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Published in:
Bulletin of the Geological Society of Denmark

Publication date:
2017

Document version
Publisher's PDF, also known as Version of record

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FINN SURLYK, MORTEN BJERAGER, STEFAN PIASECKI & LARS STEMMERIK

Surlyk, F., Bjerager. M., Piasecki. S. & Stemmerik, L. 2017. Stratigraphy of the marine Lower Triassic succession at Kap Stosch, Hold with Hope, North-East Greenland. © 2017 by Bulletin of the Geological Society of Denmark, Vol. 65, pp. 87–123. ISSN 2245-7070. (www.2dgf.dk/publikationer/bulletin).

Received 3 April 2017
Accepted in revised form 8 June 2017
Published online 25 September 2017

The classical marine uppermost Permian – Lower Triassic succession exposed on the north-east coast of Hold with Hope in East Greenland, south-east of Kap Stosch, is placed in the Wordie Creek Group. A new lithostratigraphic subdivision of the group is proposed here. The group comprises the revised Kap Stosch Formation overlain by the new Godthåb Golf Formation. The Kap Stosch Formation is dominated by alternating fine- and coarse-grained, cliff-forming units that constitute the basis for the erection of eight new members. They are (from below): 1. The Nebalopok Member, uppermost Permian, *Hypophiceras triviale* ammonoid zone, and lowermost Triassic, lower Griesbachian, *Hypophiceras triviale* – *H. martini* ammonoid zones, composed of basinal and base-of-slope siltstones and turbiditic sandstones. 2. The conglomeratic Immaqa Member (*H. martini* ammonoid zone), consisting of a thick clinoform-bedded unit commonly overlain by horizontally bedded deposits, representing the foreset and topset, respectively, of a Gilbert-type delta. 3. The fine-grained Fiskeplateau Member (*H. martini* ammonoid zone), composed of siltstones and fine-grained sandstones, representing basinal and delta front deposits. 4. The conglomerate-dominated Knolden Member (*H. martini* ammonoid zone), comprising a clinoform-bedded unit overlain by horizontally-bedded deposits, representing foreset and topset, respectively, of a Gilbert-type delta. 5. The fine-grained Pyramiden Member, (lower–upper Griesbachian *Metophiceras subdemissum*, *Ophiceras commune* and *Wordieoceras decipiens* ammonoid zones), composed of variegated siltstones and sandstones deposited in proximal basin and slope environments. 6. The Naasut Member (top Griesbachian, probably *Wordieoceras decipiens* ammonoid zone), dominated by thick structureless coarse-grained sandstones commonly showing clinoform bedding, deposited in slope, base-of-slope and proximal basin environments. 7. The Falkeryg Member (lowermost Dienerian, *Bukkenites rosenkrantzi* ammonoid zone), comprising thick, commonly pebbly sandstones deposited in shelf, slope and base-of-slope environments. 8. The Vestplateau Member (lower Dienerian, *Bukkenites rosenkrantzi* ammonoid zone) composed of siltstones and fine-grained sandstones deposited in basinal environments. The overlying Godthåb Golf Formation (Dienerian, *Anodontophora breviformis* – *A. fassaensis* bivalve zones) is dominated by shallow marine sandstones with several coarser grained levels.

The rich ammonoid faunas of the Wordie Creek Group allow a biostratigraphic zonation which can be correlated with schemes from other parts of the Arctic region. This zonation is complemented with information on palyno, conodont, fish and isotope stratigraphy.

Keywords: Lower Triassic stratigraphy, Hold with Hope, East Greenland, Wordie Creek Group, Kap Stosch Formation, Godthåb Golf Formation.

Finn Surlyk [finns@ign.ku.dk], Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark. Morten Bjerager [mbj@geus.dk], Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark. Stefan Piasecki [stefan.piasecki@snm.ku.dk], Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark. Lars Stemmerik [lars.stemmerik@snm.ku.dk], Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark.

The marine uppermost Permian – Lower Triassic successions exposed in northern East Greenland have generally attracted much less attention than the underlying Upper Permian Foldvik Creek Group. Most work has focused on the rich Triassic vertebrate faunas (Nielsen 1932, 1935, 1942, 1952, 1954) and the stratigraphically important ammonoid faunas (Spath 1927, 1930, 1935; Trümpy 1969; Teichert & Kummel 1976; Bjerager *et al.* 2006), particularly at the classical Permian–Triassic boundary localities along the north coast of Hold with Hope (Figs 1, 2). The stable isotope record across the Permian–Triassic boundary and into the marine, Lower Triassic at Hold with Hope was recently described by Sanson-Barrera *et al.* (2015). The Early Triassic facies associations and tectonics were described and interpreted by Oftedal *et al.* (2005).

The present paper extends the stratigraphical and sedimentological studies of the Lower Triassic marine deposits in Jameson Land and Traill Ø (Clemmensen 1980a, b; Seidler 2000) to include the classical and well exposed succession on the north coast of Hold with Hope in the northernmost part of the marine Triassic basin, the type area for the marine Triassic in East Greenland (Koch 1929) (Figs 1, 2). This area is commonly referred to as Kap Stosch or the Kap Stosch area after the cape forming the north-western corner of the north coast. Here, marine Lower Triassic sediments are exposed in more than 750 m high coastal cliff sections over a distance of approximately 30 km, from Ekstraelv south-west of Kap Stosch in the west to Fosdalen in the east. The position of these locations is shown in Nielsen (1935, fig. 13), Teichert & Kummel (1976, fig. 1) and Larsen *et al.* (2001). The Triassic sediments were discovered in 1926 (Wordie 1927) and independently by Koch in the same year (Koch 1929).

The rich ammonoid faunas were first described by Spath (1927, 1930, 1935) and subsequently by Trümpy (1969), Teichert & Kummel (1976) and Bjerager *et al.* (2006). The Triassic succession was placed in the Cape Stosch and Wordie Creek Formations by Koch (1929). Koch (1931) and Nielsen (1935) used a number system (0–26 from west to east) for all rivers terminating in a delta and draining the steep slopes on the north coast of Hold with Hope. This number system has proved very useful and has been used by most subsequent authors. The position of the locality Wordie Creek has been much debated, but most authors tend to agree that it is either Blåelv (River 16 of Koch 1931) or River 15 (Nielsen 1935) and both the place name and formation names were considered obsolete by Teichert & Kummel (1976). These names were, however, used by Trümpy in Callomon *et al.* (1972) and the term Wordie Creek Formation has since then been used to cover all the marine Lower Triassic sediments from Jameson Land in the south to Clavering Ø in the north. The equally poorly defined Foldvik Creek Formation of Koch (1929) has subsequently been raised to group level and used for the underlying Upper Permian, mainly marine succession of East Greenland (e.g. Surlyk *et al.* 1984, 1986).

The aim of this paper is to present an up-to-date stratigraphic synthesis of the marine Triassic succes-

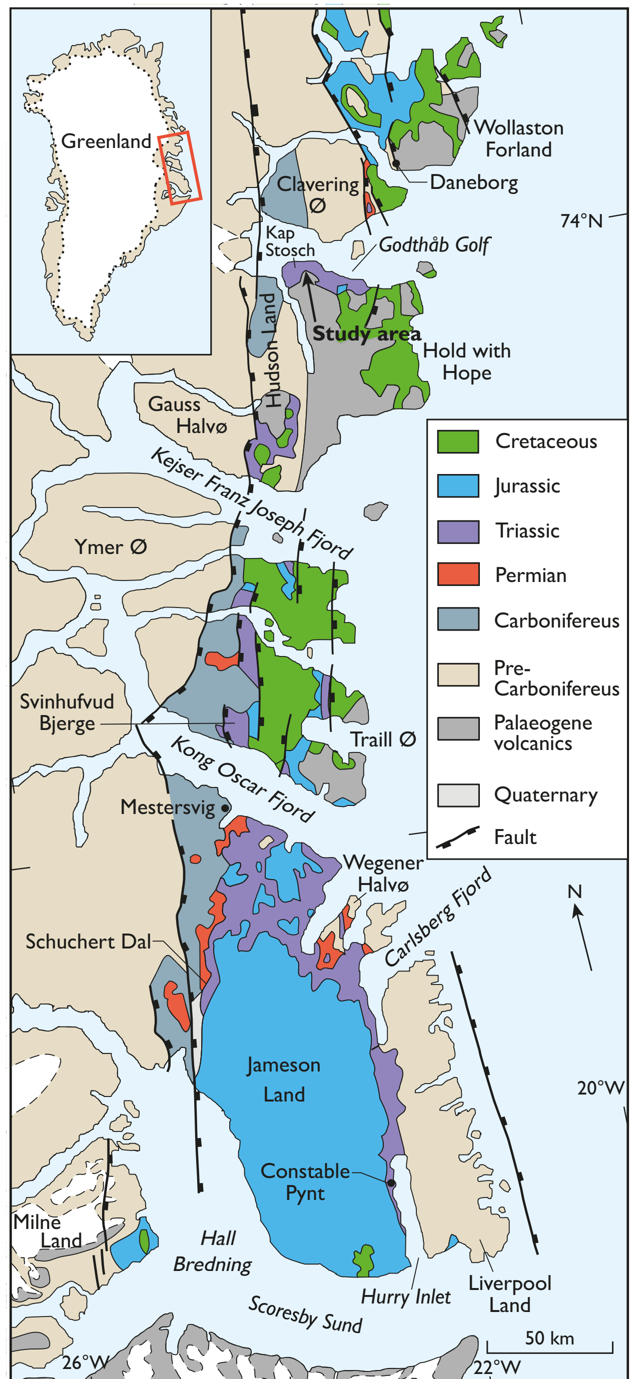

Fig. 1. Geological map of northern East Greenland, showing the main localities mentioned in the text (modified from Bjerager *et al.* 2006).

sion in the Hold with Hope Subbasin along the north coast of Hold with Hope, including a new lithostratigraphic scheme, a biostratigraphic overview based on new spore-pollen and ammonoid data, and a review of previously published data. Based on our interpretation of the depositional evolution of the Hold with Hope area, we have found it logical to raise the Lower Triassic Wordie Creek Formation (Koch 1929) to group status, and to subdivide it into two new formations, the Kap Stosch Formation and the overlying Godthåb Golf Formation (Fig. 3). These formations correspond to two distinctive stages in the evolution of the Triassic basin in the study area (e.g. Seidler *et al.* 2004). The Kap Stosch Formation was deposited in relatively deep, partly isolated turbiditic basins, where fine-grained sedimentation occasionally was interrupted by deposition of coarse-grained conglomeratic and sandy units. Four coarse-grained units form a very characteristic part of the formation and have all been designated member status (Figs 3, 4, 5). In contrast, the overlying Godthåb Gulf Formation was deposited under relatively shallow marine conditions.

Geological setting

The late Permian – early Triassic marine basin in East Greenland is N–S to NW–SE oriented and at least 400 km long (Fig. 1). It is limited to the west by the post-Devonian Main Fault – Stauning Alper Fault system, separating Upper Palaeozoic and younger sediments to the east from the stable Greenland craton to the west. Correlative marine sediments have been drilled offshore Norway, suggesting that the outcropping sections in East Greenland represent the western margin of a wide marine seaway extending southwards between Greenland and Norway from the northern Boreal Sea (e.g. Bugge *et al.* 2002; Seidler *et al.* 2004; Müller *et al.* 2005; Nøttvedt *et al.* 2008).

Marine deposition in East Greenland started during the mid-Permian as reactivation of older, Carboniferous faults, and associated subsidence was followed by transgression from the north. The Upper Permian Foldvik Creek Group rests unconformably on older sedimentary rocks and basement (e.g. Surlyk *et al.* 1986). The upper boundary towards the uppermost Permian – Triassic Wordie Creek Group is a major unconformity marked by incised valleys and submarine canyons north of Jameson Land and along the south-eastern basin margin (Surlyk 1990; Seidler 2000). Locally, in the southern central basin, it is a conformable mudstone–mudstone contact, preserving complete and expanded Permian–Triassic boundary sections (e.g. Piasecki 1984; Stemmerik *et al.* 2001; Twitchett *et al.* 2001; Bjerager *et al.* 2006). In the study area on the north coast of Hold with Hope an unconformity is present in the uppermost Permian, but about a metre of Upper Permian sediment is present above the unconformity and the Permian–Triassic boundary appears to be continuous in well-exposed sections in the central part of the coastal profile.

Early Triassic deposition in central East Greenland was governed by several rift events (Koch 1929; Nielsen 1935; Seidler *et al.* 2004; this study). Latest Permian – earliest Triassic movements along intrabasinal faults subdivided the East Greenland basin into half-grabens, 10–60 km wide and 50–100 km long (Fig. 1) (Seidler *et al.* 2004; Bjerager *et al.* 2006). The Hold with Hope Subbasin is the northernmost of these half-grabens, possibly up to as much as 60 km wide east–west, limited to the west by the Post-Devonian Main Fault and to the east by the Clavering Ø Fault. Cretaceous sediments are downfaulted against Triassic deposits to the east by the Fosdalen Fault (30 km ESE of Kap Stosch) (Fig. 1). Source areas for the sediments deposited into the Hold with Hope Subbasin were uplifted terrains to the north and subordinately to the east. In the southern part of the Triassic Basin, sediments were mainly sourced from uplifted areas to the west except for the Wegener Halvø Subbasin where the source area was the uplifted Liverpool Land High to the east (Seidler *et al.* 2004). The upper boundary of the Wordie Creek Group is diachronous from south to north, being youngest at Hold with Hope where the youngest marine sediments are included in the Dienerian *A. fassaensis* bivalve zone, unconformably overlain by Jurassic and Cretaceous sediments or Cenozoic sediments and plateau basalts (Figs 3, 4). In Jameson Land, the top of the Wordie Creek Group belongs to the upper Griesbachian *W. decipiens* ammonoid zone.

Shallowing of the basins following deposition of the Wordie Creek Group is seen in all outcrop areas in East Greenland, but only in the Traill Ø Subbasin is the top part of the relatively deep marine succession intercalated with a coarse-grained tongue of the mainly fluvial Svinhufvuds Bjerge Member overlain by shallow marine sandstones and carbonates of the Ødepas Member (Fig. 4; Clemmensen 1977, 1980b); elsewhere it is erosionally overlain by non-marine sediments of the Pingo Dal Formation, notably in Jameson Land and Wegener Halvø (Grasmück & Trümpy 1969; Birkenmajer 1977; Clemmensen 1980b; Seidler 2000). Shallowing started earlier at Traill Ø, in the *Bukkenites rosenkrantzi* ammonoid zone, than at Hold with Hope, where the lowest shallow marine sandstones occur at or near the base of the *Anodontophora fassaensis* bivalve zone (Fig. 5). Early Triassic sedimentation was governed by a series of gradually fading rift events which can be recognized throughout the outcrop areas in East Greenland.

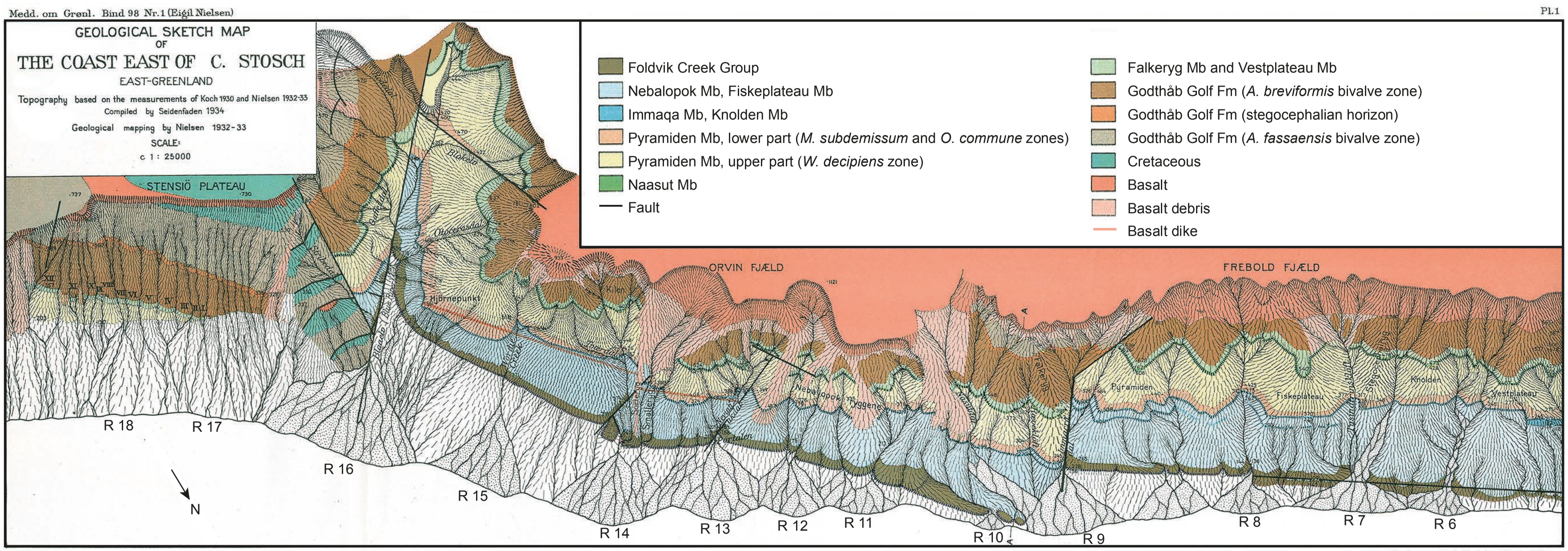

Fig. 2. Geological map of the north coast of Hold with Hope east of Kap Stosch. Copy of Plate 1 in Nielsen (1935) with new stratigraphic names indicated in the legend.

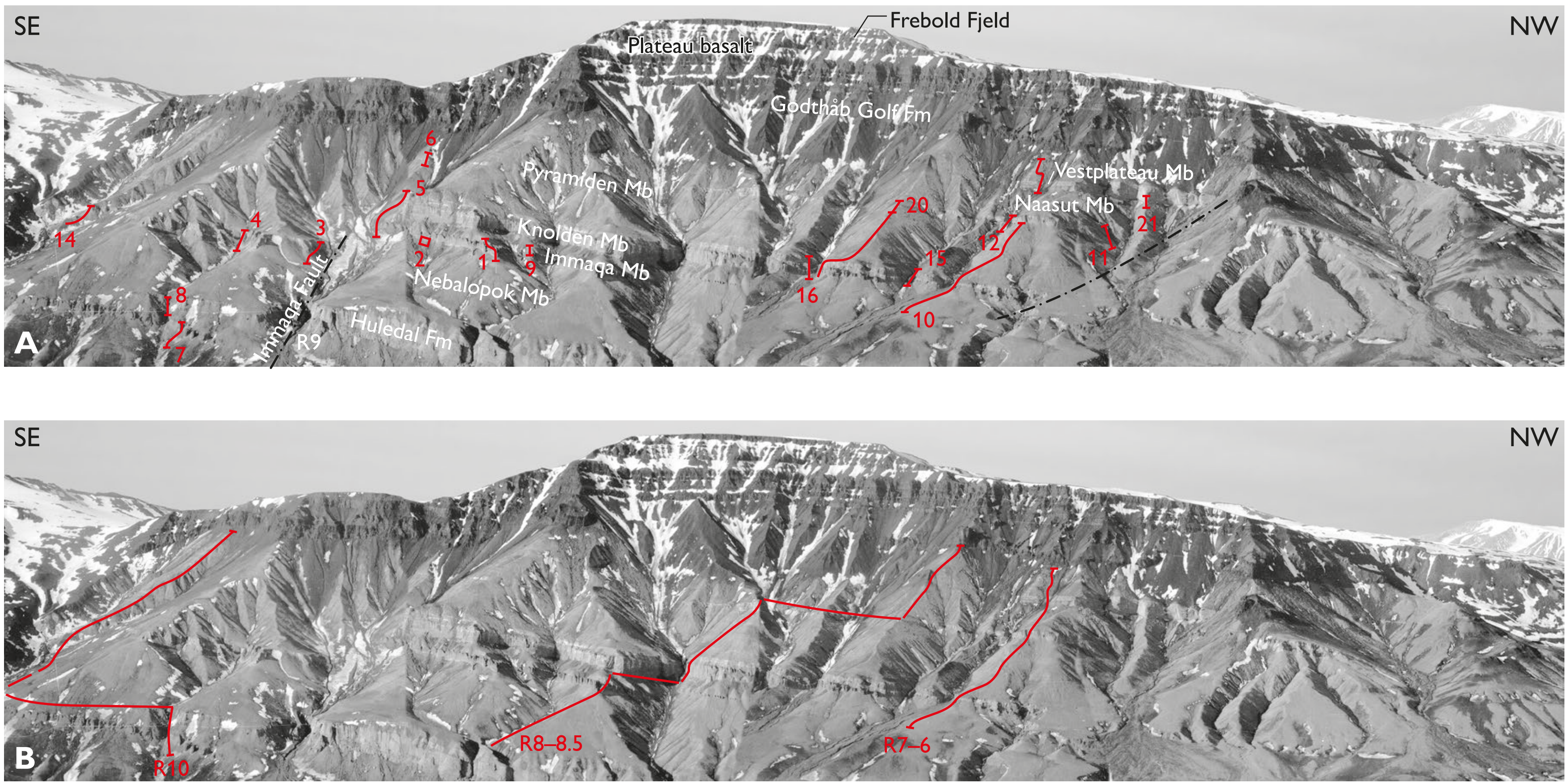

Fig. 3. Photograph of the north coast of Hold with Hope, showing the Upper Permian – Lower Triassic succession unconformably overlain by Palaeogene plateau basalts. New lithostratigraphic units and measured sections are indicated on A, whereas B shows the positions of the sections in Fig. 5. The profile is *c.* 6.5 km long and Frebold Bjerg is *c.* 1150 m high.

Stratigraphy

The existing lithostratigraphic names are not well defined. The problem with a type locality for the Wordie Creek Formation is solved by elevating it to group status, essentially covering all Lower Triassic marine rocks in northern East Greenland. Fortunately, there are quite a number of place names available in the study area on the north coast of Hold with Hope. They are marked on the excellent map of Nielsen (1935, plate 1) reproduced here as Fig. 2. Some of the new lithostratigraphic units have not yielded age diagnostic fossils and their ammonoid biozonal indication is based on interpolation between well-dated under- and overlying units. The biozonal names are given with lower case 'z' as none of them are formally defined with type sections. The most up-to-date biostratigraphical scheme is used (Bjerager *et al.* 2006). A total of two new formations and eight new members are defined here. Some of the coarser grained units have previously been referred to as 'Conglomerate I, etc.', a system introduced by Koch (1929) and indicated on the map of Nielsen (1935, plate 1). However, it is important to note that the use of conglomerate numbers vary between the different early workers. Thus, in some cases 'conglomerate 1' was not the stratigraphically lowest but simply the lowest met in a particular section (Nielsen 1935). Conglomerate I of Nielsen (1935) is the thick Permian Huledal Formation of the Foldvik Creek Group (Fig. 3; Surlyk *et al.* 1986) and he thus recognized five conglomeratic units in the coastal section along the north-east coast of Hold with Hope, whereas we in our field work only numbered the Triassic conglomeratic units (conglomerates 1–4) roughly equivalent to the 'coarse grained units CGU' 1–4 of Oftedahl *et al.* (2005). Nielsen (1935) noted that earlier workers tended to name all units forming prominent vertical walls 'conglomerates' although several consist of hard sandstones. In the present paper we use the new lithostratigraphic names proposed here and only refer to conglomerate numbers of earlier workers if considered relevant.

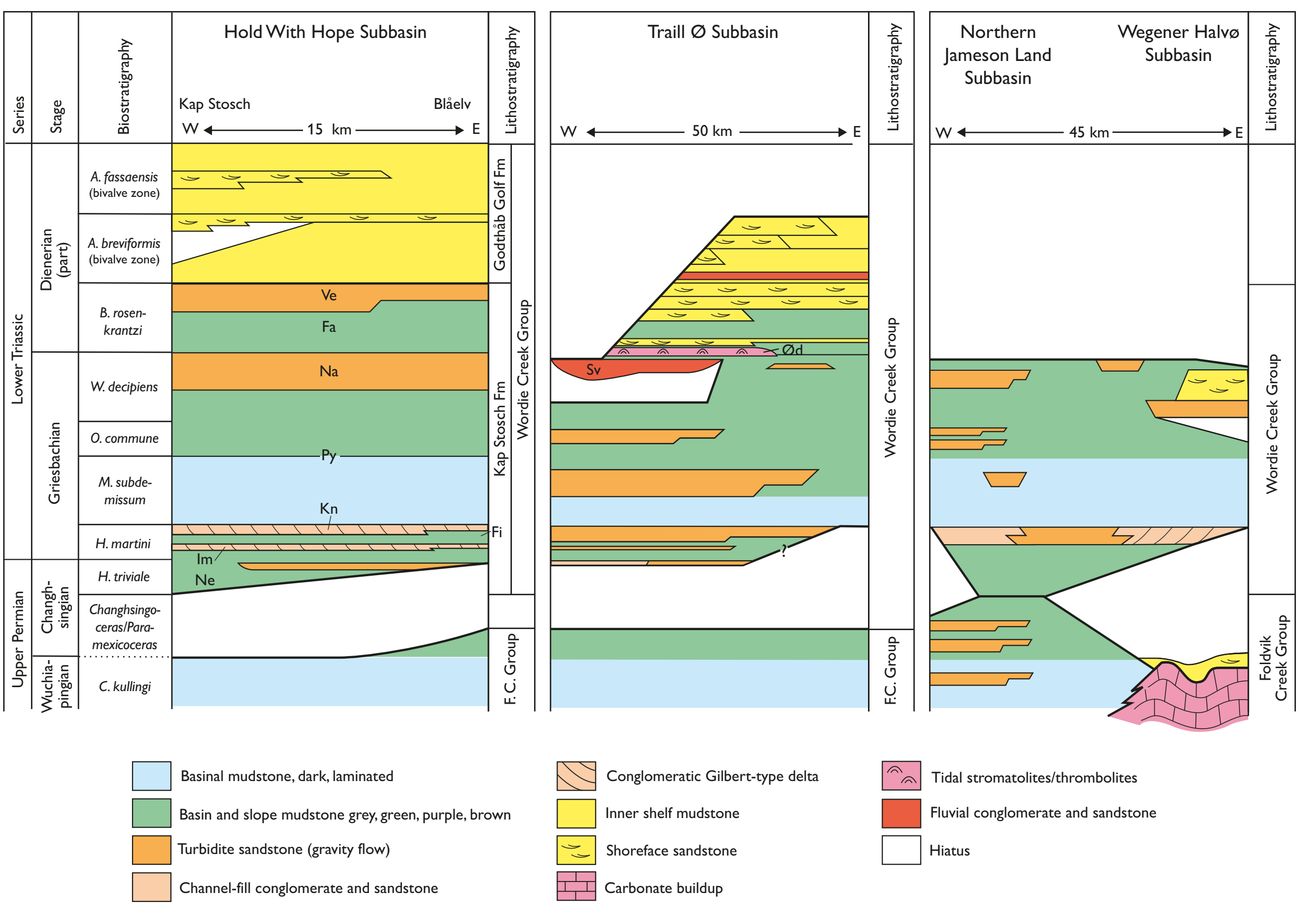

Fig. 4. Stratigraphic schemes of the Lower Triassic of Hold with Hope, Traill Ø, northern Jameson Land and Wegener Halvø. Note the correlation of coarse-grained units (indicated in orange and dark red). The abbreviations in the Hold with Hope Subbasin column indicate the following members, from below: Ne: Nebalopok, Im: Immaqa, Fi: Fiskeplateau, Kn: Knolden, Py: Pyramiden, Na: Naasut, Fa: Falkeryg, and Ve: Vestplateau Members. Sv and Ød in the Traill Ø Subbasin column indicate the Svinhufvuds Bjerge and Ødepas Members, respectively.

Wordie Creek Group

New group

History. The Wordie Creek Formation, originally defined by Koch (1929), is raised to group status and subdivided into the new Kap Stosch and the overlying Godthåb Golf Formations. The Wordie Creek Formation was originally defined to include marine strata of Triassic age in the coastal cliffs south-east of Kap Stosch and appears to some extent to correspond to or include the strata here defined as the Godthåb Golf Formation. The name-giving locality Wordie Creek is believed to be Blåelv or the creek immediately west of Blåelv (Rivers 16 and 15, respectively in Fig. 2; Nielsen 1935, plate 1). The Triassic strata of the type area were subdivided into five units by Nielsen (1935). They are from below: (1) *Otoceras* beds; (2) *Vishnuites* beds; (3) *Proptychites* beds; (4) *Anodontophora* (breviform) beds; and (5) *Anodontophora fassaensis* beds. These units are easily recognizable in the field and are here correlated with the new lithostratigraphy (Fig. 5).

Name. After Wordie Creek, an unofficial name for Blåelv (River 16) or River 15 immediately west of Blåelv (Fig. 2; Nielsen 1935, plate 1).

Type area and reference sections. The type area is Wordie Creek/Rivers 15 and 16, north coast of Hold with Hope (Fig. 2). Perch-Nielsen *et al*. (1974) established reference sections at Wegener Halvø in the south-eastern part of the marine Triassic basin and at Rødstaken, western Jameson Land in the south-western part of the basin (Fig. 1).

Lithology. In the type area, the lower part of the group (Kap Stosch Formation) consists of recessive units of greenish weathering, marine mudstone with a variable content of thin fine-grained sandstones interbedded with up to 50 m thick cliff-forming units of yellow to greyish weathering conglomerates and coarse sandstones deposited from a variety of sediment gravity flows. The upper part of the group (Godthåb Golf Formation) consists of shallow marine sandstones interbedded with red and green siltstones and sandstones. The lithology of the group in the southern part of the basin is described by Perch-Nielsen *et al*. (1974), Clemmensen (1977, 1980b) and Seidler (2000).

Boundaries. In most areas, the group rests unconformably on sediments belonging to the Upper Permian Foldvik Creek Group. Along the north coast of Hold with Hope the boundary is commonly marked by a red horizon, reflecting prolonged subaerial exposure of the underlying mudstones of the Upper Permian Ravnefjeld Formation. At Oksedal and Triaselv in western Jameson Land, the boundary is conformable, apparently without a hiatus, and marked by a shift from greyish siltstone to more greenish siltstone (Perch-Nielsen *et al*. 1974; Stemmerik *et al.* 2001; Twitchett *et al*. 2001).

At Hold with Hope, the group is unconformably overlain by Cenozoic sediments and volcanics west of Blåelv, and Cretaceous and Jurassic sediments east of Blåelv (Nielsen 1935; Stemmerik *et al.* 1993; Vosgerau *et al.* 2004). In northern Jameson Land, Wegener Halvø and Traill Ø the upper boundary is characterized by an abrupt change to coarse-grained, non-marine sediments partly belonging to the Pingo Dal Formation (Perch-Nielsen *et al.* 1974; Clemmensen 1977, 1980b; Seidler 2000), or the group is overlain by Jurassic or Cretaceous sediments (Bjerager *et al.* 2006).

Thickness. The group is up to 750 m thick according to Rosenkrantz (1930). It is 520 m thick at River 15 (Fig. 2). Towards the north-west it thickens and attains a thickness of more than 650 m at River 7, bordering Fiskeplateau to the west (Fig. 2). River 7 is named Tusindtrinskløften (meaning 'the creek of thousand steps') on the map of Nielsen (1935, plate 1). The group is up to 750 m thick at south-western Traill Ø (Seidler 2000), and up to 500 m thick in Jameson Land and at Wegener Halvø (Perch-Nielsen *et al.* 1974; Seidler 2000).

Distribution. From northern Jameson Land and Wegener Halvø in the south to Clavering Ø in the north (Fig. 1).

Chronostratigraphy. The bulk of the group belongs to the Lower Triassic, Griesbachian–Dienerian (e.g. Nielsen 1935; Spath 1935; Trümpy 1969; Teichert & Kummel 1976; Balme 1979). The basal 20–25 m of the group at Triaselv, western Jameson Land, is of disputable age and may belong to the uppermost Permian, Changhsingian Stage (Twitchett *et al.* 2001). Similarly, the lowermost part of the group may be uppermost Permian elsewhere in the basin, but so far no Permian macrofossils have been found *in situ* in the group. For a more precise biostratigraphic zonation, see Figures 4, 5.

Subdivisions. The Wordie Creek Group in the study area is subdivided into the Kap Stosch Formation and the overlying Godthåb Golf Formation (Fig. 5). In Jameson Land the continental Pingo Dal Formation is probably a correlative of the Godthåb Golf Formation. At Traill Ø it can probably be correlated with the uppermost part of the Wordie Creek Formation as defined by Clemmensen (1980b). Two members, the Svinhufvuds Bjerge and the Ødepas Members, are distinguished in the Wordie Creek Group at Traill Ø (Fig. 4; Clemmensen 1980b).

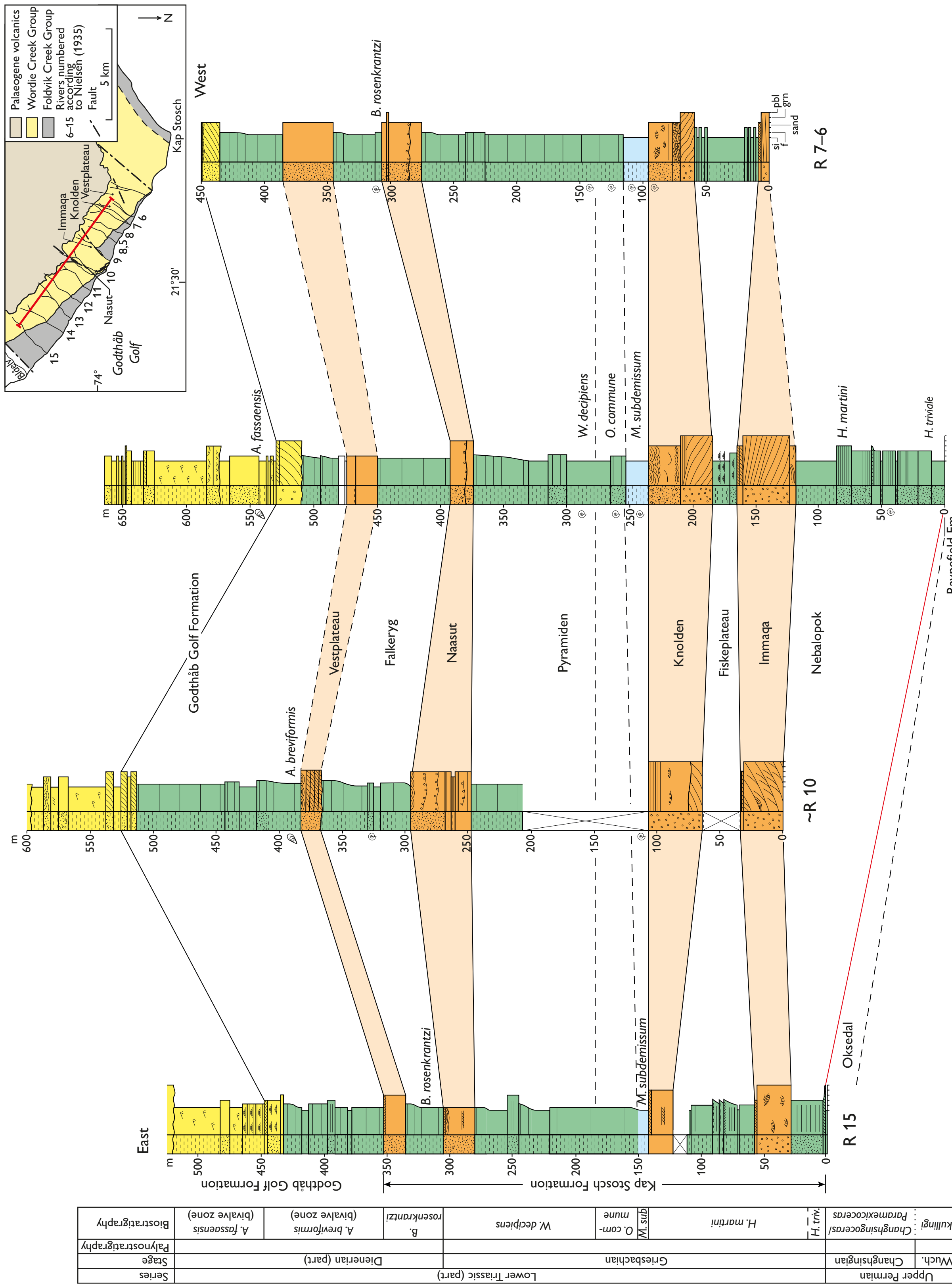

Fig. 5. Correlation scheme of four key sections along the north coast of Hold with Hope, showing the new lithostratigraphy and biostratigraphic zonation. Orange: coarse-grained sediments, yellow: shallow marine sandstones; green and light blue: fine-grained sediments. The top of the Knolden Member is used as a datum as the uppermost metres of the member comprises the Gilbert delta topset which was deposited at about 0 m water depth.

Depositional environment. The Kap Stosch Formation comprises thick coarse-grained pebbly sandstones and conglomerates representing Gilbert-type delta topsets and slopes and deeper water slopes, alternating with relatively deep marine, commonly turbiditic delta front and basin floor sandstones and siltstones. The overlying Godthåb Golf Formation consists of shallow marine, commonly grey or variegated sandstones.

Kap Stosch Formation

Revised formation

History. The Triassic succession along the north coast of Hold with Hope was discovered in 1926 independently by Wordie (1927) and Koch (1929). The formation was erected by Koch (1931) but the lower and upper boundaries are difficult to identify from his description and are here defined more precisely. Rosenkrantz (1930) misused the term as he restricted the formation to cover only the fossiliferous white blocks of Upper Permian limestones which occur in the conglomerates of the formation. This unusual practice is a major reason for much of the subsequent confusion in the stratigraphic terminology and probably reflects a lack of understanding of the US-inspired lithostratigraphic concept introduced for Greenland stratigraphy by Koch (1929).

The ammonoid-dominated faunas brought back from the expeditions of Wordie and Koch were described by Spath (1927, 1930, 1935). The succession was later subdivided into five units on the basis of fossil content by Nielsen (1935), and the Kap Stosch Formation as defined here corresponds to his *Otoceras*, *Vishnuites* and *Proptychites* beds.

Name. From Kap Stosch, a cape forming the north-western corner of Hold with Hope (Fig. 1).

Type and reference sections. A composite type section is based on sections at Rivers 6, 8, 10 and 15 (Figs 2, 3, 5).

Thickness. The formation is about 350 to 475 m thick in the type area and about 400 m thick between Rivers 7 and 9 (Fig. 2).

Lithology. The formation consists of recessive siltstone and sandstone with four prominent cliff-forming units of coarse-grained sandstones and conglomerates. The two lower coarse-grained, conglomerate-dominated units are clinoform-bedded and wedge out eastwards where they pass into basinal sandstone and siltstone. The upper two units are mostly composed of massive sandstones with pebble stringers. The fine-grained unit below the lowest conglomerate thins eastwards from 140 m at River 8 to less than 30 m at River 15, but the E-ward wedging and fining of the coarse-grained members makes it difficult to distinguish these units towards the east and the correlation shown on Fig. 5 is made with some hesitation.

Fossils. The formation contains a diverse fauna of ammonoids, fishes and labyrinthodont amphibians in the lower part (Spath 1930, 1935; Nielsen 1935, 1942, 1954; Stensiö 1932; Teichert & Kummel 1976; Bjerager *et al.* 2006). In the uppermost part of the formation ammonoids are missing and are replaced by a low diversity fauna of bivalves and gastropods and locally vertebrate remains (Spath 1930, 1935; Nielsen 1935). Conodonts are found in the lower part of the formation (Sweet 1976) and spores and pollen are common throughout (Balme 1979).

Boundaries. The lower boundary corresponds to the base of the group and is placed where greenish siltstone and fine-grained sandstone rest unconformably on a thin red horizon developed atop a thick unit of black or greyish mudstones of the Upper Permian Ravnefjeld Formation, or locally towards the east (e.g. at Rivers 14 and 15) atop approximately 30 m of calcareous, siliciclastic sediments equivalent to the Oksedal Member (Schuchert Dal Formation) in Jameson Land. The red mudstone is barren of both macro- and organic microscopic fossils. Coalified black, rounded grains are abundant in the mudstone, presumably reflecting exposure and severe oxidation of the strata before the following marine transgression. The lower boundary is thus a low angle erosional unconformity and variable amounts of Foldvik Creek Group sediment are eroded away prior to deposition of the Wordie Creek Group.

The upper boundary is placed at the top of a prominent sandstone bed, the Vestplateau Member, that marks a change from basinal to shallow marine sedimentation.

Distribution. The formation is well-exposed along the north coast of Hold with Hope from Kap Stosch in the west to Diener Bjerg in the east. Scattered outcrops are present some kilometres to the south-west of Kap Stosch, along the east side of Loch Fyne, and inland along Guleelv (Nielsen 1935). The position of these locations, which are situated outside the study area, can be found in Nielsen (1935), Teichert & Kummel (1976) and Larsen *et al.* (2001). The formation is also exposed on Clavering Ø to the north and on Gauss Halvø, Traill Ø and Jameson Land to the south.

Chronostratigraphy. Uppermost Permian – Lower Triassic, Griesbachian, *Hypophiceras triviale* ammonoid zone – *Anodontophora breviformis* bivalve zone. Locally, the basal metre of the formation contains a sparse microflora of pollen and spores indicating a Late Permian, latest Changhsingian age by correlation to the Fiskegrav succession in Jameson Land (Stemmerik *et al*. 2001) (Fig. 4). It is followed by a significant shift in composition of organic content and the appearance of a rich spore and pollen flora. At River 8, conodonts from this level indicate an earliest Triassic age (J.A. Rasmussen, personal communication 2016) in concert with the palynoflora (Stemmerik *et al*. 2001). The basal 1.0 m of the formation is therefore Upper Permian, uppermost Changhsingian (Fig. 4), but the bulk of the formation is Lower Triassic, Griesbachian. An important turnover of the palynoflora occurs at the base of the Falkeryg Member where the lower Dienerian *Bukkenites rosenkrantzi* ammonoid zone is also represented.

Subdivisions. The four distinctive coarse-grained, sandy to conglomeratic units and the intervening mudstones and sandstones are here defined as new members. In the Jameson Land – Traill Ø area the Svinhufvuds Bjerge and Ødepas Members are recognized in the correlative part of the Wordie Creek Group (Clemmensen 1980b; Bjerager *et al.* 2006). At Hold with Hope the coarse-grained members thin and become finer-grained towards the east, making their identification difficult and in this area it may be useful only to recognize the formation.

Depositional environment. The fine-grained facies with common thin sandstone turbidites were deposited in relatively deep marine water, passing upwards into base of slope and slope pebbly sandstones or conglomeratic Gilbert-type delta foresets.

Nebalopok Member

New member

History. Indirectly this member plays a major role in the literature as it probably conceals the Permian–Triassic boundary in the lower part. It has, however, not received much lithological and sedimentological study.

Name. After the ridges Nebalopok Ryggene between Rivers 11 and 12 of Nielsen (1935) (Fig. 2).

Type section. A type section is designated at River 8 (Figs 3, 5).

Thickness. The member is 140 m thick in the type section, but the thickness varies along the coastal profile and it is only 30 m thick at River 15.

Lithology. Sandstones, commonly pebbly, dominate and show irregular lamination, low-angle scour-and-fill cross-bedding, linguoid, current and climbing ripples, and scattered flute casts and are interpreted as turbidites. Dark mudstones and clay beds also occur and commonly contain fossils, notably ammonoids. Fossiliferous limestone beds occur towards the west according to Nielsen (1935), but they may be carbonate-cemented sandstones. The lowermost part contains worn brachiopods and bryozoans reworked from the underlying Upper Permian Foldvik Group (Nielsen 1935; Teichert & Kummel 1976). The succession is slight upwards coarsening, especially towards the top, and is in some cases topped by sharp-based sandstone beds showing symmetrical ripples with NNE–SSW striking crests.

Depositional environment. Deposition took place from suspension and a variety of sediment gravity flows, including turbidity flows in a basin plain environment, mainly below wave base. A few palaeocurrent measurements from the upper part of the member show transport direction towards the SSE. The symmetrical ripples, interpreted as wave ripples, suggest a NNE–SSW trending coast line.

Fossils. The member is highly fossiliferous and includes several ammonoid species of *Otoceras* and *Hypophiceras* and fish remains of *Bobasatrania*, scales of ganoids, and elasmobranch fin-spines, (fish zone 1 of Nielsen, 1935). Reworked Permian fossils, including bryozoans and brachiopods also occur. Conodonts are found in the lower part of the formation, especially in the fine-grained beds (Sweet 1976), and spores and pollen are common throughout (Balme 1979).

Boundaries. The lower boundary is the same as for the formation. The upper boundary is irregular at the base of the clinoform-bedded conglomeratic Immaqa Member.

Distribution. The member reaches westwards to Rivers 0 and 1 and occurs eastwards at least to Blåelv, i.e. River 16 of Nielsen (1935). At River 8 it is 110 to 140 m thick, thinning eastwards to Rivers 14 and 15 where only the basal 2–3 m of mudstone is overlain by up to 30 m of fine-grained sandstone. Locally, at River 14, the overlying Immaqa Member rests directly on sediments belonging to the Permian Foldvik Creek Group. Thickness estimates in the easternmost out-

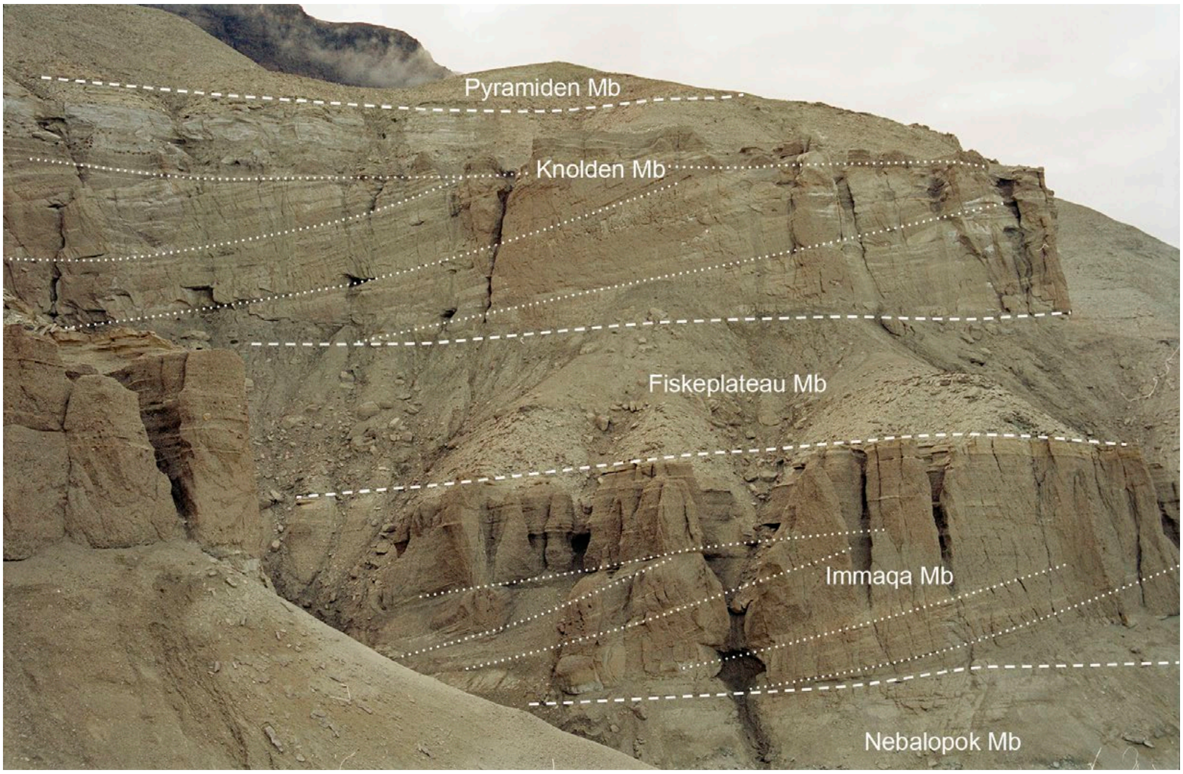

Fig. 6. The five lowest members of the Kap Stosch Formation immediately west of River 9 in Fig. 2. Note the bipartite divisions of both the Immaqa and Knolden Members with a lower clinoform-bedded unit and an upper horizontally-bedded unit, corresponding to the foreset and topset, respectively of a Gilbert-type delta. The Immaqa Member is about 33 m thick.

Fig. 7. The Immaqa Member showing the lower clinoform-bedded part and the upper horizontally-bedded part, corresponding to the foreset and topset, respectively, of a Gilbert-type delta. Person (encircled) for scale. Immediately west of River 9 (Fig. 2).

crops are difficult as the conglomeratic Immaqa and Knolden Members have wedged out or become much finer grained and are mainly represented by sandstone (Fig. 5).

Chronostratigraphy. The lower part of the member belongs to the *Hypophiceras triviale* ammonoid zone, probably uppermost Permian, uppermost Changhsingian (Bjerager *et al*. 2006). The higher parts belong to the lowermost Triassic, lower Griesbachian *H. triviale – martini* ammonoid zones (Bjerager *et al*. 2006).

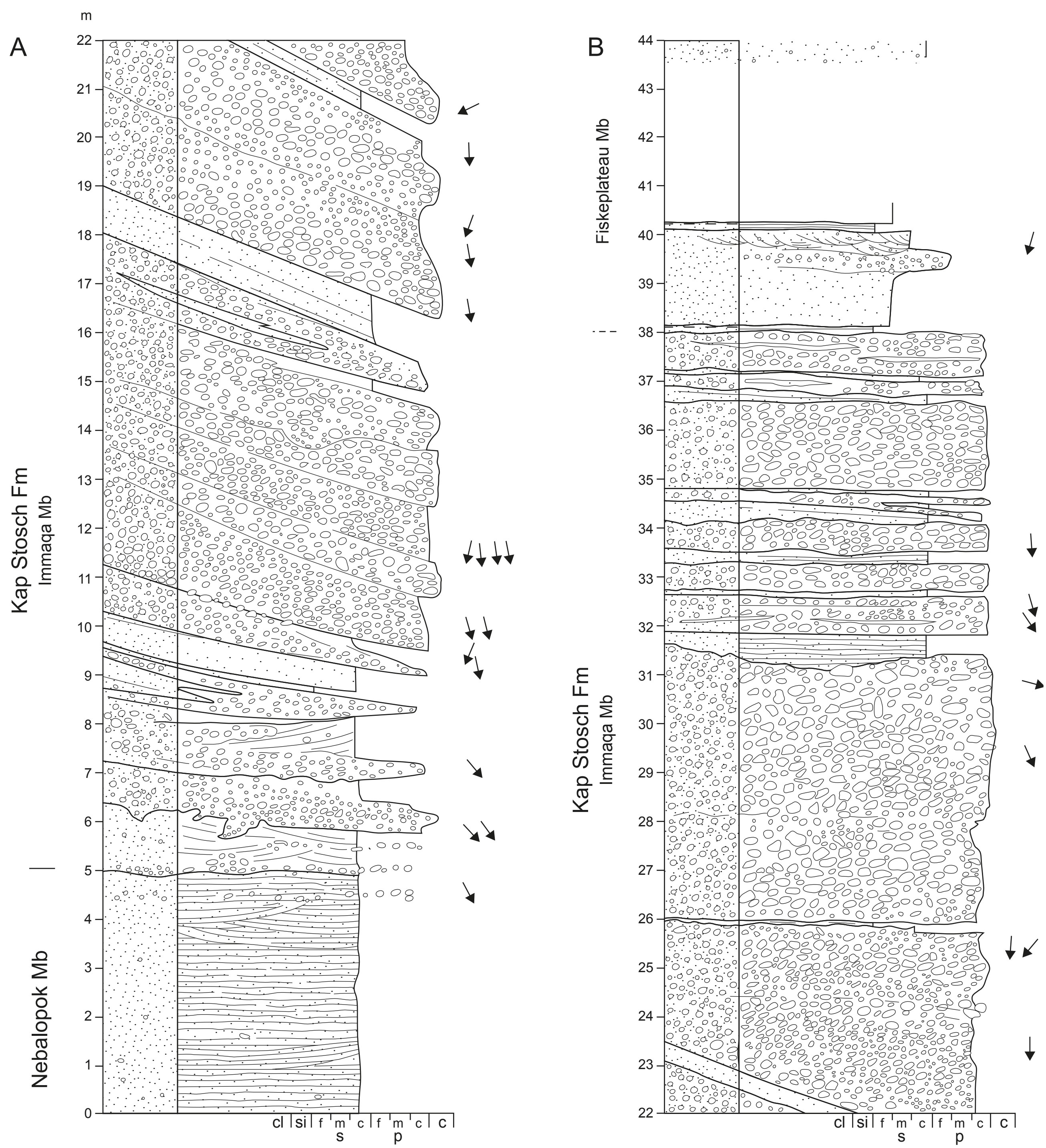

Fig. 8. Type section of the Immaqa Member (Section 1) located immediately west of River 9 (Figs 2, 3). Note the lower clinoform-bedded part overlain by the upper horizontally-bedded part, corresponding to the foreset and topset, respectively of a Gilbert-type delta. The section is shown as three consecutive logs (A, B and C). Legend for all measured sections is shown as D.

Immaqa Member

New member

History. The member forms a distinctive cliff-forming unit (Figs 6, 7) mapped as conglomerate II by Nielsen (1935, plate 1), as conglomerate 1 by us in the field (samples, notes etc.), and as the lower part of coarse-grained unit (CGU) 1 by Oftedal *et al.* (2005).

Name. From Immaqadal/River 9, the creek between Pyramiden and Falkeryg as indicated on the map of Nielsen (1935, plate 1), approximately 7.5 km south-east of Kap Stosch (Figs 1, 2). Nielsen (1935) spelled the name 'Immacra', but the correct modern Greenlandic spelling is 'Immaqa' and this is used here. Note that 'q' should be pronounced as 'kr'. The word means 'maybe' in Greenlandic. The member is exposed on both sides of the creek but displaced by a later fault in a very confusing way, so that the conglomerates of the Lower Triassic Immaqa Member east of the creek are down-faulted to the same level as the conglomerates of the Upper Permian Huledal Formation to the west of the creek (Fig. 3).

Type and reference sections. Section 1, located approximately 500 m west of River 9 (Fig. 2) is designated as type section (Figs 2, 3, 6, 8). Reference sections are section 5, immediately west of River 9, showing a more sandy development, and section 7 located in the first gully east of River 9 (Fig. 10).

Thickness. The member is 33 m thick at the type section, a little more than 32.5 m at section 7, and thins both towards the west and to the east where it passes into coarse-grained sandstone, making it difficult to distinguish from the underlying Nebalopok and overlying Fiskeplateau Members (Figs 5, 9).

Lithology. The member consists of conglomerates and coarse-grained sandstones with subordinate amounts of silty material. The bulk of the member show large-scale high-angle clinoforms (dipping up to 24°), passing downwards into tangential bottomsets and basinal siltstones (Figs 6, 7, 11, 12). The clinoform beds are up to about 20 m thick. The upper part of the member is horizontally bedded, forms an up to about 10 m thick topset, and contains wave rippled sandstone beds. The thickness of bottomsets, foresets and topsets

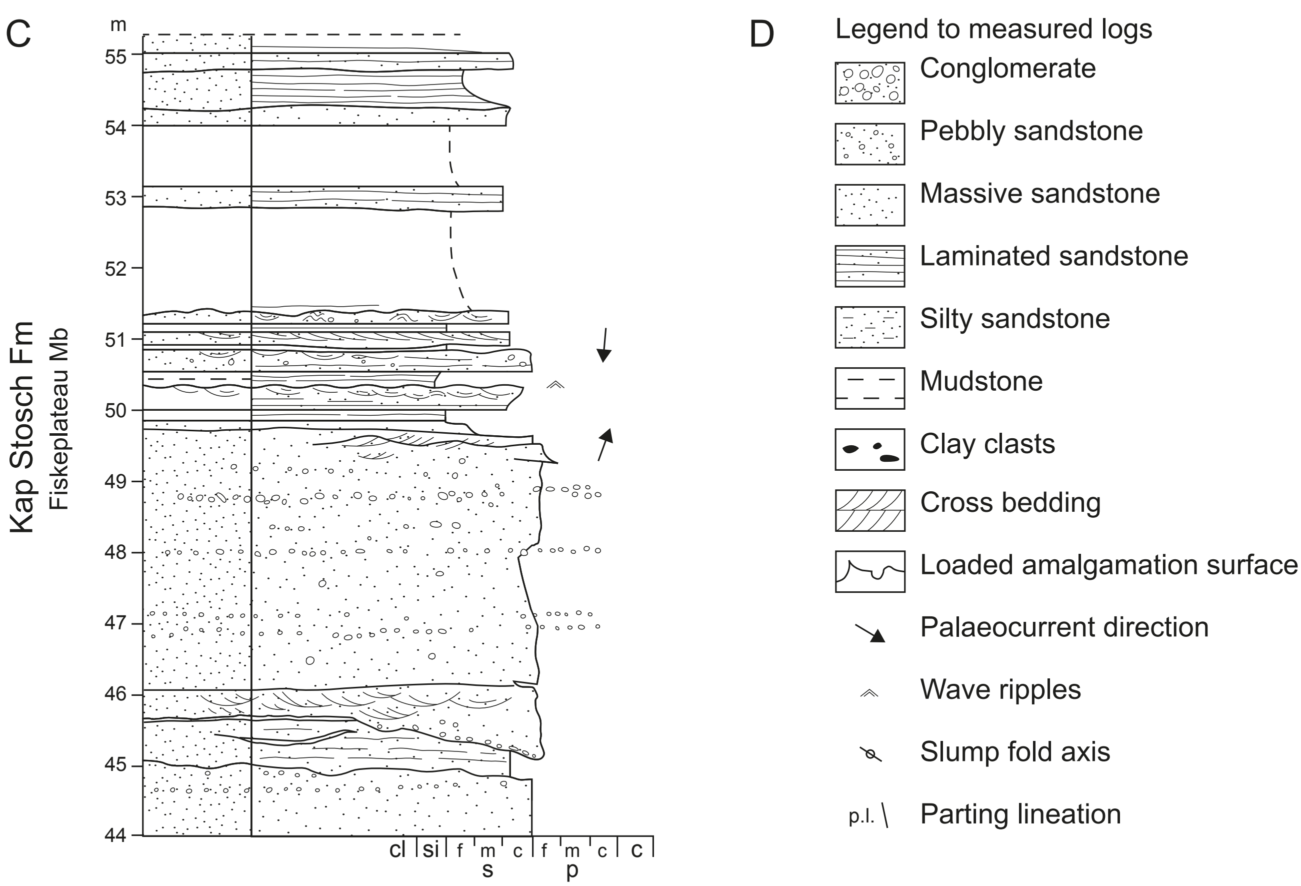

Fig. 8. continued.

vary markedly, laterally from the west to the east. In some cases, a topset is missing and the member consists solely of an about 30 m thick clinoform bed. The clasts mainly consist of basement rocks (Fig. 13), but subangular cobbles and boulders of Upper Permian limestone are common, especially in the upper part.

The conglomeratic foresets are intercalated with sandstone beds and may be mud- or silt-draped (Figs 11, 12). Clast packing is denser in the topset than in the sand-rich foresets. Outrunner clasts or clast lenses are common. The dominantly coarse pebble conglomerates of the foresets show non-grading,

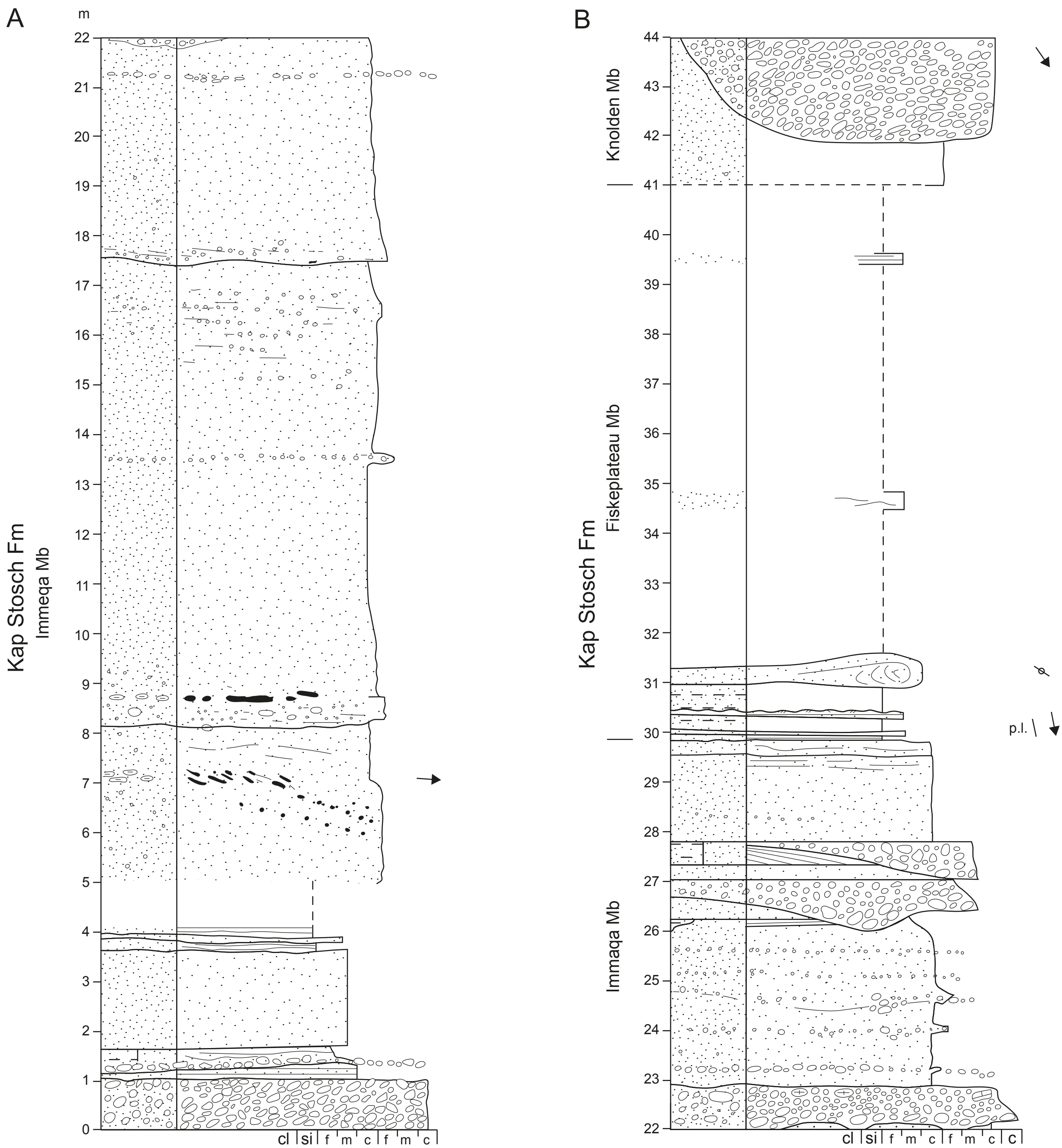

Fig. 9. Reference section of the Immaqa and Knolden Members. Type section of the Pyramiden Member (Section 5), western branch of River 9 (Figs 2, 3). The Immaqa Member is here developed in mainly sandy facies. Only the basal few metres of the Pyramiden Member is shown. The section is shown as four consecutive logs (A, B, C, D). Legend in Fig. 8D.

inverse, inverse-to-normal, and normal grading (Fig. 12). The topset beds are non-graded. Conglomerate-filled chutes are eroded into the sandstones, but can only be clearly seen in strike sections (Fig. 14). Some of the thicker foresets show internal large-scale trough cross-bedding. Isolated mound-like beds of structureless sandstone are common in front of the toesets (Fig. 15). An example of a strongly overturned foreset with dips reaching 50° has been observed immediately west of River 9.

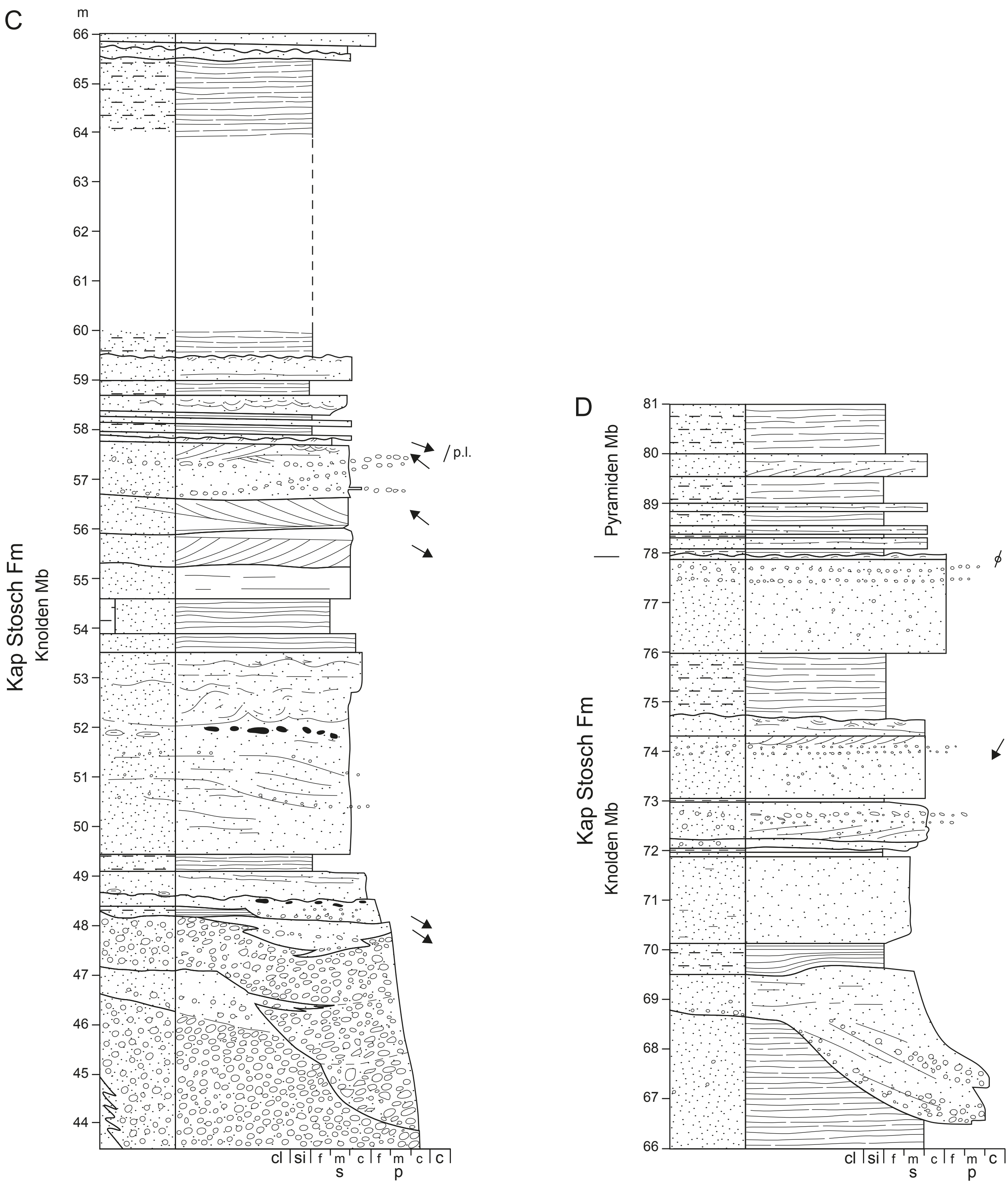

Fig. 9. continued.

Depositional environment. Deposition took place in Gilbert-type deltas where the topset was reworked by waves or fluvio-marine currents. There is, however, no direct evidence for terrestrial environments. Transport down the steep delta slope was by a variety of sediment gravity flows. The average palaeocurrent directions are towards the south, varying from SSE to SSW (Figs 8, 9). The NW–SE oriented modern coastline thus offers an overall oblique section of the depositional system with respect to the direction of delta progradation.

Fossils. So far no fossils have been reported, except those found in clasts of Upper Permian limestone derived from the Foldvik Creek Group.

Boundaries. – The lower boundary is highly irregular and characterized by small-scale interfingering between conglomerates/coarse-grained clinoform-bedded sandstones and fine-grained basinal sediments of the underlying Nebalopok Member (Figs 6, 8). The upper boundary is placed at a marine erosional flooding surface at the top of the cliff-forming sandstones and conglomerates characterizing the member (Figs 6, 8).

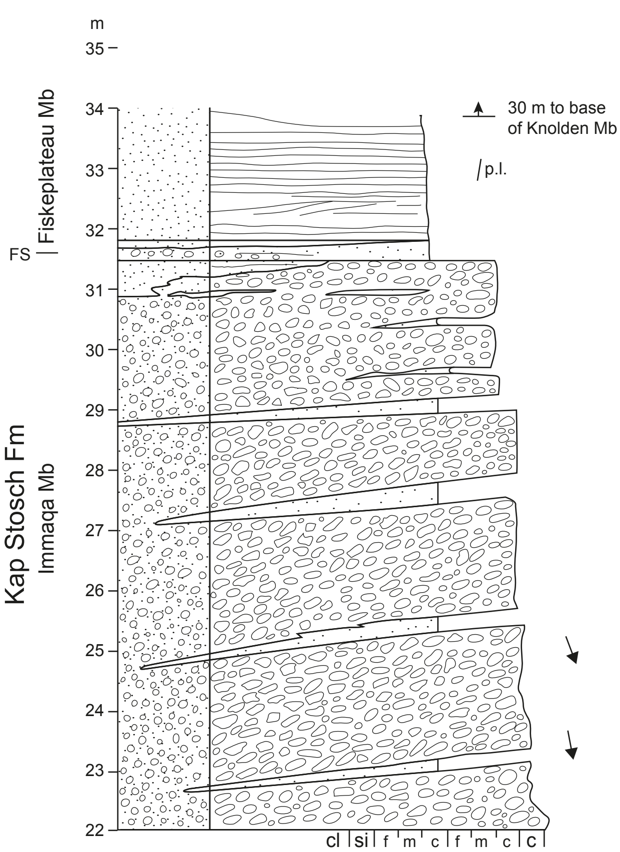

Fig. 10. Reference section of the Immaqa Member (Section 7), showing low-angle clinoform bedding of the top part of the member. East of River 9 (Figs 2, 3).. Legend in Fig. 8D.

Distribution. The member is only known from the north coast of Hold with Hope, from Kap Stosch eastwards to the eastern slopes of Blåelv (Fig. 2). It becomes markedly thinner and finer grained towards the east (Nielsen 1935).

Chronostratigraphy. Lower Triassic, lower Griesbachian *Hypophiceras martini* ammonoid zone based on the fossils found in the underlying Nebalopok Member and the overlying Fiskeplateau Member (Nielsen 1935; Spath 1935; Trümpy 1969; Teichert & Kummel 1976; Bjerager *et al.* 2006).

Fiskeplateau Member

New member

History. The member was included as the upper part of coarse-grained unit (CGU)1 of Oftedal *et al.* (2005).

Name. From Fiskeplateau, the plateau between Rivers 7 and 8 on the map of Nielsen (1935, plate 1), approximately 4.5 km south-east of Kap Stosch (Figs 1, 2).

Type and reference sections. The slope east of River 9 is designated type section (Fig. 6), and reference sections are at sections 1 and 5 (Figs 3, 8, 9).

Thickness. The thickness varies greatly from about 11 to about 44 m, reflecting the gently mounded cross section geometry of the underlying Immaqa Member.

Lithology. The member consists of variegated, grey-green and red-brown siltstones, fine-grained sandstones interbedded with thin conglomerates, and coarse-grained sandstones with pebble stringers. The sandstones show parallel lamination, parting lineation, climbing ripples, cross-stratification, and clay clasts. Transport directions are towards the SSE to S.

Depositional environment. Deposition took place from both turbidity flows and traction currents on a gentle slope in a relatively shallow water prodelta environment below wave base.

Fossils. No macrofossils are recorded from this interval, whereas spores and pollen are common.

Boundaries. The lower boundary towards the Immaqa Member is a pronounced drowning surface, commonly characterized by a 10 cm silt layer overlying conglomerates or pebbly sandstones of the Immaqa Member. The upper boundary is placed at the base of the cliff-forming coarse-grained sandstones and conglomerates of the Knolden Member.

Fig. 11. Alternating sandy and pebbly toesets of the lower part of the Immaqa Member, immediately west of River 9 (Fig. 2).

Fig. 12. Toeset of the Immaqa Member, showing coarse-tail graded conglomerate. Immediately west of River 9 (Fig. 2). Pencil (15 cm) in lower right corner for scale.

Fig. 13. Rounded to subrounded basement pebbles in a matrix of coarse-grained sandstone. Note the long (a) axis imbrication marked with black lines, indicating transport and deposition from a highly concentrated density flow from right to left in the picture. Pencil 14 cm long in picture. Lower Immaqa Member, immediately west of River 9 (Fig. 2).

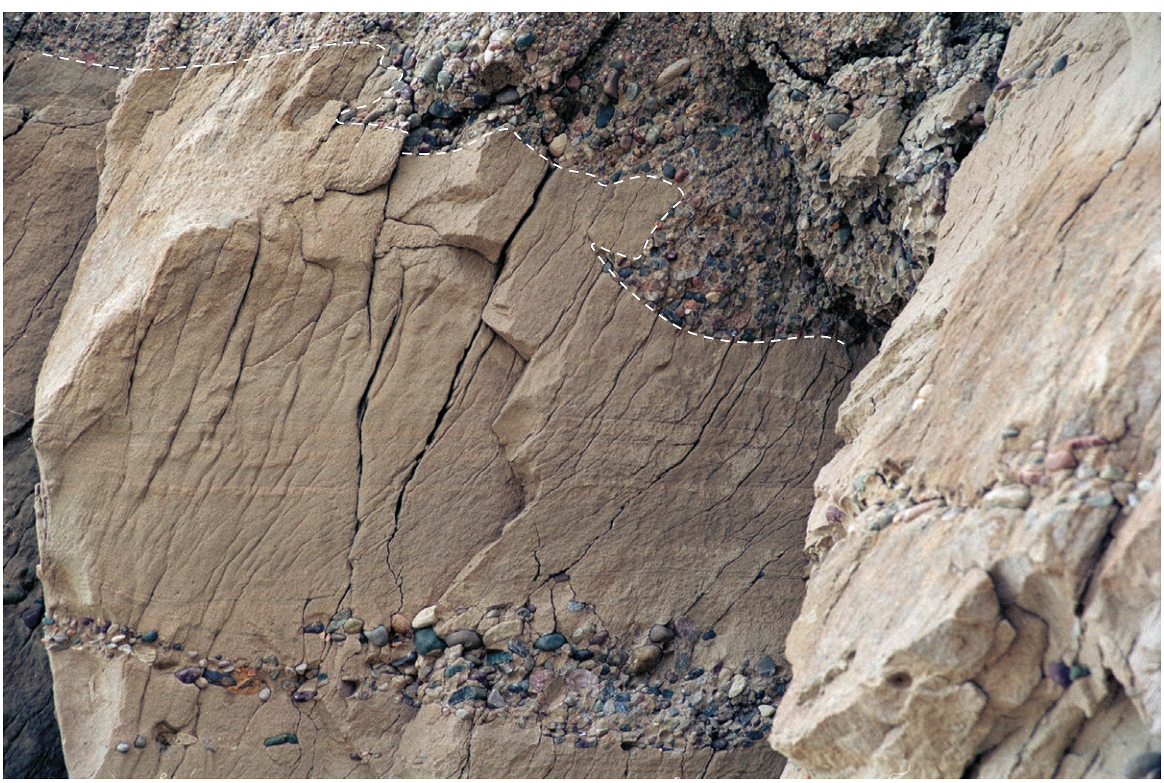

Fig. 14. Conglomerate-filled chute with internal overhangs eroded into sandstone of the clinoform-bedded lower part of the Immaqa Member. Section shown in Fig. 8, at the 6 m level. The sandstone bed immediately to the left of the chute is about 1 m thick.

Fig. 15. Bar-like structureless sandstones in front of the toes of the Immaqa Member clinoform foresets interpreted to have formed by 'freezing' of highly concentrated gravity flows. Immediately west of River 9 (Fig. 2).

Distribution. The member is only known from the north coast of Hold with Hope from Kap Stosch in the west to the eastern slopes of Blåelv to the east (Fig. 2).

Chronostratigraphy. Lower Triassic, lower Griesbachian *Hypophiceras martini* ammonoid zone (Nielsen 1935; Spath 1935; Trümpy 1969; Teichert & Kummel 1976; Bjerager *et al*. 2006).

Knolden Member

New member

History. The member forms a distinctive cliff-forming unit mapped as Conglomerate III by Nielsen (1935, plate 1), coarse-grained unit (CGU) 2 by Oftedal *et al.* (2005), and Conglomerate 2 by us in the field.

Name. From Knolden, the ridge between Rivers 6 and 7 on the map of Nielsen (1935, plate 1, approximately 5 km south-east of Kap Stosch (Fig. 2).

Type and reference sections. Section 15 is designated as type section (Fig. 16), and sections 5 and 8 as reference sections (Figs 3, 5, 17).

Thickness. The thickness varies greatly, reflecting the lobate geometry seen in cross sections of the member, and measured values are 37 m in section 5 (western wall of River 9; Fig. 2), at least 41.5 m in Section 9 (western corner of the mouth of River 8.5), at least 53 m in section 15 (at River 6). The member thins towards both the east and the west.

Lithology. The member consists of conglomerates and coarse-grained sandstones with subordinate layers of siltstone. It is markedly bipartite in several sections with a lower conglomeratic, commonly clinoform-bedded part with coarse-grained and pebbly sandstones with internal loaded amalgamation surfaces and clay clasts, overlain by horizontally bedded coarse sandstones, pebbly sandstones and lenticular conglomerates (Figs 6, 16, 18). The conglomerates mainly show normal grading and internal scour surfaces, and laminated coarse-grained sandstone beds are commonly truncated by steep-walled chutes with a highly complex fill of conglomerates and sandstones (Figs 19, 20).

A variegated siltstone up to 8 m thick with thin sandstone beds occurs at some localities between the two coarse-grained units (e.g. in section 5; Fig. 9). The sandstones in the top part of the lower, coarse-grained unit may show bidirectional cross-bedding, and the top drowning surface of this unit shows apparent wave ripples. White Upper Permian limestone clasts with productid brachiopods occur scattered (Fig. 21). Other sections (e.g. Section 8, Fig. 17) are dominated by conglomerate beds up to 20 m thick, with possible internal amalgamation surfaces represented by thin wedging-out sandstones. The foresets of the lower clinoform bed are commonly very steeply dipping, up to 34°, outlined by coarse-grained sandstones with thin pebble layers (e.g. Section 15, Fig. 16). The clinoforms are mainly sigmoidal and pass gradually up-

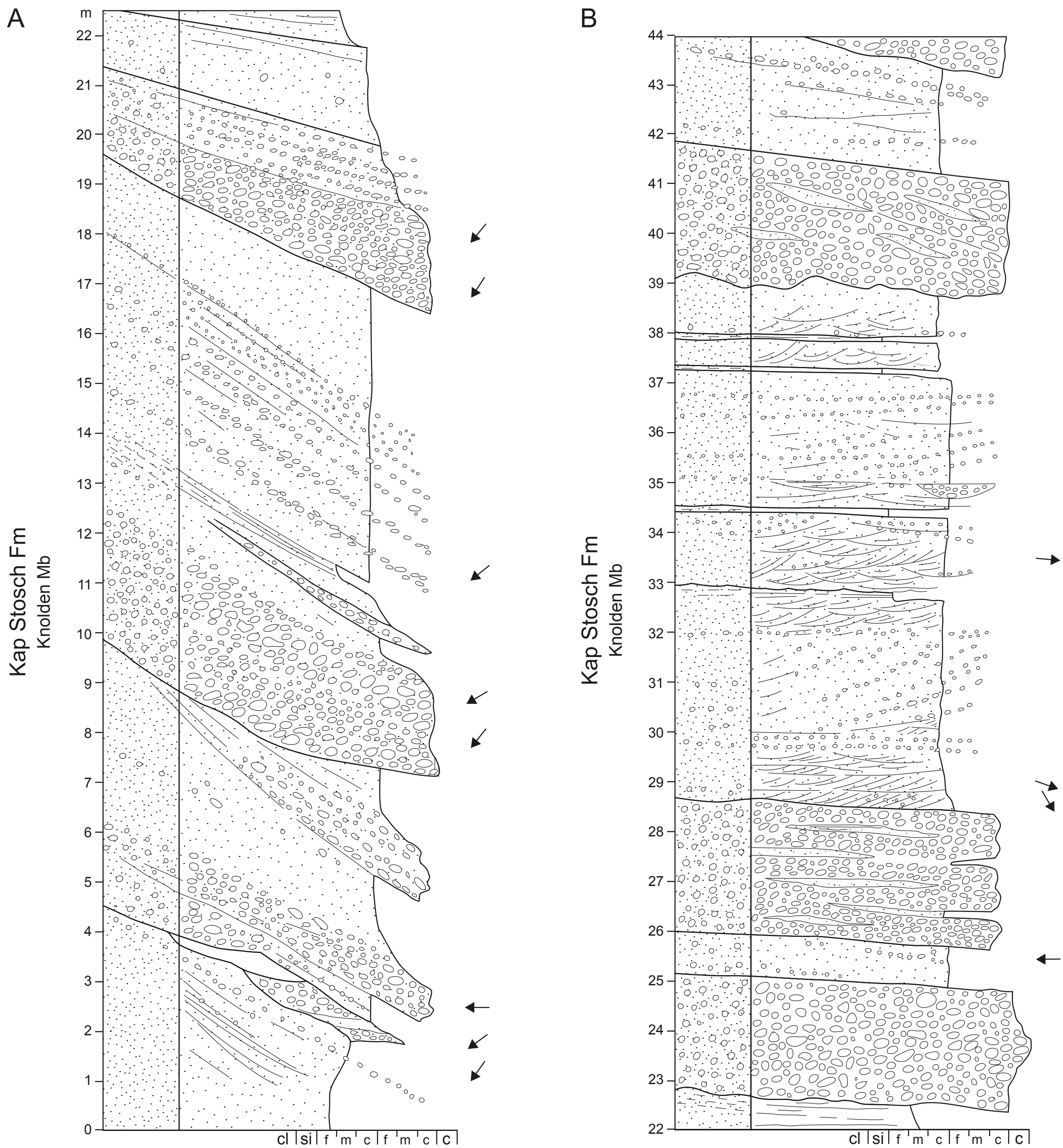

Fig. 16. Type section (section 15) of the Knolden Member, eastern bank of River 6 (Figs 2, 3). Note the steeply dipping clinoform foresets below, overlain by the horizontally-bedded topset, corresponding to the foreset and topset, respectively of a Gilbert-type delta. The member is topped by a sharp drowning surface overlain by the Pyramiden Member. Legend in Fig. 8D.

wards into the horizontally-bedded, coarse-grained, pebbly topset showing large-scale tabular and trough cross-bedding.

Depositional environment. Deposition took place in low- and high-angle Gilbert type deltas during rising relative sea level as indicated by the sigmoidal clinoforms and thick topset. The lower part of the member was deposited by high-concentration sediment gravity flows. Transport directions in the lower part are mainly towards the S to SW and towards the SE in the overlying topset. Wave ripple crests on the top drowning surface of the member strike N–S to NNE–SSW, interpreted to indicate the orientation of the coastline.

Fossils. So far no fossils have been reported except for Permian fossils occurring in reworked white limestone clasts.

Boundaries. The lower boundary is placed at the transition from interbedded fine-grained sandstone and siltstone of the Fiskeplateau Member to conglomerates and coarse-grained sandstones (Fig. 6). The upper boundary is placed at a marine drowning surface, commonly topped by wave ripples, overlain by siltstones and fine-grained sandstones of the Pyramiden Member (Figs 6, 9).

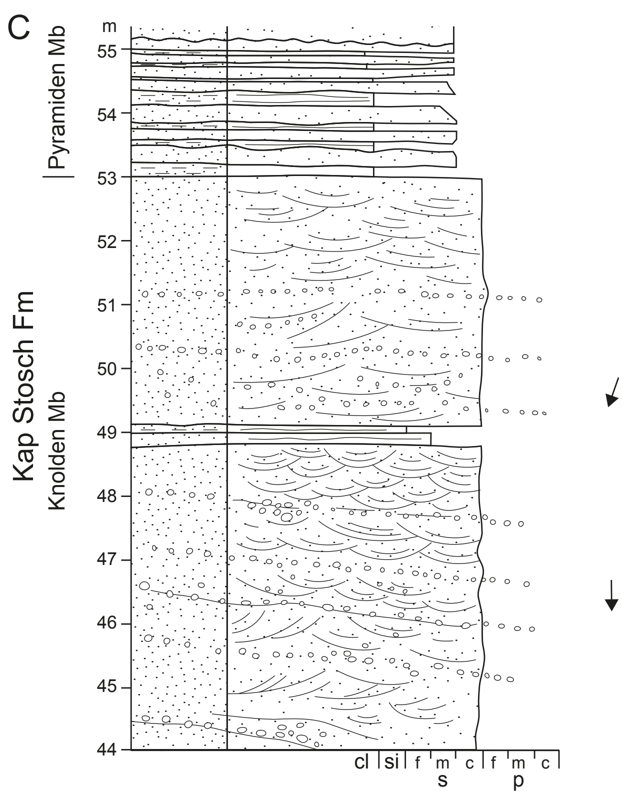

Fig. 16. continued

Distribution. The member is only known from the north coast of Hold with Hope from Kap Stosch in the west and eastwards to the eastern slopes of Blåelv. It is probably time equivalent with the conglomeratic unit at the base of the Triassic succession at Paradigmabjerg in Wegener Halvø and with the conglomerate and sandstone units that mark the top of the *H. martini* ammonoid zone at Traill Ø, northern Jameson Land and elsewhere at Wegener Halvø (Bjerager *et al*. 2006) (Fig. 4).

Chronostratigraphy. Lower Triassic, lower Griesbachian *Hypophiceras martini* ammonoid zone (Nielsen 1935; Spath 1935; Trümpy 1969; Teichert &Kummel 1976; Bjerager *et al.* 2006).

Pyramiden Member

New member

History. Described as fine-grained unit (FGU) 2 by Oftedal *et al.* (2005).

Name. From the plateau Pyramiden between Rivers 8.5 and 9 on the map of Nielsen (1935, plate 1), approximately 6.5 km south-east of Kap Stosch (Figs 1, 2).

Type and reference sections. Section 5 is designated as type section (Figs 3, 9). The measured part of this section only shows the lower few metres of the member, but the type section continues upwards to the base of the coarse-grained Naasut Member.

Thickness. Varies between about 140 and 175 m, reflecting the draping nature of the member over the gently mounded cross section of the underlying Knolden Member (Fig. 5).

Lithology. Variegated siltstones with mainly thin fine- and medium grained sandstones. The lower part is commonly dominated by dark grey to black laminated mudstones with abundant concretions, passing upward into silty and sandy grey and greenish grey mudstones. Thicker sandstones are common in the higher parts of the member and show convolute bedding, parting lineation, slump folds, flute casts, linguoid ripples and clay chips. Transport was towards the SSE.

Depositional environment. Proximal basin plain passing into lower slope environments as indicated by slump folds. Deposition took place from suspension fall-out and a variety of sediment gravity flows, mainly turbidity flows.

Fossils. The member contains a highly diverse macrofauna of molluscs and vertebrates. The rich ammonoid assemblages comprise *Hypophiceras*, *Thompophiceras*, *Ophiceras*, *Discophiceras*, *Wordieoceras* and *Vishnuites*. The bivalve *Claraia* occurs in abundance and the gastropods *Naticopsis* and *Bellerophon* are common. Vertebrates include the fishes *Birgeria groenlandica*, *Glaucolepis arctica*, *Australosomus kochi*, *Bobastrania groenlandica*, *Perleidus stoschiensis*, *Ospia whitei*, *Broughia perleididoides*, *Helmolepis gracilis* from fish zones 2–4 of Nielsen (1935). Spores and pollen are common and the assemblage is dominated by bisaccate pollen.

Boundaries. The lower boundary is placed at a marked, sharp drowning surface where the fine-grained deposits of the member overlie sandstones and pebbly

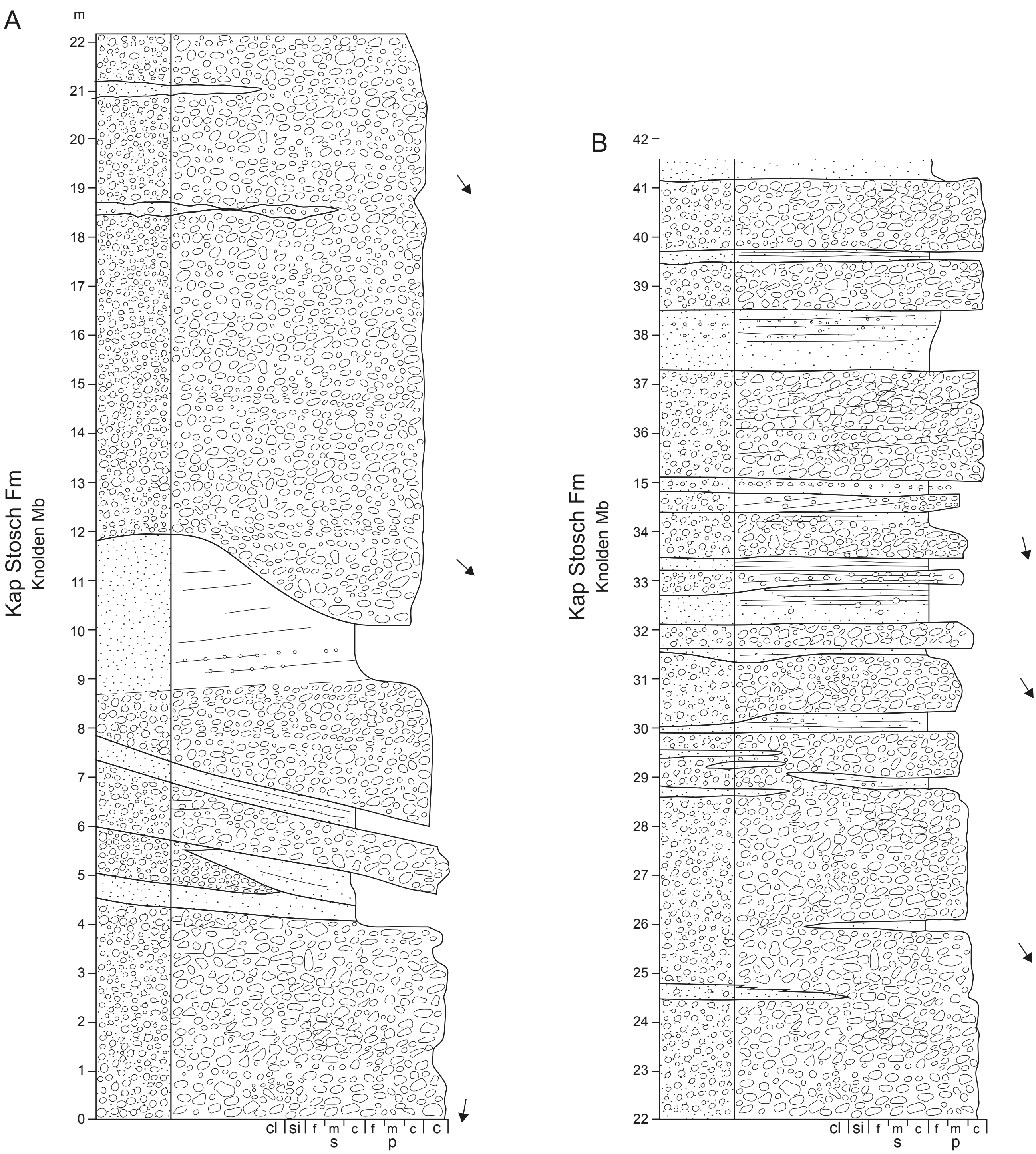

Fig. 17. Reference section of the Knolden Member (section 8), eastern bank of River 9 (Figs 2, 3). Legend in Fig. 8D.

Fig. 18. The conglomeratic Knolden Member sharply overlain by the fine-grained Pyramiden Member, which is again overlain by coarse-grained sandstones of the Naasut Member. Note the steeply dipping clinoform foresets of the Knolden Member, overlain by the horizontally-bedded topset, corresponding to the foreset and topset, respectively of a Gilbert-type delta. The member is about 50 m thick. River 9 (Fig. 2).

Fig. 19. Conglomerate-filled chutes (dashed outlines) eroded into sandstones in the upper part of the clinoform-bedded lower part of the Knolden Member. Wall about 25 m high. Strike section. West of River 9 (Fig. 2).

Fig. 20. Conglomerate-filled chute eroded into sandstone of the clinoform-bedded Knolden Member. The chute was filled in several steps (1–3) by conglomerate and sandstone. An alternative interpretation is that the chute was sinusoidal in plan view and deposition of the coarsest part of a flow took place along the inner bend (1) whereas the sandy part was deposited from suspension laterally to the left (2). Pencil in oval is 15 cm long. Eastern bank of River 9 (Fig. 2).

Fig. 21. Clast of Upper Permian limestone with large, white productid brachiopods to the left. Section 5, at the 45 m level in the Knolden Member (Fig. 9).

sandstones of the Knolden Member (Fig. 9). The irregular upper boundary is placed at the base of the commonly erosional sandstones of the Naasut Member (Fig. 23).

Distribution. The member is only known from the north coast of Hold with Hope from Kap Stosch in the west and eastwards to the eastern slopes of Blåelv. A partly similar sedimentological development is seen in the time-equivalent middle part of the Wordie Creek Group on Traill Ø, northern Jameson Land and Wegener Halvø.

Chronostratigraphy. Lower Triassic, lower–upper Griesbachian *Methophiceras subdemissum*, *Ophiceras commune* and *Wordieoceras decipiens* ammonoid zones (Bjerager *et al.* 2006).

Naasut Member

New member

History. The member corresponds to Conglomerate IV in the top of the *Vishnuites* beds of Nielsen (1935) and the lower part of coarse-grained unit (CGU) 3 of Oftedal *et al.* (2005).

Name. From Nasutdal, River 10 on the map of Nielsen (1935, plate 1), approximately 8 km SE of Kap Stosch (Figs 1, 2). Nielsen (1935) spelled the name Nasut, but the correct modern Greenlandic spelling is Naasut, meaning 'flowers' in Greenlandic, and this form is used here.

Type and reference sections. Section 4, eastern bank of Immaqadal (River 9) on the map of Nielsen (1935, plate 1) is designated type section (Figs 3, 22). Section 6, located in the inner part of Immaqadal above the major SW-striking fault shown on the map of Nielsen (1935, plate 1) and Section 17 (Figs 3, 23, 24) are designated reference sections.

Thickness. The thickness varies strongly from west to east. It is 97 m at Rævekløft, 63 m at section 4 and 13 m at section 6. A thickness change across the Immaqa Fault was also noted by Nielsen (1935) and Oftedal *et al.* (2005).

Lithology. The member is mostly composed of thick, massive to crudely bedded sandstones with some silty intervals and an eastwards decreasing content of pebble stringers and thin conglomerates. The member shows both clinoform and horizontal bedding (e.g. Section 4) (Figs 24, 25, 26). The clinoforms are commonly sigmoidal. Bottom- and toesets contain abundant deformed clay clasts (Fig. 27). The maximum recorded dip of clinoforms is 20°. Low-angle cross stratification is common at the top of clinoform beds. The member is topped by a marked drowning surface overlain by grey-green siltstone. At some localities the topmost part shows hummocky cross stratification (Fig. 28). An up to 74 m deep erosional channel or canyon occurs at Rævekløft (Section 18; Fig. 2). The channel wall is steep and the channel fill is loaded into the adjacent and underlying grey-green siltstone (Fig. 29). The horizontally bedded sections show bed thicknesses up to about 6 m, mainly separated by diffuse, commonly loaded amalgamation surfaces (Section 4; Fig. 22). Scour-and-fill cross-stratification occurs at some levels. The 9.5 m thick top bed of the otherwise horizontally bedded Section 4 shows a diffuse low-angle clinoform bedding (Fig. 22). The progradation direction of the clinoform beds is towards the west to north-west. This is in contrast to the interpretation of Oftedal *et al.* (2005), who in their reconstruction depict a transport direction towards the south along the axes of the tilted fault blocks.

Depositional environment. The member was deposited mainly below wave base by high-concentration, commonly highly erosive sediment gravity flows. The top part was in places reworked by deep storm waves. Deposition took place in a slope, base-of-slope to basin environment, apparently derived from an eastern source area, in contrast to the other coarse-grained members.

Fossils. No fossils have been reported so far.

Boundaries. The lower boundary is a sharp, commonly slightly erosional surface, separating interbedded siltstones and fine-grained sandstones of the underlying Pyramiden Member from massive medium-grained sandstones and in some cases, pebbly sandstones. The upper boundary is placed at a sharp marine drowning surface where the member is overlain by laminated greenish or variegated siltstones of the Falkeryg Member (Figs 23, 26).

Distribution. The member is only known from the north coast of Hold with Hope, from the eastern slopes of Blåelv westwards to Kap Stosch (Figs 1, 2). It is possibly a correlative of the Svinhufvuds Bjerge Member at Traill Ø (Fig. 4).

Chronostratigraphy. Lower Triassic, upper Griesbachian *Wordieoceras decipiens* ammonoid zone based on fossils in the under- and overlying members.

Falkeryg Member

New member

History. Corresponds to the *rosenkrantzi* beds of Nielsen (1935).

Name. From the ridge immediately east of River 9 on the map of Nielsen (1935, plate 1). The member corresponds to the upper part of coarse-grained unit (CGU) 3 and the lower part of coarse-grained unit (CGU) 4 of Oftedal *et al.* (2005).

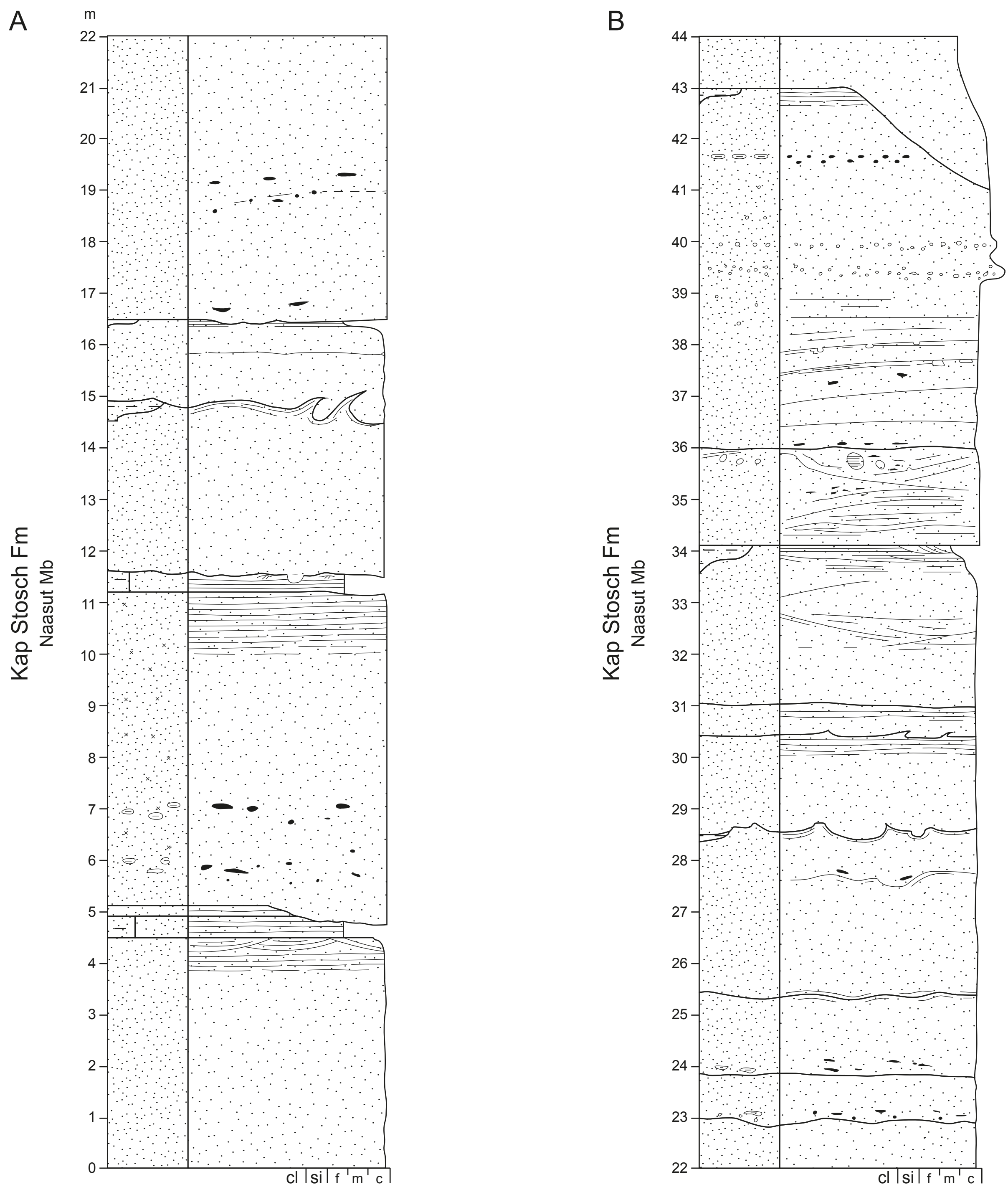

Fig. 22. Type section of the Naasut Member (Section 4), showing thick, mainly structureless beds of coarse-grained sandstone. Loaded amalgamation surfaces and intraformational clay clasts are common. East of River 9 (Figs 2, 3). Legend in Fig. 8D.

Type section. The plateau named Fiskeplateau by Nielsen (1935) between Rivers 7 and 8 is designated type section (Fig. 2).

Thickness. The member is 65 m thick in the type section, but the thickness varies strongly and is only about 35 m in a section at River 15, and only a few metres in Section 17 (Fig. 24).

Lithology. Monotonous laminated siltstones and thin sandstone beds showing cross lamination and load casts. The succession coarsens upwards in the top part. Bivalve biostromes and shell plasters occur at several levels (Figs 30, 31).

Depositional environment. Basin plain.

Fossils. The ammonoids *Bukkenites rosenkrantzi*, *B. anomalus*, *B. intermedius*, *B. simplex*, *Ophiceras dubius*, the gastropod *Naticopsis arctica*, the bivalves *Loxonema*, *Claraia* and *Myalina*, the serpulid and spirorbid *worm tubes*. Vertebrates from fish zone 5 comprise common species of *Perleidus*, *Ospia*, *Broughia*, and more rarely *Saurichthus* and *Birgeria*. Fragments of the stegocephalian *Lycocephalus* are common (Nielsen 1935). Spores and pollen are common and the assemblage is dominated by trilete spores.

Boundaries. The lower boundary is a marked drowning surface where coarse-grained sandstones of the Naasut Member are overlain by siltstones and fine-grained sandstones of the Falkeryg Member (Figs 23, 25, 28). The upper boundary is placed where the fine-grained deposits of the member are overlain by coarse-grained, pebbly sandstones of the Vestplateau Member.

Chronostratigraphy. Lower Triassic, lower Dienerian *Bukkenites rosenkrantzi* ammonoid zone.

Vestplateau Member

New member

History. The member corresponds to the upper part of coarse-grained unit (CGU) 4 of Oftedal *et al*. (2005).

Name. From Vestplateau, the ridges immediately west of River 6 on the map of Nielsen (1935, plate 1), approximately 4.5 km south-east of Kap Stosch (Figs 1, 2).

Type and reference sections. The slope Fiskeplateau is designated type section. It extends upwards from the Falkeryg Member type section (Figs. 2, 3, 24).

Thickness. The member is 28 m thick in the type section and thins towards the east (Figs 2, 5).

Lithology. Massive medium-grained and conglomeratic sandstones and diffusely laminated or structureless fine-grained sandstones with thin siltstone beds. Cross bedding occurs at some places.

Depositional environment. Deposition took place from concentrated sediment gravity flows in a base-of-slope environment.

Fossils. No fossils have been reported so far.

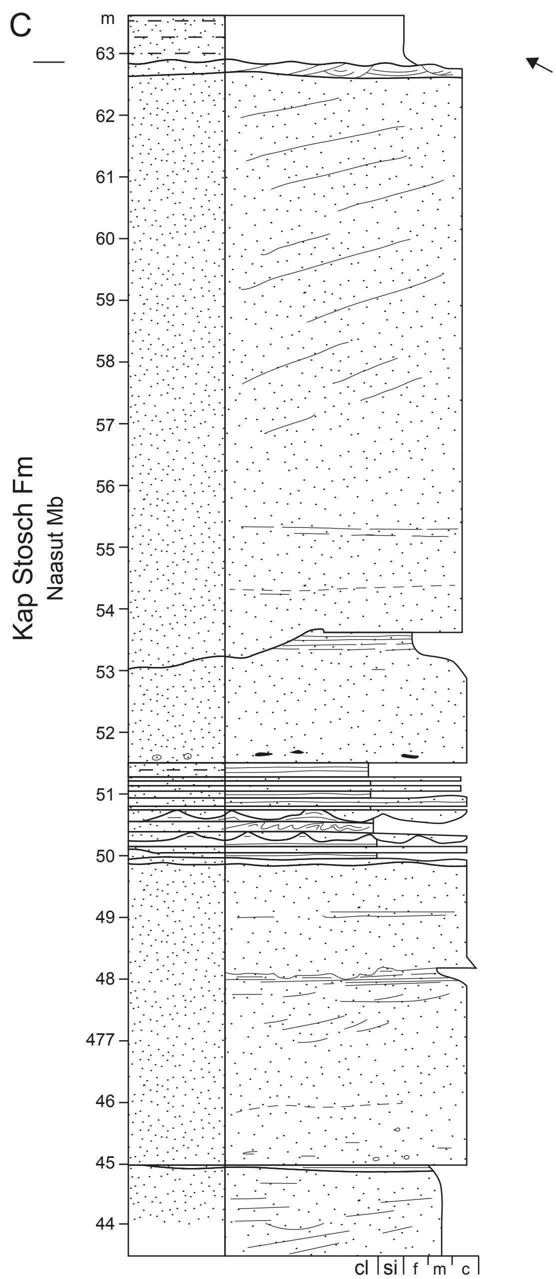

Fig. 22. continued.

Boundaries. The lower boundary is a sharp, commonly slightly erosional transition from interbedded siltstones and fine-grained sandstones of the Falkeryg Member to massive medium-grained sandstones and conglomeratic sandstones. The upper boundary is placed at the top of the thick, commonly cliff-forming sandstone unit where it is overlain by siltstones and fine-grained sandstones of the Godthåb Golf Formation.

Distribution. The member is only known from the north coast of Hold with Hope from the eastern slopes of Blåelv westwards to Kap Stosch (Figs 1, 2).

Chronostratigraphy. Lower Triassic, lower Dienerian, probably *Bukkenites rosenkrantzi* ammonoid zone,

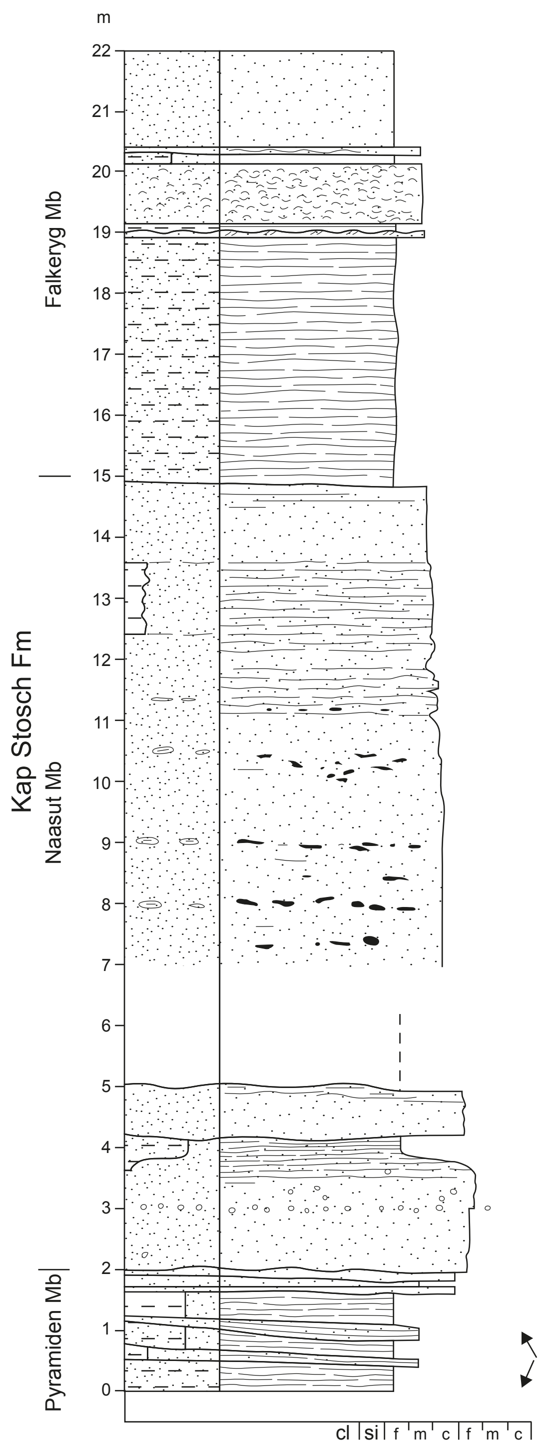

Fig. 23. Reference section of the Naasut Member (Section 6), underlain by the Pyramiden Member and sharply overlain by the Falkeryg Member. Inner part of River 9 immediately west of fault (Figs 2, 3). Legend in Fig. 8D.

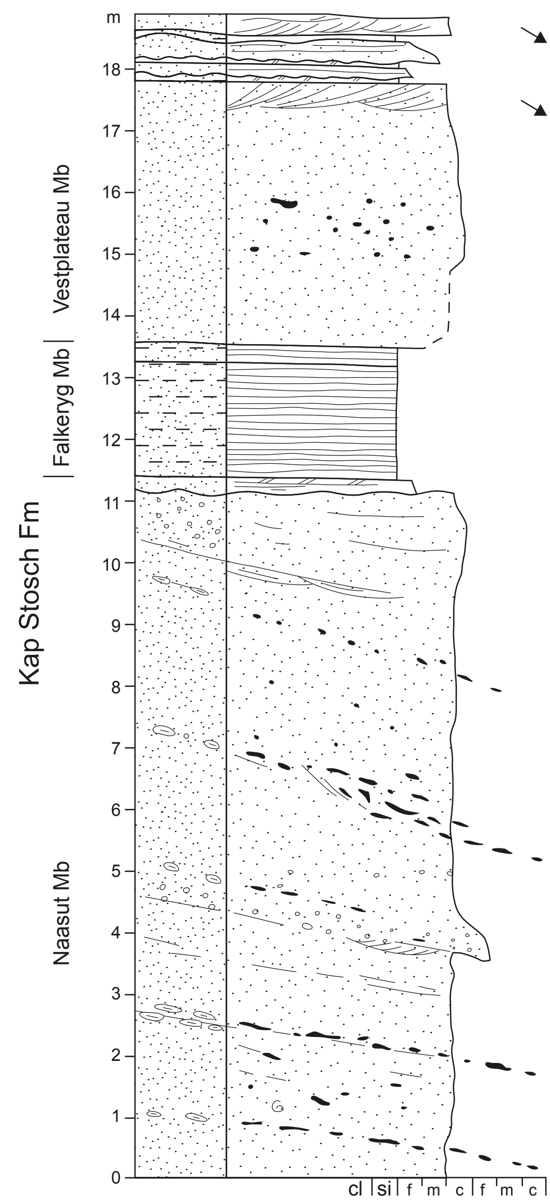

Fig. 24. Reference section of the Naasut Member (section 17) showing diffuse clinoform bedding, and overlain at a sharp drowning surface by the Falkeryg Member. Western bank of River 9 (Figs 2, 3). Legend in Fig. 8D.

Fig. 25. Structureless sandstones of the Naasut Member, overlain by the Falkeryg Member at a sharp drowning surface. Diffuse clinoforms dip to the left in the picture. The protruding ridge in the centre with holes after modern wind erosion can be seen at the top in Fig. 26, giving the scale (by the person in the centre in oval). Eastern bank of River 9 (Fig. 2).

Fig. 26. Westward-dipping clinoforms in otherwise structureless sandstone of the Naasut Member. Person in centre in oval for scale. Eastern bank of River 9 (Fig. 2).

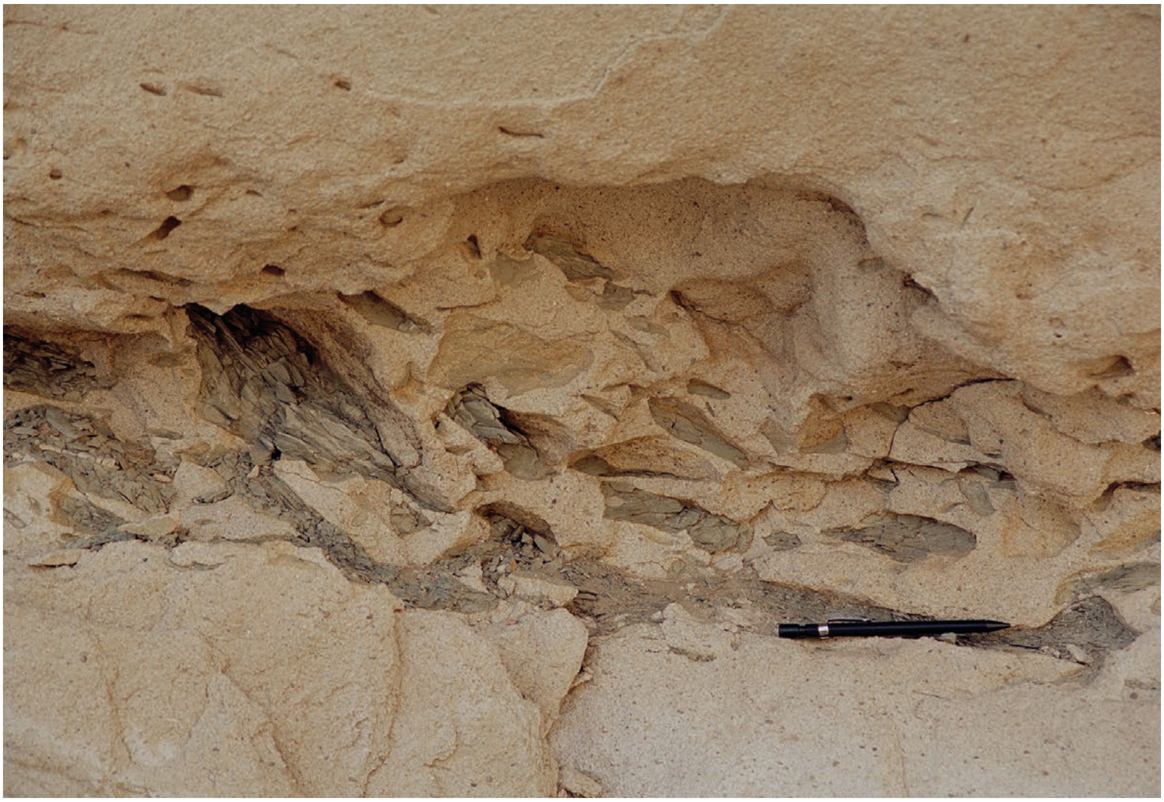

Fig. 27. Deformed green claystone clasts along clinoform of the Naasut Member. Section 6 at the 8 m level (Fig. 23). Pencil 15 cm long.

Fig. 28. Sharp drowning surface at the top of structureless sandstones of the Naasut Member overlain by the Falkeryg Member. The top of the Naasut Member shows hummocky cross-stratification formed by deep storm waves. Eastern bank of River 9 (Fig. 2).

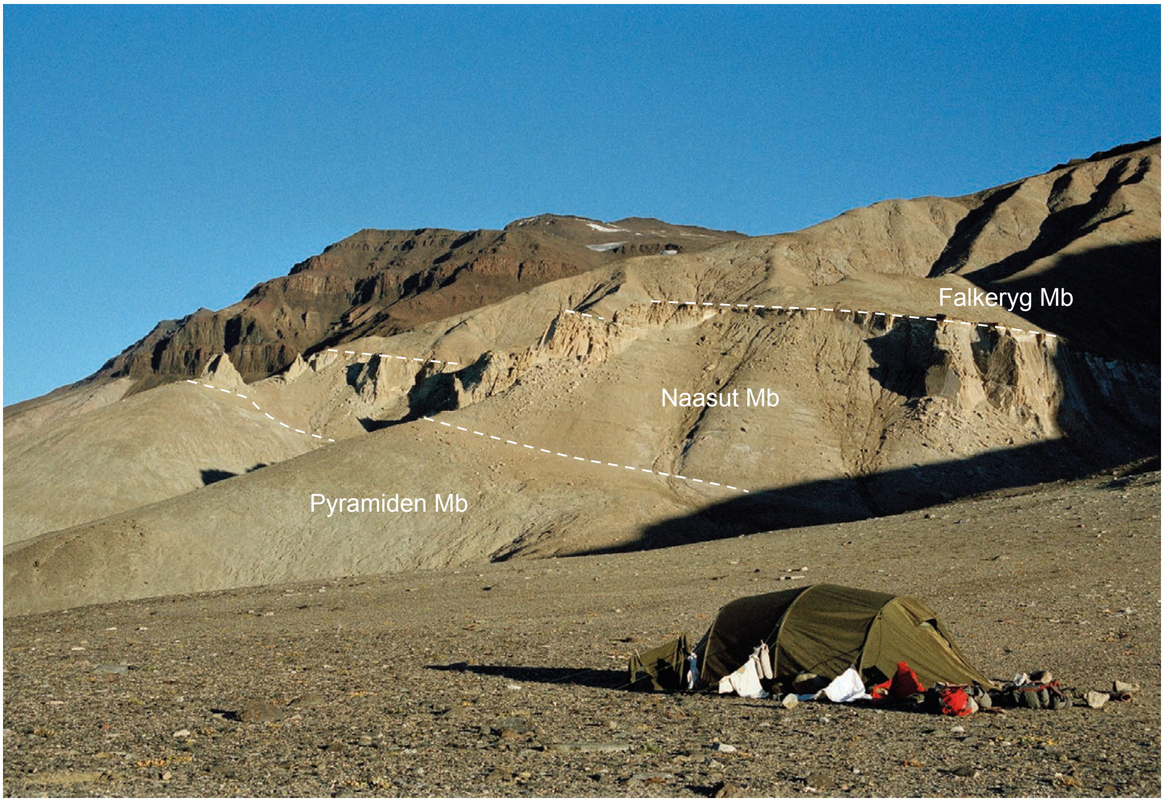

Fig. 29. Canyon or channel cut into the fine-grained Pyramiden Member and filled with structureless sandstone beds of the Naasut Member. East of River 9 (Fig. 2). The Naasut Member is about 60 m thick to the right in the picture and thins to about 20 m to the left.

Anodontophora breviformis bivalve zone and *Densosporites* palynomorph assemblage zone.

Godthåb Golf Formation

New formation

History. The formation as defined here corresponds to the *Anodontophora* (breviform) – *A. fassaensis* beds, including the *Myalina kochi* zone and stegocephalian horizon of Nielsen (1935).

Name. After Godthåb Golf, the fjord immediately to the north of the outcrops, forming the northern border of Hold with Hope (Fig. 1).

Type and reference sections. The combined type section is at Fiskeplateau and Stegocephalryg immediately to the west (Fig. 2). A reference sections is located at River 15 above section 15 (Figs 2, 3).

Thickness. The formation thins from 220 m at River 10 to 170 m at River 15 towards the east (Fig. 5). The thickness variations reflect post-depositional erosion.

Lithology. The lower part of the member consists of mudstones and siltstones with thin sandstones showing load casts, passing upwards into fine-grained sandstones. A prominent medium-grained sandstone, in places with a strongly erosional base and showing large-scale cross bedding, occurs in the lower to middle part of the member (Figs 4, 5).

Depositional environments. Shallow marine shelf and possibly coastal plain at the top (Oftedal *et al*. 2005).

Fossils. The formation contains a low diversity fauna of bivalves and gastropods, and a distinct horizon with abundant stegocephalian remains of *Wetlugasaurus groenlandicus* and *Stoschiosaurus nielseni* and with some ganoid and coelecanthid fish remains occuring in the middle part (Nielsen 1935; Spath 1930, 1935). The bivalve *Anodontophora breviformis* has its lowest occurrence immediately above the base of the formation, whereas *A. fassaensis* and *Myalina kochi* occur together with serpulids in the upper part. Other bivalves and serpulids also occur (Nielsen 1935). Spores and pollen are common and the assemblage is dominated by trilete spores.

Boundaries. The lower boundary is placed at the top of

Fig. 30. Bedding plane with abundant shells of the bivalves *Anodontophora* and a few *Myalina*, top of *Anodontophora* bed, Falkeryg Member. Section 6, western bank of River 9, west of fault (Fig. 2). Pencil 15 cm long.

Fig. 31. Bivalve biostrome, Falkeryg Member. Section 6, western bank of River 9, west of fault (Fig. 2). Pencil 15 cm long.

prominent cross-bedded conglomerates and conglomeratic sandstones of the Vestplateau Member. The upper boundary is a low-angle unconformity overlain by Cretaceous sediments east of Blåelv and Cenozoic sediments and plateau basalts west of Blåelv.

Distribution. The formation is well exposed east of Blåelv and occurs scattered below the Cenozoic basalts in the area between Blåelv and River 6 (Figs 1, 2).

Chronostratigraphy. Lower Triassic, Dienerian *Anodontophora breviformis* and *A. fassaensis* bivalve zones, *Densosporites* palynomorph assemblage zone.

Subdivisions. The formation is not subdivided.

Biostratigraphy

Ammonoids

Six ammonoid zones are recognized in the Wordie Creek Group in the study area. They are from below: the *Hypophiceras triviale*, *H. martini*, *Metophiceras subdemissum*, *Ophiceras commune*, *Wordieoceras decipiens* and *Bukkenites rosenkrantzi* zones (Figs 4, 5; Nielsen 1935; Spath 1935; Trümpy 1969; Birkelund & Perch-Nielsen 1976; Teichert & Kummel 1976; Bjerager *et al.* 2006). The zonation is valid for East Greenland and can be correlated with the Boreal zonations in Arctic Canada, Svalbard and northeast Asia (Tozer 1981, 1994; Bjerager *et al.* 2006).

New finds of ammonoids combined with the very detailed descriptions of Nielsen (1935) allow the zonation to be linked to our sedimentological sections with great confidence, the only exception being the boundary between the *H. triviale* and the *H. martini* zones. The *H. triviale* zone is approximately 30 m thick in the westernmost outcrops south-west of Kap Stosch (Nielsen 1935), thinning to less than 10 m in the area east of River 6 (Teichert & Kummel 1976); this thinning corresponds to a general eastward thinning of the lower part of the Kap Stosch Formation below the Immaqa Member (Fig. 5).

The overlying *H. martini* zone thins from approximately 220 m at River 8 to 135 m at River 15 (Fig. 5). The top of the zone is placed at the top of the Knolden Member, although ammonoids have not been found in the Immaqa, Fiskeplateau and Knolden Members.

The *M. subdemissum* zone is very thin, approximately 20 m at Kap Stosch. Ammonoids belonging to this zone have been found in dark siltstones immediately above the Knolden Member at Rivers 6 and 9, and are described from the same stratigraphic position elsewhere at Kap Stosch by Nielsen (1935). At Rivers 6 and 9, the upper limit of the zone is defined by the occurrence of ammonoids belonging to the *O. commune* zone 20–25 m above the top of the Knolden Member.

The *O. commune* zone is also thin, 20–30 m, at Rivers 6 and 9. Similar thicknesses of 40–50 m for the combined *M. subdemissum* and *O. commune* zones are given as typical for the entire area by Nielsen (1935). The overlying *W. decipiens* Zone is much thicker, up to 160 m at Rivers 6 and 10, thinning to 120 m at Rivers 15 and 7 (Figs 2, 5). The top of the zone is placed at the top of the Naasut Member, although this member contains no ammonoids.

The *B. rosenkrantzi* zone is identified in the fine-grained sediments of the Falkeryg Member immediately overlying sandstones and conglomerates of the Naasut Member (Fig. 5). Ammonoids characteristic of this zone are restricted to the lower 20–25 m of the Falkeryg Member, and they are the youngest Triassic ammonoids found at Hold with Hope and elsewhere in East Greenland (Nielsen 1935; Spath 1935; Trümpy 1969; Teichert & Kummel 1976; Bjerager *et al.* 2006). The upper part of the Kap Stosch Formation, from approximately 25 m above the top of the Naasut Member, and the Godthåb Gulf Formation are accordingly not dated by ammonoids.

Bivalves

The Godthåb Golf Formation is subdivided into two local bivalve zones (Nielsen 1935; Spath 1935). The *Anodontophora breviformis* zone (below) has at most localities a maximum thickness of 80–100 m from the uppermost occurrence of ammonoids to the lowermost occurrence of the bivalve *A. fassaensis*. However, immediately east of River 9 the zone is much thicker, close to 200 m, comparable to the 250 m suggested by Nielsen (1935). The overlying *A. fassaensis* Zone has a maximum thickness of 150 m at River 6 (Fig. 5).

Spores and pollen

Palynostratigraphic correlation of the uppermost Permian – lowermost Triassic successions in the present day Arctic region is complicated because most studies of spores and pollen are from more southern regions. Furthermore, both Late Permian and Early Triassic floras are strongly climatically and environmentally dependent (Utting & Piasecki 1995) and consequently palynostratigraphic zonations from geographically distant areas are not easily correlated. Marine plankton is limited in these sediments and comprises mainly acritarch species not so well taxonomically classified from this stratigraphic interval.

Vigran *et al.* (2014) introduced a palynozonation based on studies in the northern North Atlantic region. It includes four zones relevant for this study. They are, from below, (1) the *Uvaesporites imperialis* composite assemblage zone, uppermost Permian, uppermost Changhsingian; (2) the *Reduviasporonites chalastus* composite assemblage zone characterizing the Permian–Triassic transition, uppermost Changhsingian – lowermost Griesbachian; (3) the *Proprisporites pocockii* composite assemblage zone, lowermost Triassic, lowermost Griesbachian; and (4) the *Maculatasporites* spp. composite assemblage zone, lowermost Triassic, upper Griesbachian/Dienerian (Vigran *et al.* 2014).

At Hold with Hope, the uppermost Foldvik Creek Group is barren of palynomorphs. Red and green colours of these beds suggest that the palynomorphs have been exposed, oxidized and destroyed. In contrast, dark marine mudstones belonging to the uppermost Foldvik Creek Group in southern Jameson Land are referred to the *Uvaesporites imperialis* composite assemblage zone in dark marine mudstones, indicating a Permian age.

Black palynomorphs appear in the basal, green mudstone beds of the Wordie Creek Group at Kap Stosch and are referred to the *Reduviasporonites chalastus* composite assemblage zone (uppermost Permian – lowermost Triassic). The flora is characterized by the appearance of presumably fungal remains and *Reduviasporonites chalastus*, trilete spores e.g. *Uvaesporites imperialis*, *Lundbladispora obsoleta*, *Maculatasporites* spp., *Aculeisporites variabilis* and *Densoisporites playfordii*, and abundant striate, saccate pollen inclusive *Crustaesporites globosus* and *Striatoabietites richteri*. Approximately 0.8–0.9 m above the base of the Wordie Creek Group, well preserved, orange palynomorphs appear and are referred to the *Proprisporites pocockii* composite assemblage zone (Triassic, lower Griesbachian). This zone extends upwards to about 38 m above the base, where the *Maculatasporites* spp. composite assemblage zone is identified with some hesitation (upper Griesbachian/Dienerian). Significant reworking of palynomorphs in the Wordie Creek Group makes stratigraphic events (especially last occurrences) useless for stratigraphy. As an example, the lowermost Triassic *Reduviasporonites chalastus* and the megaspore *Otynisporites* spp. occur throughout the Wordie Creek Group. This makes palynostratigraphy above the lowermost zones rather uncertain.

The next higher, well-defined palynological marker event occurs at the base of the Falkeryg Member and is a characteristic change in composition of the palynoflora from a dominance of bisaccate pollen to a dominance of trilete spores. The shift can be correlated with the Griesbachian–Dinerian transition (e.g. Hochuli *et al.* 2016) and occurs in the *B. rosenkrantzi* ammonoid zone. Dominance of trilete spores continues to the top of the Godthåb Golf Formation. The spore-dominated interval is of Dinerian–Smithian age in the North Atlantic region (Vigran *et al.* 2014).

Conodonts

Conodonts have been recovered from both the Foldvik Creek and Wordie Creek Groups at Kap Stosch. Sweet (1976) identified a clearly Permian, *Neogondolella rosenkrantzi* fauna in the Foldvik Creek Group, and an *Anchignathodus typicalis* fauna/zone which at the time was considered to straddle the Permian–Triassic boundary. However, Sweet (1976) considered the entire *A. typicalis* fauna at Kap Stosch as Triassic. Rasmussen *et al.* (1990) focused on the Permian part of the succession and also recovered a *N. rosenkrantzi* conodont fauna. Preliminary data from new studies of the Foldvik Creek–Wordie Creek boundary strata at River 8 reveal an earliest Triassic conodont assemblage only 1.0 m above the base of Wordie Creek Group (J.A. Rasmussen, personal communication 2016).

Isotope stratigraphy

Sanson-Barrera *et al*. (2015) identified six chemostratigraphic intervals in the Wordie Creek Group and the underlying Upper Permian Ravnefjeld Formation in the Kap Stosch area, based on detailed analysis of the organic carbon isotope variations. Isotope zone 1 corresponds to the Ravnefjeld Formation. Zones 2 and 3 correlate with the lower Kap Stosch Formation below the Naasut Member, and the base of isotope zone 4 most likely corresponds to the base of the Naasut Member. Isotope zone 5 corresponds to the Vestplateau Member, and the Godthåb Golf Formation correlates with their zone 6 (see Sanson-Barrera *et al.* 2015, fig. 6).

Regional correlations

The ammonoid zonation can be correlated with the ammonoid zonation of the Boreal Realm in the Sverdrup Basin, Arctic Canada (Tozer 1994), and in other Boreal regions such as Svalbard and north-east Siberia (Bjerager *et al.* 2006). The *H. triviale* and *H. martini* zones most likely correlate with the *Otoceras concavum* zone, and the *M. subdemissum* zone is correlated with the *O. boreale* zone of Arctic Canada. The overlying *O. commune* zone is well known also from Arctic Canada. The *W. decipiens* zone partly correlates with the *Bukkenites* *strigatus* zone of Arctic Canada, while the correlation of the *B. rosenkrantzi* zone is more problematic (Bjerager *et al.* 2006). The zone is also present on Svalbard (Weitschat & Dagys 1989); it might correlate with the upper part of the *B. strigatus* zone of the Sverdrup Basin or more likely with an interval above this zone, i.e. with the Dienerian. The ammonoid zonation thus allows a firm correlation of the lower Wordie Creek Group with the Boreal Griesbachian Stage (Fig. 5). The uppermost ammonoid zone, the *B. rosenkrantzi* zone probably belongs to the Dienerian (Fig. 5; Tozer 1994) and the lowermost *H. triviale* zone may include sediments of latest Permian age (see discussion in Bjerager *et al.* 2006). The conodonts provide correlation to the base-Triassic type section in China as well as North Atlantic successions. The spore and pollen stratigraphy correlates with other successions in East Greenland and on Svalbard.

The upper part of the Wordie Creek Group is characterized by the two local bivalve zones of no chronostratigraphic significance and by the *Densoisporites* assemblage palynomorph zone. This zone can be correlated with the ?upper Griesbachian – Dienerian O zone of Hochuli *et al*. (1989). However, the spore and pollen assemblages generally indicate this part to be Dienerian as the assemblage dominated by trilete spores is not replaced higher up by bisaccate spores. The upper boundary of the zone is poorly defined but seems not to be present at Kap Stosch, so based on combined ammonoid and palynological data the upper part of the group, above the Naasut Member, belongs to the Dienerian (Figs 4, 5).

Tectonic control on sedimentation

The coarse-grained members have for a long time been interpreted as reflecting important phases of rifting (Koch 1929; Nielsen 1935; Oftedal *et al.* 2005). They represent significant deepening events marked by the flooding surfaces at the top of the underlying coarse-grained members, which represent shallowing, in some cases leading to emergence. Similar coarse-grained members are known from Traill Ø and Wegener Halvø (Grasmück & Trümpy 1969; Seidler *et al.* 2004; Bjerager *et al.* 2006). The coarse-grained members and units in these areas and at Hold with Hope appear to be contemporaneous, indicating that the rift events recognized at Hold with Hope are of regional significance and not just local. Thus the Immaqa Member – Knolden Member rift event has distinct correlatives on Traill Ø and Wegener Halvø (Fig. 4). It is remarkable that the 'basin floor fan' of Seidler (2000) is very similar to the Gilbert-type fan deltas of the Immaqa and Knolden Members, and it is here reinterpreted as a Gilbert-type fan delta with well-defined clinoform-bedded foresets and horizontally-bedded topset. The Naasut Member rift event likewise has correlatives in the northern Jameson Land, Wegener Halvø and Traill Ø Subbasins (Fig. 4). On Traill Ø this unit is recognized as the Svinhufvuds Bjerge Member (Clemmensen 1980b). The Vestplateau Member rift event has a counterpart on Traill Ø, whereas correlative rocks are absent on Wegener Halvø and northern Jameson Land due to later erosion (Figs 4, 5). The Immaqa–Knolden Members display a similar bipartite set of coarse-grained units as present on Wegener Halvø, but the biostratigraphic resolution does not allow clear identification of two distinct rift events in the earliest Triassic, although it is clearly a possibility. The combined Immaqa–Knolden Members have a relatively uniform thickness at Hold with Hope. In contrast, the higher coarse-grained members show marked thickness differences across major intrabasinal faults, indicating growth across these faults and break-up of the first-formed wide fault block. This was already recognized by Nielsen (1935 and references therein) in his impressive and detailed study of the stratigraphy of the Lower Triassic of Hold with Hope. Early rifting in the Late Permian thus reached a climax in the Early Triassic with four and possibly five gradually fading rift events in the Griesbachian and early Dienerian. The last event is represented by the coarse-grained unit in the *A. fassaensis* zone, but correlative rocks are not represented in the southern outcrop areas, so whether it was a regional event cannot be documented (Fig. 5).

Acknowledgements

We gratefully acknowledge support by the Carlsberg Foundation and GEUS. We thank Jette Halskov for patient and meticulous drafting and Annette Ryge for palynological preparation. Atle Mørk and Lotte Melchior Larsen contributed with highly appreciated comments and suggestions.

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