section (Fig. 8Cc), giving a sandstone/mudstone ratio < 1 (Fig. 8Cd).

Systematic variation in bed thicknesses within the sandy turbidite packages in the section has been observed, with thickening upward cycles being separated by 2.5–3.5 m thick mudstone units (Tc/e facies) (Figs 14, 15). Within each cycle the sand/mud ratio is > 1.

Channels have not been observed in this uppermost part of the formation. The bed shape is normally planar, but some lateral wedging out of several of the medium-bedded turbidites does occur. Directional palaeocurrent data from the Lauge Koch Land Formation in Hand Bugt show a westward sediment transport which is parallel to the trend of the observed minor channel in the lower part of the formation (Fig. 7c).

Monograptus priodon (GGU 315475) has been recovered from the section about 100 m above the base (section 14b, 790 m). This species has a long range, from the Late Llandovery *crispus* Zone to the Middle Wenlock *riccartonensis* Zone (Bjerreskov, 1981, 1986) and is thus of minor stratigraphic importance. From the Repulse Havn some 30 km west of Hand Bugt Hurst & Surlyk (1982) recorded Middle and Late Wenlock graptolite assemblages from the Lauge Koch Land Formation. These authors also report graptolites from the latest Llandovery *sakmaricus–laqueus* Zone from this locality. However, it is not clear where in the stratigraphic column this assemblage occurs. It seems more likely that the assemblage comes from below the Thors Fjord Member, i.e. in the Merqujôq Formation which these authors did not recognise in northern Nyeboe Land.

The Lauge Koch Land Formation at Hand Bugt can be no younger than Early Ludlow because the overlying Wulff Land Formation yields graptolite assemblages of this age (see below). Deposition of the Lauge Koch Land Formation therefore most probably took place in Wenlock time as suggested by Larsen & Escher (1985).

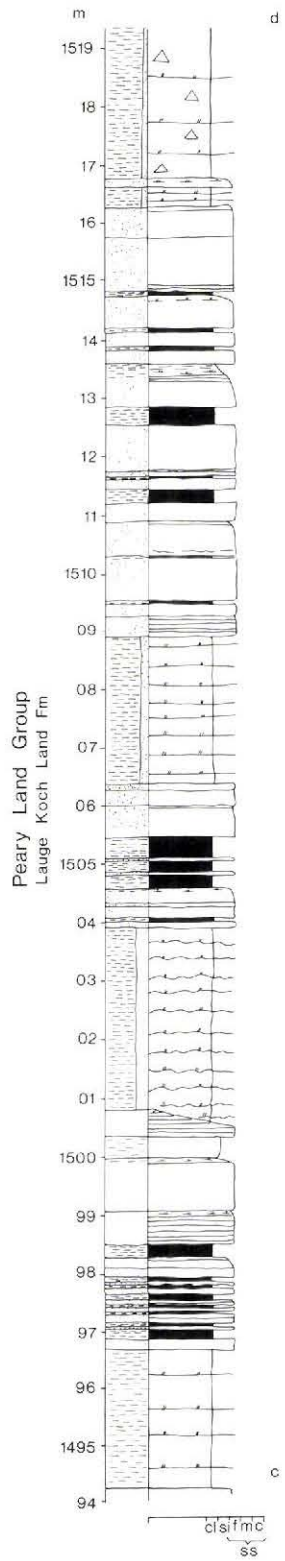


Fig. 14. Detailed log of part of section 14b (Plate 1, c-d) of the Lauge Koch Land Formation. Legend given in Fig. 4.

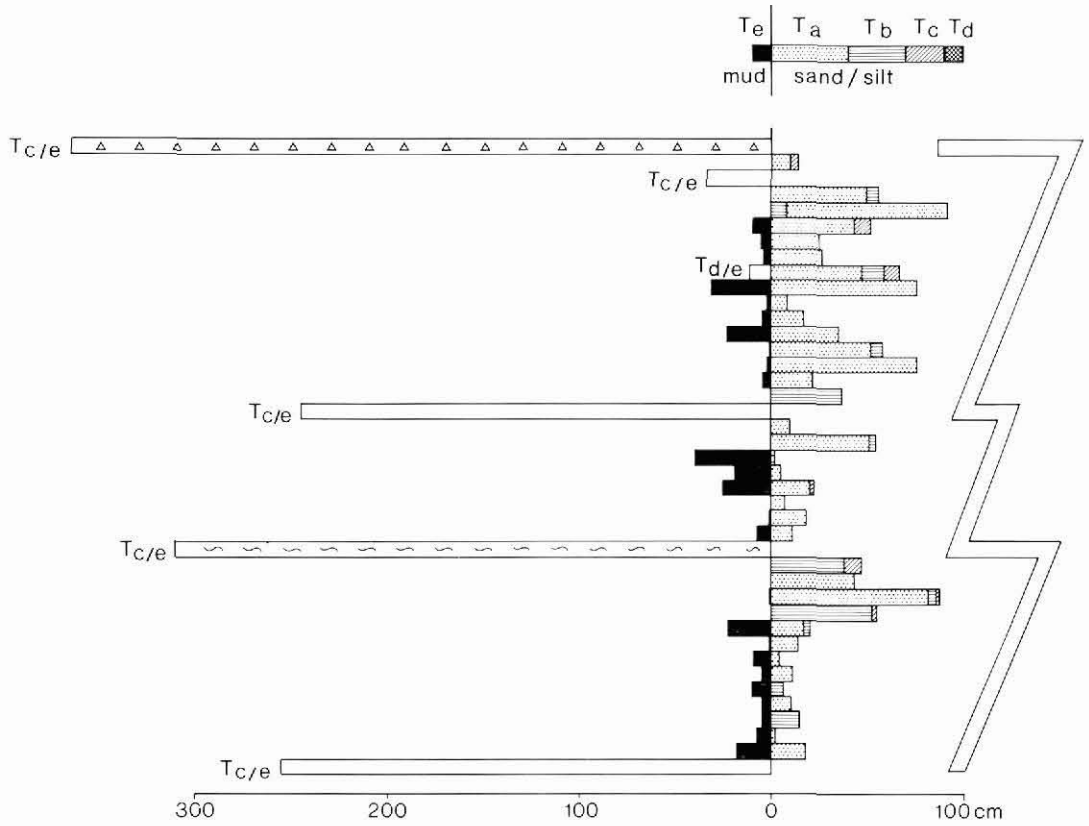


Fig. 15. Bed thickness diagram showing thickning-upward cycles of sandstone turbidites separated by Tc/e facies (Plate 1, section 14b, 1494–1520 m). The diagram represents the section in Fig. 14.

Wulff Land Formation

The Wulff Land Formation was erected by Hurst & Surlyk (1982) for a sequence of black mudstones and fine grained black or green siltstones distributed throughout North Greenland.

At Hand Bugt a 665 m thick mudstone and siltstone dominated sequence occurs overlying the Lauge Koch Land Formation (section 14b, 1532–2197 m). Larsen & Escher (1987) referred this sequence to the Wulff Land Formation which, east of Hand Bugt, splits into two members, the Hand Bugt Member and the Repulse Havn Member, separated by an interbedded conglomerate dominated sequence; the Hendrik Ø Member of the Nordkronen Formation.

At Hand Bugt the base of the Wulff Land Formation is placed where the mudstones change colour from grey or black to green to brownish red. The lowest 93 m of the formation (section 14b, 1532–1625 m) is referred to as interfingering Lauge Koch Land Formation and Wulff Land Formation because of a relative high content of sandstone turbidites. This sequence is characterised by units of thin–bedded silty mudstone turbidites (50–400 cm thick) interbedded with medium to thick-bedded, calcareous, silty sandstone turbidites. The silty mudstone units are green to brownish red, often burrowed and bioturbated. Starved ripples, as well as pyrite concretions (1 cm across) are abundant throughout the sequence. The silty mudstone units are separated by medium to thick-bedded often calcareous silty sandstone and very fine grained sandstone turbidites. Bouma sequences with missing bases, Tbc and Tb, are most abundant, but Tabc and Tab types also occur. The Tb division often shows pronounced convolute bedding (Fig. 16). The sandy turbidites have a dark red, rusty weathering colour which is conspicuous throughout the sequence. The rusty colour is due to weathering of a high content of disseminated pyrite (framboids) in the turbidites.

A statistical representation of bed thicknesses and the sand/mud ratios of the lowermost 93 m of the Wulff Land Formation is shown in Fig. 8D. The very fine grained sandstone turbidites occur in beds from a few centimetres to 2 m in thickness. The medium-bedded

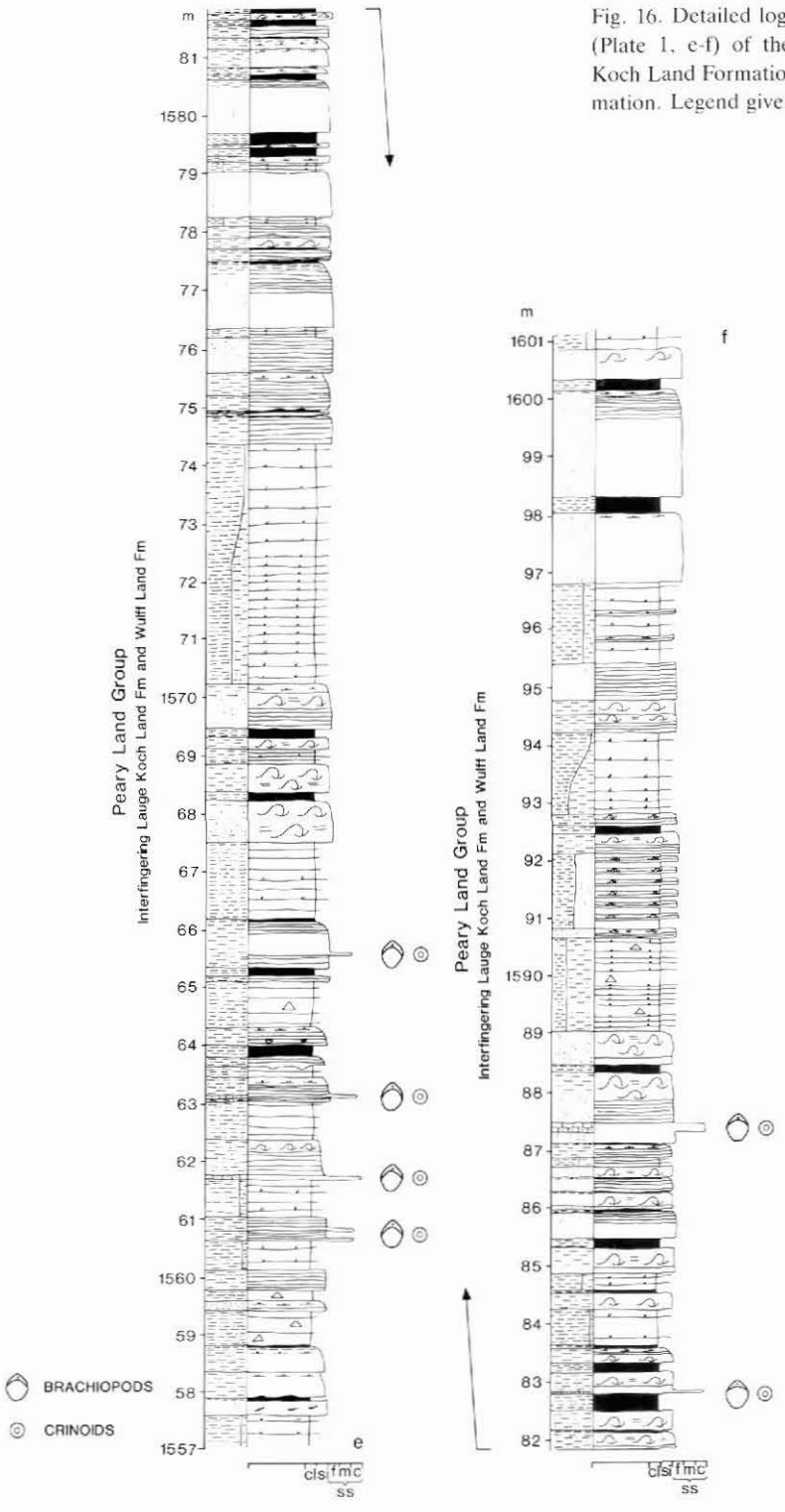


Fig. 16. Detailed log of part of section 14b (Plate 1, e-f) of the interfingering Lauge Koch Land Formation and Wulff Land Formation. Legend given in Fig. 4.

and thick-bedded turbidites are the most abundant types comprising more than 80% of the beds (Fig. 8Da). The thick-bedded turbidites make up approximately 60% of the cumulative thickness of the very fine grained sandstone turbidites (Fig. 8Db), while the sandstone turbidites taken together account for approximately half

of the measured section (Fig. 8Dc). Mudstone turbidites (Te divisions) together with the Tc/e-facies account for the other half. The sandstone mudstone ratio is > 1 (Fig. 8Dd).

Sandstone beds (2–10 cm thick) with a high content of crinoid and brachiopod debris often occur within individual turbidites (Fig. 16). Sometimes these beds are found at the base of the Ta division but normally they are associated with the base of Tb divisions. Trace fossils are abundant at the base of the silty fine grained sandstone beds throughout the sequence. Neither channelling nor clear systematic variation in bed thickness have been observed. The few palaeocurrent measurements indicate a northward sediment transport.

The remaining part of the Wulff Land Formation at Hand Bugt (section 14b, 1625–2197 m) is dominated of thick units (1–100 m) of thin-bedded mudstone and siltstone turbidites (Tc/e and Tde) set against a background of silty mudstone. The silty mudstones are mainly dark green but lighter colours such as light green, greyish green and grey may occur. The colour changes gradually up the sequence and greyish tones are most conspicuous near the top, where also several intervals of paper shales occur. Throughout the sequence the silty mudstones and shales are often bioturbated and contain abundant starved ripples and pyrite concretions. In two 80 m intervals (1717–1796 m and 1892–1968 m) the grade is generally uniform fine grained silt, and layering is only indicated by the colour banding in various shades of green to brownish red. The thin-bedded silty mudstone units are interbedded by thicker-bedded (10–50 cm) silty sandstone and fine grained sandstone turbidites, commonly Tc and more rarely Tabc, Tbc and Tb sequences, often with convolute bedding.

In some intervals 20–30 m fine grained sandstone packages interfinger with the mudstone and siltstone dominated sequences (Fig. 17 and section 14b, 1834–1861 m). Above level 1834 m in section 14b these sandstones are buff-yellow to brown weathering medium to thick-bedded sandy turbidites. In this way they differ from the red coloured, often calcareous very fine grained sandstone turbidites described from the lower part of the Wulff Land Formation (section 14b, 1532–1834 m). Ta, Ta/c and Ta/cd sequences are most abundant, but non-graded structureless fine grained sandstone divisions also occur (Fig. 17).

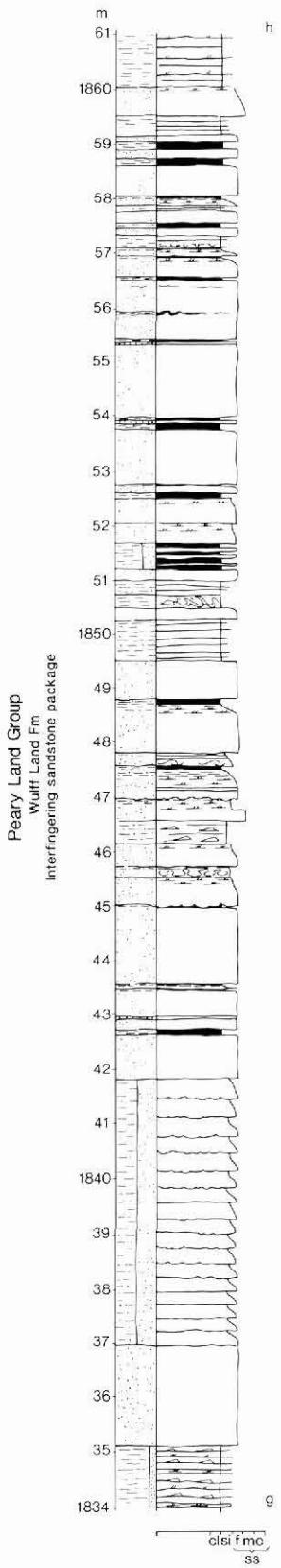


Fig. 17. Detailed log of part of section 14b (Plate 1, g-h) of an interfingering sandstone package in the Wulff Land Formation. Legend given in Fig. 4.

From studies of aerial photographs the sandstone packages between levels 1834 m and 2050 m in section 14b can be traced into the conglomerate dominated sequence occurring east of Frankfield Bugt; they might therefore be interpreted as distal sandstone lobes of the Hendrik Ø Member of the Nordkronen Formation. The sandstone turbidites or sandstone packages occurring above level 2050 m are interpreted as interdigitations of the overlying Nyeboe Land Formation into the Wulff Land Formation.

Bohemograptus bohemicus (GGU 319269), *Monograptus uncinatus* (GGU 319269) and *Pristiograptus* sp. (GGU 319269–270) collected within the 665 m thick Wulff Land Formation at Hand Bugt indicate an Early to Middle Ludlow age. This is in accordance with graptolite assemblages collected within the Hand Bugt and Repulse Havn Members to the east of Hand Bugt (Hurst & Surlyk, 1982; Larsen & Escher, 1985, 1987). *Bohemograptus bohemicus* (GGU 319246, 319249, 319252), *Monograptus ?micropoma* (GGU 319252) and *Pristiograptus dubius* (GGU 319249) collected from the Wulff Land Formation in Hall Land also indicate an Early to Middle Ludlow age for the Formation.

Nyeboe Land Formation

Outcrops of the Nyeboe Land Formation in section 14b are separated into a basal sequence (2197–2310 m) and an upper sequence (2346–3296 m) by the intervening Castle Ø Member of the Nordkronen Formation.

Basal sequence. This 113 m thick sequence (section 14b, 2197–2310 m), corresponding to the basal part of the Nyeboe Land Formation of Larsen & Escher (1987), is characterised by buff-yellow weathering fine grained sandstone turbidites interbedded with finer grained siltstone and mudstone intervals. The sand/mud ratio is > 1.

The sequence was not logged in detail and no faunal assemblages were recovered. However, graptolites described from the underlying Wulff Land Formation (see above) indicate that the base of the Nyeboe Land Formation cannot be older than Early Ludlow.

Upper sequence. This fine grained sandstone turbidite dominated sequence (section 14b, 2346–3296 m) corresponds to the main part of the Nyeboe Land Formation of Larsen & Escher (1987). The sequence has been examined only briefly at Hand Bugt, and its thickness is estimated to approximately 950 m. It is the southernmost very steeply dipping unit within the Nyeboe Land linear belt and interdigitates with the overlying Chester Bjerg Formation (Figs 2, 3).

No graptolites were recovered from the formation at Hand Bugt. However, as Early to Middle Ludlow graptolites were recovered from the underlying Wulff Land Formation (see above) and as the base of the overlying Chester Bjerg Formation might be older than Pridoli (see later), the age of the Nyeboe Land Formation seems to be Ludlow, possibly Late Ludlow (Larsen & Escher, 1987).

Castle Ø Member (Nordkronen Formation)

The Castle Ø Member of the Nordkronen Formation (Larsen & Escher, 1987) at Hand Bugt comprises a 36 m thick sequence characterised by chert pebble conglomerates (section 14b, 2310–2346 m). A basal megabed (5.5 m thick) of coarse chert pebble conglomerates is overlain by medium to thick-bedded generally coarse pebble conglomerates interbedded with fine grained sandstone turbidites and few thin mudstone intervals (Fig. 18). The conglomerate beds are structureless and sometimes graded. Sub-horizontal clast orientation may occur and rare weakly imbricated horizons have been observed.

The conglomerates are clast supported, well sorted and generally the clasts are sub to well rounded. The clasts are predominantly black, green and grey cherts (*c.* 90%), the remainder consisting of quartzites, carbonates and intraformational turbidite sandstones. The matrix of the conglomerates is well sorted, fine grained sand corresponding to the lithology of the interbedded fine grained sandstone turbidites.

The fine grained sandstone turbidites are normally thick to very thick, structureless and non-graded beds; they are closely associated with the conglomerates.

No palaeocurrent indicators or faunal assemblages were found. Age constraints imposed by the underlying and overlying turbidite sequence of the Nyeboe Land Formation, discussed elsewhere, indicate that the Castle Ø Member of the Nordkronen Formation can be no older than Early Ludlow, possibly Middle Ludlow.

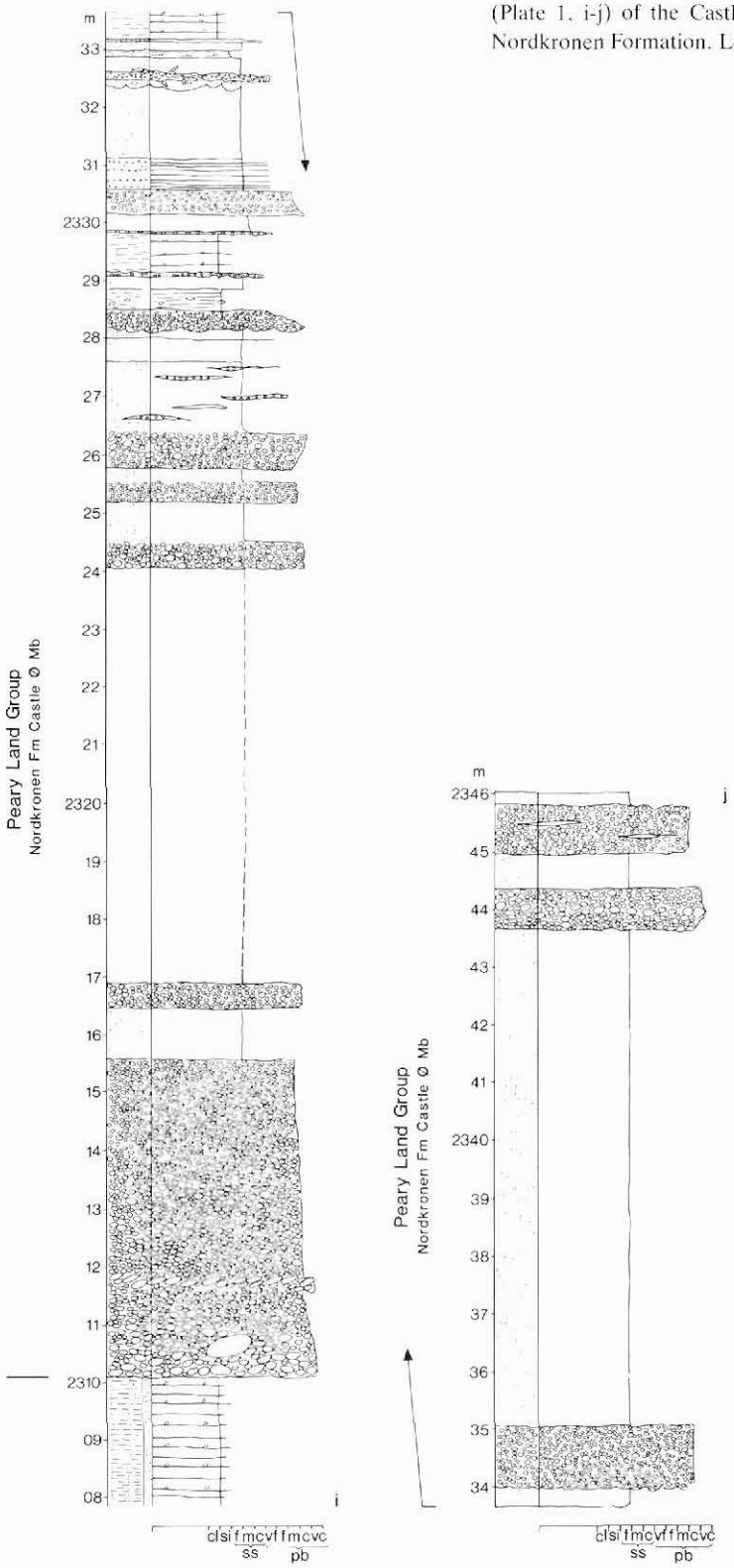


Fig. 18. Detailed log of part of section 14b (Plate 1, i-j) of the Castle Ø Member of the Nordkronen Formation. Legend given in Fig. 4.

Chester Bjerg Formation

The Chester Bjerg Formation defined from western North Greenland by Hurst & Surlyk (1982) is the uppermost lithostratigraphic unit of the Peary Land Group. It interfingers with and overlies the Nyeboe Land Formation (Larsen & Escher, 1987) and is exposed in section 14b between 3296 and *c.* 4096 m.

The formation is characterised by laminated light green weathering mudstones or siltstones. Its stratigraphic thickness has not been measured, but may be estimated to 500–800 m (Dawes, 1976; Hurst & Surlyk, 1982; Larsen & Escher, 1985).

The formation was only briefly examined at Hand Bugt. The graptolite *Pristiograptus dubius* (GGU 315484) was collected within the formation 7 km south of Hand Bugt, indicating that the base of the Chester Bjerg Formation might be older than Pridoli, i.e. Ludlow. The occurrence of *Pristiograptus separabilis* (GGU 319223) in Hall Land confirms the Pridoli age for the formation suggested by earlier finds (Hurst & Surlyk, 1982; Dawes & Peel, 1984). No unequivocal faunal evidence for the presence of Devonian strata within the formation has been found.

Summary and discussion

Two stratigraphic sections 14a and 14b covering the base and upper part of the Silurian Peary Land Group have been logged at Hand Bugt (Plate 1 and Figs 1–3). The work documents thickness, age and sediment characteristics of the various lithostratigraphic units of the group plus an estimate of the total thickness of approximately 6300 m for the Silurian turbidite succession in western North Greenland (Fig. 2).

Faunal evidence points to a Late Llandovery age for the basal 2800 m of turbidites referred to the Merqujôq Formation. The Merqujôq Formation is overlain by an 83 m thick mudstone unit, the Thors Fjord Member of the Wulff Land Formation. Graptolite assemblages suggest that the Thors Fjord Member in the Hand Bugt area marks the Llandovery – Lower Wenlock transition. The Thors Fjord Member is succeeded by 852 m of mainly sandstone turbidites belonging to the Lauge Koch Land Formation which contain sparse graptolite material indicating a Wenlock age. The Lauge Koch Land Formation is succeeded by 665 m of mainly mudstone and siltstone turbidites, with few interdigitations of sandy turbidites, referred to the Wulff Land Formation; graptolite assemblages suggest an Early to Middle Ludlow age. The Wulff Land Formation is overlain by a succession of 1100 m of mainly sandstone turbidites of the Nyeboe Land Formation. Approximately 110 m above the base of this formation, a 35 m thick sequence of chert pebble conglomerates occurs, which is referred to the Castle Ø Member of the Nordkronen Formation. The Nyeboe Land Formation and Castle Ø Member have not yielded faunal assemblages but age constraints imposed by underlying and overlying sequences suggest Middle to Late Ludlow. The measured sequence is topped by the Chester Bjerg Formation (at least 800 m), which is dominated by mudstone and siltstone turbidites. The base of the Chester Bjerg Formation might be older than Pridoli and the formation may extend through to the end of the Silurian, or even beyond.

The palaeocurrent directional measurements from the logged turbidite column show a unimodal westward sediment transport (Fig. 7d). This is in agreement with data obtained by Hurst & Surlyk (1982) who suggested an eastern Caledonian source for the deep-water sediments. However, the high lime mud content of the shales and the calcareous turbidites occurring in the Thors Fjord Member, the few northward directed palaeocurrent measurements obtained in the sandy turbidites interfingering the Wulff Land Formation higher in the succession and the crinoid and brachiopod detritus frequently found in these often calcareous turbidites suggest that some material was derived from the south where the deep-water basin was fringed by large, degrading carbonate mound complexes on the slopes of a drowning carbonate platform (Sønderholm *et al.*, 1987; Sønderholm & Harland, 1989; Higgins *et al.*, in press).

The general evolution of the Silurian deep-water basin in North Greenland was described by Hurst & Surlyk (1982) and Surlyk & Hurst (1983, 1984). These authors regarded the Peary Land Group as representing a longitudinal E–W trending deep-water fan system fed from the east as mentioned above. In their model the sandstone turbidite sequences in northern Nyeboe Land are distal in respect to the source and were thus interpreted as representing outer fan or fan fringe depositional environments, while the mudstone sequences were regarded as basin plain or lower slope deposits. Our data presented here are in good agreement with these interpretations.

In the most distal western parts of the turbidite basin in Hall Land Hurst & Surlyk (1982) noted characteristically alternating turbidite units and mudstone sequences. They tentatively suggested that the mudstones were reminiscent of levée deposits bordering wide E–W trending deep-sea channels which were thought to have migrated laterally across the basin plain. The coarse units thus corresponded to channel deposits.

The isolated sandstone packages occurring in the mudstone dominated Wulff Land Formation reported here from the section at Hand Bugt may be interpreted in the same way. The alternating sequences of sandstone packages and mudstone units described from the top of the Merqujôq and Lauge Koch Land Formations at Hand Bugt may be more proximal in character. The coarse units may reflect periods of active turbidite deposition either as deep-sea channel deposits or as sandstone lobes in an outer fan or fan fringe environment. The mudstone units may reflect periods of non-deposition directly from turbidity currents and thus represent temporary interchannel or interlobe deposits consisting of pelagic and hemipelagic material, and occasionally diluted suspension deposits derived from bypassing turbidity currents plus resedimented material from the deep-water circulation.

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Plate 1

Section 14 measured in 1984–85 at Hand Bugt, northern Nyeboe Land. The section shows the basal part (section 14a) and the upper part (section 14b) of the 6330 m thick Silurian turbidite sequence of the Peary Land Group. Lines a-b, c-d, etc. indicate those parts of the sections which have been expanded and incorporated in the text under the appropriate figures. GGU sample numbers indicate graptolite assemblages.

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22488
Enclosure (1/1)

Section 14a

Section 14b